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Journal

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INSIDE THIS ISSUE

Nineteenth-Century Extraterrestrials • Opposition of Mars

La trigonométrie sphérique en astronomie • Pluto's Atmosphere

Heliocentric Conjunctions of Jupiter, Saturn, Uranus, and Neptune

August/août 2003

Journal

Vol. 97, No.4 Whole Number 701

contents

table des matières

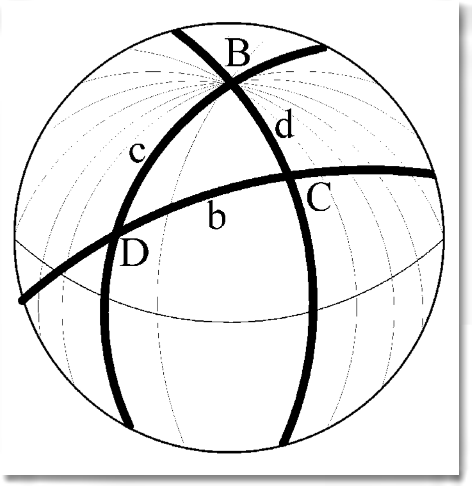
FEATURE ARTICLES/ARTICLES DE FOND

158 The Plurality of Worlds: Nineteenth-Century Theories of Extraterrestrials
by Brett Zimmerman

163 La trigonométrie sphérique en astronomie
par Raymond Auclair

RESEARCH PAPERS/ARTICLES DE RECHERCHE

173 Heliocentric Conjunctions of Jupiter, Saturn, Uranus, and Neptune
by Jim Decandole



La trigonométrie sphérique en astronomie
p. 163

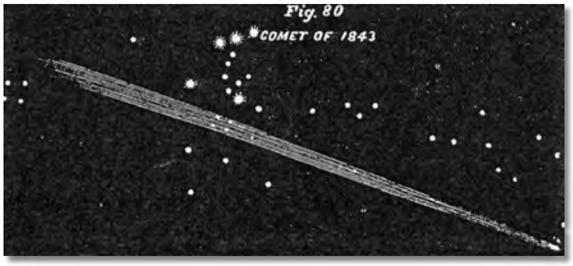
COLUMNS/RUBRIQUES

169 Reflections: Martian Discoveries
by David M.F. Chapman

171 Second Light: Pluto's Expanding Atmosphere
by Leslie J. Sage

180 Orbital Oddities: Martian Motion III: Zoom Out
by Bruce McCurdy

184 Scenic Vistas: The Beta/Zeta Arc
by Mark Bratton



The Plurality of Worlds: Nineteenth-Century Theories of Extraterrestrials
p. 158

Orbital Oddities
p. 180

DEPARTMENTS/DÉPARTEMENTS

150 President's Corner
by Rajiv Gupta

152 Editorial
by Suzanne E. Moreau

154 Correspondence / Correspondance

155 News Notes / En manchettes
Meteorite Finders vs. Meteorite Keepers; MegaPrime Unleashed; More, by Jupiter!; The Universe is Just a "Click" Away; Halting Giant Planet Migration; Savage Award

172 From the Past / Au fil des ans
The Riddle of Mars


Okanagan Centre
Astronomy Contest
p. 179

ACROSS THE RASC
DU NOUVEAU DANS LES CENTRES

177 An Evening with Rajiv Gupta
by James Edgar

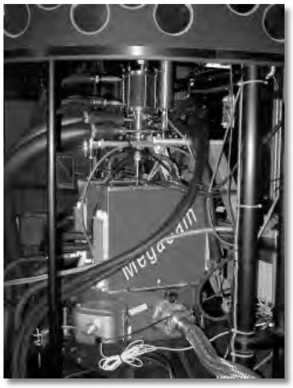
179 Okanagan Centre Astronomy Contest
by Guy Mackie

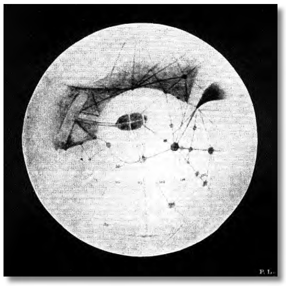
186 Astronomy —A Personal Journey
by Ron Waldron


Astronomy –
A Personal Journey
p. 186

1 S	C	2 H	W	3 A	R	4 Z	S	5 C	H	6 I	L	7 D
H	■	U	■	B	■	E	■	L	■	R	■	E
8 O	U	N	C	E	■	9 N	E	U	T	R	A	L
R	■	T	■	L	■	I	■	S	■	I	■	E
10 T	R	I	P	L	E	T	■	11 T	W	I	S	T
■	■	N	■	■	■	H	■	E	■	■	■	E
12 L	A	G	O	13 O	N	■	14 T	R	I	15 F	I	D
O	■	■	■	P	■	16 M	■	■	■	A	■	■
17 R	A	18 L	P	H	■	19 E	P	20 S	I	L	O	21 N
E	■	O	■	E	■	I	■	H	■	L	■	I
22 N	E	B	U	L	A	S	■	23 E	R	I	N	G
T	■	E	■	I	■	S	■	L	■	N	■	H
24 Z	O	D	I	A	C	A	L	L	I	G	H	T

AstroCryptic Answers
p. 185


MegaPrime Unleashed
p. 156


Cover:
Martian Discoveries
by David M.F. Chapman
p. 169


Moon hunters
p. 156

President's Corner

by Rajiv Gupta (gupta@interchange.ubc.ca)

As you read this month's column, you may also have recently received your annual renewal notice for membership in the Society, since the month in which the greatest number of memberships expires — about one-third of the total — is September. You are very likely to renew, with about an 85% chance according to our renewal statistics, but this year I'd like you to consider sending in a voluntary donation along with the usual membership fee. What better way this year to express your pride in belonging to this very special organization called the *Royal* Astronomical Society of Canada than a voluntary financial contribution!

Of course many of you already donate heavily to the Society, in the form of your time. The value of the time that members donate both to their Centre and to national activities is immeasurable, surely greater than the total amount recorded in the official annual financial records of the Society. Without the generosity of members in the form of their time and dedication, the Society would certainly not be the huge success that it has been for over a century.

Nevertheless, there are real costs to running the Society. The $26.40 received by the Society as its portion of the annual membership fee for a member who is attached to a Centre actually covers only a small portion of the cost of running the Society. As shown in the financial statements included with the 2002 Annual Report, revenue from sales of publications, most notably the *Observer's Handbook* and *Observer's Calendar,* accounted for more than twice as much revenue as membership fees, which made up only about 30% of the Society's total revenue. Without the large net income provided by our publications, the Society would have to either reduce services to members or increase membership fees markedly.

We're lucky to have such low fees, and I hope we continue to be so fortunate. Our attractive membership fee — *very* low when one considers the number of publications and level of service it provides — allows those who share a passion for astronomy to become a part of our unique national astronomical organization with relatively little financial encumbrance. And, we've been doubly blessed that we have mostly enjoyed financial surpluses in recent years in spite of our low membership fees.

There's a cloud though on the horizon, one that could have a significant impact on our finances. While most Canadians regard the recent increase in the value of the Canadian dollar relative to the American dollar as a good thing, it actually has quite an adverse effect on the Society's finances. Most of our

Journal

The *Journal* is a bi-monthly publication of the Royal Astronomical Society of Canada and is devoted to the advancement of astronomy and allied sciences. It contains articles on Canadian astronomers and current activities of the RASC and its Centres, research and review papers by professional and amateur astronomers, and articles of a historical, biographical, or educational nature of general interest to the astronomical community. All contributions are welcome, but the editors reserve the right to edit material prior to publication. Research papers are reviewed prior to publication, and professional astronomers with institutional affiliations are asked to pay publication charges of $100 per page. Such charges are waived for RASC members who do not have access to professional funds as well as for solicited articles. Manuscripts and other submitted material may be in English or French, and should be sent to the Editor-in-Chief.

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publication sales come from south of the border, and we charge in fixed American-dollar prices. When the American dollar goes down, our Canadian-dollar-equivalent income from American sales also goes down. The roughly 10% drop in the American dollar in the first half of this year could result in a $15,000 (or more) shortfall in publication revenue, and there is a serious possibility of a deficit this year.

In 2002, the Society recorded only $1400 in donations (not including donations to Centres), and I think it should be possible to increase this amount by a factor of 10 or more. Your renewal form has a spot for a donation; please use it! You can allocate your donation to your Centre (if any) if you prefer, instead of to the Society; also, you can indicate in the comments section of your renewal form that your donation is to be allocated to one of the Society's special funds — the Millman Endowment Fund, which supports the ongoing general operation of the Society, or the Northcott Fund, which supports special projects — instead of to general operating income. In any event, you'll receive an income tax receipt; and more importantly you'll experience a warm, fuzzy glow knowing that you've made a voluntary contribution to a special organization that is celebrating 100 years of Royal recognition this year, a contribution that might help to assure the Society's financial health during its special year. Why not express your appreciation for your beloved *Observer's Handbook*, for example, by donating to the Society the amount it would cost you to purchase a copy at your local astronomy store? I hope many of you will join me in chipping in something a little extra on your membership renewal form this year, and thanks!

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Editorial

by/par Suzanne E. Moreau (semore@sympatico.ca)

In his editorial in last February's issue of the *Journal*, Wayne Barkhouse discussed light pollution and the absence of the Milky Way under urban light-polluted skies. It reminded me of an incident a few years ago that I always mention to my students when, because of cloudy conditions, I have to substitute the International Dark-Sky Association's slide presentation on light pollution for the missed observing session that is normally part of the course.

It was around 9:00 p.m. on September 6, 2000 when I stood on my front stoop to say goodnight to a fellow member of the astronomy club I now belong to here in Montreal. I live in the middle of the city, on a hill with tall light standards overhanging the street. The closest one is almost directly across the street and so bright I never need a light to find the lock on the front door at night. This particular evening turned out warmer than the day and the wind had died down. There was a gorgeous sky, deep blue-black, with stars that barely twinkled — ideal observing conditions. The Summer Triangle was directly overhead.

As we stood debating whether we should go to our favourite observing site (it was a weekday and we both had to work the next day), I commented that I hadn't seen such a good sky in years — no clouds or haze anywhere, whereupon my friend said "I see some clouds up there!" She has better eyesight than I have, so I looked to where she was pointing. After searching the area, I too could just make out the faint patch, a spot of haze about 1° to $1\frac{1}{2}$° in size, with a clearly defined curved edge on the left and some fading towards the right. This patch was some 3° to 5° almost directly south of ζ Cygni. There was no movement in the cloud and the few stars embedded in it appeared as bright as the rest. Finally, I said to her "Ildi, that's not clouds, that's the Milky Way!" I stared at the astonishing sight for several minutes to fix it well in my mind. I knew this view of the Milky Way, despite the bright lights on the street, was likely a once-in-a-lifetime occurrence.

Why do I never fail to mention this incident to my students? Who better to recruit as supporters and spokespersons for light-pollution abatement programmes? After all, anyone interested enough in astronomy to want to take a course in the subject already has a stake in the need for dark skies. In fact, they, like the rest of us, have another stake as taxpayers. I've been teaching an average of 18 students per session since 1995, some 200 enthusiastic new observers who have families, friends, and colleagues to talk to knowledgeably about light pollution and to demonstrate the problems it causes them when they want to go observing — without having to travel far out of town. It's a cohort I'm trying to add to and motivate to get involved each time I teach the course.

In this province of abundant hydro power and a penchant for bright "security" lighting as garden accessories, the occasional mention of light pollution in public presentations or newspaper articles has only the briefest impact. It's a subject that needs to be hammered at repeatedly by people who are directly affected. I know my part of this presently uncoordinated campaign is small and those responsible for public-lighting regulations will only listen to presentations that address technical problems and, above all, cost savings. However, at some point politicians do take notice when there are many people demanding change. Educating our own students and club members, and encouraging their efforts to fight light pollution, are important steps in the process. The more numerous we are to push for change, the more attention we will garner for a solution to the problem.

This is *my* bit for the cause! Wayne's editorial mentions other ways to contribute and get involved. Self-interest alone should be a powerful incentive for all RASC members to participate in the campaign to reduce light pollution.

Dans l'éditorial du *Journal* de février dernier, Wayne Barkhouse évoquait la pollution lumineuse et le fait que la Voie lactée disparaissait lorsque le ciel était éclairé par les lumières de la ville. Cela m'a rappelé un incident, survenu il y a quelques années, que je ne manque jamais de décrire à mes étudiants lorsqu'un ciel nuageux m'oblige de recourir à la présentation de diapositives de l'International Dark Sky Association sur la pollution lumineuse en remplacement de la séance d'observation normalement prévue dans le cadre du cours.

Cela se passait le 6 septembre 2000, vers 21 heures, alors que je me trouvais sur le pas de la porte d'entrée pour prendre congé d'une amie, membre du club d'astronomie dont je fais partie ici même, à Montréal. J'habite sur une colline située en pleine ville, dans une rue bordée de très hauts lampadaires dont le plus proche est presque en face de chez moi et dont la lumière est si forte que je n'ai jamais besoin d'éclairage supplémentaire pour ouvrir la porte le soir. Ce soir-là, la température était plus élevée que pendant la journée et le vent était tombé. Le ciel était magnifique, d'un bleu-noir intense et les étoiles scintillaient à peine; en bref, des conditions idéales pour observer la voûte céleste. Le Triangle d'été se trouvait juste au-dessus de nos têtes.

Pendant que nous discutions pour savoir si nous devions aller dans notre lieu d'observation préféré (c'était un jour de semaine et nous devions travailler le lendemain), j'ai fait remarquer qu'il y avait des années que je n'avais vu un ciel si propice, sans nuages ni brume, sur quoi mon amie a déclaré qu'elle voyait de léger nuages. Comme elle a une vue meilleure que la mienne, j'ai regardé dans la direction qu'elle m'indiquait et au bout d'un moment j'ai pu moi aussi apercevoir une légère trace de brume mesurant 1° à 1,5°, avec un bord recourbé nettement défini vers la gauche et s'estompant vers la droite. Cette tache se trouvait à environ 3° à 5° presque directement au sud de ζ Cygni. On n'y distinguait aucun mouvement et les quelques étoiles au sein de ce nuage paraissaient aussi brillantes que les autres. J'ai dit qu'il ne sagissait pas d'un nuage, mais que c'était bien la Voie lactée. J'ai regardé ce spectacle pendant plusieurs minutes afin de bien m'en pénétrer, sachant que malgré les lumières de la ville cette vue de la Voie lactée était sans aucun doute extrêmement rare.

Pourquoi est-ce que je ne manque jamais d'en parler à mes étudiants? Tout simplement parce qu'ils sont mieux placés que quiconque pour faire valoir et appuyer les programmes visant à réduire la pollution lumineuse. Après tout, les personnes qui s'intéressent suffisamment à l'astronomie pour vouloir suivre un cours sont déjà conscientes du fait que seul un ciel sans lueurs leur permettra d'observer les étoiles. En fait, elles ont aussi un autre intérêt puisque, tout comme nous, elles paient des impôts. Depuis 1995, j'ai enseigné à quelque 18 étudiants par session, soit environ 200 nouveaux observateurs enthousiastes qui ont une famille, des amis et des collègues auxquels ils peuvent parler en toute connaissance de cause de la pollution lumineuse et leur décrire les problèmes qui se posent lorsqu'ils veulent observer le ciel sans trop s'éloigner de la ville. C'est un groupe que je m'efforce d'élargir chaque fois que je dispense ce cours, cherchant à éveiller l'intérêt des participants de manière qu'ils y prennent une part active.

Dans cette province où le potentiel hydro-électrique est abondant et où l'on a tendance à assurer un vif éclairage dans les jardins "aux fins de sécurité", toute mention de la pollution lumineuse dans les conférences publiques ou les articles de journaux ne suscite qu'un faible intérêt. C'est un sujet sur lequel les personnes affectées doivent insister continuellement. Je sais bien que mon rôle est bien modeste dans ces programmes non concertés qui sont mis en oeuvre à l'heure actuelle et que ceux à qui il incombe d'assurer la réglementation de l'éclairage public n'écoutent que les arguments relatifs à des problèmes d'ordre technique et surtout ceux que permettraient de réduire les coûts, mais les politiciens finissent quand même par prêter l'oreille lorsque les demandes de changement se font plus pressantes. Dans cette optique, il est important de faire prendre conscience à nos étudiants et aux membres de nos clubs de la nécessité de combattre la pollution lumineuse et de les encourager dans leurs efforts vers cet objectif. Plus nous serons nombreux à exiger des changements, mieux nous réussirons à attirer l'attention sur la nécessité d'apporter une solution au problème.

Voilà donc *ma* contribution à la cause. Dans son éditorial, Wayne décrit d'autres façons de se mobiliser et d'intervenir. Ne serait-ce que dans leur propre intérêt, et c'est là un motif plus que suffisant, tous les membres de la SRAC devraient participer à une campagne en vue de réduire la pollution lumineuse. ◉

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Correspondence
Correspondance

Dear Sir,

A recent editorial (*JRASC*, October 2002) mentions some of the innovative science that will flow when a researcher can amalgamate and analyze observations of an object made at different wavelengths. The article points out that such "panchromatic" datasets are the basis of the National Virtual Observatory (or its eventual successor, the International Virtual Observatory), a major project to federate and cross-correlate data from many different sources and wavelengths automatically. "Observations like these" (the editorial concludes) "help pry open the door to a better understanding of the Universe around us."

Absolutely — but that is not the only foreseeable mode in which a Virtual Observatory can operate. A key characteristic of celestial objects is variability. Changes that are periodic are commonly associated with double or multiple systems, pulsation or rotation; random or secular events such as flares, outbursts, or even evolution itself produce observable changes in numerous forms. Each can produce radial-velocity, photometric, or spectrum changes, and over time-scales that can be anything from relatively short (*e.g.*, ~a year, a day, or less) to decades that begin to approach the very extent of documented astronomy.

Photometric, spectrum, or radial-velocity variability, whatever the causes, can only be identified when the observations span appropriate time intervals. For refining the elements of periodicity, a dataset of observations — not necessarily panchromatic ones — covering a suitable time-span is essential, while longer runs can yield evidence of period modulations. Studies involving the longest time-scales require access to data from different epochs of observational history, a demand that presents a major challenge because of the technological divides that need to be crossed. But if a Virtual Observatory could offer runs of ready-to-use historic observations as well as panchromatic ones, how much richer the research?

Some time-sensitive research is of course already possible. Radial-velocity measurements dating back over 100 years are documented in the literature; the AAVSO maintains records of photometric measurements extending back even further. However, little effort has been dedicated to creating accessible digital archives of *spectra* that delve very far into astronomy's history. The spectroscopic observations in question are distributed worldwide in observatory photographic plate archives. The change in technology from photography to digital detectors was a major one, and has created a historical cutoff: very few photographic records can be accessed today in digital form — both the equipment and the expertise to do so have become scarce.

All is not yet lost, and Canada is foremost in the rescue. A plate-scanning laboratory, known as the Spectroscopic Virtual Observatory (SVO), is being planned, and will be hosted at the Dominion Astrophysical Observatory in Victoria. The intention is to digitally transfer the information from photographically-observed spectra into forms that can be readily assimilated into modern research. It is a fairly tall order; the world houses an estimated one-million stellar spectrograms, so the SVO must select observations that are likely to contribute the most worthwhile returns, viz. coudé and any other high-dispersion plates, plus observations of objects known or expected to show some form of variability. Even so, that subset will occupy a five-man team for about five years, but what a resource will emerge!

Notwithstanding the dismissive attitudes towards older-style observing that occasionally prevail, research based on some of those observations has a distinguished pedigree. Astrophysics was born and bred on photographic data, and we have not felt obliged to rediscover the laws of astrophysics just because the observing medium is different now. In fact, the contributions of the older observations to astrophysics become increasingly important as the included time-spans lengthen.

In a subject like astronomy, "history" is but a previous phase in a continuum of progress and evolution in research. When that continuum of progress becomes interrupted by an abrupt change, such as a new medium for recording or storing observations, it must be the corporate responsibility of those who can to build a connection between the old and the new in a way that data-flows can be maintained unimpaired. To fail to do so causes a loss of contact with data that are unrepeatable, and that could be vital to the solution of any number of astrophysical problems.

Elizabeth Griffin (Life Fellow)
and Frank Younger,
DAO, Victoria, B.C.

Corrigendum:

Due to a production error, a reference to *Nature* was mistakenly omitted (*JRASC*, 97, April 2003, p. 68). The correct reference is March 13, 2003.

News Notes
En Manchettes

METEORITE FINDERS VS. METEORITE KEEPERS

In the last few decades the collecting of rare meteorites has exploded into a multi-million dollar industry, but unlike many trendy collectibles, meteorites have enormous scientific value. Meteorite researchers and curators are facing increasing competition from dealers and collectors. In the so-called meteorite black-market, specimens are smuggled or misidentified in order to hide their place of origin, resulting in valuable data being lost — sometimes forever.

To help address the issue of meteorite ownership and control, Douglas G. Schmitt of the Vancouver law firm of McEwen, Schmitt & Co. has published a summary of the relevant laws in different countries and made recommendations to protect their scientific value (*Meteoritics & Planetary Science* (Supplement), Dec. 2002). Working with meteorite researchers from around the world, Schmitt concluded that the laws related to ownership of meteorites differ significantly from country to country. Most laws favor the landowner and do not insist that the find be reported. Of the reported laws, only those in India, Switzerland, the Chaco Province of Argentina, and four Australian states or territories appear to favor the scientific community. The rest give control to either the landowner or the finder. In a number of countries, such as China and Russia, it was difficult to determine the state of the law.

Here in Canada the law is based on two systems depending on the province. Common law derived from English common law applies to all provinces except Quebec, where a civil code derived from the French civil code applies. Under Common Law the landowners are legally in control of any meteorite found on their property. Only if the owner plans to permanently or temporarily export the meteorite are they obliged to inform the government and seek an export permit. In the five years prior to May 23, 2001 there have been twenty-two export applications — two of which were refused. The two refusals were simply a six-month delay period during which Canadian institutes had the right to purchase a meteorite — after which an export permit was allowed in both cases.

Laws in France, and hence Quebec, appear to be somewhat unclear on the subject of meteorite ownership. Previous French cases suggest that if the meteorite had become embedded into the ground it would become the property of the landowner. However, if the meteorite is merely resting on the surface it becomes *res nullius* — a thing with no owner — and can be lawfully collected by anyone who was not clearly trespassing. According to Schmitt, in future cases this rather odd situation will most likely resolve itself in the favor of the landowner in all circumstances.

What appears to be needed, according to Schmitt is a "uniform law that gives optimum research data and samples to scientific institutions and at the same time fairly compensates the finder." Schmitt goes on to suggest that the solution already exists under the framework of the UNESCO Cultural Property Convention. However, he warns that ratification of the convention does not ensure that countries will enact appropriate legislation. Schmitt also recommends that pristine areas such as the Antarctic should be reserved for scientific collecting only.

One thorny issue is the role of professional meteorite dealers who rightfully claim that many samples would remain undiscovered if it were not for their efforts. At the same time scientific research gives the collector a standard of value by determining such things as a meteorite's rarity and significance. Because of this, collectors are usually quite willing to share their finds with the scientific community. According to Dr. Howard Plotkin, a researcher at the University of Western Ontario and a contributor to the document, the future looks bright. Plotkin suggests that, "… both sides are coming to realize that they need each other … The result of this [cooperation] is bound to be a healthier and more productive relationship between collectors, dealers and researchers."

MEGAPRIME UNLEASHED

The National Research Council (NRC) of Canada recently unveiled for general scientific use MegaPrime, the world's largest digital camera. Installed on the renowned 3.6-m Canada-France-Hawaii Telescope (CFHT) at the summit of Mauna Kea, MegaPrime provides the two-decade-old telescope with unprecedented capabilities. Indeed, with MegaPrime the CFHT will outperform newer and larger telescopes with respect to its capacity to observe large areas of the sky and in the production of high-resolution images.

MegaPrime is a collaborative project between several research institutes in France, and NRC's Herzberg Institute of Astrophysics in Victoria, B.C. Several major industrial contractors participated in building the large optical and mechanical components of the new camera, which is mounted at the prime focus of the CFHT. At the heart of MegaPrime is MegaCam, a unique camera built by the French Commissariat à l'energie atomique. This camera is an array of 40 charge-coupled detectors, each of which has nine million individual pixels. In routine use, MegaCam produces an image containing 324 million pixels.

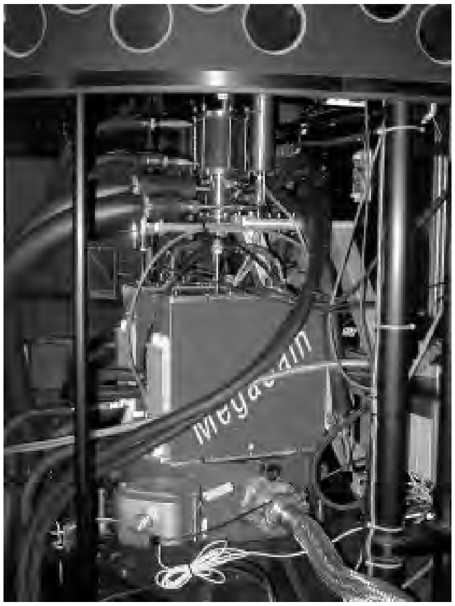


Figure 1.— MegaCam (image courtesy of the NRC). Further details on, and images obtained by, MegaPrime may be found at the following Web site: `www.cfht.hawaii.edu/News/MegaPrime/`.

MORE, BY JUPITER!

So far this year, Jupiter has gained 21 new distant satellites, with the most recent announcement of satellite S/2003 J 21 on June 3rd at the annual Canadian Astronomical Society meeting in Waterloo, Ontario. These new discoveries put Jupiter far ahead of the all other planets, with 61 known moons. Astronomers from the University of British Columbia (Professor Brett Gladman and postdoctoral researcher Lynne Allen) and the National Research Council of Canada (Dr. J.J. Kavelaars) are the discovery team.

The new satellites were a challenge to detect because most are only about 1-5 kilometres in size. Their small size and their distance from the Sun prevent the satellites from shining any brighter than magnitude 24, about 100 million times fainter than can be seen with the unaided eye. To locate these new moons, the Canadian team has been using the brand-new MegaPrime mosaic of CCD cameras mentioned above. Covering all the sky in which satellites could be found required this new large-mosaic camera, enabling the team to quickly obtain images of the entire sky around the planet. They used computer algorithms to search the images for the faint points of light moving across the sky in the manner expected for Jupiter moons.

Figure 2.— Moon hunters: Brett Gladman and Lynne Allen point out one of their newly discovered Jovian moons. (Image courtesy B. Gladman).

It now appears that each giant planet's irregular satellite population is the result of ancient collisions between former moons and passing comets or asteroids. "These collisions result in the production of families of satellites in similar orbits," said Gladman, "which seem to be the rule." Interestingly, of all the Jovian satellites discovered in the last two years, it is the second to most recent one, S/2003 J 20, that stands out from the pack. The Canadian team has been tracking the satellite steadily this year, improving its orbital elements and yielding two surprises. First, its orbit stands apart from all other previously known Jupiter moons, thus appearing not to be part of one of the known "families" of objects. Secondly, Valerio Carruba (of Cornell University) has confirmed that this object is lodged in an interesting orbital resonance with Jupiter. The specific resonance involved sets an upper limit to the orbital inclination of any moon; should the moon become more inclined than this limit then its orbits will distort periodically every century and drop it down into the collisionally dangerous realm of Jupiter's larger satellites. The new satellite S/2003 J 20 is right on the edge of the stability region, barely avoiding this fate.

THE UNIVERSE IS JUST A "CLICK" AWAY

The Canadian Astronomy Education Web page is now available for viewing at `www.cascaeducation.ca`. This new Web site has been specifically constructed to provide teachers, students, and the general public with access to a wide variety of Canadian astronomical resources, from what's in the sky tonight, to complete lesson plans and group activities. The bilingual Web site, designed and created by Canadian Astronomical Society Education Coordinator Heather Scott, and Travis Whyte, Web developer and founder of Educational Media Technologies in Edmonton Alberta, is the first of its kind in Canada, putting astronomy news and resources within reach of the public.

The Canadian Astronomy Education Web page has been made possible through financial support from the Canadian Astronomical Society, the National Sciences and Engineering Research Council of Canada Promoscience Program, and the Ontario Ministry of Enterprise, Opportunity, and Innovation.

HALTING GIANT PLANET MIGRATION

If you look at the planets in our Solar System there seems to be a rational order — rocky planets on the inside and gas planets on the outside. The gaseous planets like Jupiter could not have formed close to the Sun because they would simply be evaporated by the Sun's radiation. It was assumed that this orderly arrangement would also be found in other planetary systems. Recent discoveries of Jupiter-sized planets orbiting extremely close to distant stars have made a mess of these orderly assumptions.

A number of competing models have emerged in an attempt to clean up this crisis in our understanding. Most theorists suggest that gas giant planets were originally formed further from the star and then migrated inward, but what ultimately stops this migration and at the same time explains why our gas giants are so much further out than the ones we see around other stars? A team of astrophysicists lead by Isamu Matsuyama of the University of Toronto has now proposed a possible solution (*Astrophysical Journal Letters,* March 10, 2003).

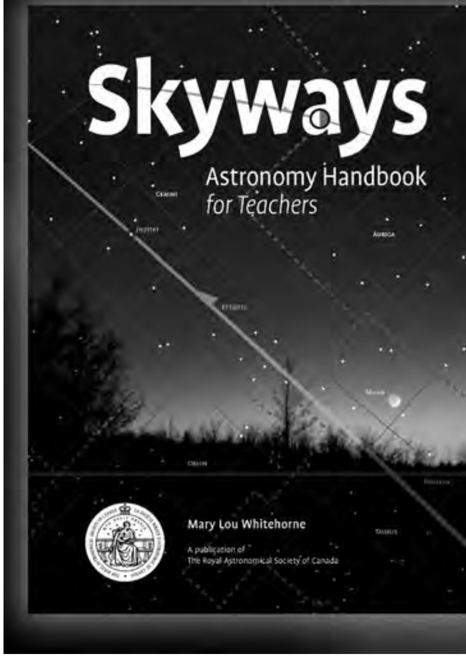
Matsuyama's team included Doug Johnstone of the Herzberg Institute of Astrophysics (National Research Council of Canada) and Norman Murray of the Canadian Institute for Theoretical Astrophysics based out of the University of Toronto. Their work suggests that photoevaporation of the surrounding disk of gas could halt the inward planetary migration. Increased extreme ultraviolet radiation from the young star would heat the surrounding gas giving it enough kinetic energy to achieve escape velocity. This would eventually produce a gap between disk material that is gravitationally bound to the central star and the gas swept away by photoevaporation. If the inwardly migrating planet fell into this gap, the "death-spiral" would cease.

The team ran computer simulations of the interaction between the central star, its surrounding gas disk, and the imbedded gas-giant planets. Their model showed this gap structure starting to form in the disk after 40 million years. Putting their virtual giant planet at an initial distance of 15 AU the team watched it migrate inward and then successfully park itself into the widening gap in the disk. The planet settled into a stable Jupiter-like orbit 3 AU from the star. Planets starting closer than about 14 AU were doomed to fall into the star before the gap could form. Running the model further showed the remaining material in the disk eventually accreting onto the star or dispersing, leaving the planets to orbit in relatively empty space.

In spite of the apparent success of the new model Matsuyama notes that, "we cannot explain the halting of planet migration by photoevaporation at very short orbital distances that are typical of hot Jupiters." The birth of our own Solar System, however, appears to have been solved, but the formation of Jupiter-like planets breathtakingly close to distant stars still remains a mystery.

SAVAGE AWARD

The inaugural offering of the Margaret and John Savage First Book Award has recently been announced and is presented to Dan Falk of the Toronto and Halifax Centres. The award recognizes Dan's debut book, *The Universe on a T-shirt: the Quest for the Theory of Everything* (Viking, Canada), and the announcement was made at the Atlantic Writing Awards ceremony held at the Alderney Landing Theatre in Dartmouth, Nova Scotia. Dan is a graduate of the journalism programme at Toronto's Ryerson Polytechnic University, and a physics graduate from Dalhousie University. He is a long-time RASC member and is well known for his many newspaper, magazine, and radio broadcasts on astronomy and related topics. Dan Falk received the Simon Newcomb Award from the RASC in 2001.



Feature Articles
Articles de Fond

The Plurality of Worlds:
Nineteenth-Century Theories of Extraterrestrials

by Brett Zimmerman, York University (bazimme@attglobal.net)

A recent issue of *Sky & Telescope* features a stimulating article on *Oliver Wendell Holmes: Poet of the Sky.* There Ted Black suggests that Holmes was many years ahead of his time in using the motif of extraterrestrials frequently in his poems, and Black provides lines from *The Secret of the Stars* as an example. In fact, Holmes was not so much ahead of his time as very much a *part* of his time (and place) in considering the possibility of life on other planets. Today many fans of science fiction may suppose that the idea of a plurality of inhabited worlds is a twentieth-century theory — or at least dates back to H.G. Wells' *The War of the Worlds.* In fact, the idea is *much* older (by many centuries) and fired the imaginations of both scientific and nonscientific people, certainly in Europe and in Holmes' America during the nineteenth century.

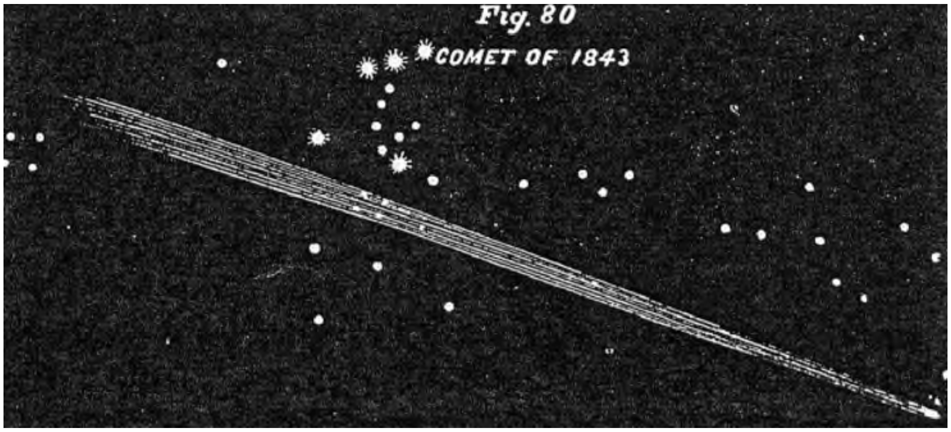


Figure 1. — From Hiram Mattison's *Atlas Designed to Illustrate Burritt's Geography of the Heavens* (New York, 1856).

A contributor to *Knickerbocker* magazine could state in March of 1862, "The question, 'Are there more worlds than one?' has occupied the thoughts and employed the pens of some of the first minds of this generation. … " A belief in other inhabited globes seems to have been thoroughly respectable; after all, one of the most important men in nineteenth-century astronomy, Sir John Herschel, sanctioned the theory. In his *Treatise on Astronomy*, he asks what purpose the stars scattered throughout space could possibly have, and then answers: they are doubtless other suns around which revolve inhabited planets. One must have studied astronomy to little purpose "who can suppose man to be the only object of his Creator's care, or who does not see in the vast and wonderful apparatus around us provision for other races of animated beings."

American men of science also advocated the theory. Theodore R. Treadwell quotes Denison Olmsted, who in his *Introduction to Astronomy* acknowledges that the stars are other suns, and then continues: "It is obvious to inquire next, to what they dispense these gifts [light and heat] if not to planetary worlds; and why to planetary worlds if not to percipient beings? We are thus led almost inevitably to the idea of a 'Plurality of Worlds.' . . ." Elijah Hinsdale Burritt, the writer of *The Geography of the Heavens,* tells us, furthermore, that, "we are bound to presume that the All-wise Creator has attempered every dwelling-place in his empire to the physical constitution of the beings which he has placed in it."

Conjectures about extraterrestrial life were still "in the air" during the second half of the nineteenth century: William Whewell's *Plurality of Worlds* appeared in 1854; in *The Extraterrestrial Life Debate,* Michael J. Crowe reports that pluralism can be found in O.M. Mitchel's *Orbs of Heaven; Harper's Magazine* carried an editorial in April, 1855 that asked "Are There More Worlds Than One?"; in an oration of 1856 called *The Uses of Astronomy,* Edward Everett admits the supposition "that the countless planetary worlds which attend these countless suns, are the abodes of rational beings like man . . ." (*Aspects of Astronomy in America in the Nineteenth Century*). In 1866, Professor Henry Draper gave a lecture before the Young Men's Christian Association of New York entitled *Are There Other Inhabited Worlds?* Draper (1866) brought his knowledge of chemistry to the issue, and finished his discussion thus:

> "I can not believe that on our little globe alone, among the infinity of worlds, life has been possible...It seems more in accordance with reason to believe that there may be on many other globes intelligent beings, formed on the same plan as we are, but differing, on some perhaps for the better, on others for the worse."

Scottish astronomer Thomas Dick combined his understanding of astronomy with his religious and philosophical beliefs, and in most of his eleven books — including his *Christian Philosopher, Celestial Scenery,* and *The Sidereal Heavens* — mixed teleological reasoning with the idea of extraterrestrials. That is, he argued that the theory of other inhabited planets is consistent with the idea of an abundantly creative God: a Universe thus designed is proof of God's existence. In Chapter IX of *Celestial Scenery* and Chapters XVI and XVII of *Sidereal Heavens,* he weaves several elaborate arguments to support the doctrine of a plurality of worlds. In part, these are based on an analogy with our own planets and solar system; in part, they are based on "Divine Revelation." In Chapter XVIII of *Sidereal Heavens*, Dick even speculates "On the Physical and Moral State of the Beings That May Inhabit Other Worlds."

Many Americans must have liked Dr. Dick's notions; in his Preface to *Sidereal Heavens* he writes, for instance, of the popularity of *Celestial Scenery* in America. Elva Baer Kremenliev also attests to the favourable attention paid to the Scotsman, whose "devout works on scientific subjects achieved wide readership on both sides of the Atlantic" (*The Literary Uses of Astronomy in the Writings of Edgar Allan Poe*). Crowe says that Dick's "warmest reception came from the United States ..."

Believers in extraterrestrial life did more than speculate generally — they considered the individual worlds of our own solar system, including the Sun! Lending his support to the theory of solar inhabitants was one of the most eminent astronomers of his day, Sir William Herschel (father of Sir John). Agnes Clerke and Dick summarize Herschel's theory: the Sun actually consists of a cool and solid "terrestrial" nucleus enveloped by two strata of "clouds." The dark inner globe is covered with earthly topographical features such as valleys, mountains, and luxuriant flora. All this is protected by a thick layer of clouds from the fiery outer atmosphere, that blazing hot region of the Sun that heats and illuminates the rest of the solar system. The Sun, then, is really another, though extremely large, planet, and resembles the others in the solidity of its central globe, its having an atmosphere, its diversified surface, and its axial rotation. All of these features lead "'us on to suppose that it is most probably also inhabited . . . by beings whose organs are adapted to the peculiar circumstances of that vast globe,'" notes Clerke, quoting Herschel (*A Popular History of Astronomy* during the Nineteenth Century).

Not all scientists agreed with the "terrestrial" theory of our star, but we should not set limits to the wise arrangements of God by denying the possibility of solar inhabitants, admonishes Dick, characteristically. For all we know

> "the sun may be one of the most splendid and delightful regions of the universe, and scenes of magnificence and grandeur may be there displayed far surpassing anything that is to be found in the planets which revolve around it, and its population may as far exceed in number that of other worlds as the immense size of this globe exceeds that of all the other bodies in the system." (*Celestial Scenery*)

This fantastic hypothesis, backed by Herschel's name, had nearly a seventy-year life span (1795-1865), according to Clerke (1885). Thus, we should not be surprised to find both Alice Lovelace Cooke (*Whitman's Indebtedness to the Scientific Thought of His Day*) and Clarence Dugdale (*Whitman's Knowledge of Astronomy*) reporting that the poet cut out a newspaper article entitled *Is the Sun Inhabited?*

Probably even more popular as a choice for the belief in extraterrestrial civilizations was the Moon. John Narrien, in *An Historical Account of the Origin and Progress of Astronomy* (1833), writes of a German astronomer, Schroeter, who held that our satellite is the "abode of living and intellectual beings: he has perceived some indications of an atmosphere . . . and certain elevations which appear to him to be works of art rather than of nature." Burritt adds detail: Schroeter, he says, "conjectured the existence of a great city on the east side of the Moon, a little north of her equator, an extensive canal in another place, and fields of vegetation in another" (*Geography of the Heavens*). Burritt also mentions Frauenhofer of Munich, who announced his discovery of something on the Moon resembling a fortification, along with several lines of road. Dick tells us that other foreign observers insisted that they too had perceived vegetation or artificial edifices on the Moon (*Celestial Scenery*). Some astronomers even proposed an attempt to communicate with the "lunarians"

> "by erecting on one of the great plains of Asia stone structures representing a certain geometrical problem, "in a right-angled triangle the square of the hypothenuse is equal to the sum of the squares of the other two sides." It was hoped that if there were intelligent inhabitants on the Moon who had discovered the truths of geometry they would answer by marking out on one of their plains some other

> problem in response." (Draper 1866; see also *Celestial Scenery*)

Both Draper and Dick questioned the validity of such an experiment, partly because they were skeptical that Earth-bound instruments had discovered evidence of lunar cities — and, thus, lunar inhabitants. No telescope in America or elsewhere had the resolving power necessary to see tokens of civilized life on the Moon (Richard A. Locke's *Wonderful Discoveries in the Moon* notwithstanding). Nevertheless, Dick refused to conclude that "Selenites" do not exist, and Draper hypothesized that air, water, and inhabitants likely could be found on the satellite's *far* side. Edgar Allan Poe also believed in the existence of lunar inhabitants (see below), and in some unpublished notes apparently to his cosmological treatise, *Eureka* (1848), he expresses his optimism that telescopes could theoretically prove him right:

> "It may be demonstrated from the laws of optics that there exists no physical impossibility to the construction of instruments sufficiently powerful to settle the question of the moon's being inhabited. The difficulty which prevented the great telescope of Herschel from revealing this secret was not so much the want of power in the lens, as of light in the tube, to render objects distinct under such an expansion of the visual rays."

In his hoax, *The Unparalleled Adventure of One Hans Pfaall* (1835), Poe has his narrator, in fact, journey to the Moon in a balloon; upon crash-landing there, he discovers a civilization of ugly, diminutive inhabitants.

Several planets in our solar system were also considered by some to be capable of supporting life, including the inner worlds. Even red-hot Mercury was thought by Dick to have a large population: "we can scarcely doubt that there are to be found on this planet millions of sentient and intelligent beings … with constitutions fitted for that sphere in which Providence has placed them …" (*The Solar System*). As for the second-nearest planet to the Sun, Venus, Dick admits the scarcity of water and possible intensity of heat on that world, but insists that it must be populated by creatures adapted to their environment. Dick calculates, in fact, that the Venusian surface is capable of containing sixty-seven times the population of Earth. The writer for *Knickerbocker,* quoted earlier, does not like the "adaptability" hypothesis employed by Dick and others but, as for Venus, he confesses, "We can hardly doubt … that it is a habitable and inhabited world …" Burritt also credited the existence of Venusians; on page 191 of *Geography of the Heavens,* he mentions the planet's "polar inhabitants."

Draper, on the other hand, dismissed both Mercury and Venus as worlds capable of sustaining animal or vegetable life, both planets being far too hot, in his opinion. His telescopic observations of Mars, however, led him to think differently about that planet's life-supporting capacities. Through his telescope Draper believed he saw "an expanse of water covering a large proportion of the Southern hemisphere, and of a greenish hue. The remaining parts … are land of a reddish tinge, assuming the figure of continents." He also noticed the northern and southern polar regions and believed he descried clouds floating in the planet's atmosphere. Thus, Mars, like Earth, has air, water, snow, rain, alternating seasons, and perhaps vegetation. "There is then another body…suited to the abode of sentient beings," he concludes. Dick also notes the supposed similarities between Earth and Mars and deduces that the Martians therefore "are in a condition not altogether very different from that of the inhabitants of our globe" (*Celestial Scenery*).

As for the giant planets of our system, Draper remarks briefly that there is reason to believe both water and air exist on two of them: Jupiter and Saturn. The more imaginative Dr. Dick goes further, marveling at the supposed beauties of the Jovian night sky, which "must exhibit many curious and sublime phenomena to its inhabitants …" (*The Solar System;* see also Burritt 1873). It should not surprise us that Dick believes Saturn likewise harbours living beings (Burritt 1873). It may startle us, however, to find him insisting on the life-supporting capacities of Saturn's *rings*. In several places he presumes that the rings are *solid* and serve as a wide and spacious abode for myriads of intelligent creatures. In a curious bit of logic, he says it is not unlikely "that a surface of 29,000,000,000 of square miles, capable of containing ten thousand times the population of our globe, would be left destitute of inhabitants. . . ." (Dick 1838).

He also takes for granted that creatures exist on Uranus and proposes that because their planet receives so little of the Sun's light, "the pupils of the eyes of the inhabitants" must be adapted by the Creator accordingly (*Solar System*). Burritt is also concerned with the dimness of Uranus: "To his inhabitants the Sun appears only the 1/380 part as large as he does to us; and of course they receive from him only that small proportion of light and heat."

Even comets were considered by some to be the homes of rational beings, although the temperature of a cometary world would vary extremely depending on its distance from the Sun. This consideration had led Dr. William Whiston to suppose that comets must be the abode of the damned. Burritt explains further:

> "According to this theory, a comet was the awful prison-house in which, as it wheeled from the remotest regions of darkness and cold into the very vicinity of the Sun, hurrying its wretched tenants to the extremes of perishing cold and devouring fire, the Almighty was to dispense the severities of his justice."

Dick, however, believes that God in his beneficence would not create comets for such a purpose and prefers to think that cometary worlds offer to their inhabitants some of the most spectacular views in the Universe. This theory could only apply to comets with solid nuclei, though, but regarding these, "there appears to be no physical impossibility, nor even improbability, of their being the abodes of sentient and intellectual beings …" (*Sidereal Heavens*). As for the objection that the extreme temperatures to which comets are subjected in their orbits would make life on them unlikely, Dick replies there is no proof that heat or cold depend upon a body's distance from the Sun (Burritt makes the same point on page 178 of his book).

This widespread belief, at least on the part of scientific men, in extraterrestrials is also reflected by men who tried to write fiction for a living. In *Herman Melville: Stargazer,* I discuss Melville's literary handling of the theory of pluralism, so here I shall cover, briefly, some of his contemporaries. Poe is well known as a pioneer of science fiction, so it might not surprise his readers that he was a believer in extraterrestrials. In *Eureka* he writes of humanity as being "a member of the cosmical family of Intelligences"; elsewhere he refers to the way the Earth must look "to an inhabitant of the Moon," and in his unpublished notes to *Eureka,* he elaborates:

> "As the earth turns round its axis, the several continents, seas, and islands appear to the moon's inhabitants like so many spots of different forms and brightness moving over its surface, but much fainter at some times than others, as our clouds cover or leave them. By these spots the Lunarians can determine the time of the earth's diurnal motion, just as we do the motion of the sun; and perhaps they measure their time by the motion of the earth's spots; for they cannot have a truer dial."

Elsewhere, he speculates on what life must be like for the lunar peoples: "If the moon have no atmosphere the lunar inhabitants must have an immediate transition from the brightest sunshine to the blackest darkness; and thus must be totally destitute of the benefit of twilight"; "There being no atmosphere about the moon, the heavens in the day time have the appearance of night to a lunarian who turns his back towards the sun." When we return to *Eureka,* we find Poe considering other cosmic bodies as habitable: he discusses a being living on the Sun and the events that took place on stars "which interested their inhabitants *ten hundred thousand centuries ago.*"

As much as Poe thought Ralph Waldo Emerson a quack, they did share a belief in life on other worlds. In his sermon *Astronomy,* first given on May 27, 1832, Emerson spoke of how astronomy "demonstrates that whatever beings inhabit Saturn, Jupiter, Herschel [Uranus], and Mercury … they must have an organization wholly different from man." Thus Emerson, like Thomas Dick and many others, believed in the theory of environmental adaptation (God-imposed rather than Darwinian) as applied to extraterrestrial life:

> "The human race could not breathe in the rare atmosphere of the moon; nor the human blood circulate in the climate of Uranus; nor the strength of men suffice to raise his own foot from the ground in the dense gravity of Jupiter.
>
> Each of the eleven globes, therefore, that revolve around the sun must be inhabited by a race of different structure."

Arthur Cushman McGiffert Jr. mentions that Emerson owned an 1814 edition of Fontenell's *Entretiens sur la pluralité des mondes*. Crowe maintains, however, that Emerson may have derived his belief in a plurality of worlds from numerous sources, including William Herschel and Swedenborg.

Perhaps Emerson's belief in extraterrestrials influenced his disciple, Henry David Thoreau. In *Walden* he exclaims, "The stars are the apexes of what wonderful triangles! What distant and different beings in the various mansions of the universe are contemplating the same one at the same moment!" Later, in the chapter *Solitude,* he remarks, "This whole earth which we inhabit is but a point in space. How far apart, think you, dwell the two most distant inhabitants of yonder star, the breadth of whose disk cannot be appreciated by our instruments? Why should I feel lonely? Is not our planet in the Milky Way?" I find it remarkable that in all the references I have found to extraterrestrials in nineteenth-century texts (with the exception of H.G. Wells), no scientist, novelist, or poet ever considers the possibility of *hostile* aliens or the prospect of invasion. They seem to have assumed the benevolence of other galactic inhabitants.

Dugdale attests that that other Transcendentalist poet, Walt Whitman, also believed in extraterrestrial life. The poet "frequently alludes to the 'lives of other globes,' to the 'myriads of myriads that inhabit them,' and to 'All that is well thought or said this day on … any of the wandering stars, or on any of the fix'd stars, by those there as we are here.'" Robert J. Scholnick (1986), in his article *'The Password Primeval': Whitman's Use of Science in 'Song of Myself',* suggests that Whitman may have been influenced in his understanding of the theory of a plurality of worlds by Robert Chambers' *Vestiges of the Natural History of Creation* (1844; see also Crowe's *Extraterrestrial Life Debate* pp. 446-47).

Mark Twain (Samuel Clemens) also made literary use of the theory of pluralism. In *A Curious Pleasure Excursion,* the advertisement mentions "The inhabitants of Stars of the tenth or twentieth magnitude," and publishes a policy toward them:

> "We shall in no case wantonly offend the people of any star, but shall treat all alike with urbanity and kindliness, never conducting ourselves toward an asteroid after a fashion which we could not venture to assume toward Jupiter or Saturn. . . . We shall hope to leave a good impression of America behind us in every nation we visit, from Venus to Uranus."

Clemens (1984) cannot help having a little jibe at the missionary fervour of American Protestantism — and in this way is similar to Herman Melville in his contempt for the arrogance of Christian missionaries: "We shall take with us, free of charge, A Great Force of Missionaries and shed the true light upon all the celestial orbs which, physically aglow, are yet morally in darkness. Sunday schools will be established wherever practicable."

Extraterrestrials are not only alluded to but also appear in Clemens' tale *Captain Stormfield's Visit to Heaven.* While waiting to enter Heaven, Stormfield loses his position in line when "a skyblue man with seven heads and only one leg hopped into my place." Later, Sandy tells the captain about other extraterrestrials — "princes and patriarchs and so on from *all* the worlds that shine in our sky, and from billions more that belong in systems upon systems away outside of the one our sun is in." Some are from Jupiter, for instance, and others from a planet called "Goobra."

The doctrine of the plurality of worlds certainly did not originate in the nineteenth century. In *The Great Chain of Being,* Arthur O. Lovejoy shows that the doctrine is as old as Western philosophy but that it "gained ground" in the sixteenth century and came to be generally accepted by the end of the seventeenth. Lovejoy goes on to provide examples of the many Renaissance thinkers who accepted the notion. Among them is Robert Burton (see the *Second Partition of The Anatomy of Melancholy,* for instance [first edition, 1621]), Michel de Montaigne (*On the Education of Children,* written after 1571) and, of course, the hapless Giordano Bruno, who, in *On the Infinite Universe and Worlds* (1584), envisioned a thickly populated boundless cosmos when Galileo of all people was still adhering to the idea of a finite Universe no bigger than our solar system.

The theory of pluralism is really part of another ancient idea as old as Western philosophy, the Great Chain of Being, according to which the cosmos is chock-full of physical and metaphysical beings, ranging from nonexistence at the bottom of the Chain to the many orders of angels and archangels right up to God at the top. God is thought of as a "Self-Transcending Fecundity" who allowed creation to emanate from himself, and there is no part of the universe devoid of his manifestation. Certainly this concept (which had its inception in Plato and Aristotle), along with natural theology, accounts for the popularity of the doctrine of a plurality of worlds in the nineteenth century. Notice how often the writers whom I have quoted appeal to the idea of a creative God who has adapted all his creatures to the celestial bodies on which they abide — whether stars, comets, frigid gas giants, or searing inner planets. In nineteenth-century America, scientists, writers, and philosophers had not separated astronomy from religion nearly to the extent we have. They supported the theory of extraterrestrials with Christianity and ancient philosophy; we support it with the Drake equation.

Our own astronomical imaginings continue to be influenced by such ancient ideas as pluralism and *something like* the Great Chain of Being is suggested, for instance, by the productions of popular culture — the universe of *Star Trek,* for example! In terms of the history of ideas, is there really anything new under the Sun?

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La trigonométrie sphérique en astronomie

par Raymond Auclair, membre indépendant et à vie, SRAC (auclair@cyberus.ca)

Voici un autre article qui nous invite à feuilleter l'*Observer's Handbook* et à utiliser les données qu'on y trouve. Pour bien profiter de cet article, il faut connaître le sens de certains mots. Nous encourageons le lecteur à consulter un dictionnaire, par exemple, le *petit Larousse illustré,* aux mots suivants: azimut, ascension, cosinus, déclinaison, écliptique, fuseau horaire, hauteur, latitude, longitude, pi, sphère, zénith.

RAPPORTS ANGULAIRES

En page 32 de l'*Observer's Handbook* 2003, sous la rubrique *ANGULAR RELATIONS,* se trouve une liste de relations trigonométriques qui accrochent rarement le regard du lecteur.

2 π radians = 360°

La longueur d'un arc de cercle est souvent donnée en fonction de l'angle au centre qui sous-tend cet arc. Par exemple, l'arc qui représente un quart de cercle mesure 90° puisque l'angle au centre qui le sous-tend vaut 90°. Une circonférence complète vaut 360°.

Le nombre π représente le rapport entre la circonférence et le diamètre (*Circ.* = π × *Diam.*). Puisque le diamètre vaut deux fois le rayon, nous avons *Circ.* = 2 × π × *rayon.*

En mathématiques, nous exprimons les longueurs sur la circonférence en fonction du rayon. Puisque la circonférence mesure 2 × π rayons, l'angle qui sous-tend un arc dont la longueur est égale au rayon vaut 360°/2π, ou 180°/π, c'est-à-dire environ 57,29577951° (57°17´44,8″). Cet angle s'appelle radian. Donc 2 π radians valent 360°.

En astronomie, nous utilisons surtout les degrés. En général, les calculatrices acceptent les angles en degrés. Cependant, pour utiliser certains chiffriers (par exemple, Excel de Microsoft), il faut transformer les angles en radians. Excel utilise la fonction **PI()**, où la parenthèse est vide, pour la valeur de π. Alors, si *x* représente la mesure d'un angle en degrés, il faudra écrire =**SIN(x*PI()/180)** pour obtenir le sinus de l'angle *x*. Aussi, lors des calculs trigonométriques, Excel donne des résultats en radians; il faudra multiplier la réponse (donnée en radians) par **180/PI()** (ou par 57,29577951) pour avoir les angles en degrés.

360° = 24 h, 15° = 1 h,
15´ = 1 min, 15″ = 1 s

En astronomie, certains arcs ou angles sont exprimés en heures. La position des astres sur la sphère céleste est donnée par l'ascension droite (symbole : α — la lettre grecque alpha) et la déclinaison (δ — la lettre grecque delta). La déclinaison (angle entre l'astre et l'équateur céleste) est normalement donnée en degrés.

À cause de la rotation de la Terre, la sphère céleste semble tourner autour de l'observateur. Elle fait un tour en environ 24 heures. En fait, lorsque nous considérons les étoiles dites fixes, elle fait un tour en $23^h56^m04{,}1^s$. Les observatoires se sont dotés d'horloges dont les aiguilles avancent à ce rythme. Ainsi est née l'heure sidérale.

L'ascension droite α des étoiles est mesurée à partir du point vernal, là où l'écliptique croise l'équateur (point où se trouve le Soleil à l'équinoxe du printemps). La position d'un astre est donnée en fonction du cercle horaire qui le traverse. Le cercle horaire passe par l'astre et par les pôles célestes. L'ascension droite de l'astre est l'angle entre le cercle horaire de l'astre et celui qui passe par le point vernal.

Réglons l'horloge sidérale à $0^h00^m00^s$ au moment où le point vernal passe au méridien. Alors, les cercles horaires vont défiler au méridien en accord avec notre horloge sidérale. Par exemple, au moment où Sirius (ascension droite = $6^h45{,}3^m$ selon la page 244 de l'*Observer's Handbook* 2003) passe au méridien, notre horloge sidérale devrait indiquer $6^h45^m18^s$.

C'est de cette façon que l'utilisation des heures pour exprimer des angles s'est implantée. Ainsi, lorsqu'on calcule des angles sur la sphère céleste, il faudra convertir en degrés les coordonnées exprimées en heures. Puisqu'il y a 24 heures dans un cercle (360°), chaque heure vaut 15°. En divisant chaque unité par soixante, nous trouvons qu'une minute vaut 15´ et qu'une seconde de temps vaut 15″ d'arc.

LA SPHÈRE

Une sphère est une surface dont tous les points sont à égale distance d'un point appelé centre. La distance entre le centre et la surface est le rayon.

Sur la sphère, il y a des grands cercles, c'est-à-dire des cercles qui sont centrés sur le centre de la sphère. Forcément, ces cercles ont le même rayon que la sphère.

Sur ces grands cercles, la longueur d'un arc est mesurée en fonction de l'angle au centre qui sous-tend cet arc.

Les longueurs sur un grand cercle terrestre

Les mathématiciens utilisent souvent la longueur du rayon comme unité. Donc ils mesurent les longueurs en radians. Comme on le voit à la figure 1, le radian mesure aussi bien des angles que des longueurs d'arc. Nous pouvons faire de même avec les autres unités qui servent normalement à mesurer des angles.

Les navigateurs utilisent les degrés et les minutes. Il y a 360 degrés dans un cercle et chaque degré compte 60 minutes. Les longueurs sur la Terre peuvent se mesurer en minutes d'arc. La longueur

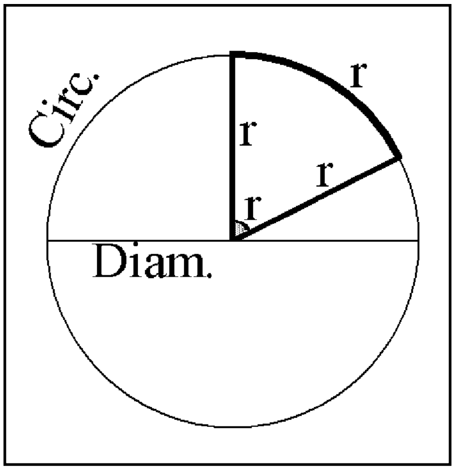

Figure 1. — Le radian et le rayon. L'angle au centre (r) vaut un radian, l'arc qu'il sous-tend vaut donc un radian c'est-à-dire que la longueur de l'arc est égale au rayon (r).

d'un arc qui correspond à un angle au centre de 1´ s'appelle le mille marin. La circonférence de la Terre est donc de 21 600 milles marins (360 × 60).

Lors de la création du système métrique, on a divisé le cercle en 400 grades, puis chaque grade en 100 centigrades. L'angle au centre qui mesure 1 centigrade correspond, à la surface de la Terre, à un arc qui mesure un kilomètre. La circonférence de la Terre est donc de 40 000 km (400 × 100).

Grands cercles et petits cercles

Les grands cercles ont le même centre que la sphère. Ils ont donc tous la même circonférence et l'unité de longueur choisie se mesure de la même façon sur tout grand cercle.

Tous les autres cercles (ceux dont le centre ne coïncide pas avec le centre de la sphère) sont appelés petits cercles; ils ne peuvent pas être directement utilisés dans nos calculs de trigonométrie sphérique. Il faut se limiter aux grands cercles.

Nous savons que la Terre n'est pas une sphère parfaite. Cependant, la précision obtenue dans la plupart des calculs nautiques suffit à la plupart des applications nautiques et astronomiques.

Sur la Terre (sphérique), l'équateur et les méridiens de longitude sont des exemples de grands cercles. Les cercles de latitudes (par exemple, sur un globe terrestre, la ligne qui indique la latitude de 60°) sont des petits cercles.

Sur la sphère céleste, l'équateur, l'écliptique, et les cercles horaires sont des exemples de grands cercles. Un cercle de déclinaison (autre que 0°) est un petit cercle.

Le triangle sphérique

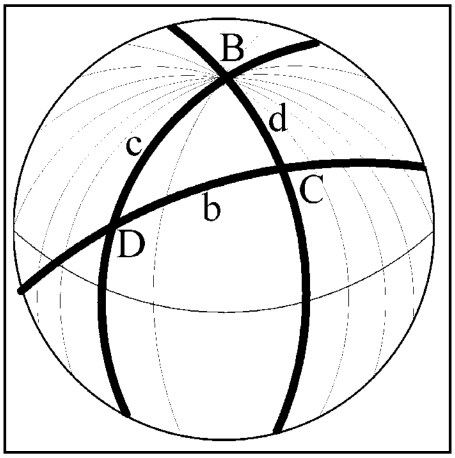

Figure 2. — Le triangle sphérique. Trois grand cercles forment un triangle sphérique BCD. La « longueur » des côtés se mesure en degrés; par exemple, la longueur du côté **c** vaut 90° moins la latitude du point D.

Sur une sphère, traçons trois grands cercles quelconques. Normalement, ces trois cercles forment huit triangles sur la sphère.

Souvent, il n'y a qu'un seul de ces triangles qui nous intéresse. Nous ne dessinons alors que le triangle d'intérêt, sans montrer les autres. Identifions les sommets (les angles) du triangle par des lettres majuscules B, C, et D et les côtés (les arcs) par des lettres minuscules sur l'arc qui fait face à l'angle correspondant : b en face de B, c en face de C, et d en face de D.

Puisque les « côtés » du triangle sont mesurés en degrés, on peut leur appliquer des fonctions trigonométriques. Voyons d'abord la formule du cosinus qui sert dans une majorité de problèmes. Elle est utilisée lorsque nous connaissons un angle et les deux côtés adjacents à cet angle (pour trouver le troisième côté), ou encore lorsque nous connaissons les trois côtés (pour trouver les angles). En permutant les angles et les côtés (mais en conservant la correspondance), nous obtenons trois versions :

$$\cos b = \cos c \cos d + \sin c \sin d \cos B$$
$$\cos c = \cos d \cos b + \sin d \sin b \cos C$$
$$\cos d = \cos b \cos c + \sin b \sin c \cos D$$

Nous omettons le signe de multiplication; cos b cos c veut dire le produit du cosinus de b et du cosinus de c. Il y a aussi la formule du sinus qui lie l'arc avec l'angle qui lui est opposé :

$$\sin b / \sin B \;=\; \sin c / \sin C \;=\; \sin d / \sin D$$

La formule du sinus ne permet pas de distinguer la bonne réponse lorsque la solution est proche de 90° alors que la formule du cosinus ne permet pas de distinguer lorsque la solution est proche de 0° ou 180°. Le deuxième type d'ambiguïté est plus rare en navigation astronomique.

Le sinus et le cosinus sont des fonctions cycliques et symétriques :

$\sin x = \sin(180° - x) \quad \sin x = -\sin(-x)$
$\sin x = -\sin(360° - x)$
$\cos x = -\cos(180° - x) \quad \cos x = \cos(-x)$
$\cos x = \cos(360° - x)$
$\sin x = \cos(90° - x) \quad \cos x = \sin(90° - x)$

La position de l'observateur

Pour utiliser les équations, nous devons connaître notre position en latitude (mesurée à partir de l'équateur) et en longitude (mesurée à partir du méridien zéro, qui passe à Greenwich).

Nous pouvons trouver des positions de plusieurs façons: utiliser un récepteur GPS, faire le point sur une carte appropriée, consulter une liste (comme dans *Norie's*) ou visiter certains sites Web‡.

Pour nos exemples, plaçons-nous

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‡ `www.msc-smc.ec.gc.ca/climate/station_catalogue/index_f.cfm`
inscrire (en regard de *nom de la station*) le nom de la ville ou de l'aéroport d'intérêt, puis un rayon (e.g., 25 km) et le résultat de la recherche est la liste des stations météo avec latitude et longitude

au port de Chicoutimi (48°25´N 71°06´W). Remarquons que les marins donnent la latitude en premier et utilisent la lettre W pour indiquer l'ouest.

Par convention, lorsque cela est nécessaire, une latitude Nord est positive alors qu'une latitude Sud est négative.

La sphère céleste

Sur la sphère céleste, le triangle sphérique qui nous intéresse le plus est celui qui permet de passer du système équatorial (ascension droite et déclinaison) au système horizontal (altitude et azimut, en anglais: *altazimuth*).

La sphère céleste est une sphère de rayon indéterminé centrée sur l'observateur. Imaginons un rayon si grand que le rayon de la Terre, en comparaison, devient négligeable. Ainsi, le centre de la sphère céleste coïncide aussi avec le centre de la Terre.

Représentons la Terre comme une petite sphère orientée de telle sorte que l'observateur soit à la verticale. À partir du même centre, dessinons la sphère céleste beaucoup plus grande. Nous laisserons l'orientation de la Terre immobile par rapport à l'observateur; c'est la sphère céleste qui tournera autour de l'observateur.

Du système équatorial, nous tirons les pôles (là où l'axe de rotation de la Terre rencontre la sphère céleste); le pôle élevé (pour nous, le pôle nord) est identifié par la lettre P. Pour notre observateur maintenant immobile, la sphère céleste semble en rotation autour des pôles célestes. À 90° des pôles, nous avons l'équateur céleste, parfois identifié par la lettre Q.

Lorsqu'un problème n'implique qu'un seul astre, la position de l'astre est indiquée par la lettre X. La déclinaison δ d'un astre est mesurée à partir de l'équateur; sur la figure 3, c'est la distance entre X et l'équateur. Le complément de la déclinaison (90°−δ) s'appelle la distance polaire; sur la figure 3, c'est la longueur de l'arc PX.

Les demis grands cercles qui vont d'un pôle à l'autre sont des cercles horaires et sont identifiés à partir du cercle horaire zéro qui passe par le point vernal. Le cercle horaire qui passe par un astre donne l'ascension droite α de cet astre.

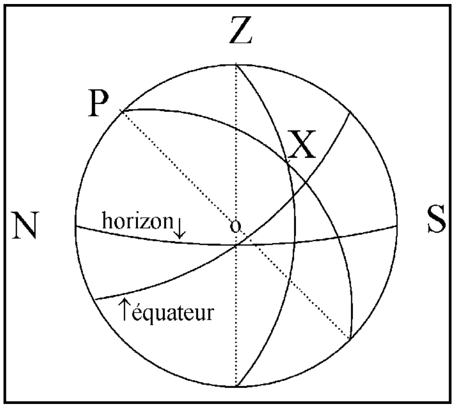

Figure 3. — La sphère céleste. On imagine l'observateur debout sur le « **o** » qui représente la Terre, au centre. L'arc NP est égal à la latitude de l'observateur.

Du système horizontal, nous tirons le zénith, le point situé directement à la verticale de l'observateur; nous l'appelons Z. Par définition, la déclinaison qui correspond à la position de Z est identique à la latitude de l'observateur. À 90° du zénith se trouve un grand cercle qui représente l'horizon. Ce serait l'horizon de l'observateur si la Terre était parfaitement sphérique et lisse, si l'œil de l'observateur était exactement à la surface de la sphère terrestre, et si la réfraction atmosphérique n'existait pas.

LE CALCUL DE LA HAUTEUR

Hauteur et distance zénithale

Un arc de grand cercle partant de Z et perpendiculaire à l'horizon est un vertical (masculin). Le vertical qui passe par le pôle et son prolongement forme le méridien de l'observateur. La partie du méridien entre le pôle élevé, en passant par Z et jusqu'à l'horizon opposé est le méridien supérieur. Pour un observateur en hémisphère nord, c'est la partie du méridien qui va du pôle nord céleste jusqu'à l'horizon au sud. Aux points où il coupe l'horizon, le méridien défini le sud et le nord.

Les verticaux qui, à Z, sont perpendiculaires au méridien se nomment premiers verticaux; ils définissent les directions est et ouest.

Sur le vertical qui passe par l'astre, l'arc entre l'horizon et l'astre (représenté par la lettre minuscule a) est la hauteur. Le complément de a (c'est-à-dire $90°-a$) est la distance zénithale (voir l'illustration HAUTEUR dans le *petit Larousse 2003*).

Le triangle PZX

Avec les points P (pôle), Z (zénith) et X (astre), nous traçons un triangle sphérique sur la sphère céleste.

Identifions les valeurs des angles et des côtés du triangle PZX :

h pour l'angle **h**oraire (l'angle au point P)
φ pour la latitude de l'observateur (le côté PZ vaut 90°-φ)
A pour l'**A**zimut (l'angle au point Z)
a pour la hauteur (le côté ZX vaut $90°-a$)
X pour l'angle au point X (rarement utilisé)
δ pour la déclinaison de l'astre (le côté PX vaut 90°-δ)

L'équation de l'angle horaire : $h = t - \alpha$

L'angle horaire h (aussi appelé angle au pôle) varie constamment. Pour les calculs avec les étoiles (ou tout autre objet fixe par rapport aux étoiles), il varie comme l'heure sidérale t. Si nous avions une horloge sidérale, nous aurions automatiquement la valeur du cercle horaire qui passe au méridien (l'arc PZ). La valeur du cercle horaire qui passe par l'étoile (l'arc PX) est l'ascension droite α de l'étoile. Donc l'angle au pôle est la différence entre ces deux valeurs: $h = t - \alpha$. Si la valeur obtenue est négative, on peut ajouter 24^h pour la rendre positive. Si la valeur dépasse 24^h, on soustrait 24^h pour que la valeur soit entre 0^h et 24^h.

L'ascension droite des étoiles les plus brillantes se trouve aux pages 242 à 250 de l'*Observer's Handbook 2003*. Nous trouvons aussi la valeur α pour d'autres objets d'intérêt aux pages 252 à 296. L'ascension droite du Soleil, à intervalles de quatre journées, se trouve en page 101. Nous verrons plus loin que nous pouvons trouver h autrement, pour le Soleil.

Calcul de l'heure sidérale *t*

Pour trouver l'heure sidérale *t* sans horloge sidérale, on peut utiliser le tableau MEAN SIDEREAL TIME, 2003 à la page 41 de l'*Observer's Handbook 2003*.

Par exemple, trouvons l'heure sidérale à la position donnée plus haut pour Chicoutimi (48°25′N 71°06′W), le 14 novembre 2003, à 21^h24^m, HNE (heure normale de l'est).

À 21^h24^m HNE le 14 novembre 2003, le temps universel (TU) est 2^h24^m (= $\mathbf{2{,}4^h}$) le **15** nov. 2003. La longitude de Chicoutimi (71°06′) correspond à $4^h44^m24^s$ (= $4{,}74^h$) en coordonnées temporelles. Enfin, notons que la correction donnée au tableau pour le 0 novembre est de 2,5926 heures.

Alors, en utilisant les équations données sous le tableau, nous obtenons:

GSMT (heure sidérale à Greenwich)
$= 2{,}5926^h + 0{,}06571\times(15^J) + 1{,}002738\times(2{,}4^h)$
GSMT $= 2{,}5926 + 0{,}9856 + 2{,}4066 = 5{,}9848^h = 5^h59^m05^s$.
LSMT (heure sidérale moyenne locale)
$= 5{,}9848^h - 4{,}74^h = 1{,}2448^h = 1^h14{,}7^m$

Si nous voulons faire des calculs impliquant **Alphératz**, l'étoile la plus brillante d'Andromède, nous trouvons en page 242 de l'*Observer's Handbook 2003:*

$\alpha = 0^h08{,}6^m$ et $\delta = +29°07'$ (c'est-à-dire 29°07′N).
Donc, à 21^h24^m HNE le 14 novembre 2003, l'angle horaire de l'étoile Alphératz est $h = t - \alpha = 1^h14{,}7^m - 0^h08{,}6^m = 1^h06{,}1^m =$ **16°31,5′**

$$\sin a = \sin \delta \sin \varphi + \cos \delta \cos \varphi \cos h$$

En passant du triangle BCD au triangle PZX (voir la figure 4), et en utilisant les symboles correspondants, nous trouvons :

$\cos d = \cos b \cos c + \sin b \sin c \cos D$
$\cos(ZX) = \cos(PX)\cos(PZ) + \sin(PX)\sin(PZ)\cos P$
$\cos(90°-a) = \cos(90°-\delta)\cos(90°-\varphi) + \sin(90°-\delta)\sin(90°-\varphi)\cos h$
$\sin a = \sin \delta \sin \varphi + \cos \delta \cos \varphi \cos h$

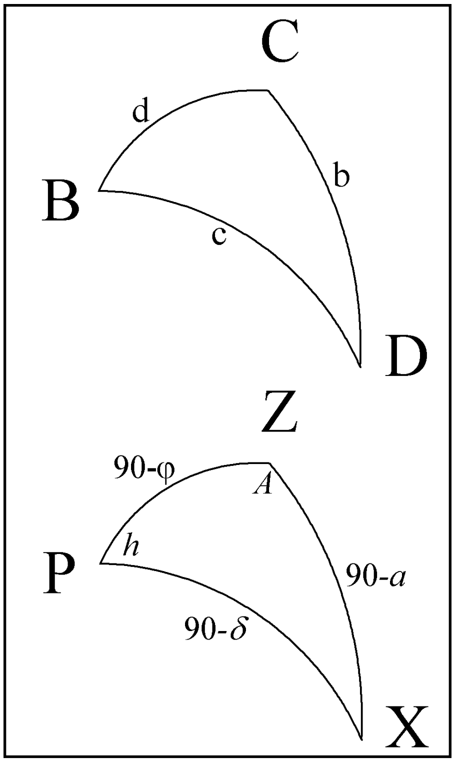

Figure 4. — Le triangle PZX. En faisant correspondre les éléments des deux triangles (BCD ⟶ PZX) on peut reformuler les formules trigonométriques appropriées

Poursuivons notre exemple où nous voulons connaître la hauteur d'Alphératz (α And) à 21^h24^m HNE le 14 novembre 2003, pour un observateur situé au port de Chicoutimi.

$\sin a = \sin 29\,07' \sin 48°25' + \cos 29°07' \cos 48°25' \cos 16°31{,}5'$
$\sin a = 0{,}363965 + 0{,}555886 = 0{,}919851$
$a = 66{,}90434° = 66°54'16''$

Notons qu'un angle de 113°05′44″ a le même sinus que 66°54′16″. Notons aussi qu'en tournant le dos à l'étoile, nous pouvons compter 90° de l'horizon au zénith, puis ajouter la distance zénithale de 23°05′16″ pour nous retrouver au même point X. Donc les deux réponses sont bonnes (66,9° et 113,1°), il s'agit de choisir celle qui nous est utile.

Le Soleil

Dans le cas du Soleil, il existe des raccourcis. L'angle au pôle *h* du Soleil change de 15° par heure. L'angle *h* vaut 0° au moment du passage au méridien (*transit* en anglais). Si nous savons à quelle heure précise *h* = 0°, alors il devient facile de calculer *h* pour toute heure de la journée.

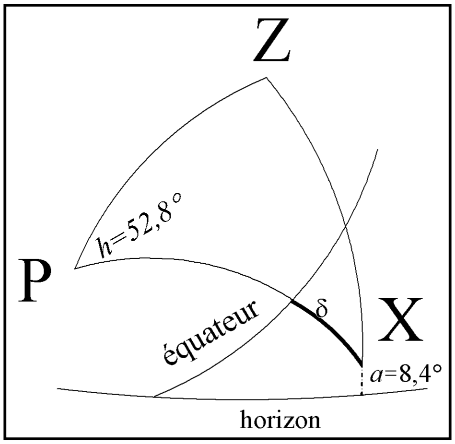

Figure 5. — Le triangle PZX pour le Soleil vu de Chicoutimi, le 14 novembre 2003, à 15^h HNE.

Les éphémérides du Soleil

À la page 101 de l'*Observer's Handbook 2003,* nous trouvons les éphémérides du Soleil pour l'année. La colonne *Transit* donne l'heure (en TU) du passage au méridien à Greenwich à intervalles de 4 journées. Nous devons interpoler.

Par exemple, le passage au méridien du Soleil le 13 novembre 2003 a lieu (à Greenwich) à $11^h44^m13^s$, et le 17 novembre à $11^h44^m53^s$. Le taux est de 10 secondes par jour.

Le passage au méridien à Greenwich du 14 novembre est donc prévu pour $11^h44^m23^s$. La longitude de Chicoutimi (71°06′W) correspond à $4^h44^m24^s$ en coordonnées temporelles. Pour les calculs impliquant le soleil, on peut utiliser directement cette valeur et conclure que le Soleil passe au méridien à Chicoutimi exactement $4^h44^m24^s$ après avoir passer au méridien à Greenwich. $11^h44^m23^s + 4^h44^m24^s = 16^h28^m47^s$ (TU) donc à $11^h28^m47^s$ HNE (écart de 5^h en hiver, 4^h en été).

Pour un excès de précision, nous pourrions ajouter que $4^h44^m = 0{,}2^J$ environ. Puisque le taux de changement est de 10^s par journée, il faut ajouter 2 secondes de temps.

Donc, le 14 novembre 2003, au port de Chicoutimi, *h* vaut 0° à $11^h28^m49^s$ HNE.

Si nous voulons déterminer la hauteur

du Soleil à 15^h (HNE) le 14 novembre, nous pouvons directement calculer $h = 15^h - 11^h28^m49^s = 3^h31^m11^s \equiv 52°47'45'' \approx 52{,}8°$.

Après *h*, trouvons δ, puis la hauteur *a*

Le tableau de la page 101 donne δ à 0^h TU le 13 novembre (17°47´S) puis à 0^h le 17 novembre (18°49´S), un intervalle de $4{,}0^J$; nous voulons connaître δ à 20^h TU le 14, c'est-à-dire $1{,}8333^J$ après 0^h le 13. Durant l'intervalle de 4^J, δ grandit de 62´ vers le Sud. Nous ajoutons la correction $(62' \times (1{,}83333 / 4) = 28{,}4')$ à la valeur donnée pour 0^h le 13 (17°47´S). La déclinaison du Soleil à 20^h TU (15h HNE) le 14 novembre est $\delta = 18°15{,}4'$S.

Nous pouvons maintenant calculer la hauteur du Soleil à 15^h HNE le 14 novembre 2003, pour un observateur situé au port de Chicoutimi.

$$\sin a = \sin \delta \sin \varphi + \cos \delta \cos \varphi \cos h$$
$$\sin a = \sin(-18°15{,}4') \sin 48°25' + \cos(-18°15{,}4') \cos 48°25' \cos 52{,}8°$$
$$\sin a = -0{,}23433 + 0{,}38108 = 0{,}14675$$
$$a \quad = 8{,}43875° = 8°26{,}3'$$

LE CALCUL DE L'AZIMUT

Définition(s)

L'azimut d'un astre indique la direction vers laquelle il faut regarder pour faire face à cet astre. Les navigateurs mesurent l'azimut en degrés en partant du nord et en tournant vers la droite. Il est convenu d'utiliser une représentation à trois chiffres. Ainsi, la direction nord est indiquée par 000°, l'est par 090°, le sud par 180°, l'ouest par 270°, le nord-ouest par 315° et ainsi de suite jusqu'à ce que nous revenions au nord où le compas passe de 359° à 000°.

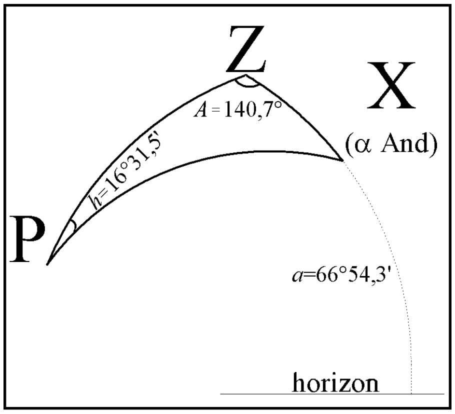

Figure 6. — Le triangle PZX pour Alphératz vue de Chicoutimi, le 14 novembre 2003 à 21^h24^m HNE.

L'azimut est aussi l'angle *A* au point *Z* (zénith de l'observateur) entre le méridien de l'observateur et le vertical de l'astre. Quand la formule du sinus ne distingue pas le nord du sud, les navigateurs utilisent la formule du cosinus à partir du pôle élevé (en hémisphère nord, le pôle nord).

La formule du sinus : $\cos \delta \sin h = -\cos a \sin A$

Une façon d'éviter les ambiguïtés est d'utiliser des signes (+ –). Puisque l'azimut est mesuré à partir du nord, la latitude et la déclinaison sont positives au nord et négatives au sud. Quant à l'angle horaire *h*, l'*Observer's Handbook* utilise une convention faisant en sorte que *h* soit positif vers l'ouest; une valeur *h* entre 0^h et $+12^h$ indique que l'astre est à l'ouest du méridien.

Cependant, l'azimut augmente positivement vers l'est et une valeur A entre 001° et 179° indique que l'astre est à l'est. Voilà pourquoi il faut un signe – dans cette première équation.

Mais d'où vient cette équation? De la formule du sinus: $\sin D / \sin d = \sin B / \sin b$.

Dans le triangle PZX, l'angle *h* est au pôle et fait face à la distance zénithale (90°-*a*) ; l'angle *A* est au zénith et fait face à la distance polaire de l'astre (90°-δ). Nous avons donc le rapport suivant :

$$\sin h / \sin(90°-a) = \sin A / \sin(90°-\delta)$$

Éliminons les fractions pour obtenir: $\sin(90°-\delta) \sin h = \sin(90°-a) \sin A$.
Puisque $\sin(90°-x) = \cos x$, nous avons $\cos \delta \sin h = \cos a \sin A$.
Et puisque l'angle *A* est mesuré du nord vers la gauche quand *h* est positif, alors il faut un signe.
Ainsi, nous avons retrouvé l'équation de l'*Observer's Handbook:* $\cos \delta \sin h = -\cos a \sin A$.
Pour calculer l'azimut *A*, nous isolons sin *A*:

$$\sin A = \cos \delta \sin h / -\cos a$$

Pour Alphératz (à 21^h24^m HNE le 14 nov. 2003) nous avons:

$\delta = 29°07'$N (nord, donc positif);
$h = 16°31{,}5'$ (positif, donc vers l'ouest),
$a = 66°54{,}3'$ (positif, donc au-dessus de l'horizon)
$\sin A = \cos \delta \sin h / -\cos a$
$\sin A = \cos 29°07' \sin 16°31{,}5' / -\cos 66°54{,}3'$
$\sin A = -0{,}633488 \Rightarrow A = -39{,}3°$

Puisque *A* est négatif, nous savons que l'angle de 39,3° sera mesuré vers l'ouest, mais nous ne savons pas si nous devons le mesurer à partir du nord (360°–39,3° = 320,7°) ou à partir du sud (180° + 39,3° = 219,3°). Nous pourrions vérifier sur un cherche-étoiles (comme le font les navigateurs), mais notre curiosité mathématique l'emporte.

La formule du cosinus: $\sin \delta = \sin a \sin \varphi + \cos a \cos A \cos \varphi$

Nous pouvons choisir le pôle à partir duquel sont mesurées la co-latitude de l'observateur et la distance polaire (90°–δ). La formule du cosinus donne toujours un angle *A* mesuré à partir de ce pôle. Cependant, elle ne permet pas de distinguer si l'angle est vers l'est ou vers l'ouest.

Prenons la version appropriée de la formule du cosinus:

$$\cos b = \cos c \cos d + \sin c \sin d \cos B$$
$$\cos(90°-\delta) = \cos(90°-\varphi) \cos(90°-a) + \sin(90°-\varphi) \sin(90°-a) \cos A$$
$$\sin \delta = \sin \varphi \sin a + \cos \varphi \cos a \cos A.$$

On peut changer l'ordre des facteurs sans changer la valeur des termes, pour retrouver l'équation telle qu'elle est présentée dans l'*Observer's Handbook*.

$$\sin \delta = \sin a \sin \varphi + \cos a \cos A \cos \varphi$$

L'azimut d'Alphératz

Puisque nous cherchons la valeur de l'angle *A*, nous devons isoler cos *A*:

$$\cos A = (\sin \delta - \sin a \sin \varphi) / (\cos a \cos \varphi)$$

Pour Alphératz, nous avons:

$\delta = 29°07'$N (nord, donc +);
$\varphi = 48°25'$N (nord, donc + ; A sera compté à partir du nord)
$a = 66°54{,}3'$ ($a > 0$, donc au-dessus de l'horizon)
$\cos A = [\,\sin 29°07' - \sin 66°54{,}3' \sin 48°25'\,] / [\,\cos 66°54{,}3' \cos 48°25'\,]$
$\cos A = -0{,}77380 \Rightarrow A = 140{,}7$

Ce qui pourrait être N140,7°E = 140,7° ou N140,7°W = 219,3°. Heureusement, nous avons déjà deux indications que l'angle doit être compté vers l'ouest:

1. l'angle horaire h est positif et inférieur à 12^h ou 180° (donc l'astre est à l'ouest), et
2. l'équation précédente (grâce au truc du signe) nous donne deux réponses à l'ouest du méridien.

Nous concluons que l'azimut d'Alphératz est de 219,3°, ce qui correspond à un des deux choix calculés plus haut.

CONCLUSION

Les équations données au milieu de la page 32 de l'*Observer's Handbook 2003* montrent les rapports qui existent entre les angles et les côtés du triangle sphérique PZX. Elles nous permettent de passer du système équatorial au système horizontal, et vice-versa.

Nos exemples nous ont montré une direction de calcul, mais les équations peuvent aussi nous faire passer dans l'autre direction. Il arrive que le navigateur ait à identifier un astre observé au sextant. Au moment de faire le point, le ciel doit être assez clair pour que l'horizon soit clairement visible. Il arrive alors qu'il n'y ait que trois ou quatre étoiles de visibles, ce qui peut rendre leur identification difficile. Le navigateur observe la hauteur avec son sextant puis détermine l'azimut approximatif (au degré près) avec l'alidade du compas. À partir de ces valeurs pour a et A, le navigateur calcule des valeurs approximatives pour α et δ, qui permettent d'identifier l'astre.

Ces calculs peuvent sembler longs et ardus. Avec le temps (et avant l'invention des calculatrices), des raccourcis et des cas spéciaux ont permis d'utiliser ces équations avec beaucoup plus de facilité. C'est ce que nous verrons lors d'un prochain article.

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webpublic.ac-`dijon.fr/pedago/physique/astronomie/lexique_astronomique` site Web de Michel Bonin (académie de Dijon); le dessin de la figure 3 est inspiré de ceux trouvés sous la rubrique « coordonnées célestes.»

L'auteur est membre de la Société royale d'astronomie du Canada (SRAC) depuis 1969. Il a été officier de navigation maritime à bord des navires de la Garde côtière canadienne, professeur à l'Institut de formation de Transports Canada, puis doyen des sciences nautiques au Collège de la Garde côtière. Il a enseigné la navigation astronomique, c'est-à-dire l'utilisation de l'astronomie pour déterminer la position du navire. Toujours à l'emploi de Transports Canada (loi et règlement sur le transport des marchandises dangereuses), il dit se préparer pour une retraite prochaine. En plus de son diplôme en sciences nautiques du collège de la Garde côtière, il détient un Baccalauréat ès Arts général (littérature française,) et un B.A. avec concentration en mathématiques. Il va bientôt compléter un B.A. avec spécialisation en mathématiques. En 1989, il a reçu la médaille du service (Service Award) de la SRAC et a été Secrétaire national de la SRAC de 1997 à 1999. Il est aussi membre de la Société d'astronomie de Montréal où il a été conseiller au début des années quatre-vingt.

SUMMARY

This article uses basic equations from spherical trigonometry to show how to derive the equations given on page 32 of the RASC *Observer's Handbook 2003*, under the heading ANGULAR RELATIONS. Two examples (one with a star, one with the Sun) show how to calculate altitude and azimuth; sources for intermediate values such as hour angle, position, sidereal time, and declination are also discussed. One example (calculating the azimuth of α And) shows the difference in the possible errors that may stem from the sine formula and the cosine formula.

A secondary objective is to help French speaking amateur astronomers to make better use of the *Observer's Handbook*. In addition, the introduction reminds the reader that at least one dictionary provides clear illustrations of many basic astronomical terms. The website given in the last entry of the bibliography is a good source of descriptive information for more advanced terminology in French.

The author has been a member of the RASC since 1969. After working as a marine navigation officer, he has taught nautical astronomy (the use of astronomy in marine navigation) and was a dean of Nautical Science. In addition to his Coast Guard College degree in Nautical Science, he holds a B.A. (French Literature) and a B.A. with concentration (mathematics); he is completing a B.A. with Honours (mathematics). He received the RASC Service Award in 1989 and served as National Secretary of the RASC in the late nineties. He still works for Transport Canada (Transportation of Dangerous Goods) and claims to be preparing for retirement.

Martian Discoveries

by David M.F. Chapman (dave.chapman@ns.sympatico.ca)

Every two years plus two or three months, the planet Mars passes through opposition, the point at which it is opposite the Sun in the sky along the ecliptic. Near this time it also has a closest approach to our planet and Earthlings have a better-than-average view of the Red Planet. (One is tempted to say the same thing in reverse about Martians, but read on.) Several discoveries have been made during oppositions of Mars, and the carmine brilliance of the planet at the nearest approaches has inspired wonder and fear.

First some basic facts: it is a peculiarity of orbital motion that we least often encounter the planets closest to us, that is, Venus and Mars. The formula for the synodic period T_s of two planets is:

$$\frac{1}{T_s}=\frac{1}{T_1}-\frac{1}{T_2}$$

where $T_1$is the shorter period and T_2 is the longer. Strictly speaking, this formula is only exact for two planets in uniform circular motion in the same plane, but it is a reasonably accurate estimate for planets in elliptical orbits with low inclination, in most cases. For the languid outer planets Jupiter, Saturn, Uranus, Neptune, and Pluto, the synodic periods relative to Earth are just over a year, the longest being a year plus 34 days in the case of Jupiter. For fleet-footed Mercury, who speeds around the Sun in 88 days, the mean time between inferior conjunctions is 116 days.

Venus is the major planet that comes closest to us, the mean approach distance being 0.277 Astronomical Units (AU). However, her sidereal period of nearly 8/13 year means that Venus only laps Earth every 584 days, almost exactly 1 3/5 years. However, Venus is shrouded in clouds, so there is very little to see at any time. Even if there were no clouds, Venus shuns Earth at inferior conjunctions by turning her back (or unlit side) to us each time.

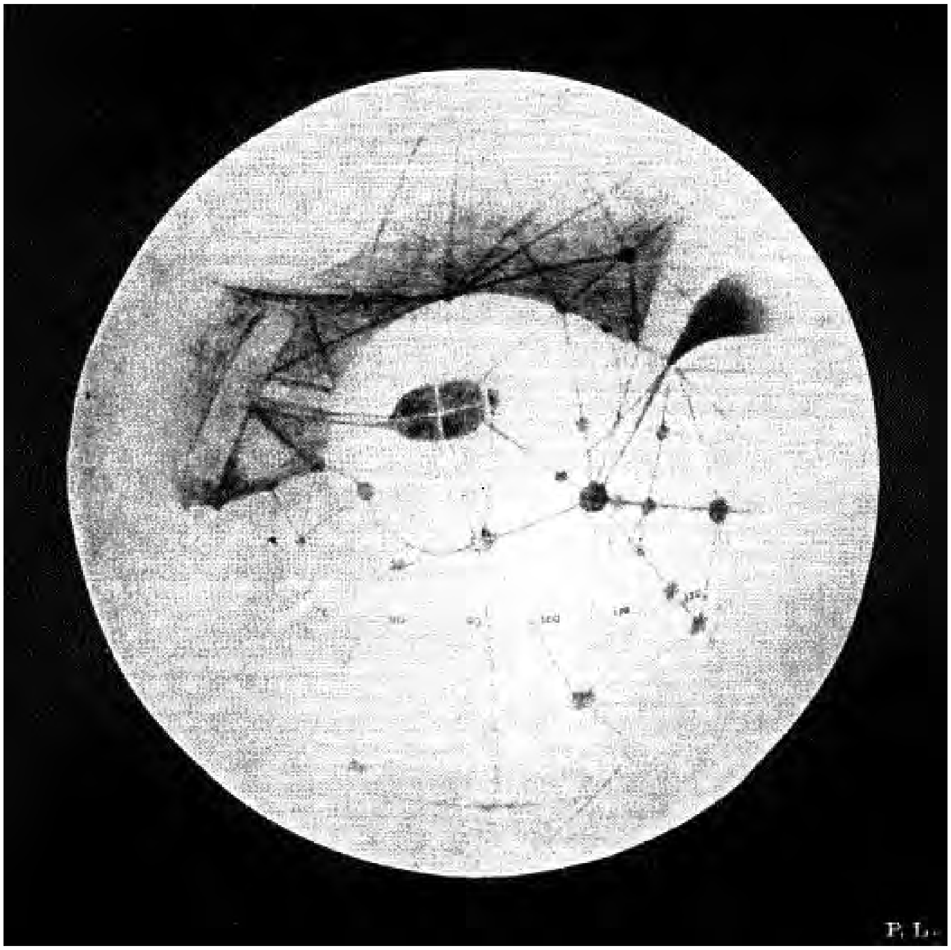

Figure 1. — One of Percival Lowell's fanciful sketches of Mars, showing "canals" with vast lakes at their intersections.

Things brings us to Mars, the next closest planet. In his case, he is in the outer lane with sidereal period 687 days, so Earth catches up with Mars only every 780 days, that is, 2 years and 50 days. The eccentric nature of the orbit of Mars has two consequences. Firstly, the time between oppositions is highly variable, being as much as one month off the mean period of 780 days. Secondly, as pointed out by Bruce McCurdy in his April 2003 *JRASC* "Orbital Oddities" column, the distance of closest approach is also variable, ranging from "far" closest approaches of about 0.68 AU to "near" closest approaches of about 0.37 AU. These nearest approaches have been dubbed "perihelic oppositions." The "distant" closest approaches occur in late winter (typically February) while the "near" closest approaches take place in late summer (typically August). This year's perihelic opposition on August

27, 2003 is the closest approach in recorded history.

The variability of Martian oppositions is remarkable: almost a factor of two in diameter and a factor of four in brightness, which translates into 1.5 stellar magnitudes. Late this summer, Mars is more than a magnitude brighter than Jupiter, yet a magnitude dimmer than Venus; unfortunately, both of these fellow travellers will not be seen in a dark sky. This summer, Mars will be the most prominent celestial object after the Sun and the Moon.

Almost all of the important observations of Mars have been made around the time of opposition, and some significant ones took place during perihelic oppositions. The Danish astronomer Tycho Brahe (1546–1601) recorded the positions of the stars and visible planets with great precision, but he was particularly interested in Mars because of its anomalous orbit, which defied his theoretical analysis. He observed and recorded positions of Mars at ten oppositions during 1576-1596, including two perihelic oppositions.

Brahe himself was never able to solve the puzzle, but Johannes Kepler (1571–1630) was able to put these observations to very good use. Using the positions of Mars at multiple oppositions, Kepler deduced that the orbit of Mars was an ellipse with the Sun at one focus, and that Mars moved along the ellipse nonuniformly. (Kepler expressed this by saying the line joining the Sun and Mars sweeps out equal areas in equal time. Today we recognize this as conservation of angular momentum.) These two laws of planetary motion (and a later third law) proved to be universal, although Kepler never understood the fundamentals of dynamics and gravitation that governed them.

Up to that time, the planets were simply wandering points of light to Earthbound observers, but the telescope changed that. During the months preceding and following the opposition of 1610, Galileo (1564–1642) observed gibbous phases of Mars, much like those of the Moon before and after Full Moon. At the opposition of 1659, Christiaan Huygens (1629–1695) observed a persistent mark on the surface of Mars (the V-shaped plateau Syrtis Major). By observing its comings and goings, he estimated the rotation period of Mars to be about the same as Earth: 24 hours. During the opposition of 1666, Giovanni Cassini (1625–1712), presumably using a better telescope, estimated the rotation period to be 24 h 30 m, and conclusively observed the polar caps.

During the perihelic opposition of 1719, a new chapter in the history of Mars began. Mars was so bright and red, people mistook it for a sinister red comet destined for Earth, and widespread fear and panic ensued. Since that time, the history of Mars has been a mixture of fact and fiction, observation tainted by wishful thinking, and scientific study mixed up with hysteria and quackery. The public — and some astronomers — did not know what to think! Some of these attitudes persist in modern times.

There has been much speculation about life on Mars, and in the early 19th century, Karl Gauss (1777–1855) and others proposed signaling to the inhabitants of Mars during opposition by lighting fires in uninhabited places such as the Sahara desert. (Remember, for the Martians, Earth would be at inferior conjunction, with our dark side facing Mars.) In 1877 Giovanni Schiaparelli (1835–1910) convinced himself he saw "canals" on Mars. Schiaparelli interpreted these markings as natural, not artificial. The possibility of intelligent life on Mars captured the imagination of the public and several astronomers. Percivall Lowell (1855–1916), a wealthy and educated young man from Boston, became so enthralled with this idea that he built a major observatory at Flagstaff, Arizona to observe Mars. He observed at several oppositions between 1896 and 1916, including the perihelic opposition of 1909. He wrote extensively about his ideas, and there is no doubt that he is the patron saint of the intelligent-life-on-Mars followers. These "observations" of canals were eventually proven to be illusions, but it took considerable time to dispel the myth, which was only laid to rest with the Mariner space probes of the 1960s. On a positive note, Lowell Observatory became a leading centre of planetary observation and research.

Meanwhile, serious astronomy was being done at perihelic oppositions. Wilhelm Beer (1797–1855), another independently wealthy astronomer, and his co-worker Johann Madler (1794–1874) produced the first good charts of Martian features in September 1830. (They reported no canals.) In September 1877 (when Schiaparelli was focusing on canals) Asaph Hall (1829–1907), observing with the new 26-inch refractor at the U.S. Naval Observatory, discovered Phobos and Deimos, the elusive satellites of Mars. In August 1892, William H. Pickering (1858–1938) observed features within the bright areas on Mars, putting an end to the "Martian seas" hypothesis. Also in 1892, Edward E. Barnard (1857–1923) observed craters on Mars, but did not have the confidence to publish his results. (The existence of craters was finally confirmed in 1965 by the Mars probe Mariner 4.)

Returning to the question of life on Mars, the idea was given a considerable boost when French astronomer M. Javelle announced he had seen bright flashes on Mars in 1894. This, combined with the claims of Schiaparelli and Lowell, may have inspired H.G. Wells to write *The War of the Worlds* in 1898. This account of the arrival of unfriendly Martians and their surprising demise became a classic of science fiction and set the tone for much of 20th century pop culture concerning Martians. (Well, Mars is the God of war!) U.S. actor Orson Welles turned the novel into a "reality radio" broadcast on October 30, 1938, with the setting moved from Britain to America. Welles' mock radio documentary actually convinced listeners that a Martian invasion was underway and thereby caused widespread panic. A Hollywood film was made in 1953; it received an Academy Award for Special Effects. I hear that a remake is nearly ready for release . . .

I hope I have convinced you that oppositions of Mars are worthy of note. The exceptional perihelic oppositions take place only every 15-17 years, so the typical Earthling only has 5-6 opportunities to get a really good look at Mars. Don't waste this one!

David (Dave XVII) Chapman is a Life Member of the RASC and a past President of the Halifax Centre. By day, he is a Defence Scientist at Defence R&D Canada–Atlantic. Visit his astronomy page at `www3.ns.sympatico.ca/dave.chapman/astronomy_page.`

Pluto's Expanding Atmosphere

by Leslie J. Sage (l.sage@naturedc.com)

Most astronomers, both amateur and professional, are aware that Pluto is moving relatively rapidly out from the Sun in its orbit; for the years 1979-1999 it was inside Neptune's orbit, but for the last four years it has again been the planet most distant from the Sun. As it moves outward, the amount of sunlight that reaches its surface decreases, so its surface will cool. The discovery by Jim Elliot of MIT and Bruno Sicardy of the Observatoire de Paris and their respective collaborators that Pluto's atmosphere is expanding, rather than contracting, therefore is quite surprising (see the 10 July 2003 issue of *Nature*).

Pluto was strongly suspected of having some kind of an atmosphere when spectroscopic measurements revealed the presence of solid methane on its surface, because there will be an equilibrium between the solid methane and gas above it. Astronomers expected that the methane would be accompanied by other gases, which were subsequently identified as nitrogen (which dominates) and carbon monoxide. But it is very difficult to study Pluto — even using the Hubble Space Telescope it is only about 5 pixels wide on the planetary camera. And it is the one major body in the Solar System that has never been visited by a spacecraft (though a flyby mission is now in the construction phase).

A very good way to study Pluto's atmosphere is to use a background star as a probe, during an occultation of the star by the planet. Because the star is a point source of light, a profile of the atmosphere can be built up as the planet passes in front. If there were no atmosphere the star would simply wink out as the edge of the planet passed in front of it, but with an atmosphere there will be a gradual dimming as the starlight has to go through the thicker gas closer to the surface.

An occultation in 1988 revealed a "kink" in the light curve that was interpreted as either a layer of haze, or a sharp inversion layer 20-50 km above the surface. Numerous other attempts to observe occultations since then have failed. The first successful ones occurred on July 20 and August 21, 2002, with the best data being obtained from several telescopes on Mauna Kea on August 21. The "kink" seen in the 1988 data is absent from the 2002 data, which means that there was some kind of rather large change in Pluto's atmosphere during the intervening time.

Further analysis of the data reveals that Pluto's atmosphere has expanded since 1988. This is surprising because there have been predictions of an overall "collapse" of the atmosphere: the gases will freeze out as the planet moves farther from the Sun and cools.

There is, however, a model of seasonal fluctuations of Pluto's atmosphere that does accommodate the data. Candice Hansen of the Jet Propulsion Laboratory and David Paige of UCLA proposed in a 1996 *Icarus* paper (volume 120, p 247) that there would be a portion of Pluto's orbit — shortly after perihelion — when the sublimation of the frozen gases around the north polar cap would proceed more rapidly than the freezing out of the atmosphere in the southern hemisphere. This is happening because Pluto's north pole is now being illuminated by the Sun after a relatively short "northern winter." The upshot is that after perihelion Pluto's atmospheric pressure will reach a peak. This model has been less successful in explaining the changes in Pluto's albedo (the amount of light reflected from the surface) though, so Elliot and Sicardy are cautious in adopting this as the explanation. Although it sounds trite, more data are necessary.

The current plan for the Pluto mission (named "New Horizons") calls for launch in 2006 and a flyby of Pluto in 2015 (or 2016, depending on the path selected). Once the spacecraft is less than 75 days from Pluto the resolution of its camera will exceed the resolution achieved by the HST. The head of the team, Alan Stern, wrote a very nice article about the mission for the May 2002 issue of *Scientific American.*

Some very alert readers of my column who compare it with the original *Nature* papers will notice that where I talk about Pluto's north pole, Elliot and Sicardy talk about the south pole. That difference comes about because there actually is a debate about which of Pluto's poles is north. The *Observer's Handbook* lists Pluto's inclination as 123 degrees (Earth's inclination is 23.4 degrees) — that means that its north pole actually points south of the plane of the Solar System. The assumption in the definition of that inclination is that north is uniquely determined by the spin of the body in relation to the general orbital motion of the rest of the planets. That sounds obscure, so let's make it more concrete. Hold your right hand in front of you, with the thumb pointing straight up. Now curl your fingers naturally into your palm. The direction your thumb is pointing represents north in the Solar System, and the curling of your fingers the direction in which the planets orbit the Sun. Now tilt your thumb so that it's pointing about 33 degrees below horizontal (towards the ground, at an angle) — that's Pluto's north pole, according to the convention used in the *Observer's Handbook*. Do you see the problem? Pluto's south pole is pointing more towards the Solar System's north than is its other pole. This ambiguity has led the International Astronomical Union to specify that a north pole must always be above the plane of the Solar System (and so in general agreement with the Solar System north) — this is the convention used by Elliot and Sicardy. But most of the papers written about Pluto (in particular the one by Hansen & Paige) use the same definition as the *Observer's Handbook*.

Some readers may remember a controversy about Pluto from several years ago: is it a planet? At the time, Harvard astronomer Brian Marsden proposed that Pluto be reclassified as a Kuiper belt object (KBO). The Kuiper (pronounced "kwiper") belt is a collection of rocky/icy objects beyond Neptune's orbit — the first official KBO was found only in 1992. The popular press — and some astronomers — reacted with horror to the suggestion that Pluto might not be a planet. The controversy was quite entertaining for those of us who were not directly involved, but opinion in the astronomical community has since swung firmly behind the view that Pluto (and its moon Charon) simply are the largest Kuiper belt objects. That position as a special case of a Kuiper belt object is being recognized by continuing to call Pluto a planet, so that textbooks do not have to be revised, but it isn't a planet in the same sense that Earth, Mars, *etc.*, are planets. Rather, it's more likely the biggest leftover from the time of planetary formation. Stern's mission to Pluto will also target at least one other KBO, so that more direct comparisons can be made. I wish we didn't have to wait till 2015 to learn more about Pluto, but it takes a long time for a spacecraft to travel over 5-billion kilometres from the Sun.

Dr. Leslie J. Sage is Senior Editor, Physical Sciences, for Nature Magazine *and a Research Associate in the Astronomy Department at the University of Maryland. He grew up in Burlington, Ontario, where even the bright lights of Toronto did not dim his enthusiasm for astronomy. Currently he studies molecular gas and star formation in galaxies, particularly interacting ones.*

FROM THE PAST AU FIL DES ANS

THE RIDDLE OF MARS

During the coming summer the planet Mars will be a very prominent feature of the heavens. As shown by the diagram on page 23 of the Handbook, its distance from the earth on April 15 will be 101,441,000 miles, and this will steadily diminish until on August 22 it will be only 34,648,000. This is an exceptionally close approach, and the planet will then have a stellar magnitude of –2.7, or a brightness nearly three times that of Sirius.

Many will peer into the face of the ruddy warrior in the hope of solving the puzzle of his wrinkles, and it is to be hoped that fresh information regarding their significance will be secured. Of late nothing has been heard regarding the proposal to utilize a mineshaft in South America as a tube of a reflecting telescope in which the mirror will be the surface of rotating mercury. This is a visionary scheme, and if funds are available for scientific investigation it would be much better to spend them upon projects which can be carried out successfully.

by C.A. Chant,
from *Journal*, Vol. 18, pp. 124, March, 1924.

HELIOCENTRIC CONJUNCTIONS OF JUPITER, SATURN, URANUS, AND NEPTUNE

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Abstract. In order to study the gravitational interactions of the four outer planets, the dates and longitudes of heliocentric conjunctions of Jupiter, Saturn, Uranus, and Neptune from 1800 to 2032 were calculated. The intervals between conjunctions of pairs of planets were determined and series of conjunctions were analysed. The mean period of 14 conjunctions of Jupiter and Neptune is 178.95 years, of 13 conjunctions of Jupiter and Uranus is 179.55 years, of 9 of Jupiter and Saturn is 178.73 years, of 5 of Saturn and Neptune is 179.35 years, of 4 of Saturn and Uranus is 181.44 years and of 1 of Uranus and Neptune is 171.44 years. A periodicity of about 179 years is evident.

Résumé. Afin de pouvoir étudier les relations gravitationnelles entre les quatres planètes extérieures, les dates et les longitudes des conjonctions héliocentriques de Jupiter, Saturne, Uranus et Neptune, entre 1800 et 2032, ont été calculées. Les intervalles entre les conjonctions de paires de ces planètes ont été établis et ces séries de conjonctions ont été analysées. La période moyenne des 14 conjonctions de Jupiter et Neptune est de 178,95 années ; des 13 conjonctions de Jupiter et d'Uranus est de 179,55 années ; des 5 conjonctions de Saturne et de Neptune est de 179,35 années ; des 4 conjonctions de Saturne et d'Uranus est de 181,44 années ; et de la seule conjonction d'Uranus et de Neptune est de 171,44 années. Il est donc clair qu'il existe une périodicité de quelques 179 années.

1. Introduction

From 1981 to 1989, the *Voyager II* spacecraft visited Jupiter, Saturn, Uranus, and Neptune using a trajectory such that each planet accelerated the probe to the next more distant planet. The "Grand Tour," as the trajectory was called, was possible because all four planets were catching up to each other. This alignment is rare, occurring "once-in-176-years" according to one source (Morrison 1999) or "only once every two centuries" according to another (Moore 2002).

The sidereal periods of revolution of each of the four planets are approximately related: 15 orbits of Jupiter total 177.9 years, 6 orbits of Saturn equal 176.5 years, 2 orbits of Uranus add up to 167.5 years, and Neptune's sidereal period is 163.7 years.

A heliocentric conjunction of Uranus and Neptune is, likewise, a rare event. Two planets are in heliocentric conjunction when they and the Sun are in line, *i.e.* the planets have the same longitude. The closest approach of Uranus and Neptune in April 1993 was a consequence of the alignment that made the "Grand Tour" feasible. Their previous opposition occurred 172 years earlier in September 1821.

These facts suggest that a study of the dates and longitudes of heliocentric conjunctions of Jupiter, Saturn, Uranus, and Neptune during the corresponding time period would be useful.

2. Method

H.M. Nautical Almanac Office (1933, 1939, 1958, 1979, 1983, 2001) has prepared six volumes of coordinates covering 220 years in *Planetary Coordinates for the Years (1800–1940, 1940–1960, 1960–1980)* and *Planetary and Lunar Coordinates for the Years (1980–1984, 1984–2000, 2000–2020)*. The tables of coordinates for the years 1800–1984 are referred to the epoch of 1950.0 and those for the years 1984–2020 are referred to the epoch of J2000.0. Tables list the calendar date (*e.g.* Oct. 16, 2009) and heliocentric longitude (*e.g.* 325.287°) of the four planets at intervals varying from 10 to 100 days. Some tables also include the total angular motion of the planet in the given interval and some include the Julian date (*e.g.* 2455120.5). When not included these values were calculated. The example is for Neptune (at 40-day intervals) found on page 292-3 of *H.M Nautical Almanac Office 2001*.

The intervals in which a heliocentric conjunction occurred were identified. First a list of heliocentric longitudes for each planet at 400-day intervals was compiled. After this narrowing down, the coordinates of the precise interval were extracted. In recent volumes, the interval of Jupiter and Saturn is 10 days and of Uranus and Neptune is 40 days. The given date is the calendar date of the start of the interval. The leading planet and the trailing planet were determined and, for each planet, the average daily motion in the interval was calculated. An equation to calculate the heliocentric longitude and the Julian date of each conjunction was derived as follows:

a = the heliocentric longitude of the leading planet on the given date
b = the heliocentric longitude of the trailing planet on the given date
c = the average daily motion (degrees per day) of the leading planet
d = the average daily motion of the trailing planet
e = the Julian date of the given date
x = the number of days between the given date and the conjunction
y = the Julian date of the conjunction
z = the heliocentric longitude of the conjunction.

To calculate x, the number of days taken by the trailing planet to catch up to the leading planet, divide the difference in their starting longitudes by the difference in their average daily motions.

$$x(\text{days}) = \frac{\text{difference in starting longitude (degrees)}}{\text{difference in average daily motion (degrees per day)}}$$

$$x = \frac{\text{longitude of leading planet} - \text{longitude of trailing planet (degrees)}}{\text{daily motion of trailing planet} - \text{daily motion of leading planet (degrees per day))}}$$

Then

$$x = \frac{a-b}{d-c},$$

$y = e + x$

and

$z = a + x(c) = b + x(d).$

For the heliocentric conjunctions of 2025 and 2032, the dates and longitudes were taken from Meeus (1983).

3. RESULTS

The results of the calculations for each pair of planets along with the periods (in days) between conjunctions are listed in Tables 1–6.

TABLE 1
Heliocentric Conjunctions of Jupiter and Neptune

Date	Julian Date	Heliocentric Longitude	Period between Conjunctions (days)
Mar. 18.9, 1805	2380399.4	238° 26′	N /A
Jan. 11.1, 1818	2385080.6	266° 2′	4681.2
Oct. 20.9, 1830	2389746.4	293° 39′	4665.8
Jul. 16.9, 1843	2394398.4	321° 25′	4652
Apr. 3.0, 1856	2399042.5	349° 21′	4644.1
Dec. 18.5, 1868	2403685	17° 28′	4642.5
Sep. 3.1, 1881	2408326.6	45° 43′	4641.6
May 27.4, 1894	2412975.9	74° 0′	4649.3
Mar. 5.0, 1907	2417639.5	102° 14′	4663.6
Dec. 24.4, 1919	2422316.9	130° 21′	4677.4
Oct. 26.4, 1932	2427006.9	158° 18′	4690
Sep. 7.4, 1945	2431705.9	186° 7′	4699
Jul. 20.5, 1958	2436405	213° 49′	4699.1
May 24.9, 1971	2441096.4	241° 25′	4691.4
Mar. 16.4, 1984	2445775.9	269° 42′	4679.5
Dec. 24.6, 1996	2450442.1	297° 21′	4666.2
Sep. 19.8, 2009	2455094.3	325° 8′	4652.2

TABLE 2
Heliocentric Conjunctions of Jupiter and Uranus

Date	Julian Date	Heliocentric Longitude	Period between Conjunctions (days)
Aug. 1.7, 1803	2379804.2	193° 4′	N/A
Sep. 19.4, 1817	2384966.9	256° 55′	5162.7
Jun. 8.8, 1831	2389977.3	313° 34′	5010.4
Nov. 25.4, 1844	2394895.9	6° 22′	4918.6
May 27.4, 1858	2399826.9	60° 39′	4931
Mar. 16.8, 1872	2404869.3	120° 59′	5042.4
Jun. 1.5, 1886	2410059	187° 27′	5189.7
Aug. 1.3, 1900	2415232.8	251° 54′	5173.8
May 2.6, 1914	2420255.1	309° 7′	5022.3
Oct. 28.3, 1927	2425181.8	2° 6′	4926.7
Apr. 21.3, 1941	2430105.8	56° 0′	4924
Jan. 26.5, 1955	2435134	115° 43′	5028.2
Apr. 3.8, 1969	2440315.3	181° 51′	5181.3
Jun. 12.5, 1983	2445498	246° 49′	5182.7
Mar. 28.3, 1997	2450535.8	305° 22′	5037.8
Sep. 24.1, 2010	2455463.6	358° 29′	4927.8

TABLE 3
Heliocentric Conjunctions of Jupiter and Saturn

Date	Julian Date	Heliocentric Longitude	Period between Conjunctions (days)
May 7.8, 1802	2379353.3	158° 47′	N/A
Sep. 15.3, 1821	2386423.8	23° 57′	7070.5
Mar. 11.7, 1842	2393906.2	279° 13′	7482.4
Dec. 28.1, 1861	2401137.6	168° 4′	7231.4
Apr. 13.1, 1881	2408183.6	32° 43′	7046
Sep. 27.7, 1901	2415655.2	286° 18′	7471.6
Aug. 22.5, 1921	2422924	177° 24′	7268.8
Nov. 15.4, 1940	2429948.9	41° 51′	7024.9
Apr. 16.3, 1961	2437405.8	293° 31′	7456.9
Apr. 16.8, 1981	2444711.3	186° 41′	7305.5
Jun. 22.9, 2000	2451718.4	52° 1′	7007.1
Nov. 2.7, 2020	2459156.2	301° 33′	7437.8

TABLE 4
Heliocentric Conjunctions of Saturn and Neptune

Date	Julian Date	Heliocentric Longitude	Period between Conjunctions (days)
Dec. 7.6, 1809	2382124.1	248° 36′	N/A
Jul. 24.4, 1846	2395501.9	328° 2′	13377.8
May 25.6, 1882	2408591.1	47° 20′	13089.2
Aug. 9.8, 1917	2421450.3	125° 9′	12859.2
Feb. 18.8, 1953	2434427.3	202° 10′	12977
Jul. 18.1, 1989	2447725.6	281° 14′	13298.3
Dec. 11, 2025	2461020.5	1° 14′	13294.9

TABLE 5
Heliocentric Conjunctions of Saturn and Uranus

Date	Julian Date	Heliocentric Longitude	Period between Conjunctions (days)
Jan. 30.5, 1806	2380717	204° 43′	N/A
Dec. 24.4, 1851	2397480.9	34° 24′	16763.9
Apr. 24.1, 1897	2414038.6	237° 29′	16557.7
Mar. 25.7, 1942	2430444.2	59° 52′	16405.6
Jun. 9.6, 1988	2447322.1	269° 5′	16877.9
Jul. 20, 2032	2463433.5	87° 47′	16111.4

TABLE 6
Heliocentric Conjunctions of Uranus and Neptune

Date	Julian Date	Heliocentric Longitude	Period between Conjunctions (days)
Sep. 27.7, 1821	2386436.2	274° 3′	N/A
Apr. 20.6, 1993	2449098.1	289° 22′	62661.9

4. Discussion

The next step in the study was to examine the conjunctions in series, using the clues presented in the Introduction. Focusing on the suggested period revealed a pattern. 14 conjunctions of Jupiter and Neptune, 13 conjunctions of Jupiter and Uranus, 9 conjunctions of Jupiter and Saturn, 5 conjunctions of Saturn and Neptune, 4 conjunctions of Saturn and Uranus, and 1 conjunction of Uranus and Neptune are series having similar periods of about 179 years.

From the data in Tables 1–6, we calculate the periods for such series in days and in years, and the difference in heliocentric longitude between the first and last conjunctions in each series. The results for each pair of planets, plus the number of conjunctions in the series, are listed in Table 7.

Table 7
Dates and Periods of Series of Conjunctions

Pair of planets	C/s*	Dates	Julian dates	No. of days	No. of years	Diff. long**
Jupiter & Neptune	14	Mar. 18, 1805- Mar. 16, 1984	2380399.4- 2445775.9	65376.5	178.99	31° 16´
		Jan. 11, 1818- Dec. 24, 1996	2385080.6- 2450442.1	65361.5	178.95	31° 19´
		Oct. 20, 1830- Sep. 19, 2009	2389746.4- 2455094.3	65347.9	178.91	31° 29´
Jupiter & Uranus	13	Aug. 1, 1803- Jun. 12, 1983	2379804.2- 2445498.0	65693.8	179.86	53° 45´
		Sep. 19, 1817- Mar. 28, 1997	2384966.9- 2450535.8	65568.9	179.52	48° 27´
		Jun. 8, 1831- Sep. 24, 2010	2380717.0- 2447322.1	65486.3	179.29	44° 55´
Jupiter & Saturn	9	May 7, 1802- Apr. 16, 1981	2379353.3- 2444711.3	65358	178.94	27° 54´
		Sep. 15, 1821- Jun. 22, 2000	2386423.8- 2451718.4	65294.6	178.77	28° 4´
		Mar. 11, 1842- Nov. 2, 2020	2393906.2- 2459156.2	65250	178.64	22° 20´
Saturn & Neptune	5	Dec. 7, 1809- Jul.18, 1989	2382124.1- 2447725.6	65601.5	179.61	32° 38´
		Jul. 24, 1846- Dec. 11, 2025	2395501.9- 2461020.5	65518.6	179.38	33° 12´
Saturn & Uranus	4	Jan. 30, 1806- Jun. 9, 1988	2380717.0-1 2447322.	66605.1	182.35	64° 22´
		Dec. 24, 1851- Jul. 20, 2032	2397480.9- 2463433.5	65952.6	180.57	53° 23´
Uranus & Neptune	1	Sep. 27, 1821- Apr. 20, 1993	2386436.2- 2449098.1	62661.9	171.56	15° 19´

*Conjunctions per series. **Difference in longitude.

Using values for the mean daily motions of the four planets given in Meeus (1997) and the method employed there, we calculate the mean periods between conjunctions of pairs of planets. The mean periods of series of conjunctions in days and in years are also calculated and the results are listed in Table 8.

Table 8
Mean Periods of Series of Conjunctions

Pair of Planets	Mean Period (days) between Conjunctions	Number of Conjunctions in Series	Mean Period of Series (days)	Mean Period of Series (years)
Jupiter/ Neptune	4668.69	14	65361.7	178.95
Jupiter/ Uranus	5044.81	13	65582.6	179.55
Jupiter/ Saturn	7253.45	9	65281	178.73
Saturn/ Neptune	13101.48	5	65507.4	179.35
Saturn/ Uranus	16567.83	4	66271.3	181.44
Uranus/ Neptune	62620.02	1	62620	171.44

The periods of the series involving Jupiter and of Saturn/Neptune are close to 179 years; the variation is from −0.27 to +0.55 years. The variation from 179 years of the periods of the other two pairs is considerably more: for Saturn/Uranus it is +2.5 years and for Uranus/Neptune, −7.5 years.

Table 9 contains a comparison of the intervals between conjunctions for each pair of planets. It includes the shortest, the longest and the mean of the intervals in the study plus the mean period calculated using mean daily motion. Calculated values of the average interval, and the percent variation of the shortest and longest from the calculated mean period, are also tabulated.

Table 9
Comparison of Intervals between Conjunctions of Pairs of Planets

Pair of Planets	Shortest (days)	Longest (days)	Mean (days)	Average of Total (days)	Calculated Mean Period (Table 8, col. 2)	Percent Variation
J / N	4641.6	4699.1	4665.8	4668.4	4668.7	+0.65/−0.58
J / U	4918.6	5189.7	5028.2	5043.9	5044.8	+2.87/−2.50
J / S	7007.1	7482.4	7268.9	7254.8	7253.4	+3.15/−3.39
S / N	12859.2	13377.8	13089.2	13149.4	13101.5	+2.10/−1.84
S / U	16111.4	16877.9	16557.7	16543.3	16567.8	+1.87/−2.75
U / N	N/A	N/A	62661.9	N/A	62620	+0.06/N/A

The periodicity of 179 years can be restated, as pointed out by McCurdy (2002), using the relation of the number of conjunctions between a pair of planets and the number of orbits of each planet. Thus the number of conjunctions equals the number of orbits of the inner planet minus the number of orbits of the outer planet. Dividing the period of each series by the sidereal period of revolution of each planet gives the number of orbits. The values are whole numbers plus a fraction of about one-tenth, as shown in Table 10.

Table 10
Orbits per Series

Pair of Planets	Number of Conjunctions	Number of Inner Planet's Orbits	Number of Outer Planet's Orbits
Uranus/Neptune	1	2.04	1.04
Saturn/Uranus	4	6.16	2.16
Saturn/Neptune	5	6.09	1.09
Jupiter/Saturn	9	15.07	6.07
Jupiter/Uranus	13	15.14	2.14
Jupiter/Neptune	14	15.09	1.09

5. Conclusion

The heliocentric conjunctions of Jupiter, Saturn, Uranus, and Neptune exhibit a periodicity of about 179 years. Series of conjunctions of the six pairs of planets have periods close to 179 years. The series are not synchronous.

Jupiter predominantly influences the periodicity. Fifteen sidereal orbits of Jupiter have a period of 177.9 years. The total mass of the four giant planets is more than 99% of the total mass of all planets and satellites. Of the combined mass of the four planets, Jupiter constitutes 71.5%, Saturn is 21.4%, Uranus is 3.3%, and Neptune is 3.8%.

The orbital motions of the planets, the elements, events, periods, and variables are the result of gravitational interaction with the Sun and each other. The sum of these interactions is the Solar System as a whole. The heliocentric conjunctions of the outer planets are fundamental gravitational interactions of the Solar System, and their common cycle, based on 15.1 orbits of Jupiter, is 179 years.

Acknowledgments

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Jim Decandole joined the Toronto Centre more than 20 years ago. Since purchasing a Random House Illustrated Encyclopedia in 1977, he has spent countless rewarding hours in his armchair studying the Universe and the unanswered questions of astronomy.

Across the RASC
du nouveau dans les Centres

An Evening with Rajiv Gupta[1]

by James Edgar (jamesedgar@sasktel.net)

You might think I am writing about the night recently when Rajiv Gupta, our National President, came to Regina on his "Prairie Tour" following the visit to Calgary Centre and just before visiting the Saskatoon Centre.

But, no, this is about the next night when our leader visited my home in Melville.

A couple of years ago I had been invited by Dr. Gupta to be the proofreader for the RASC *Observer's Handbook,* so we had previously known each other, mostly through emails, and then I actually met him at the London General Assembly in 2001, and then again in Montreal at the 2002 GA. (From here on, I'm going to use his first name, rather than the more formal, and correct, Dr. Gupta.)

When I heard about Rajiv's proposed visit to Regina, I was determined to make it to the evening supper and to hear his talk at the IMAX Centre. Living as far away from Regina as I do, "making it" means the occurrence is rare—I can only get to a few (very few) meetings a year. Nevertheless, persistent I was and arrived in Regina shortly after 4:00 p.m., Saturday, April 19.

A phone call to the Travelodge before I left Melville got me through to Rajiv's room and we made quick plans to have a chat before supper. Then we walked across the street to Earl's for a pleasant evening meal with a good representative gathering of Regina Centre folk. In spite of it being a Holiday weekend, there were at least 16 people out to dinner.

During dinner, after I found out he was going to have a free day on Sunday, I invited Rajiv to Melville for an overnight stay at my home. (Then I quickly confirmed by cellphone that my wife, Jodie, would be prepared for such a visit! She was.) He accepted.

His talk centred on his unique computer program "Registar" and its ability to accurately line up stars in two or more images to make some very exciting composite images. He demonstrated by means of a laptop computer and projector some of the various methods of obtaining and enhancing astroimages. The Saturday events ended with some time in the dome of the Kalium Observatory, checking out the Saskatchewan Millennium Telescope.

On Sunday, April 20, Rajiv Gupta arrived in Melville for the first time in his life – probably the only time! He expressed an interest in the railyard, since it is a very prominent feature, being over two miles long and dominating the southern landscape of the city. Since I work for CN, and having been the one-time supervisor of the railway terminal, I offered Rajiv a tour.

Most people tend to take trains and their movements for granted and don't give much thought to the logistics of assembling and operating such a large collection of men, machinery, and manufactured products. It's a very complicated procedure. Rajiv was fascinated by all that goes into getting a train together, properly sorted (he equated it to a mathematical problem—not surprising for a UBC Math Professor), and moving. Trains in recent years are operated, weather permitting, up to 12,000 feet long and often weighing as much as 18,000 tons.

After a supper of barbequed steaks, we had another tour, this time of my woodworking shop. To demonstrate the tools I've collected over the past 35 years, I built a small desk clock out of a piece of maple that Rajiv assures me will grace a prominent place in his home.

By the time the short clock-making episode was over, a completely cloudless evening twilight was descending on Melville, and Rajiv was eyeing my 8-inch telescope, then the sky, then my telescope, then the sky, so I suggested a little star-gazing might be in order. He jumped at the chance! Usually I drive about a mile away from home to a location adjacent to the railway tracks—the spot is affectionately known to locals as "Beer Bottle Hill." The name arose from the practice of throwing emptied bottles at passing trains by the teens who partied there in the "old days." Nothing like that happens anymore in our quiet little city!

So, there we were at Beer Bottle Hill as the sun finally gave up its last light and stars flickered into view. We set up my Orion 8-inch Dobsonian and my trusty 10 × 50 binoculars-on-a-tripod, firstly to have a look at the asteroid Vesta as it slowly crept across the northern fringe of the constellation Virgo. (I'm convinced we saw it—just don't ask me which tiny pinpoint of light it was!) Rajiv remarked how his brain was still in the southern

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[1] This article appears in the May/June issue of the Regina Centre newsletter *Stargazer*.

hemisphere mode, having just recently returned from an astrophotography trip to New Zealand and Australia. To him, all the constellations were "upside down," so even with a star chart it took us both a while to find the right spot in Virgo!

Stars were still quite dim, so we started looking at the obvious bright lights. Jupiter and its moons became the first target and we weren't disappointed. In fact, it seemed there were six Galilean moons instead of the usual four. We both knew six was two too many and it turns out the "extra" moons were dim stars, almost exactly lining up on Jupiter's equatorial plane with the four real moons. Io and Ganymede lined up to the west of the giant planet, with Europa and Callisto to the east. (The other two "moons" are HIPPARCOS objects, both about magnitude 8× making them appear much the same as the Jovian moons.) The seeing was great and Jupiter's coloured bands very distinctly stood out against the lighter clouds.

Then I swung the Dobsonian around to Saturn. It's always a pleasure to look at what Galileo called the "eared" planet. I was immediately taken by how clearly the moon Titan showed up in the eyepiece (we were using a 25-mm with a 2× Barlow) and I remarked that I was sure I had the large Saturnian moon in the eyepiece. Rajiv stooped to look, and after a short pause, he agreed and then said he thought he could see three, possibly four, more moons about a ring-width to the right of the planet. Rajiv then remarked how seldom he actually uses an eyepiece to look at the sky, since most of his stargazing comes following a two-hour exposure on medium format film, taken with his custom-made camera.

When I took my turn to view the tiny specks he mentioned, it was a real test to see what he had described. Tiny indeed! But sure enough, with patience and a bit of averted vision, three, possibly four, very small specks floated into comprehension just to the right of the planet as seen through the inverted image of the reflecting telescope.

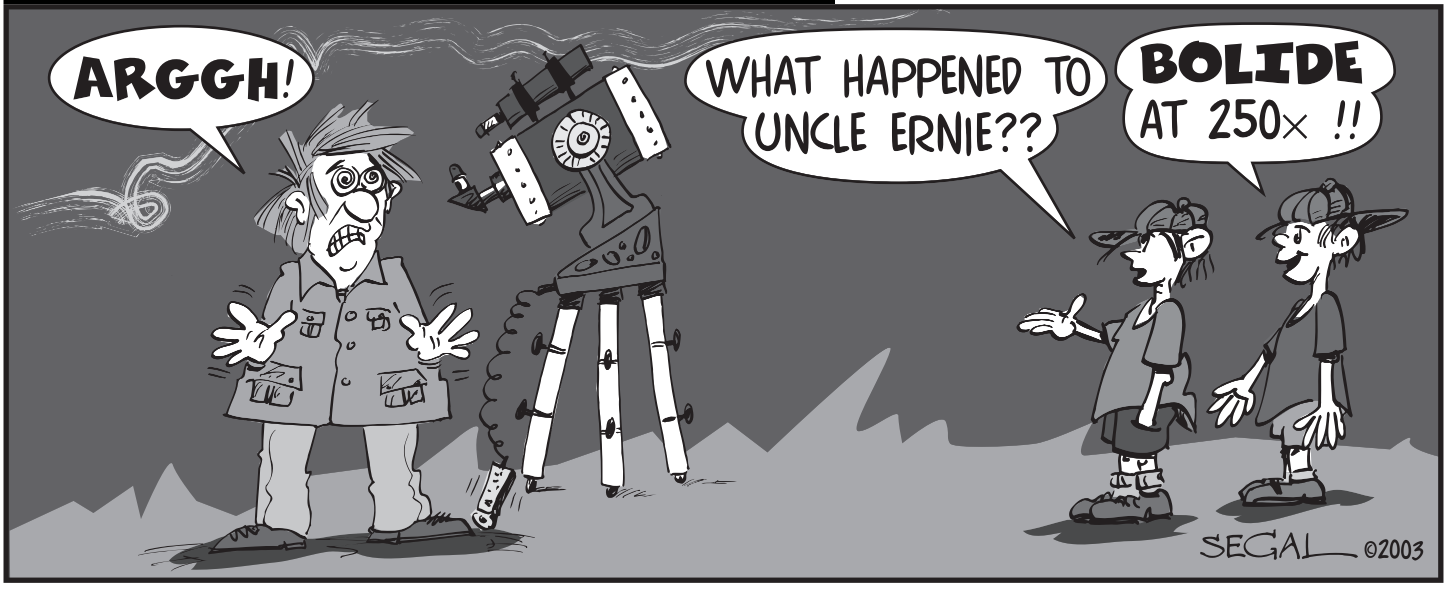
As an aside to the great time we were having looking at the stars and planets, the Aurora began to dance in the north, eventually dominating half of the sky with brilliant moving curtains and long spikes into the upper atmosphere. We spent a bit of time trying to see colours in the fringes and sure enough, apart from the usual green, we saw red, blue, and yellow. Most of the light was green but the other colours were faintly there.

By that time, I noticed the chilly prairie air had its usual negative effect—Rajiv was shivering uncontrollably. Being from Vancouver he was not acclimatized to what we "Flatlanders" think of as warm, so we decided to called it a night. Actually, once back at my home, we spent a bit more time at the computer looking at images of Saturn on Starry Night Pro. What we found was that the barely visible four moons were only half of at least eight that should have been visible in the eyepiece. Apart from Titan, we saw Rhea, Enceladus, Tethys, and Dione, plus three we failed to identify—Mimas, Hyperion, and Iapetus. All these moons fall into the magnitude range 8.4 to 14.3. Pretty good I'd say for an 8-inch telescope!

By then, the evening had waned to almost midnight, and the day's activities had taken their toll on us both. We were tired, but pleased, I think, at having become a little better acquainted and from sharing some quality time together. I know it was an evening I won't soon forget.

James Edgar is an RASC Life Member, attached to the Regina Centre. His serious love affair with astronomy began in Vancouver, B.C. in the early 1970s when he volunteered as a docent at the MacMillan Planetarium. He enjoys many dark-sky nights from his home in Melville, Saskatchewan.

ANOTHER SIDE OF RELATIVITY



Okanagan Centre Astronomy Contest

by Guy Mackie (guy.m@shaw.ca)

For the second year in a row Okanagan Centre members have challenged grade 7 to 9 students in the Okanagan region to enter an essay contest to win a free telescope. Entrants were asked to research specific astronomy topics as well as to describe their personal astronomical experiences and goals. Participation in the contest tripled this year as students competed for a grand prize of a new 6-inch SkyWatcher Dobsonian Telescope! Thanks to the generous sponsorship of astronomy retailer Perceptor (John and Susanne Kidner), Heritage Office Furnishings (Neil Campbell) and Vector Research Labs (Vince Geisler), the telescope was part of a complete observing prize package including eyepieces, filters, resource materials, and even a red LED flashlight! Okanagan Centre members gave their support by way of one-year Youth memberships in the Royal Astronomical Society of Canada Okanagan Centre for the 1st-, 2nd-, and 3rd-place entries. The Okanagan Centre members targeted grade 7 to 9 students for the contest because we felt it would be a benefit for that age group to consider astronomy and its allied sciences as one of the many possible life interests from which they could choose.

The winner of last year's contest, 13 year-old KLO Middle School student Stephanie Fromberg, was very active in promoting the 2003 contest in her school with the result that her school had the most entries from any single school in this year's contest! Contest entries were accepted through our `www.m51.ca` Web site from March 3 to 31, and three weeks later the contest judges Stephanie Fromberg, Jim Tisdale, Terry Adrian, Guy Mackie, and Sharon MacKenzie (referee) had picked the winning entries. The prize presentation took place "in school" where rounds of applause and the cheering of their peers celebrated the announcement of the contest winners. Deirdre Lucas (second place) and Natalia Snarski (third place) each received RASC Youth memberships for their excellent essays, and a very appreciative Allyce Kranabetter won the Grand prize.

Figure 1. — Photo by Jim Failes: left to right, Guy Mackie, Deirdre Lucas, Allyce Kranabetter, Natalia Snarski, and sponsor representatives Neil Campbell and Vince Geisler.

It was a pleasure for Okanagan Centre members to organize this essay contest and we are confident the contest will continue to grow in years to come. There is no higher education than astronomy!

Guy Mackie is president of the Okanagan Centre of the Royal Astronomical Society of Canada. He enjoys observing "Old Light" with his 12.5-inch telescope and then sketching and writing descriptions of what he sees. Always a bit of a daydreamer, Guy was pleased to discover at an early age that it was possible to dream at night as well, without being asleep.

Orbital Oddities

Martian Motion III: *Zoom Out*

by Bruce McCurdy, Edmonton Centre (bmccurdy@telusplanet.net)

Lost in space
A bubble drifting into a place
Where planets shift and the moon's erased
Its features lift in the glare
And I'm pretending to care
When I'm not even there
Gone, but I don't know where
— Aimee Mann, *Lost in Space*

One of the most treasured items in my home library is *Astronomical Tables of the Sun, Moon and Planets* (1983-1995), written or at least tabulated by one of my heroes, the Belgian astronomical calculator Jean Meeus. Neatly inscribed on the title page in my own hand is the subtitle, "The Sheet Music of the Spheres."

The book consists almost entirely of dates and numbers, but there are places where it practically sings to me. Many of the tables are only for 60 years or so, barely enough to establish the base rhythm or a snippet of melody. An exception is the enormous table "Oppositions of Mars 0-3000," which, with 1406 entries, provides what amounts to an extended passage with an evolving melody and counter-melody. The time signature is very complex; variations of the theme subtly shift against the pulse, necessitating the addition of an extra beat here, an extra measure there.

The great perihelic opposition of 2003 represents a crescendo in the Mars melody, but to put this cymbal crash in context we need to listen to some of the tune.

Let's start by humming a few bars. The base rhythm of Mars' oppositions is apparent from Table 1 following, showing the date and distance (in millions of km) of the Red Planet at closest approach to Earth for the years 2001-2050.

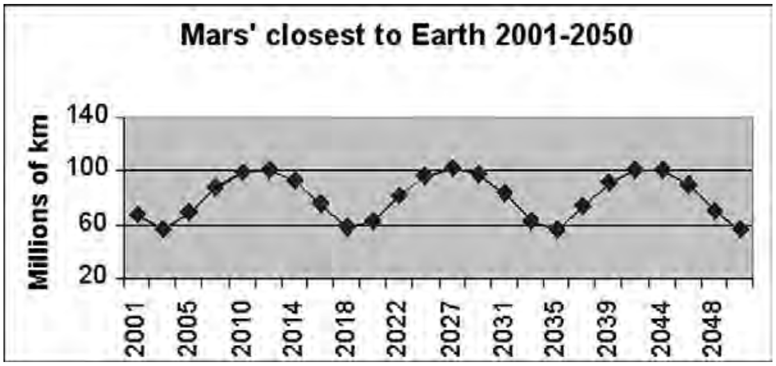


Figure 1. — A graphic representation of the data in Table 1. The troughs of the waves show a much more significant variation than the crests, roughly 3.6 to 1.2 mk; due to Mars' faster speed through perihelion, close approaches are much more sensitive to the timing of Earth's passage. Note how the record events of 2003 and 2027 are evenly balanced on the "shoulders" of their sub-maxima, a sure sign of a true peak.

Table 1.

2001 June 21	67.34
2003 Aug. 27	**55.76**
2005 Oct. 30	69.42
2007 Dec. 18	88.17
2010 Jan. 27	99.33
2012 Mar. 5	*100.78*
2014 Apr. 14	92.39
2016 May 30	75.28
2018 Jul. 31	**57.59**
2020 Oct. 6	62.07
2022 Dec. 1	81.45
2025 Jan. 12	96.08
2027 Feb. 20	*101.42*
2029 Mar. 29	96.82
2031 May 12	82.78
2033 Jul. 5	63.28
2035 Sep. 11	**56.91**
2037 Nov. 11	73.84
2039 Dec. 28	91.39
2042 Feb. 5	*100.49*
2044 Mar. 14	99.79
2046 Apr. 24	89.32
2048 Jun. 12	70.86
2050 Aug. 15	**55.96**

The Red Planet shifts in a clear ebb-and-flow pattern, graphically represented in Figure 1. A full cycle "breathes" every 15.8 years, during which time Mars experiences one **perihelic** opposition of less than 60-million kilometres (mk), followed a half-cycle later by one *aphelic* opposition of greater than 100 mk. With rare exceptions, noted below, there is exactly one event exceeding each threshold during each cycle.

Interestingly, the record perihelic opposition of 2003 is followed only 23.5 years later by a record aphelic one. At 101.42 mk Mars will achieve its most distant "closest" approach since the year 0, and presumably for tens of millennia before that.

Why 23.5 years? An aphelic opposition will occur when both Earth and Mars are on opposite sides of their orbits. This should happen at intervals representing one-half of previously identified periodicities, but only when a particular condition is met: that the given periodicity is an *odd number* of both Earth and Mars revolutions. Where one of the numbers is even, the two planets would be in conjunction, not opposition. Talk about orbital oddities!

Table 2 identifies half-periods that bear a relationship between shallow perihelic and deep aphelic oppositions.

TABLE 2.

Earth years	Mars revs	Half-cycle?
15	8	No
32	*17*	No
47	*25*	23.5 years
79	42	No
126	*67*	No
205	*109*	102.5 years
284	*151*	No
363	*193*	181.5 years

This relationship has predictive accuracy. From the present close perihelion we can forecast not only the distant opposition of 2027, but also others in 2106 and 2185 (each 101.41 mk, the two deepest aphelic oppositions of the 22nd century).

An interesting aspect to the 23.5-year semi-periodicity is that it is nearly equal to two full revolutions of Jupiter. In August 2003, Jupiter is in conjunction with the Sun among the stars of Leo; in February 2027, it will be in the same place in the sky but near opposition, reasonably aligned with Mars and adding its own gravitational tug to pull Mars slightly further from Earth. This explains to my satisfaction why the aphelic opposition of 2027 is ever so slightly further than the theoretical peak in the series in 2106, when Jupiter's influence is relatively neutral. (See also Table 5)

By now the attentive reader may be asking, why not 23.5 years ago? Didn't we find last time, that in 1980 Mars reached opposition and aphelion on the same day — while in true conjunction with Jupiter? Wouldn't those be optimum circumstances? The answer is that Earth is not a neutral observer, but has its own mildly eccentric orbit ($e = 0.0167$), which lends a bias to observations. Although Mars' orbit is far more eccentric ($e = 0.0935$), as it brakes to the stop line at Aphelion Station, its *changing* distance from the Sun is near a standstill. Earth is speeding away from perihelion in late February, and gets a little further — some 0.03 mk — from the Sun every day. Under such circumstances a bicycle can gain on a sports car, regardless of their true capabilities. The maximum "least separation" between the two orbits therefore occurs a few days *before* Mars reaches the extreme point on its orbit; the approach of February 20, 2027 is a full 0.10 mk more distant than that of February 26, 1980.

This same effect happens in compressed form for an optimum perihelic approach to Earth. Consider this sequence in 2003: Jul. 4, Earth at aphelion; August 27, Mars and Earth at minimum separation; August 28, Mars at opposition; August 30, Mars at perihelion. (Gupta 2002)

My "stroboscopic" pattern-finding method hinges on determining an appropriate threshold. In the case of Mars, aphelic oppositions exceeding 100 mk fairly jump off the page, one per 15.8-year cycle, like clockwork. However, on very rare occasions, two consecutive oppositions occur where each (barely) exceeds the threshold of 100 mk, balanced precariously on the "shoulders" of the implied peak. There were only 9 occurrences of double 100 mk oppositions in Meeus' *Astronomical Tables,* which I have identified as two separate series in Table 3.

TABLE 3.

Series 1
1158-60 (100.10, 100.04)
1521-23 (100.08, 100.11)
1884-86 (100.09, 100.21)
2247-49 (100.06, 100.28)
2610-12 (100.06, 100.38)
2973-75 (100.02, 100.48)

Series 2
1963-65 (100.30, 100.00)
2326-28 (100.29, 100.09)
2689-91 (100.27, 100.20)
3052-54 (figures not available)

As we noted about close oppositions in Part I of this series, the instances of deep doubles are increasing as time goes by: none in the first 1000 years, four in the next 1000, five in the current millennium. Each series occurs at 363-year intervals; when both are active, 79, then 284 years separate them. The first series is likely at its end in 2973-75, as the first of the two terms has diminished to just 100.02. The newer cycle on the other hand has generally higher-valued pairs, and therefore will contain more occurrences, likely 10 or more. The relationship between consecutive series will take the form ($363x + 79$). Using this algorithm, I projected that a new series might have been expected to start in 2768-2770; the actual values are (100.46, 99.98). Without the data at my disposal, I would be prepared to make a sizable wager that these conditions will be satisfied in 3131-3133, and Series 3 will commence.

To my amazement, similar pairings of consecutive perihelic oppositions closer than 60 mk currently occur at almost an identical frequency. (My surprise stems not from the similarity of the patterns at opposite extremes of Mars' orbit, but at being able to access two such beautifully round threshold numbers as 60,000,000 and 100,000,000 km; typically I'm forced to work with "threshold" numbers, like 356,500, which are much harder on the eyes.) Table 4 details the dates and distances of the eight pairs from 900-3000. Once again, each series occurs at 363-year intervals, with adjacent series offset by 79 years.

TABLE 4.

Series 1
976-78 (59.31, 59.95)
1339-41 (59.46, 59.73)
1702-04 (59.63, 59.56)
2065-67 (59.78, 59.34)
2428-30 (59.90, 59.10)

Series 2
2144-46 (59.15, 59.87)
2144-46 (59.15, 59.87)
2507-09 (59.31, 59.66)
2870-72 (59.49, 59.44)

Let's compare the dates of *aphelic*

Series 2 against its **perihelic** counterpart: *1963*, **2144**, *2326*, **2507**, *2689*, **2870**. The two are offset by 363/2 = 181.5 years, a perfectly symmetrical point-counterpoint.

For ease of comparison I have omitted from Table 4 a "Series 0" of perihelic pairs (171-73, 534-36, 897-99). This has no aphelic counterpart as in the expected years one of the distances falls just shy of the threshold; *e.g.* 353-55 (99.92, 100.04). The round number symmetry is surprisingly good, but it's neither perfect nor permanent.

Tabulating extreme aphelic oppositions further supports a 363-year periodicity. In Table 5 I have chosen not a specific number as the threshold, but simply all events that exceed the previous record. In the period 800-3000 C.E., new records — with the distance incrementally increasing from 101.26 to 101.50 mk — occur in the following years:

TABLE 5.

859	938	1017
1222	1301	
1585	1664	1743
	2027	
	2390	2469
	2753	2832

The 2027 event stands alone as the single biggest advance, a Beamonesque "leap" that will shatter the previous mark by ~40,000 km and that will stand until 2390. (Note the "gap" at 2106.) The unbroken central series of events is tabulated at 363-year intervals; the adjacent partial series are ∀ 79 years, raggedly sloping from upper left to lower right.

In his exploration of this subject, Meeus (2002) alludes to "accurate" periodicities of both 284 and 363 years. I find that the data in Tables 3-5, together with relevant sequences in Part I, make a very strong case for the 363-year periodicity as the "best fit" for certain Earth-Mars relationships. Marked against the slowly advancing perihelion point of Mars' orbit, there is something very close to an integer relationship between the two, 363:193.

With the fascinating exception of resonant systems developed by tidal interaction, orbital relationships cannot be represented by exact integer ratios, which by definition make them irrational numbers. Indeed, last year at this time I was invoking the so-called "most" irrational of all numbers (although certainly not the most illogical), M, as I examined a first-order pseudo-Fibonacci relationship between Earth and Mars. While we found this breaks down over the longer term, one of its abiding principles does not, namely self-similarity at larger scales. What is identified as a very good fit at one scale becomes a secondary but still important factor at subsequent levels. The best cycle in a human lifetime is that of 79 years where Mars returns to opposition within a degree or so of its original position in the sky. Over longer terms the interval of 79 years is frequently a correcting factor, not a series in itself but the shift *between* related series, a steadying hand against the inevitable phasing out of even the best long phrases. Like the leap day, an extra measure is written in — or omitted as appropriate — and there is a recapitulation of the main theme, with subtle chromatic variations revealing its evolution.

It is interesting to compare the pattern revealed by Tables 3 through 5 to another requiring very precise parameters, namely transits of Earth as seen from Mars. In Table 6 are the May series (Mars at descending node) from 1600-3000 (Meeus 1989).

TABLE 6.

Series C	Series B	Series A
	1621 May 5	1700 May 8
	1905 May 8	1984 May 11
	2189 May 10	2268 May 13
2394 May 10	2473 May 13	2552 May 16
2678 May 13	2757 May 16	
2962 May 16	(3041 May 19?)	

In all cases there are presently two active series. Some of the same periodicities are at play, but the primary period for transits is 79 + 205 = 284 years, whereas that for perihelic/aphelic oppositions is 79 + 284 = 363 years. Furthermore, the shift between consecutive series of transits is forward, not back, taking the form (284*x* − 79) as compared to (363*x* + 79); the table itself slopes the other way, from upper right to lower left. These are two distinct types of events pegged against different points on Mars' orbit, which slowly but inexorably rotate in opposite directions: the regression of the nodes and the advance of perihelion. Lunar aficionados will recognize these terms, as the Moon displays these effects in much shorter (indeed observable) cycles, with similarly interesting consequences.

In comparing the extremes of perihelic and aphelic oppositions, we have zoomed out to consider both constraining boundaries of the Mars-Earth relationship, from *fortissimo* to *pianissimo*. We have nonetheless restricted ourselves to the ultimately narrow 3,000-year slice of available data. If we were to expand our search to the extreme distances *possible,* they cannot occur in the same epoch. As noted in Part I, extreme perihelic oppositions occur when Mars is at high eccentricity, Earth's aphelion point nearest Mars' perihelion, and Mars at low inclination. An extreme aphelic opposition would require the first two of those parameters be satisfied, but that Mars have an extremely *high* inclination. And in the search for extremes, two out of three ain't good enough.

Just as I was finalizing this last of the Martian Motion series, NASA released the first image of Earth taken from Mars' orbit (Figure 2). Perfect timing from my perspective, as I have occasionally been lost in the head-space of Mars myself recently, imagining the view of Earth in retrograde motion or in transit across the Sun. Suffice it to say the mind's eye can be a pretty reliable observatory, especially with a selection of planetaria on one's desktop!

That said, in the current case I can issue this disclaimer: No planetarium software was abused, or even used, in researching the foregoing column. Sometimes the sheet music is enough.

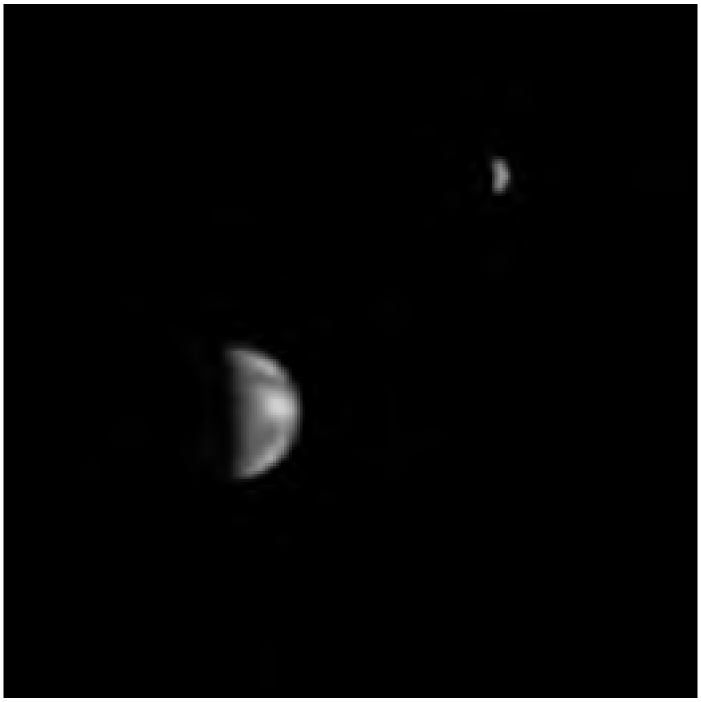


Figure 2. — The Earth-Moon system as imaged by Mars Global Surveyor, May 8, 2003. (Science@NASA 2003) Although the timing of the picture was dictated by a conjunction with Jupiter, by coincidence the Moon was almost in alignment beyond Earth. The Earth-facing side of the Moon was therefore also facing Mars, and its phase as seen from both planets was temporarily similar; from Earth, the Moon was one day before first quarter.

On August 27, 2003, the orientation of Earth and Moon as seen from Mars would be nearly identical, with the Moon again almost directly beyond the then-dark Earth. New Moon indeed occurs on August 27 within hours of Mars' closest approach. The Moon thus will have its tiny effect on maximizing the close encounter, pushing Earth an additional 0.00003 AU in the direction of Mars.

Image courtesy of NASA/JPL/Malin Space Science Systems.

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Bruce McCurdy is Education Development Coordinator of Sky Scan Science Awareness Project, a not-for-profit initiative that introduces radio astronomy to Grade 9 science classes in Alberta. In his "spare time," he frequently meditates about mysteries mathematical, musical, and Martian.

The Beta/Zeta Arc

by Mark Bratton, Montreal Centre (mbratton@generation.net)

Bright stars are few and far between in autumn skies, particularly south of the celestial equator. Most observers are familiar with the fact that Fomalhaut, the "Solitary One" is the only first-magnitude star in this sector of the sky. The second-brightest star, surprisingly, is β Ceti, or Diphda, at magnitude +2.04. This is the principal star of the constellation Cetus the Whale and one of those rare instances where the brightest star in the constellation is not designated "alpha" (this honour goes to the star Menkar at magnitude +2.53).

Diphda is the starting point for this month's observing exercise, the Beta/Zeta Arc, a collection of twelve deep-sky objects (all but one are galaxies) bounded by β Ceti in the west and ζ Ceti (magnitude +3.73) in the east. All but two of the objects are plotted on *SkyAtlas 2000.0* and should therefore be accessible with telescopes in the 150- to 200-mm range (6 to 8 inches) used under dark skies. The unplotted objects, NGC 586 and NGC 600, should be good observing tests for smaller instruments.

Our starting point is actually about three degrees south-southeast from Diphda and one of the brightest galaxies in autumn skies. NGC 247 is the northernmost member of the Sculptor Group of galaxies, a clutch of galaxies situated about 8 to 12 million light years from our own Milky Way. At magnitude +9.51 and with dimensions of about 18 by 5 arcminutes, this is a system of stars viewed edge-on that is probably very similar in structure to M33 (the Triangulum spiral) in our own Local Group of galaxies. In my 15-inch reflector NGC 247 appeared very large, and fairly bright though rather diffuse. Much elongated almost due north/south, the southern extremity of the galaxy is marked by a magnitude +10 field star. The galaxy appeared slightly brighter to the core but the core is much offset to the north. The galaxy appeared better defined to the south and tapered to a point near the magnitude +10 field star. To the north, the galaxy is blunter and most diffuse.

Heading north through Diphda and continuing on for about six degrees we arrive at the next two objects in the arc. NGC 246 is one of the dozen best planetary nebulae in the sky. Although listed at magnitude +10.9, NGC 246 is also fairly large (about four arc minutes in diameter) so overall it appears rather faint and diffuse. The central star is easily visible, however, as are three other stars that appear set within the nebula. In my 15-inch reflector the shell of gas appeared quite mottled with dark zones visible and the edges, particularly to the west, seemed brighter than the central region.

Immediately to the north north-east of NGC 246 is NGC 255, a moderately large and fairly bright galaxy, though fairly diffuse. It is best at medium magnification, pretty much round and slightly brighter to the middle.

To the northeast and nearly at the same declination as η Ceti is NGC 309. In photographs, this is a beautiful multi-armed face-on spiral galaxy, somewhat reminiscent of M74 in Pisces. In my 15-inch reflector, the galaxy appeared large, though fairly dim, and very gradually brighter to the middle with a fairly grainy looking surface to the outer envelope. The extremities were irregular and poorly defined. When observing visually, these are classic signs of open-armed spiral galaxies viewed face-on.

To the northeast, passing the star θ Ceti along the way, we come to a lazy chain of six galaxies oriented roughly east/west and stretching for a distance of about two degrees. With radial velocities in the 1800-1900 km s^{-1} range, this is almost certainly a related group of galaxies and is sometimes known as the NGC 584 Group.

At magnitude +10.5, NGC 584 is a very bright, though small galaxy, well-condensed with a much brighter core. A grainy envelope surrounds the core and a much fainter and diffuse secondary envelope is also visible. Oval in shape, the galaxy is oriented east-northeast/west-southwest. NGC 586, which is almost immediately east-southeast, is quite a bit fainter at +13.2 and may be a bit of a challenge for smaller apertures. It is well-condensed however, much elongated north/south with a brighter core and diffuse extensions.

To the east, NGC 596 and NGC 600 can be seen in the same medium magnification field. NGC 596 is very bright and located immediately west of a sixth magnitude field star. In my 15-inch reflector it is quite round and compact with well-defined edges and traces of a brighter nucleus. NGC 600 is located south-southeast from NGC 596 and is a much more difficult object; a round diffuse glow with low surface brightness and poorly concentrated to the middle. Although it is listed at magnitude +12.4, it will be much more of a challenge than NGC 586 for a small telescope.

NGC 615, the next galaxy in the chain, is an SB-type spiral that appears very much like a distant version of the Andromeda Galaxy in photographs. In my 15-inch reflector it was very bright and well-defined, appearing like an edge-on galaxy with tapered points. A magnification of 272× brought out a small, stellar core and averted vision revealed traces of the faint spiral arms, visible as a diffuse halo. The galaxy is much elongated in a north-northwest/south-southeast direction.

The final galaxy in the chain, NGC 636, is fairly bright and rather small but well-condensed with a bright core at 272×. Though the edges are well-defined there is a trace of graininess here and the galaxy appears slightly elongated northeast/southwest.

The "Beta/Zeta Arc" terminates with two galaxies visible in a low-magnification field with ζ Ceti. NGC 681 is located due west of ζ Ceti and in photographs is a very interesting galaxy. Reminiscent of the Sombrero Galaxy, NGC 681 features a very thin dust lane crossing in front of a bright elliptical halo of stars. This thin dust lane was not visible visually in my 15-inch reflector; the galaxy appeared bright with an overall boxy form and a very faint glow visible as a secondary envelope. Five magnitude +9–10 field stars were visible close by with one of the stars almost touching the galaxy to the northwest.

North from ζ Ceti is NGC 701, a bright well-defined galaxy oriented northeast/southwest. Quite bright along its major axis, the overall texture of the galaxy seemed quite smooth.

On cloudy evenings (there seem to be quite a lot of those!) or clear nights when the full Moon shines, it is sometimes worthwhile to pull the star charts down from the library shelves and plot out interesting paths through the night sky. Many imaginary arcs and chains of interesting targets can be identified in this way and may be useful in giving you some guidance on your next night under the stars.

RASC member Mark Bratton, who is also a member of the Webb Society, has never met a deep sky object he did not like. He is one of the authors of Night Sky: An Explore Your World Handbook.

Astrocryptic

by Curt Nason, Moncton Centre

Answers to last issue's puzzle:

1 S	C	2 H	W	3 A	R	4 Z	S	5 C	H	6 I	L	7 D
H	■	U	■	B	■	E	■	L	■	R	■	E
8 O	U	N	C	E	■	9 N	E	U	T	R	A	L
R	■	T	■	L	■	I	■	S	■	I	■	E
10 T	R	I	P	L	E	T	■	11 T	W	I	S	T
■	■	N	■	■	■	H	■	E	■	■	■	E
12 L	A	G	O	13 O	N	■	14 T	R	I	15 F	I	D
O	■	■	■	P	■	16 M	■	■	■	A	■	■
17 R	A	18 L	P	H	■	19 E	P	20 S	I	L	O	21 N
E	■	O	■	E	■	I	■	H	■	L	■	I
23 N	E	B	U	L	A	S	■	22 E	R	I	N	G
T	■	E	■	I	■	S	■	L	■	N	■	H
24 Z	O	D	I	A	C	A	L	L	I	G	H	T

Astronomy — A Personal Journey

by Ron Waldron (rmwaldron@shaw.ca)

I am not sure when I first began to notice the night sky. Maybe it was after I observed my first shooting star. Or maybe it was the result of looking for and finding the "man in the Moon." In any case, at some point in my elementary school years I became fascinated with the stars and the mysteries that surrounded them. For me it was the beginning of a journey that will likely last a lifetime.

When I was eight years old, my father purchased a set of softcover science books called the *Science Service* series. Each book covered a different topic and there were coloured stickers that you could lick and place in the correct squares within the pages of each book. The first book was an introductory gift in the series and was titled *The Universe*.

I never really got very far past that first book; I was enthralled and hooked almost immediately. I credit this book with my entry into the world of astronomy. I read it cover to cover many times over. This event was followed by trips to the J.S. Wood Library in Saskatoon where I would borrow the maximum number of books possible on the topic of astronomy. One memorable book was titled *The Stars* by H.A. Rey. I renewed it many times as I began to teach myself the northern constellations one by one.

This was followed by the purchase of my first telescope, a 2.4-inch refractor on a wooden altazimuth mount, and an objective lens made of real glass (not like the plastic lenses often found in similar telescopes today). It had one eyepiece to magnify objects 40×. I have fond memories of the Moon, Jupiter, and Saturn with that telescope. I recall looking at the Sun using projection techniques, not knowing I was melting the glue that held the lenses in place in the eyepiece.

It was not long after the repair of the telescope that I was thirsting for more power and the ability to track the objects I was viewing. I sold that first telescope and purchased my next one, another 2.4-inch refractor on an equatorial mount with setting circles. I recall having eyepieces that would take this telescope to 250× (although I do not ever remember seeing anything distinct at that magnification). There were many trips outside the city to view beyond the Moon and planets. I remember my first view of the Andromeda galaxy and the globular cluster M13 in Hercules. Those can be memorable events in the life of any budding young astronomer.

"I sold that first telescope and purchased my next one, another 2.4-inch refractor on an equatorial mount with setting circles."

As I entered university, the need for extra cash forced me to sell that second telescope. I knew I wanted more light-gathering power so in my spare time (when I should have been studying) I began to grind an 8-inch mirror to build my next telescope. Like many telescope mirrors started in the 70s, it was never finished. I still have the ground glass but have yet to find a company that might finish the process for me.

Meanwhile, to keep up my interest in the stars I purchased a good set of 7×50 binoculars. I did not know it at the time

"I had to have it, and the means came about with a larger than average income-tax return."

but this set of hand-held optics would be my only astronomical companion for the next 30 years as I married and raised three children.

Then, after a 30-year drought in instrumentation, I was ready to revitalize my observing by purchasing a decent telescope (by today's standards). Having been a self-taught astronomer, I was not interested in gadgetry that would automatically locate the object and track it; rather, the fun for me was seeking and finding all the objects I wanted to see. I knew I wanted to see much more than my two refractors were ever able to reveal, so I set my eyes upon a Dobsonian design.

The SkyWatcher Telescope series, distributed by Pacific Instruments in Vancouver, had just come out in a 10-inch Dobsonian. I first read about it in a review written by Terence Dickinson in the Jan/Feb 2003, issue of *SkyNews* magazine. Here was a telescope that appeared to have everything I was looking for: maximum light- gathering power in a simplistic design. Not only that, the weight of the telescope was manageable as the mirror was only one-inch thick, not the traditional two inches of most other telescopes. The icing on the cake was the focal ratio of f/4.7, which resulted in a tube length of only 44 inches. This telescope was completely portable and would fit nicely across the back seat of my Toyota Corolla.

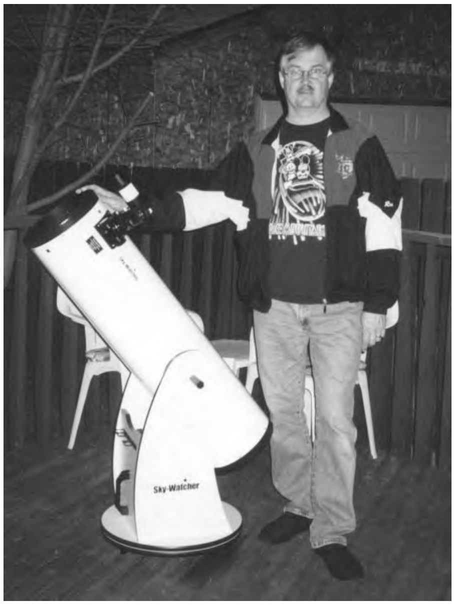
I had to have it, and the means came about with a larger than average income-tax return. I shopped online across Canada for the best price and finally settled with Focus Scientific, a company out of Ottawa.

The new telescope arrived on Monday, April 14, delivered by parcel post. The postman brought it into my house and plunked it solidly on the floor, oblivious of the fact that it was an optical instrument. Within one hour, I had the telescope mounting built and the entire instrument ready for first light.

I have to admit, I could not wait for first light and trained the instrument on the Sun that afternoon, clearly observing three clusters of sunspots projected neatly on a piece of white cardboard.

That evening, I invited the neighbour's two boys to come and view Jupiter and Saturn with me. Neither they nor I were disappointed. It is hard to describe or convey the beauty of Jupiter's cloud-belted disk flanked by four stately moons, or the rings of Saturn displayed broadside to the viewer. My reaction as I viewed them can be stated in the five words, "it was worth the wait!"

What I like about the SkyWatcher is the fact that I can easily take it anywhere I want to go. It sets up in five minutes and takes down just as quickly. There is no levelling of the stand, alignment on the North Star, or anything else that might detract from the sheer joy of observing. And the best part is that I still have to use all my skills to hunt and find the objects using star charts, just like I did when I was eight years old. An unexpected bonus when aiming and pointing a Dobsonian telescope is that one usually ends up hugging the tube. To my surprise and delight, it often feels like the telescope is hugging you back!



"Within one hour, I had the telescope mounting built and the entire instrument ready for first light."

I look forward to future views of deep-sky objects with my new telescope as I take it to dark sites outside of the city. Astronomy Day at the Beaver Creek, Saskatchewan dark site and the Saskatchewan Star Party at Cypress Hills simply cannot come soon enough. I look forward to sharing my telescope views with the views of those around me.

For me astronomy has been a journey, one that began with the reading of a single astronomy book at the age of eight. This journey has never ended and is rewarding every time I or someone else looks through my telescope. As our knowledge of the universe continues to expand, the avid amateur can still contribute and find personal reward in the stars from his or her own backyard.

Ron Waldron is a teacher and Vice Principal of 28 years experience with the Saskatoon Board of Education. His current posting is Brunskill/KCC Elementary School where he teaches grade 8. His passion is the teaching of science from grades 5-8 and astronomy plays a major role in that teaching.

Ron is a member of the RASC Saskatoon Centre and is looking forward to becoming much more active, now that he owns a telescope.

Great Images*

The Milky Way in Large Scale

The centre of our galaxy lies just below the Lagoon (M8) in the middle of this image, which, from upper left to lower right, highlights the Eagle (M16), the Swan (M17), the great star-cloud M24, M8, and the red emission nebulae NGC6357 and 6334 ("Cat's Paw"). To the right of centre is the large dark nebula, the Prancing Horse.

— Photo by Ben Gendre from the 2001 RASC Calendar, August

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*From time to time, as space permits, the *Journal* features outstanding astronomical images.

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Observer's Calendar — 2004

This calendar was created by members of the RASC. All photographs were taken by amateur astronomers using ordinary camera lenses and small telescopes and represent a wide spectrum of objects. An informative caption accompanies every photograph.

It is designed with the observer in mind and contains comprehensive astronomical data such as daily Moon rise and set times, significant lunar and planetary conjunctions, eclipses, and meteor showers. The 1998, 1999, and 2000 editions each won the Best Calendar Award from the Ontario Printing and Imaging Association (designed and produced by Rajiv Gupta).

Individual Order Prices: $16.95 CDN (members); $19.95 CDN (non-members)
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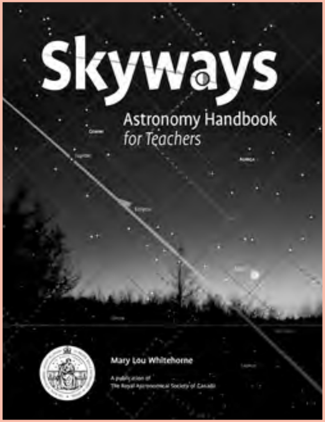

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