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This note summarizes Gedex's thinking regarding future space exploration activities, and competitiveness of Canadian industry in that context.

About Gedex

Gedex is a geophysics exploration and technology company located in Mississauga, just west of Toronto. The company's current business plan is based on developing and bringing into use a highly sensitive gravitational sensor (which we call the high Definition Airborne gravity Gradiometer, or HD-AGG^{TM}), which will be used for carrying out airborne geophysical surveys, to explore for mineral and oil & gas deposits. The exquisite sensitivity of this instrument (rather better than anything previously developed for airborne surveying) has attracted strong interest from many of the leading global mining and petroleum companies, resulting in several of them (Rio Tinto, De Beers, Anglo American and Cliffs Natural Resources) supporting Gedex by direct investment or other means. Gedex's objective is to become one of the world's leading exploration companies over the next 10 years, using gravity gradiometry as well as other geophysical measuring techniques, in order to help create a resurgence of discovery of large mineral deposits, and aid in the discovery of new oil & gas deposits, and the depletion management of existing oil & gas reservoirs.

In addition, Gedex is laying the groundwork for applying this gravity gradiometer technology to other application areas. Several of those application areas are in space. They include Earth science and environmental monitoring, with the possibility of developing a made-in-Canada successor to the very successful GRACE and GOCE Earth gravity monitoring missions, which have provided a new means for taking monthly "snapshots" of large-scale movement of groundwater, river-basin fill levels, and glacier masses throughout the world. They also include space exploration, with the possibility of developing similar gravity instruments to measure the details of the gravity fields of the Moon (as a follow-on to the GRAIL mission), Mars and asteroids from orbit, as well as the local gravity field on the surface of such planetary bodies (via surveys carried out using a rover-carried instrument). Gedex's objective in these application areas is to become the world's leading space geophysics exploration company, using gravity gradiometers and other types of geophysical instruments. Note that Gedex has recruited several highly-experienced space system design engineers (essentially the original senior design team for the MOST microsat mission), including me.

Past and Current Science-Driven Space Exploration

At Gedex we foresee positive changes in the manner in which space exploration activities are financed and carried out. In the past, space exploration was pursued exclusively as a government-initiated and -funded activity, led by national space agencies and governments including NASA, the USSR, JAXA and ESA, through many famous programs and missions

including Apollo, Mariner, Surveyor, Venera, Lunokhod, Viking, Spirit & Opportunity, Phoenix, Voyager, Galileo, Giotto, etc. These have mainly been conducted for "non-economic" purposes: at first as part of the capitalism-versus-communism politico-ideological struggle of the 1960s, and later for national-pride and idealistic reasons, providing opportunities for scientists to collect data from cameras and other instruments on or near planets, moons and asteroids for the general advancement of human knowledge. Activities such as these will continue in the future, probably at a level similar to that of today --- which is to say, many missions flying at any given time, but not nearly enough to satisfy the wishes of the growing number of space and planetary scientists around the world. Canada has begun the process of contributing occasionally to such missions (most notably through the LIDAR Mars weather station on Phoenix, the NEOSSat mission to search for Earth-approaching asteroids, and the LIDAR mapper that CSA is contributing to NASA's OSIRIS-REx asteroid sample-return mission), and will likely continue to proceed with such science-driven mission participation.

Future Profit-Driven Space Exploration and Exploitation

What is yet to come is space exploration activities aimed at *economic* purposes --- specifically, aimed at the eventual goal of exploiting mineral resources located in space. A concise term for this is "space mining," although many other related activities are included beyond the actual mining (initial exploration, detailed surveying, discovery of deposits, determination of deposit size and ore concentrations and form, refining, and transport of ore or refined products back to Earth or to other markets in-space). There exists a vast amount of mineral deposits in places that are relatively easy (in space-travel terms) to reach and return from --- mainly the Moon and asteroids. There are good reasons for believing that some of those deposits will, before long, be able to be economically extracted and brought to market. Examples include platinum-group metals (PGMs) present in nickel-iron asteroidal material (in asteroids, and as impact debris on the Lunar surface) for sale to people on Earth, and volatile materials (such as water, and carbon-based compounds) that are useful for in-space applications such as rocket propellant production (at the Lunar poles, and in asteroids) for sale to owners of spacecraft needing rocket propellants, to operators of space habitats such as the International Space Station, etc. The former markets could make sense because of the scarcity and usefulness of PGMs on Earth; the latter markets could make sense due to the high cost of hauling bulk materials (such as rocket propellants, air and water) into space from Earth's surface for in-space activities carried out for other reasons.

In the past wherever there were accessible mineral resources and markets for those, commercial exploitation eventually began, at which point wealth was created. The potential amount of mineral wealth on the Moon and in the asteroids could be many, many times larger than the accessible mineral resources remaining on Earth --- while the Earth contains a much larger *volume* of material than these bodies, almost all of it is too deep to find, let alone to mine. Explorers and miners need new mineral-rich *surface area*, and most of the accessible surface area of the Earth has already been explored (albeit not yet with high-sensitivity airborne gravity gradiometers, hence Gedex's current business plan) and mined. The Moon, and particularly the asteroids (because, being small, their surface-area-to-volume-ratio is much higher than for the Moon or Earth), provide a vast amount of new, untapped surface area to explore and mine --- not only that, their lower gravity fields will make it feasible to mine down to grater depths than on

Earth (smaller (km-sized) asteroids can conceivably be taken completely apart, to extract *all* of their useful minerals).

The lure of that wealth will eventually draw privately-financed ventures into space exploration, with investors drawn by the potential for large returns on their investment – just has happened many times in many places on Earth, including very notably here in Canada. When this happens, it will draw far more funding into space exploration than the governments of the world could ever justify providing from their taxpayer-funded coffers for science purposes alone. It is reasonable to anticipate that eventually there will be a very large amount of mining-related space activity underway; the main uncertainty is the timing for that to happen. It seems very likely, given the current state of space technology and current trends in its development, that active mining of the Moon and asteroids could be well underway within a century from now, although probably not within the next 10-20 years. That dichotomy of time-frames has important implications for private companies, and for governments, including the government of Canada.

Note that people have been saying things like this for many years, decades even. Space exploration for the purpose of economic exploitation has been foreseen since before the dawn of the space age, but for most of that time there was no sign of private investors beginning to spend their own money on any such activities. *That may now be starting to change.* Very recently, the Seattle-based company Planetary Resources Inc. announced their intention to begin privately-financed asteroid exploration for the purposes of eventual asteroid mining, with water and PGMs as their stated target commodities. This announcement divulged the names of some of their investors, several of whom (Charles Simonyi from Microsoft, Eric Schmidt and Larry Page from Google, and Ross Perot Jr.) are extremely-high-net-worth individuals, making it clear that this venture is backed by serious people with serious financial resources. This comes on the heels of several start-up companies being formed to compete for the Google Lunar X-Prize, some of which have stated their intent to carry out Lunar exploration leading to a Lunar-ice mining business. These have been enabled partly by the future-oriented vision of some of the many people who became extremely wealthy as a result of the growth of the internet in the past 15 years, and partly by improvements in space technologies and resulting lowering of the cost of launching into space and building spacecraft during that period. Which is to say, the fact that this has not happened in the past, is *not* a reason to think that it won't happen in the future, not even in the relatively near future.

Why Should the Canadian Government Care?

To understand why, consider a scenario 100 years from now, in 2112, in which large-scale Lunar and asteroid mining is underway. These activities themselves will be generating a huge amount of wealth in the form of profits (such activities won't be undertaken unless this is so), which will flow to those who have financed these ventures. They will employ a great number of people --- some actually working in space, most however being on the ground, designing and building the equipment to be used in exploration, mining, refining and transport, and helping to control from the ground the space-robotic equipment used in many of these activities. The employment and income-tax benefits resulting from these activities will flow to the countries in which these people work; it is reasonable to assume that a few countries will be dominant in this new area of economic activity, while most countries will participate less, or not at all. This will result in

wealth, and hence power on the world stage, for those dominant countries (which will be even greater for those countries in which the financiers of these activities reside) --- this has been the case with all previous resource booms in history, as Canada well knows, as do many other countries (e.g., consider the influence oil resources have had on the stature of several Middle East countries in world economic and political affairs).

This note is mainly about considering the potential for Canada to be among the dominant countries in that scenario, or alternately to be among the "have-not" countries of the future. Canada currently has an enviable position in the world, in terms of wealth, prosperity, well-being of its population, and political and moral influence. This is somewhat unusual given the relatively small size of Canada's population --- these desirable outcomes have mainly accrued to the nations of the world with the larger populations (the BRIC countries being exceptions due to historical circumstances, but they're now moving up the ranks of dominant countries quickly). Some of this has been due to geography, Canada's position of being literally "between" the U.K. and USA during WWII. However, much of it has been due to Canada's immense size --- its immense *surface area* --- relative to its population, which has resulted in Canada being blessed with far more natural resources per capita than most other countries in the world.

This happy situation for Canada is not guaranteed to continue. As the government of Canada well knows, maintaining the conditions that Canadians desire and have come to expect is not easy. Natural resources can be depleted, as demonstrated by the Canada's dwindling boreal forests, an ever-growing number of ghost-towns around played-out mines, the Grand Banks denuded of cod, etc. The Oil Sands in Alberta and Saskatchewan are currently saving Canada's economic bacon, and the Ring of Fire mineral deposits in northern Ontario hold out hope for another Sudbury. However these, too, will come and go. A century from now, these deposits too may well be played-out. I think we would all agree that we would not like to see Canada's fortunes decline as a result --- the world is littered with once-great countries whose basis for greatness was eventually exhausted, and which have since declined, and their situation is (to put it mildly) not desirable.

While this may not seem relevant to most of us *as individuals*, who won't be alive a century from now (although our descendants hopefully will be, and hopefully we give thought to them), this *should* be relevant to the government of Canada. They are the caretakers of the legacy left to all of us by the generations of Canadians who came before, and it is their duty to do their best to preserve and maintain that legacy, and hopefully to expand on it, rather than to let it decline.

To put it in plain terms: the world of the not-very-distant future will very likely include in its economy a space-mining component, and the countries which participate in and control this will benefit in terms of economic wealth and global power. Countries which fail to catch this wave will end up being relatively disadvantaged. The Canadian government should take steps to help ensure that Canada benefits from these future activities, rather than being left behind.

Canada could afford to follow a policy in the past of doing nothing in this area, when other countries were also doing nothing --- with nobody else moving forward, we weren't falling behind. Of course, government-based space exploration *has* been underway for the past 60 years, with Canada contributing almost nothing to that endeavour until very recently. Fortunately for

us, some other governments and space agencies (notably NASA) has been extremely generous in giving away for free the fruits of their early exploration efforts, to everyone including Canada. Once commercial space exploration begins to take hold, however, the days of such "freebies" will be over. Just as mining companies on Earth don't give away their survey results (indeed, they hoard them as precious secrets, the keys to their future wealth), future space exploration companies won't give away their exploration data.

To be fair, Canada's *didn't* do *nothing* about this in the past. The Canadian government took steps to foster the development and growth of a small but capable Canadian space industry, starting with Alouette in the 1960s, and Telesat Canada in the 1970s, the Canadarm and Space Station programs of the 1970s through the past decade, the Canadian astronaut program, the Radarsats, and recent space science and exploration satellites and instruments. All of that has resulted in a small but capable Canadian space industrial base --- indeed, the very industrial base which the Aerospace and Space Review is meant to benefit. That gives us a nascent capacity to build on, a basis on which to get involved in these future activities. Of course, numerous other countries have done the same thing, many of them to a far greater extent than Canada has, so this doesn't give as a particular *advantage* over other countries --- however, it has kept us from being completely *disadvantaged*.

Of course, in this new area of endeavour, Canada does not have the initiative, not by a long shot. The initiative is primarily with the USA, driven by the extremely powerful entrepreneurial capitalist culture there. It is easy to imagine others in China, Russia, Europe and India being in a good position to start to take part in privately-led space exploration activities as well, possibly with significant state support. This must be kept in mind, when thinking about what *could* be done here in Canada.

Should **Canada Do Anything?**

First it's worth facing the question, *can* and *should* anything useful be done in this regard, here in Canada? While, if this economic prognostication plays out as described above, we would *like* Canada to achieve a significant and important role in these future activities, is there any reason for believing that Canada and Canadians *could* do so? The Americans are out front of everyone, and many other countries have much larger and more capable space industries than Canada has; does Canada have any realistic hope of getting into this game and prospering?

There are some important reasons for thinking that the answer to those questions is "yes."

The first reason is that Canada has a tremendous level of capability, as compared to many other countries, in the field of mining and all its related activities. This includes not only mining itself, but also exploration, and financing of exploration and mining ventures, as well as other business and legal aspects of all of these. Much of the activity on Bay Street in Toronto is (quietly) devoted to these activities.

This is a far from trivial advantage. The business of economic exploration (here on Earth) is very different from the "business" of space exploration, as practiced to date. The companies which have been building space exploration spacecraft (to travel to the Moon, Mars, the asteroids,

Jupiter, Saturn, etc.) for national space agencies for many years, are characterized by being extremely risk-averse in the business sense, reflecting the same attitude in their space-agency customers where the risk of mission failure is concerned (such agencies typically demand analysis demonstrating a risk of mission of failure of, at worst, a few percent, from their contractors). This is reflected in the fact that almost all funding of such companies for such spacecraft to date has been on the basis of "cost-reimbursable" contracts, in which the company typically takes *zero* risk --- if the cost of developing the spacecraft inflates, the government pays the extra bills, and if the spacecraft fails to work, the company loses no money. Mind you, the actual *profits* made by companies for such work are very small (typically less than 10% of the total contract price) --- but those profits are almost guaranteed (and the amount of company overhead costs covered by such contracts can be truly immense!). This behaviour is typical of companies that are part of what Eisenhower named the "military-industrial complex." Whether they are building bombs or planetary spacecraft, their behaviour is much the same. They are typically blue-chip companies, funded by pension plans and other similar risk-intolerant investors.

Real exploration companies, on the other hand, *thrive* on risk. Exploring for new mineral deposits, or for new oil or gas deposits, is one of the riskiest business propositions imaginable --- one simply doesn't know what's below a particular patch of ground until one's drilled into it, and that's expensive and frequently finds nothing of value. The most extreme example of this can be seen in deep-sea oil exploration, in which a single exploration hole can cost $50M to drill --- and comes up dry *90% of the time*. Which is to say, the risk of "failure" in such exploration ventures is 90%, after the best geophysical surveying and geological interpretation has been done to reduce risk! And still, explorationists "roll the dice" on such gambles routinely --- not that anyone *likes* that level of risk, but what other choice have they? The investors who back such ventures are a very different breed than the conservative investors backing the Boeings and Lockheed Martins of the world; they place large bets, on ventures with a large risk of failure, in return for which they expect a commensurately high potential rate of return on those investments which succeed. (To go back to the example above, a successful deep-sea "gusher" could end up being worth many billions of dollars to its owners, which will pay for a lot of drill-holes, so long as you have the guts and dollars to keep exploring.)

The important point here is that Canada (specifically, Toronto) is a hotbed of exploration and mining driven investment activity. Large-scale commercial-driven space exploration won't happen until potentially high-payoff ventures are conceived, which will require some initial smaller-scale, less-costly exploration to "prime the pump" by scouting out potentially lucrative finds. When that day comes, space explorationists will want to tap into the same financial markets that terrestrial explorationists are tapping, in order to finance their ventures. And one of the biggest such markets is in Toronto. Canada could leverage that to our advantage, to draw commercial space exploration ventures to operate in Canada because "this is where the money people gather" (the same reason so many exploration and mining companies have offices in Toronto now).

To expand on that point, Canada, particularly Toronto, is also *seen to be* a centre for the global exploration and mining business sector. This is particularly visible in the fact that the world's largest annual get-together for exploration and mining sector participants, the Prospectors and

Developers Association of Canada (PDAC), is held every year in Toronto, attracting upwards of 20,000 attendees. This is an event at which global exploration and mining business leaders gather to meet each other, and to do the deals that makes this business sector go. Less visibly, most of the world's exploration and mining companies have offices in Toronto, and list their stocks on the Toronto stock exchange. And, there are numerous major exploration and mining companies based in and around the Toronto area (which is part of the reason for Gedex being located here). For these reasons, Toronto is widely accepted to be the "exploration capital of the world." While this currently refers exclusively to *terrestrial* mineral exploration, it is a powerful brand to own, and could be a foundation for extending this brand to include *commercial space exploration* (so long as someone/someplace else doesn't gain that brand before we do).

The second reason is that, while Canada's expertise in space technology is relatively narrowly focused, at least it is focused in some areas which are very relevant to commercial space exploration. The prime example of this is that Canada leads the world in space robotics expertise, via the development of the Canadarms and related activities that have been sponsored by the Canadian government. Space robotics of all types will be an essential part of commercial space exploration and mining, ranging from rovers to robot arms to earth-moving equipment. Companies in Canada are very well-positioned to be the suppliers of choice for the early space-exploration and mining ventures; a very early example is that MDA in Brampton is the contractor developing the rover for the Odyssey Moon Google Lunar X-Prize (GLXP) team. Of course, the GLXP is also encouraging numerous others into this particular area, and NASA, ESA and JAXA have long been competing with the CSA when it comes to funding indigenous development of space robot arms. Which is to say, while Canada has a world-leading position in this area, it is one that could quickly be eroded if not suitably supported.

Similarly, Canada has at least a foot-hold in some other areas relevant to the early stages of commercial space exploration. The NEOSSat microsatellite mission (funded by CSA, and hopefully to launch before 2013) is Canada's first asteroid-exploration mission, with 50% of its time dedicated to the Near Earth Space Surveillance (NESS) mission, searching for near-Earth asteroids, some of which could be early candidates for more-detailed *in situ* prospecting, and eventual mining --- near-Earth asteroids being easier, quicker and less-expensive to reach, as compared to the main-belt asteroids and the Lunar surface. This is based in part on experience from the highly-successful made-in-Canada MOST space astronomy microsat mission, in which a Canadian industry/academia team showed the way to developing highly capable space mission hardware at the low cost level that will be needed by future commercial space exploration and mining missions (if they are to be profitable, that is). NEOSSat will be followed by NASA's OSIRIS-REx asteroid sample-return mission, for which Canada is providing an imaging LIDAR instrument to measure the asteroid's topography in detail, with that instrument's science team being led by University of Calgary's Alan Hildebrand, who is also leader of the NESS science team (and Canada's *de facto* leading asteroid explorationist).

(Note that there is an important Gedex connection here, in that several of Gedex's senior engineers (including me) were at the head of the MOST development team, and that I was the mission and system architect for NEOSSat in its early stages, and continue as a member of the NESS science team.)

These do not in any way *guarantee* Canada any role, let alone a leading role, in future commercial space exploration and exploitation ventures. However, they do provide a solid foundation on which to build such a role.

"What do you mean, a century from now?!"

This section is a brief tutorial in a fundamentally important fact of life in the world of terrestrial exploration, provided here as a precursor for certain recommendations later.

To people who know something about stock markets, the idea of being able to attract capital to support a mining-targeted exploration venture that "almost certainly" won't result in refined product coming to market any sooner than 20 years from now, may seem preposterous. In a world in which the CEOs of many publicly-traded companies maintain a laser-like focus on the next financial quarter (lest they be turfed from their jobs by boards of directors stacked with activist investors), the idea of capital that's patient enough to worry about things that'll happen 5 years from now seems unlikely, never mind 20 years from now (let alone 100 years from now!).

And yet…the mining and oil and gas businesses, are different from most other businesses in that regard. It can take many, many years of exploration before a big new deposit is discovered, and quite a few more years of detailed surveying to map it sufficiently well to know how big it is, how it is distributed, and to come up with a viable plan for how to finance a mine or well, and develop the resource and bring it to market. This sort of activity frequently spans market several cycles of whichever commodity is in play, with work being put on the back-burner during downturns in that commodity's price. It can easily take decades to go from initial surveying, to having a mine's output appearing on world markets. The companies who undertake these activities are in it for the long haul.

That being said, these companies are financed by real people, most of whom generally have much shorter-term investment horizons. They want some sort of return on their investment (be it profits from selling refined products of a mine, or an increase in their share price) within a reasonable period of time --- generally, for there to be at least a potential for "getting out" with a decent profit within a small number of years. There seems to be an obvious disconnect between the expectations/needs of real-world investors, and the time-scales imposed by the realities of finding and developing mines and wells. But there's not, obviously (or else there wouldn't be any mines or oil-wells).

The thing which makes financing such activities at all possible is *mining property rights*. Basically, the right to develop a mine or an oil or gas well on a particular piece of land is treated as a piece of property. As such, it possesses some of the key attributes of other pieces of real property. The key attribute here is the ability to indisputably determine who the owner is. This enables the mining right to be sold by its present owner, and bought by a new owner, with the new owner having a high degree of certainty that his ownership will not be challenged.

How does this help with financing the exploration phase of such properties? By creating a market in mining property rights, in which an investor can "get in" by buying into a mining claim, own it for as long as he or she likes, and then "get out" by selling it on to another investor.

During which time, the managers of the mining claim will do whatever they can to increase the value of the claim, thus increasing the price that new investors will be willing to pay. How? As is generally true for all capitalistic ventures, price goes up when risk goes down. Early in the life of a mining claim, there generally exists a large risk that there will be nothing valuable under that piece of land. That risk can be *quantified* to some extent, by carrying out exploration activities: conducting geological, geophysical and geochemical exploration. (For us at Gedex, that is our bread and butter, so we know it well, as does everyone else in this business.) If the exploration results are favourable, i.e., if they indicate a higher-than-average chance of valuable ore in the claim, then the risk has *de facto* been decreased, and the value of the claim generally increases. At this point some investors will sell at the increased share price; others who are more patient may stick it out, in the hopes of cashing in with a huge payday if the claim turns out to be unusually rich. Thus exploration is financed by a market of investors who get in and get out on varying time-scales, according to their own risk-tolerance and investment horizons. The Toronto stock exchange is one of the premier such markets in the world. Eventually, those few claims which turn out to hold a minable resource reach the point of being turned into a mine, either by the then-investors taking the step of becoming a mining company, or by selling the claim on to an existing mining company. Further financing is then needed for mine development, and development of processing facilities to extract marketable minerals from the ore, and transport them to market; the risks associated with those activities are very different from those during the exploration phase, and at this point the financing approach is more typical of that used by other publicly-traded companies.

The very earliest stages of exploration, which are the riskiest, are the hardest to finance. Canada has developed an important mechanism for helping explorationists in Canada through this phase, in the form of "flow through shares," which are a form of tax credit in which losses by an exploration company meeting certain requirements (e.g., conducting exploration activities in Canada) are allowed to "flow through" to investors in that company, with the investor then free to immediately use those losses to offset profits made from their other activities. This is a practical means for coping with the fact that exploration companies may go for years before making any profits; while losses might otherwise be carried-forward until profitability is reached, the fact is that this may be many years in the future, during which time the time cost of money will discount any such carry-forwards down to be worth little or nothing. Indeed, for many exploration companies, profitability is *never* reached, and any such carry-forwards would thus be "wasted." Flow-through shares allow the tax-losses due to exploration expenditures to be used with certainty, without discounting, and thus are more valuable in the hands of the venture's investors (so long as they have other profitable activities against which to write them off).

The Canadian government, and several provincial governments, have implemented flow-through shares in order to accomplish various important public-policy objectives. Principally, these make Canada a more-attractive venue for exploration than many other jurisdictions around the world. More exploration inevitably results in more discoveries (eventually), which has had the result in recent years of increasing Canada's mineral reserves substantially (previously they had been on a trajectory towards being dangerously depleted). Also, when these discoveries are turned into mines and wells, they will result in increased economic activity for Canada and the provinces, in the form of royalties paid to governments. In the meantime, the exploration activities themselves produce *immediate* economic activities --- Canadian jobs, many of them well-paying, with

resulting income taxes flowing back to the governments of Canada and the provinces --- those income taxes at least partially offsetting the immediate income-tax revenue losses resulting from the tax write-offs. These are undoubtedly part of the reason that Toronto has become such a mecca for mining-sector financing --- they are attractive enough to attract a significant amount of foreign investment into the Canadian exploration sector.

What *Can* Be Done?

What then *could* the Canadian government usefully do, in order to position Canada and Canadians to be significant players in the developing commercial space exploration and development arena?

Recommendation: Focus some of the Canadian Space Agency's resources and activities on promoting Canadian capabilities and activities in this area.

The CSA's current approach to space exploration is to choose exploration projects to support based primarily on *science* objectives. Sometimes this results in projects which have no purpose or utility beyond pure science, for example the Thermal Plasma Analyzer instrument on JAXA's Nozomi Mars mission, which would (had Nozomi not failed) have measured Mars' upper atmosphere, and the LIDAR weather station that CSA contributed to NASA's Phoenix Mars lander, which made science measurements of Mars' atmosphere from the ground.

However, some CSA-sponsored space exploration missions/instruments not only carry out excellent science, but also help build Canadian capabilities and expertise that will be useful to future commercial space exploration activities. In particular, the aforementioned NEOSSat mission (with MOST as a technology precursor) and the OSIRIS-REx Laser Altimeter have established a toe-hold for Canada in the field of asteroid exploration. It would be good for the CSA to adopt as a criterion that future proposed Canadian space-exploration activities include a rationale as to the contribution that they would make towards future Canadian space mining. While it would be excessive to insist that *all* Canadian space exploration activities must include such a component (there are, after all, good reasons to carry out occasional pure-science missions), there should be at least as many economic-exploration-oriented Canadian missions as pure-science ones, and missions which accomplish both should be pursued above other alternatives (NEOSSat and the OSIRIS-REx laser altimeter being good examples of a confluence of interest here, rather than a conflict).

There is the inescapable fact that few people working at CSA know much about potentially-workable avenues of commercially-aimed space exploration. This is natural, as this overlaps very little with their work as defined in the past. The future of commercially-oriented space exploration has, until now, been mapped almost entirely by visionaries in the private sector, with very infrequent exceptions (the most notable being Werner von Braun). Private-sector entrepreneurs are now starting to enter the field in a serious way --- that is, they are succeeding in convincing private investors to bankroll their vision-driven activities. In order for the CSA to be able to engage meaningfully with such people, people at the CSA will need to do some serious learning. A most important fact is that they must understand that *the initiative for such*

activities must come from the private sector, in order to succeed. The Canadian government's role in this arena is *not* to be the one to *plan out* the future of space-mining in Canada; it is to be *supportive* of Canadian private-sector players who start to take part in this arena.

Note: this recommendation is written assuming that the CSA should be the government agency leading the support of Canadian economic-driven space exploration. At present they are the natural choice for this role, given their (fairly recent) experience with science-driven space exploration missions. However, it may well be that some other government agency (perhaps even a new one) would eventually be a better "home" for this --- the CSA is very unused to engaging with entrepreneurial explorationist companies, and the cultural mismatch between the them may be too large to bridge. Or perhaps not: NASA has recently at least partially transformed itself from one of the most bureaucratic of government organizations, capable only of the most hideous cost-plus military-industrial-complex contracting, into an agency capable of supporting SpaceX's thrust to transform human spaceflight into a commercial activity. If NASA can change, perhaps so can the CSA, with proper leadership and vision, policy and strategy.

Recommendation: Introduce the recognition by Canada of space mining property rights, and take a leadership role in encouraging other countries to do the same.

As discussed above, mining property rights are the key enabling concept which allows private investors to invest in exploration for mineral and oil & gas resources here in Earth. The same will be true for mining-driven exploration in space, due to the similarly-long (or even longer) time-scales between initial investment and profits flowing from a working mine.

The fact is that mining property rights on Earth are tied to government jurisdictions. For example, Canada enforces those rights for land in Canada, as do other countries within their geographic boundaries. However, *no* country owns any land in space. Indeed, the one space-related treaty dealing with this topic that has been signed by almost all countries in the world (including Canada), the Outer Space Treaty from the 1960s, holds that no country (i.e., no "state party to the treaty") shall make territorial claims in space. For many years this was interpreted by some to mean that *nobody* could own property in space --- an interpretation which was encouraged for obvious ideological reasons by the communist-bloc countries in those Cold-War days, giving it some apparent credence. However, the Outer Space Treaty does *not* say that nobody can own property in space --- it is silent on the rights of individuals and corporations. Recent interpretations of that treaty have opened the door to the legality (within the framework of that treaty) of states recognizing individual and corporate property rights. (For example, see the recent white-paper on the topic by Rand Simberg, which I submitted to the Aerospace and Space Review's Space Working Group --- if an additional copy is needed, let me know. His paper focuses on space *land ownership* around *manned bases*, but there are obvious ways to extend the idea to ownership of *mining rights* on claims staked by *robotic exploration* with no manned base nearby.) The basic concept being that, at this point, a state could unilaterally accept a claim on the Moon or asteroid from a person or company, and that if claims were accepted from all comers (not just citizens of that country), then this would *not* be tantamount to that country exerting a territorial claim to that celestial body.

This concept does not, in and of itself, sweep away all issues associated with space mining rights. It is only a start, albeit an important one, one which may have the power to sweep away the cobwebs of previous communist-era arguments on this topic, and allow clear thinking to begin to take place. One obvious issue is the question of how such claims should be registered, and who should run that registry --- on Earth, the registry is run by the country whose land the claim is on, but no country holds territory in space. Another is the question of gaining universal acceptance of such claims among the many countries of Earth --- it's fine for *one* country to unilaterally accept a claim to a particular plot of land on the Moon by some company, but what if some *other* company gets a *competing* claim accepted unilaterally in another country? Such a scenario would not produce the level of certainty of ownership that investors would need, in order to be able to confidently buy shares in an exploration venture with the certainty that they could sell them with uncontested ownership of the underlying asset. Would there be claim license fees, as it typical in most jurisdictions on Earth? If so, then who would collect them? And how often? (Mining claim fees in many jurisdictions must be paid every year, and frequently the size of the claim reduces after the initial claim, with the claim-holder having to decide which portion of the claim to give up after awhile, a condition which encourages prompt exploration and development.)

At this point, *nobody* has all the answers to such questions. And, nobody will, until some country begins the process of taking these questions seriously. Past governments have basically "punted" such questions to the future, for future governments to deal with. At this point in time, the future is now approaching rapidly, and may (hopefully!) soon be upon us.

What can and should the government of Canada do, now, about this? *It could treat the current situation as an opportunity for Canada* to strengthen the position of Canadians and Canadian companies, in the field of economics-driven space exploration, by taking a leadership position on the issue of space mining rights. Canada has shown willingness in the past to take a leadership position on stalled international topics (e.g., with the landmine treaty, and many years ago on the Suez crisis), by bringing creative diplomacy and policy-making to bear. This is one of the things that other countries of the world have come to *expect of* Canada, and *respect about* Canada --- one of the reasons that Canada continues to have a seat at the grownup table of world policy despite its small size and military power. Canada is possibly in a unique position to tackle the process of building a consistent international approach to the topic of space mining rights --- in part because Canada is a world leader in the terrestrial mining field, and in part because Canada is small enough that the major powers need not feel threatened by us, whereas (for example) the USA, Russia and China would each not tolerate either of the others talking the lead in this. That is, Canada *should* take on this initiative, because we *can*, where others *cannot*.

What would this involve? At the start, studying the issue, with a view to developing an action plan to resolve it. Those studying this should include people from the Canadian government organizations likely to be involved in developing a policy solution (NRCan, DFAIT, CSA), as well as representatives from Canadian space terrestrial and space exploration companies, with outreach to the international companies who are active in space exploration aimed at space mining. Scholars from the McGill Centre for Space Law would provide a pool of talent to help with this; they have been doing so at an internationally-recognized level for many years. The end goal would be for Canada to implement a registry of mining claims on celestial bodies, as soon

as possible, with that registry to be coordinated with similar unilateral registries in like-minded countries. Part of the goal would be for Canada to initiate an international process leading to international coordination of unilateral registries. In this way space property rights would be officially accepted at the national level in many countries, where those rights could be protected by legal means by the laws of the countries holding such registries.

Note: a perhaps-tempting path would be to punt this issue out to the United Nations, which after all has a mandate to broker international agreements on many topics. There is a danger in doing so, as the UN functions on a nearly consensus basis, via which numerous small-population countries can hold international initiatives hostage in return for benefits. The UN has a poor history of being able to forge a consensus on the topic of extra-national property rights, as witness the "glacial" pace of progress in dealing with undersea property rights, and the Antarctic Treaty. Indeed, the most recent attempt by the UN to address space property rights, in the 1970s, was held hostage in just this way by the communist-bloc countries, aided by numerous small non-space-faring nations, resulting in the much-reviled Moon Treaty, which fortunately no space-faring nation ever ratified. This treaty aims to make all things of value in space be the common property of everyone in the world, in the naïve belief that this will prevent the injustice of economic benefits flowing only to some and not to all. It *would* accomplish that, but only by enforcing the result of *no* benefits flowing to *anyone*: under its regime, no investor would ever invest in off-planet exploration or mining, as they would see almost none of any resulting profits. Only state enterprises could conceivably find a reason to expend resources exploring space under that regime, but the communist-nation state enterprises of the 1970s have now been consigned to the trash-heap of history.

Unfortunately, the UN is bound to respect the Moon Treaty, through its official body for these matters, the Committee for the Peaceful Uses of Outer Space (COPUOS), which led the development of that treaty. It is possible that the UN and COPUOS may, at some time in the future, become useful in brokering a replacement for the Moon Treaty which helps unleash the power of private capital to take space exploration and development to a useful level. The recommendation here is to not *wait for* that time to come, but to *help* that time to come, via taking a leadership role in unilateral, bilateral and multi-lateral activities outside of COPUOS.

Recommendation: Extend the current Canadian government flow-through shares for exploration, to apply to space-mining-focused space exploration activities carried out in Canada.

As discussed above, Canada's existing flow-through shares mechanism has been very successful in attracting private capital, both Canadian and foreign, into Canadian exploration for mineral, oil and gas resources. This has resulted in a spike in exploration activity in Canada, with all manner of resulting benefits to Canada.

The fact of the matter is that *space exploration spending takes place here on Earth*. Canada should encourage space exploration spending to take place *in Canada*. It is obviously impossible to get *foreign governments* to spend much of their *science-driven* space exploration spending in Canada; part of their rationale for that spending is to promote their local industries, as is also the

case here. However, *commercial* space exploration is financed by private investments, and its spending is not tied to be spent in the investors' own countries. *It could be spent in Canada*, if there was a good reason for them to want to. Which could result in an immediate surge in Canadian jobs, in highly technical, highly-paid industries, designing and building spacecraft, operating them as they fly through space to their targets, receiving their exploration datasets, processing and interpreting them.

Extending the flow-through shares mechanism, to companies carrying out mining-driven space exploration in Canada, would be a powerful incentive for space explorationists worldwide to locate in Canada. Of course, the rules around this would have to be crafted to support the desired type of activities as much as possible, with as little of the tax breaks as possible going towards marginal or not-really-related activities. This would require care: for example, should a space telescope mission such as NEOSSat, which searches for Earth-approaching asteroids, qualify for this benefit? Where is the line between pure science, and a mining-driven mission? In some cases, a mission may accomplish both; should it then be given less than full credit? To help sort this out, the relevant Canadian government departments (CRA, NRCan, CSA, others?) should set up a joint study activity, with Canadian space industries and international space explorationists involved as equal study partners. The goal would be to develop, as soon as possible, an initial set of criteria for determining what new activities would qualify for this benefit, and under what conditions. There is no need to get this perfectly right the first time, as the space-exploration sector will soon evolve fairly rapidly, and so will be a moving target that needs frequent updates to the rules; however, suitable safeguards must be built in from the start, to avoid the sort of fraud-fest debacle that the R&D Tax Credits were in their first two years.

Recommendation: The Canadian government should purchase early space exploration data on a "space data purchase" basis from the private sector.

The Canadian government's traditional way of engaging with industries in the Canadian space sector has tended to follow the "military-industrial-complex" model, buying space systems on a cost-reimbursable basis, with the government agency closely controlling the development of the resulting system. As noted in a separate submission by me to this Review, this tends to result in systems that are developed at a much higher cost than they could be developed for under other circumstances (rather than repeat those details here, the reader is referred to that other submission). The main point being that government-purchased space systems tend to be extremely expensive, with costs that would be prohibitive for commercially-driven space exploration --- the up-front costs would never be recovered. This is a primary reason why private space exploration has been so long in coming onto the scene --- it has awaited a large drop in these costs, driven by an increasing number of industry players making a business of developing much lower-cost space systems, and selling them or their fruits to entrepreneurs, an obvious chicken-or-egg dilemma that has taken time and creativity to resolve. The act that Planetary Resources Inc. didn't spring up until after Elon Musk's SpaceX brought the Falcon launcher to market is not a coincidence.

Eventually, mining-driven space exploration will likely be a completely private activity, not wanting or needing any sort of direct government funding. However, in its very early stages, it

will likely benefit usefully from funds that governments are willing to target their way --- as long as those funds don't come with unacceptable strings attached. Such strings, as discussed at length in the above-cited submission, are often in the form of heavy oversight by the funding agency, which distorts the way that the company carries out its space systems design and building activities, driving the cost up to no good end. *That* submission recommends one particular approach to dealing with this problem; *this* recommendation aims at another approach.

If the problem is to get out from under the cost-effectiveness-sapping government-agency oversight during system development, a technique that a growing number of space companies have turned to is to sell *space services* rather than *space systems*. Earth observation companies in the USA were among the first to go down this road, selling imagery to NASA, NOAA and various defence agencies, where 10-20 years earlier they (or their precursors) had sold them Landsat satellites and spy-satellites. Canada's recent experience with this includes Radarsat-2, which MDA developed under an agreement which contemplated MDA funding the development privately, eventually to recover their costs and make a profit by selling imagery to the Canadian government, among other customers. The Canadian government helped seed this venture by agreeing to pre-purchase a large amount of imagery --- no more than it eventually expected to order anyway, but taking a risk in case the satellite failed to launch, or to work on-orbit. This turned out to be a fairly successful public-private partnership (although marred by the US government attempting to derail the program).

Another very recent such example in Canada is the company exactEarth, created by Comdev to buy and/or make satellites to collect AIS ship-tracking data from orbit, and then sell it on a commercial basis to various customers (including numerous Canadian government departments). exactEarth is now operating several AIS satellites in orbit, with more in the pipeline being prepared for launch, and has taken on a global leadership role in this data-services market --- hopefully it will be profitable for them! The fact that exactEarth can purchase very low-cost satellites for this purpose will help enormously with that; their satellite purchase prices are *much* lower than typical government satellite purchase prices, mainly because the onerous government agency oversight is absent. By selling data services to the government, exactEarth is able to get their government customers the data they need, risk-free, by using industry-internal best-practices to allow the underlying satellite systems to be developed much more cost-effectively.

This recommendation aims at including space-exploration data in the types of data for which the Canadians space agency is willing to make space data purchase agreements. This would represent an initial way for the CSA to "meet space explorationists half-way," in terms of the currently-incompatible corporate cultures of the two different types of organizations. A very visible worked example of this sort of thing is the way that NASA has been able to meet SpaceX half-way, as it were, via the COTS and ISS resupply launch services contracts. At the beginning of that process there were many in NASA who misunderstood, feared and disliked SpaceX and the change that it represented; now NASA and SpaceX are "best friends," with each providing invaluable help to the other.

The CSA has reasons to want to carry out science-driven space exploration missions, sending sensors of various sorts to various planetary destinations, in order to send data back to scientists in Canada. This might be data on the atmosphere of Mars, the gravity field of the Moon, the

geochemistry of rocks on the surface of the Moon, etc. Currently the CSA's missions in this area of exploration have been few and far between, mainly because the estimated cost of buying the space systems to carry out these missions has been so high, and the CSA's budget too low to be able to afford to proceed more often than very occasionally. I suggest that these missions could be carried out on a much lower cost basis, and so the CSA could afford to carry out more missions for a given amount of money, if the heavy government-agency oversight was removed. And that one way to do that is by converting space exploration *systems* purchases into space exploration *data* purchases.

The whys and wherefors of this would need to be carefully worked out, to provide a suitable balance of government and industry risk, to provide industry with the potential for making temptingly-high profits in case of success to offset the taking-on of the various risks involved, and to provide for fairness for competitive offerings (and avoid corruption in the awarding of such contracts). Fortunately the growing number of data-purchase arrangements from space systems in Earth orbit provides an excellent starting-point and experience-base for this.

Note that this "space data purchase" approach is, from Gedex's perspective, simply an extension to the space domain of the exploration-industry standard contract for carrying out a geophysical survey. This contracting approach would be very familiar to any experienced explorationist, who deals in raw and interpreted data, not in selling hardware. Speaking as a company entrenched in the terrestrial entrepreneurial exploration sector, Gedex would have zero interest in working for agencies like the CSA, if it involved selling them space systems under the CSA's "usual" development-oversight approach. Gedex has a strong interest in expanding its activities into the space exploration sector, aimed at space mining, and would be very interested in doing so for partners like the CSA, if they were willing to adapt to exploration-industry contacting approaches like this. And sees this as a useful first step down the road which hopefully lead to Canadian companies dominating space mining 100 years from now!