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What can space resources do for astronomy and planetary science?

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ABSTRACT

The rapid cost growth of flagship space missions has created a crisis for astronomy and planetary science. We have hit the funding wall. For the past 3 decades scientists have not had to think much about how space technology would change within their planning horizon. However, this time around enormous improvements in space infrastructure capabilities and, especially, costs are likely on the 20-year gestation periods for large space telescopes. Commercial space will lower launch and spacecraft costs substantially, enable cost-effective on-orbit servicing, cheap lunar landers and “interplanetary cubesats” by the early 2020s. A doubling of flagship launch rates is not implausible. On a longer timescale it will enable large structures to be assembled and constructed in space. These developments will change how we plan and design missions.

1. More light

Like the great poet and polymath Goethe, astronomers will be calling for “more light” on their deathbeds (Fig. 1).[1] We are always seeking larger telescopes to collect the faint light arriving from the most distant stars, galaxies and quasars in the earliest times of the Universe; or else we are slicing up the light from bright stars exceedingly fine to look for signatures of small planets, other earths. There is no limit to what we crave. But we are in trouble. Our telescopes have grown in expense far faster than the economies they depend on. “*If something cannot go on forever, it will stop*” as Herbert Stein's Law states in economics [1]. What can we do to ensure that ever greater observatories lie ahead?

The new large space telescopes now being discussed will not launch for 15–25 years. On that timescale much is going to change that could help our field. In this paper I look at the rapid developments occurring in commercial space activities and examine how they could provide a way out of our dilemma.

These developments are numerous. In Fig. 2 the timelines for major astronomy decisions to be made is compared with that for major developments anticipated for commercial space, including space resources. Clearly many relevant commercial space activities are set to happen before the next generation of major astronomy observatories are launched, or even begin their final design/build stages (phase C/D in NASA terminology). Planning to take advantage of these developments would seem advisable.

2. The funding wall

Astronomers are already planning telescopes for the late 2020s. For example, the X-ray telescope ATHENA[2] has been selected as the second European Space Agency (ESA) Large mission (L2). It has an intended launch date of 2028. In the US the jostling for position to be given the #1 recommendation for large space missions in the 2020 “decadal study” has already begun. The astronomy management organization AURA has issued a report entitled “From Cosmic Birth to Living Earths”.[3] This report advocates for a telescope double the size of the *James Webb Space Telescope* (JWST) to take this #1 spot. This “High Definition Space Telescope” (HDST) would have advanced coronagraphic (starlight-suppressing) optics that would allow it to directly detect the light from a twin of the Earth around nearby stars. Their nominal launch date is 2035.

Why plan so far ahead? Are astronomers just keen on delayed gratification? There is a deeper reason for these long timescales.

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[1] In Goethe's case this may well be mythical; for astronomers, not so much.

[2] http://sci.esa.int/cosmic-vision/54517-athena/.

[3] http://www.hdstvision.org. See also my critique: arXiv:1509.07798, and the response: arXiv:1511.01144.

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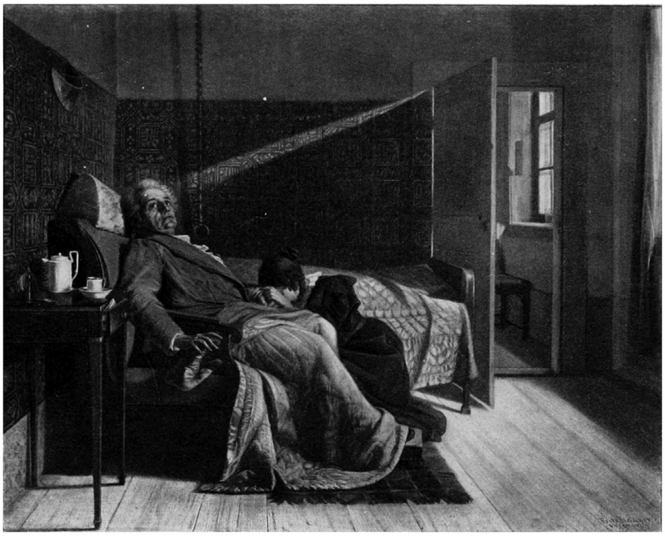

Fig. 1. Johann Wolfgang von Goethe calls for more light on his deathbed (F. Fliescher; source: commons.wikimedia.org).

2.1. Growing ambitions, growing costs

The reason we are making plans so far in advance is that our telescopes, in every band of the electromagnetic spectrum, have grown over the past few decades from small exploratory devices to Great Observatories. These flagship missions have enormous costs and take many years from conception to launch.

The prototypes for *Hubble* were space telescopes looking in ultraviolet light (which does not get through our atmosphere): the *Copernicus* Orbiting Astronomical Observatory, followed by the *International Ultraviolet Explorer* (IUE). These carried quite modest 80 cm and 45 cm diameter mirrors, respectively. *Hubble* has a 3–5 times larger mirror. JWST, billed as *Hubble's* successor, has a 6.5 m telescope, almost 3 times larger still. If built, HDST would be another doubling. This tendency to grow in jumps of 3 or so in diameter, or about 10 in mirror area, is exponential growth. It is baked into our research programs, as discoveries just possible with the previous generation always need more light to discern what they are and how they work. Without an order of magnitude leap in at least one capability there is virtually no chance that your favorite flagship will fly. The problem is that, historically, larger telescopes cost more.

Cost growth can be tracked for any class of space missions. For many years my field was X-ray astronomy. The breakthrough satellite missions[4] came from NASA and were: *UHURU* (SAS-A, launched in 1970), the *Einstein Observatory* (HEAO-B, launched in 1978) and *Chandra* (AXAF, launched in 1999). Over the course of these 3 decades X-ray astronomy gained a factor of over 1 million in sensitivity. That is a truly huge advance, and is something that took optical astronomy about 200 years. The resulting impact on astrophysics was profound [2].

But the price was high. Fig. 3 shows how the (inflation-corrected) cost of these missions increased by a factor of about 20 over 30 years. This is an exponential growth rate of 10% per year. The same plot for other wavelength bands would be much the same. Ian Crawford has shown that Mars landers have grown even faster, at about 15% per year [3]. Historical growth rates for the US GDP have been fairly steady at about 2% a year for the past century and more (1871–2001).[5] Clearly, growth rates for astronomy that are four times faster than that of the economy are unsustainable.

Exponentially rising curves become all but vertical, so this mismatch of rates is often called “the funding wall” [4]. At some point the costs are more than a government can abide. Particle physics hit its funding wall in the US when the Superconducting Super-Collider, already far along in construction in Texas, went over budget one too many times and was cancelled.[6] Is astronomy next?

We may well be up against the funding wall right now. JWST is costing NASA almost $9 B up through launch in 2018, with another $1 B or so coming from ESA and Canada. Cost growth led to repeated cancellation threats but a de-scope in 2001 and a re-plan in2011[7] averted this [5]. The HDST concept, AURA officials suggest,[8] would cost about the same, though many outsiders are quietly skeptical that it would be so cheap. NASA currently has a budget of about $5 B per decade for large new space telescopes.[9] Each JWST-class mission thus takes 100% of nearly 20 years of this funding line. So building HDST by 2035, about 10 years after the launch of the Wide-Field Infrared Survey Telescope (WFIRST) in the early 2020s[10], would require roughly doubling the available budget. A few billion more for such a major mission does not sound like an impossible target. But there is a catch.

2.2. The need for pan-spectral coverage

The problem is that modern astrophysics depends on simultaneous access to the entire electromagnetic spectrum. Stars, galaxies, quasars, and even planets, blithely ignore the limitations of our technologies, emitting light across all wavelengths, from the radio and infrared to the optical, ultraviolet and X-rays. Once astronomers see a cosmic object across the spectrum problems that had seemed deeply mysterious are answered, like jigsaw pieces fitting together, as in the case of the “exploding galaxy” Messier 82 (Fig. 4).

No one observatory can give the whole picture; together the story is clear: a giant burst of star formation in the center of the Messier 82 galaxy (*Hubble*, in green) forces a huge plume of gas heated to millions of degree (*Chandra*, in blue) out of the spiral disk, following the path of least resistance, with cool gas and dust following it around the edges. Here we are witnessing the process of young massive stars exploding as supernovae and sending their newly synthesized elements into space. It is from such materials that planets, and us, are formed. There are many such examples. They are the norm in 21st century astrophysics.

The synergy between these spectrum-spanning telescopes is surely a major reason that we are in a Golden Age of Astronomy.

We have been very fortunate, in fact, that this synergy has already lasted for 35 years, beginning around 1980 when we had

[4] With apologies to the many other fine missions that did sterling work, including Ariel V, which I used for my PhD thesis. Nonetheless, the factor 100 steps in sensitivity were those listed.

[5] The fastest decade of growth in US GDP since 1871 was in the 1941–1950 decade when the rate reached 3.87%. http://socialdemocracy21stcentury.blogspot.com/2012/09/us-real-per-capita-gdp-from-18702001.html.

[6] Appell, D., (2013), http://www.scientificamerican.com/article/the-supercollider-that-never-was/.

[7] http://www.space.com/12759-james-webb-space-telescope-nasa-cost-increase.html.

[8] Calla Cofield, Space.com, http://www.space.com/29878-alien-life-search-hdst-space-telescope.html.

[9] http://files.aas.org/head2015_workshop/HEAD_2015_Paul_Hertz.pdf, integration of slide.14.

[10] http://www.nasa.gov/content/goddard/qa-session-about-nasas-wfirst-mission.