COMMERCIAL SPACE ENABLING OF ASTRONOMY IN THE 2020s

Martin Elvis[1], [1]Center for Astrophysics | Harvard & Smithsonian, 60 Garden St., Cambridge MA 02138 USA; *melvis@cfa.harvard.edu*.

Introduction: For the past 3 decades astronomers have not had to think much about how space technology would change within their planning horizon. This is no longer the case.

This time around enormous improvements in space infrastructure capabilities and, especially, costs are likely within the Astro2020 horizon: commercial space is greatly lowering launch costs; lower spacecraft costs are emerging; the Commercial Crew program may enable cost-effective LEO servicing, by the early 2020s. A doubling of flagship launch rates is not implausible. By the late 2020s large structures may be assembled and constructed in space. These developments will change how we plan and design missions and need to be considered by the Astro2020 Decadal.

Lower Launch Cost: For decades cost/kg to LEO was a constant, high, number, ~$10,000 - $20,000. With the advent of the partly re-usable Falcon 9 from SpaceX, the advertised cost is ~$3000/kg. (The cost to NASA is closer to $4500/kg.) Falcon Heavy reaches $1400/kg [1]. The F-H payload mass is an enormous 63.8 mt to LEO. (Competition from Blue Origin's New Glenn and ULAs Vulcan will keep prices low.) The direct savings of ~$200M per mission are good. The end of the mass-cost relation is probably more important. Most obviously, inherently heavy yet (relatively) simple payloads such as a scaled-up modern Fermi LAT become possible. More generally, the need to minimize the mass of all components is greatly eased. Studies suggest factors of several in mission cost reduction [1].

Lower Spacecraft Cost: New developments in spacecraft design are lowering costs dramatically. Blue Canyon Technologies [2] and OneWeb [3] are producing capable satellite buses in the low millions, roughly an order of magnitude lower cost than traditional suppliers. Lower cost spacecraft lend themselves to constellations of observatories. If the trend continues to buses capable of accommodating large telescopes then even the cost of flagship missions could be cut in half, or more.

Cost-effective Servicing in LEO: The *Hubble* experience tells us that servicing missions can be extremely valuable scientifically, indeed they can rescue the mission. Yet at a cost of ~$1B/SM, *Hubble's* example was not reproducible. The imminent advent of Commercial Crew to the International Space Station provides relatively low cost access to LEO by astronauts. Despite the limitations of LEO for astronomy, this new capability could allow enhancement and life extension for flagship missions.

On-Orbit Assembly: Launcher fairings are presently about 5 meters in diameter. The limit of mirror diameter achievable by unfolding from a 5 meter fairing[4] appears to be ~12m. (For comparison JWST originally had an 8 m mirror.)

Fairings are getting larger: New Glenn will have a 7 m fairing[1], while the SpaceX Super Heavy will have a ~9 m fairing. The later SLS (Block 2B, "late 2020s") fairing is intended to reach 10 meters[2]. These capabilities should be exploited by astronomers.

Mirrors and antennas larger than ~20 m are desirable for many purposes. These will require on-orbit assembly. With commercial space stations as bases, improved robotics, and relatively low-cost access to LEO for astronauts, on-orbit assembly may become a sensible option toward the end of the Astro2020 planning horizon.

Conclusions: Previous Decadal studies in astronomy have been able to assume a stable baseline set of capabilities for space activities. For the Astro2020 Decadal this assumption no longer applies. The many new developments will complicate the Decadal planning process. More importantly they open up possibilities for dramatically cheaper missions, and so more of them, as well as cost-effective missions larger than we have so far imagined. The Astro2020 Decadal process needs to incorporate the changes being wrought by commercial space.

References: [1] U.S. Congress, Office of Technology Assessment, 1990, *AFFORDABLE SPACECRAFT: Design and Launch Alternatives*, M. Granger Morgan (Chair), http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1010&context=spacelawdocs; Callaham, M.B. (1990) "Making Spacecraft Affordable: An Assessment of Alternatives", *SAE Technical Paper* 901020, doi:10.4271/901020; Elverum, G. (1973) "Scale Up to Keep Mission Costs Down", *International Astronautical Federation Congress*, 24, 6. [2] https://www.spacex.com/about/capabilities. Accessed 7Feb2019. [3] http://bluecanyontech.com/buses/.

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