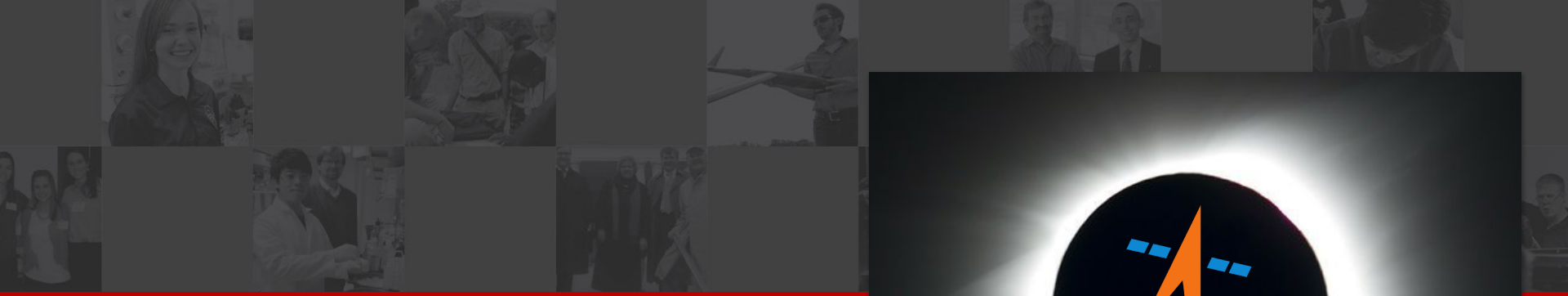

THE OHIO STATE UNIVERSITY
COLLEGE OF ENGINEERING

India: A Global Space Power

Possibilities and Precautions for US / India Collaboration

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Why Space?

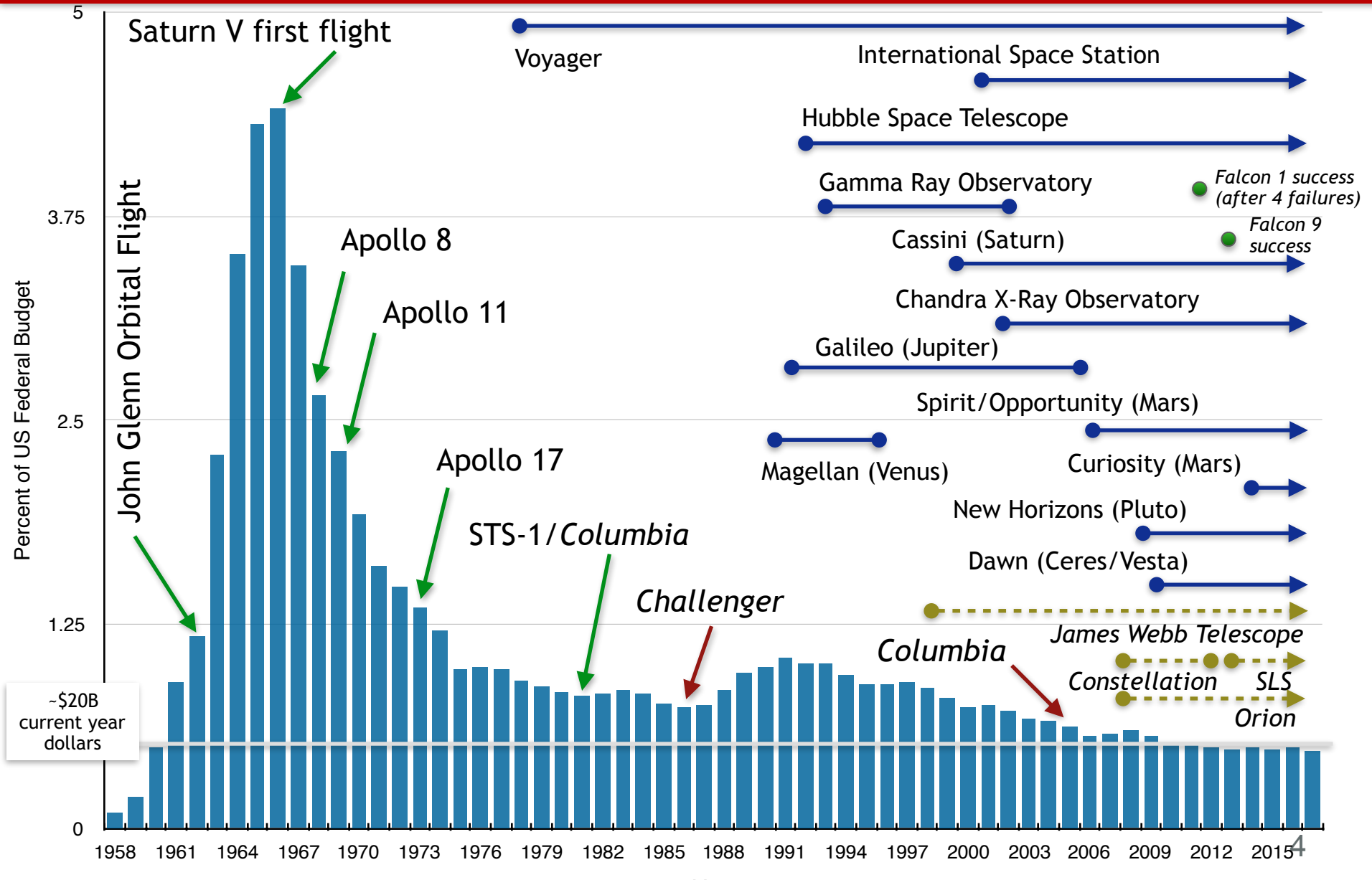
- **Built from every engineering discipline:** Materials, Chemical, Fluids, Industrial, Thermal, Aerodynamic, Systems, Computer, ...
- **Leverages every science discipline:** Physics, Chemistry, Biology, Geology, Meteorology, Oceanography, ...
- **Leverages every business discipline:** Budget, Accounting, HR, Contracts, Finance, ...
- **Driven by Policy:** Instrument of Executive Branch (in the US), fortification of Economic competitiveness (e.g., European), Government funded, ...
- **National Prestige Driven Past:** With significant parts of this remaining…
- **Commercially Driven Future:** SpaceX, PlanetLabs, SkyBox, Firefly, BridgeSat, UrtheCast, NanoRacks, ExactEarth, Blue Origin, Virgin Galactic, ...
- **Harshest environments:** Hard vacuum, radiation, large energy requirements, high velocity, thermal extremes, ...
- **Highest Consequences of Failure:** *Challenger*, *Columbia*, Apollo 1, Hubble mirror, ...

A deeply integrated endeavor. "At the edge" of human capability. Collaboration and cooperation are natural.

"When Will India be a Space Power?"

India <u>ALREADY IS</u> a Global Space Power.
Not "peer" to US or Russia (yet), but a very high-quality program.

NASA Budget as a Percentage of United States Federal Budget



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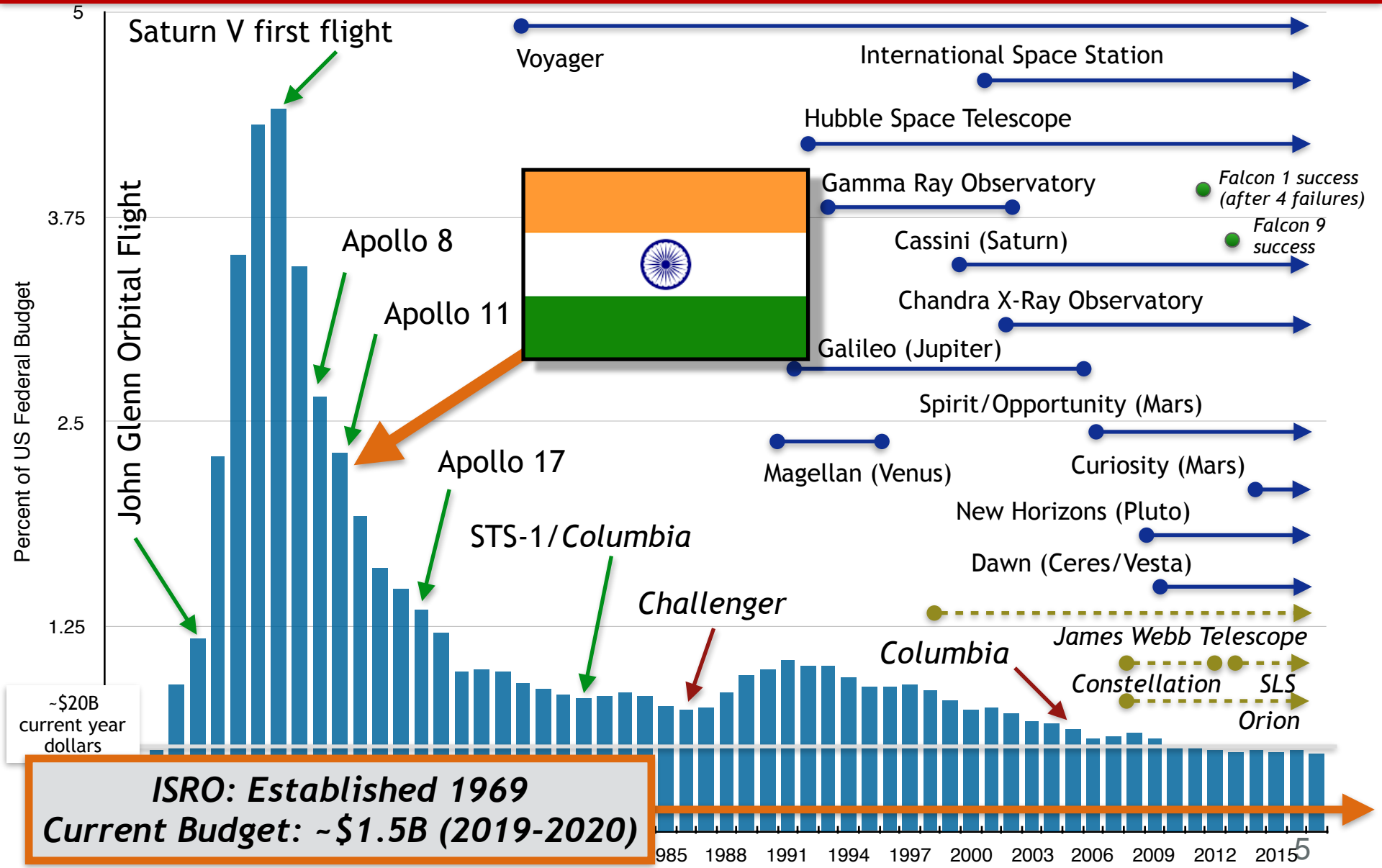
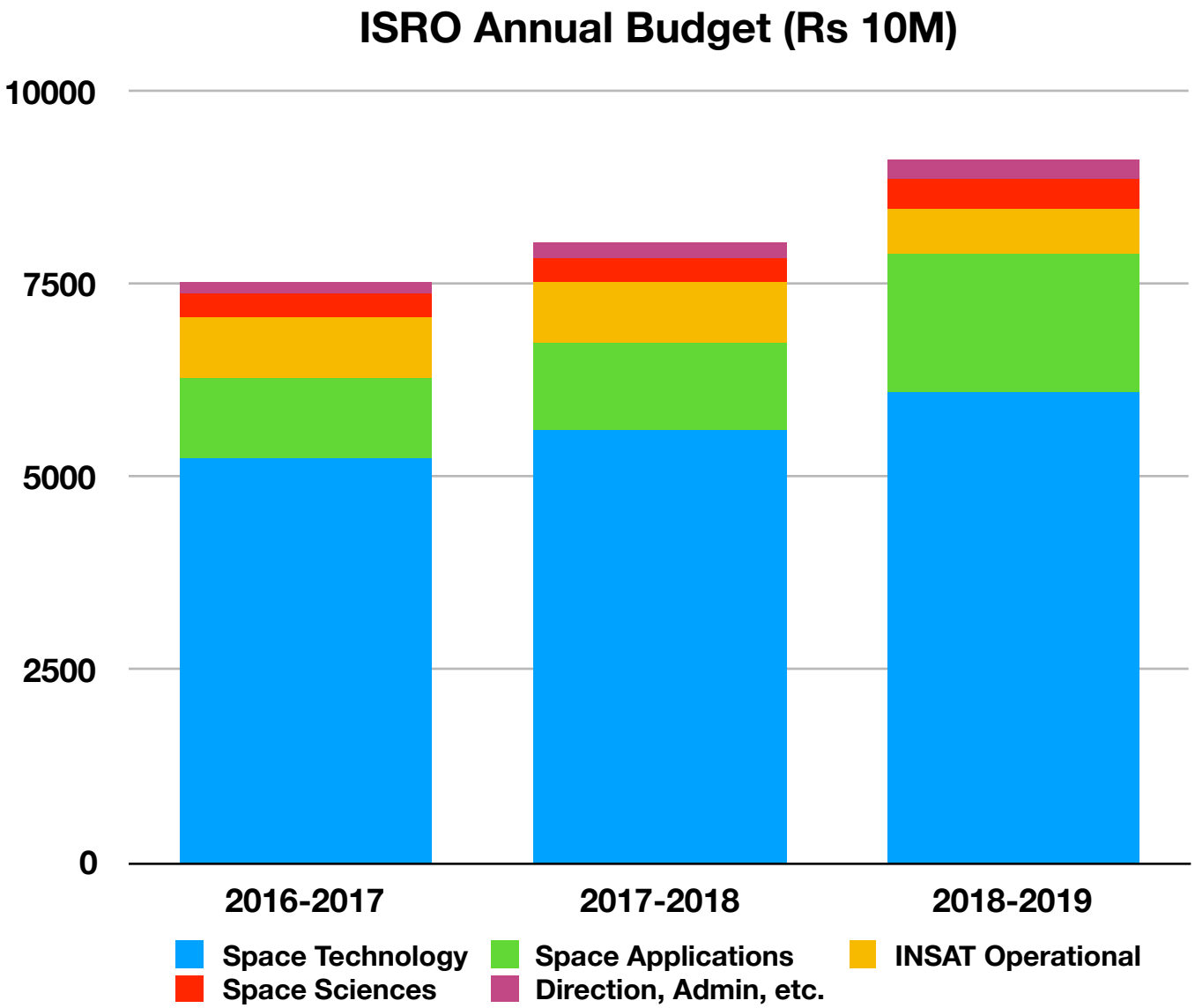


ISRO: Established 1969
Current Budget: ~$1.5B (2019-2020)

India Space Budget (2016 - 2019)



- *Supports over 16,000 people. (NASA has about 20,000)*
- *Significant growth in past three years.*
- *~10% of the NASA budget total.*
- *Per-Capita Citizen Budget, even smaller.*
- *2020, ~10,252 Rs Crore*

India in Space

- **India Space Strategy - executed through ISRO**
  - *"…harness space technology for **national development** while pursuing space science research and planetary exploration…". - ISRO*
  - *"…if Indians were to play meaningful role in the community of nations, they must be second to none in the **application of advanced technologies to their real-life problems**. They had no intention of using it merely as a means of displaying our might." - Abdul Kalam*
- **Integrated Spaceflight Program Priorities:**
  - *Launch Vehicles*
  - *Satellite Programs - Earth, Mars, and More*
  - *Human Spaceflight (in preparation)*
- **The Current "Hot" Topic (Lunar Exploration):**
  - *Chandraayan-1*
  - *Chandraayan-2*
  - *Vikram Lander and Rover*

First Satellite: 1975 (Soviet Launch Vehicle) *Aryabhata*

First "All India" launch: 1980 (*Rohini*)

India Launch Vehicles

Polar Satellite Launch Vehicle (PSLV)

- *Among the most reliable anywhere in the world (45/48).*
- *Ability to maintain high-launch cadence (~15 per year)*
- *Medium-Class LV, ~8,000 lb to LEO*
- *~$25M per launch (very inexpensive)*
- *"Polar" Satellites most useful for remote sensing.*

Geosynchronous Satellite Launch Vehicle (GSLV)

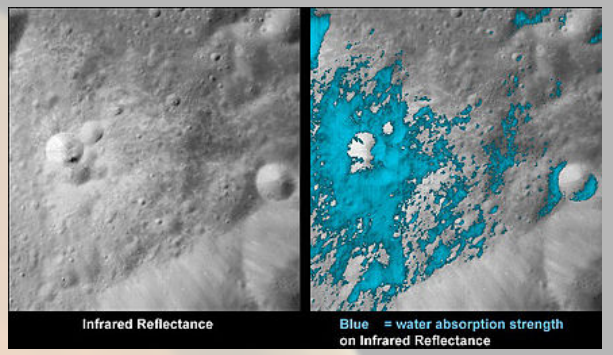
- *Fewer flights than PSLV, now in 3rd Generation*
- *~11,000 lb to LEO, 6,000 to GTO*
- *"Geo" satellites most useful for telecommunications, and weather observations of the sub-continent.*

Exceptional Launch Capabilities.
When it comes to Launch Vehicles, the US worries about ITAR/proliferation, and impacts to US Commercial Companies

India Satellite Programs (some)

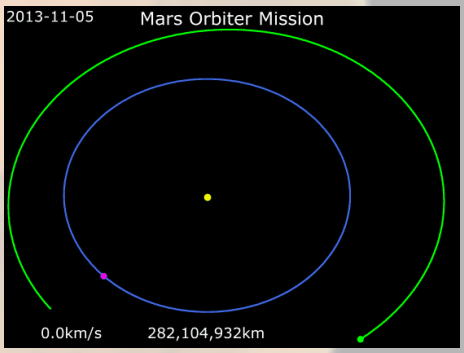
Chandraayan-1

- *Lunar Orbiting Satellite, with 11 instruments*
- *Launched 2008, aboard a modified PSLV.*
- *US/NASA Contributed "Moon Mineralogy Mapper" (M3) instrument to this spacecraft. (1 of 6 from outside India.)*
- *M3 instrument: Discovery of water on the Moon.*



Mangalyaan (Mars Orbiter Mission)

- *PSLV launch, 298 day transit, orbit insertion 24 Sept 2014.*
- *$73M mission. First Asian Nation to reach Mars Orbit*
- *"Geo" satellites most useful for telecommunications, and weather observations of the sub-continent.*

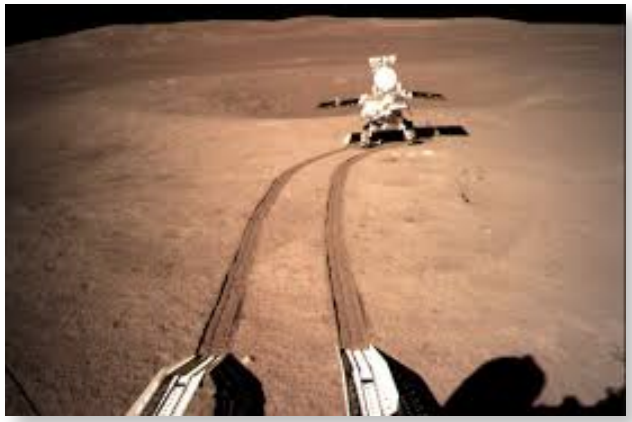


In Science, Collaboration is the "norm."

Landing on the Moon

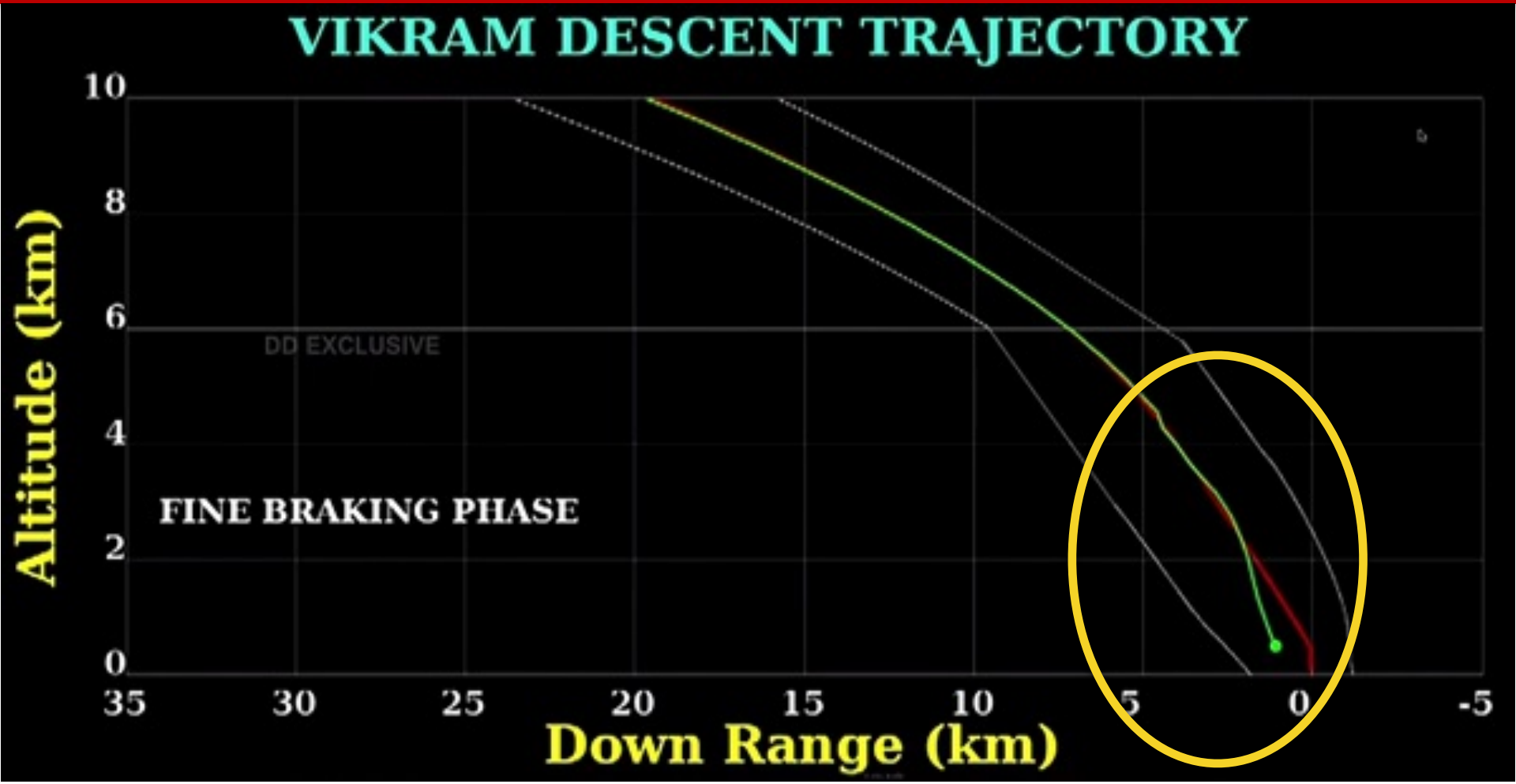
- **It's VERY difficult.**
  - *No atmosphere to slow you down.*
  - *No certainty about the place you are trying to land (rocks, craters, slopes, …)*
  - *An "inverse launch," with power-on all the way down.*
  - *Everything must be automated.*
  - *Generally brake in stages - big engines first, then small engines take over*

- **Successes:**
  - *Soviet (Luna), US (Surveyor) in 1960's and 1970's*
  - *China just this past year, with Chang'e-4.*
  - *Many unsuccessful attempts.*



Vikram was a very ambitious attempt, that almost succeeded.

Vikram's Status



Malfunction or 'event' during final braking phase, about 2 km up.
Green - Actual trajectory. Red - Planned trajectory.

All Hope is not lost

- **The lander has been spotted (9 September).**
  - *Chandraayan-2 orbiter sees the lander from above.*
  - *This is not all that surprising, since one "knew where to look."*
  - *Clearly a very "hard landing." But how hard?*
  - *ISRO Reports "Lander is in one piece, but tilted."*

- **Possible Futures:**
  - *Landing was too hard, Vikram is dead*
  - *Landing was hard, but not sufficient to 'break' the lander. Antenna are pointing in the wrong direction.*
  - *Contact *could* be restored, but perhaps severely degraded.*

Design lifetime is about 14-days on the Lunar Surface…
But the ORBITER WILL CONTINUE ITS MISSION.

I would be happy to answer any questions you may have.