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University of Colorado **Boulder**

Corona II: Returning Large Amounts of Data to Earth

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Overview

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- Downlinking data over planetary distances is hard
  - Range to Earth
  - Range to Sun (Power)
  - Deep Space Network (or other antenna) time
  - Example of a CubeSat asteroid encounter
- Is there a more mechanical solution?
  - Example of a CubeSat asteroid encounter
- An even more mechanical solution
  - This may not be entirely serious…

MarCO and IRIS 2.1

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- This presentation uses MarCO/IRIS 2.1 and as example
- Only flight-proven CubeSat deep space transponder
- Supports variable rates from 62.5 bps to 256 kbps
- 35 W input power
- 0.5 U and 1.2 kg for IRIS transponder
- 0.3 x 0.6 m antenna
- Antenna and power system to support telecom ~2 U
- 8 kbps from 0.87 AU
- What could this do on a 3 AU asteroid flyby mission?

Downlinks from 3 AU

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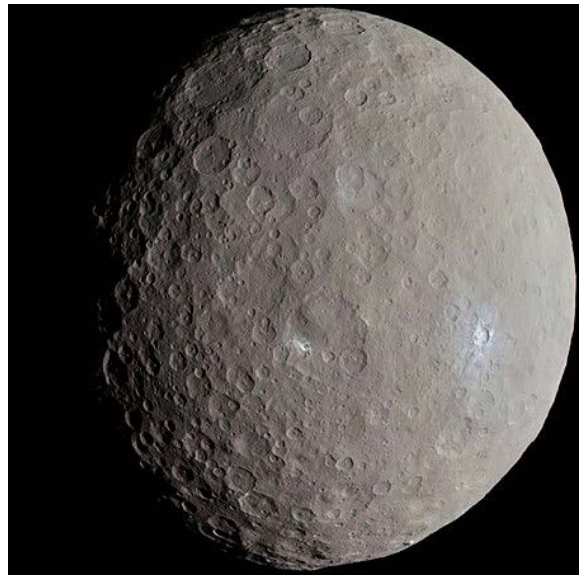
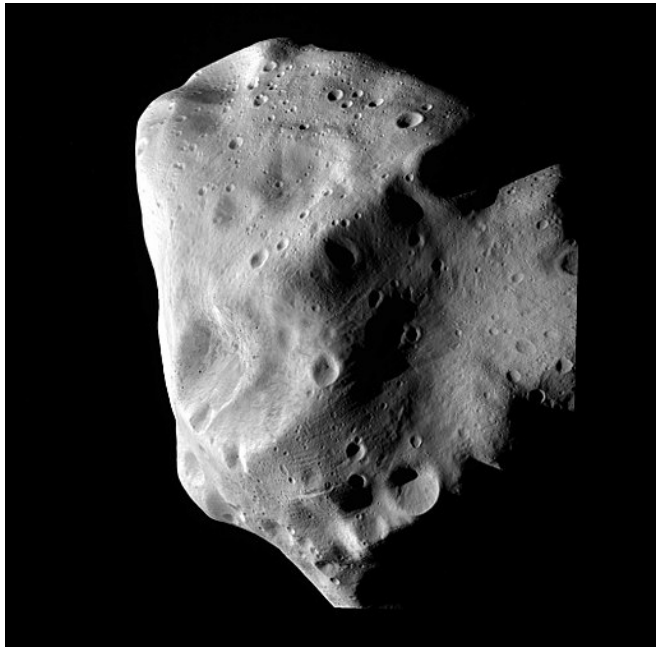
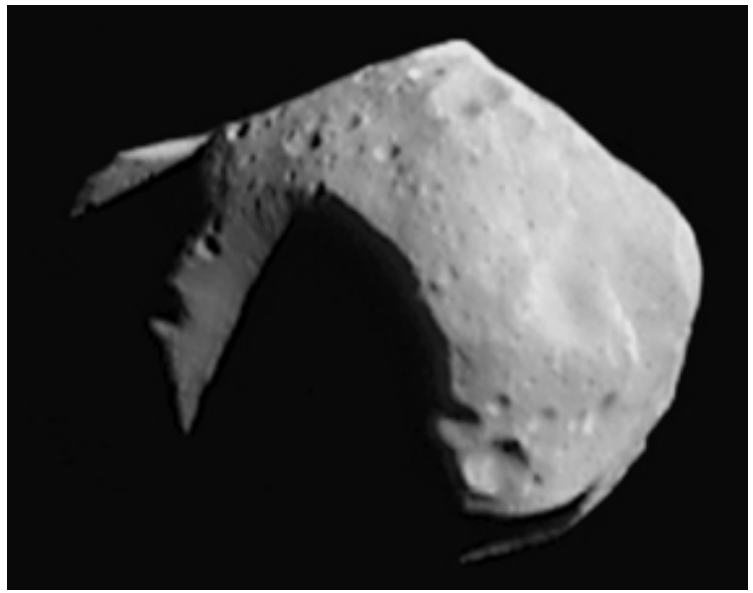
- Solar power at 3 AU provides 44 W/m^2
  - Assuming 29% efficiency for solar arrays
  - 35 W for IRIS transponder unlikely to be available
  - Even 30 W (2, 20x90 cm arrays) would be optimistic
- Power downlinks from batteries, recharge in between
- 8 hour downlinks with 35 W power requires 280 W-hrs
  - That is quite a bit for a CubeSat
  - Short downlinks make inefficient use of ground antenna time
- 6 W would support one, 8-hour track every other day
- 250 to 1000 bps at 2 to 4 AU range to Earth
  - >70 min. for a 1024x1024x16 bit image at 4:1 compression







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Deep Space Network Availability

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- There are only ten 34-m and three 70-m stations
- Eventually four 34-m stations per complex (12 total)
  - A spacecraft which would have used a 70-m will use arrayed 34-m's
- These antennas have to support many missions
- A CubeSat is not going to be a very high priority
- Some missions can send back > 1 Mbps from Mars
  - 0.1% of that will seem like an efficient use of antenna time
- Planetary CubeSats may place a huge demand on DNS
  - Multiple spacecraft at Venus, Moon, Mars, asteroids, comets…
  - Expecting one to get many tracks per week is unrealistic

Data Storage

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- Storing data is easier than broadcasting it
- A €40 memory stick stores 128 GB (1 Tbit)
  - Mass and volume are almost all packaging (too big to misplace)
  - Not a fair comparison since these are not flight rated, but…
- This is also more than a CubeSat asteroid mission needs
  - Cassini used 4 Gbits per satellite encounter at Saturn
  - New Horizons used 64 Gbits during the Pluto flyby
  - 250, 1024x1024x16-bit images, in five filters is 5.25 Gbits
- Data from flyby would depend on number of instruments
  - Optimal design would balance payload and telecom resources

Why not bring the data home?

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- Use a 1 x 3.15 AU heliocentric orbit for the asteroid flyby
- Use very low downlink rate during encounter
  - Just enough to validate operations and data collection
  - Most data stored, downlink a few highly compressed thumbnails
    - Apoapsis rates support ~2 images per week at 4:1 compression
- 3 year orbital period, returns to Earth at perihelion
  - Not a targeted return to Earth, just getting close (e.g. < 0.1 AU)
- 35 W for transponder requires 30 x 30 cm array
  - Still want to downlink on batteries but with higher duty cycle
- 256 kbps downlink (IRIS v2.1 max) within 0.15 AU of Earth
  - One image every 17 seconds, not 70 minutes
- 60 Gbits returned with 1 downlink / 2 weeks

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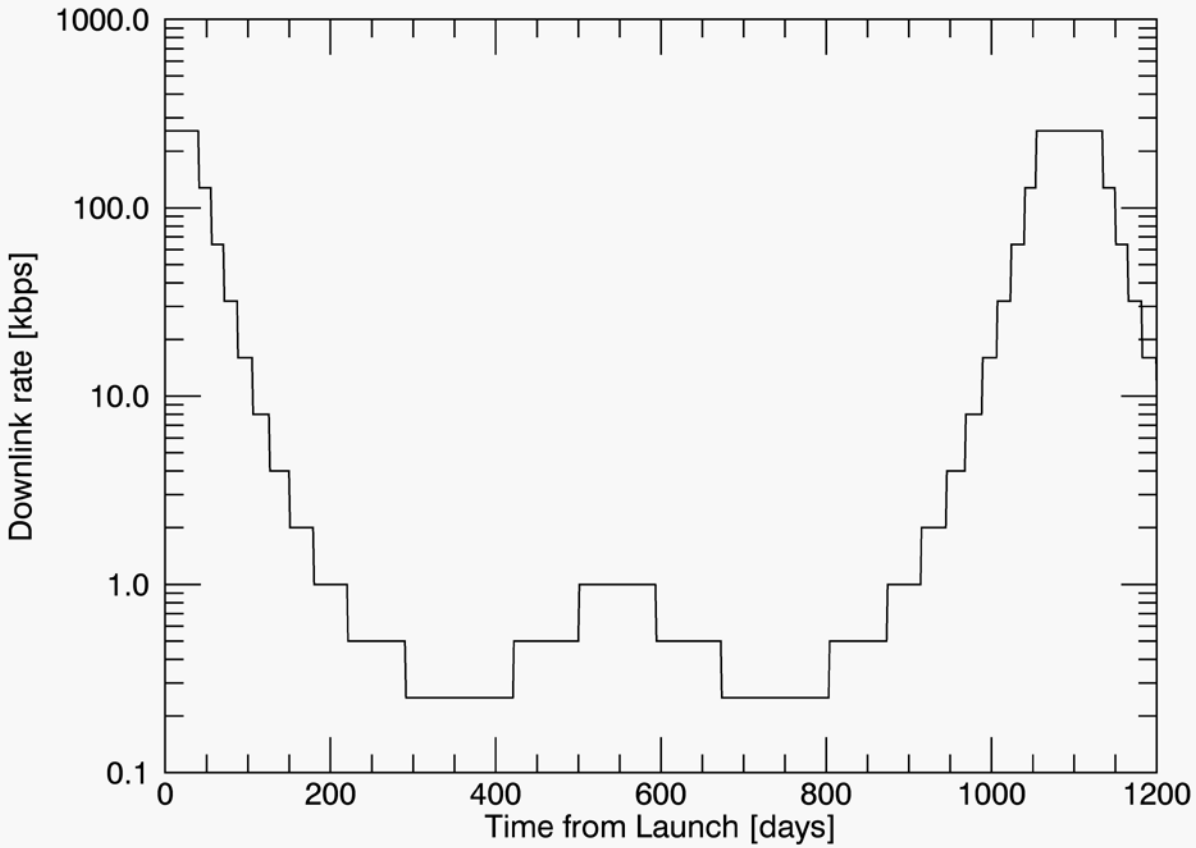

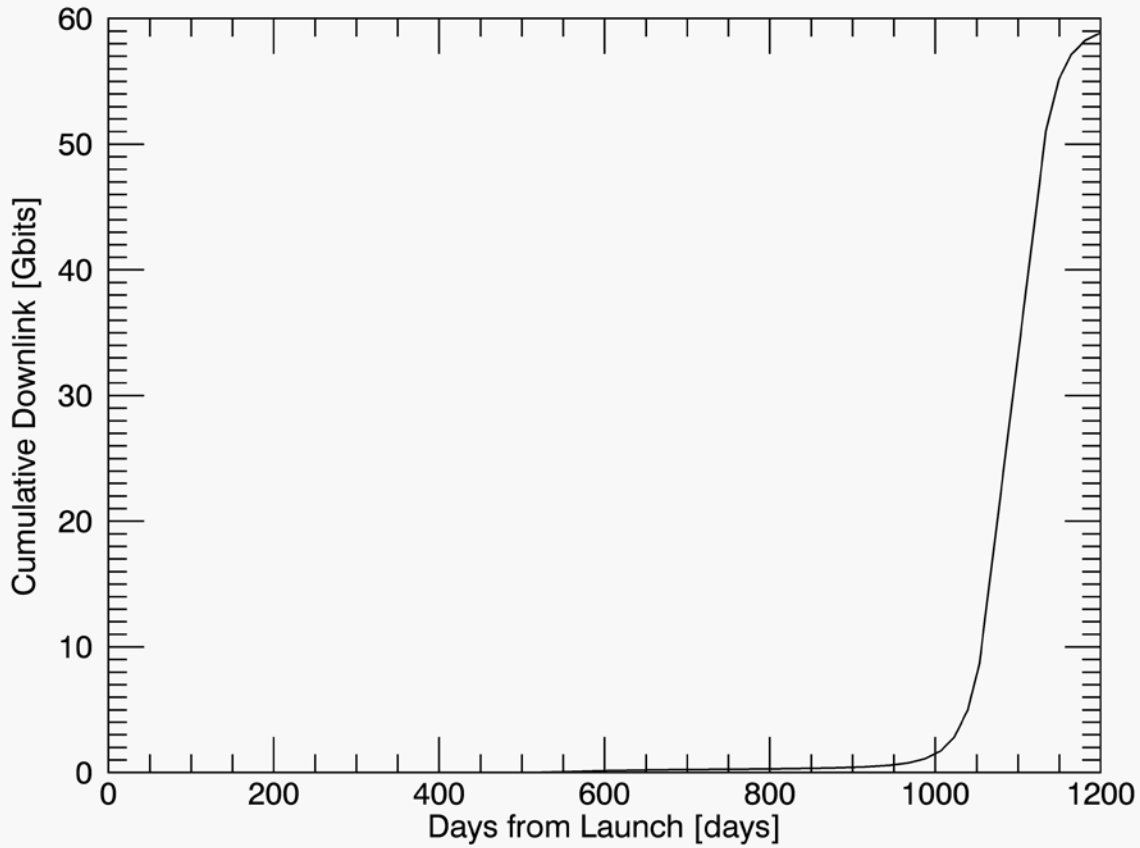

Would you really do it that way?

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- No, not exactly; this was just an illustration
- Increases required duration of the mission
- Payload and telecommunications should be balanced
  - More instruments and smaller antenna?
- Operational issues
  - Is the aphelion downlink rate enough for operations?
  - One contact every two weeks? Is that safe?
  - How much would spacecraft autonomy affect this?
- Transponder with low power mode?
  - Encounter period with more frequent, lower rate sessions
- Any N:1 mean motion resonance would be similar
  - 2.17 AU aphelion with 2 year period, 4.04 AU and 4 years

Corona II: Taking the idea a bit further

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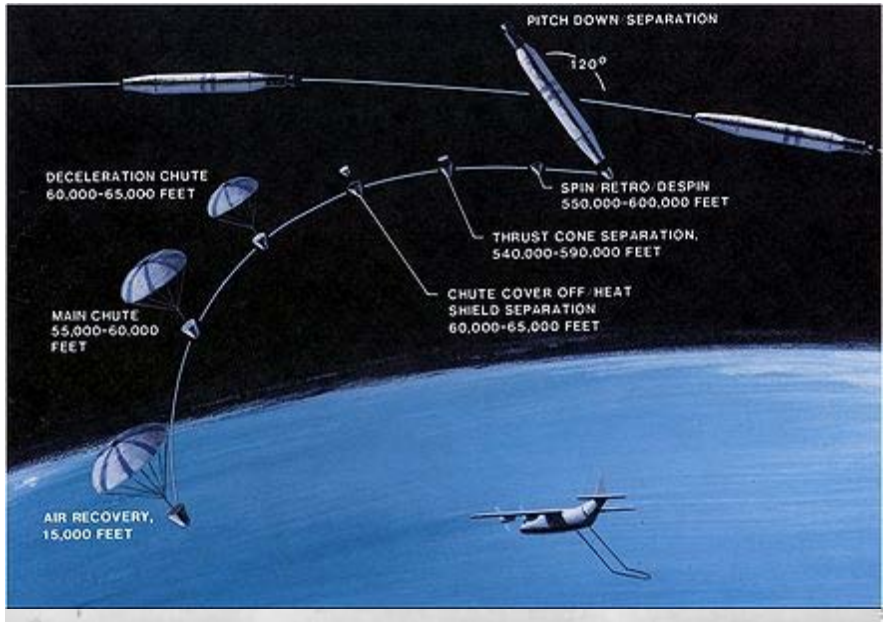
- To return a very large data volume…
- Returning data as physical payload has been done before (Corona, 1959—1972)
- How small can you make a reentry capsule? 1U? 0.5U?
- How much mass memory would fit in it?
- Excessive for most planetary applications
- There are some terrestrial applications
  - Very high rate, short duration magnetospheric missions



Small entry vehicles

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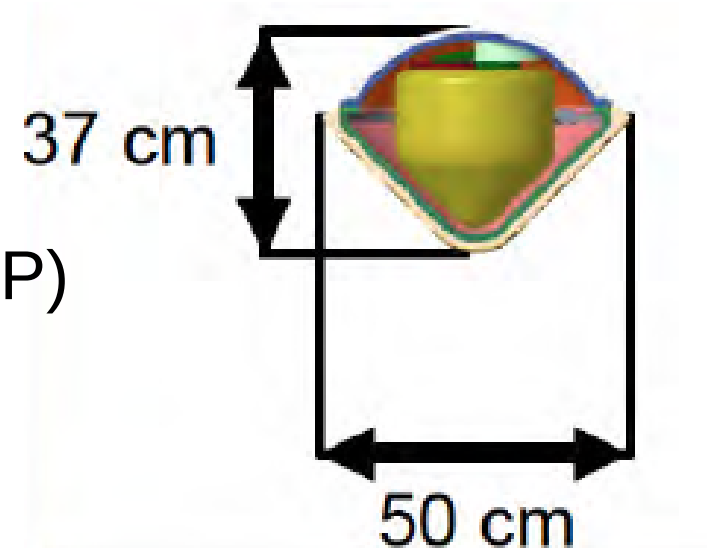
- Corona reentry capsules weren't huge
  - 66 x 76.2 x 76.2 cm
- Small planetary entry vehicles have been considered more recently
  - Small Next-generation Atmospheric Probe (SNAP)
  - Admittedly for Uranus
  - 22.4 km/s entry speed
  - Sayanagi et al. (PSDS3 study report)
  - 30 kg, 4 kg payload
- For a 13.5 km/s entry into Earth's atmosphere, could you make one 10x smaller?



Conclusions

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- Sending data over planetary distances is difficult
- Especially for small spacecraft
- This can be solved by returning the data to Earth
  - At least for flyby missions
  - Heliocentric orbit with an Earth-resonant orbit
  - Return to the vicinity of Earth (< 0.1 AU)
  - Data rates are 1000x greater than at target
- Does require longer mission (and patients)
- For extreme applications, a reentry capsule with flash memory might even make sense