Laboratory for Atmospheric and Space Physics
University of Colorado Boulder

A small spacecraft to explore the Sun’s control of Jupiter’s magnetosphere

Frank Crary and Fran Bagenal

University of Colorado

Laboratory for Atmospheric and Space Physics

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Jupiter's Magnetosphere and the Sun

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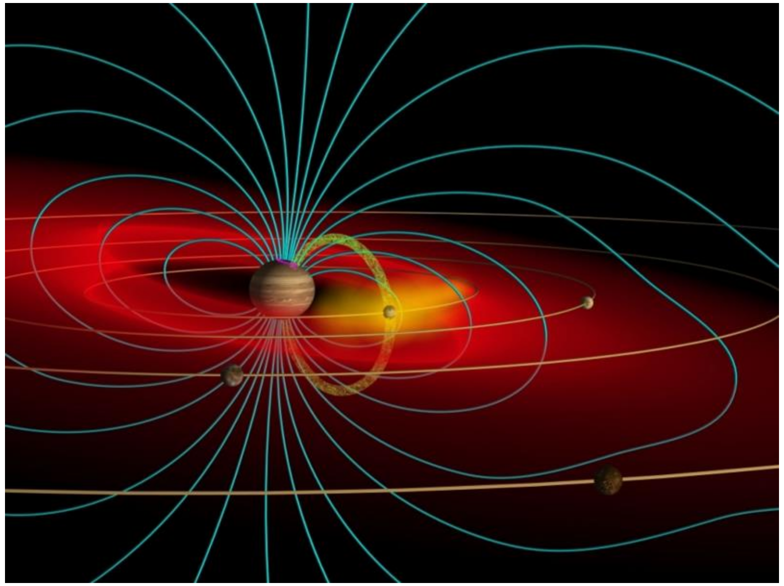
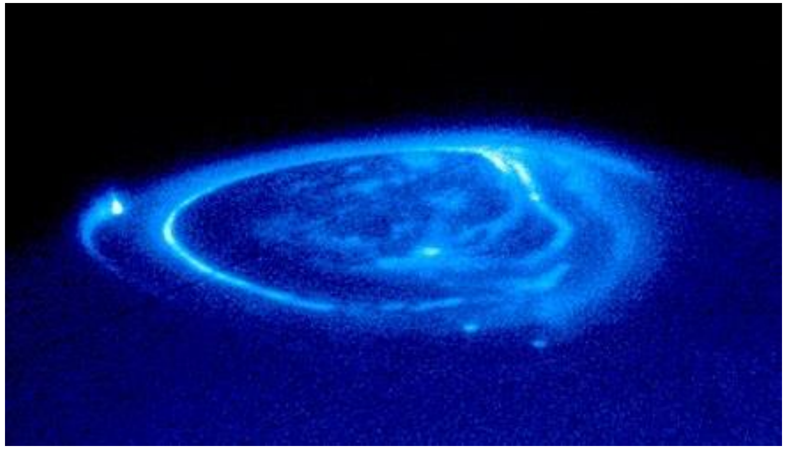
- Jupiter's magnetosphere is big
  - Magnetopause at 75 R_J (Earth's is at 10 R_E)
- Dynamics are mostly driven by Io
  - ~1000 kg/s of sulfur and oxygen ions
  - Coupling to planet's rotation
  - Transport out of plasma torus
- But what does "mostly" mean?
  - 99%? 75% 51%
  - Observations also show solar wind driver
  - Aurora and auroral radio emissions
  - Connected to regions deep in magnetosphere
- How? Theoretically very hard to explain





Limits to Current Data

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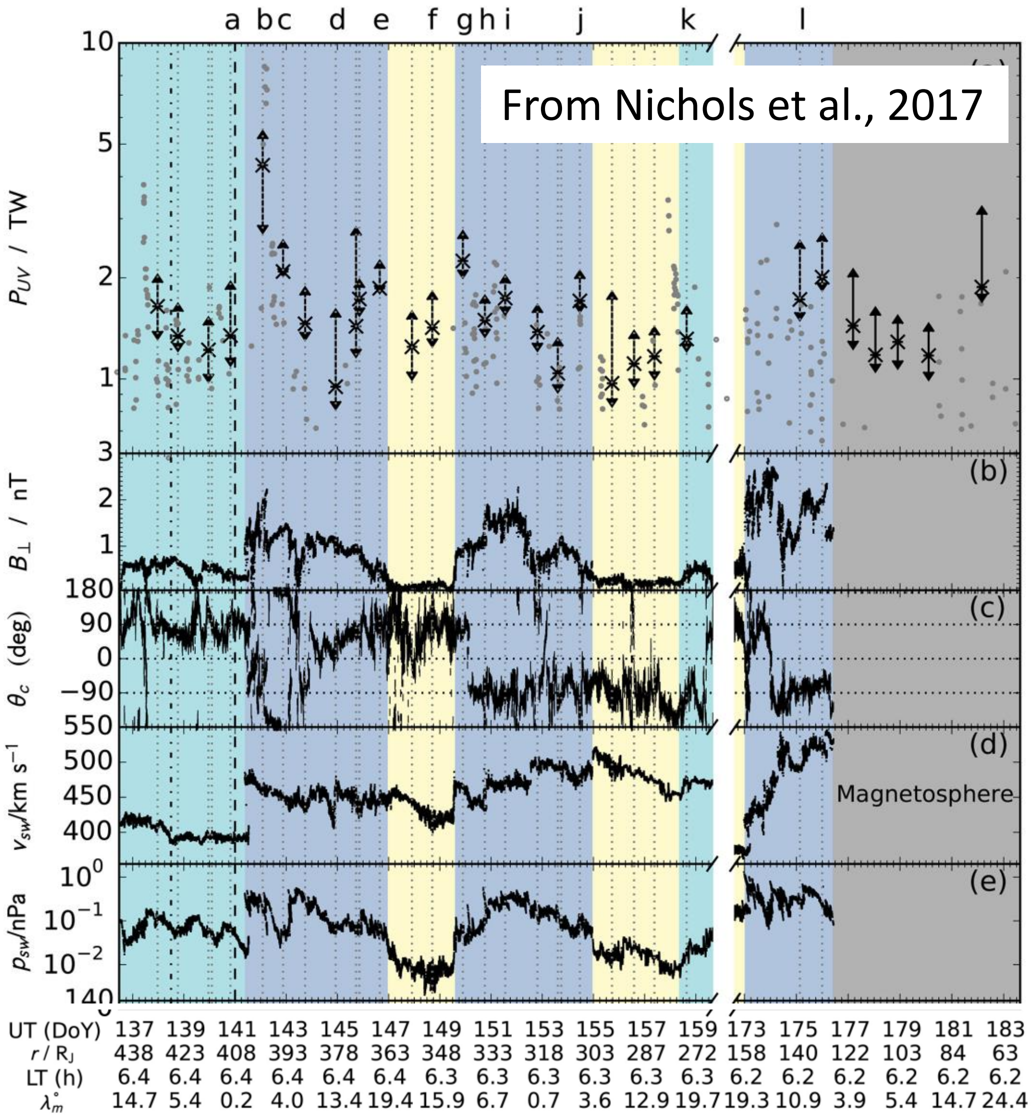

- Few frequent, long-term data sets
  - Propagation from Earth is uncertain ±20 hr. or worse
  - In situ solar wind measurements near Jupiter are rare
  - Large amounts of observing time on major telescopes is hard to get
    - Exception is Hisaki (but unresolved)
- Example: Juno approach phase
  - Best available data set
  - 47 Hubble orbits (~30 min)
    - Roughly 1/day
  - 56 days of solar wind data
    - With a 14-day gap
  - Only one clear event

Slow Jovian Flyby Mission Concept

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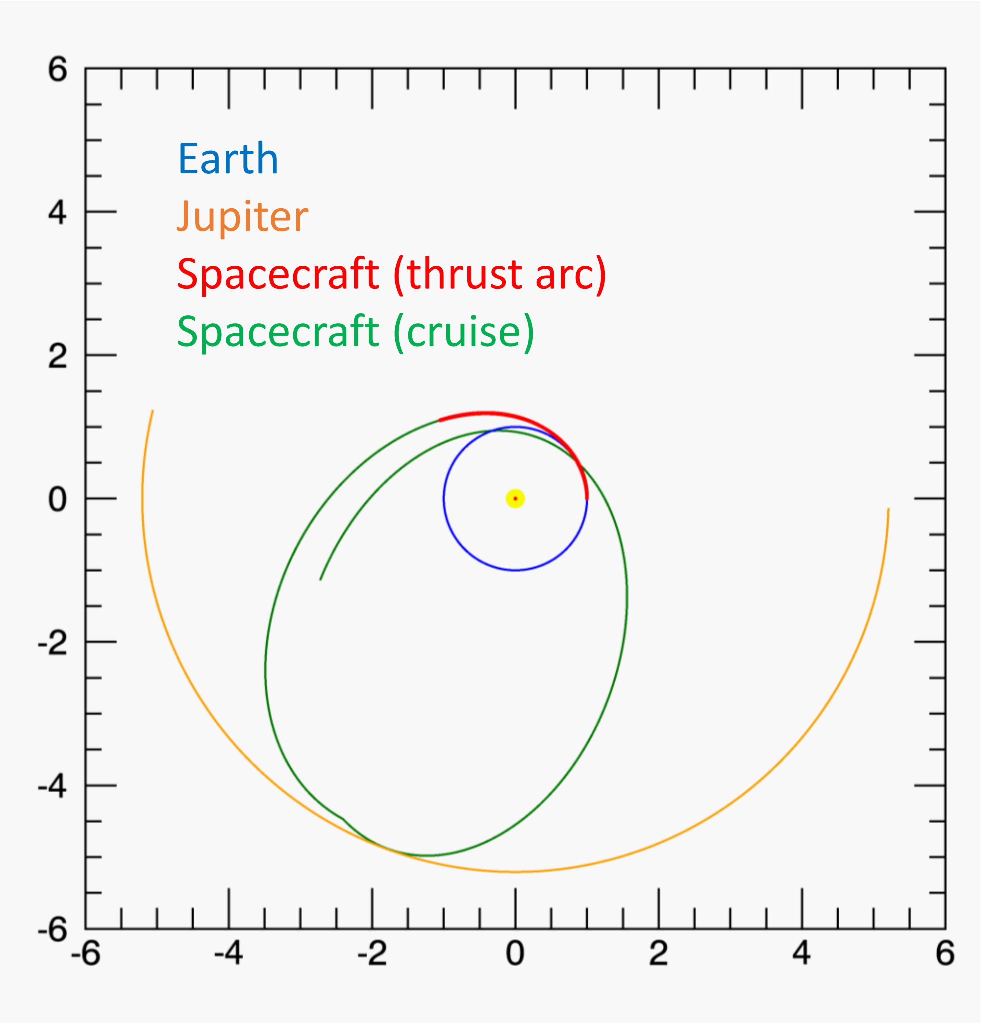
- Small spacecraft to observe near Jupiter
  - Near Jupiter but not in orbit, within 1000 R_J (~0.5 AU)
  - Near-Continuous observations for 300 days (135 inside 500 R_J)
- ESPA Grande secondary payload launched to $C_3 \sim 0$
  - For example, SIMPLEx mission launched with IMAP (Oct. 2024)
- Slow flyby of Jupiter
  - Image Jupiter's aurora at HST-quality resolution (< 500 R_J)
    - 8 times per rotation (74.4 min.), 90% duty cycle due to downlinks
  - Observe solar wind conditions continuously
- Return minimum data set during encounter
- Return full data set after encounter, when Earth is closer
  - All data returned by NEO departure +2245 days (6 years)

Trajectory

- Secondary payload launched to $C_3 = 0$
- Commission in Near Earth Orbit
- Wait for departure window
  - Flexible launch as secondary payload
- Solar electric propulsion
  - Raise aphelion to 5.1 AU
  - 148 days under thrust
  - 80% duty cycle
  - Large solar arrays for SEP also power spacecraft at aphelion
- Eject SEP stage after thrust arc
  - Electric propulsion and magnetic cleanliness
- Jupiter encounter: Departure + 1070 days
- Next perigee: Depature + 2175 days



Payload and Measurements near Jupiter

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- Far ultraviolet auroral imager (est. 5 kg)
  - 37.5 km/pixel at 250 R_J (0.5 mrad/pixel)
  - Better than Hubble Space Telescope STIS at 500 R_J
  - Two filters, Lyman and Werner bands of H_2 (120-165 nm)
  - Frame edited to 1.5 x 0.75 R_J images (north and south aurora)
  - Compressed to 4 bits/pixel (average, 3:1)
- Solar wind ion spectrometer (est. 1 kg, <15 bps)
  - High energy resolution (<3%) over 500 eV to 8 keV
  - Limited angular resolution, 5-minute time resolution
  - On-spacecraft calculation of density, speed, temperature
- Magnetometer (est. 1 kg plus boom, <10 bps)
  - Low time resolution (20 s) with high rate mode, ±10 pT
  - 2 meter boom (2x spacecraft bus dimensions)
- Other instruments desirable but not in baseline
  - E.g. auroral radio emissions, EUV spectra of Io plasma torus

ESPA Grande Secondary Payload

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- 4 secondary payloads per ESPA ring
- 24” diameter port, 42” x 46” x 38” maximum volume
  - 106 x 116 x 96 cm volume
  - Approximately 10 x 11 x 9 U (990 U)
- 180 kg maximum mass
  - NASA SIMPLEx AO gives 180 kg limit for ESPA Grande
    - That is actually mass limit for ESPA, ESPA Grande is 320 kg
  - That’s ok. Surface area and volume are more constraining
- The current concept is not fully optimized
  - Number of thrusters is quantized
    - Adding more without adding power to operate them doesn’t help
  - Surface area can be used to solar arrays or antenna area
  - Result is viable, but could be improved

Solar power

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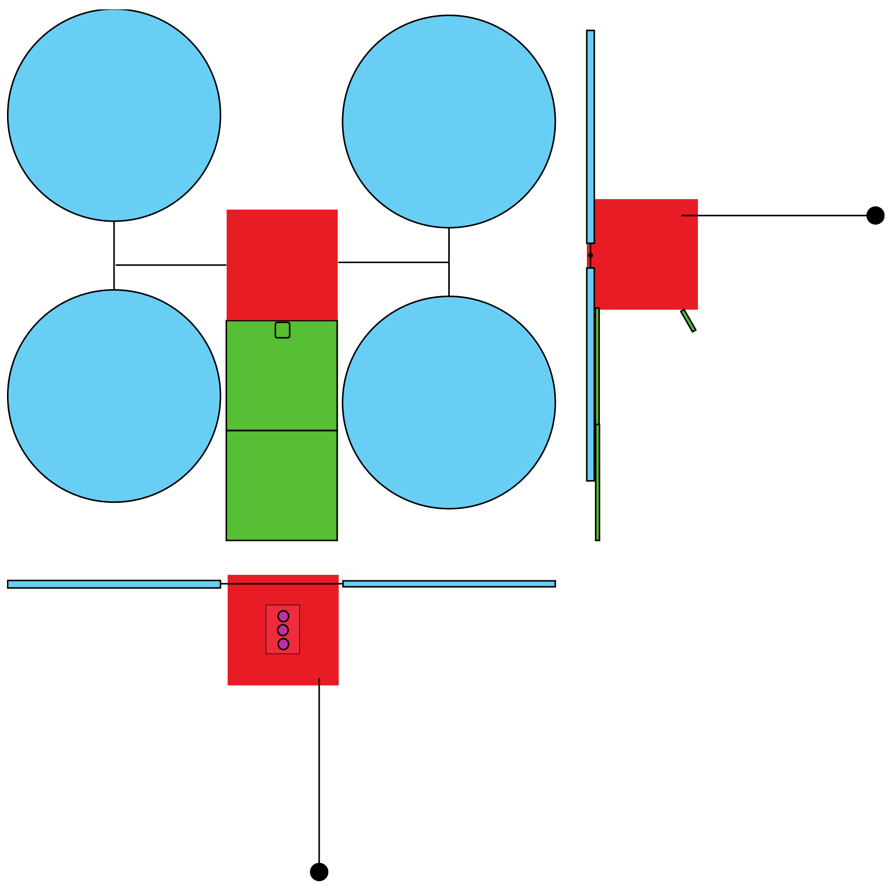
- Power SEP inside 1.5 AU: 2525 W at 1 AU
- Power spacecraft at 5.2 AU: 90 W at 5.2 AU
- 4, Northrop Grumman UltraFlex arrays
  - 1.95 m diameter
  - 17 kg total mass
  - ~ 4 x (1 m x 0.12 m x 0.12 m) stowed
- 1 axis articulated to stay Sun pointed with
  - Telescope-to-Jupiter
  - HGA-to-Earth
  - SEP pointing
- Accommodating full articulation is difficult
  - Seems to fit, but with little margin
  - Antenna area (width) versus clearance



Solar Electric Propulsion System

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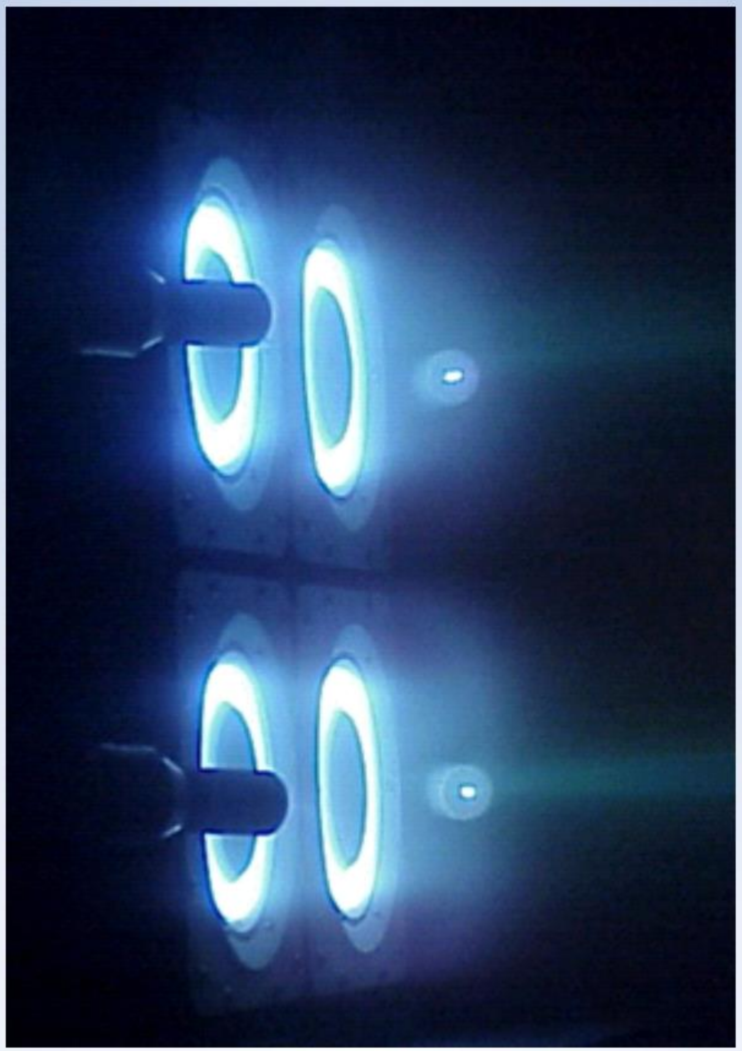

Multiple BHT-600 in a Cluster

- 3, Busek BTH-600
  - 200-800 W each
  - 39 mN at 600 W
  - I_{sp} of 1500 s
  - Iodine propellant
  - 8.5 kg (3 thrusters+cathode)
- Assumes 80% duty cycle
- Throttled and switched off as solar power decreases
- < 3200 hours on time per thruster
- Ejected at end of thrust arc
  - Greatly simplifies EM cleanliness

Telecommunications

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- Modeled on MarCO, except:
- IRIS transponder, 35 W input
  - Assumes Ka not X band
- Larger retroreflector antenna
  - 1.7 x 1 meter
- Use 34 not 70-m DSN stations
  - One 8-hour track every 99 hrs.
    - 10 Jovian rotations
- 1 kbps during Jupiter encounter
- Up to 128 kbps after encounter
  - Near perihelion, at 0.6 AU range

Difference from MarCO	Gain
Ka instead of X band	+6 dB (approx.)
34-m instead of 70-m	-6 dB (approx.)
1.7 m^2 instead of 0.18 m^2	+9.75 dB
Free space loss	+3.22 dB at 0.6 AU
	-17.06 dB at 6.2 AU
Net	+13.0 to -7.3 dB

Downlink data rate	128 kbps at 0.6 AU
	1 kbps at 6.2 AU

The Rest of the Spacecraft

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Item	Mass [kg]
Propulsion	
3, Busek BTH-600 Hall effect thrusters	8
Iodine propellant	86
Fuel tank	8.5
Power, 4, 1.9 m dia. UltraFlex arrays	18.25
Payload	7
"Everything Else"	32.5
Margin	19.75
Total	**180**

- Margin assumes
  - 10% for existing (COTS) systems
    - Solar arrays and thrusters
  - 30% of new systems
  - What is the margin policy for COTS hardware?

- "Everything else" includes:
- Attitude control
  - Reaction wheels
  - Star trackers
  - Cold gas thrusters (desat.)
  - Use BCT-based system?
- Command & Data Handling
  - Normal functions plus:
  - Image compression
  - Frame editing
  - Solar wind moment calculations
- >100 Gbits data storage
  - 12 Gbytes ($25 memory stick…)
- Mechanical structures
  - Booms for solar & magnetometer

Conclusions

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- Understand solar wind's influence on Jupiter's magnetosphere
  - Small Spacecraft making focused observations near Jupiter
  - Slow flyby rather than orbit, but near-continuously for ~10 months
- ESPA Grande secondary payload launched to C_3 ~ 0
  - Checkout in solar near Earth parking orbit
  - No conflict between primary and secondary launch windows
- Electric propulsion to a 1.1 x 5.1 AU orbit, aphelion near Jupiter
- Power for Hall thruster @1.5 AU = power for spacecraft @5.1 AU
- Only transmit small fraction of data during Jupiter encounter
  - Performance floor: 1 edited image set per rotation and solar wind data
- Return all data by departure +2175 days (5.95 years)
  - Mostly near perihelion, spacecraft-Earth range down to 0.6 AU