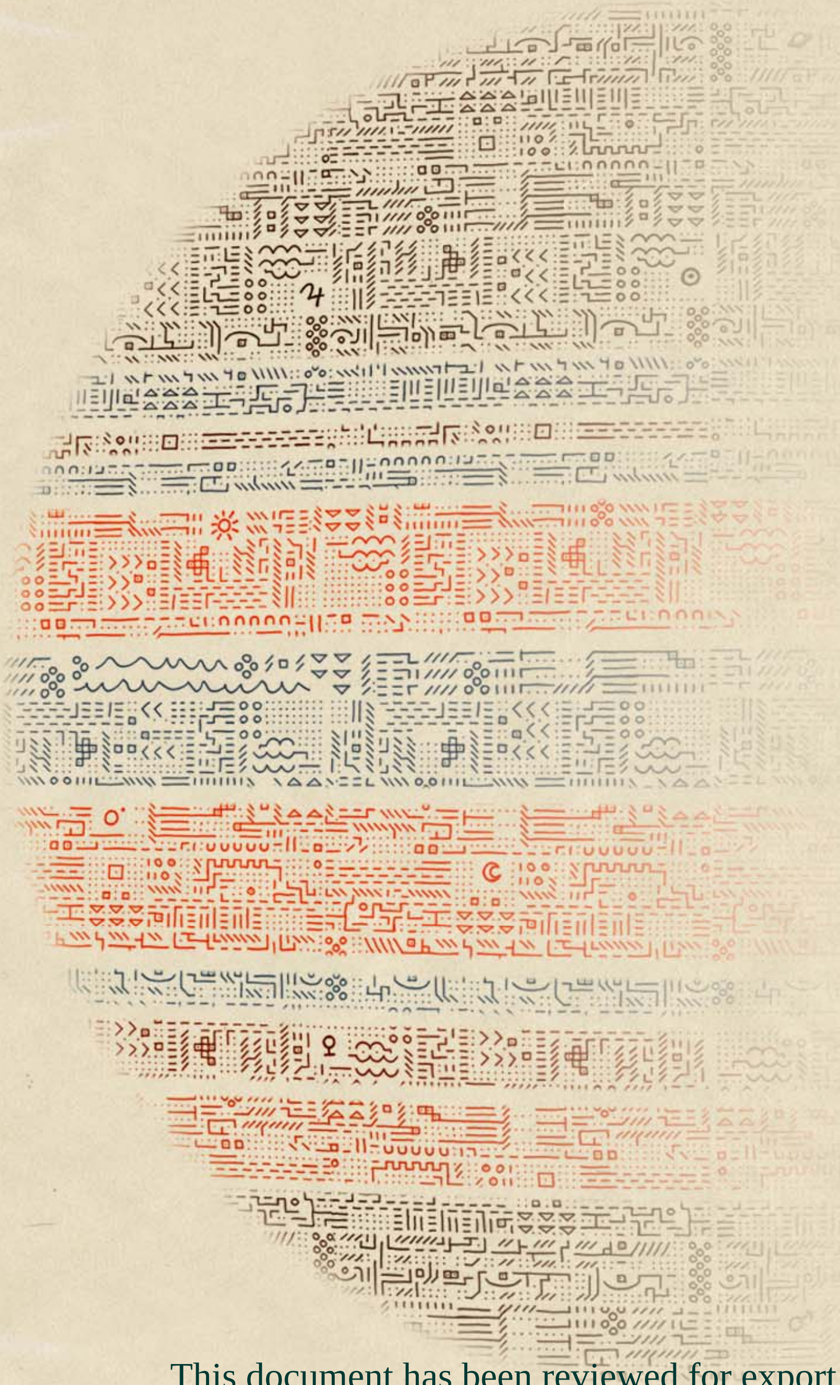

Radiation: Lessons Learned

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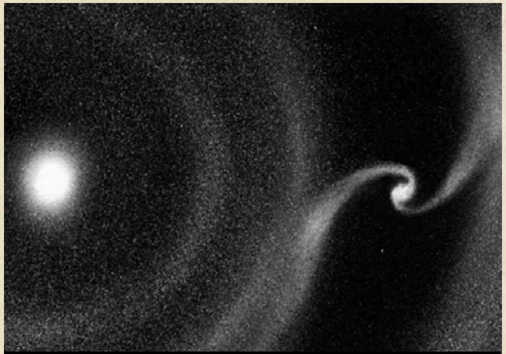
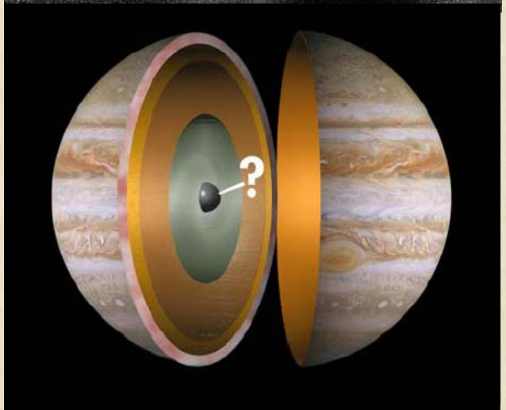
Southwest Research Institute

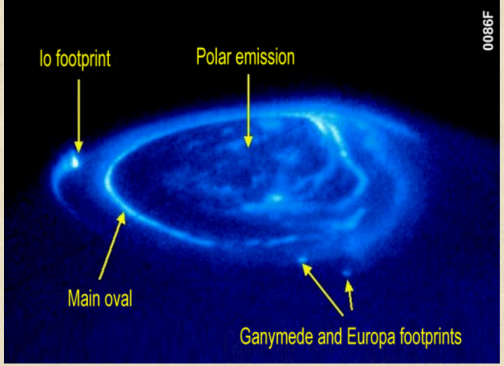
Insoo Jun
Jet Propulsion Laboratory

Juno Science Objectives

- **Origin**
  - Determine O/H ratio (water abundance) and constrain core mass to decide among alternative theories of origin.
- **Interior**
  - Understand Jupiter's interior structure and dynamical properties by mapping its gravitational and magnetic fields.
- **Atmosphere**
  - Map variations in atmospheric composition, temperature, cloud opacity and dynamics to depths greater than 100 bars.
- **Polar Magnetosphere**
  - Explore the three-dimensional structure of Jupiter's polar magnetosphere and aurorae.







Juno Payload

Gravity Science (JPL/Italy)

Magnetometer— MAG (GSFC)

Microwave Radiometer— MWR (JPL)

Energetic Particles —JEDI (APL)

Plasma ions and electrons — JADE (SwRI)

Plasma waves/radio — Waves (U of Iowa)

Ultra Violet Imager — UVS (SwRI)

Visible Camera – Juno Cam (Malin)

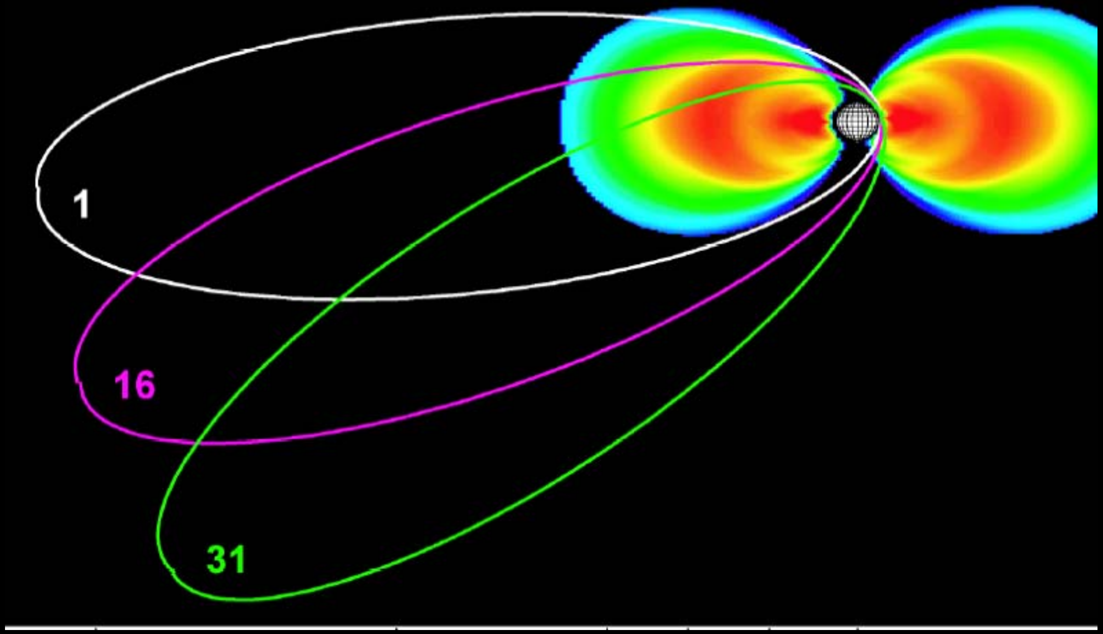
InfraRed Imager – JIRAM (Italy)

Juno Mission Design

Launch: August 2011

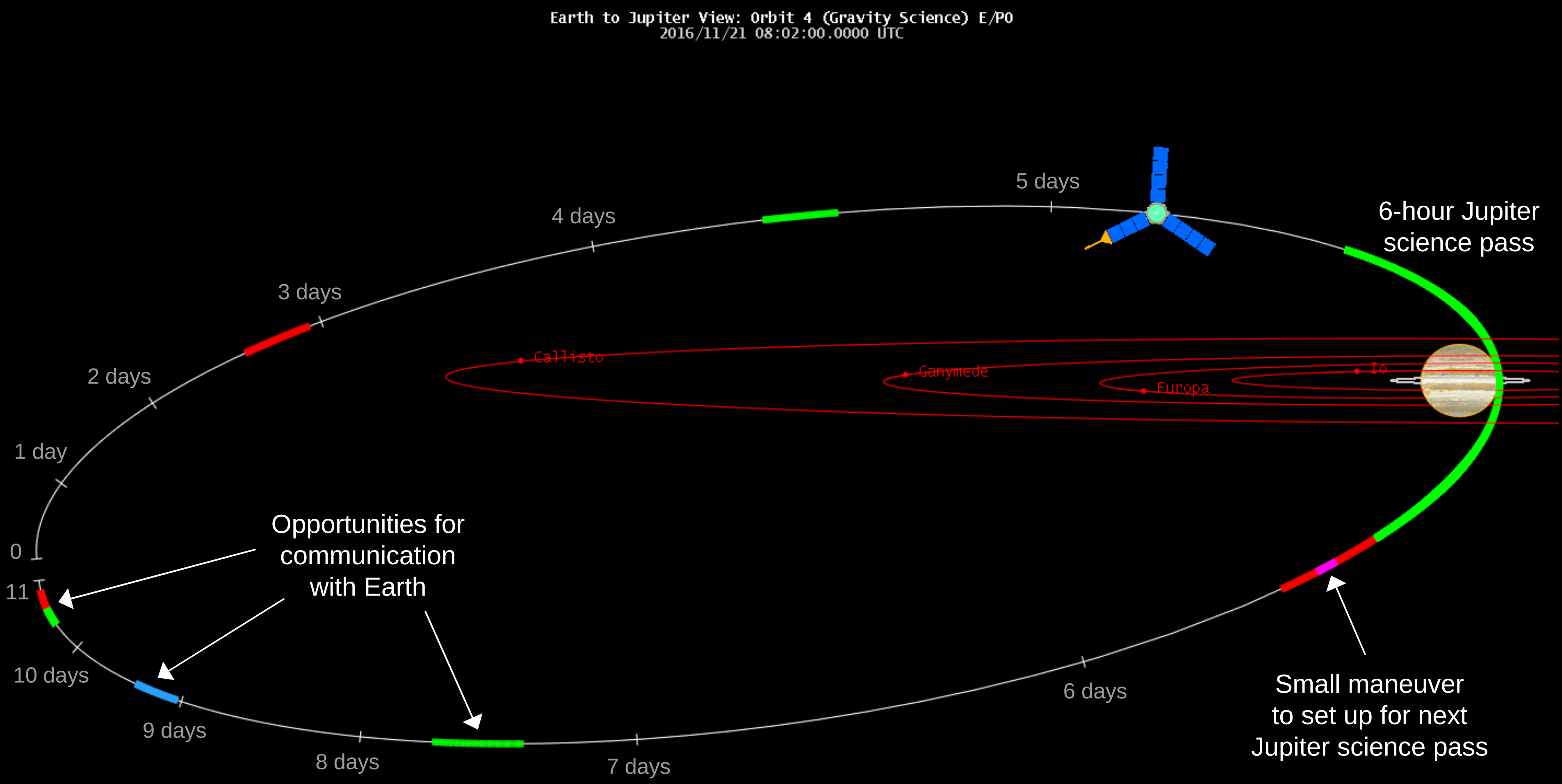
5 year cruise

Baseline mission:
- 32 polar orbits
- Perijove ~5000 km
- 11 day period
- Spinner
- Solar-powered



Orbit is designed to avoid radiation from the inner belts of Jupiter. Dips inside inner belt at perijove and goes above belts (Juno is in polar orbit).

Juno Orbit 4: Gravity Science

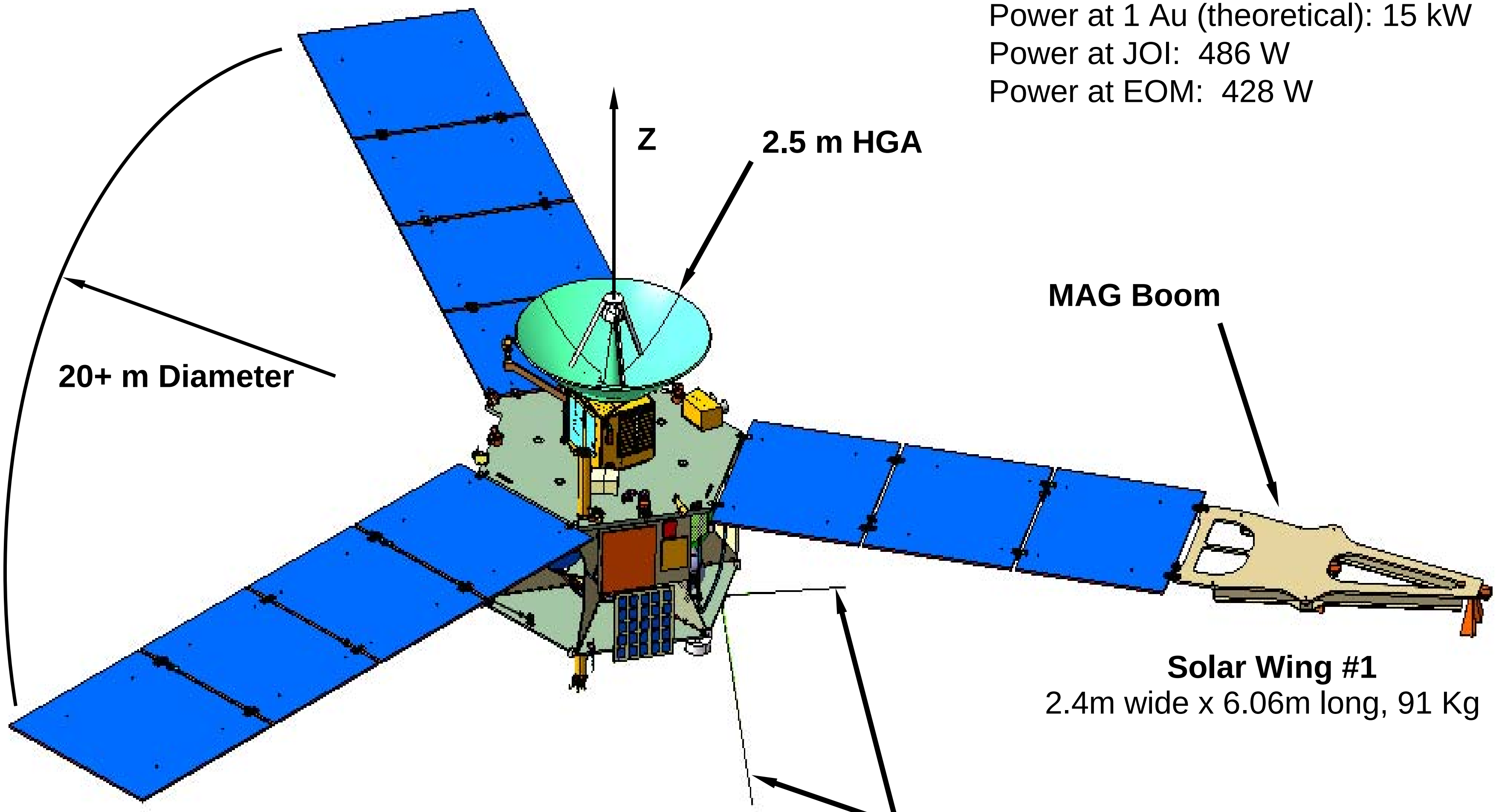


6-hour Jupiter science pass

Opportunities for communication with Earth

Small maneuver to set up for next Jupiter science pass

Juno Flight System



Solar Wing #3

Power at 1 Au (theoretical): 15 kW
Power at JOI: 486 W
Power at EOM: 428 W

Z

2.5 m HGA

MAG Boom

20+ m Diameter

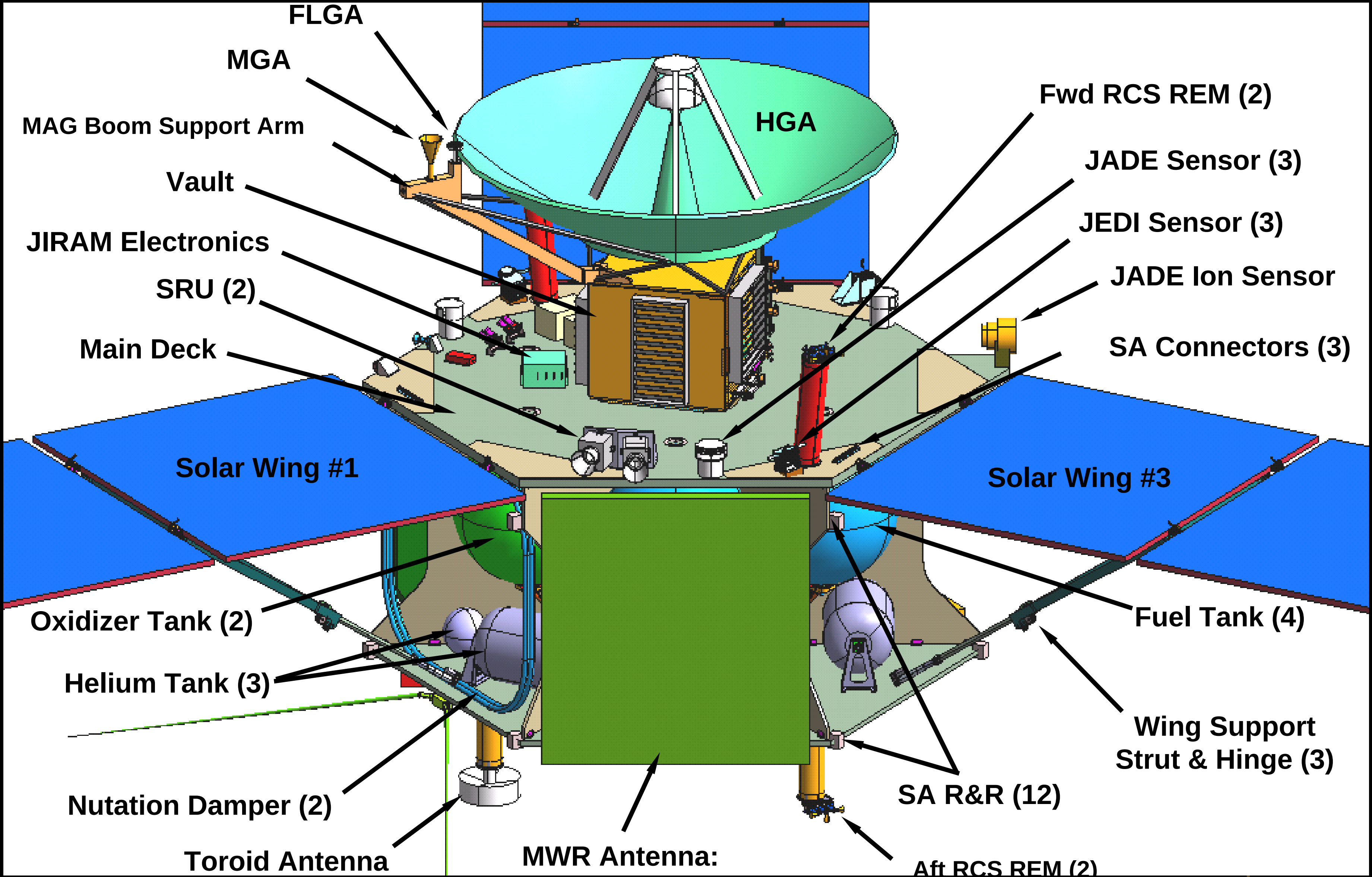
Solar Wing #1
2.4m wide x 6.06m long, 91 Kg

2.36m wide x 8.7m long; 99.6 Kg
Solar Wing #2

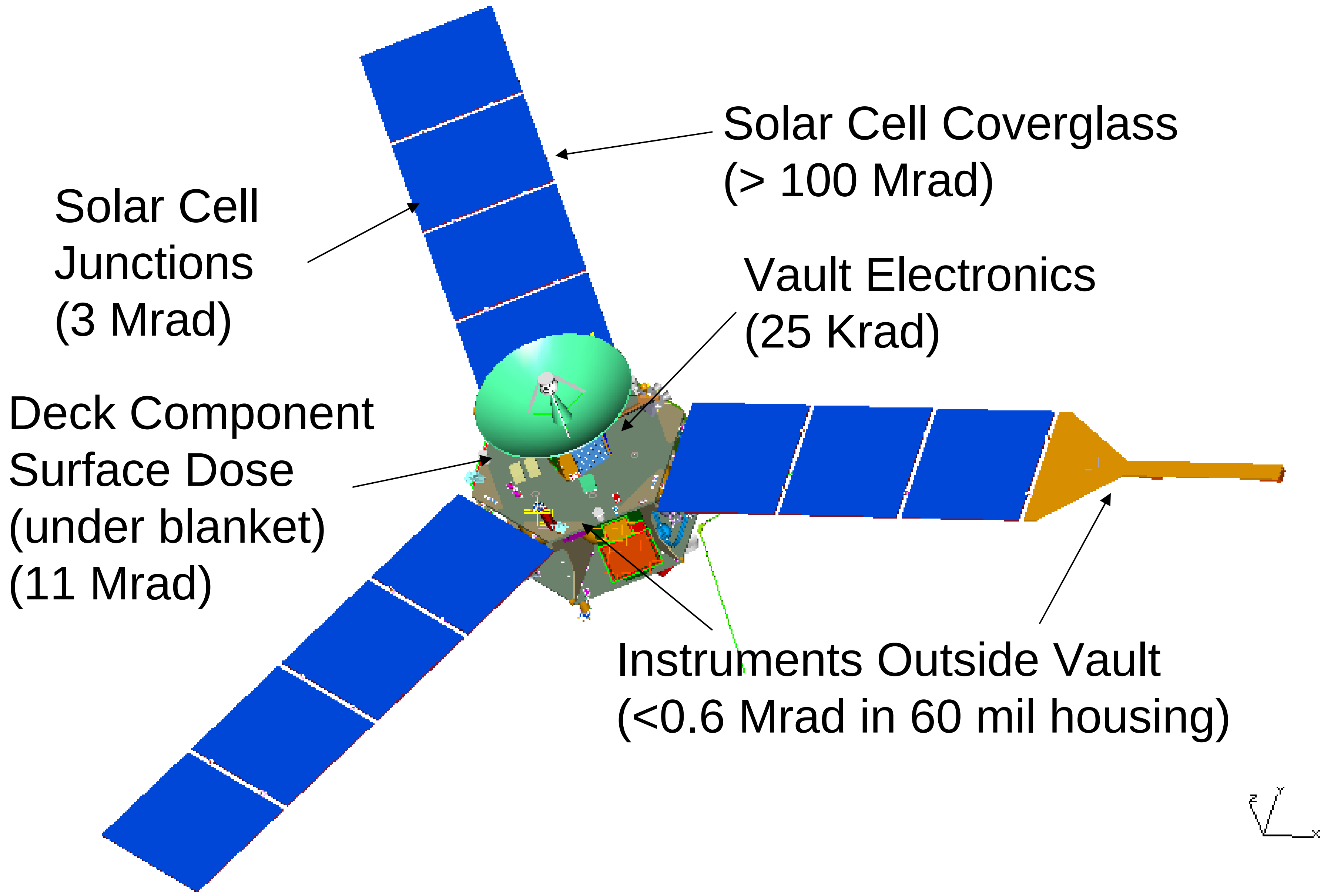
WAVES Electric Antenna

Spacecraft: 1600 Kg dry mass; 3625 kg wet mass

Sensitive electronics are in a vault



End of Mission Radiation TID Levels



Solar Cell Coverglass
(> 100 Mrad)

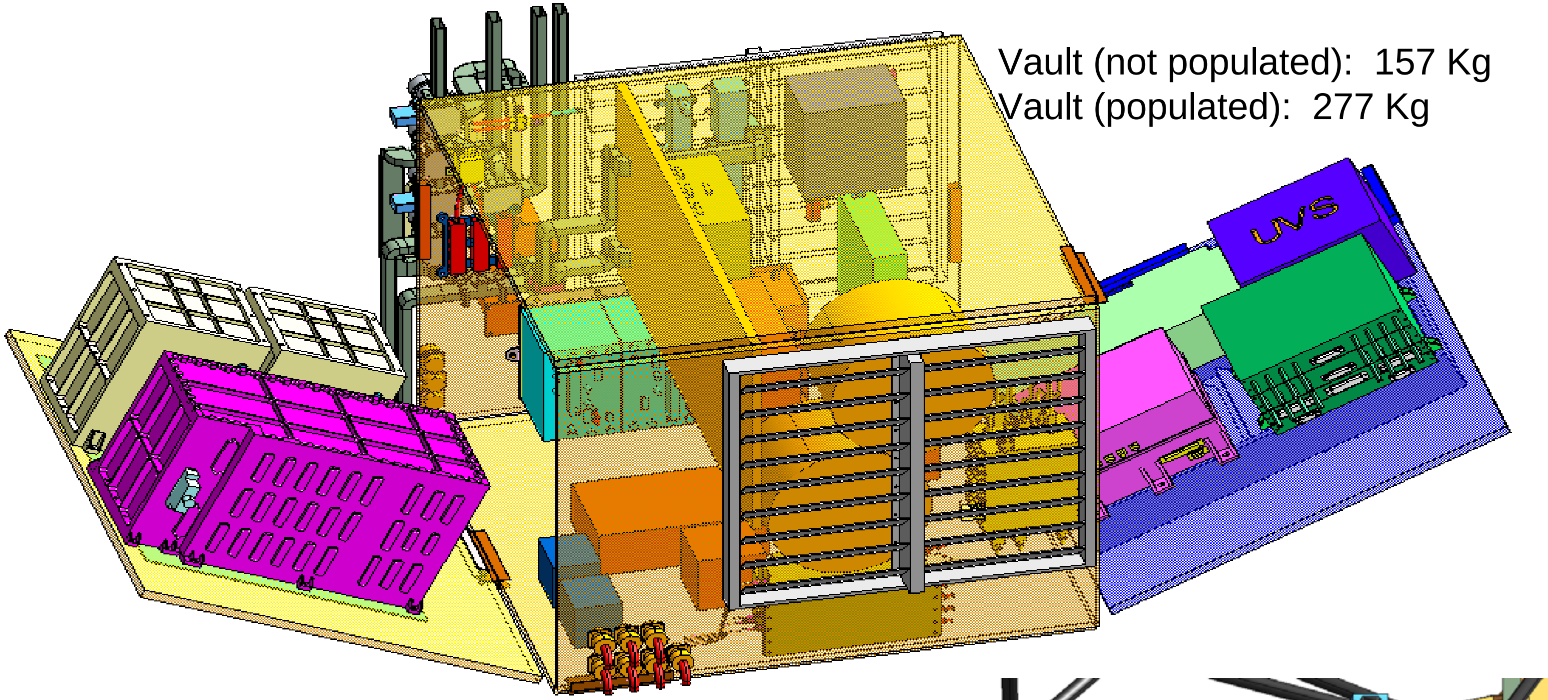
Solar Cell
Junctions
(3 Mrad)

Vault Electronics
(25 Krad)

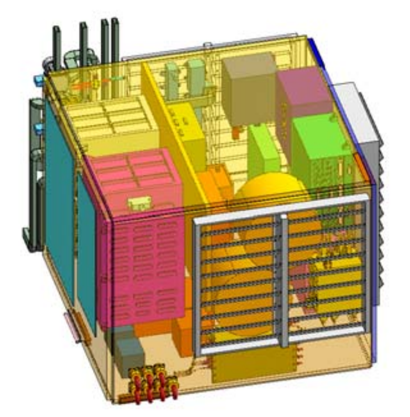
Deck Component
Surface Dose
(under blanket)
(11 Mrad)

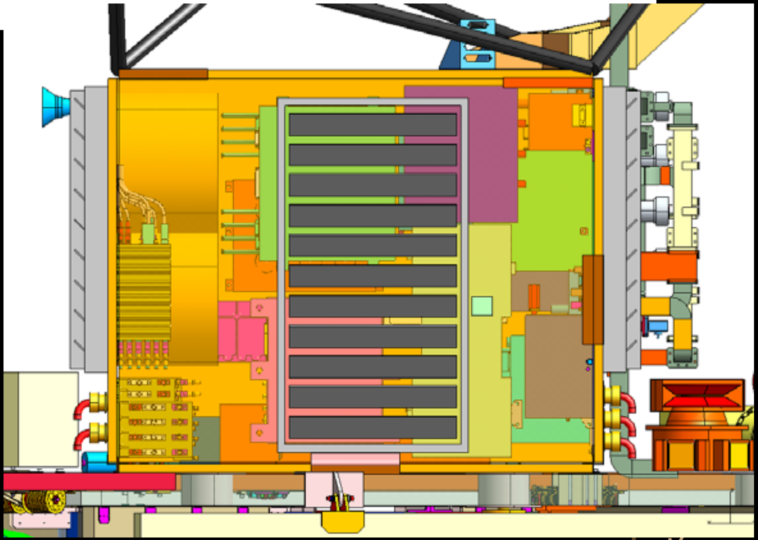
Instruments Outside Vault
(<0.6 Mrad in 60 mil housing)

Electronics Vault



Vault (not populated): 157 Kg
Vault (populated): 277 Kg





Radiation

- Radiation effects come in two flavors:
  - Total ionizing dose (TID)
  - Instantaneous flux levels

- Can induce electronic failures, data corruption, and/or noise.

- RDF of 2 is usual design factor for TID

Good practices

- Understand model and spectrum of radiation.
- Selection of parts consistent with flux and TID (spectra important)
- Transport code can model shielding options
- Generally shielding is preferred to new board designs…stay within heritage if possible.
- Be conservative and use RDF=2 (some call this RDM)

Where to begin

Identify contacts for radiation group (at least one per hardware institute)

Develop list of heritage parts for all components

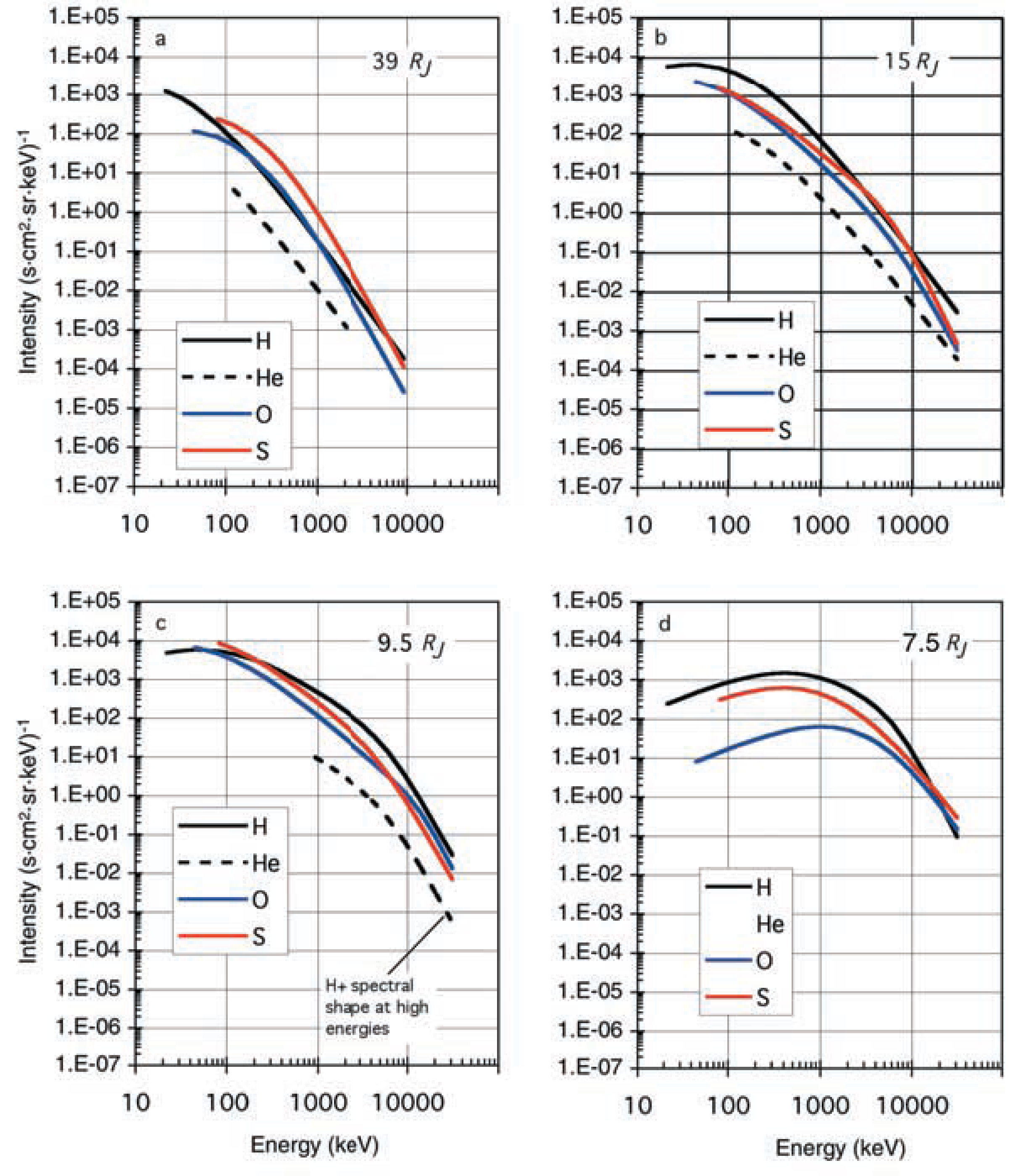
Evaluate potential areas in need of spot shielding

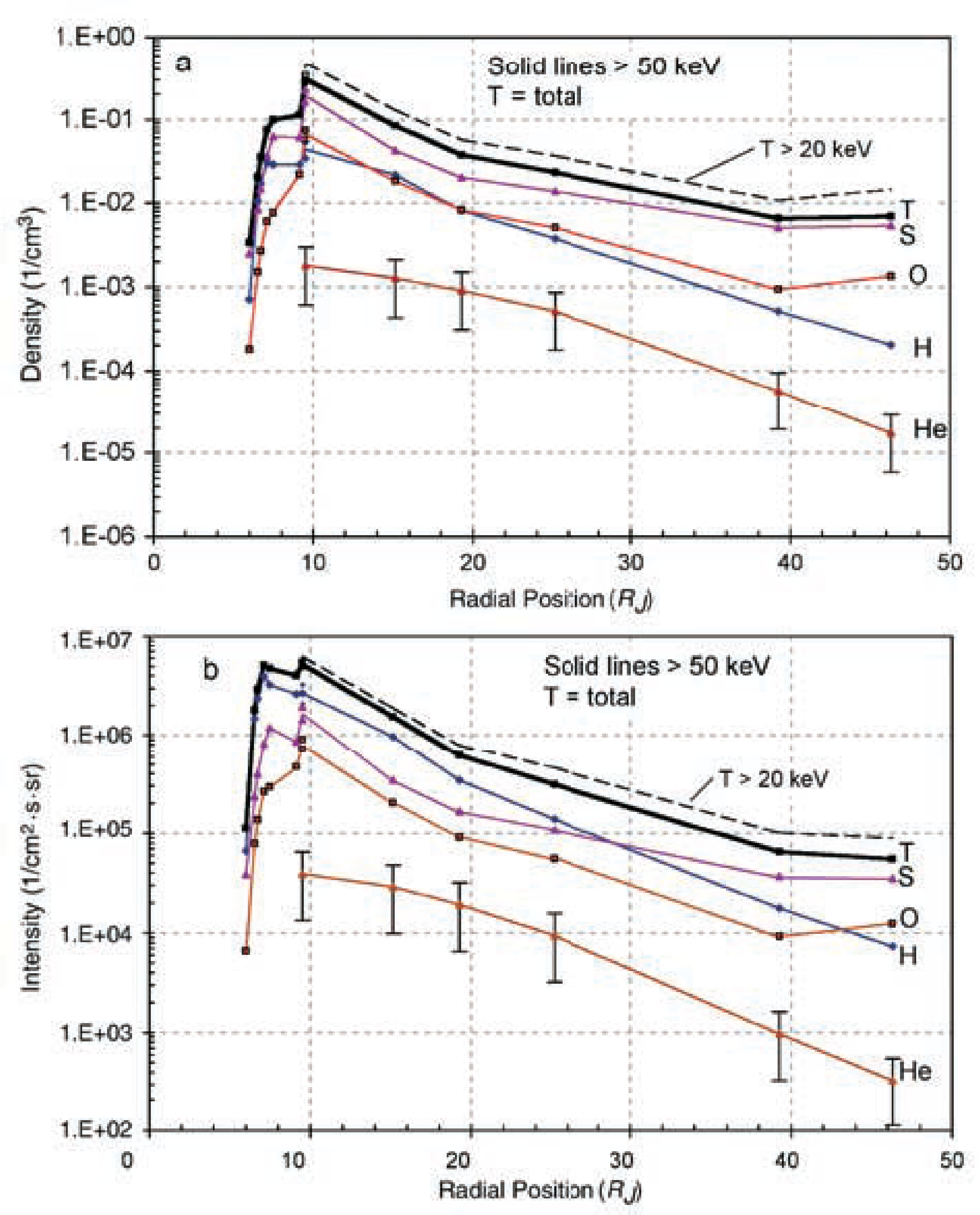
Estimate box sizes

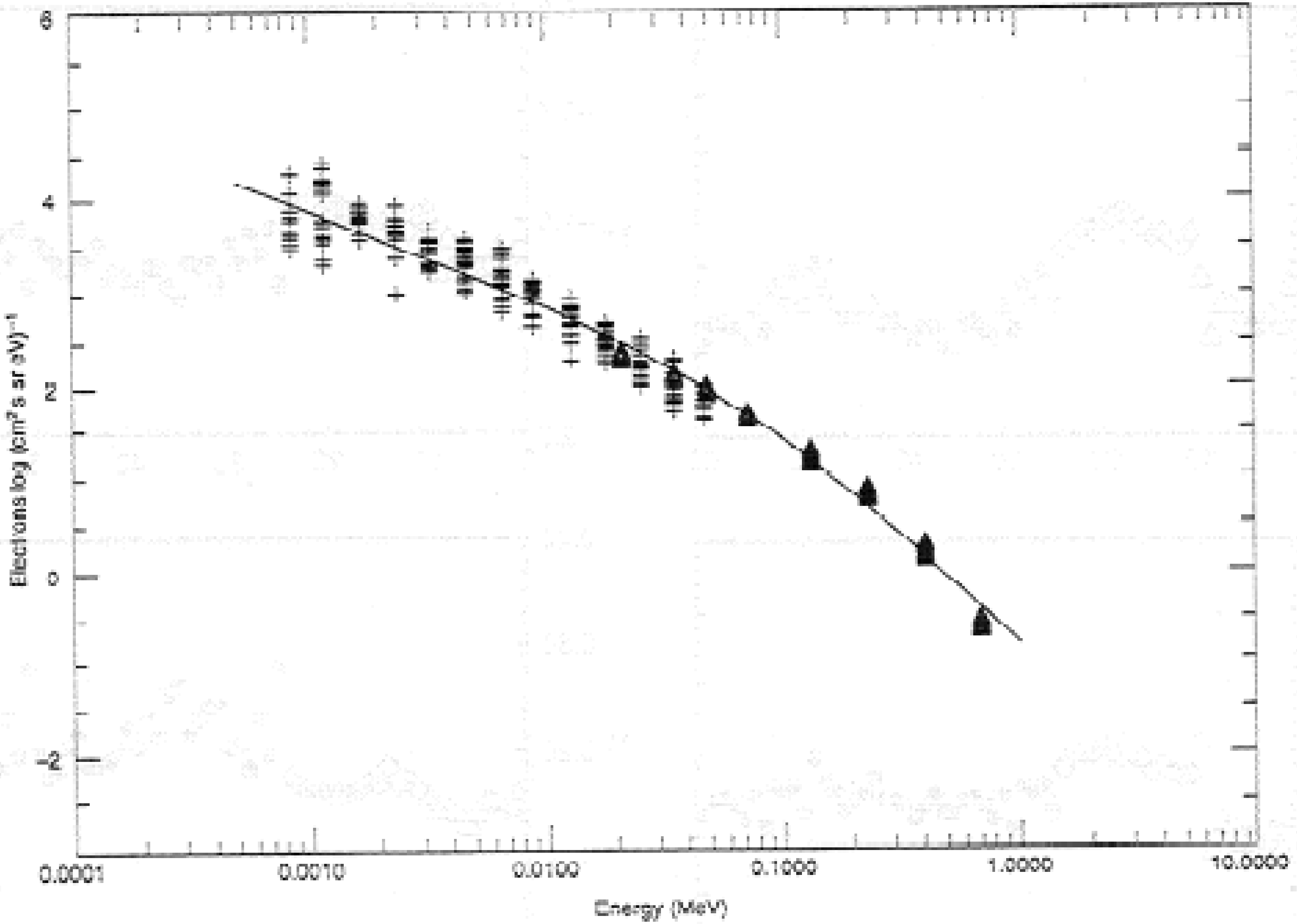
Estimate mass required for shielding (both housing and spot)

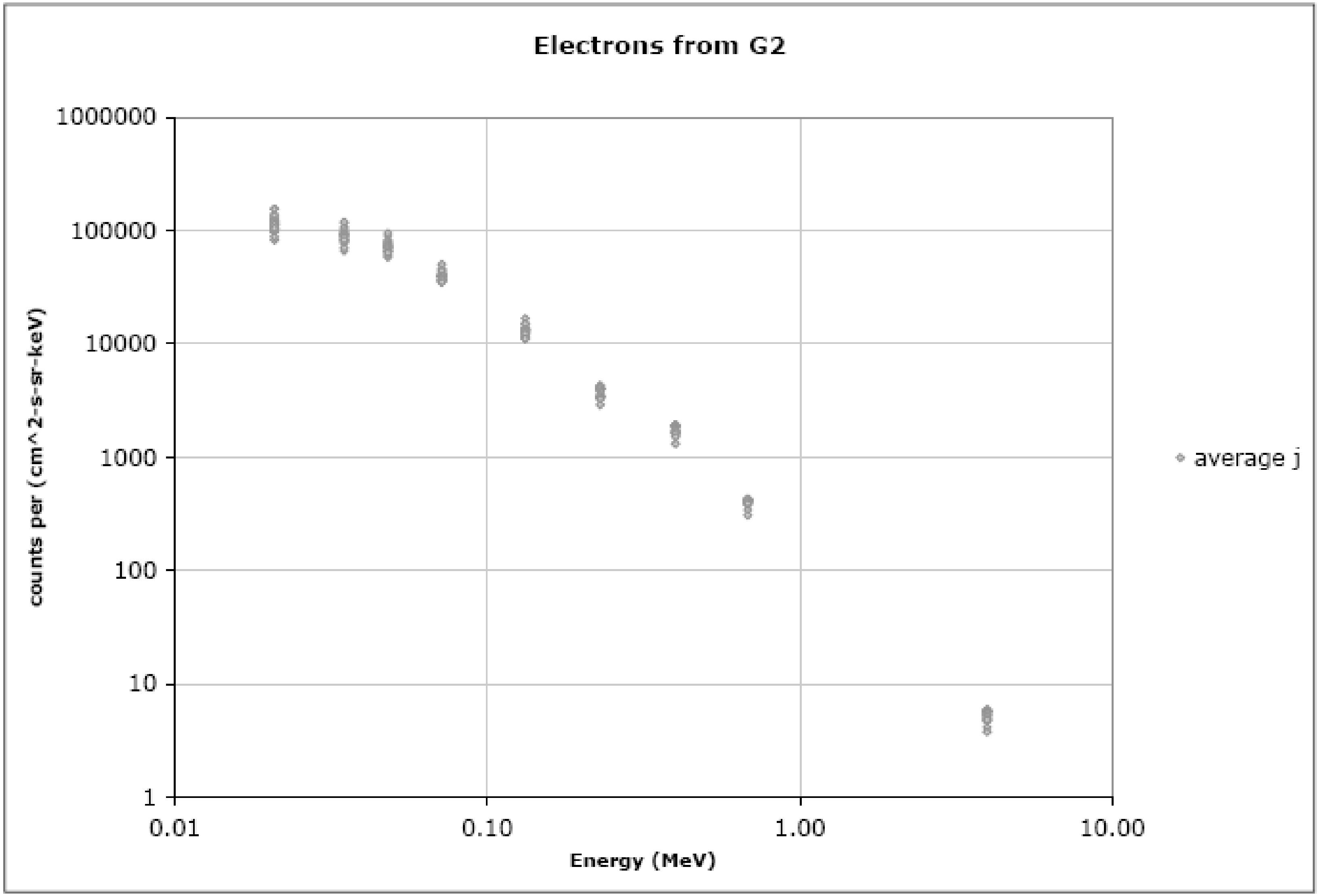
Identify problem parts that are candidates for redesign.

Radiation strategy should including cables, connectors, etc.

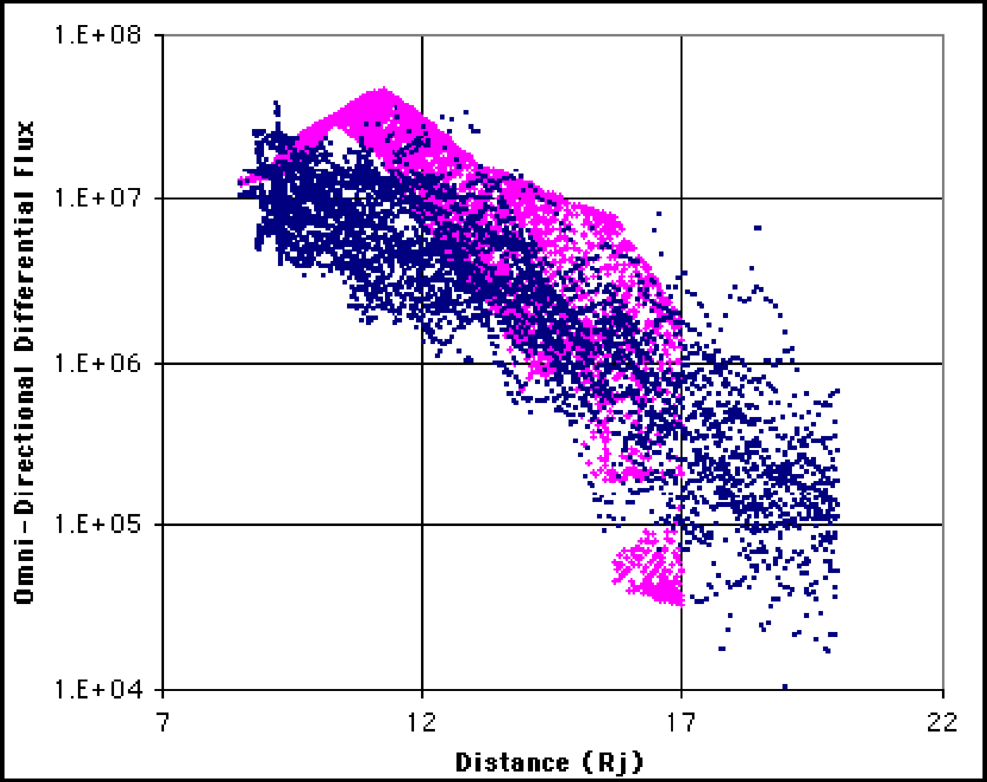

a
39 R_J
b
15 R_J
c
9.5 R_J
d
7.5 R_J
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
Intensity (s·cm²·sr·keV)⁻¹
10
100
1000
10000
Energy (keV)
H
He
O
S
H+ spectral shape at high energies


a
Solid lines > 50 keV
T = total
T > 20 keV
T
S
O
H
He
Density (1/cm³)
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
0
10
20
30
40
50
Radial Position (R_J)
b
Solid lines > 50 keV
T = total
T > 20 keV
T
S
O
H
He
Intensity (1/cm²·s·sr)
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
0
10
20
30
40
50
Radial Position (R_J)

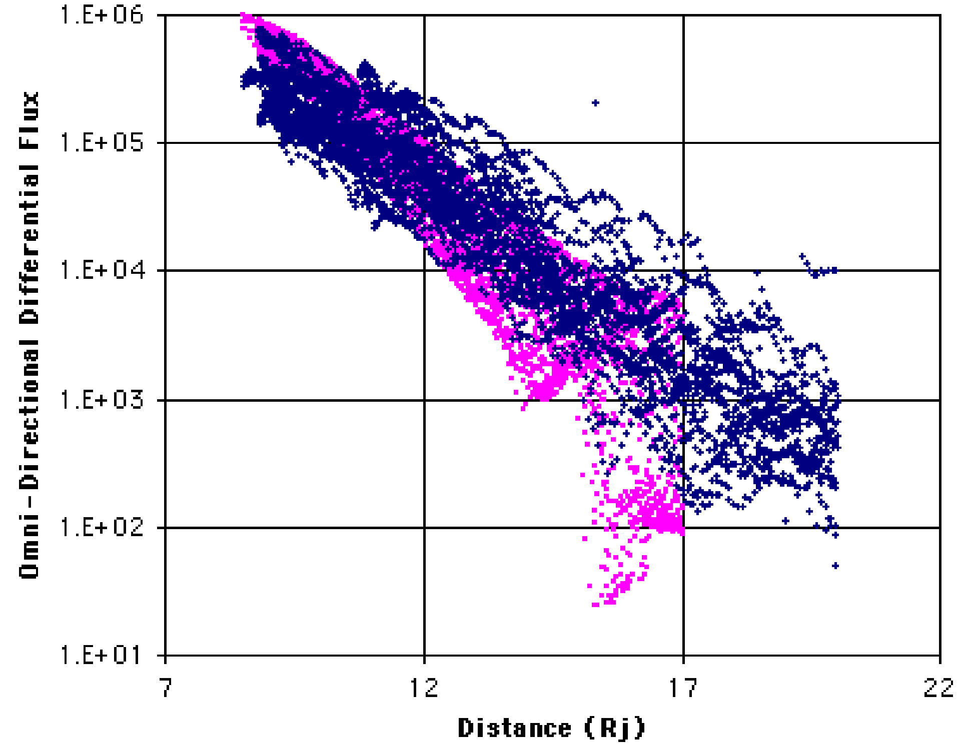

Electrons log (cm² s sr eV)⁻¹
6
4
2
0
-2
0.0001
0.0010
0.0100
0.1000
1.0000
10.0000
Energy (MeV)

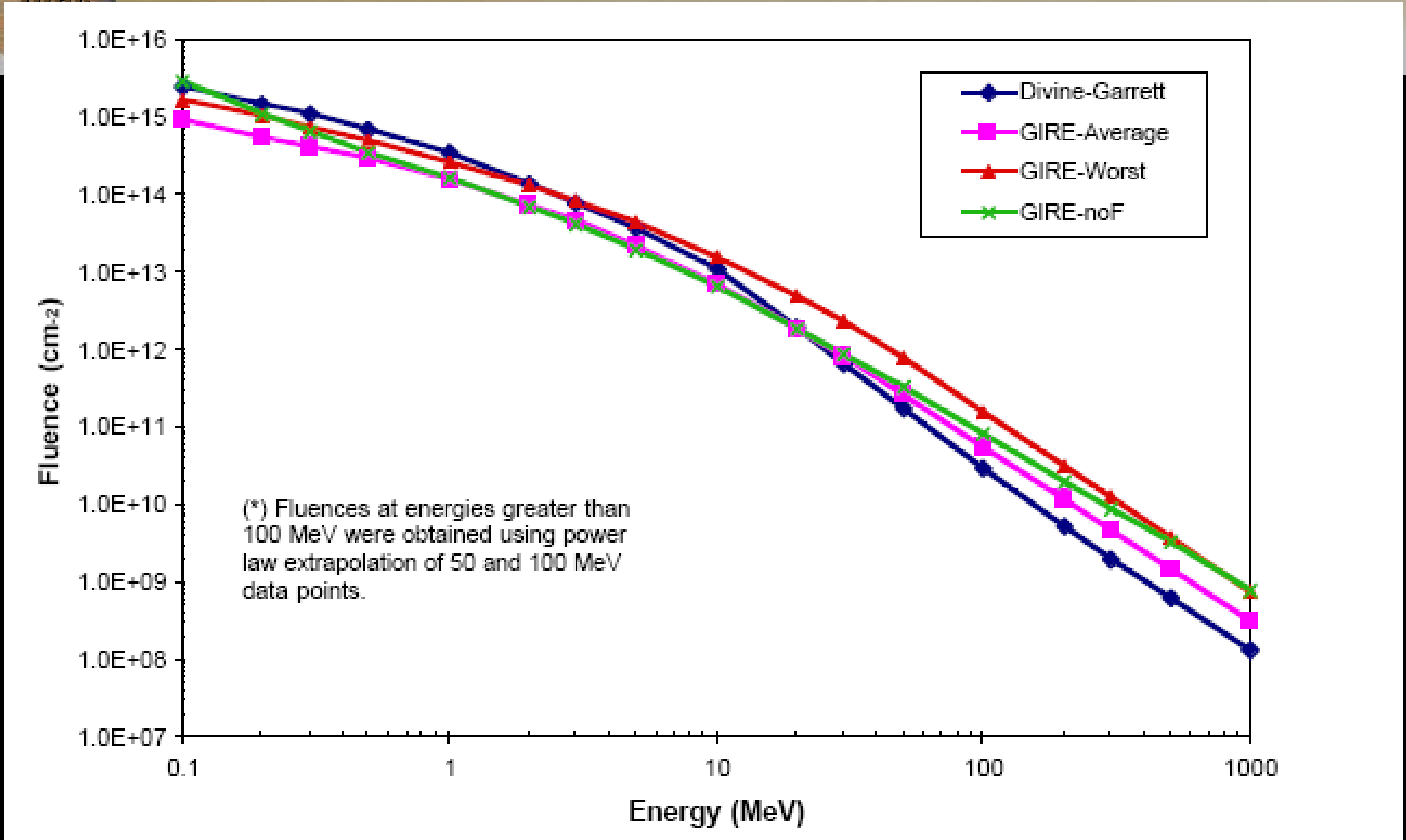

Electrons from G2
1000000
100000
10000
1000
100
10
1
counts per (cm^2-s-sr-keV)
0.01
0.10
1.00
10.00
Energy (MeV)
◆ average j

1.5 MeV electrons
Blue – Galileo
Lavender - Pioneer



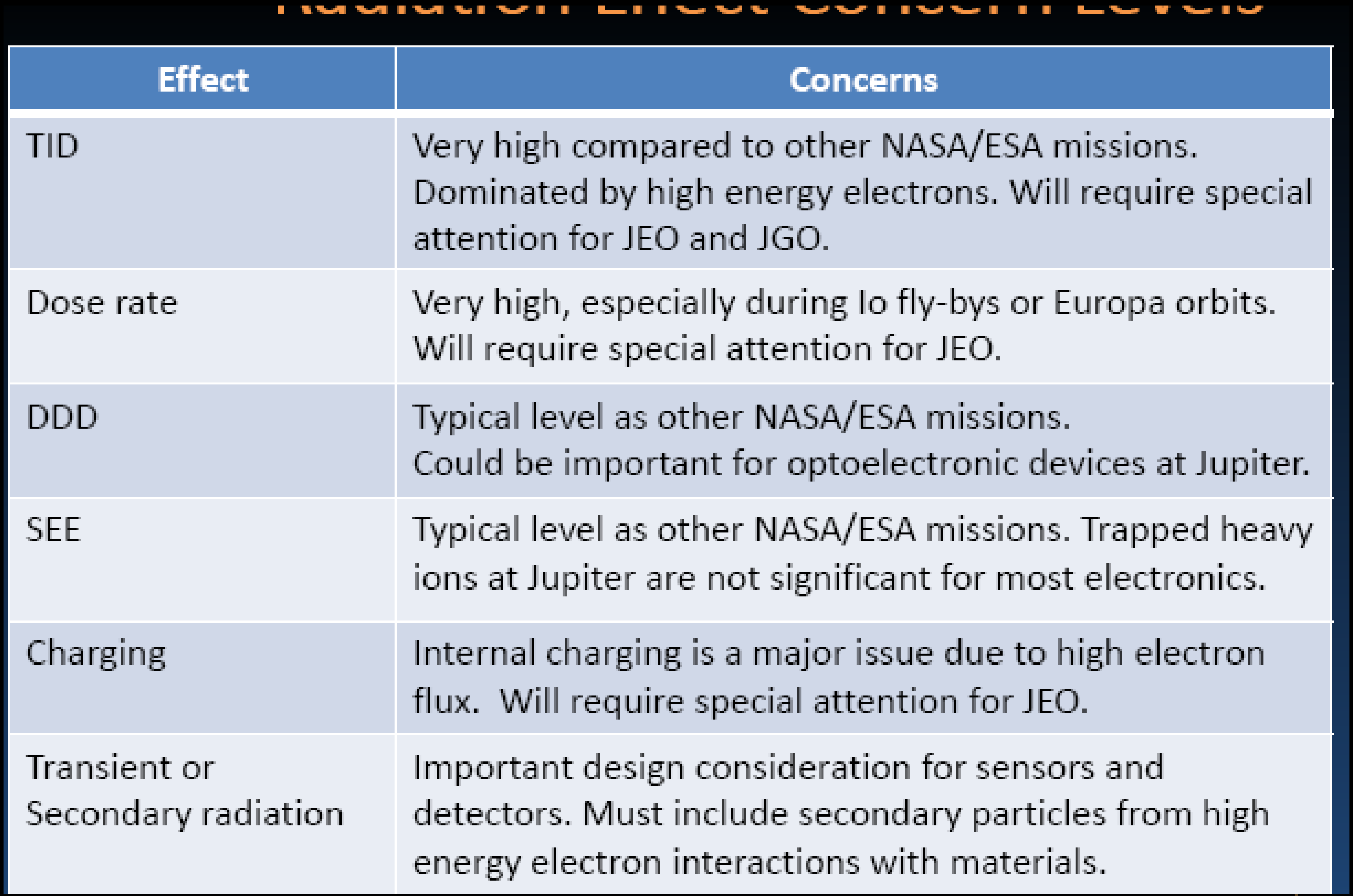
>11MeV electron flux
Blue – Galileo
Lavender - Pioneer





(*) Fluences at energies greater than 100 MeV were obtained using power law extrapolation of 50 and 100 MeV data points.

Fig. 26. The GIRE model integral spectra corrected for pitch angle and extrapolated from 50 MeV to 1000 MeV are compared with the Divine model spectrum for the complete Europa mission trajectory.



Effect	Concerns
TID	Very high compared to other NASA/ESA missions. Dominated by high energy electrons. Will require special attention for JEO and JGO.
Dose rate	Very high, especially during Io fly-bys or Europa orbits. Will require special attention for JEO.
DDD	Typical level as other NASA/ESA missions. Could be important for optoelectronic devices at Jupiter.
SEE	Typical level as other NASA/ESA missions. Trapped heavy ions at Jupiter are not significant for most electronics.
Charging	Internal charging is a major issue due to high electron flux. Will require special attention for JEO.
Transient or Secondary radiation	Important design consideration for sensors and detectors. Must include secondary particles from high energy electron interactions with materials.

- Generally, the RDF of 2 is conservative. GLL was only designed to about 150 mrad, yet survived a much higher dose.