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A lobster eye telescope for the Jovian system

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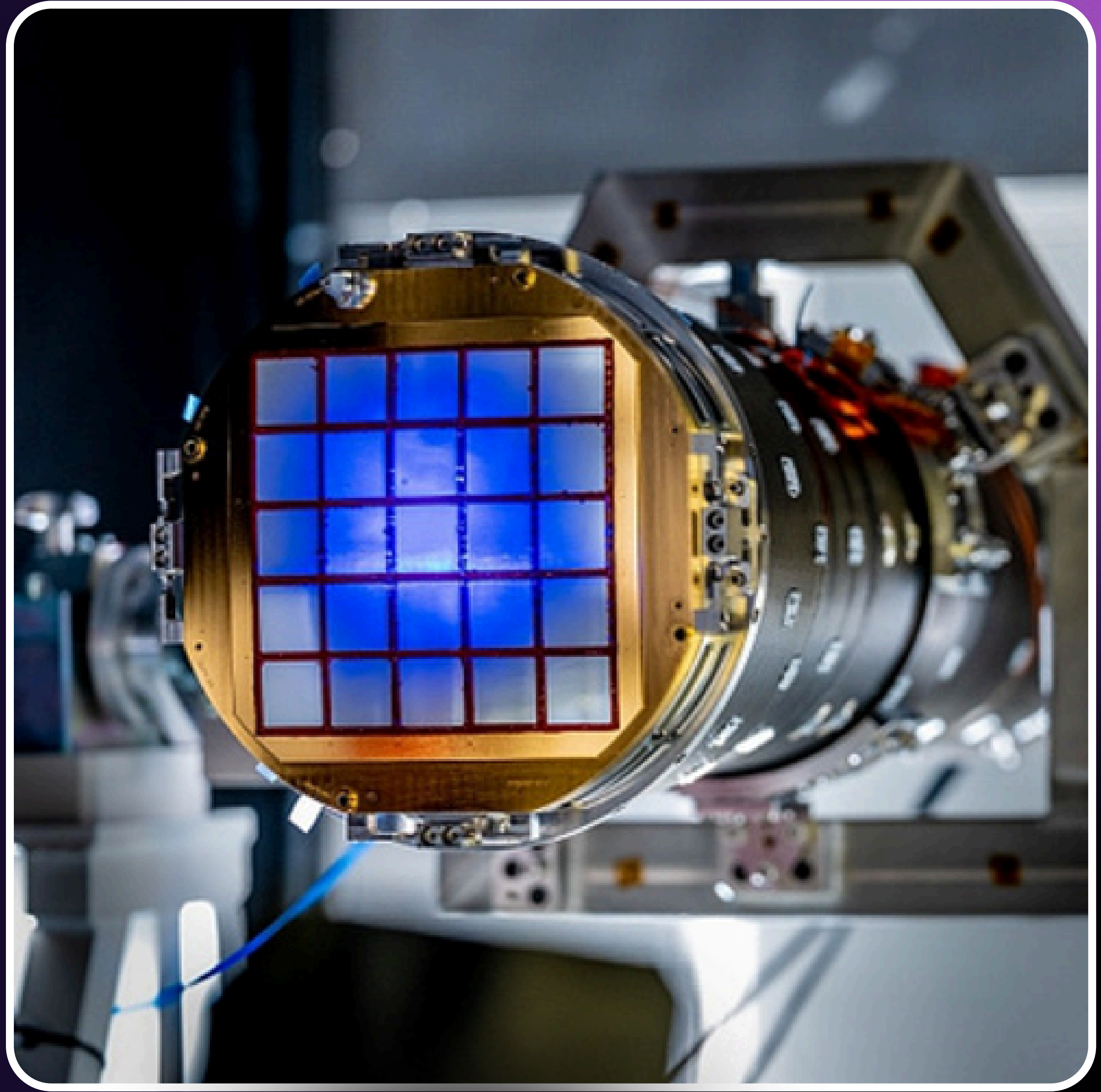
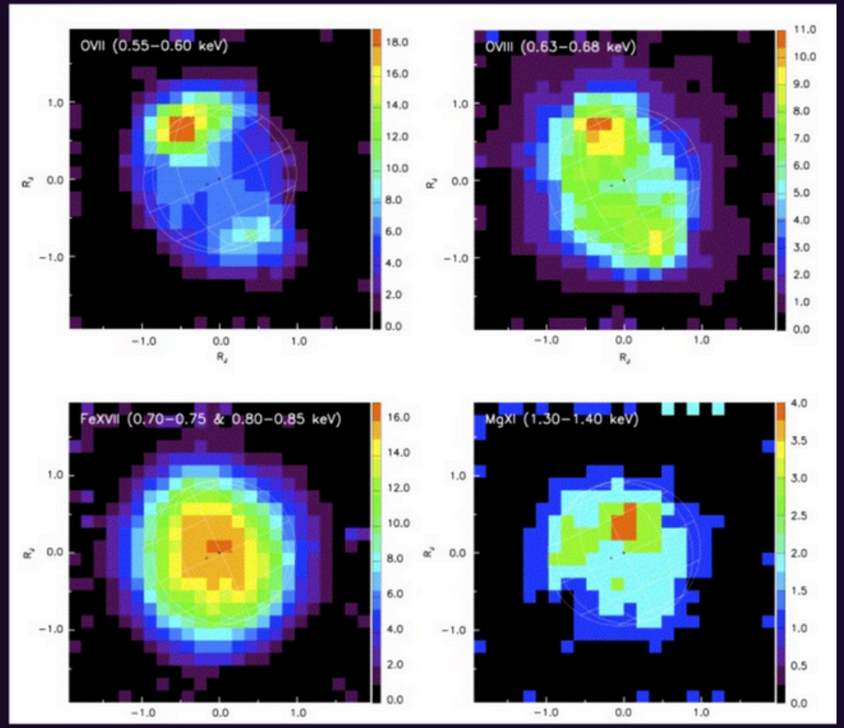
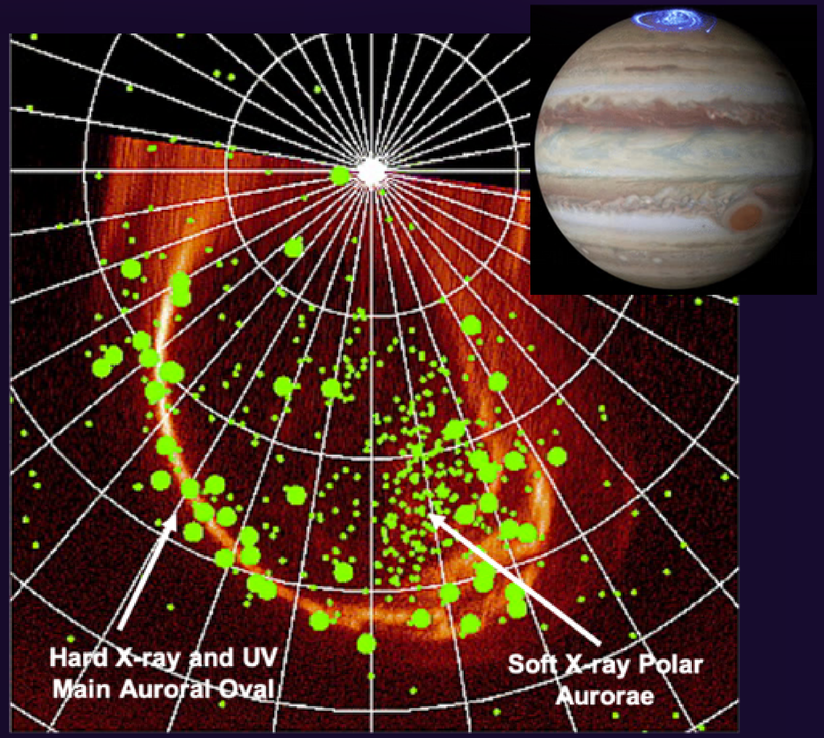


X-rays in the Jovian System

EQUATORIAL EMISSION

Solar protons
Thompson and k-shell scattering
(Branduardi-Raymont, 2007)



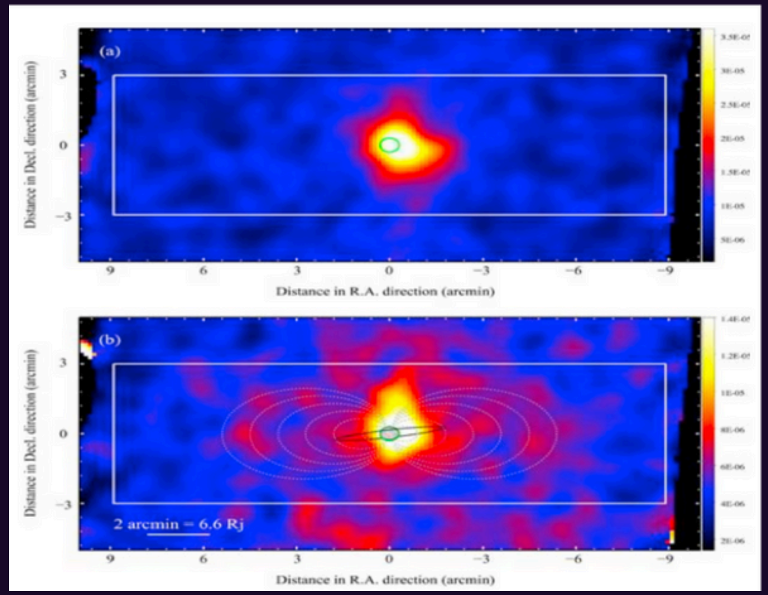


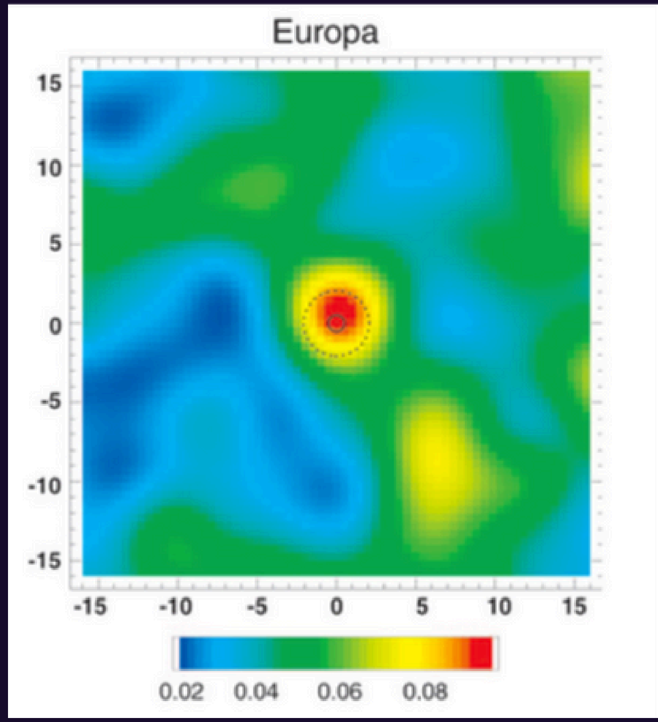
X-RAY AURORAE

Bremsstrahlung hard and soft X-rays
(Branduardi-Raymont, 2007)
(Nichols, 2016)

RADIATION BELTS AND IO PLASMA TORUS

Inverse-Compton, ultra relativistic electrons
Charge exchange, collisions and solar protons
(Ezoe, 2010)





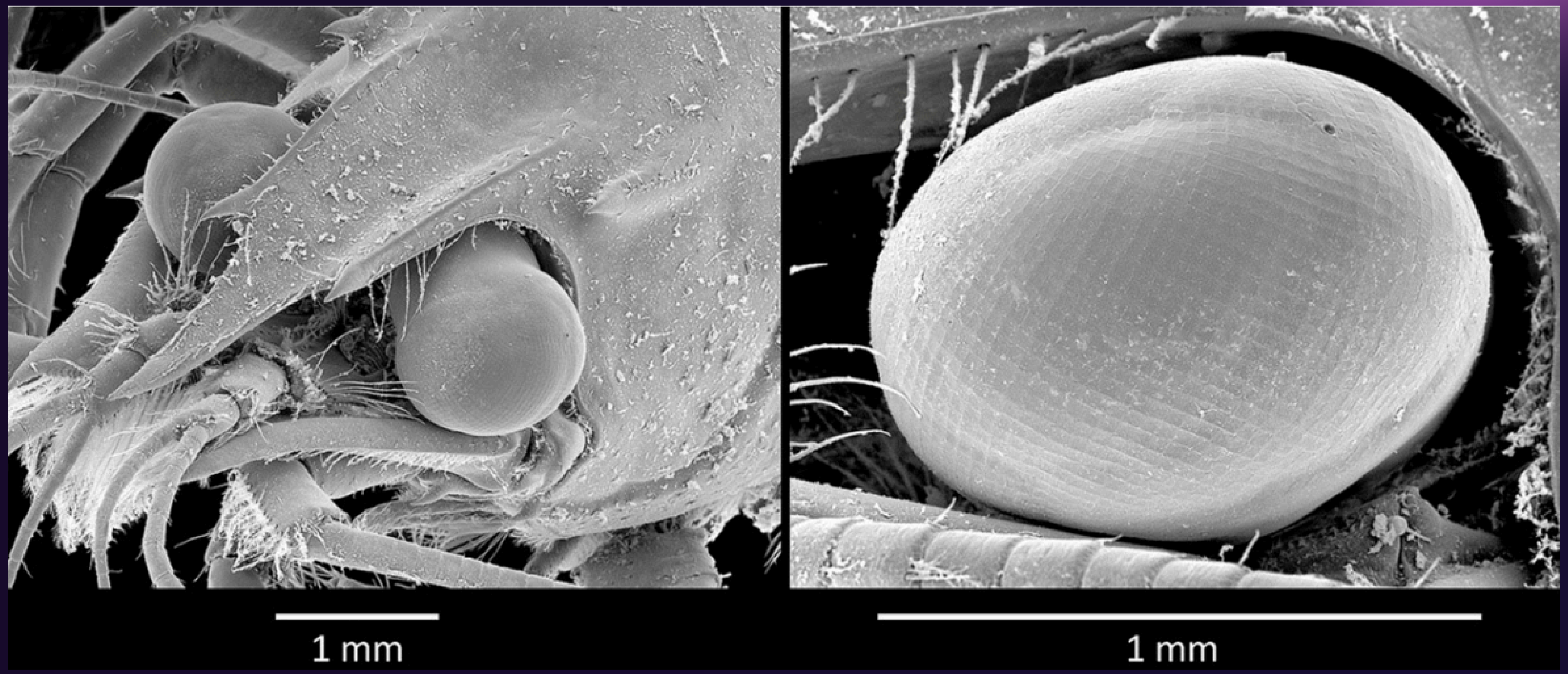
GALILEAN MOONS

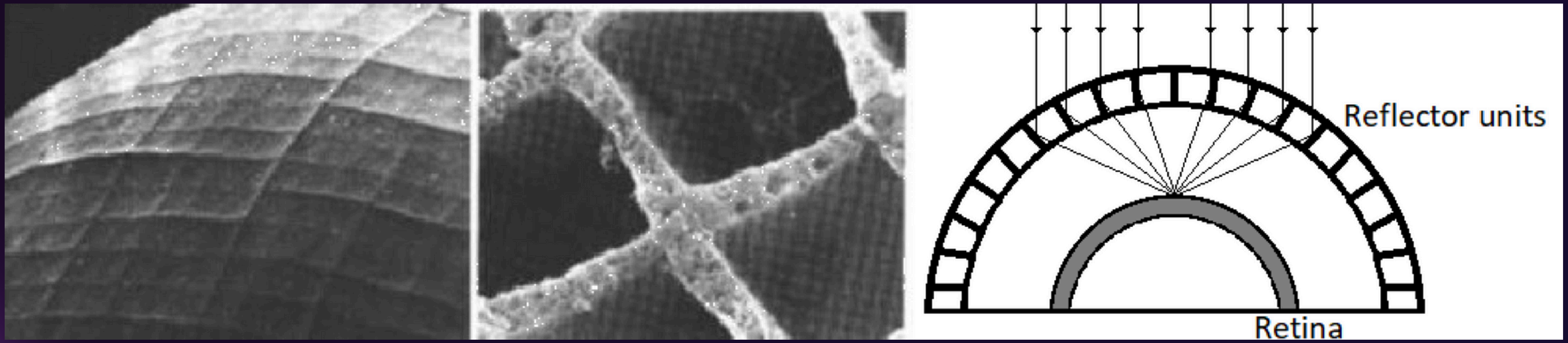
Electron and particle induced X-ray emission (EIXE and PIXE)
(Elsner, 2002)

Novel X-ray Optics

Lobster Eye Optics

- Inspired by the eyes of crustaceans
- Tiny pores which focus low flux light effectively
- Pores arranged over a sphere – large FOV

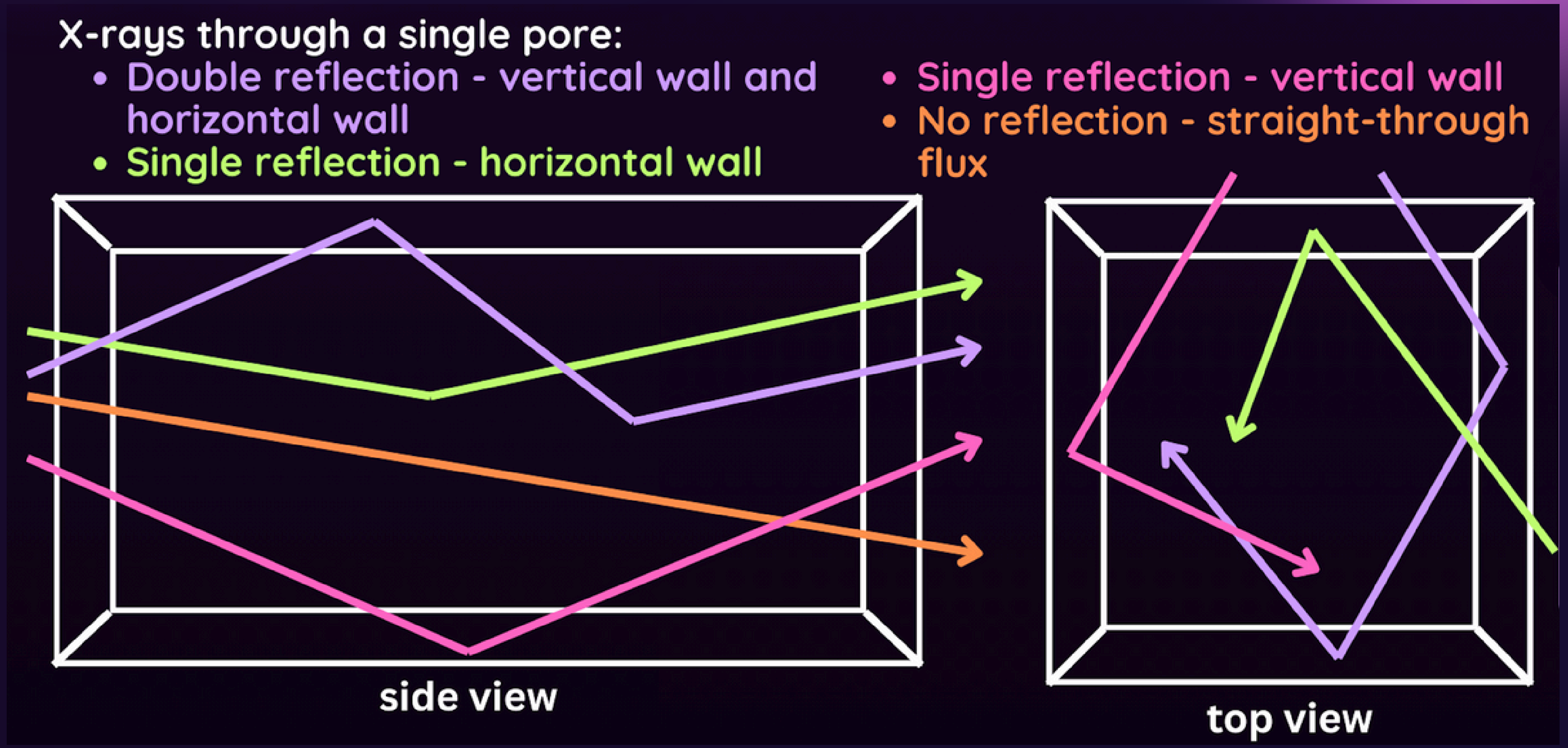


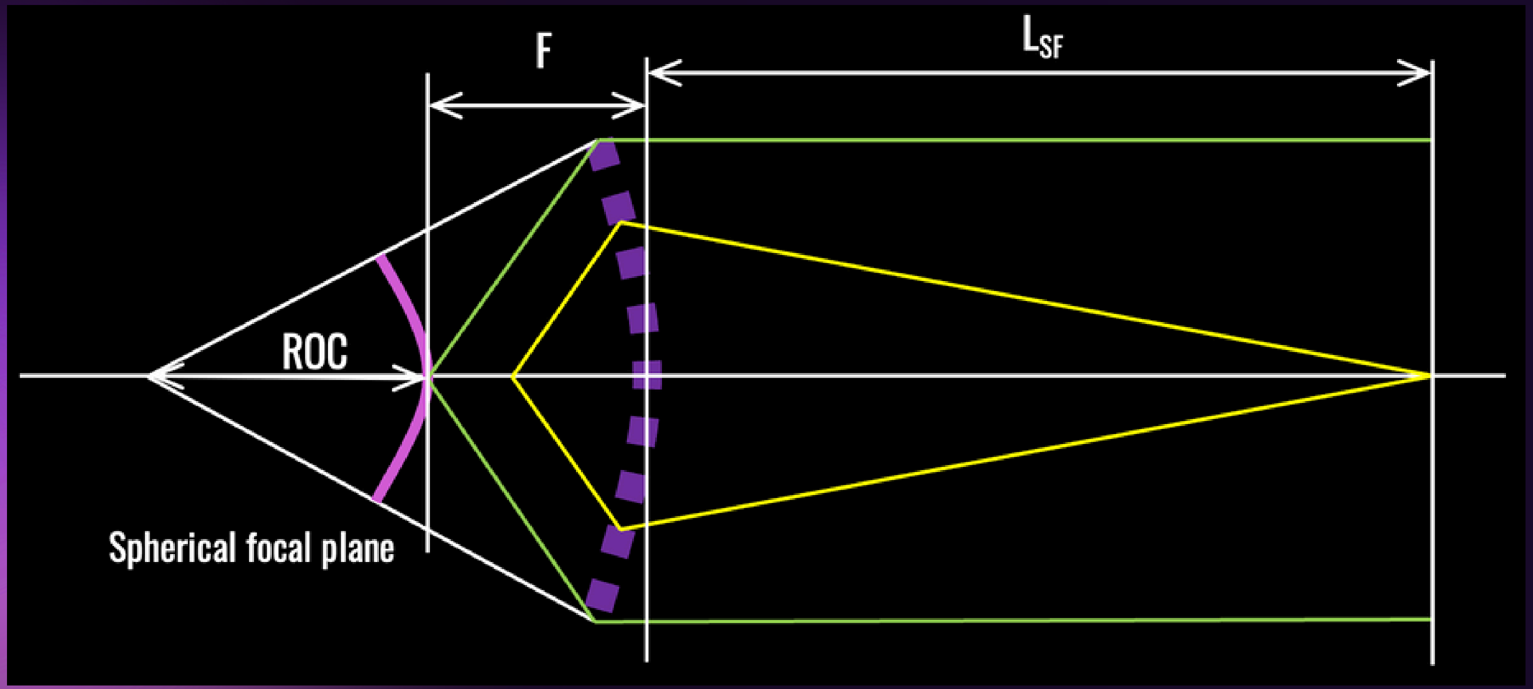


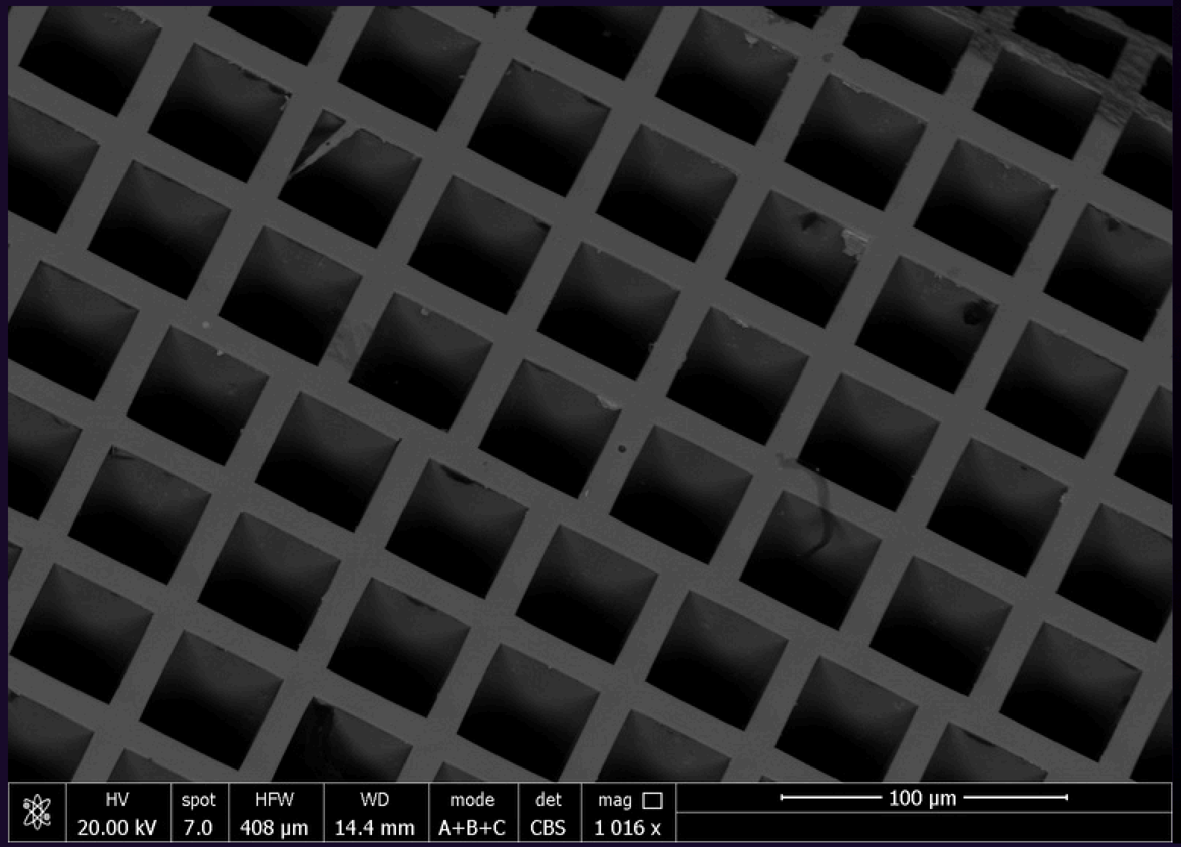
Novel X-ray Optics

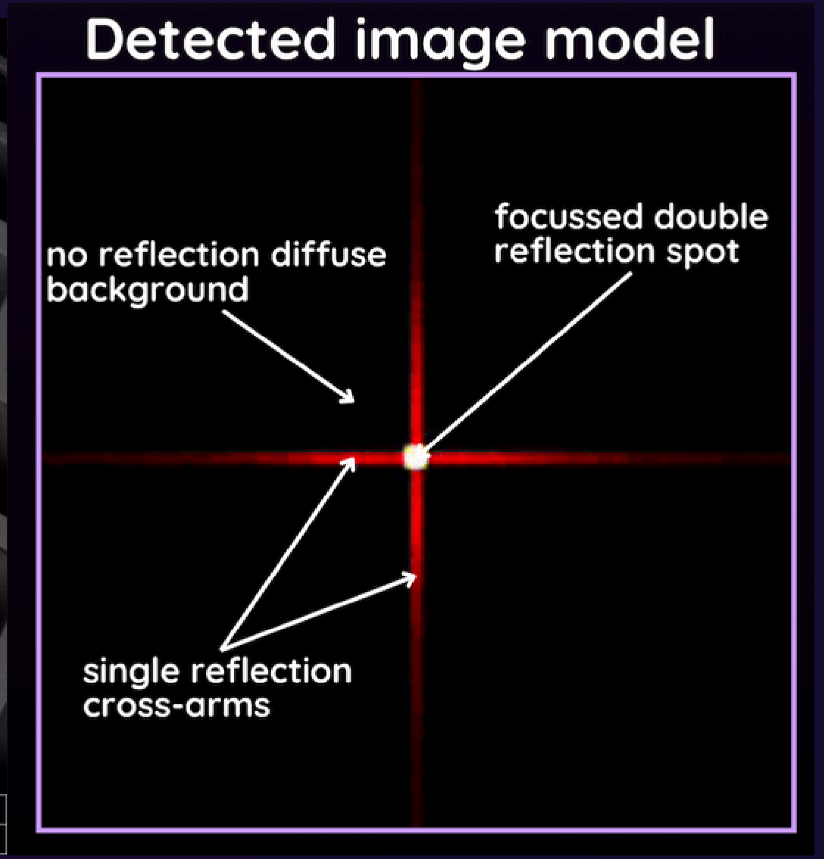
Micropore Optics

- Grazing incidence optics
- An array of square pores
- X-rays reflect once or twice off the pore walls
- X-rays focus to a central point and vertical and horizontal cross-arms



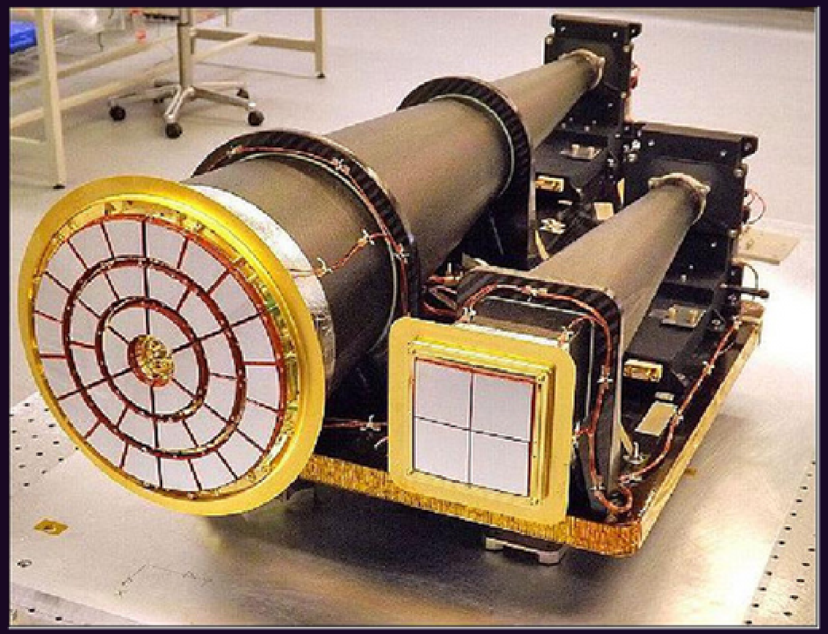
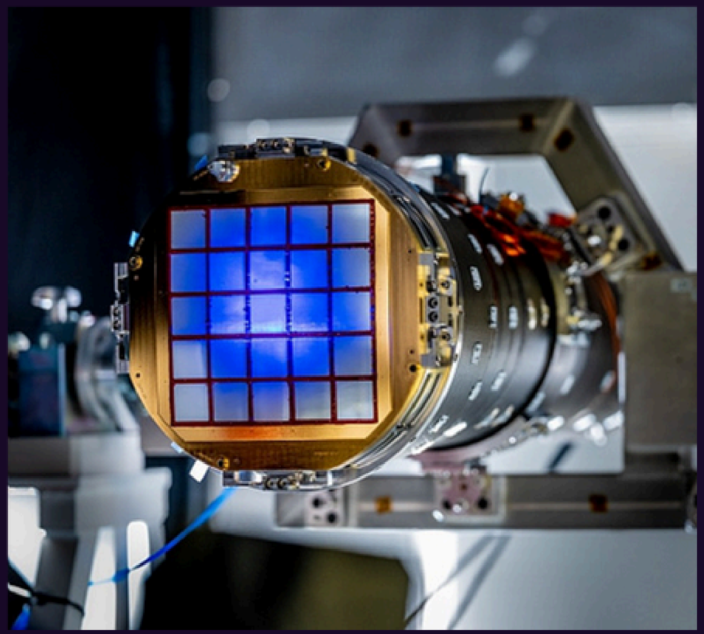
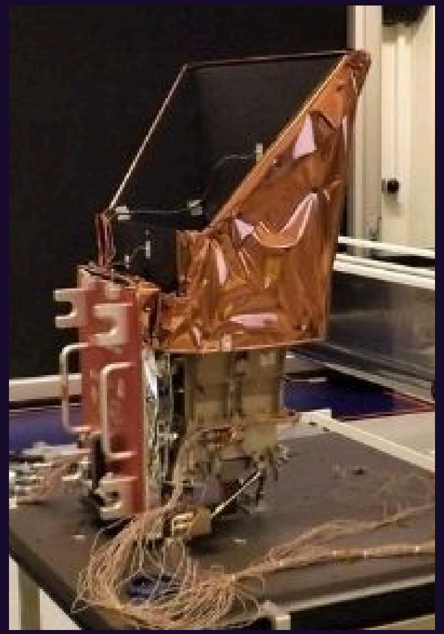
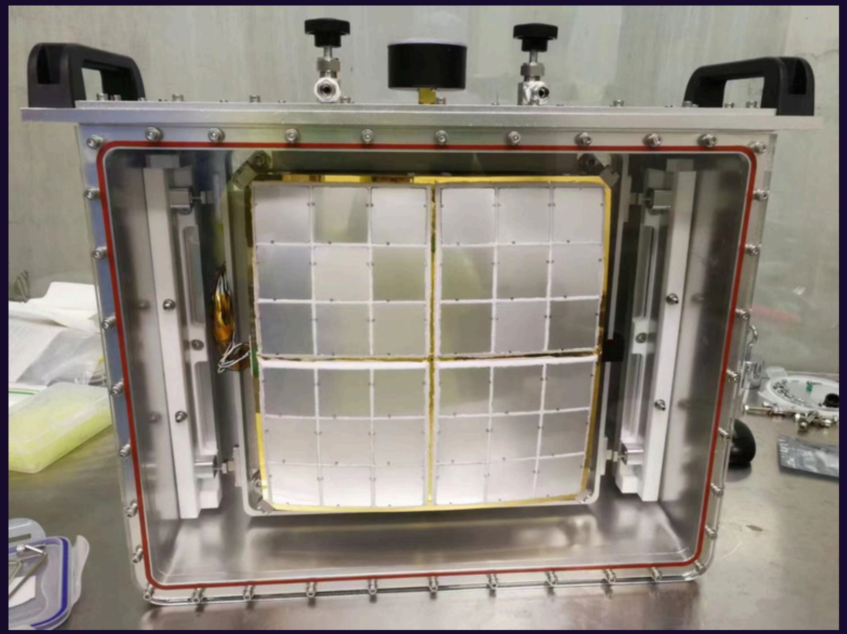
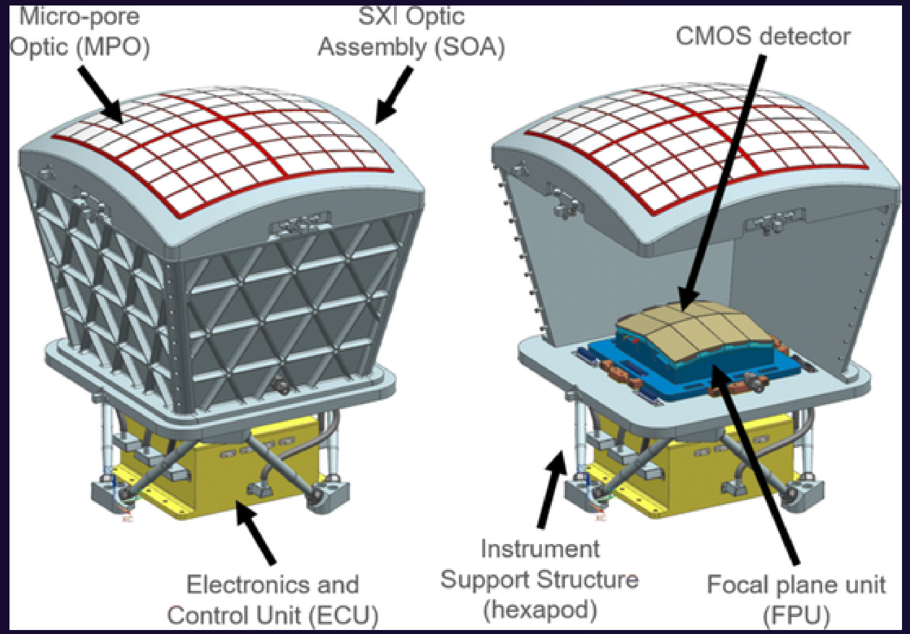






Telescope Design

Heritage in X-ray telescopes

Left to right: BepiColombo Mercury Imaging X-ray Spectrometer (Bunce, 2020), SVOM Microchannel X-ray Telescope (Mercier, 2018), SMILE Soft X-ray Imager (Sembay, 2023), Einstein Probe Wide-field X-ray Telescope (Yuan, 2018), THESEUS (O'Brien, 2020).

Recontextualising for a Jovian mission

Specifications – Spatial resolution, radius of curvature, number of MPOs, focal length, detector etc.

Produce instrument specifications by considering:

- Size of Jupiter, the system, moons, auroral features etc.
- Current MPO resolutions and the potential of future improvements
- Orbital parameters of the COMPASS concept mission (Clark, 2025. Under review)

X-ray Telescope Specifications

COMPASS Orbits

- Furthest apojove = 60 RJ
- Closest perijove = 1RJ

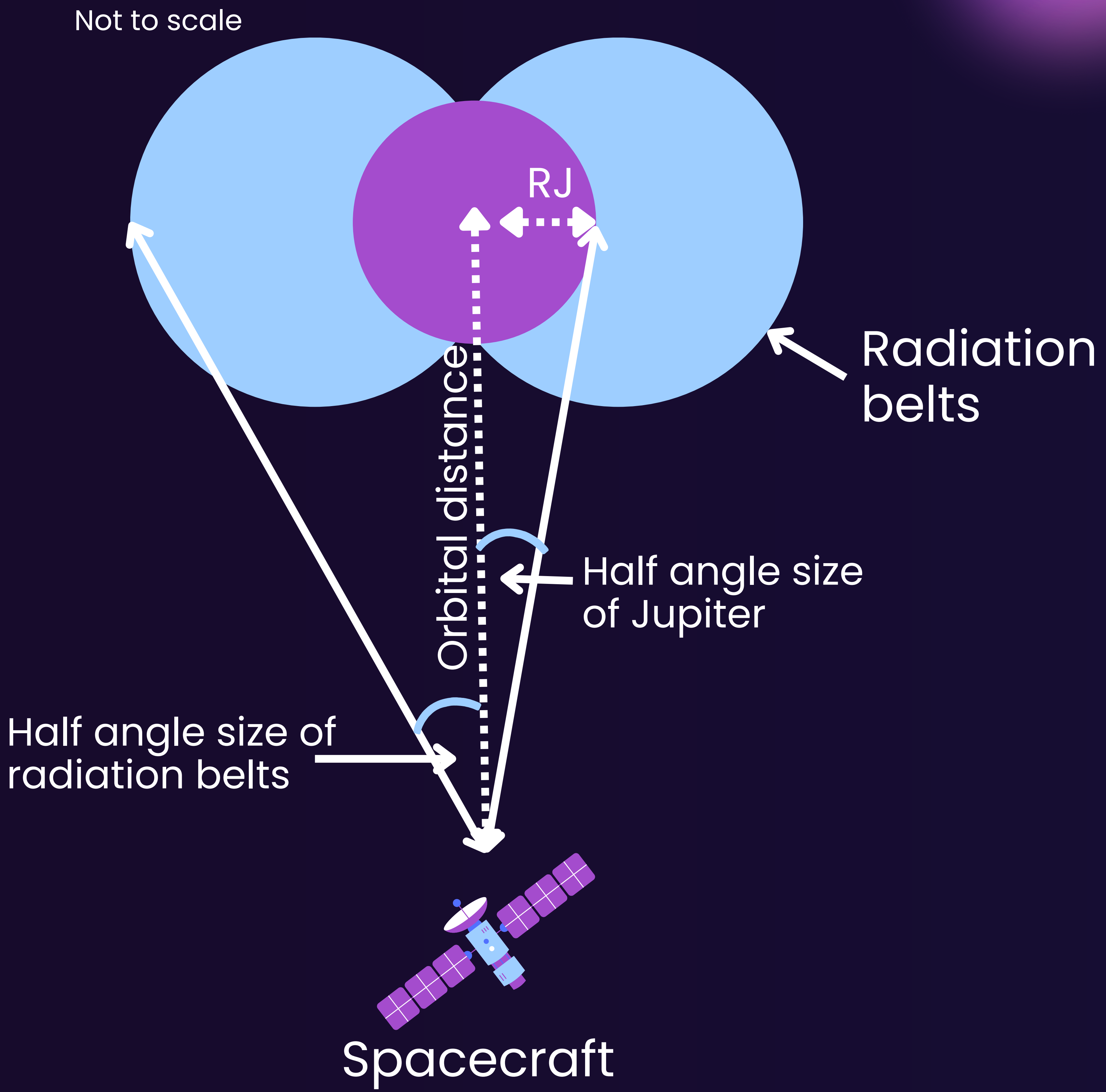
Orbital distance from Jupiter (RJ)	Size of Jupiter (degrees)	Size of radiation belts (degrees)
60	1	6.3
5	11	53

Current MPOs

- Resolution = 11' (0.16. deg)

Spatial resolution of the MPO affects the ability to observe features - e.g. auroral arc

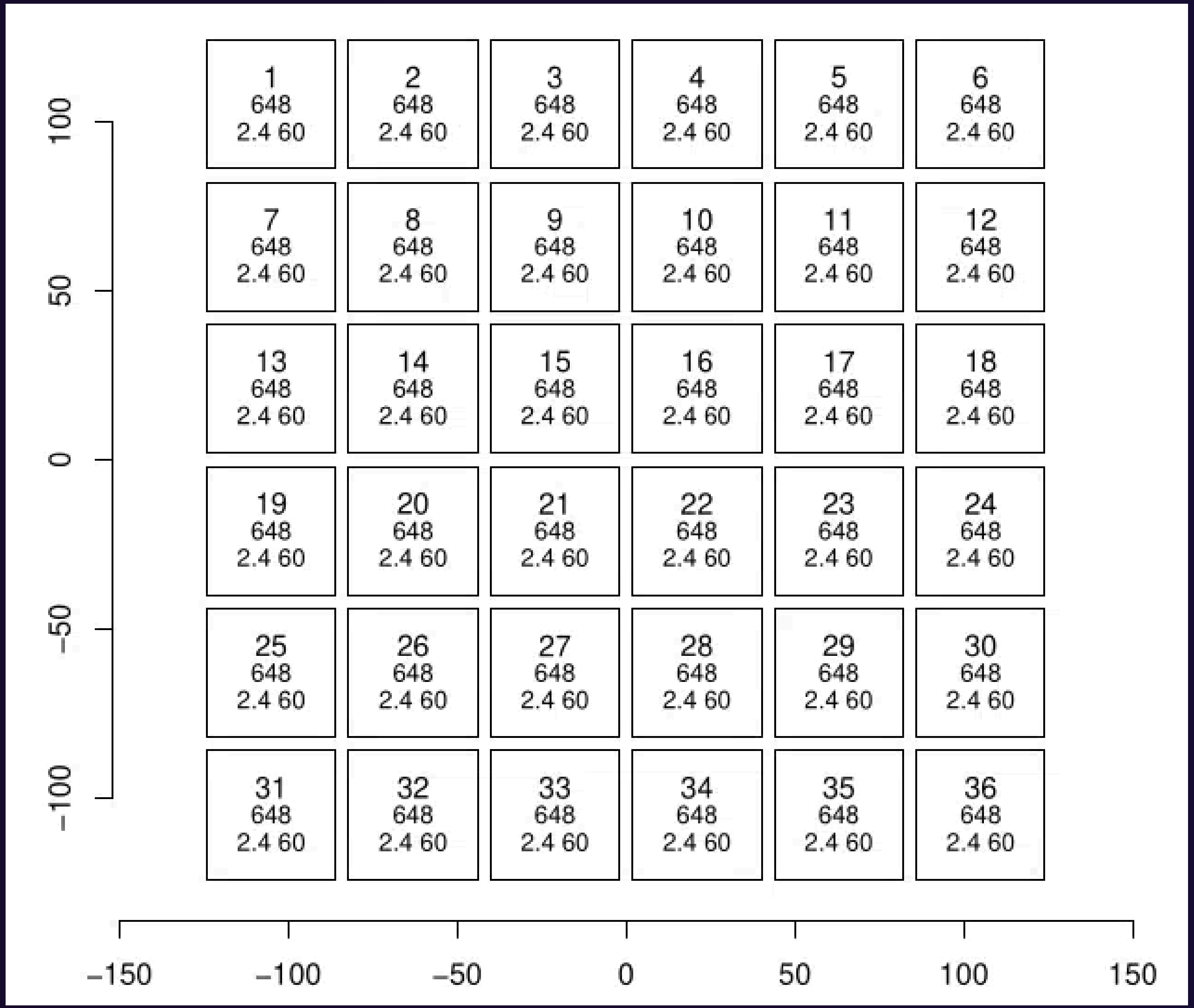
MPO resolution		Resolution at 5RJ	
arcmin	degrees	km	RJ
3	0.5	311.9	0.0044
5	0.083	517.8	0.0072
8	0.13	811.1	0.0113
11	0.16	998.2	0.0149



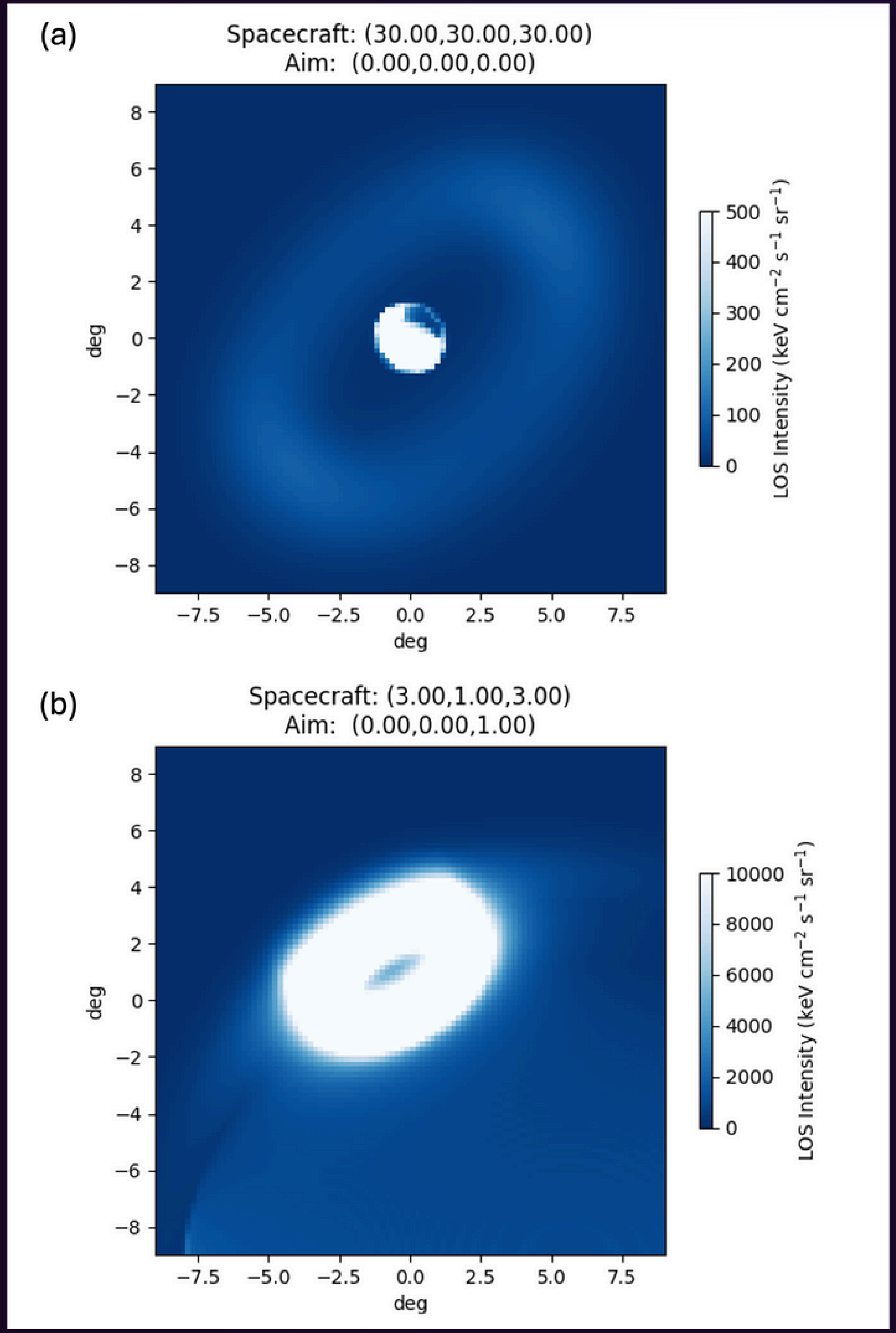
Telescope Optics Design

- 6x6 array of 40mm x 40mm MPOs - 4mm gap between each aperture (38mm x 38mm)
- 650mm radius of curvature
- 19 degree field of view
- Detector - TBD

These specifications can be used in Q to simulate the PSF of the instrument

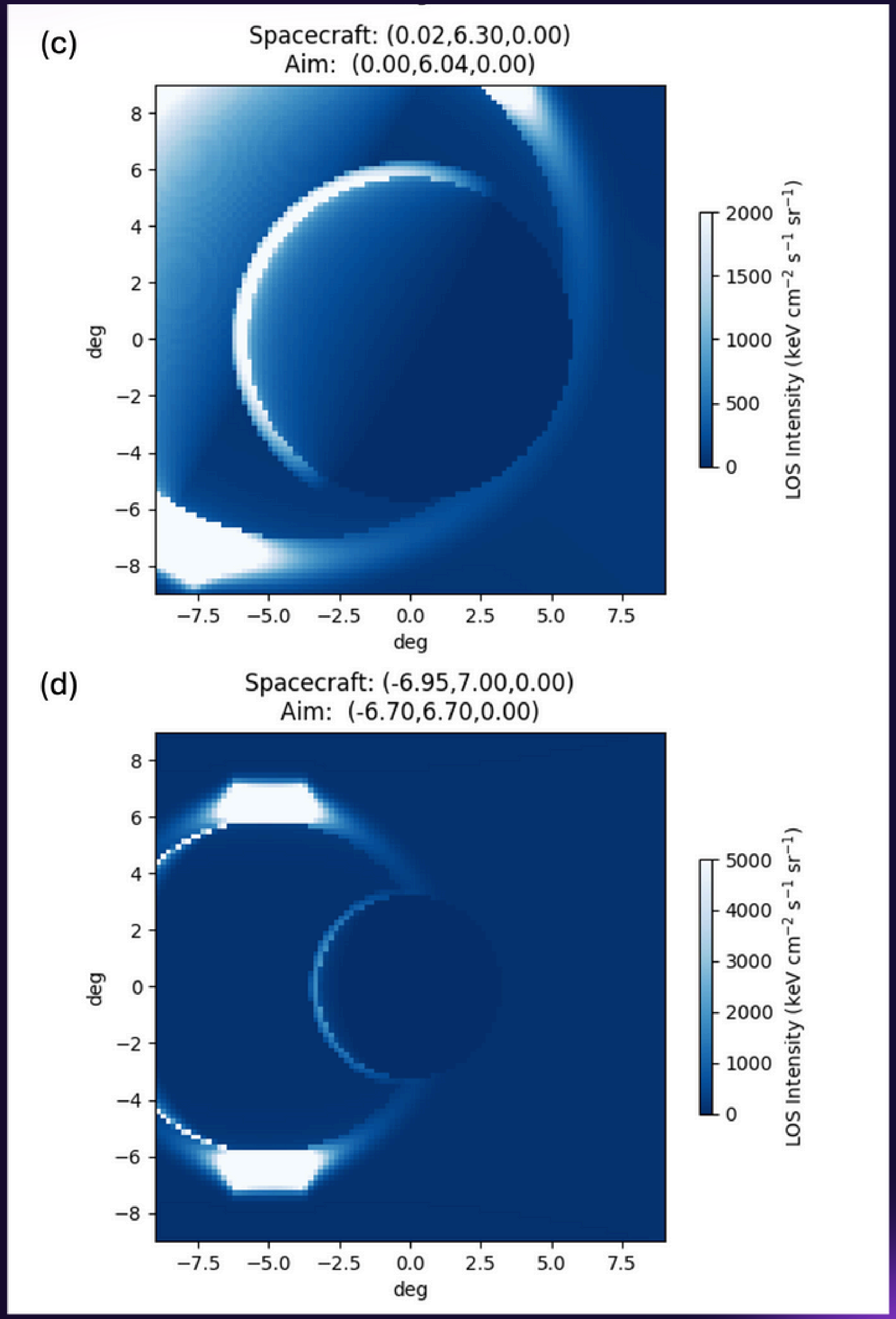


Modelling the Jovian System



- Line of sight integrated images through an emissivity model - similar FOV as telescope concept
- Based on Wharton et. al., 2025 a & b - empirical X-ray models for SMILE have been developed to simulate X-ray images at Jupiter

a - Jupiter and radiation belts from a distance
b - Close-up view of the northern aurora
c - Side-on view of Io with Jupiter in the background
d - Nightside view of Europa with Jupiter in the background
(Images by S. Wharton (University of Leicester) for use in paper in progress by N. Carr (University of Leicester))



Modelling MPOs

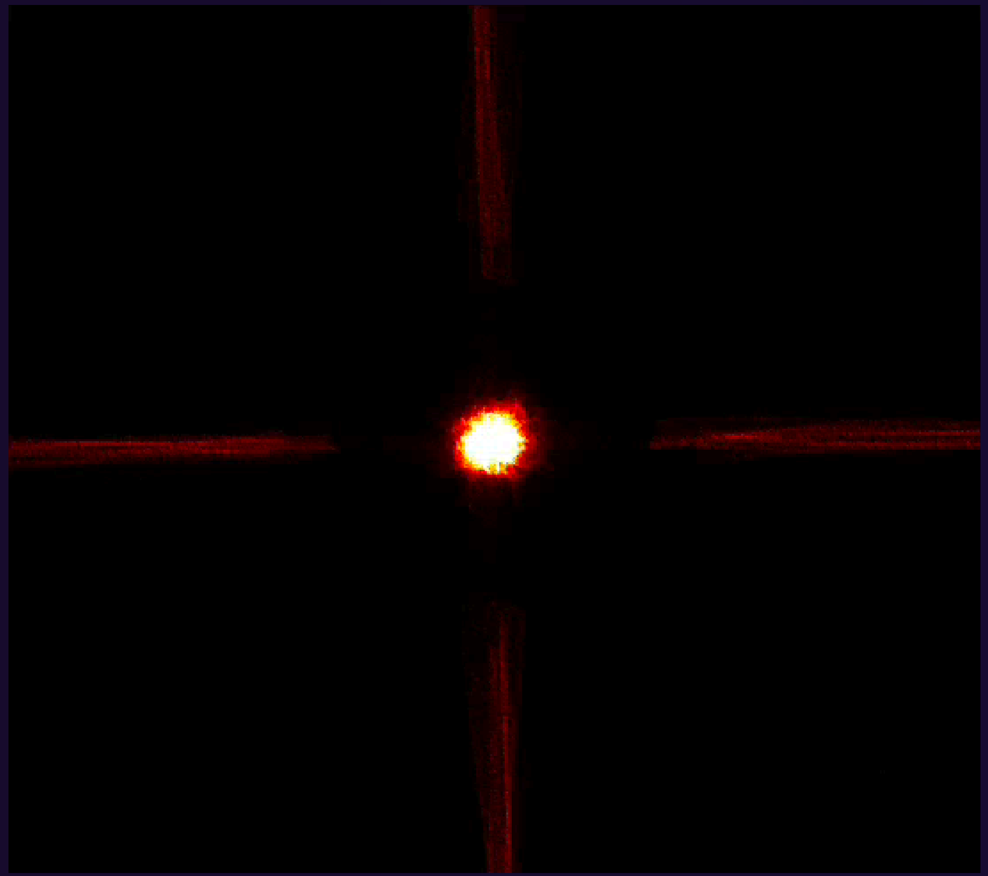
Q - X-ray optics modelling programme

For this purpose:

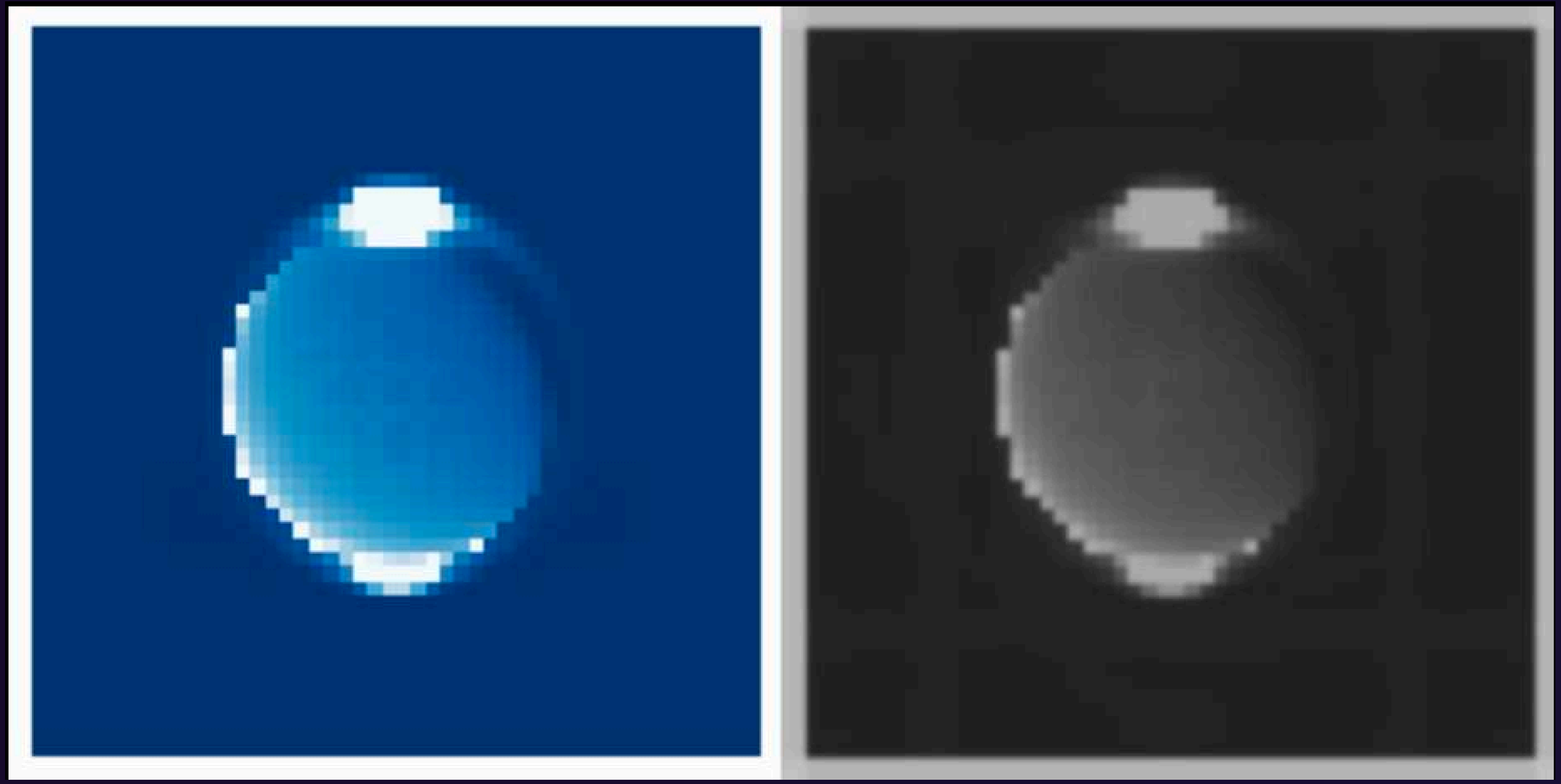
- Monoenergetic 1.49 keV X-rays - Vertical Test Facility
- One million X-ray photons
- Produces a clear and useful image of X-rays being focussed from infinity onto a detector surface

Convolution onto Jovian X-ray image

- PSF produced by Q used as a convolution matrix
- Simple convolution of PSF matrix over the image produced by Wharton of the X-rays from Jupiter
- Starts to build an idea of the possible science with current MPO technology



a) PSF produced by X-rays being focussed by a 6x6 MPO array with deformations



b) Comparison of X-ray image from Wharton model vs. X-ray image after being focussed through 6x6 MPO array

Summary and Future Work

- Novel X-ray optics have opened a new pathway of in situ X-ray observations
- Current MPOs provide a suitable spatial resolution to resolve finer details in aurorae etc.
- Plethora of high energy planetary science to be studied

- Further development of Jupiter and optics X-ray models - quantify results
- Produce PSFs with VTF and TTF to compare with model results
- Working alongside industry partners to further improve the optics performance

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