



Post-AO high-resolution imaging in the visible of moons and asteroids in the Solar System with SHARK-VIS@LBT

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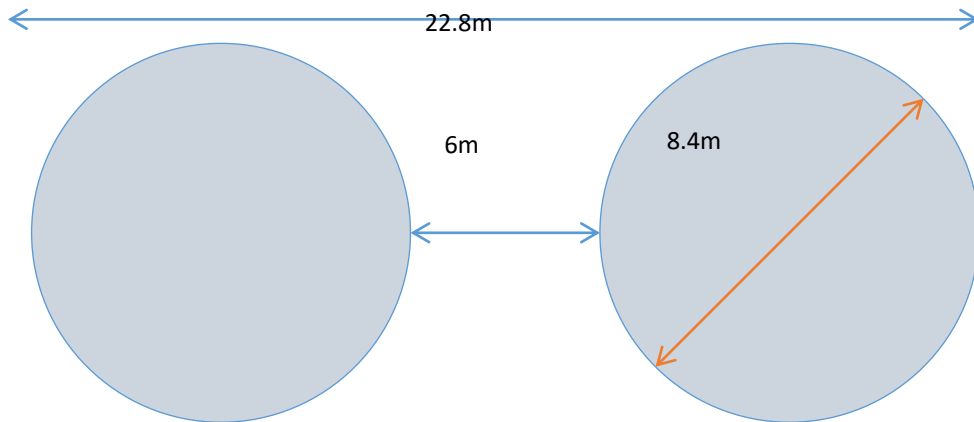
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⁶European Southern Observatory, Alonso de Cordova, 3107 Vitacura, Santiago, Chile

⁷Lowell Observatory, 1400 W Mars Hill Rd, Flagstaff, AZ, USA

The Large Binocular Telescope (LBT)

Mount Graham 3200m, Arizona

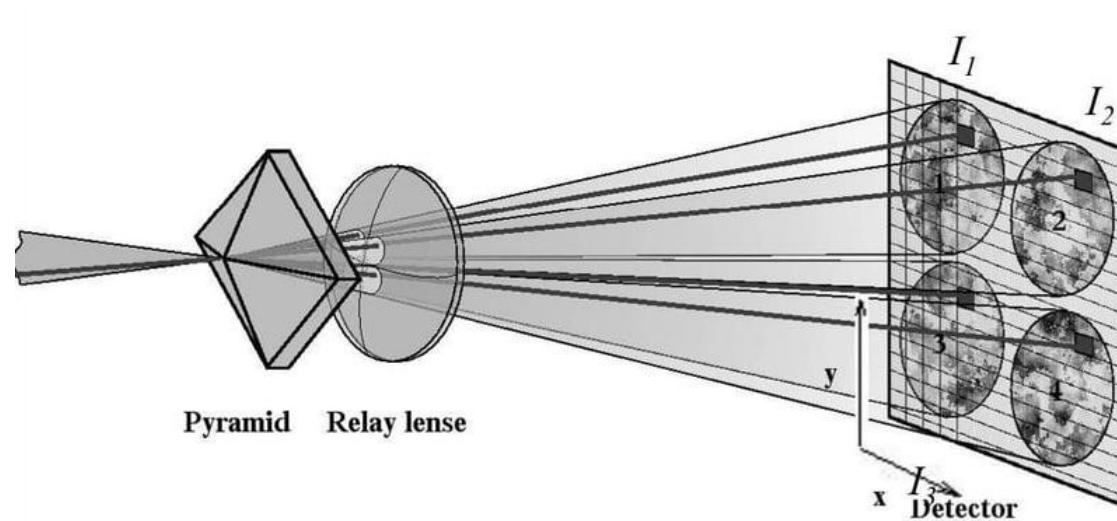
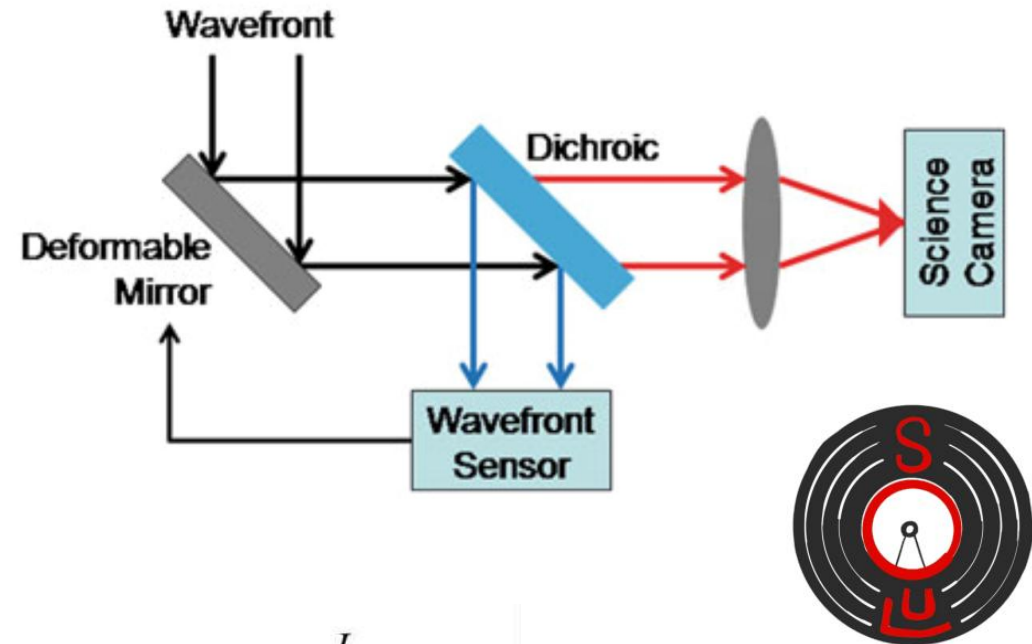


LBT main collaborators: INAF + Arizona + Ohio

The LBT Adaptive Optics “SOUL” (Pinna+ 2023, AO4ELT7 813, 80)



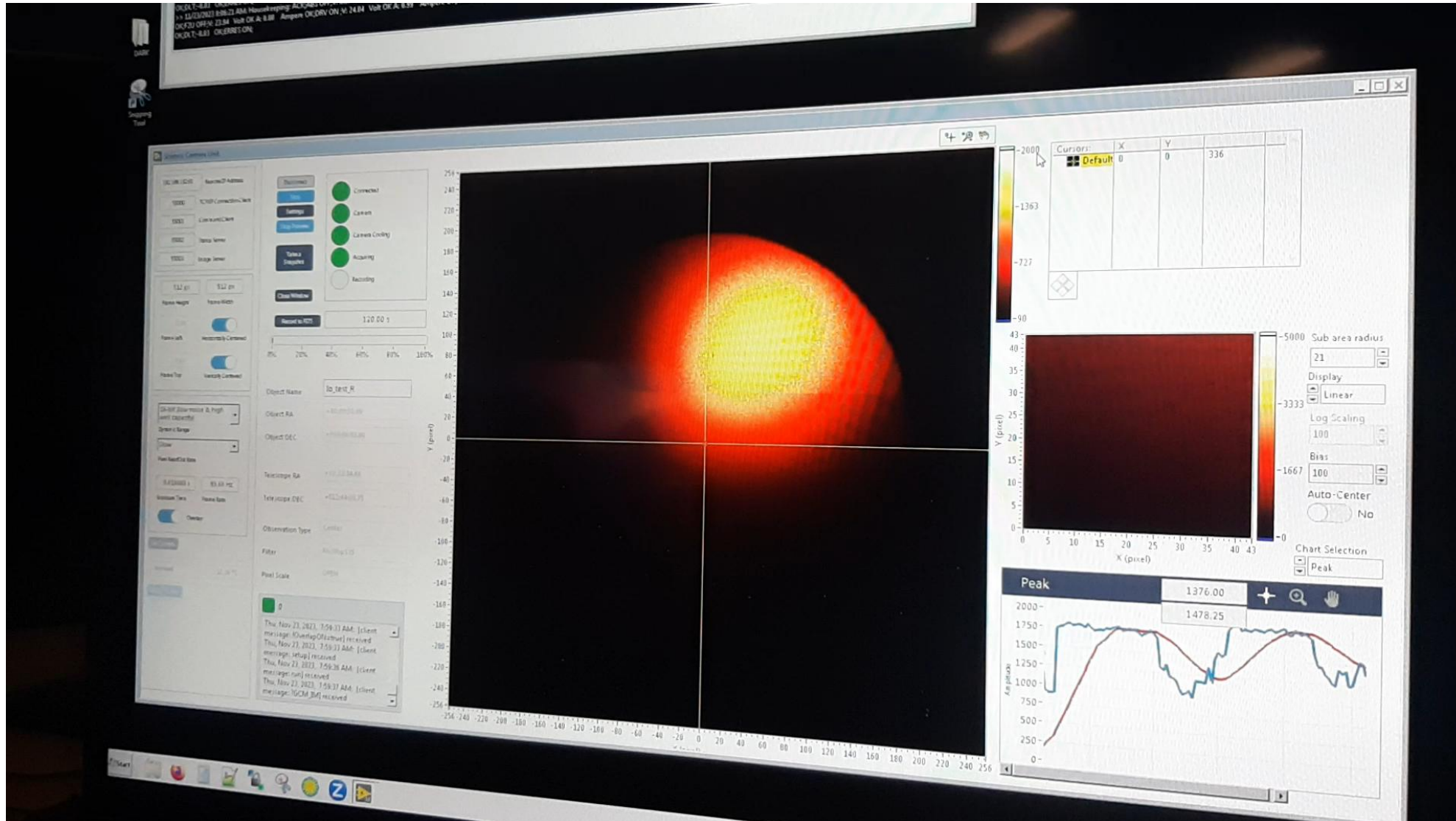
LBT Gregorian Secondary Mirror with 672 actuators



2kHz images

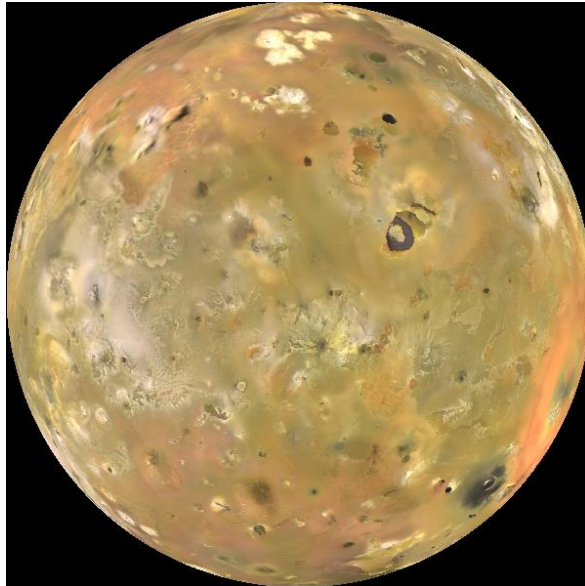
The LBT Adaptive Optics “SOUL” (Pinna+ 2023, AO4ELT7 813, 80)

SOUL Adaptive Optics closing the loon on Io in a 1'' seeing



LBT Theoretical Diffraction Limit in the Visible

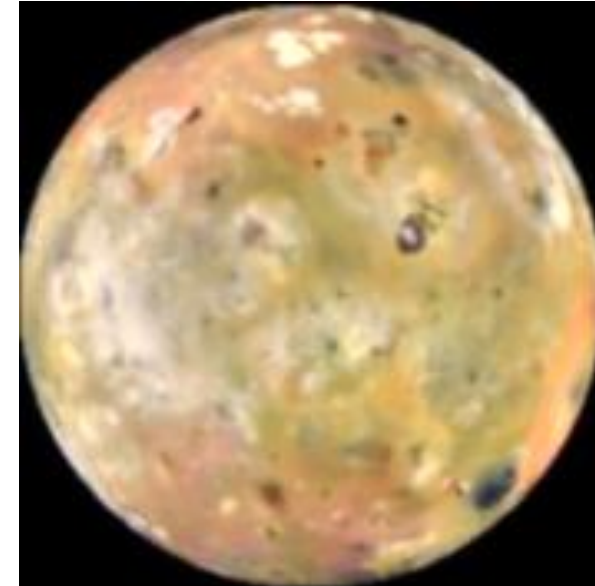
$$\lambda / D = \begin{cases} 17 \text{ mas at } \lambda = 600\text{nm} \\ 12 \text{ mas at } \lambda = 500\text{nm} \\ 10 \text{ mas at } \lambda = 400\text{nm} \end{cases}$$



Io reference map
(Voyager/Galileo)

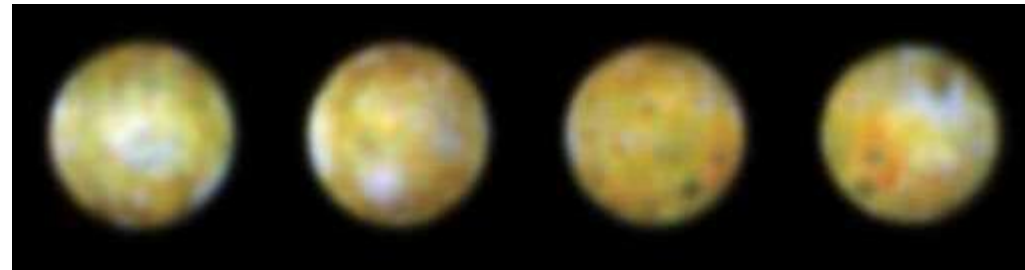


Airy PSF



Diffraction limit
simulation

HST Cycle 4 images of Io (March 1994)

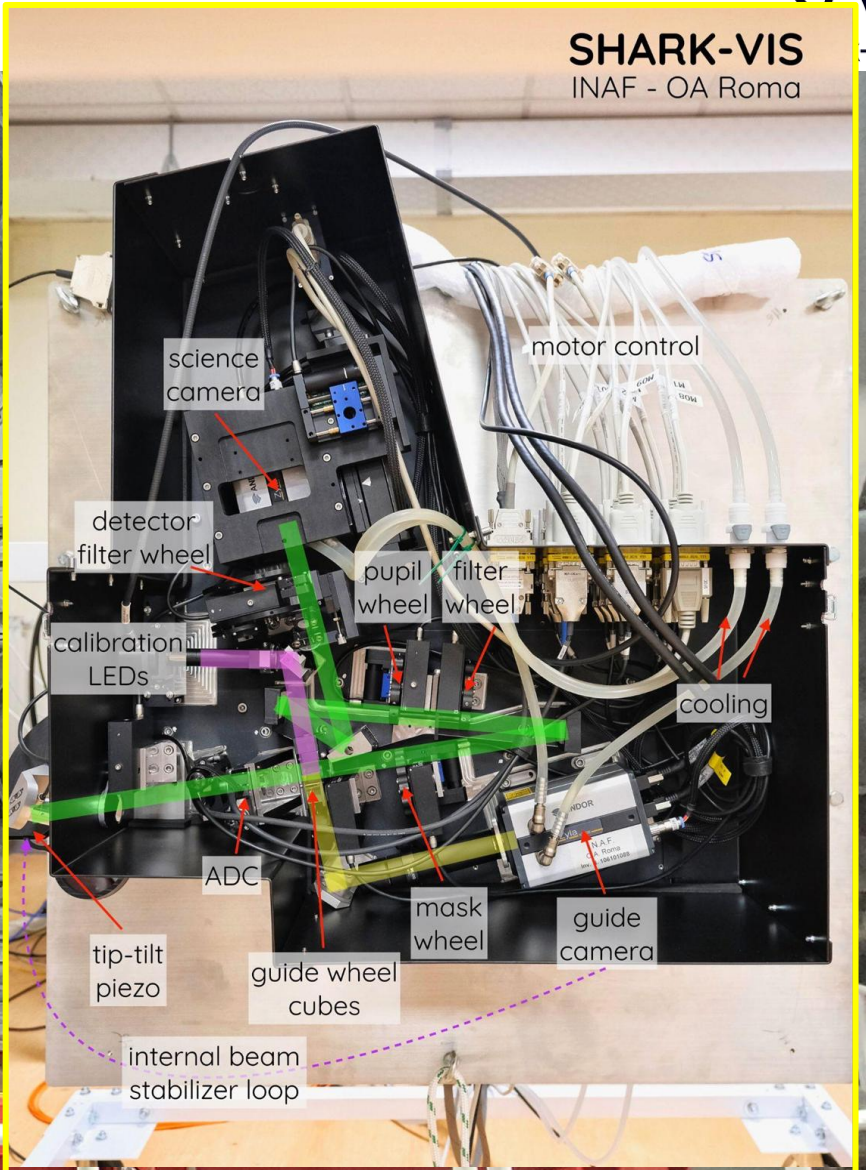
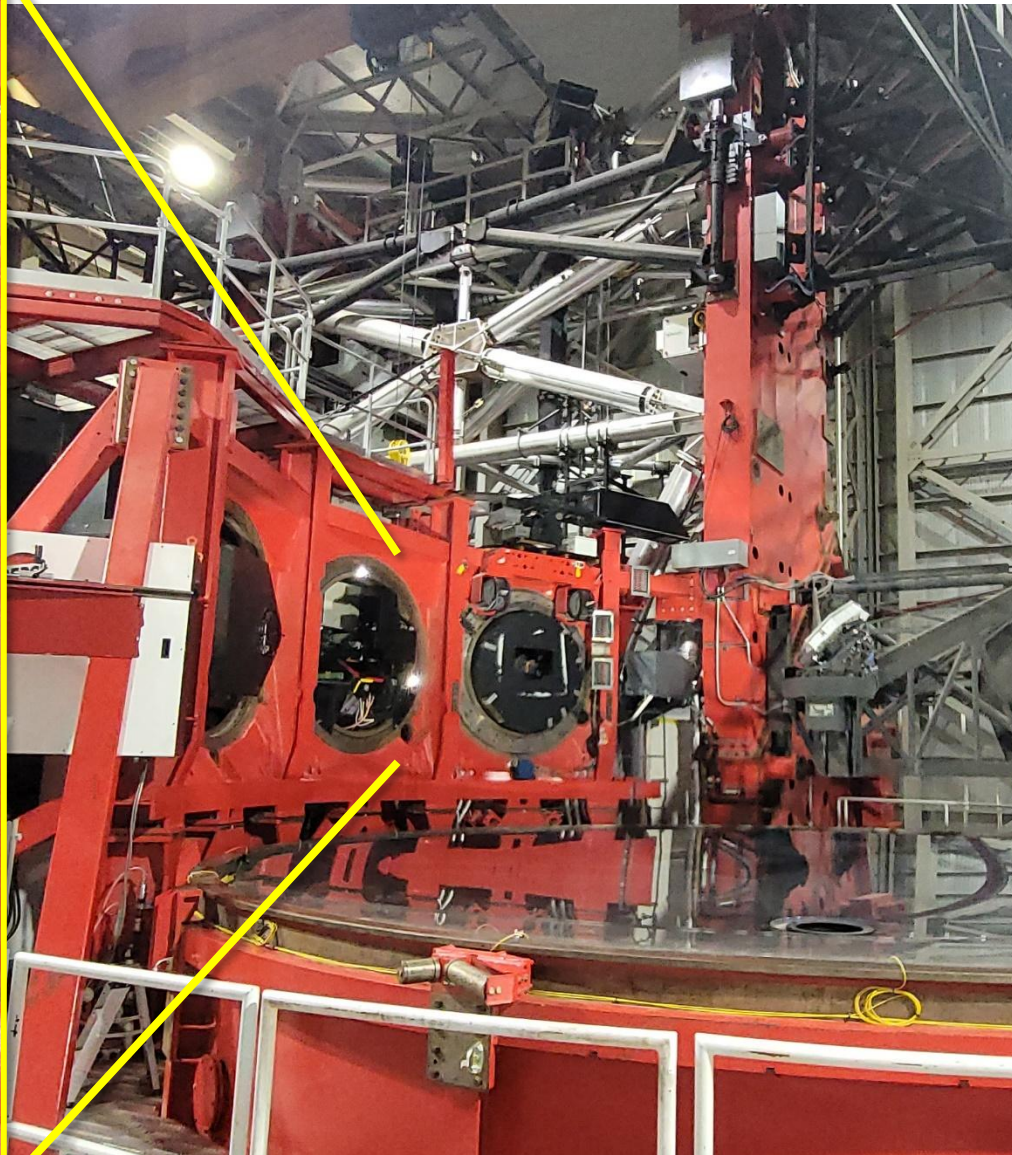


The SHARK-VIS instrument @LBT (Pedichini+ 2024, Proc. SPIE Vol. 13097)



-vis

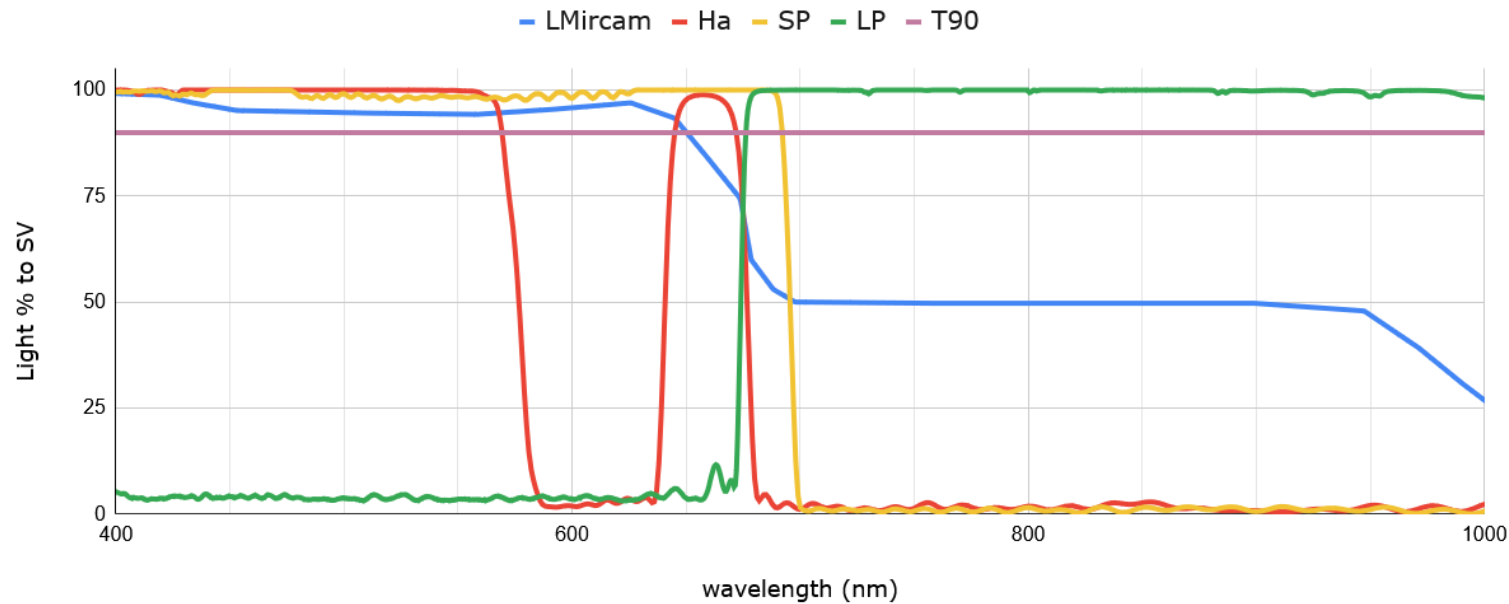
SHARK-VIS
INAF - OA Roma



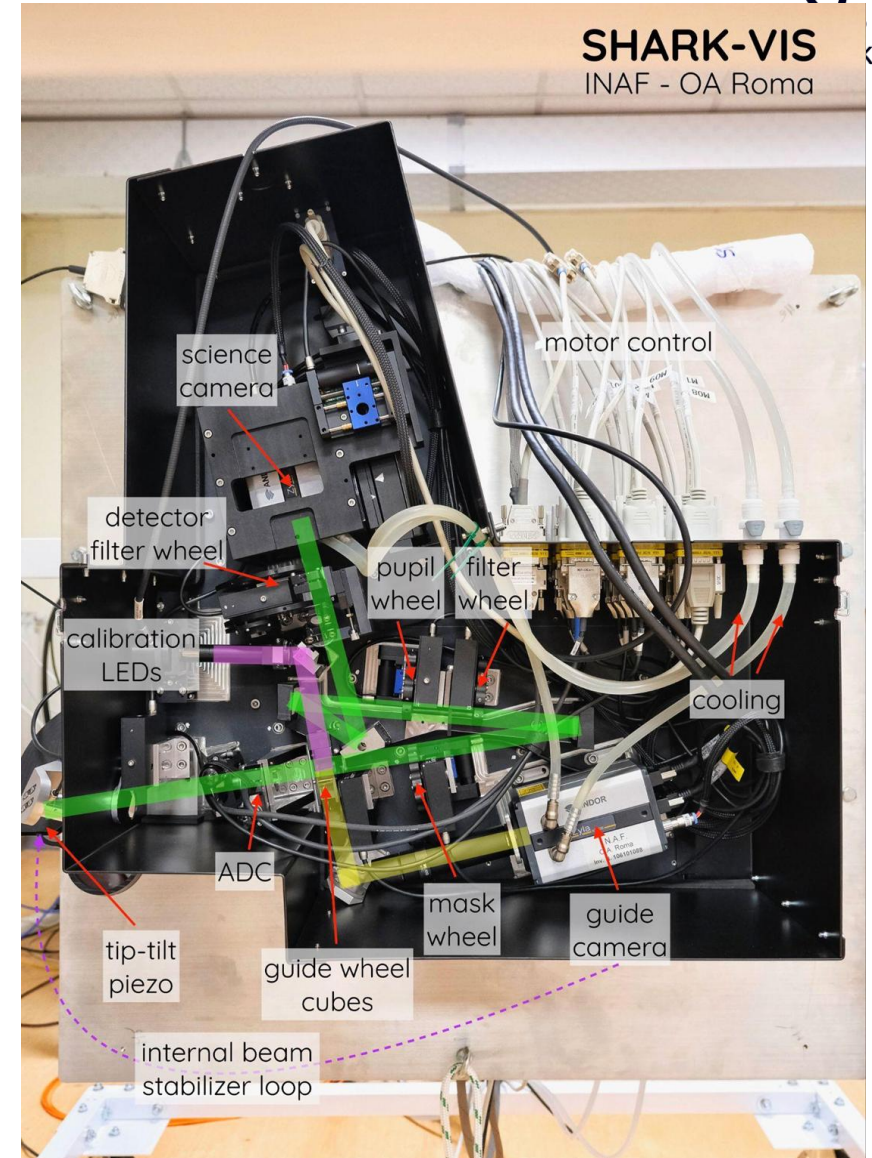
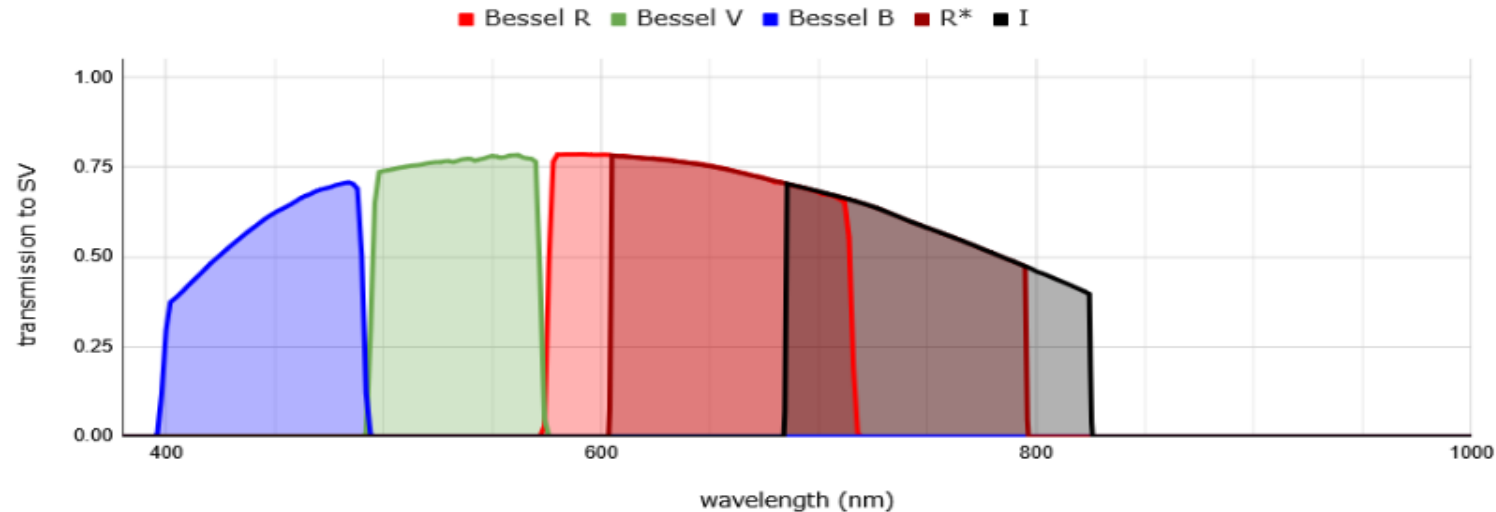
The SHARK-VIS instrument @LBT (Pedichini+ 2024, Proc. SPIE Vol. 13097)



SV input dichroics



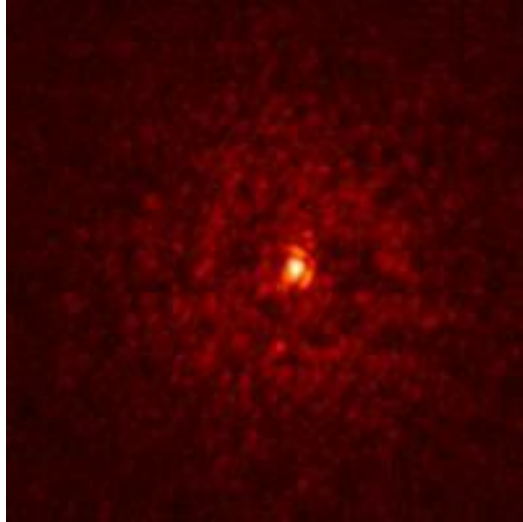
SV wideband filters (filter wheel)



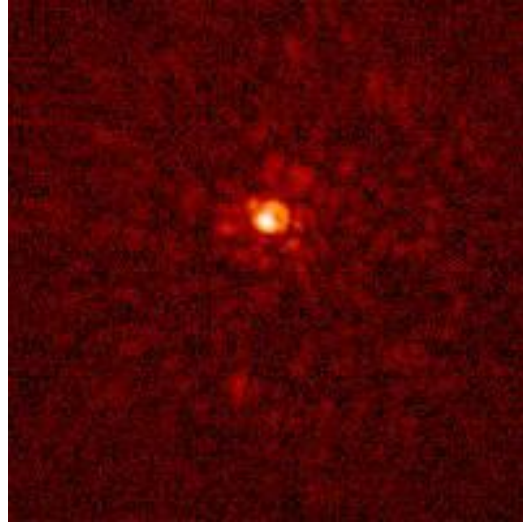
SHARK-VIS
INAF - OA Roma

SHARK-VIS
INAF - OA Roma

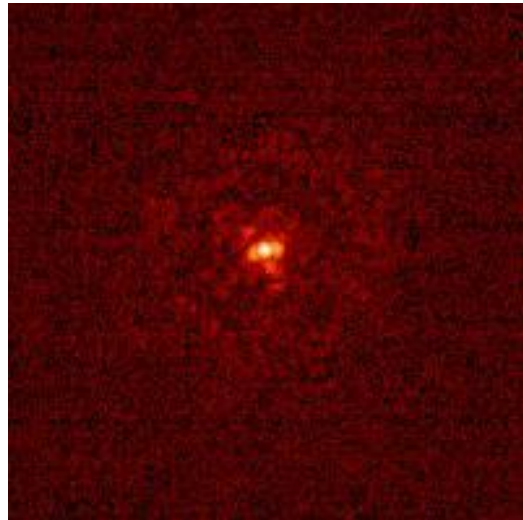
Post-AO Fast-Imaging PSF in the visible (Stangalini+ 2017, JATIS 3(2), 025001)



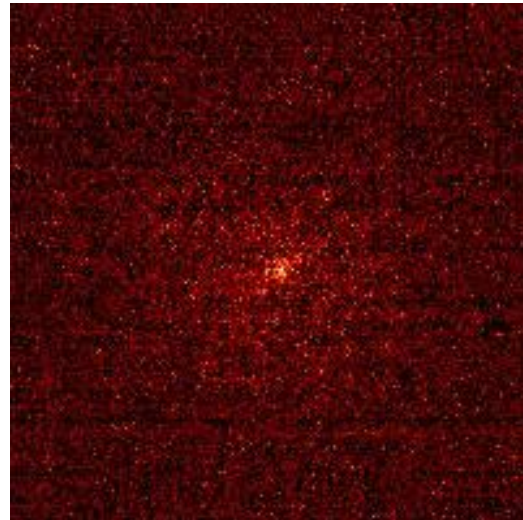
mag 2.1 - 1 kHz (1ms)



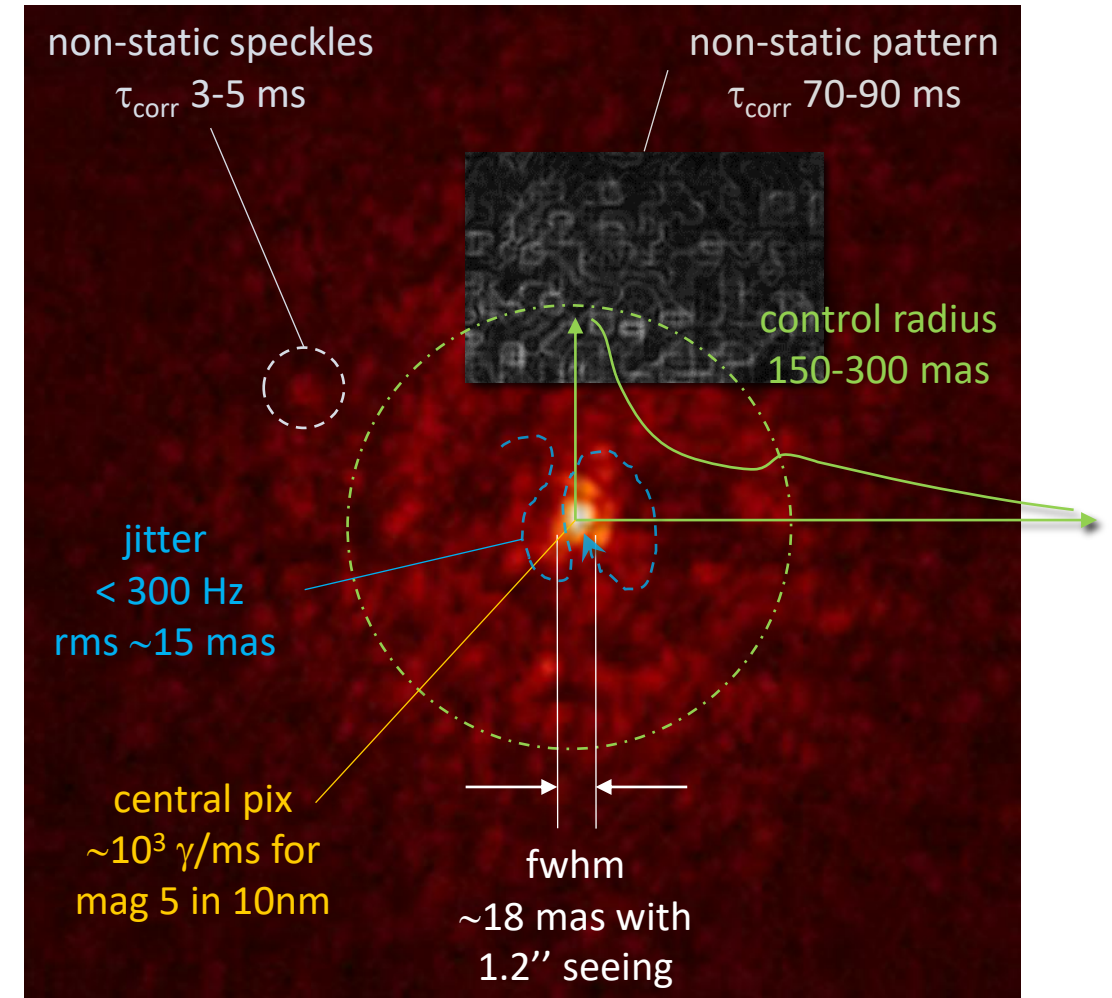
mag 5.7 - 1 kHz (1ms)



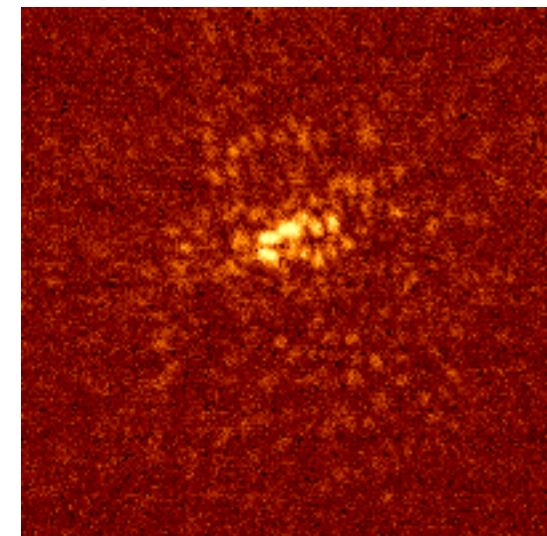
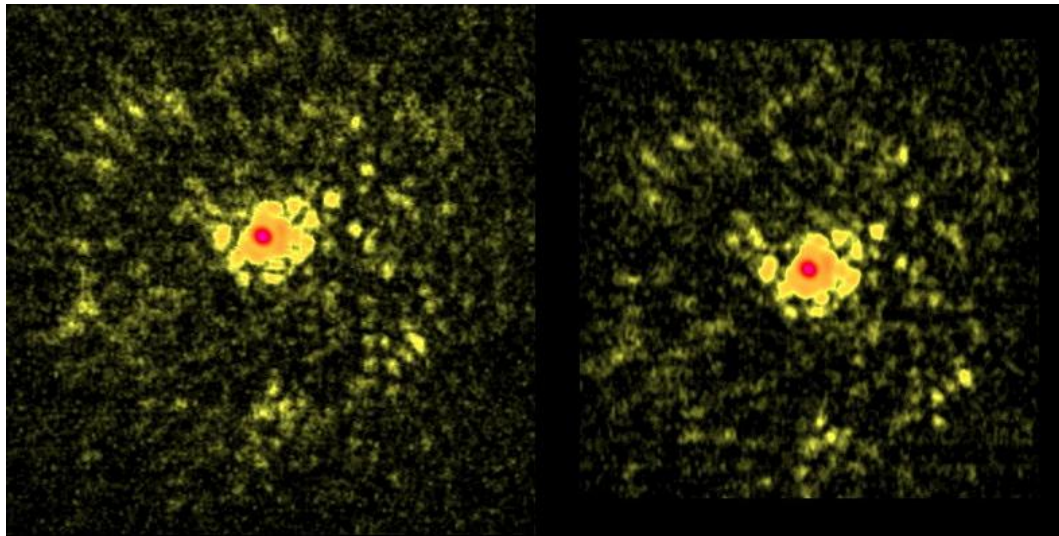
mag 7.7 - 400 Hz (2.5ms)



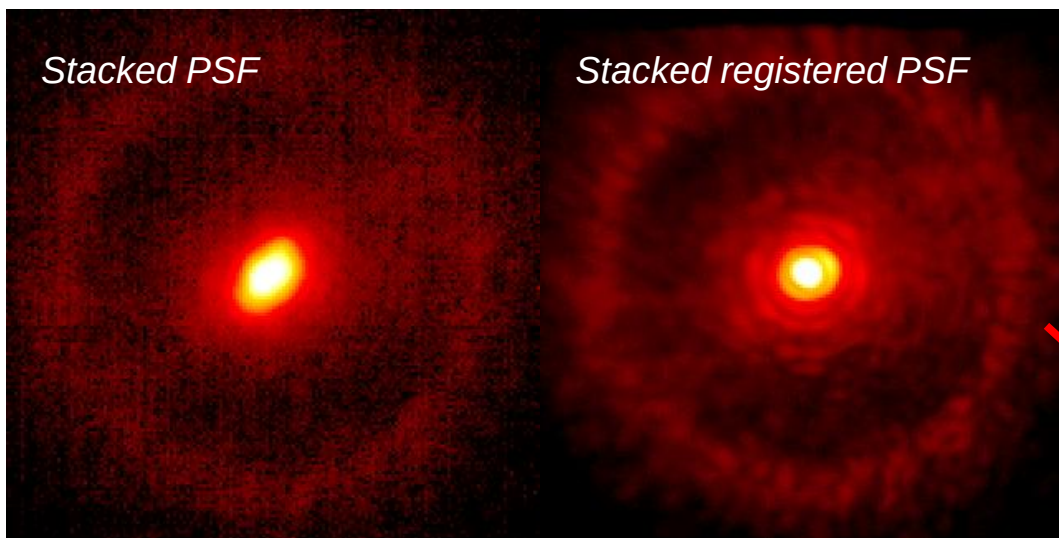
mag 9.5 - 20 Hz (50ms)



Post-AO Fast-Imaging PSF in the visible (Stangalini+ 2017, JATIS 3(2), 025001)



Bad frames (5-10% time)



Stacked PSF

Stacked registered PSF

Long exposure

Stacked short exposures



Airy PSF

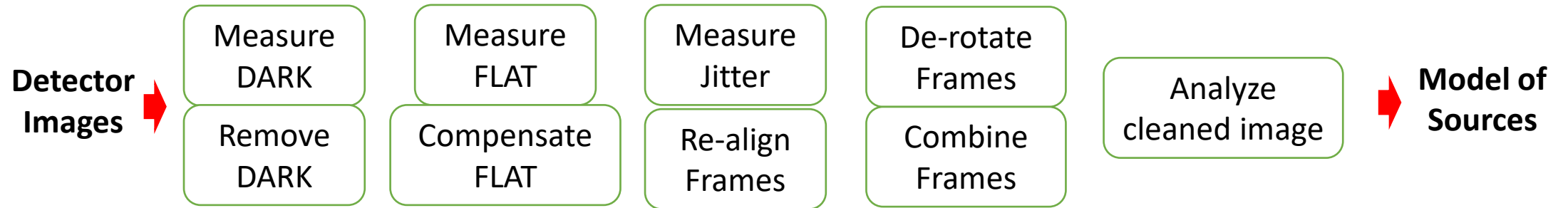


Model PSF and Deconvolve

Data Reduction + Data Modeling

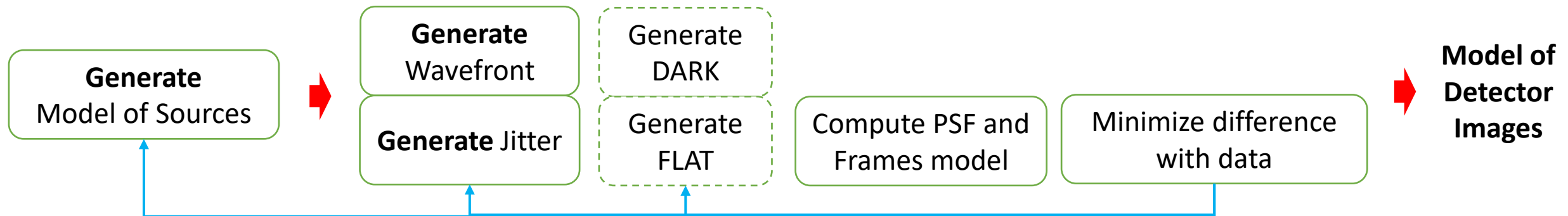
Data Reduction: from measured data to astronomical signal

Compensating observational effects going backward from detector image to astronomical signal



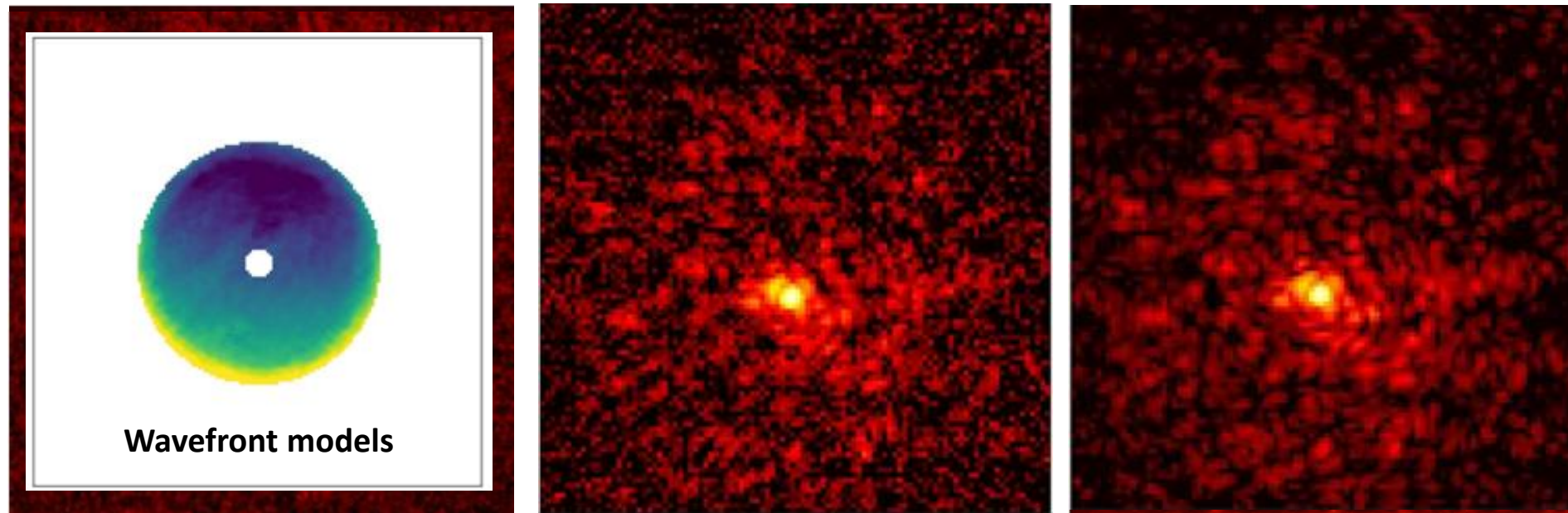
Data Modeling: from astronomical signal to measured data

Simulating natural information flow going forward from astronomical signal to detector image



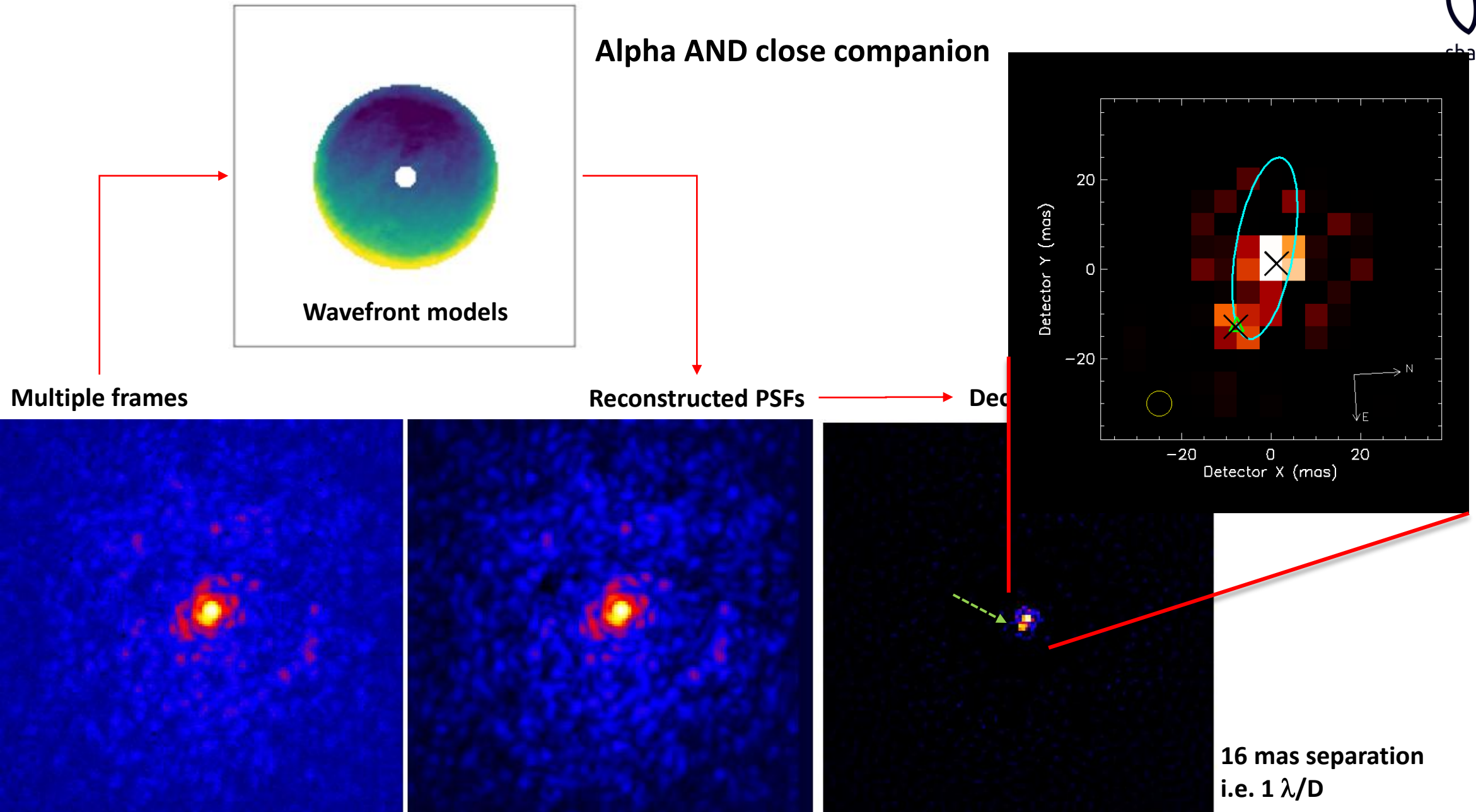
Data Reduction + Data Modeling

...in case of a star it's like if we had a machine that generates PSFs and discard them until finding one that equals the data



A Data-Modeling algorithm does this, not thus random but following precise convergence criteria and wavefront models

Kraken Multi-Frame Blind Deconvolution (MFBD) (Hope+ 2022, ApJ 926 88)



Jupiter's Io with Kraken MFBF in 2024 Jan 9 (Conrad+, GRL, 51, 2024)



First ever **highly detailed view from Earth** and discovery of **re-surfacing at Pillar Patera**

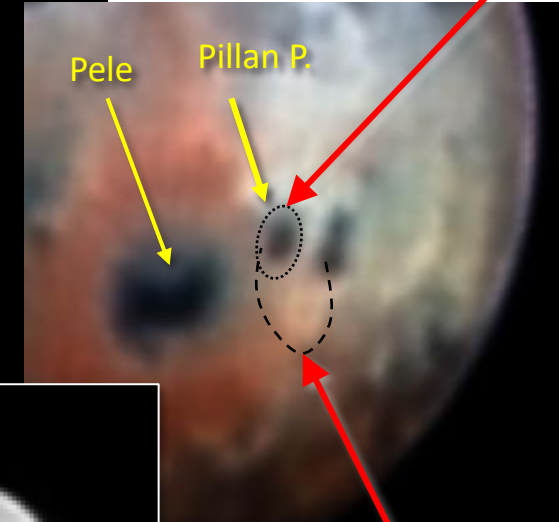


Galileo probe



VRI

IO in I, R, and V filters
(rendered as r, g, b)



on-going volcanism

Pele

Pillan P.

sulphur dioxide ice (SO₂)



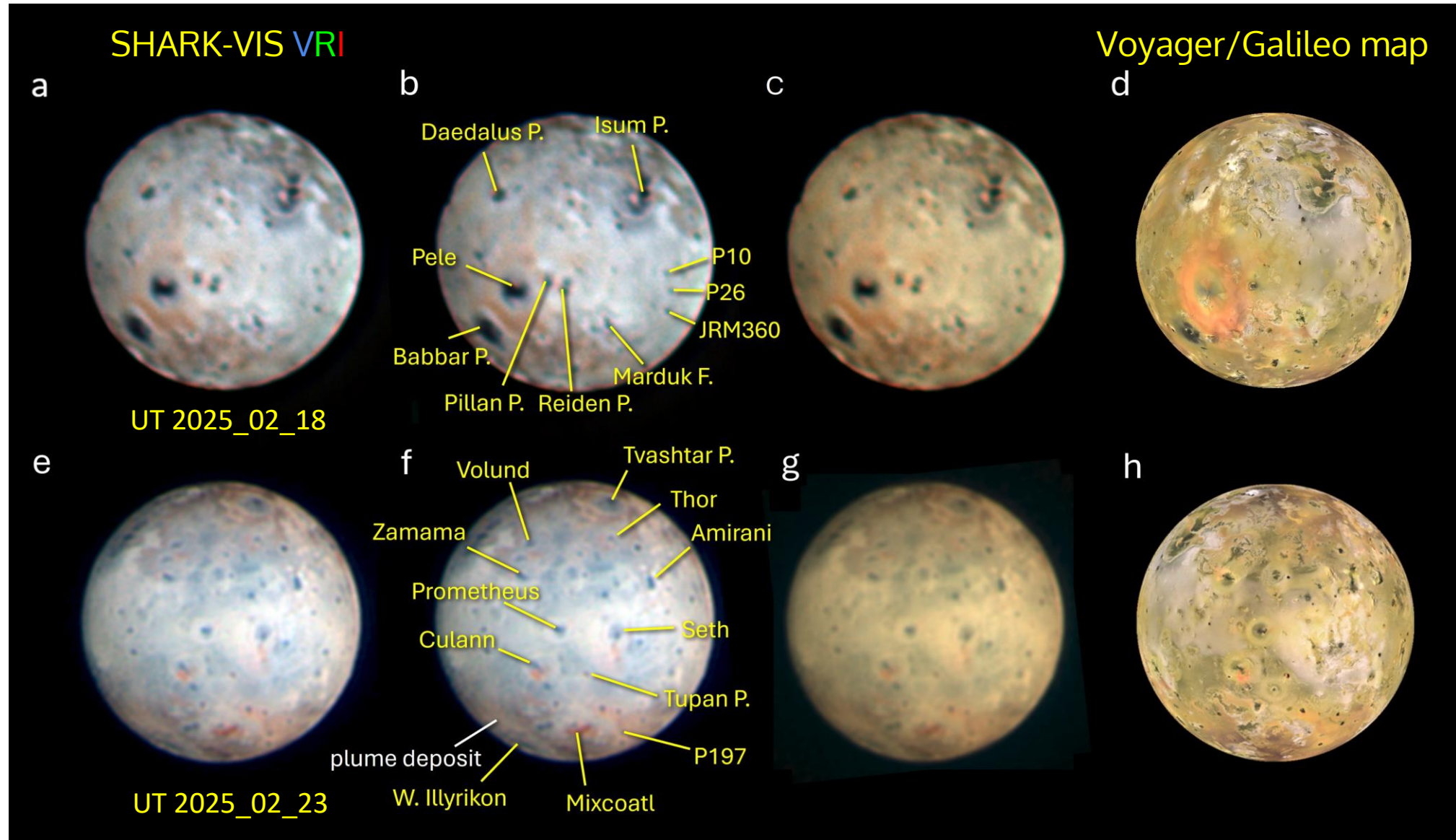
(4) Vesta

SHARK-VIS + Kraken MFBF

Credits: INAF/Large Binocular Telescope Observatory/Georgia State University, IIRV-band observations by SHARK-VIS@LBT (P.I. F. Pedichini); processing by D. Hope, S. Jefferies, G. Li Causi.

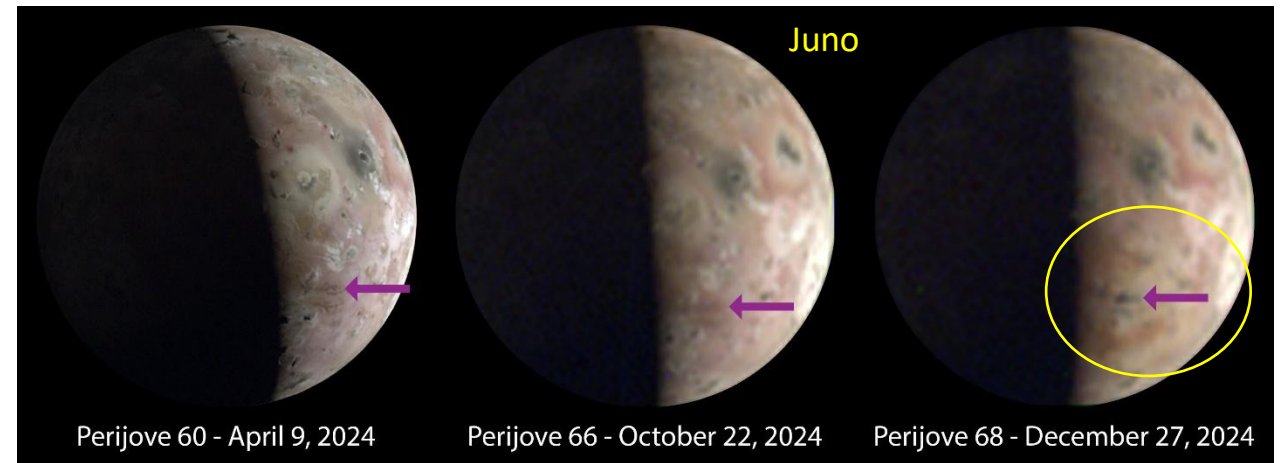
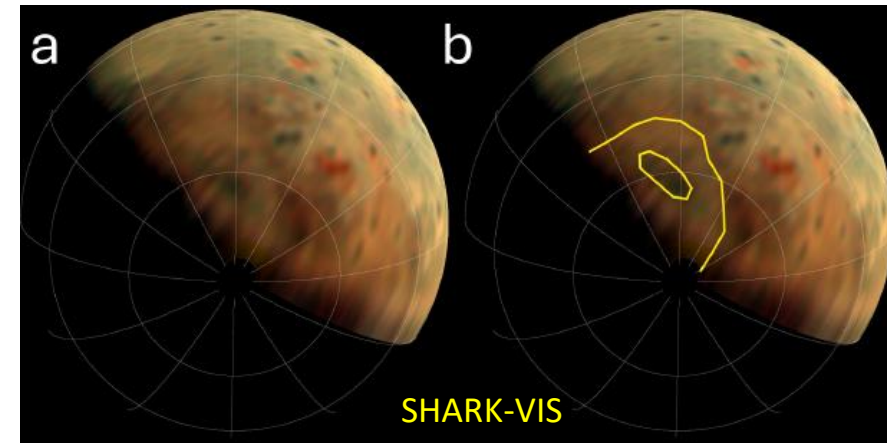
Jupiter's Io in 2025 Feb 18-23 (Davies+, PSJ, 6, 2025)

Discovery of **multiple surface changes**



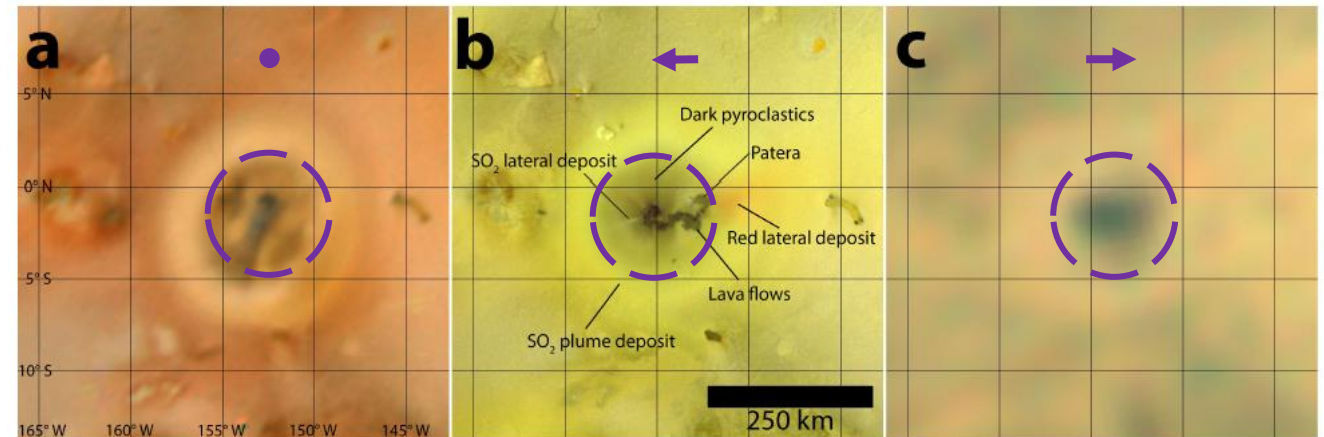
Jupiter's Io in 2025 Feb 18-23 (Davies+., PSJ, 6, 2025)

Change in the **plume deposit of West Illyrikon eruption**



Jupiter's Io in 2025 Feb 18-23 (Davies+, PSJ, 6, 2025)

Change in the **source location of Prometheus plume**



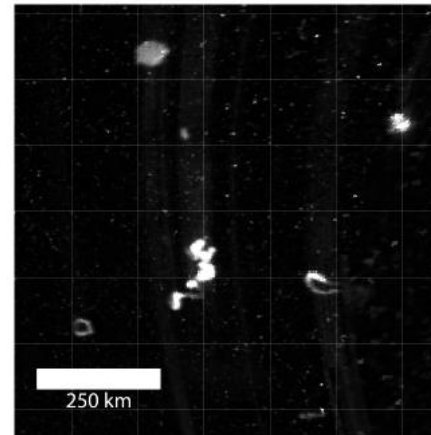
Voyager (1979)

Galileo (2001)
→ 80 km to west

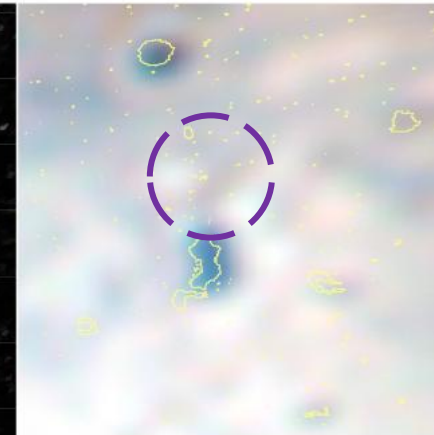
SHARK-VIS (2023)
→ 80 km to east

Jupiter's Io in 2025 Feb 18-23 (Davies+, PSJ, 6, 2025)

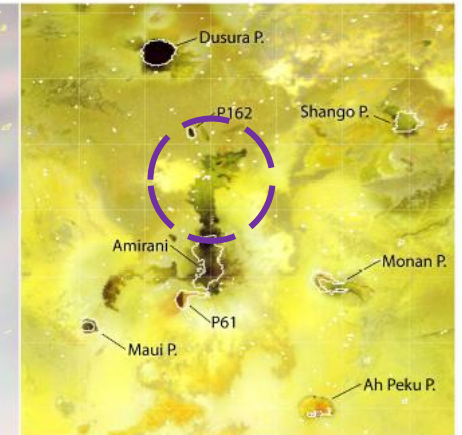
Change in the **cooling of northern Amirani lava flow**



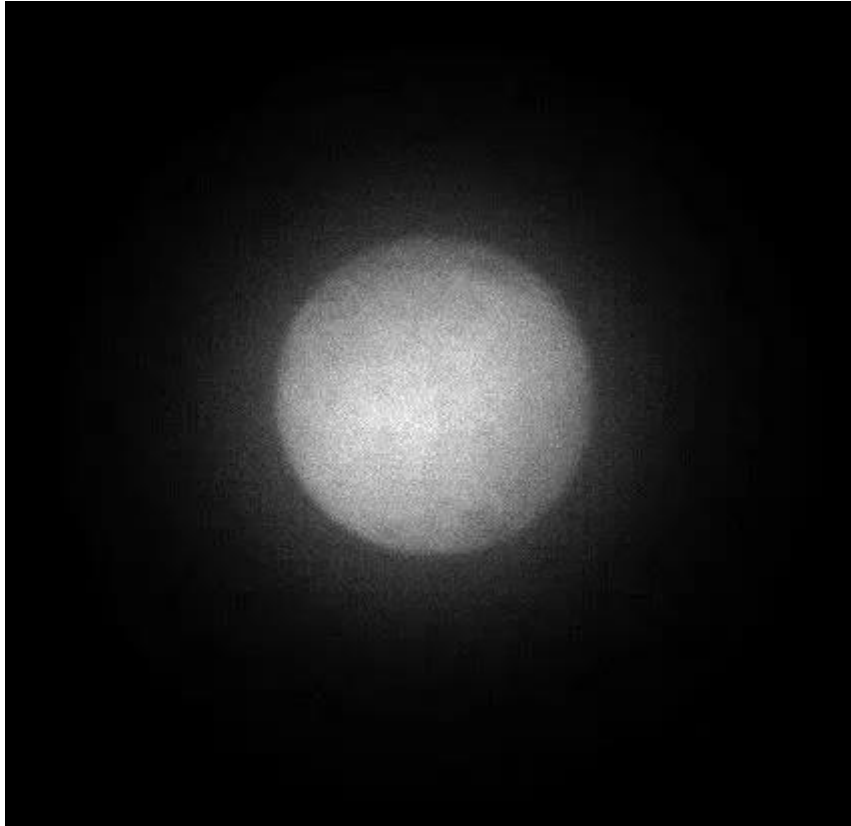
JIRAM M (2023)
thermal emission



SHARK-VIS (2023)



Galileo (2001)

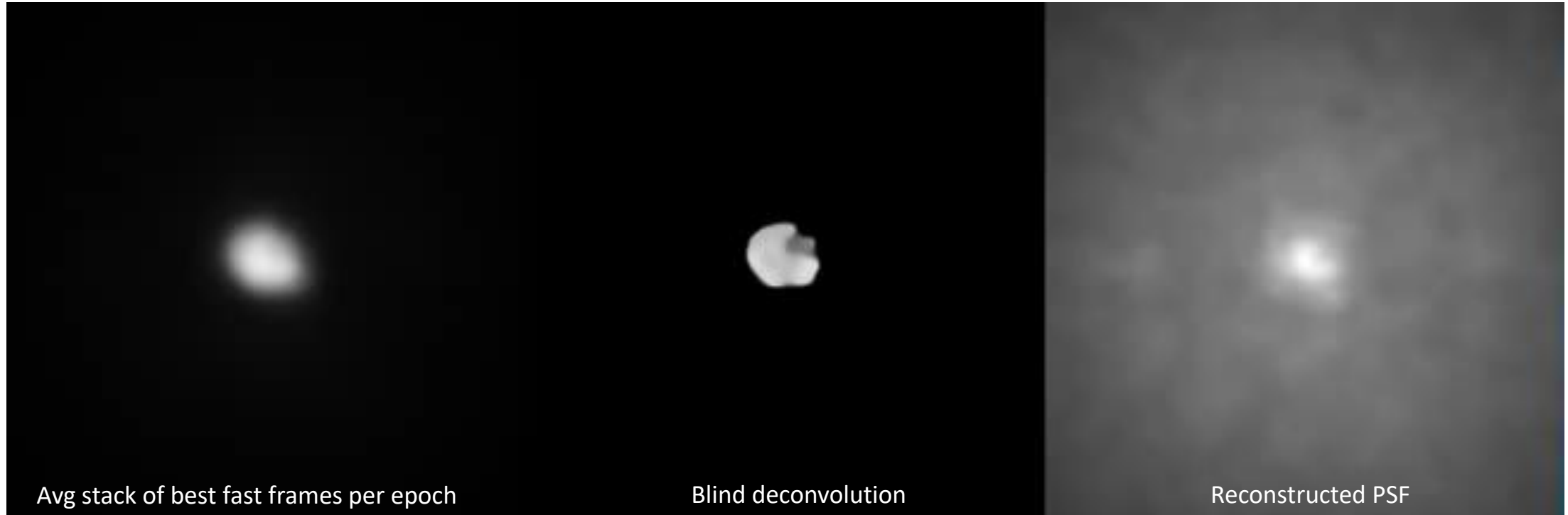


- ✓ **Detector Cleaning**
(Dark, AutoBias, Flat, ...)
- ✓ **Split Intervals wrt body rotation**
- ✓ **Compute Quality Indicators**
(entropy, edge blur, hi-freq snr, motion, ...)
- ✓ **Select Frames, Make Reference, Align by Correlation & Fourier translation, Derotation**
- ✓ **Deconvolution**
- ✓ **Color composite**



Sharp-Edges Blind Deconvolution (Berdeu A&A, 688, A18, 2024)

Disclosing the **complex shape of (44) Nysa asteroid** (Minker+, A&A, 712, L26, 2026)

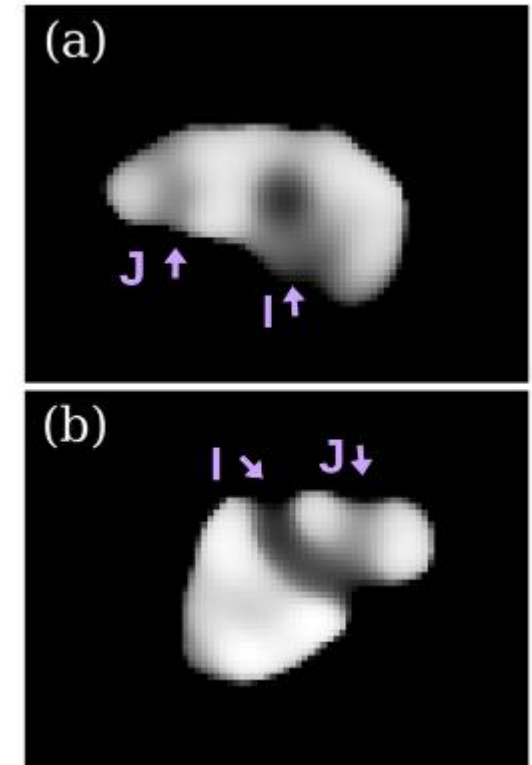
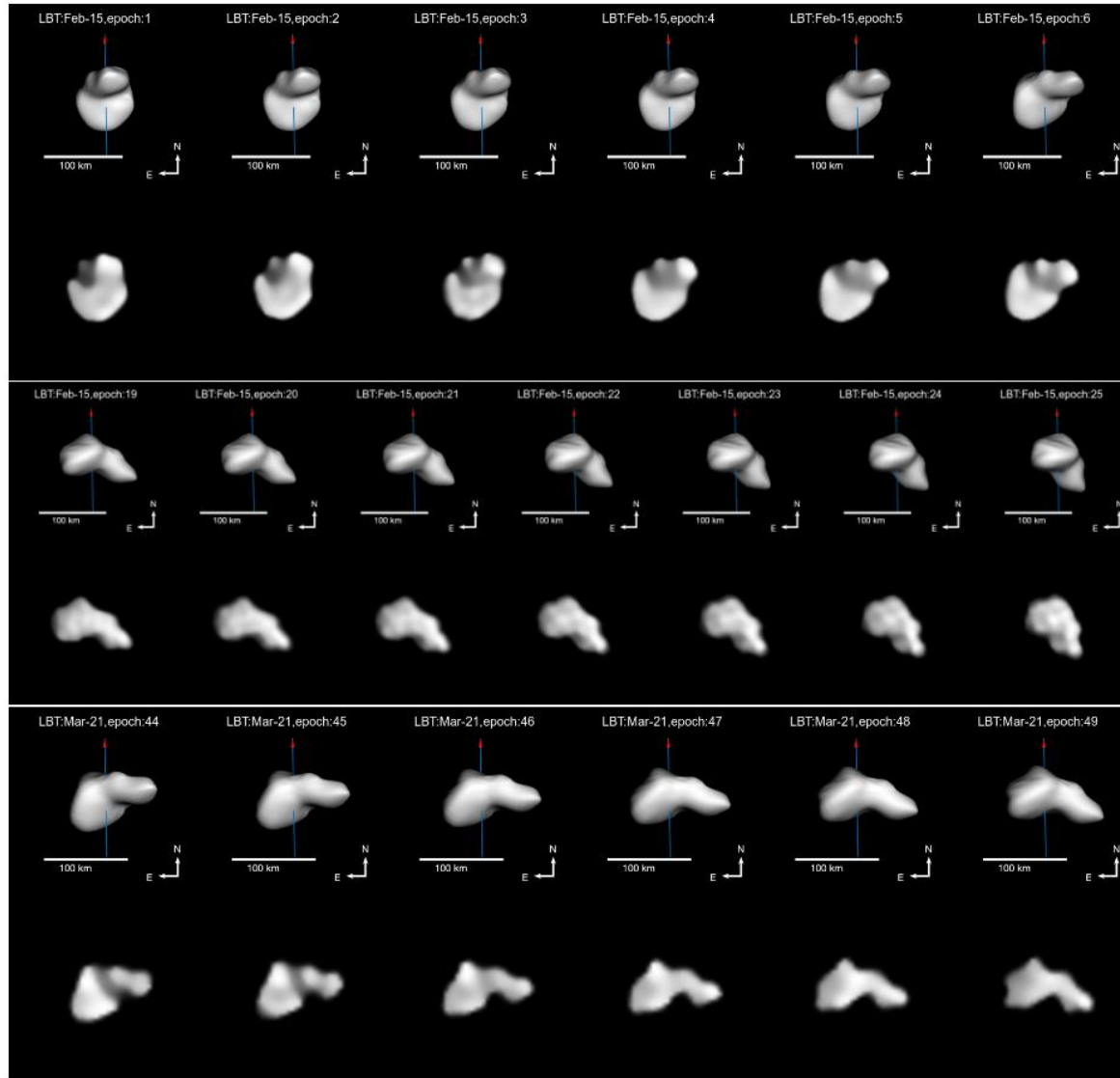


Sharp-Edges Blind Deconvolution (Berdeu A&A, 688, A18, 2024)

Discovery of the **trilobate shape of (44) Nysa asteroid** (Minker+, A&A, 712, L26, 2026)

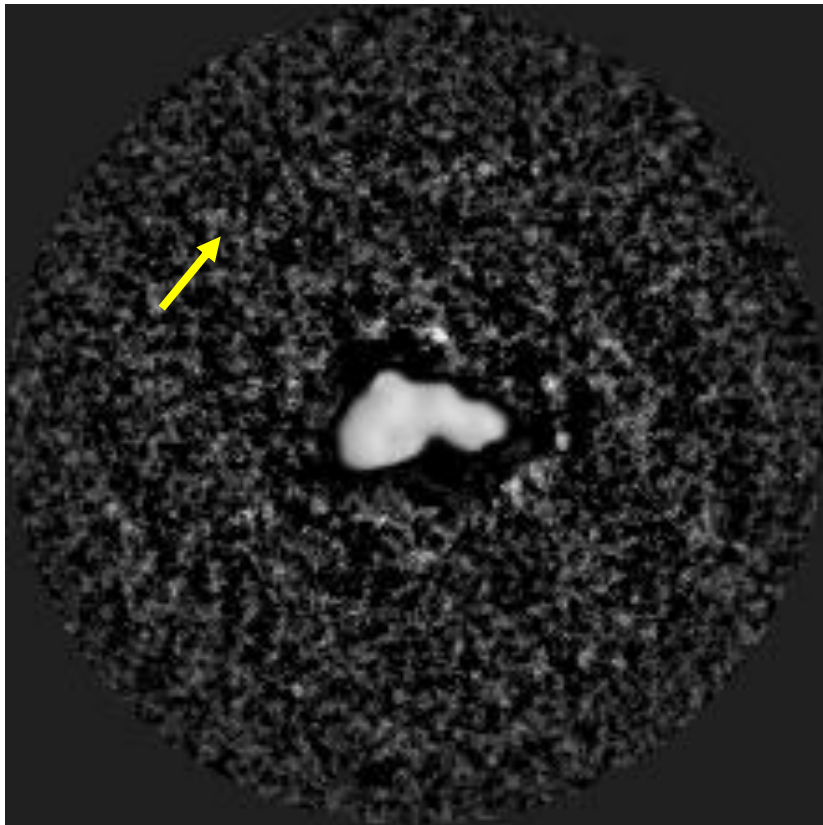
3D Models →

Observations →
(after deconvolution)



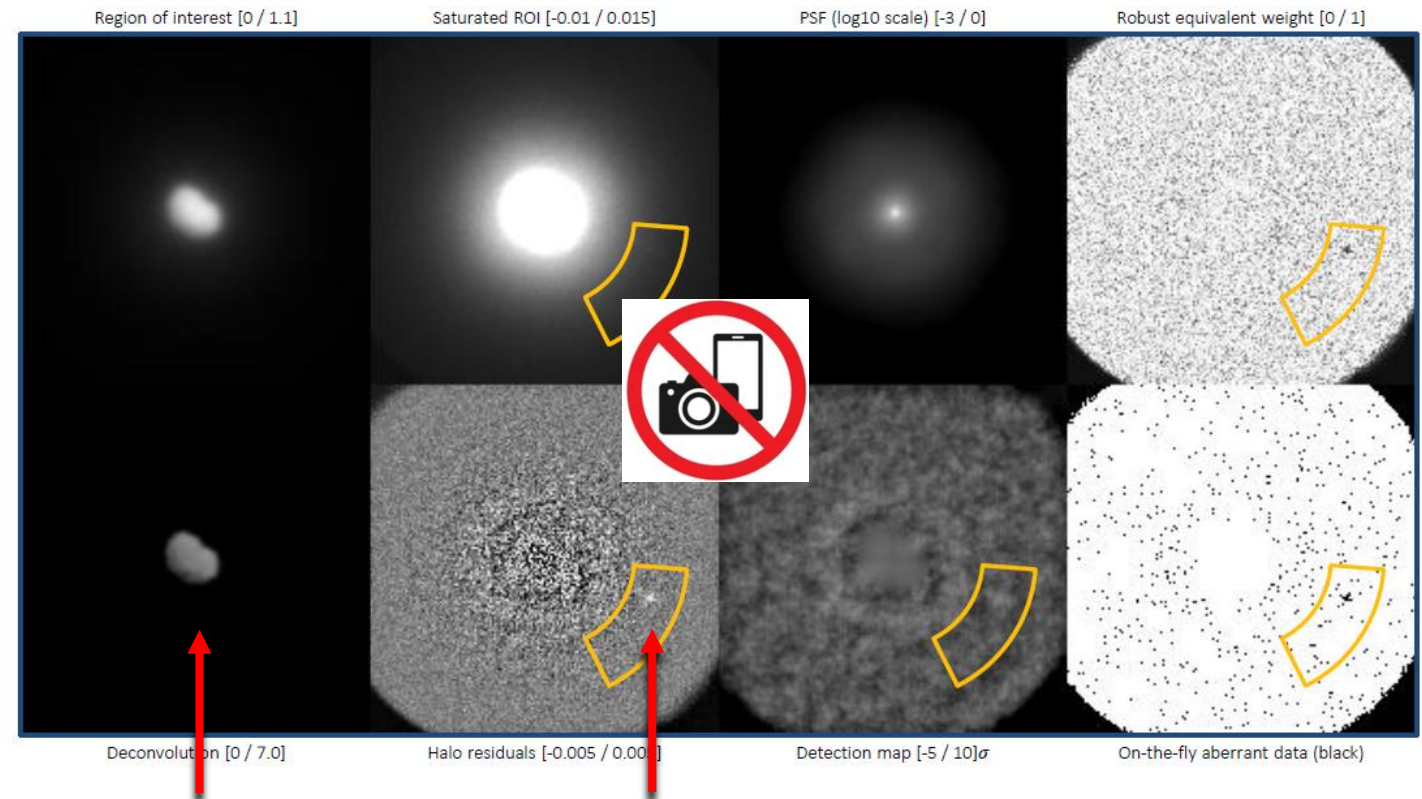
Sharp-Edges Blind Deconvolution (Berdeu A&A, 688, A18, 2024)

Discovered **moon of (44) Nysa**
(Minker+, A&A, 712, L26, 2026)



Nysa's moon in residual of blind deconvolution

(41) Daphne's moon Peneius
(Minker+ in prep.)

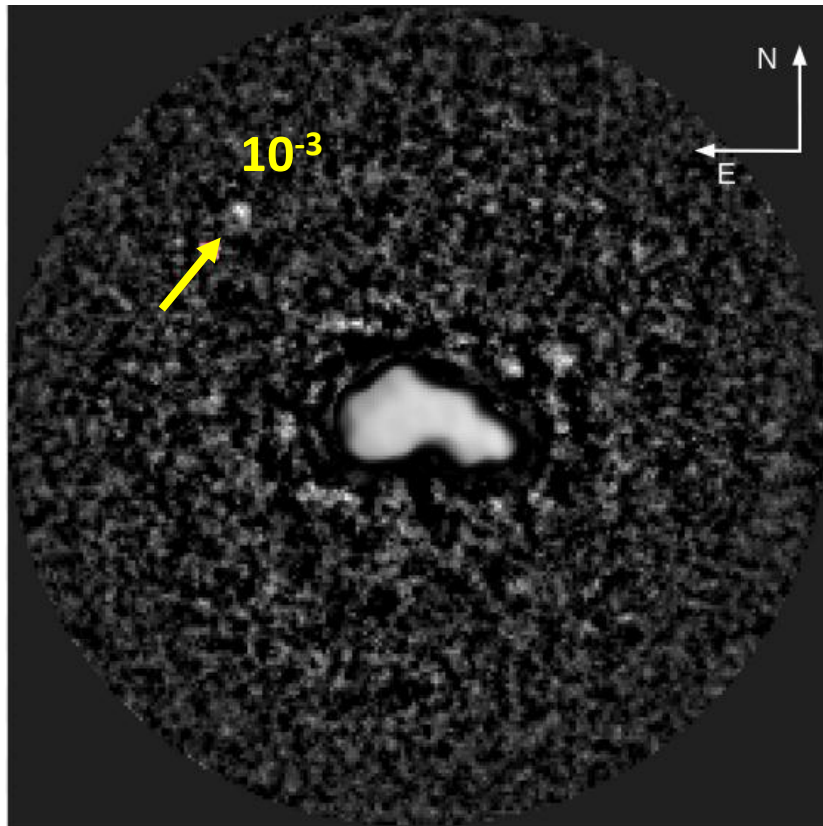


**Asteroid shape
and surface details**

**Moving moon
in deconvolution residual**

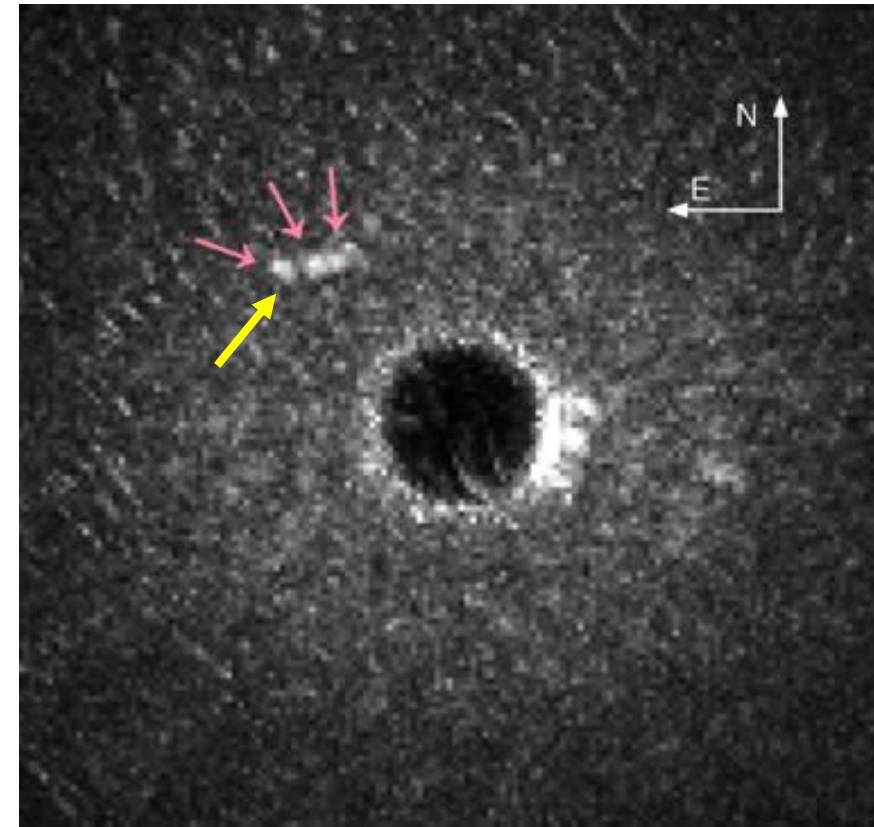
(44) Nysa's moon with Angular Differential Imaging (ADI)

Discovered **moon of (44) Nysa**
(Minker+, A&A, 712, L26, 2026)



Nysa's moon in residual of blind deconvolution

(Minker+, A&A, 712, L26, 2026)



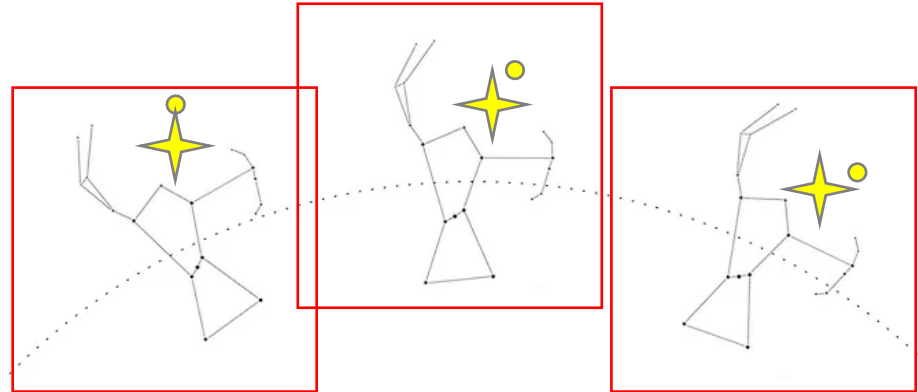
**Nysa's moon in
Principal Component Analysis - Angular Differential Imaging
(PCA-ADI)**

Angular Differential Imaging (ADI)

Mathematically disentangle fixed PSF from sky rotation in Pupil-Stabilized meridian-crossing observations



Azimuthal mount



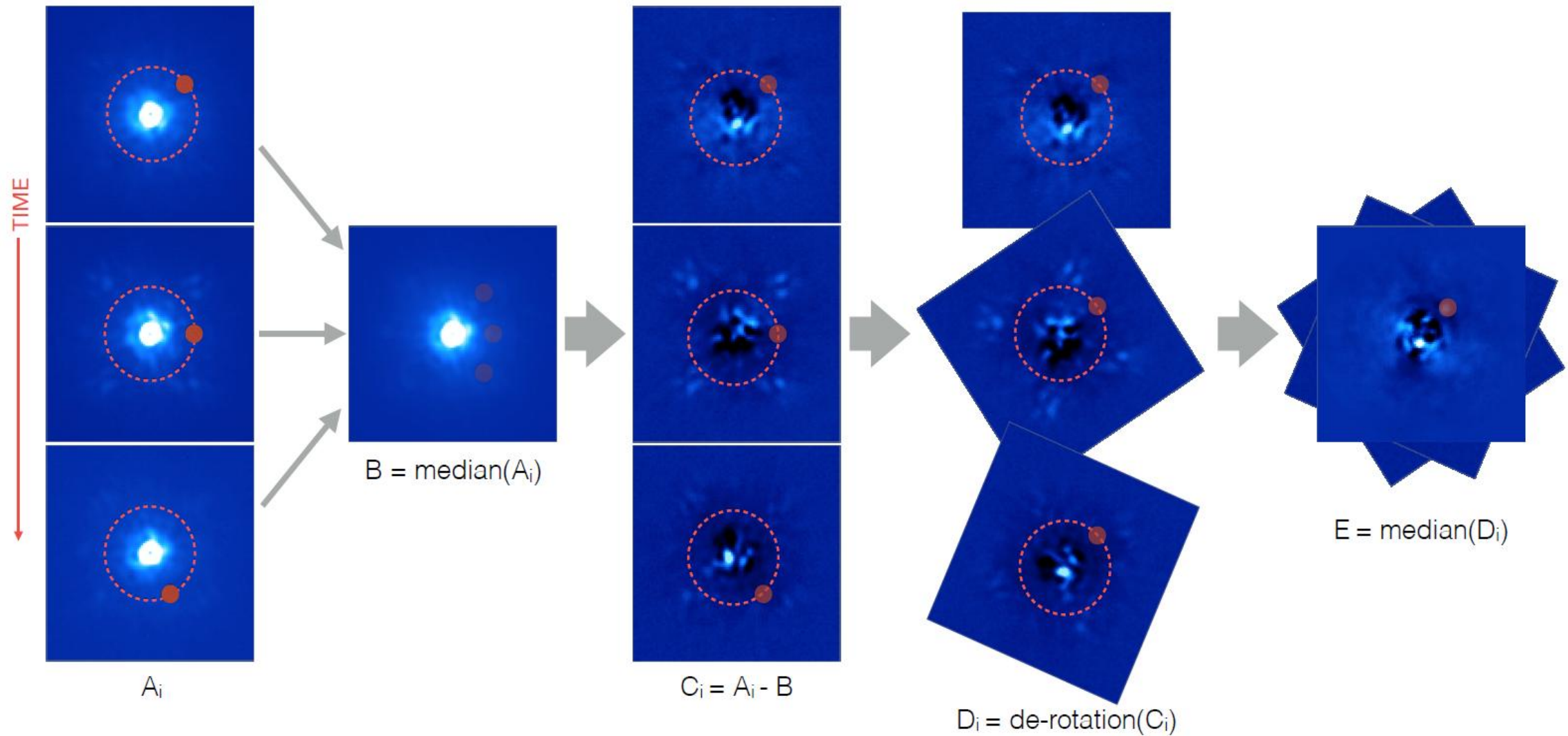
Meridian-crossing observation with no de-rotator

Parallactic Angle variation



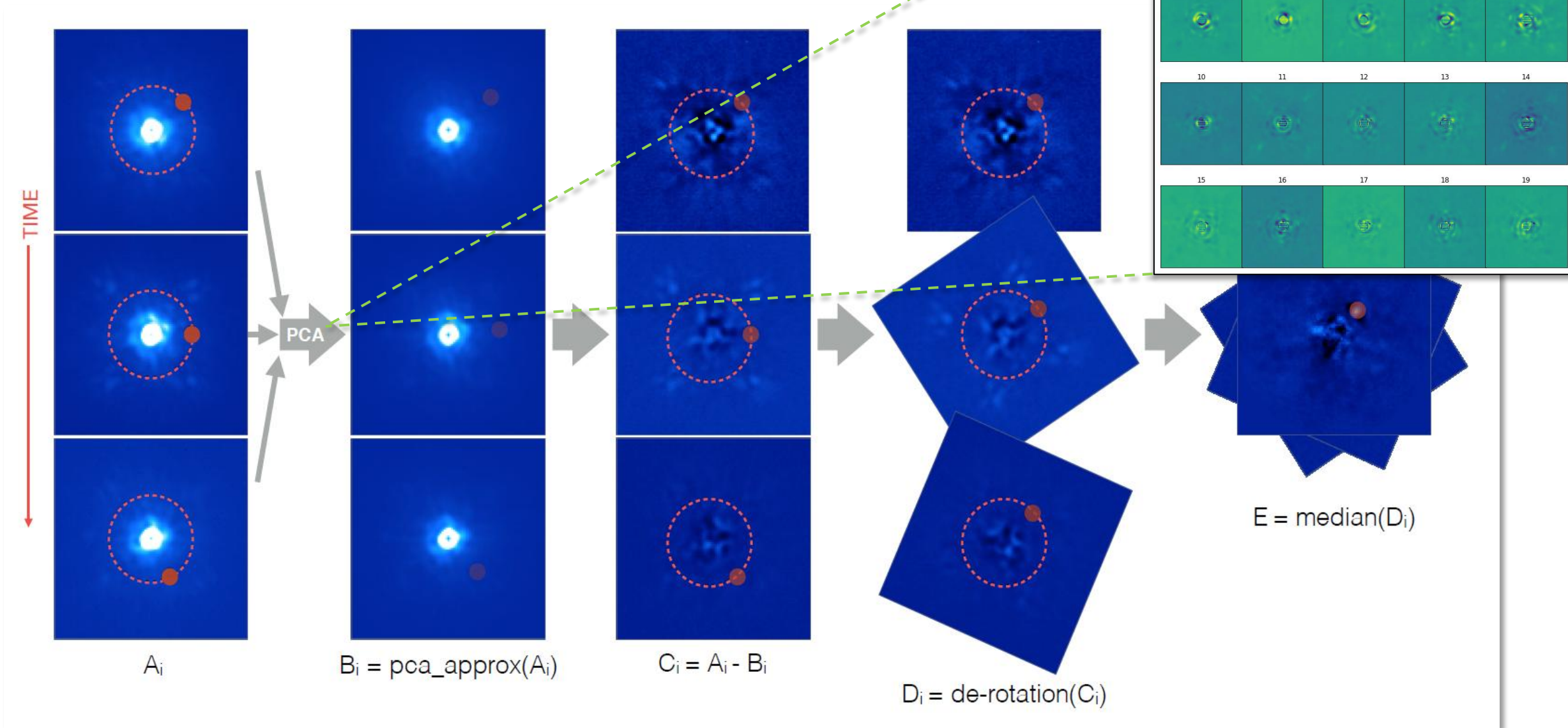
Angular Differential Imaging (ADI)

ADI: Subtract median of frames from each frame, then de-rotate and median stack

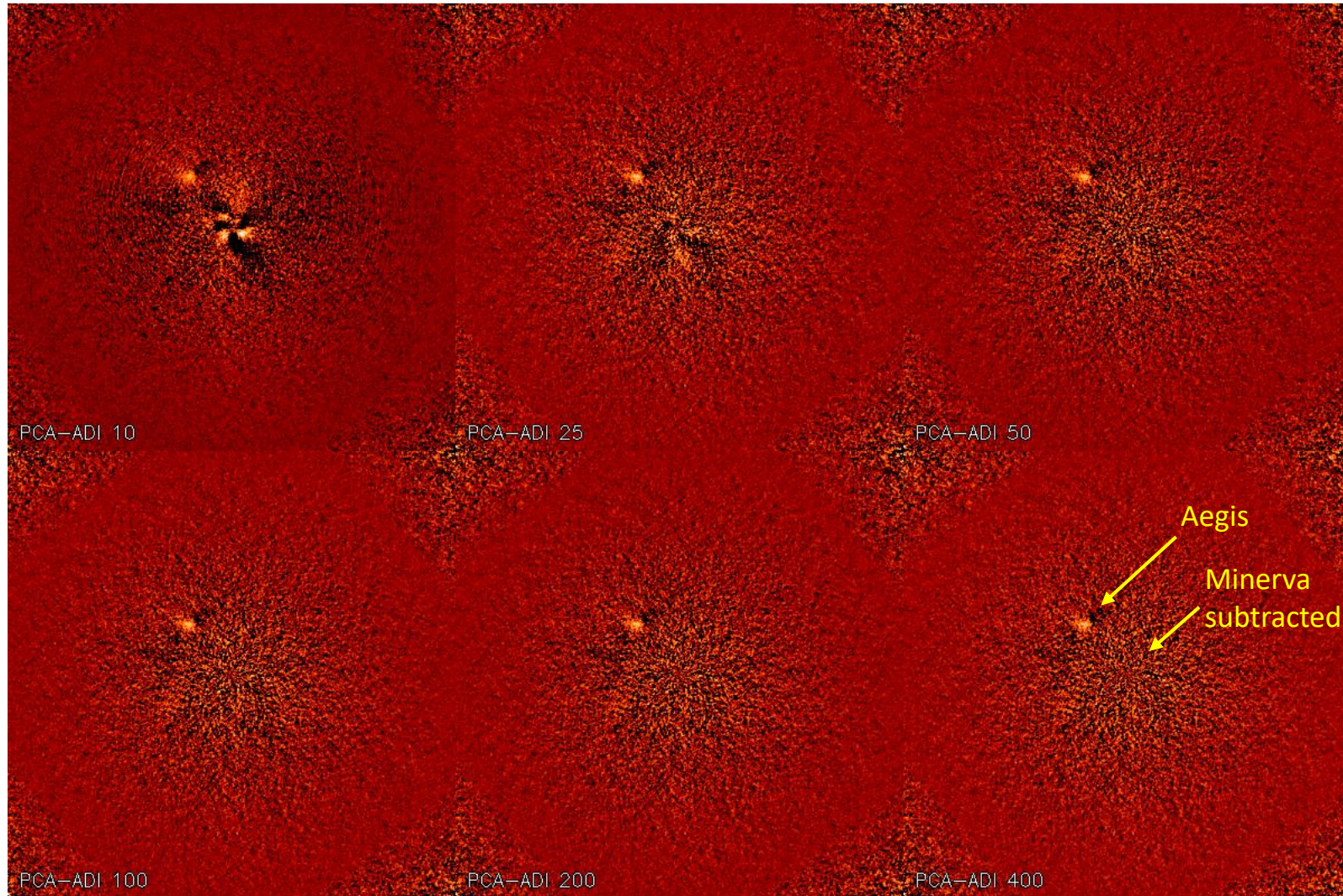


Principal Component Analysis ADI (PCA-ADI)

PCA-ADI: Subtract a few PCA components, then de-rotate and average stack

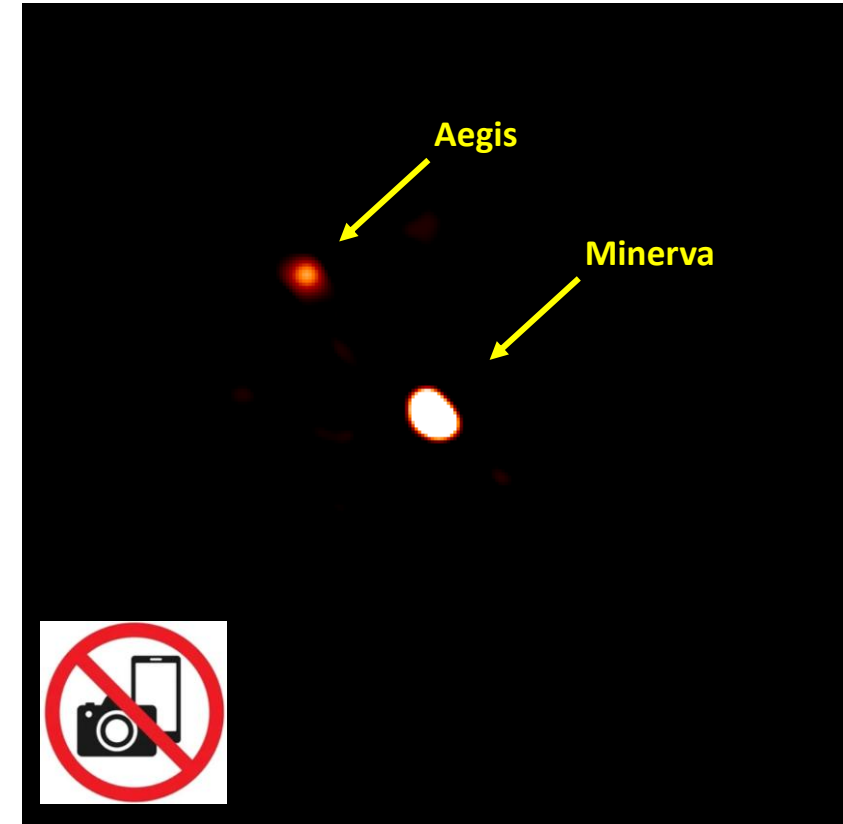


Moon of (93) Minerva with PCA-ADI



(93) Minerva's moon Aegis

(UT 2025-02-05)



(Minker+, in prep)

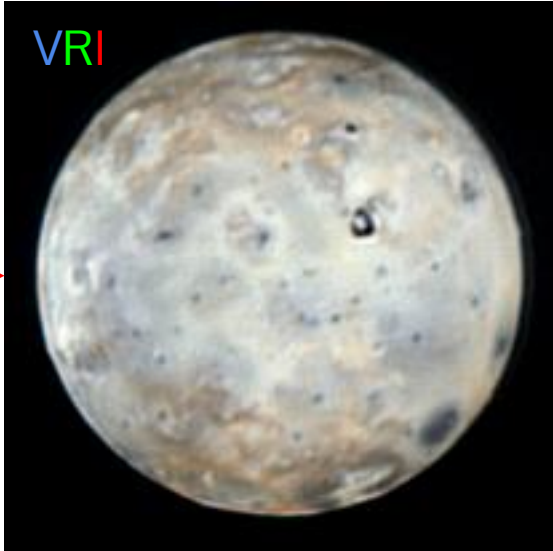
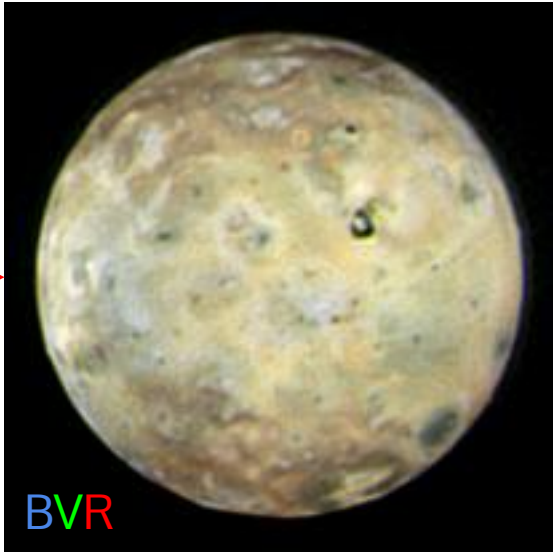
Diffraction Limit by Parametric PSF Blind Deconvolution (Jefferies+, in prep)



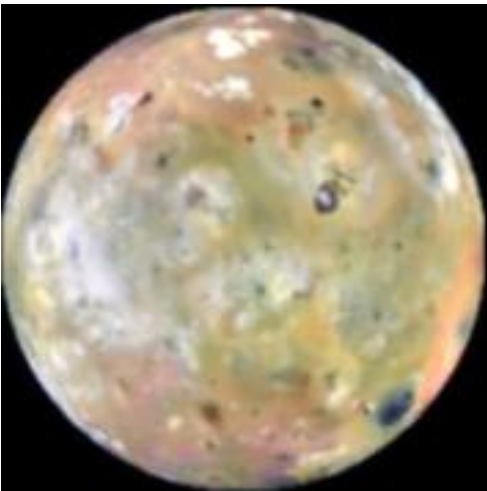
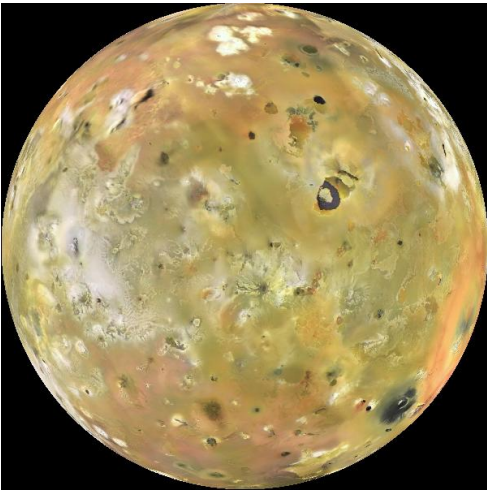
Avg stack of best 1000 Io frames (2026)



Deconvolution



Voyager/Galileo
reference map



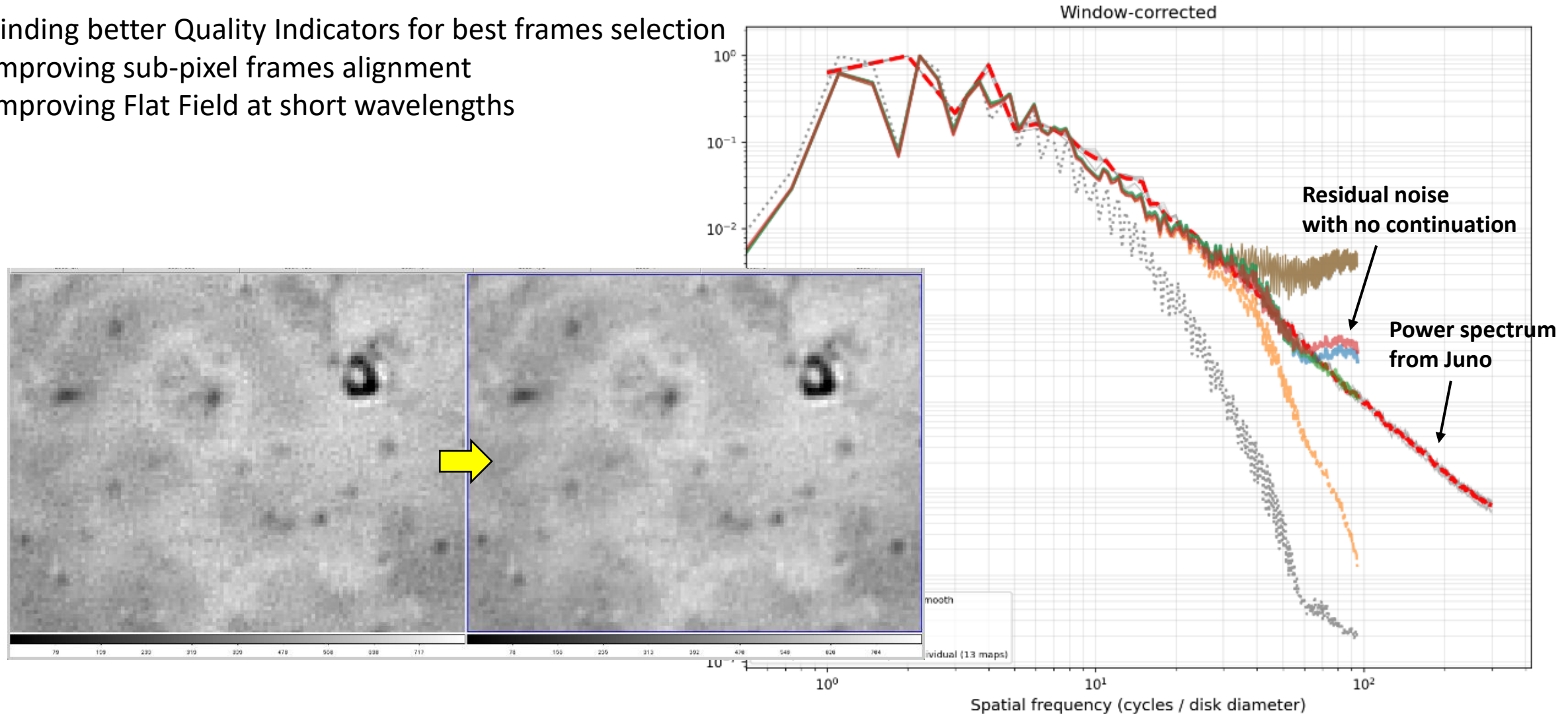
Diffraction limit
simulation

λ / D !! (50-60 km on surface)

What next?

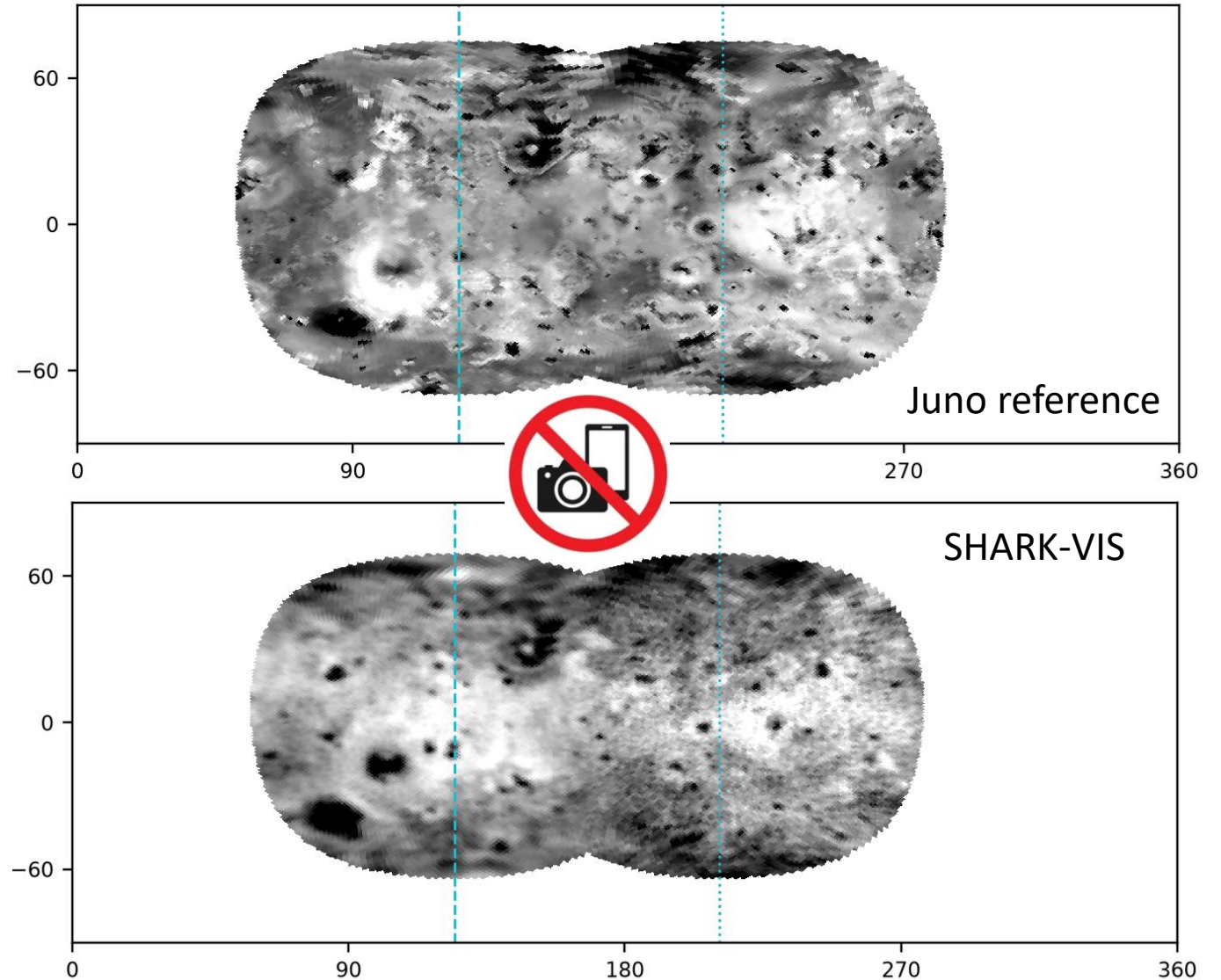
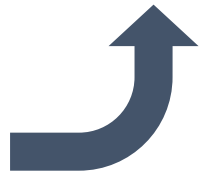
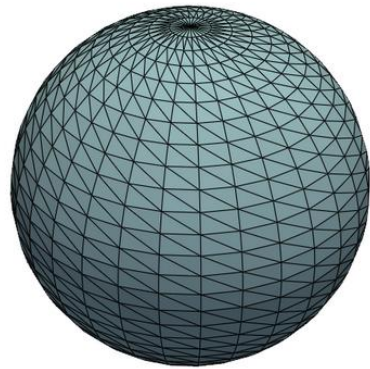
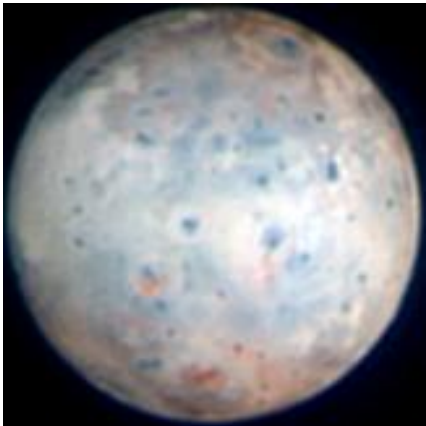
Beyond diffraction limit with bayesian Power Spectrum Continuation (Baron+, in prep)

- Finding better Quality Indicators for best frames selection
- Improving sub-pixel frames alignment
- Improving Flat Field at short wavelengths



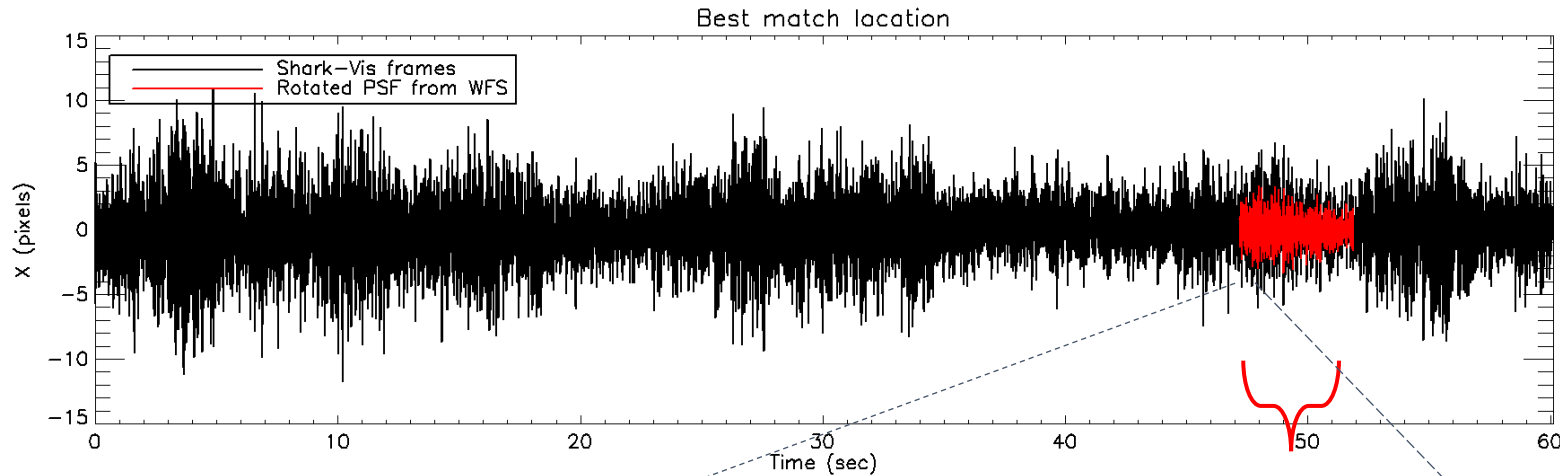
What next?

On-The-Sphere multi-epoch deconvolution (Baron+, in prep)



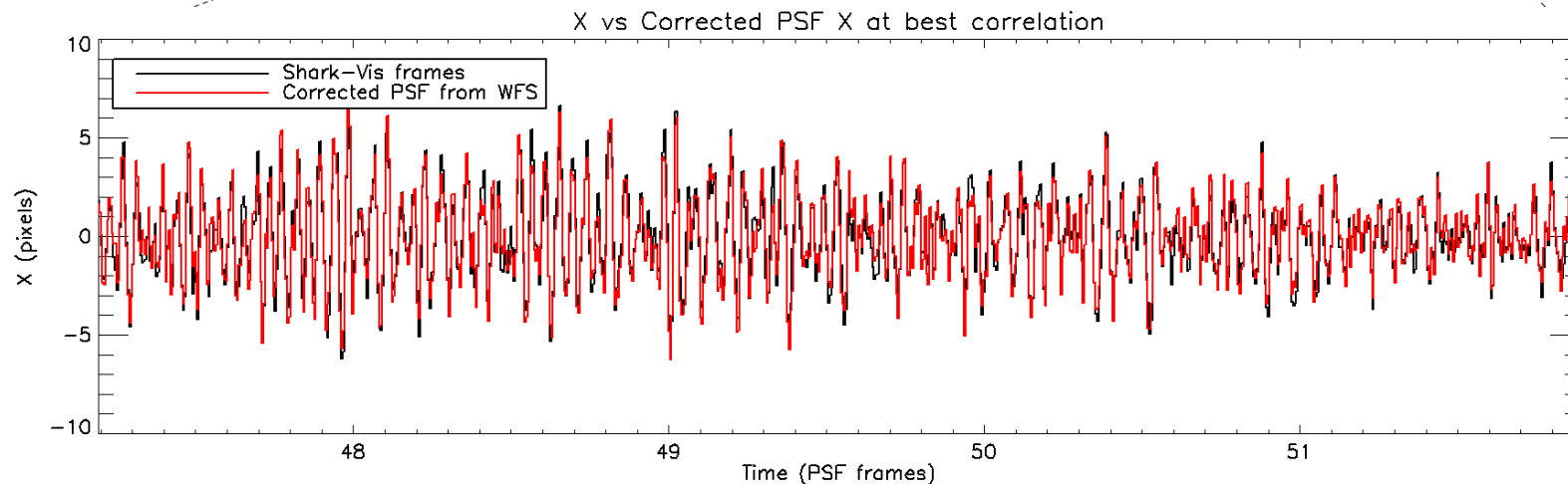
What next?

PSF from Wavefront Sensor Telemetry (preliminary)

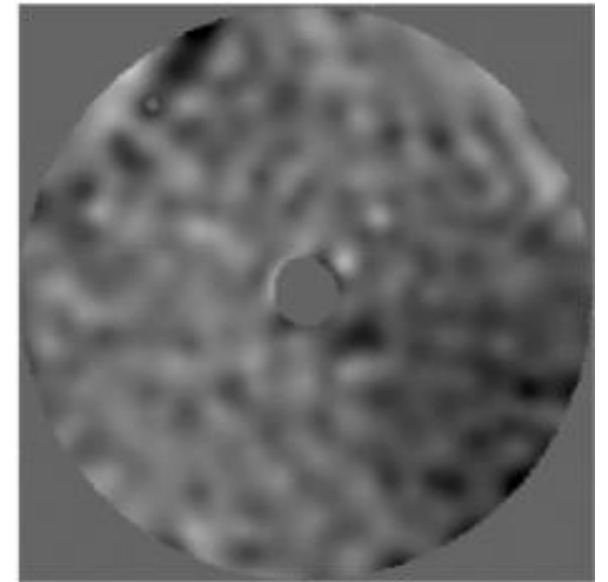


2025_02_18 – Io SV data

SOUL WFS data (max 4000 frames at 850 Hz ~ 4.7sec)

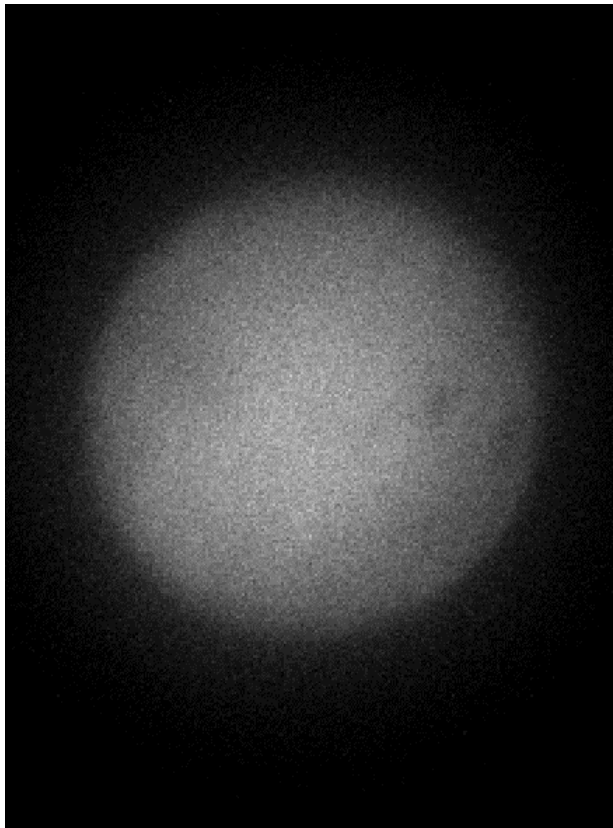


Reconstructed wavefront

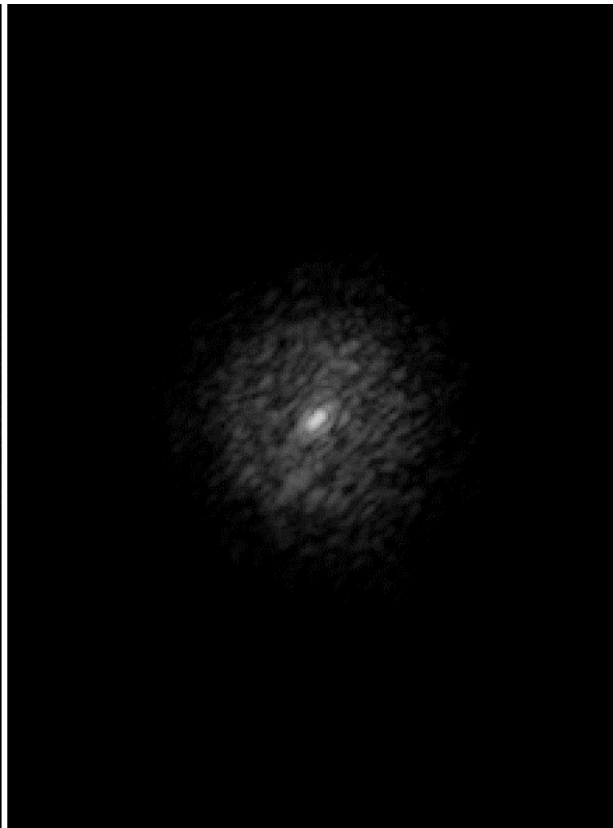


What next?

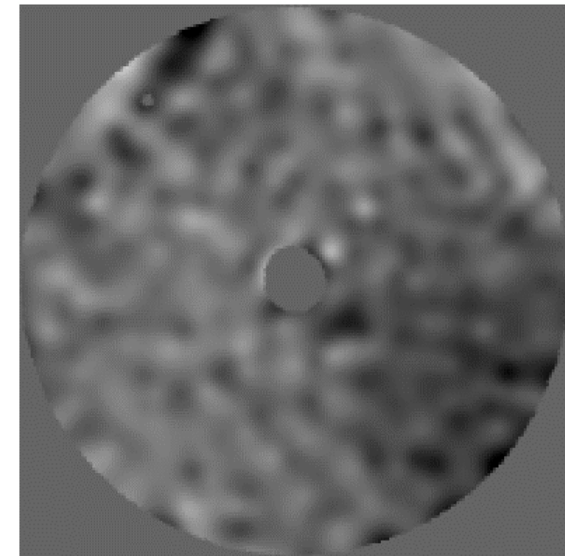
PSF from Wavefront Sensor Telemetry (preliminary)



10 SHARK-VIS frames
5ms DIT (200 Hz)



Synchronized PSF model
integrated from 850Hz



Synchronized wavefront
integrated from 850Hz

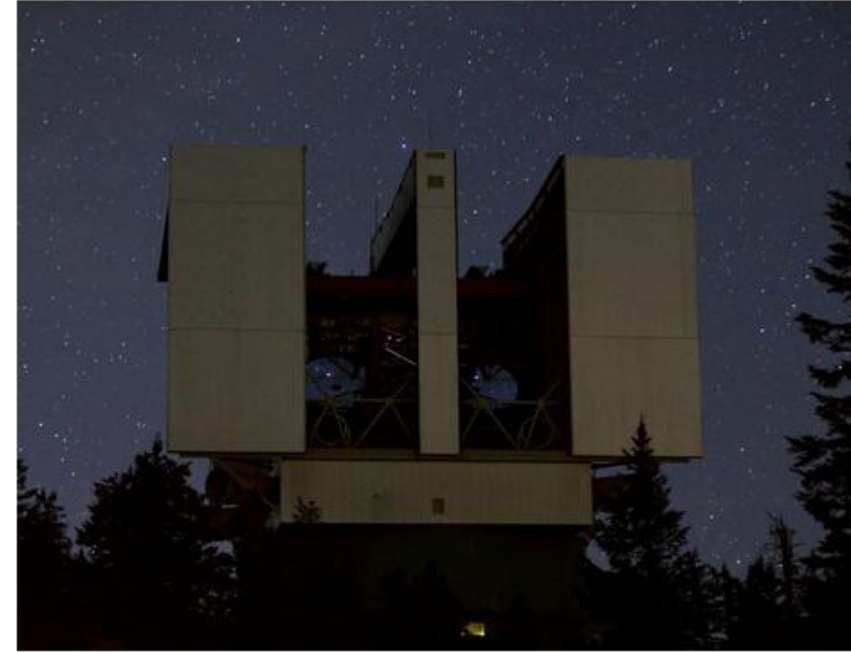
How to access the SHARK-VIS instrument



<https://sites.google.com/inaf.it/shark-vis>

how to access the instrument

Access to the instrument can be obtained through standard calls for proposals of the LBT partners or [DDT proposals](#). However, Shark-Vis is a PI instrument, so the proponents must contact the instrument team in advance (see contacts). This allows the instrument team to verify the feasibility of the proposed observations, to select the most suitable setup, to estimate the expected performance, and to check for possible target conflicts with ongoing programs of the SHARK-VIS scientific team.



contacts

To contact the team send an email to: sharkvis.oaroma-at-inaf.it



shark-vis