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TWILIGHT OBSERVING WITH SCALES

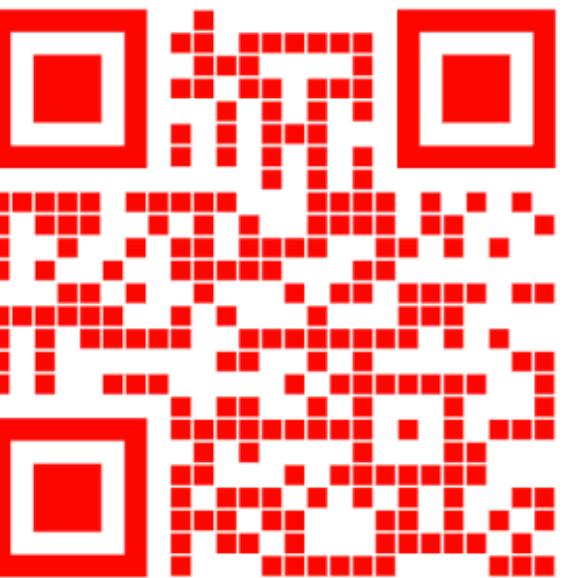
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While astronomical twilight closes the observing window for optical astronomers, the infrared sky remains dark through sunrise, allowing IR astronomers to observe through twilight. The Slicer Combined with an Array of Lenslets for Exoplanet Spectroscopy (SCALES) instrument is a 1-5μm coronagraphic integral field spectrograph and imager scheduled to arrive at Keck in 2025. SCALES will execute exciting science and support the astronomy community and upcoming NASA missions through a dedicated cadenced twilight observing program. This work presents the scientific motivation and high-level feasibility of two primary science cases, monitoring of Solar System objects and a high-contrast imaging search for exoplanets around bright nearby stars, taking lessons from the existing NIRC2 and OSIRIS Twilight Zone program & considering increases in program scope.



I SHOULD BE ON STRIKE:
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Busting and **aggressive**
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THE TWILIGHT ZONE™

- At dawn and dusk, the sky brightens in the optical, but remains nearly unchanged in the IR
- The Twilight Zone™ program (Imke de Pater, Ned Molter, Carlos Alvarez) takes advantage of astronomers voluntarily yielding unused morning twilight time to do cadenced monitoring of Solar System bodies with OSIRIS & NIRC2
- ~100 triggers (~40hrs of data) & 5 papers since 2017!
- SCALES is a thermal infrared integral field spectrograph coming to Keck in 2025, and will expand scope of twilight program

RECLAIMING SCIENCE TIME

There is a **discrepancy** between science-capable twilight time available (≤ 45 mins each morning & evening twilight) and time being used.

Current Twilight Zone™	10 hr / yr	1 Keck night
6% of nights Morning twilight only		
12° twilight - sunrise 20% of K1 nights, 35% of K2 nights Morning & evening twilight (~90 mins) Accounting for avg. weather	210 hr / yr	21 Keck nights
12° twilight - sunrise 20% of K1 nights, 35% of K2 nights Morning twilight only (~45 mins) Accounting for avg. weather	105 hr / yr	10.5 Keck nights

WHAT'S NEXT?

- NIRC2 & OSIRIS Twilight Zone™ observations will continue!
- SCALES arrives @ Keck in Fall 2025
- Towards a dedicated twilight program at Keck: the challenge is programmatic, not technical
 - Twilight time (science-capable) is occupied by observatory operations activities
 - Need study of Keck instrument calibrations to set optimized, minimal calibration routines & free up twilight time
- Minor AO upgrade: wavefront sensor background subtraction → account for brightening sky in R-band

TWILIGHT SCIENCE

Twilight observing lends itself well to **cadenced, long-baseline monitoring** and **shallow snapshot surveys**.

SOLAR SYSTEM MONITORING

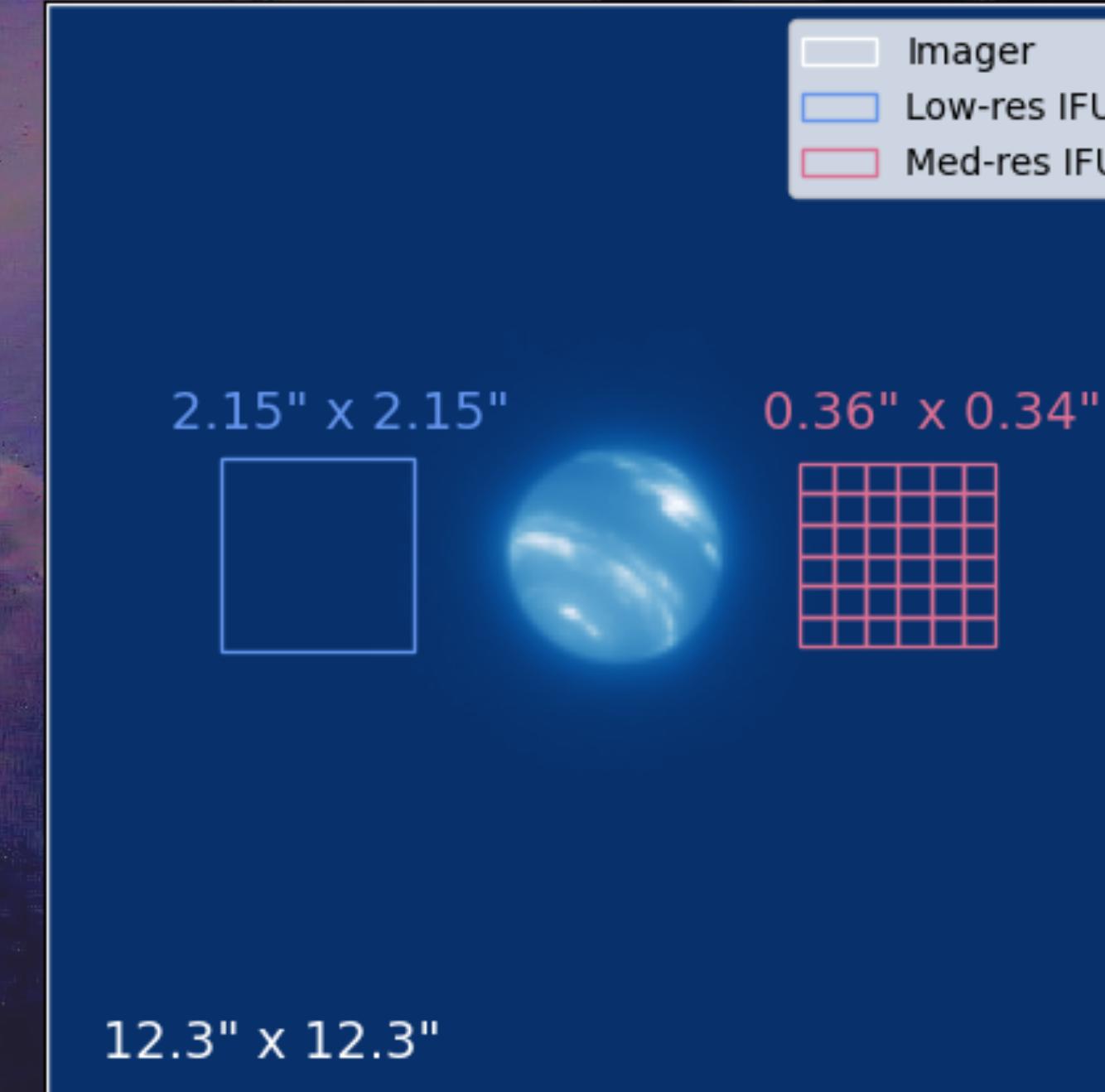


Fig. 1: scalessim image of Neptune. FOV of imager, low-res IFU, & tiled med-res IFU modes overlaid. Data courtesy of Imke de Pater.

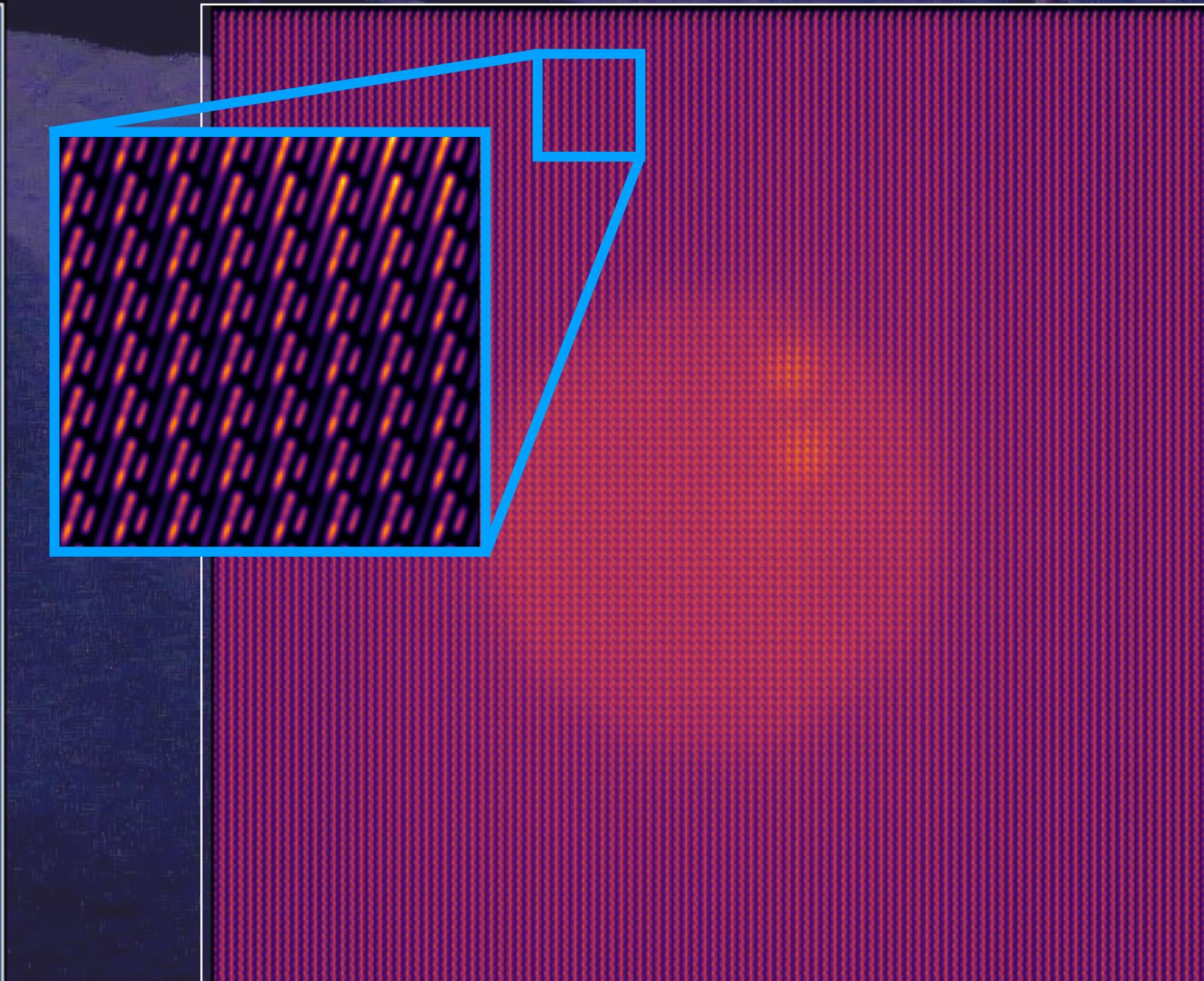


Fig. 2: scalessim raw IFU image of Jovian moon Io, showing two erupting volcanoes. Data courtesy of Imke de Pater.

- The transient Solar System: long-term evolutions (e.g. Neptune storms, left) and short-duration transient events (e.g. volcanic eruptions on Io, right) reveal atmosphere & interior dynamics
- Crucial to support NASA missions, e.g. Europa Clipper, Uranus and Neptune Orbiter (UNO)
- SCALES is uniquely suited to SS observations:
 - 1-5μm coverage
 - 12.3" x 12.3" FOV imager
 - 2.15" x 2.15" FOV low-res IFU (*great for constraining volcano blackbody temp*)
 - 0.36" x 0.34" FOV med-res IFU (*great for resolving atmospheric chemical abundances*)
 - Internal <1kHz tip-tilt stage for easy image tiling

EXOPLANET SNAPSHOT SURVEY

- Solar System targets are down during winter
- Shallow (30min integrations) survey of BAF stars (young, likeliest to host young hot bright planets)
 - *Blind*: 1% occurrence for wide-separation companions (Bowler+2018)
 - *Targeted*: Gaia DR4 will provide astrometric & RV clues in late 2025
- Keck is the exact right facility (too difficult for <10m, too exploratory for ~30m)

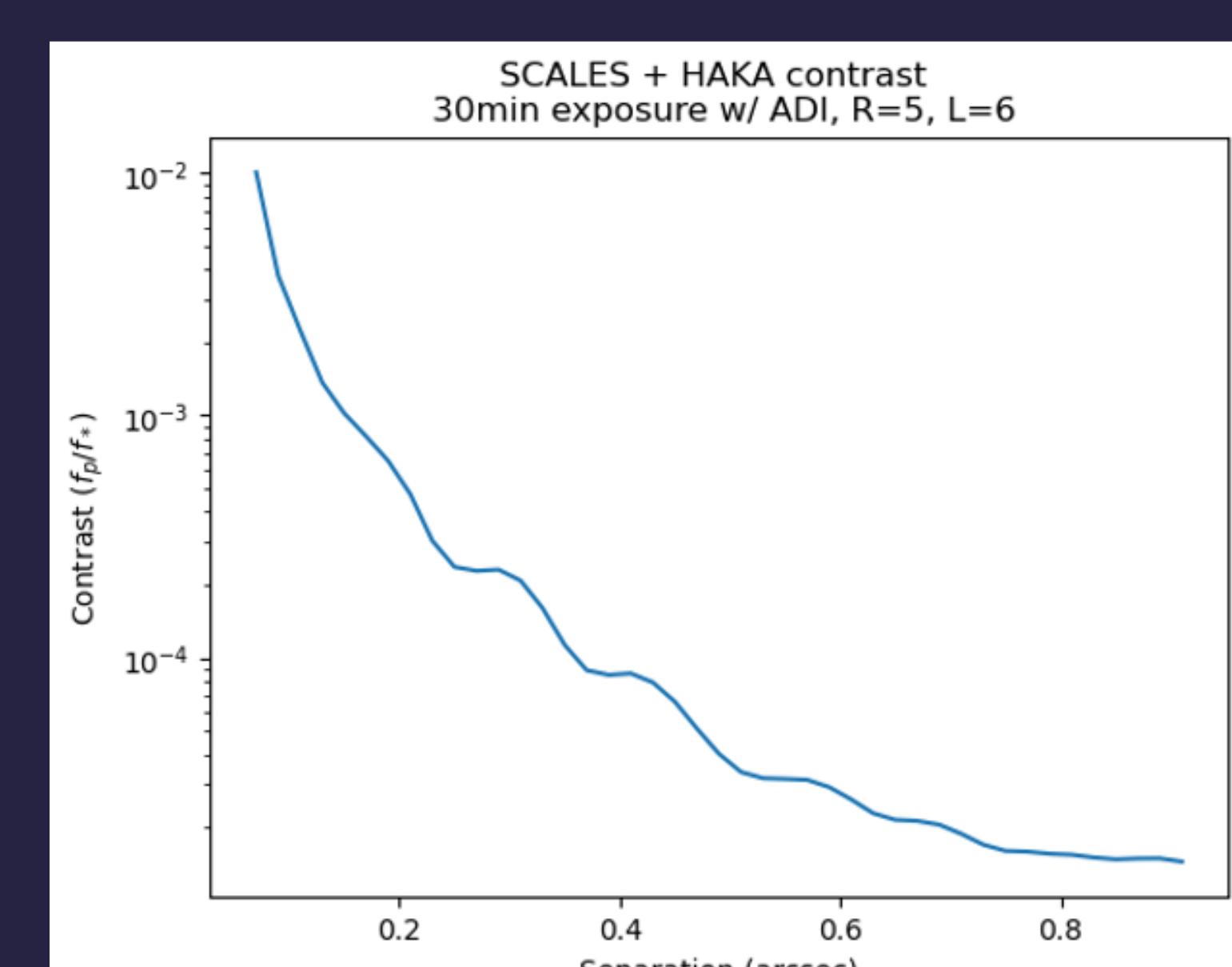


Fig. 3: SCALES predicted contrast performance for a snapshot survey of bright, nearby stellar hosts.

YOUR SCIENCE COULD GO HERE!