Space – Ground Hybrid Instruments Enable New Astronomy

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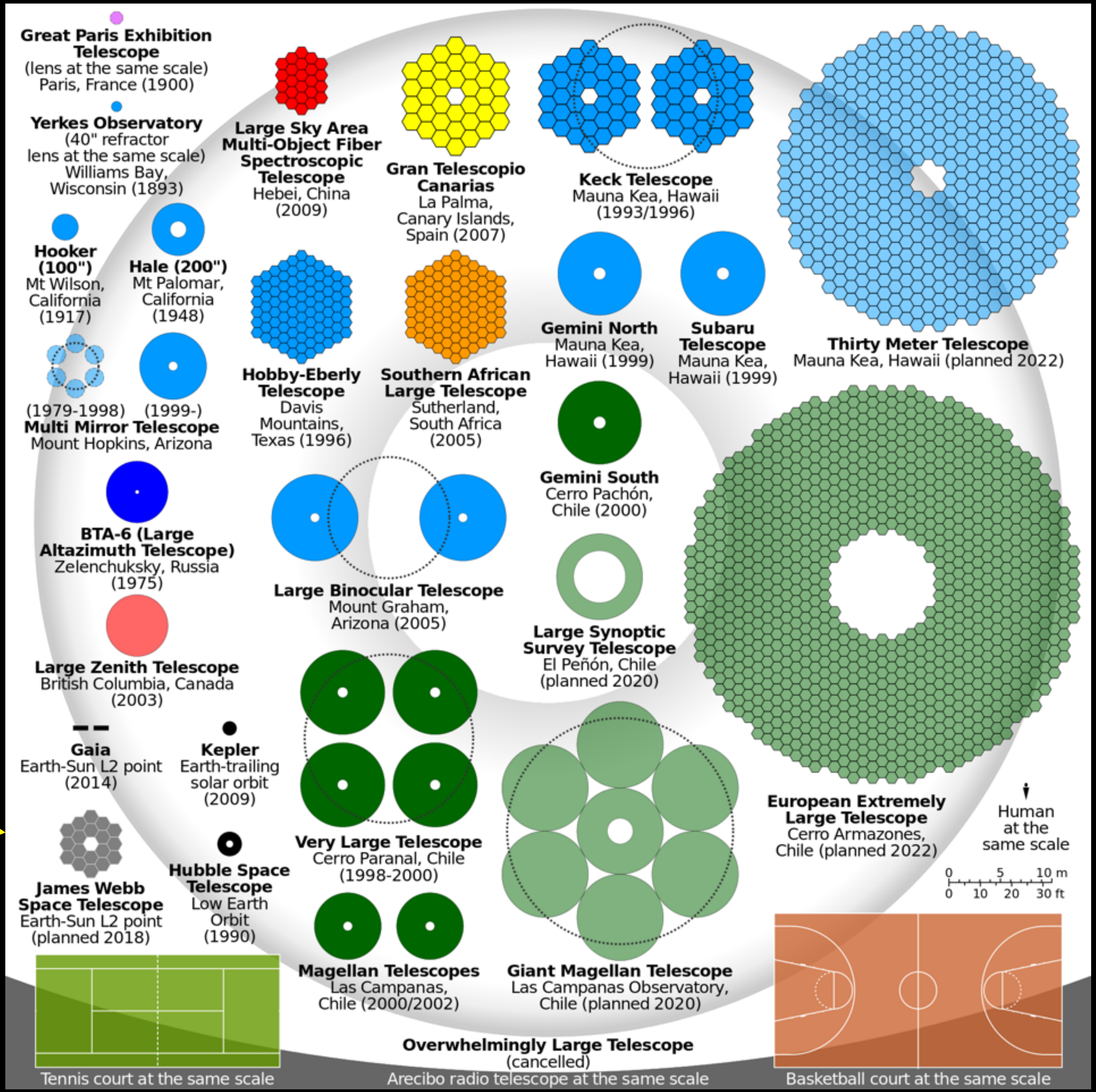
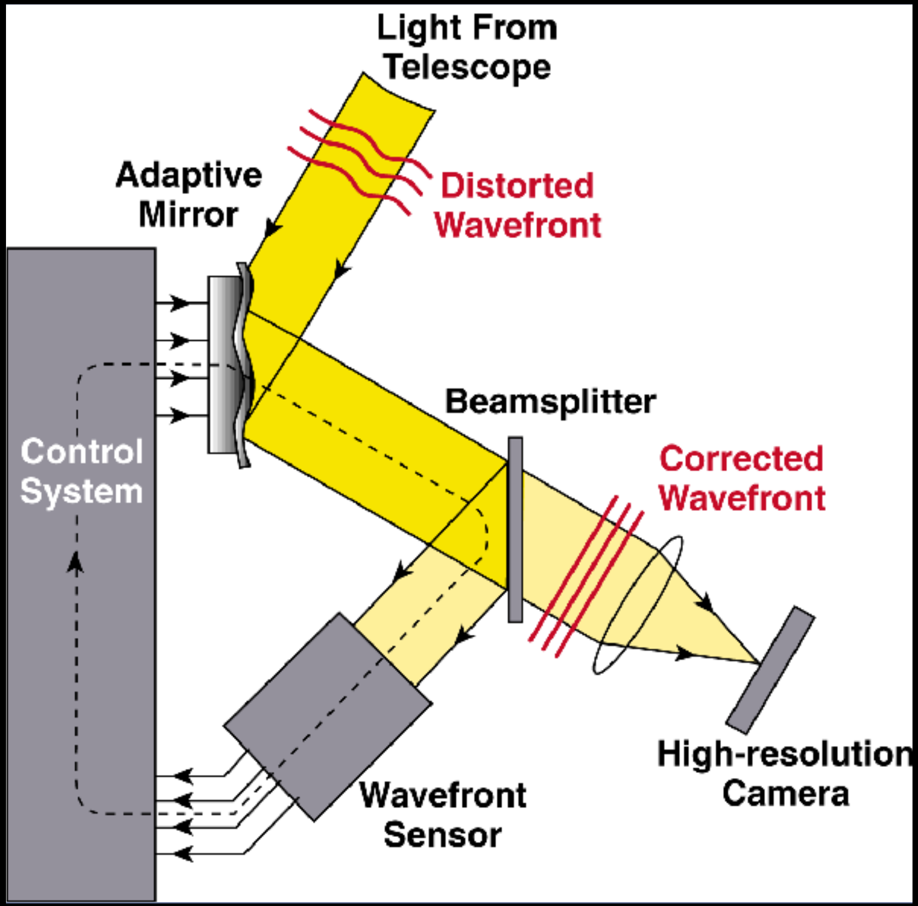
Adaptive Optics (AO) enables space quality images from the ground



Extremely Large

Large

Adaptive Optics (AO) Principles



- Compensate for turbulent atmosphere
- Requires bright star(s) to focus on
  - We provide them!
- Not easy: fast camera in wavefront sensor, fast computer, fast deformable mirrors
- Result: sharp image, almost like being in space
  - But: only works over narrow angle
  - But: sky is darker in space

Diagram: CfAO (Center for Adaptive Optics)

Orbiting Configurable Artificial Star (ORCAS) Study selected

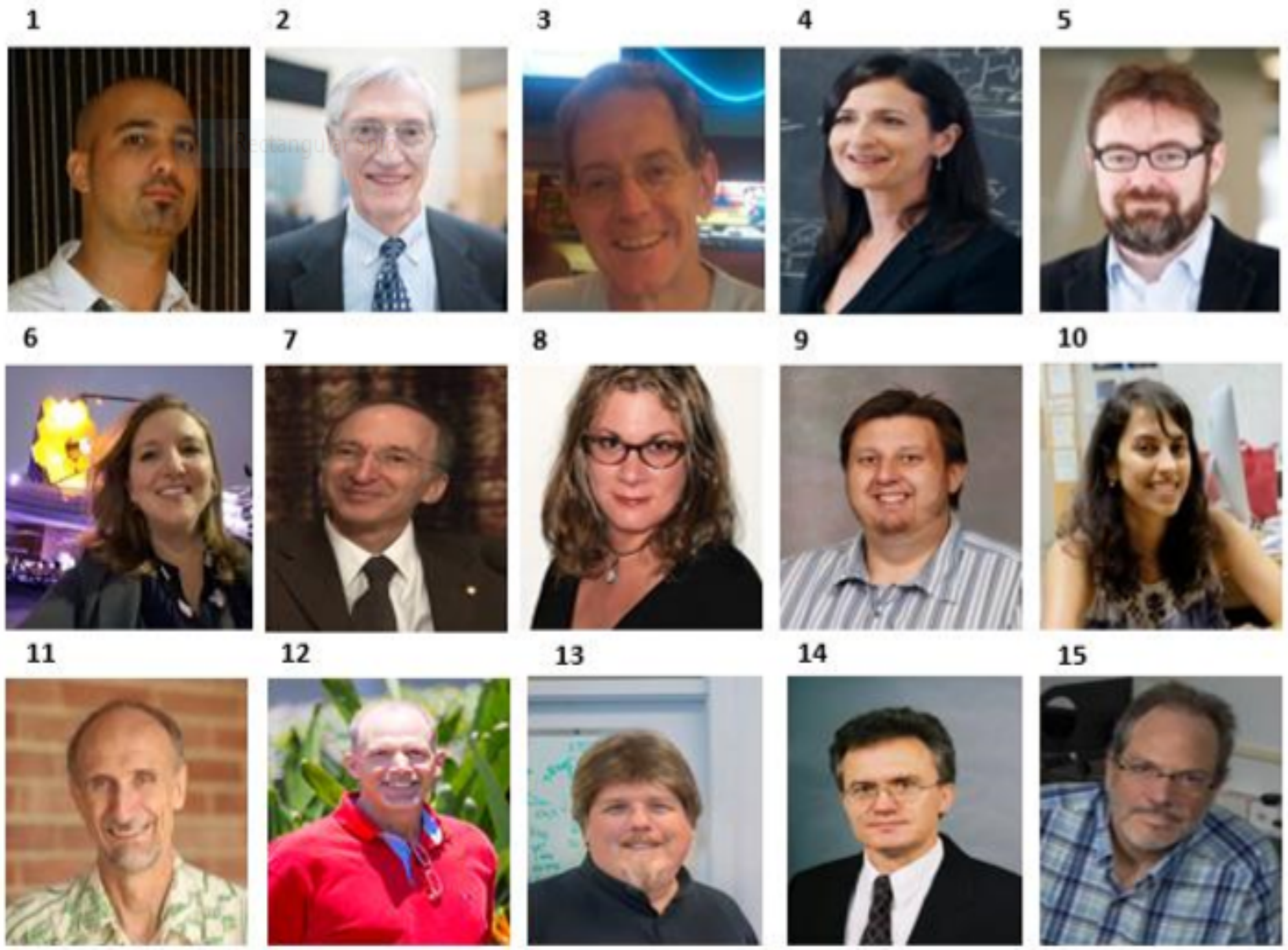
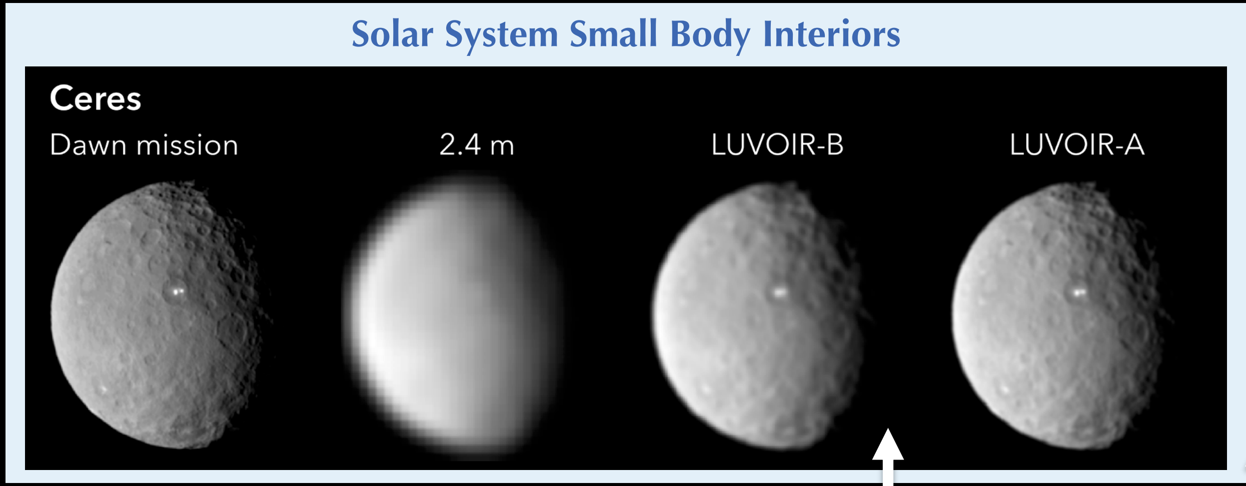
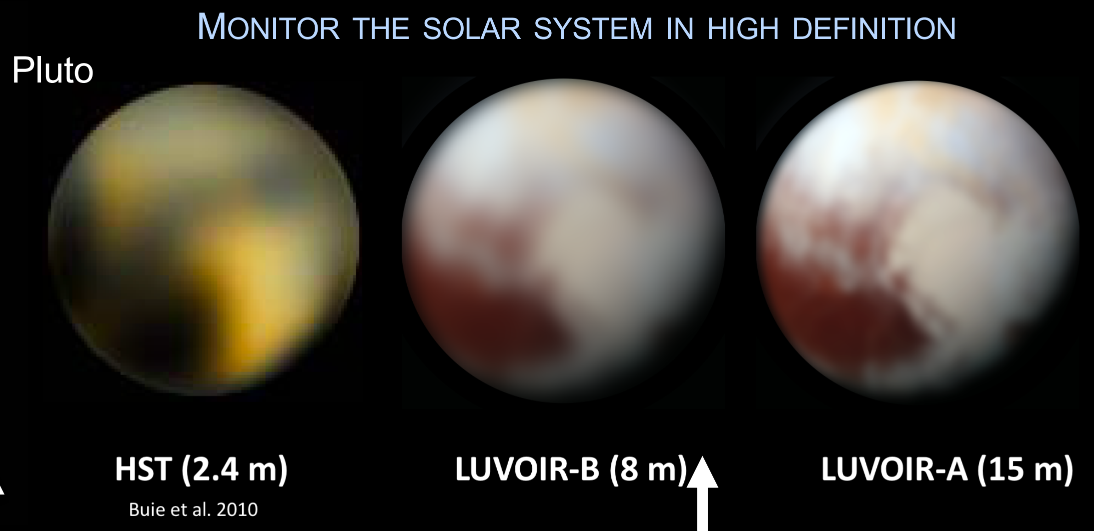


Figure 5.1 – Team members: Eliad. Peretz (1), John C. Mather (2), Richard. Slonaker (3), Sara. Seager (4), John O'Meara (5), Stefanie Milam (6), Saul Perlmutter (7), Rebecca Oppenheimer (8), Peter Plavchan (9), Shobita Satyapal (10), Peter Wizinowich (11), Randy Campbell (12), Greg Aldering (13), Piotr Pachowicz (14), Robert Lafon (15).

Visible Band AO could beat space resolution





Keck AO TMT AO

Keck AO TMT AO

Images from LUVOIR final report

Visible band AO could beat space sensitivity

- Point source observing speed proportional to D^4/B (D = diameter, B = background)
- Sky darkest at visible wavelengths
- Keck diameter 4x HST, TMT 3x Keck
- Ground + AO with 2x aperture could beat space for 0.3-0.9 μm

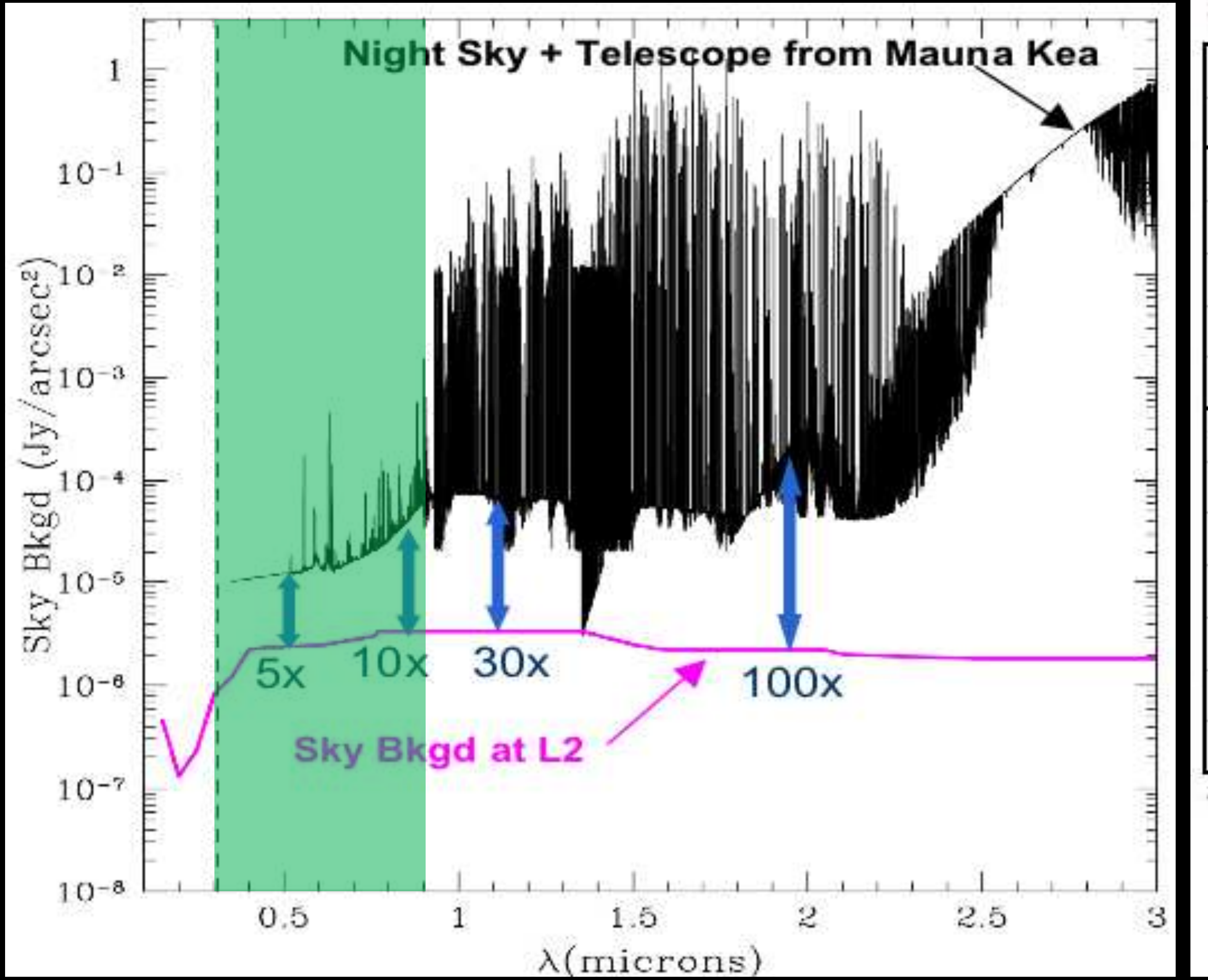
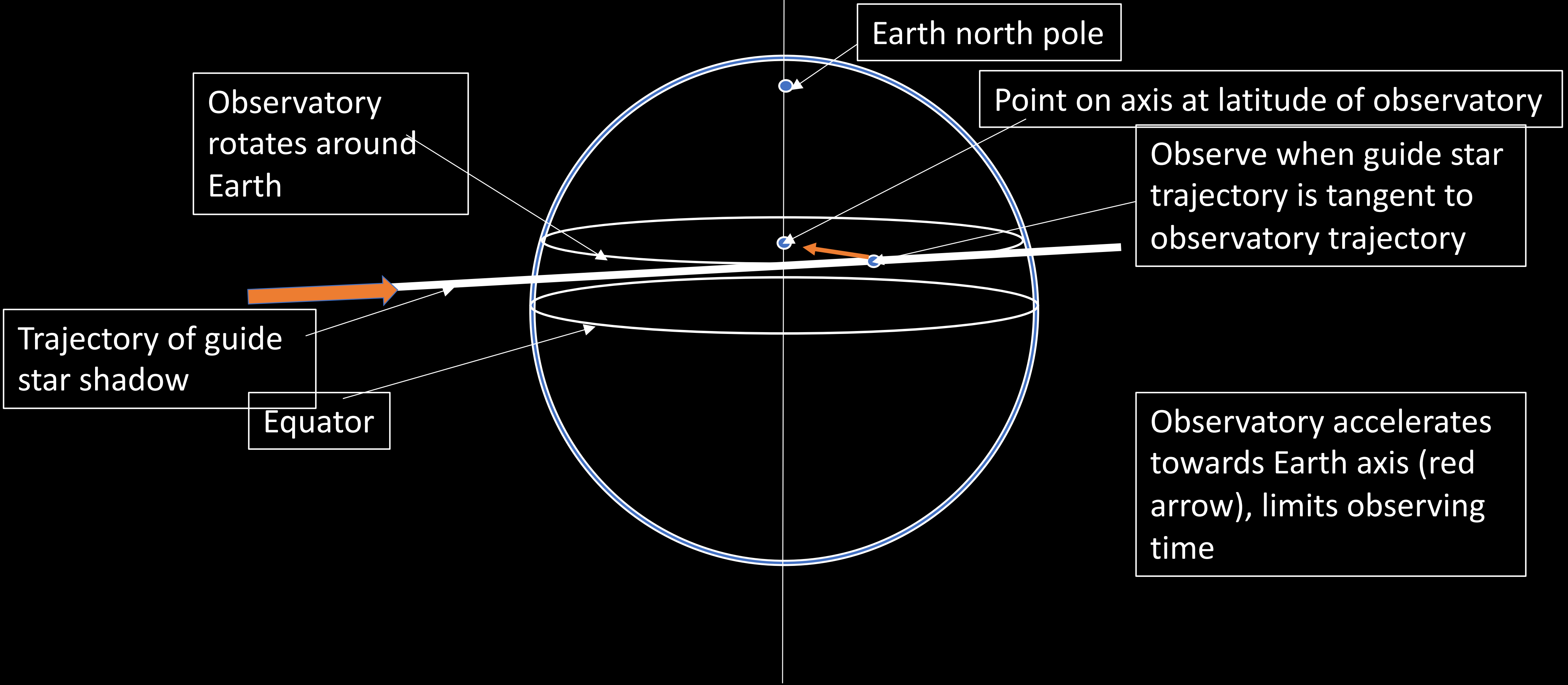


Image: Comparison of optical observational capabilities for the coming decades: ground versus space, Matt Mountain et al., 2009

Orbit choice: shadow of orbiting target matches observatory trajectory



Event Horizon Telescope – mm VLBI could be dramatically improved with orbiting antennas

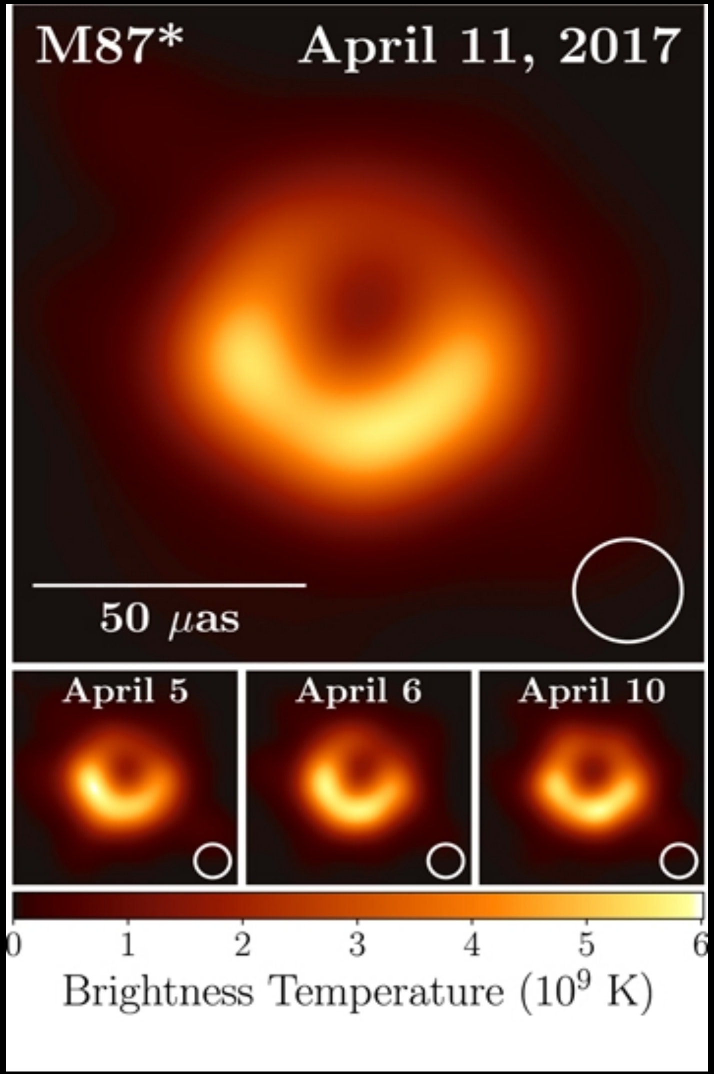


Figure 3 from First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole, The Event Horizon Telescope Collaboration et al. 2019 ApJL 875 L1

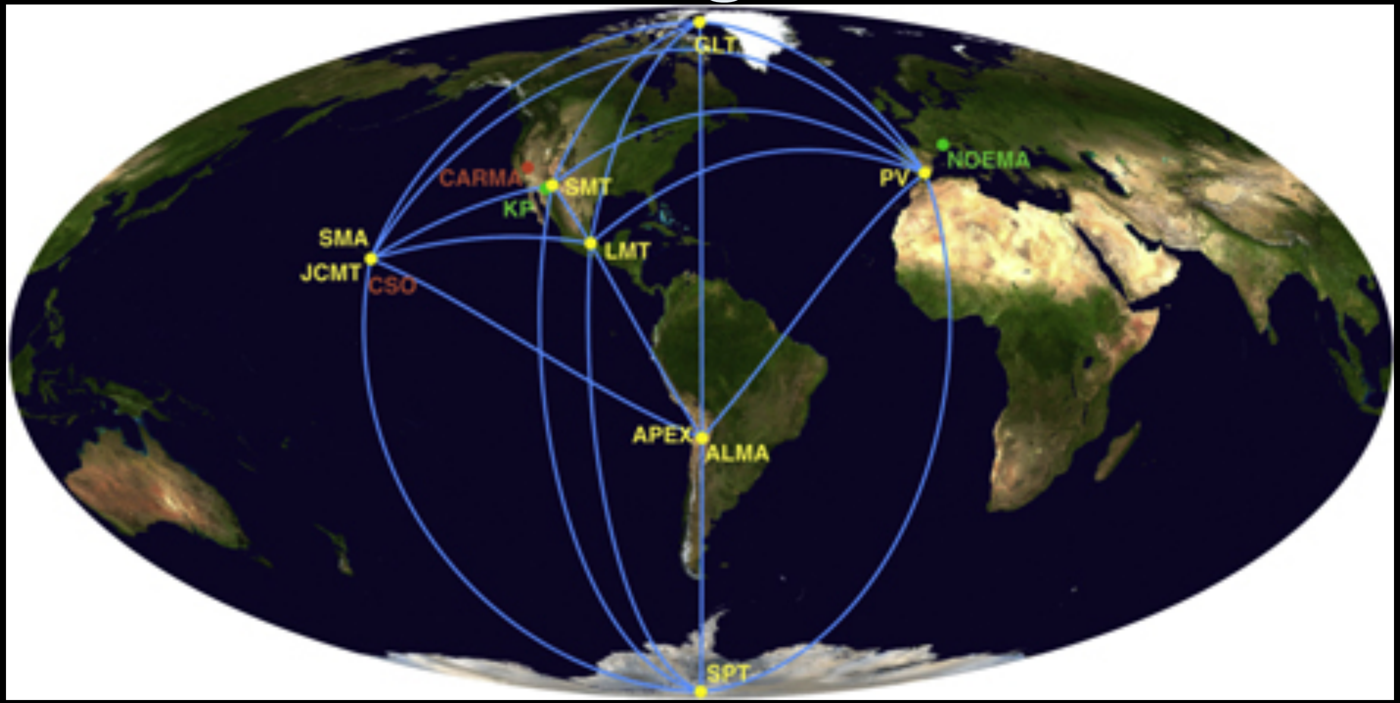
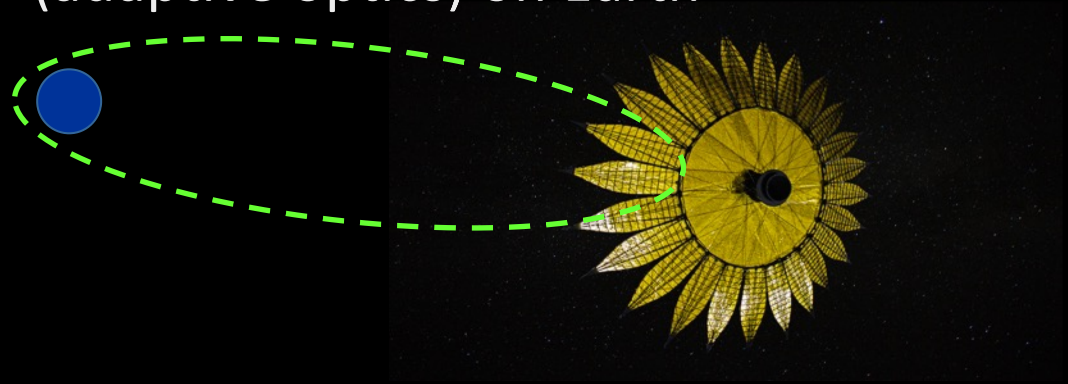


Figure 1 from First M87 Event Horizon Telescope Results. II. Array and Instrumentation The Event Horizon Telescope Collaboration et al. 2019 ApJL 875 L2

With a 100 m starshade, could see other solar systems

24-39 m Extremely Large Telescope (ELT) with visible AO (adaptive optics) on Earth



* 170,000 km altitude matches observatory
v ~ 400 m/sec
* Laser beacon enables AO

Solar System at 5 pc
in 1 minute

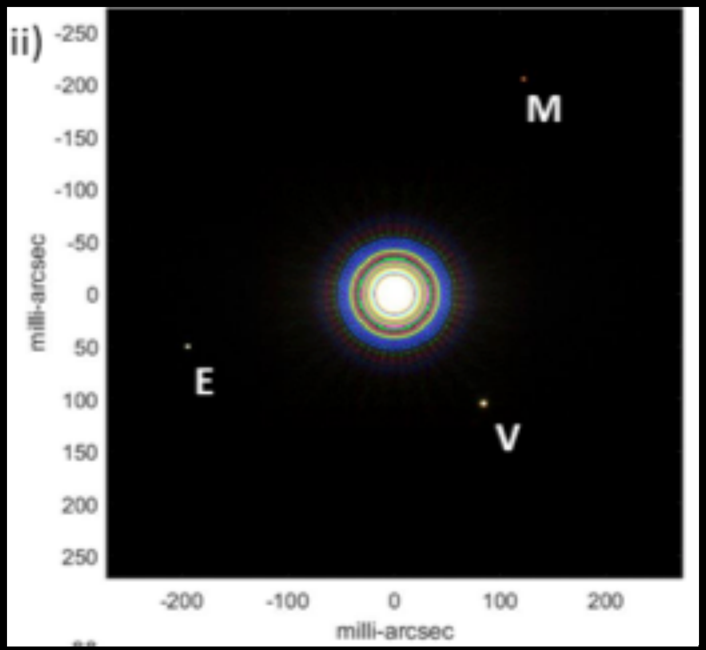
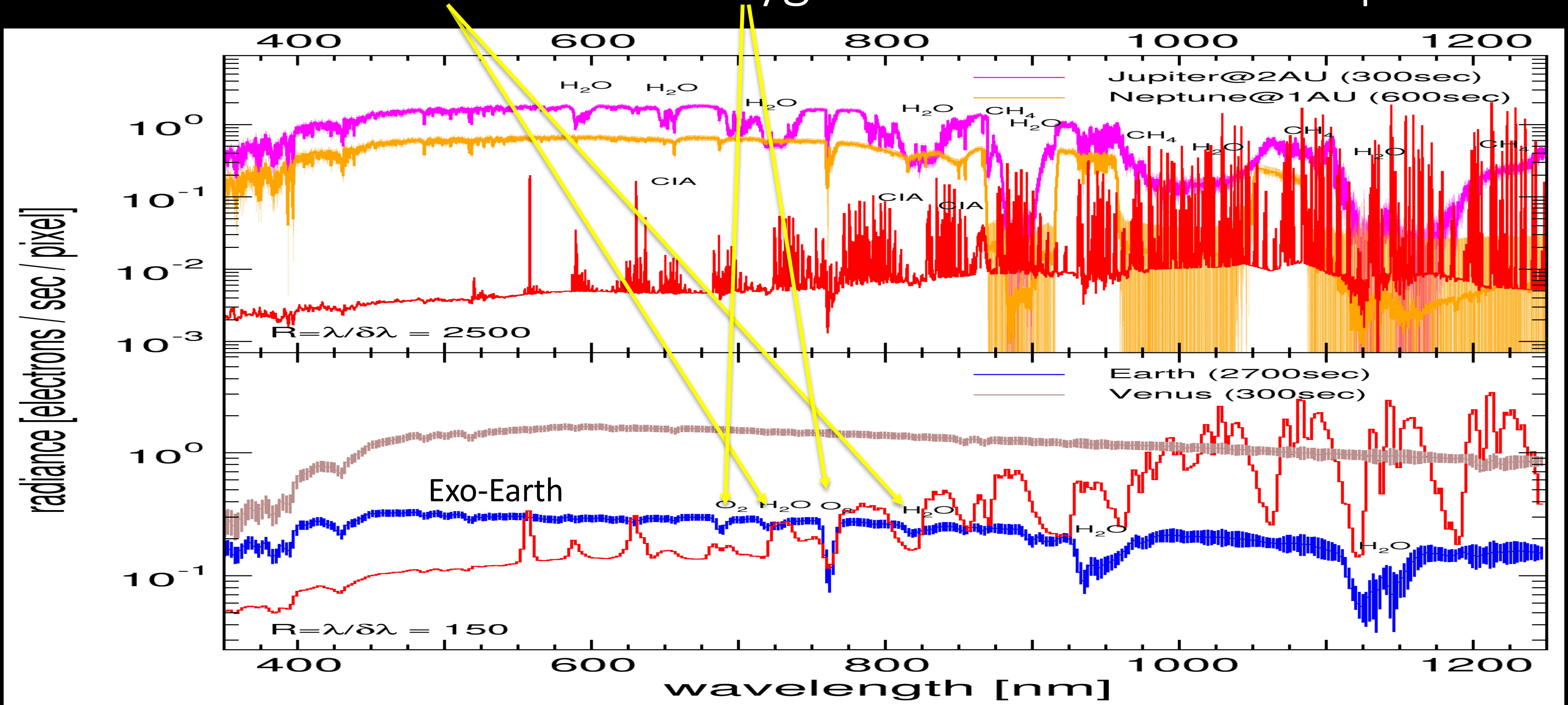


Image by Shaklan

Exo-Earth water and oxygen could be seen at 5 pc



Simulated spectra for planets at 5 pc with Strehl = 0.5. Top panel R = λ/δλ = 2500, bottom R=150. 1 pixel = λ_0/2R = 0.14 nm for R = 2000 and 2.34 nm for R = 150 at λ_0 = 700 nm. Red curves are sky brightness at the ELT in Chile. Widths of curves are ± 1σ. Water and oxygen are seen on exo-Earth and not on exo-Venus, and methane registers on a 2 AU Jupiter. [S. Kimeswenger, W. Kausch, S. Noll, N. Przybilla]

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