NAS Space Studies Board

The lunar pole - a uniquely powerful site for UVOIR and cryo telescopes

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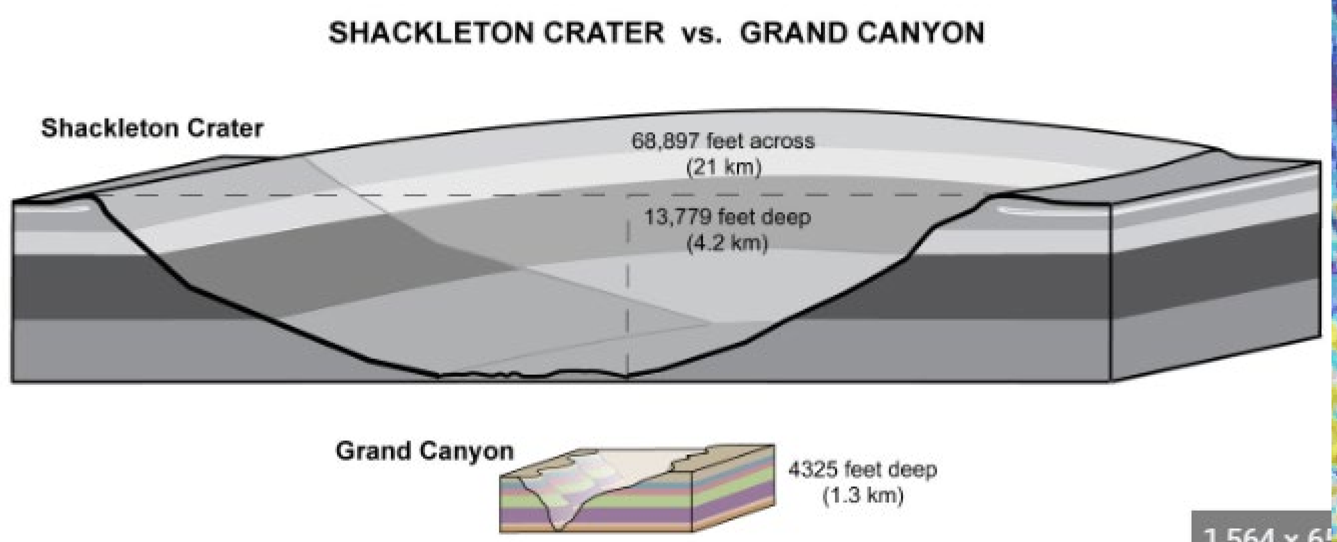
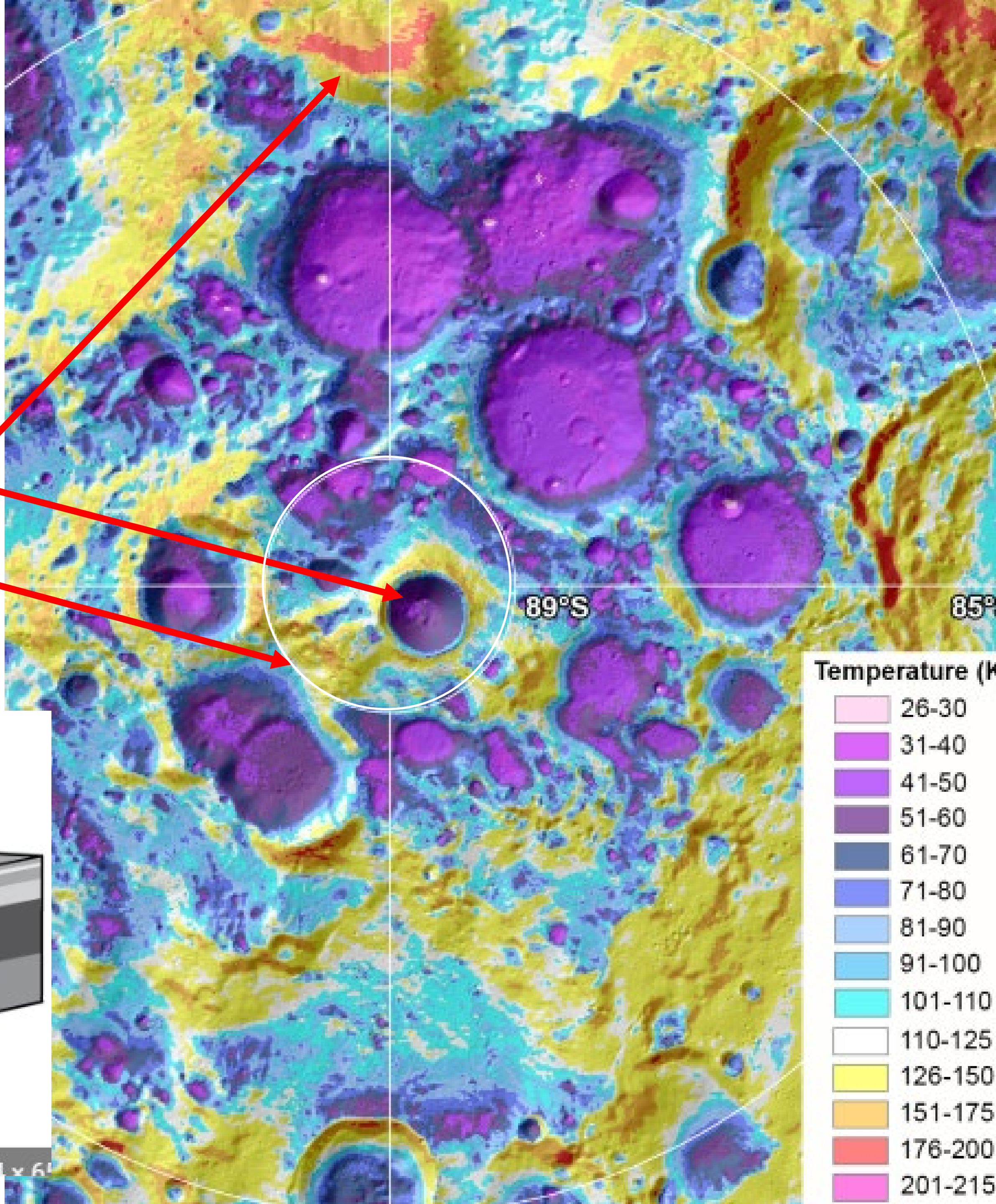
Cryo IR telescope at S. Pole

- Susante et al 2002 proposed 8 m cryo telescope in Shackleton crater, 35K
- 89° south circle , radius 29 km
  - communication from Malapert mountain, always facing Earth
  - But Shackleton cold and hard to navigate:



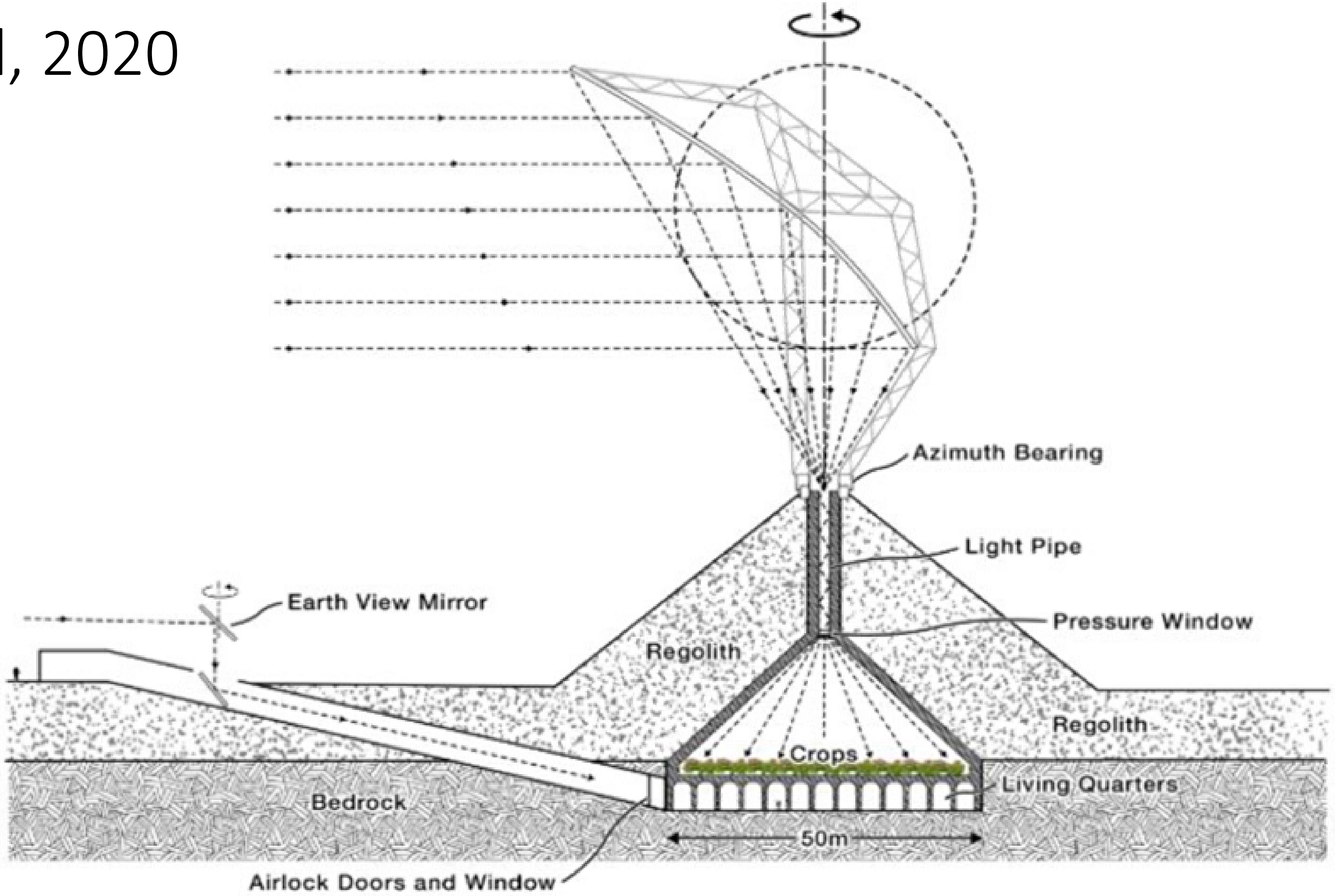


Suppose a polar base is built – for example:

Pantheon habitat made from regolith, with a focusing solar reflector

Woolf and Angel, 2020

- 25 m thick regolith cone balances 14 psi atmosphere inside
- Growing area 50 m diameter
- Feeds 40 inhabitants
- Some could work with infrastructure to build telescopes



Roman Pantheon

Dome structures:

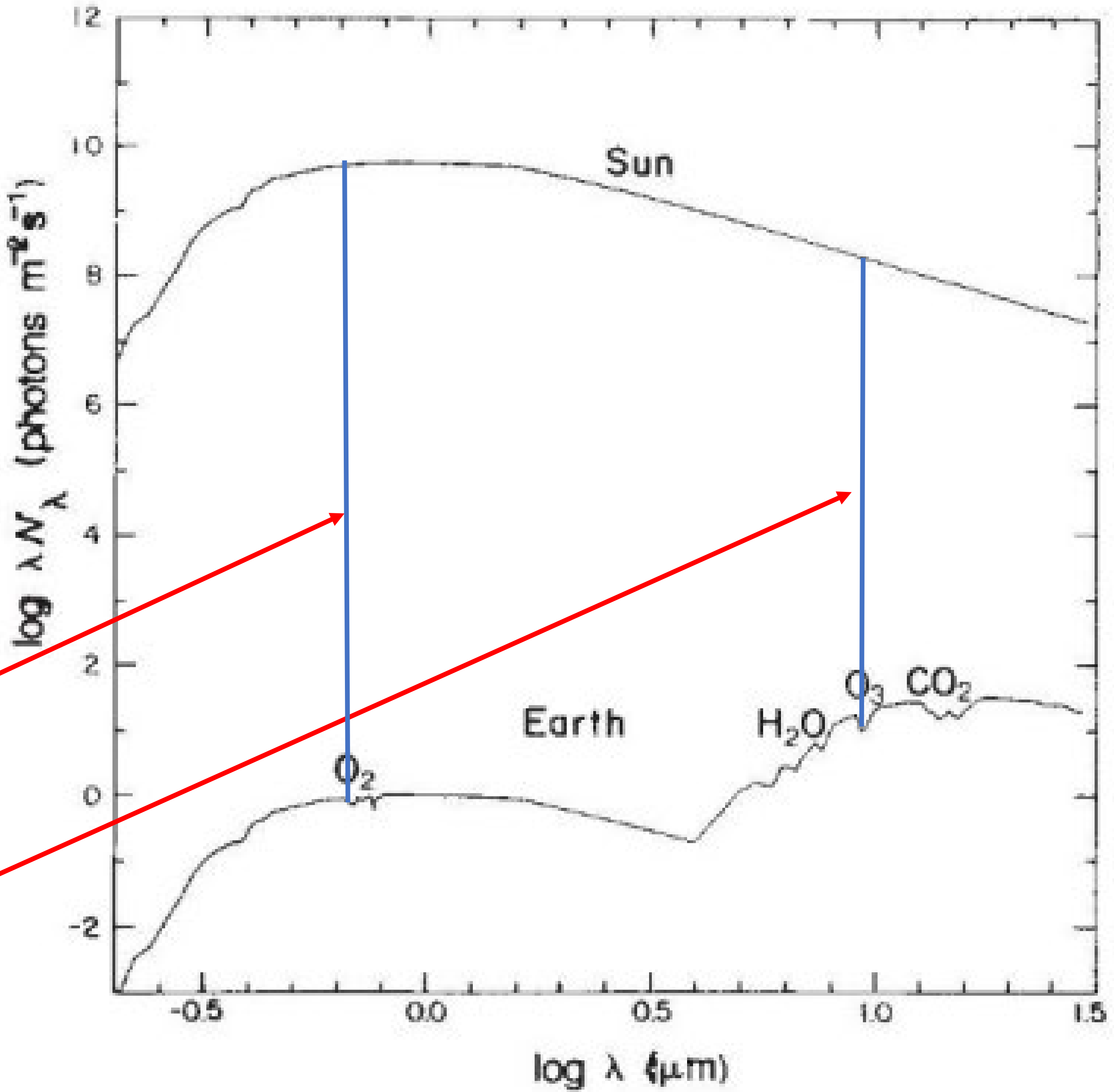
- Let in light
- stable and long-lived

Ozone as biosignature

"A space telescope for infrared spectroscopy of Earth-like planets"
Angel, Cheng & Woolf, Nature 1986

Earth 10 billion times fainter than sun in visible light

- but only 10 million for infrared, ozone absorption.



Model of 4 x 7 m mirror telescope

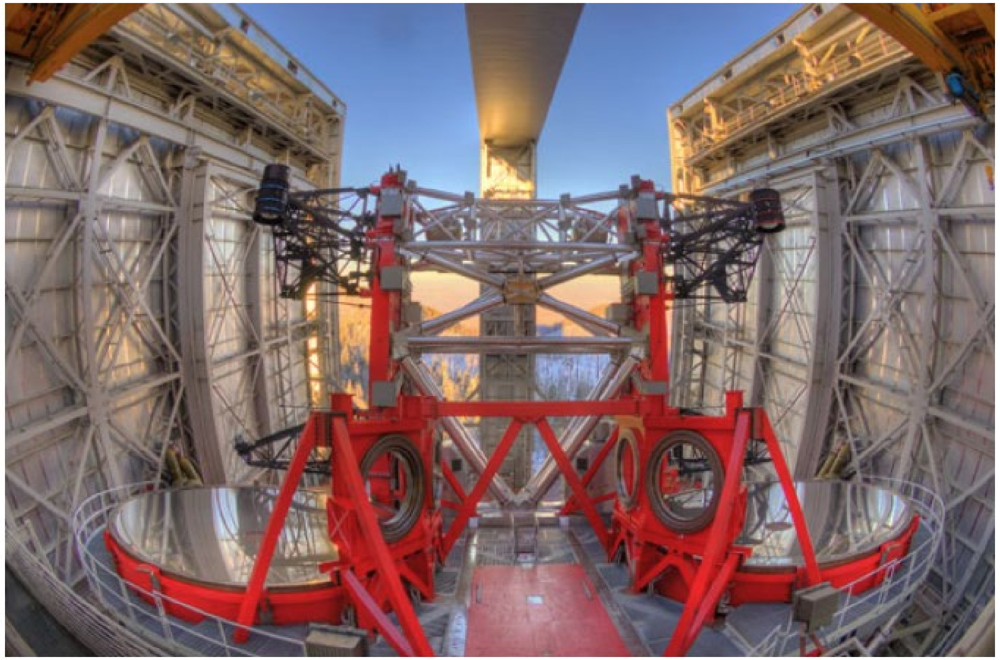
- 40 m baseline
- used as Bracewell double nulling interferometer to interfere out the central star
- At 10 µm, 10^{-8} null at 0.1 arcsec – 1 AU at 10 pc
- Also 5x resolution of JWST

Example from close mirror array - LBT image of Io

Two phased 8.4 m mirrors, 6 m separation

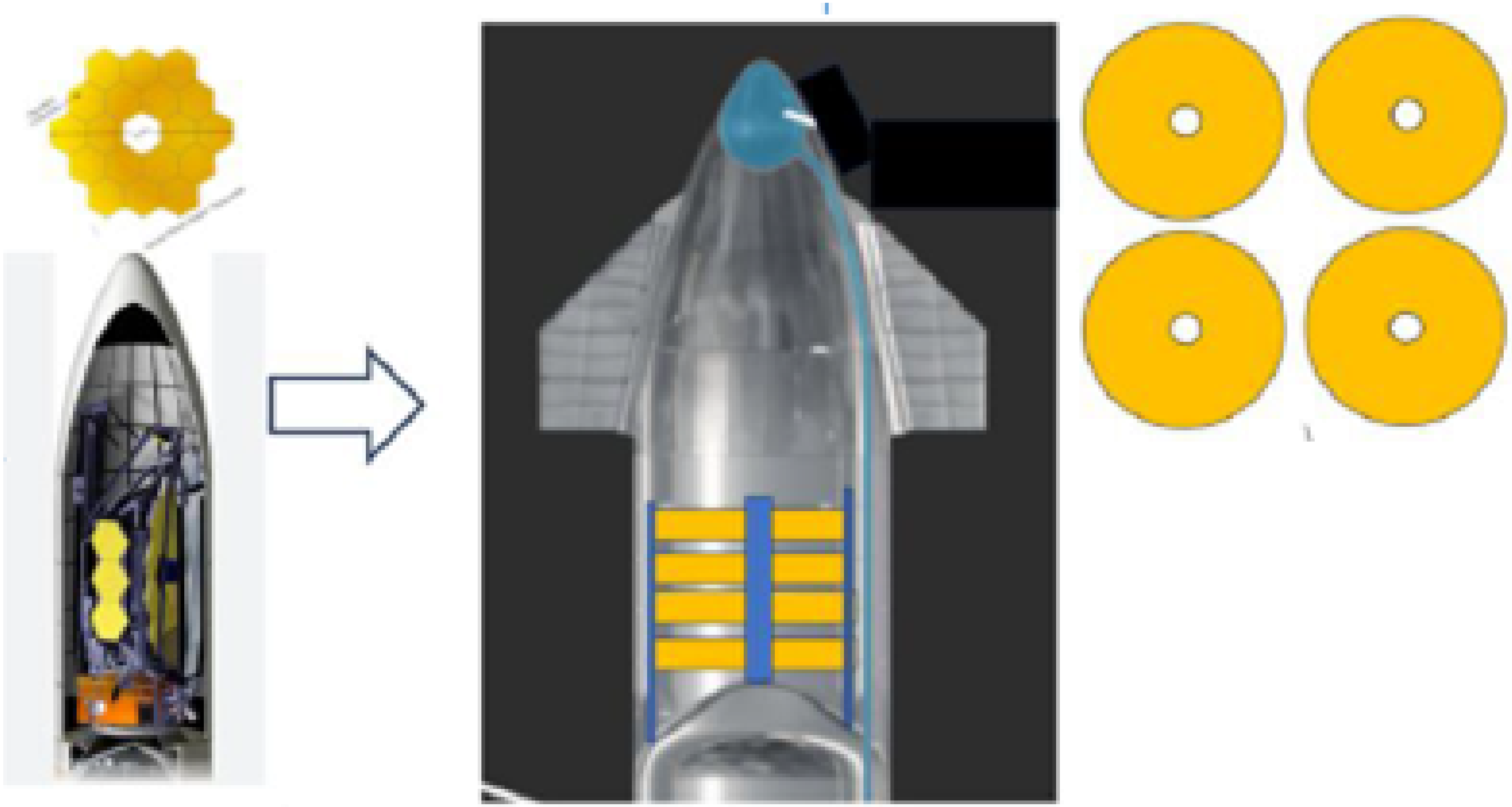
Earth rotation for full cover of Fourier plane.

With adaptive secondary mirrors, obtained optical diffraction limit at 23 m baseline



SHARK-VIS tri-color image of Io, processed with the Kraken deconvolution code.

Four 7 m mirrors could be taken as a single Starship payload



Ariane 5, and 25 m^2 JWST

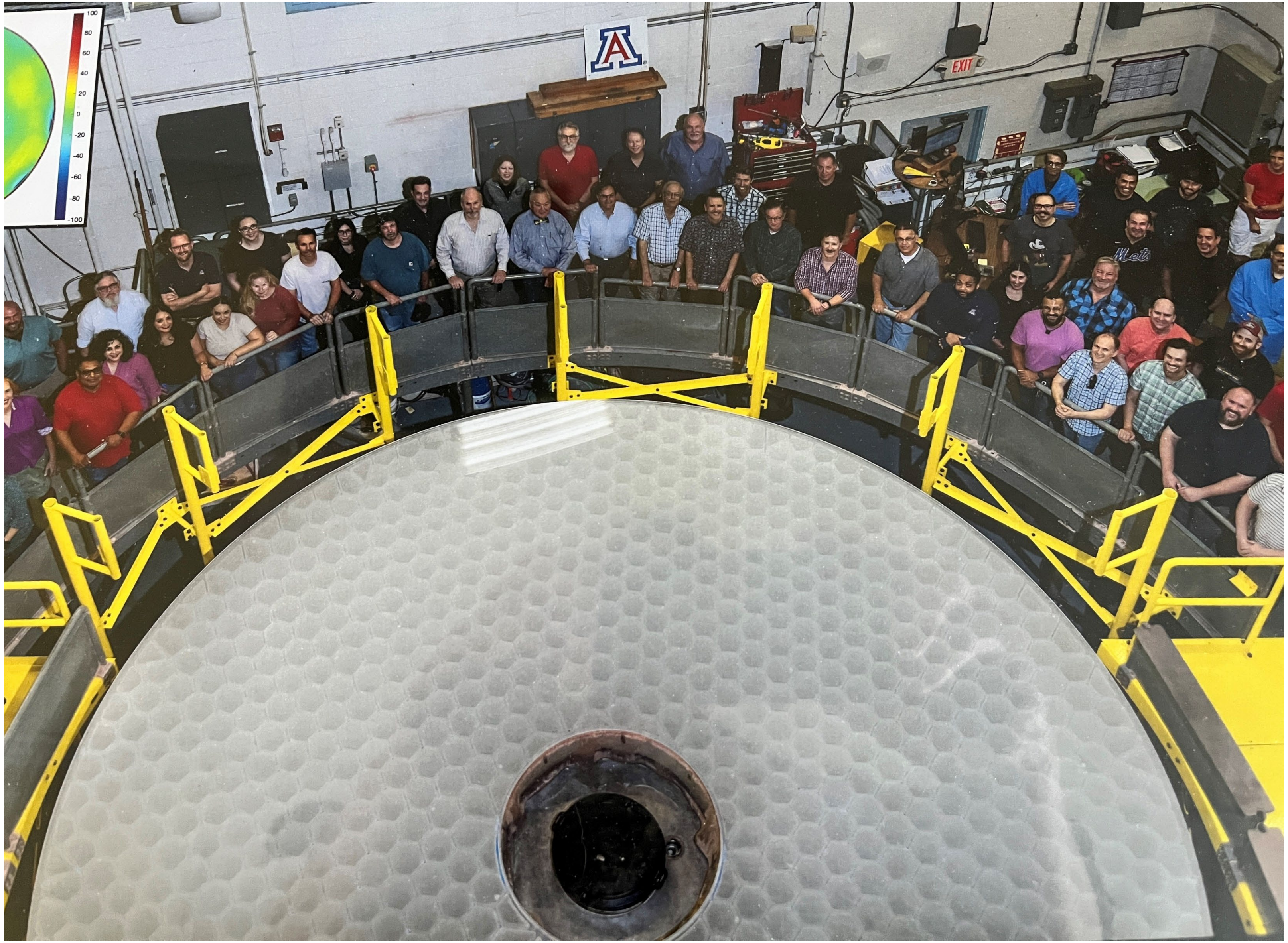
SpaceX Starship with four 35 m^2, 7 m monolithic telescopes

6.5 m mirror at the University of Arizona Caris Mirror Lab

Finished in 2024 to better than diffraction limited

Borosilicate honeycomb glass

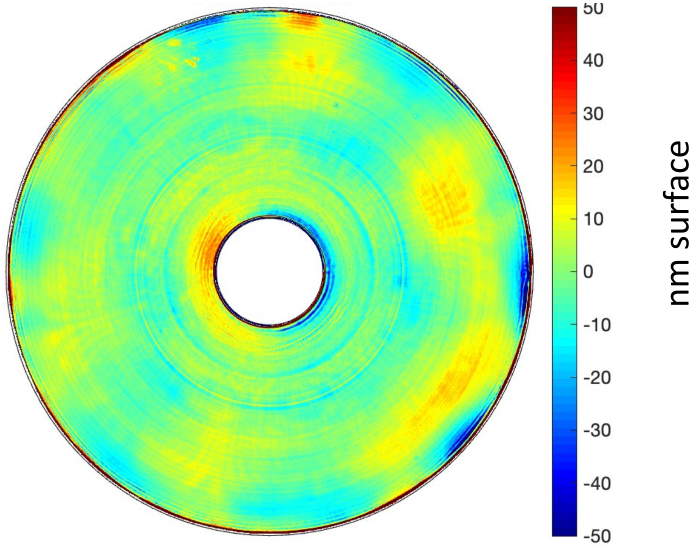
Dr Buddy Martin, Project Scientist for Mirror Polishing



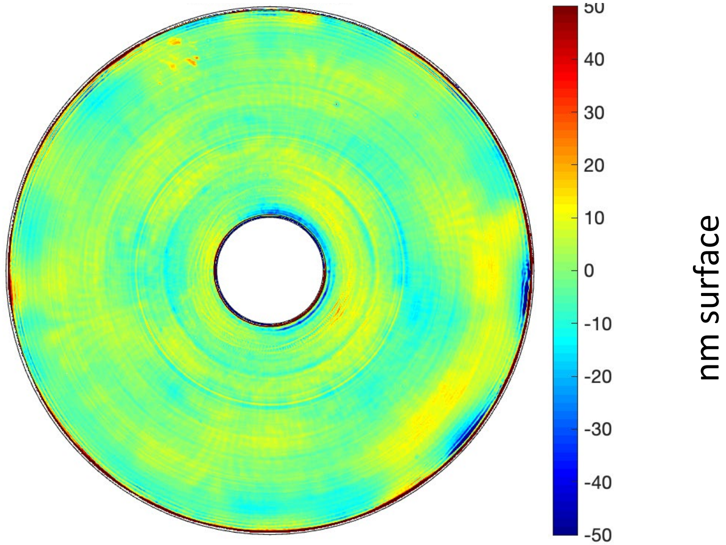
Surface error after bending correction

Same rms wavefront error as HST after its correction, but for 2.5 x larger aperture and thus sharper images

9.4 nm rms over clear aperture

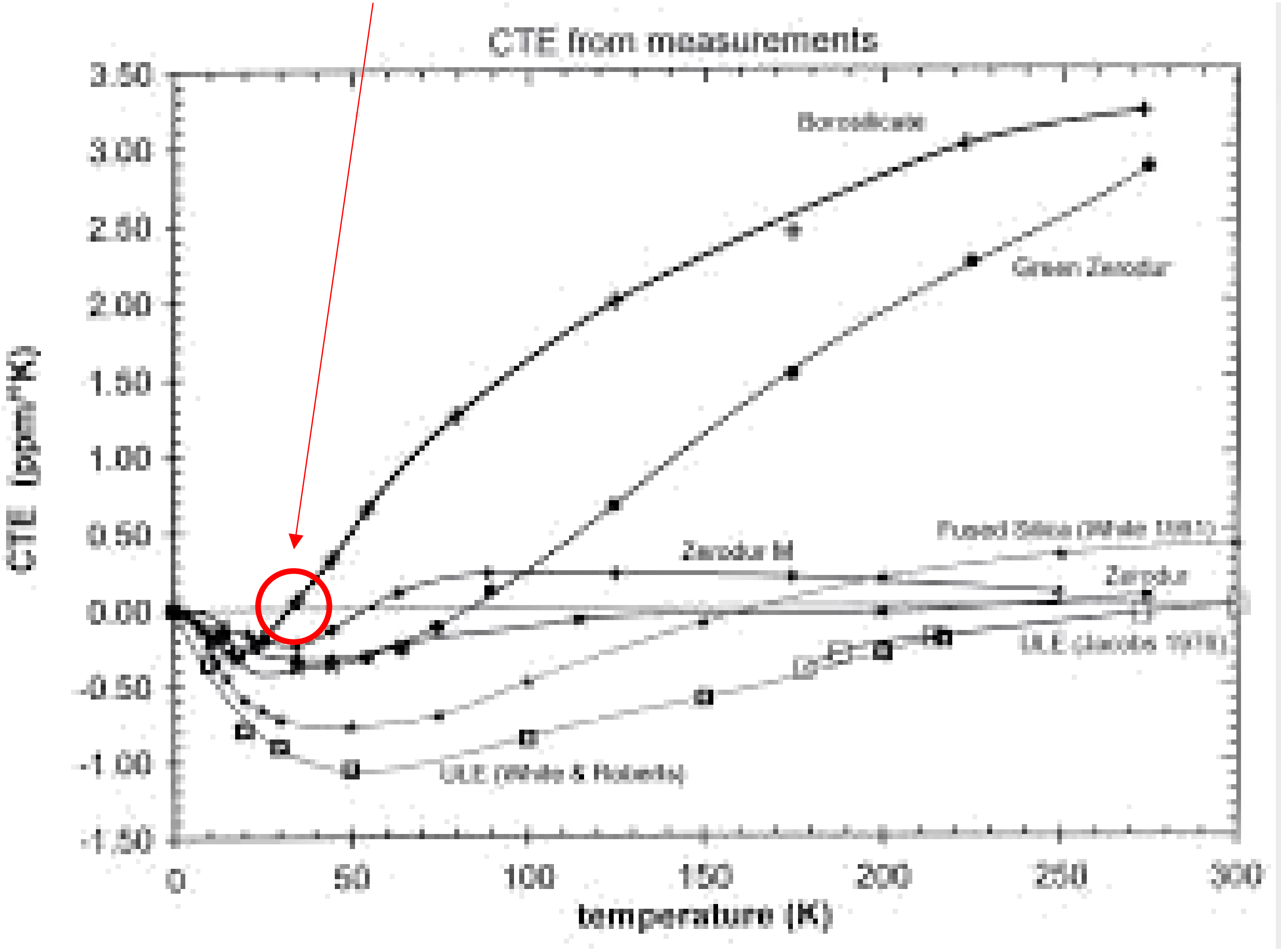


8.1 nm rms over clear aperture

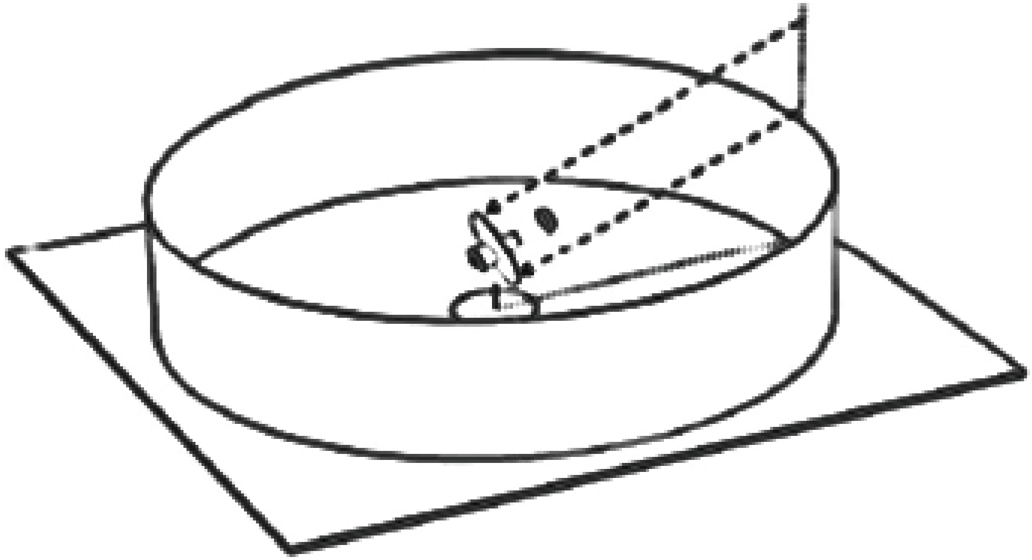


- End-to-end simulations show the as-figured surface would allow a contrast of $<10^{-8}$ on Alpha Centauri A.

Borosilicate that we use is good to hold high accuracy, only glass type with zero expansion coefficient at ~40°K



Rather than trek down into Shackleton, build the telescope on flat land, near the rim



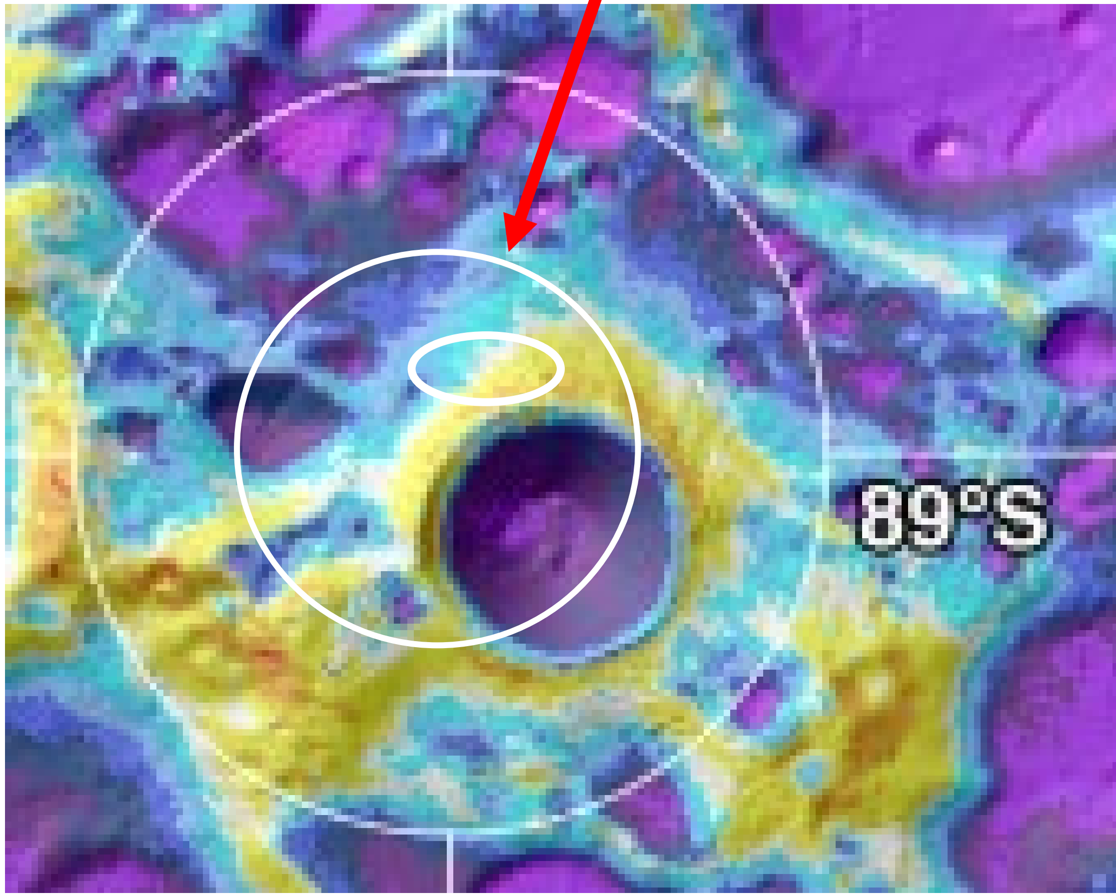
- After construction is complete, cool to 35°K, by erecting a lightweight plastic sunshield
- For a start, test with a single 6.5 m mirror here, then at the lunar pole

Need to be within 15 km (1/2°) of pole

- This is because the Moon s spin axis tilted at only 1½°to the ecliptic plane, so a low screen then does it.
- It can shade for dark sky at all times, while allowing access to all S sky down to 15 degree elevation

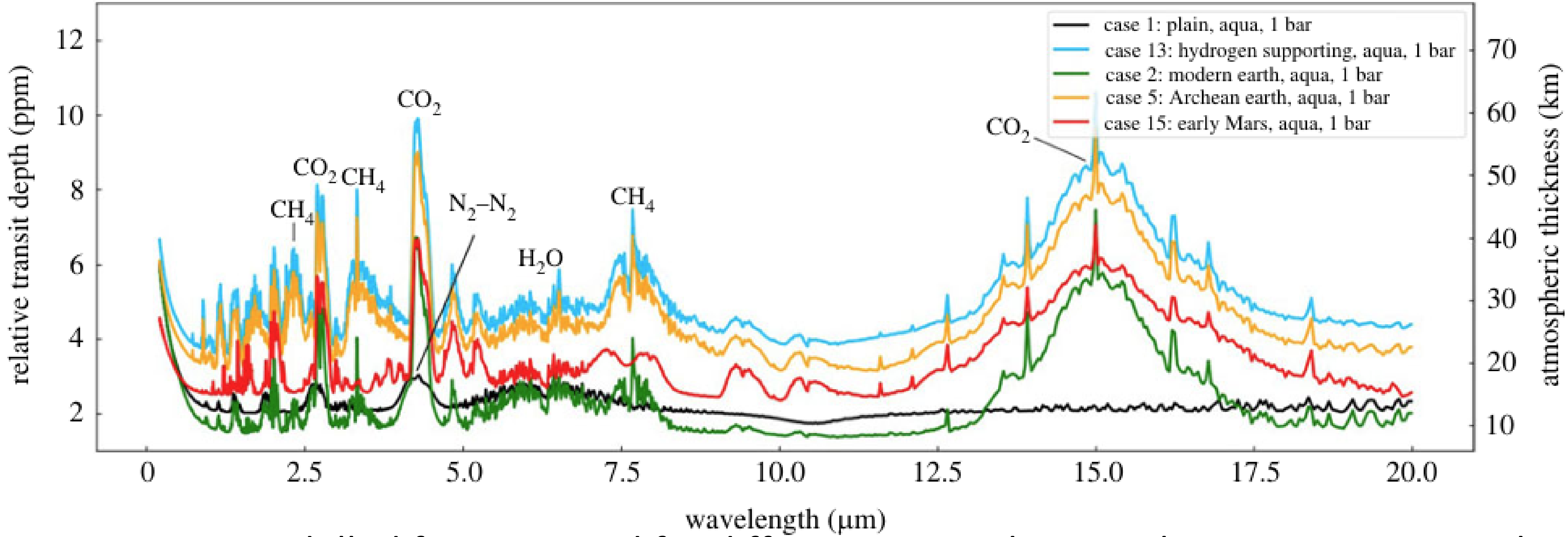
Need to protect this ½ degree, 15 km radius area, so telescopes won't be compromised

- The site could easily be spoilt if:
  - launch facilities or water mining operations were built with line of sight of the telescopes
  - Could blast regolith or debris at the telescopes.
- Plenty of water in bigger, equally cold craters at -88 or -87 latitude
- Planning must take into account the very long shadows cast when sun is only at one degree elevation
  - 100 m habitat casts 6 km long shadow!



Exoplanet transit spectroscopy

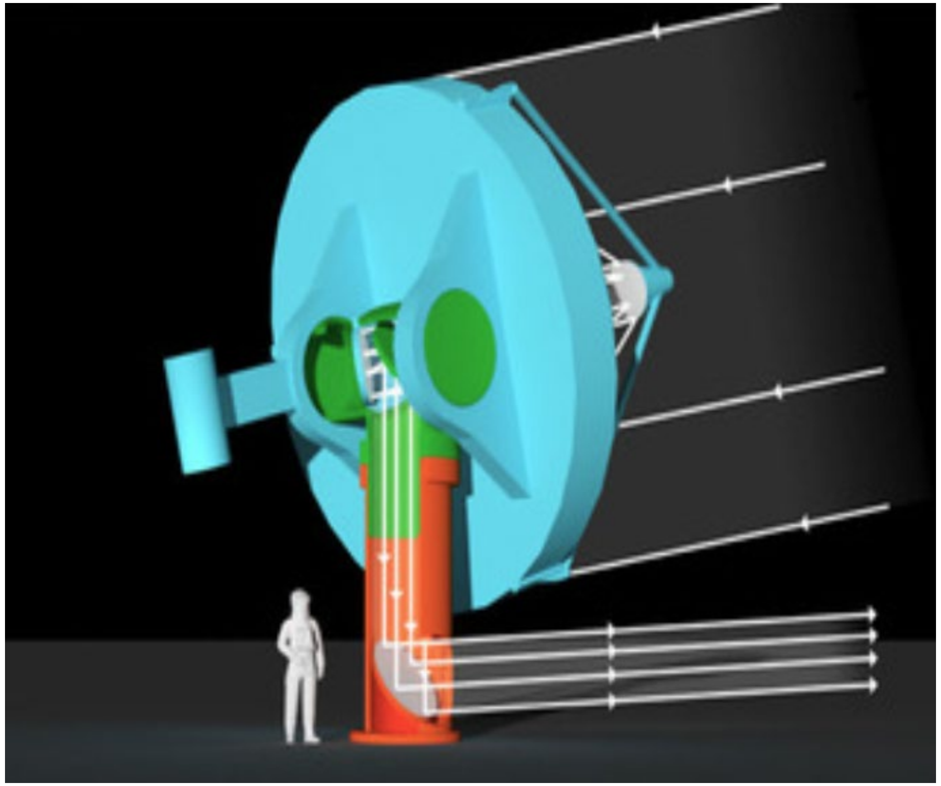
Has no need for interferometry or big field of view
Needs huge aperture to measure features of few ppm depth
and cold telescopes to observe 2 – 20 micron spectra



Transit spectra modelled for TOI-700 d for different atmospheric archetypes - Suissa et al

A 600 m^2 array of 6.5 m telescopes at the lunar pole

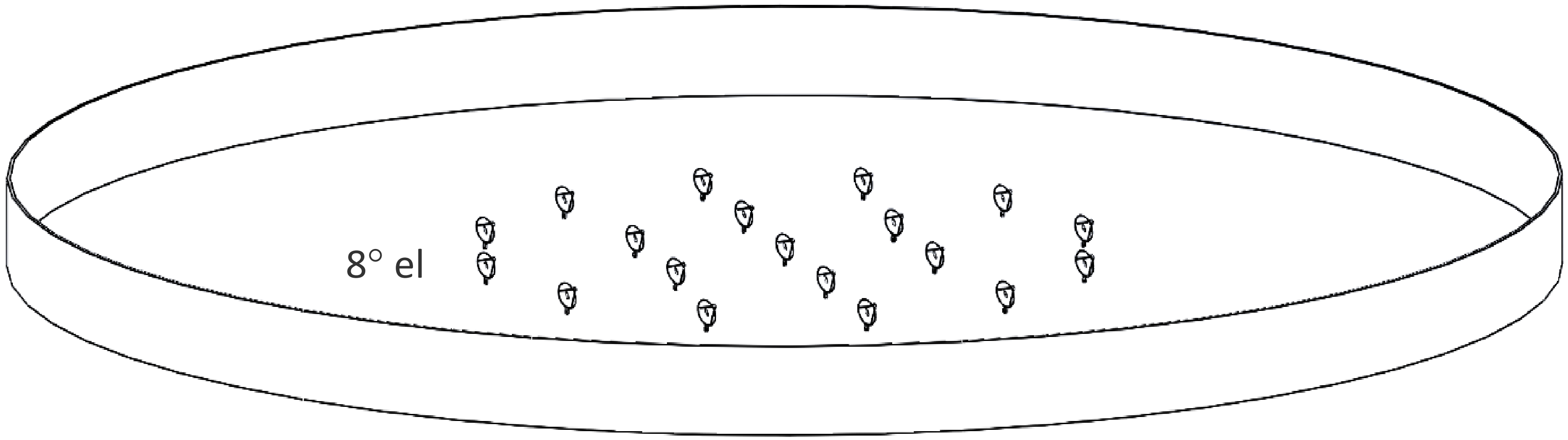
Angel, Phil Trans Royal Society, 2024



- 18 telescopes, 6.5 m aperture, in 200m dia. array
- within 1/2° (15km) of lunar pole
- Perimeter screen for shade and cooling to cryo temp
- 500m diameter for unobscured access down to 8°el.
- Central beam combiner for single image from 0.4μm to 10μm.
- High res. and multi-object spectrographs to cover combined 2’ field with the diffraction limited resolution of 6.5 m aperture.
- Apps. e.g. search for molecular biosignatures in transiting exoplanets, and galaxy evolution to > z=10

- Cost, including delivery to the Moon by SpaceX Starship for installation using lunar base infrastructure, around $10 billion

200 m diameter array surrounded by a cylindrical thermal shield 500 m in diameter



For location within ½ degree from the pole, the sun doesn’t illuminate the most distant telescope of the array, and all telescopes have an unobscured view for el.> 8°

Conclusions

- Something great for polar habitat occupants to build
- Get started by putting one cryo telescope, shaded, within ½ degree of the pole
- Make clear to lunar infrastructure builders why the closest 15 km to the poles should be protected and un-shadowed, - for astronomy.