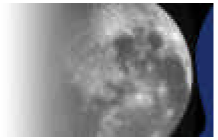
Center for Astronomical Adaptive Optics
STEWARD OBSERVATORY THE UNIVERSITY OF ARIZONA



Deep -FieldInfrared Observatory Nearthe LunarPole

PI: Simon “Pete” Worden

Roger Angel[1], Dan Eisenstein[1], Suresh Sivanandam[1], Simon P. Worden[1], Jim Burge[2], Ermanno Borra[3], Clément Gosselin[3], Omar Seddiki[3], Paul Hickson[4], Ki Bui Ma[5], Bernard Foing[6], Jean-Luc Josset[7], Simon Thibault[8]

[1]Steward Observatory, The University of Arizona, 933 N. Cherry Avenue, Tucson, AZ USA 85751
[2]Optical Sciences Center, The University of Arizona, Tucson,1630 E. University Blvd., Tucson, AZ USA 85721
[3] Université Laval, Faculté des sciences et de génie, Pavillon Alexandre-Vachon, Québec Canada G1K7P4
[4] Department of Physics & Astronomy, University of British Columbia, 6224 Agricultural Road Vancouver, B.C,. V6T 1Z1, Canada
[5] Texas Center for Superconductivity, University of Houston, Houston TX USA 77204
[6] Chief Scientist, ESA/ESTEC/SCI-S, postbus 299 Noordwijk 2200 AG Noordwijk, The Netherlands
[7] Space-X Space Exploration Institute, 1 rue Jaquet-Droz, CH-2007 Neuchâtel, Switzerland 2020
[8]Immervision, 2020 University Avenue, Montreal, Québec, Canada, H3A 2A5

NASA Institute of Advanced Concepts

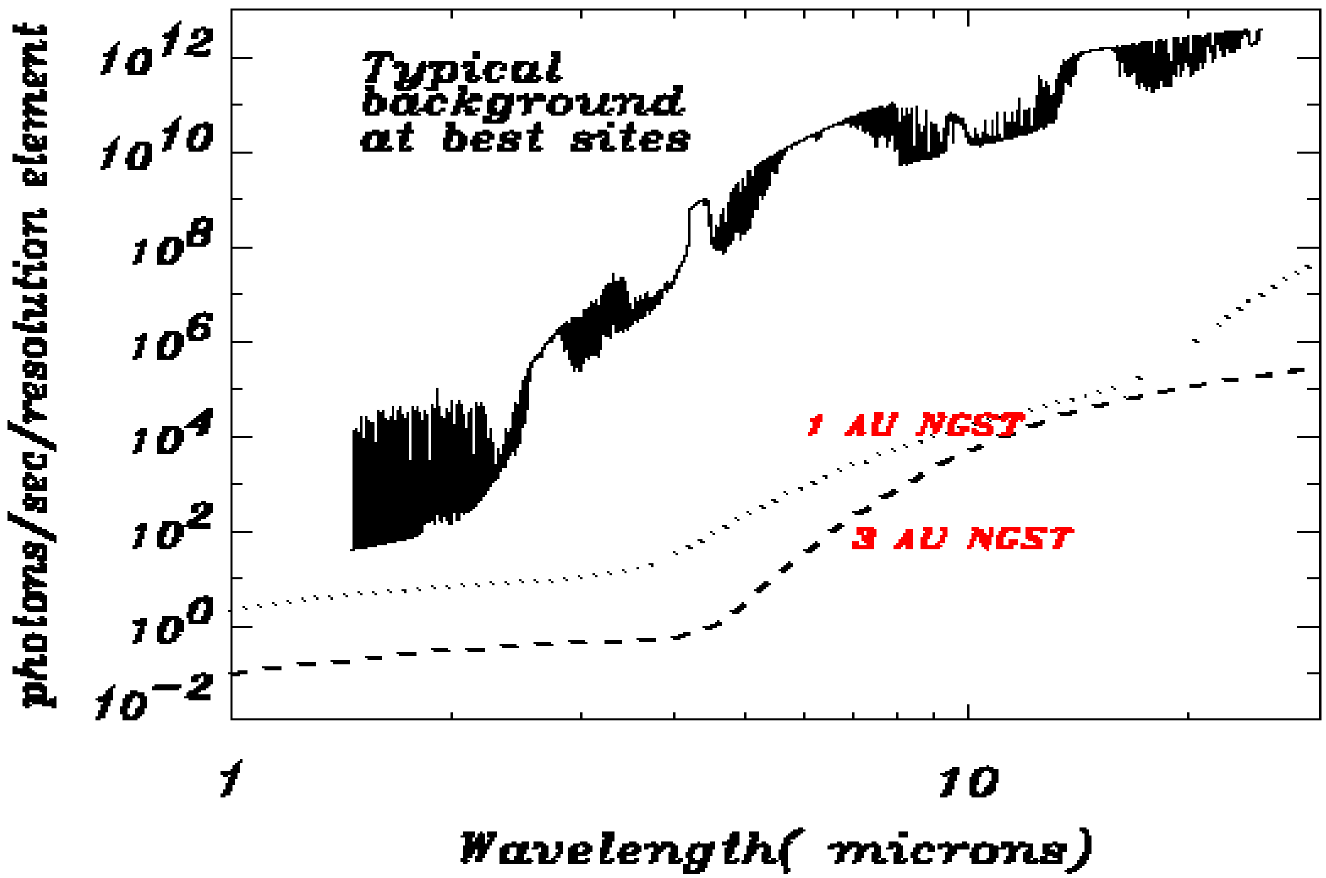
7th Annual Meeting: 11 Oct 2005

Whyan observatoryon theMoon?

- Advantages common to free space:
  - No atmospheric aberration or distortion
  - Strong radiative cooling possible for infrared spectrum (at poles)
- Unique lunar advantages
  - Large stable platform for many telescopes
  - Exploration initiative may result in infrastructure for large telescope assembly and maintainance
  - Gravity
- Lunar disadvantage vs L2
  - Powered descent needed for surface landing
  - dust might be a problem for optics or bearings
  - bearings and drives required for pointing and tracking (versus gyros for free space)

Backgroundlight inspace

- Lunar sky is ~ 10^6 times fainter than Earth's at 10 um
- -> 1000 times fainter detection limit

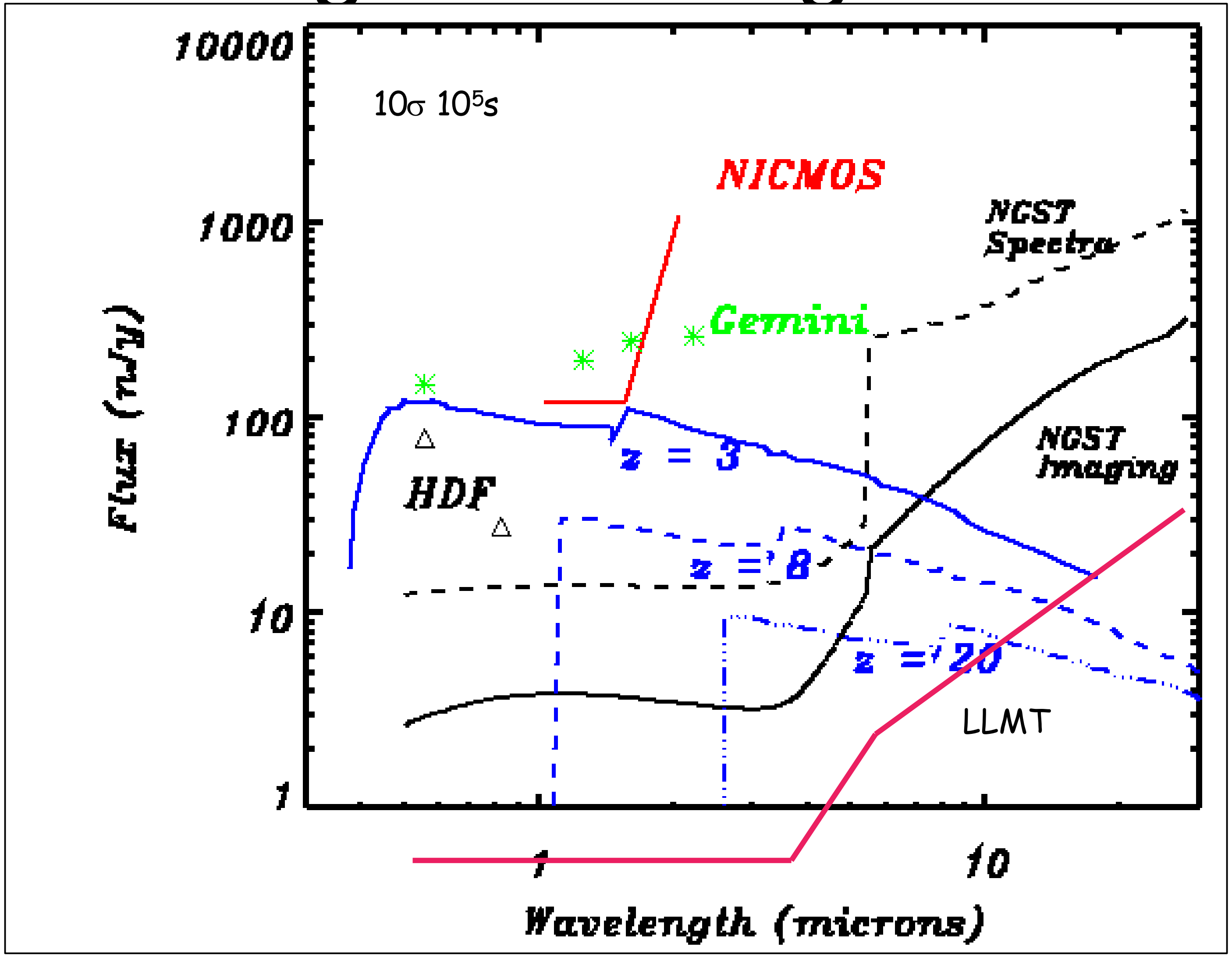


Space Telescope Science Institute

Ultradeep fieldobservatory can takebest advantageof moon

- Deep extragalactic fields are a goldmine for understanding origins of universe and cosmology
  - Hubble, ground optical and radio, Spitzer, Chandra
- Any direction clear of absorption by our galaxy is good
- A suite of telescopes co-pointed along moon's spin axis
  - Simple telescopes long exposure with no tracking
  - Could provide ultimate deep field, across the electromagnetic spectrum
- Infrared especially important to see first, highly redshifted stars, galaxies and forming quasars
  - Far ultraviolet Lyman limit shifted from 912 A to 2 microns at z=20

High-redshiftgalaxies



JWST

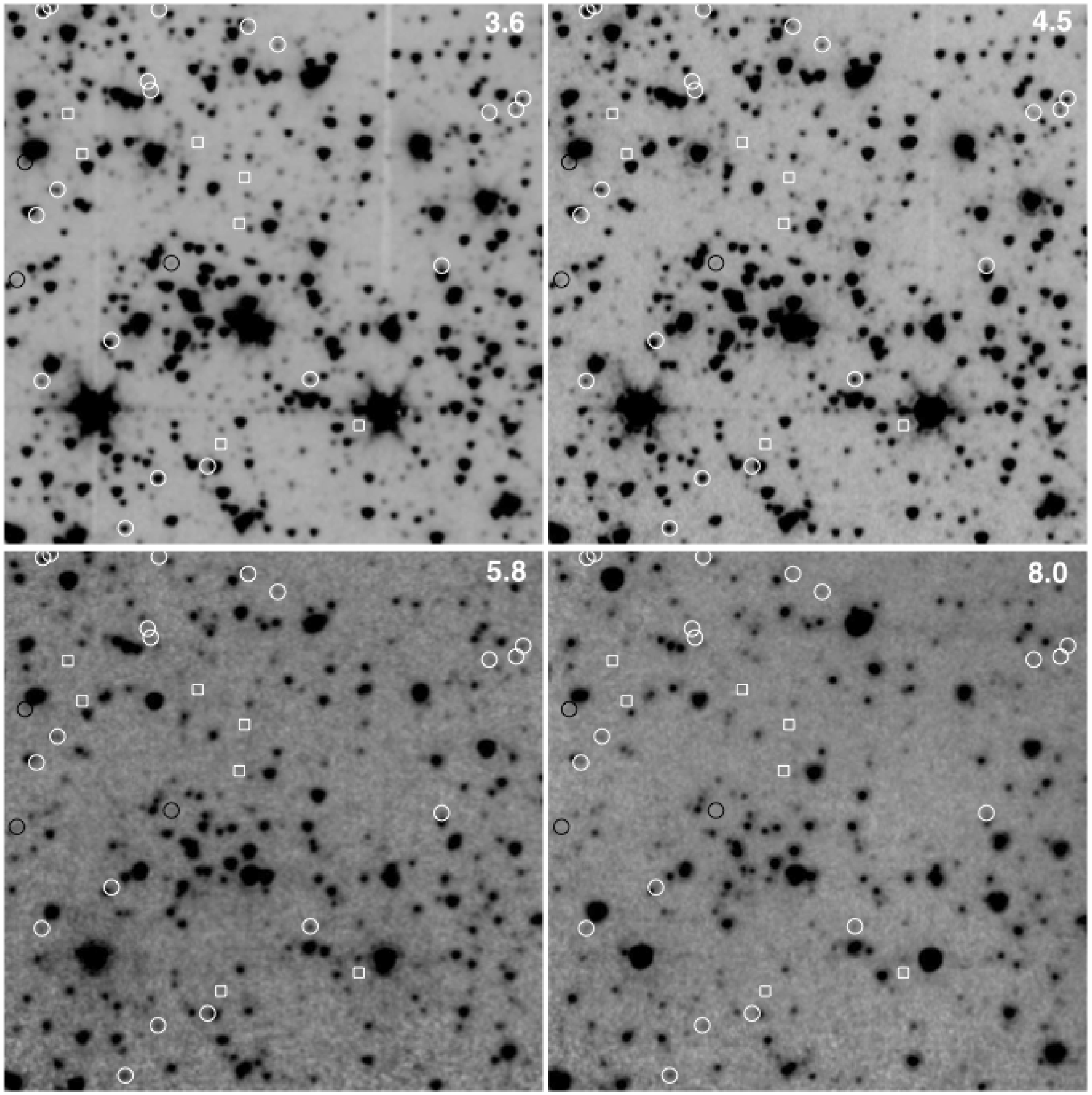
Galaxyevolution
(Spitzer0.85 mcold telescope)

- Assembly of galaxies
- Formation of the Hubble sequence
- Role of interactions and starbursts
- Development of AGN
- Evolution of disks
- Role of the environment

Advantages of LLMT:

Better sensitivity

Better resolution



3.5 x 3.5 arcmin Spitzer/IRAC images (Barmby et al 2004)

Needfor verylarge aperture

- Lunar telescope would go to the next level of sensitivity, beyond HST and JWST
- JWST will be 6.5 m diameter D, cooled infrared telescope at L2, with longest integrations of t~ 1 month
- Lunar telescope should have D > 20 m and integrate for many years
- Sensitivity as D2√t: compared to JWST
  - 20 m for 1 year will be 30 times more sensitive
  - 100 m would be 1000 times more sensitive
  - Virtually impossible by rigid mirror technology

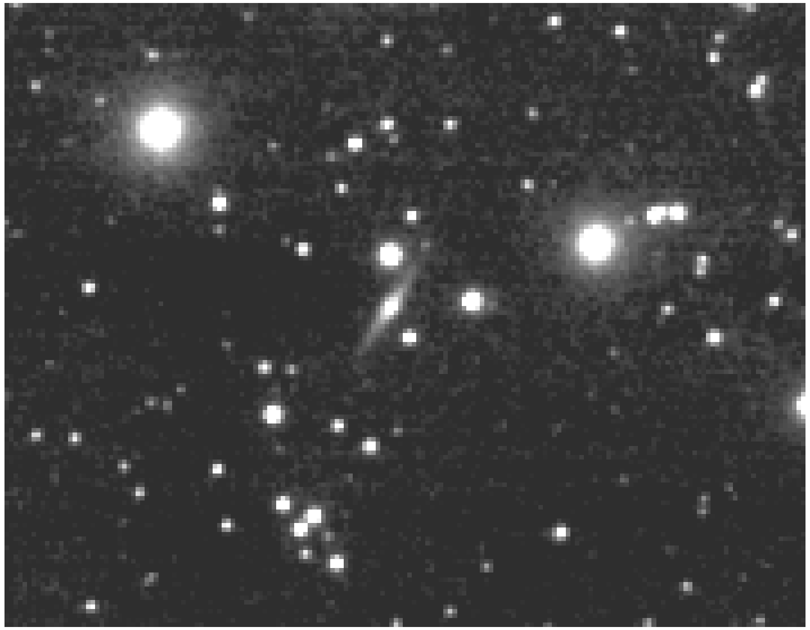
Liquidmirror telescope

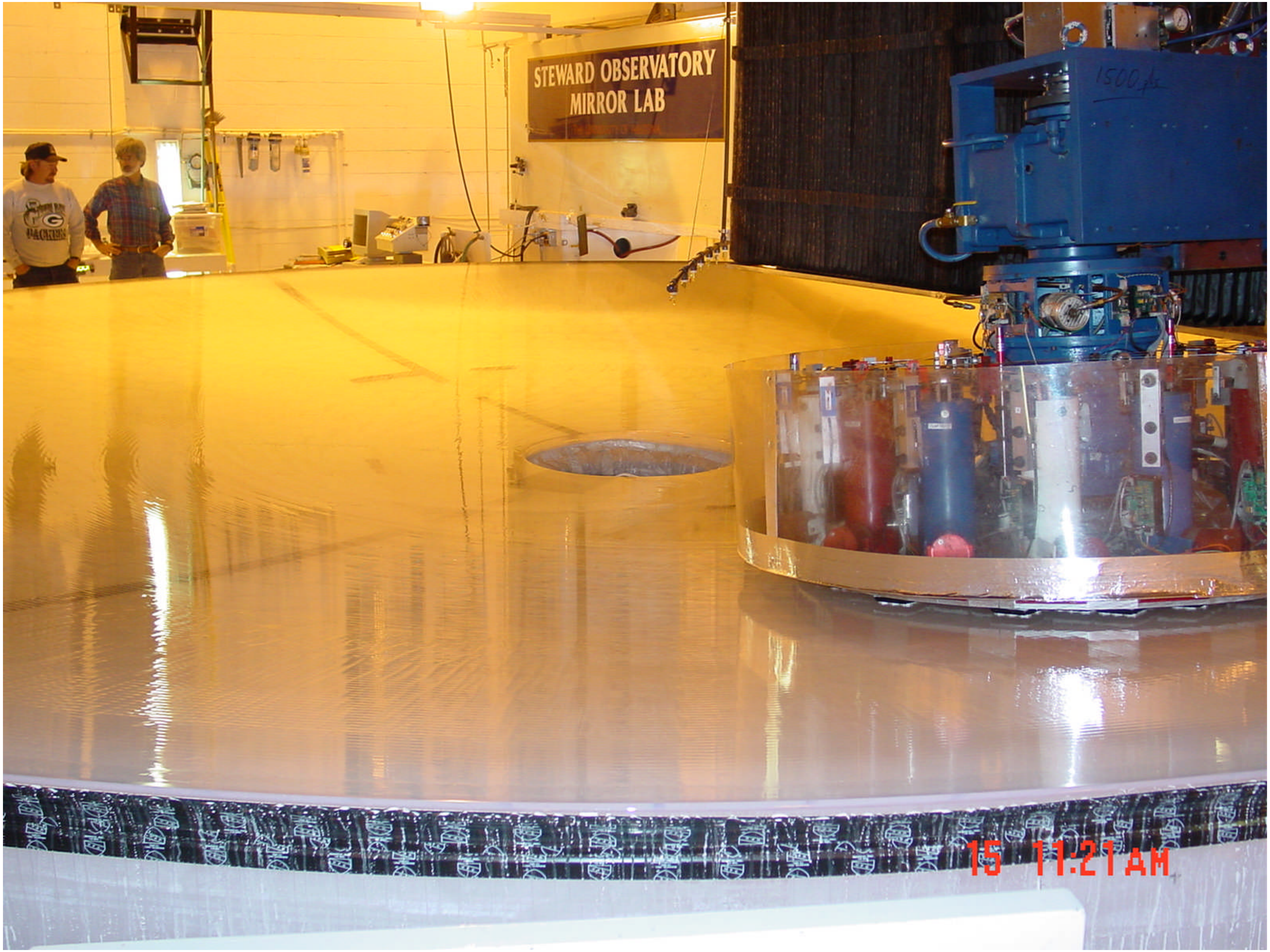
- Way to get very large apertureat low cost
  - Proven on ground to 6 m
  - Borra and Hickson in Canada
- Currentground status
- Lunar locationat poles
  - Superconducting bearing
  - Reflective coating a cryogenic liquid
  - Optical design for long integration

The 6 m diameter mercury liquid mirror of the LZT
(courtesy P. Hickson)

6m performance (nearVancouver!)

- Seeing-limited (FWHM ~ 1.4”)
- R_{AB} ~ 22.5 in 100 sec
- 30 sq degrees every clear night
- Testbed for future projects

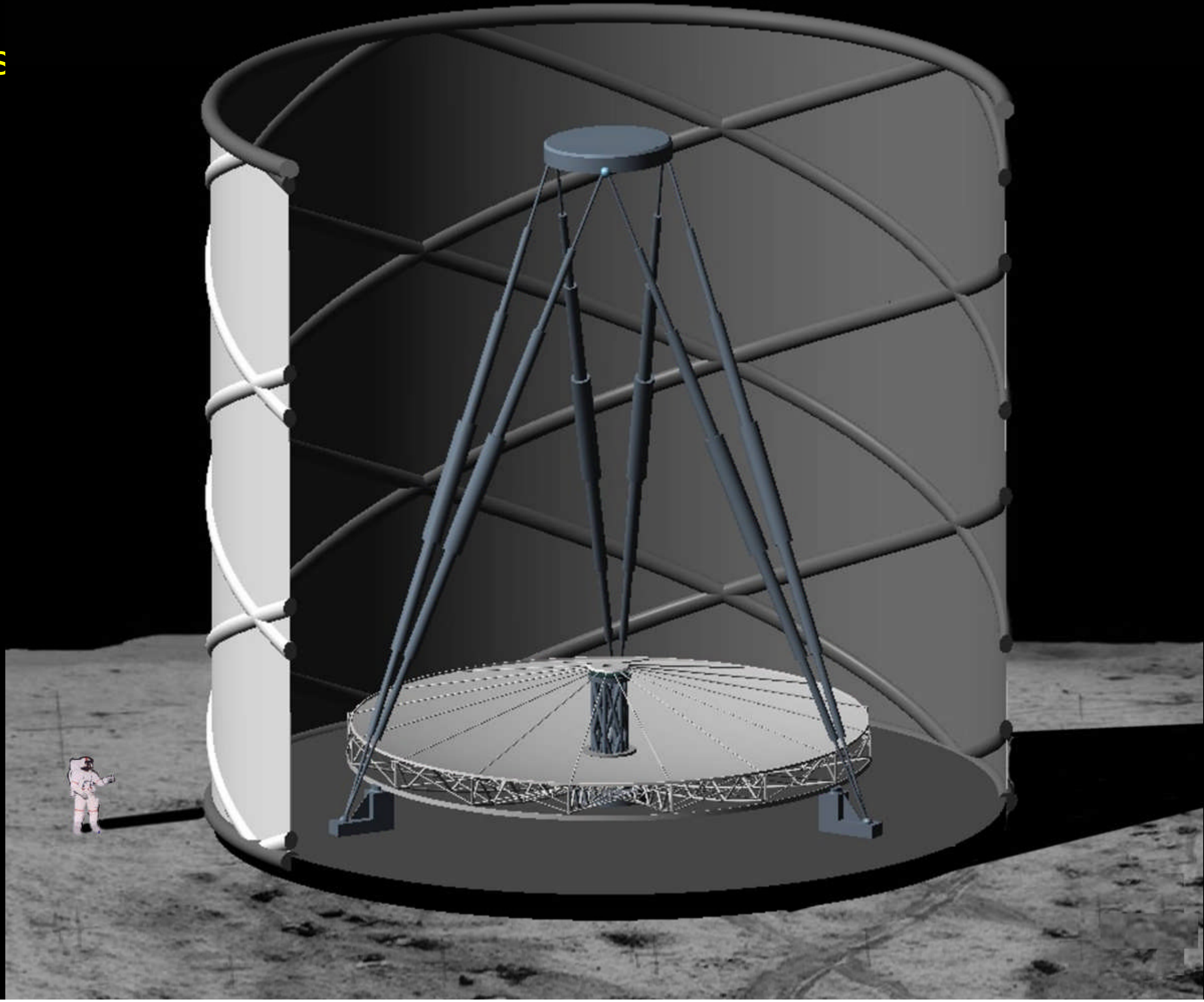



STEWARD OBSERVATORY
MIRROR LAB
15 11:21 AM

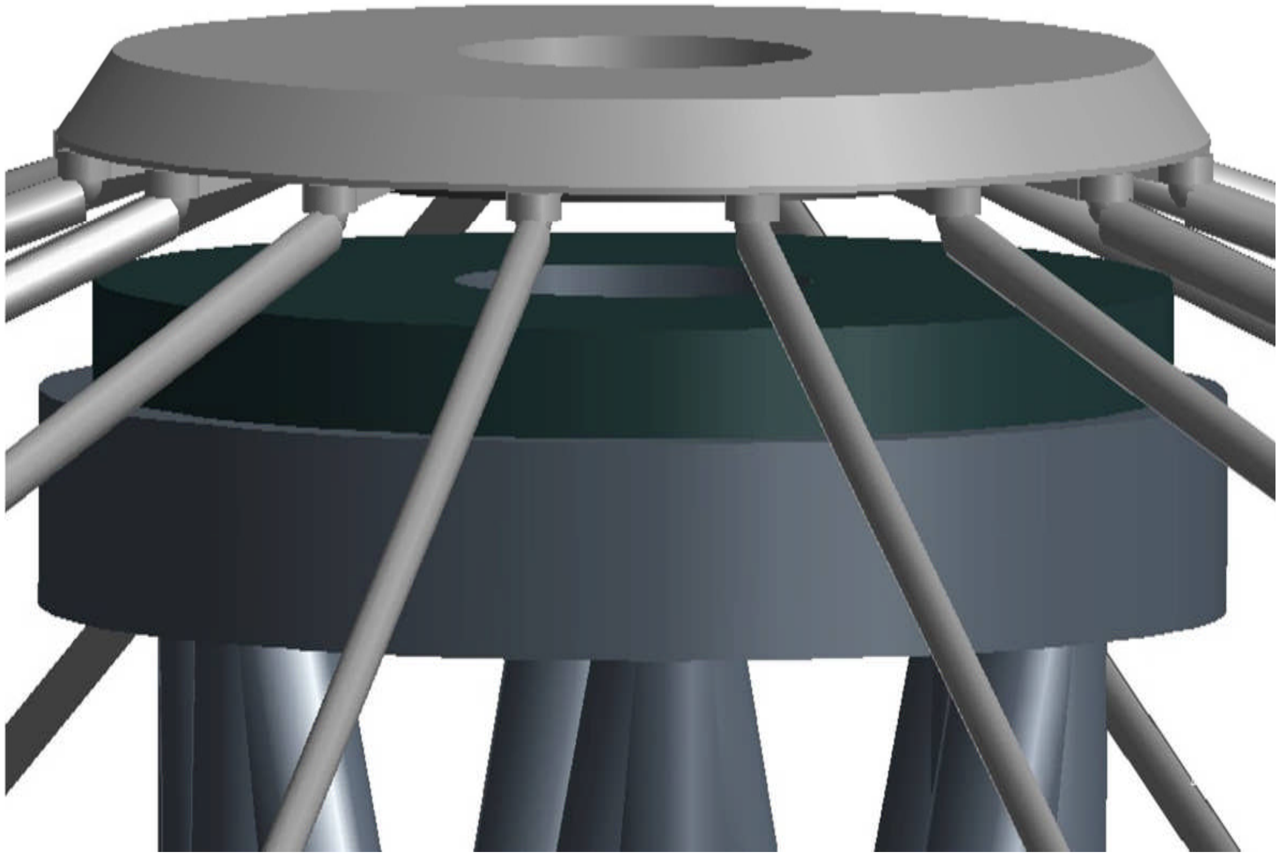
Locationat lunarpole

- Zenith view fixed on sky along spin axis
- Deep integrationwith no steering
- Strong radiative cooling for high infrared sensitivity possible
  – Use cylindrical radiation shield
  – Shields from sun always on horizon

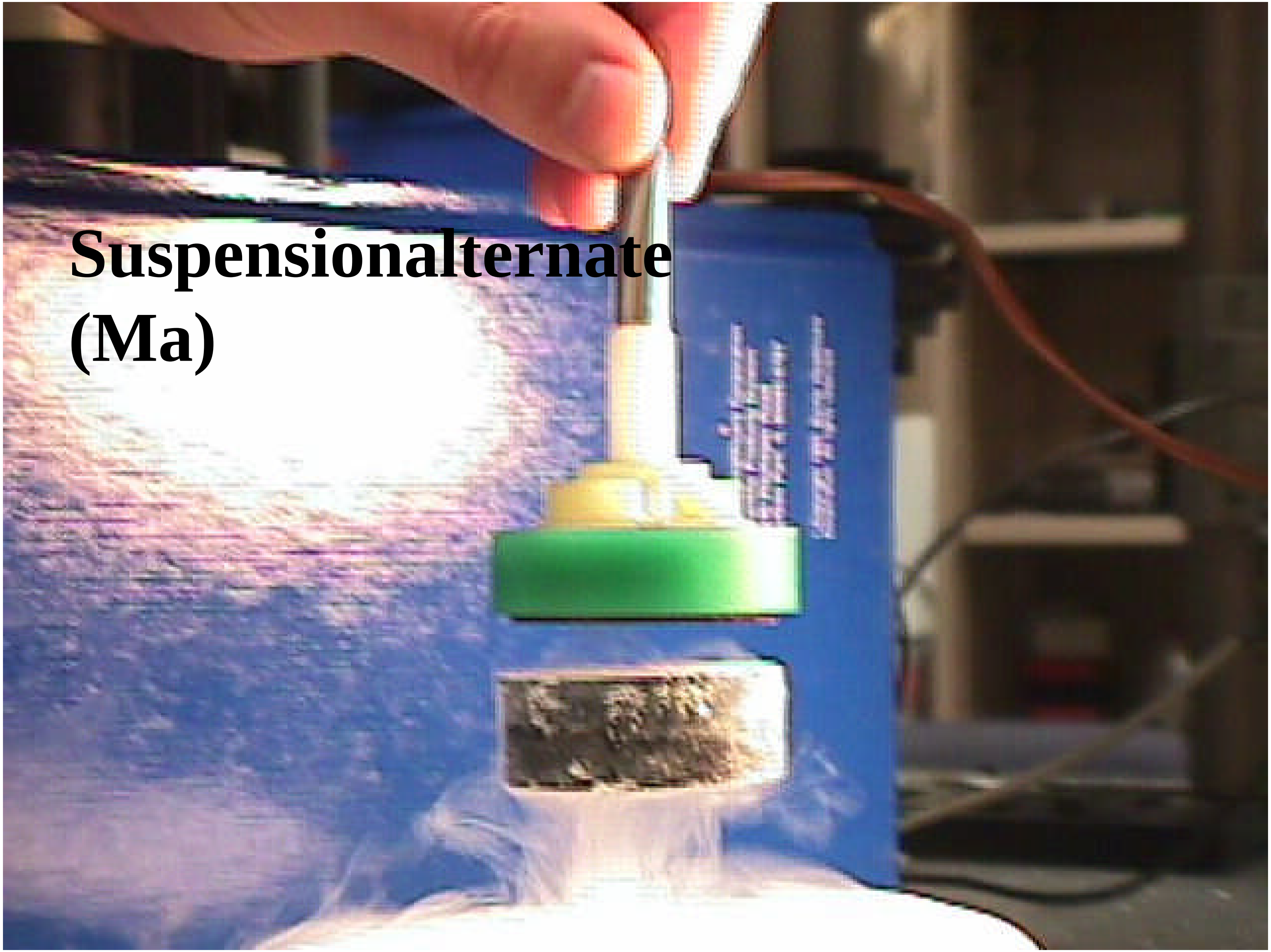
Artist's impression of the 20 m telescope. The secondary mirror is erected by extending the six telescoping legs, and the sunshield by inflation. The scientific instruments are below the bearing pier, shielded by lunar soil.
(Tom Connors

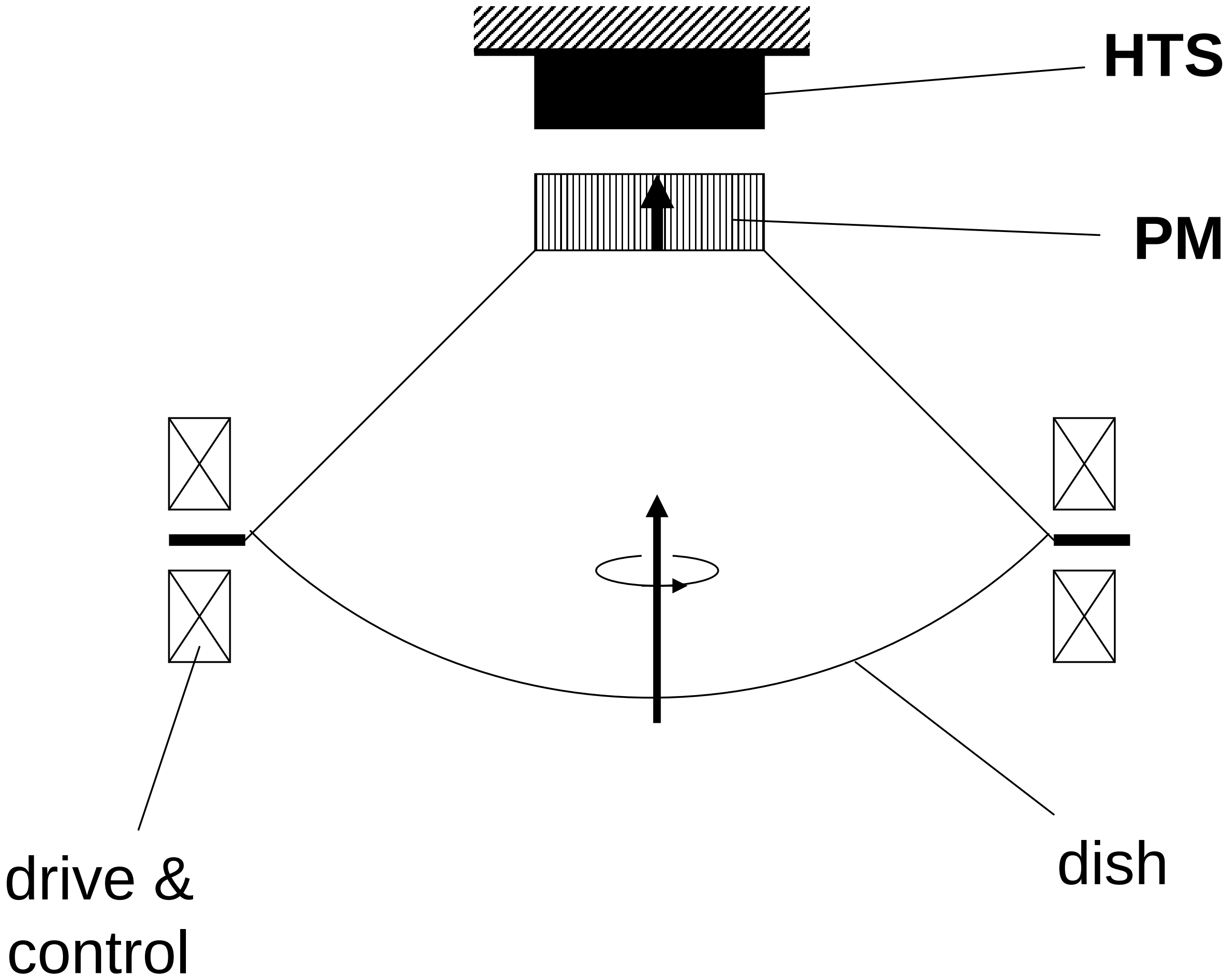


Firstconcept forsuperconducting levitationbearing



Suspensionalternate (Ma)




HTS
PM
drive &
control
dish

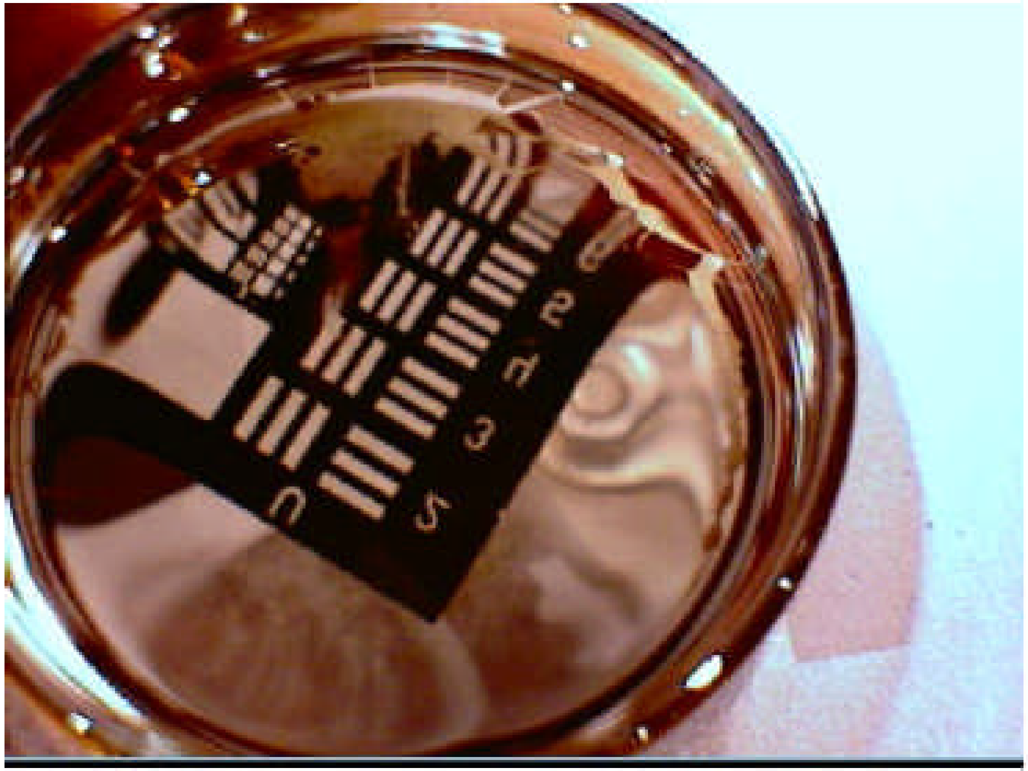
“toy” systemand scaling

- Bearing
  - Superconductor diameter, 1 in., height, 0.5 in. 55g
  - Permanent magnet, 0.875 in., height 0.5 in. 30 g
  - Gap of a few mm, different each time

- Suspended mirror assembly
  - Suspension length 12.75 in.
  - Weight 180g
  - The speed of rotation 40 RPM to 60 RPM
  - Liquid surface 6” diameter, f/1

- Scaling
  - increasing all dimensions increases bearing mass as cube, load as square
  - simple 30” scale up model would weigh 2.5 tons and lift 1 ton mass on the moon
  - Optimization could improve high mass ratio by 10 x

Mirror surface of silver on polypropelene glycol deposited by Ermanno Borra, Université Laval

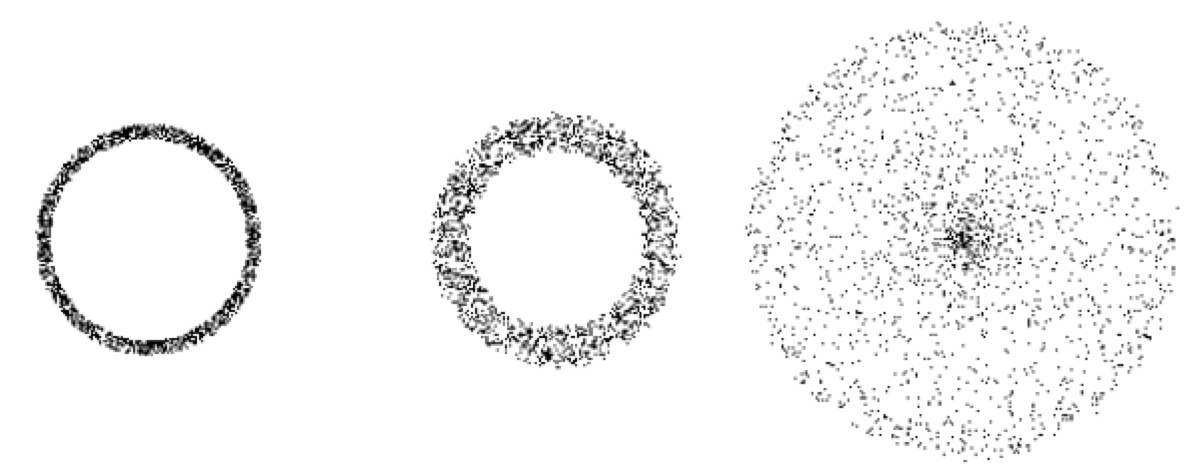


RECENT RESULT – SUCCESS WITH SILVER ON AN IONIC LIQUID (LOW TEMPERATURE) – Promises a suitable liquid can be found

Locationand opticaldesign

- Wide field imaging best close to zenith
- Only at pole is zenith view constant
  - Location very close to pole strongly favored
- Moon's spin axis precession
  - 18 year period
  - 1.55 degree tilt angle
- Axis point moves at 1/2º/year in 3º dia circle
- ½ degree field will allow for 1 year integrations
- Another possibility is to make optics to track ecliptic pole at 1.55 field angle
  - Small field correctable, but always in view

Effect of location on sky access for a zenith-pointed telescope with 0.2 degree field of view



The integrated exposure over 18 years is shown in each case.

Left – at the pole, over 18.6 years the field sweeps out an annulus 3.1 degrees in diameter centered on the ecliptic pole, with continuous integration of ~ 5 months on any one spot.

Center – 0.2 degrees from the pole, the field sweeps out a half degree annulus each month, covering any one spot every month for a year

Right – 1.55 degrees from the pole. Each month the field sweeps a 3.1 degree annulus, covering any spot for about 15 hours. The ecliptic pole is seen for this time every month, for a total integration time of 5 months over 18 years

Possiblesequence

- Micro site survey
- 1.7 m robotic wide field survey
  - Complements Spitzer and JWST
- 20 m
  - Follow up spectroscopy of JWST candidates
- 100 m
  - Completely unique

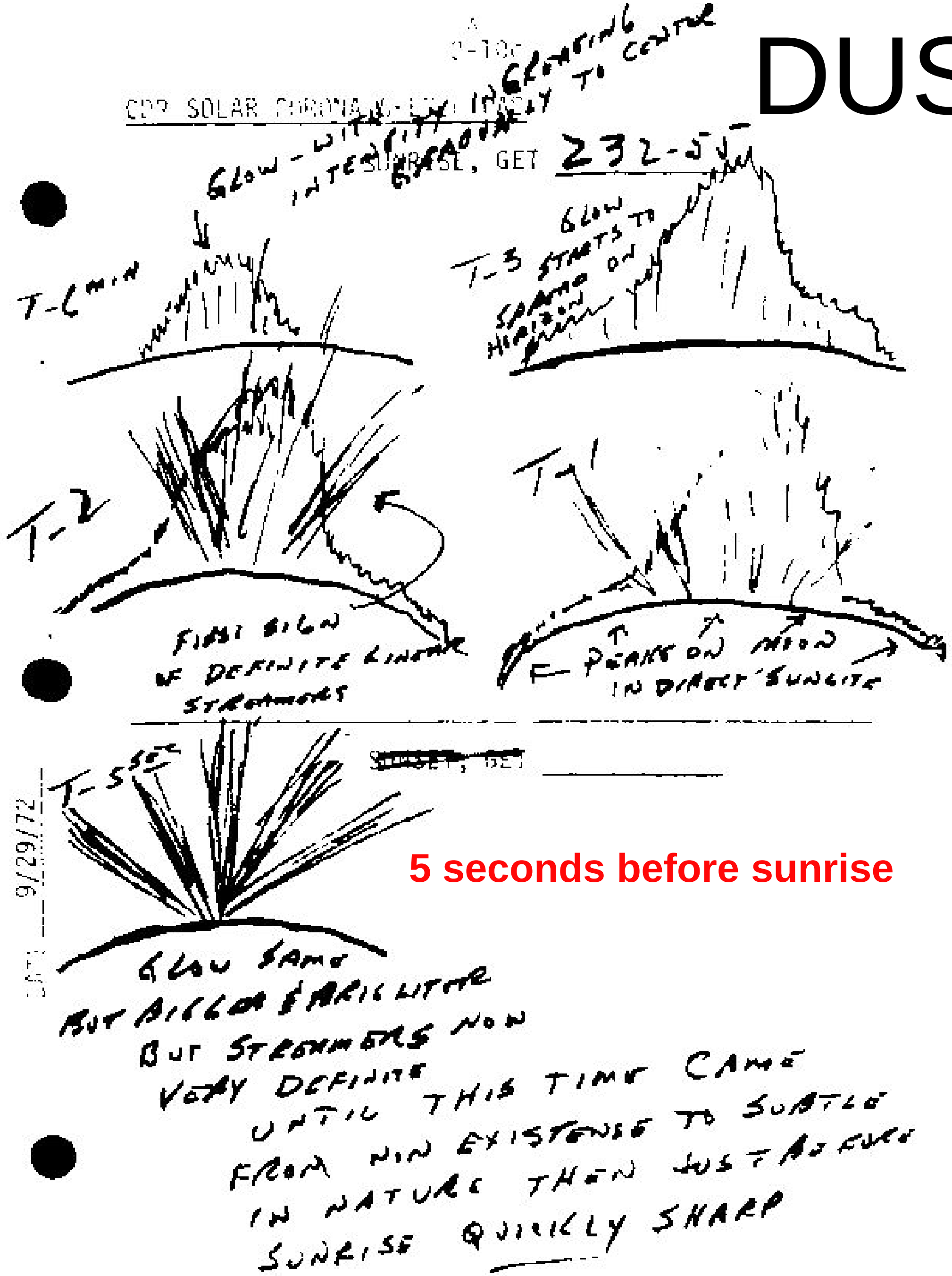
SiteSelection: Northor SouthPole

Sky Considerations:

- Dust contamination/atmosphere [Both?]
  - Circumstantial evidence supports dust levitation and dust atmosphere.
  - Dust may contaminate optics, introduce stray light, and increase sky background.
- Stellar field contamination [South?]
  - Large Magellanic Cloud (LMC) contaminates South pole sky view.

Note: [?] indicates we need to investigate that location further.

DUST



5 seconds before sunrise

Sketch by Apollo 17 astronaut, Capt. Cernan.

- Streamers observed in lunar orbit at a 100 km altitude while approaching the terminator from the dark side.
- Streamers interpreted to be similar to those observed terrestrially as sun sets over irregular horizon.
- Possible evidence for lunar dust atmosphere extending beyond orbital module’s altitude or local scattering layer since streamers are generated by forward-scattered light.
- **No mechanism that generates a high-altitude lunar dust atmosphere is known.**

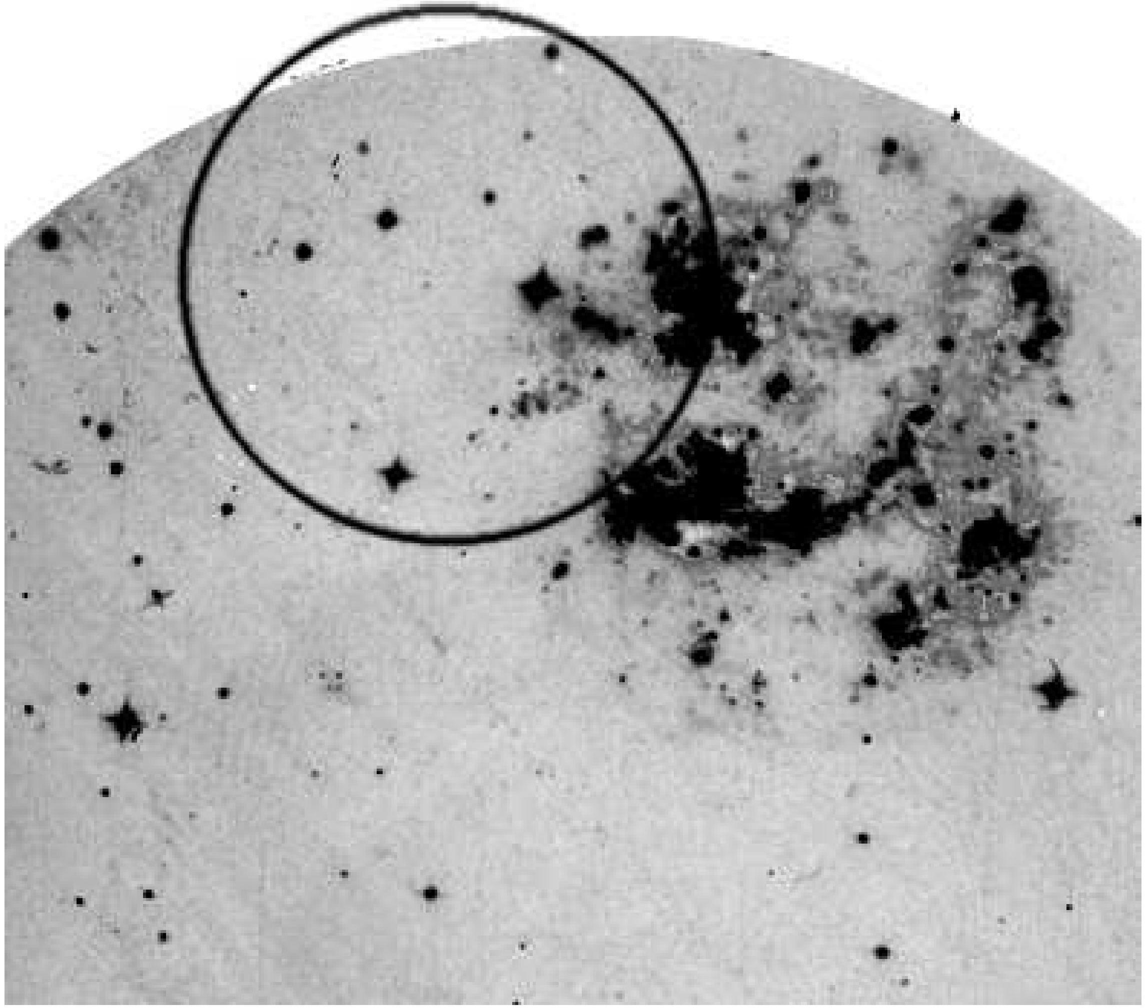
Moreon DUST

- Observed horizon glow from Surveyor 7 images.
  - Modeled to be low-level levitation (10-30 cm) of micron-sized dust particles powered by photoelectric charging of lunar surface by solar UV/X-ray photons.
- Anomalous Lunokhod-II sky brightness measurements.
  - Observed over-brightness correlated with solar zenith angle.
- Anomalous brightness in solar corona observed by astronauts just after sunset.
  - Hypothesized to be forward-scattered light.

But conditions may be fine for proposed work:

- Solar flux in polar regions much smaller.
- Lunar retro-reflectors have shown little degradation.

Require in-situ observations for confirmation.

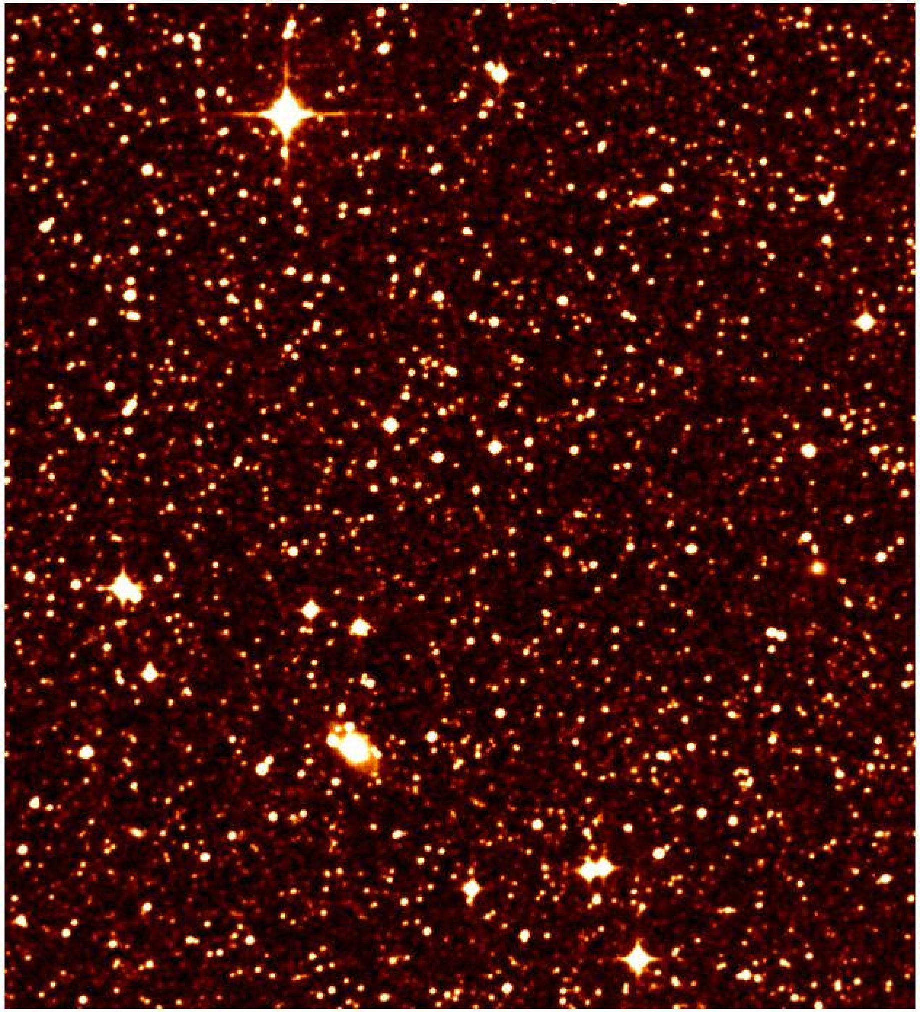


The circle shows the 6° diameter field accessible to the lunar zenith pointing telescope.

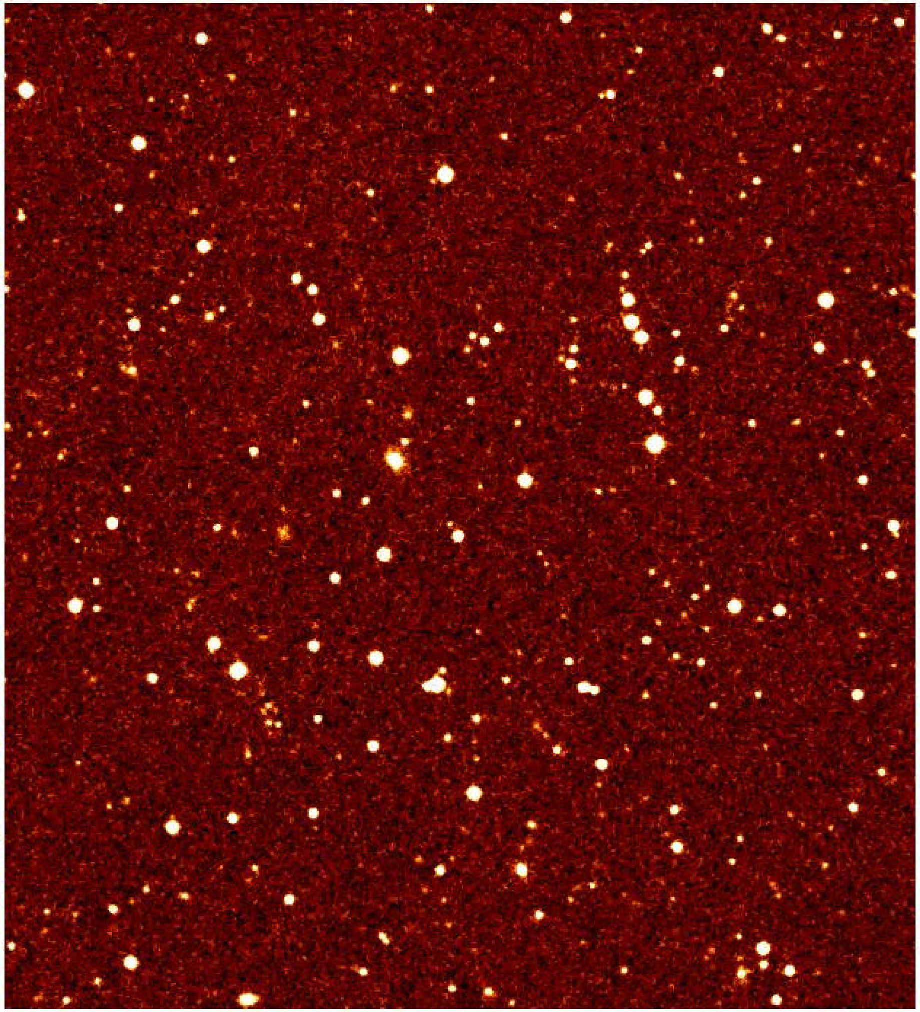
Ultraviolet image from the Moon, John Young & Charles Duke

Stellar Contaminationat ecliptic poles

POSS2 Red Images (12’ by 12’ FOV, 2” resolution, R_{limit} = 21):



South pole view

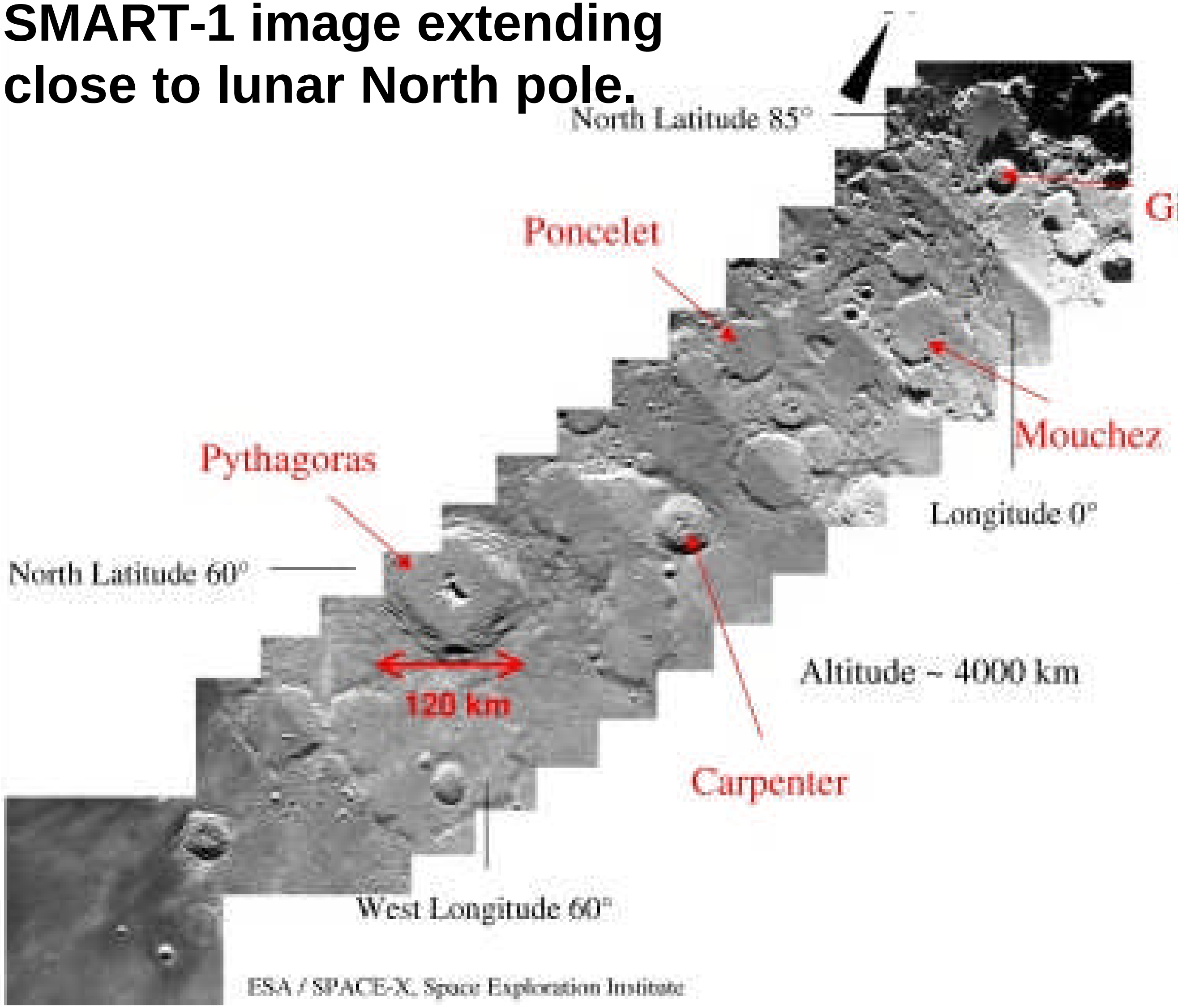


North pole view

May be confusion-limited by LMC stars at the South pole.

NorthPole Illumination:SMART -1

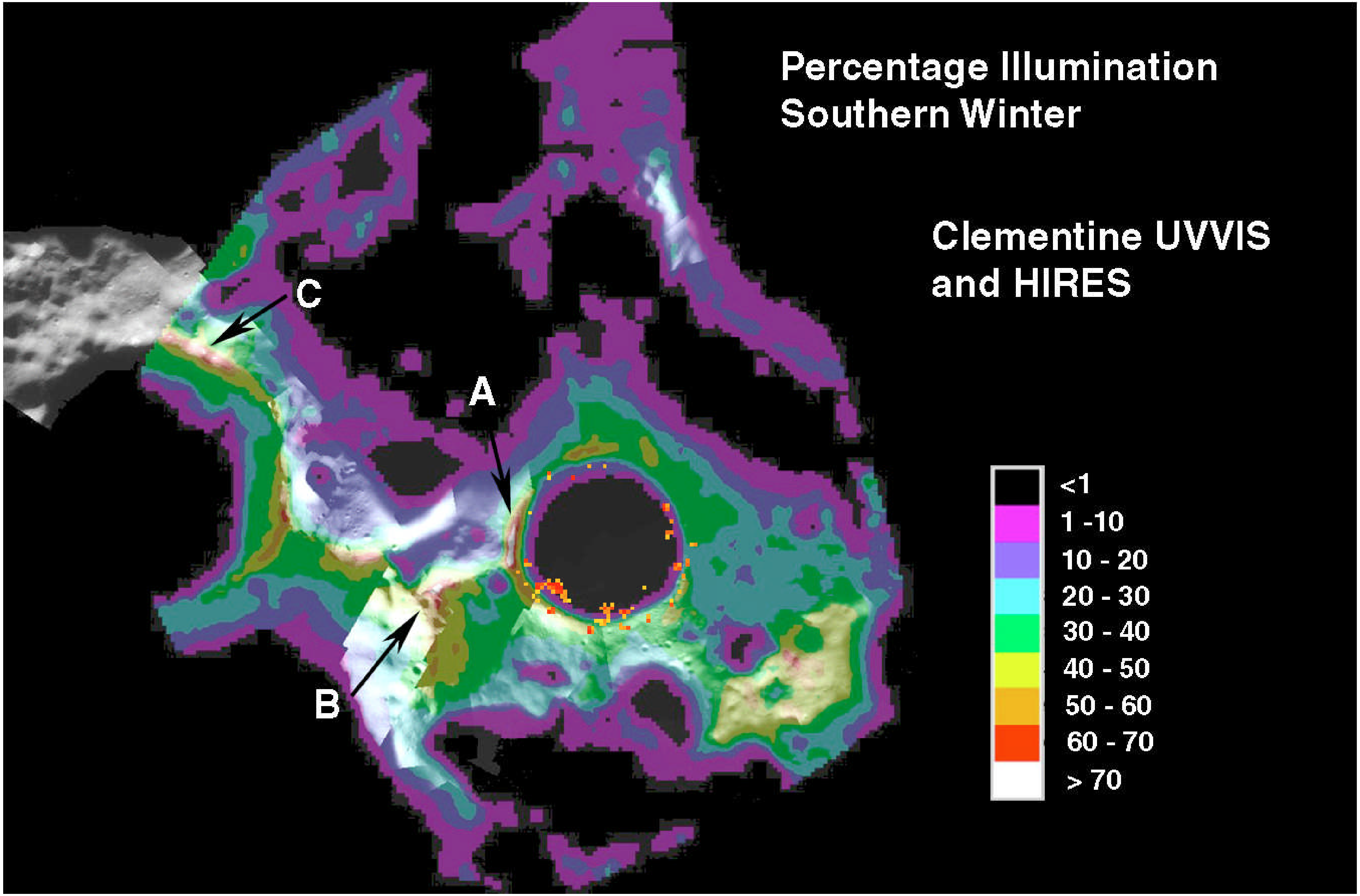
SMART-1 image extending close to lunar North pole.



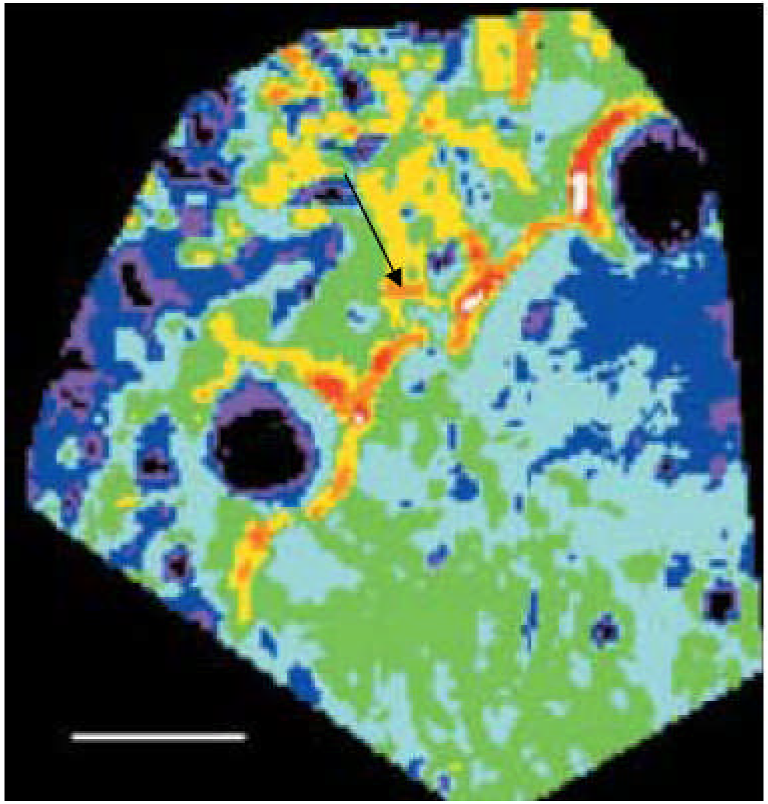
- ESA's SMART-1 lunar probe has made observations of the North pole during January 2005, the middle of the lunar winter in the northern hemisphere.

- We will analyze the data in the near future to determine if there are peaks of eternal light in the North pole as seen in the South pole.

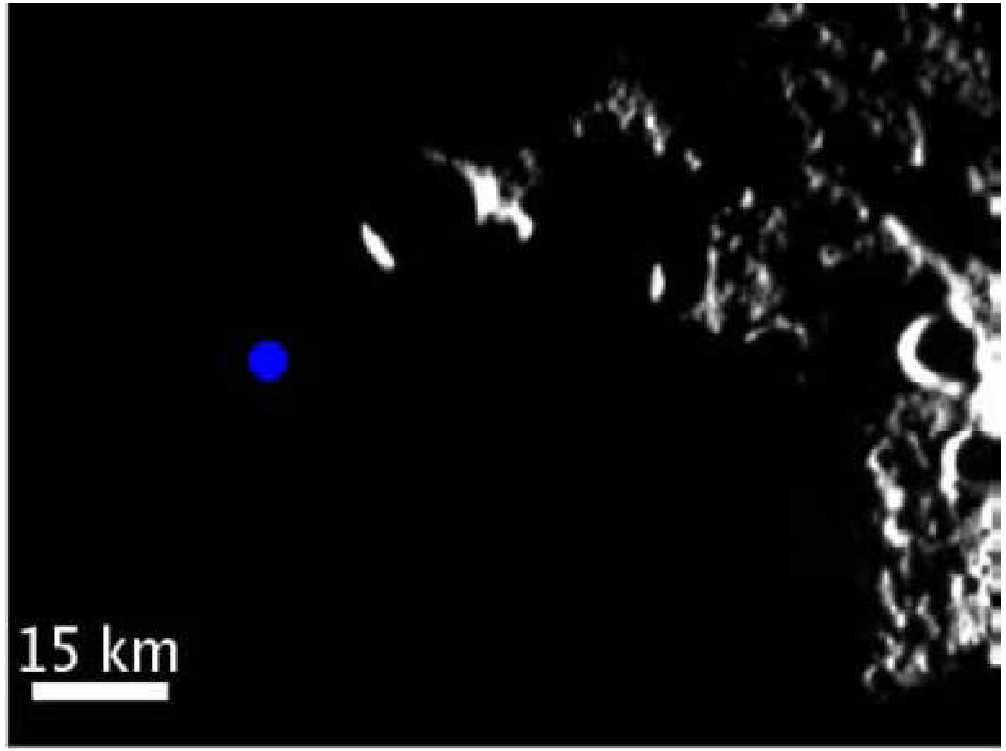
Power: South Pole Illuminationi n Winter



TheNorth Pole?



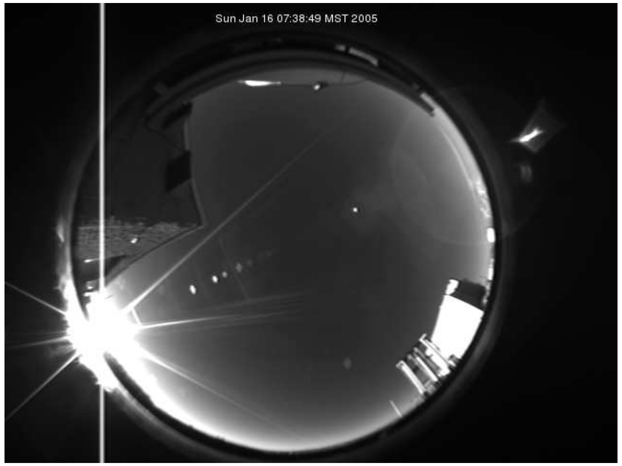
Summertime illumination map generated from Clementine data of the North Pole (marked by arrow). The scale bar on the left is 15km in length.

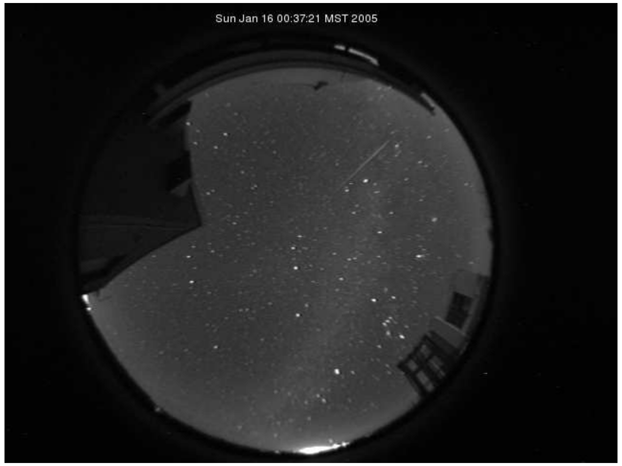


SMART-1 AMIE image of the North pole in mid-winter. The dark pole is marked in blue, and the nearest crater is still showing illumination. 15 km distant is the top-right crater at left, which has 100% summer illumination. Solar panels on this ridge would provide power for at least some of the winter months (Credit: ESA/SMART-1/AMIE team/Space-X Space Exploration Institute)

SiteSurvey Proposal

- Determine Sky Brightness in the IR and Visible
- Determine Dust Environment – Expose Liquid Test Cell
- Small Fisheye Cameras – for Visible
- Cooled IR Zenith Camera

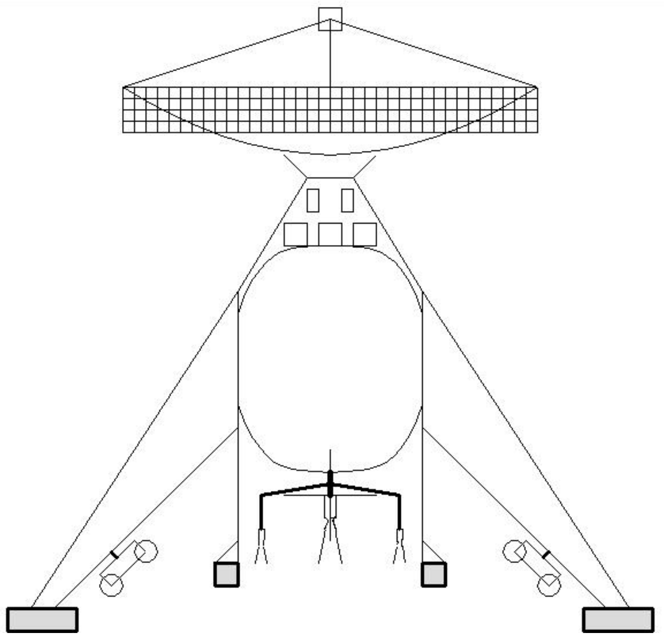


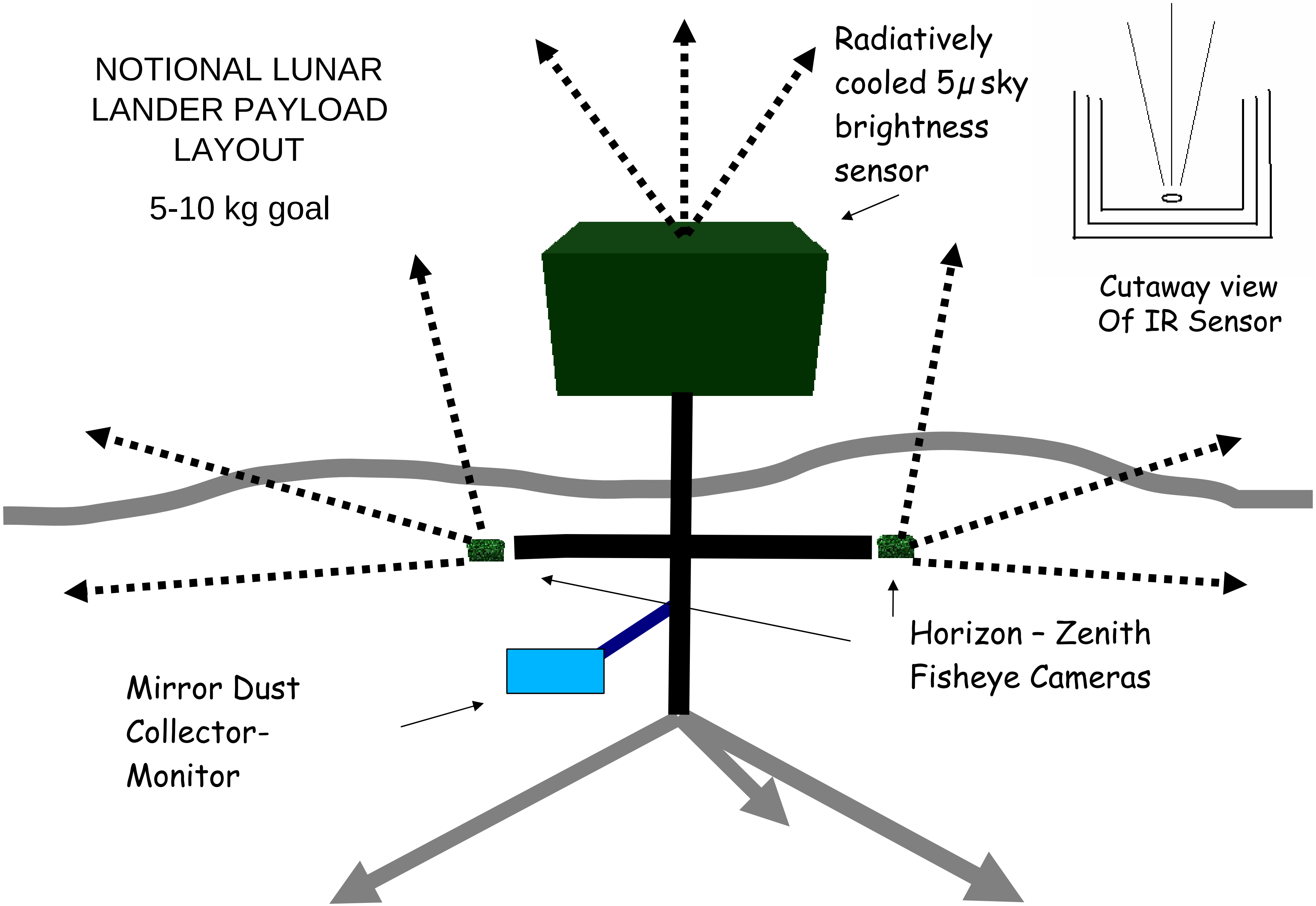


Fisheye Images from the MMT, Mt Hopkins, AZ

CommercialLunar Lander – MillenniumSpace Design

Subsystem	CBE Mass (kg)
Structure	22.80
Communications	4.66
Power	11.18
Attitude Control	1.69
Avionics	1.55
Propulsion	39.62
Thermal	2.10
Mechanisms	3.20
Payload	5.30
Propellant	533.50
Launch Vehicle Adapter	2.11




NOTIONAL LUNAR LANDER PAYLOAD LAYOUT
5-10 kg goal
Radiatively cooled 5μ sky brightness sensor
Cutaway view Of IR Sensor
Horizon – Zenith Fisheye Cameras
Mirror Dust Collector-Monitor

Workto BeDone inPhase II

- Lunar polar telescope sites appealing – issues to be resolved
  - Dust
  - Solar and Terrestrial access
  - Deepest Fields Possible? N vs S Pole
- Value of Science versus alternatives
- Key Technical Issues
  - Cost
  - Telescope design refinement
  - Choice of cryogenic liquid
- Low Cost Survey Mission Possible to resolve issues – Definition Needed
- As in Real Estate – LOCATION, LOCATION, LOCATION!