NIAC Atlanta

A deep field infrared observatory near the lunar polar

Roger Angel and Pete Worden

March 15 2005

personnel and areas of expertise

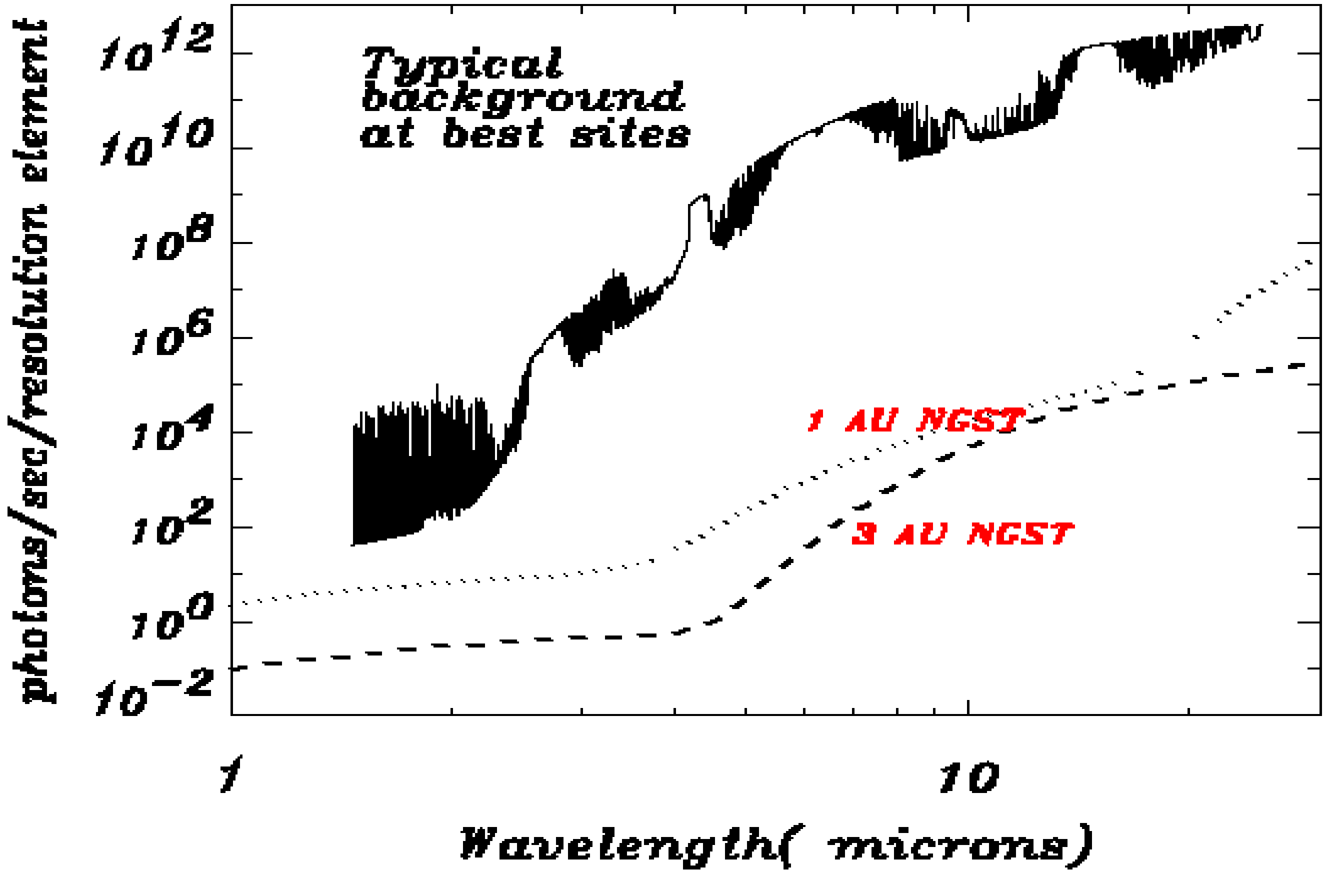
Roger Angel	U. Arizona	PI	Design of space and ground telescopes
Ermanno Borra	U. Laval	Unpaid Co-I	Liquid mirror telescopes
Paul Hickson	UBC	Unpaid CoI	Science, liquid mirror telescopes
K. Ma	U Houston	Co-I	Superconducting bearings
Pete Worden	U Arizona	Co-I	Lunar logistics, site survey mission
Gil Moretto	National Solar Obs	consultant	Optical design
Suresh Sivanandam	U Arizona	grad student	Liquid mirrors, lunar pole sites, choice of pole

Why an observatory on the Moon?

- 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)

Background light in space

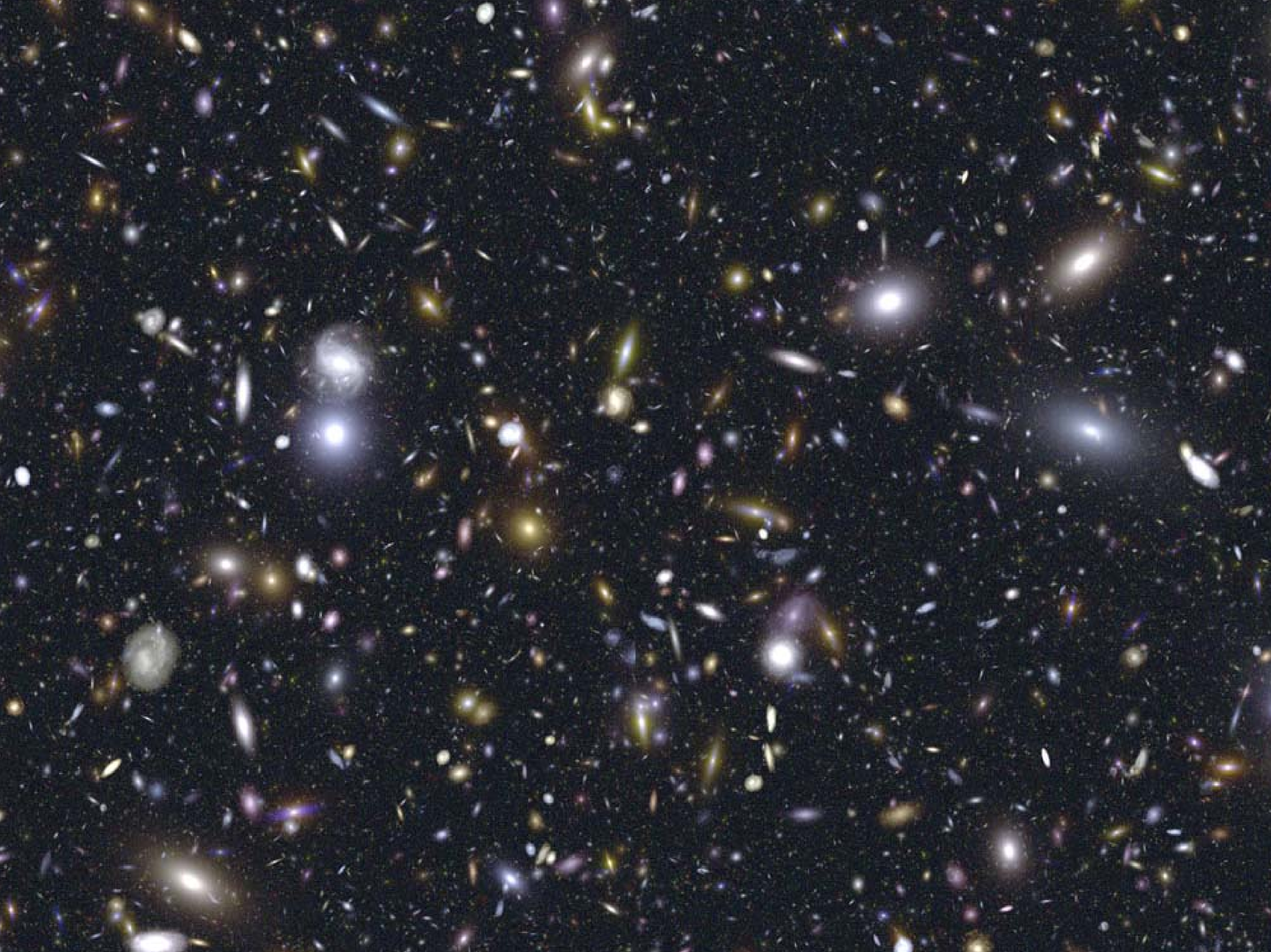
- Lunar sky is ~ 10^6 times fainter than Earth's at 10 um
- -> 1000 times fainter detection limit



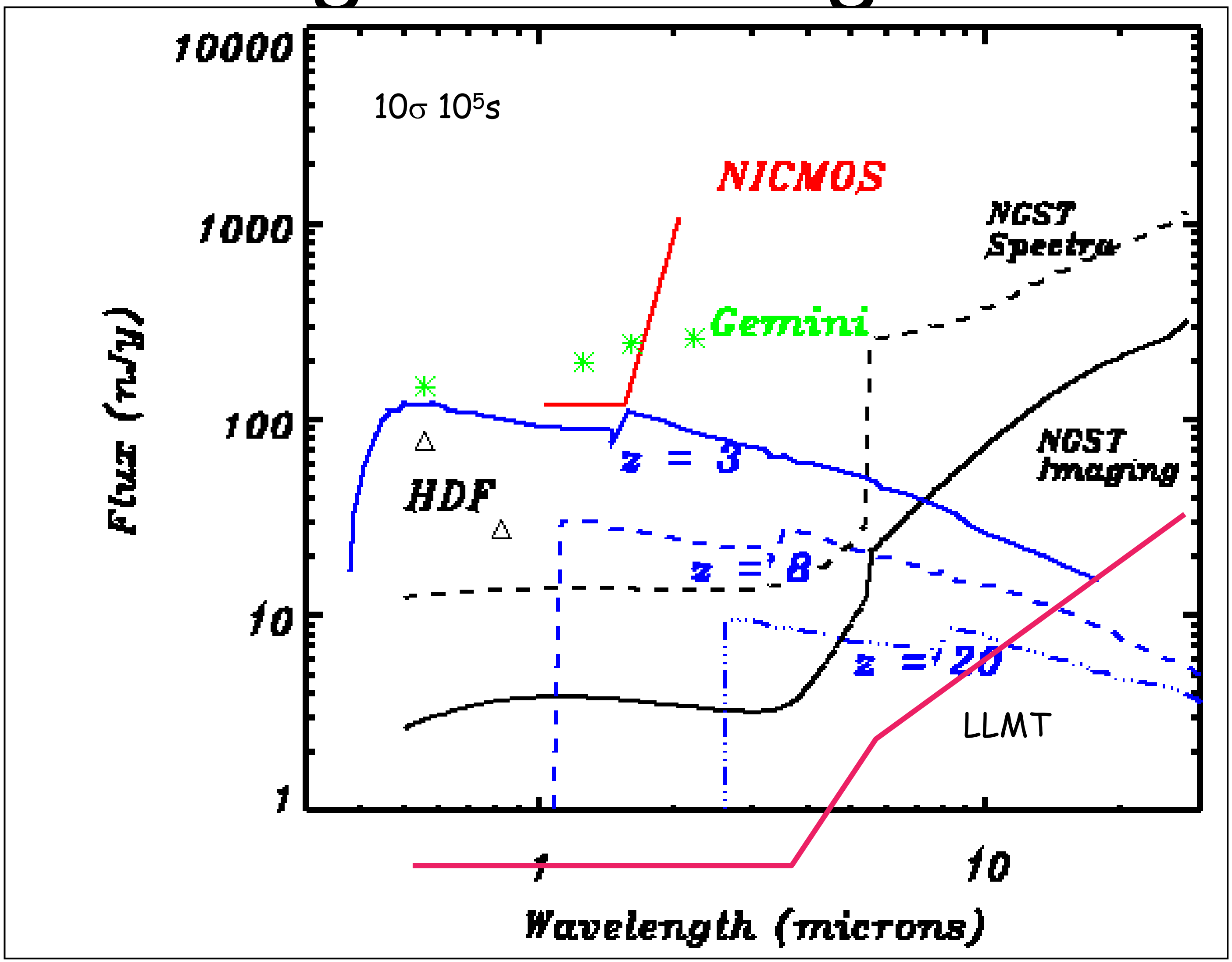
Space Telescope Science Institute

Ultradeep field observatory can take best advantage of 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
- Interferometers to look out on spin axis also require no moving parts, greatly simplified
  - High resolution at longer IR and sub-millimeter wavelengths



High-redshift galaxies



JWST

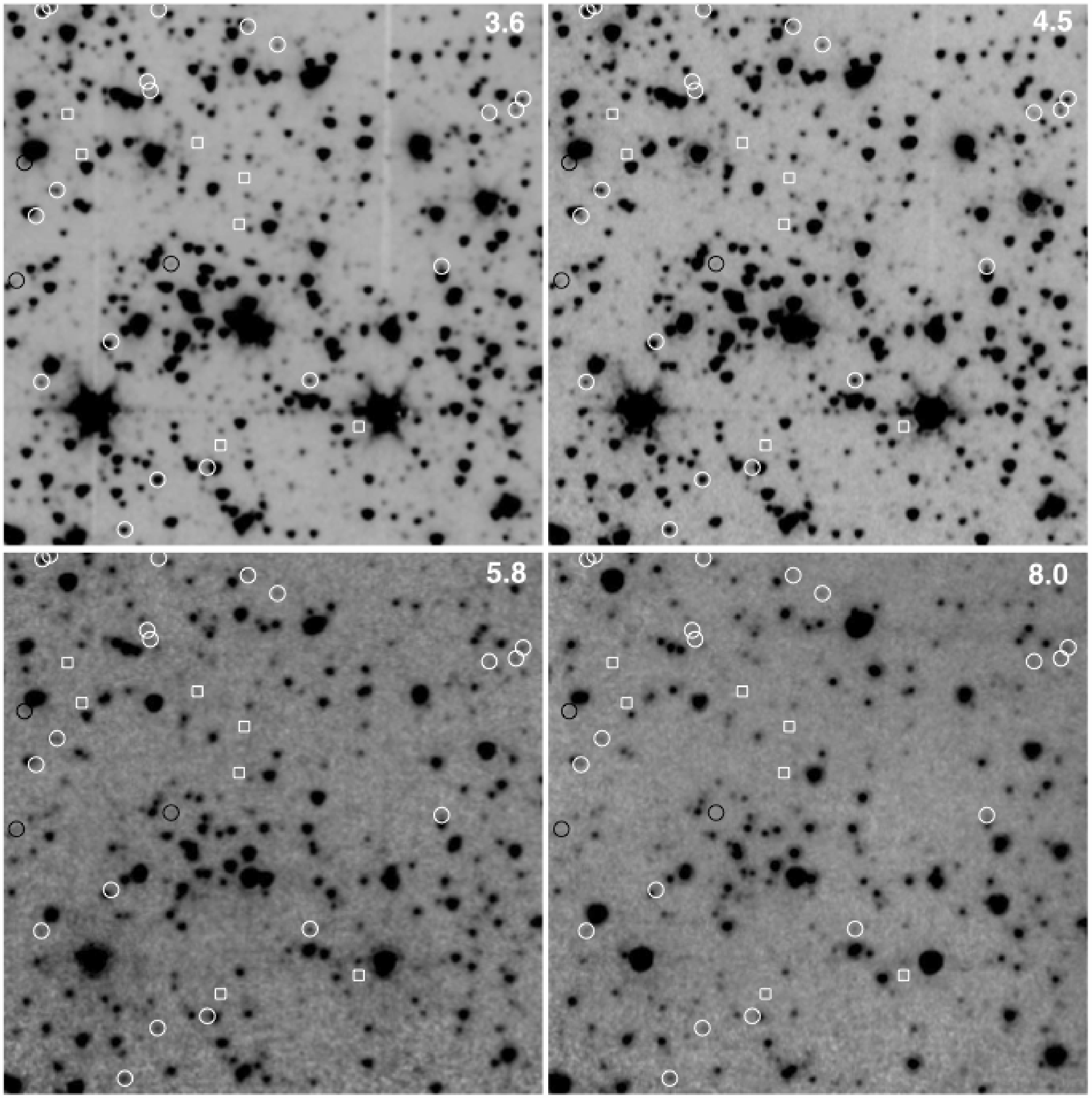
Galaxy evolution (Spitzer 0.85 m cold telescope)

- 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)

Need for very large 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

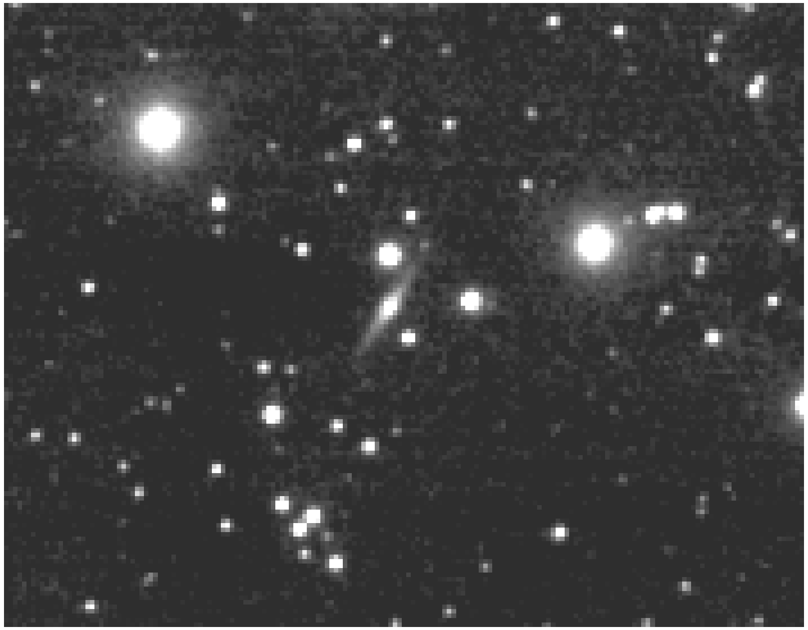
Liquid mirror telescope

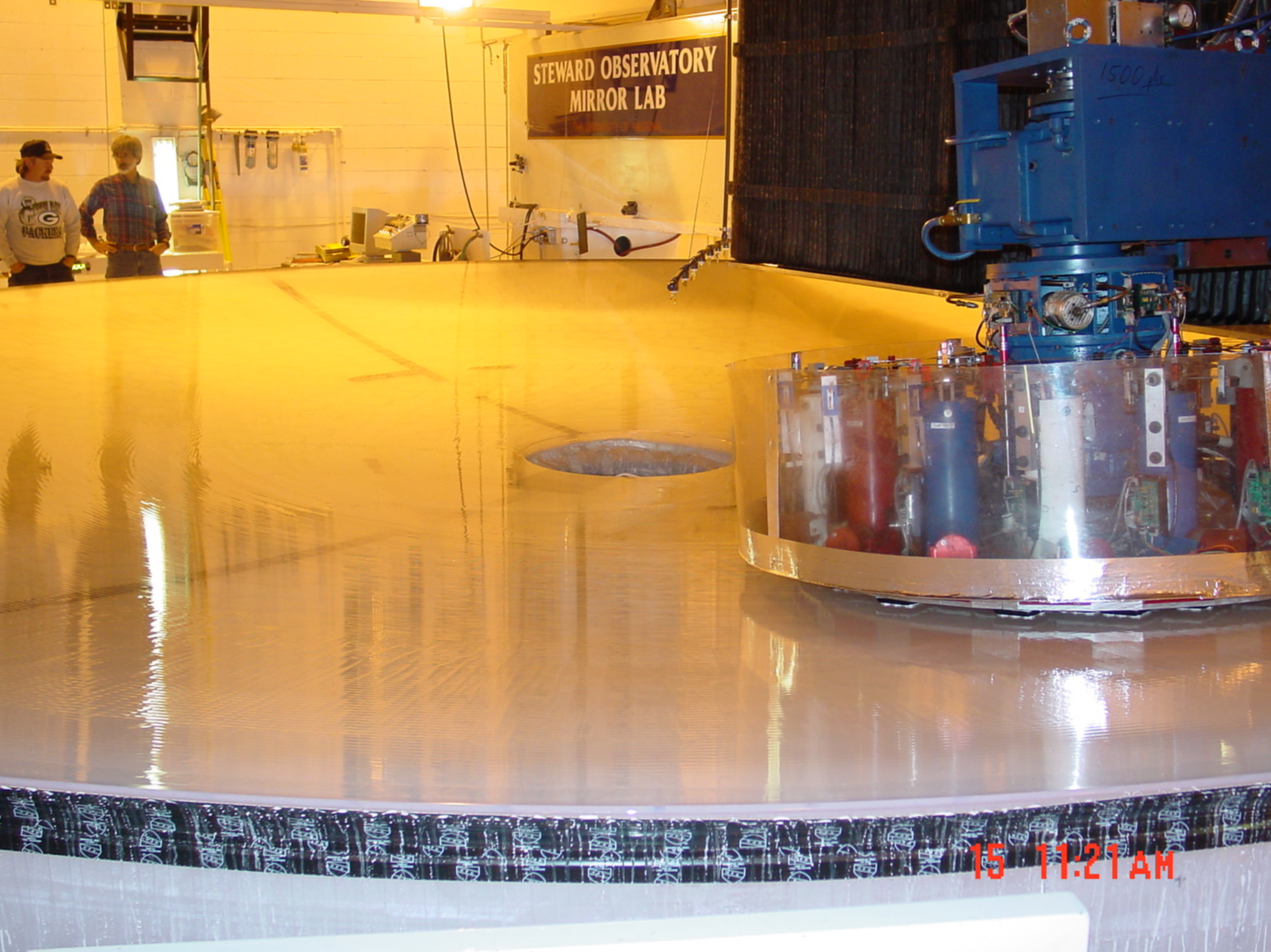
- way to get very large aperture at low cost
  - Proven on ground to 6 m
  - Borra and Hickson in Canada
- Current ground status
- Lunar location at poles
  - Superconducting bearing
  - Reflective coating a cryogenic liquid
  - Optical design for long integration

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

6 m performance (near Vancouver!)

- 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
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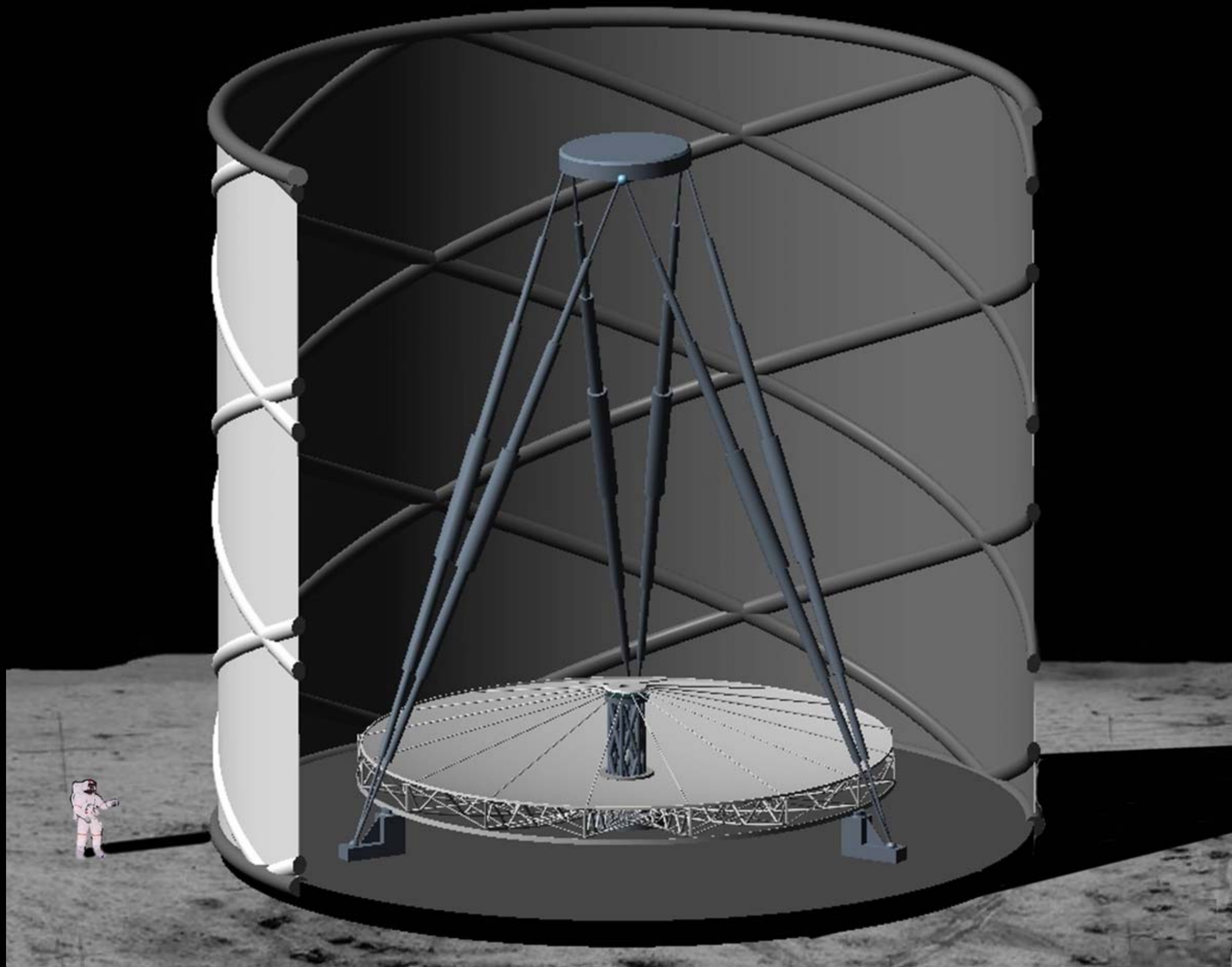
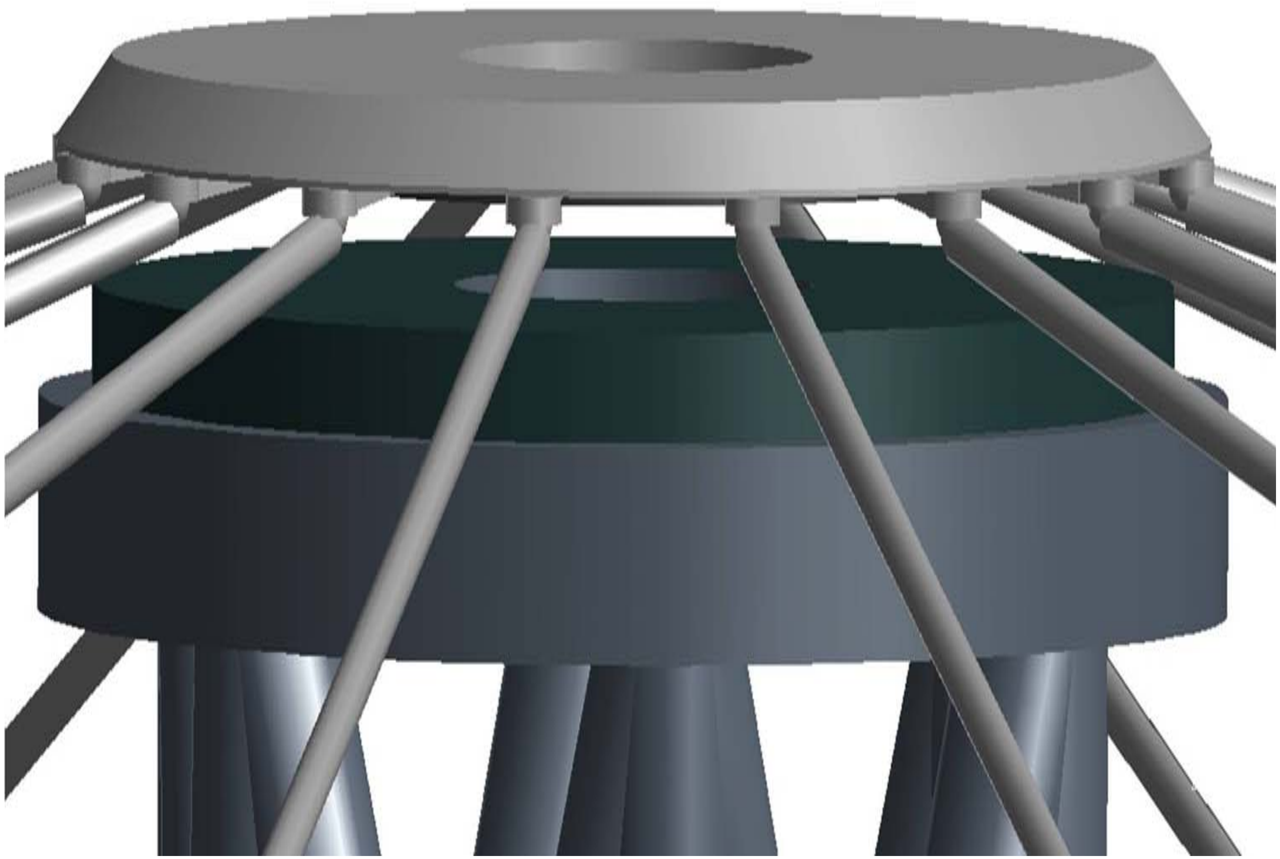
Location at lunar pole

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

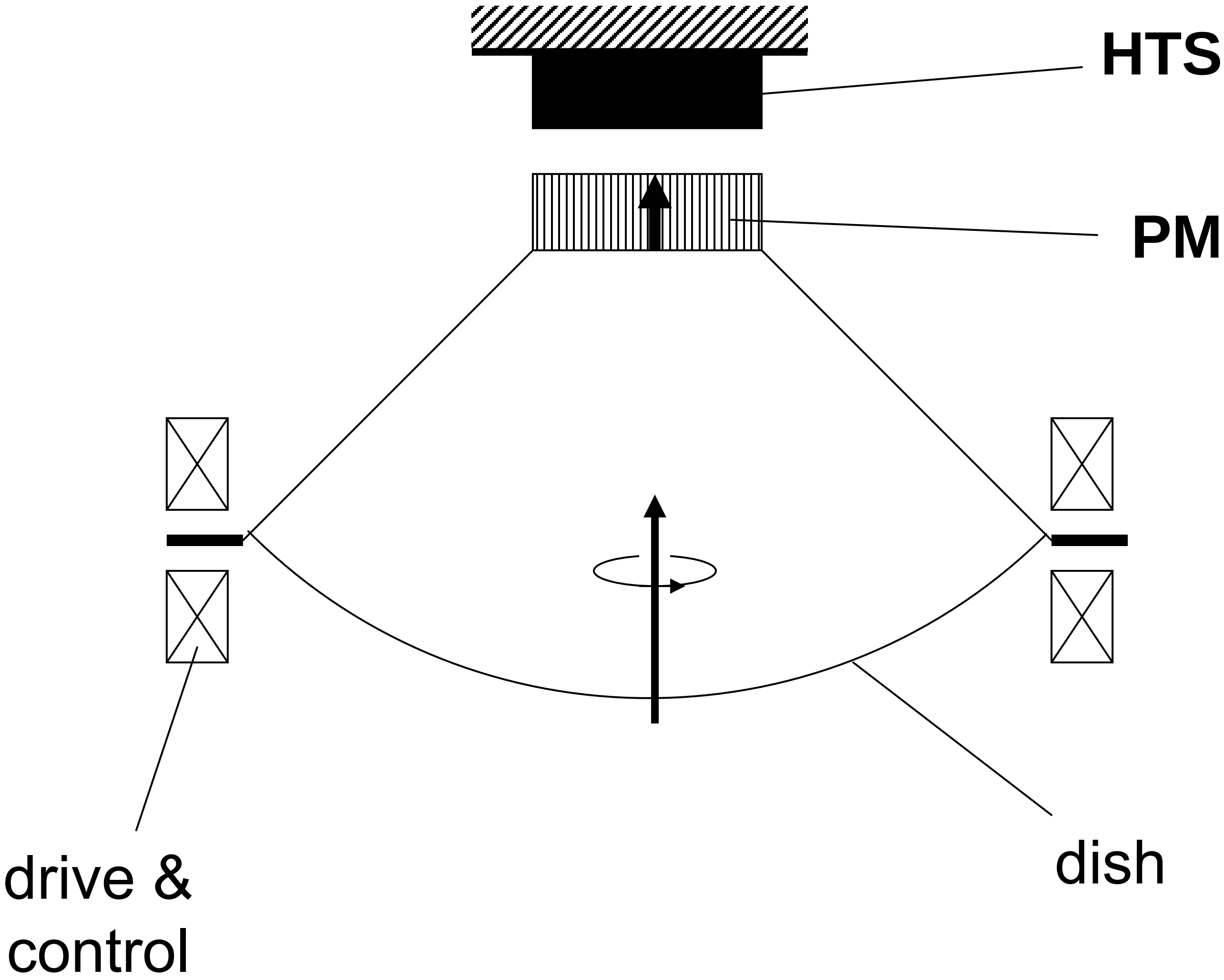
Artist's impression of the 20 m telescope. The secondary mirror is erected by extending the six telescoping legs, and the sunshield by inflation. The scientific instruments are below the bearing pier, shielded by lunar soil.
(Tom Connors)



First concept for superconducting levitation bearing



Suspension alternate (Ma)

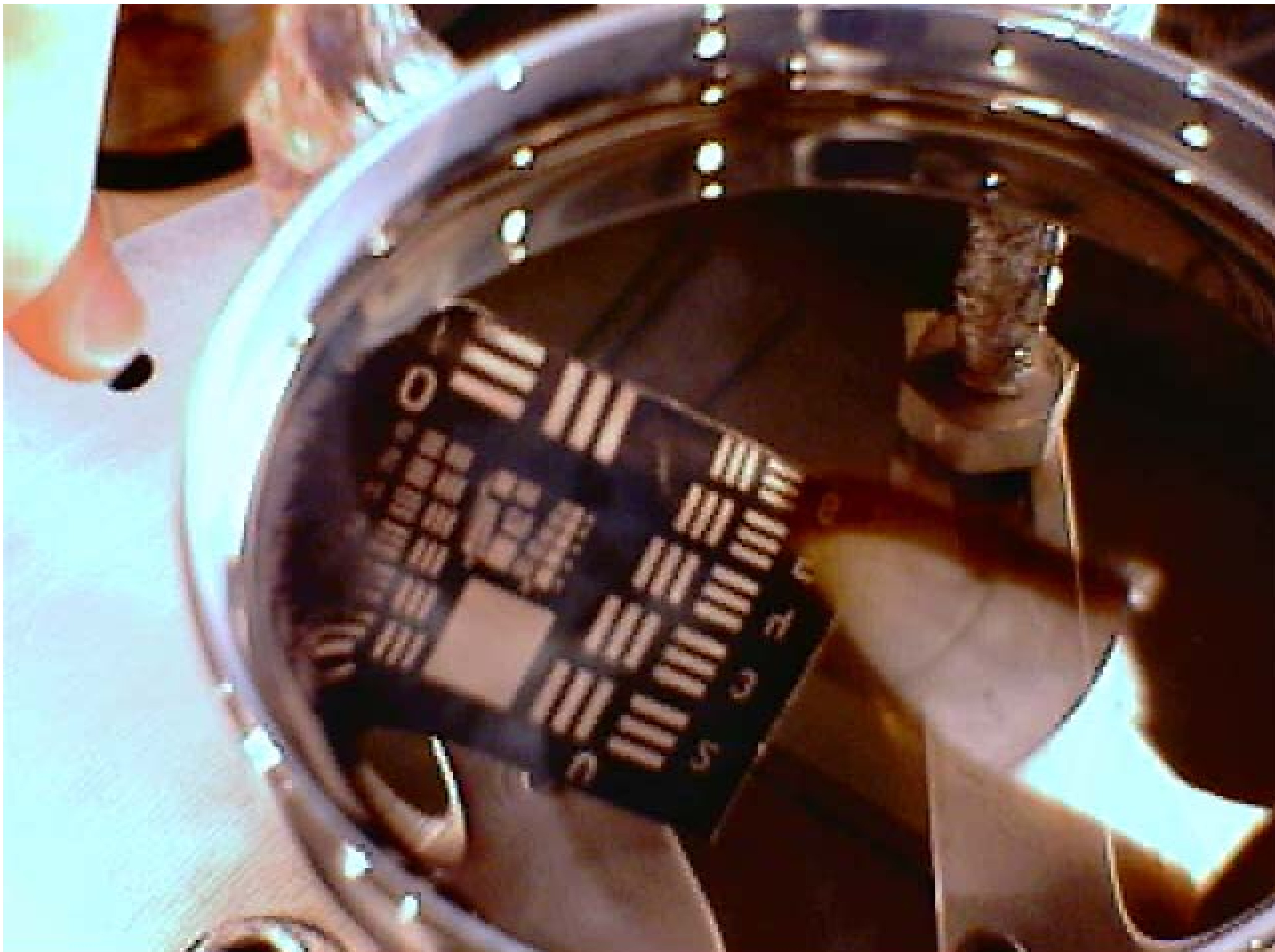

HTS
PM
drive &
control
dish

“toy” system and 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

First success in metallizing liquid

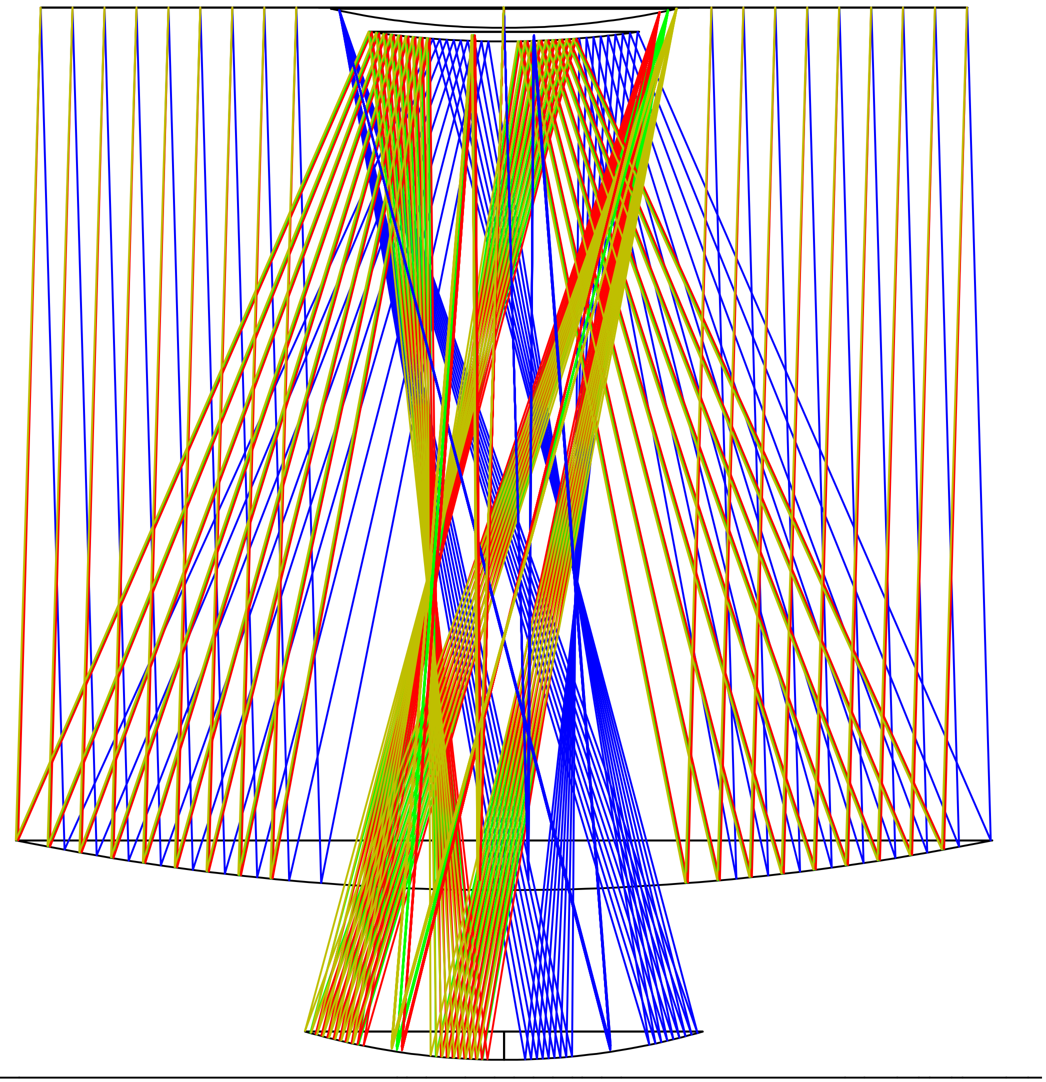
Polypropelyne glycol with vacuum deposited tin (Borra)



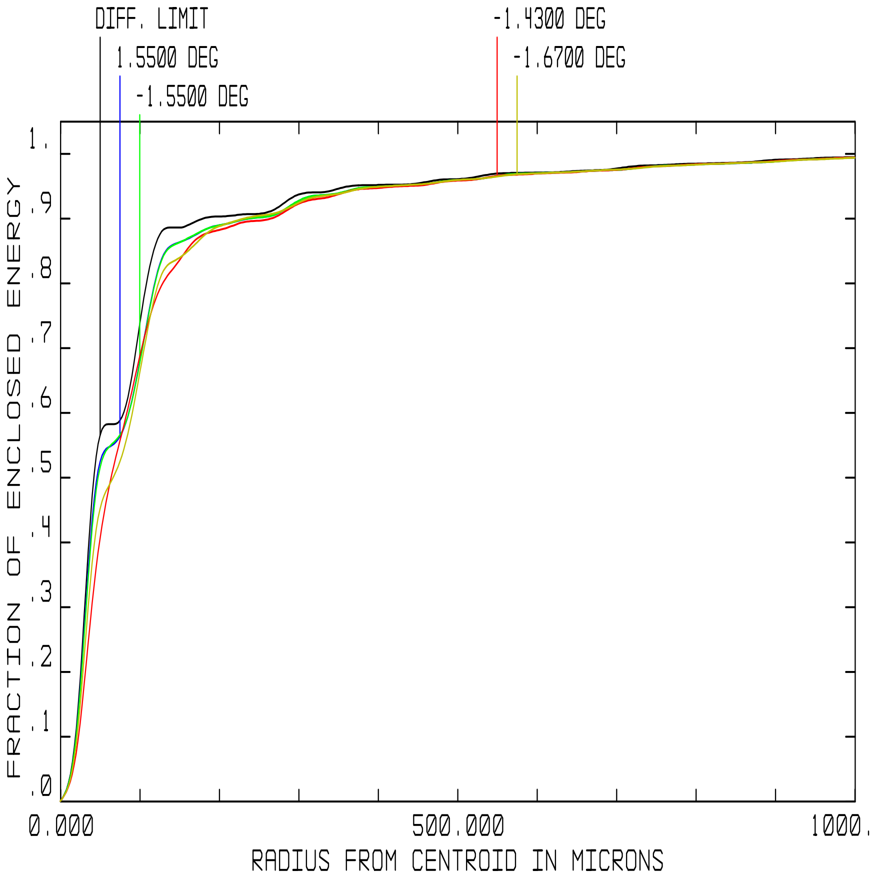
Location and optical design

- 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

3-mirror design for 1.55º annular field



Field angle 1.43 – 1.67°



Encircled energy at 2.5 μm (1.7 m)

1.7 m precursor details

- Diffraction limited resolution
  - 0.3 arcsec at 2.5 μm
  - 0.6 arcsec at 5 μm
- 3 degree annular field, 14 minute wide
  - 2 square degrees
  - 4096 x 0.2 arcsec pixels wide
  - 30 square degrees covered during 18 yr precession
- 18 year mission
  - average 2 years integration on typical field point
  - ~2 weeks on each of 40 differently filtered detectors in ring
  - Limiting sensitivity as D2√t, 25x Spitzer in same broad bands (4 of the 40 slots) i.e. 20 nJy at 3.5 μm.

Possible sequence

- 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

Lunar Liquid Mirror Telescope Operational Considerations

S. Pete Worden
Steward Observatory
The University of Arizona
The Ides of March, 2005

Site Selection: North or South Pole

Sky Considerations:

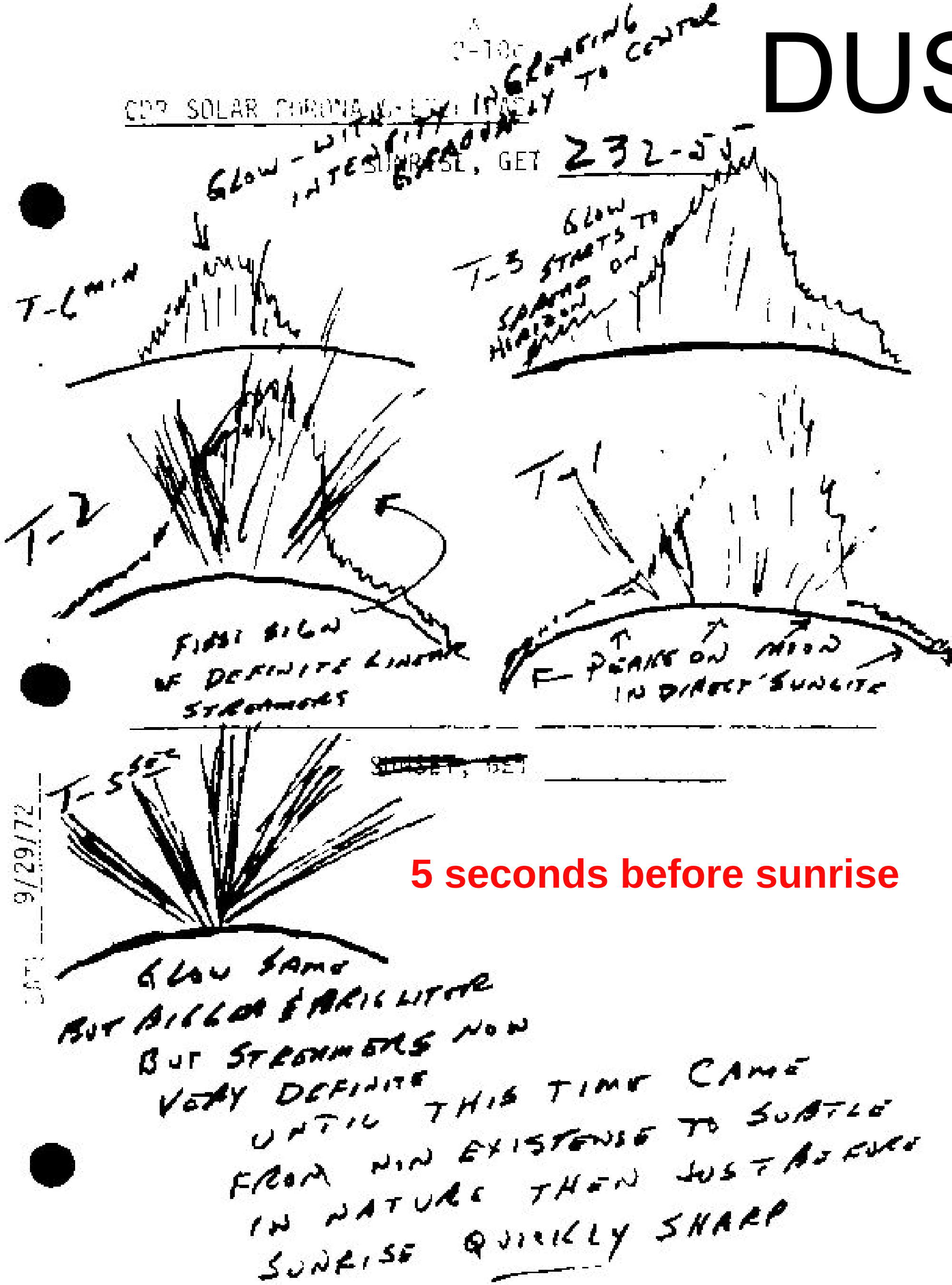
- Dust contamination/atmosphere [Both?]
  - Circumstantial evidence supports dust levitation and dust atmosphere.
  - Dust may contaminate optics, introduce stray light, and increase sky background.
- Stellar field contamination [South?]
  - Large Magellanic Cloud (LMC) contaminates South pole sky view.

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

Operational Considerations

- Power - Site illumination [North?]
  - North pole winter illumination not known.
  - South pole illumination mapped by Clementine
  - Desire “Peak of Eternal Light” – series of points in permanent sunlight
- Communications
  - Either need earth line of sight or orbiting relay
- Positioning
  - Precise map of surroundings needed
- Maintenance
- Site Survey

DUST



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.**

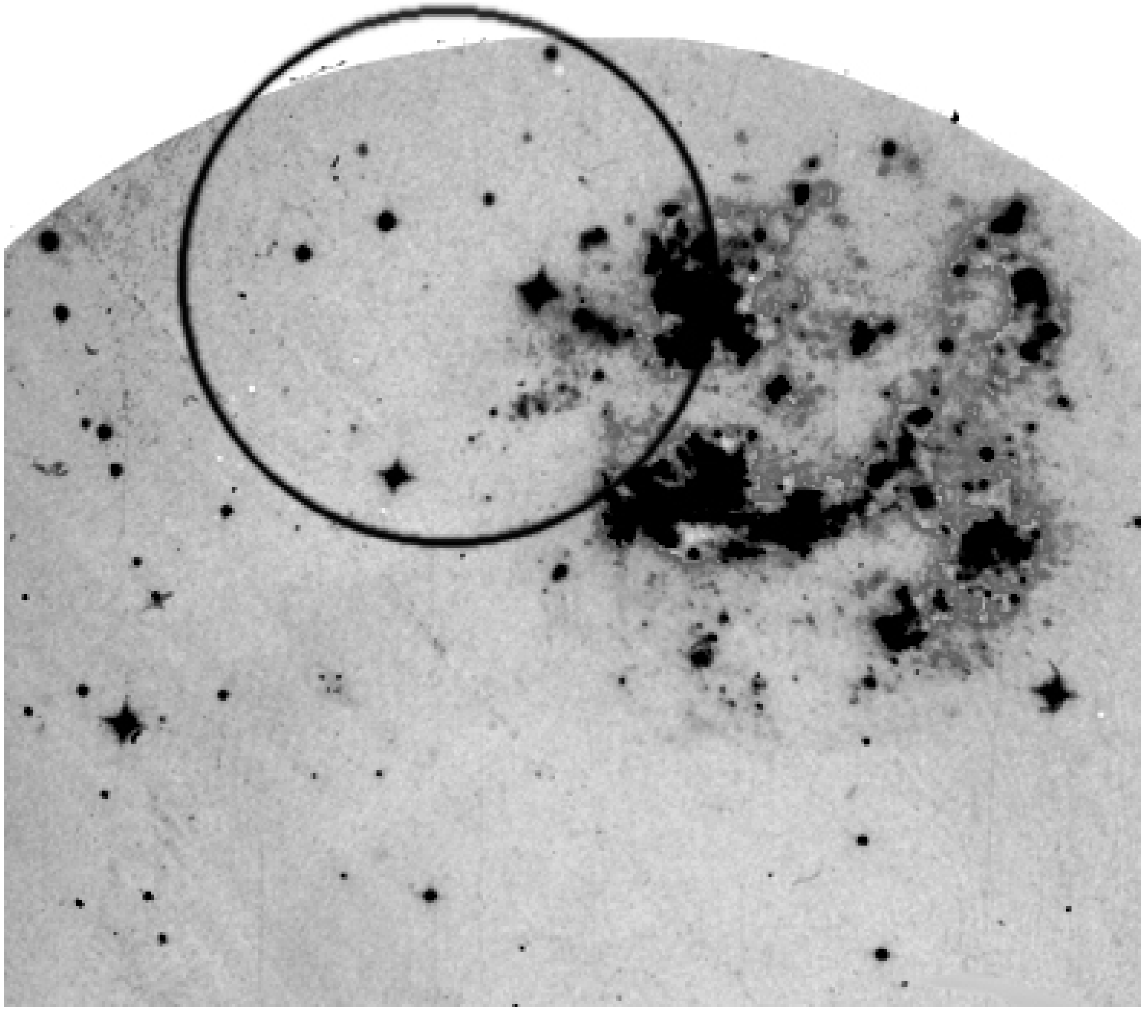
More on DUST

- 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.

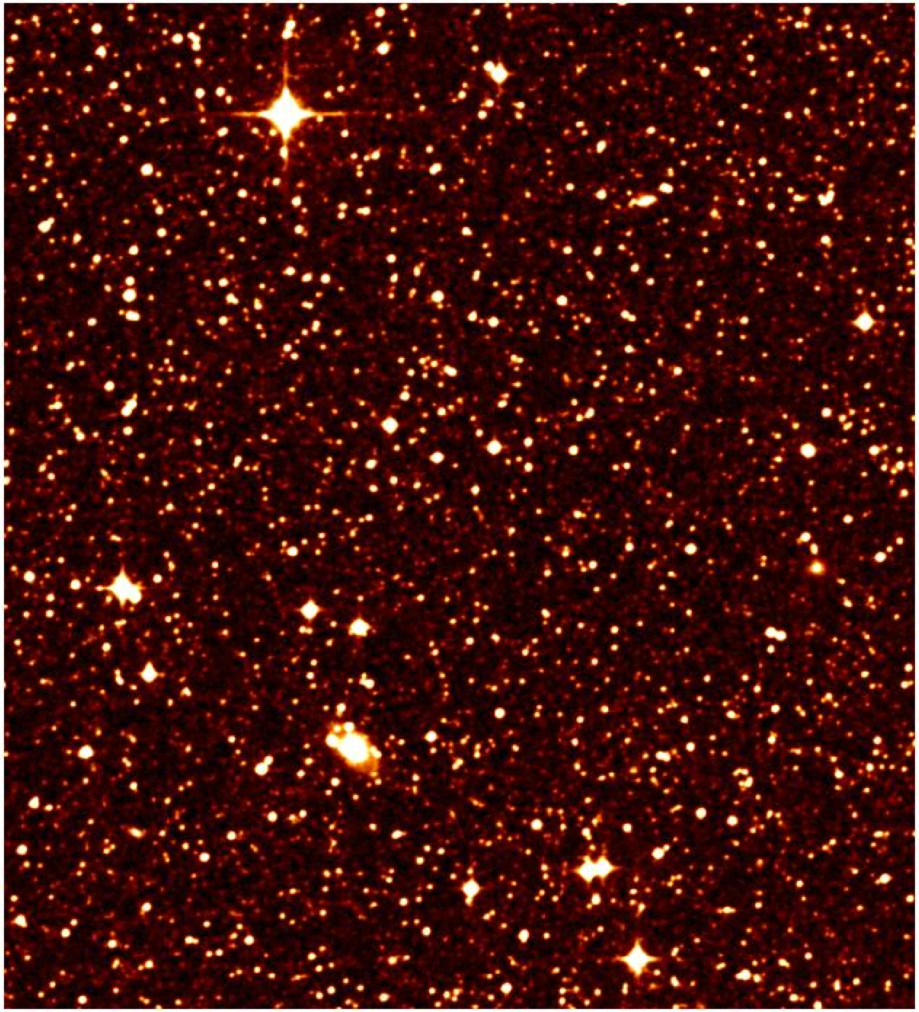


The circle shows the 6° diameter field accessible to the lunar zenith pointing telescope.

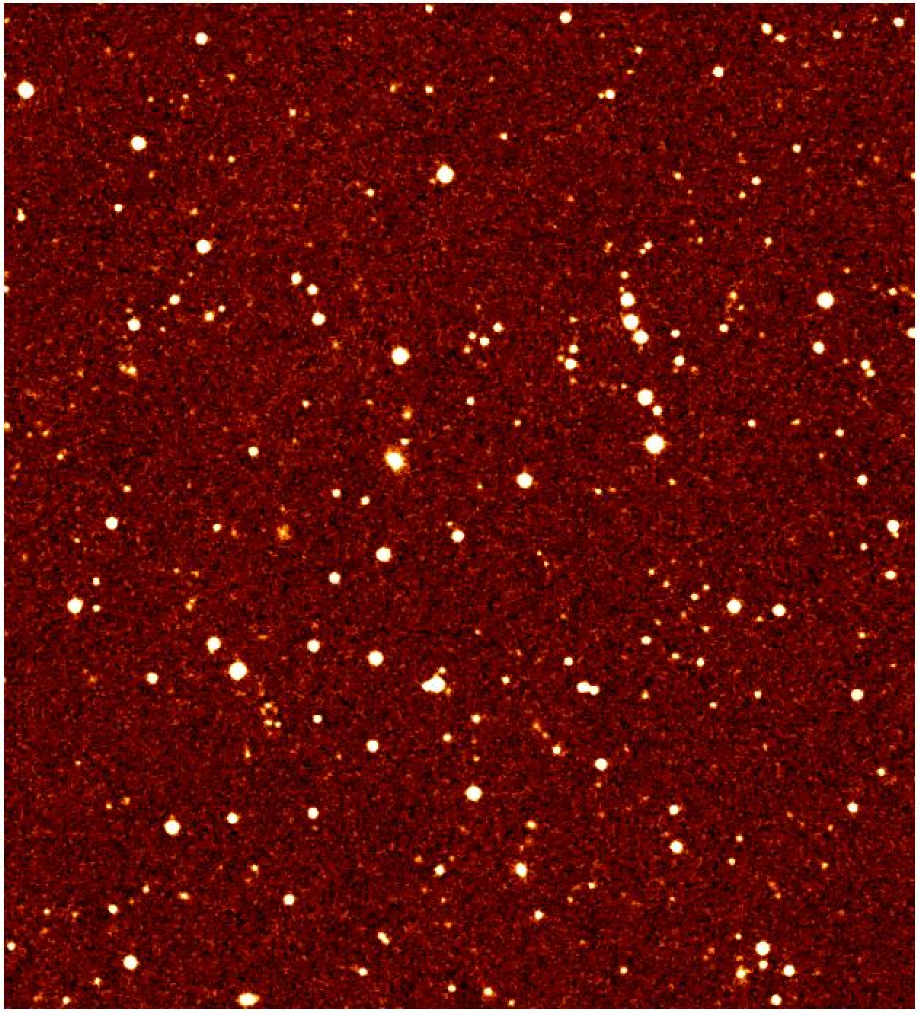
Ultraviolet image from the Moon, John Young & Charles Duke

Stellar Contamination at ecliptic poles

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



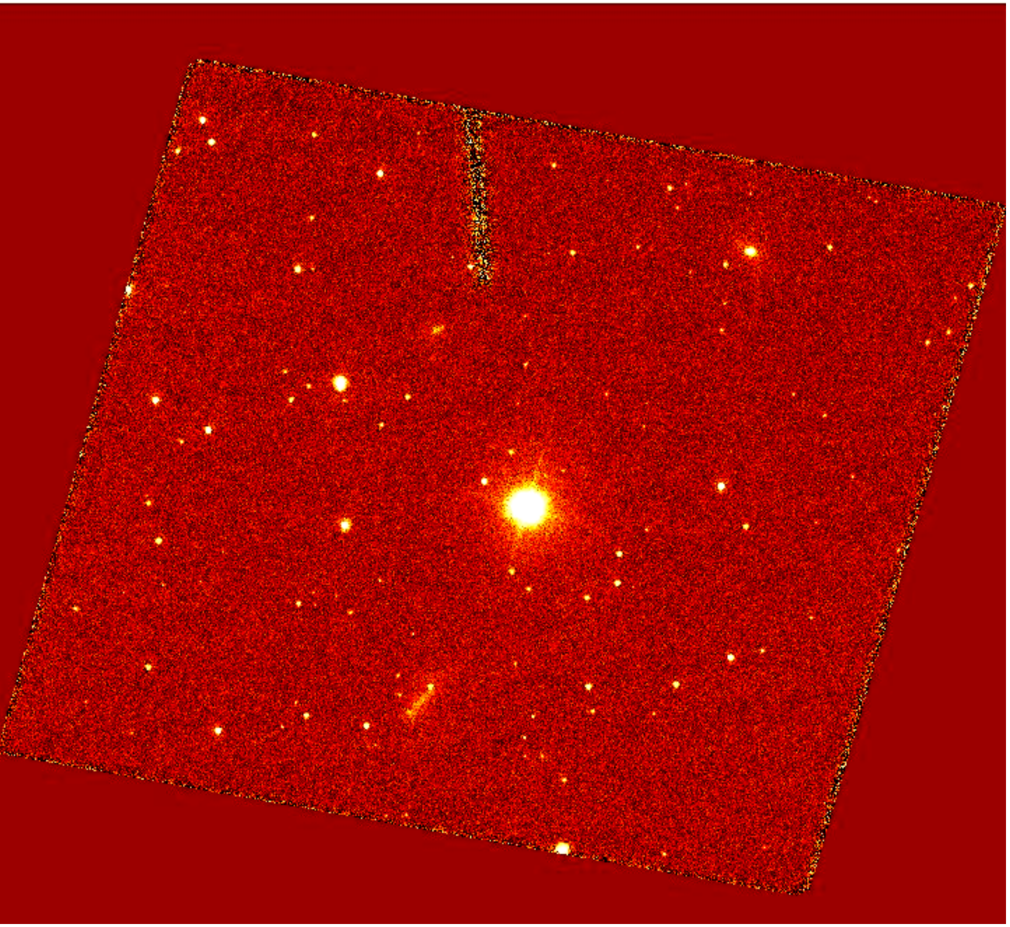
South pole view



North pole view

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

Can we resolve LMC stars?



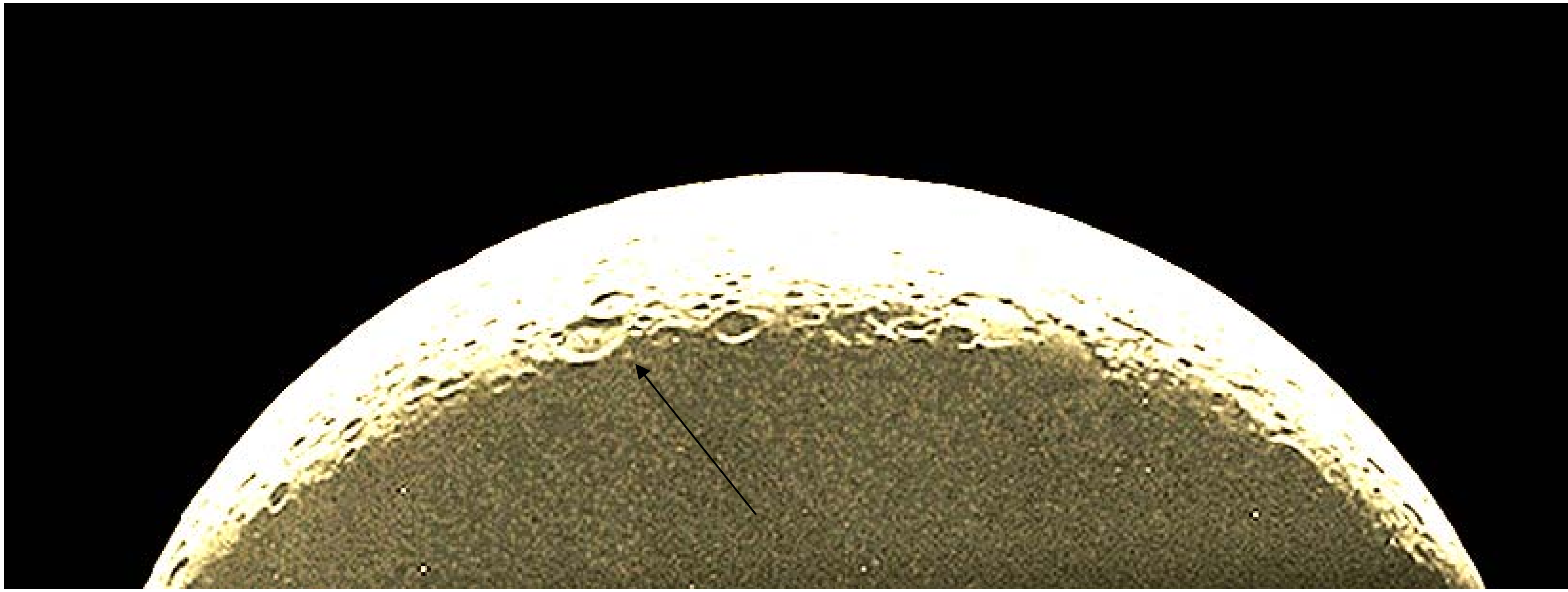
HST ACS HRC F606W Image of field near the south ecliptic pole. (29” by 26” FOV, diffraction-limited 0.06” resolution)

- To first order, HST can resolve LMC stars, though this image is not nearly as deep as will be obtained from moon.

- The lunar pole telescope will have higher diffraction limited resolution in infrared than this visible image

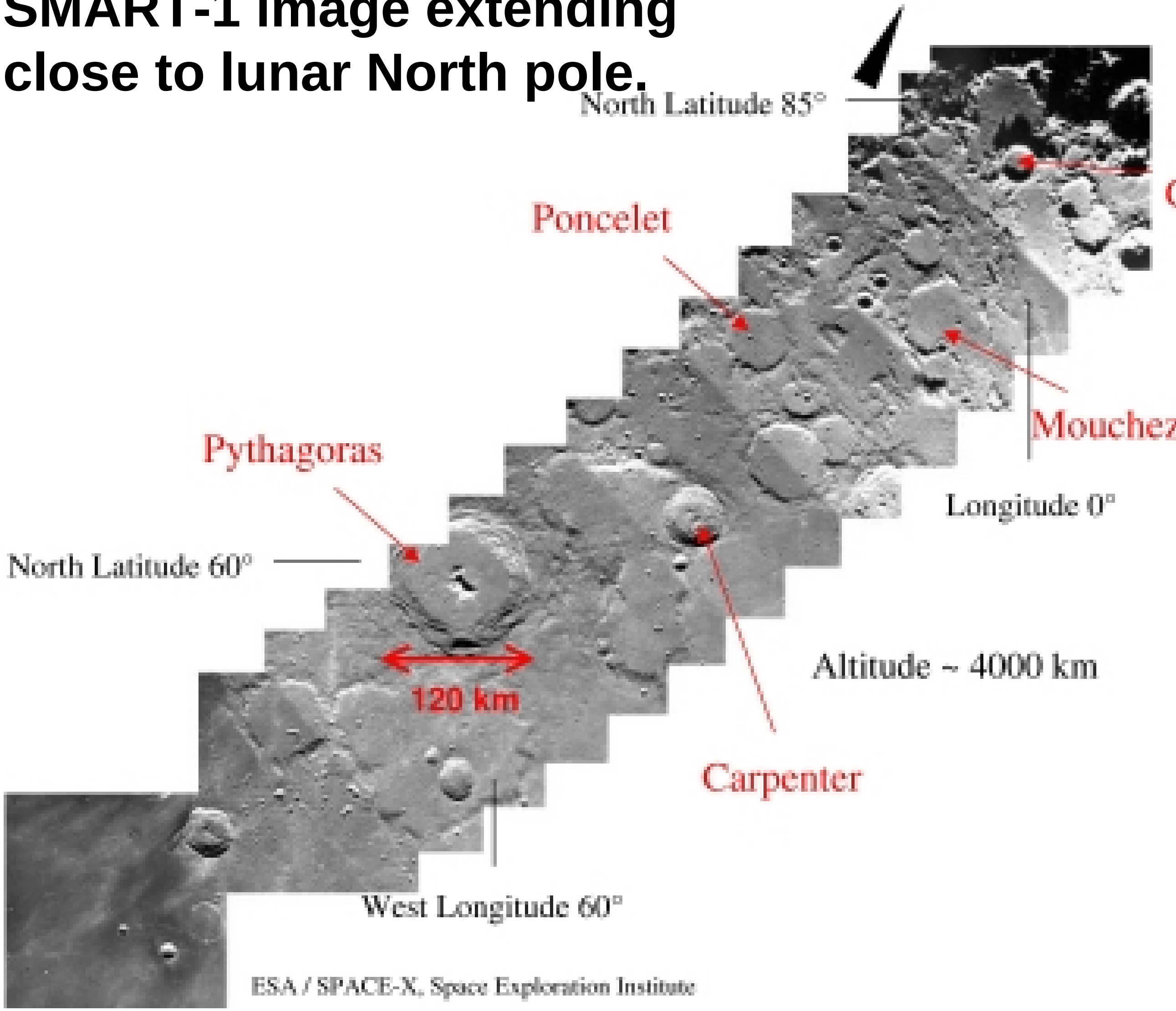
- Suresh is modeling the faint-end of the LMC stellar population using a LMC star catalogue.

- He will determine the average separation of stars to deep field magnitude limit



North Pole Illumination: SMART-1

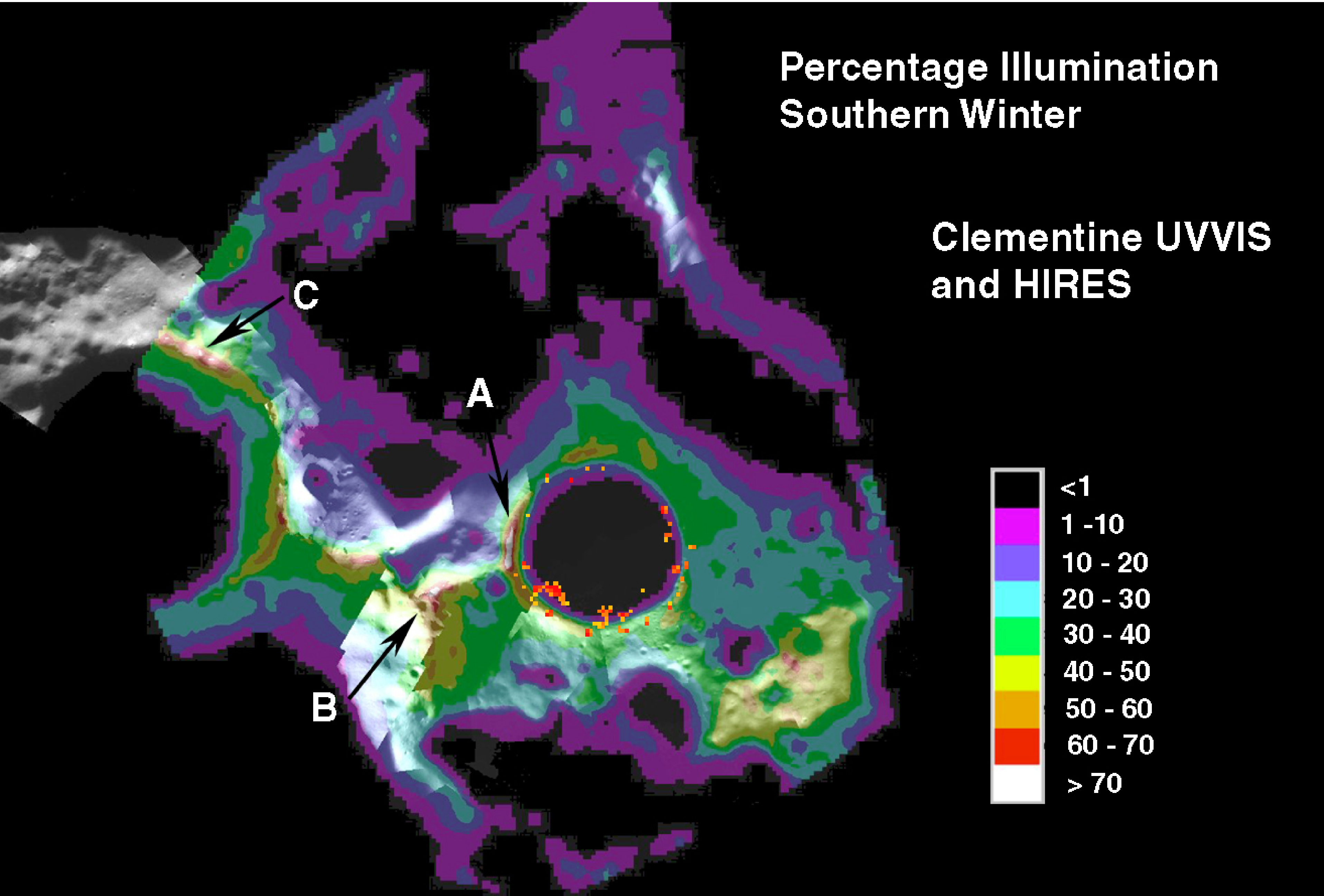
SMART-1 image extending close to lunar North pole.



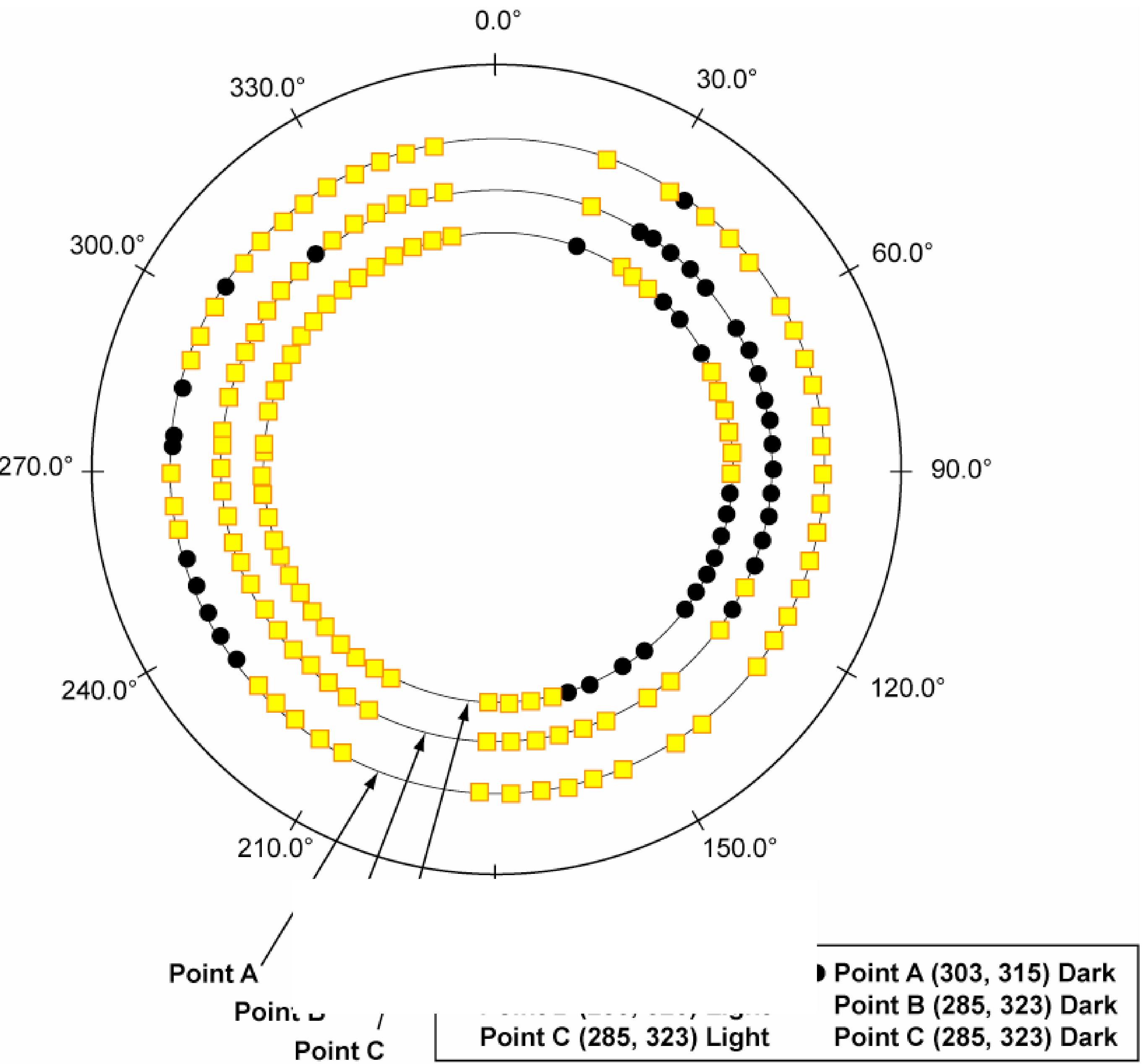
- ESA's SMART-1 lunar probe has made observations of the North pole during January 2005, the middle of the lunar winter in the northern hemisphere.

- 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 Illumination in Winter



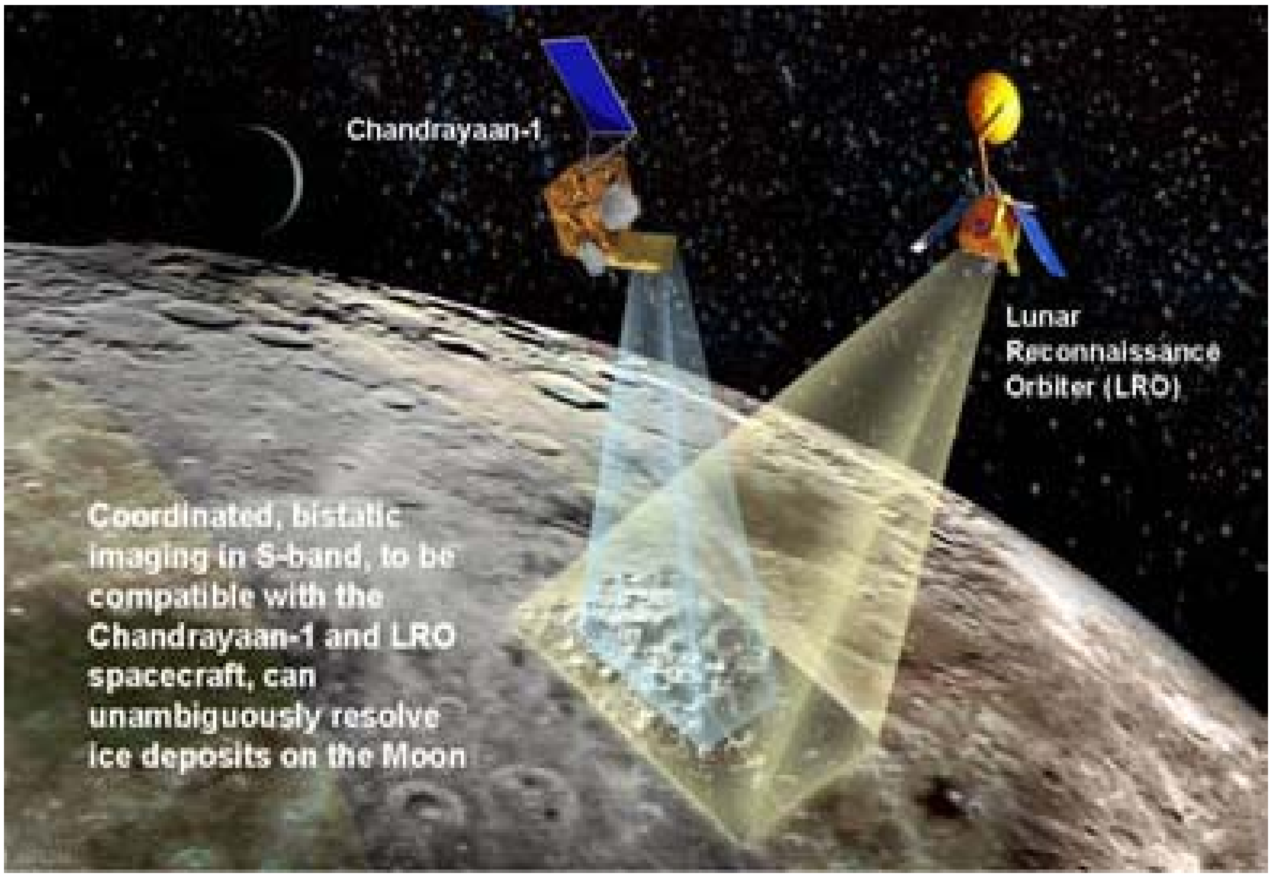
Power: South Pole Illumination in Winter



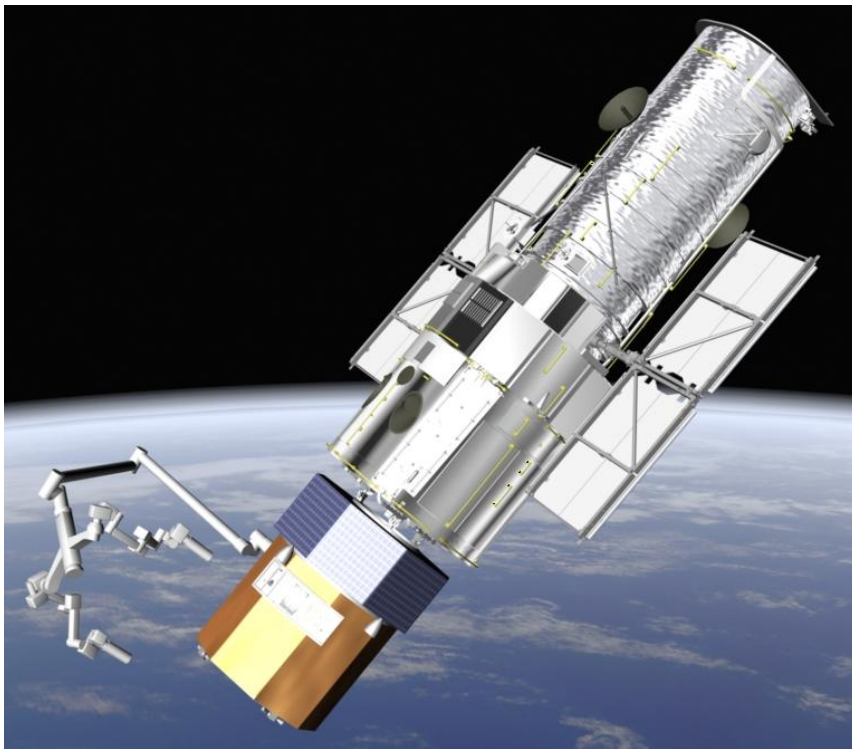
Communications

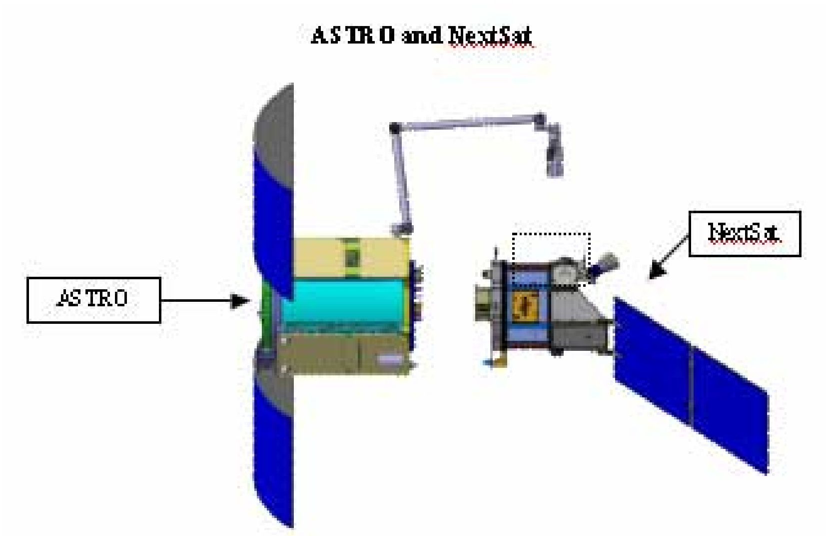
- Store and Forward via polar relay
- Direct line of sight – need to determine horizon features of selected sites – Is the earth permanently in view?

Numerous Lunar Polar Orbiters Planned – Communications and Situation Awareness



Tele-robotics vs Autonomous Operation





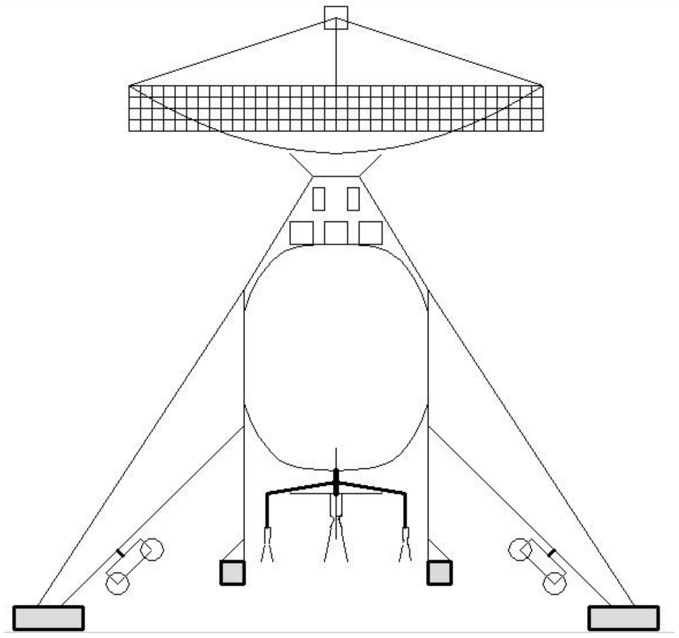
Site Survey Proposal

- 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

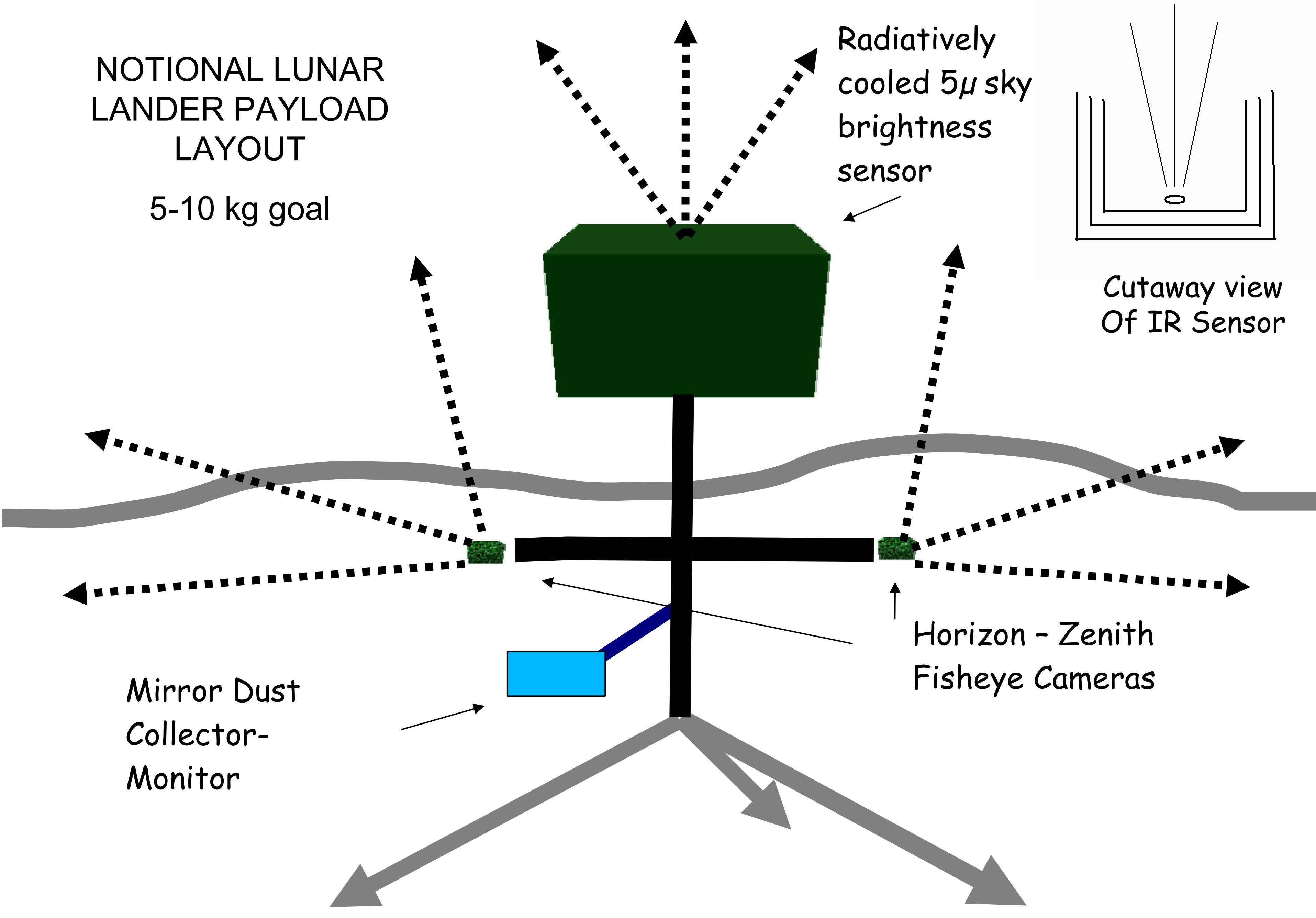
Commercial Lunar Lander – Millennium Space Design

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



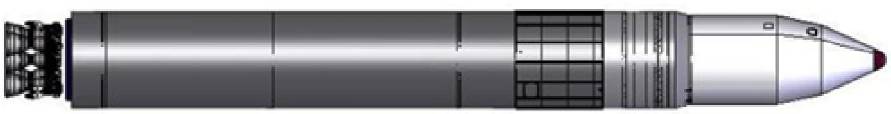
NOTIONAL LUNAR LANDER PAYLOAD LAYOUT

5-10 kg goal



New Launch Options – Low Cost

- Space-X FALCON
- Falcon I – 500kg to LEO - $5.9M
- Falcon V – 5000kg to LEO - $15M
- “BFR” -- TBD



CONCLUSIONS

- Lunar polar telescope sites appealing – issues to be resolved
  - Dust
  - Solar and Terrestrial access
  - Deepest Fields Possible? N vs S Pole
- Low Cost Survey Mission Possible to resolve issues – Definition Needed
- As in Real Estate – LOCATION, LOCATION, LOCATION!