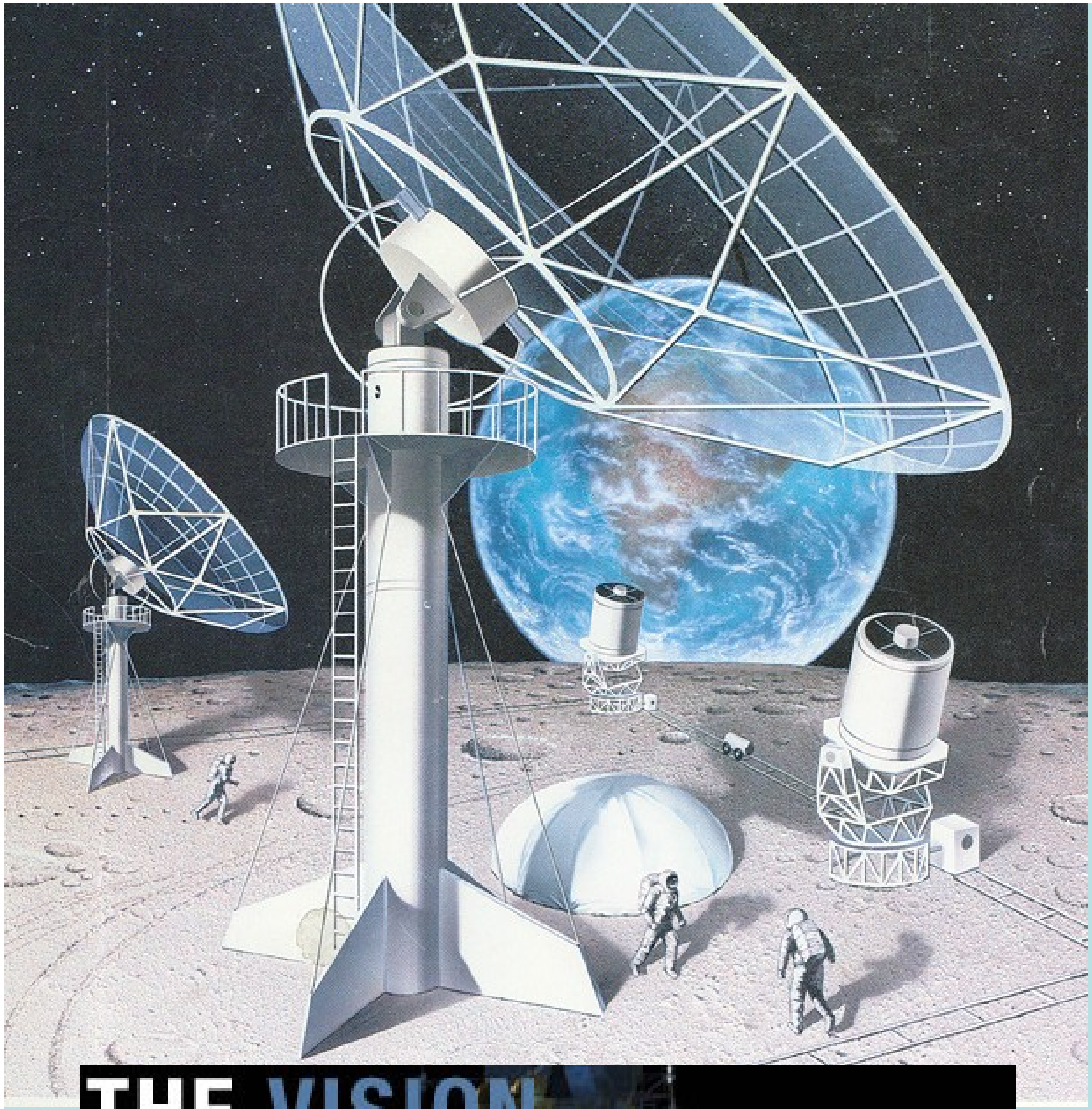
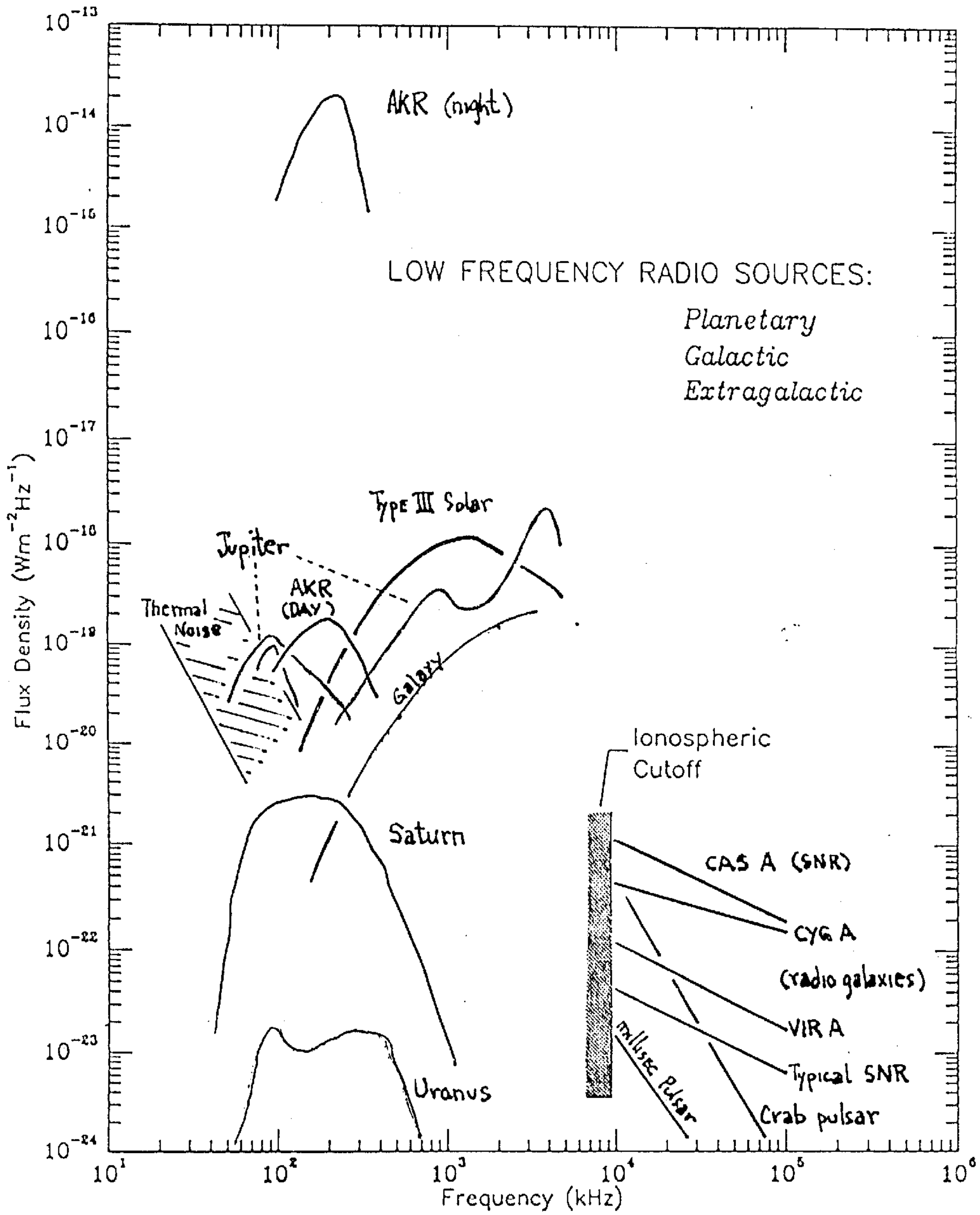


Advantages & Challenges of Interferometry on the Moon

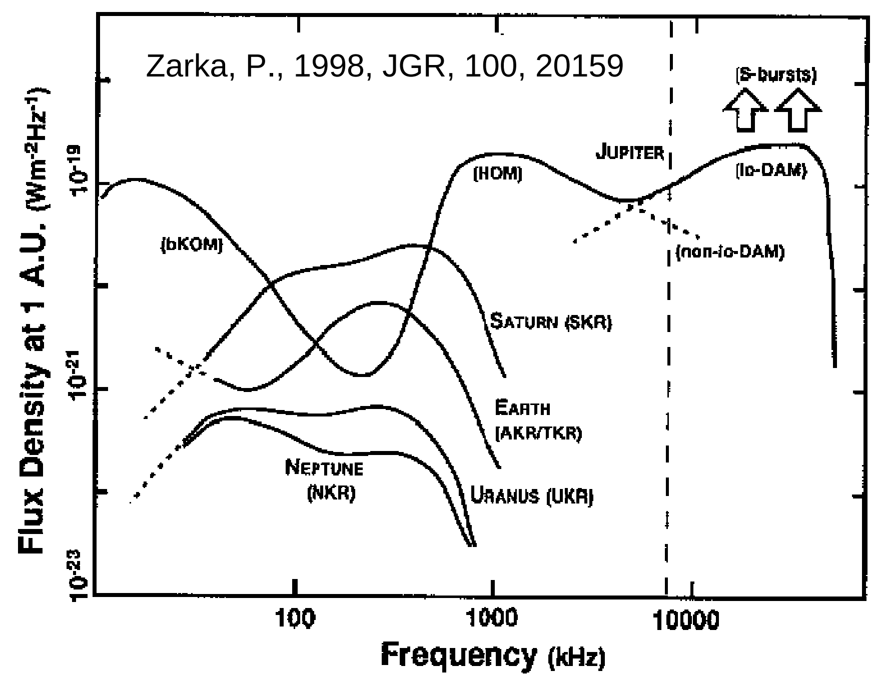
Jack Burns
Center for Astrophysics
and Space Science
University of Colorado, Boulder

STScI Conference on *Astrophysics Enabled by a Return to the Moon* –
November 28, 2006

Low Frequency Environment from the Moon

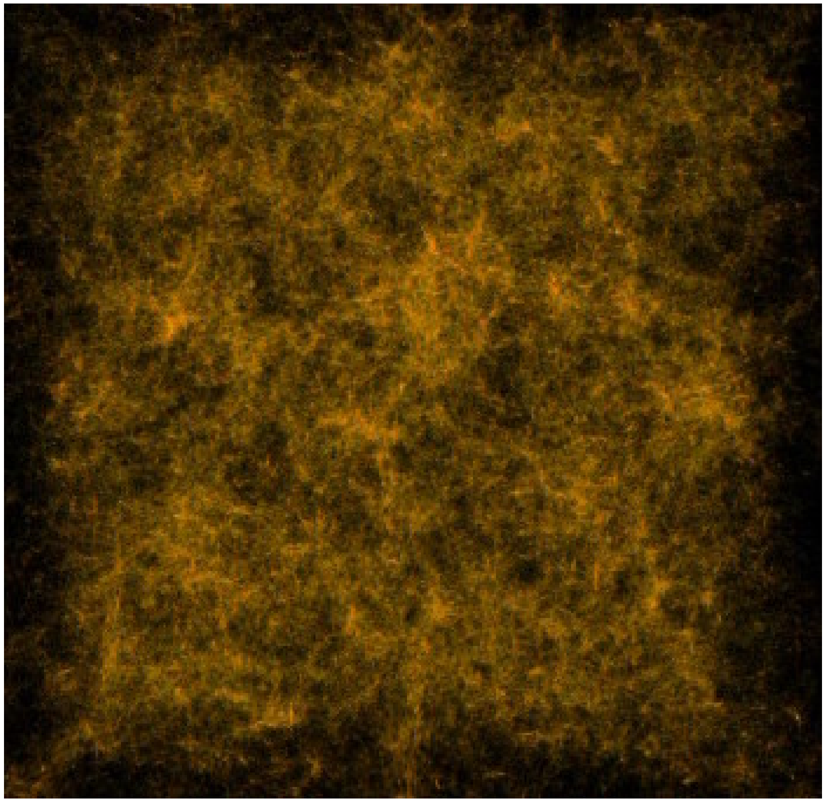


- >1 MHz interference is from Earth ionospheric breakthrough.
- <1 MHz interference comes from Earth's auroral kilometric radiation (AKR) peaking at 200 kHz.
- Cyclotron radiation from magnetospheres of all the planets at 100's of KHz.
- Type III solar bursts.
- Milky Way becomes opaque at <2 MHz.



Exciting Science at Long Radio Wavelengths

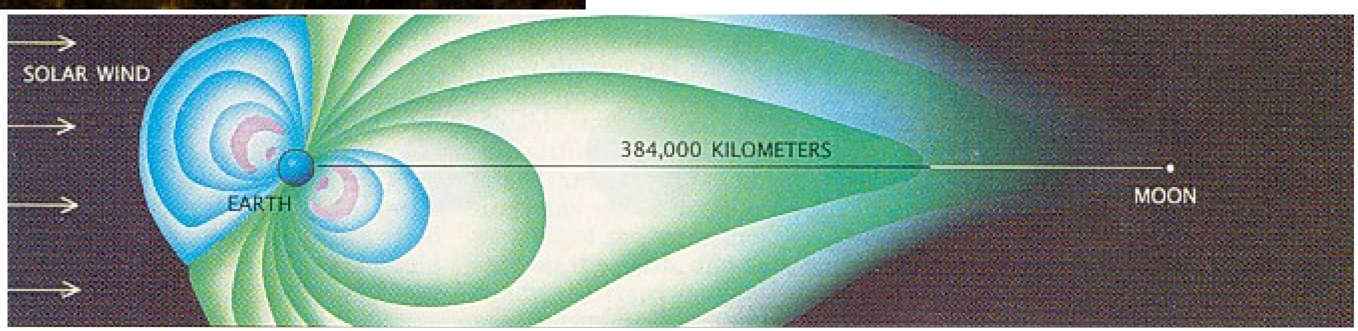
Baryons in z=10 universe from simulations



• ***Epoch of Reionization*** – When was "first light" in the Universe? Epoch of formation of the first sources of ionizing radiation from redshifted HI in emission and absorption (z = 6-50).

• ***Extrasolar Planets –*** Can modulated electron cyclotron emission from extra-solar planets be detected at low frequencies?

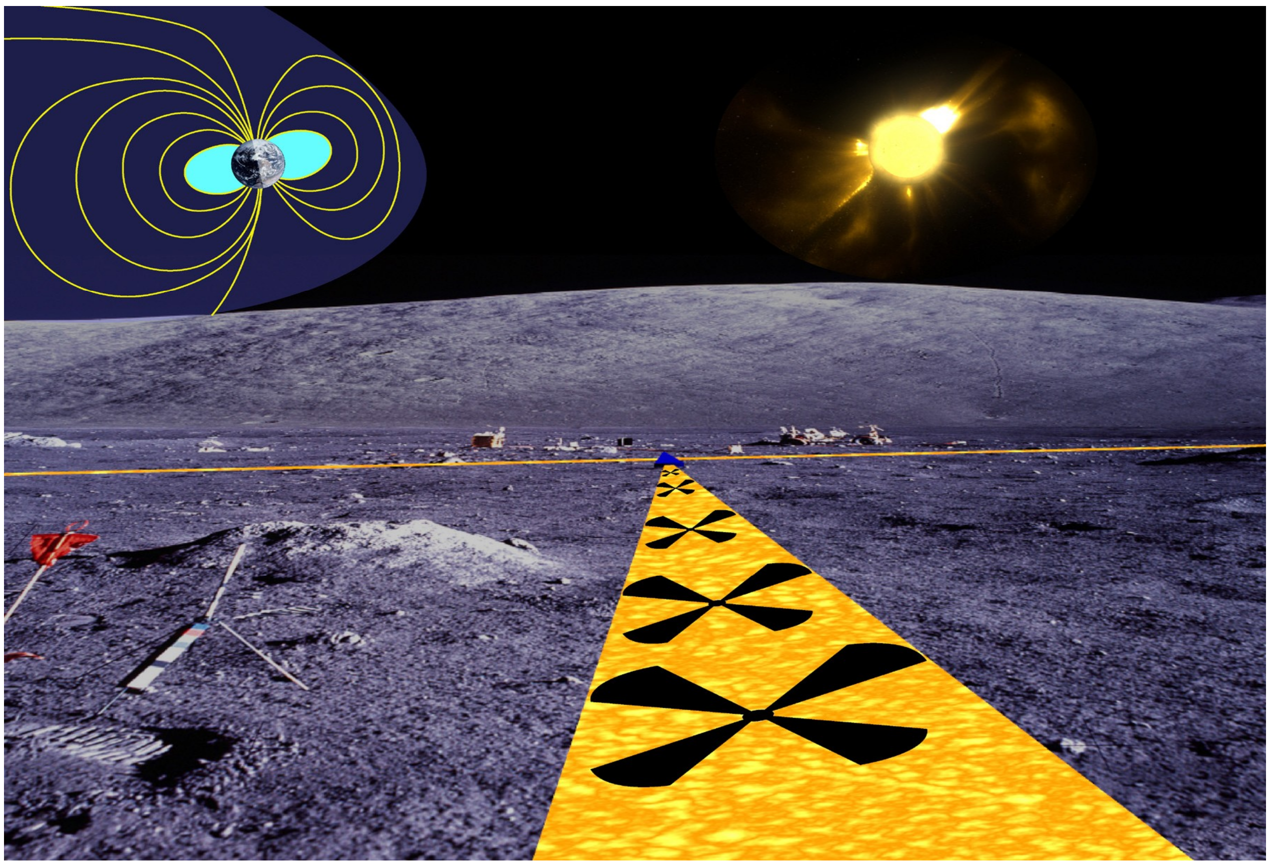
• ***Particle Acceleration –*** What are the low energy "seeds" from which the highest energy particles result?



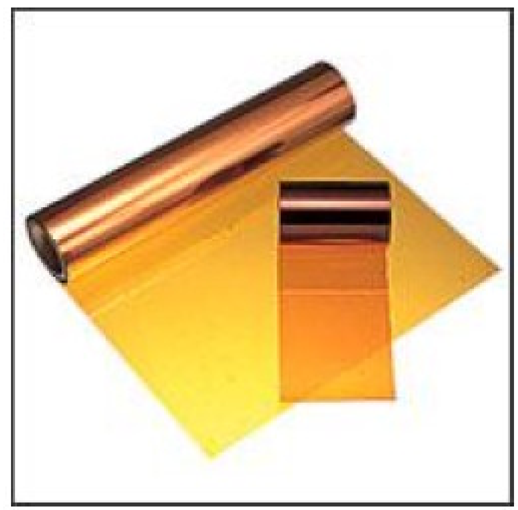
ROLSS: Radio Observatory for Lunar Science Sortie

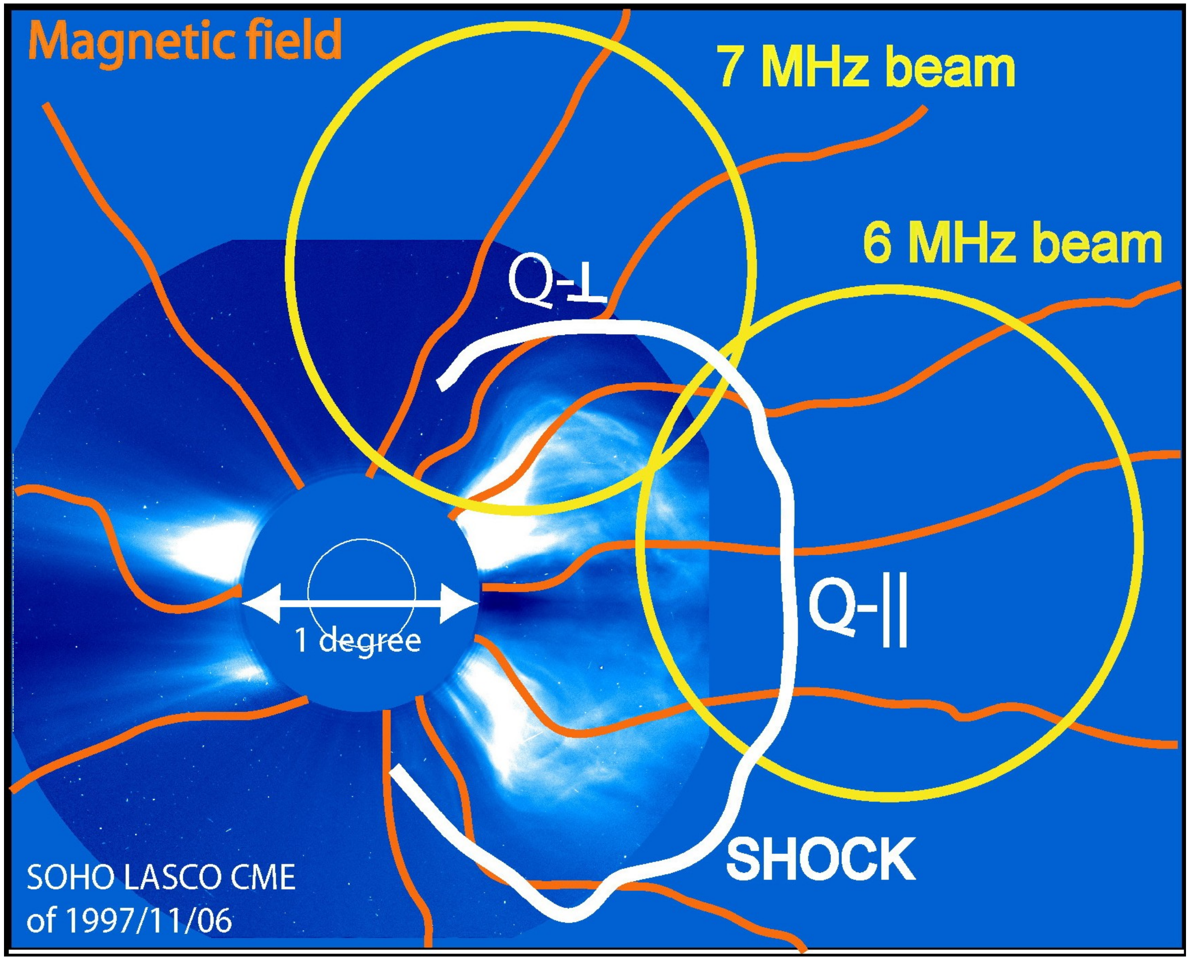
J. Lazio & K. Weiler, NRL; R. MacDowell, L. Demaio, N. Gopalswamy, & N. Kaiser, GSFC;
J. Burns, U. Colorado; D. Jones, JPL; S. Bale, U.C.-Berkeley; J. Kasper, MIT

- A Pathfinder for future long-wavelength farside lunar arrays targeting EoR, extrasolar planets, etc. -- interferometers grow as you go.
- Operating at 1-10 MHz (30-300 m), produces factor of 10 increase in resolution (2º) and sensitivity over previous space missions (e.g., RAE).
- Array consists of three 500-m long arms forming a Y; each arm has 16 antennas.



- Arms are a thin polyimide film on which antennas & transmission lines are deposited.
- Arms are stored as 25-cm diameter x 1-m wide rolls (<10 micron thickness).





Science with ROLSS

- Will produce first images of the Universe at <10 MHz.
- Key science is study of ***particle acceleration***.
- For the Sun, ROLSS will image sites of shock acceleration at 2-10 R_{Sun}.
- For nearby, luminous radio galaxies, ROLSS will detect or set limits on the minimum electron energy (E<50 MeV).

ROLSS will distinguish between radio emission at nose of coronal mass ejection (CME) (shock normal is parallel to B-field, Q-¦) vs. from the flanks (Q-_).

The Lunar Ionosphere

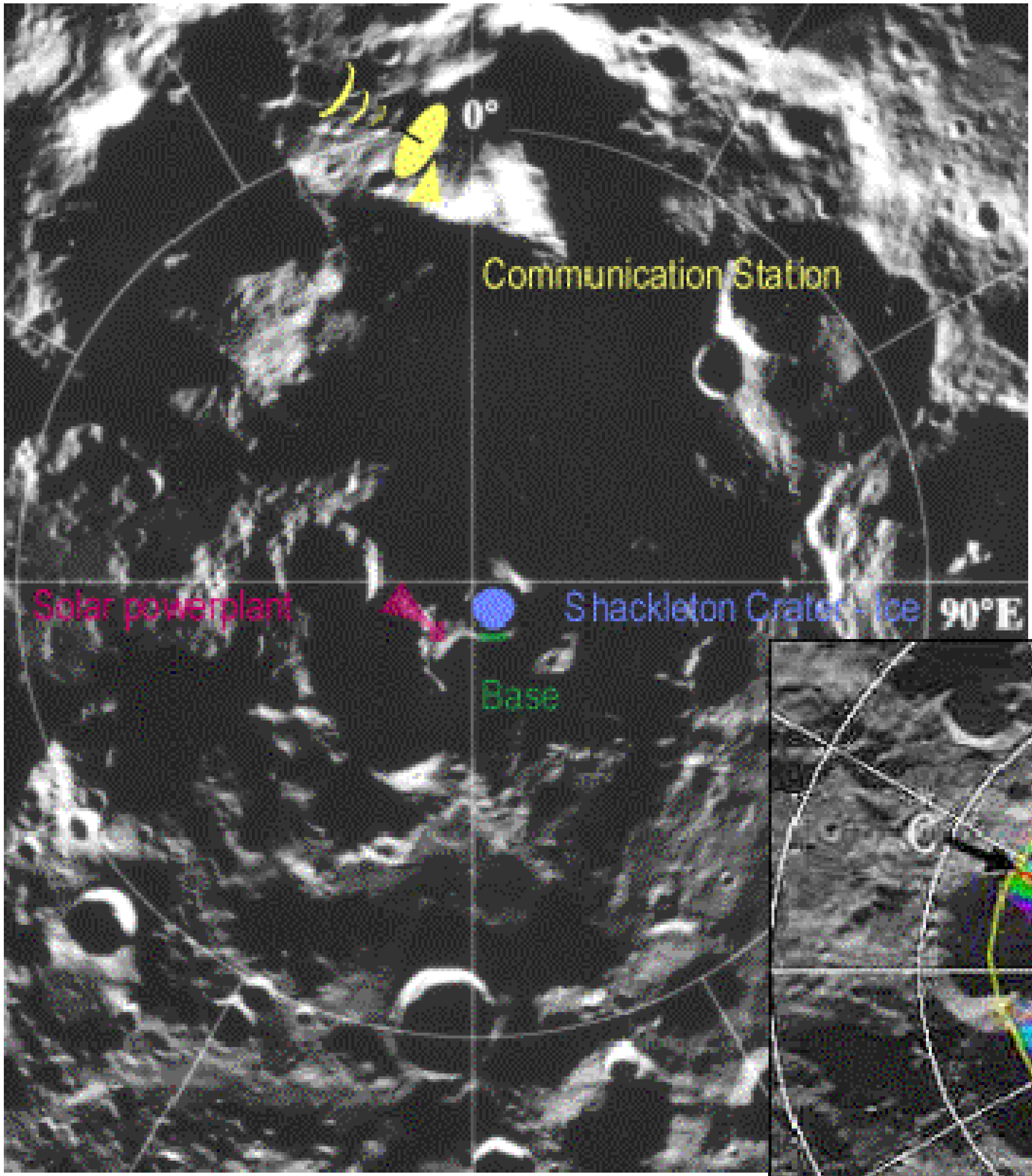
- Uncertainty about the density, geometry, & generation of a lunar ionosphere.
- A lunar atmosphere would have environmental implications for crewed operations on the Moon.
- Radio waves don't penetrate below the plasma frequency (9 kHz $(n_e)^{1/2}$). Range of densities (100 to 5 x 10^4 cm^{-3}) imply frequencies 90 kHz - 2 MHz.

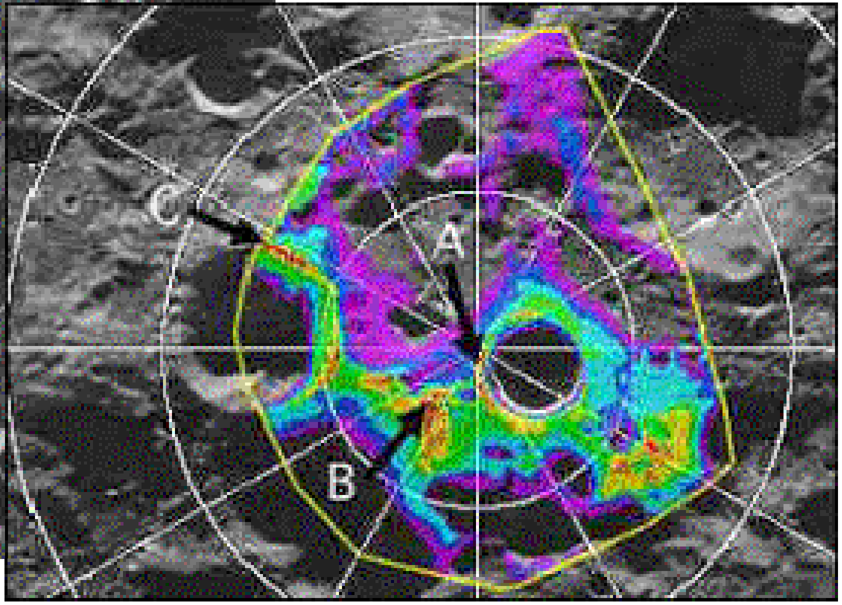
ROLSS will use background Type III solar bursts to set limits on lunar ionospheric cutoff.

Potential Advantages of the Lunar Surface for Telescopes
following Smith (1990) in *Observatories in Earth Orbit & Beyond*
(# = unique to the Moon versus L-2)

- *Large, solid, stable surface (#).* Minimal tectonic activity (10^{-8} of Earth). "Huge vacuum optical bench" for large interferometric arrays.
- *Dark & Cold Sky (partial #).* With good passive shielding, telescopes in Shackleton crater may achieve temperatures of 7 K (Lester et al. 2003).
- *Rotation.* Access to entire sky at mid-latitudes. Facilitates lunar-rotation aperture synthesis for interferometers. Long integration times.
- *The Lunar Farside (#).* Shielding from terrestrial interference, AKR, & solar flares. Free from atmospheric absorption & distortion.
- *Raw materials (#).* Potential water, fuel for nuclear power generators (He^3), and building materials.

Possible Site for a Lunar Base – Shackleton Crater





plenty of sunlight for power production
- rim receives sunlight 80% of time
- 2 other sites within 10 km collectively receiving sunlight 98% of time

close to ice resources in the permanent shadowed crater

high ground for siting communication antenna
- 120 km from 6000m high Mount Malpert which has constant view of earth

loose regolith on crater rim is useful for covering base

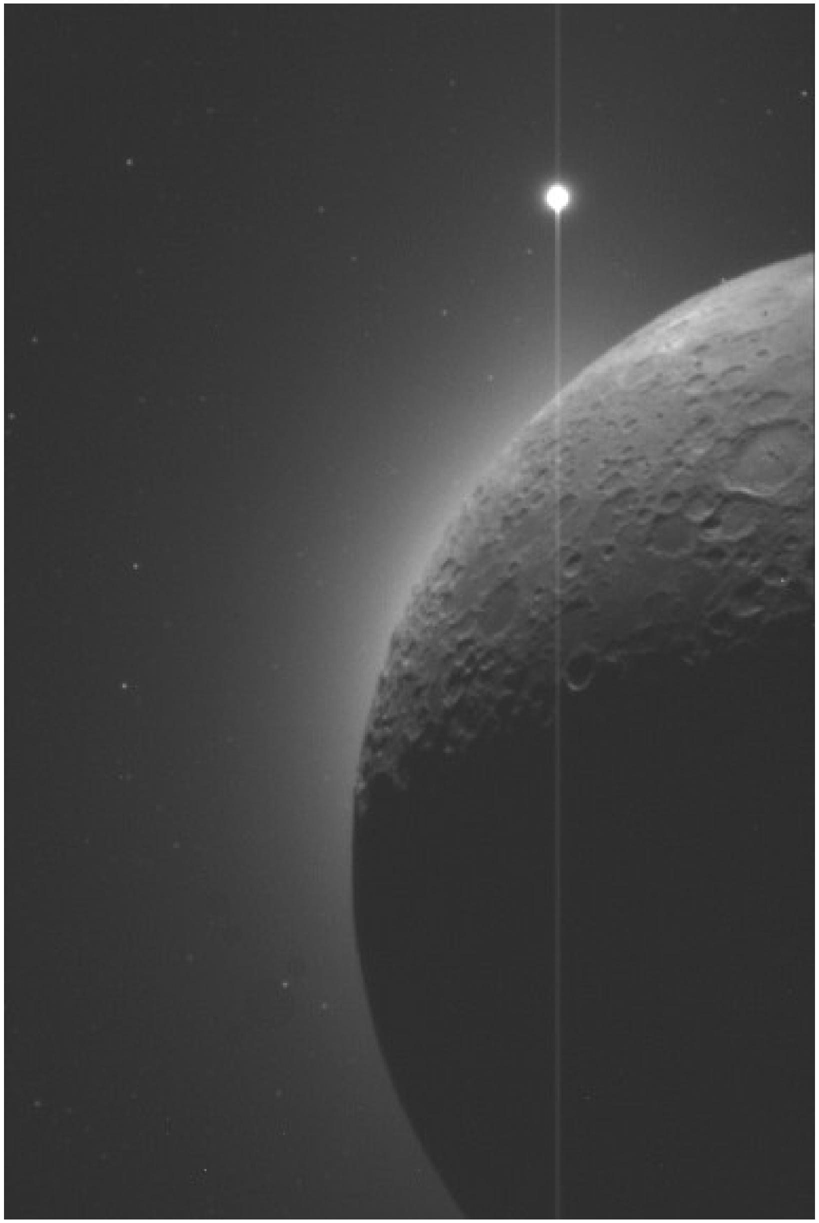
Concerns with the Moon's Surface

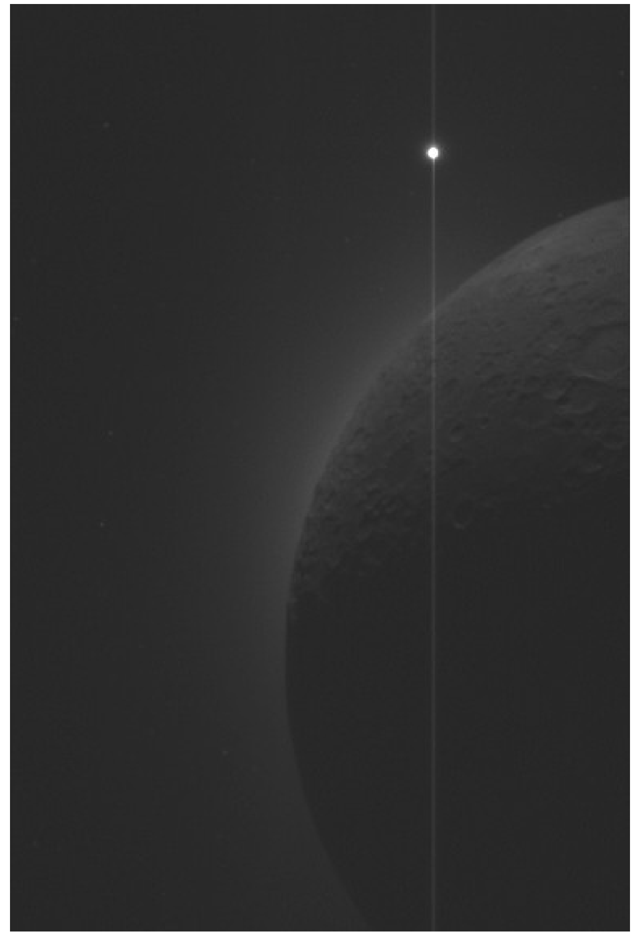
following Lester, Yorke, & Mather, 2003 in *Space Policy*

- *Dirt & Dust* kicked up by lunar activities threaten contact bearings & optical surfaces. Electrostatic charging leads to "static cling". Although laser retroreflectors show little degradation after 30 yrs.
- *Solid surface* may not be ideal for telescopes. Free-space is very stable place to put a telescope or array.
- *Gravity* presents loading problems with structural deformations. Telescopes must be stiffer and, thus, more costly & technologically challenging for large apertures. Exception is liquid mirror, transit telescope (R. Angel).
- *Ultra-cold crater* may be a challenge for both astronauts & equipment to function over long periods. Solar power not available. Sky coverage limited at Shackleton.
- *People pollute.* May stir up dust near telescopes. Mining may grow the atmosphere & increase optical depth. Communication satellites may destroy radio-quiet environment of farside.

Harrison Schmitt at Apollo 17 site.
Note dust clinging to space suit.

Possible Evidence for “Dust Streamers” extending off the limb of the Moon
(David Darling)

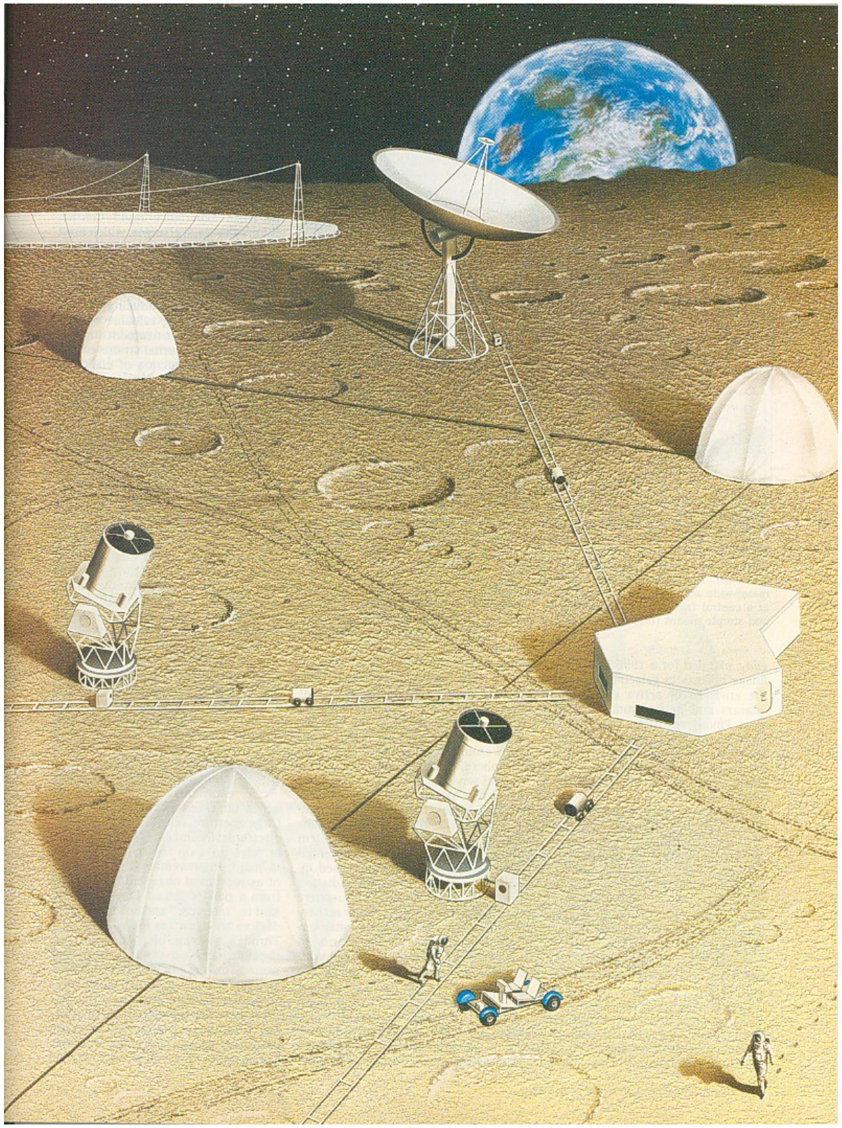




LBA5881Z Clementine Star Tracker Camera

Extrasolar Planet Imaging with a Lunar Optical Interferometer

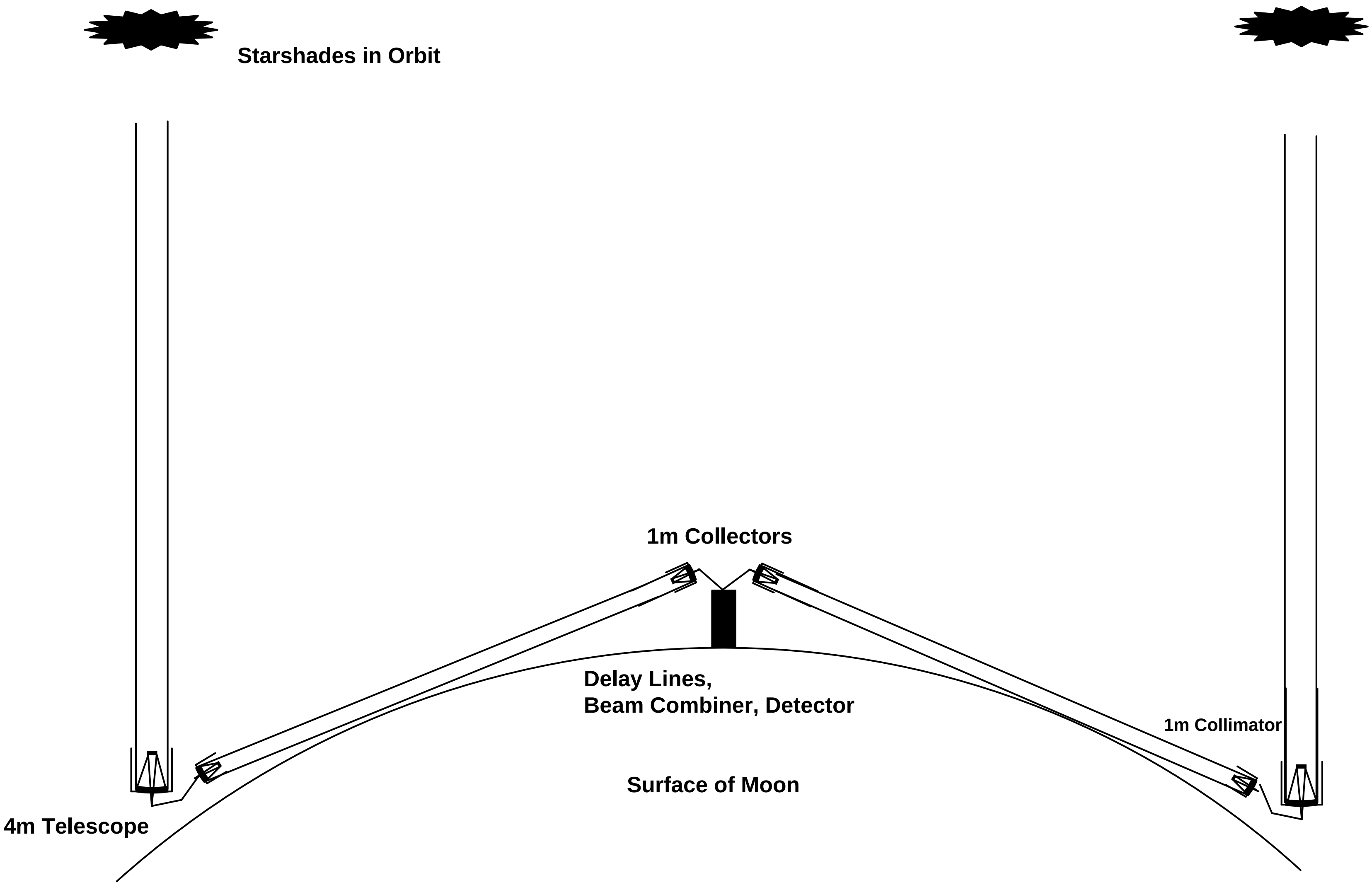
following Burns, Johnson, & Duric (1990) in *A Lunar Optical-uv-IR Synthesis Array*



- Long-baseline array of 43, 1.5-m aperture telescopes distributed in concentric rings ranging from 0.5 to 10 km.
- Microarcsecond imaging and 0.1 microarcsec astrometry.
- At a distance of Tau Ceti, a Jupiter-like planet would have 100 resolution elements in an image.
- But, need high sensitivity (planet is 26^m) and high dynamic range.

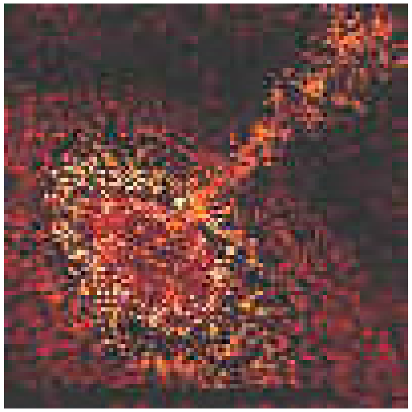
A Lunar Optical Interferometer with Star Shades

concept by W. Cash (2006)

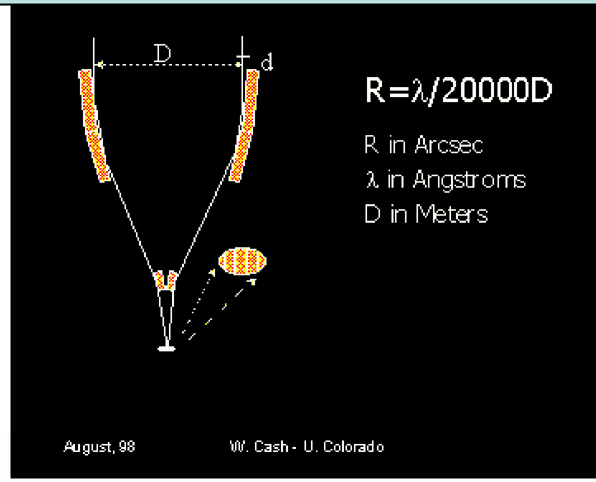


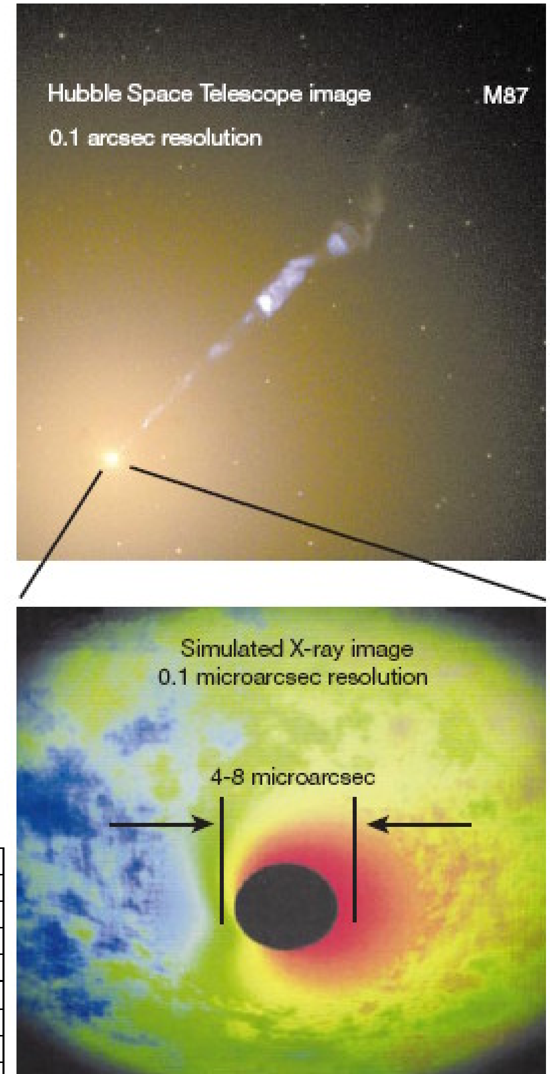
IMAGING THE EVENT HORIZON AROUND AN AGN BLACK HOLE WITH A LUNAR X-RAY INTERFEROMETER

(based on concept from Cash, W. et al. 2000, Nature, 407, 160.)



- Imaging Event Horizon around M87 black hole requires 0.1 – 1.0 μarcsec.





White, N., 2000, Nature, 407, 146.

Table 1: X-ray Interferometer Tolerances

Resolution Arcseconds	1	0.1	10^{-2}	10^{-3}	10^{-4}	10^{-5}.	10^{-6}	10^{-7}
Mirror Length (m)	0.1	0.1	0.3	3	3	3	3	3
Position Stability (μ)	200	20	2	0.2	0.2	0.2	0.2	0.2
Angular Stability (arcsec)	50	10	2	.3	.1	10^{-2}	10^{-3}	10^{-4}
Figure	λ/5	λ/20	λ/50	λ/100	λ/100	λ/100	λ/100	λ/100
Polish (Å rms)	50	30	20	20	20	20	20	20
Baseline (m)					1	10	100	1000
Angular Knowledge (as)	.3	.03	$3x10^{-3}$	$3x10^{-4}$	$3x10^{-5}$	$3x10^{-6}$	$3x10^{-7}$	$3x10^{-8}$
Position Knowledge (nm)					20	20	20	20
E/dE Detector					10	100	1000	10000

Pathfinder Event Horizon

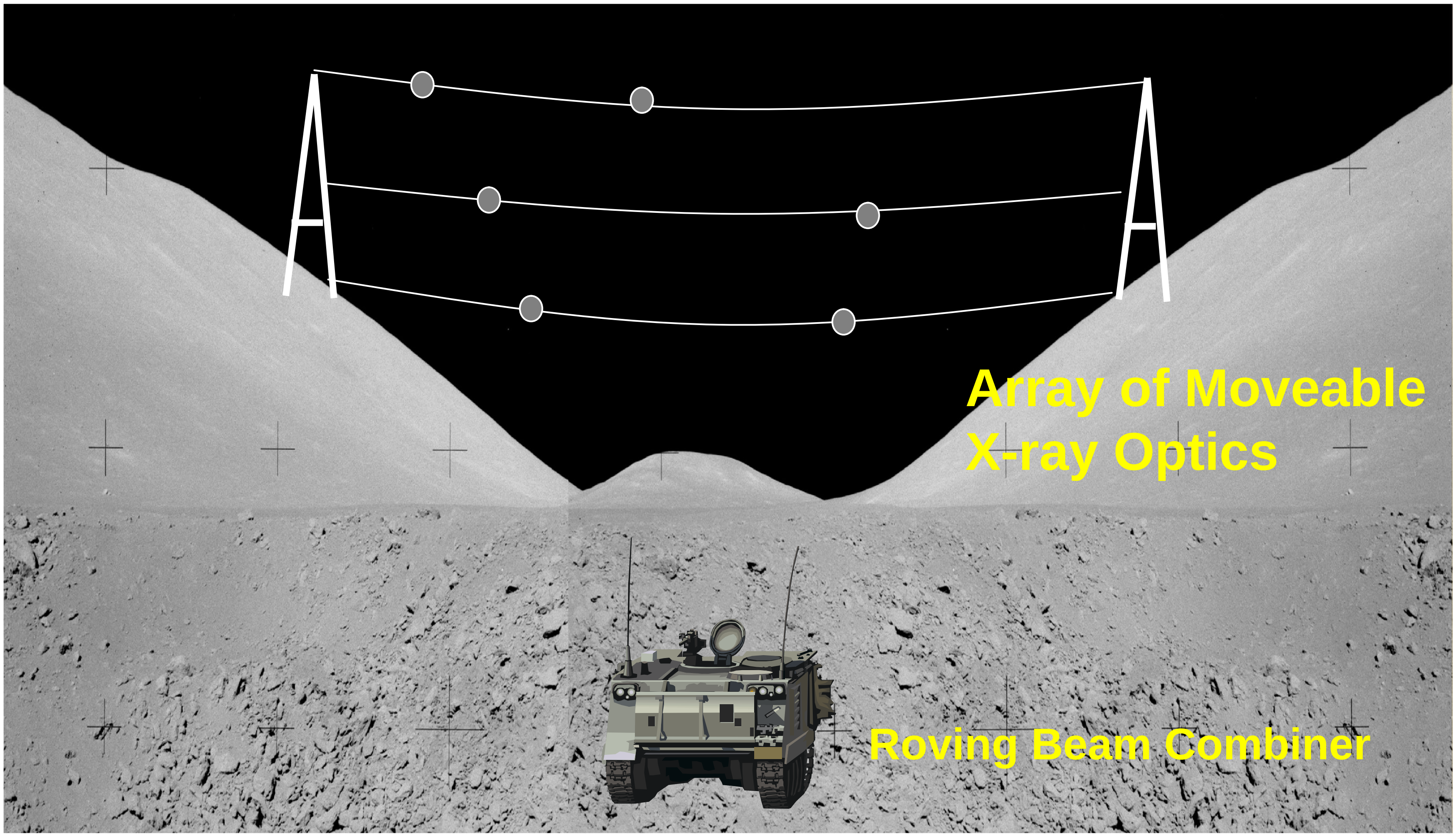
- Lunar X-ray interferometer achieves needed resolution using grazing incidence mirrors separated by 0.1 -1 km baseline with X-ray detector placed 500 km behind the mirrors.

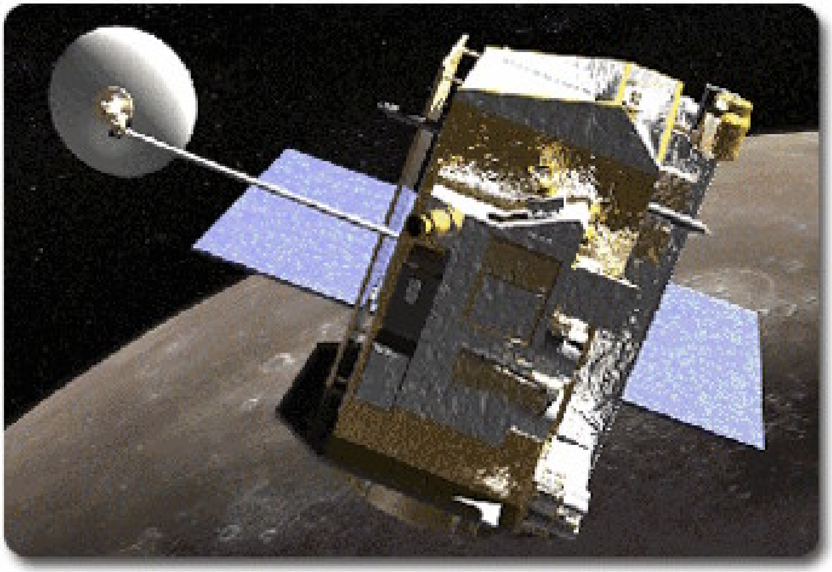
Black Hole Imager Concept

X-ray Interferometry

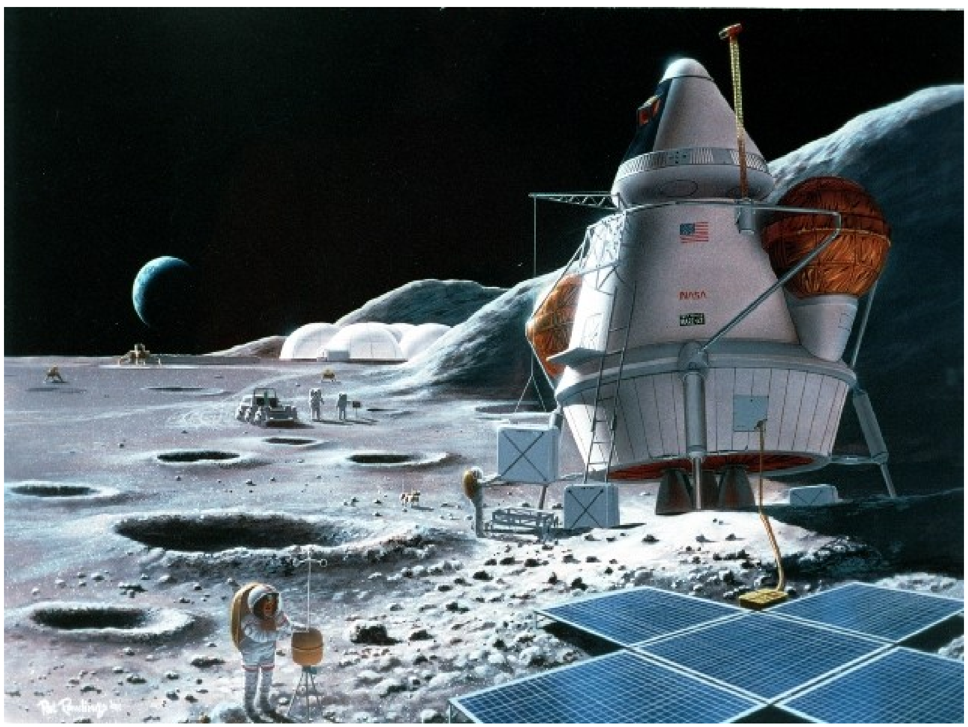
Using Lunar Stability and Topography

W. Cash 11/06





Lunar Reconnaissance Orbiter (LRC)



What's Needed Next?

- An environmental impact assessment of Moon is needed before serious planning for lunar telescopes can be conducted.
- More data required on lunar surface conditions – dust, thermal environment, ionosphere.
- Dust measurements via scattered light could be made with LRC camera (7 filters, 300-700 nm).
- Measure ionospheric density using ROLSS or via orbiting spacecraft.
- Measure baseline of background radio emission on lunar farside before human habitation of Moon.