LAMA

Large Astronomical Mercury-Mirror Array

Paul Hickson	University of British Columbia
Ken Lanzetta	SUNY Stony Brook
Rick Puetter	UC San Diego
Gene Sprouse	SUNY Stony Brook
Amos Yahil	SUNY Stony Brook

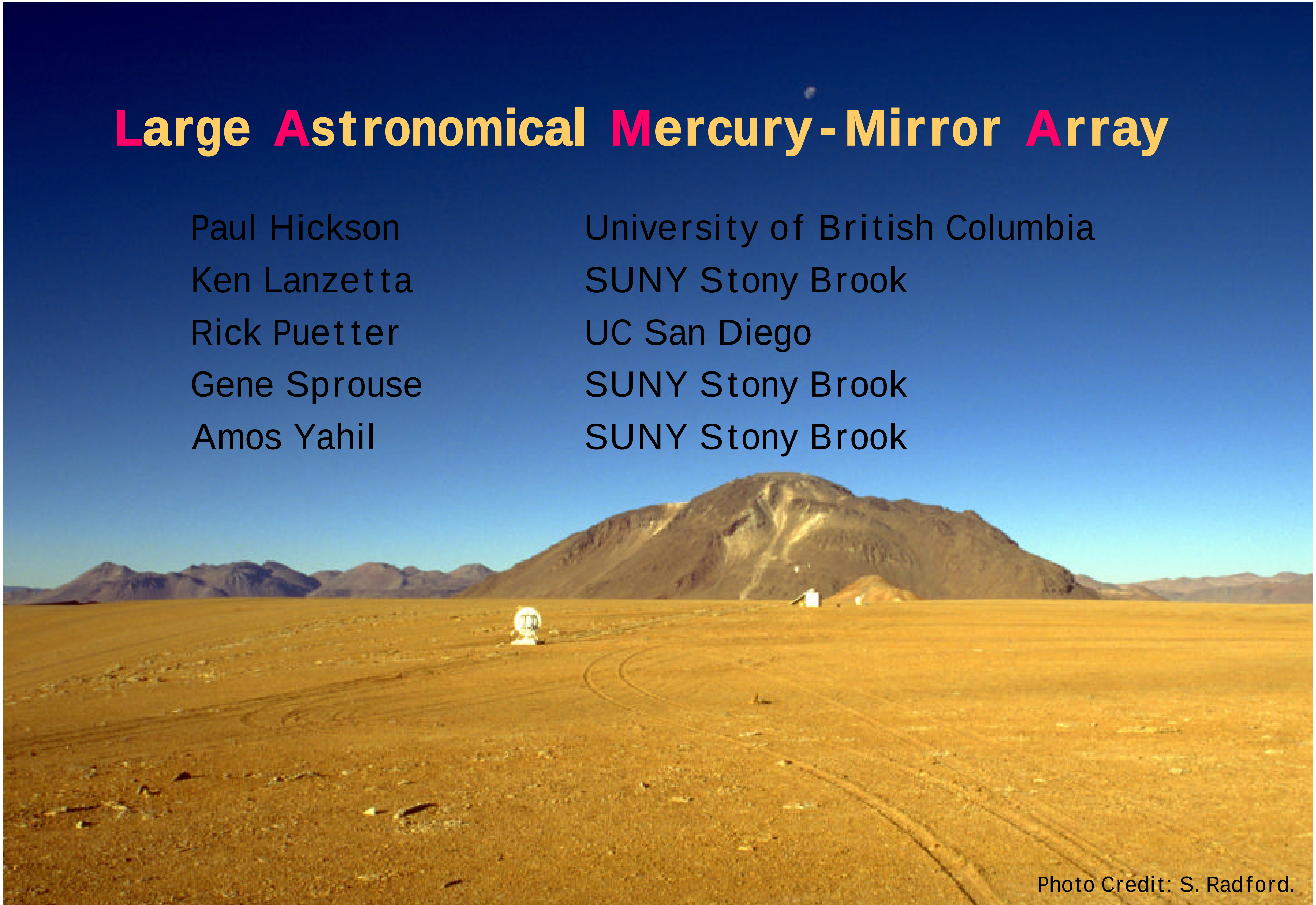


Photo Credit: S. Radford.

Very Large Optical Telescope Concepts

- "Continued progress in optical astronomy requires a telescope of aperture and resolution significantly larger than that of present instruments" – Next Generation CFHT Committee
- Aperture in the range 30-100 meters is needed

Major Optical Telescope Projects/Proposals

Project	Aperture	Cost	First Light
NGST	8 m (space)	~ 800 M$	2007
CELT	~ 30 m	~ 600 M$	2010?
MAXAT	~ 50 m	~ 1000 M$	2012?
OWL	~ 100 m	> 1000 M$	2015+

Primary Science Goals

- Detect and study the first luminous systems
- Study the process of galaxy formation and evolution from redshift $z \sim 20$ to the present
- Determine the star formation history of the Universe
- Determine the cosmological parameters
- Resolve the innermost regions of AGN and QSOs
- Detect and study the oldest and faintest stars

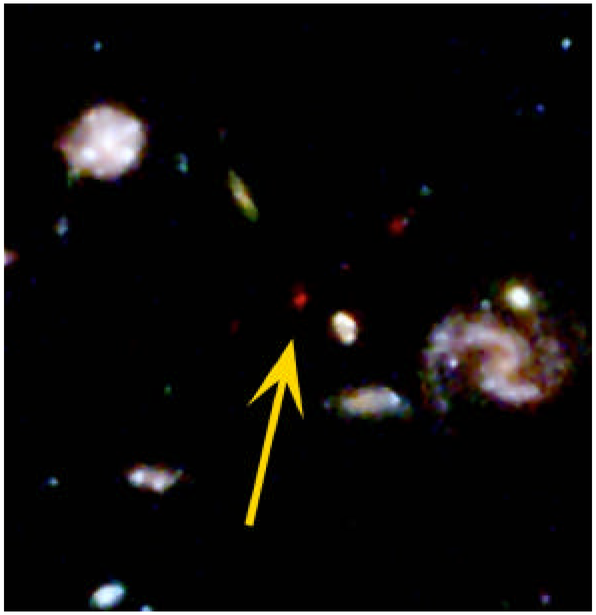
Observing Galaxy Formation

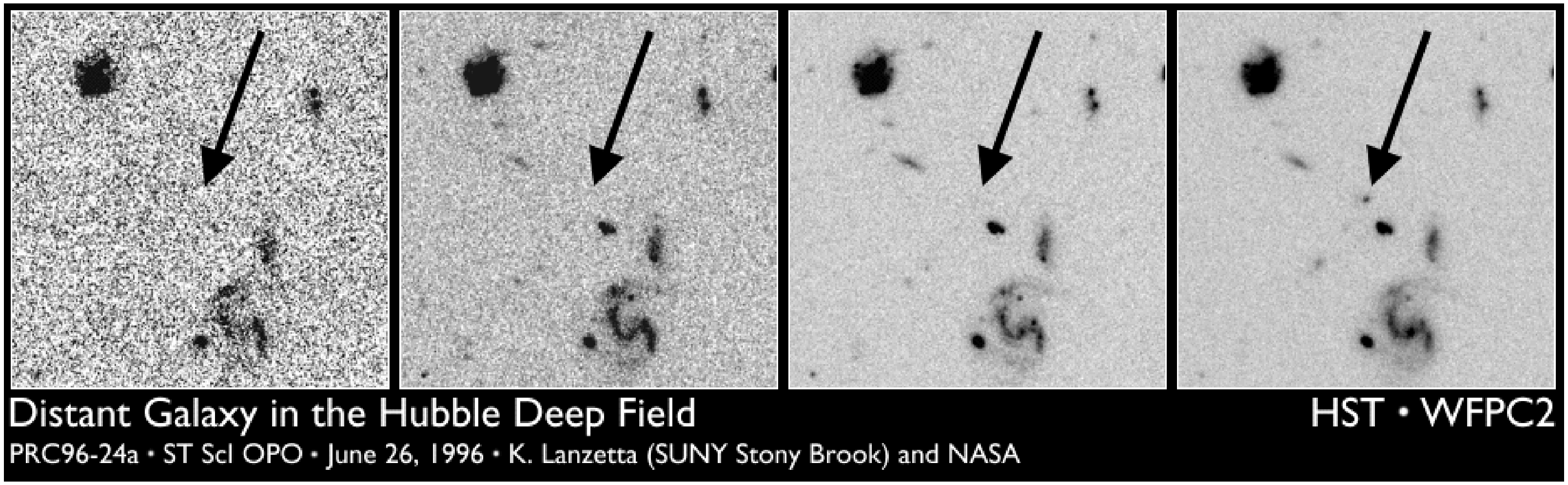
Photo Credit:NASA.

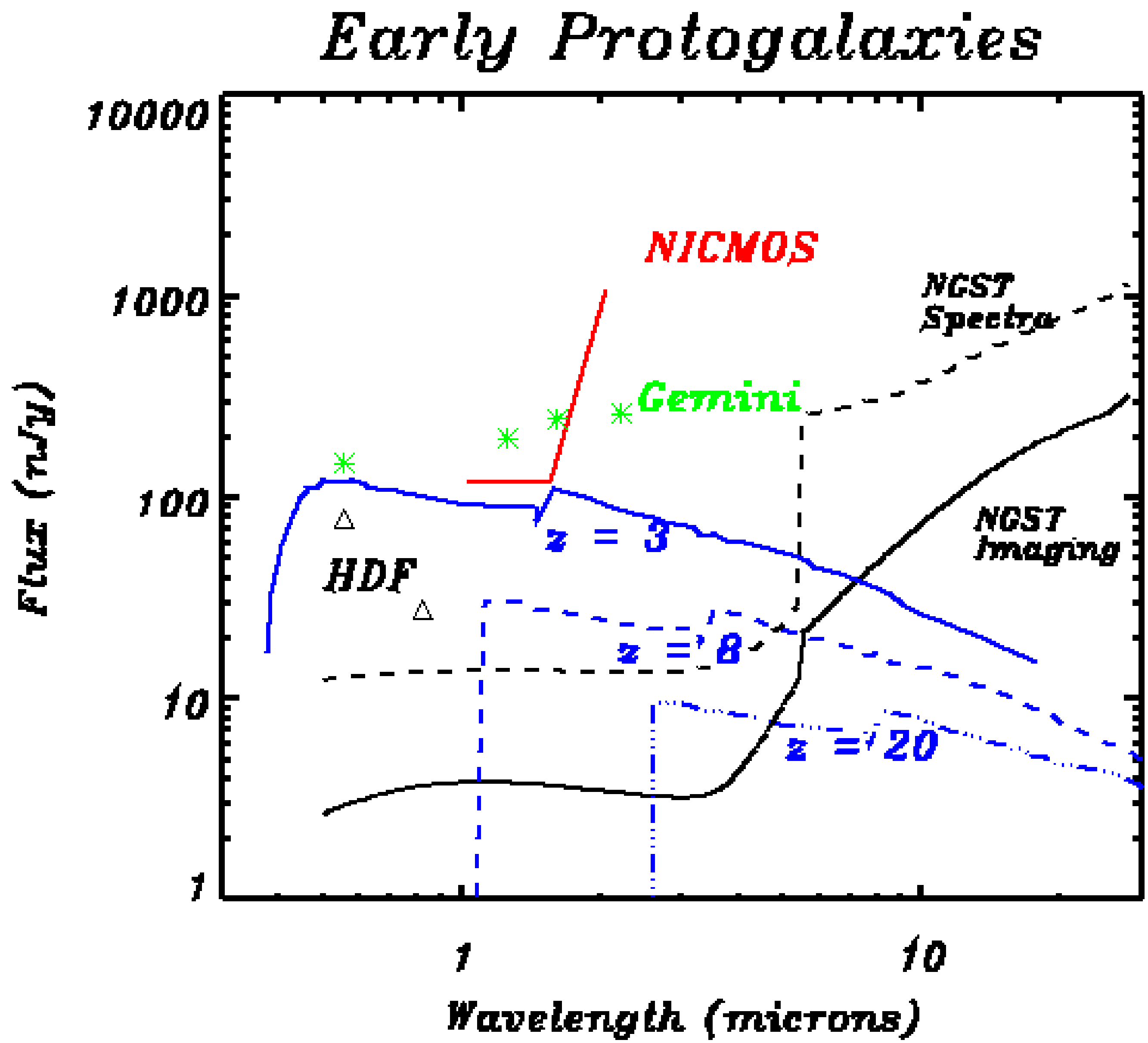
LAMA

Finding The First Galaxies

- Wavelength range 0.4 < ? < 2.5 um
- Lyman-a visible to z = 19.6



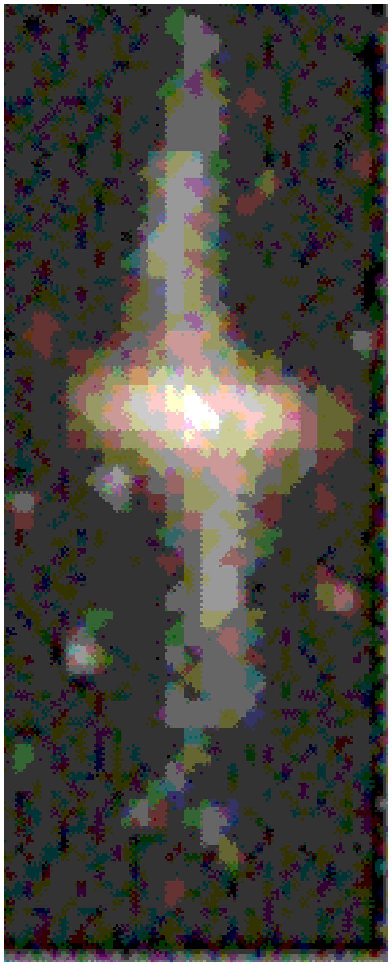



Early Protogalaxies
10000
1000
100
10
1
Flux (nJy)
NICMOS
NGST
Spectra
Gemini
HDF
z = 3
z = 8
z = 20
NGST
Imaging
1
10
Wavelength (microns)

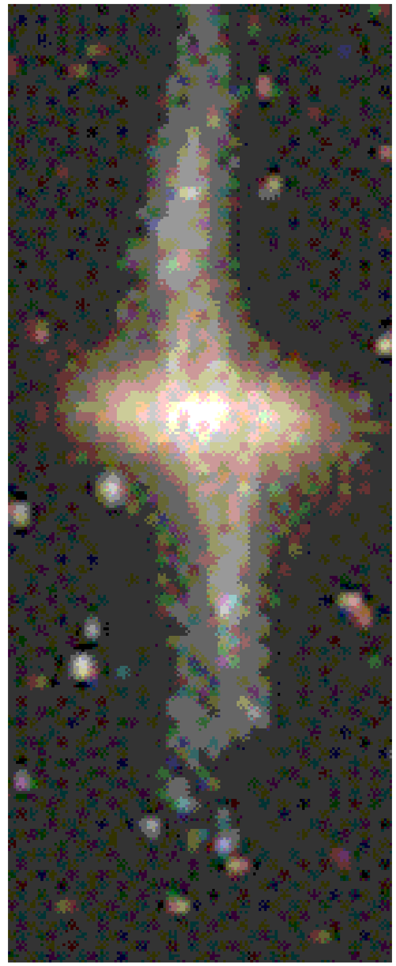
Credit: NGST

Importance of Resolution

HST 2.4m



NGST 8m



LAMA 60m

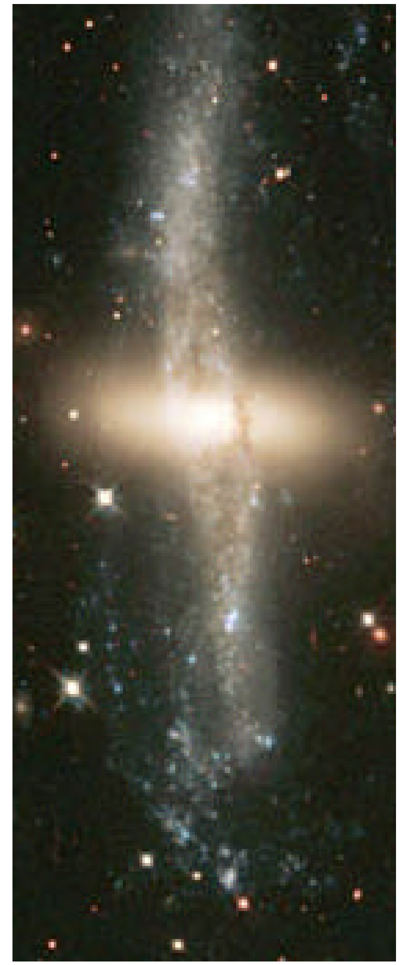
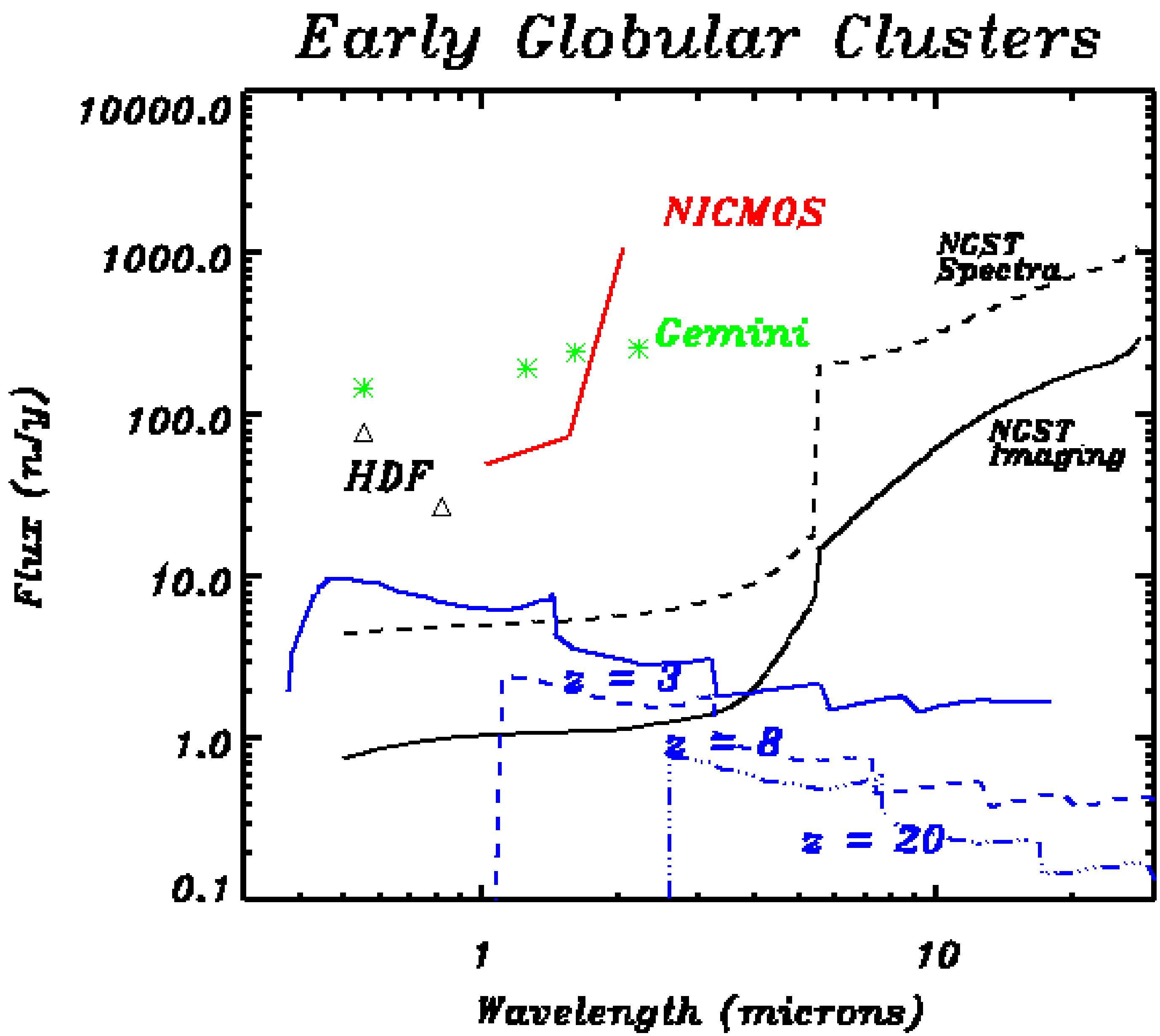
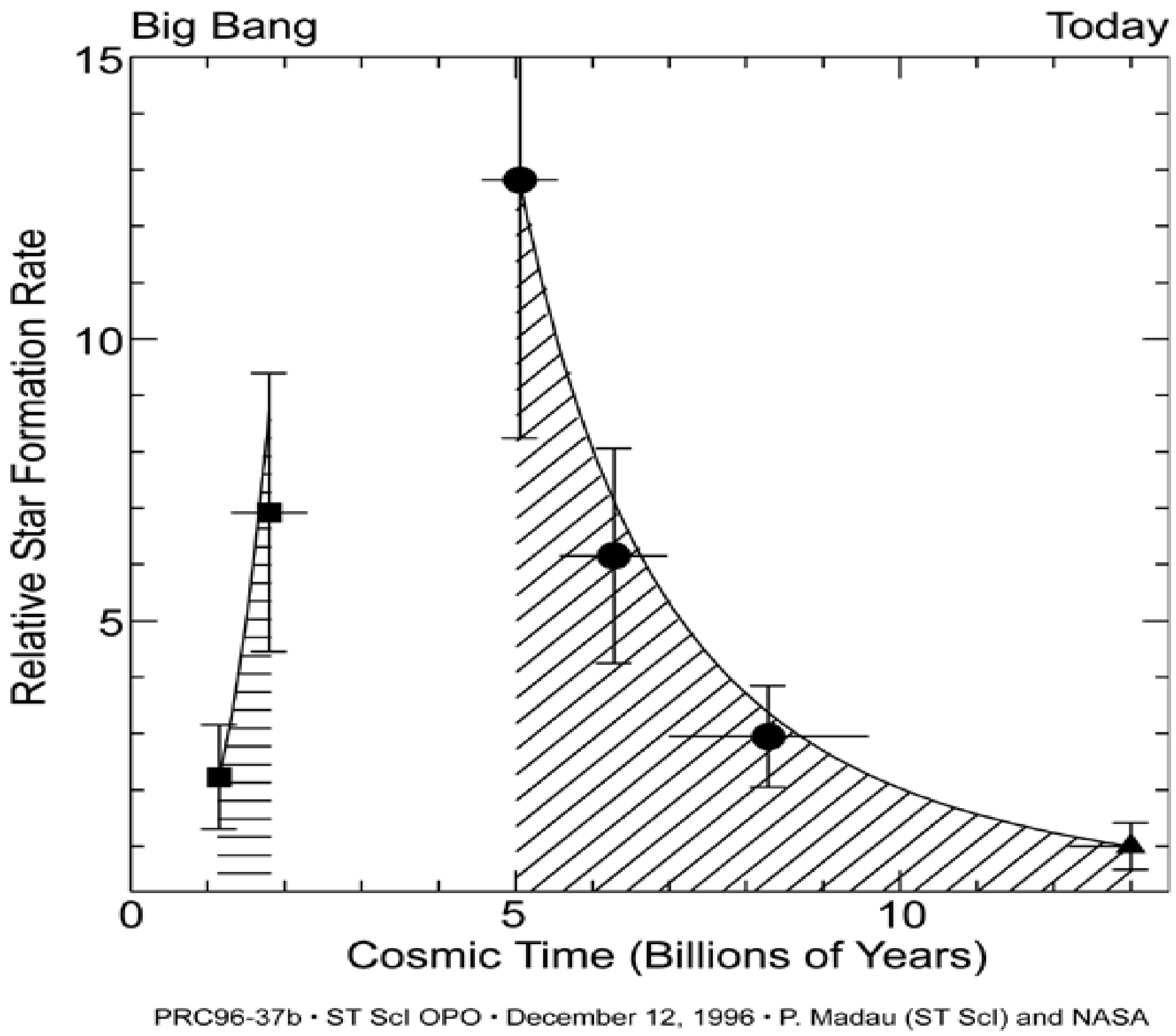


Photo Credit:NASA


Early Globular Clusters
NICMOS
NGST Spectra
Gemini
NGST Imaging
HDF
z = 3
z = 8
z = 20
Flux (nJy)
Wavelength (microns)
10000.0
1000.0
100.0
10.0
1.0
0.1
1
10

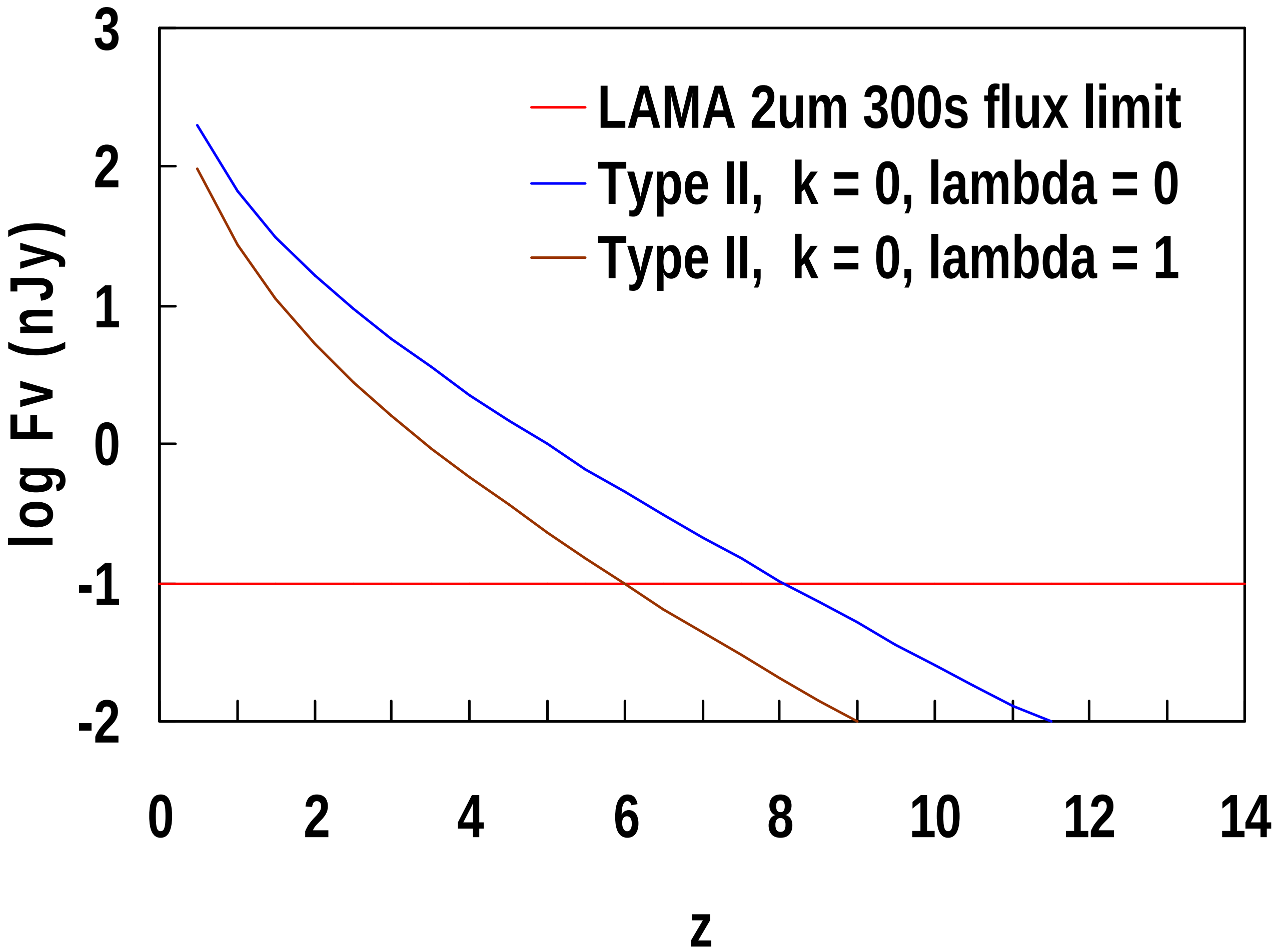
Credit: NGST

Star-Formation History of the Universe?



Credit: NASA

Supernova Detection



Object Counts (per square arcmin)

Flux (nJy)	10 (K_{AB} = 28.9)	1 (K_{AB} = 31.4)
Galaxies	781	2628
z < 5	708	1757
5 < z < 10	67	778
z > 10	2	20
Lyman-a emitters (R = 100)	57	
z < 5	51	
5 < z < 10	5	
z > 10	0.3	
Supernovae II per year	0.5	1
Active Galactic Nuclei	78	
z < 5	74	
5 < z < 10	4	
z > 10	0.4	
Strong Gravitational lenses	3	17

Performance Goals

- 0.4 – 2.5 um wavelength range
- < 0.1 nJy detection limit for point sources
- < 1 nJy detection limit for galaxies
- Milliarcsec resolution
- ~ 100 square arcmin survey area:
  - > 10^5 galaxies
  - ~ 100 supernovae per year

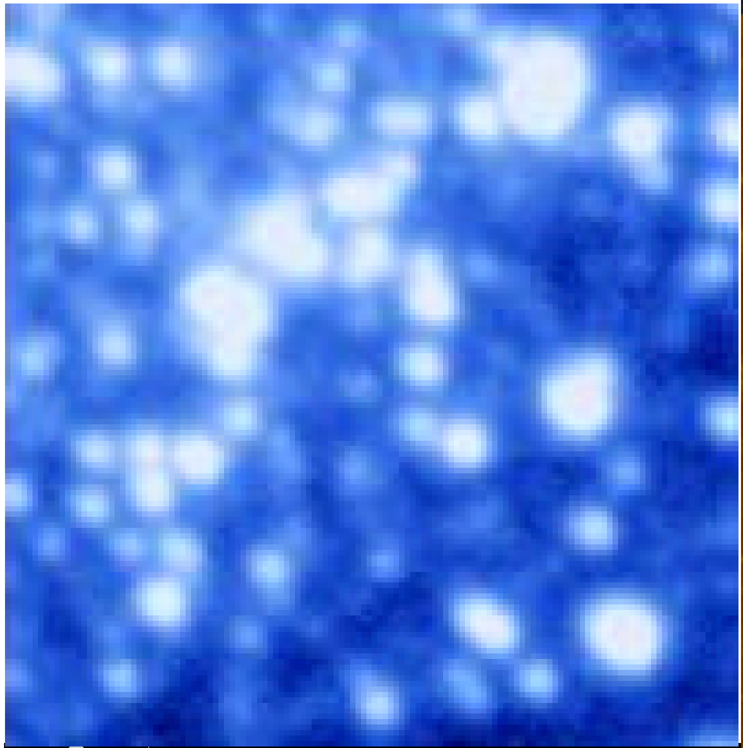
Emerging Technologies

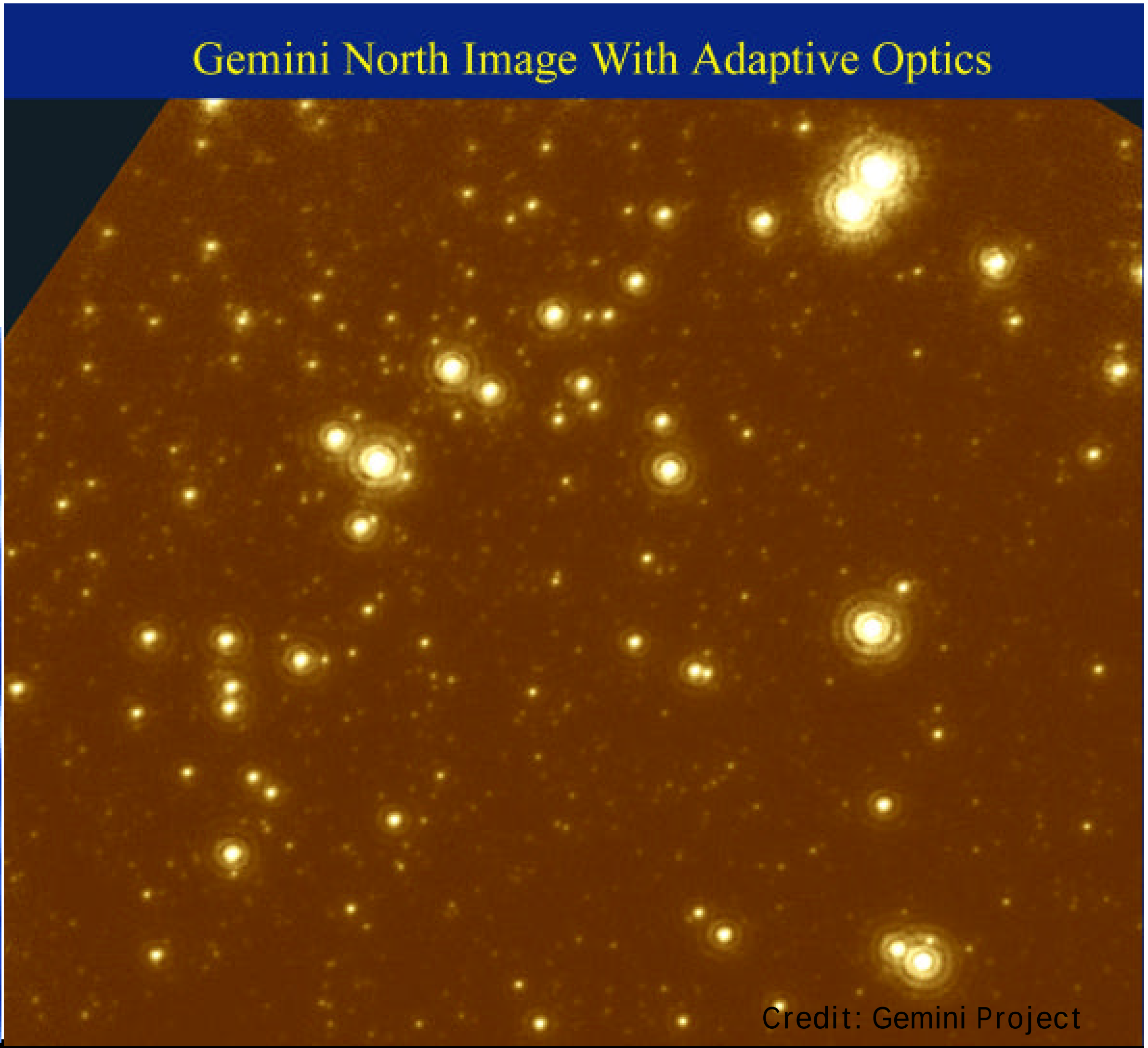
- Adaptive Optics
- Optical interferometry
- Large mercury mirrors
- Near-zenith tracking optics
- OH absorption cell
- Large VIS/NIR arrays

Adaptive Optics

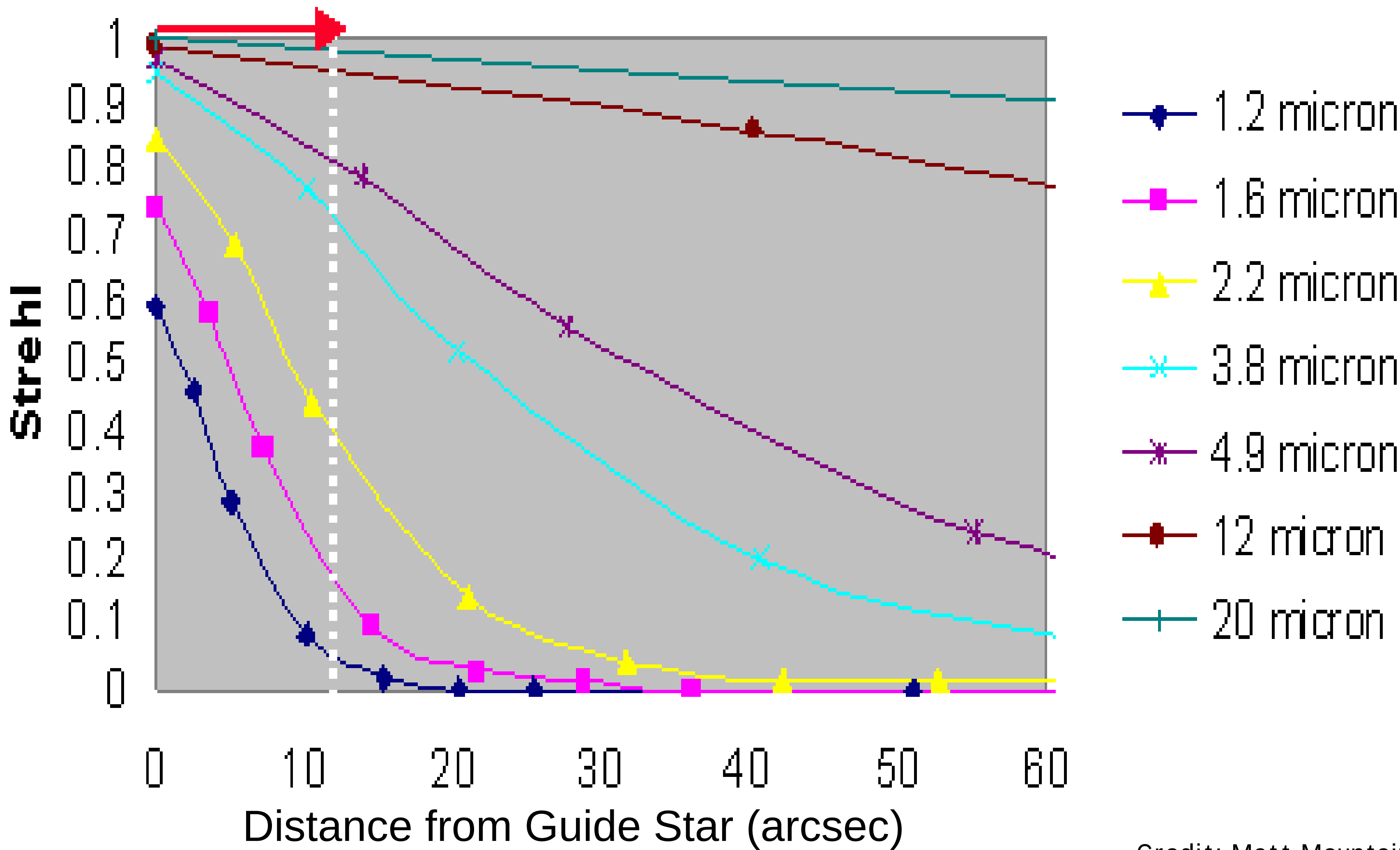
FWHM = 0.08 arcsec

FWHM = 0.8 arcsec



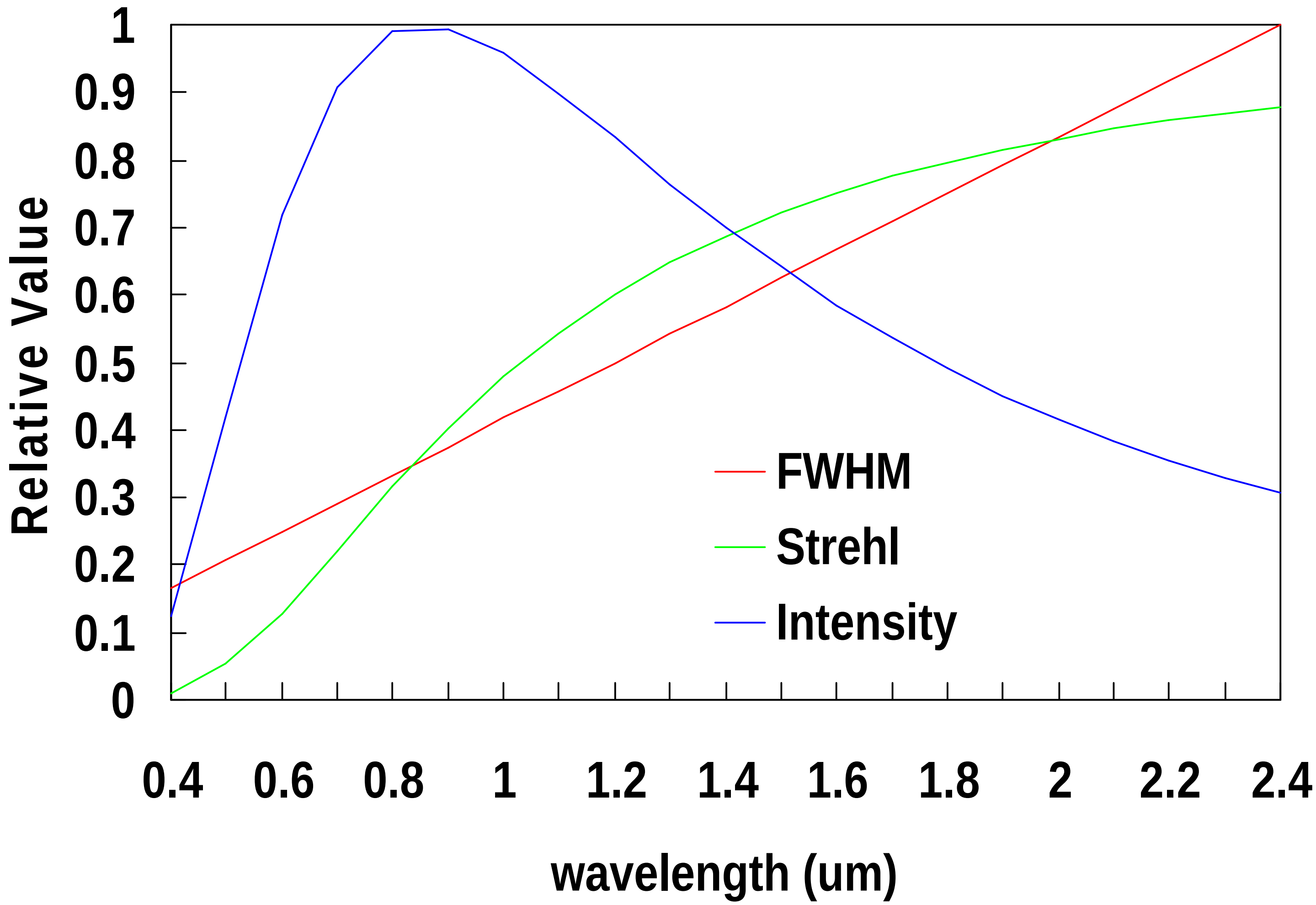


Adaptive Optics Performance



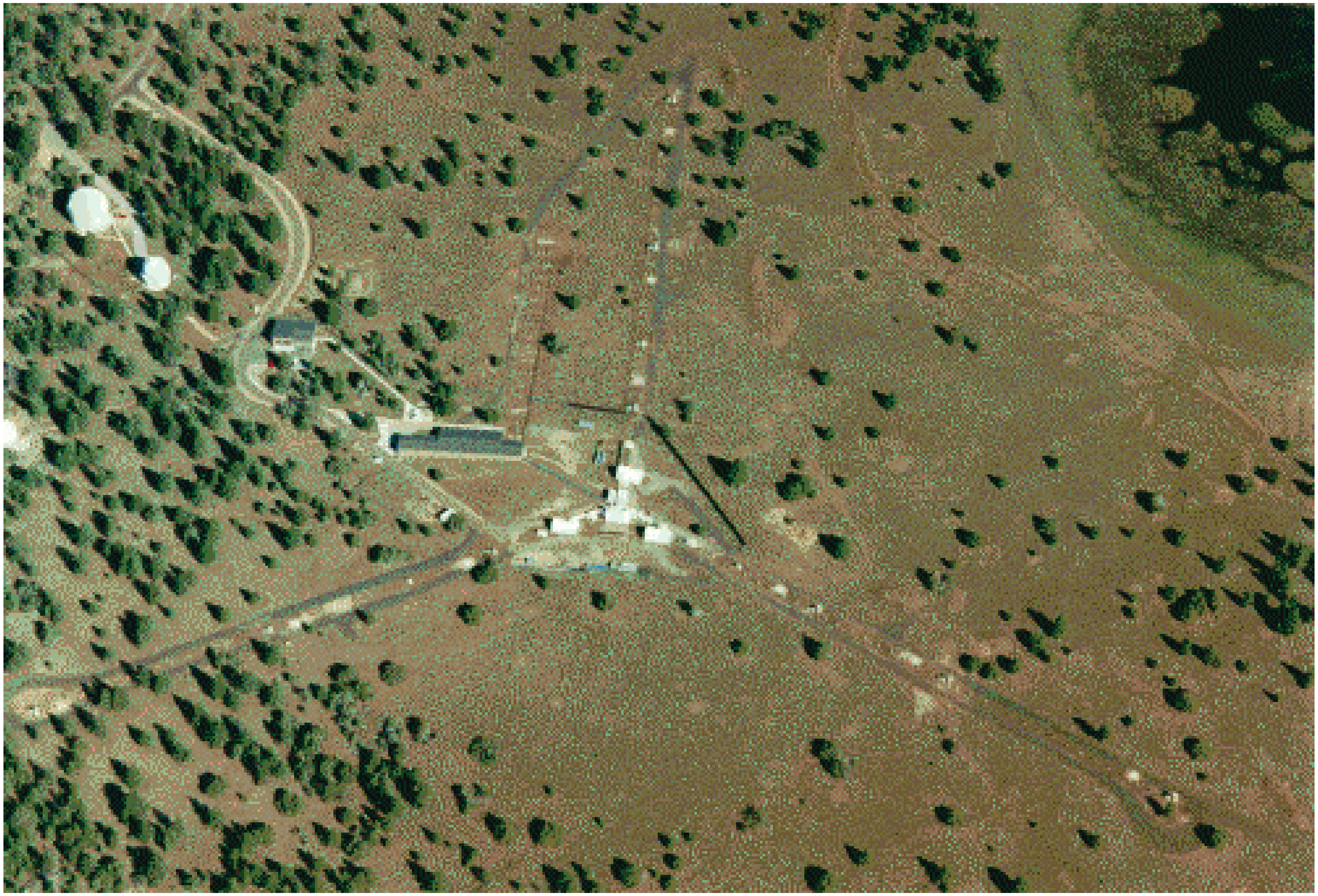
Credit: Matt Mountain

Image Intensity



Optical Interferometry

NPOI



Optical Interferometry

- Frontier technology
- Phase closure with independent telescopes has been demonstrated
- Prototype arrays: I2T, MkIII, IRMA
- Operational arrays: PTI, IOTA, NPOI, ISI, GI2T, SUSI
- Upcoming arrays: COAST, VLTI, Keck
- Phase errors within individual apertures are corrected with adaptive optics
- Moving mirrors remove zero-point (piston) phase differences
- Phase tracking on light from natural guide star
- LBT design gives interferometric imaging over 40 arcsec

LBT Imaging Interferometer

- 2 x 8.4 m interferometer
- 22.8 m baseline
- f/15 phase-combined beam
- Laser guide-star AO on individual telescopes
- Phase tracking on natural guide star
- 40 arcsec FOV
- 5 mas resolution in optical
- 80-96% Strehl ratio in interferometric image

Liquid-Mirror Telescopes

- Three 3m telescopes in operation
- A 6m nearing completion
- A 4m project in Chile


Photo Credit: Chip Simons Photography

Liquid-Mirror Technology

- Strehl Ratio

  S = central intensity/ideal central intensity

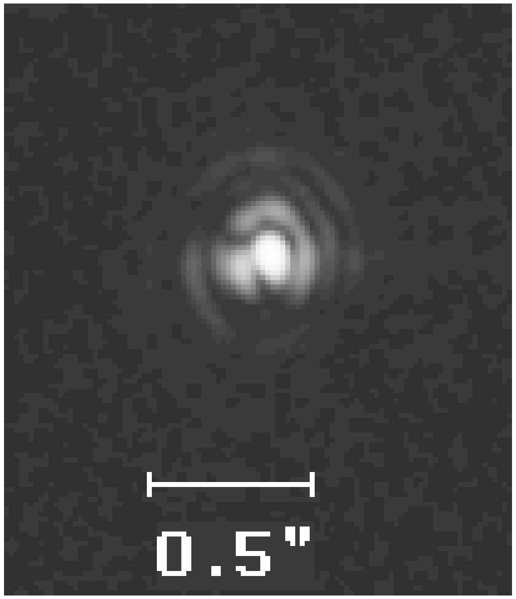
- S = 0.81 measured in lab tests of 2.5m LM

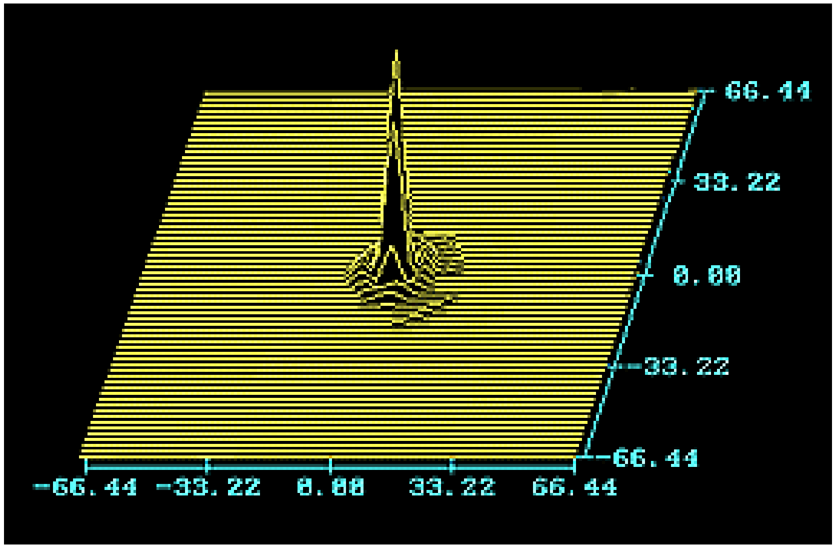
- S ~ 0.5-0.7 estimated for NODO 3m telescope

- $S \sim \exp(-k^2\sigma^2)$

  $k = 2\pi/\lambda$

  σ = RMS OPD error





Images courtesy of Dr. E. Borra, Universite Laval

Liquid-Mirror Interferometric Testing

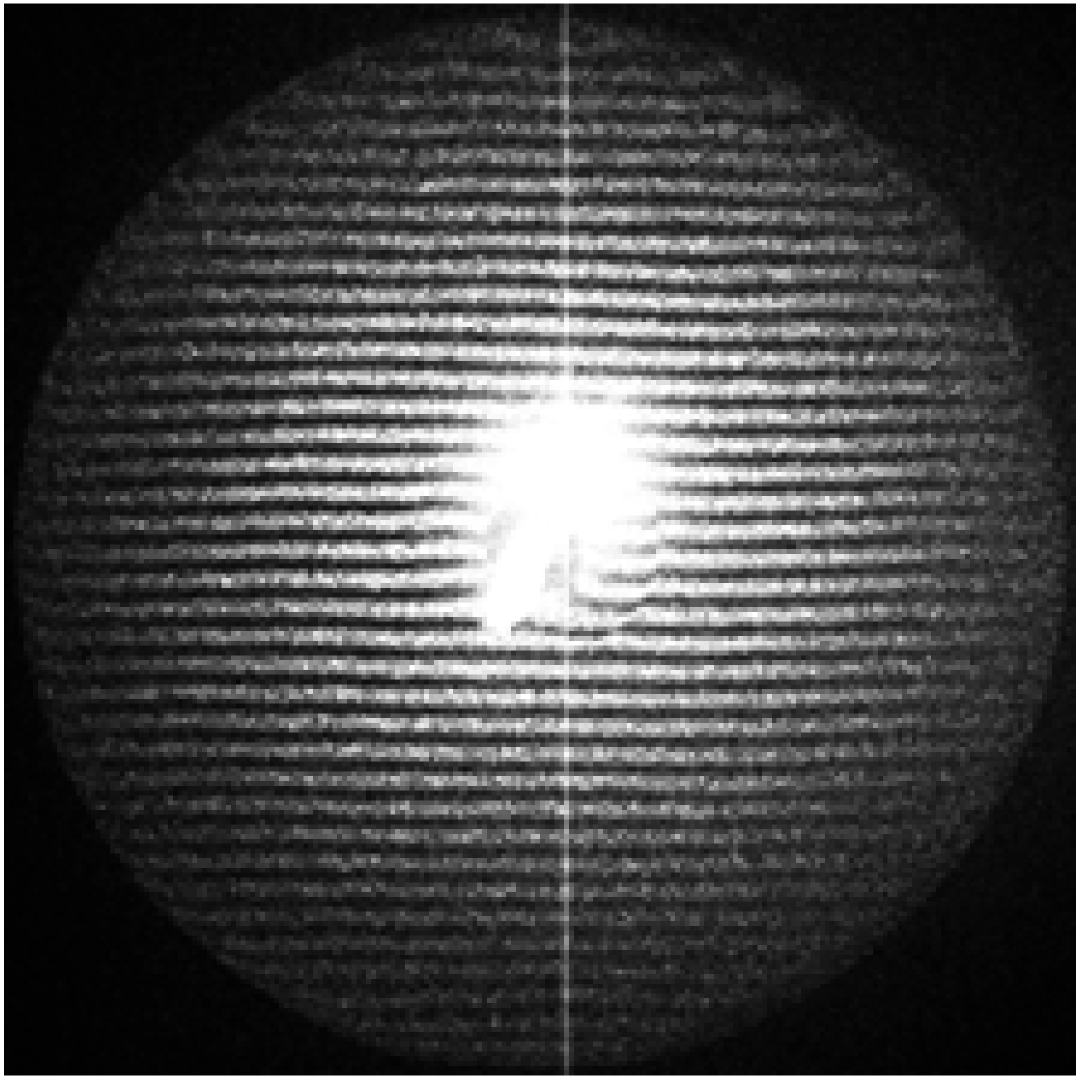


Image courtesy of
Dr. E. Borra, Universite
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Liquid-Mirror Surface Quality

- 85 nm RMS error ⇨ S = 0.93 at λ = 2 um

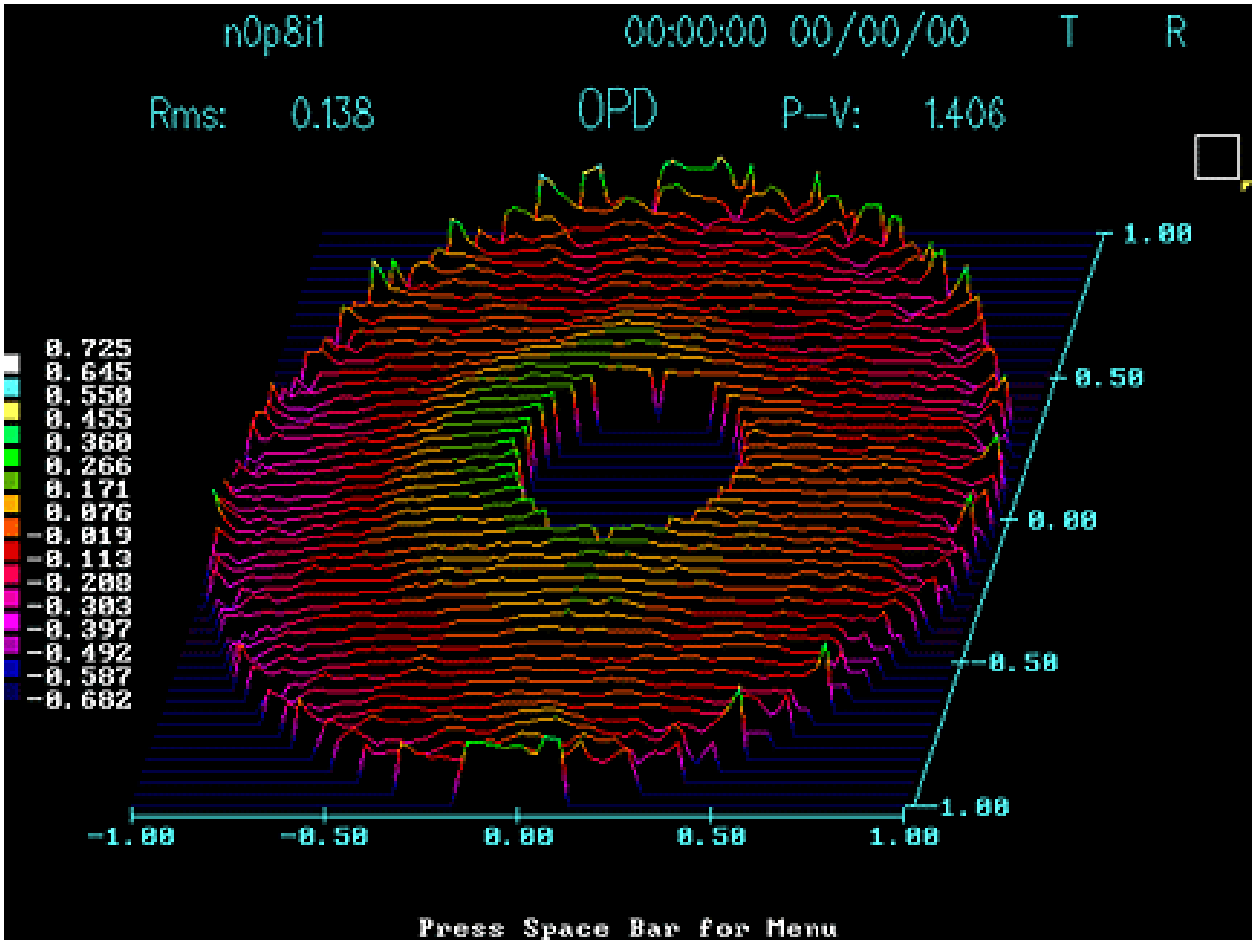
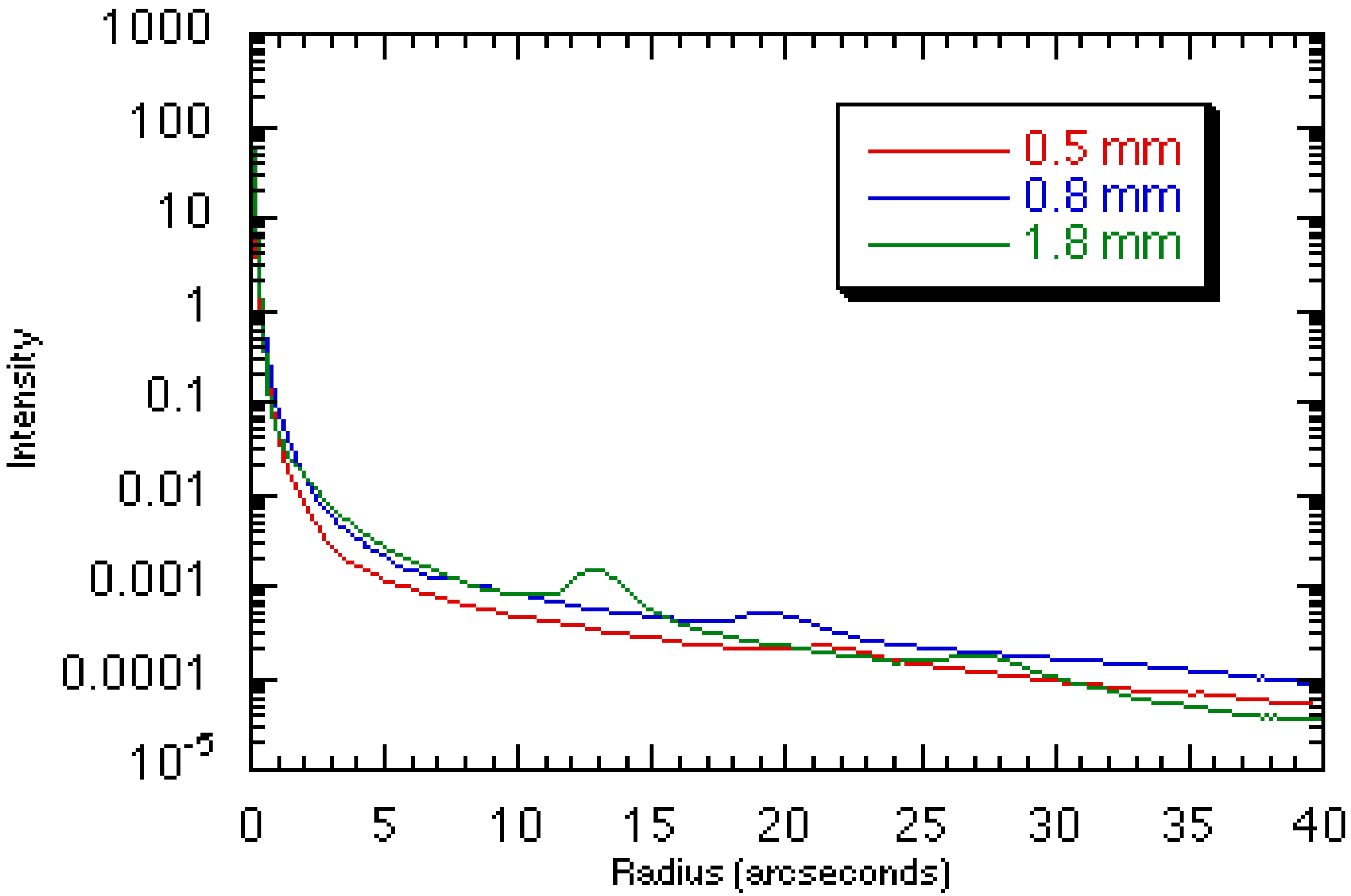


Image courtesy of Dr. E. Borra, Universite Laval

Scattered Light

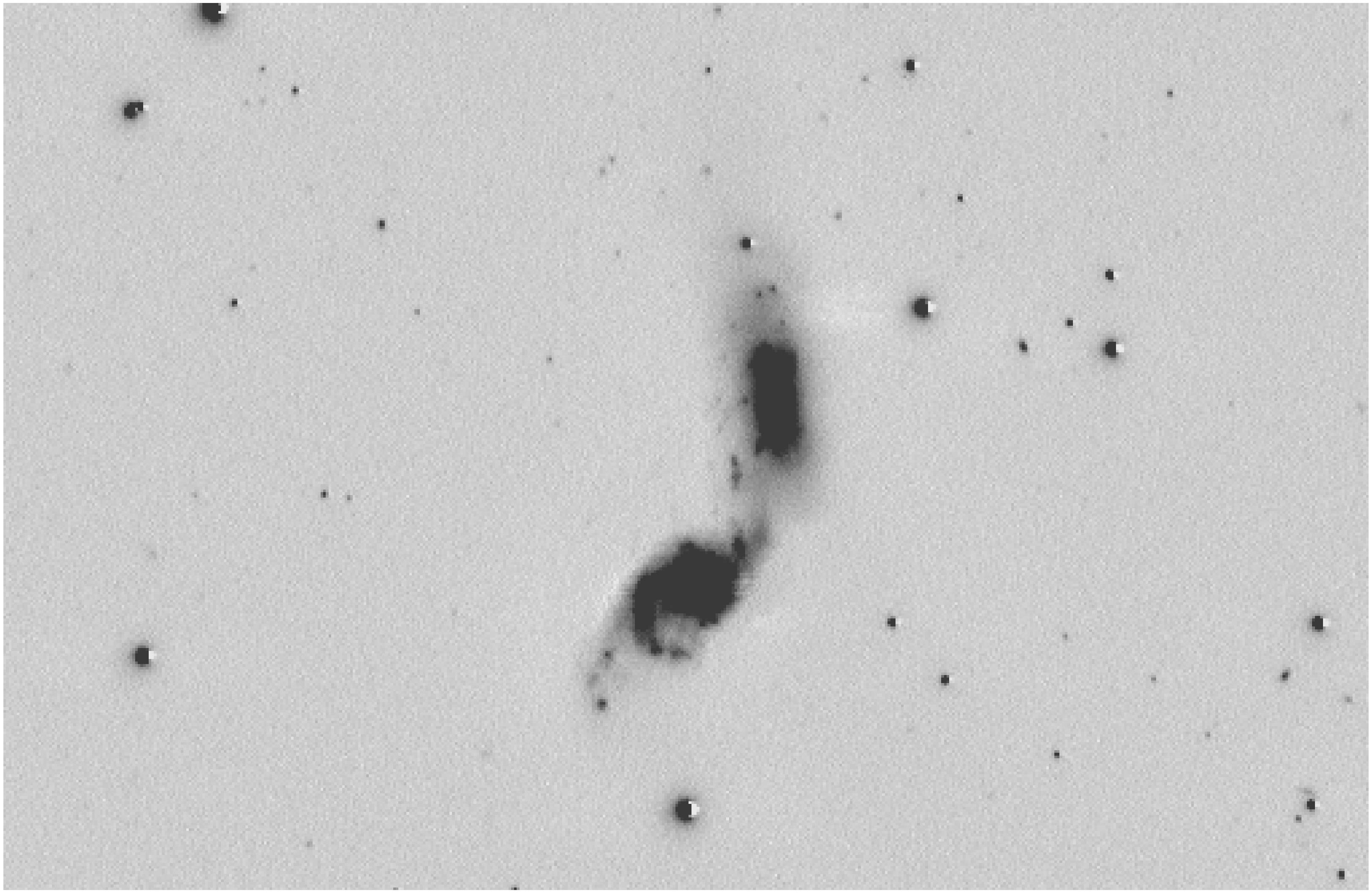


Credit: Dr. E. Borra, Universite Laval

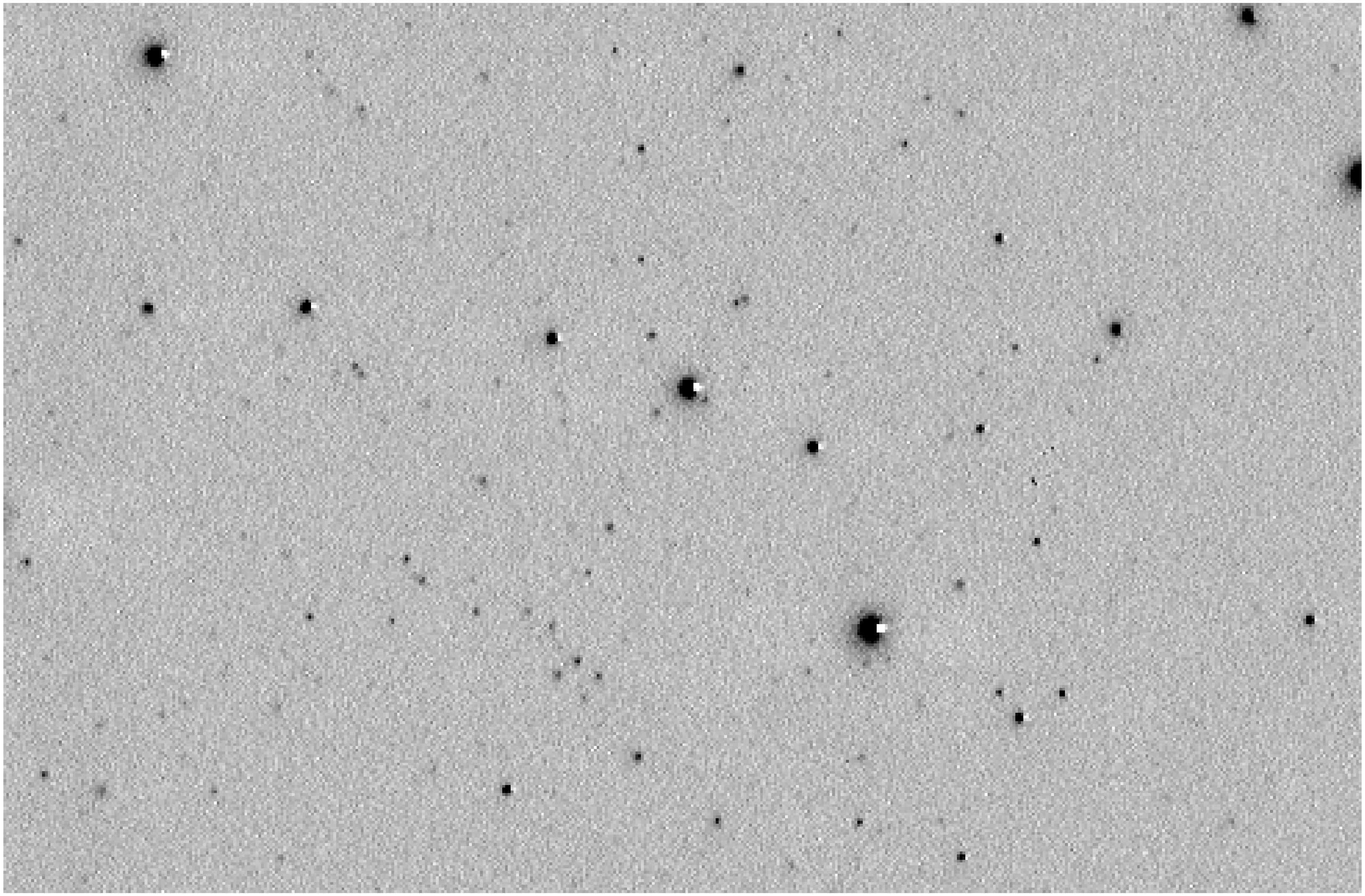
Mercury Telescopes NODO

Photo credit: Mark K. Mulrooney

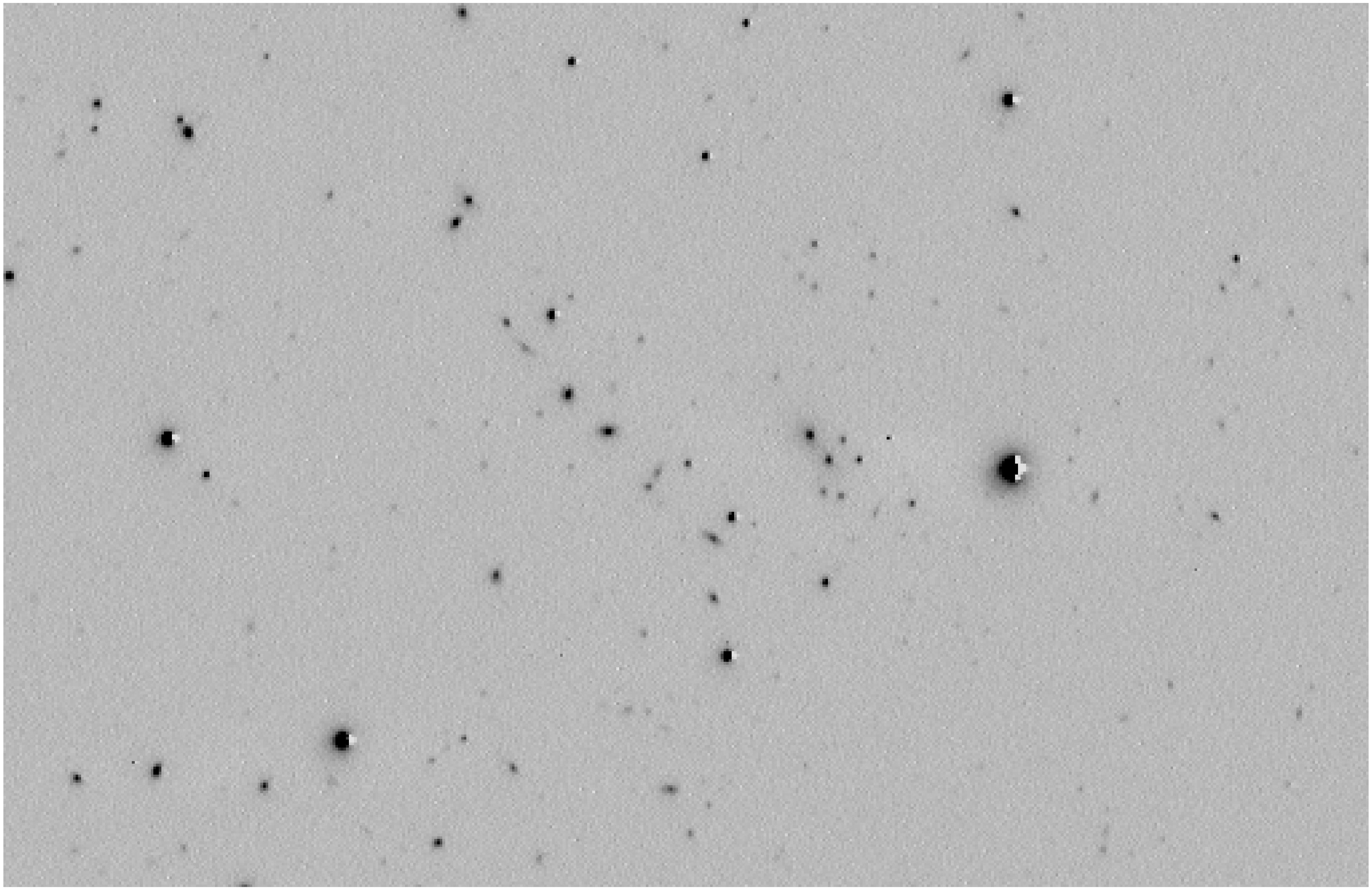
LMT Imaging Arp 270



LMT Imaging Field Galaxies



LMT Imaging Distant Cluster



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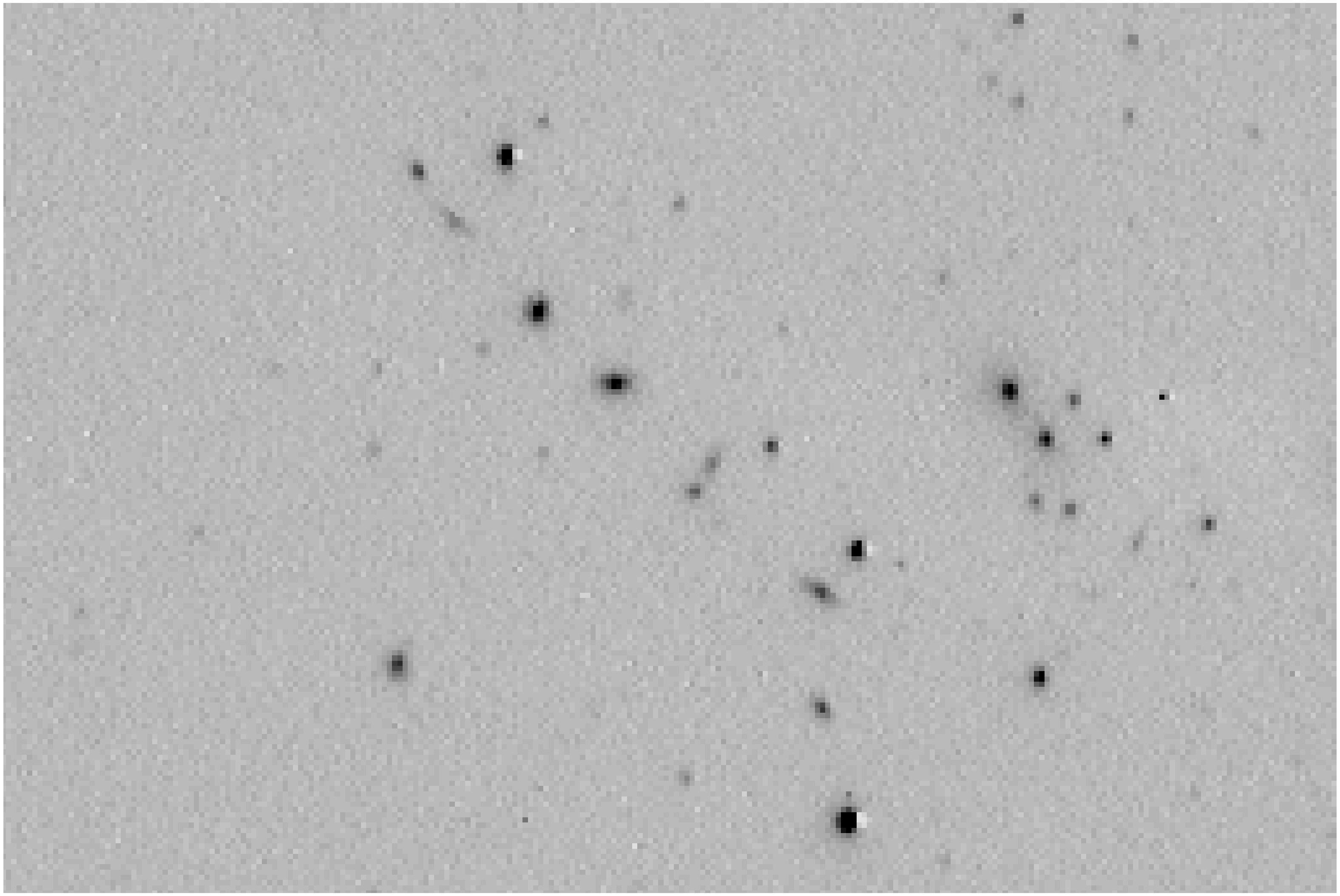
LMT Imaging Cluster Core

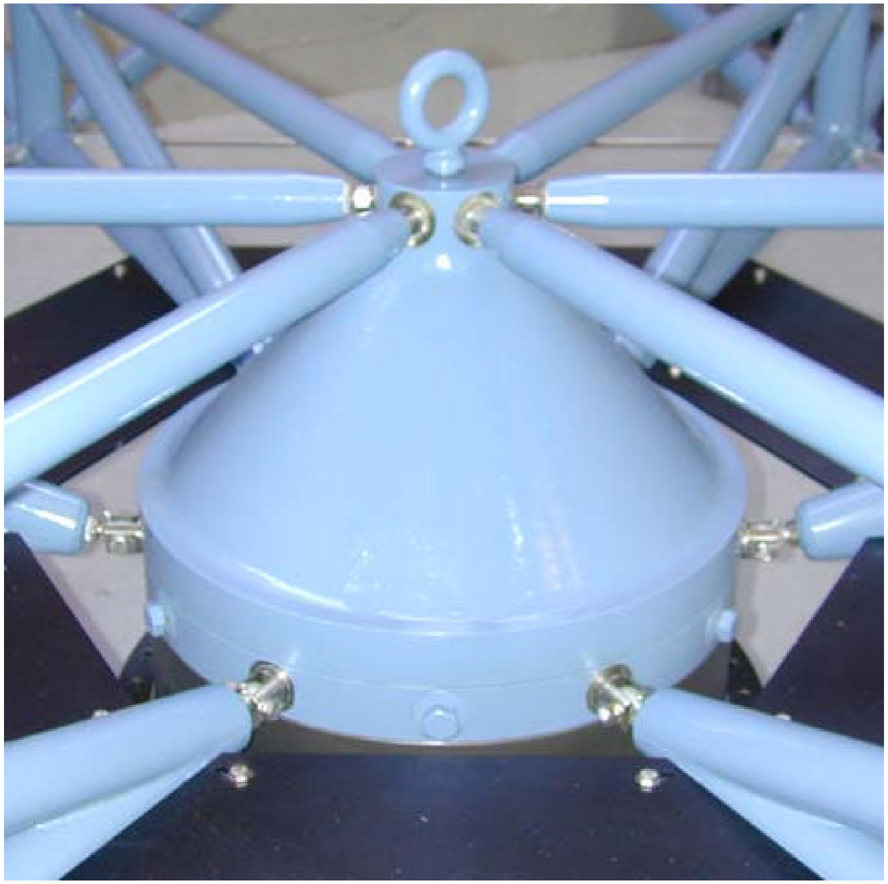


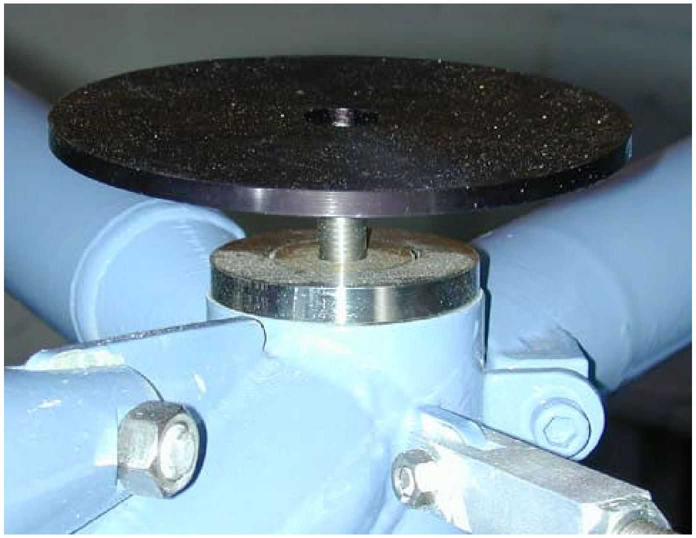
LAMA

Large
Zenith
Telescope

6m Primary Mirror Truss

LZT Mirror Truss



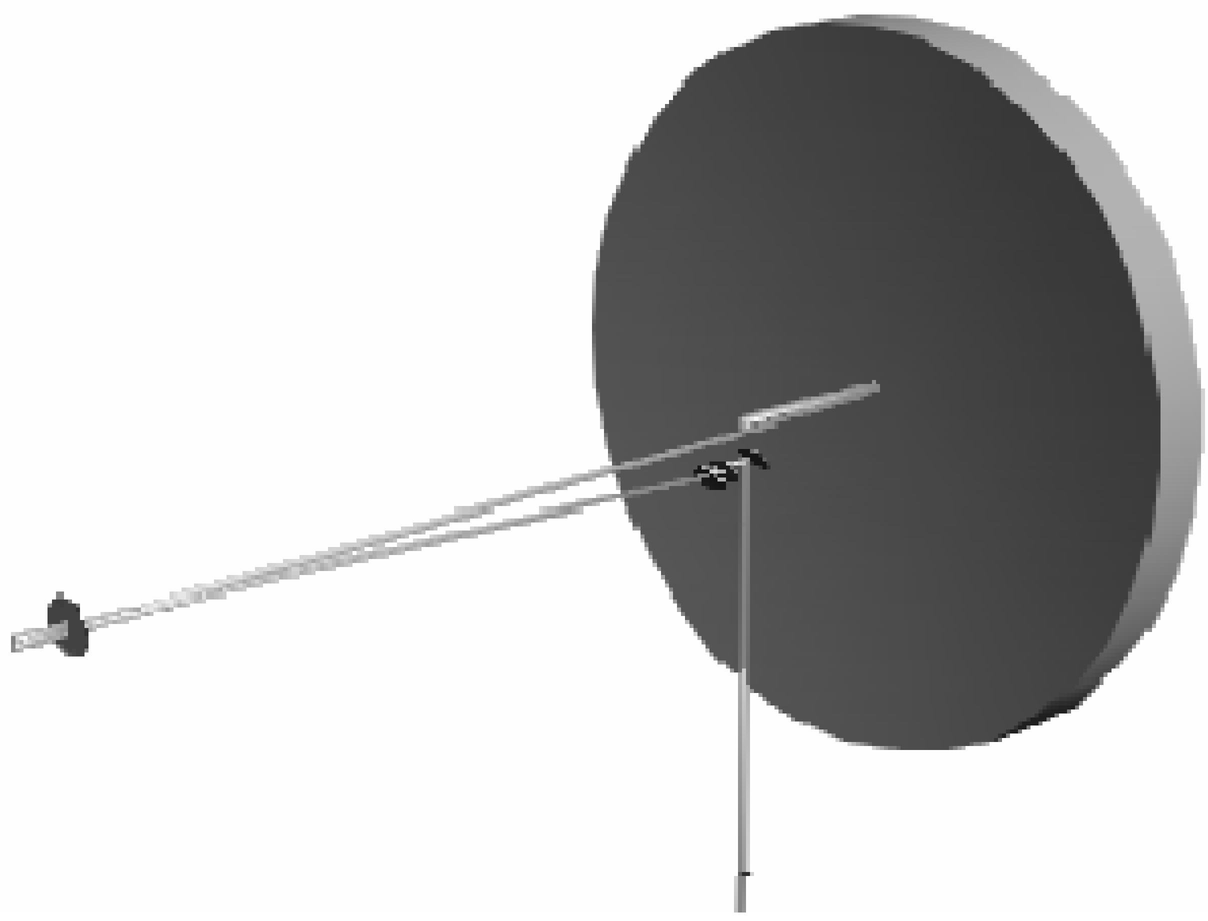


Making the mirror-segment mold

LAMA

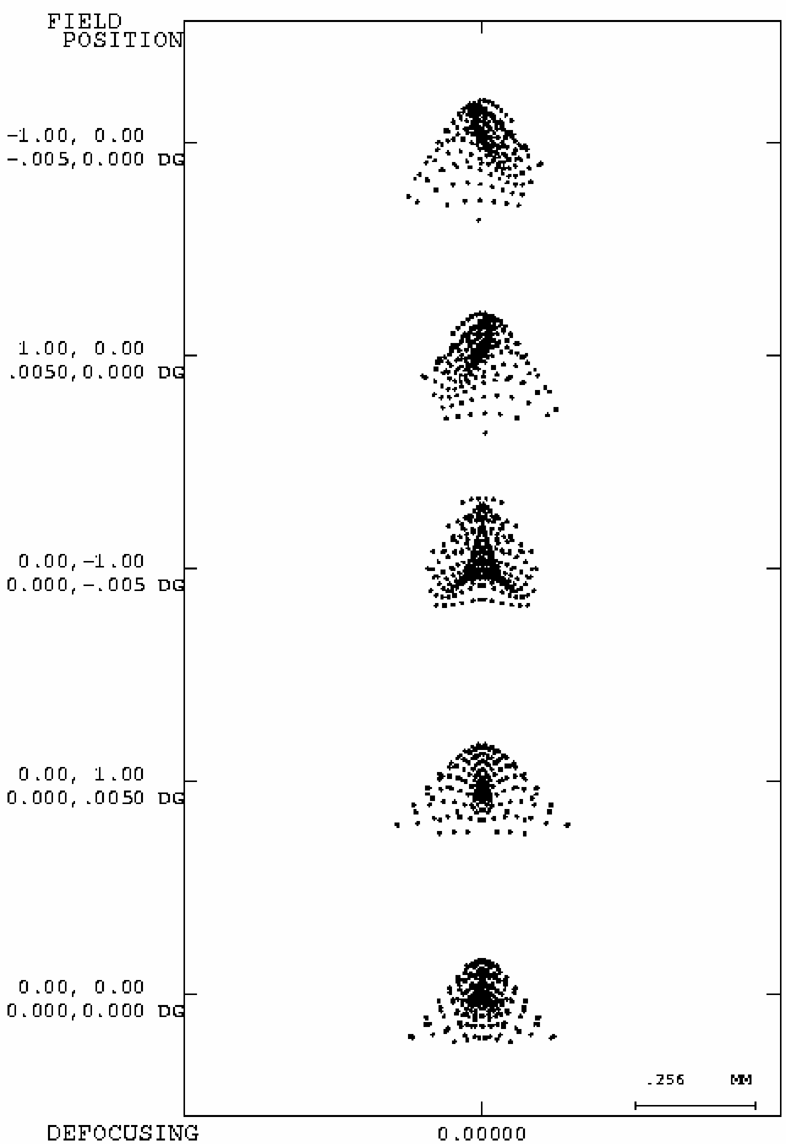
LZT Air Bearing

LMT Tracking Optics

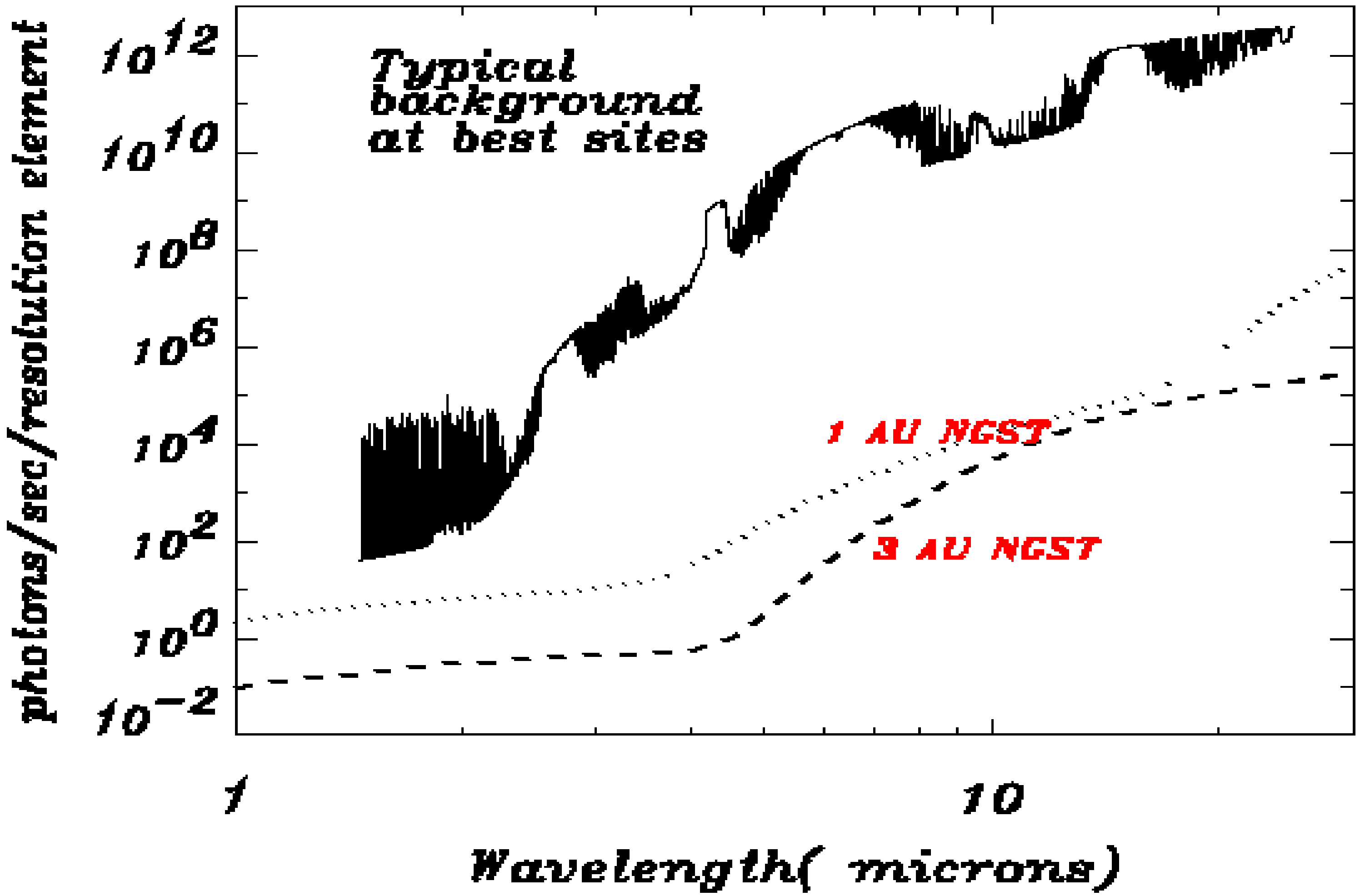


Preliminary Design (Single element)

- M1: 10 m f/1.5 parabolic
- M2: 0.75 m hyperbolic
- M3: 0.2 m flat
- 2 compensation lenses
- 5 min tracking
- RMS spot dia < 150 mas
- Strehl ratio > 0.1 @ 2 um



Background Light

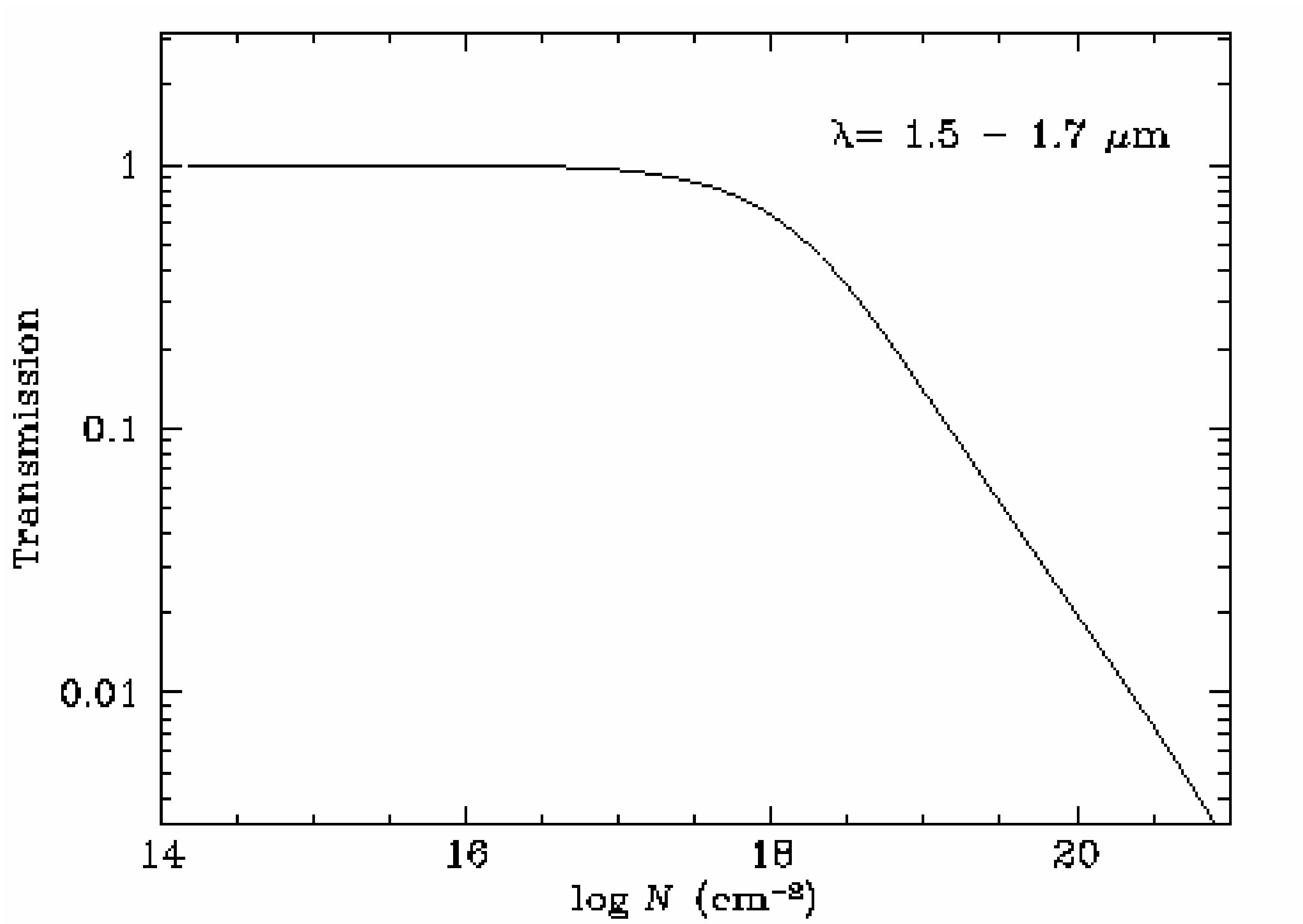


Credit: Space Telescope Science Institute

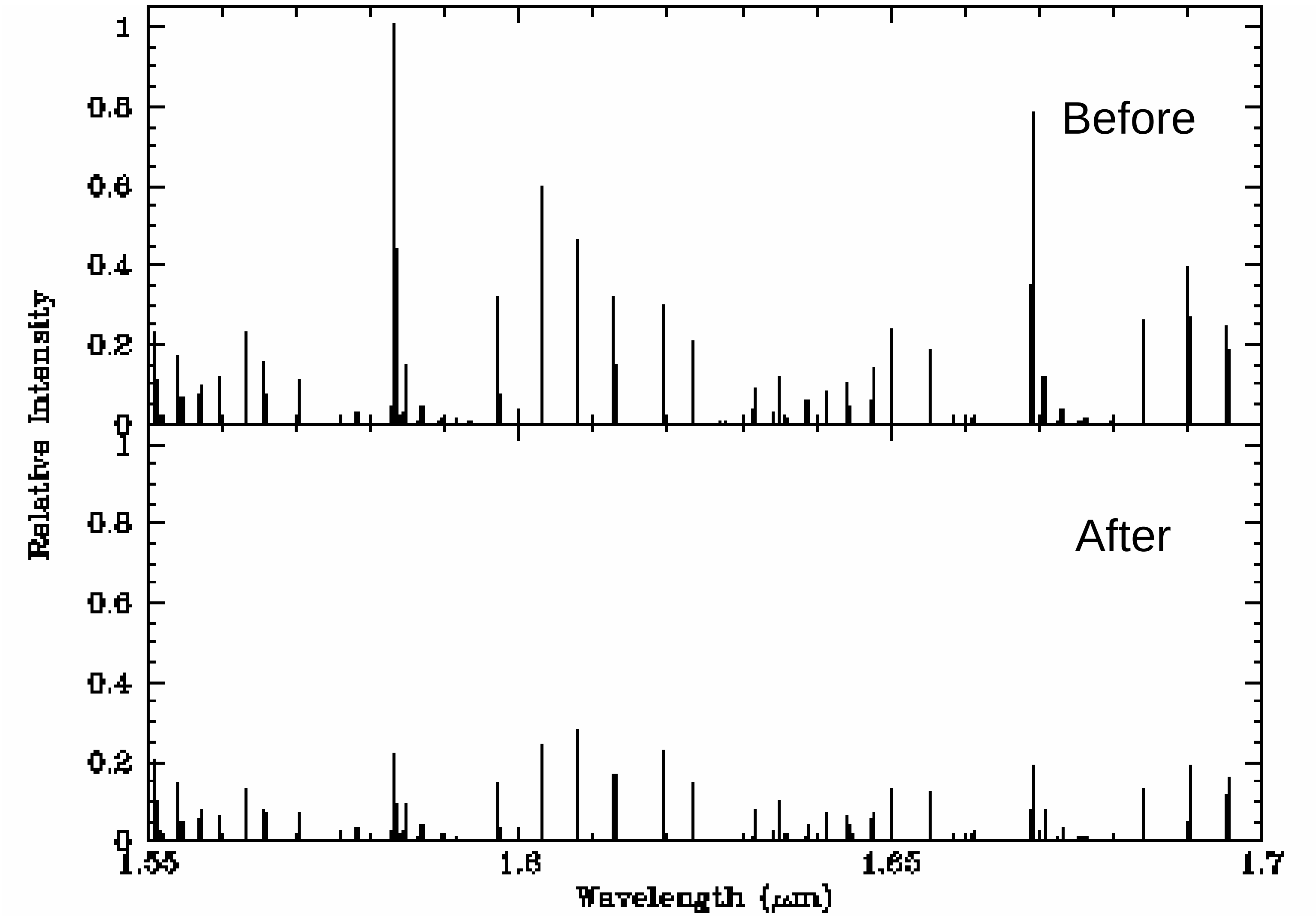
OH Absorption Cell

- NIR sensitivity is directly proportional to background
- Gain of ~ 100 is possible
- OH Production: $O_3 + H \rightarrow OH + O_2$
- Radiative excitation by Meinel photons
- Collisional dexcitation in ~100 us
- Column density > 10^{18} cm^{-2}
- Path length ~ 10 m
- Pressure ~ 0.1 Torr
- Lifetime ~ 10 ms
- Gas consumption ~ 2 kg/hr O_3, 40 g/hr H

OH Absorption vs Column Density

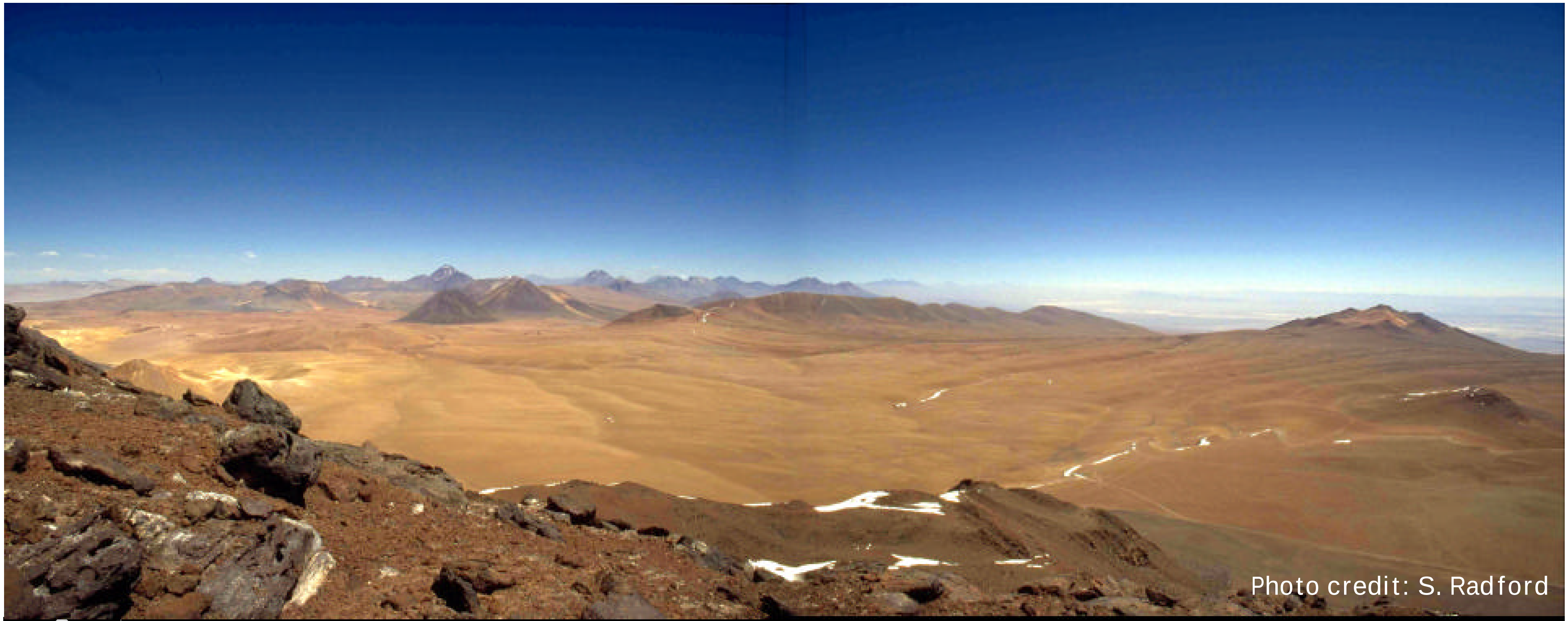


Sample Model Calculation (N = 10^{18} cm^{-3})

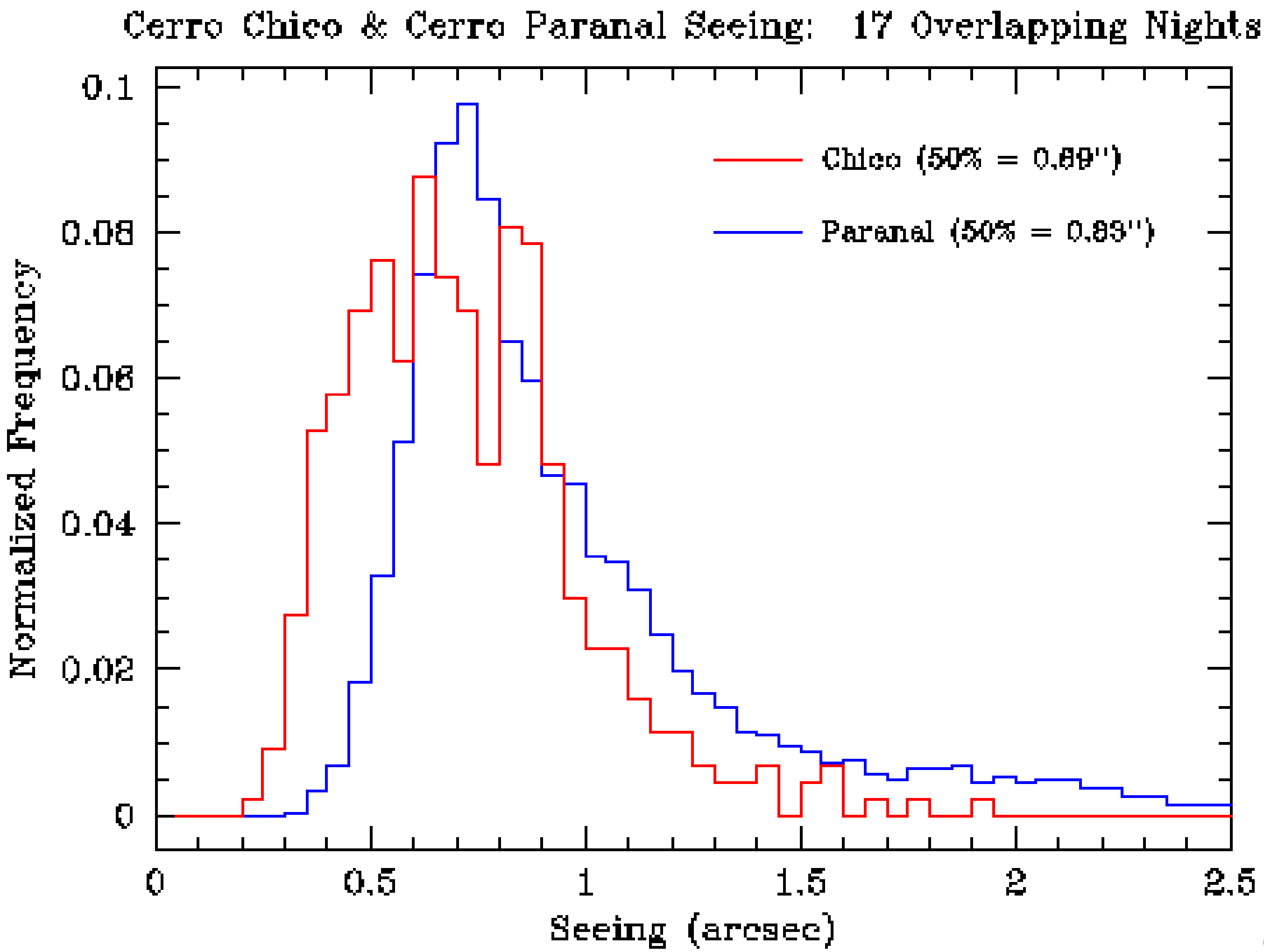


Cerro Chanjnantor

- 5000 m high desert in Northern Chile
- Site of ALMA millimeter array
- Proposed site of Cornell IR telescope and several others



Chajnantor Seeing vs Paranal (ESO VLT)

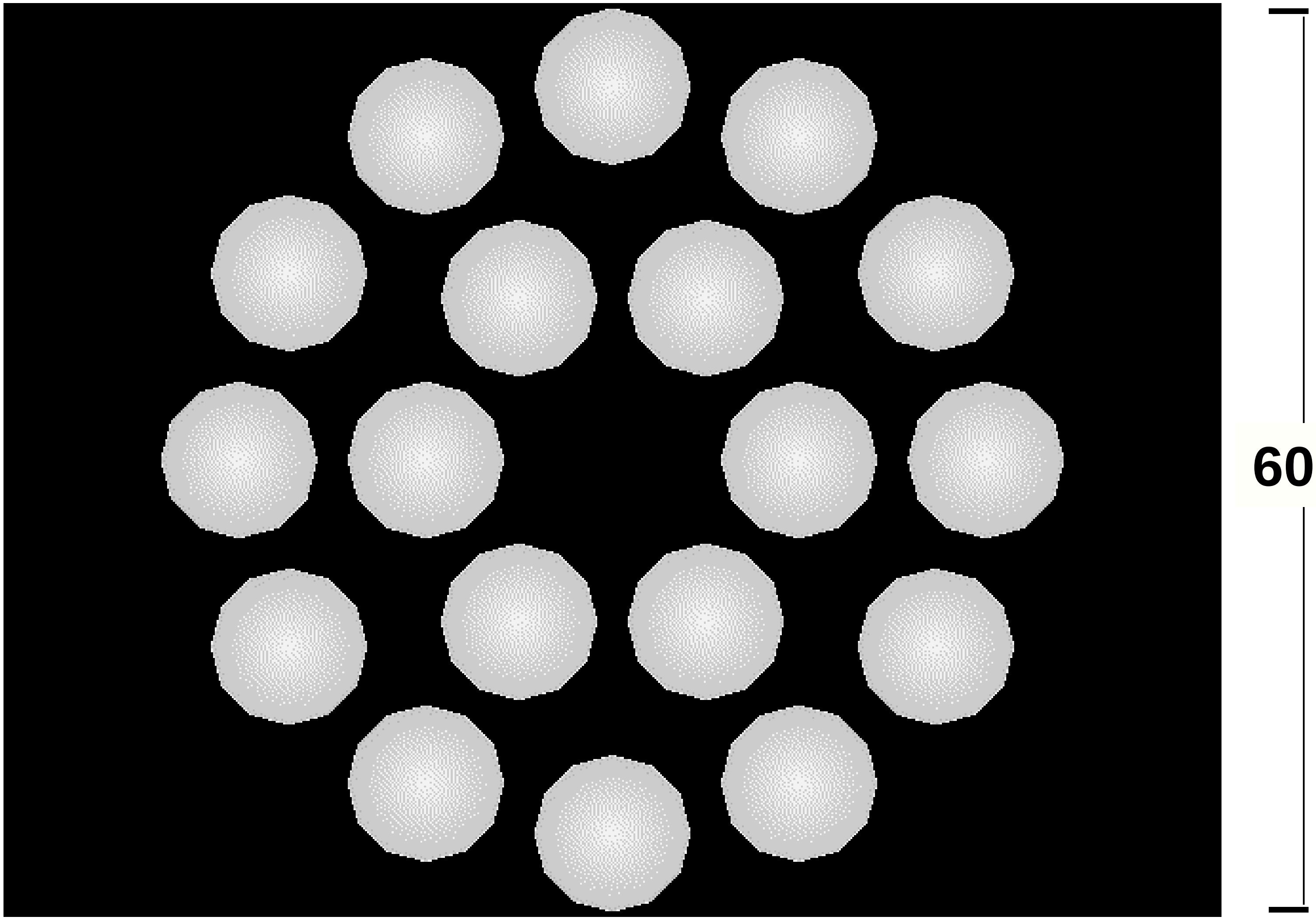


Credit: Cornell University

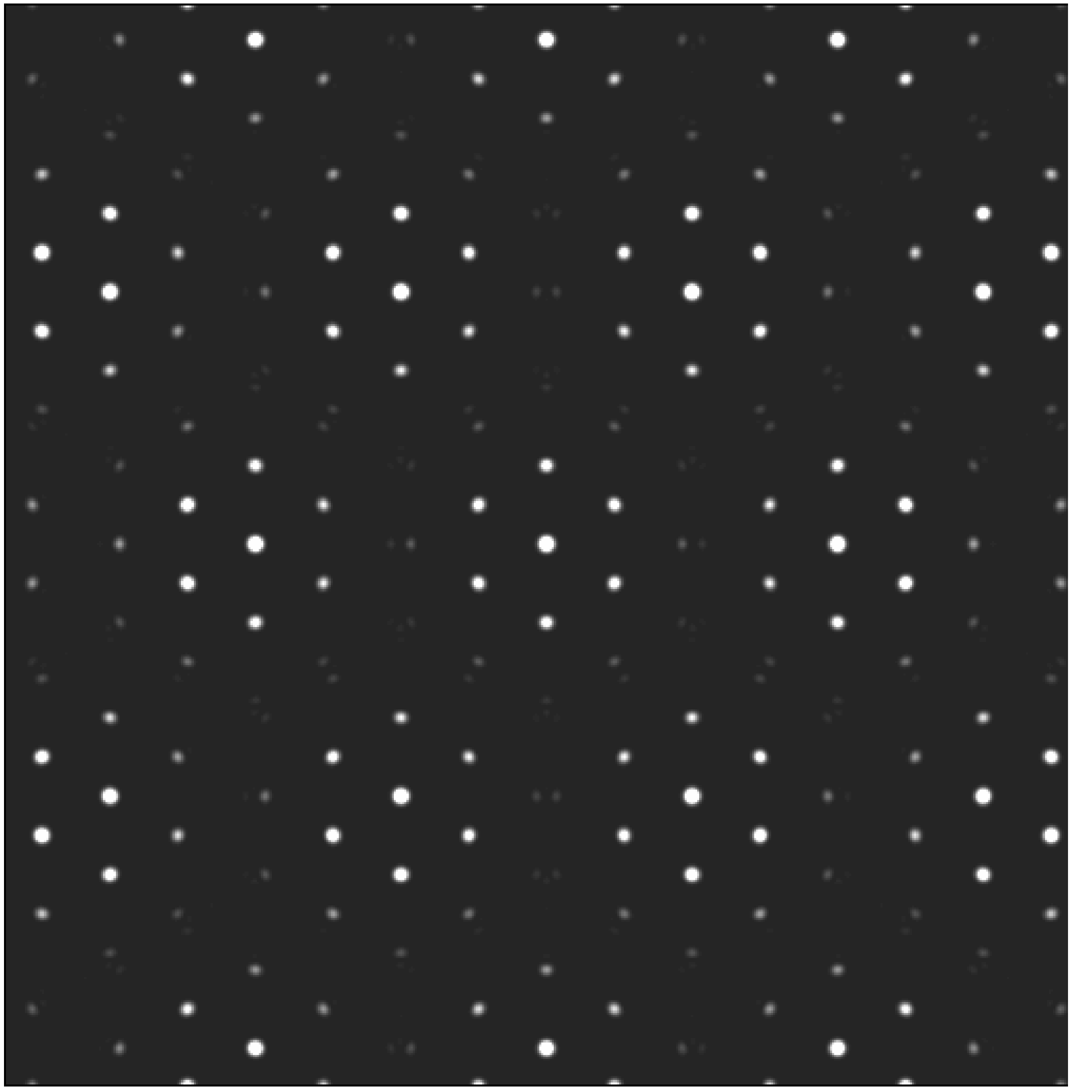
LAMA Concept

- Optical-NIR interferometer
- Near-zenith pointing and tracking
- Survey fields around natural guide stars
- Wavefront control on each element (AO)
- Phase tracking on all beams
- Diffraction limit of 60m telescope
- Equivalent area of 42m telescope
- Fully sample isoplanatic area
- Background reduction by gas-phase OH absorption cells
- 0.1 nJ point source sensitivity (AB = 33.9)
- Mercury primary mirrors
- High dry site (eg. Alto-Plano)
- Low project cost (~ $50M)

Array Geometry



Array Transfer Function



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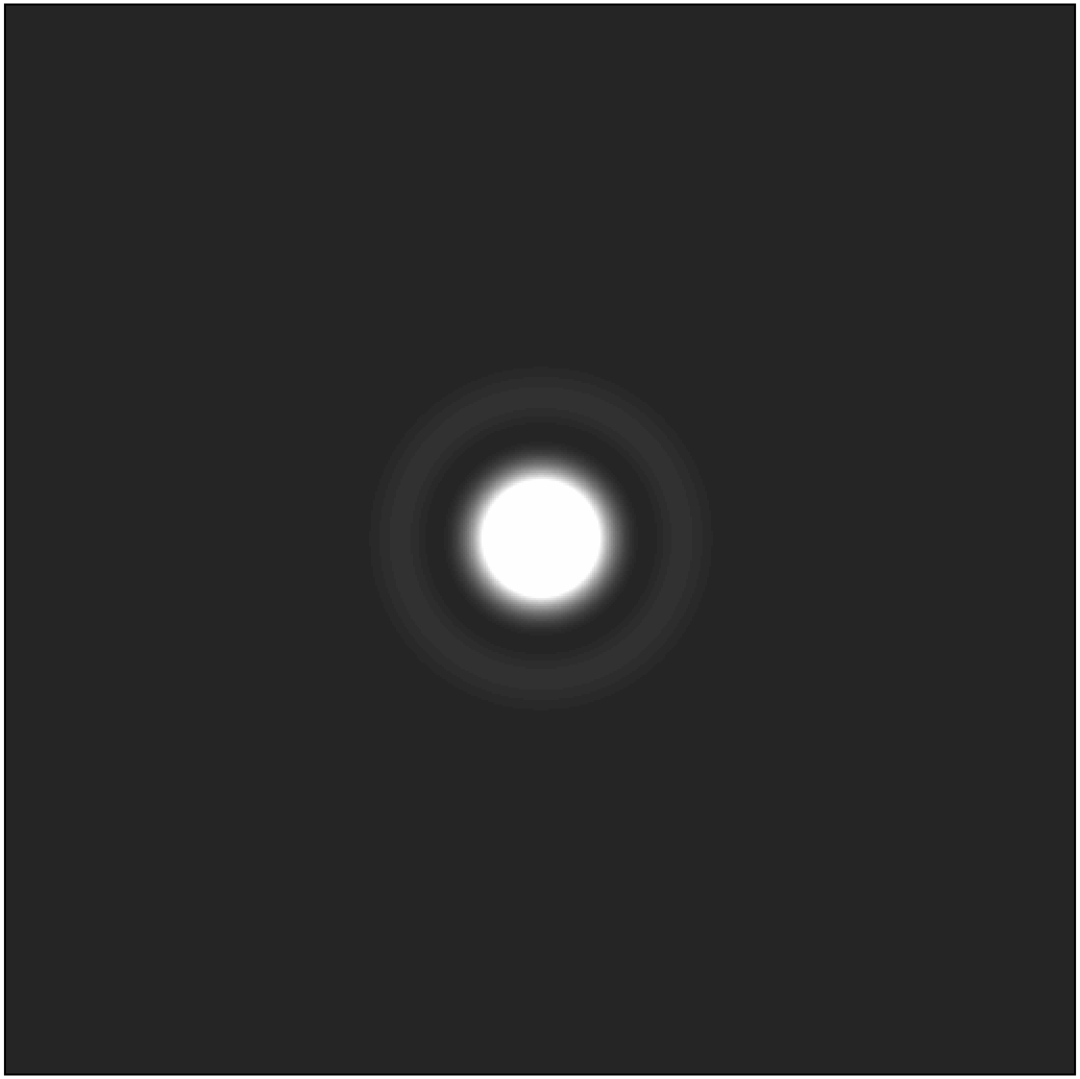
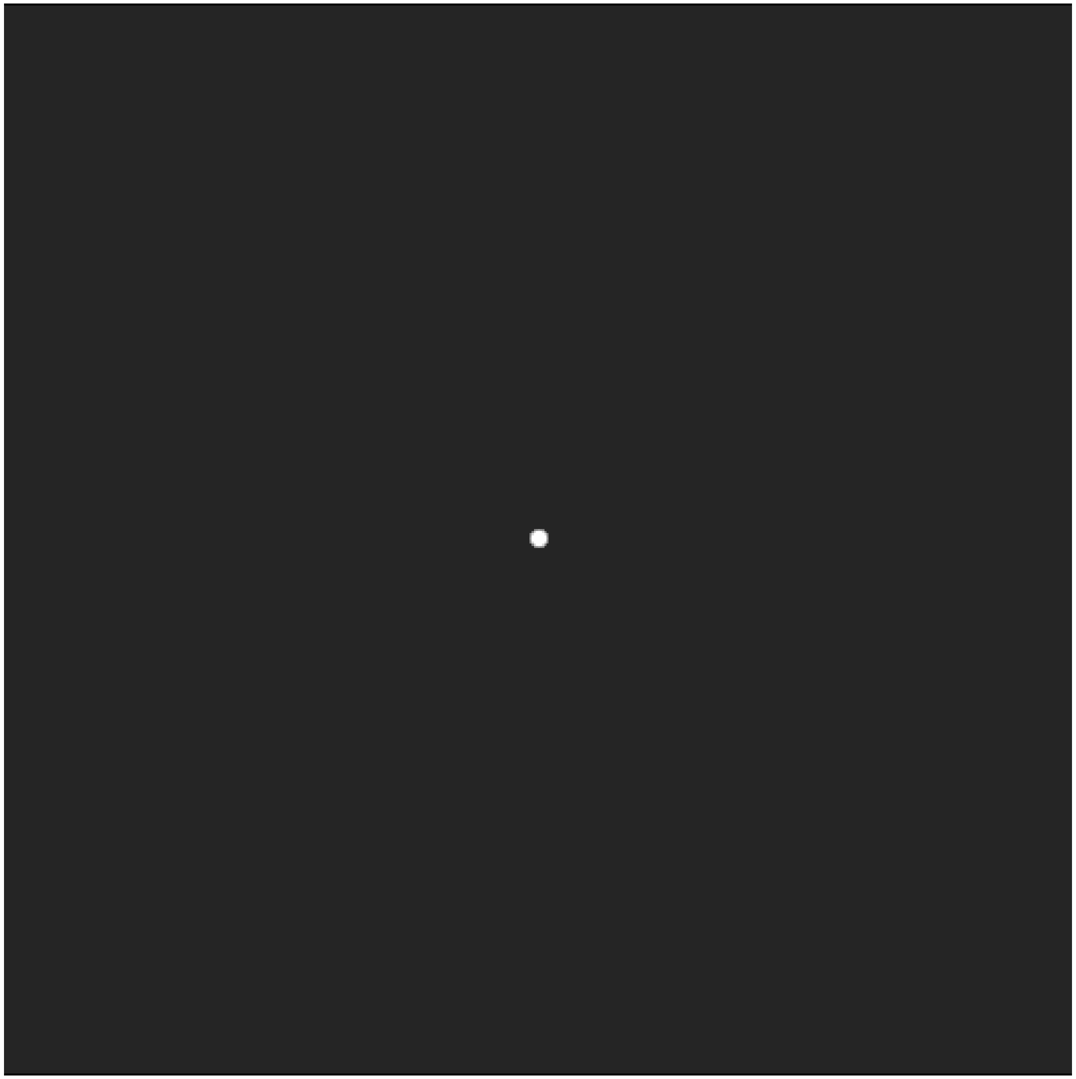
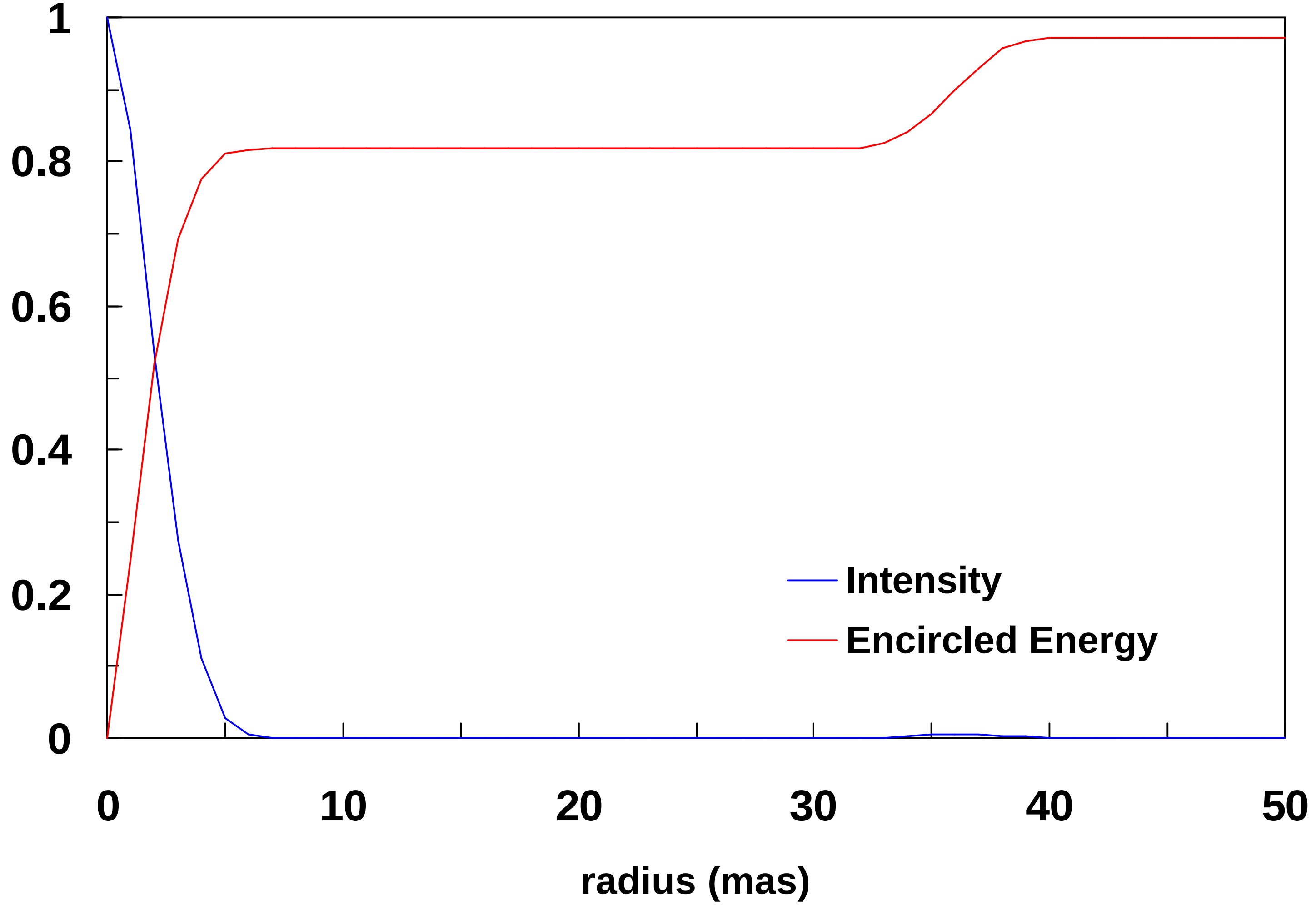
Single-Element PSF



LAMA PSF

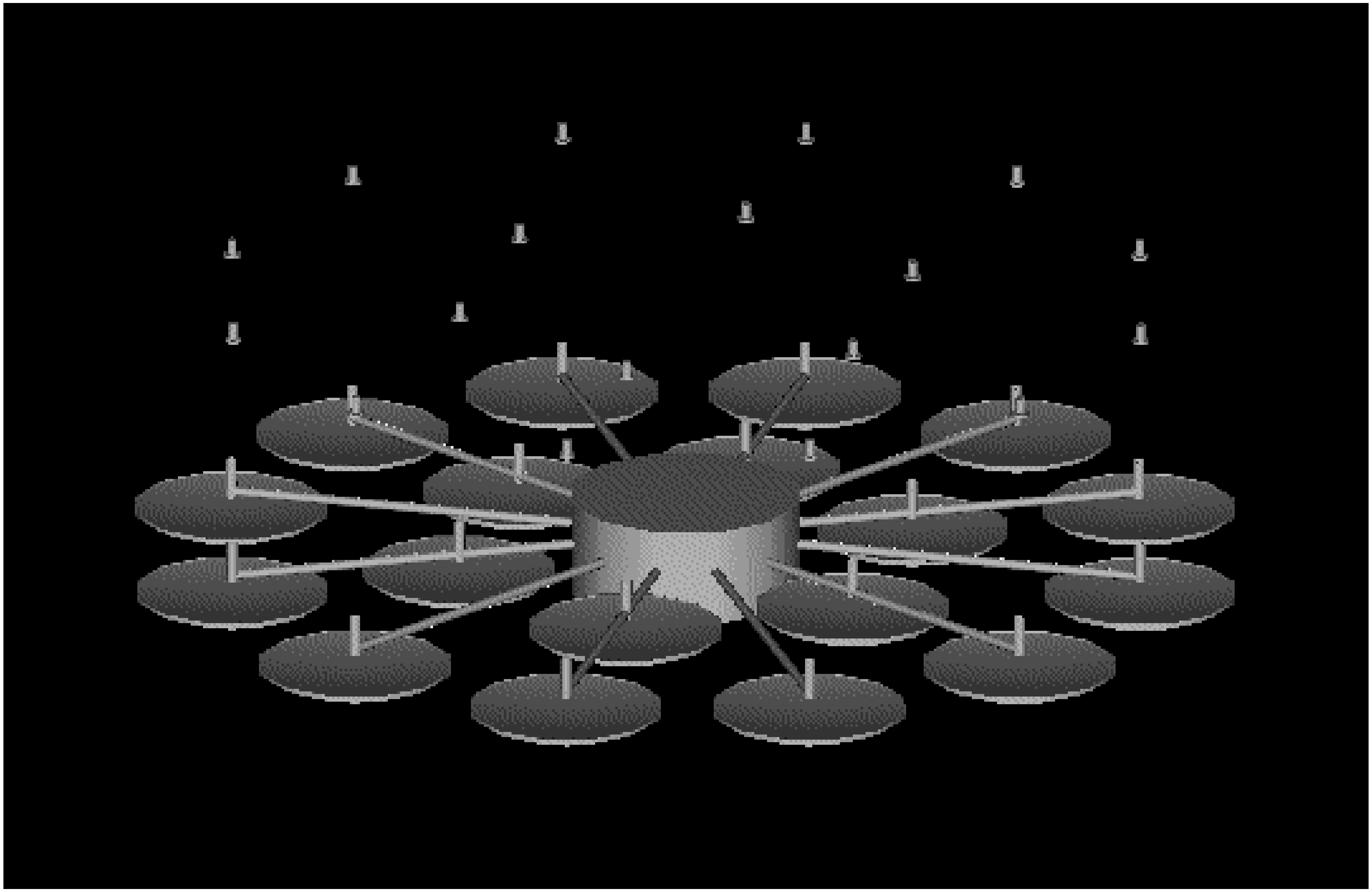


PSF Profile

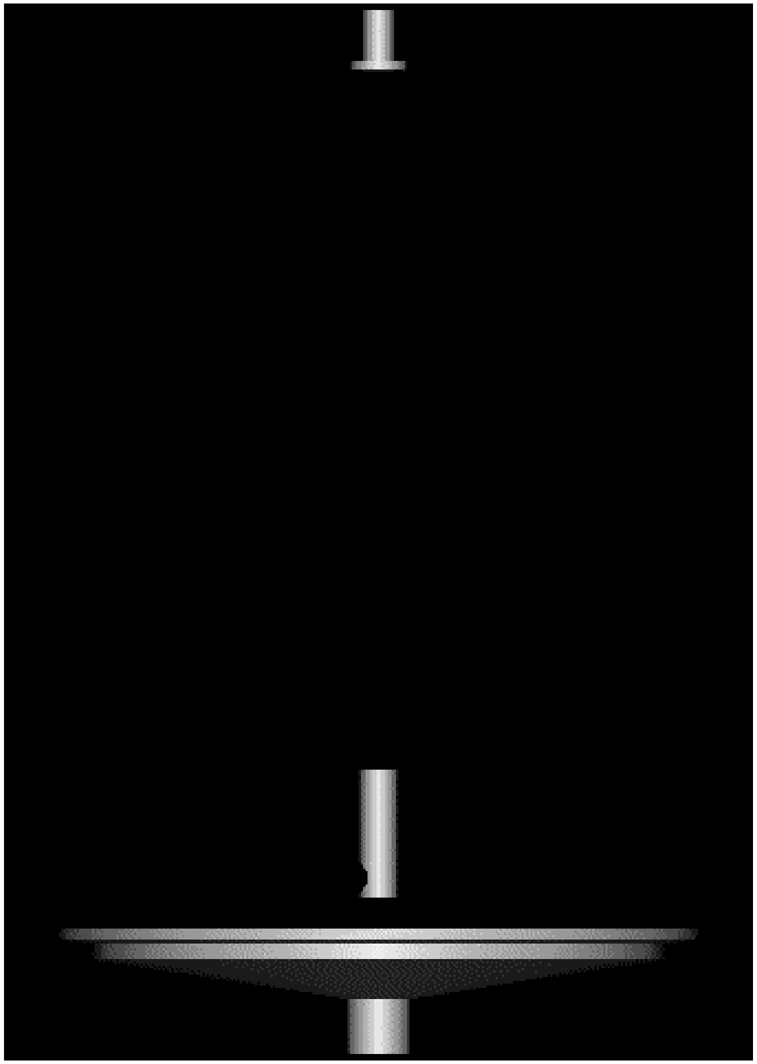


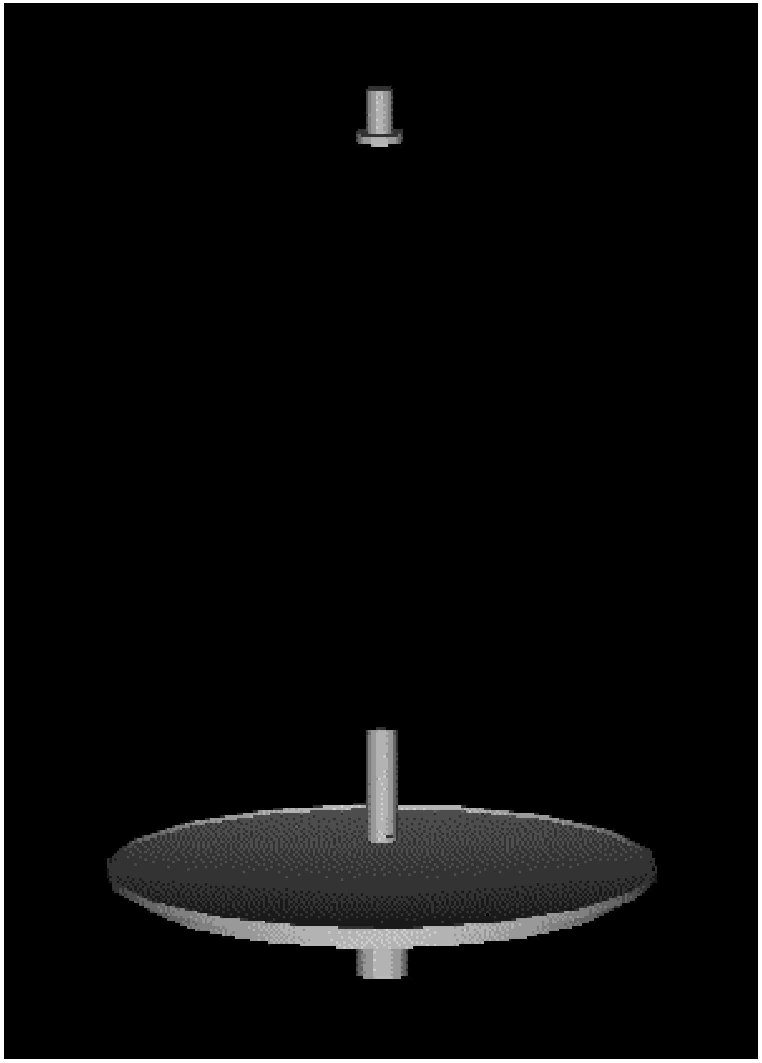
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
radius (mas)
Intensity
Encircled Energy

Conceptual Design



10m Array Element





Survey Mode

~ 360 survey fields, each 30 x 30 arcsec

~ 150 observations per year for each field

⇩

90 square arcmin in one year

~ 40,000 sec integration time

⇩

100 pJy detection limit for galaxies (0.1”)

10 pJy detection limit for point sources

Summary

- A Very-Large Optical Telescope is feasible now
- A 60 m optical interferometer would provide unprecedented sensitivity and resolution
- Gains of an order of magnitude or more over NGST are possible for survey-type observations
- Liquid-Mirrors provide a way to beat the cost curve by a factor of 10-50
- Such a telescope could be built on a relatively short timescale (~ 6 yrs)