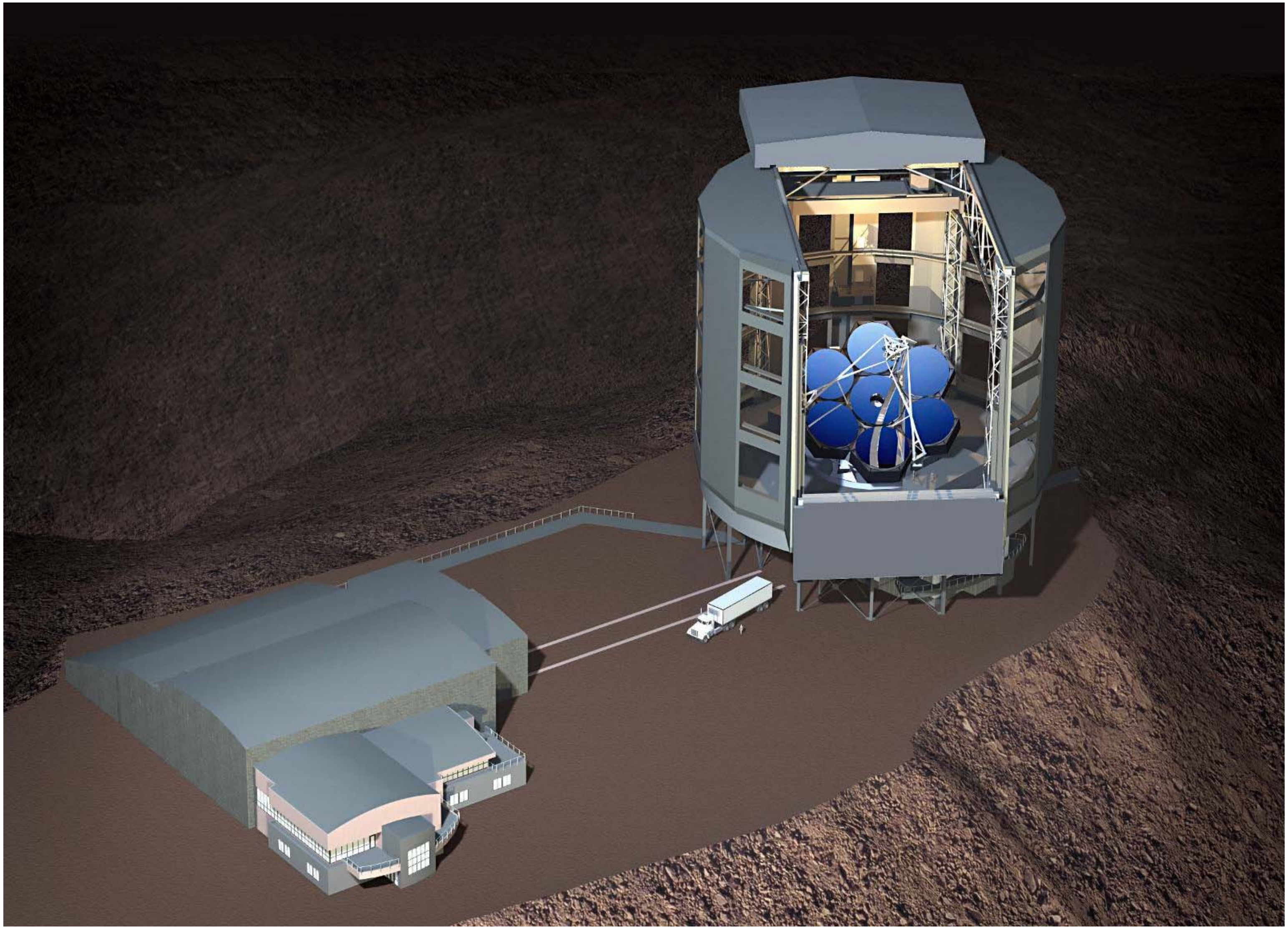
Giant Magellan Telescope



GMT Partners

Astronomy Australia Limited

Australian National University

Carnegie Institution of Washington

Harvard University

Korea Astronomy & Space Science Institute (KASI)

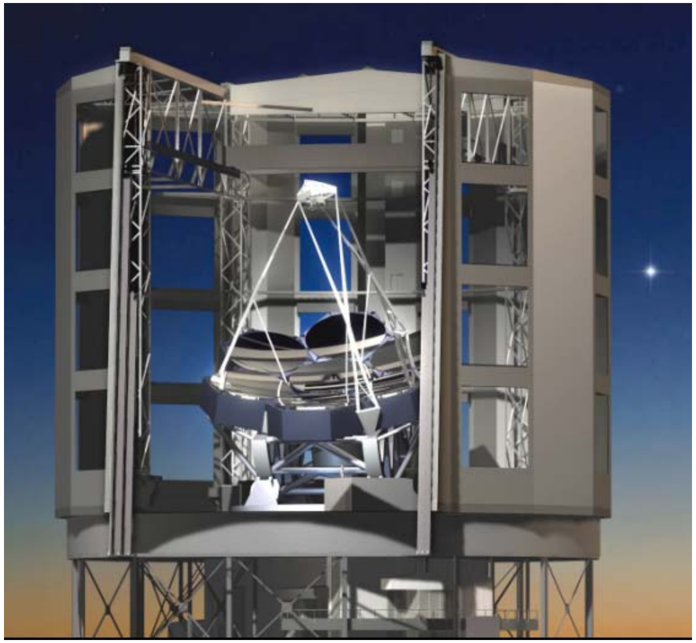
Smithsonian Institution

Texas A&M University

U. of Arizona

U. of Texas at Austin

+ *others…*



Site Characteristics

Seeing

Location	FWHM 25% arcsecs	FWHM 50% arcsecs	FWHM 75% arcsecs	FWHM 90% arcsecs
Manquis Ridge	0.55	0.67	0.85	1.07
Manqui Peak (Magellan)	0.51	0.62	0.79	0.99
Alcaino Peak	0.50	0.62	0.79	1.01
Campanas Peak	**0.50**	**0.63**	**0.79**	**0.99**

PWV (preliminary)

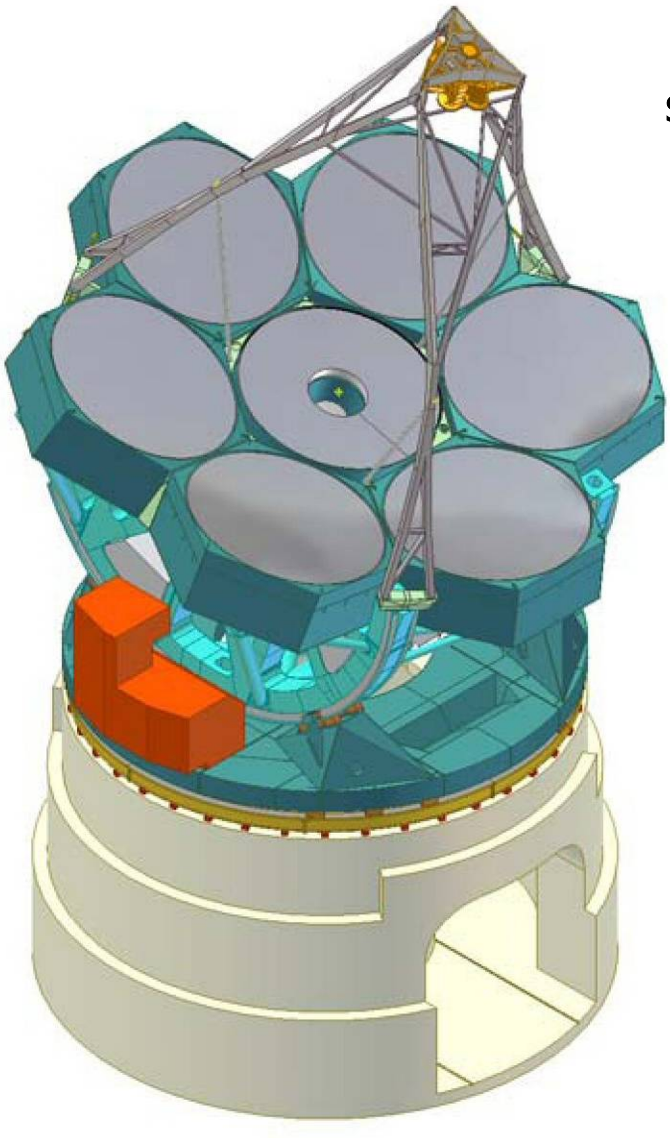
Pwv (mm)	10%	25%	50%	75%	90%
Clear nights	1.1	1.4	2.2	2.9	5.7

Telescope Concept

Alt-az mount

Laser house

Pier



Seven x 1.06 m segmented secondary mirror (3.2 m Φ)

Seven x 8.4 m segmented borosilicate primary mirror

Telescope stats

Height: 38.7 meters

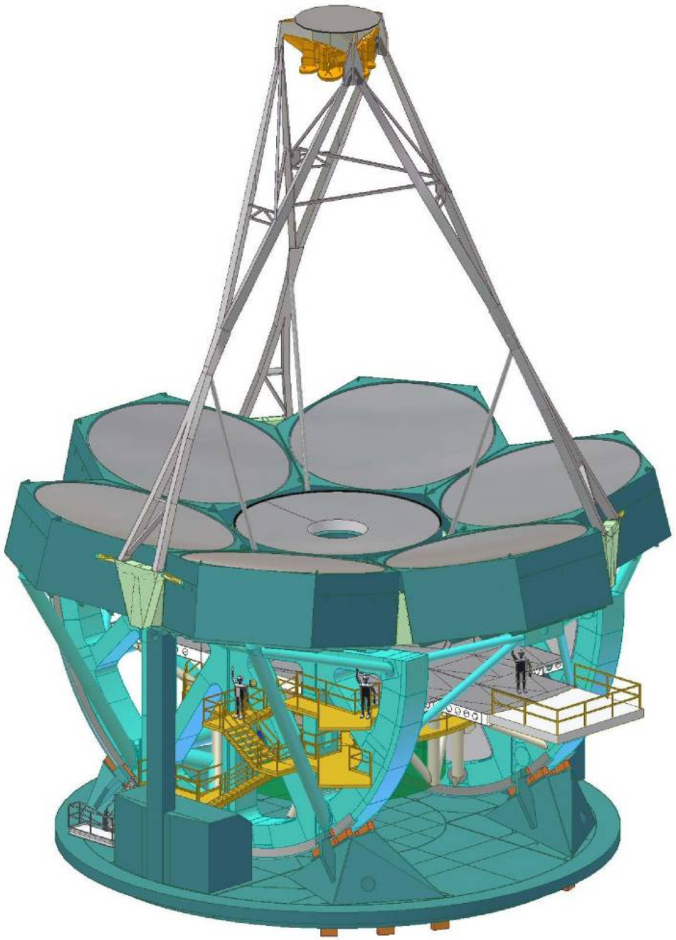
1,125 metric tons

Lowest Mode: 4.5 Hz

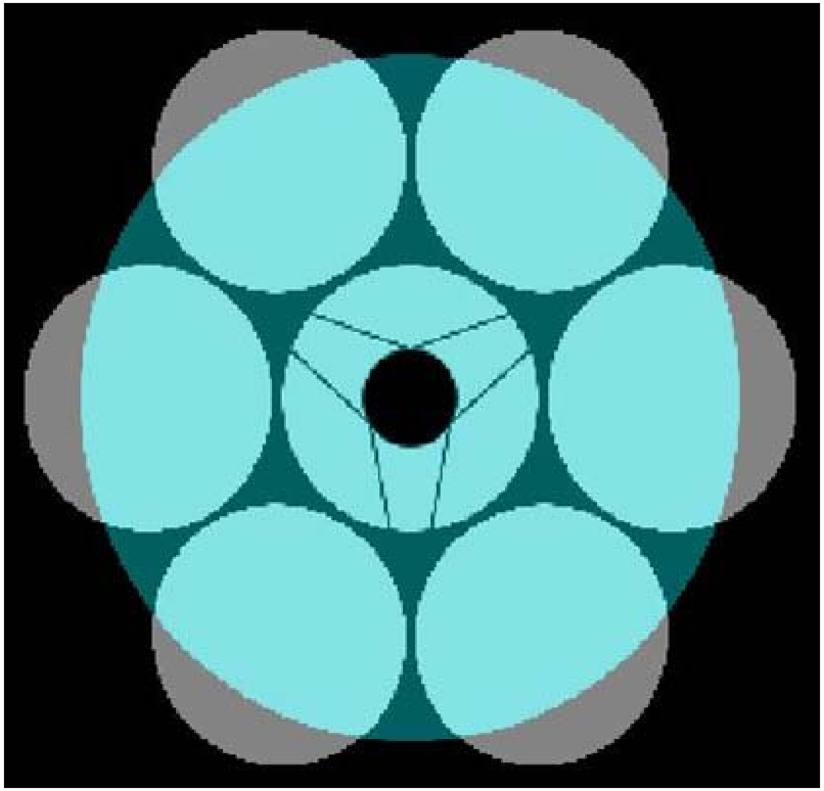
(4.3 Hz with pier)

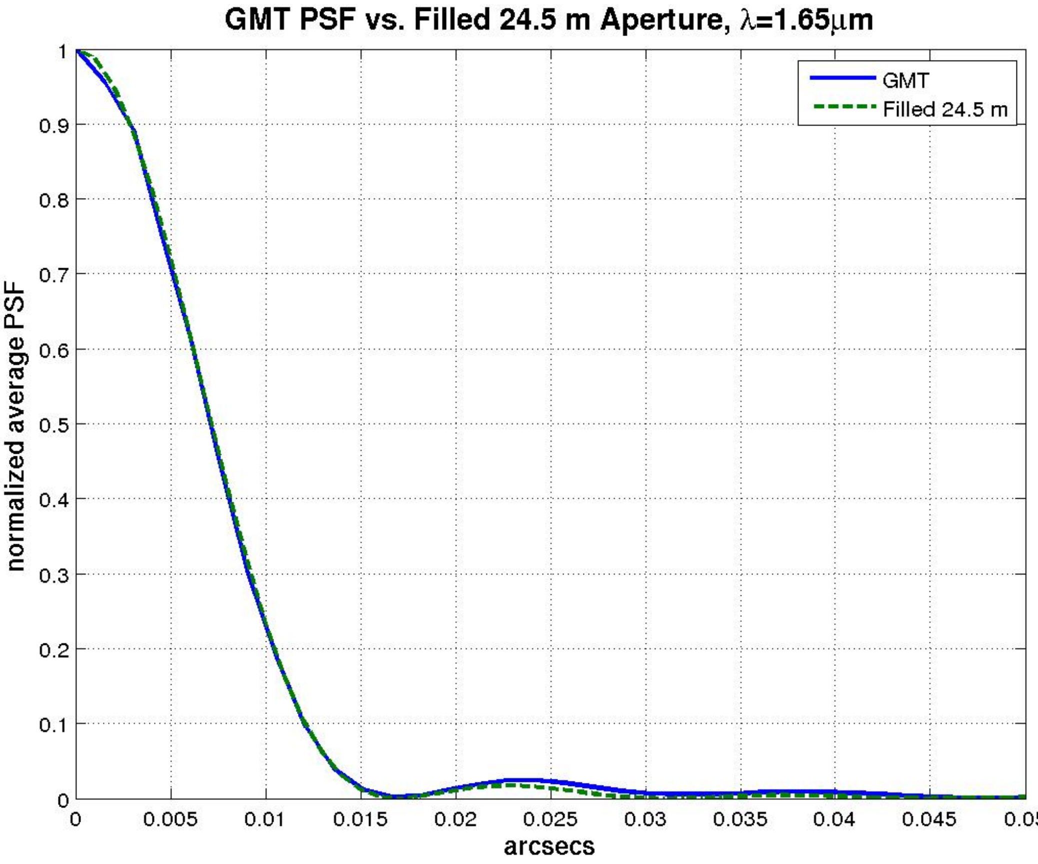
Operating modes

- **Natural seeing operation**
  - 20´ "Wide-Field" mode
- **Multiple AO modes**
  - Laser Tomography AO (LTAO)
  - Ground layer AO (GLAO)
  - High contrast AO (ExAO)
  - Future: MCAO, MOAO



How Big Is It?





Full Diameter: 25.4 m

Circular aperture 22 m

Diffraction limit equivalent 24.5 m

8.4 m Primary Mirror Segments

Off-axis, highly aspheric require the development of new casting/generating/polishing techniques

Metrology challenge

- Provide multiple independent surface figure verification tests

Each mirror takes ~3.5 years

- Production pipeline to produce a mirror every 10-12 months

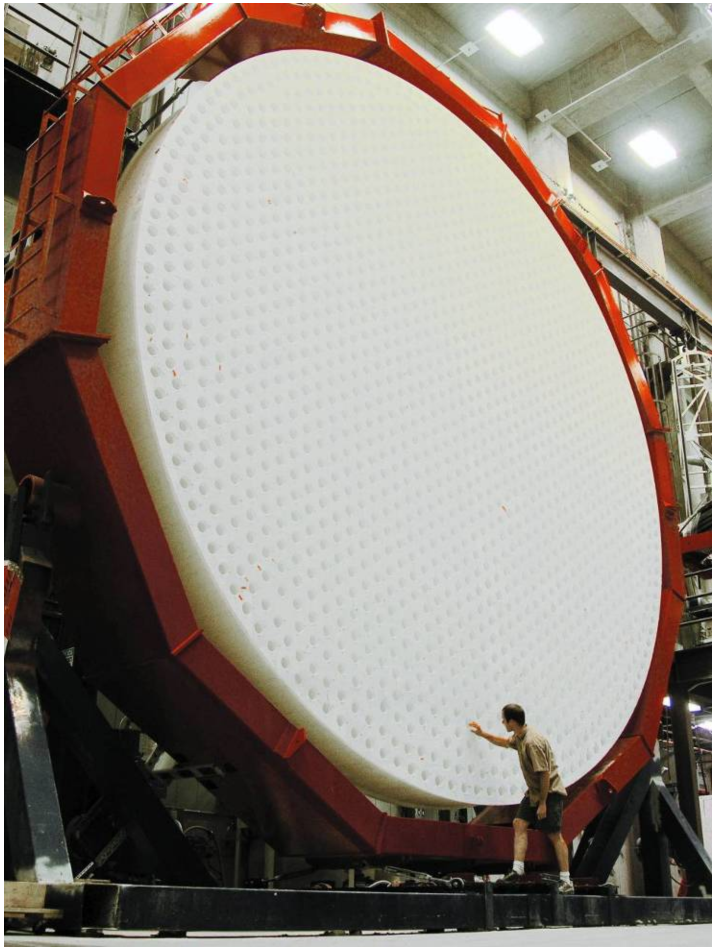
Pacing item for GMT completion

Prototype off-axis segment to retire technical & schedule risk

Processing stages

Pipeline processing

1. Casting
2. Clean-out
3. Rear surface processing
    a. Generating
    b. Grind & polish
    c. Loadspreader attachment
4. Front surface processing
    a. Generating
    b. Grind & polish
    c. Final figuring



Mar 2006

GMT

Optical Testing

Metrology is the greatest challenge

- High degree of aspheric departure ~14 mm
- Requirement that segments match to high accuracy
  - $\Delta Rc \leq 0.3$ mm (0.0006%)
  - Repeatability over 10 years of production
- Use compensators to relax tolerances

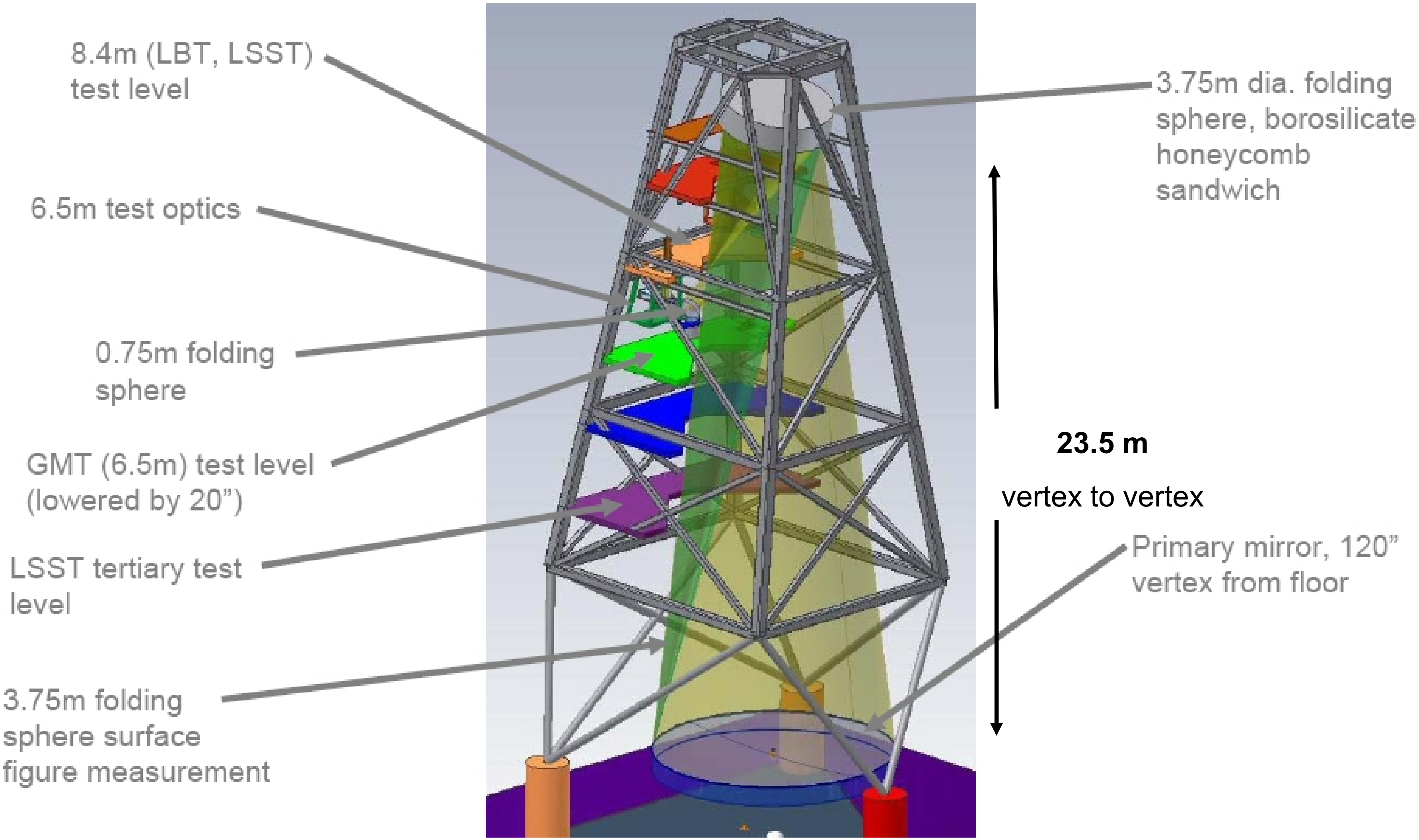
Principal test – full aperture, null interferometer

- In-process testing during polishing

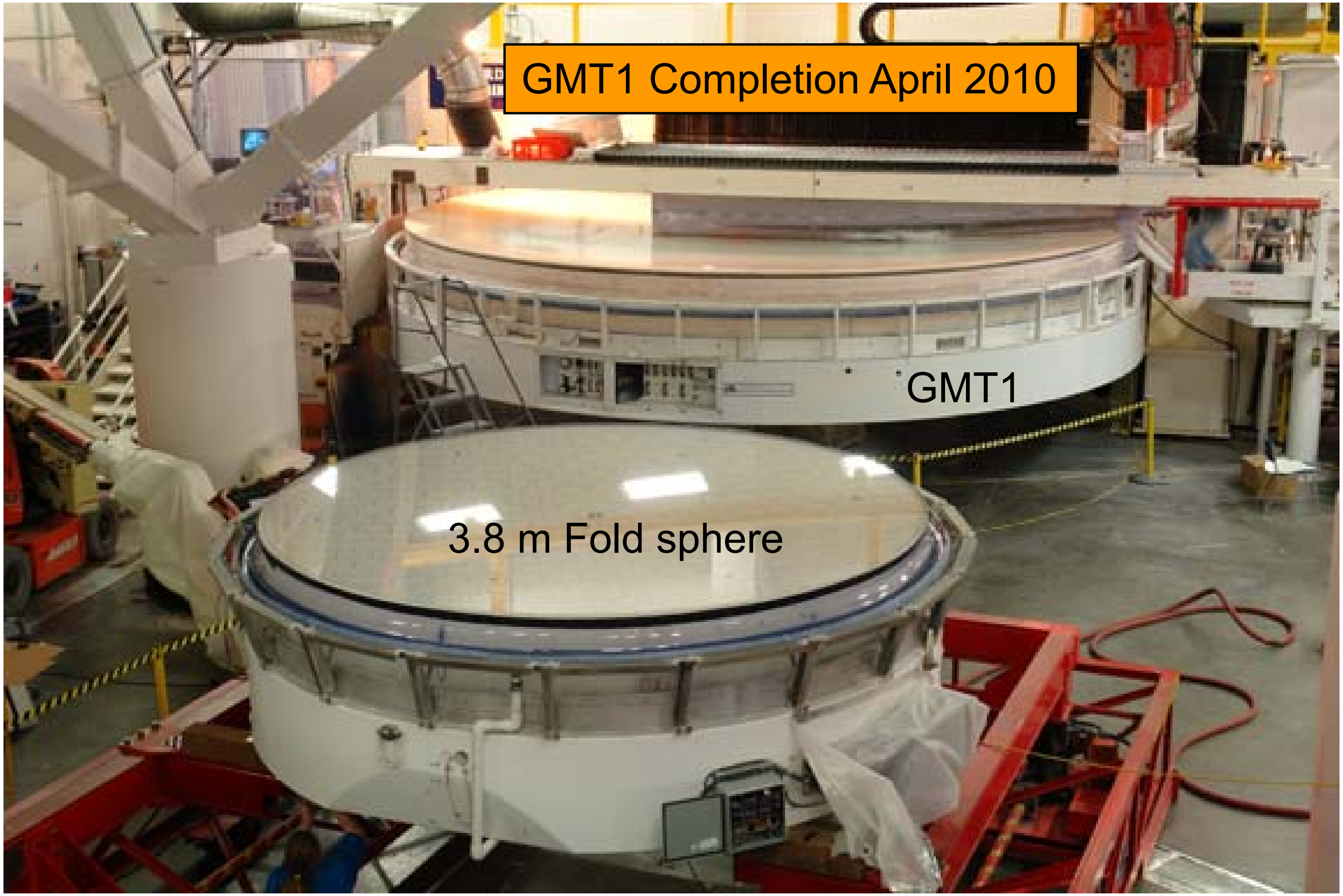
Verification Tests:

1. Laser tracker Plus test- pre-polish generation & independent low-order figure verification
2. Scanning pentaprism- final low-order figure verification
3. Shear test- high frequency errors

New Test Tower



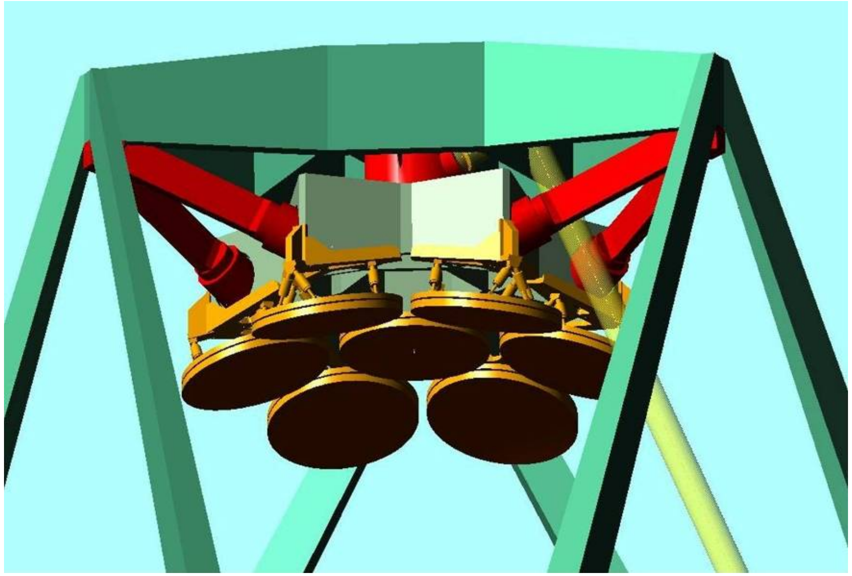
M1 Fold sphere & GMT1

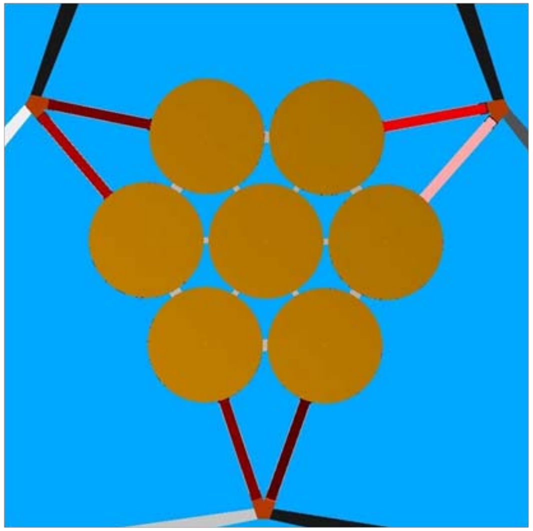


Jan 2008

GMT

Segmented Gregorian Secondary Mirrors



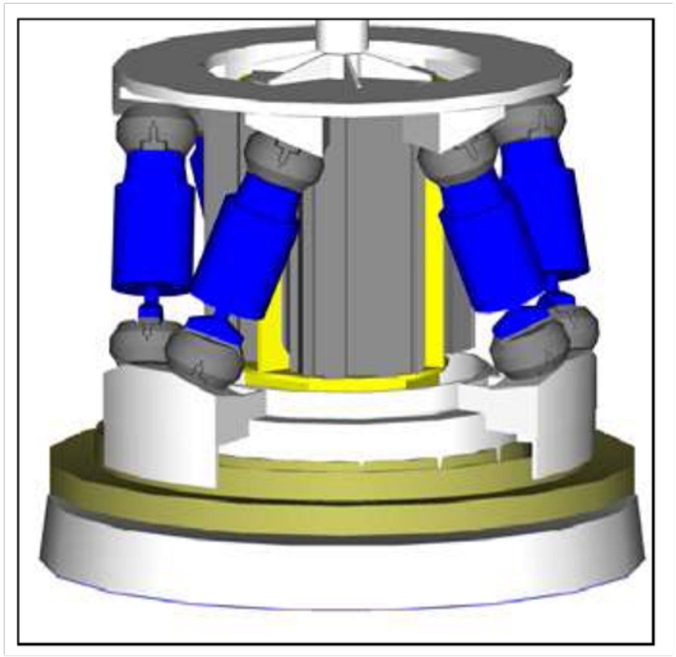


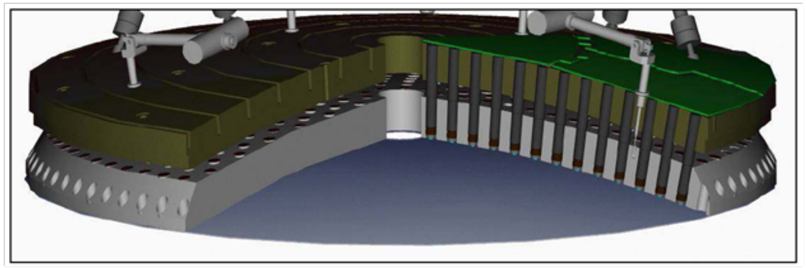
View from below

Fast-steering secondary (FSM):

- Seven 1.06 m segments aligned with primary mirror segments
- Segment position compensation at *either* Primary or Secondary
- Rigid lightweighted Zerodur segments
- Slow hexapod position actuators
- Fast-steering piezo tip/tilt actuators

Adaptive Secondary Mirror (ASM)

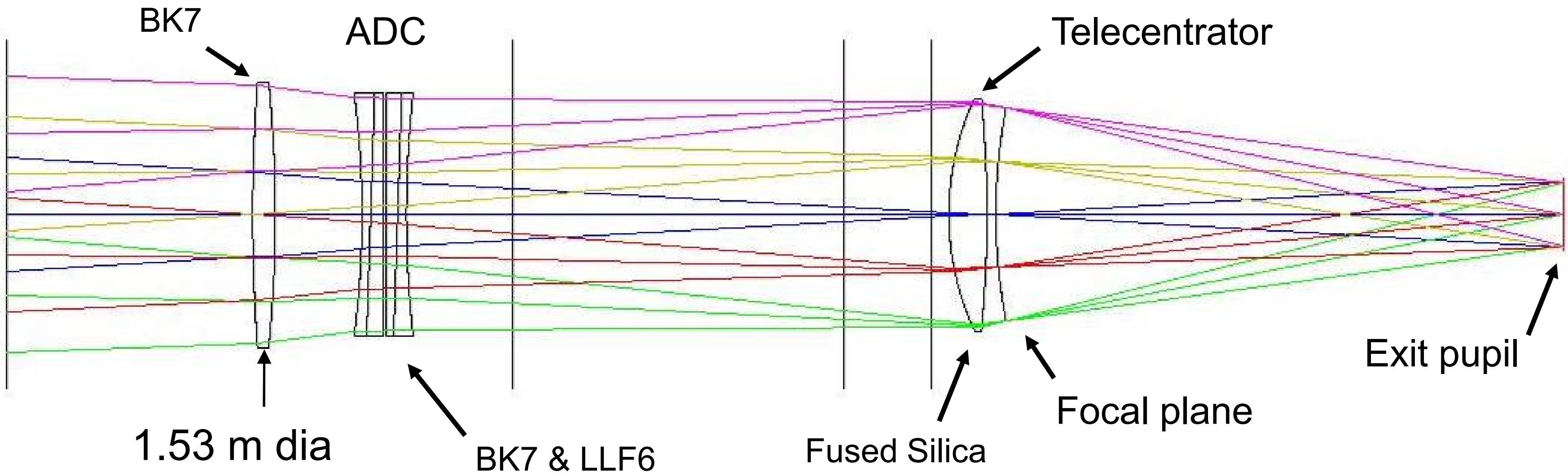




- Deformable mirrors replace FSM rigid segments
- Thin facesheet technology developed for MMT, LBT, & VLT
- ~700-1000 actuators per segment
- ~5000-7000 actuators total
- Hexapod gives 6 DOF positioning for each segment.
- Capacitive position sensors allow non-AO operation without optical feed back.
- In-telescope calibration source.

Design Study with ADS/Microgate currently underway

“Telecentric” Corrector/ADC (20’ FOV)



<u>RMS polychromatic image diameter at r = 10′</u>

uncorrected = 0.62 arcsec

corrected = 0.07 arcsec

<u>Residual dispersion @ ZD = 50º</u>:

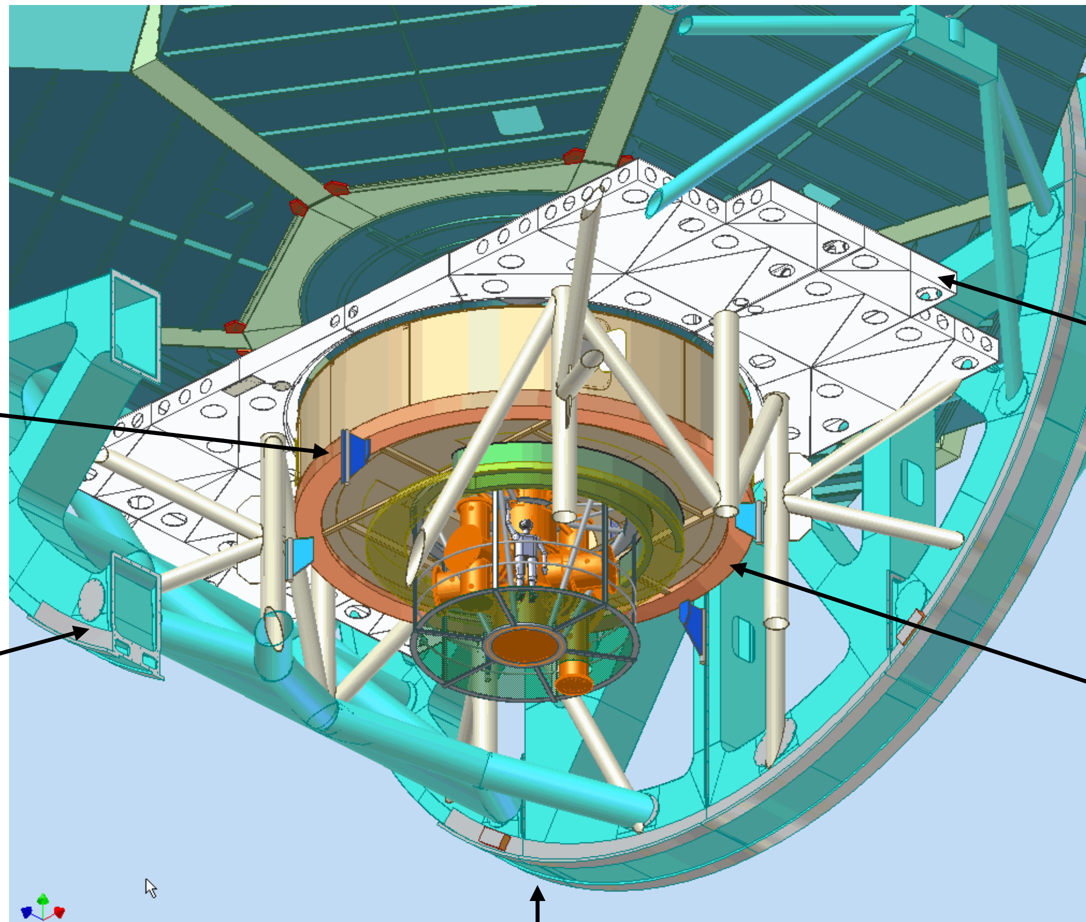
No ADC correction: 1.97″

With ADC: 0.17″

Instrument Platform/Gregorian Inst. Rotator

Intermediate size & AO instruments - always “hot” – above

Large survey instruments mount below – integrated package

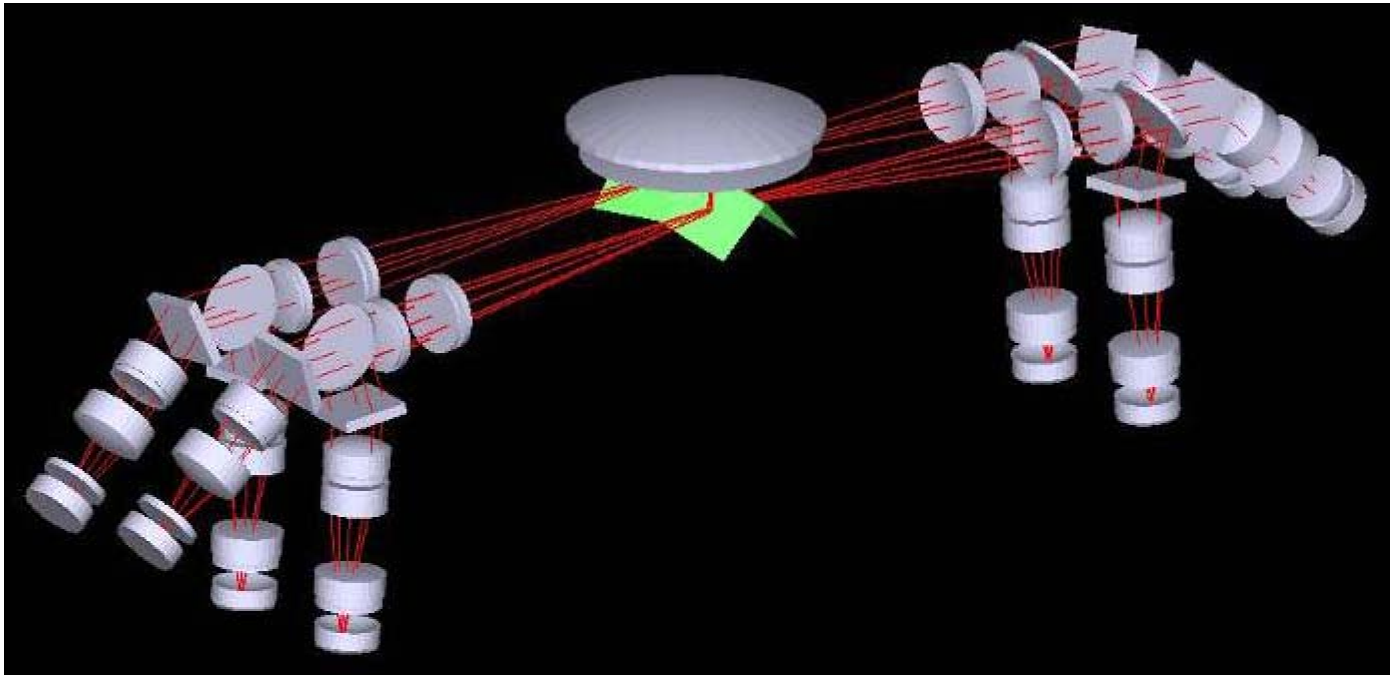


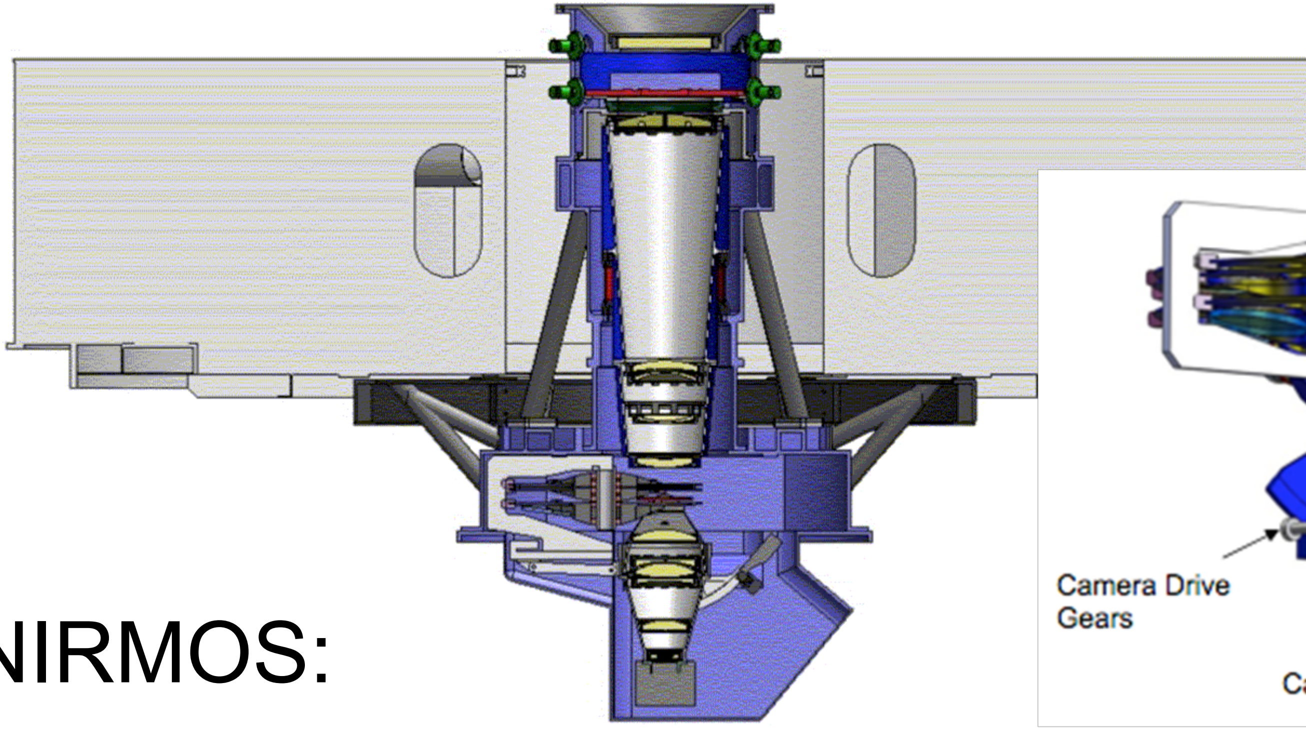
Instrument Concepts

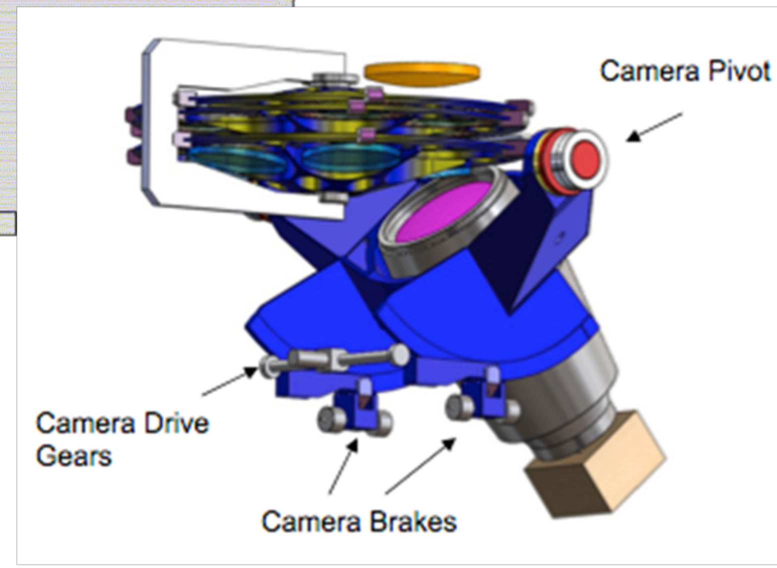
Instrument	Function	λ range (microns)	Resolution	FOV
GMACS	Optical Multi-Object Spectrometer	0.35-1.0	250-4000	36-144 arcmin^2
NIRMOS	Near-IR Multi-Object Spectrometer	1.0-2.5	Up to ~4000	49 arcmin^2
QSpec	Optical High Resolution Spectrometer	0.3-1.05	30K 1" slit	3" + fiber mode
GMTNIRS	Near-IR High-Resolution Spectrometer	1.2- 5.0	25K-100K	Single object
TIGER	Thermal IR Imager /Spectrograph	3.0-25.0	1500	30"
HRCam	Near-IR AO Imager	0.9-5.0	5-5000	30"
GMTIFS	NIR AO-fed IFU	0.9-2.5	3000-5000	3"

GMACS

- Multi-object, multi-slit spectrograph
- 4x spectrographs, each with
  red and blue arms, VPH gratings
- Field of view: 8 x 18 arcmin
- Wavelength range 0.36 – 1.02 μm
- Collimated beam diameter: 300 mm
- Resolving power w/ 0.7 arcsec slit:
  R ~ 1400 in blue
  R ~ 2700 in red
  (for accurate sky subtraction)
  cross-over at 6500 Å
- Separate 8 x 9 arcmin imaging channel





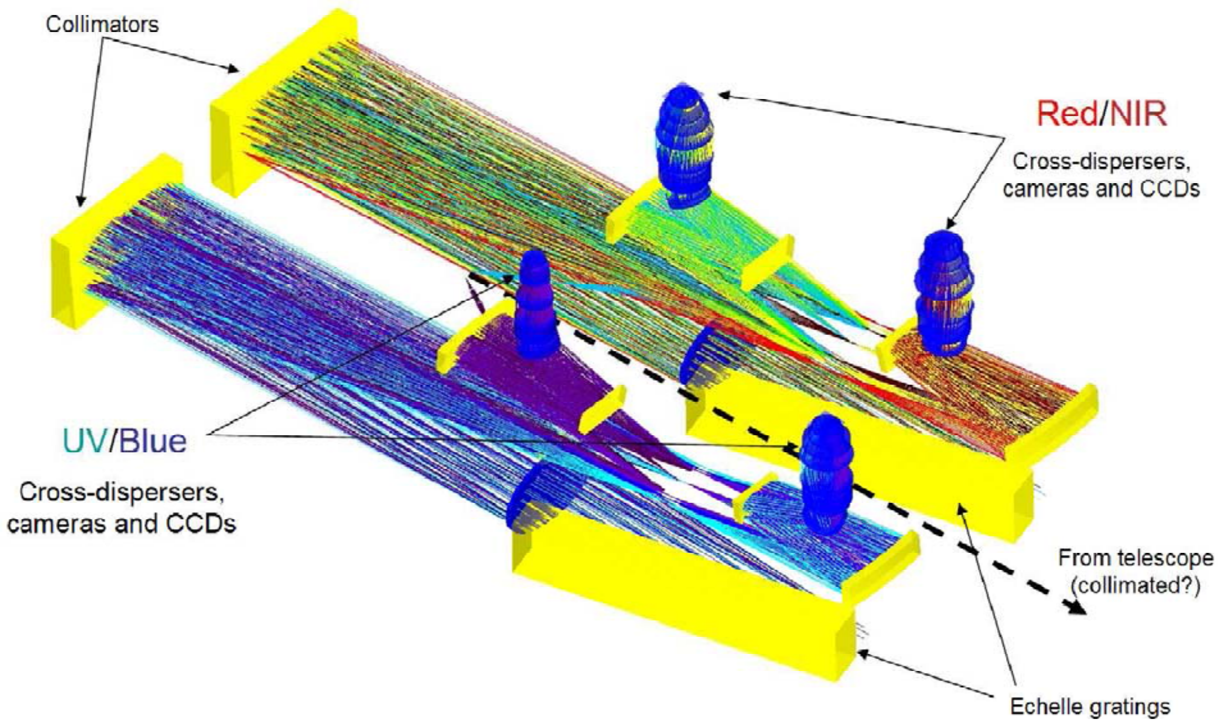


NIRMOS:

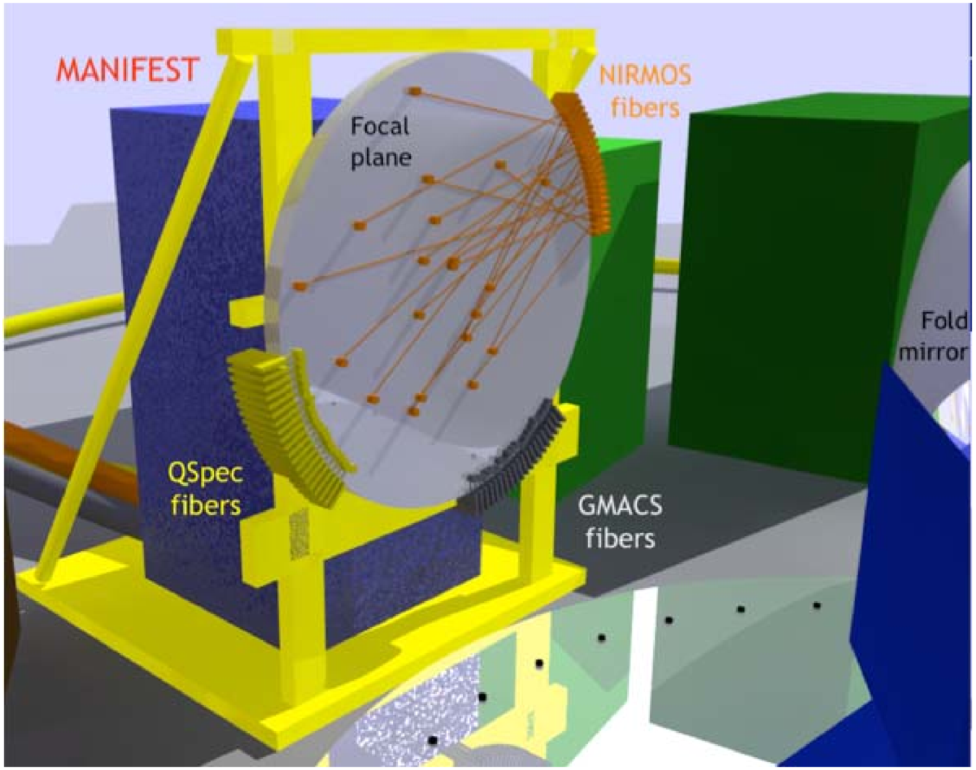
- Wavelength range: 0.85 – 2.5 μm
- Imaging Mode:
  - 7 x 7 arcmin field of view
  - 0.067 arcsec/pixel
  - 6kx6k detector
- Spectroscopy Mode:
  - Multi-slits: 140 x 3 arcsec long, full wavelength coverage
  - 5 x 7 arcmin field of view
  - R ~ 3000 with 0.5 arcsec slits
- Augmented by GLAO

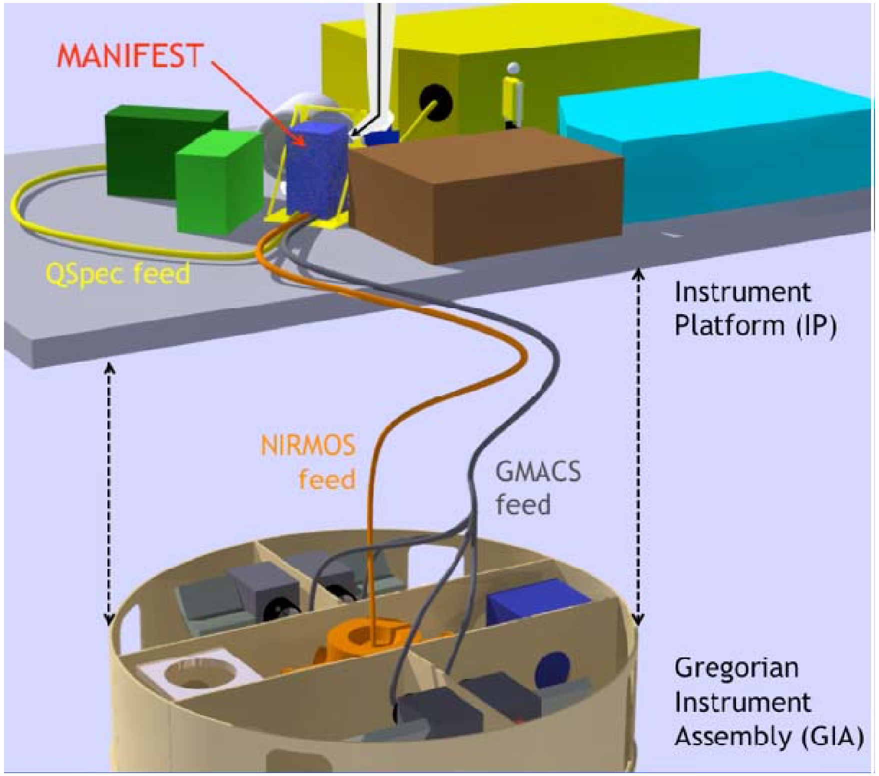
QSpec

- Four beam instrument
- 450 mm beam diameter
- *R*4 echelle gratings (x2):
  200 x 1600 mm
- *Rφ* = 30,000 arcsecs
- λλ = 300 nm to 1.07 μm
  (in four channels)
- 2-pix resolution:
  R=125,000
- Pupil anamorphism
- White pupil design
- VPH grating cross-dispersion
- Four catadioptric cameras
- 4k x 6.5k to 6k x 8k CCDs
  (15 μm pixels)



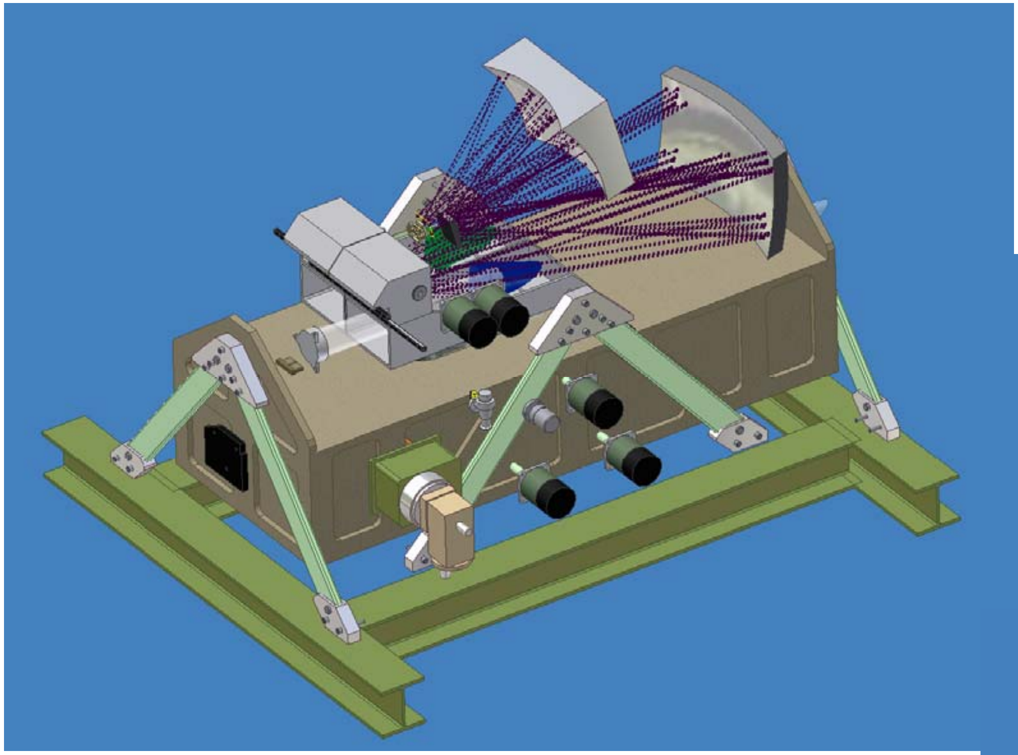
MANIFEST Fiber System





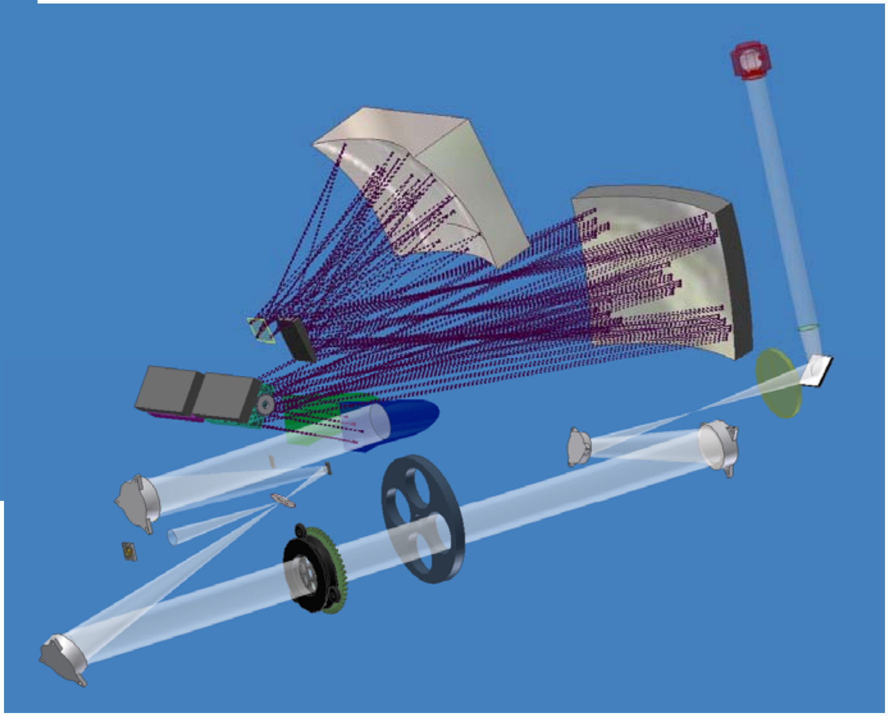
Matthew Colless -- AAO

GMTNIRS – High Resolution IR Spectrograph (Silicon Immersion Gratings)



LM unit is ~1m x 1m x 0.7m

2λ/D (AO) Slit gives 100,000 at 4.6 μm.



JHK unit is 2m x 1.5m x 1.5m

0.3” (seeing limited) Slit at R=50,000

TIGER – Thermal IR Imager/Spectrograph

Two Reflections: Primary – Secondary – TIGER

Table 1: Operational modes for TIGER

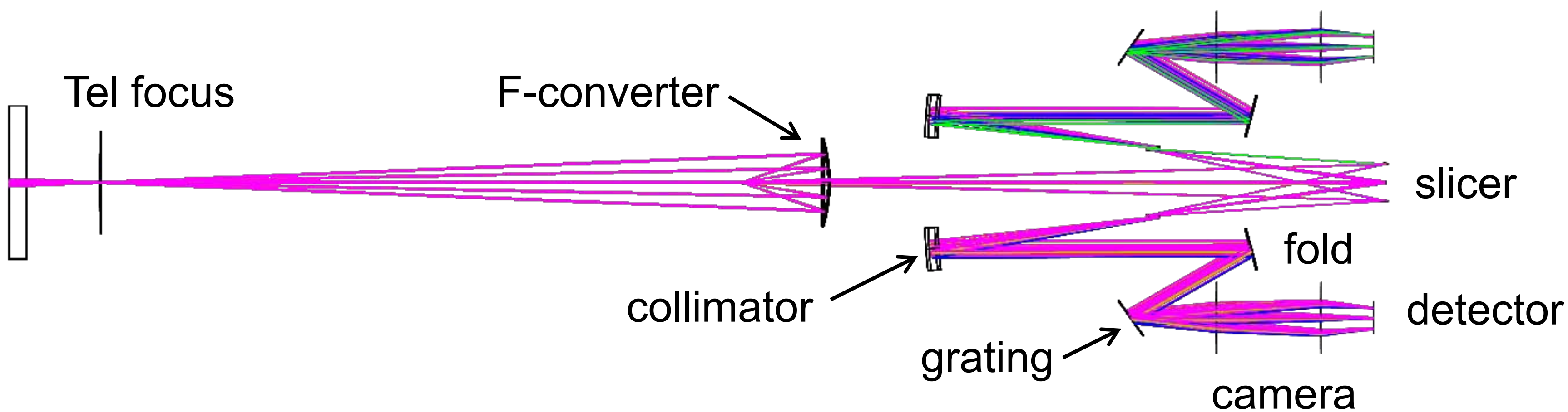
Optics Mode	Wavelength Mode	λ (μ m)	Field	Focal ratio
Standard	Imaging	3-5	40"	f/5
	Spectroscopy	3-5		f/5
	Imaging	8-25	30"	f/15
	Spectroscopy	8-25		f/15
Coronagraphy	Imaging	3-5	40"	f/5
	Spectroscopy	3-5		f/5
	Imaging	8-25	30"	f/5
	Spectroscopy	8-25		f/5
Nulling	Imaging	8-25	30"	f/15
	Spectroscopy	8-25		f/15

- Resolving power: R ~ 1500
- Short wavelength channel: 3-5μ,
  0.010 arcsec/pixel
- Long wavelength channel: 8-25μ,
  0.030 arcsec/pixel

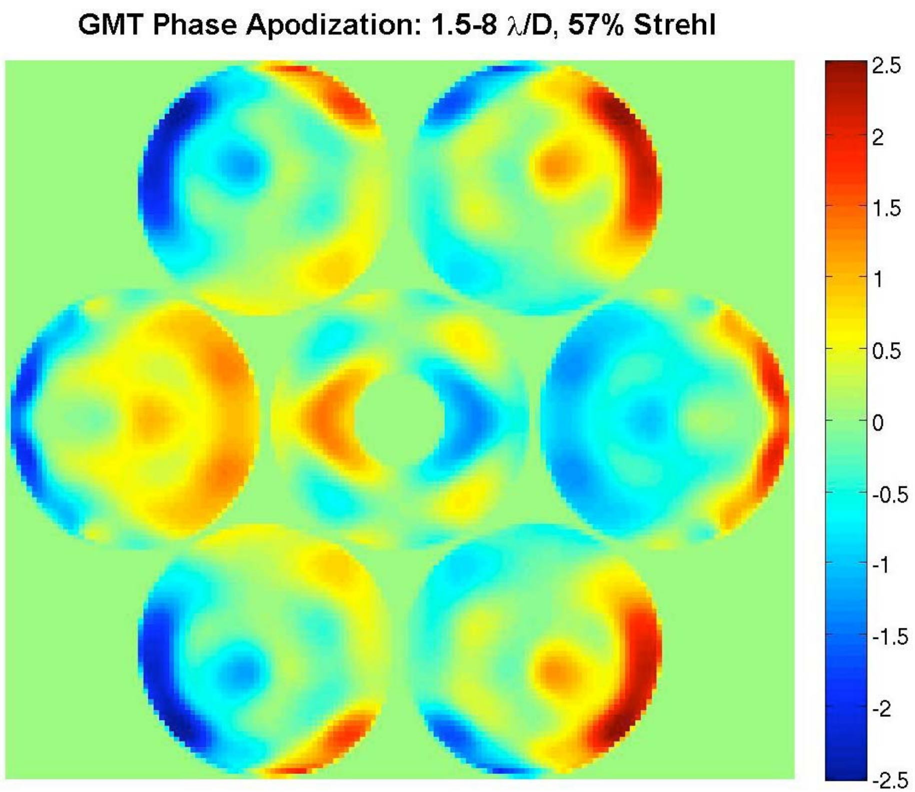
GMTIFS – GMT Integral Field Spectrograph

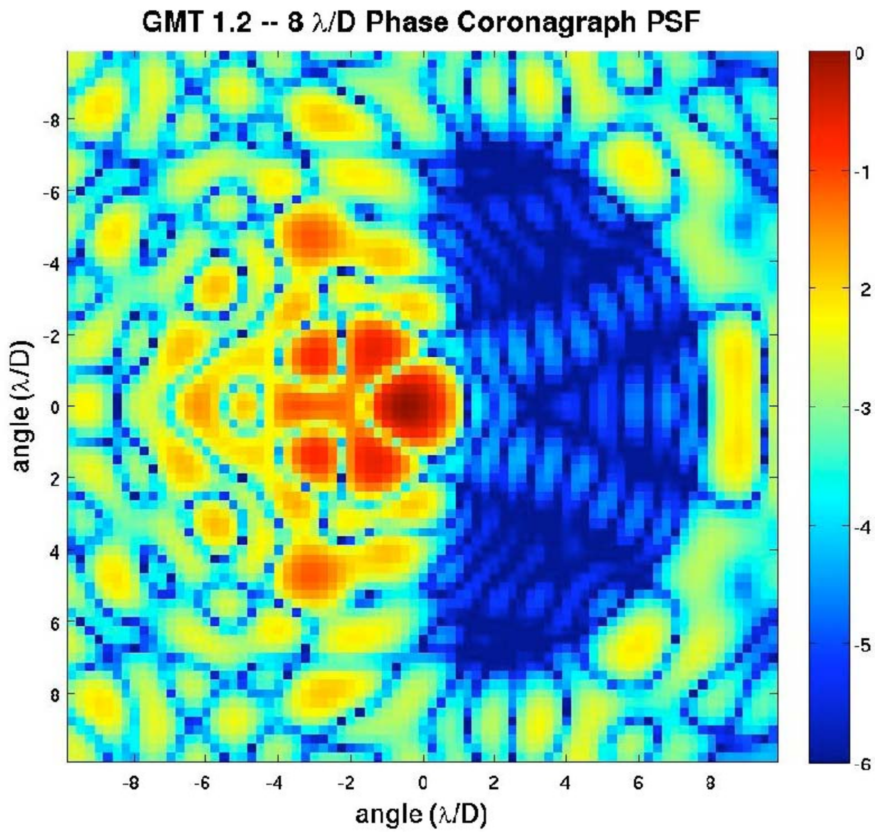
- Single-object, AO-corrected, integral-field spectroscopy
- Wavelength range: 1.0 – 2.5 μm
- Resolving power: 4000 – 5000
- Range of spatial sampling and fields of view:
  - Galaxy dynamics: 0.05-0.10 arcsec sampling, 2-3 arcsec FOV
  - Black hole masses: Diffraction-limited sampling, small FOV

Spaxel size along slit (arcsec)	0.008	0.016	0.032	0.054
Slitlet width (arcsec)	0.020	0.040	0.080	0.135
Field of view (arcsec)	0.80	1.6	3.2	5.4



HRCAM/ExAOCAM





GMT

Instrument Timeline

Milestone	Date
Call for Letters of Intent	10/15/08
LOI due	1/15/09
RFP for conceptual design	4/15/09
Proposals due	9/1/09
Conceptual design starts	11/15/09
Conceptual design reviews	January 2011
Down-select 1st generation instruments	April 2011
Start Final Design Phase	January 2012
Start Instrument Fabrication Phase	March 2014
Start of instrument commissioning	2019

GMT

Status and Schedule

Milestone	Date
Start of Conceptual Design	03/2004
Casting of GMT Segment #1	06/2005
Conceptual Design Review	02/2006
Site Selection	03/2007
Start of Design Development Phase	04/2007
Signing of Founders' Agreement	05/2008
Selection of First Instrument Suite	10/2009
Start of Construction	01/2012
Commissioning	06/2018
Start of Full Science Operations	06/2019

GMT Science Case

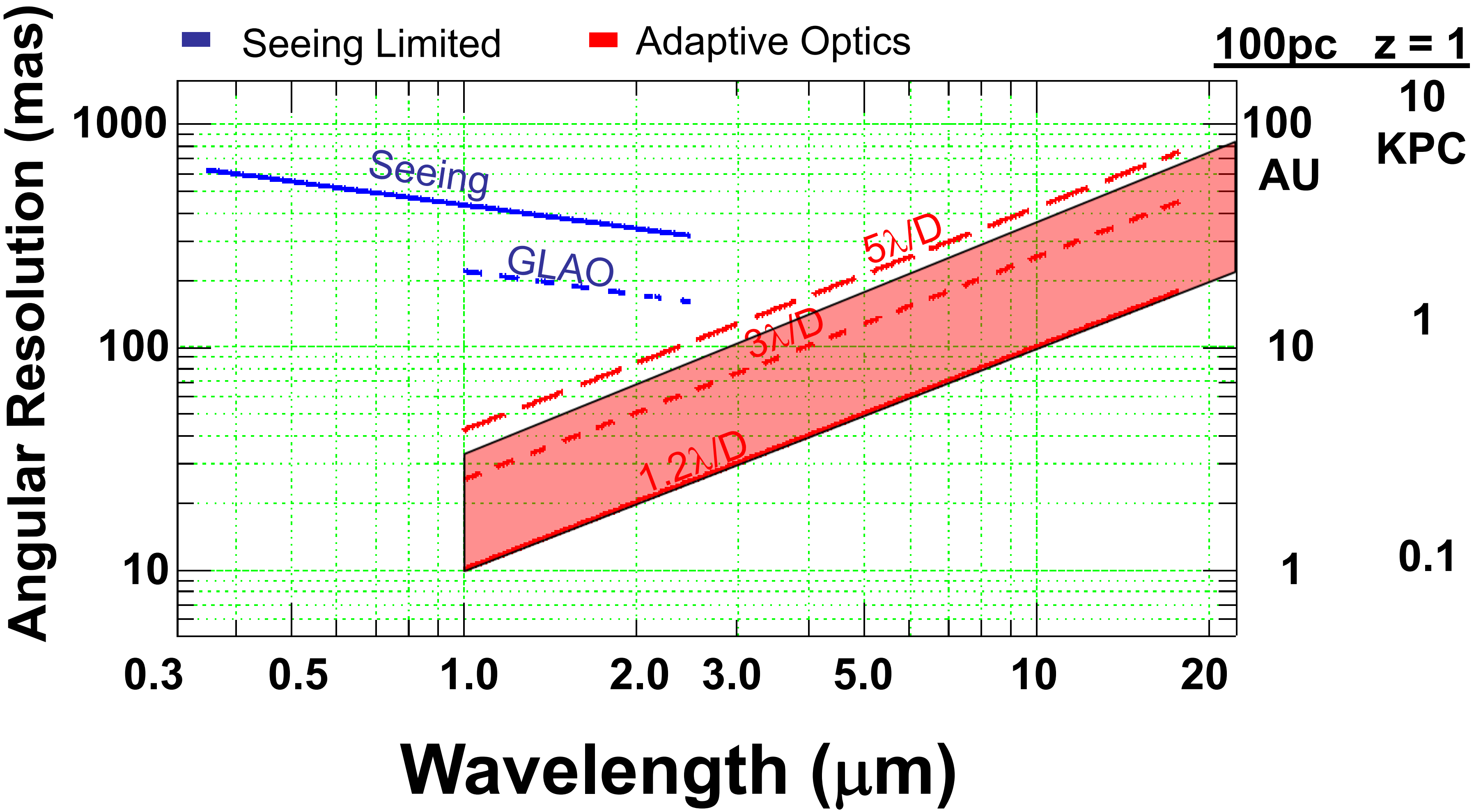
Three Approaches:

Discovery Space

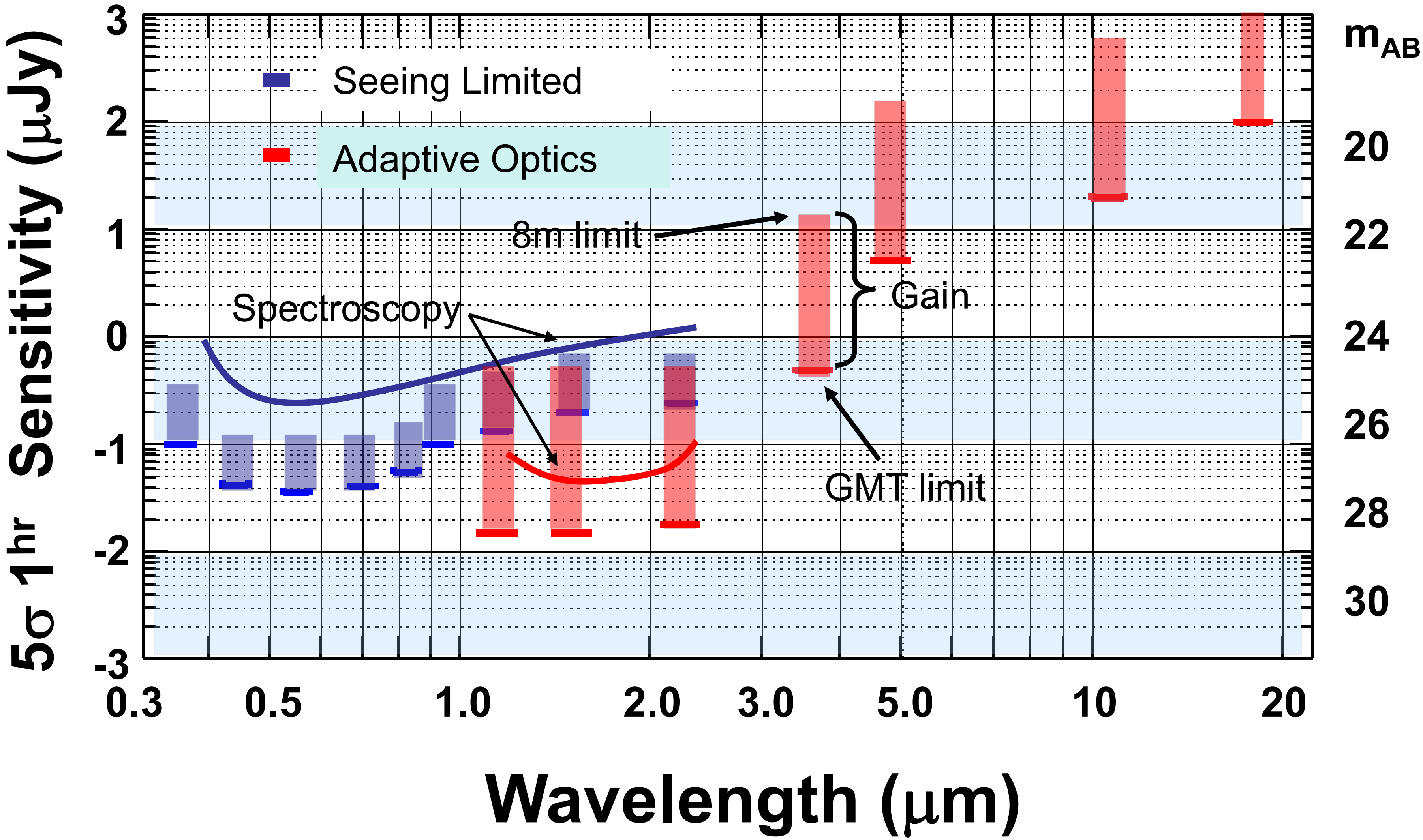
Synergy

Contemporary Science Drivers

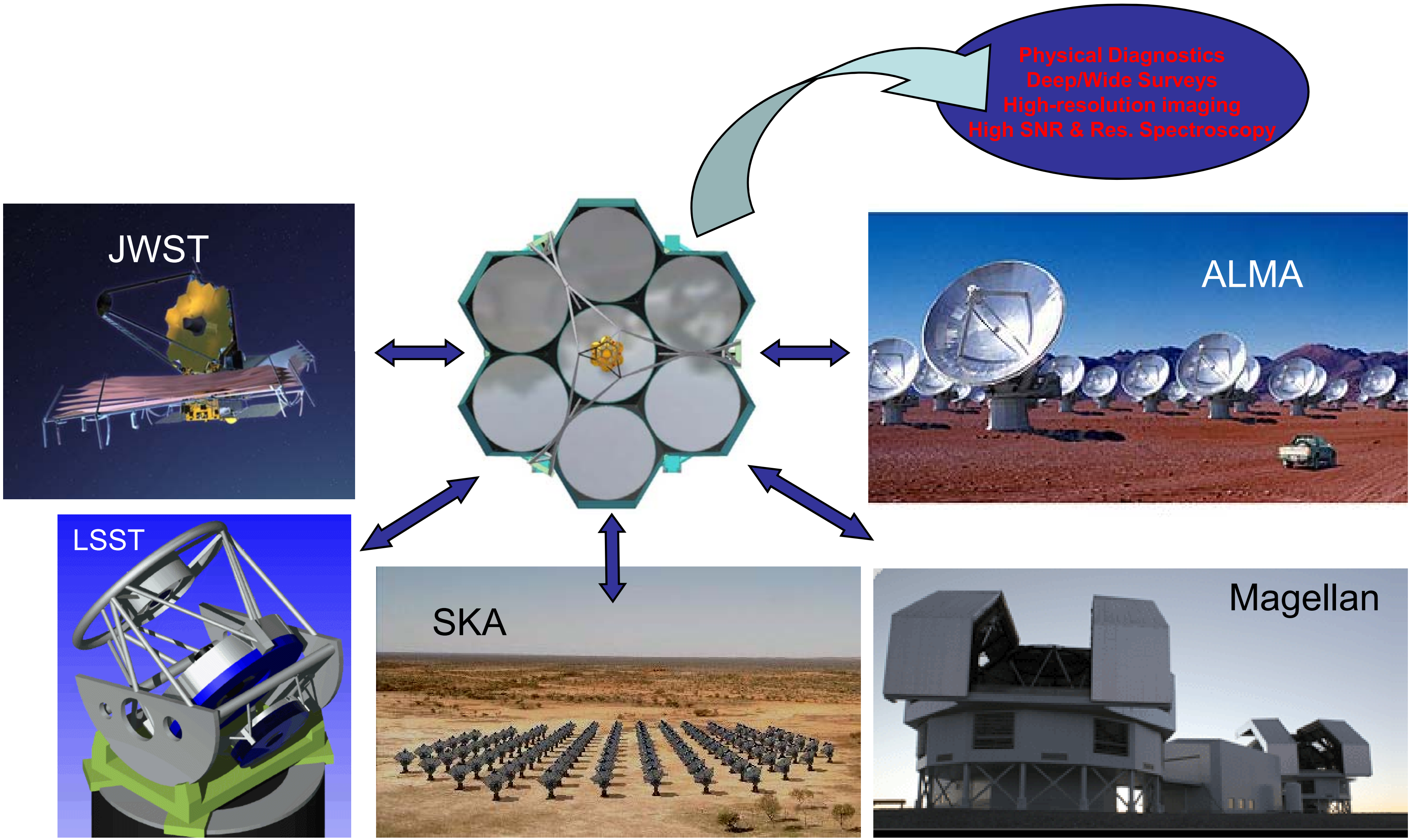
Discovery Space



Discovery Space



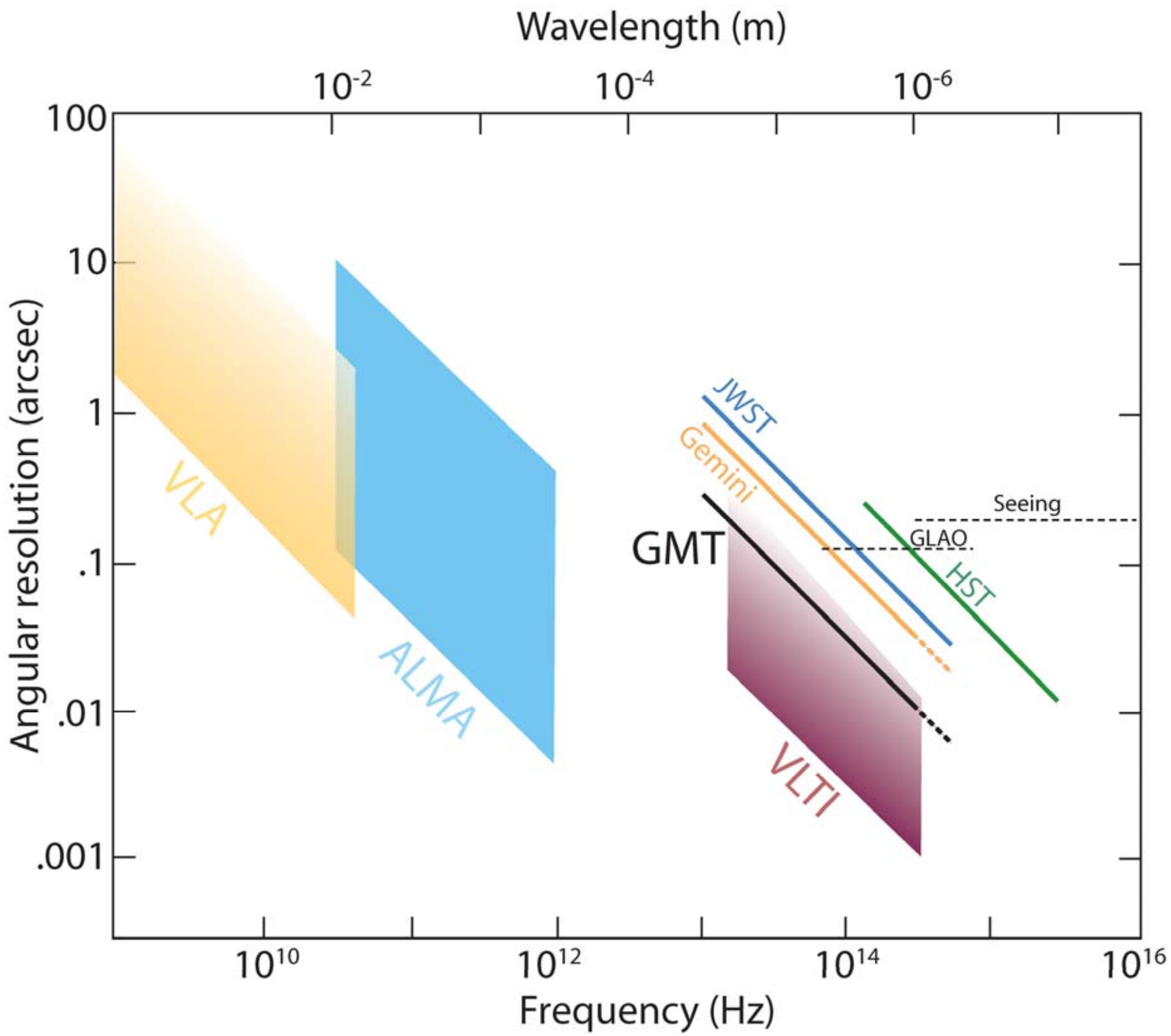
GMT SCIENCE: CONTEXT & SYNERGY



Common Science Drivers

GMT	ALMA	JWST	SKA	LSST
Galaxy Assembly	Galaxies & Cosmology	Assembly of Galaxies	Galaxy Evolution & Cosmology	
Formation of Stars and Planets	Star and Planet Formation	Birth of Stars and Protoplanetary Systems		
Stellar Populations and the IMF	Stars and Their Evolution			Galactic Structure
Exoplanets	Solar Systems	Planetary Systems & the Origin of Life	Cradle of Life	Solar Systems
First Light & Reionization		First Light & Reionization	Probing the Dark Ages	
Black Hole Growth			Strong Tests of GR	
Dark Matter & Dark Energy				Dark Energy
			Cosmic Magnetism	
				Optical Transients

ALMA-ELT Synergy



ELTs & ALMA probe similar spatial scales but different temperature and density regimes

GMT Science Goals

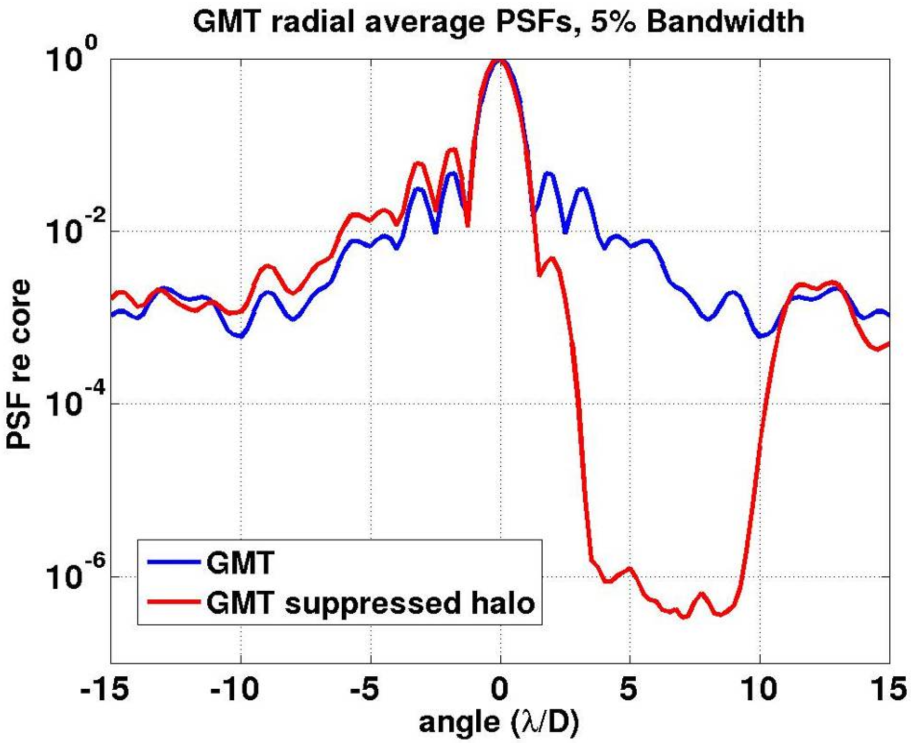
- Planets and Their Formation
- Stellar Populations and Chemical Evolution
- Assembly of Galaxies
- Black Holes in the Universe
- The Accelerating Universe
- First Light and Reionization of the Universe

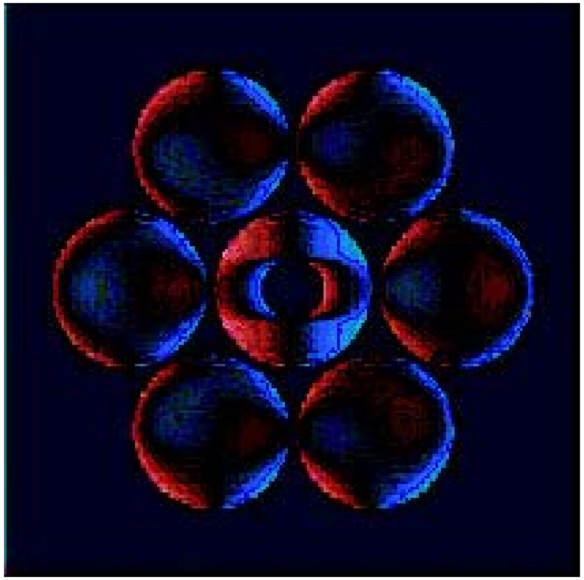
![GMT logo] GMT

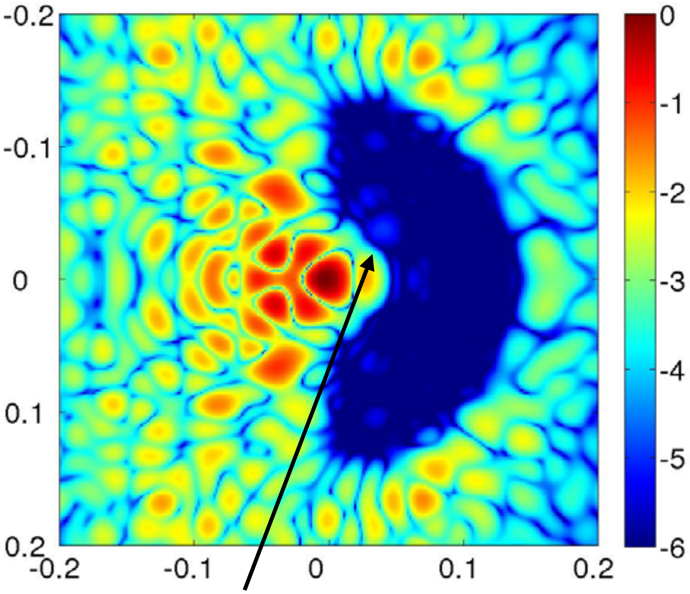
GMT PSF
with phase apodization

1.65 μm, 5% bandwidth

10^{-6} suppression at 4 λ/D, 56 mas



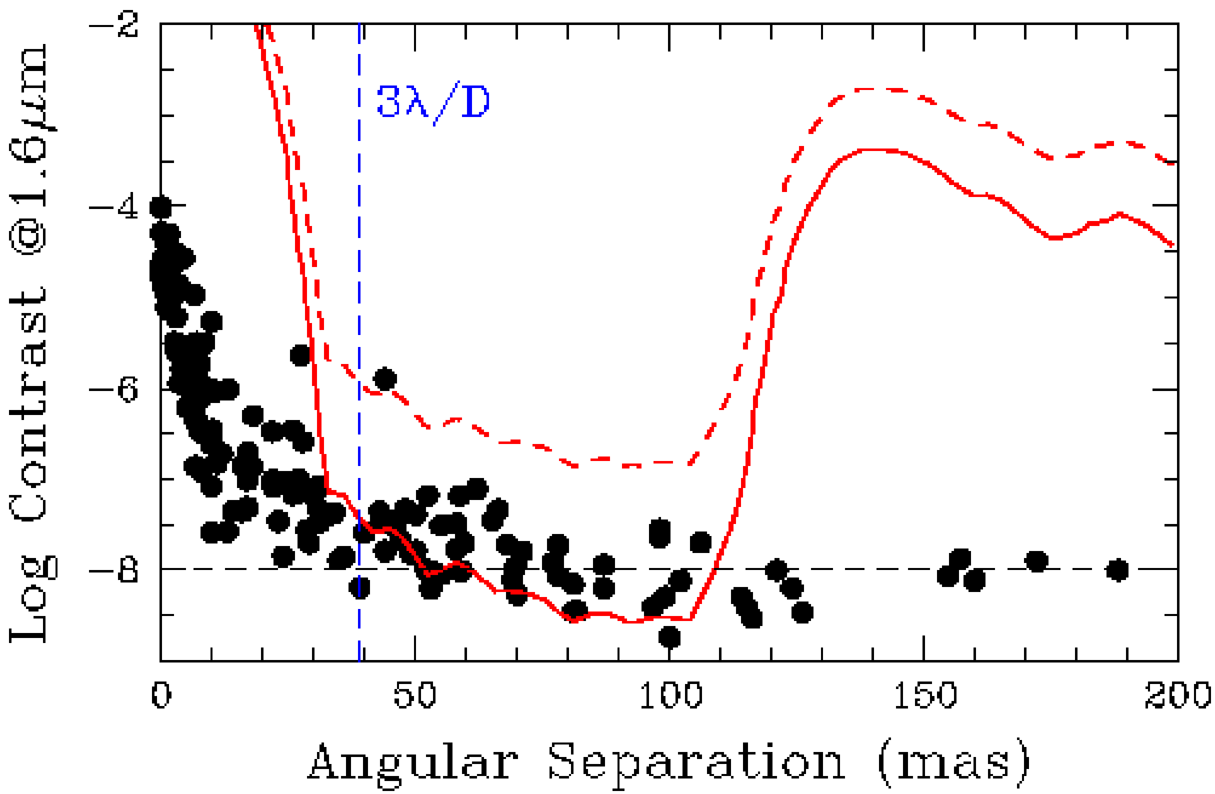




10^{-5} companion

Exoplanets in Reflected Light

Contrast vs. Separation for exoplanets discovery via radial velocity surveys

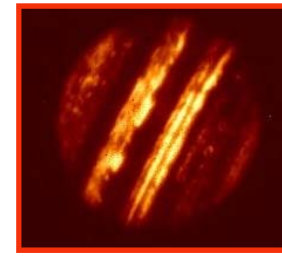


~ two dozen exoplanets are detectable in reflection with GMT

Mid-IR Imaging of Exoplanets

L band detection limit 40x improved with ~3x larger diameter

1 hour 5 sigma limits



3.8 um: 25 μJy
3 λ/D: 0.48"

10 um: 750 μJy
3 λ/D: 1.0"

Detect 5-10 M_J giant planets
100-300 zody warm debris disks

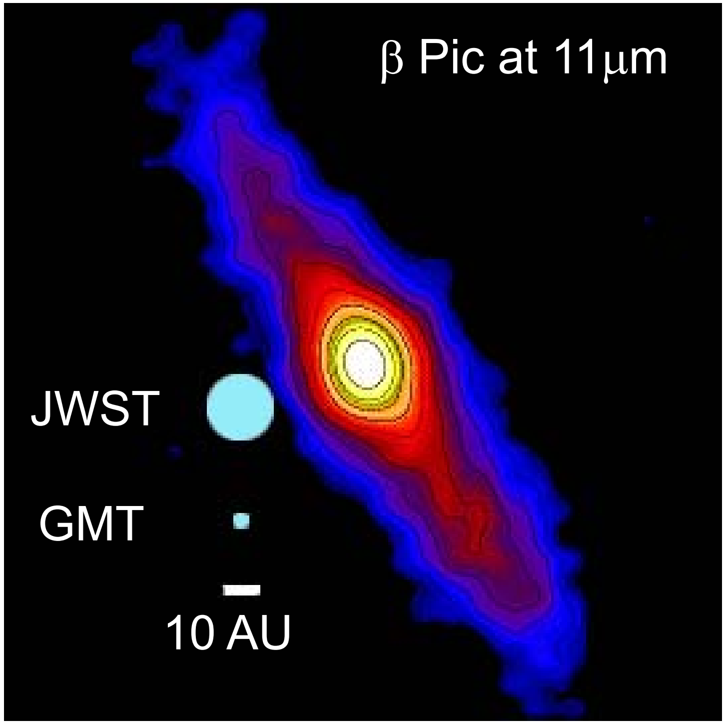
3.8 um: 0.6 μJy
3 λ/D: 0.11"

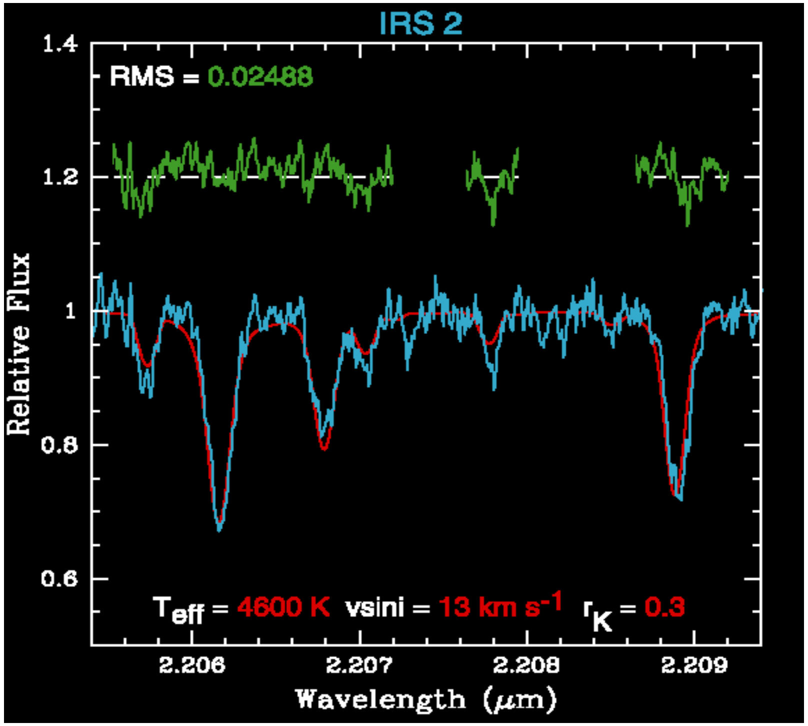
10 um: 18 μJy
3 λ/D: 0.25"

Detect <1 M_J planets
3-10 zody warm debris disks

GMT can undertake comprehensive study of giant planets in > 3 AU range around stars at 30 pc.

Synergy with JWST



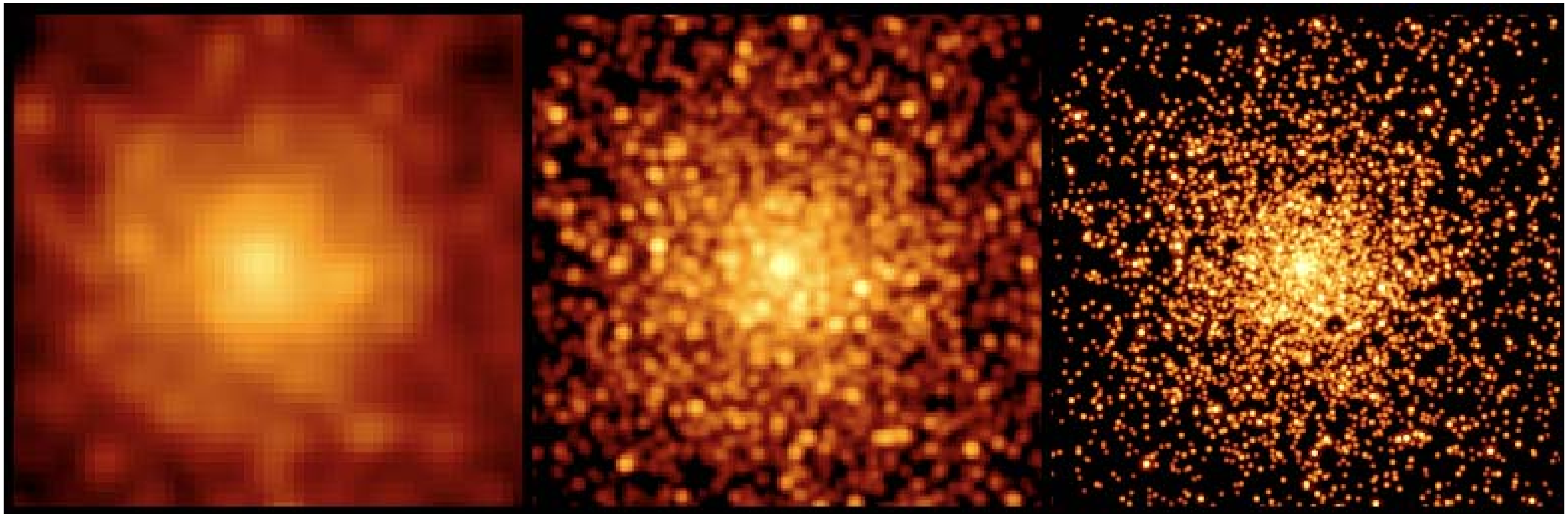


GMT has 4 times the *spatial* resolution…. and up to 100 times the *spectral* resolution

AO Imaging of Resolved Stellar Systems

Globular Cluster around Cen A   3.8Mpc   3pc core radius   H-band

HST   Gemini   GMT

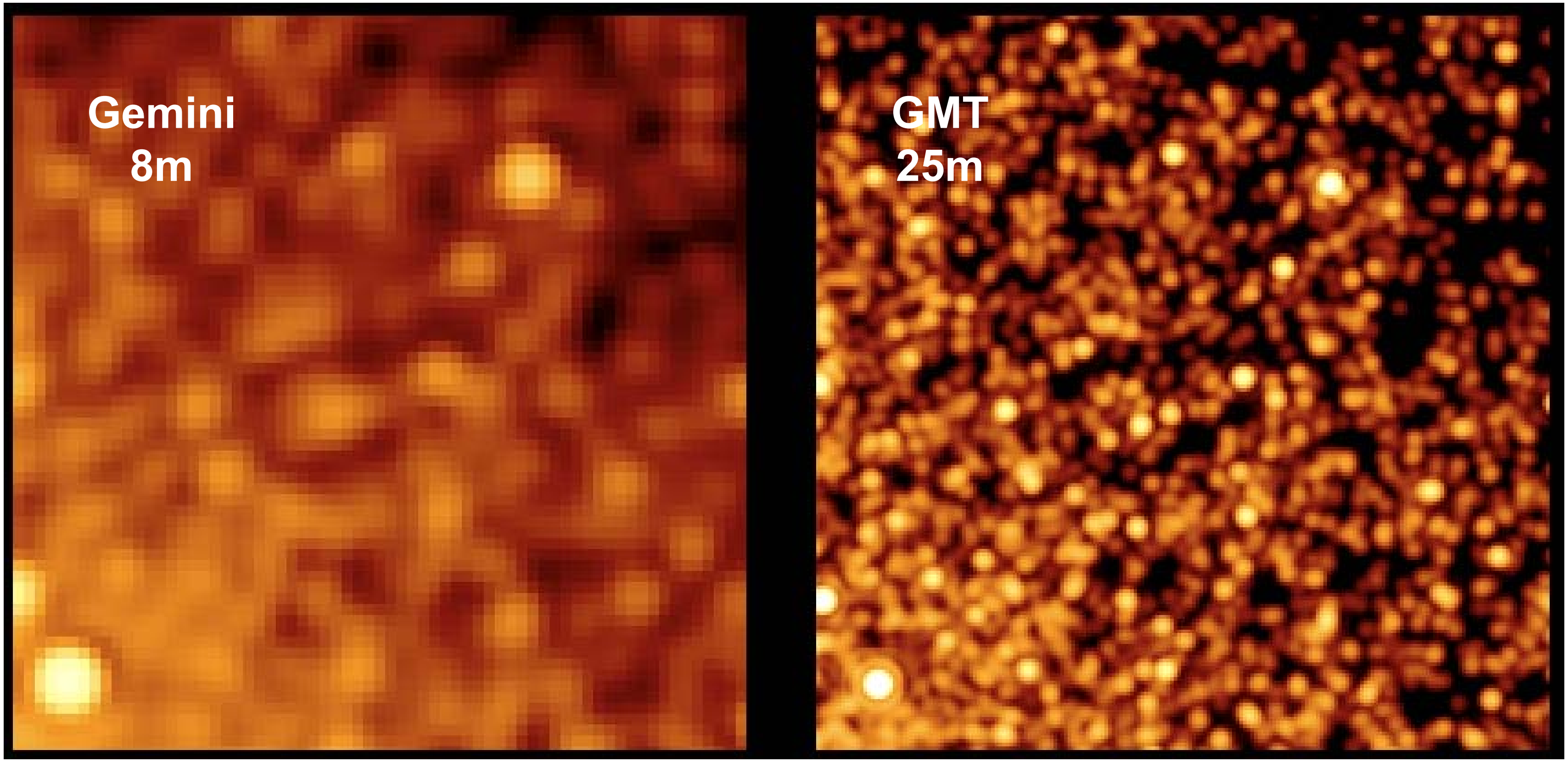


2″   4mas pixels

Laser Tomography Adaptive Optics

AO Imaging of Resolved Stellar Systems

Globular Cluster around Cen A   3.8Mpc   3pc core radius   H-band

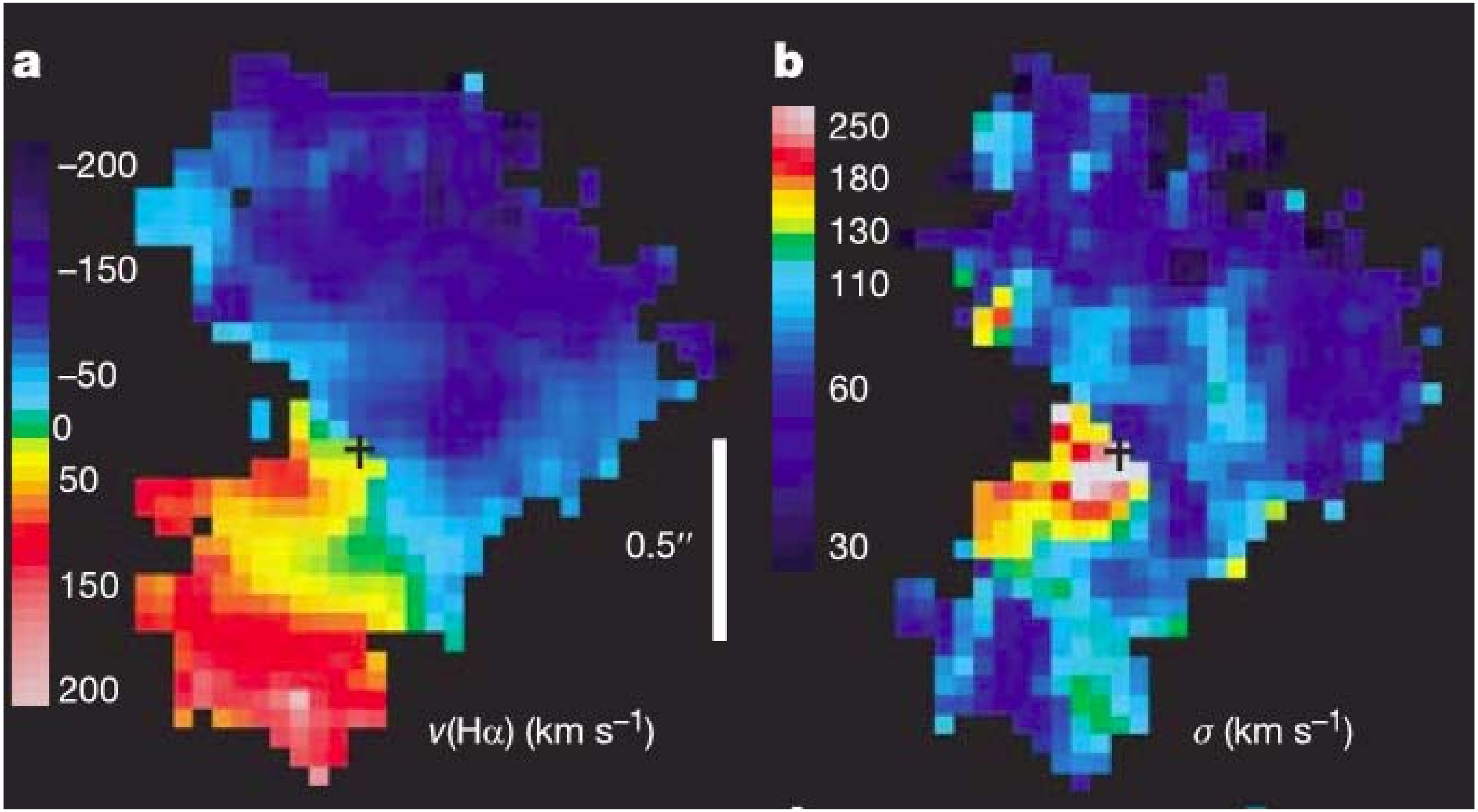


Galaxy Evolution in the Early Universe

Multiple approaches:

- Diffraction-limited studies of internal dynamics
- Ground-Layer AO studies of large samples
- Stellar Populations in old galaxies at redshifts ~ 2 - 3
- Galaxies at the end of the dark ages z > 6

Internal Dynamics in Galaxies



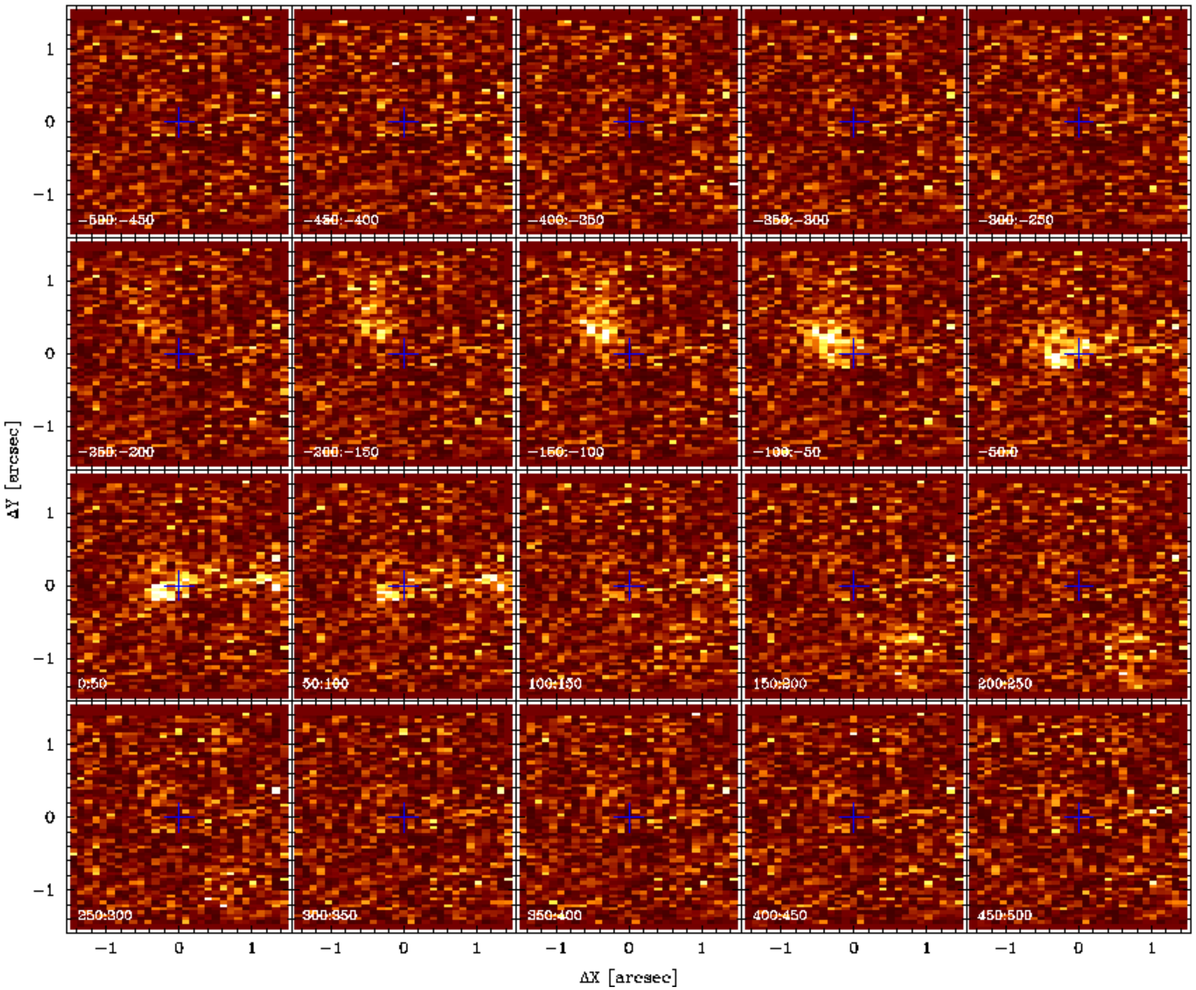
Z = 2.5 H alpha velocity maps

Genzel et al. Nature

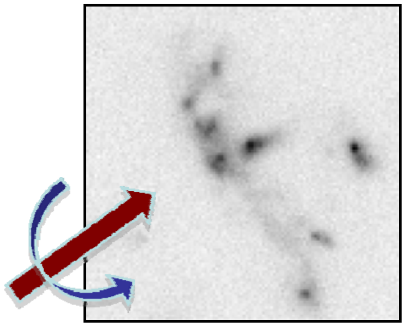
SINFONI on VLT

UDF 6462, H-band, NIFS, Hα

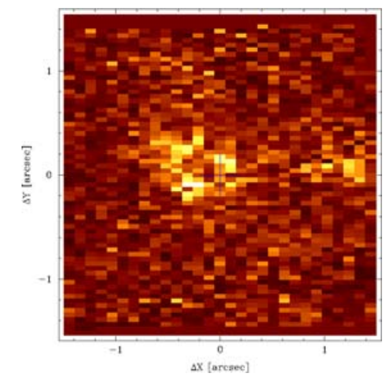
$z = 1.57$, $M_B = -21.0$, 5 hr object, 5 hr sky



HUDF - i



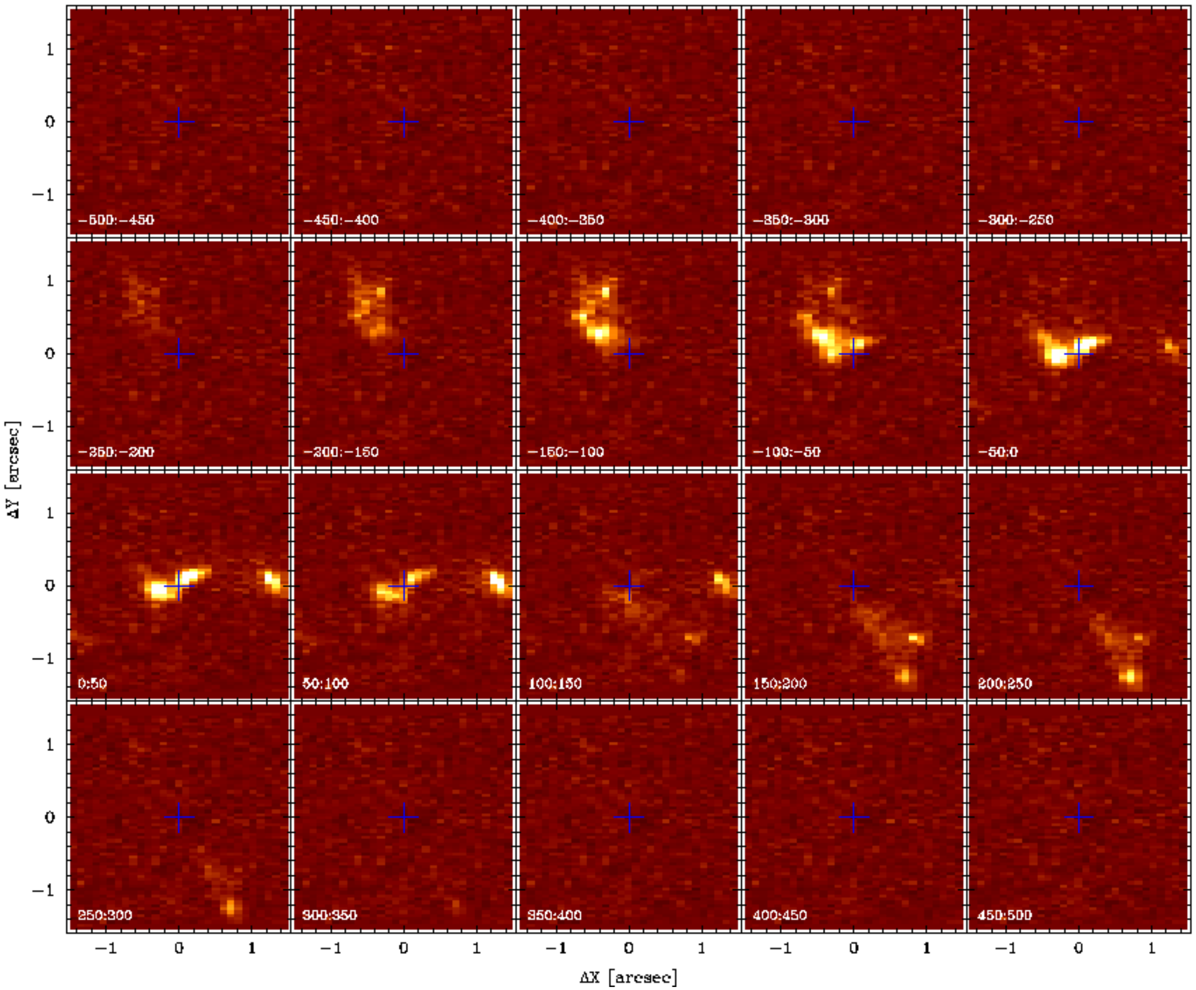
NIFS - Sum



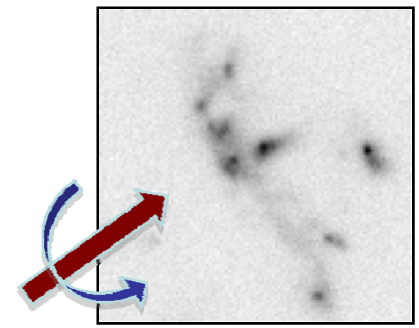
50 kms x 10kpc x 10kpc

UDF 6462, H-band, GMTIFS, Hα

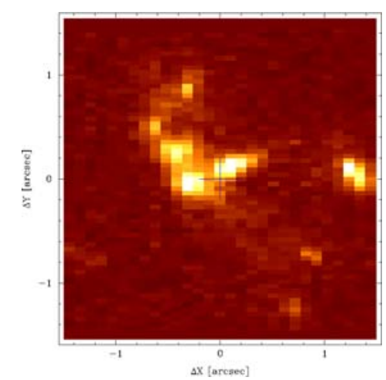
z = 1.57, M_B = -21.0, 5 hr object, 5 hr sky



HUDF - i

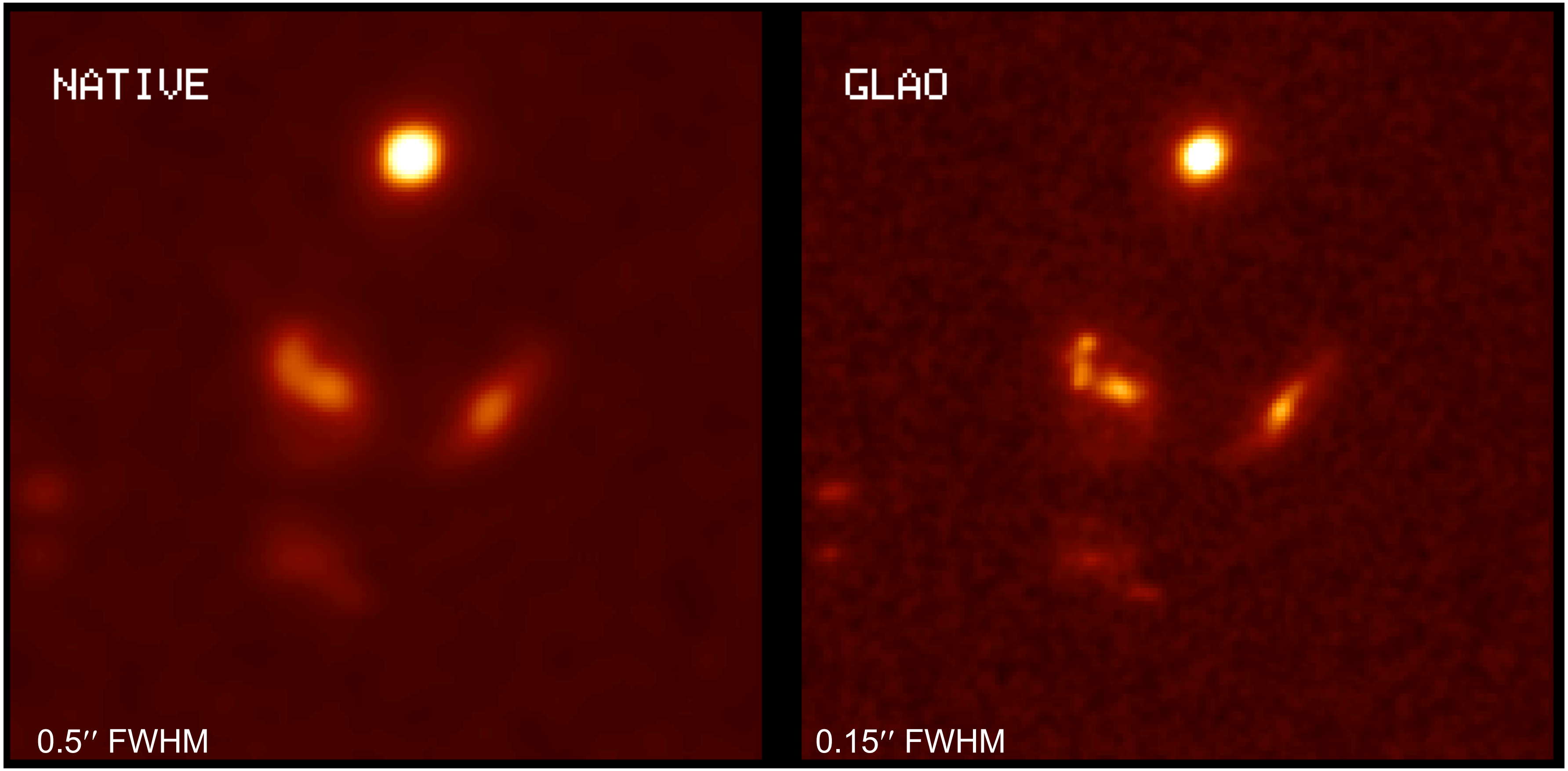


GMT - Sum

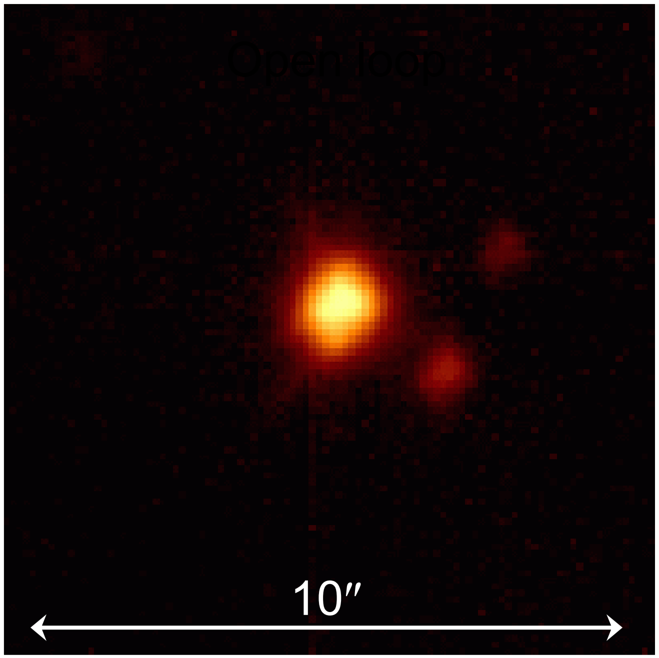


50 kms x 10kpc x 10kpc

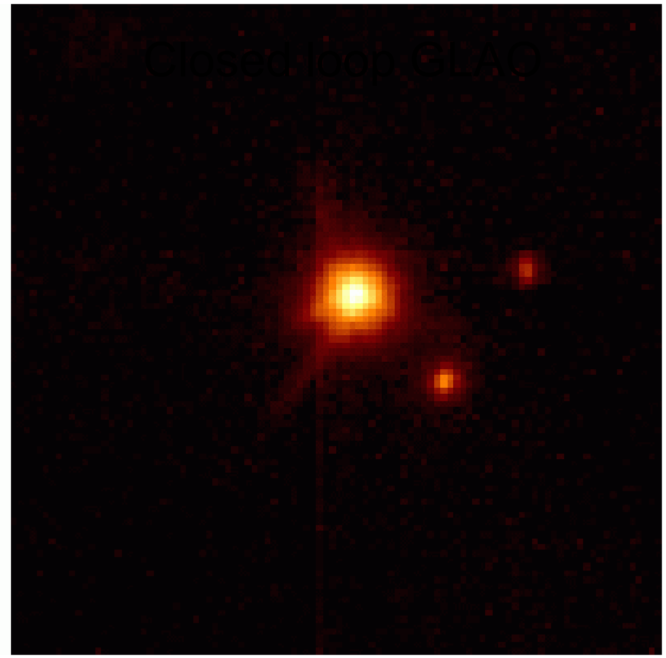
Galaxy Evolution with GLAO



Sample PSFs



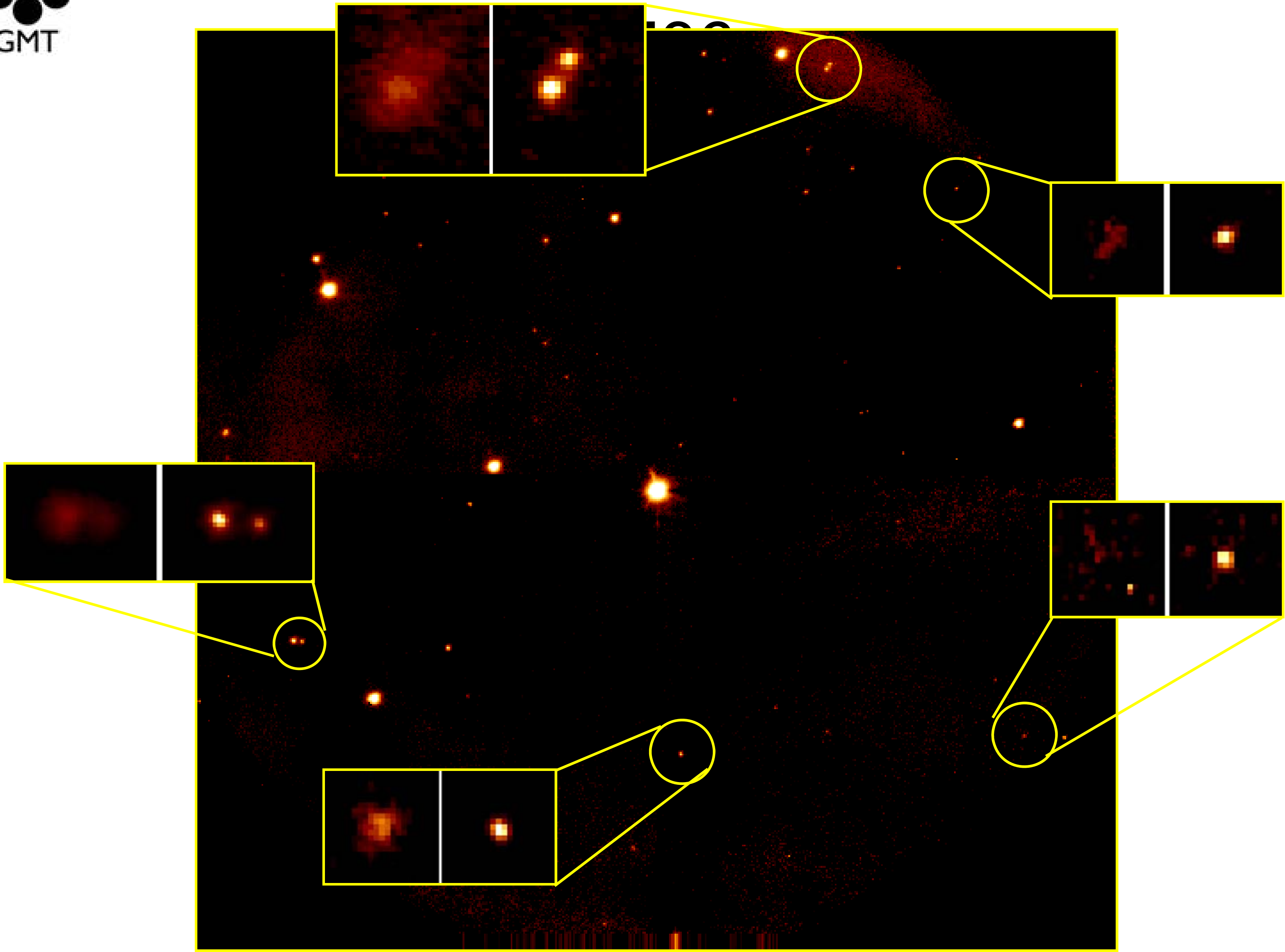
Seeing: 0.61″



Seeing: 0.22″

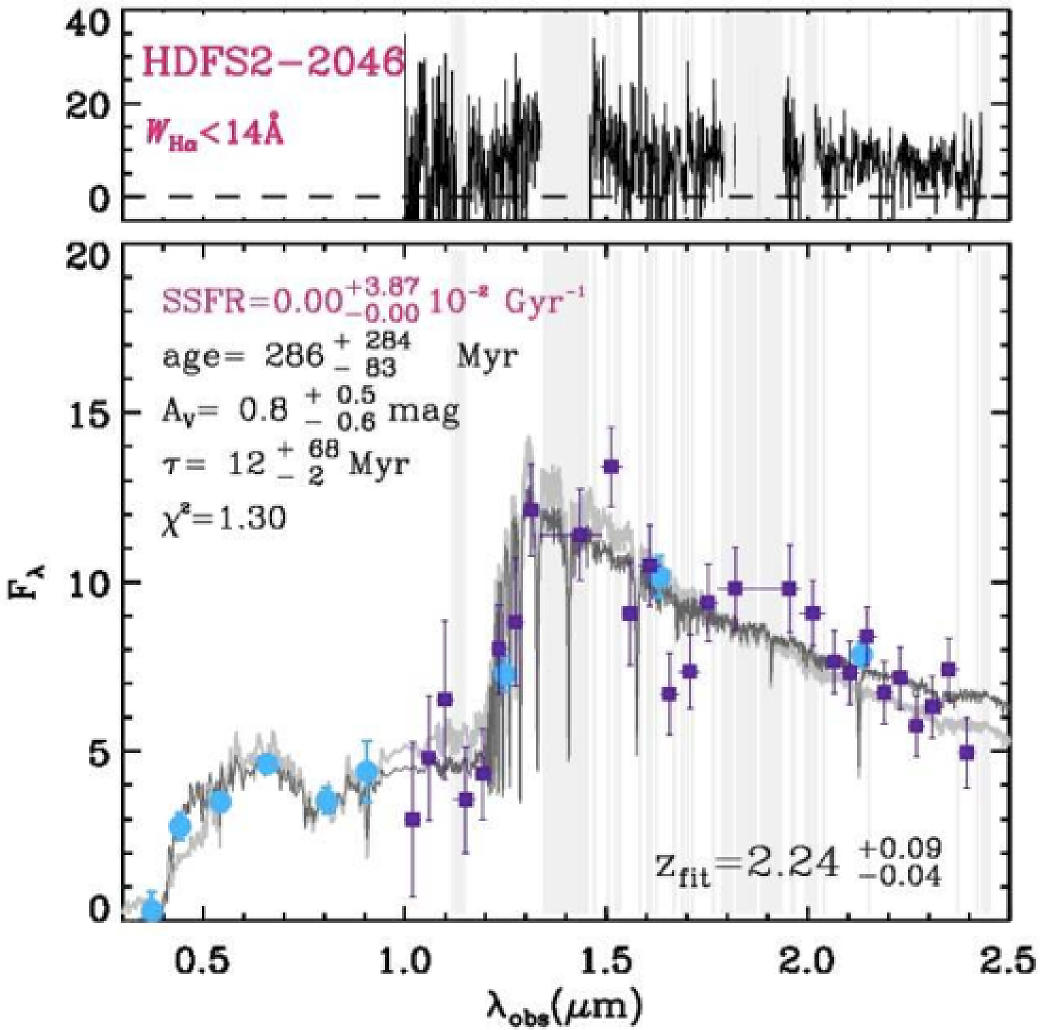
- Center of M34
  - Log intensity scaling
  - K_s band
  - 60 s exposiures

M. Hart – Steward Observatory
MMT GLAO System



M. Hart – Steward Observatory
MMT GLAO System

Stellar Content of Massive Galaxies



State of the art IR spectroscopy on Gemini 8m

Kreik et al.

GNIRS

The sky may no longer be the limit!

Photon counting

Detector + OH Suppression

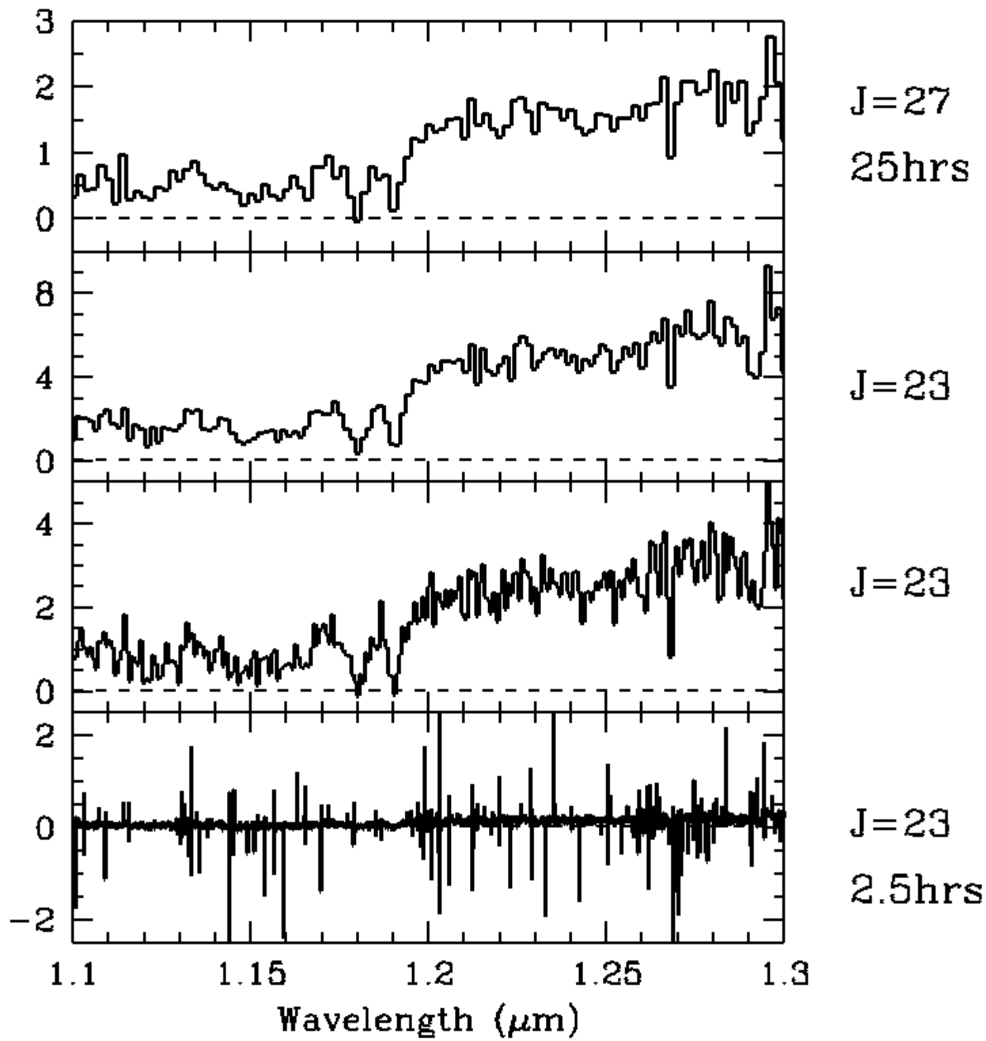
OH suppression

Before dispersion

OH removed in

Post processing

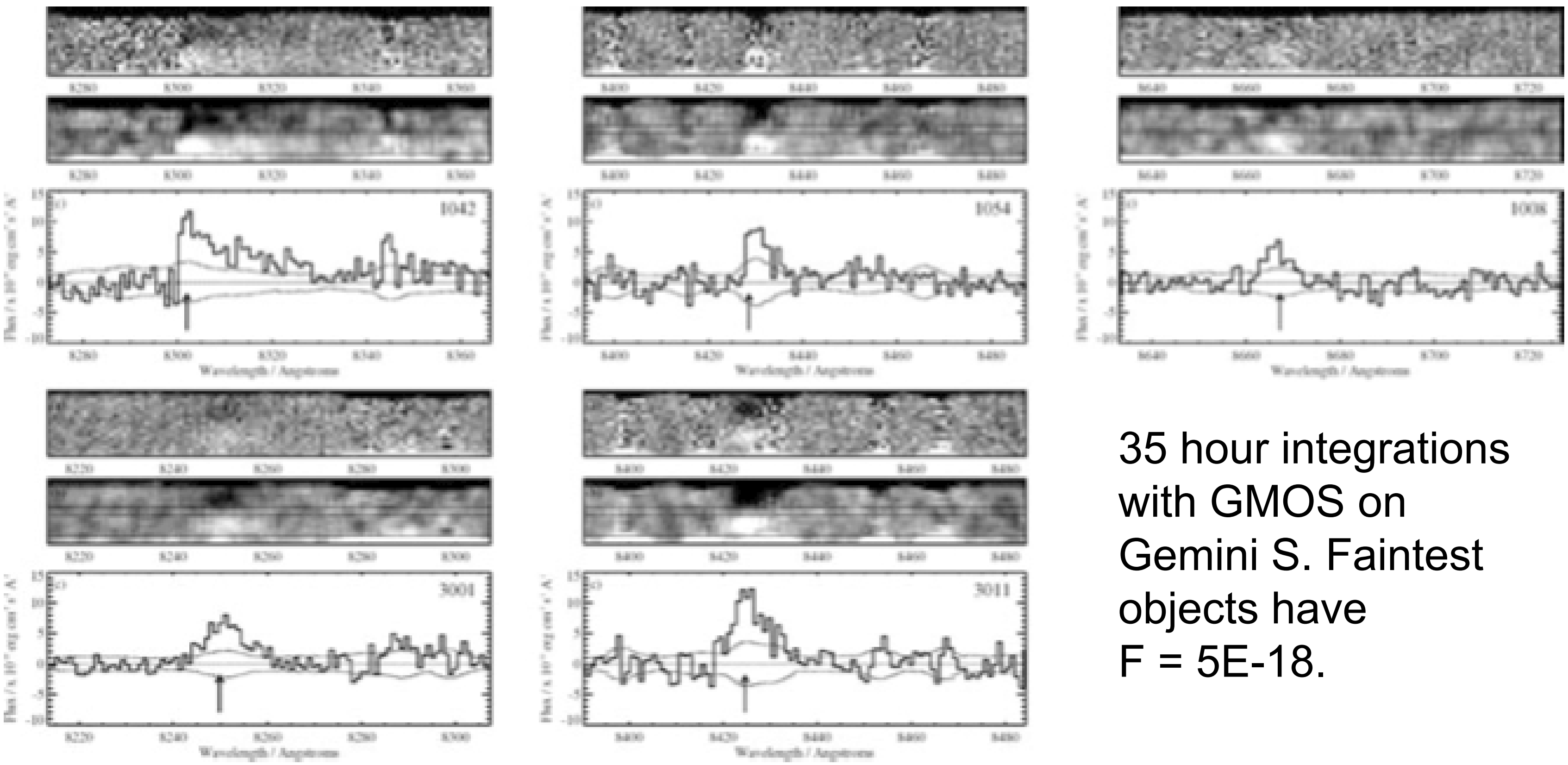
Sky subtracted



Z = 2

Old Galaxy

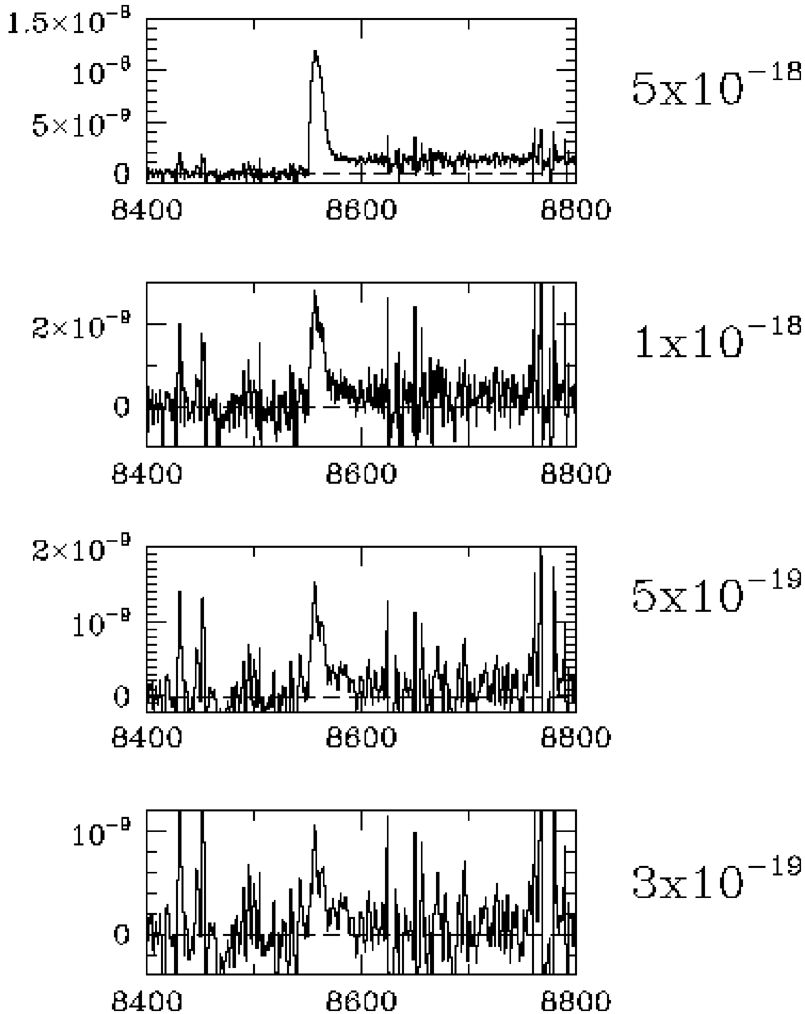
First Light and Reionization
Lyα at z ~ 6



35 hour integrations with GMOS on Gemini S. Faintest objects have F = 5E-18.

Stanway et al. 2006.

Lyα at z ~ 6



500 km/s FWHM

W_λ = 100Å

30hr integration with GMACS using 0.5” slits in 0.5” seeing

30% throughput

Gemini sky spectrum

Nod & Shuffle sky rejection

R = 5000 rebinned to

R = 1200, Gaussian smoothing

ALMA & ELTs Enable a Broad Range of Science

- Combine high sensitivity with high angular resolution
- Naturally sample different regions
- Provide platforms for technology development
  - focal plane arrays
  - adaptive optics techniques
- General purpose facilities, rather than survey instruments

GMT Adaptive Optics Modes

AO Mode	Resolution	Field of View
Laser Tomography	diffraction limited	30″ - 60″
Ground Layer Correction	2-3 x improved seeing	up to 8′
Multi-Conjugate	diffraction limited	60″ - 120″
Extreme AO	high contrast diff. limited	~2″

Diffraction limit = 10 mas @ 1μm

Lyα at z ~ 9

Lyα at z = 8.7

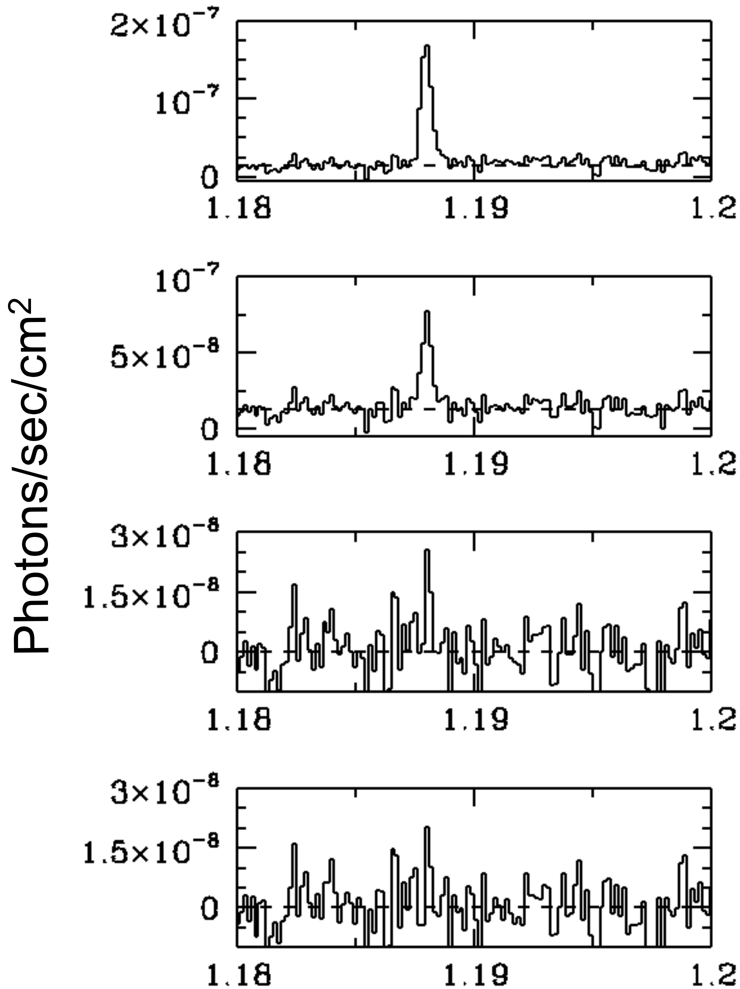
in the J-band

NIRMOS Properties with current Near-IR detectors

200 km/sec line widths

25 hour exposures

7′ x 7′ field of view



$5x10^{-18}$ — $5x10^{42}$

$2x10^{-18}$ — $2x10^{42}$

$5x10^{-19}$ — $5x10^{41}$

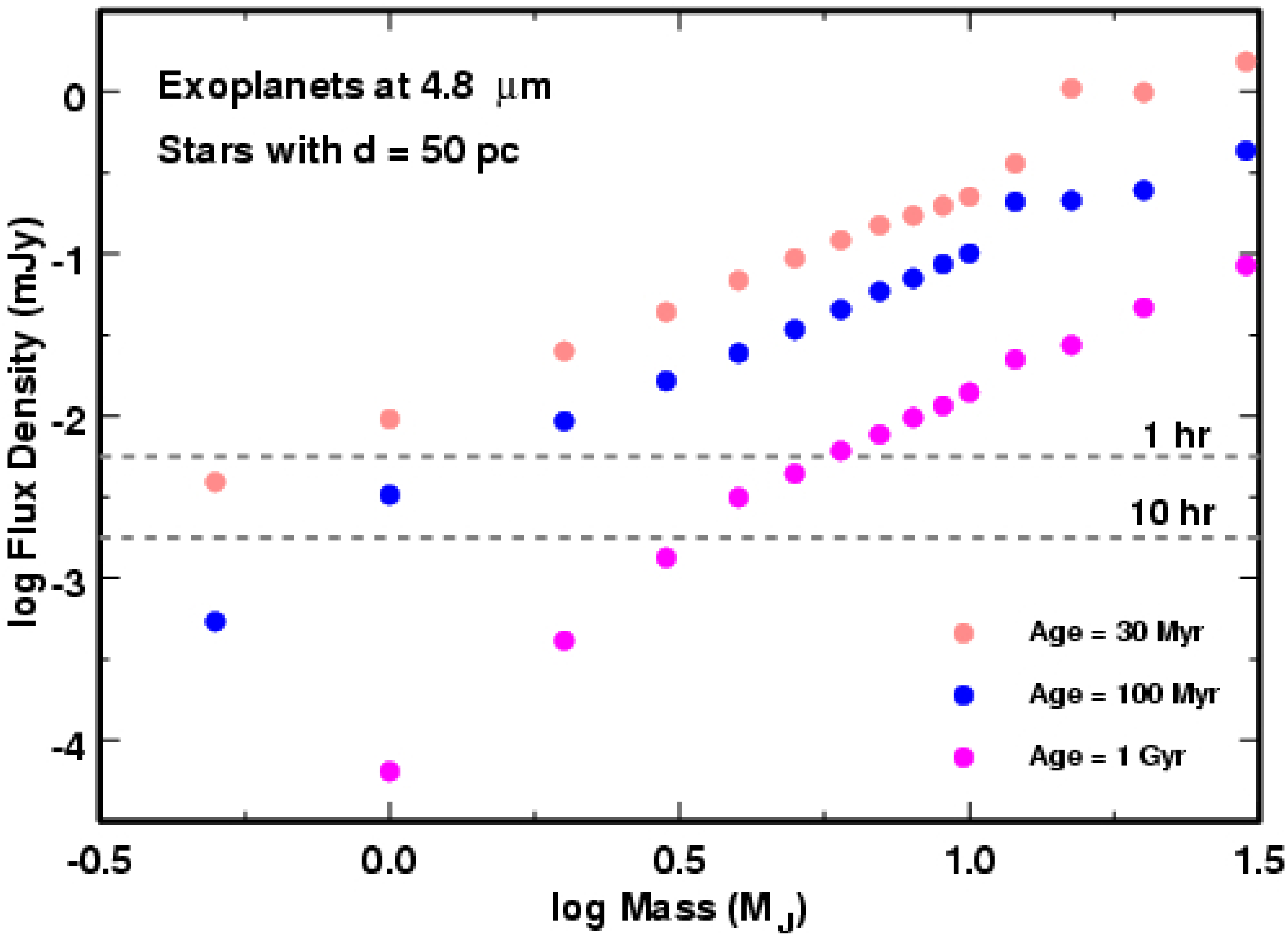
$3x10^{-19}$ — $3x10^{41}$

$4M_{sun}$/yr

MW Star formation rate!

MW Star formation rate?

Mid-IR Imaging of Exoplanets



Strengths of the GMT

- Low technical risk and low cost (relatively!)
- Combination of adaptive optics and wide-field
  - *diffraction limit: 10mas (GMT) - 8mas (TMT) - 6mas (E-ELT)*
  - *D^4 speed factor*
  - *GLAO field of view: ~8′ (GMT)*
  - *wide-field seeing limited instruments*
- Optimal approach to AO - Adaptive Secondary
  - *high throughput, low background, wide-field*
- Excellent site
  - *Las Campanas is owned by Carnegie, dark skies, excellent seeing, excellent weather, existing infrastructure*
- Balanced partnership
  - *all partners aiming for 10-20% shares, no dominant institution*
- Synergy
  - *same hemisphere and longitude as ALMA and LSST*