GMT

Sharp Images and Wide Fields

The scientific power of GMTIFS and MANIFEST on GMT

Lecture 2

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USP/IAG Advanced School on Astrophysics

Sao Paulo, 26 February – 2 March 2018

Structure

GMT

- ❑ Lecture 1 – Sharp Images and Wide Fields
- ❑ Lecture 2 – The GMT Integral Field Spectrograph
- ❑ Lecture 3 – The MANIFEST fibre facility

Outline of Lecture 2

GMT

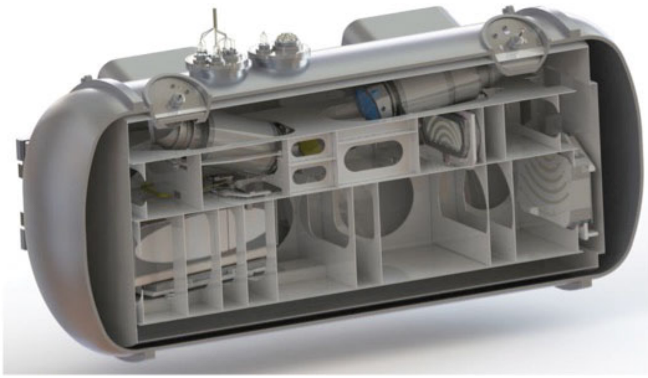
- Introduction and review
- GMTIFS key science cases
- GMTIFS science requirements
- GMTIFS instrument design
- GMTIFS simulations
- Summary

Introduction and review

GMT

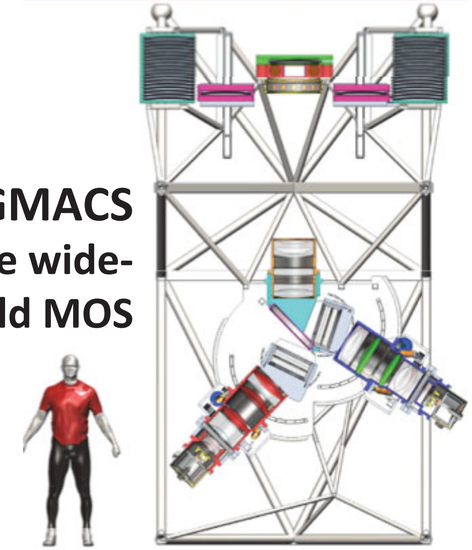
First-generation GMT instruments

GMT

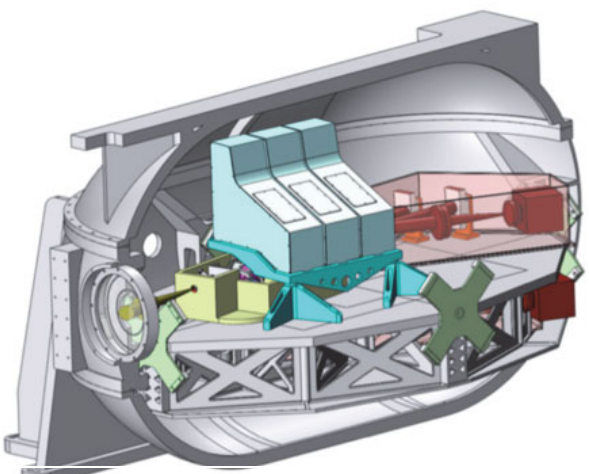


G-CLEF
high-resolution echelle

GMACS
visible wide-field MOS

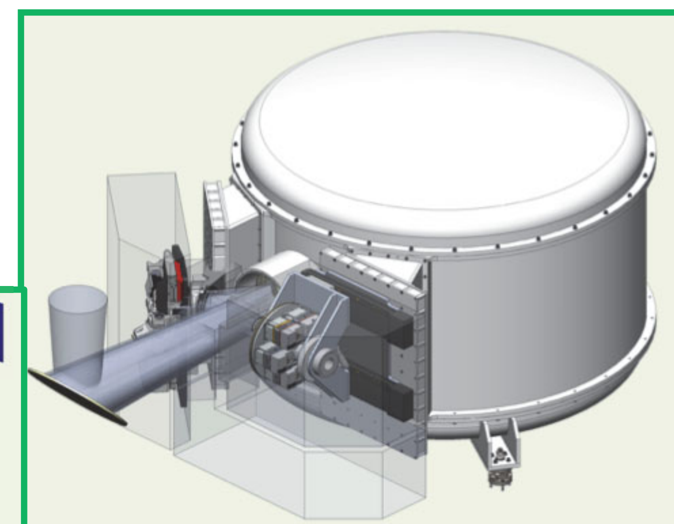


MANIFEST
facility fibre system



GMTNIRS
AO-fed 1-5 micron echelle

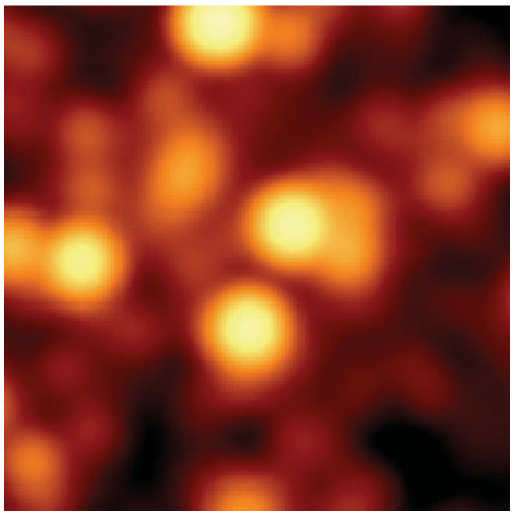
GMTIFS
AO-fed IFU spectrograph and imager



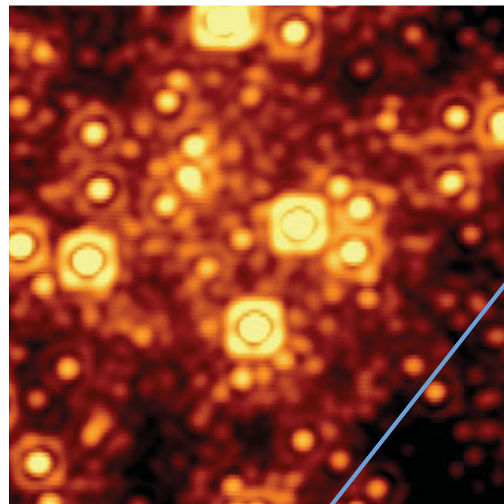
GMT image sharpness

GMT

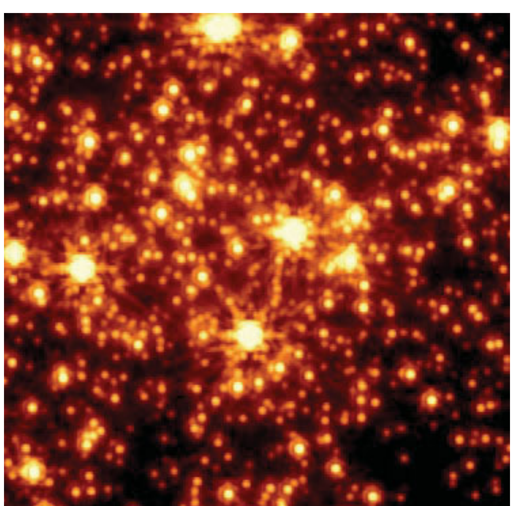
Natural Seeing 0.6”



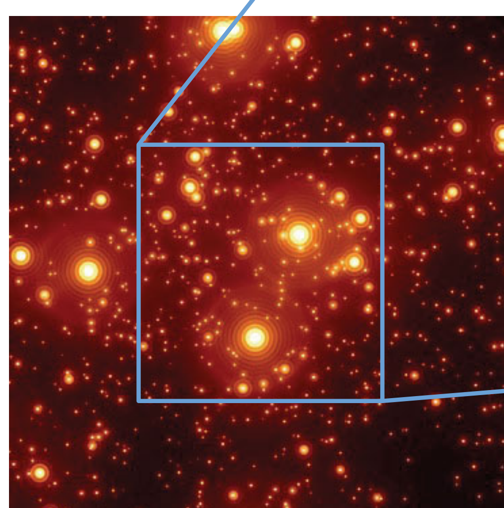
HST/NICMOS



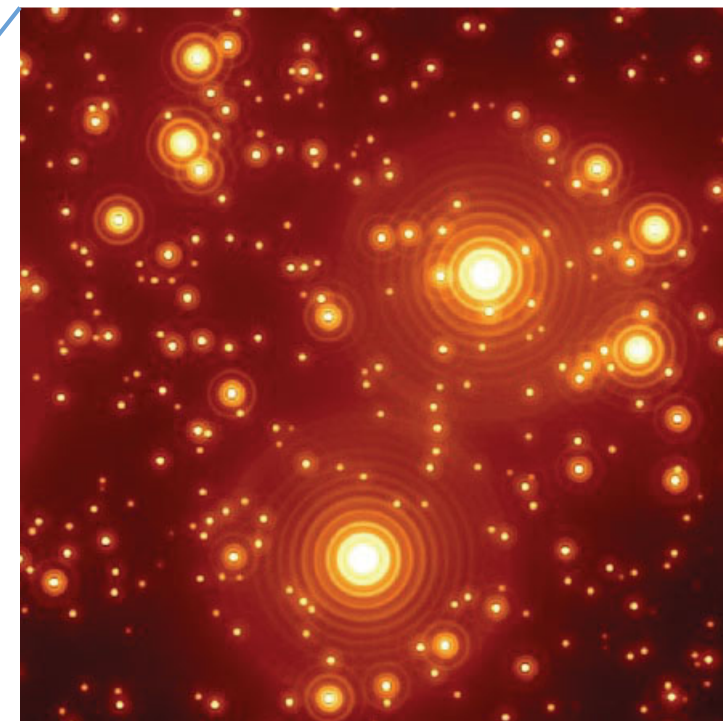
JWST NIRCAM



GMT Strehl: 80%

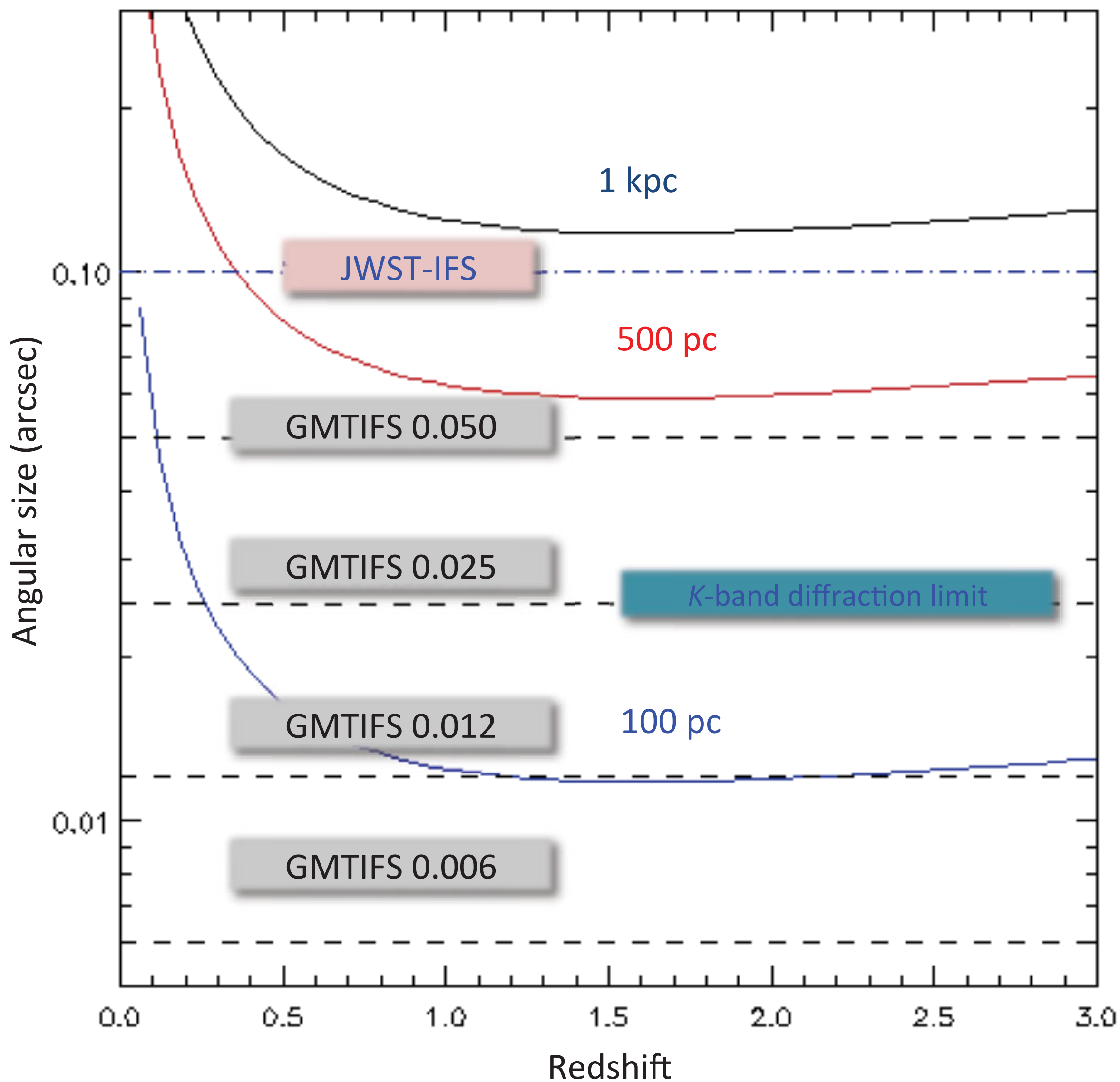


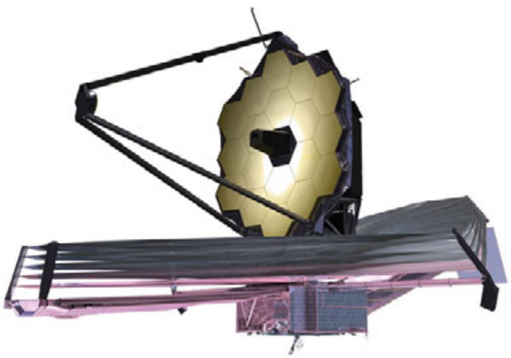
GMT Strehl: 80%

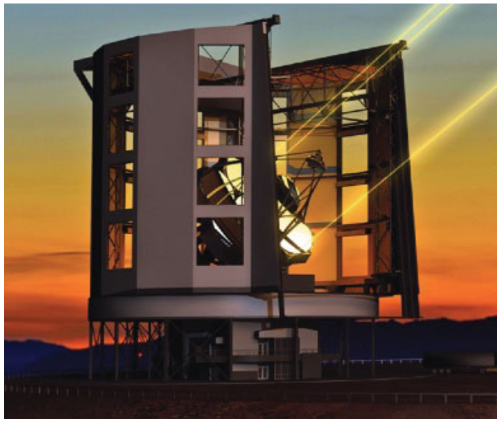


Spatial resolution is key

GMT



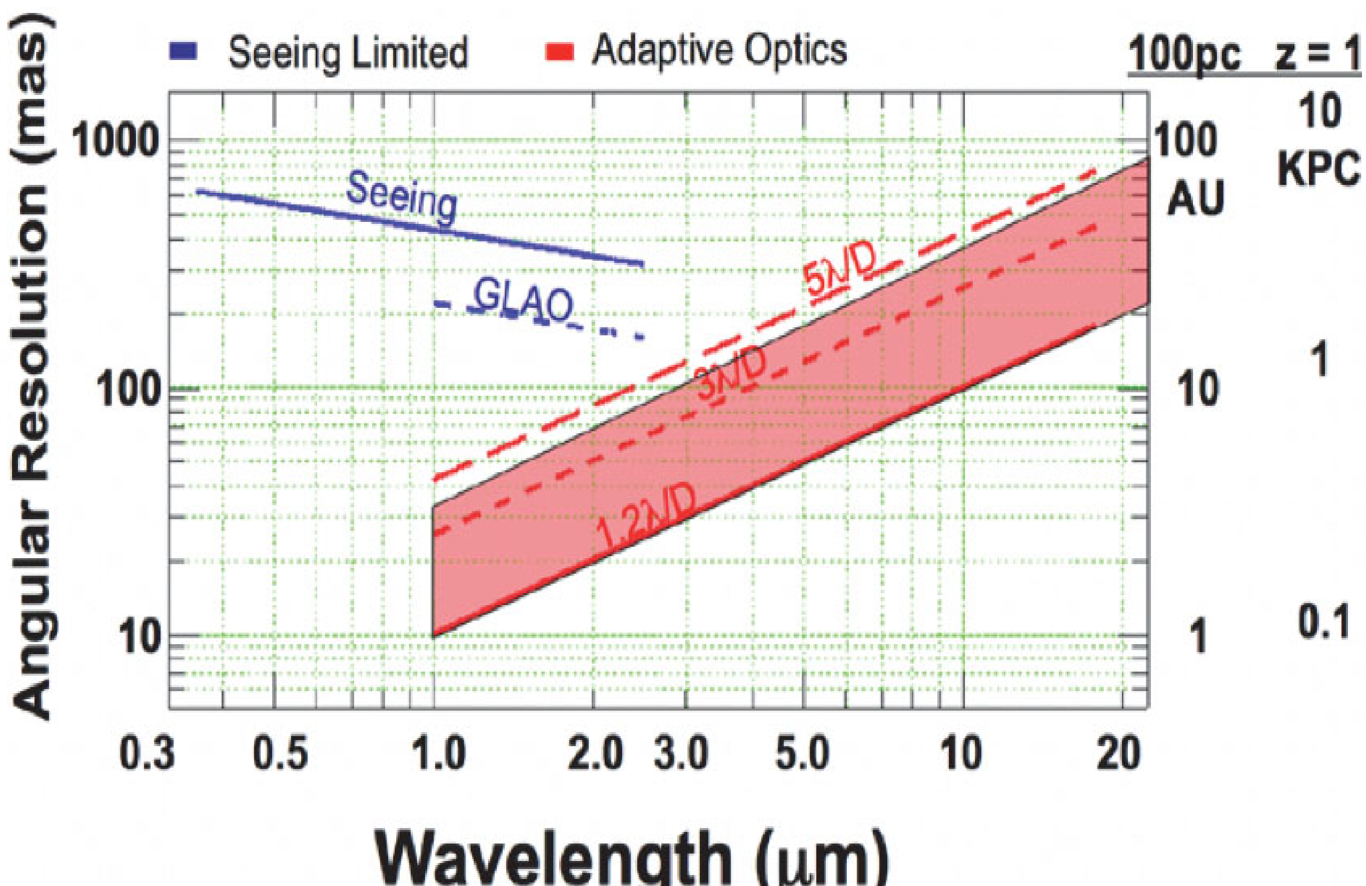




GMT gains in angular resolution

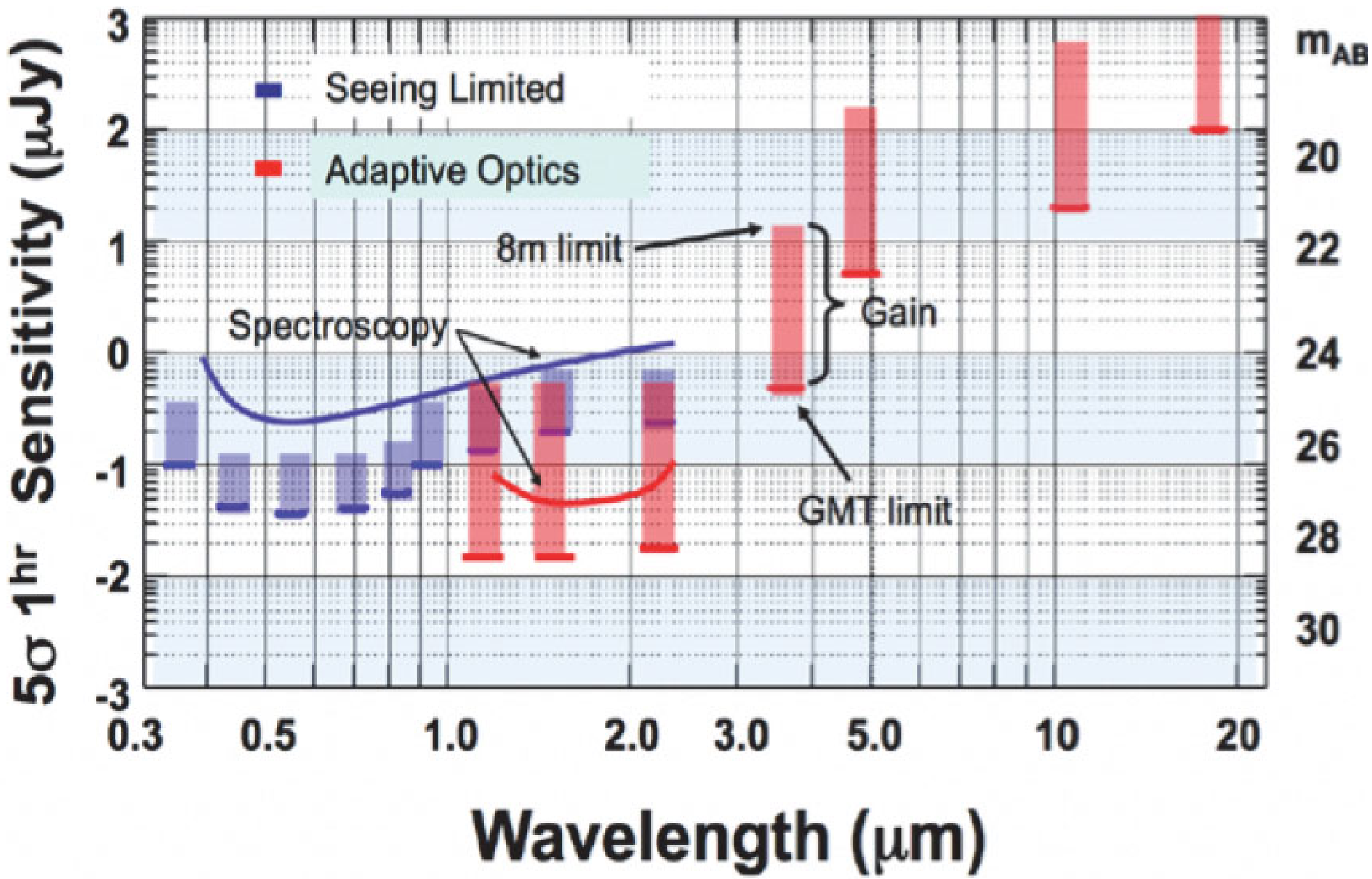
GMT

The gains in angular resolution of GMT+AO relative to 8m+AO – top of range is 8m diffraction limit and bottom is GMT diffraction limit (defined by 1.2λ/D Rayleigh criterion); dashed lines show GMT's 3 and 5 λ/D resolution for contrast limited cases (e.g. exoplanet around bright star); seeing-limited and GLAO resolutions do not scale with aperture



GMT gains in sensitivity

GMT's imaging sensitivity relative to that of an 8m telescope for a 5σ detection in one hour – top of range is 8m sensitivity and bottom of range is GMT sensitivity for natural seeing and adaptive optics; also spectroscopic sensitivity curves



GMTIFS science

GMT

- Extra-solar Planets
- Stellar Populations
- Chemical Abundances
- Black Hole Growth
- Galaxy Assembly
- Cosmological Physics
- First-Light and Reionization

GMTIFS
high spatial resolution
imaging & spectroscopy

GMTIFS science & technical reqs

GMT

Science Application	λ range	λ/Δλ	Notes
Internal structure and dynamics of distant galaxies	1-2.5 μm	5,000	Kinematics, line widths, abundances, star formation rates [LTAO coarse pitch]
Black hole masses and AGN physics	1-2.5 μm	5,000	Emission line kinematics, bulge velocity dispersions, line ratios [LTAO fine pitch]
Young stellar objects	1-2.5 μm	5,000	Outflows, line profiles, excitation levels [LTAO fine pitch]
IMF in dense star clusters	1-2.5 μm	5,000	Line indices, velocities [LTAO fine pitch]
SNe and GRB spectroscopy	1-2.5 μm	5,000	SNe and GRB redshifts, SNe physics, reionization studies [LTAO coarse pitch]
Technical Parameter	**Requirement**	**Goal**	**Notes**
Wavelength range	1-2.5 μm	0.9-2.5 μm	
Spectral resolution	R > 3,000	R > 5,000	Resolution for fine spatial scale
Spatial resolution element fine pitch	≤ 10 mas	–	
Spatial resolution element coarse pitch	≥ 30 mas	50 mas	
Field of view fine pitch	1 $arcsec^2$	1″ x 1″	
Field of view coarse pitch	7 $arcsec^2$	3″ x 3″	
Image quality	Diffraction-limited	–	
Throughput	≥ 20%	–	Exclusive of atmosphere, telescope, and slit losses
Imaging mode	–	Full LTAO field	Optional

GMTIFS key science cases

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Science requirements

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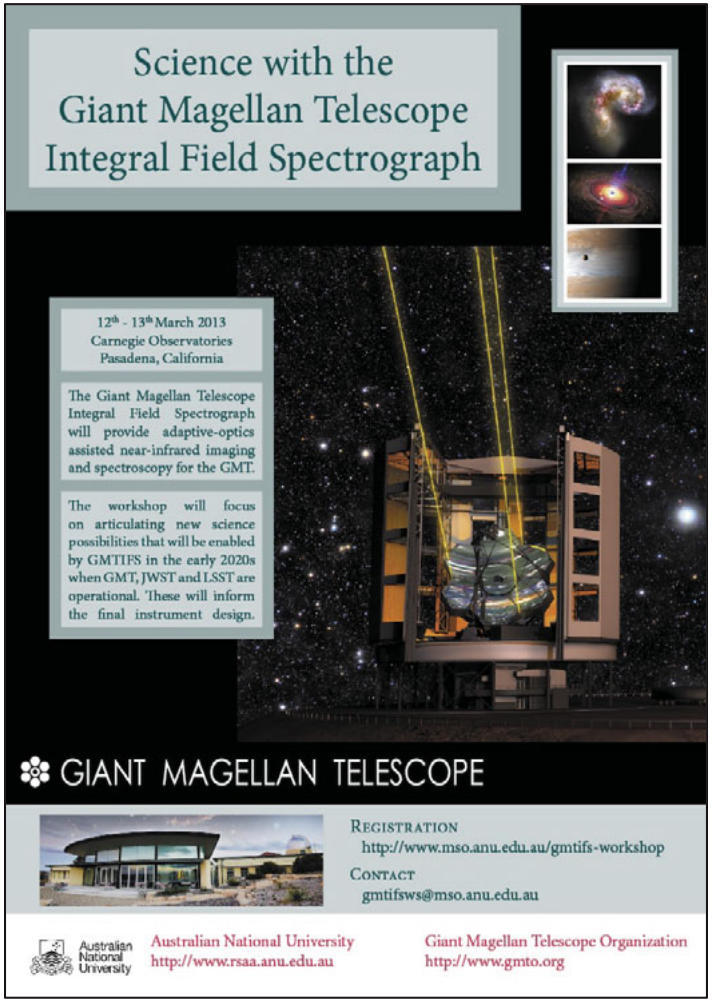
- Explore science cases that push boundaries of instrument technical specifications – challenging requirements selected
- Some components are a bit arbitrary:
  - Sample sizes (how many sources for statistical significance?)
  - Signal-to-noise levels (e.g. is S/N~20 or S/N~30 required?)
- Margin of safety
  - Requirements expressed with low margin of safety built in
  - E.g. the sky coverage assumes average statistics - should a higher quartile be considered?
- Some design solution assumptions necessary/unavoidable
  - Required to inform even the most abstract cases
  - Some assumptions need verification

Science team review

GMT

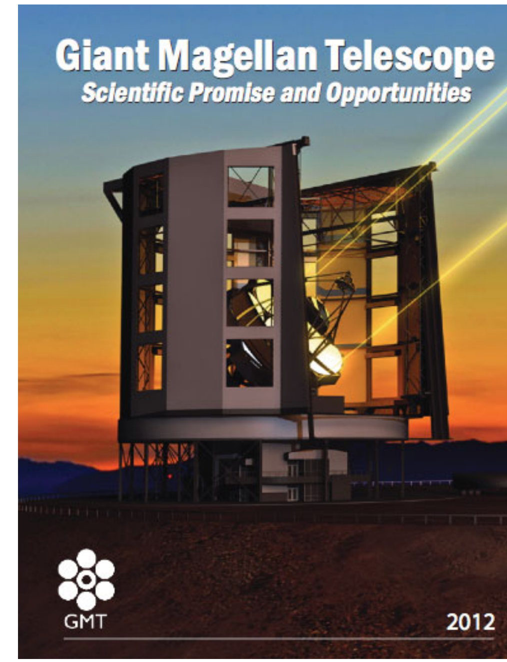
- Major science topics of the GMTIFS science case are aligned with the overall GMT science case
- Conceptual Design Review document
  - Reviewed by community & key experts
  - Confirmed key elements of preliminary instrument design
  - Highlighted additional specifications
- Pasadena workshop in March 2013
  - Confirmed span of science cases
  - Feedback introduced new twists
  - Ruled out some things on the wish list
- Science case will continue to be revised, developed and reviewed

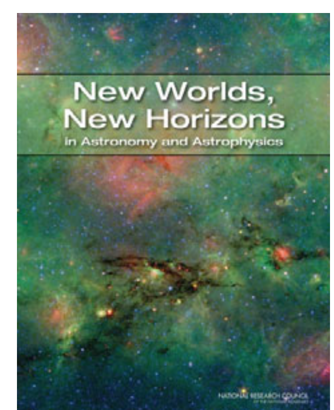


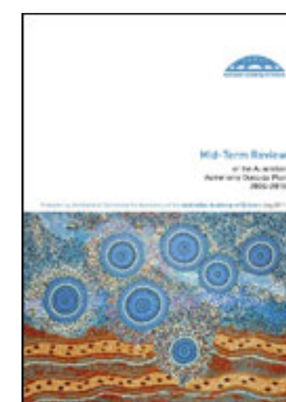
GMT + GMTIFS science

GMT

- Galaxy assembly & evolution
  - Dynamic and morphological studies
  - Black-hole growth
- First light & reionization
  - Direct spectroscopy of first-light galaxies
  - Gamma-ray burst IGM probes
- Stellar populations & chemical evolution
  - Resolved stellar populations in nearby galaxies
- Transient phenomena
  - Gamma-ray bursts, supernovae
- Formation & properties of exoplanets
  - YSO spectroscopy
  - Angular differential imaging (ADI)
- Dark matter, dark energy & fundamentals



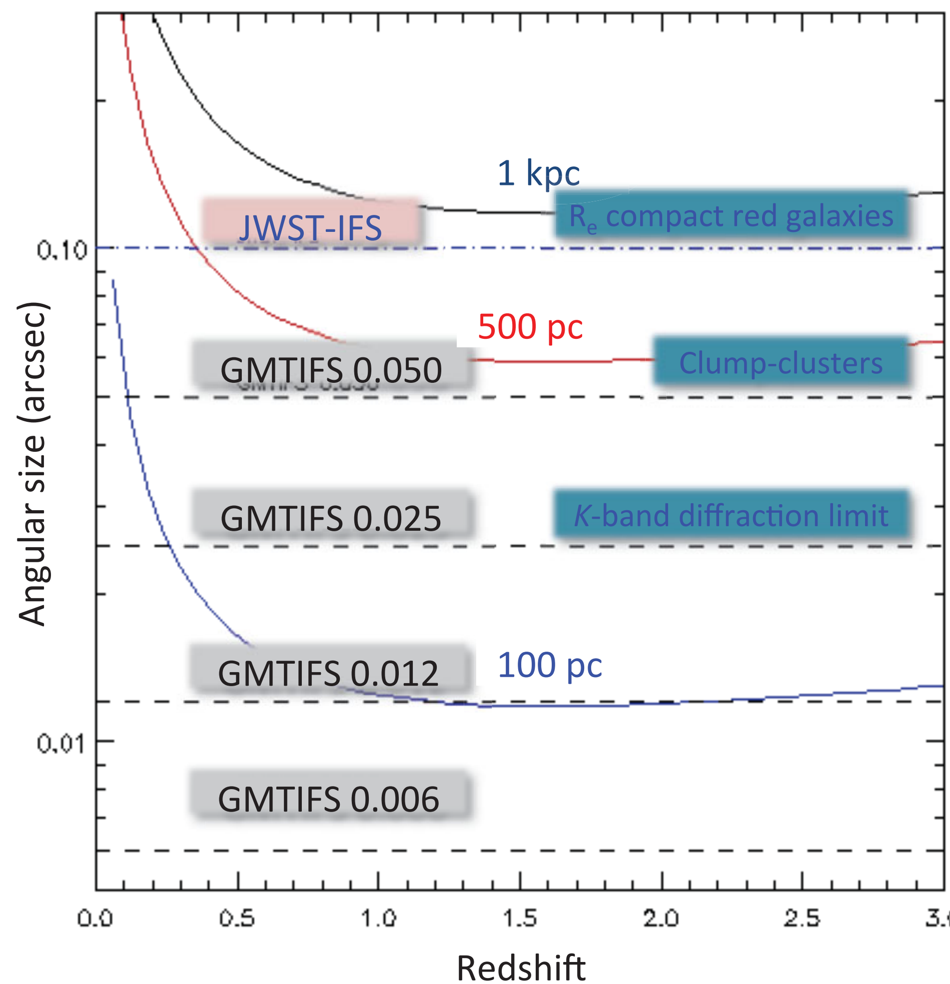




Key science cases

GMT

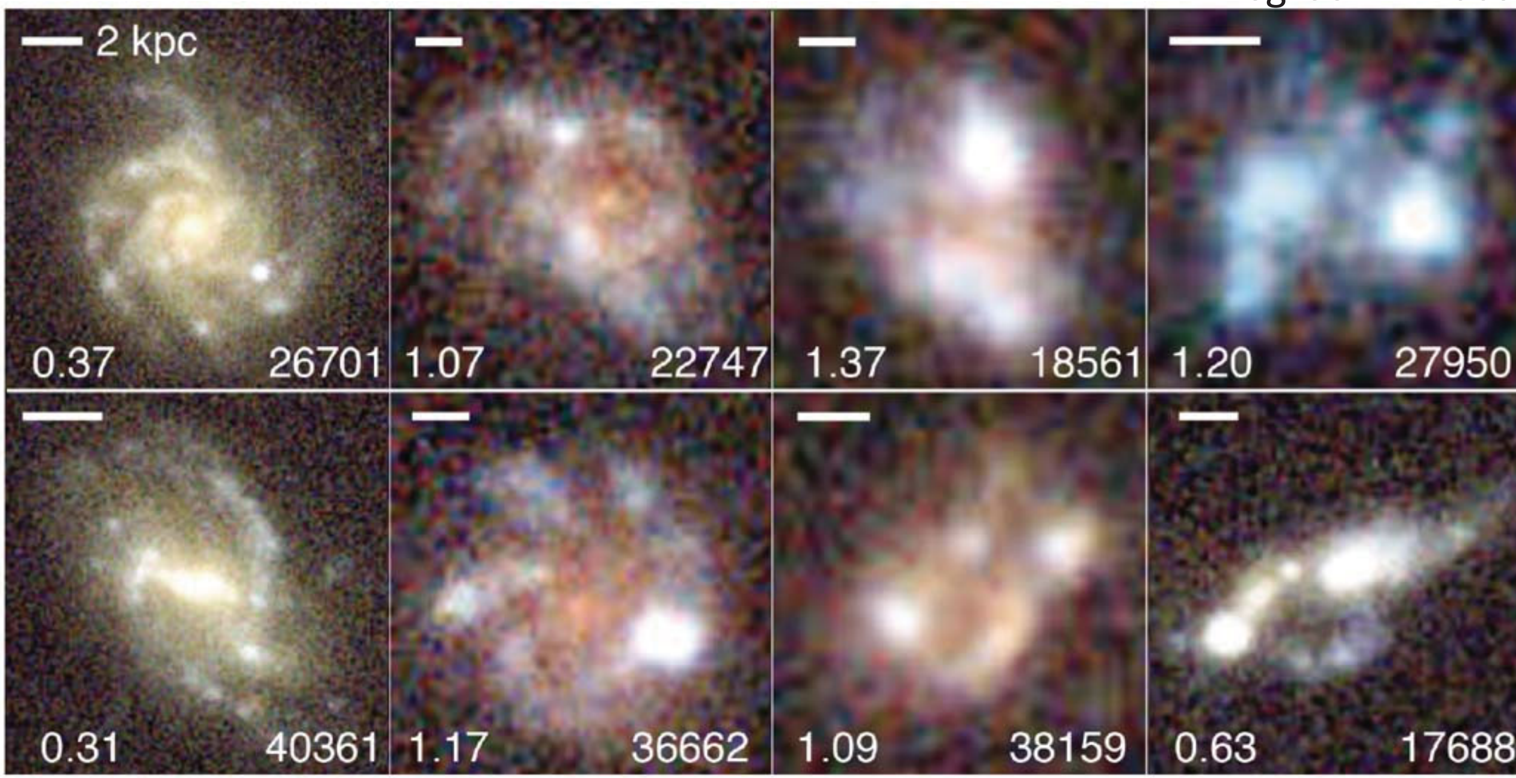
- The key science cases are a subset of the full set of science cases and define the operational parameter space of GMTIFS
- Galaxy Evolution
  - Dynamical – IFS
  - Morphological – imager
- First Light/Reionization
  - The first galaxies – IFS
  - Gamma-ray bursts - IFS
- Black holes
  - Most-massive BH - IFS
  - Intermediate-mass BH - IFS
- Exoplanets
  - Direct detection – imager



Formation of disk galaxies

GMT

Elmegreen++ 2009

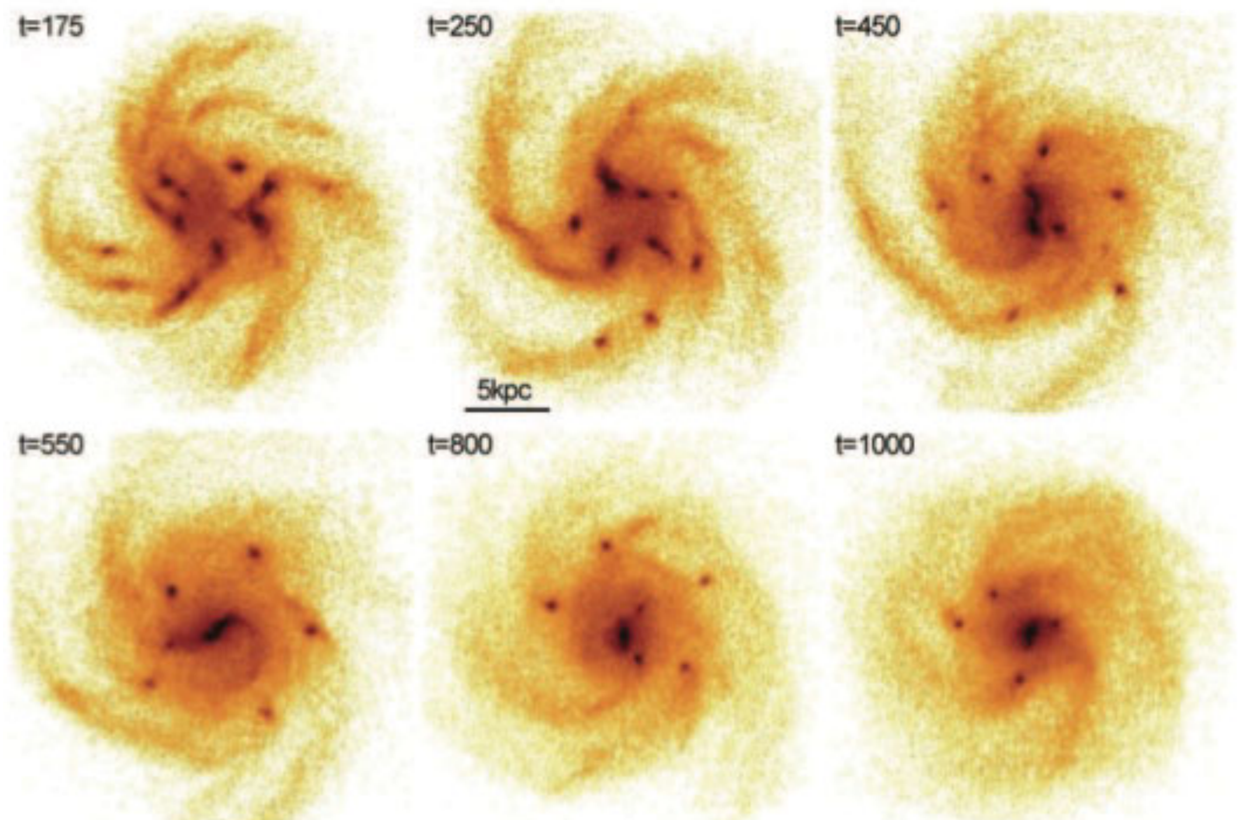


Mature Spiral ← Flocculent Spiral ← Early Bulge ← Clump Cluster

Mode of formation

GMT

- Cold accretion and disk fragmentation?
  - Cold gas accretes onto a turbulent disk
  - Fragments into a long- lived clump
  - Turbulence supports gas against collapse leading to larger clumps
  - Gas dynamical interaction leads to clump migration, forming secular bulge

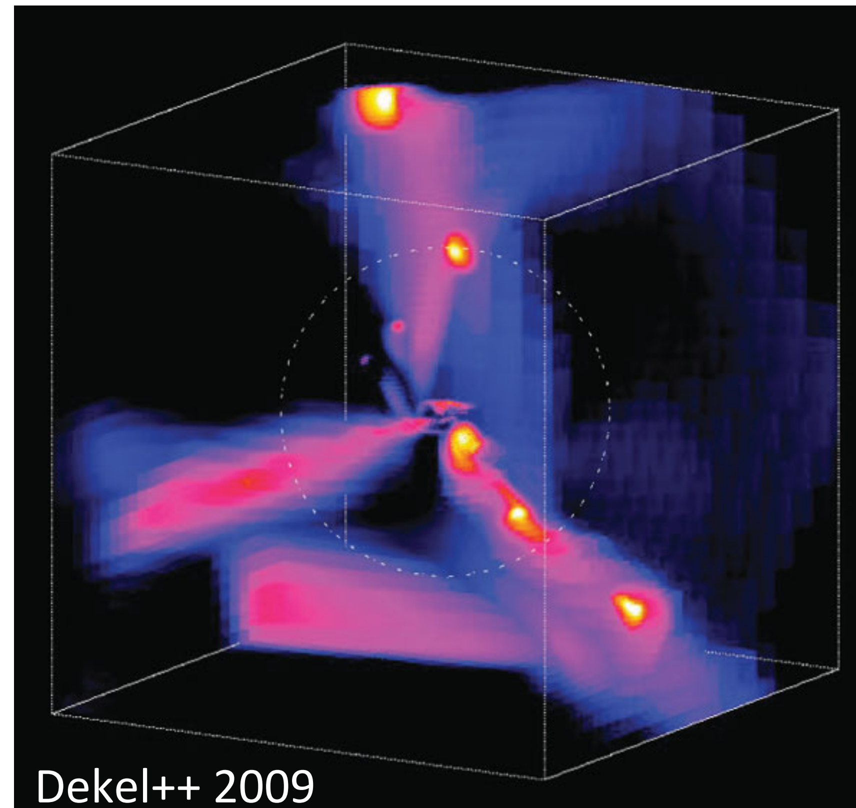


Elmegreen++ 2008

Cold flows or simply feedback?

GMT

- How can we tell?
  - Steady infall with or without moderately pulsed perturbations provides steady impulse to stir the gas disk
  - Leads to larger fragmentation scales and higher-mass clumps of star formation

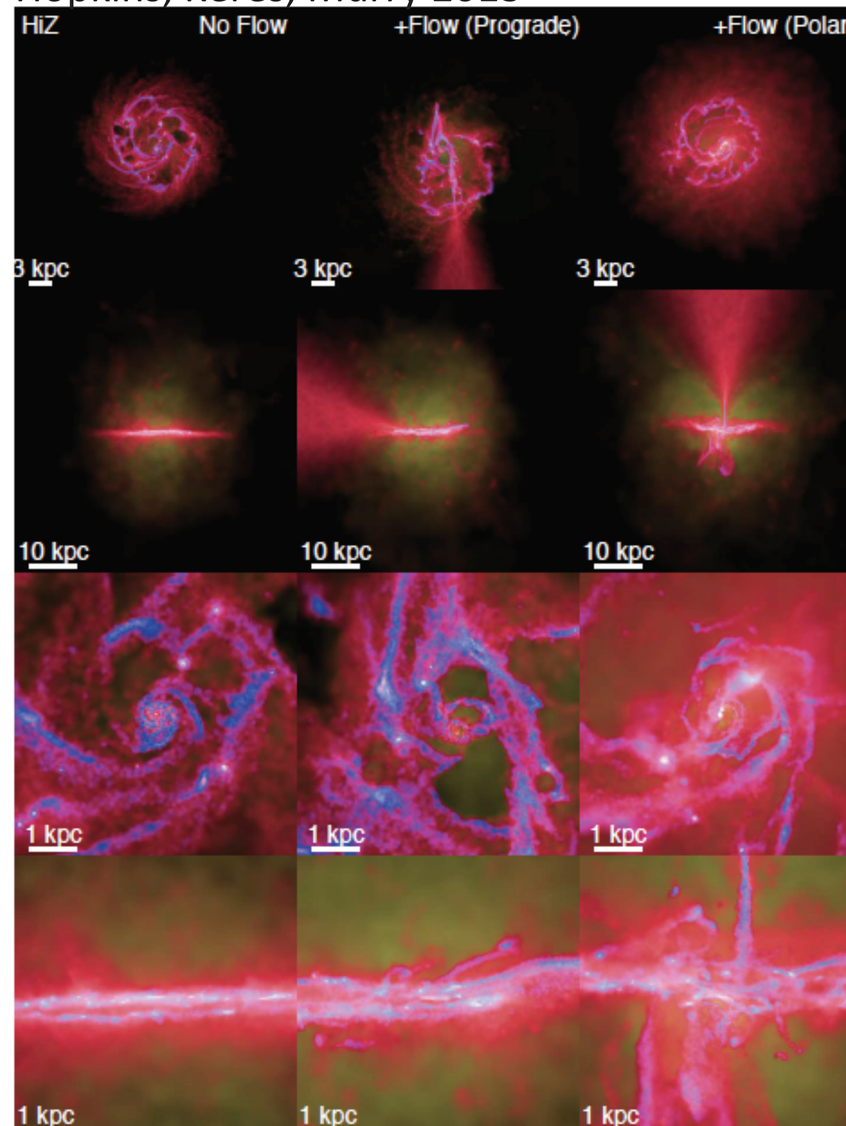


Cold flows or simply feedback?

GMT

- Gas inflow essential to maintain observed star-formation rates over extended periods
- Geometry of flow has little impact
- Star-formation feedback seems to drive fragmentation and clumping on its own
- What are the boundary conditions for feedback?

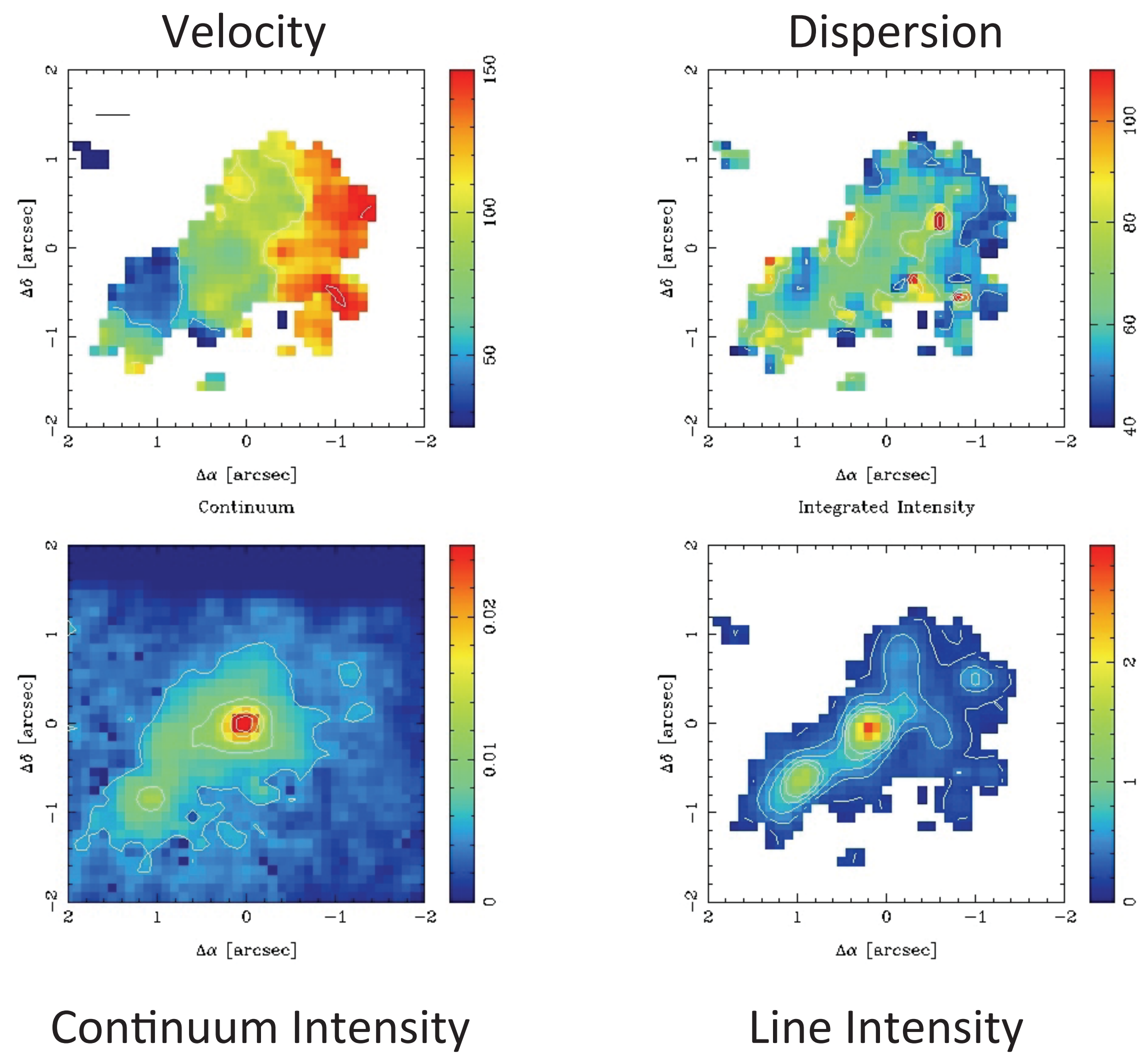
Hopkins, Keres, Murry 2013



Keck/OSIRIS Pa-α – local analogue

GMT

- ❑ Natural seeing (1”) IFS indicated a high dispersion disk
- ❑ Keck/OSIRIS + AO observations confirm…
  - ▶ high dispersion
  - ▶ clumped star formation
  - ▶ but disk rotation less clear



Questions and requirements

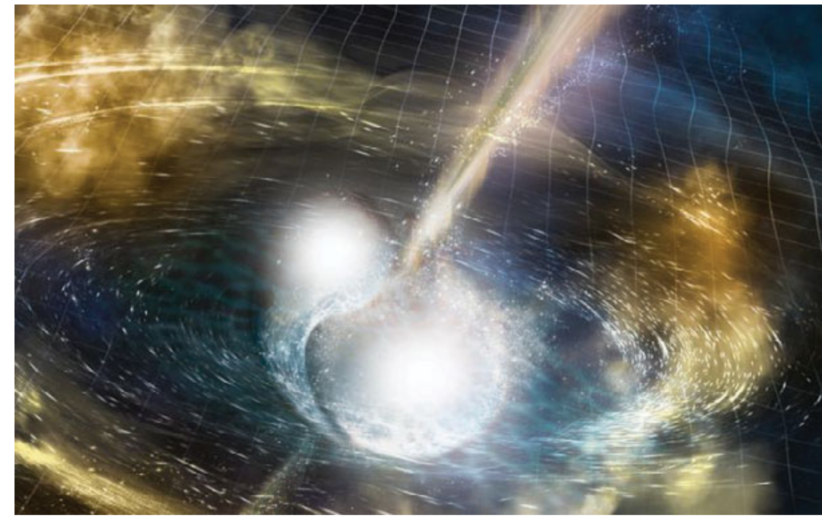
GMT

- What are the clump lifetimes?
  - Are they short-lived structures?
  - Associated with significant mass concentrations?
- What is the physics of their high dispersion?
  - Local pressure support?
  - Stellar winds and SNe?
- Ionization and metallicity diagnostics
  - High S/N necessary for secondary lines
  - ELT-AO resolution to overcome blending
- The key is resolving the structures in question
  - Spatial resolution required is <500 pc (<25-50 mas)
  - Spectral resolution required is $R > 3000$ (<100 km s^{-1})

Stellar deaths

GMT

- ❑ Supernova and kilonova explosions release enough light and energetic particles to be seen across universe
- ❑ GMT's sensitivity gains will reveal the *onset* of stellar explosions, when only faint outer layers are visible, and the *conclusion*, when inner structure and composition of the star is revealed

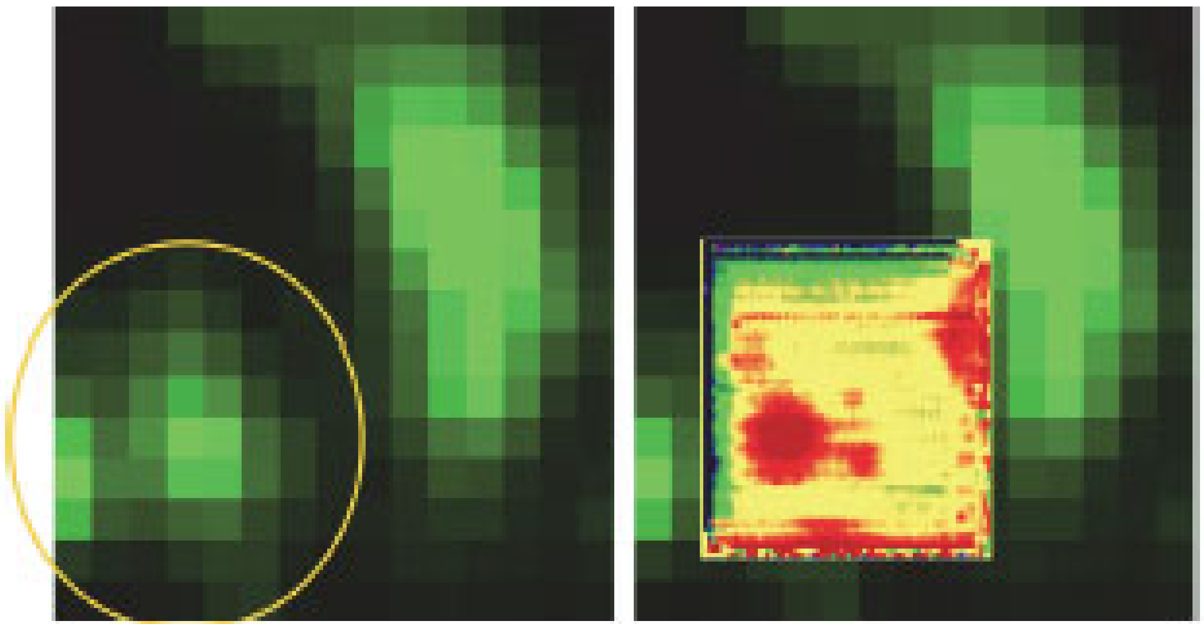


- ❑ GMT will address this with its high sensitivity & broad spectral coverage
  - ▶ Detect NIR spectral features of H, He, Fe-peak elements & molecules
  - ▶ High velocities ⇒ broad spectral lines ⇒ modest spectral resolution
- ❑ GMTIFS' high angular resolution will separate the light around the dying star from the background light of the parent galaxy
  - ▶ With up to 0.01" resolution at 1μm, can probe host galaxies of transients at high spatial resolution (~50 pc) when universe only 600 Myr old

Environments of SNe

GMT

GMT's high resolution will reveal the galactic environments of distant SNe



Optical image of a SN site; image is 220 pc on a side; SN is at centre of the 2" radius circle

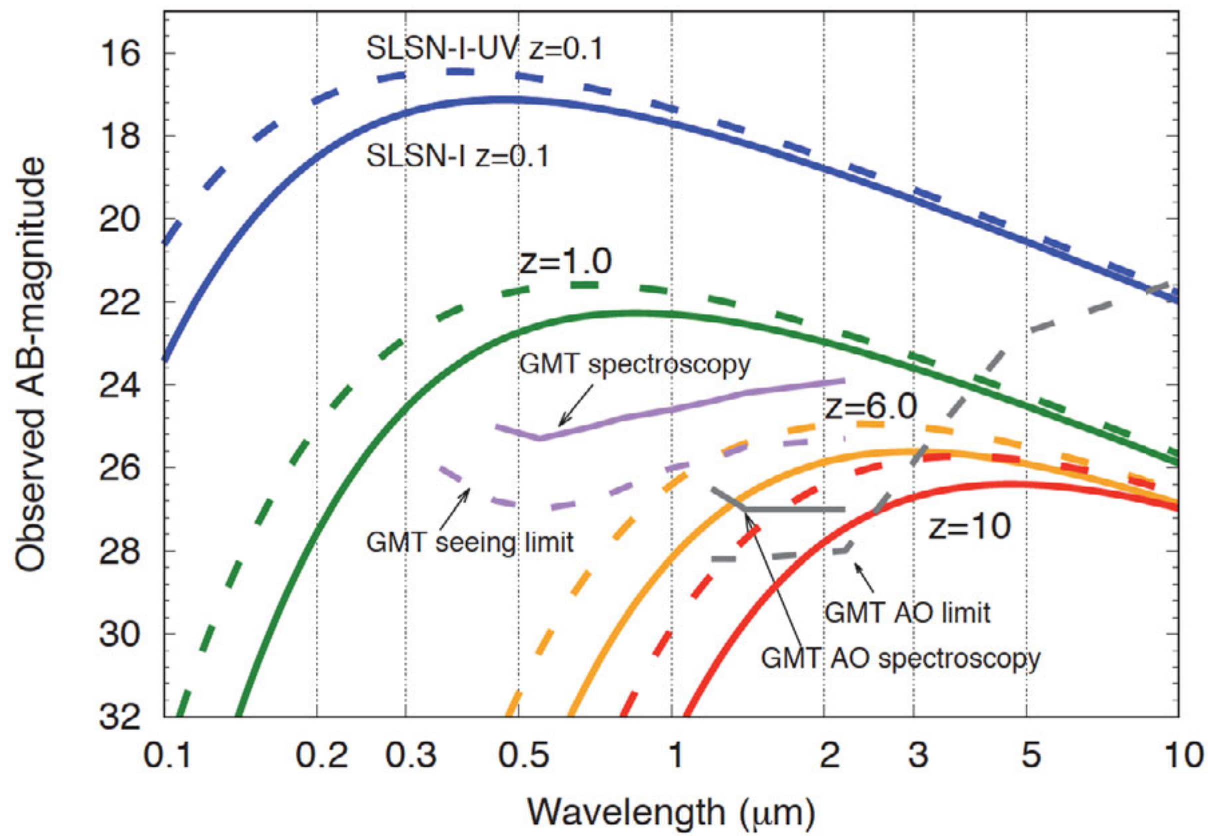
Same, but with higher-res NIR image superposed; the single cluster is resolved into multiple clusters

GMT will offer 17x more spatial resolution & 80x more sensitivity (Kuncarayakti++ 2015)

Superluminous supernovae

GMT

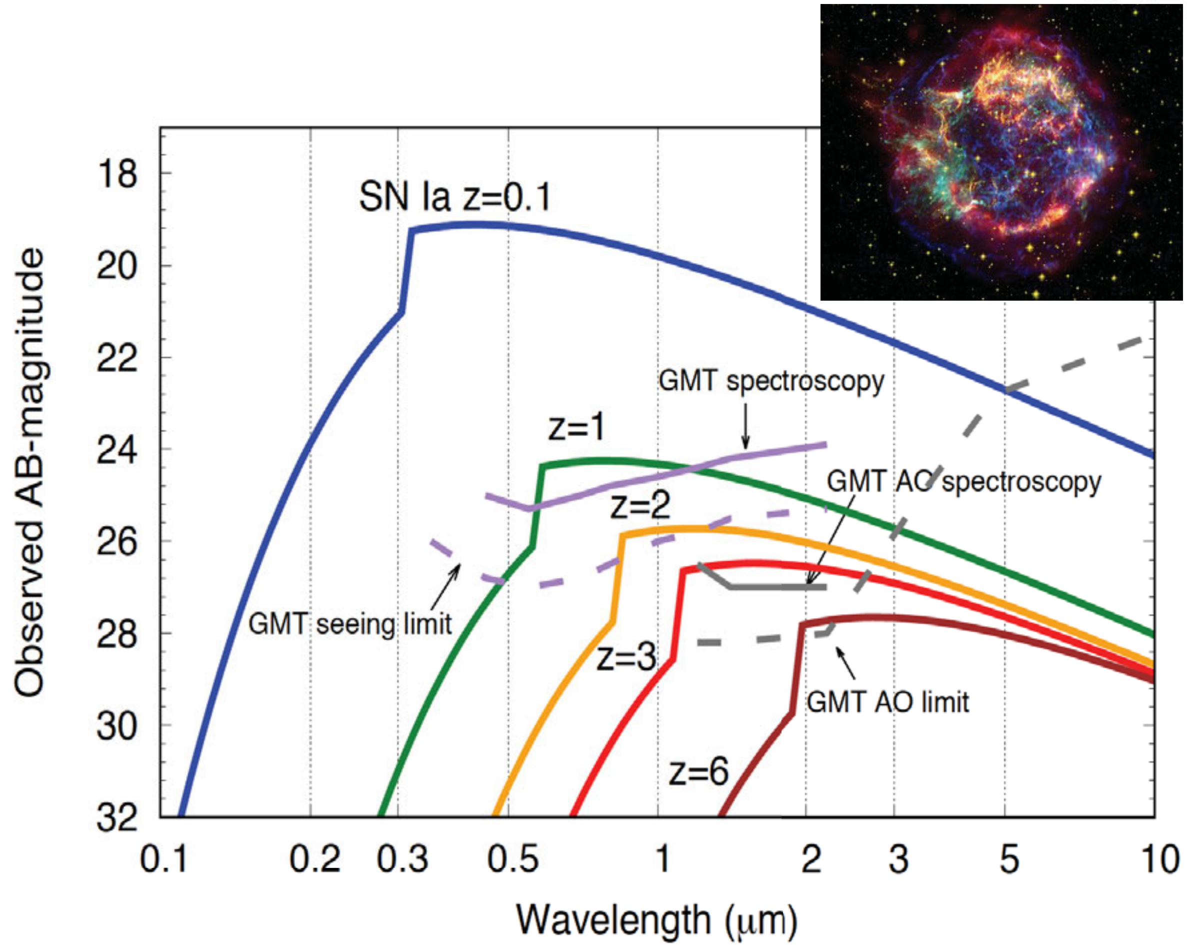
- GMT can detect superluminous supernova (SLSN) among the first stars forming at the end of the cosmic dark ages
- With AO at 2 μm, GMTIFS can observe spectra for SNSL out to z = 6-10 (depends on the photospheric temperature) and images at z >10



Predicted AB magnitudes of SLSN-I with wavelength at various redshifts; solid lines for a model with photospheric temperature of 12000K, dashed lines for 15000K. *[Credit: J. Vinko]*

Young supernova remnants

- Stellar populations in galaxies at z = 3-5 are the right age to produce SN Ia from low mass stars in binary systems
- Without AO, GMTIFS can get spectra of SN Ia to z~1 at 2 μm
- With AO, spectra could be obtained at z~3 and imaging could extend to z~6



Predicted AB magnitude of SN Ia with wavelength at various redshifts; note the steep drop of flux to the blue at each epoch. *[Credit: J. Vinko]*

Massive galaxy formation & evolution

GMT

GMTIFS

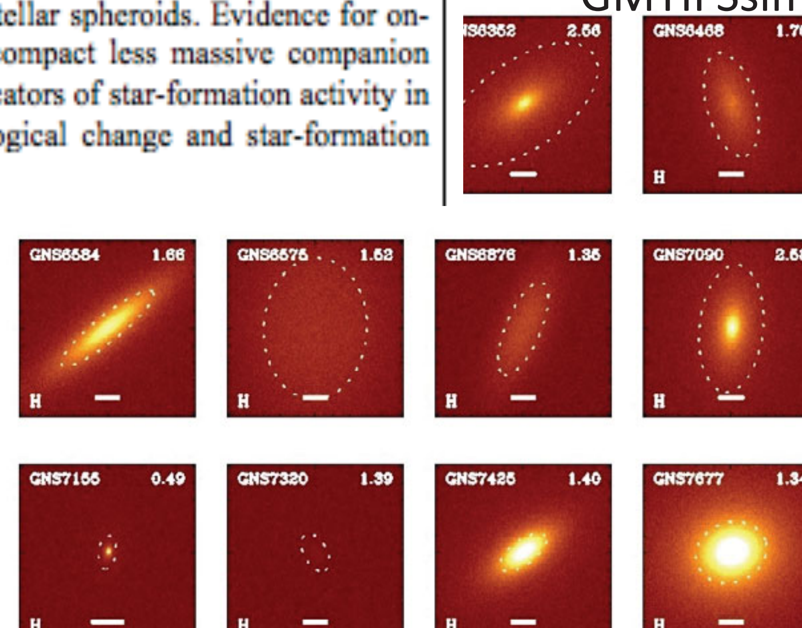
GMTIFS-SCI-TPD-0011
Created: 19 November 2012
Last modified: 30 January 2014

Title:	**Formation and Evolution of Massive Galaxies**
Originator:	Peter McGregor (ANU)

Summary of Scientific Objectives:

The GMTIFS Imager will be used to probe how early massive galaxies formed at $z > 3$ and evolved to larger sizes and different shapes over cosmic time. The Imager will be used to study the structures of early massive galaxies at 3× higher angular resolution than possible with JWST. Effective radii and Sersic shapes of their high-surface-brightness central regions will be measured. Bulge/disk deconvolution will be used to trace the transition from pure disk to developing stellar bulge components to pure stellar spheroids. Evidence for on-going minor mergers at $z \sim 2$ will be sought through the detection of compact less massive companion galaxies. These morphological transitions will be compared with other indicators of star-formation activity in order to determine the (possibly separate) mechanisms driving morphological change and star-formation quenching at early times.

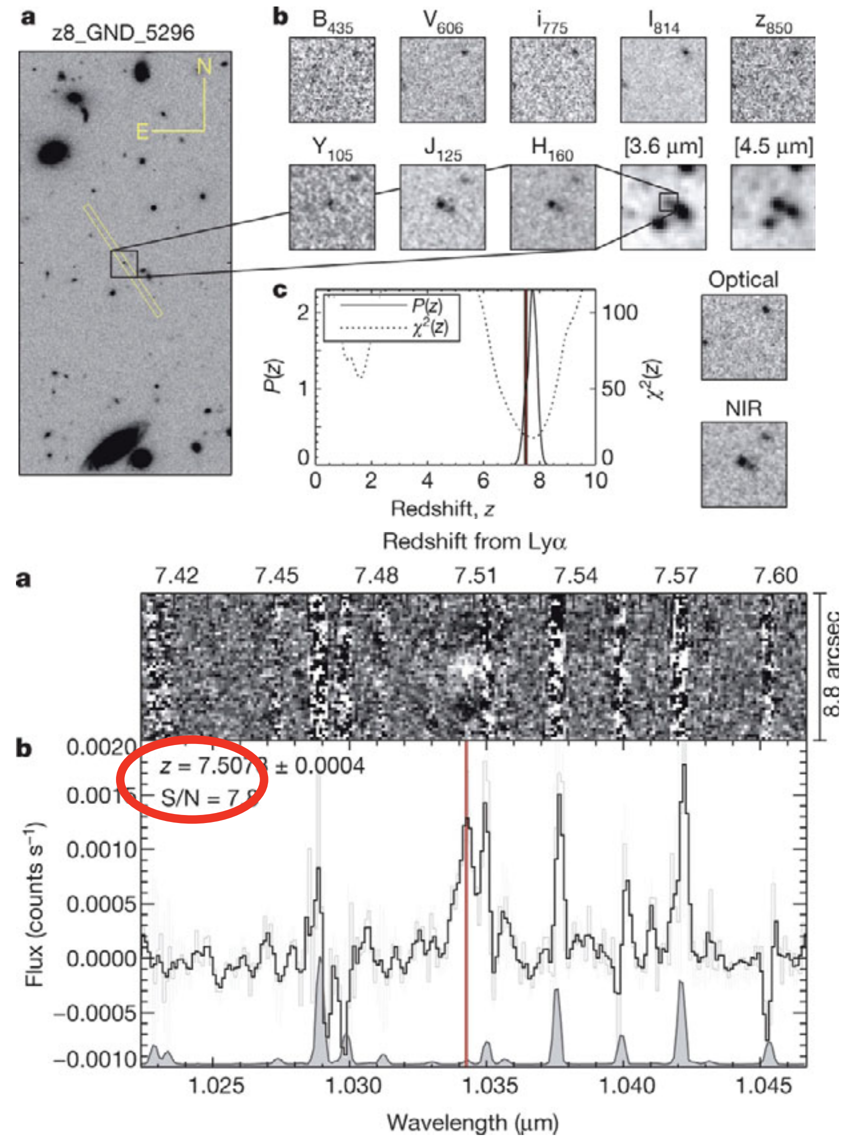
GMTIFSsim



First-light galaxies

GMT

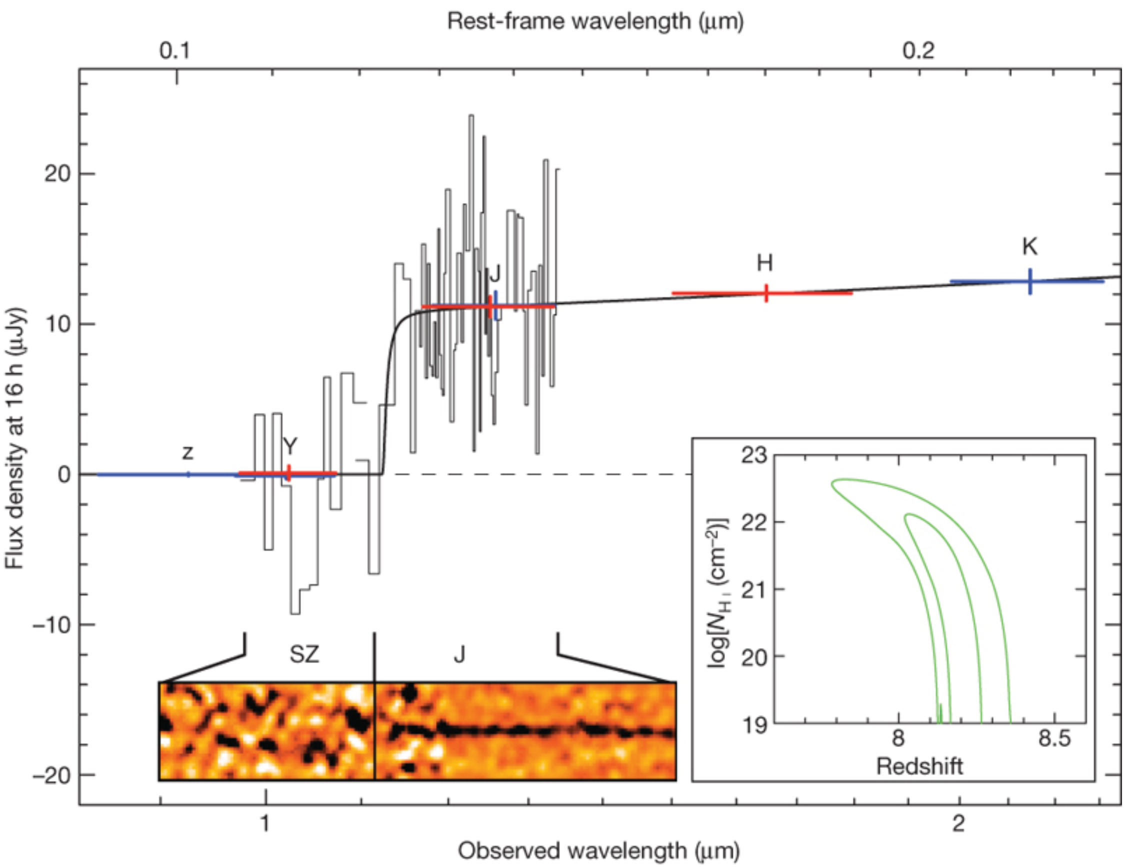
- Current generation observations can probe formation of *super-luminous* galaxies at high redshift
- But GMTIFS will probe to 1-10 L*
- Competitive with JWST for isolated sources, due to read noise limits
- Real power is for extended lenses
  - Requires extensive sky coverage
- Lyα emission is historic indicator
  - Not always present due to resonance absorption
  - Other lines are intrinsically weaker (but stronger if low metallicity)
  - Broad wavelength coverage crucial



Finkelstein++ 2013 Nature, 502, 524

GRBs as probes of the IGM

GMT



Tanvier++ 2009 Nature 461 1254

GRB @ z~8.2

K(Vega)~18 @ 1800s post-outburst

K(Vega)~20 @ 17.4h post-outburst

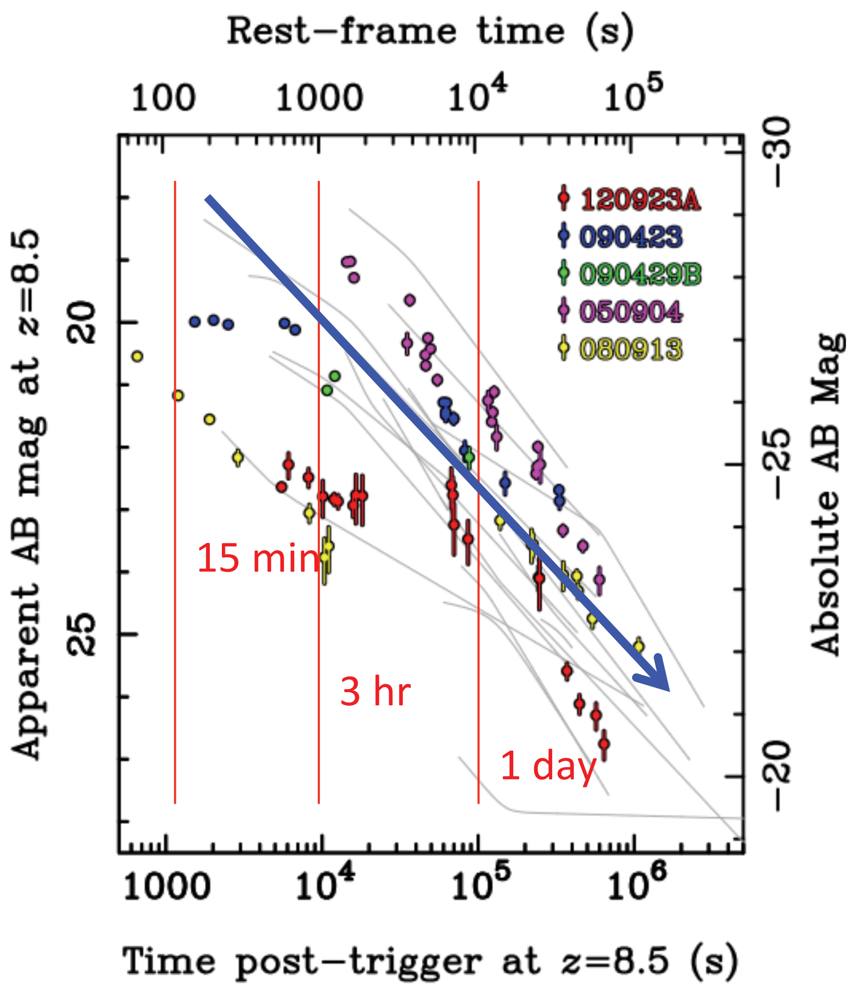
GMTIFS

K(Vega)~18
S/N ~ 50 per pixel @ R~10,000

K(Vega)~20
S/N ~ 15 per pixel @ R~10,000

GRBs as probes of the IGM

GMT



Tanvir++ arXiv:1307.6156

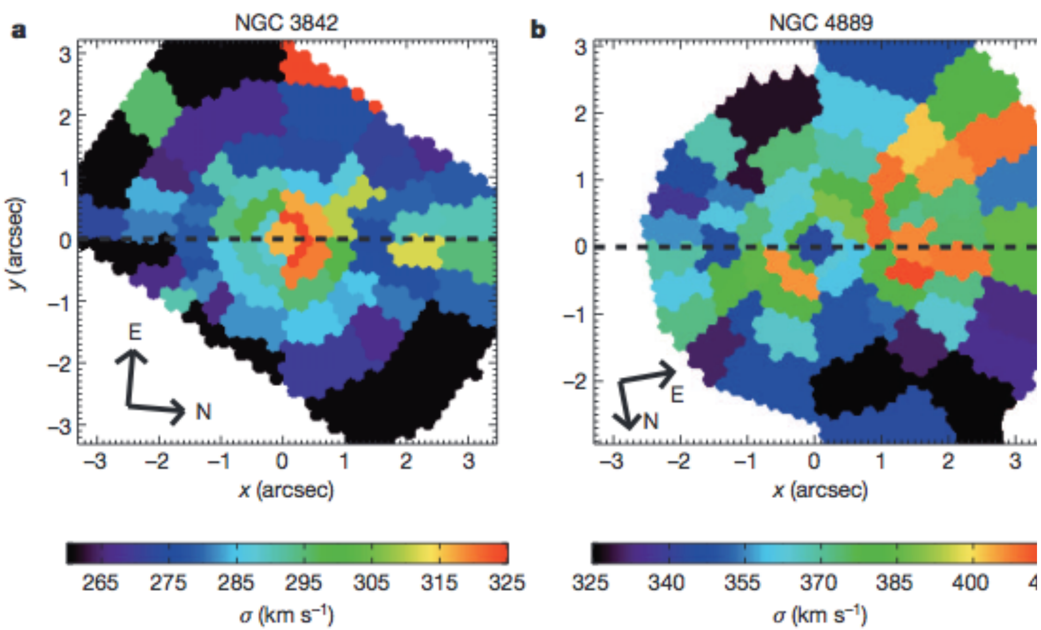
The key requirements are…

- Prompt response
- Sky coverage
- High resolution
  - HI : R < 3000
  - IGM : R~10,000

Black holes near & far

GMT

Schwarzschild modeling of the most massive black holes

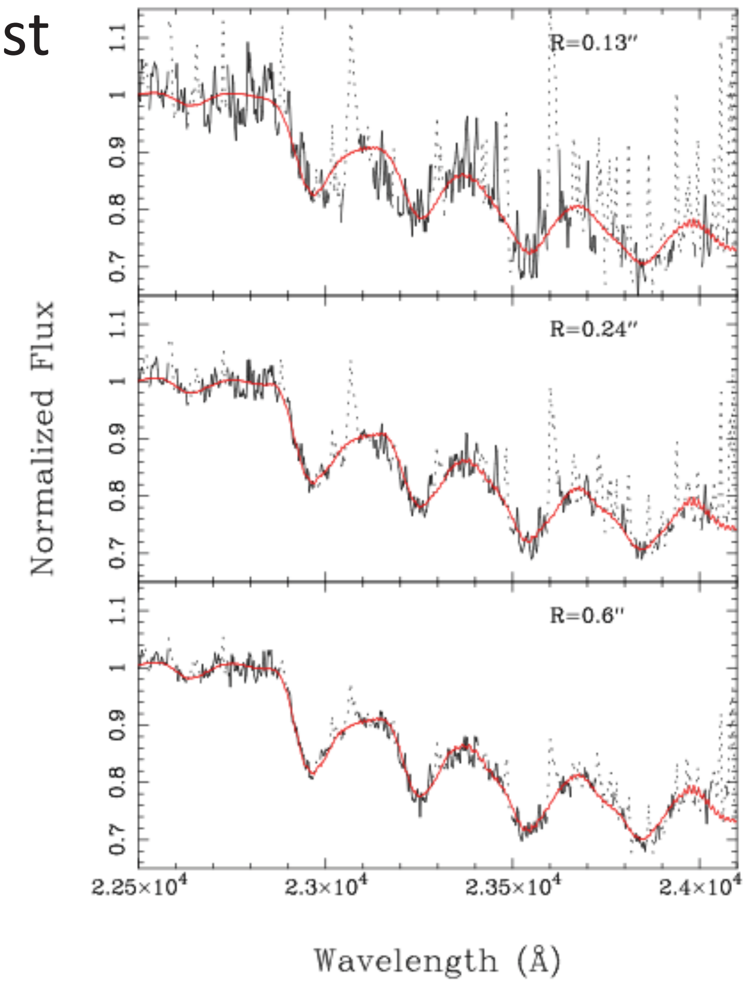


McConnell, *et al.* 2011

GMOS+OSIRIS+VIRUS-P

NGC 3832: 98 Mpc, 9.7 x 10^9 M_{sun}

NGC 4889: 103 Mpc, ~10^{10} M_{sun}



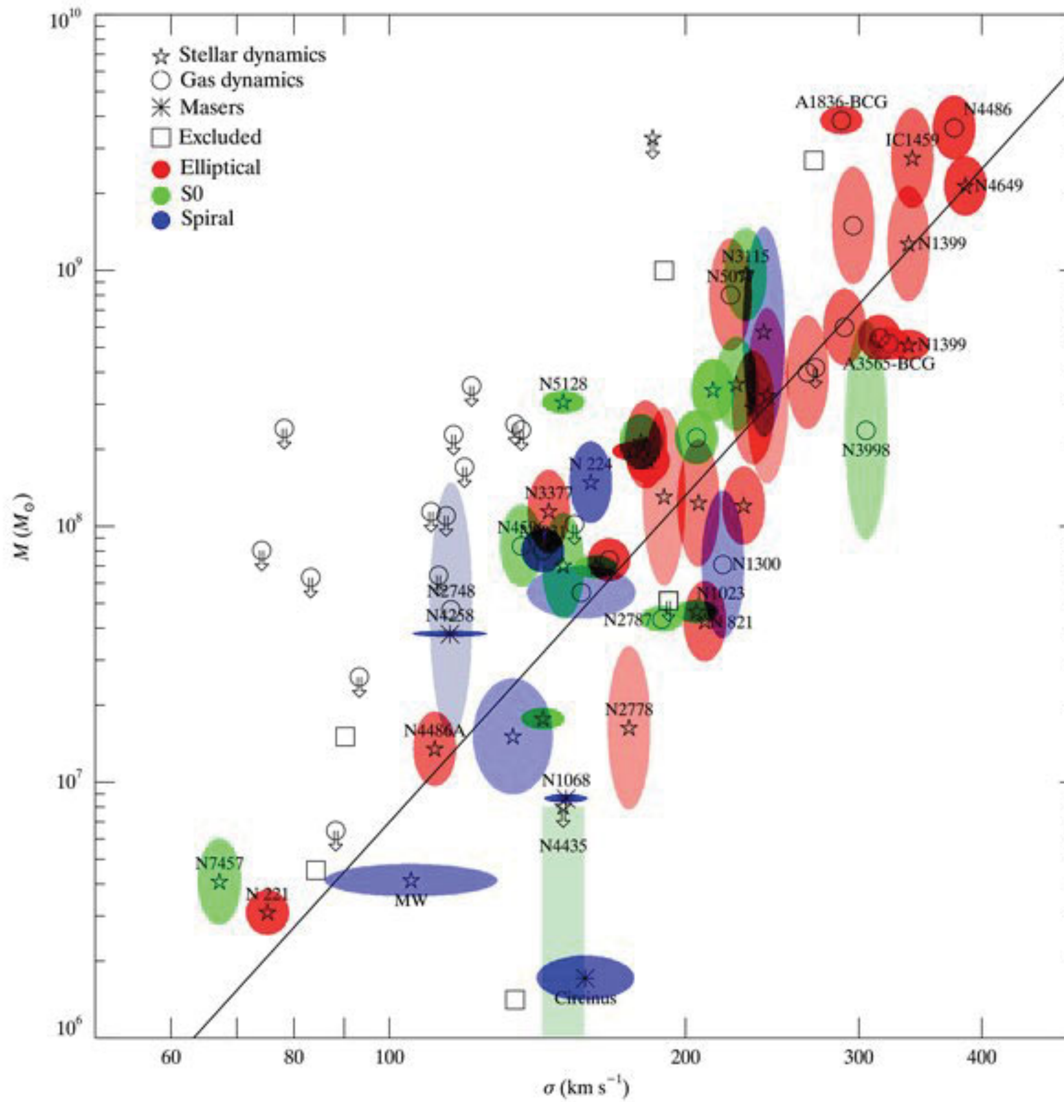
Gebhardt *et al.* 2011, NIFS

M87: 16.4 Mpc (Virgo), 6.6x10^9 M_{sun}

Black holes near & far

GMT

Highest mass sources appear to depart from the M_{BH}–$\sigma_\star$ correlation



Gultekin++ 2009, ApJ, 698, 196

Role of GMT/GMTIFS

- Spatial resolution is key
  - Move beyond Virgo/Coma/Fornax clusters
  - Volume increases rapidly with distance
  - Trade-off between image quality and sky coverage
    - High image quality allows greater distance (more volume)
    - Better sky coverage allows closer targets (better data)
  - Need to work at short wavelength
    - Once ^{12}CO(2,0) lost, we need CaII triplet
- Modest spectral resolution requirements
  - Template cross-correlation removes most artifacts
- Good stability required
  - Long integrations over multiple nights
  - Good cross-calibration and template library stability

Black holes near & far

GMT

What about intermediate mass systems?

$$R_{sph} = 1.18 \times 10^{-3} (M_{BH}/M_{sol})^{0.506} \text{ pc}$$

$$\theta_{sph} = R_{sph}/D_{Ang}$$

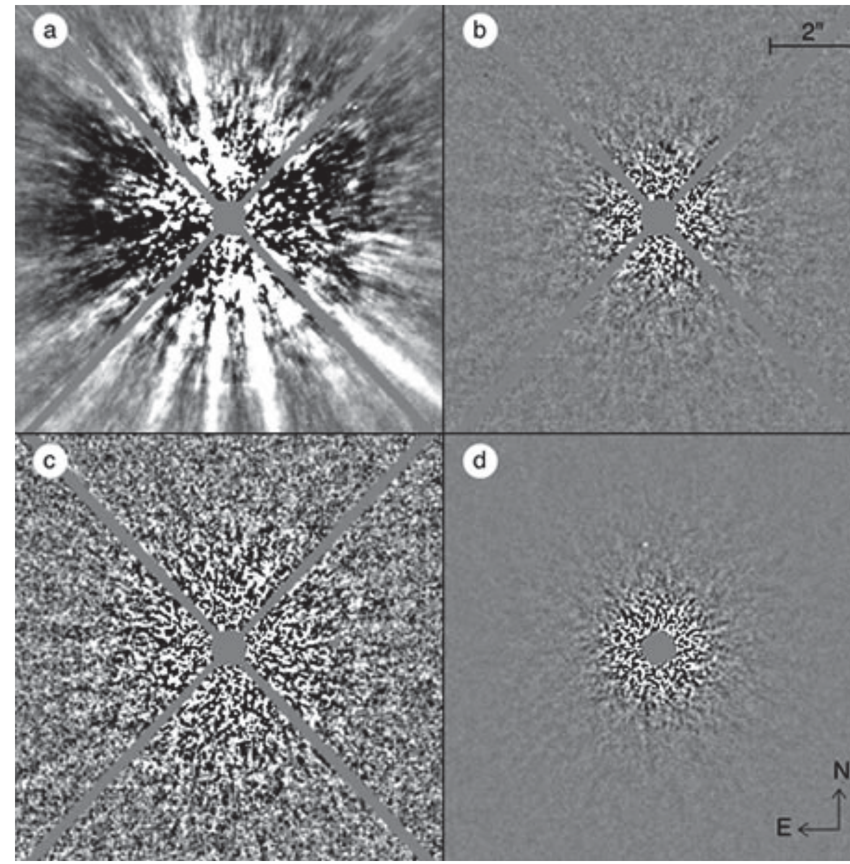
M_{BH}/M_{sol}	R_{sph} pc^{-1}	θ_{sph}	
		2 Mpc	10 Mpc
1×10^4	0.125	12 mas	2.6 mas
1×10^5	0.4	43 mas	8.2 mas
1×10^6	1.28	132 mas	26 mas

To anchor the low mass end of M_{BH}–$\sigma_\star$ relation, we need to access a larger volume than accessible to 8m AO; requires spatial resolution *and* spectral resolution

Angular differential imaging (ADI)

GMT

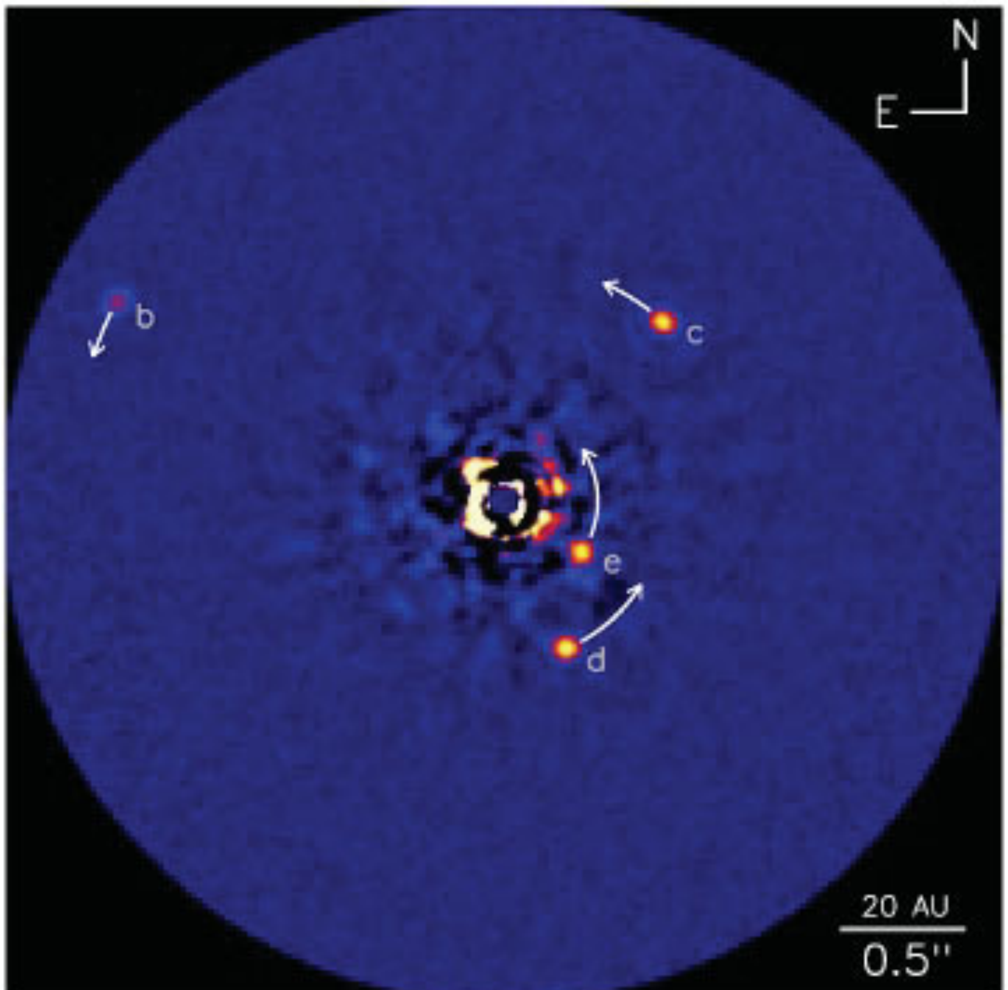
- First measurements performed with non-optimized AO systems
- Defined parameter space for later well-optimized instruments
- GMT/GMTIFS might be able to do same early science prior to new set of optimized systems
  - Likely won't push the inner radial boundary
  - Light gathering power probes fainter systems at large radii
    - Direct spectroscopy



http://www.gemini.edu/index.php?q=node/256

First generation ADI measurements

GMT



HR8799 NIRC2-Keck
Marois *et al.*, 2010,
Nature, 468, 1080

NIRC2 is just occulting spots on an AO camera

GMTIFS science requirements

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Science requirements flow-down

GMT

- Galaxy evolution
  - Workhorse programs for IFS and imager
  - Drives basic operational requirements
- First light & reionization
  - Challenging sky coverage
  - Target of opportunity model
- Black holes
  - AO precision
  - Spectrograph stability
  - Acquisition procedure
- Exoplanets
  - Operational challenges

Extragalactic requirements

GMT

- Wavelength range
  - Emission line requirements ⇒ broad wavelength range
  - Sensitivity & volume coverage ⇒ intermediate resolution
- Image quality
  - Largely ~8m AO scales
  - High encircled energy (EE)
  - Good sky coverage
    - Interestingly, it's not obvious that >80% coverage is essential
    - Real survey fields are usually not the median statistic
    - Lensing is the big challenge – we want the best lenses
- Observing blocks
  - Good duty cycle requires 2-3 hour observing blocks
  - Acquisition and relative alignment limits are challenging

High contrast requirements

GMT

- Challenges for ADI and spectroscopy…
  - Segmented pupil
    - Bright secondary maxima to large radii
  - Wide range of occultation required
    - Design solution assumed
    - Minimum opacities
    - Angular sizes
  - Semi-transmissive
    - Aids alignment
    - Concern over ghosting impacts sensitivity

Black hole requirements

GMT

- Needs all instrument modes
  - High spatial resolution
  - Wide field of view
    - Lower spatial resolution
  - Excellent relative sensitivity
  - Range of resolutions
  - Imager provides unique data
  - Challenging operationally
    - Duty cycle
    - Acquisition
    - AO requirements

GMT system requirements

GMT

- Deliverable image quality
  - Vibration at GIR
  - Adaptive optics performance
  - Optimal IFS scales for short wavelengths
  - Imager pixel size/field of view
- Sensitivity
  - Mirror coatings
  - Thermal and sky emission
    - Open/closed top end
    - M2 sizing
- Sky Coverage
  - Critical modes
- Tracking
  - ADI exposure times
  - Solar system object restrictions
- Target of Opportunity
  - Triggered ToO
  - Regular monitoring programs
- Operational concepts
  - Acquisition procedure
    - Image quality from repeatability
  - Hand-offs between subsystems

Sensitivity

GMT

- Mirror coatings
  - Minimum reflectivity between recoating
  - Tertiary coating and cleaning
- Thermal emission
  - Top end structure open to sky in *K*, closed off in *J/H* (?)
- No significant tension between requirements affecting sensitivity

Image quality – external factors

GMT

- Operational concepts
  - Target (re)acquisition
  - Minimum observing block
    - Duty cycle and efficiency
- AO performance model
  - What precision do we really need to achieve?
  - Optimal suite of IFS sizes
  - Best Imager pixel scale and field of view
- Atmospheric Dispersion Compensation (ADC)
  - Within exposures
  - Impact on repeatability
  - Impact on AGWS tracking
    - Assumed small?
- Vibration
  - GIR rotation
  - Transmission from other instruments
  - Generated by GMTIFS

Sky coverage

GMT

- There remains some disconnect between assumptions in science requirements and LTAO specifications
- LTAO high-Strehl sky coverage most problematic
- A better understanding of which limits are physical and which are instrumental is required

NGSAO
Strehl(K) > 0.75, V~8 guide star , 120s

LTAO
Strehl(H) > 0.3, 20% sky coverage, 120s

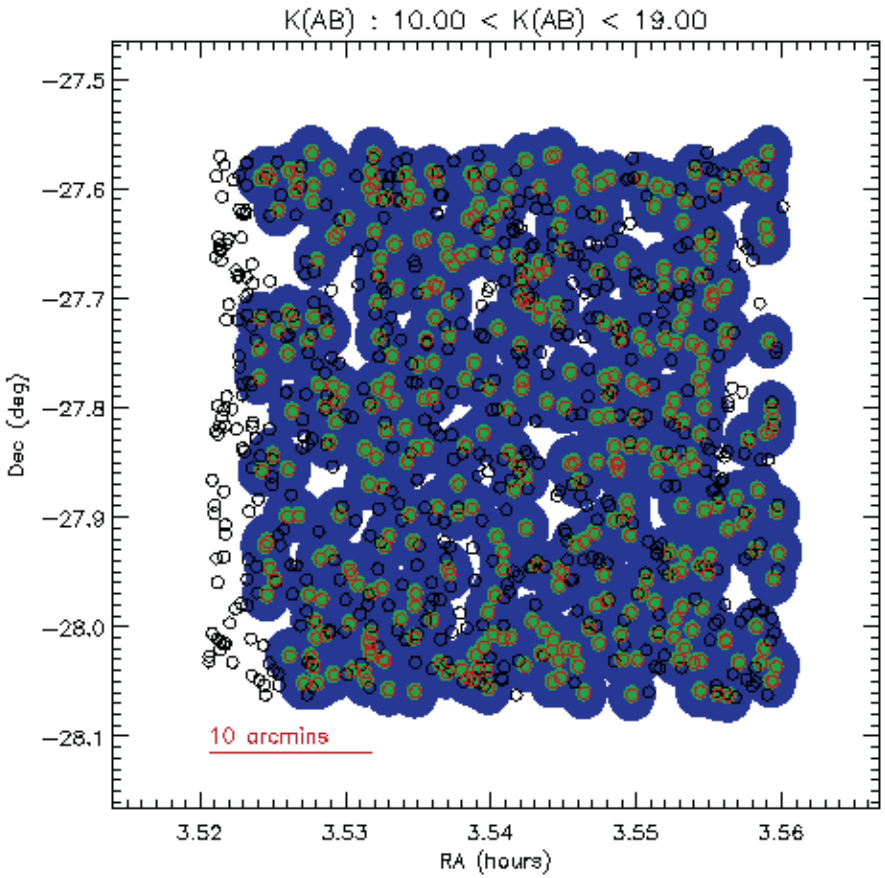
EE(K) 50x50mas > 0.4, 50% sky coverage, 900s

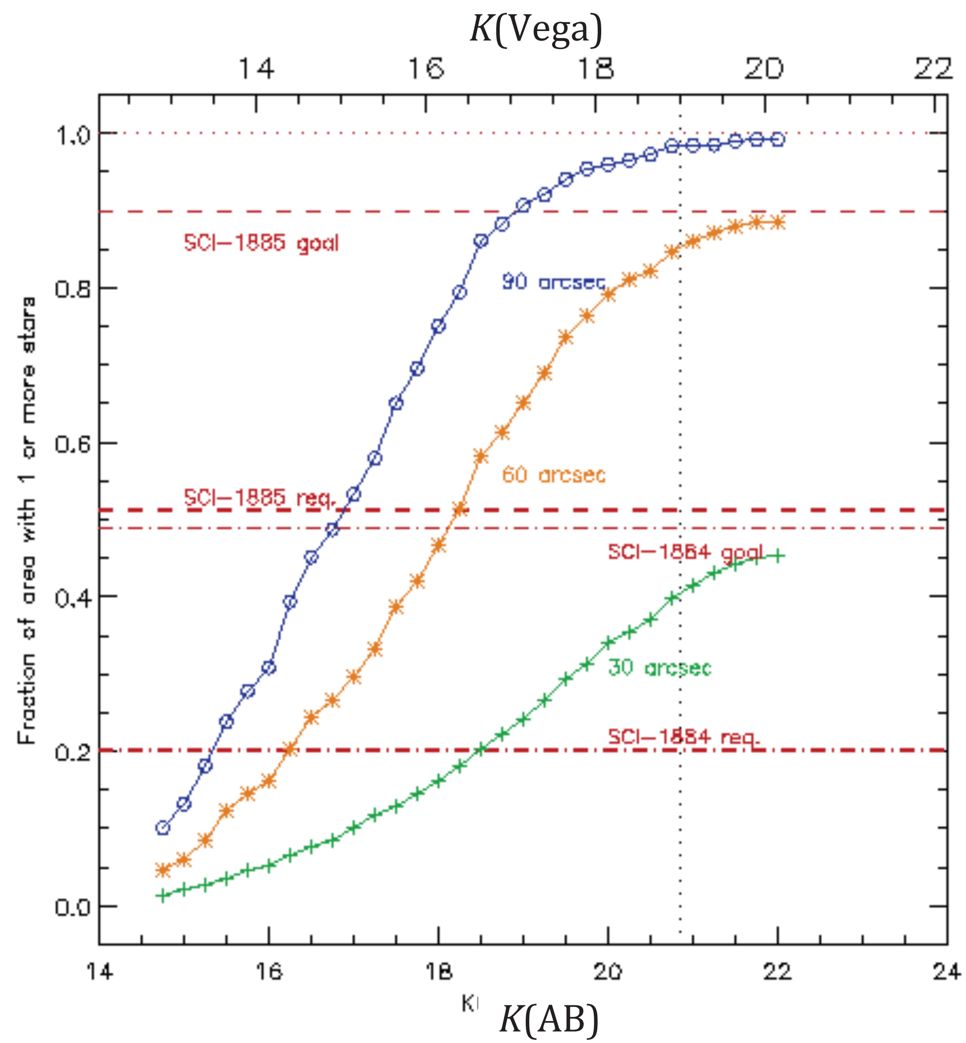
EE(K) 85x85mas > 0.5, FWHM < 20 mas, K~15 guide star, 900s

Sky coverage

GMT

AO sky coverage in the
HST Chandra Deep Field South





Targets of Opportunity

GMT

- ToO programs assumed to be possible
  - Essential for exciting GRB work (and similar)
  - Requires rapid cold start of GMTIFS and LTAO systems
- Monitoring programs
  - Need resolution of GMT, but not really the sensitivity
  - Respond to optimized AO conditions
  - How to pre-define observation sets?
  - Monitoring over an extended interval via ‘queue’ support

GMTIFS science & technical reqs

GMT

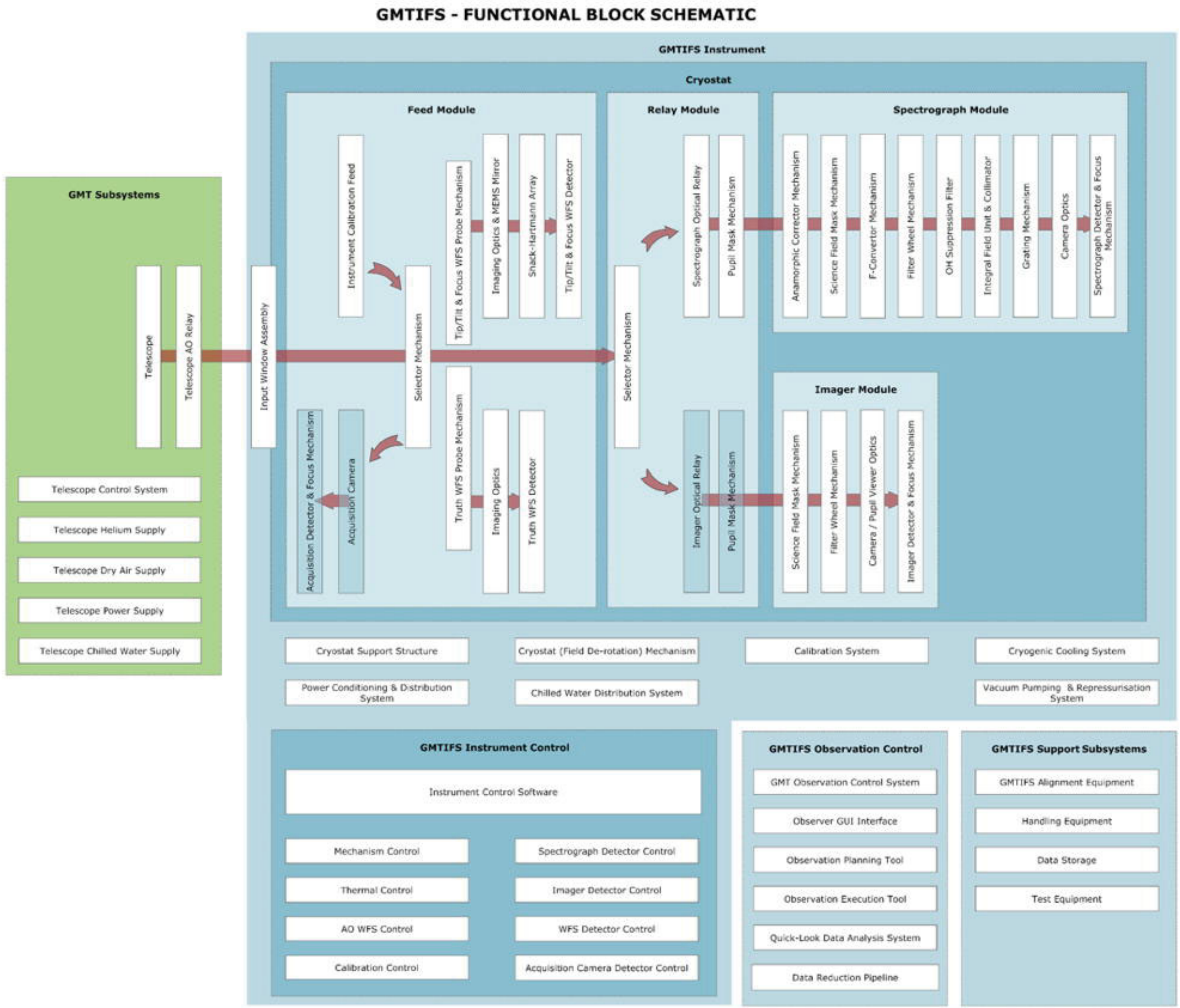
Science Application	λ range	λ/Δλ	Notes
Internal structure and dynamics of distant galaxies	1-2.5 μm	5,000	Kinematics, line widths, abundances, star formation rates [LTAO coarse pitch]
Black hole masses and AGN physics	1-2.5 μm	5,000	Emission line kinematics, bulge velocity dispersions, line ratios [LTAO fine pitch]
Young stellar objects	1-2.5 μm	5,000	Outflows, line profiles, excitation levels [LTAO fine pitch]
IMF in dense star clusters	1-2.5 μm	5,000	Line indices, velocities [LTAO fine pitch]
SNe and GRB spectroscopy	1-2.5 μm	5,000	SNe and GRB redshifts, SNe physics, reionization studies [LTAO coarse pitch]
Technical Parameter	**Requirement**	**Goal**	**Notes**
Wavelength range	1-2.5 μm	0.9-2.5 μm	
Spectral resolution	R > 3,000	R > 5,000	Resolution for fine spatial scale
Spatial resolution element fine pitch	≤ 10 mas	–	
Spatial resolution element coarse pitch	≥ 30 mas	50 mas	
Field of view fine pitch	1 arcsec^2	1” x 1”	
Field of view coarse pitch	7 arcsec^2	3” x 3”	
Image quality	Diffraction-limited	–	
Throughput	≥ 20%	–	Exclusive of atmosphere, telescope, and slit losses
Imaging mode	–	Full LTAO field	Optional

GMTIFS instrument design

GMT

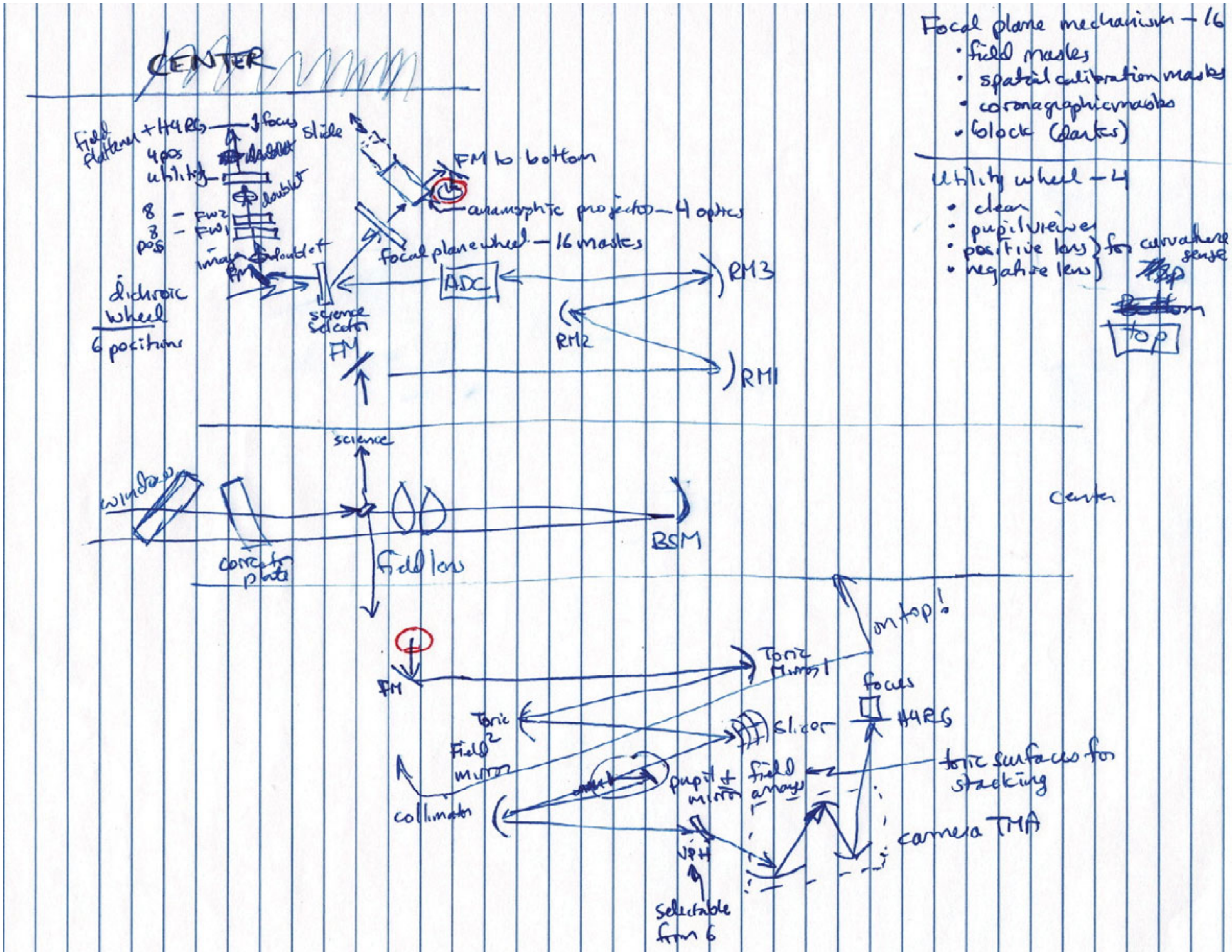
GMTIFS – initial block schematic

GMT



GMTIFS – initial light-path layout

GMT



GMTIFS – specifications

GMT

- Integral-Field Spectrograph – near-infrared, image-sliced
  - Field of view ~4”x2” with 50 mas spaxels
  - Three finer scales (25, 12, 6 mas) with proportionally reduced fields
  - Spectral resolution R ~ 5,000 and R ~ 10,000 (VPH gratings)
  - Wavelength range $\lambda \sim 0.95\text{-}2.4\ \mu m$
- Imager – near-infrared, 22”x22” field of view
  - Matched to the expected ASM corrected field
  - 5 mas pixel sampling (matched to *J*-band)
- Detectors
  - IFS: 1×H4RG (15 μm pixels)
  - Imager: 1×H4RG (10/15 μm pixels)
  - OIWFS: 2×H2RG (18 μm) or 2-3×eAPD (Vacarella++ 9908-111)
- Atmospheric Dispersion Compensator (ADC)
  - Full correction, imager+IFS (simultaneous observations)

GMTIFS – project status

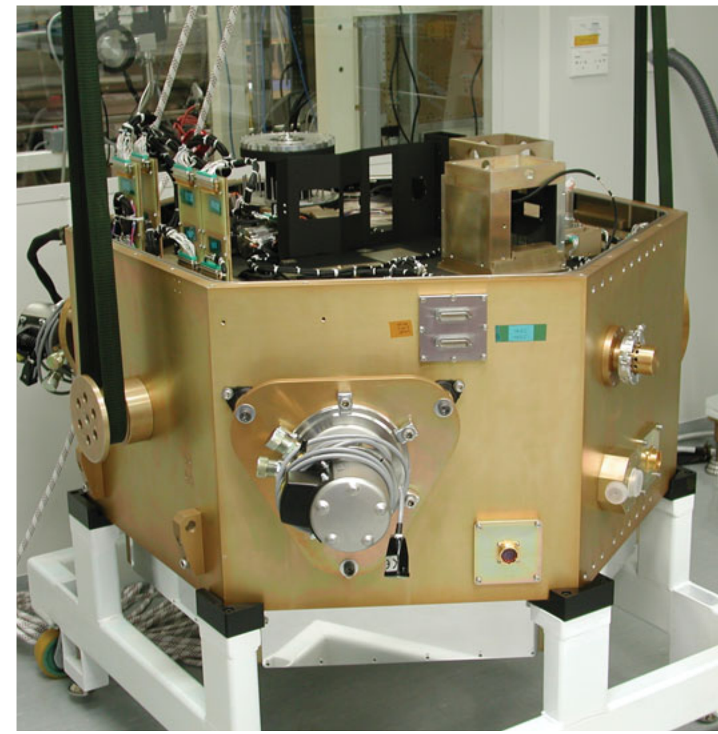
GMT

- Competitive Conceptual Design Review process
  - Jacoby++, 2012, SPIE, 8446, 1
- Selected as first-generation AO instrument
  - Commissioning GMTIFS in 2023/2024
  - GMT AO modes: NGS, LTAO and GLAO
- Preliminary design study 2014-2018
  - Refine science requirements
  - Full preliminary design
  - Risk mitigation: optical design (Hart++ 9908-349), IFS camera optics, cryostat design, mechanisms (Espeland++ 9912-210), detector system development (Vaccarella++ 9908-111), AO beam steering mirror (Espeland++ 9912-42)
- On-Instrument Wave-Front Sensor (OIWFS)
  - Appended to instrument program 2016 Q3/4
  - OIWFS deformable mirror (Copeland++ 9909-276)

ANU instrumentation heritage

GMT

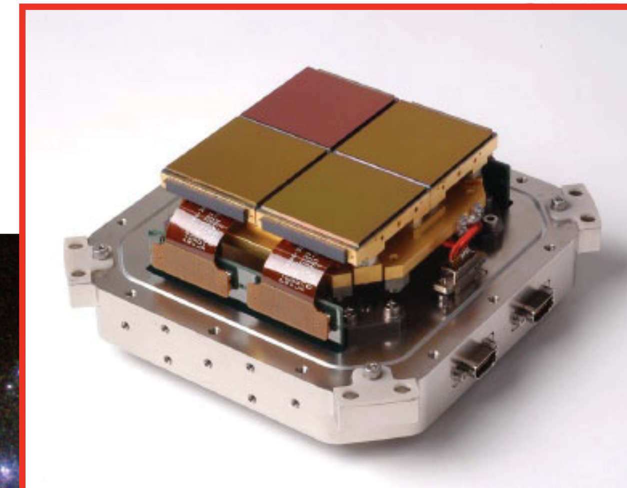
Gemini/NIFS with ALTAIR AO

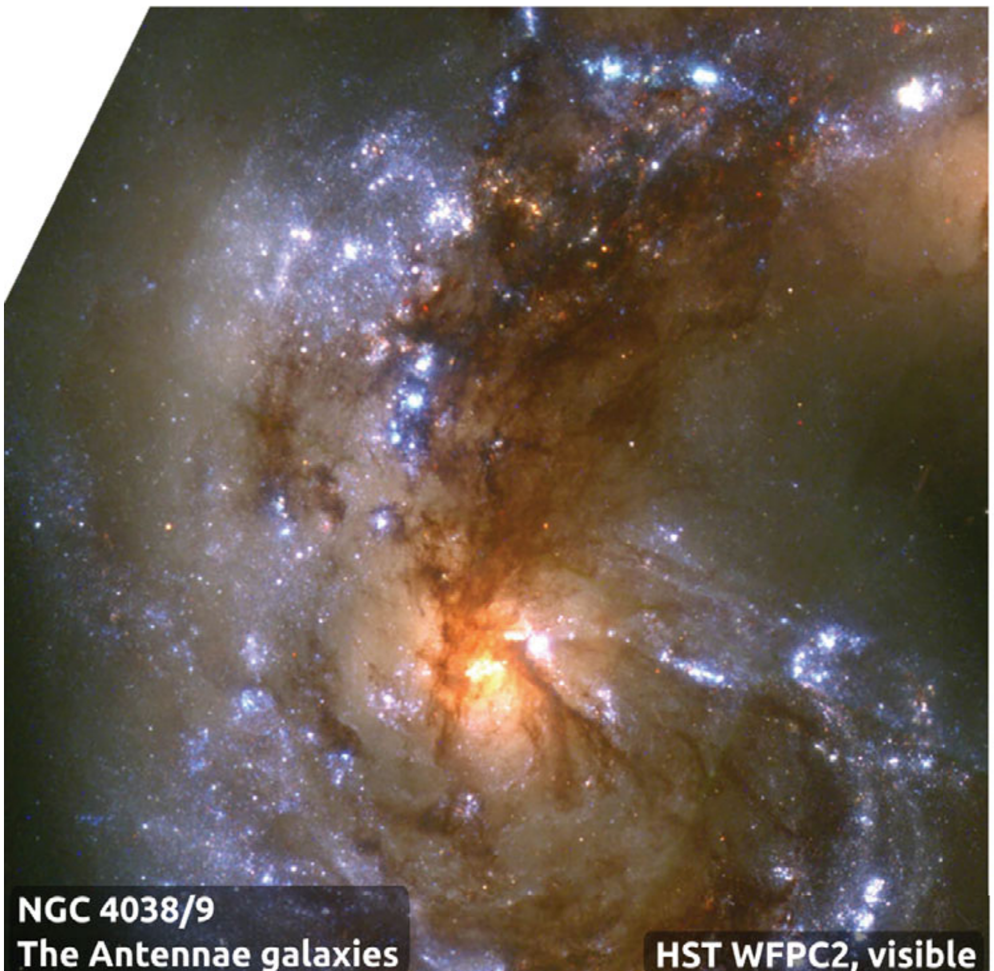


GSAOI imager on Gemini with GeMS MCAO system

ANU 2.3m and WiFeS optical IFS

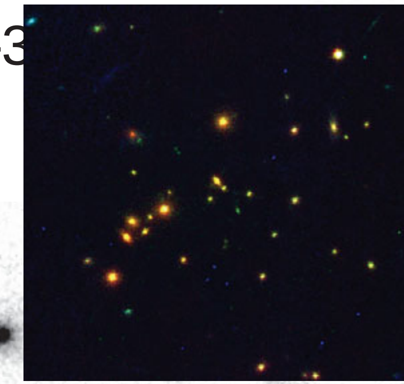
AO imager heritage



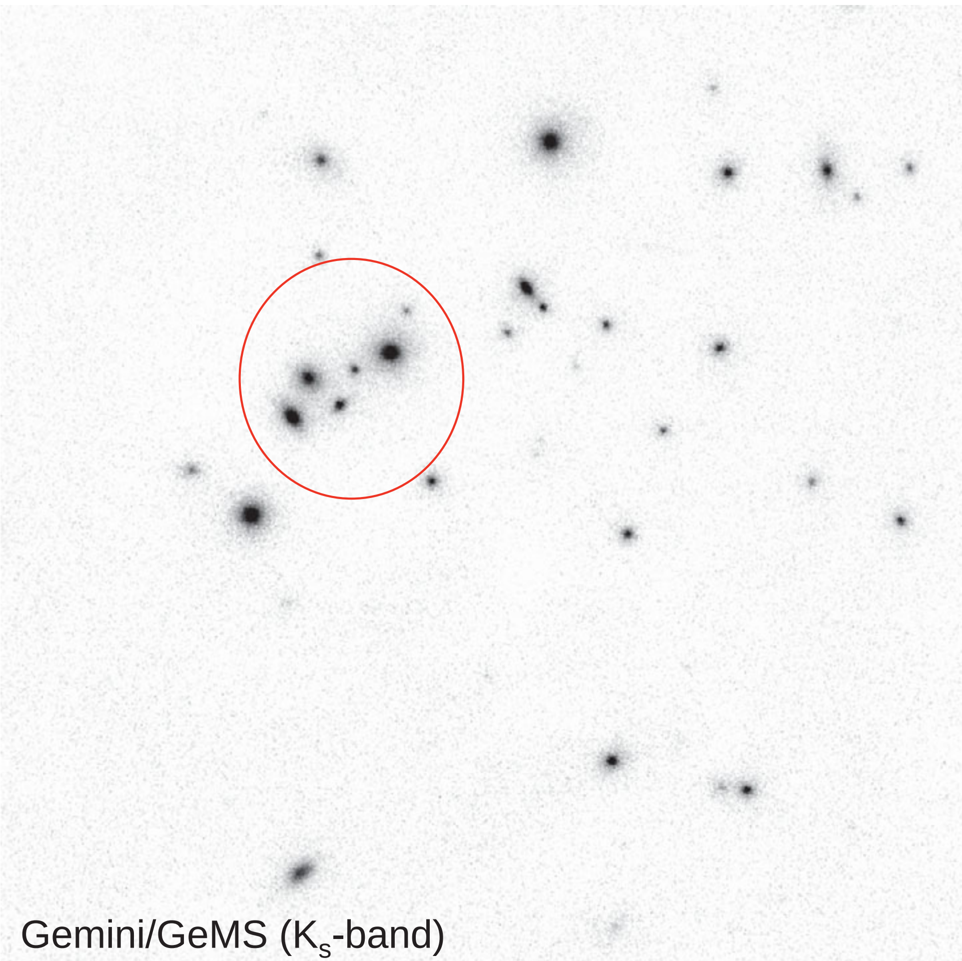


Gemini/GEMS vs HST/ACS

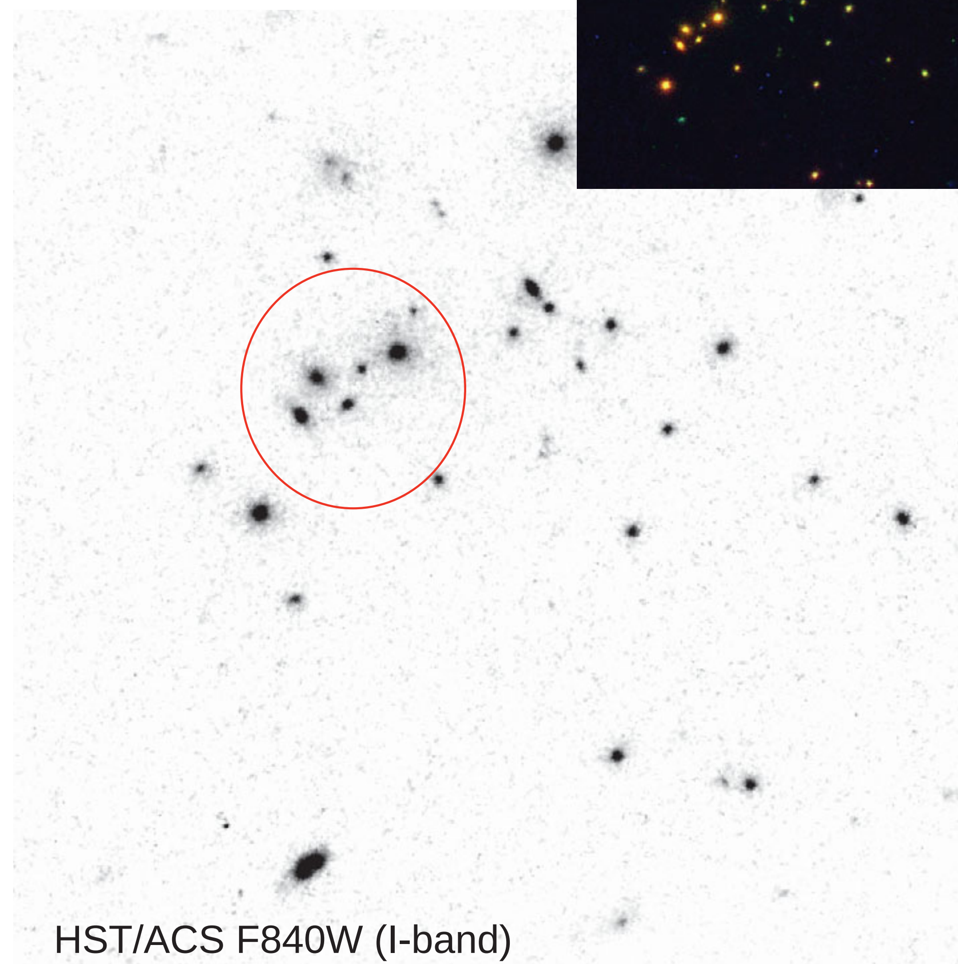
GMT



- K-band/I-band~3.1 : Gemini/HST~3.3 : GMT/JWST~3
- z = 1.07 galaxy cluster SPT-CL J0546-5345



Gemini/GeMS (K_s-band)



HST/ACS F840W (I-band)

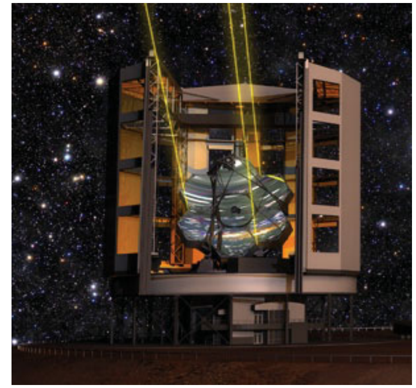
Multiple roles for the imager

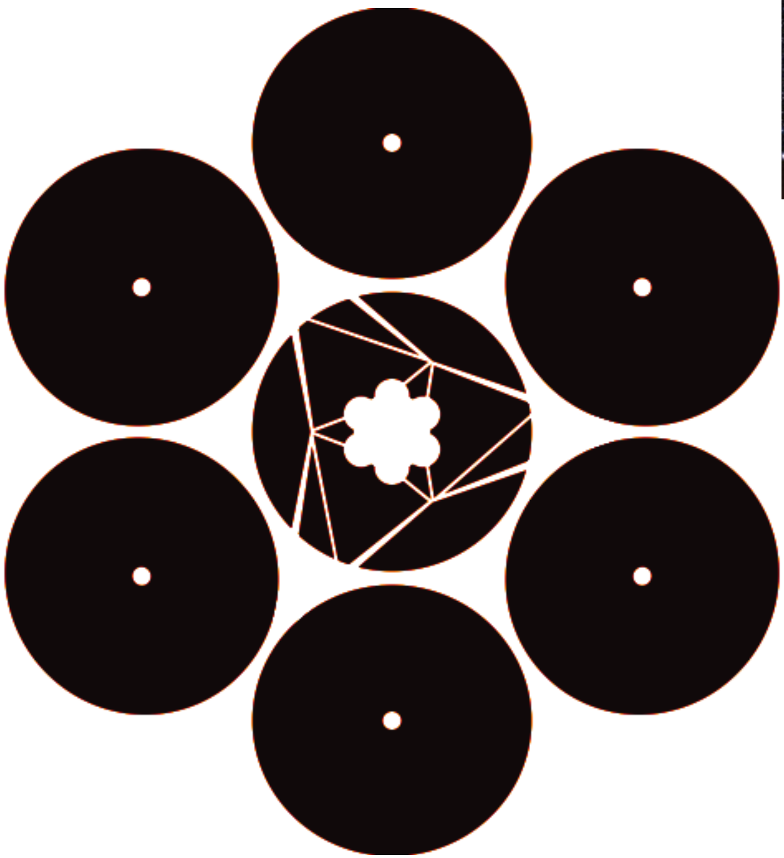
GMT

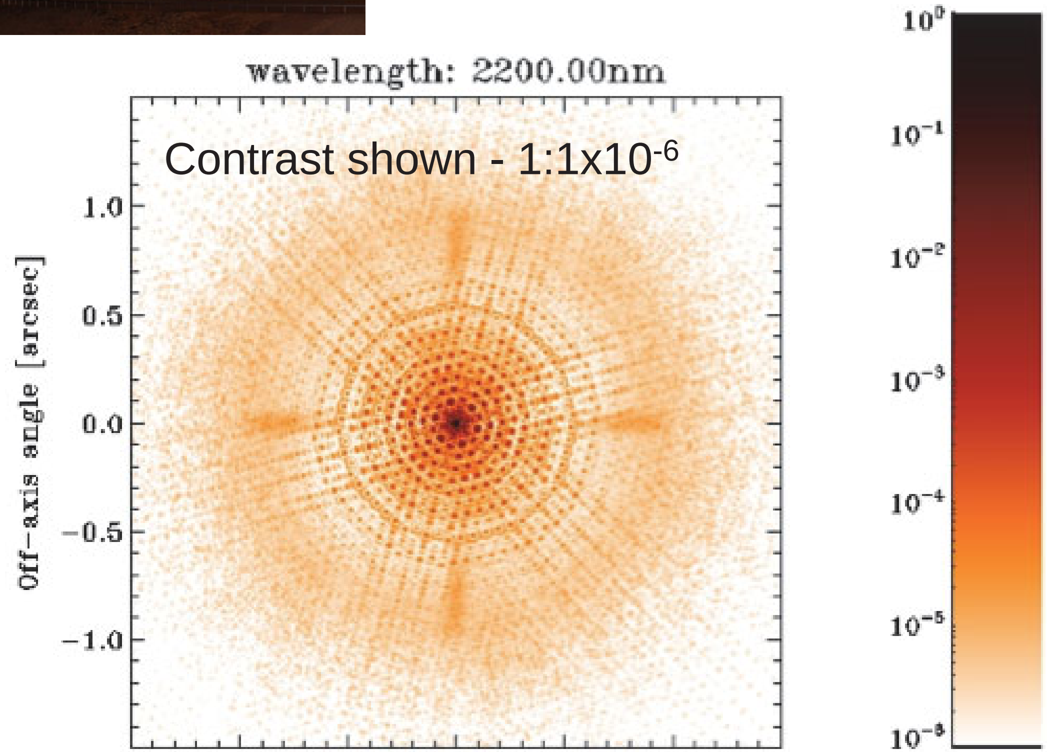
- Science instrument in it's own right
  - ADI planet observations
  - Resolved stellar populations
  - Galaxy morphology
  - Astrometric data for crowded field deconvolution
- Target acquisition
  - Critical for fast transient acquisition?
  - Fully integrated with GMTIFS control system and GMT
  - Response time likely limited by telescope (longest instrument delay is 3 minutes AO slew)
- Guide star access for central science field
  - On-detector guide windows

Clean but segmented pupil

GMT

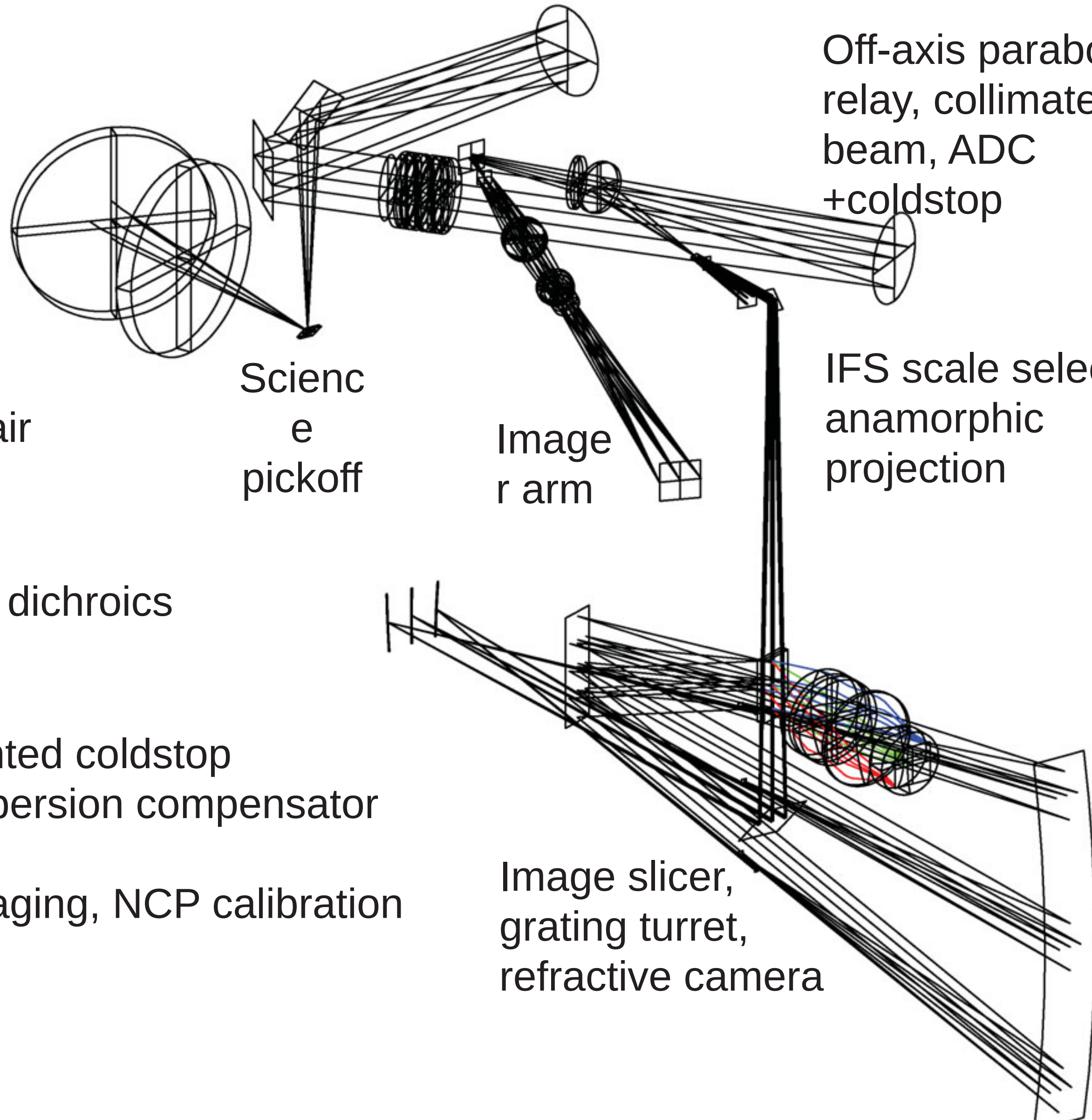






Polychromatic simulations in prep.
Instrument component to be included

GMTIFS – basic layout & design



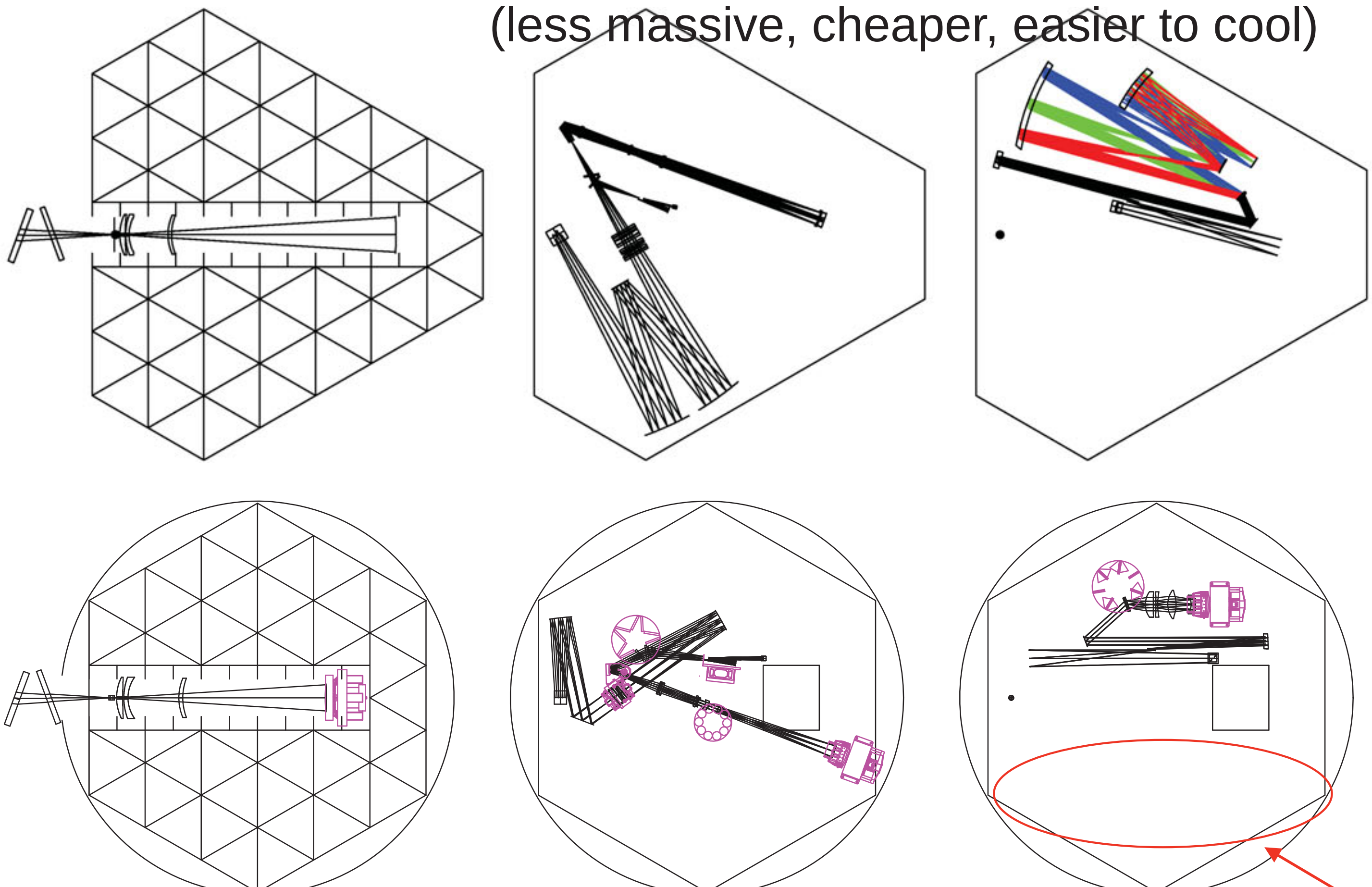
Moving parts…

Science selector dichroics
Grating selection
IFS plate scale
Rotating segmented coldstop
Atmospheric dispersion compensator
(ADC)
Imager: pupil imaging, NCP calibration

Layout evolution

GMT

Cylindrical cryostat with 2/3 size now possible retaining 3-layer structure
(less massive, cheaper, easier to cool)



CoDR Baseline 2011/12

PDR 2016

Mid Chamber

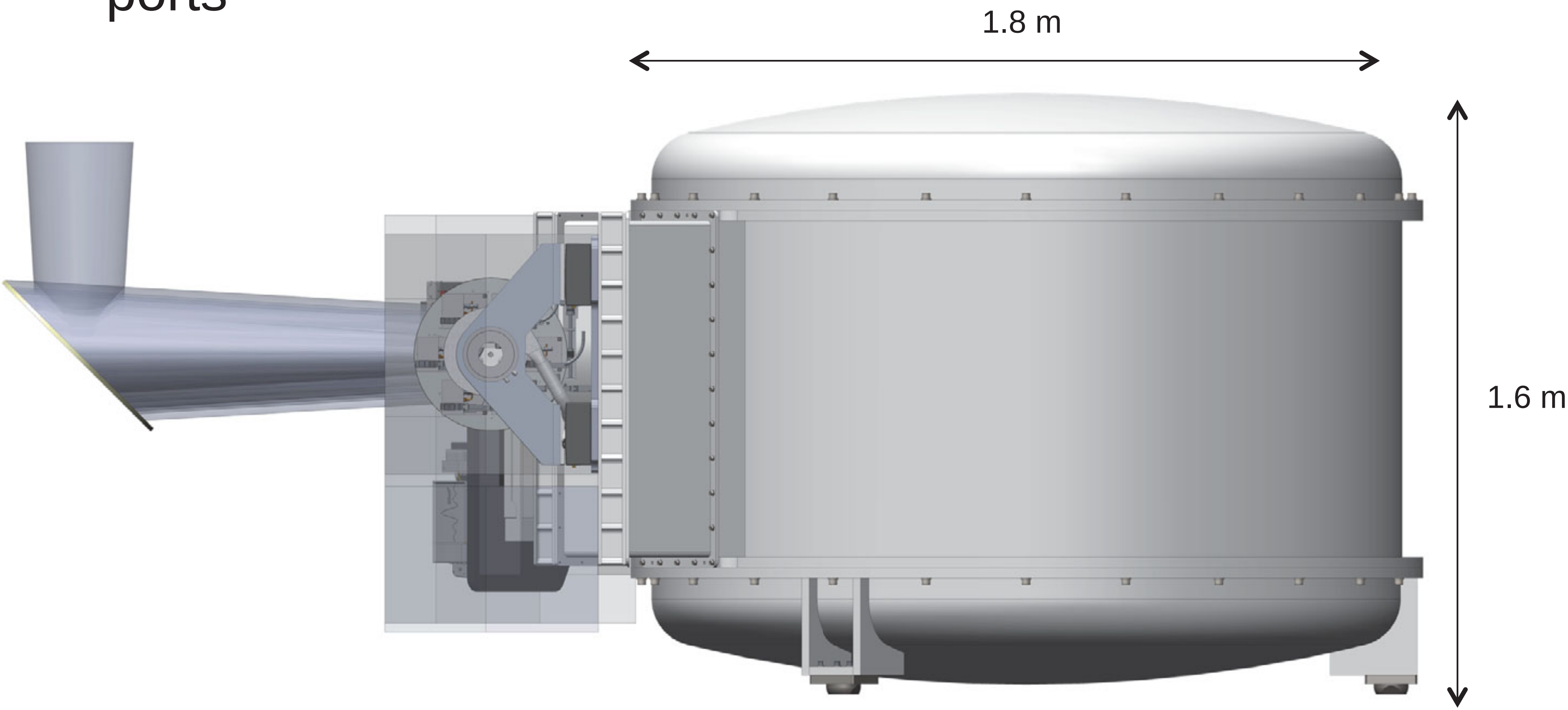
Upper Chamber

Lower Chamber

Instrument specifications

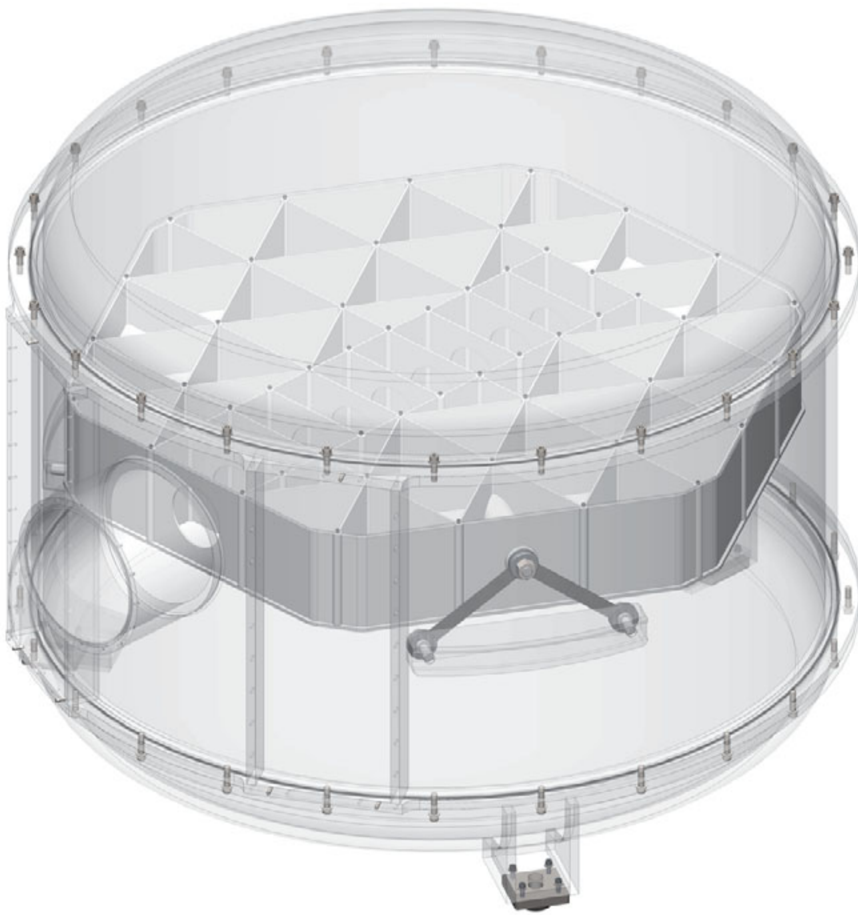
GMT

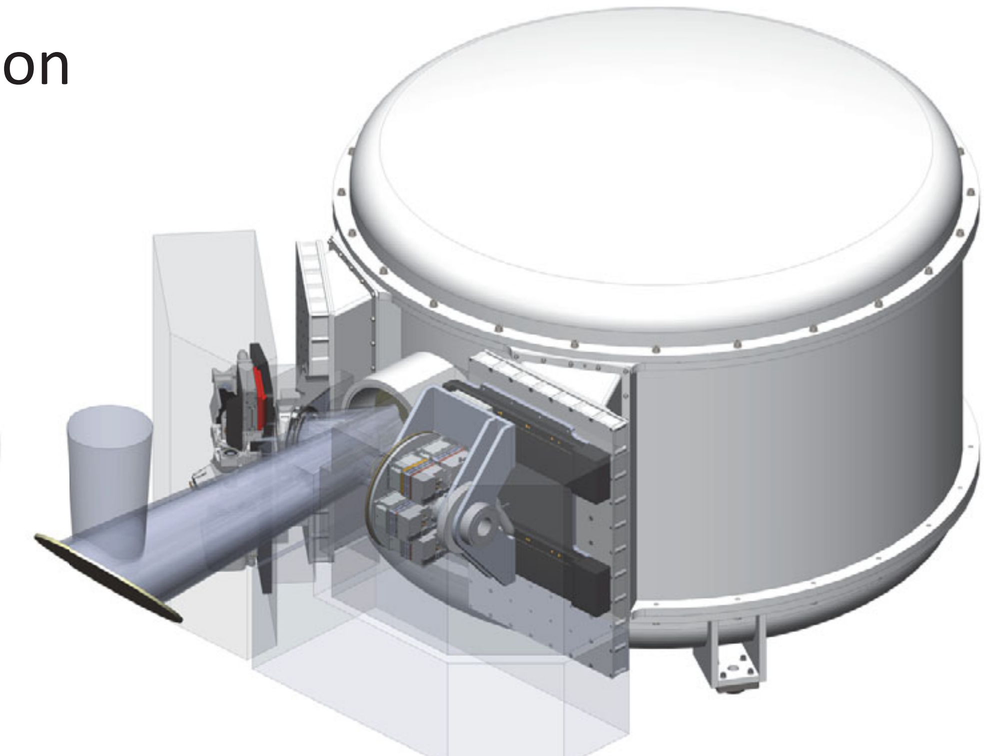
Mass budget: ~1 tonne cryostat, ~1 tonne instrument
Located at one of the folded Gregorian instrument ports



Instrument specifications

NGSAO and LTAO WFS hosted on cryostat

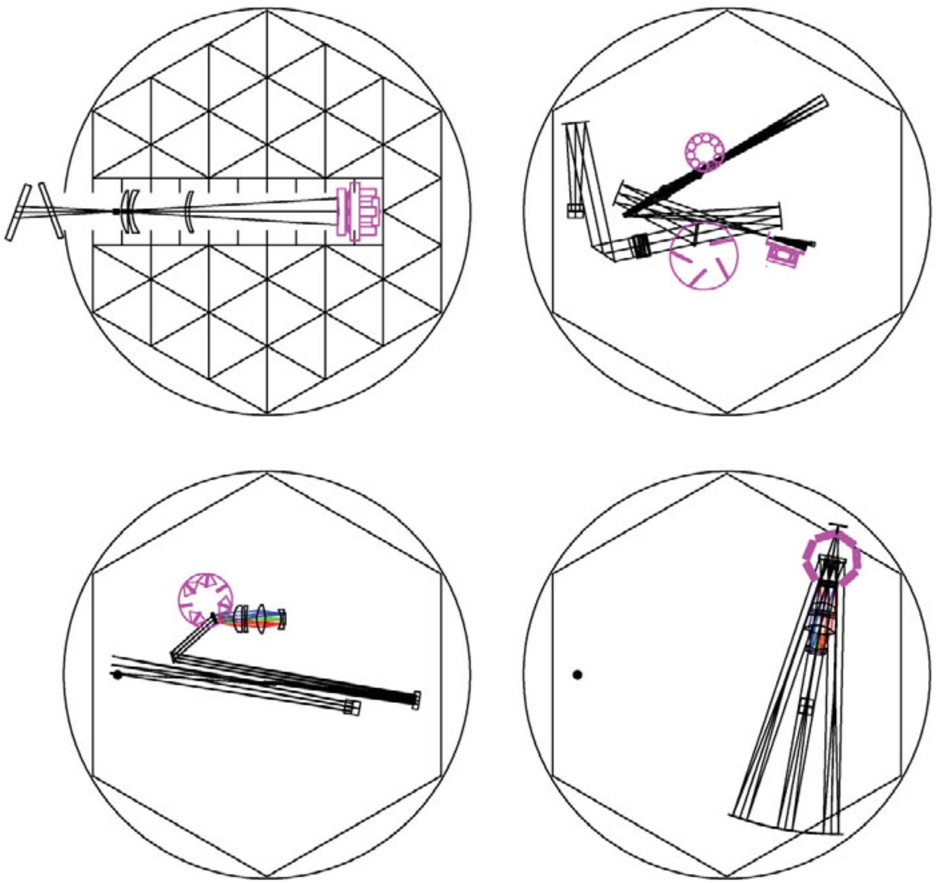


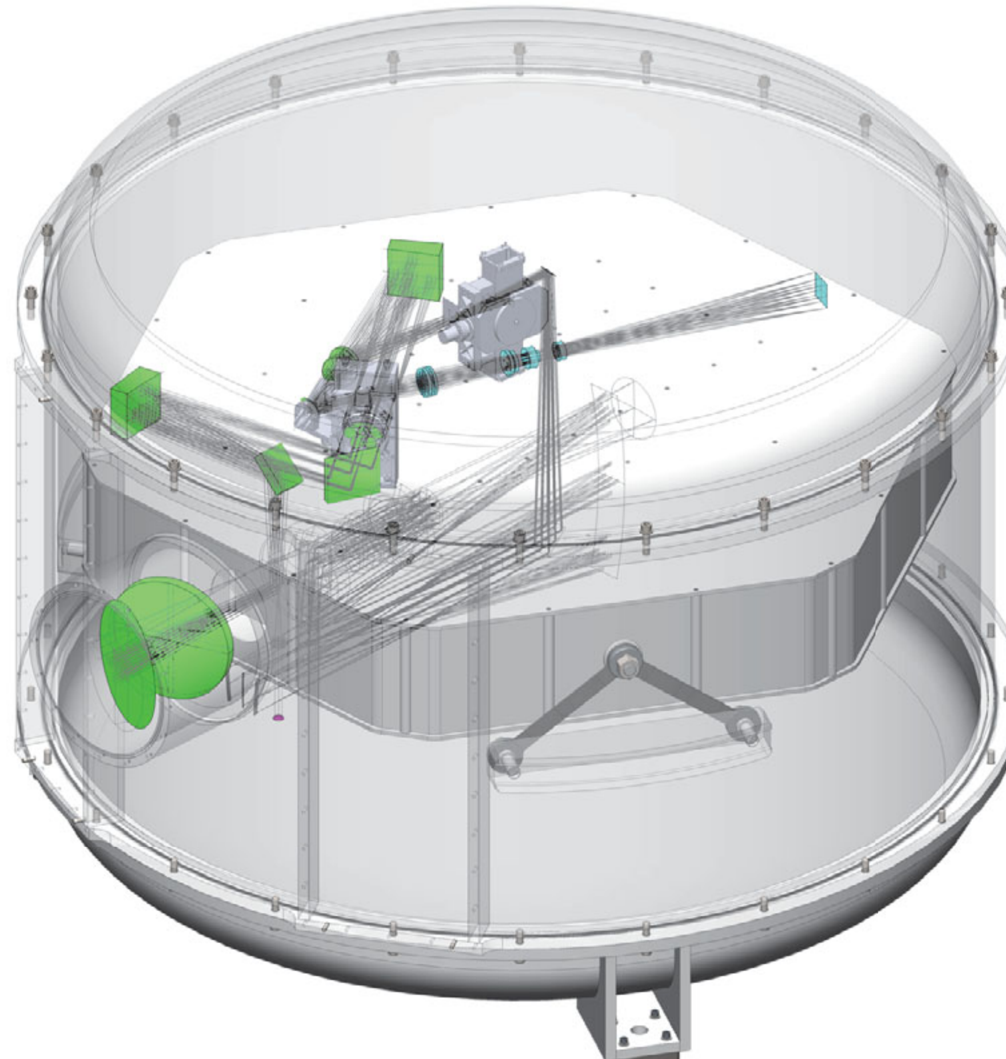


Instrument specifications

GMT

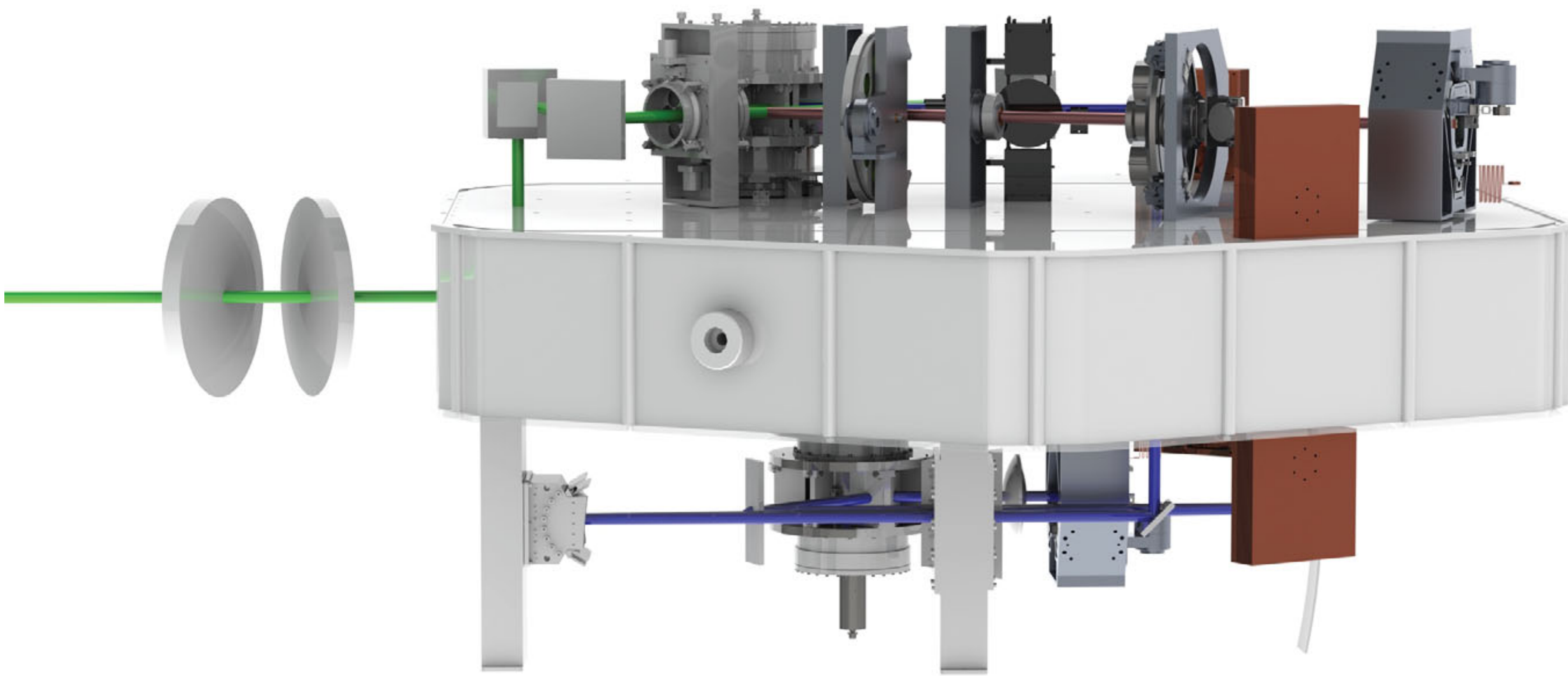
Packaging is a challenge,
but near completion



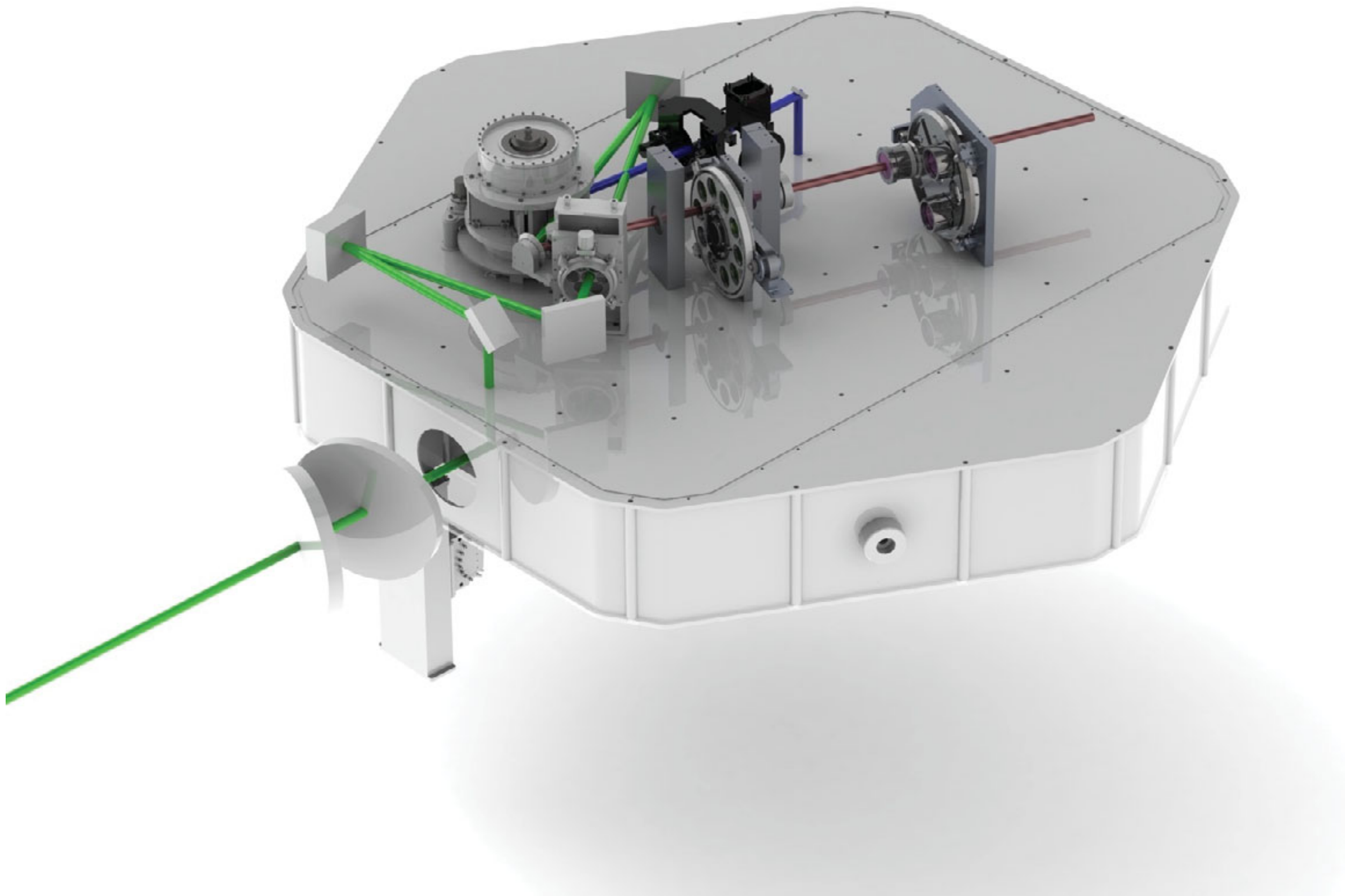


GMTIFS – physical layout

GMT



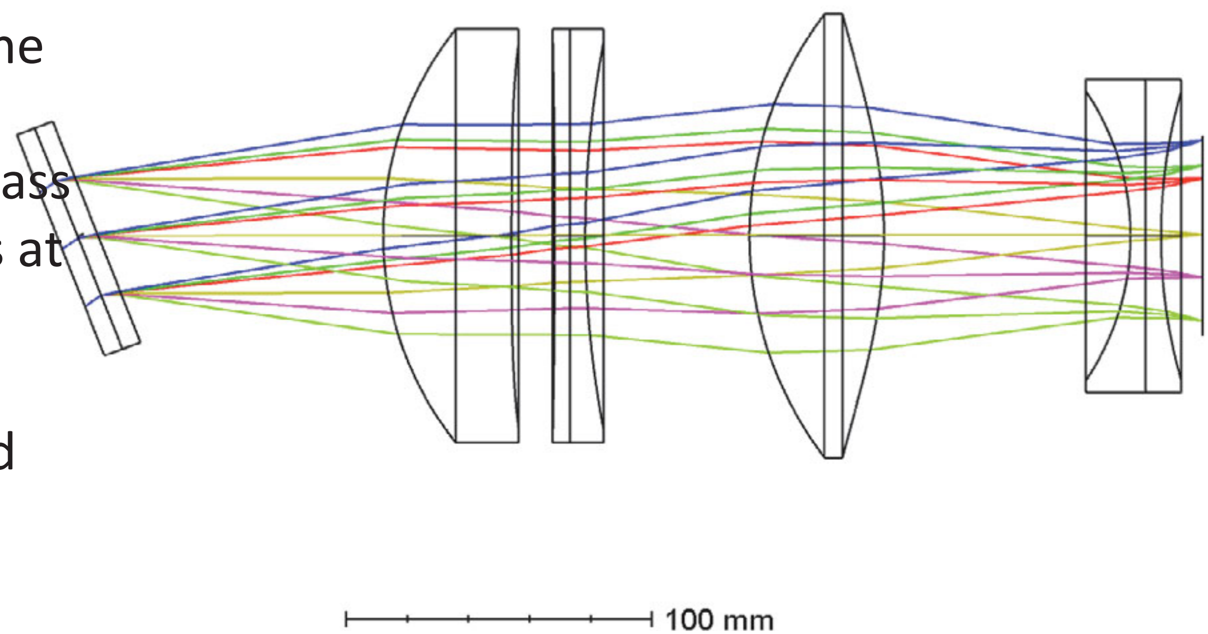
GMTIFS – physical layout



Refractive IFS camera

GMT

- CoDR 3-mirror anastigmat camera design deemed risky
- Refractive IFS camera design allows cryostat size reduction
- Only four elements:
  1. BaF_2 asphere on the concave side
  2. Ohara S-NPH2 glass leads to losses at 2-2.5 μm
  3. CaF_2 with tricky asphere on second convex face
  4. Infrasil 302



Current throughput estimates

GMT

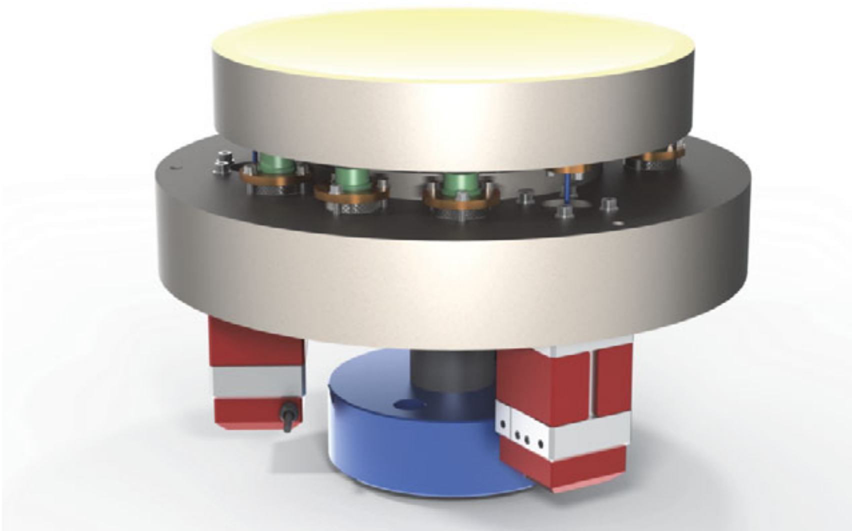
Wavelength range	Y	J	H	K
IFS (R~10,000)	0.33	0.35	0.39	0.35
IFS (R~5,000)	0.37	0.43	0.46	0.43
Imager	0.46	0.52	0.55	0.47

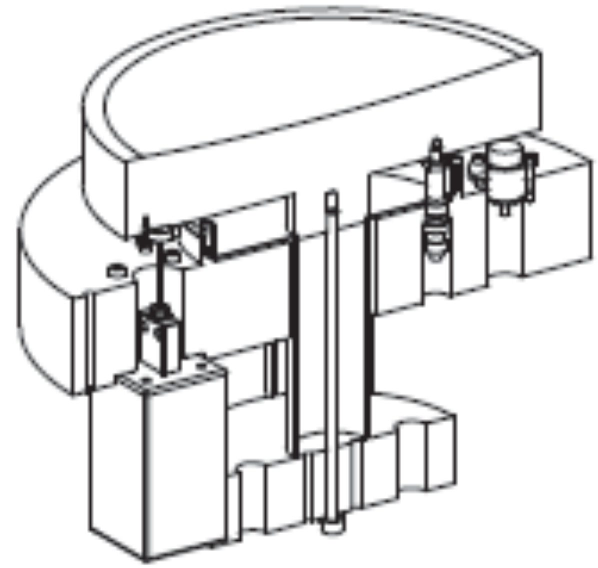
(excluding telescope and atmospheric transmission plus detector QE)

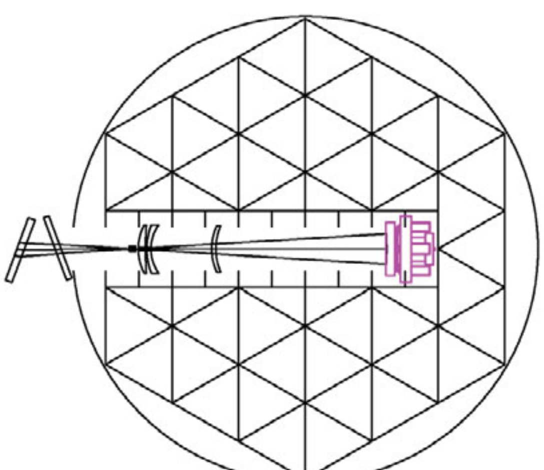
Instrument specifications

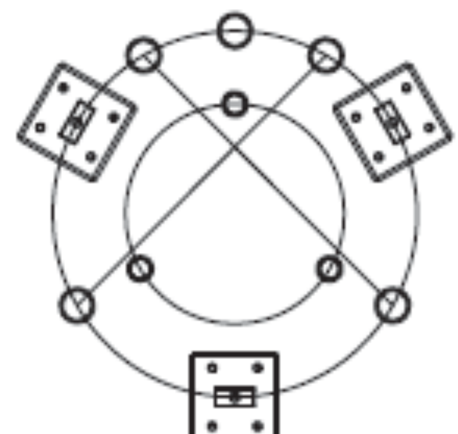
GMT

High sky coverage AO with LTAO
(Espeland++ 9912-42)









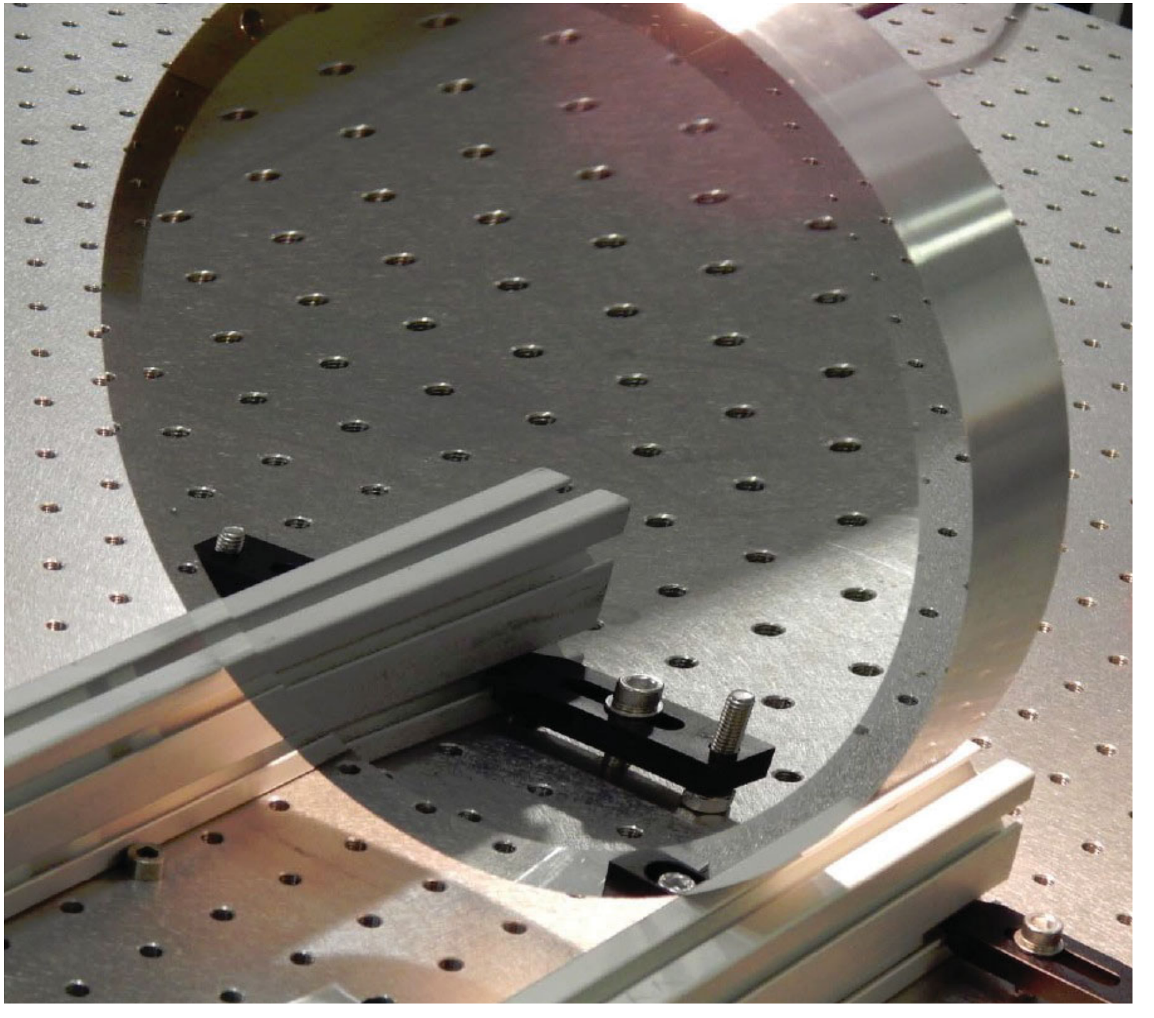
Beam-steering mirror

GMT

BSM may be first production optical element of the GMT AO system optics

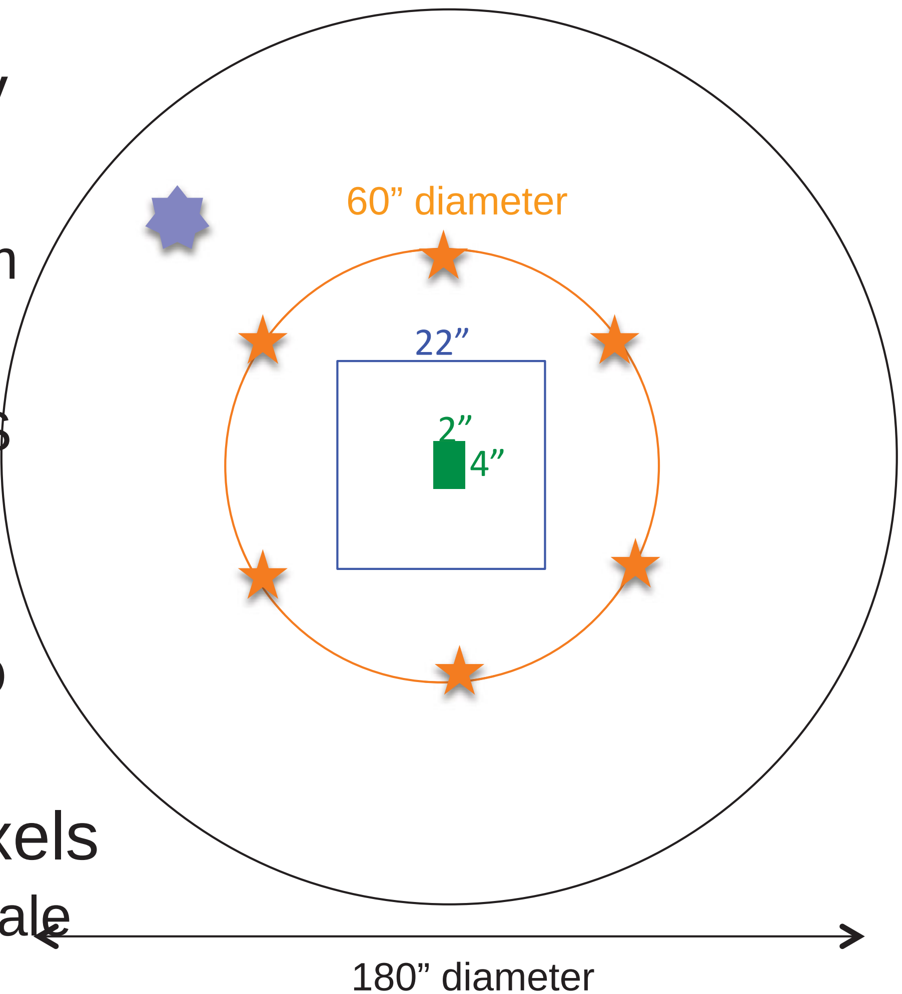
Testing for:

- surface figure and roughness
- mechanical control of the BSM (challenging tolerances & high dynamic range)



GMTIFS fields

- 180" diameter field passed by GMT
  - Partial correction by ASM system
- 60" diameter LTAO asterism
  - Externally reflected to laser WFS
- 22"x22" imager science field
  - Central field picked-off by fold
  - Field matched to expected LTAO corrected field
- 4"x2" IFS field @ 50mas spaxels
  - A range of field sizes and IFS scale



AO system basics

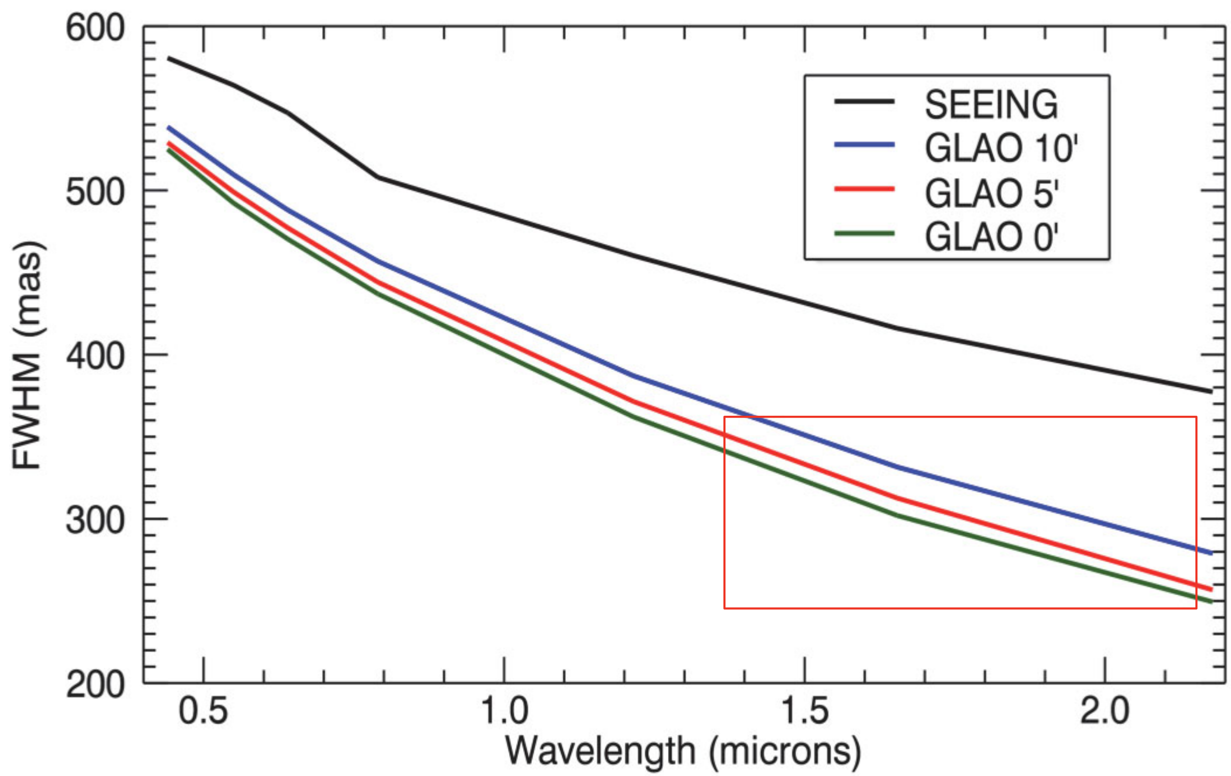
GMT

- Spatial, not spectral, guide field split
  - $\lambda < 1$ μm external NGSAO/LTAO system
  - $1 < \lambda < 2.5$ μm OIWFS Tip-Tilt and Truth
    - access 3 arcmin guide field with MOAO correction
- Warm optical system
  - Active M1 – Aluminum (at first light)
  - Adaptive M2 – Aluminum (at first light)
  - Pupil steering M3 – Gold
  - Single warm cryostat dichroic pressure window (CaF_2)
- No independent AO feed
  - Instrument integrated into delivering the AO corrected field
- NGSAO – external optical system
  - Optical Pyramid WFS (Arcetri Observatory)
- LTAO – external (but expected to be a GMTO/ANU collaboration)
  - OIWFS – Internal Tip-Tilt + True (low read-noise avalanche photodiode likely)
  - MOAO – Corrected off-axis star (cooled DM – trade study underway)
- GLAO – default operations for telescope phasing

Ground Layer Adaptive Optics

GMT

- GLAO is default mode of operation for mirror phasing
- FWHM ~ 250-350 mas
- Early commissioning mode for GMTIFS
- Minimal dependence on AO WFS components



Natural Guide Star Adaptive Optics

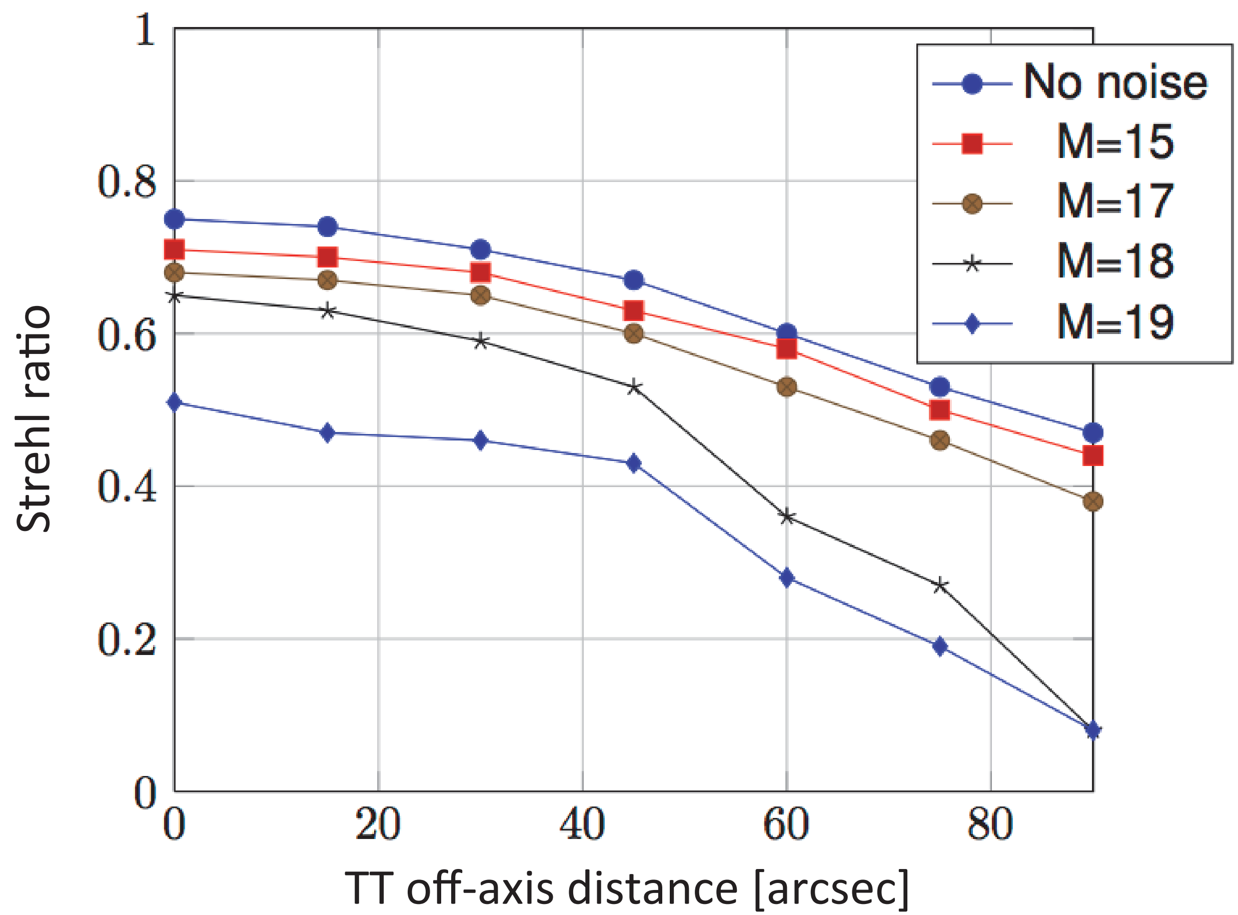
GMT

- NGS AO simulations
  - Including wind shake (75th %-ile used for baseline)
- Instrumental wavefront error budget
  - Challenging but tractable
  - Non-common path correction off-loaded to ASM
  - Slow flexure correction from OIWFS
- Require K-band Strehl $S_K > 75\%$; simulations show:
  - $M_V < 8 \rightarrow S_K \sim 89\%$
  - $M_V < 12 \rightarrow S_K \sim 74\%$

Laser Tomography Adaptive Optics

GMT

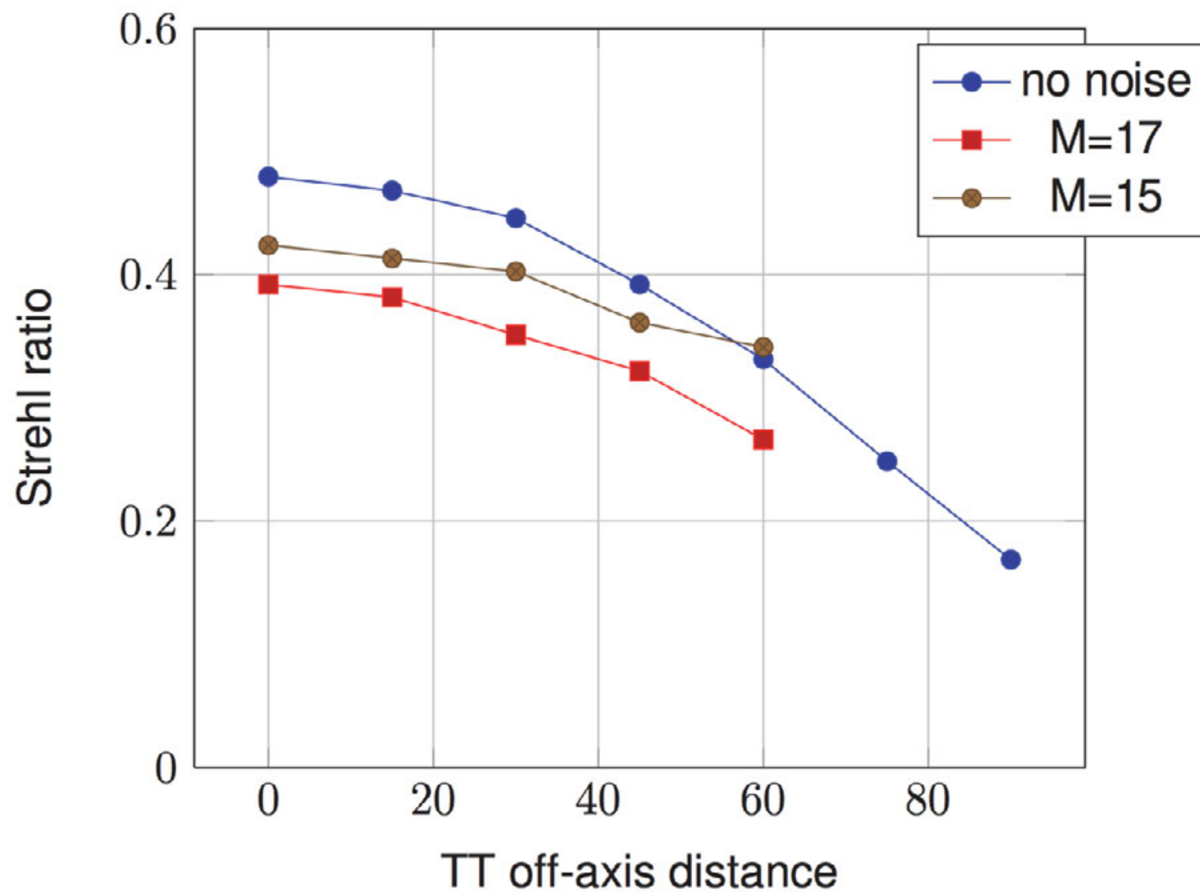
- On-axis field
- Off-axis guide star with own DM (MOAO)
- Including wind shake
  - ▶ 75th %-ile conditions
- Requirement: $S_K >$ 0.4
- Sky coverage trades with Strehl



LTAO *H*-band performance

GMT

- Requirement: S_H > 30% for 50% of sky at b~90°
- Simulations indicate that ~80% sky coverage likely



GMTIFS simulations

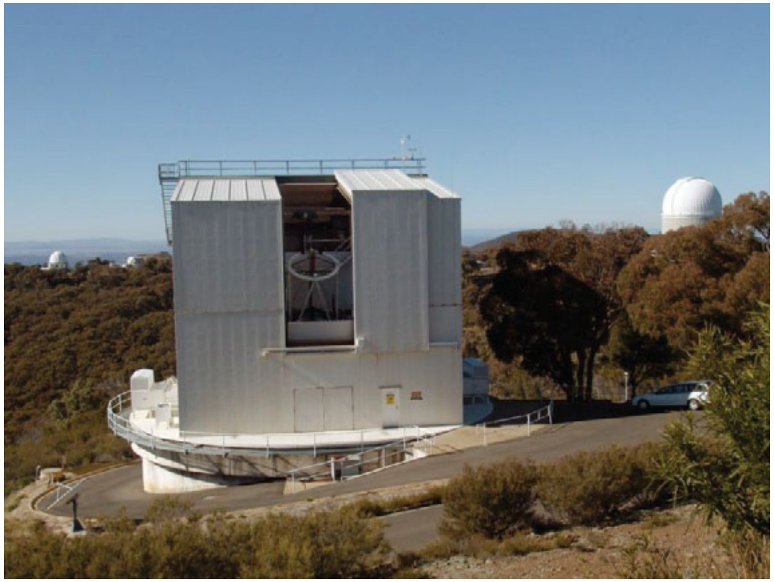
Data simulation/reduction: PyWiFeS

GMT

http://www.mso.anu.edu.au/pywifes/doku.php

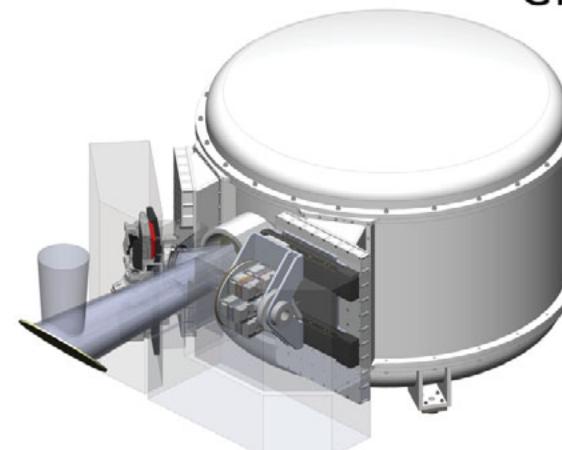
[Childress, Vogt, Nielsen & Sharp, 2014, ApSS, 349, 617]

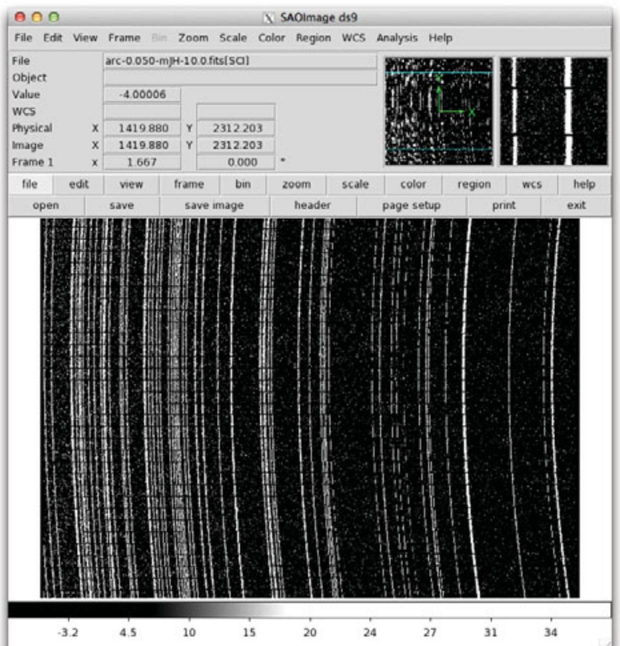
- ❑ Quick-look pipeline: cut down version of science pipeline
- ❑ Daytime and library calibrations
- ❑ Integrated with acquisition

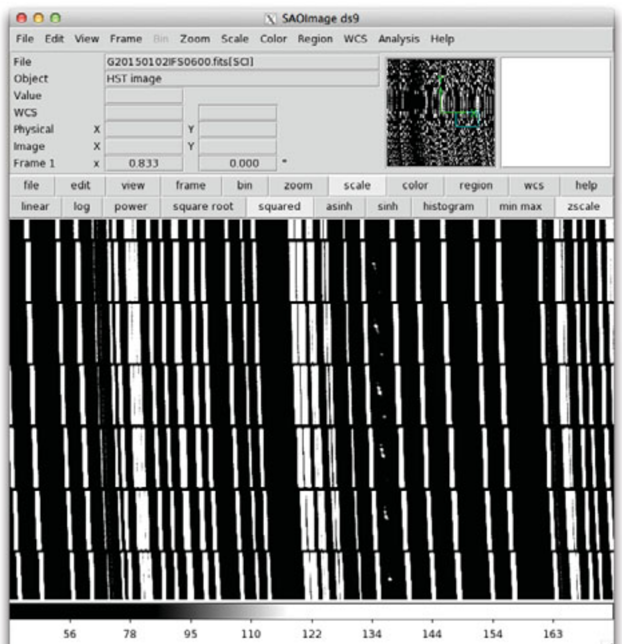


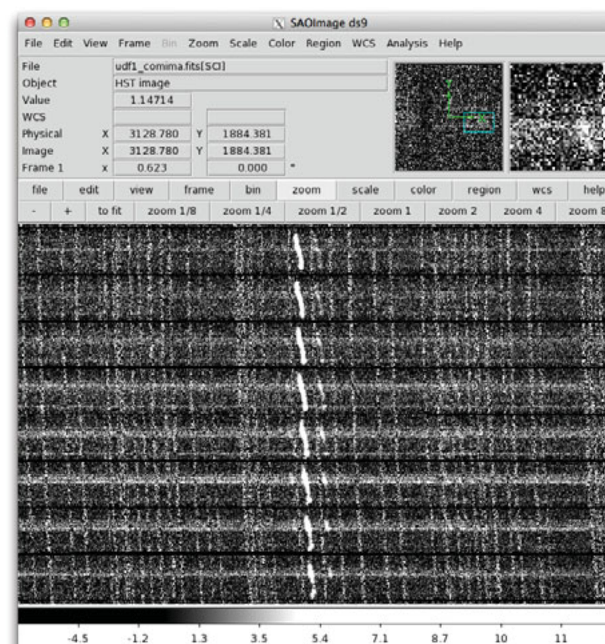
GMTIFSsim – instrument simulator

GMT



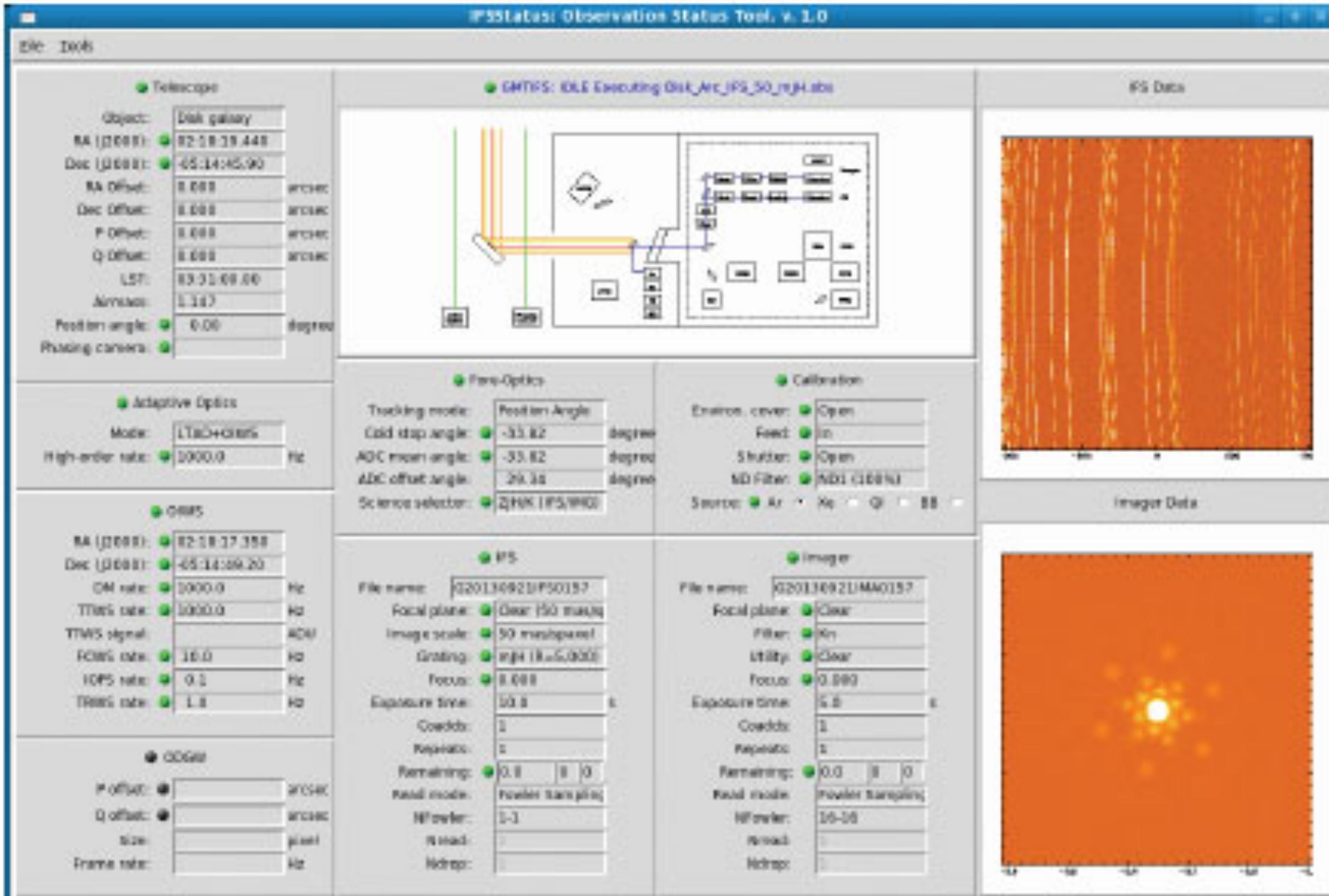






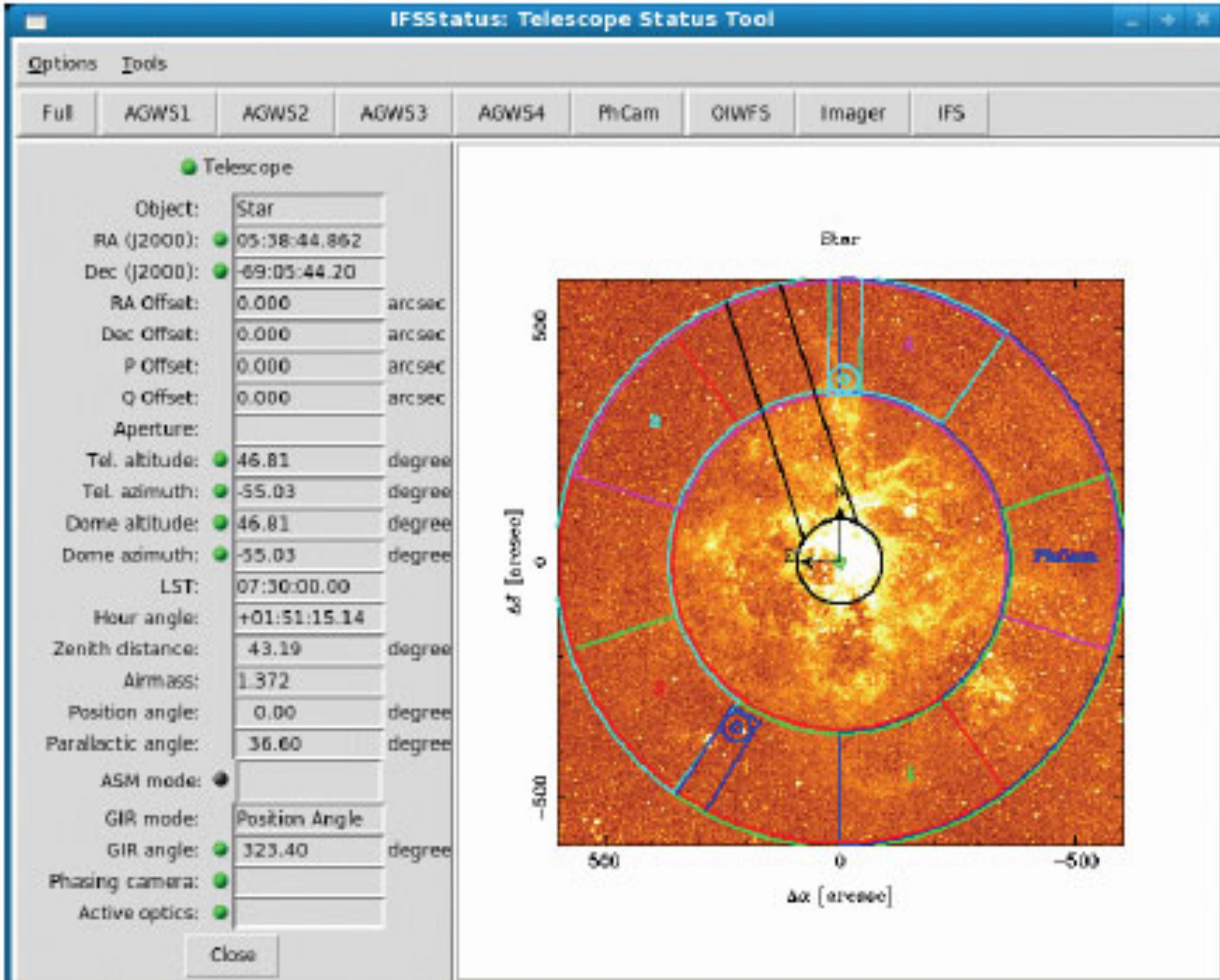
GMTIFSsim – instrument simulator

GMT



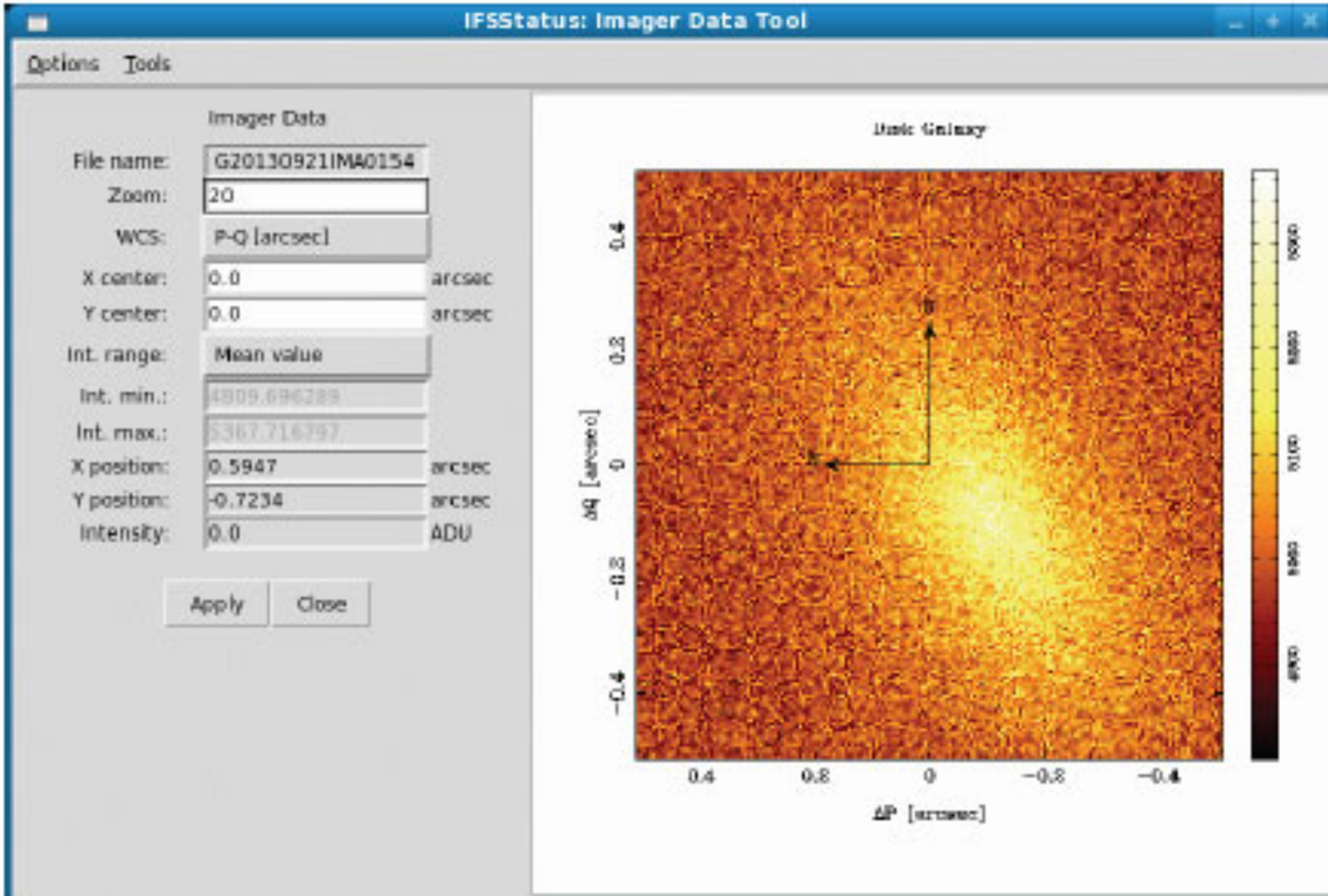
Acquisition process

GMT



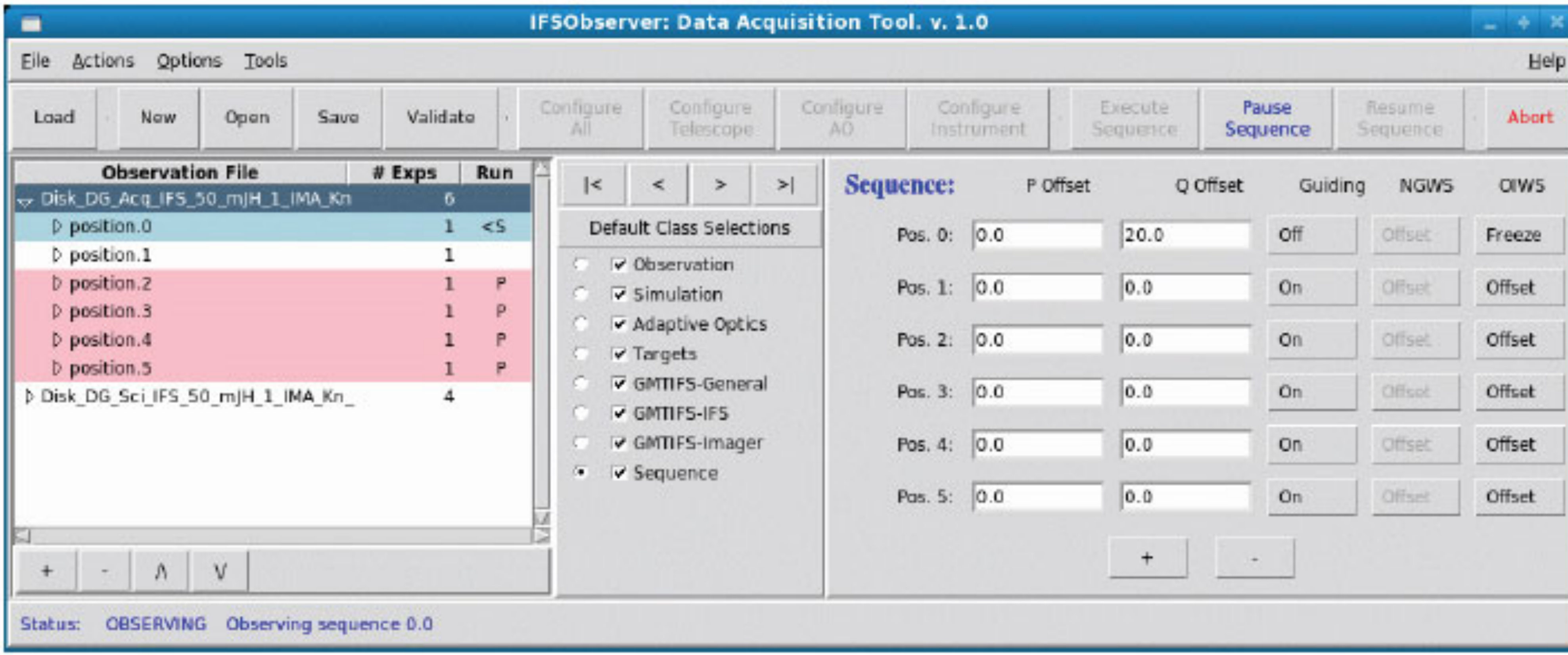
Simulated data

GMT



Operational Concepts

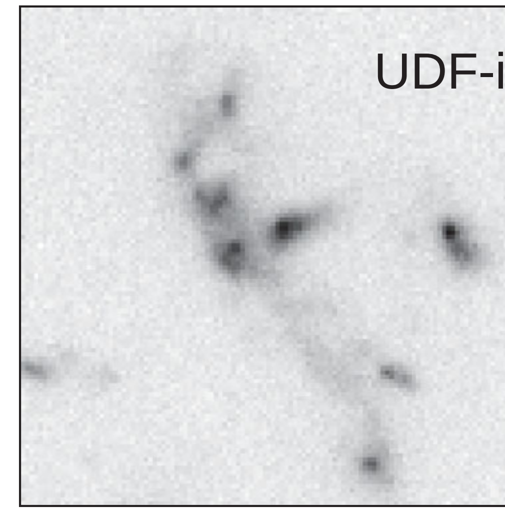
GMT

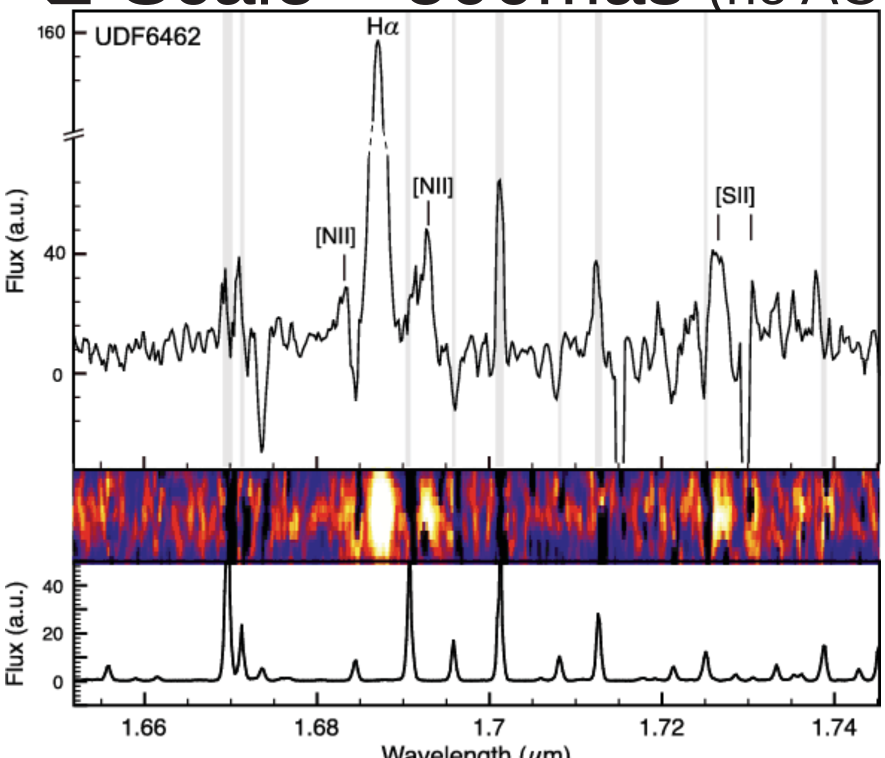


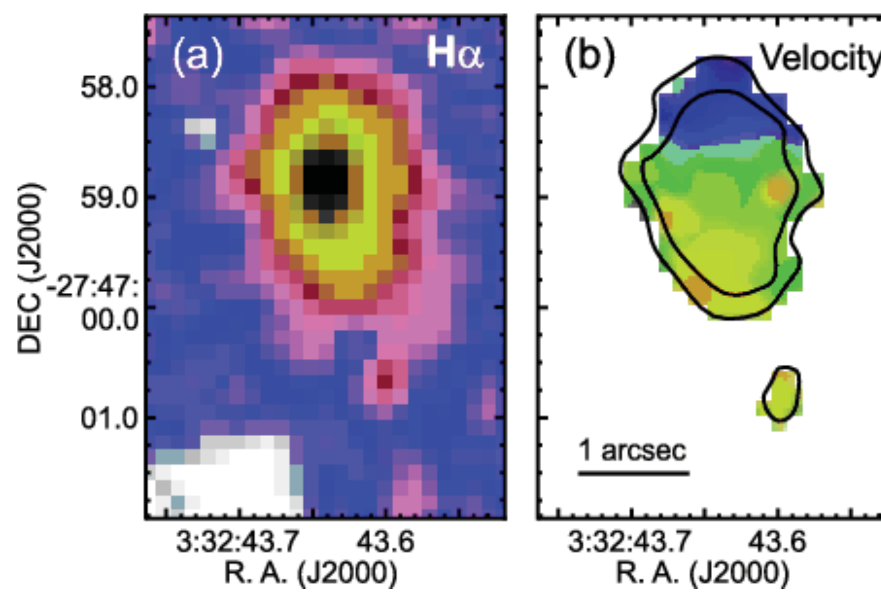
UDF6462 @ z=1.57

GMT

- VLT+SINFONI, 5 hours (Bournaud+ 2008)
- R ~ 3,000
- Scale ~ 500mas (no AO guide star

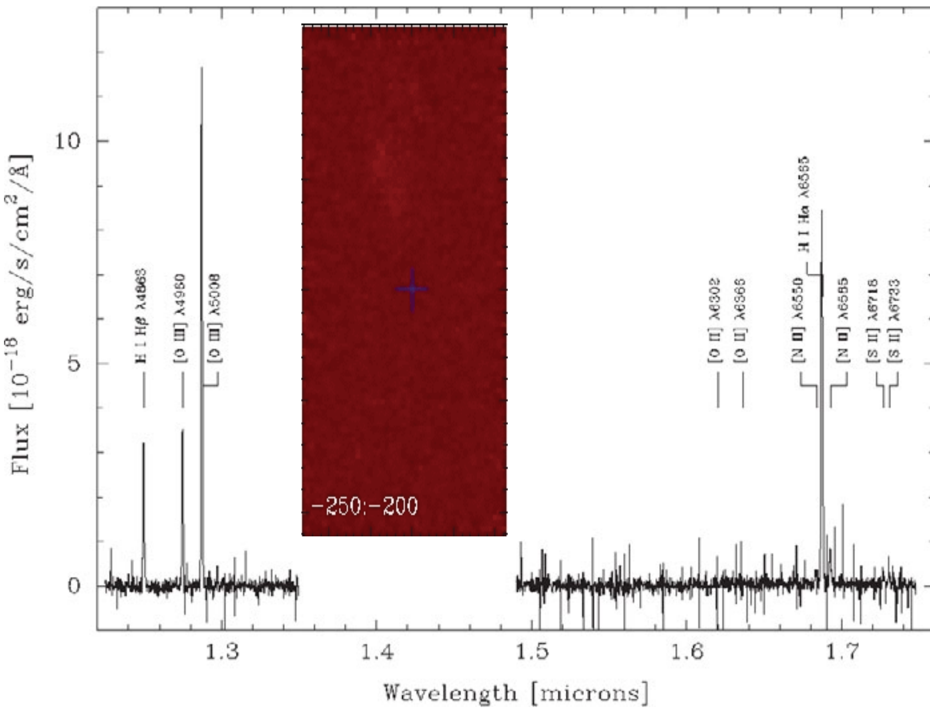




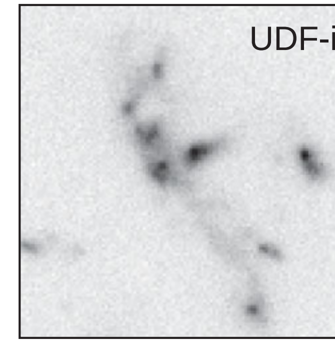


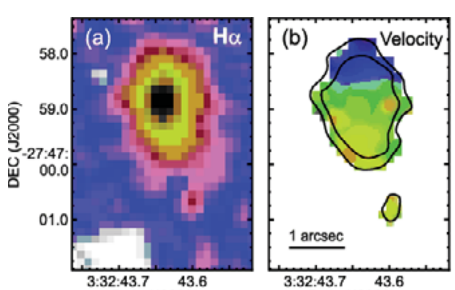
UDF6462 – GMTIFSsim

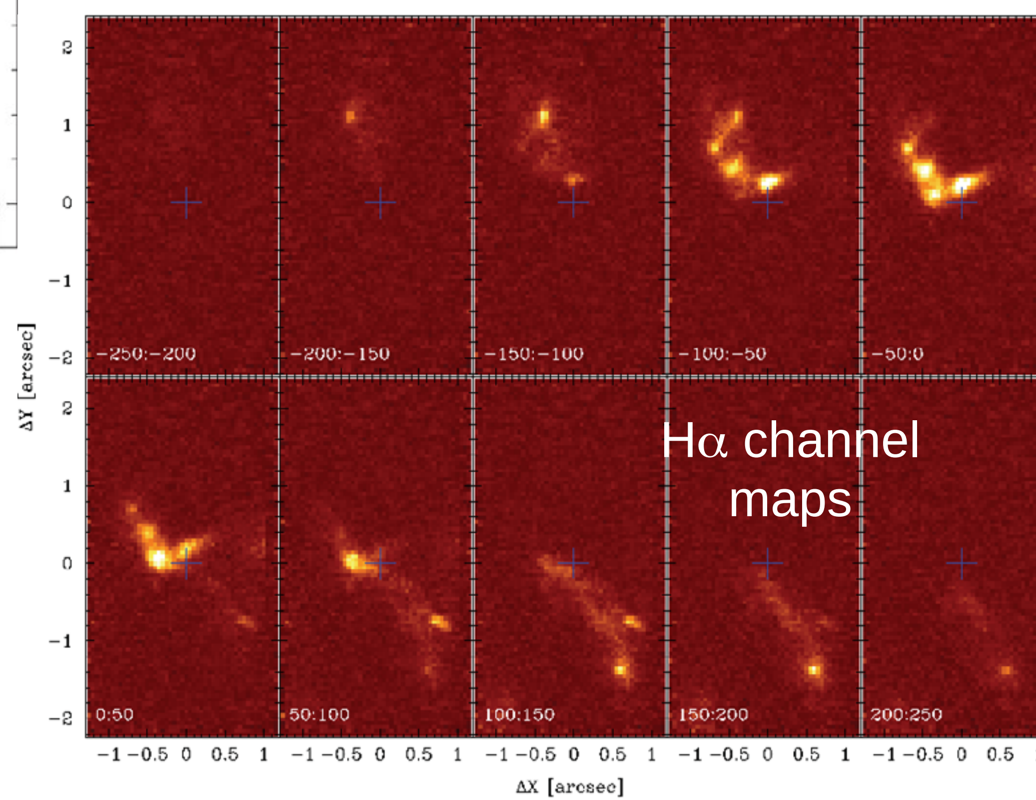
GMT



- Integration = 9+3 hours
- R ~ 5000
- Scale = 50mas
- Simulate using…
  - UDF i-band morphology
  - integrated line flux





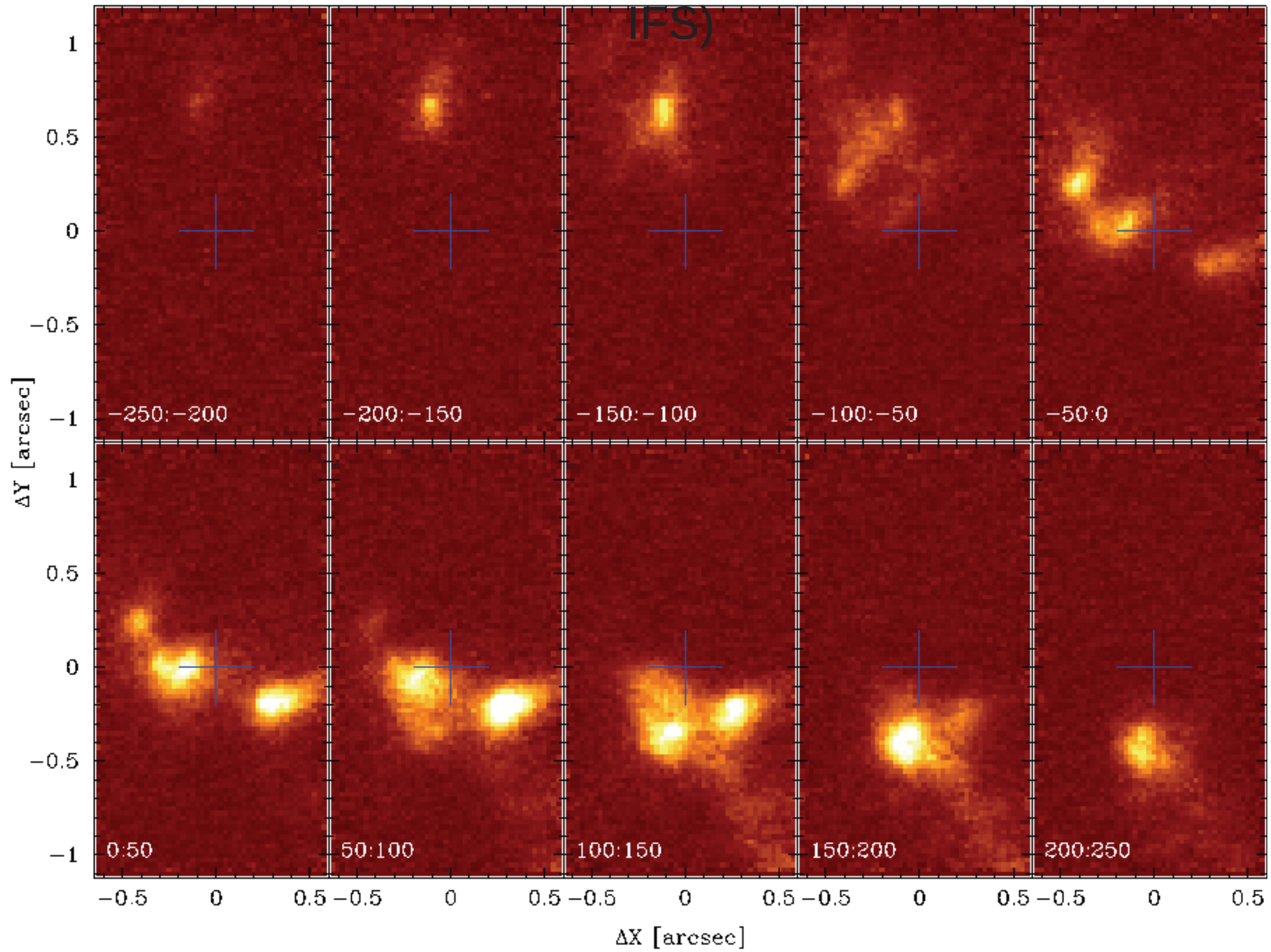


UDF6462 – GMTIFSsim

GMT

Simulation at 25mas/spaxel (x4 resolution of JWST/NIRSpec IFS)

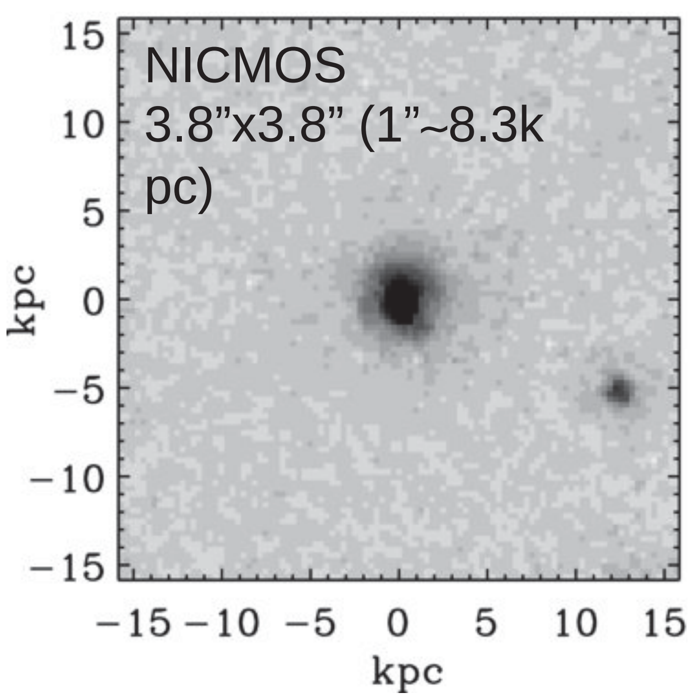
- High spatial resolution practical on bright clumps
- Galactic chemistry
- Photo/shock-driven evaporation
- Cleanly identify AGN emission
- R~10,000 (30 km/s) observations probe clump dynamics

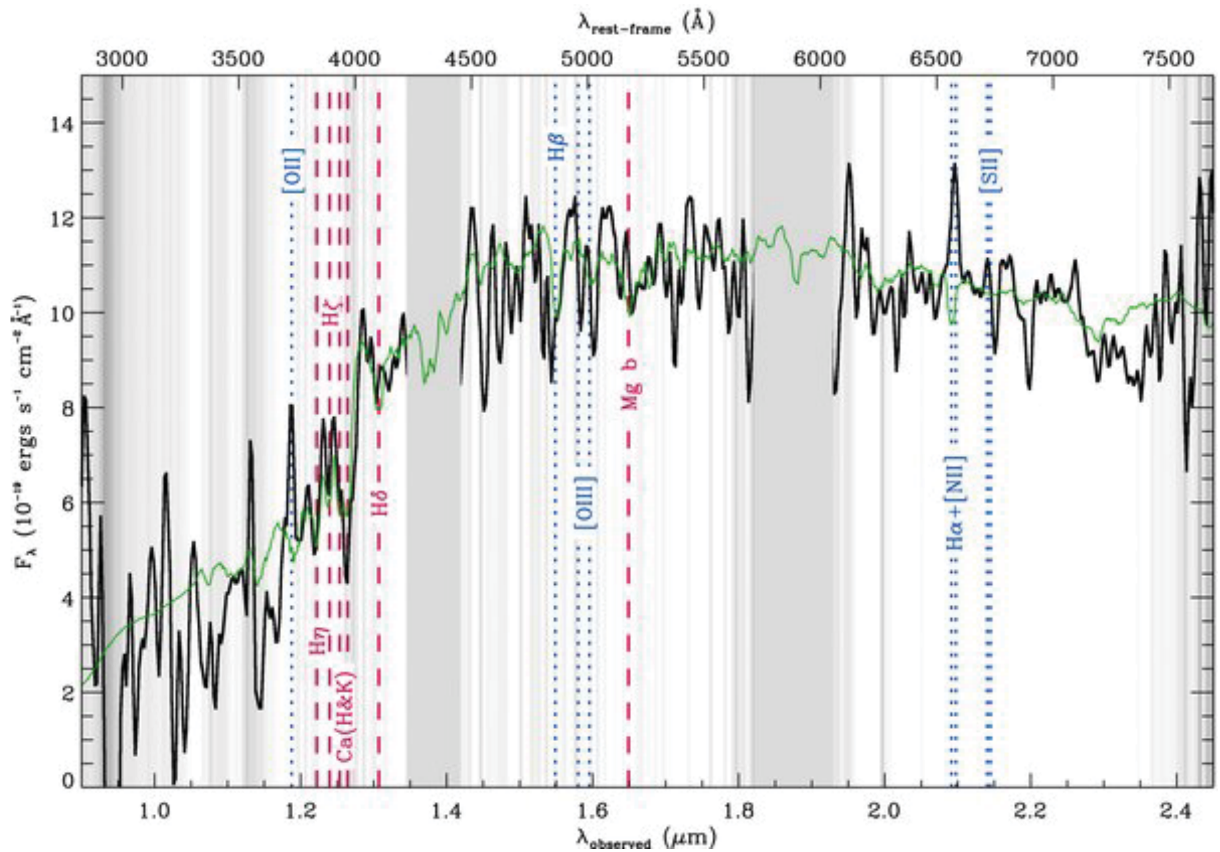


Very massive galaxies

GMT

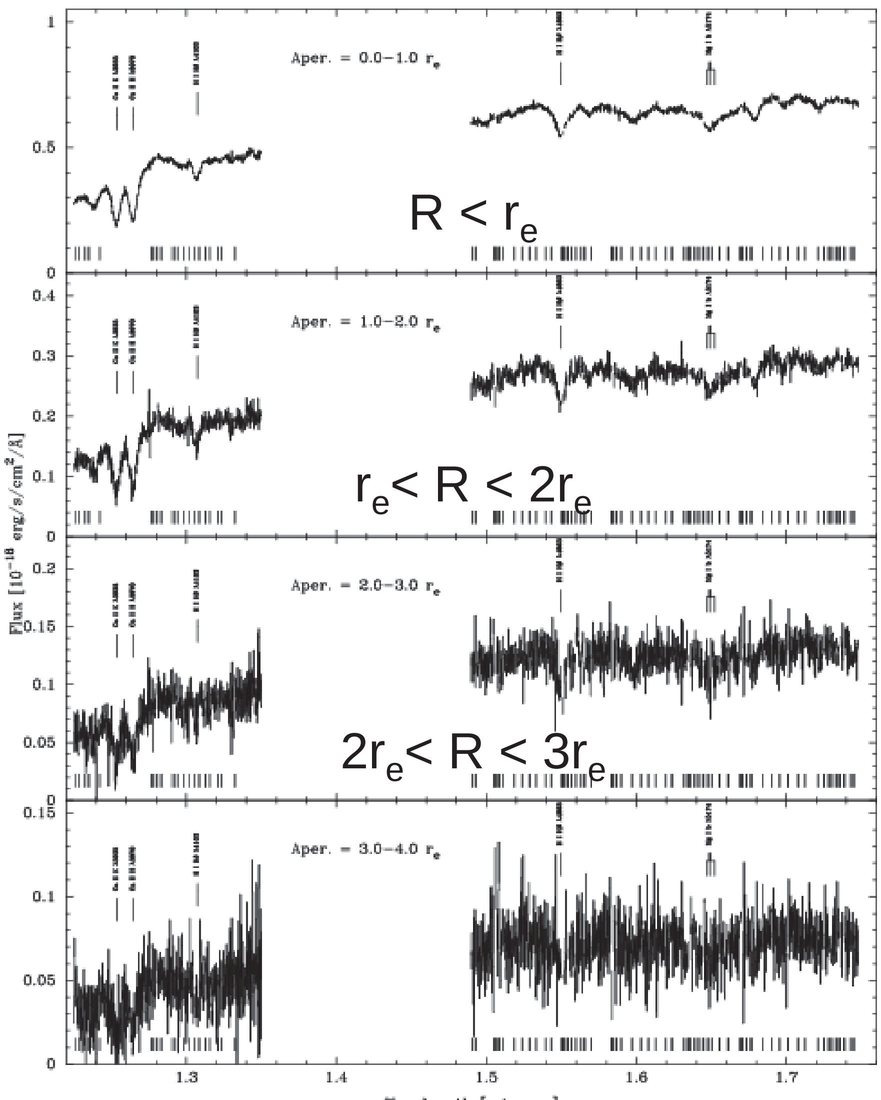
- Gemini-GNIRS 29 hours @ R~320 (i.e. 50A), smoothed
  - z=2.1865, r_e=0.78kpc [Kriek++ 2009 & Van Dokkum++ 2008]
- Compact sources with high inferred mass



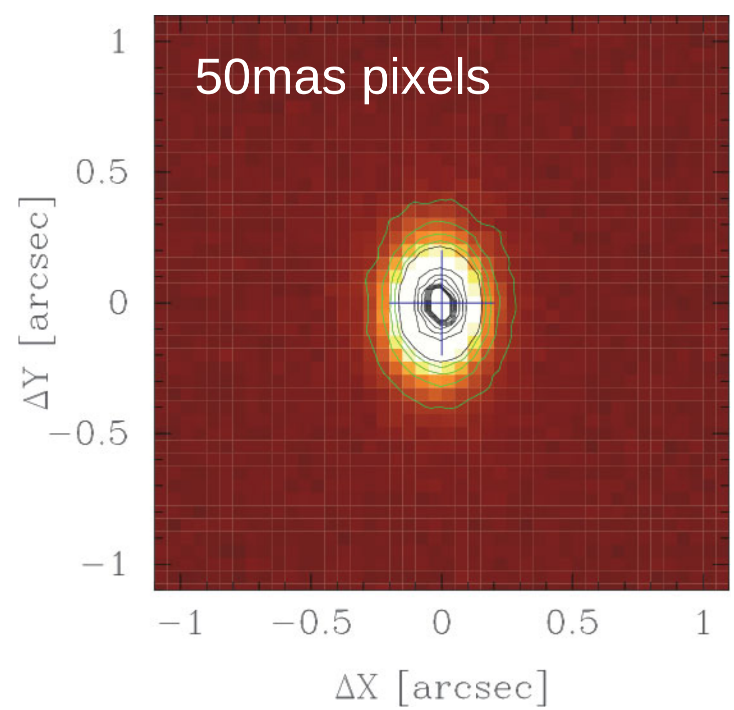


Very massive galaxies – GMTIFSsim

GMT



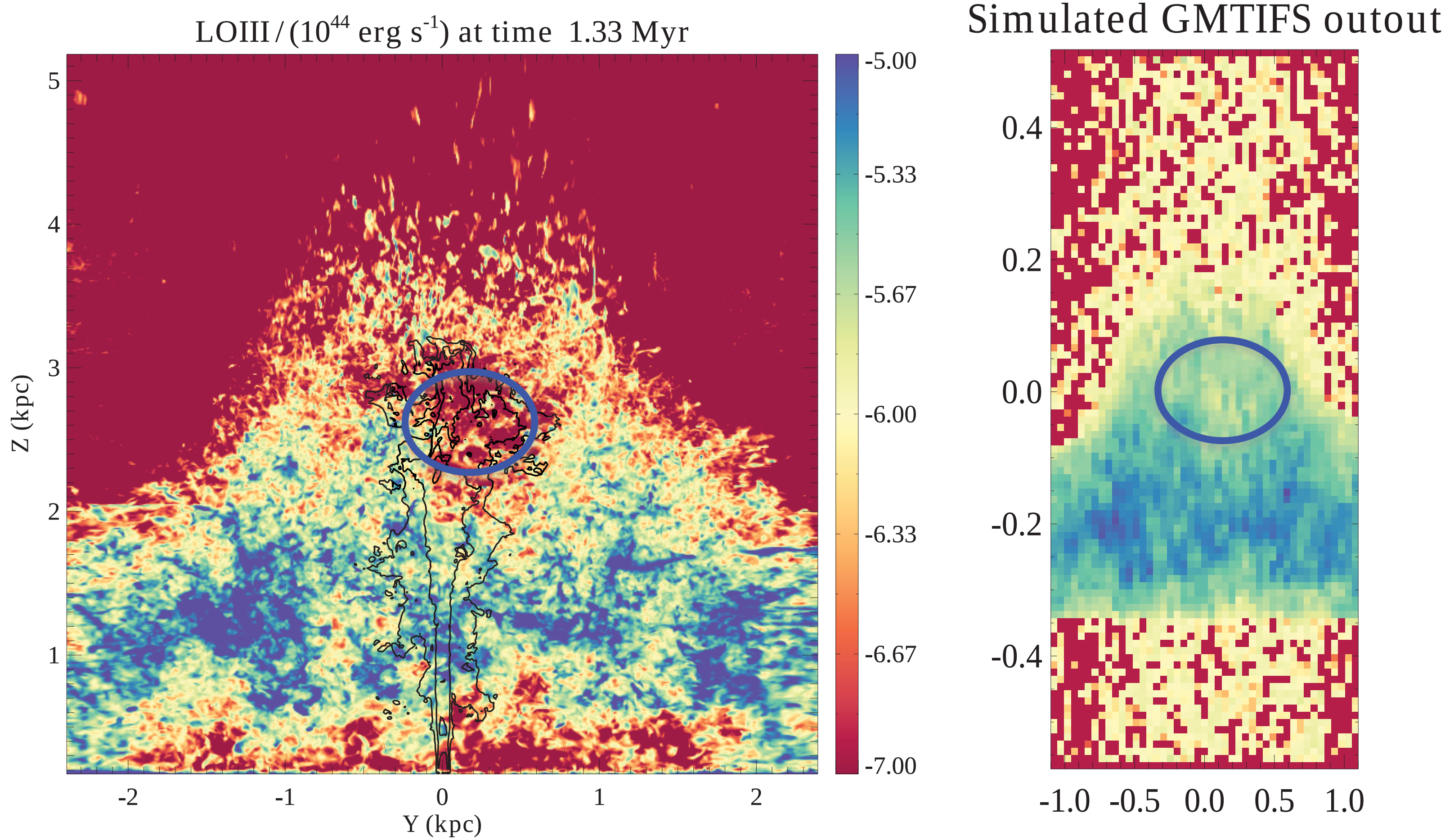
- 14 hours on-source
- Source profile from Kriek++ 2009
- Dynamical mass confirmation
- Resolve profile below r_e
- Luminosity profile beyond $2r_e$



AGN feedback – GMTIFSsim

GMT

MHD simulations of jet/ISM interactions at high redshift



MHD simulations and GMTIFS 'observation' R~10,000, 12mas spaxels, 3 hours on-source simulated integration; change in angular resolution from 8m to 25m is sufficient to begin to resolve structures [Mukherjee++ 2016]

Summary

GMT

GMT + GMTIFS will be coming soon to a mountain near you!