

# The InfraRed Multi-Slit Spectrometer (IRMS)

Luc Simard

(On behalf of Bahram Mobasher)

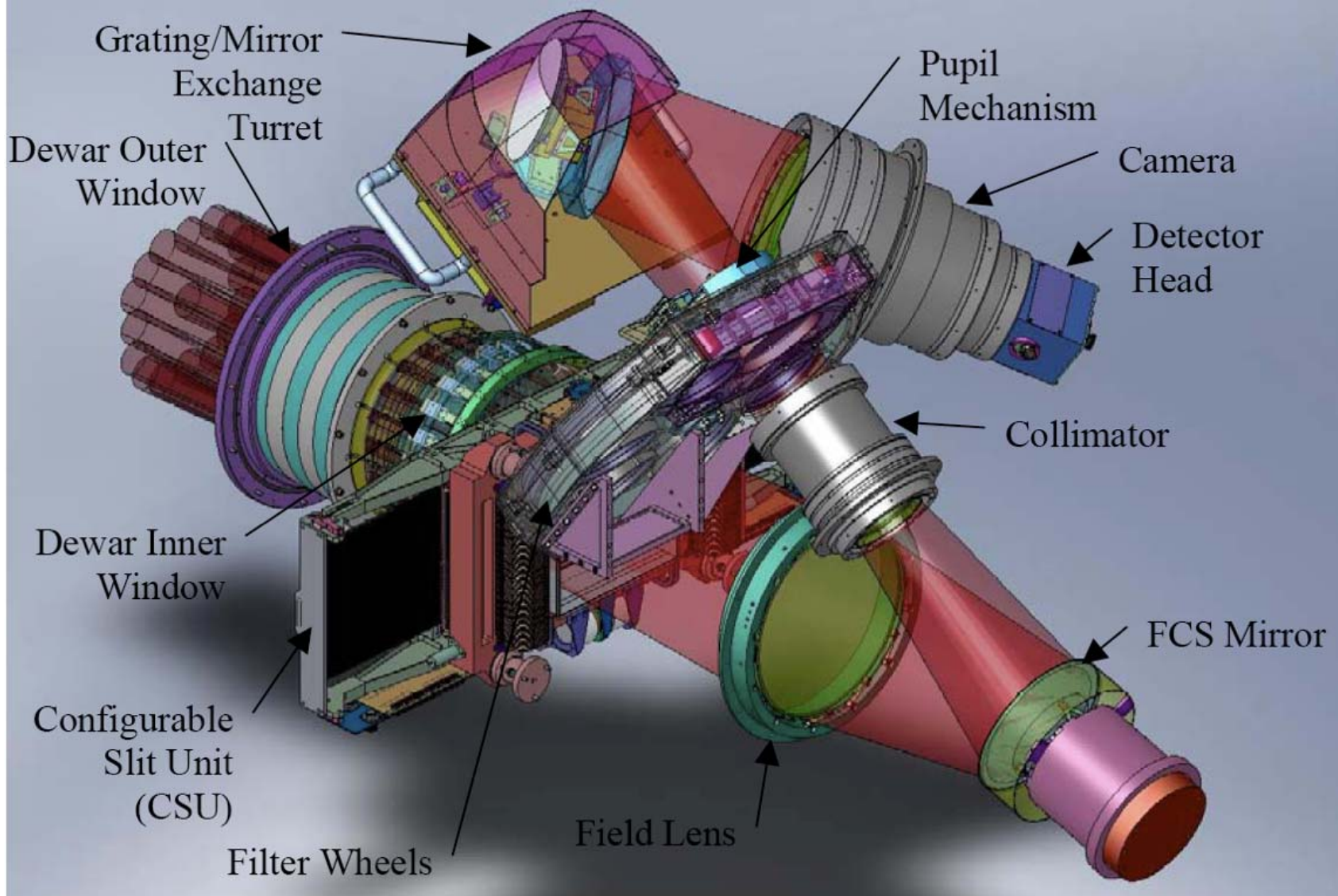
TMT Science Forum, Waikoloa, Hawaii

July 22-23, 2013

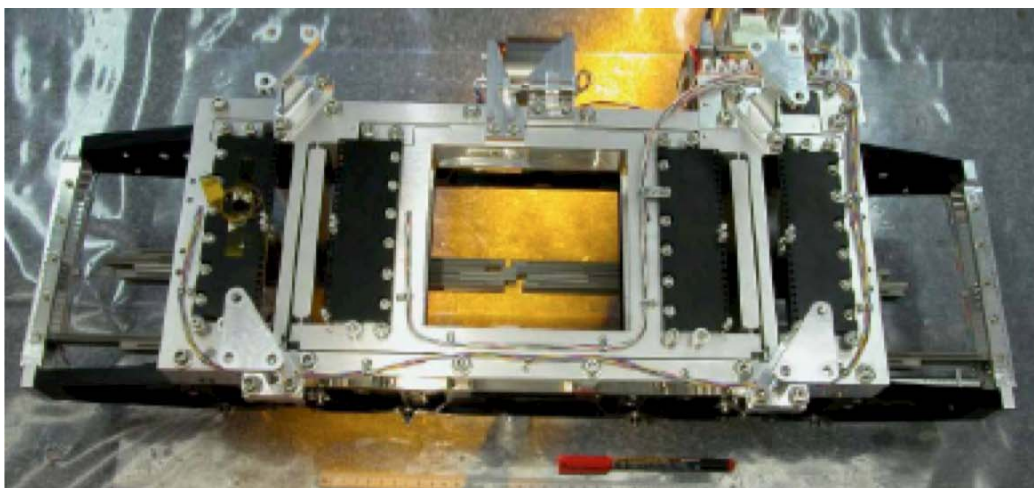
# IRMS Top-Level Requirements

Requirement #	Description	Requirement
[REQ-1-ORD-3840]	Wavelength Range	The instrument shall operate over the Y, J, H, K bands.
[REQ-1-ORD-3845]	Wavelength Coverage	The instrument shall cover an entire band at a time.
[REQ-1-ORD-3850]	Image quality	Aberrations uncorrectable by an order 60x60 AO system should not add wavefront errors larger than 30 nm RMS
[REQ-1-ORD-3855]	Field of View	Shall utilize the 2 arcminute NFIRAOS technical field.
[REQ-1-ORD-3860]	Spectral Resolution	$R > 3000$ with a 120 milliarcsecond slit
[REQ-1-ORD-3865]	Throughput	$> 35\%$ , not including telescope or NFIRAOS
[REQ-1-ORD-3870]	Imaging mode	Shall provide imaging over the full field of NFIRAOS

# InfraRed Multi-slit Spectrometer (IRMS) (aka Keck/MOSFIRE on TMT)

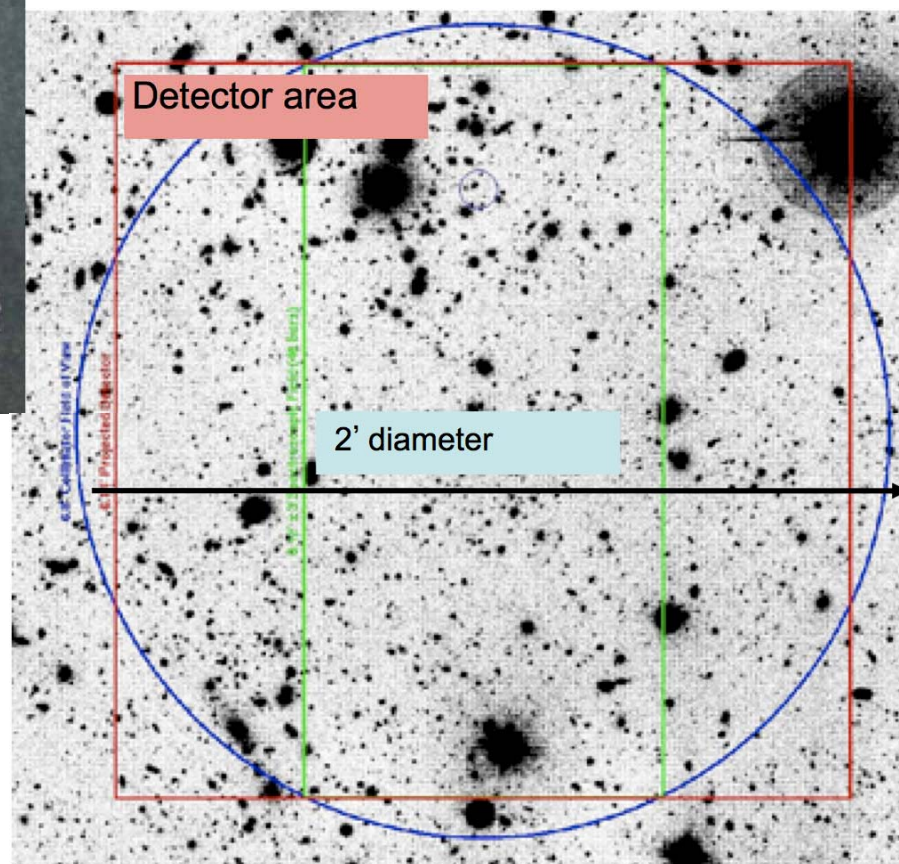


## IRMS Slit Unit & Field



CSEM configurable slit unit

- Slits formed by opposing bars
- Up to 46 slitlets
- Reconfigurable in ~3 minutes



# MOSFIRE at Keck



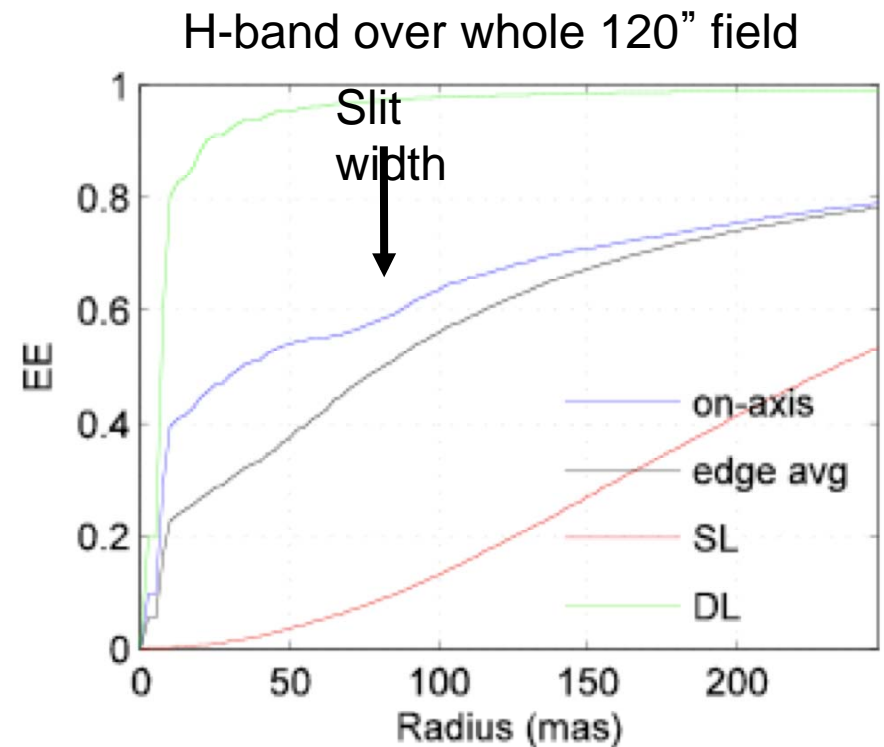
# IRMS and NFIRAOS

- IRMOS (deployable MOAO IFUs) deemed too risky and too expensive for first light

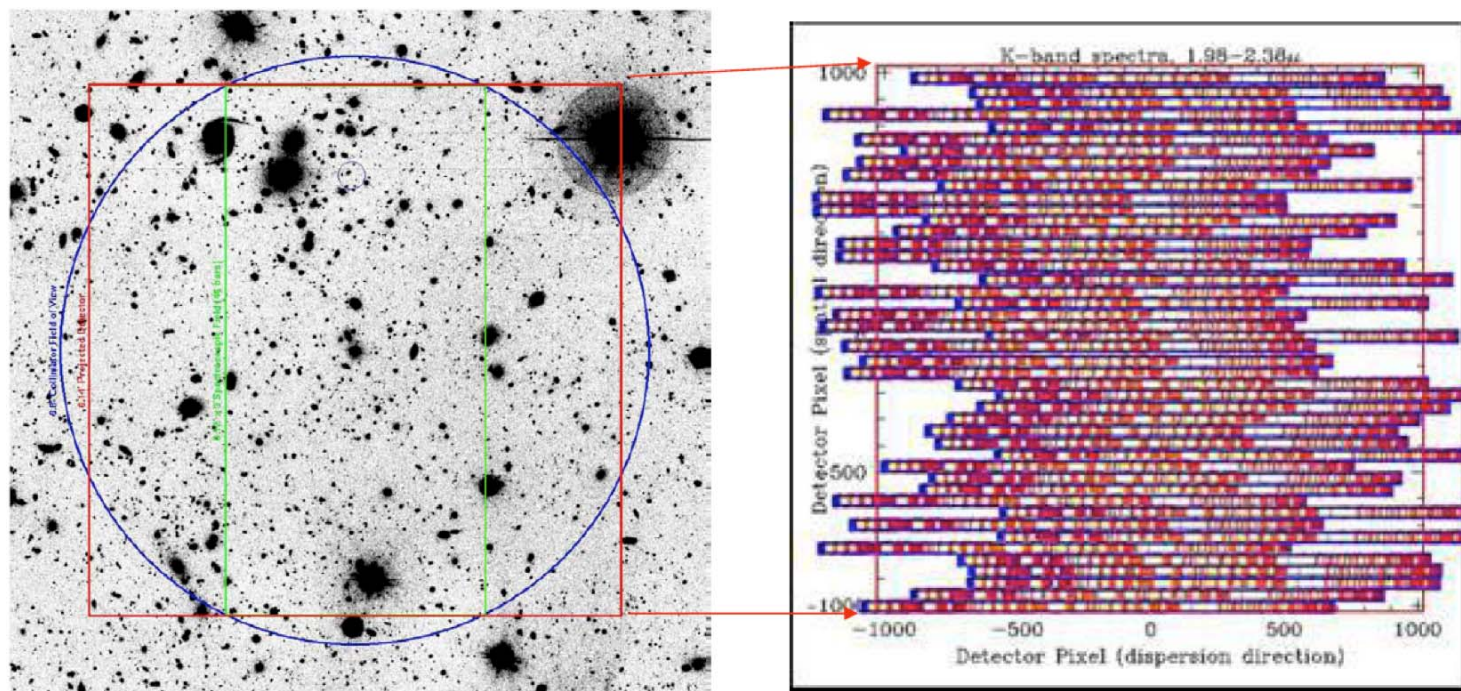
=> IRMS: clone of Keck MOSFIRE; Step 0 towards IRMOS

- Multi-slit NIR imaging spectro:
  - 46 slits, W:160+ mas, L:2.5"
- Deployed behind NFIRAOS
  - 2' field
  - 60mas pixels
  - EE good (80% in K over 30")
  - Only one OIWFS required
- Spectral resolution up to 5000
- Full Y, J, H, K spectra

- Imager as well



# IRMS Spectra



Full Y, J, H, K spectra with  $R \sim 5000$  with 160mas (2 pix) slits in central  $\sim 1/3$  of field

# Broad IRMS Science

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- ✓ Near-IR spectroscopy of resolved faint sources (nearby or at high-z)
  - ✓ Spectroscopy of sources with number densities  $\sim 10$  per arcmin<sup>2</sup>
    - ✓ Spectroscopy requiring low sky background
    - ✓ Spectroscopy requiring high spatial resolution
  - ✓ High spatial resolution imaging of faint sources
    - ✓ Imaging/spectroscopy of crowded fields
  - ✓ Narrow-band selection of line-emitting sources

# First Light

- 
- Primordial (population III) stars are expected to be at  $z \sim 7-20$  (Ciardi et al 2006). Confirming the presence of such stars and studying the redshift distribution of their host galaxies provides strong constraints on galaxy formation scenarios.
  - Population III stars produce a radiation field which would ionize primordial Helium gas. Therefore, presence of **HeII1640 A** reveals existence of such population. This has 10% of the strength of Ly $\alpha$  lines in these systems
  - Since Pop III stars are short-lived (a few Myrs), a number of such systems have to be studied.

TMT/IRMS can detect HeII 1640 lines out to  $z \sim 13$ , due to high spectral resolution, wavelength coverage and multiplexing capability of IRMS. Since the number density of Pop III stars is high and their life-time short, the spectroscopic field of view of IRMS is crucial

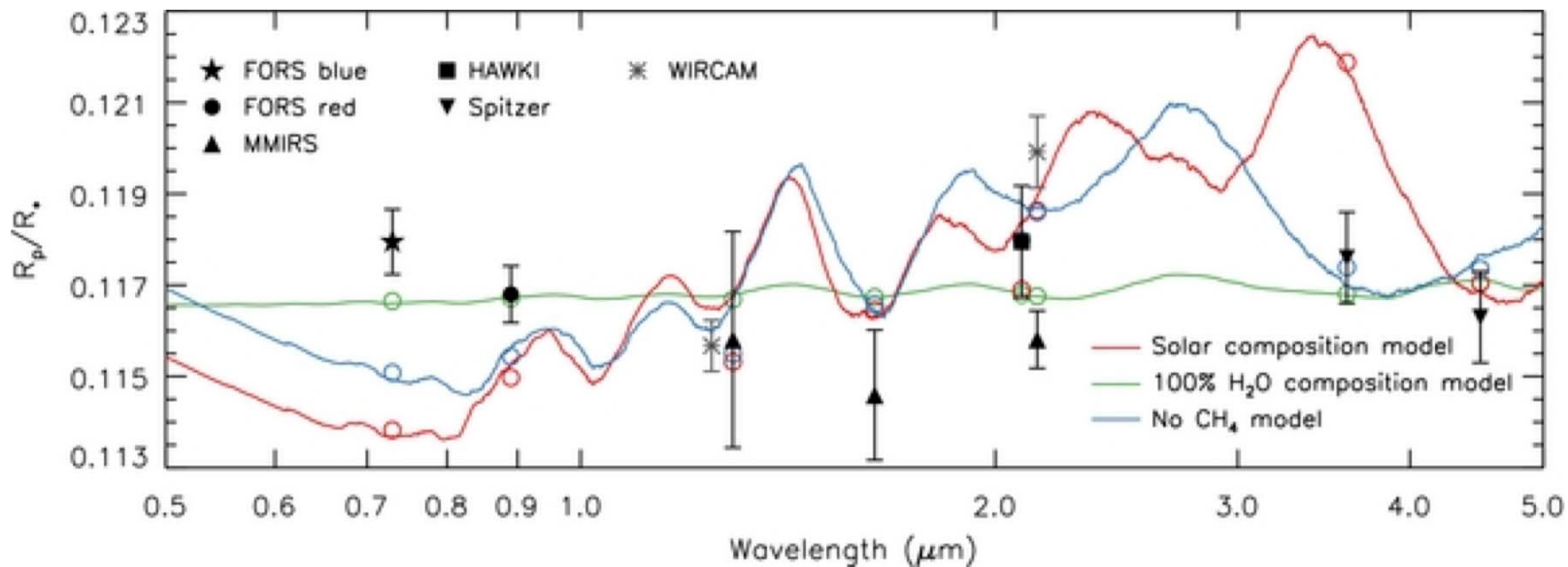
# Gamma Ray Bursts and Supernovae

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- TMT/IRMS can detect optical afterglow of GRBs to  $z \sim 10$ , where one could detect Lyman alpha line emissions in the J-band. For GRBs at  $z \sim 4-5$  one could measure [NII]/Ha and hence, the metallicity of the GRB progenitor and hence, their nature.
- TMT/IRMS can do follow-up spectroscopy of type II SNe to  $z \sim 6$ . The progenitors of these SNe are massive stars ( $80 M_{\text{Sun}}$ ). Such observations allow study of the high-end of the stellar luminosity function and the IMF.

# Transiting Exoplanet Atmospheres

- Near-IR multi-object spectroscopy is needed to reveal atmospheric compositions of exoplanets



Broadband measurements of the transmission spectrum of GJ 1214b (filled points) compared to theoretical models (lines). The models were binned over the bandpasses of the measurements (open circles) and scaled to give the best fit to the data. (From Bean et al. 2011)

# IRMS Predicted Sensitivity

Passband	Spec. Sky Brightness (mag arcsec <sup>-2</sup> ) Vega (AB)	Vega (AB) mag for SNR = 10 in 1000s, R=3270 with 0".23 slit	Line flux for SNR = 10 (unresolved line) in 1000s, R=3270 (ergs s <sup>-1</sup> cm <sup>-2</sup> )
Y (0.97 to 1.13 μm)	17.3 (17.9)	23.4 (24.0)	7.0x10 <sup>-19</sup>
J (1.15 to 1.35 μm)	16.8 (17.7)	23.0 (23.9)	7.4x10 <sup>-19</sup>
H (1.48 to 1.80 μm)	16.6 (18.0)	22.7 (24.1)	4.7x10 <sup>-19</sup>
K (1.95 to 2.40 μm)	14.4 (16.3)	21.2 (23.1)	8.5x10 <sup>-19</sup>

Table notes: Spectroscopic limits assume 0.05 e-/s dark current and effective read noise of 4 e-/pixel, with background for spectral regions between OH line, evaluated over a 3-pixel resolution element and assuming a 0.05 arcsec<sup>2</sup> extraction aperture

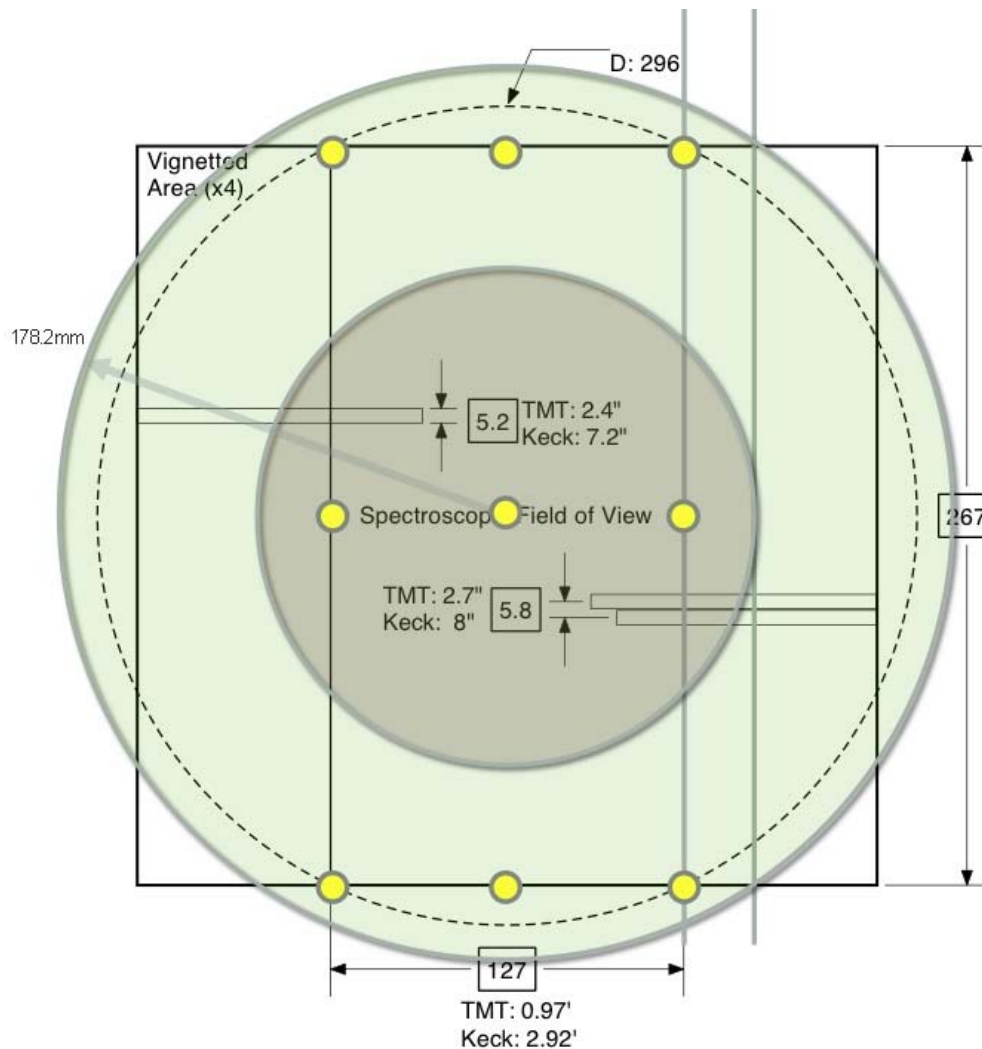
Source: Table 5-1, TMT Detailed Science Case: 2007



**TMT**

THIRTY METER TELESCOPE

# IRMS NFIRAOS Encircled Energy



NFIRAOS simulation results  
Ensquared energy in 160mas

enc(:, :, J) =

0.2110	0.2364	0.2126
0.3081	0.4733	0.3134
0.2114	0.2367	0.2139

enc(:, :, H) =

0.2891	0.3234	0.2916
0.4167	0.5874	0.4227
0.2921	0.3242	0.2952

enc(:, :, Ks) =

0.3783	0.4148	0.3828
0.5218	0.6816	0.5339
0.3854	0.4233	0.3896

● = field points reported above

# Exposure Time Calculator

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- IDL widget by Vivian U (UC Riverside), but can work as a stand-alone piece of software for users without IDL license (using IDL virtual machine)
- Based on MOSFIRE ETC (written by Gwen Rudie)



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# ETC GUI

XTCalc: IRMS Exposure Time Calculator v0.1 by Vivian U (Adopted from MOSFIRE ETC by Gwen Rudie)

Atmospheric Window **K** NFIRAOS mode **no AO**

Slit Width  arcseconds      Number of Exp.

Angular extent  arcseconds      Fowler Sampling  paired reads

Input a line flux or broad-band magnitude:  
 Use Line Flux     Use Magnitude

Line Flux   $1E-18$  erg/s/cm<sup>2</sup>

Central Wavelength   Angstroms     Microns

Redshift

Source FWHM  km/s

Magnitude   AB     Vega    Type of Spectrum

Filename  ASCII: (Iam f\_nu)

wavelength unit  Angstroms     Microns    Redshift

Input an exposure time or a desired signal to noise ratio:  
 Determine Exposure Time     Determine Signal to Noise

Total Exposure Time  seconds    Desired S/N

Optional Input: Airmass and Water Vapor  
 Use Default     Input Airmass and Water Vapor Column

Airmass:  1.0     1.5     2.0

Water Vapor (mm):  1.0     1.6     3.0     5.0

```

*****
IRMS XTCalc
*****
Calculation for a 1000.00 second integration
through a 0.2 arcsecond slit in K band

```

Wavelength	2.1658	micron
Resolution	6.0	FWHM in angstrom
Dispersion	2.17	angstrom/pixel
Throughput	0.34	
Signal	15498.78	electrons per FWHM
Sky Background	251362.85	electrons per FWHM
Sky brightness	15.38	AB mag per sq. arcsec
Dark Current	171.06	electrons per FWHM
Read Noise	10.34	electrons per FWHM
Total Noise	719.91	electrons per FWHM
S/N	21.4	per observed FWHM
Total Exposure Time	1000.00	seconds
Max e- per pixel	8024	electrons per pixel per exp

Plot Observations     Plot Signal to Noise

Plot Wavelengths  Default     User Specified     ---  micron

Write to File  Throughput     Transmission     Background  
 Signal     Noise     S/N



# ETC GUI

XTCalc: IRMS Exposure Time Calculator v0.1 by Vivian U (Adopted from MOSFIRE ETC by Gwen Rudie)

Atmospheric Window  NFIRAOS mode

Slit Width  arcseconds      Number of Exp.

Angular extent  arcseconds      Fowler Sampling  paired reads

Input a line flux or broad-band magnitude:  
 Use Line Flux    Use Magnitude

Line Flux   $1E-18$  erg/s/cm<sup>2</sup>

Central Wavelength

Redshift

Source FWHM  km/s

Magnitude    Type of Spectrum

Filename  ASCII: (lan f\_04)

wavelength unit   Redshift

Input an exposure time or a desired signal to noise ratio:  
 Determine Exposure Time    Determine Signal to Noise

Total Exposure Time  seconds      Desired S/N

Optional Input: Airmass and Water Vapor  
 Use Default    Input Airmass and Water Vapor Column

Airmass	Water Vapor (mm)
<input type="button" value="1.4"/> <input type="button" value="1.5"/> <input type="button" value="2.0"/>	<input type="button" value="1.4"/> <input type="button" value="1.6"/> <input type="button" value="3.0"/> <input type="button" value="5.0"/>

Plot Observations  Plot Signal to Noise

Plot Wavelengths  Default    User Specified    ---  micron

Write to File  Throughput    Transmission    Background  
 Signal    Noise    S/N

Input:

Filter: Y, J, H, K

NFIRAOS: AO / no AO

Slit Width

Angular Extent

Number of Exposures

Fowler Sampling



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# ETC GUI

XTCalc: IRMS Exposure Time Calculator v0.1 by Vivian U (Adopted from MOSFIRE ETC by Gwen Rudie)

Atmospheric Window  NFIRAOS mode

Slit Width  arcseconds Number of Exp.

Angular extent  arcseconds Fowler Sampling  paired reads

Input a line flux or broad-band magnitude:

Use Line Flux  Use Magnitude

Line Flux   $1E-18$  erg/s/cm<sup>2</sup>

Central Wavelength   Angstroms  Microns

Redshift

Source FWHM  km/s

Magnitude   AB  Vega Type of Spectrum

Filename  ASCII: (lan f\_04)

wavelength unit  Angstroms  Microns Redshift

Input an exposure time or a desired signal to noise ratio:

Determine Exposure Time  Determine Signal to Noise

Total Exposure Time  seconds Desired S/N

Optional Input: Airmass and Water Vapor

Use Default  Input Airmass and Water Vapor Column

Airmass  Water Vapor (mm)

Calculate  Exit

\*\*\*\*\*  
IRMS XTCalc  
\*\*\*\*\*  
Calculation for a 1000.00 second integration  
through a 0.2 arcsecond slit in K band

Wavelength	2.1658	micron
Resolution	6.0	FWHM in angstrom

Input:

Line – Flux,  $\lambda_c$ , z, FWHM  
or  
Magnitude – AB/Vega,  
Spectrum, z

Transmission

Atmosphere  
Throughput  
Sky Resid  
Science

Wavelength [micron]

Write to File  Throughput  Transmission  Background  
 Signal  Noise  S/N

# ETC GUI

XTCalc: IRMS Exposure Time Calculator v0.1 by Vivian U (Adopted from MOSFIRE ETC by Gwen Rudie)

Atmospheric Window  NFIRAOS mode

Slit Width  arcseconds Number of Exp.

Angular extent  arcseconds Fowler Sampling  paired reads

Input a line flux or broad-band magnitude:  
 Use Line Flux  Use Magnitude

Line Flux   $1E-18$  erg/s/cm<sup>2</sup>

Central Wavelength   Angstroms  Microns

Redshift

Source FWHM  km/s

Magnitude   H $\beta$   Vega Type of Spectrum

Filename  ASCII: (lan f<sub>nu</sub>)

wavelength unit  Angstroms  Microns Redshift

Input an exposure time or a desired signal to noise ratio:  
 Determine Exposure Time  Determine Signal to Noise

Total Exposure Time  seconds Desired S/N

Use Default  Input Airmass and Water Vapor Column

Airmass  Water Vapor (mm)

Calculate  Exit

```

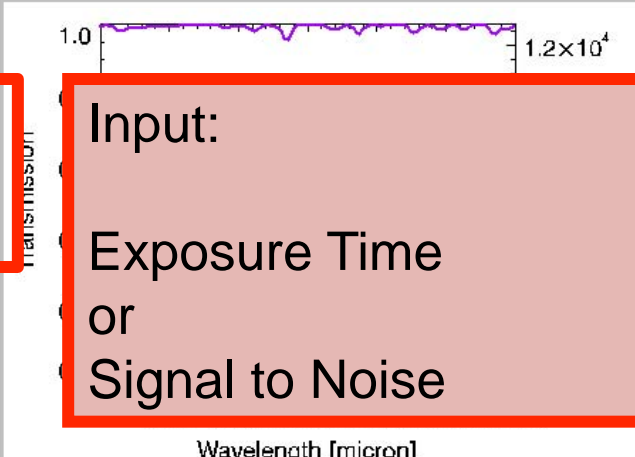
*****
IRMS XTCalc
*****
Calculation for a 1000.00 second integration
through a 0.2 arcsecond slit in K band

```

Wavelength	2.1658	micron
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Dispersion	2.17	angstrom/pixel
Throughput	0.34	
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Total Noise	719.91	electrons per FWHM
S/N	21.4	per observed FWHM
Total Exposure Time	1000.00	seconds
Max e- per pixel	8024	electrons per pixel per exp

Plot Observations  Plot Signal to Noise

Plot Wavelengths  Default  User Specified   micron



transmission

Wavelength [micron]

Write to File  Throughput  Transmission  Background  
 Signal  Noise  S/N

Input:

Exposure Time  
or  
Signal to Noise



# ETC GUI

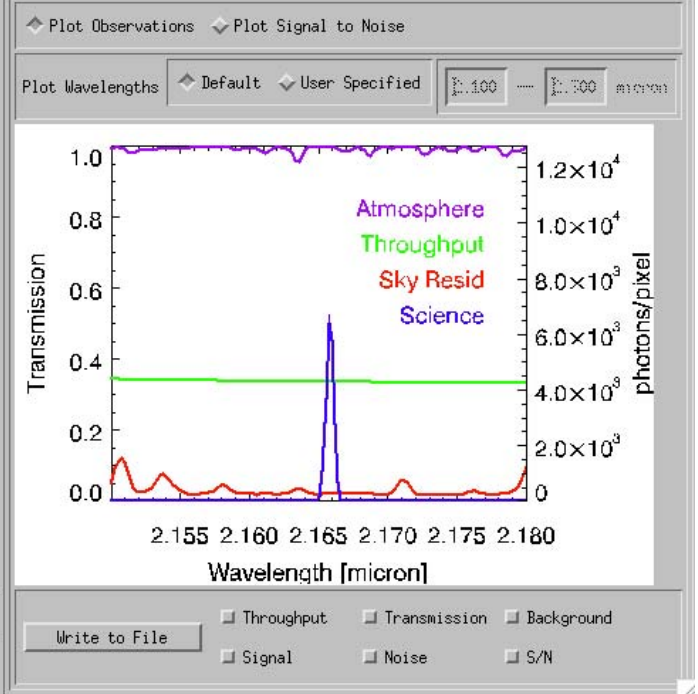
Output:

- Wavelength
- Resolution
- Dispersion
- Throughput
- Signal
- Sky Background
- Sky Brightness
- Dark Current
- Readnoise
- Total noise
- S/N
- Exposure Time

(Adopted from MOSFIRE ETC by Gwen Rudie)

IRMS XTCalc  
Calculation for a 1000.00 second integration through a 0.2 arcsecond slit in K band

Wavelength	2.1658	micron
Resolution	6.0	FWHM in angstrom
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S/N	21.4	per observed FWHM
Total Exposure Time	1000.00	seconds
Max e- per pixel	8024	electrons per pixel per exp





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# ETC GUI

XTCalc: IRMS Exposure Time Calculator v0.1 by Vivian U (Adopted from MOSFIRE ETC by Gwen Rudie)

Atmospheric Window: K      NFIRAOS mode: no AO

Slit Width: 0.16 arcseconds      Number of Exp.: 2

Angular extent: 0.7 arcseconds      Fowler Sampling: 16 paired reads

Input a line flux or broad-band magnitude:  
 Use Line Flux     Use Magnitude

Line Flux: 3.0 1E-18 erg/s/cm<sup>2</sup>

Central Wavelength: 2.563     Angstroms     Microns

Redshift: 2.3

Source FWHM: 30 km/s

***** IRMS XTCalc *****		
***** Calculation for a 1000.00 second integration through a 0.2 arcsecond slit in K band *****		
Wavelength	2.1658	micron
Resolution	6.0	FWHM in angstrom
Dispersion	2.17	angstrom/pixel
Throughput	0.34	
Signal	15498.78	electrons per FWHM
Sky Background	251362.85	electrons per FWHM
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Total Noise	719.91	electrons per FWHM
S/N	21.4	per observed FWHM
Total Exposure Time	1000.00	seconds
Max e- per pixel	8024	electrons per pixel per exp

Plot Observations     Plot Signal to Noise

Plot Wavelengths:  Default     User Specified    [ 1.100 ] [ 3.000 ] micron

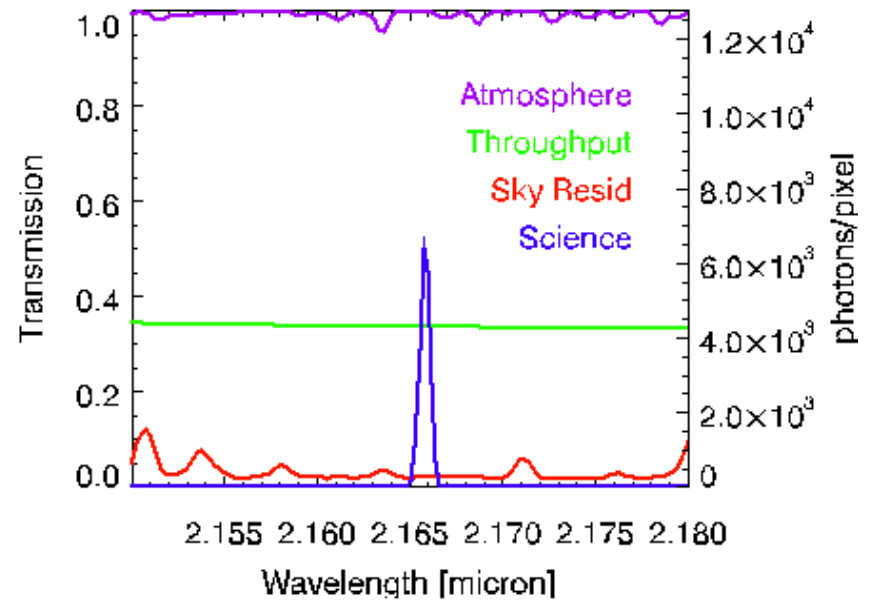
Write to File     Throughput     Transmission     Background  
 Signal     Noise     S/N

Output:

Plot observations or S/N  
Can write to file

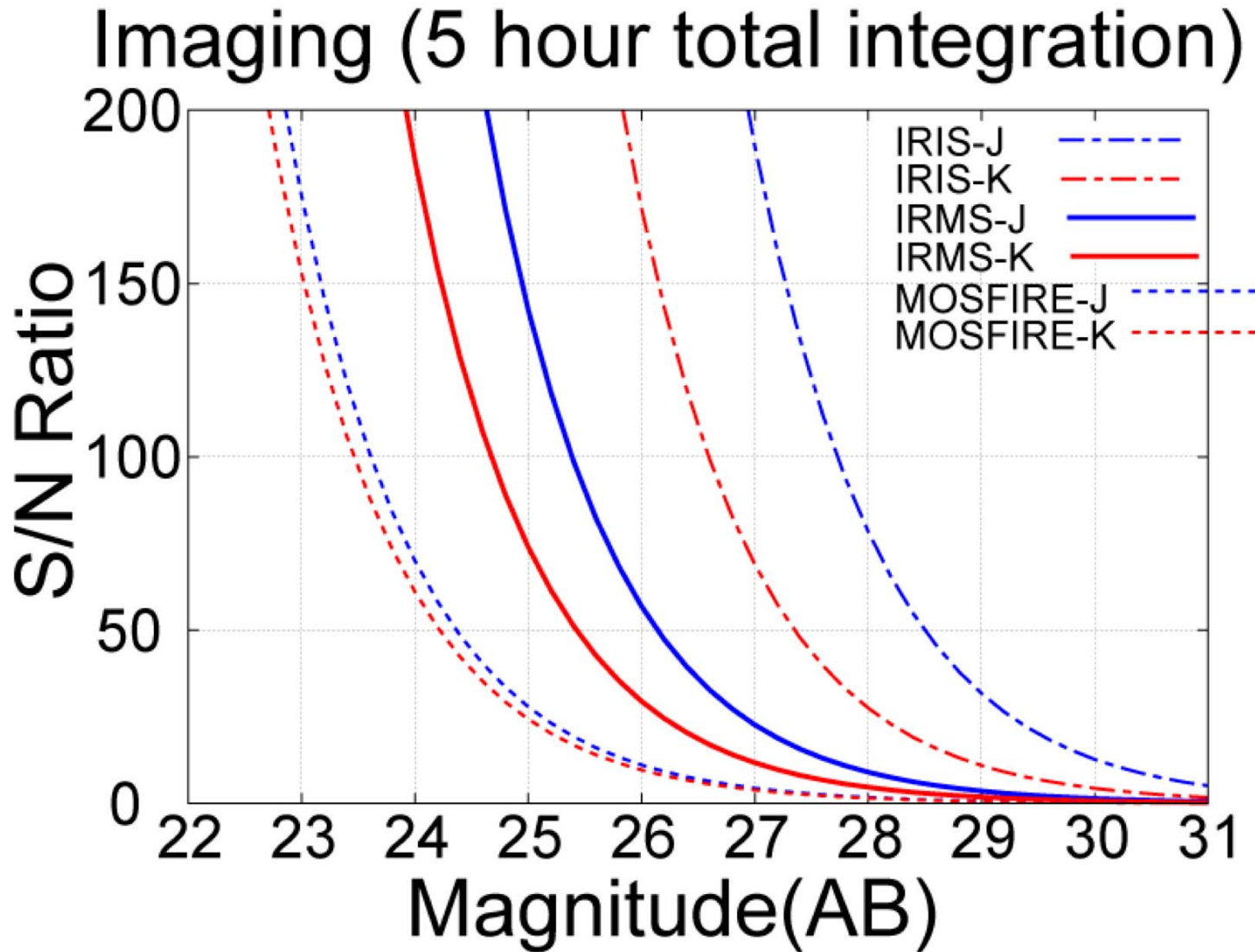
## ETC Example

- H $\alpha$  at  $z = 2.3$
- FWHM = 6Å
- Dispersion = 2.17 Å/pixel



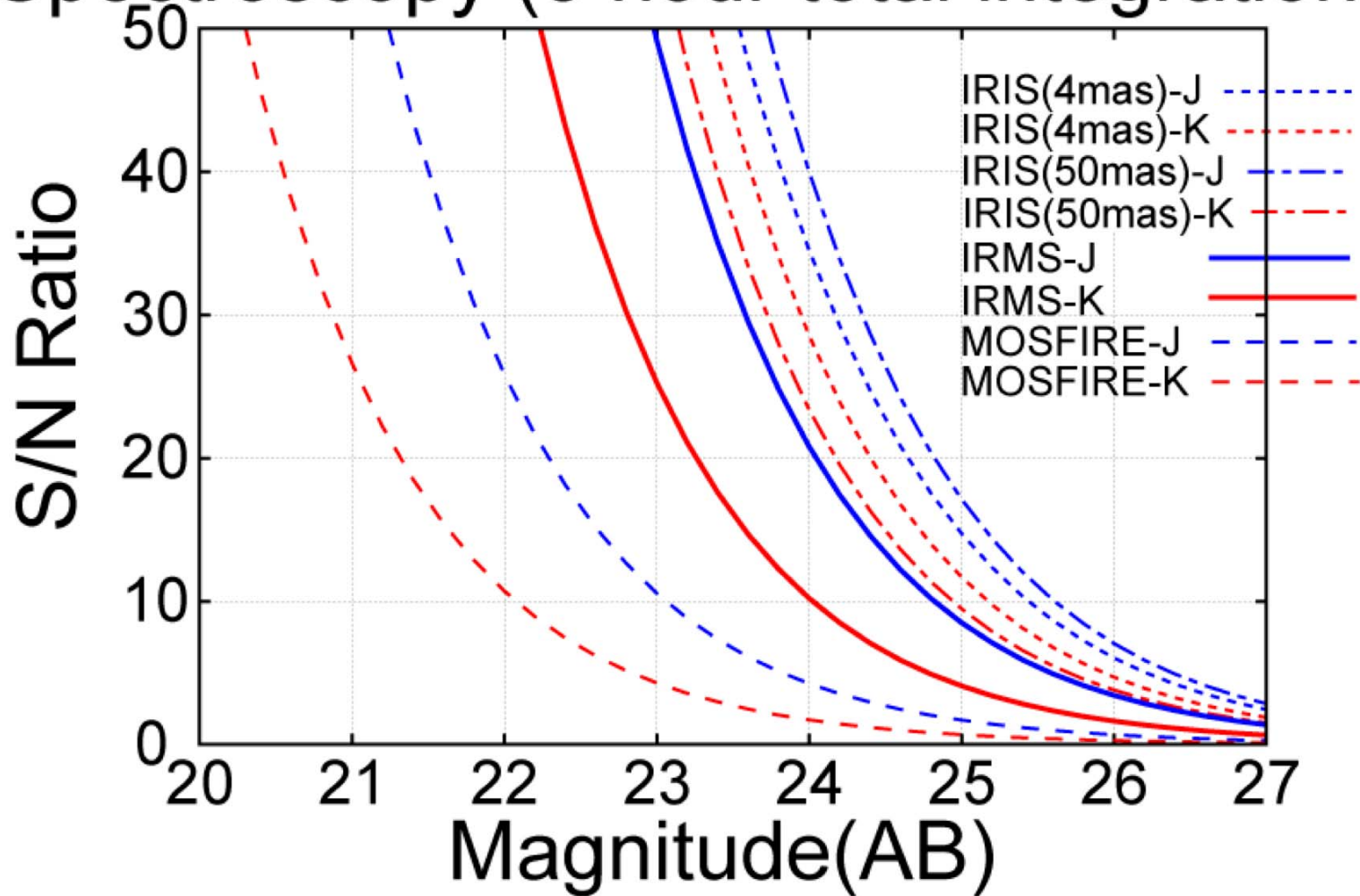
- Exposure time of 1000sec in non-AO yield SNR of 21.4 per observed FWHM

# IRMS Imaging Sensitivity: Comparison with IRIS and MOSFIRE



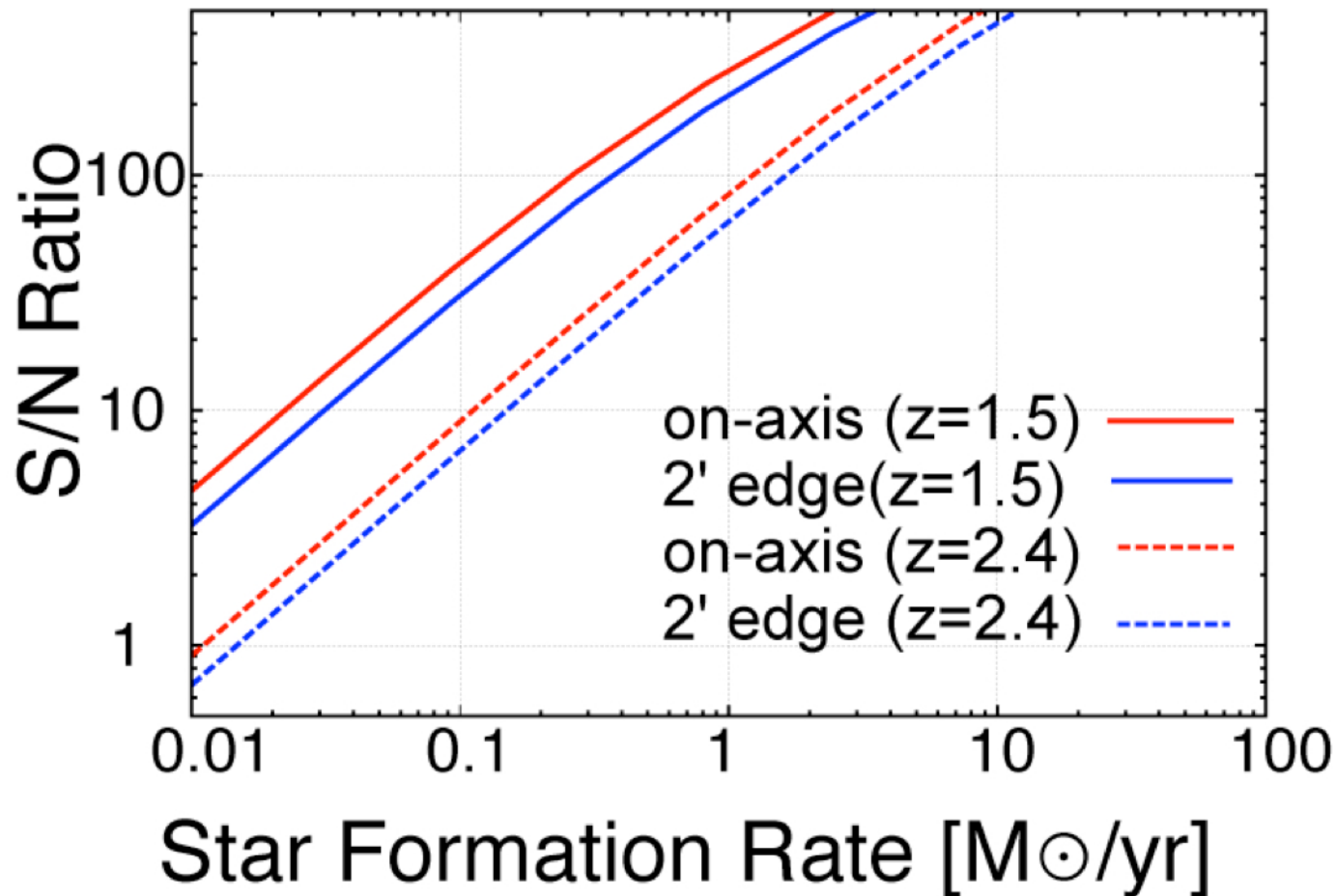
# IRMS MOS Sensitivity: Comparison with IRIS and MOSFIRE

Spectroscopy (5 hour total integration)



# IRMS MOS Sensitivity: H-alpha Emission Line

H $\alpha$  (5 hour total integration)

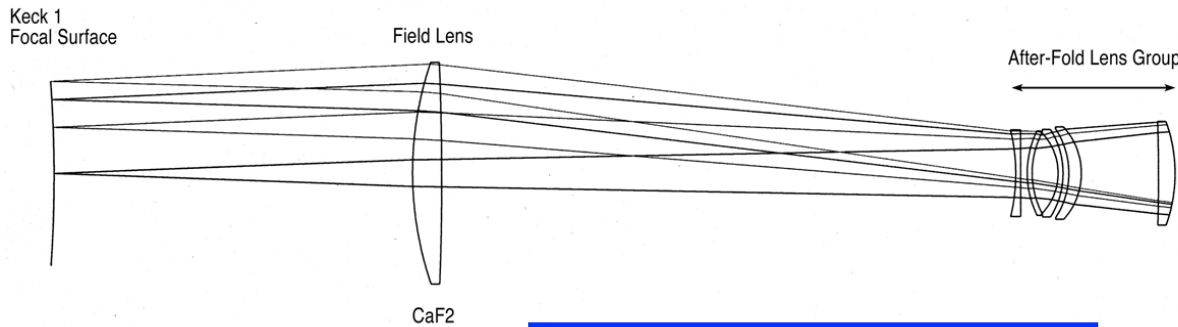


H $\alpha$ @z=1.5 (H-band)  
 H $\alpha$ @z=2.4 (K-band)

Dispersion 80 km/s  
 5 hour exposure

160mas  
 1.37kpc@z=1.5  
 1.32kpc@z=2.4

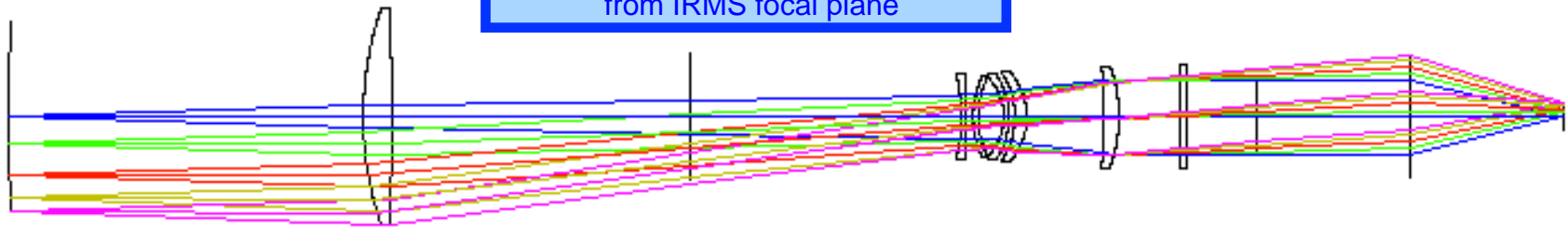
# IRMS Mini-study Optical Design



Keck: 2.1-m ROC focal plane with exit pupil 20m away from MOSFIRE focal plane

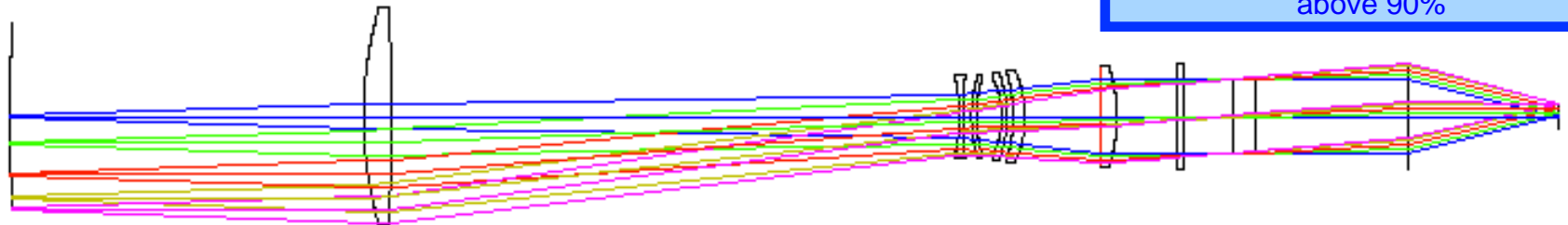
TMT Focal Surface

TMT/NFIRAOS: -1.3-m ROC focal plane with exit pupil 188m away from IRMS focal plane



Yields 85% ensquared energy in all fields and bands with almost all above 90%

After Collimator+Camera Reoptimization

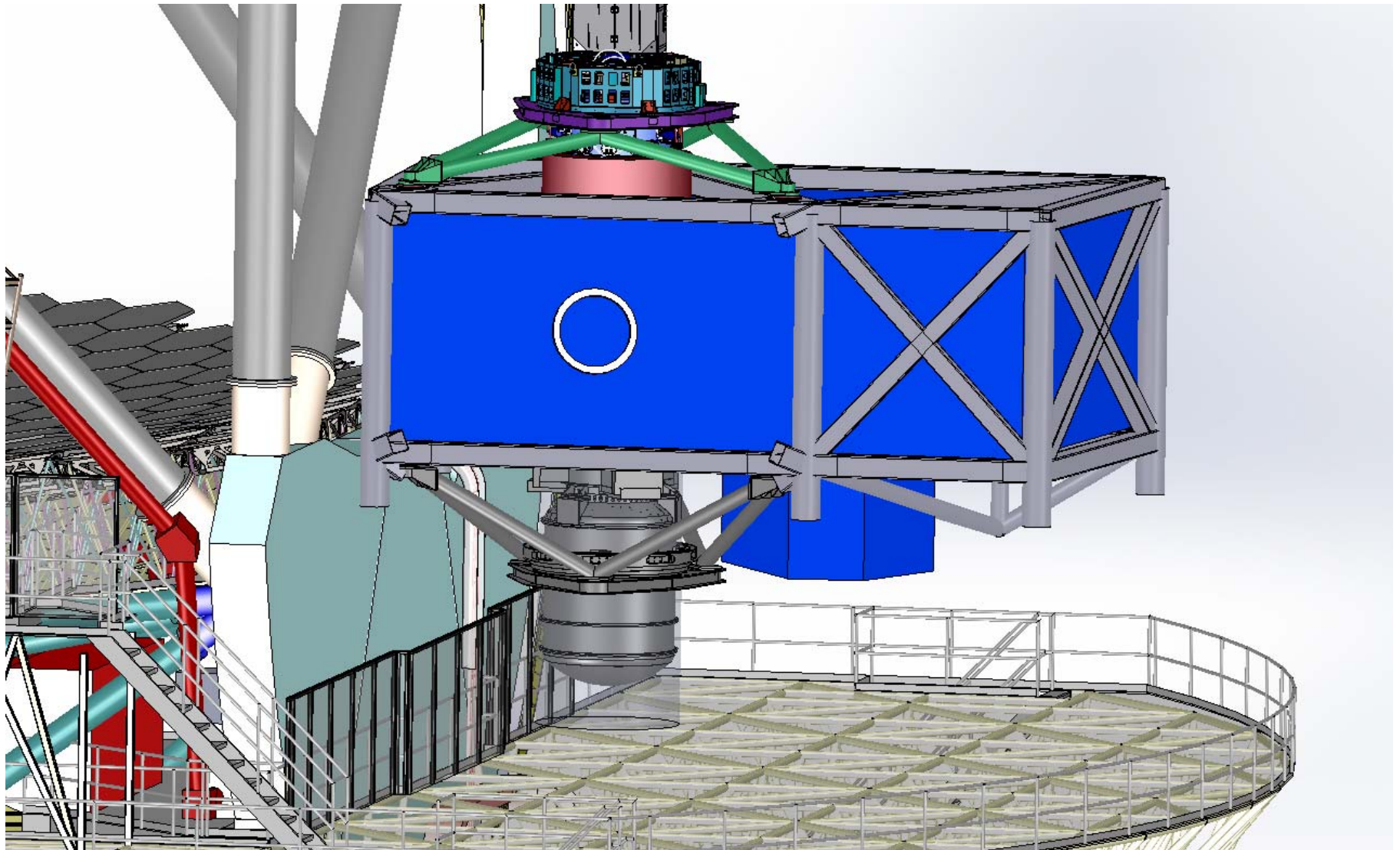


# Collimator Barrel

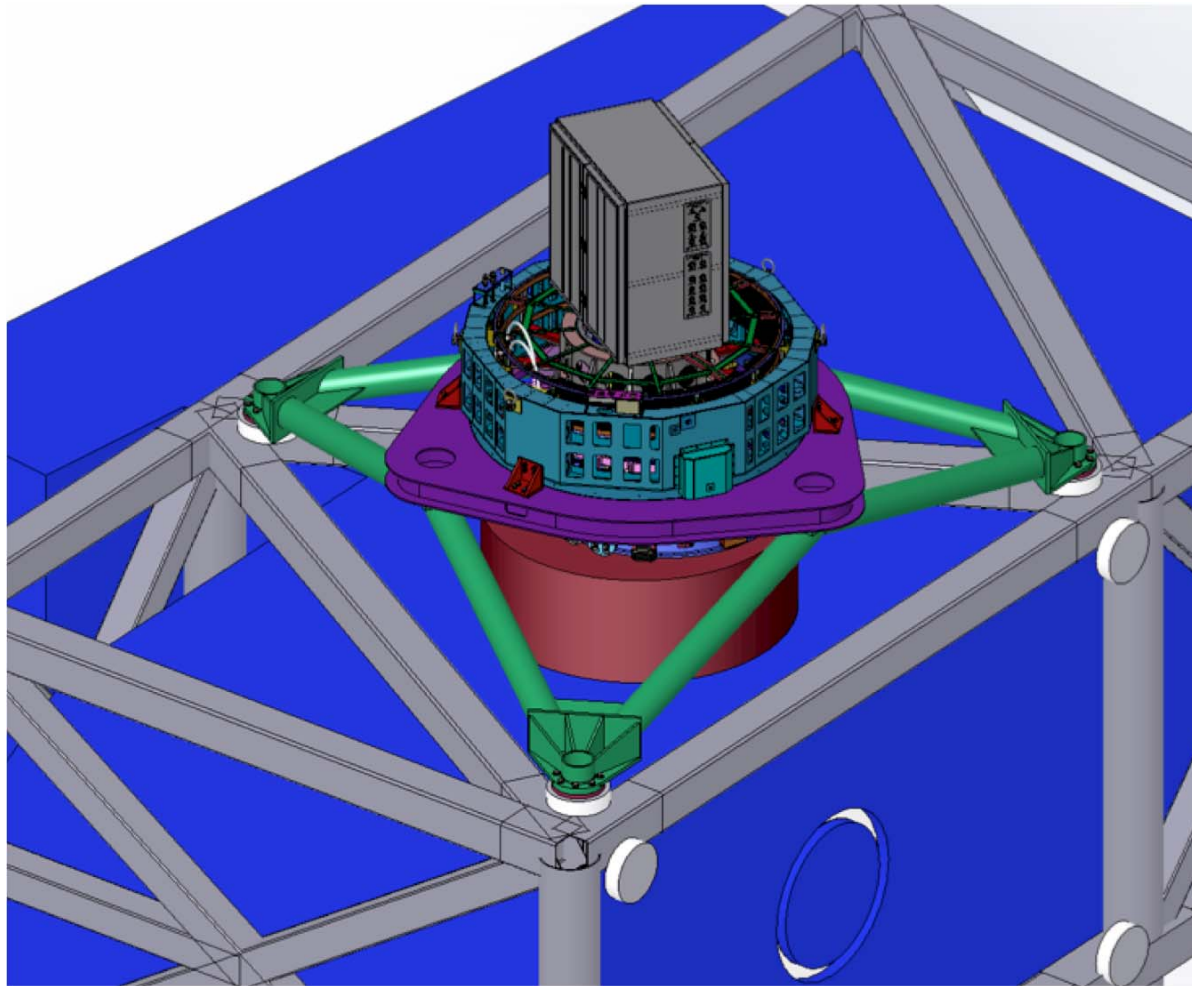
- Girdle center shifts: Col #2= -0.5 mm, Col #3= 2.7 mm, Col #4= 1.6 mm, Col #5= 0.03 mm, Col #6= -0.05 mm.
- These relatively small shifts in the lens girdle centers should be achievable through a combination of cell spacer shim alterations and/or altering mount flexure pocket depths.
- Girdle widths are all comparable or slightly larger than MOSFIRE design- no bonding issues.



# Telescope Structure Interface: IRIS and IRMS on NFIRAOS



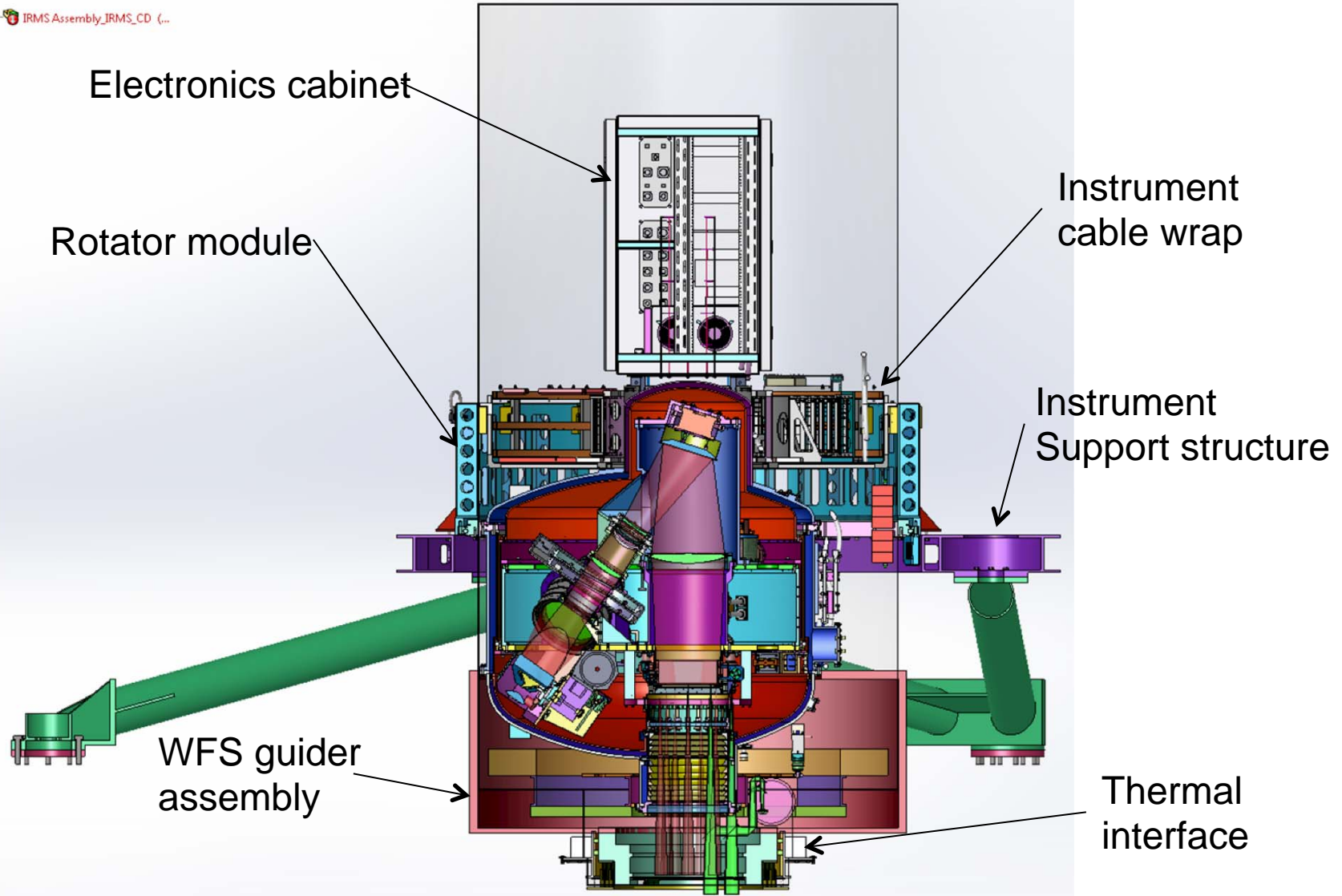
# IRMS on NFIRAOS



Instrument mass = 2.5 T  
Rotator module mass = 1.1T  
Support Structure mass = 2.3T  
Total mass = 5.9T

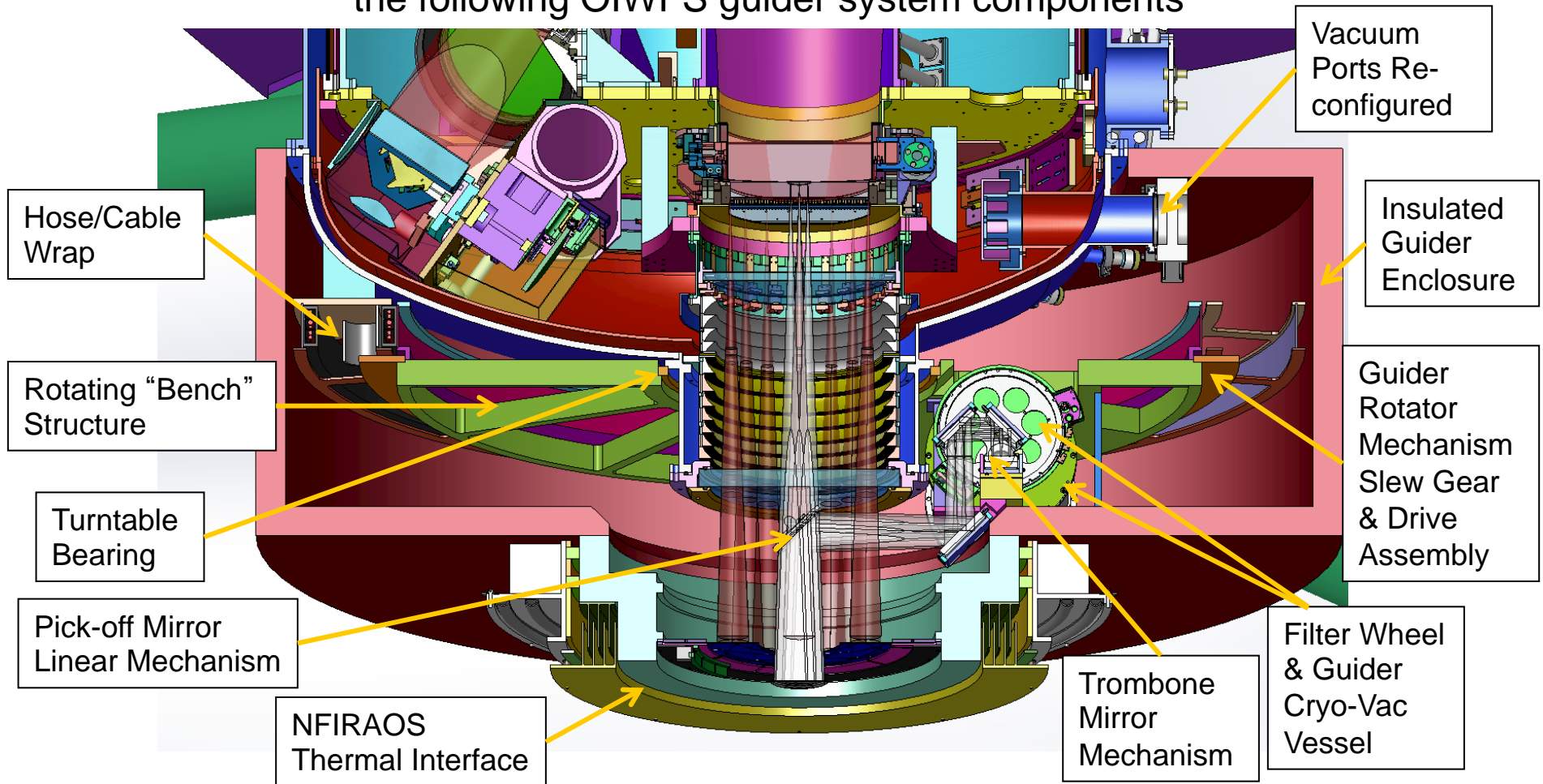
# IRMS Mini-study Mechanical Design

IRMS Assembly\_IRMS\_CD (...)



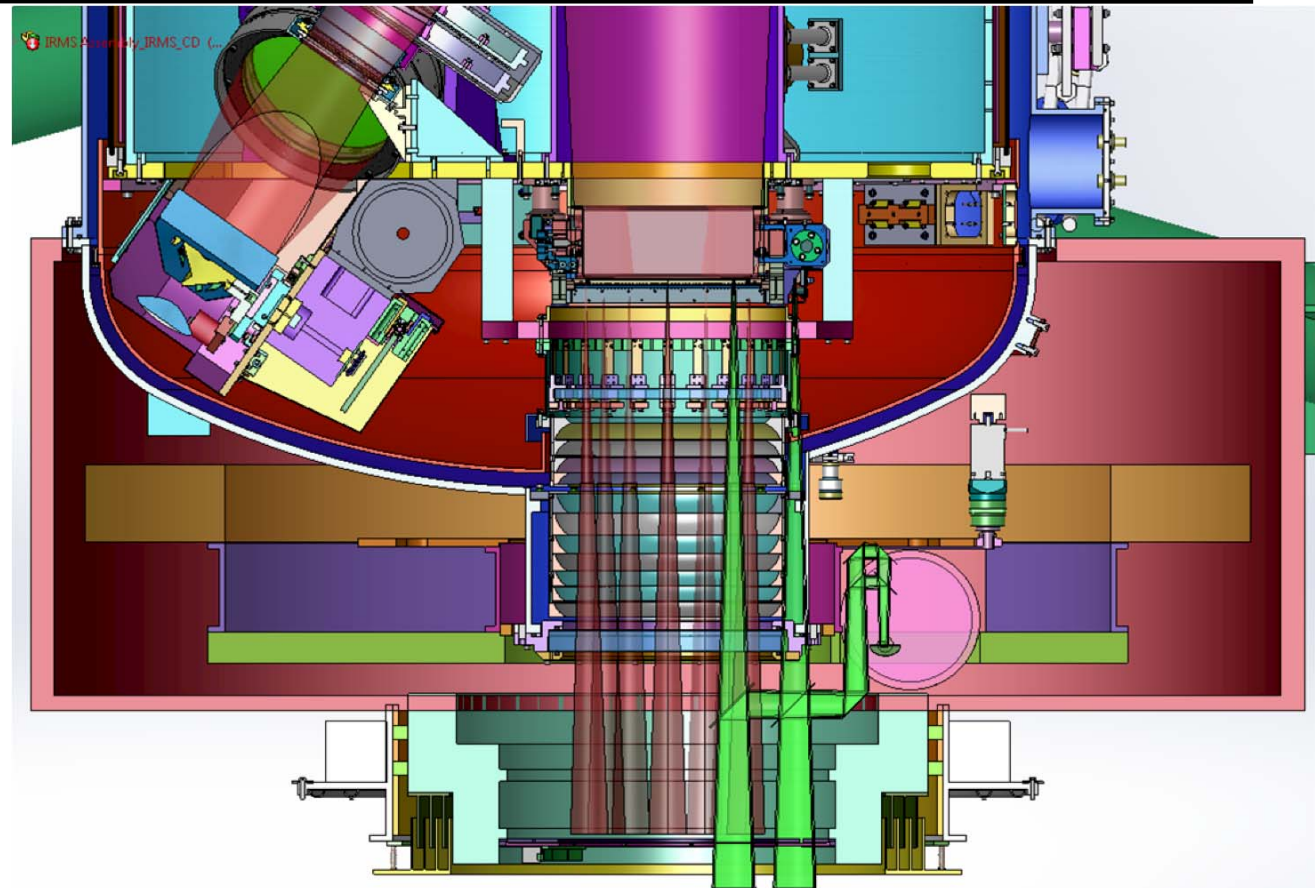
# IRMS Front-end modifications

The external MOSFIRE guider & sheet metal enclosure will be replaced with the following OIWFS guider system components

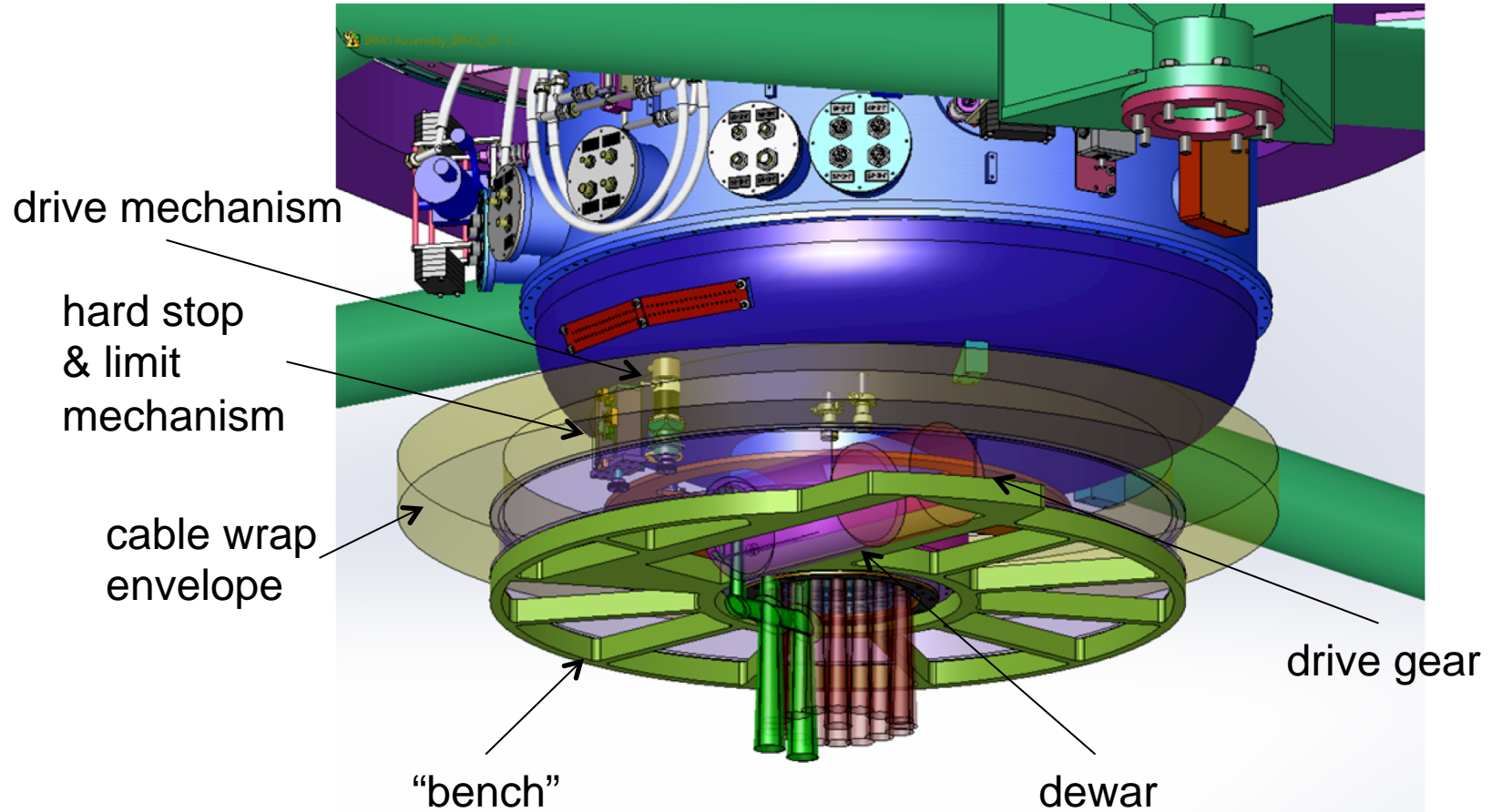


# IRMS OIWFS Mechanical Layout

- Design consists of an r-theta pick-off mirror with a “trombone” mechanism to maintain optical path length
- An optical “bench” is mounted on a turntable bearing from the instrument “snout”
- Requires a “cable wrap” device to control interconnecting cables/hoses



# IRMS Mini-study OIWFS



OIWFS guide probe can be positioned around full 360° field

# Acknowledgments

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The TMT Project gratefully acknowledges the support of the TMT collaborating institutions. They are the Association of Canadian Universities for Research in Astronomy (ACURA), the California Institute of Technology, the University of California, the National Astronomical Observatory of Japan, the National Astronomical Observatories of China and their consortium partners, and the Department of Science and Technology of India and their supported institutes. This work was supported as well by the Gordon and Betty Moore Foundation, the Canada Foundation for Innovation, the Ontario Ministry of Research and Innovation, the National Research Council of Canada, the Natural Sciences and Engineering Research Council of Canada, the British Columbia Knowledge Development Fund, the Association of Universities for Research in Astronomy (AURA) and the U.S. National Science Foundation.