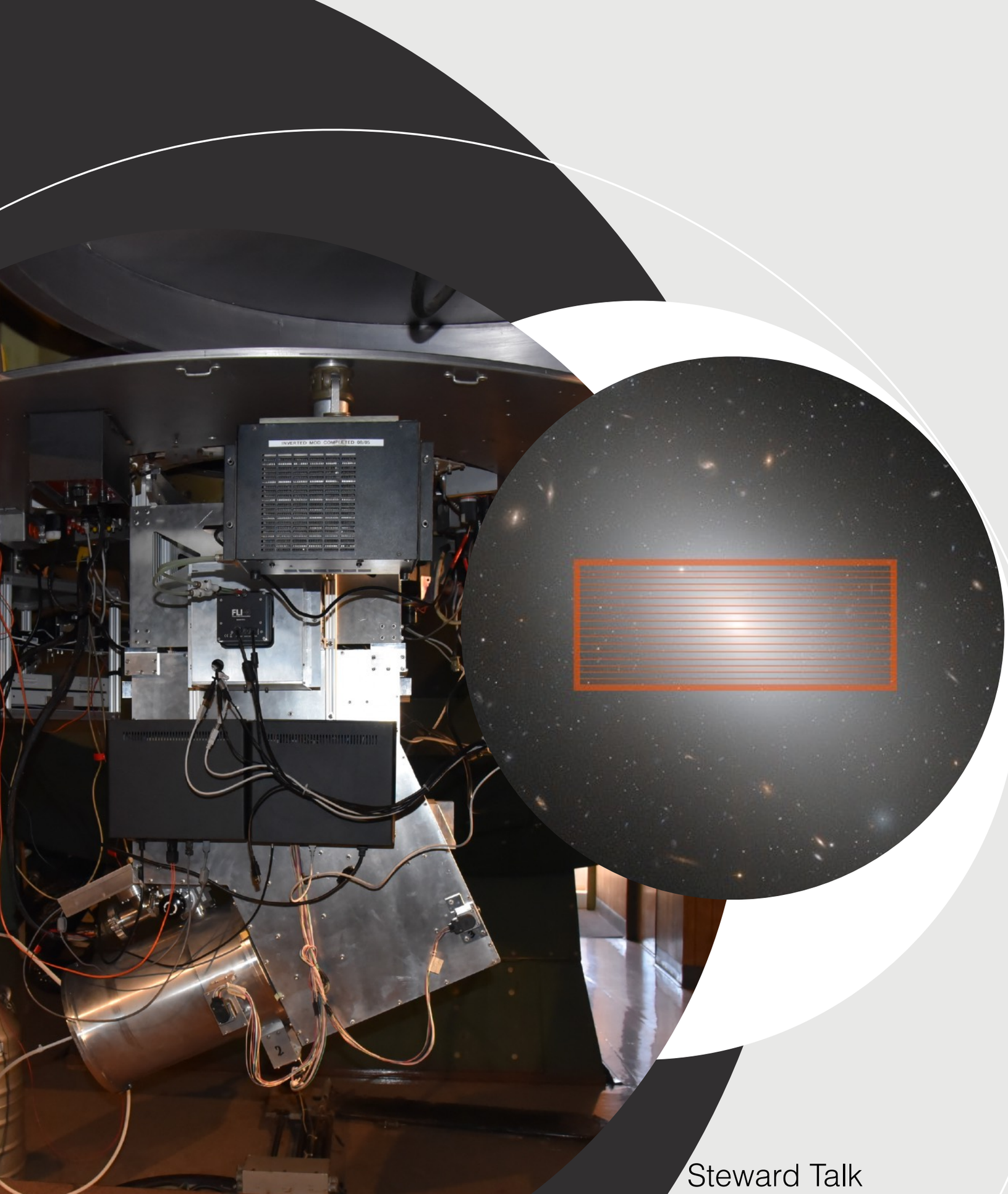

DUNLAP INSTITUTE
for ASTRONOMY & ASTROPHYSICS

Wide Integral Field Infrared Spectrograph at the 90”

Suresh Sivanandam
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D. Zaritsky (UAz), J. Eisner (UAz),
S. Eikenberry (UFlorida),
E. Meyer, ***J. Grunhut*** (Toronto),
R. Chou (ASIAA), ***M. Jarvis***
(MPA), ***K. Ma***, KASI

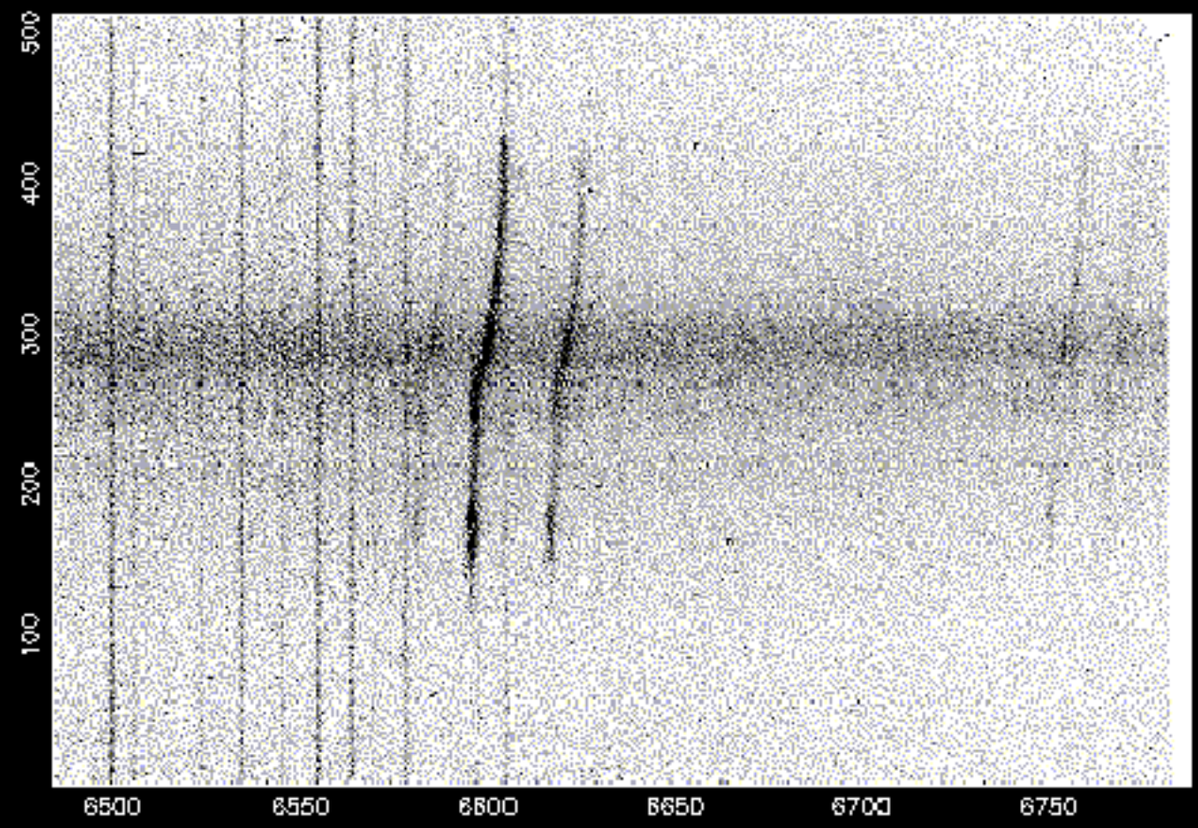
Dunlap Institute for
Astronomy & Astrophysics
UNIVERSITY OF TORONTO

Steward Talk

Outline

1. Need for 2D Spectroscopy
2. Science Drivers
3. Commissioning Results

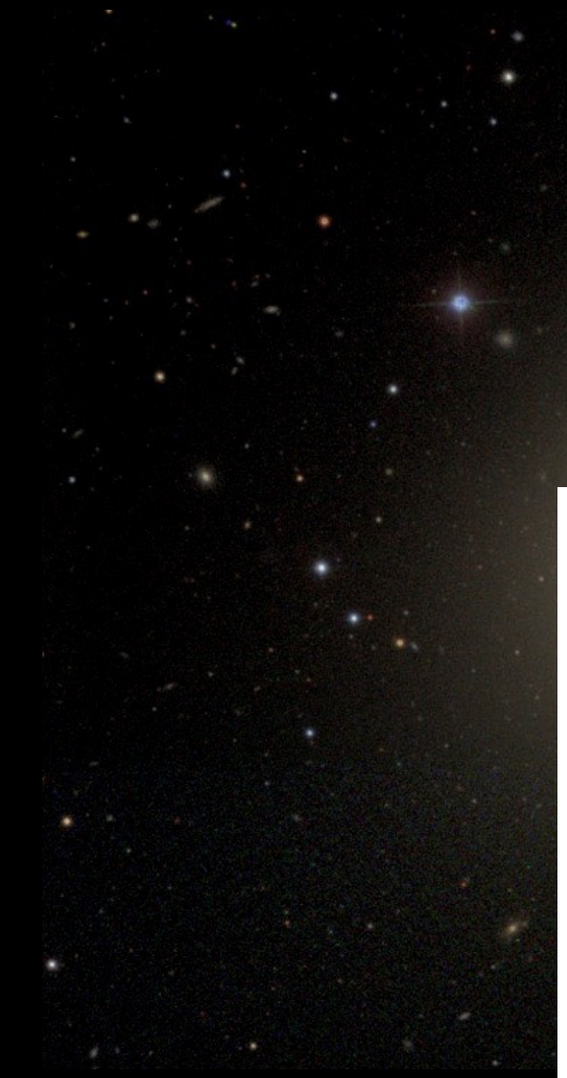
Traditional Spectroscopy

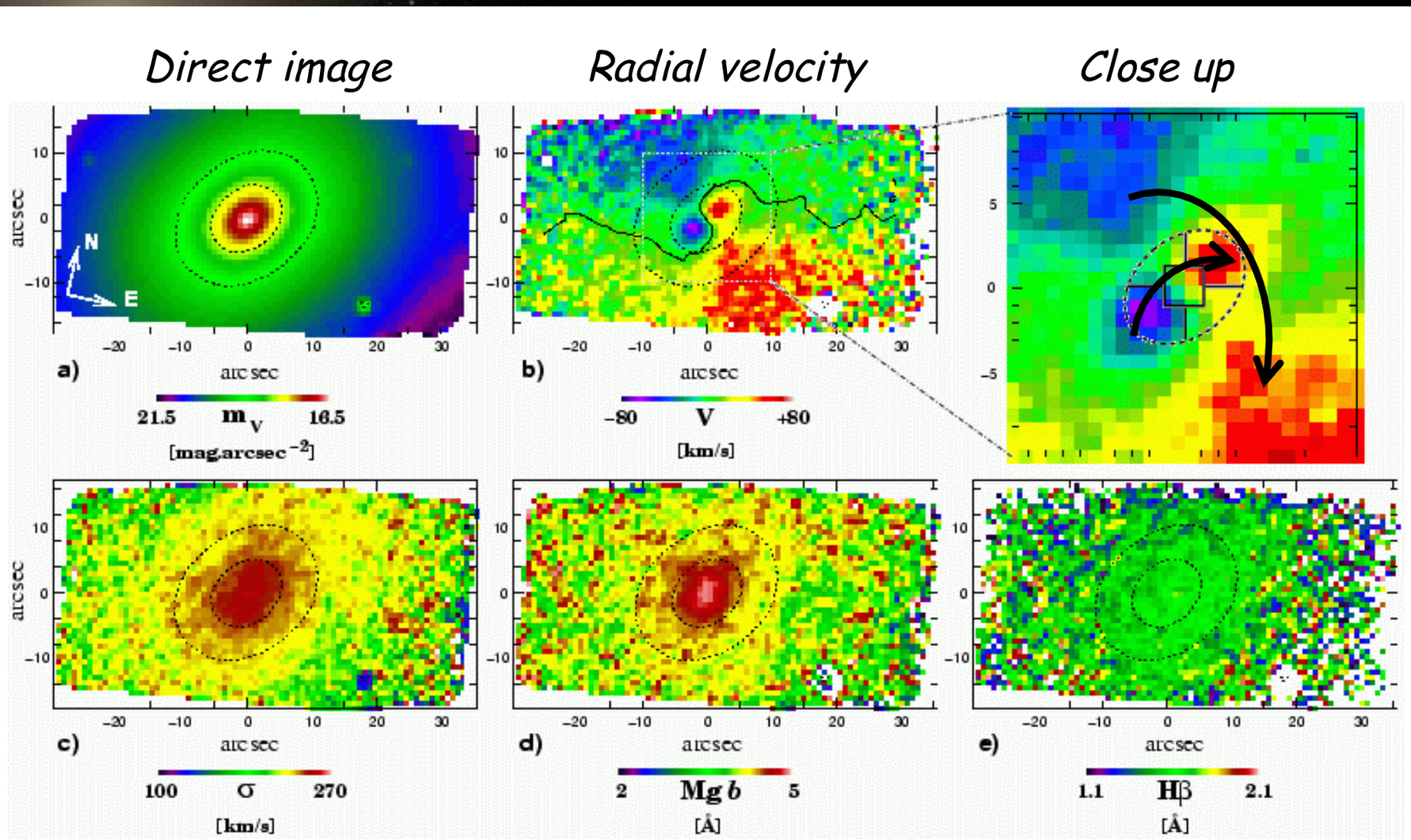


Single slit that is placed over object of interest

- Slit typically several arc minutes in length
- Produces 1D spatially-resolved spectrum

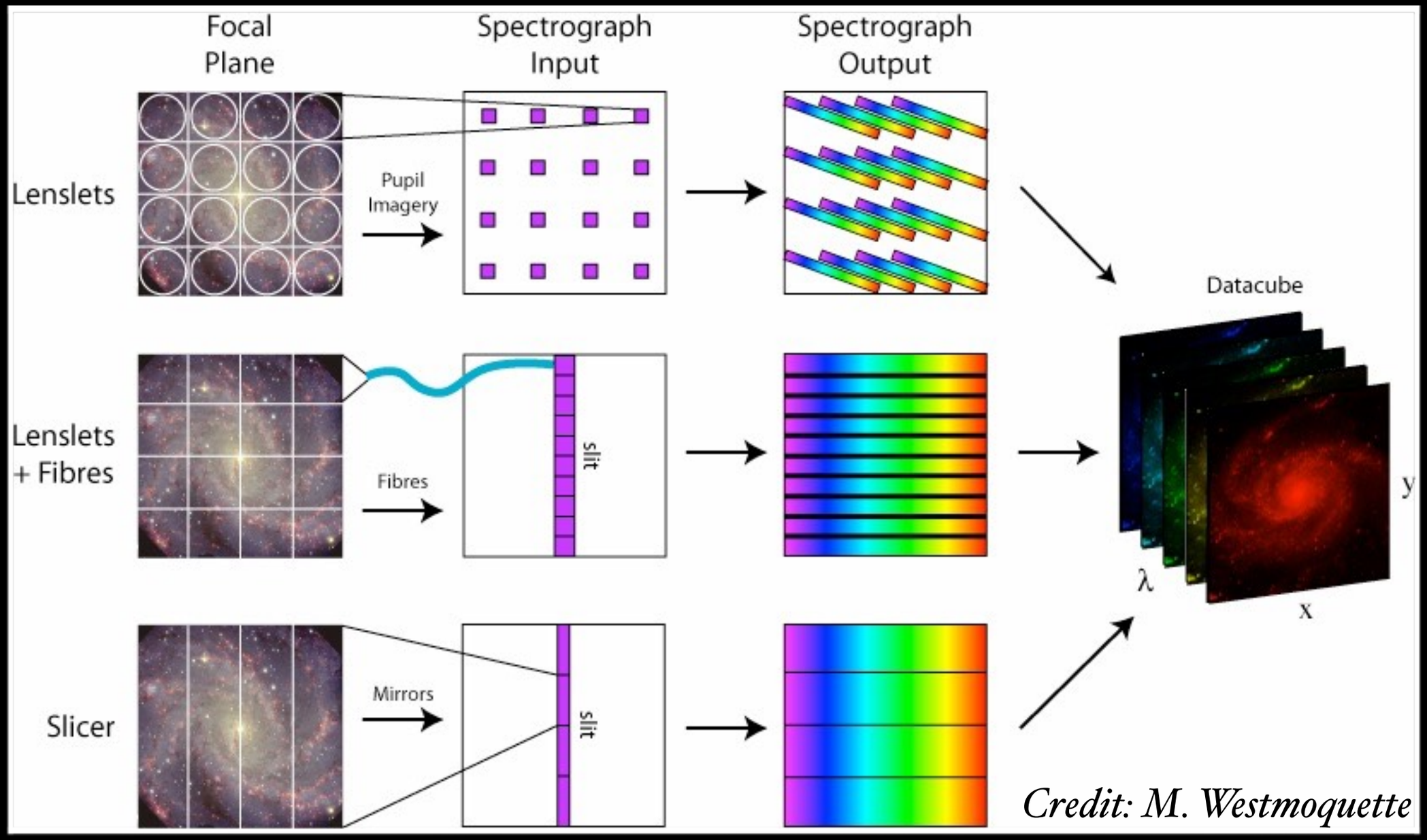
Why is 2D Spectroscopy Important?





SAURON: NGC 4365 (Lyon/Durham/Leiden/ESO)

What is Integral-Field Spectroscopy?

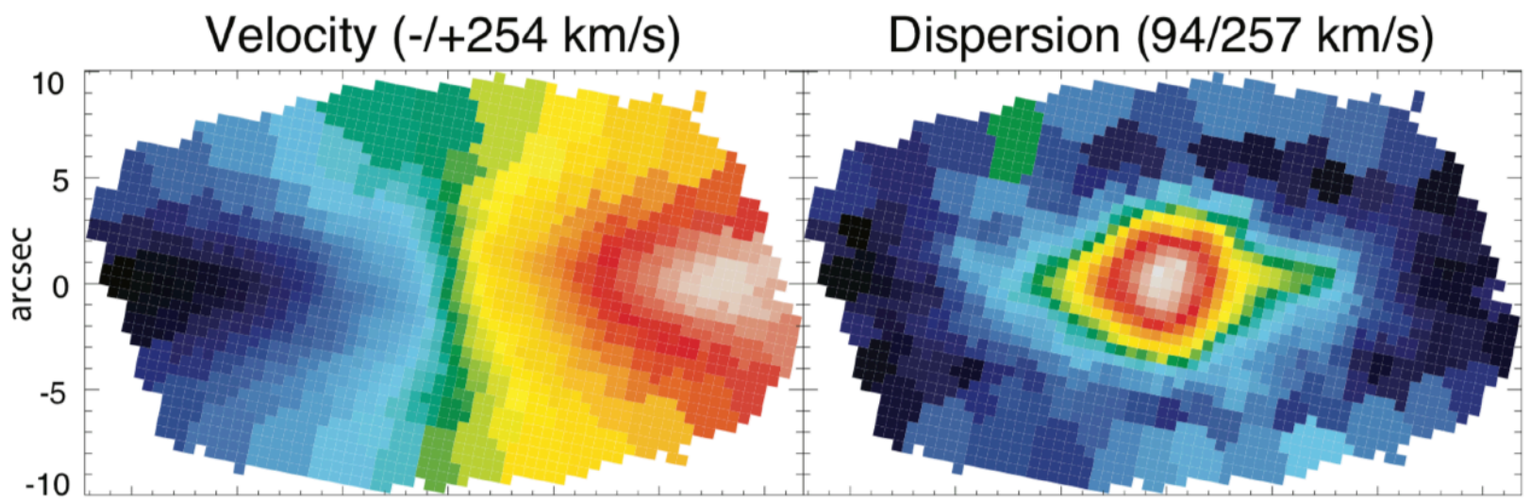


Require a method to reformat the telescope field into the spectrograph

Individual lenslets and fibres to not preserve spatial information

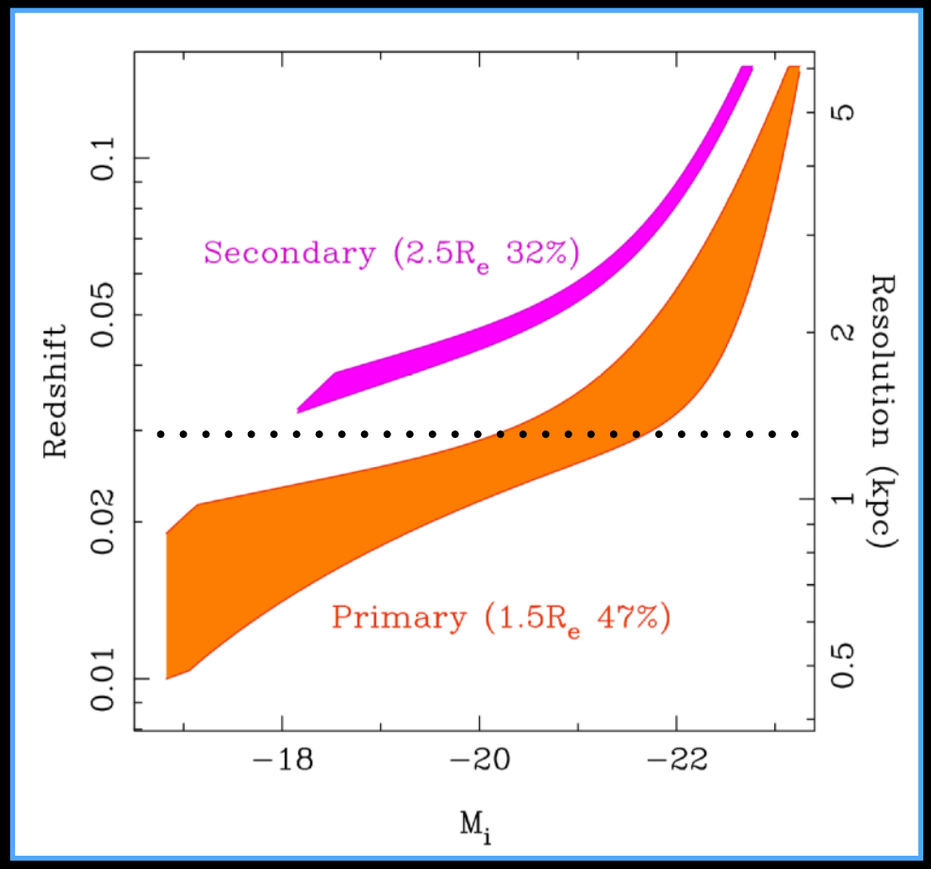
Individual slices do preserve spatial information in one direction

Age of Integral Field Spectroscopy of Nearby Galaxies



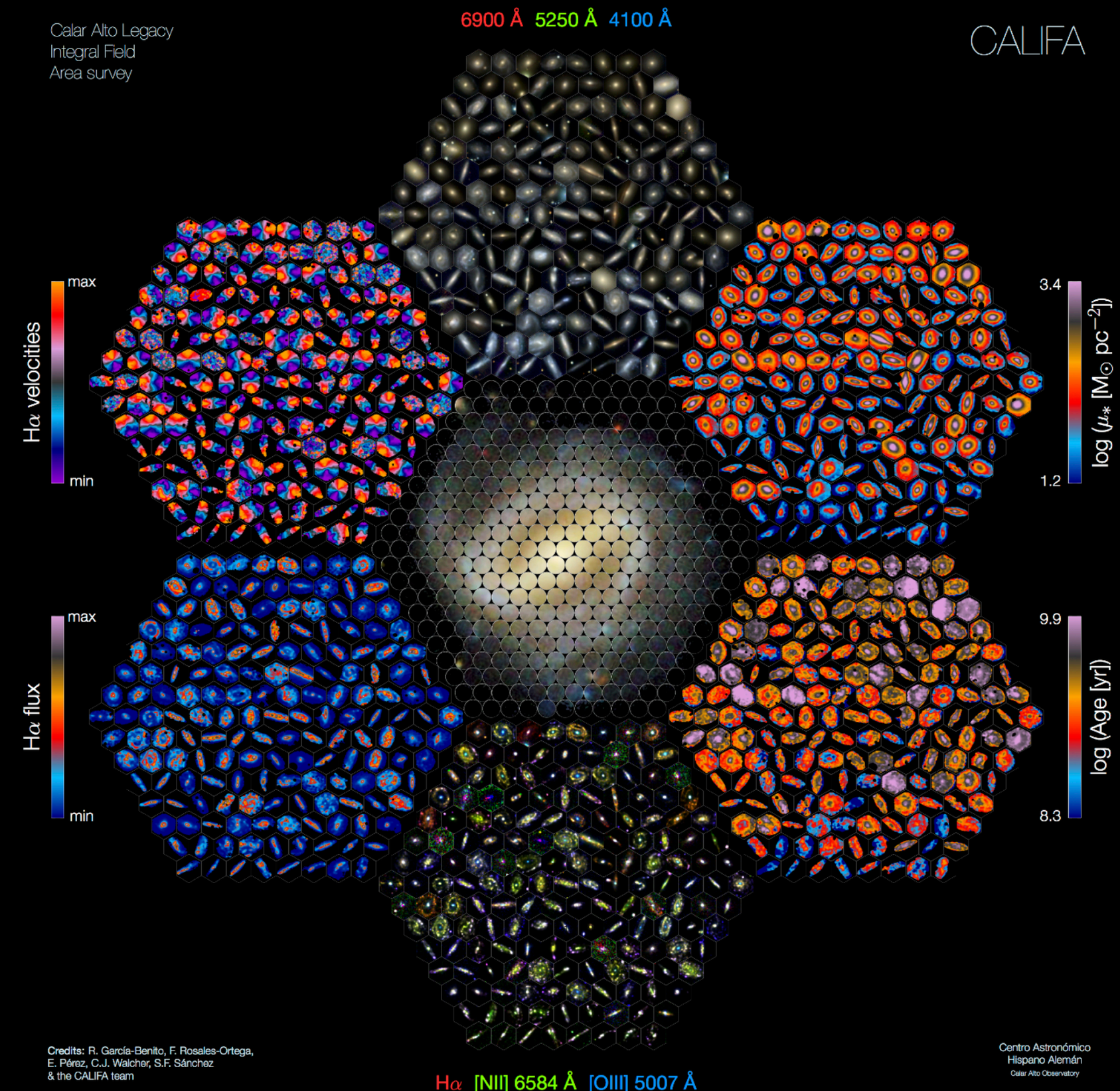
MaNGA Bundy et al. (2015)

1. How do galaxy disks grow?
2. How do bulges and ellipticals grow?
3. What affects star formation?
4. How have galaxies assembled?



Spatial Resolution

Age of Integral Field Spectroscopy of Nearby Galaxies



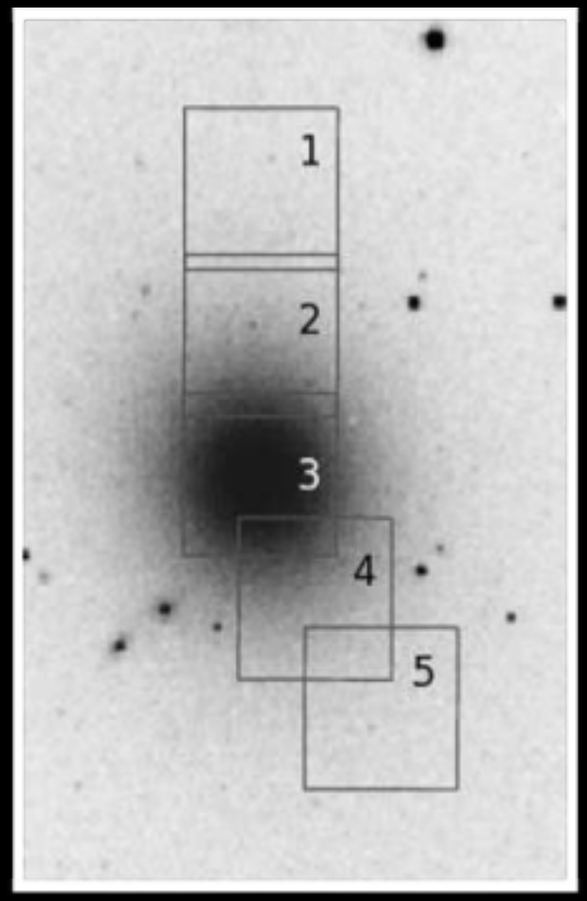
- ***Star formation***
- ***Gas Kinematics***
- ***Gas Metallicities***
- ***Stellar Populations***
- ***Stellar Dynamics***
- ***Stellar Metallicities***
- ***Star formation history***

CALIFA survey

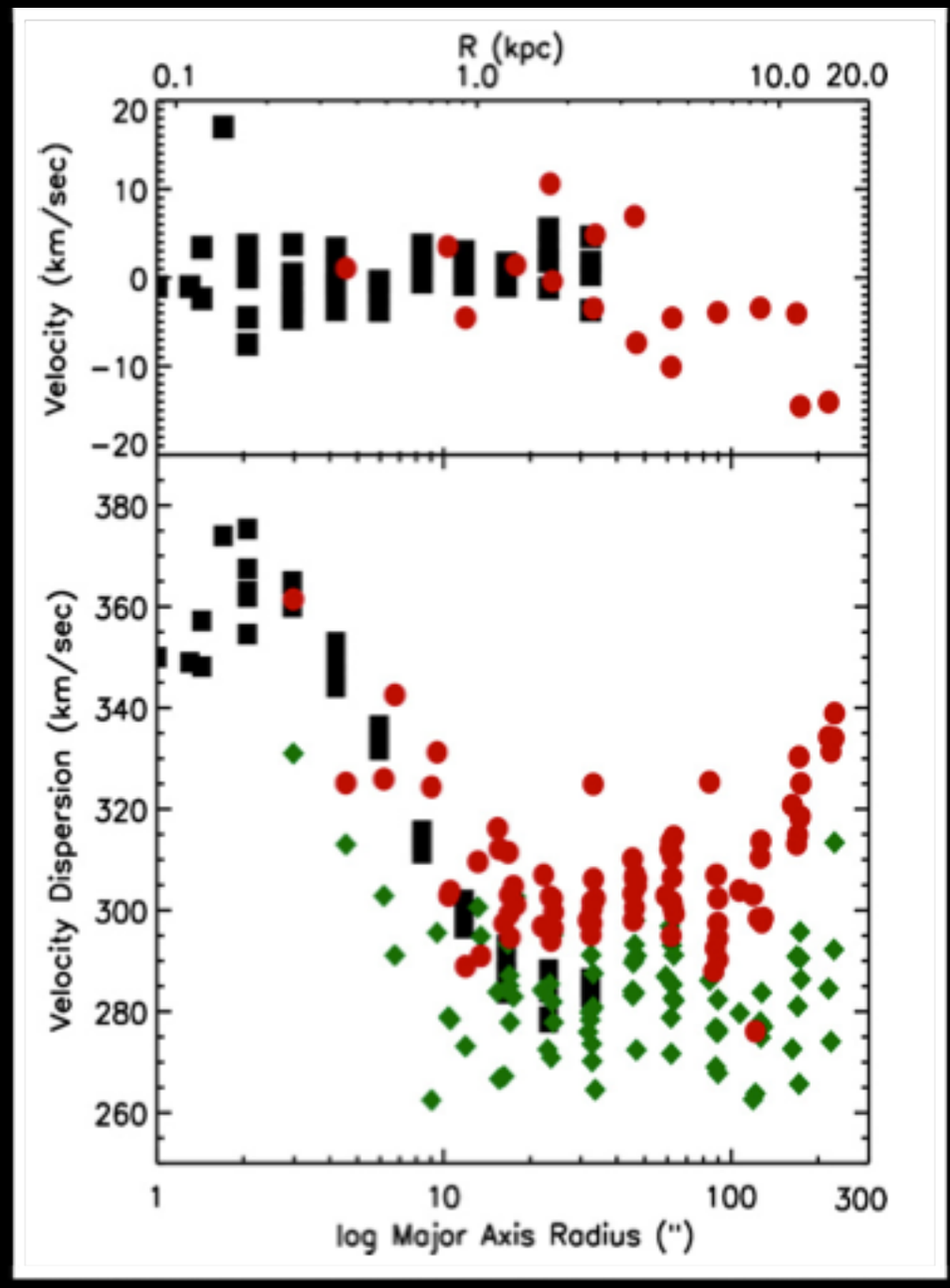
Age of Wide Integral Field Spectroscopy

Light Bucket Observations

VIRUS-P



M87



Kinematics out to ~5 r_e!

Murphy et al. (2011)

Age of Large Scale IFS Surveys

Visible

★ Several wide integral fie
spectroscopic survey

★ Focus mainly on ne

- **SAURON (N_{ga}**
- **ATLAS^{3D} (N_{ga}**
- **CALIFA (N_{gal}**
- **SAMI (Ongoin**
- **MaNGA (Ongoi**

★ **Increasing utility of 2
telescopes**

?

Infrared

w integral field
surveys

alaxies (z~1-4) or
alaxies

60)

g-limited)

(N_{gal} = 600)

(N_{gal} = 1000)

**perture 8-10 meter class
copes**

Observing Galaxies in the IR

Current State:

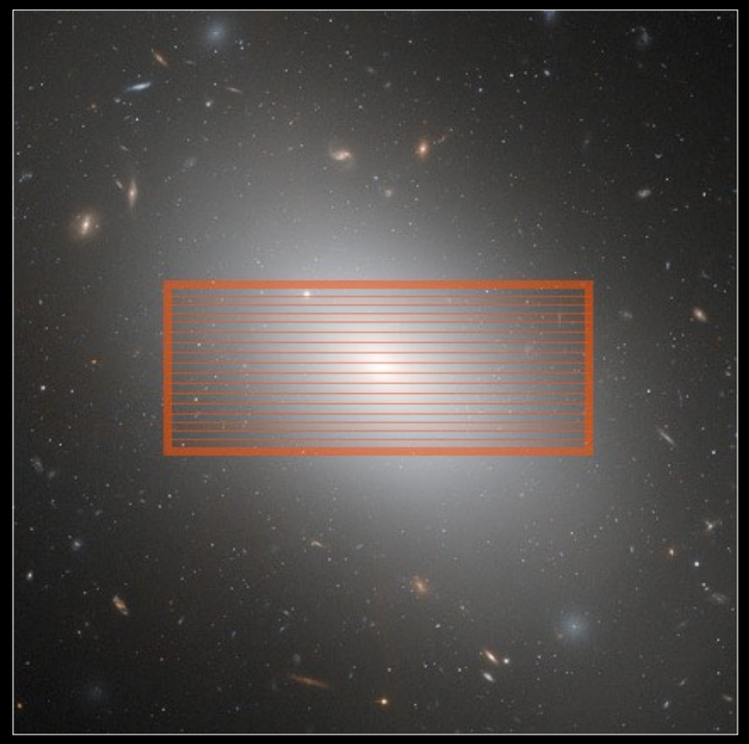
- ***Near-IR IFS surveys mostly target high-z galaxies***
  - FOV better fit high-z targets
  - Study rest-frame optical features
- ***AO-fed IFSes only observe single objects***

Opportunities for Nearby Galaxies:

- Large range in wavelength
- Low extinction
- Rich in spectral features of late-type stars and giants

Opportunities for Distant Objects:

- Large redshift coverage due to broad wavelength range
- Search for bright line emitters over large cosmic volume



NGC1132 with large integral field overlaid

WIFIS: Wide Integral Field Infrared Spectrograph

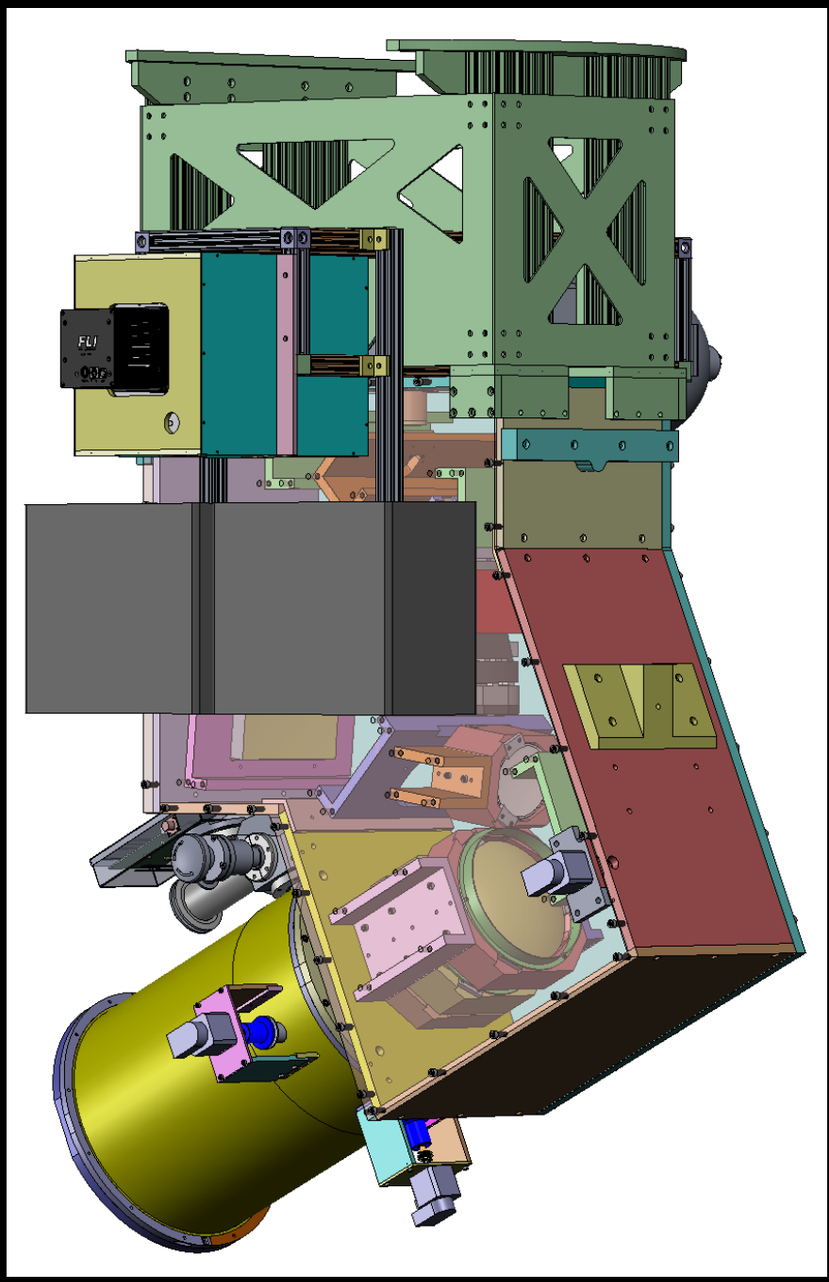
PI: D.-S. Moon
Project/Instrument Scientist: S. Sivanandam

Instrument Parameters		
Field of View	50” x 20”	
Spatial Sampling	1.1”/slice	
Telescope	UAz Bok 2.3-meter (90”)	
Modes	0.9-1.35 μm	1.5-1.7 μm*
Spectral Resolution	3,000	2,200

* Reduced sensitivity due to background

- Potentially adaptable to different telescopes
  - e.g. 6.5-meter MMT

5 feet

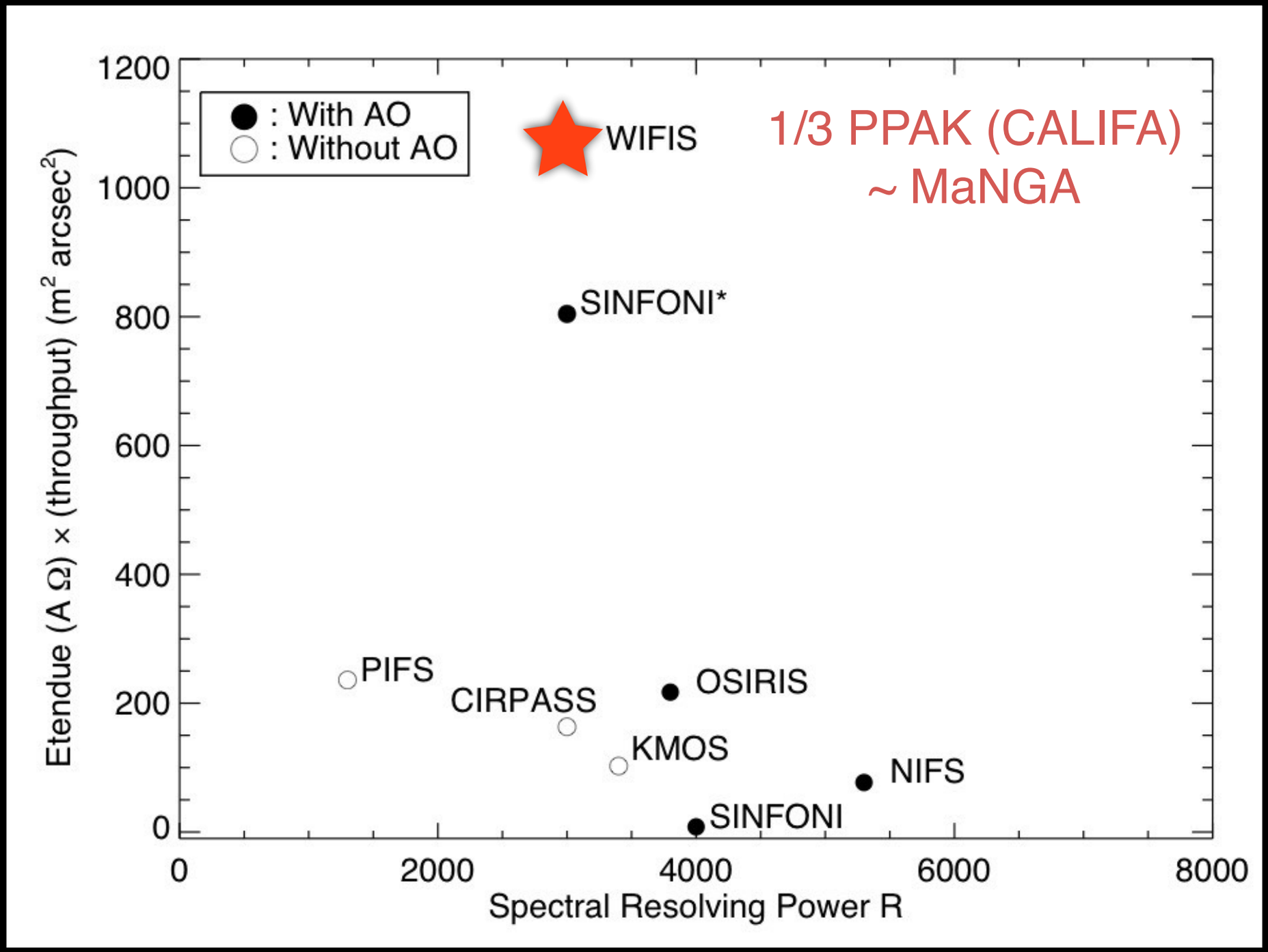


CAD Model of WIFIS

Comparison of Fields of View of IR IFSes

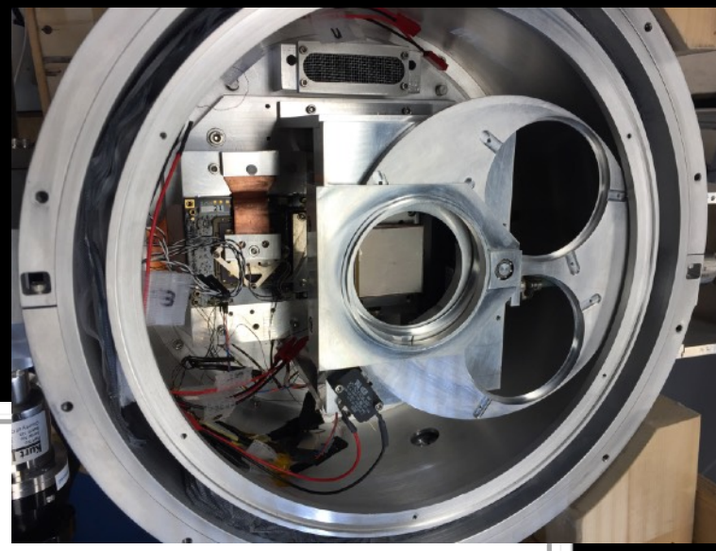
Visible IFS, Infrared IFS

Figure of Merit: Etendue (ηAΩ)

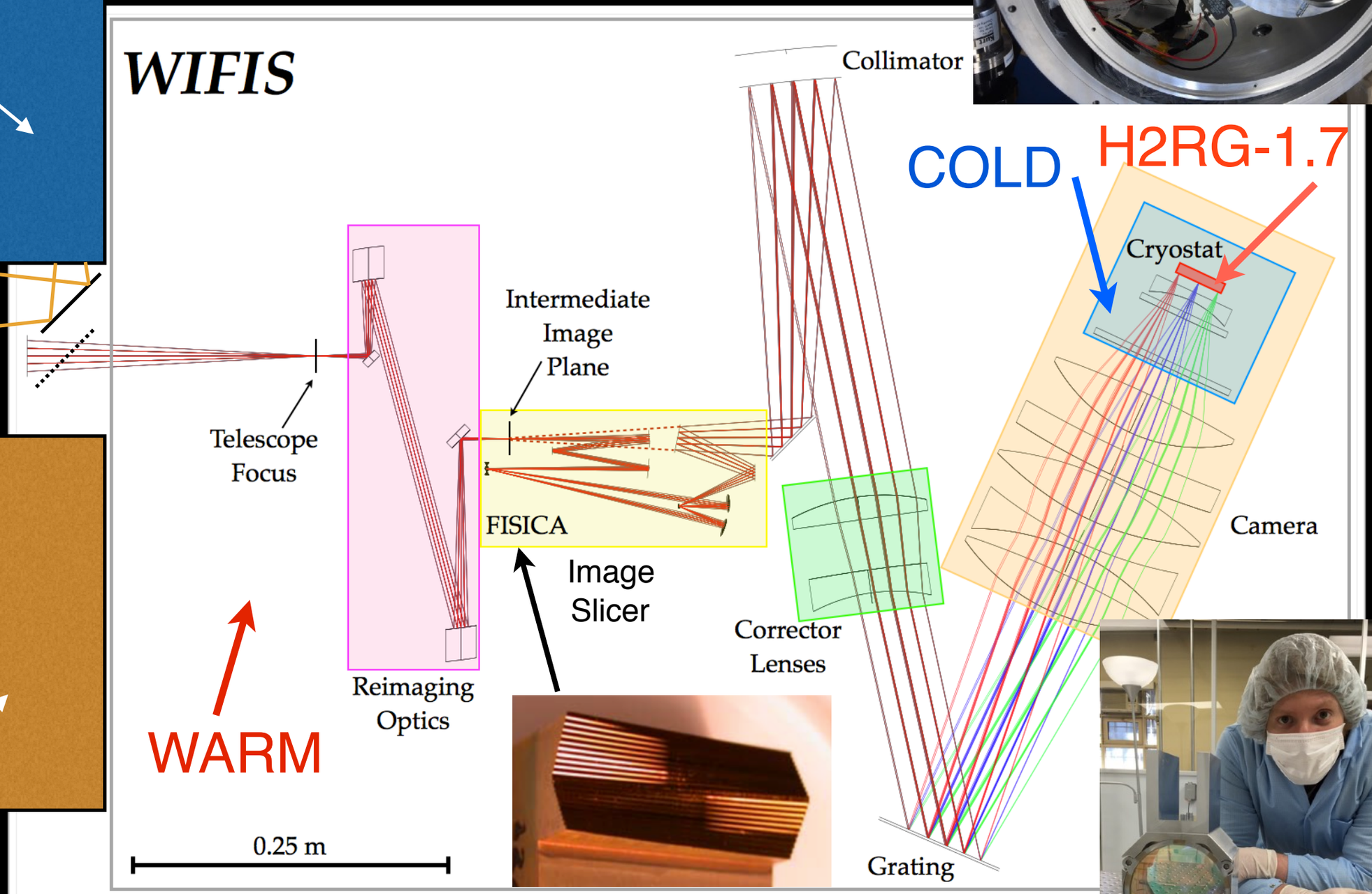


Near-infrared IFS Comparison

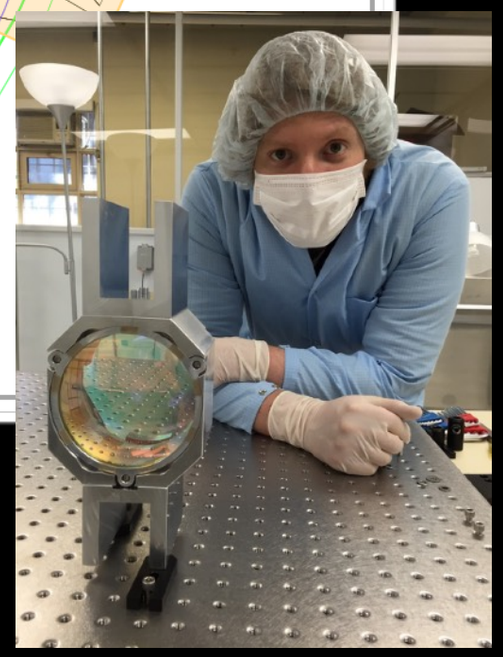
Optical Layout



Acquisition/
Guider
Camera



Calibration
System

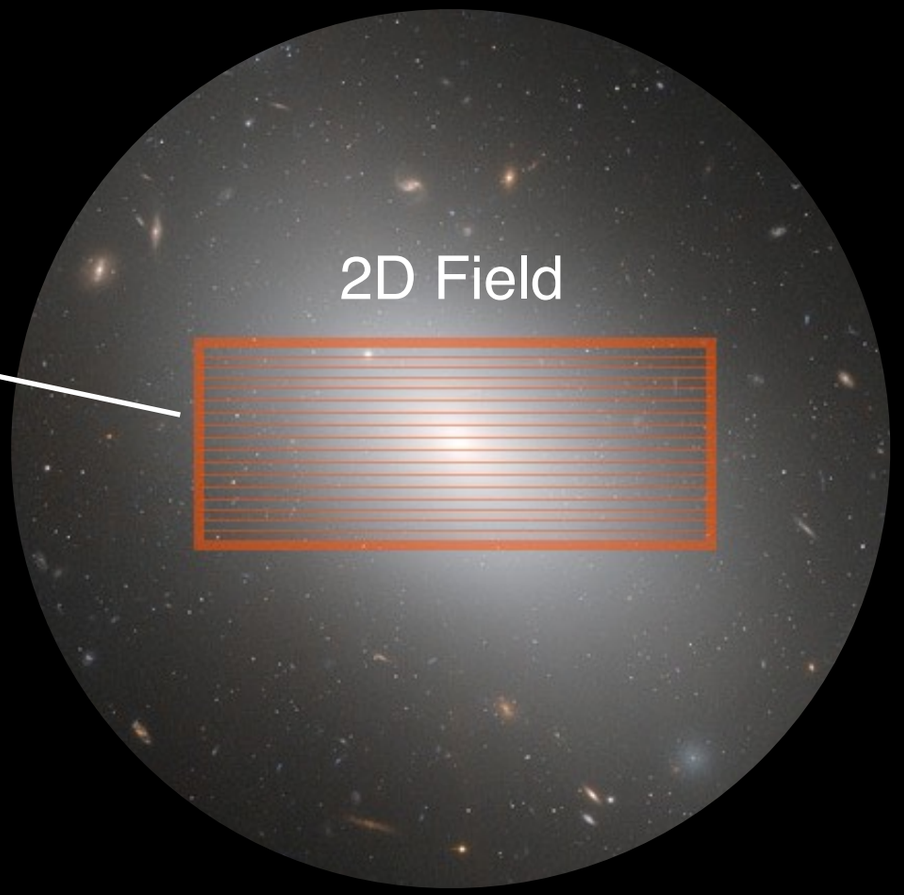


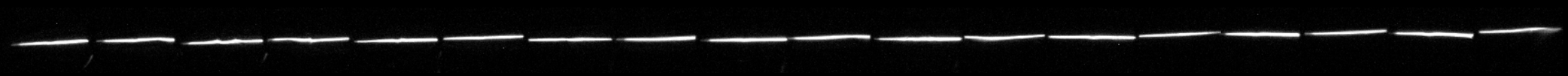
Chou et al. (2010), Sivanandam et al. (2012),
Meyer et al. (2014)

Integral Field Unit - Image Slicer

18-mirror metallic slicer

UFlorida Contribution (Eikenberry et al.)

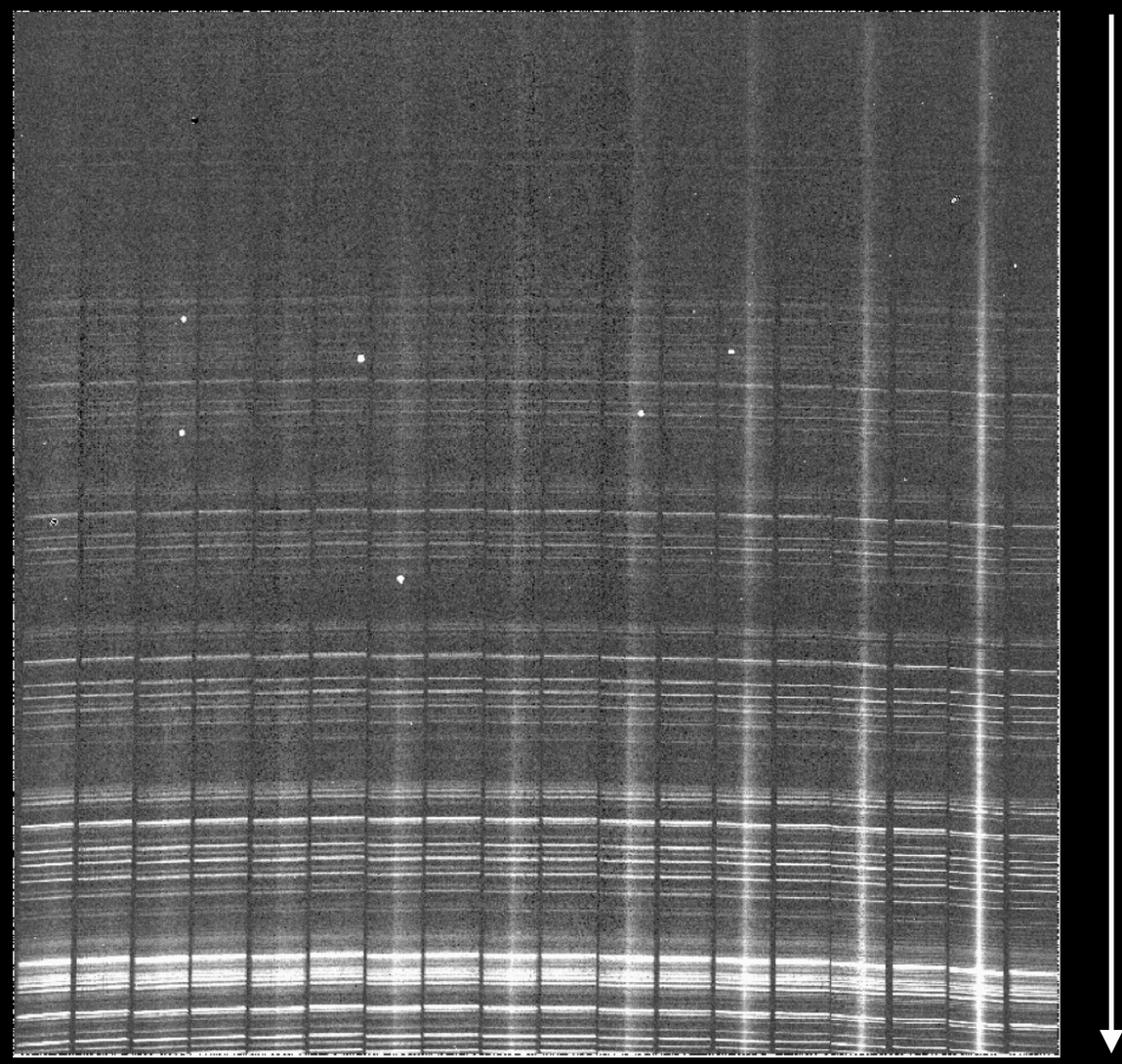




1D Pseudo-slit Image

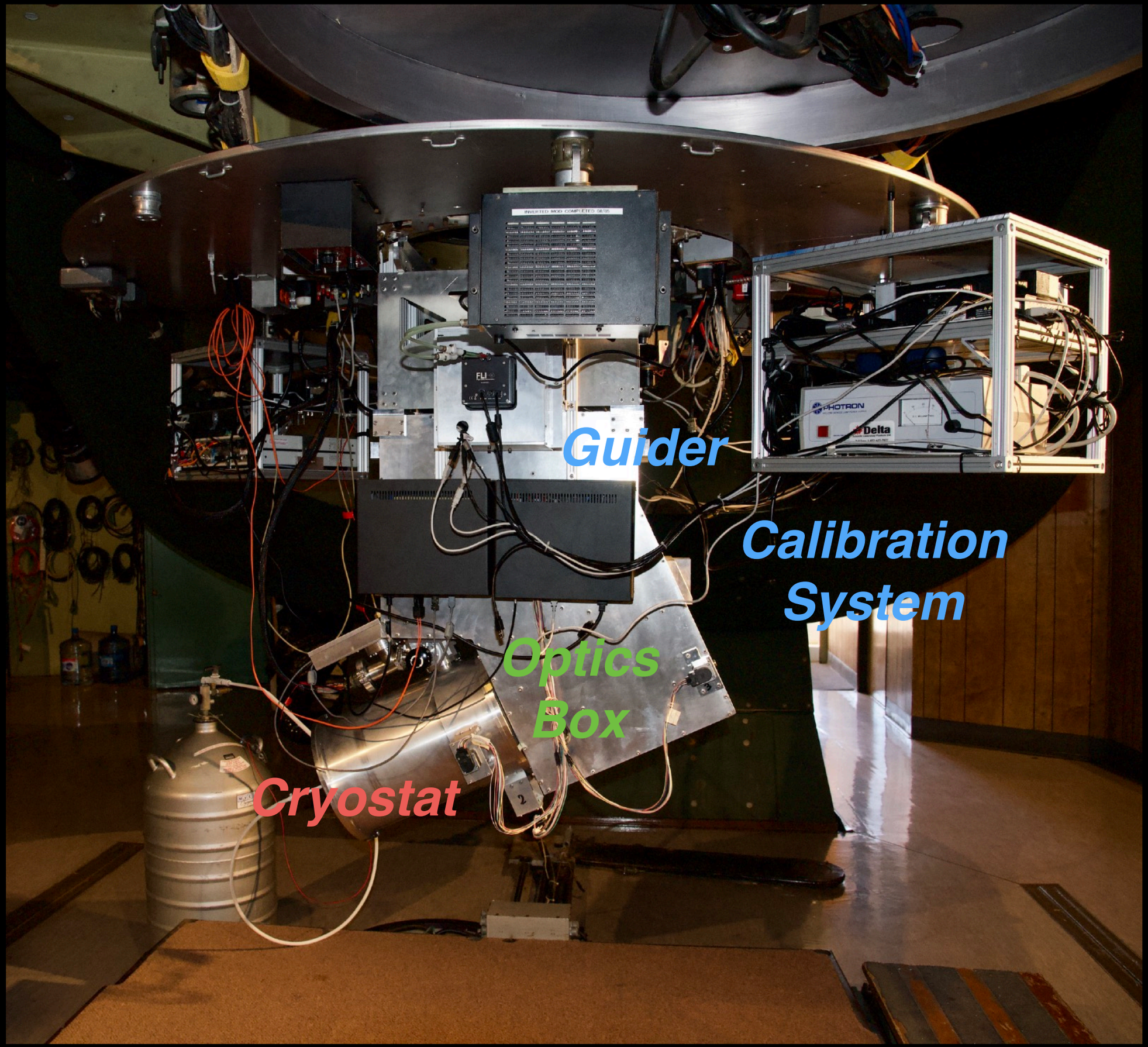
Image slicer type integral field units convert a 2D field into a 1D slit image

- Slicers are diamond-turned (freeform) optics that consist of individual slices that are small powered mirrors

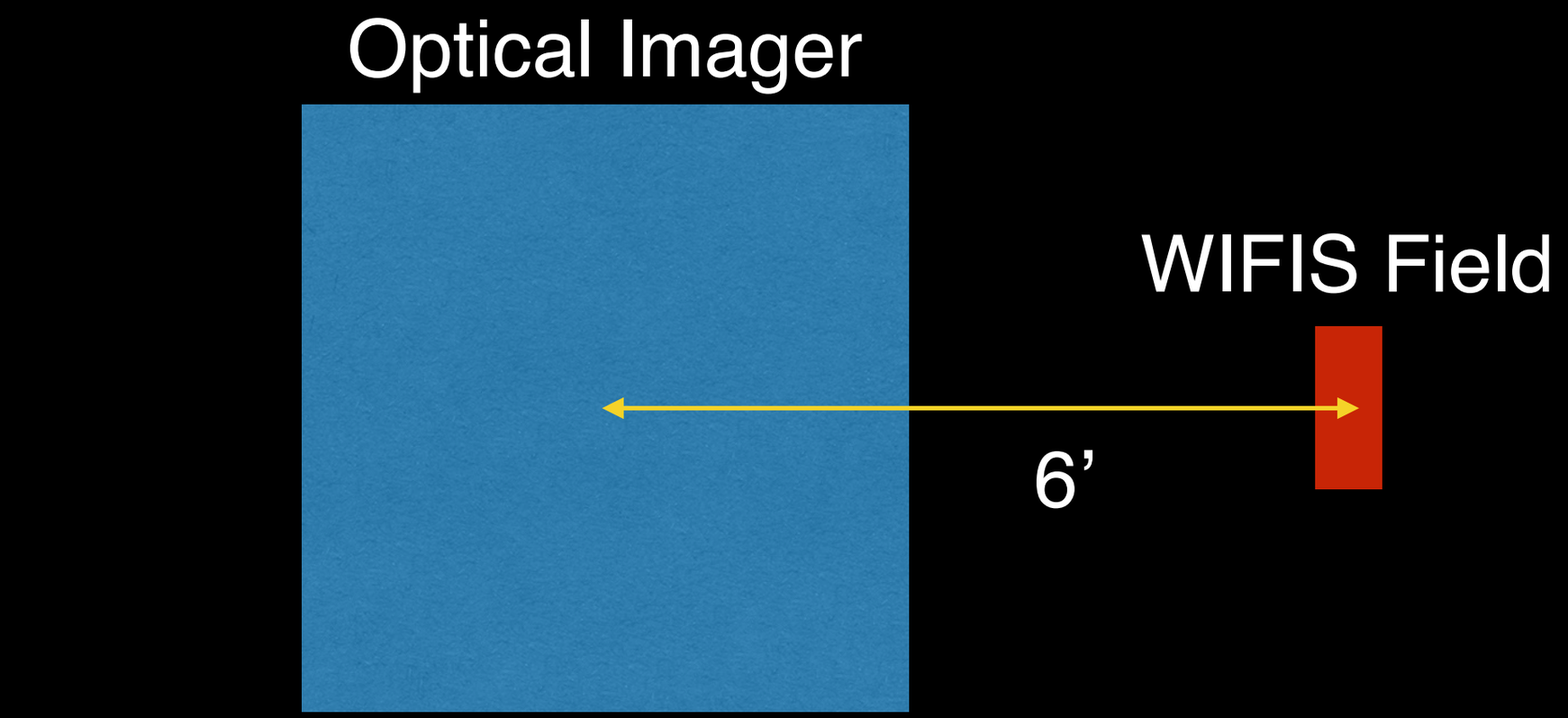


First light run
5-minute on-sky exposure
Thermal background subtracted

E. Meyer (PhD student), Moon (PI), and Sivanandam
at 2.3-meter Bok telescope
First Light May 2017


Guider
Calibration System
Optics Box
Cryostat

Optical Imager/Offset Guider



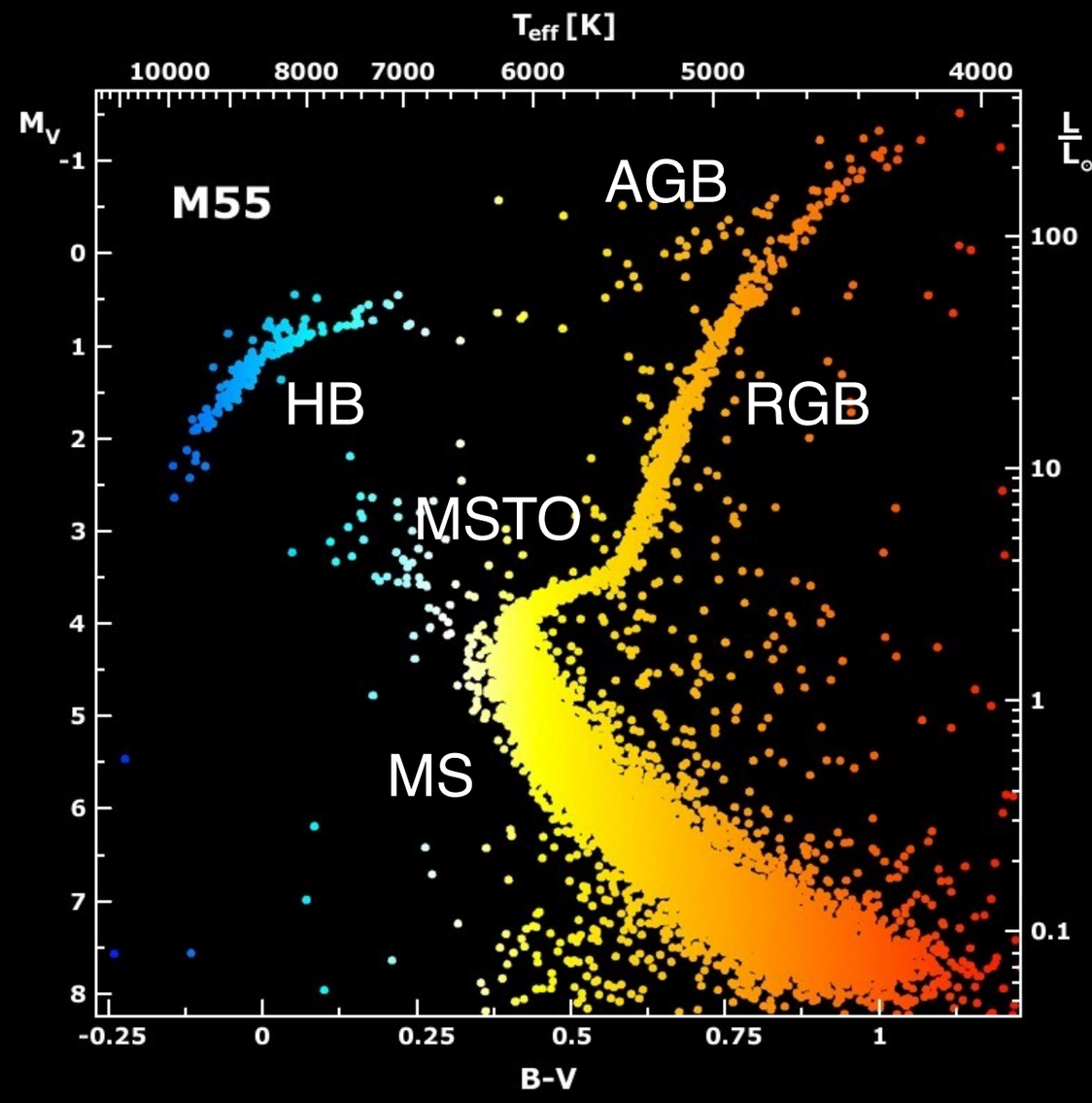
5x5’
0.3”/pixel
1024x1024 pixels
Red sensitive frame transfer CCD
Filters: *g*,*r*,*i*,*z*,Hα
Peltier cooled (-30C)

Stellar Populations in the INfrared Survey (SPINS)

Study Stellar Populations in Nearby Galaxies through IR Integral Field Spectroscopy

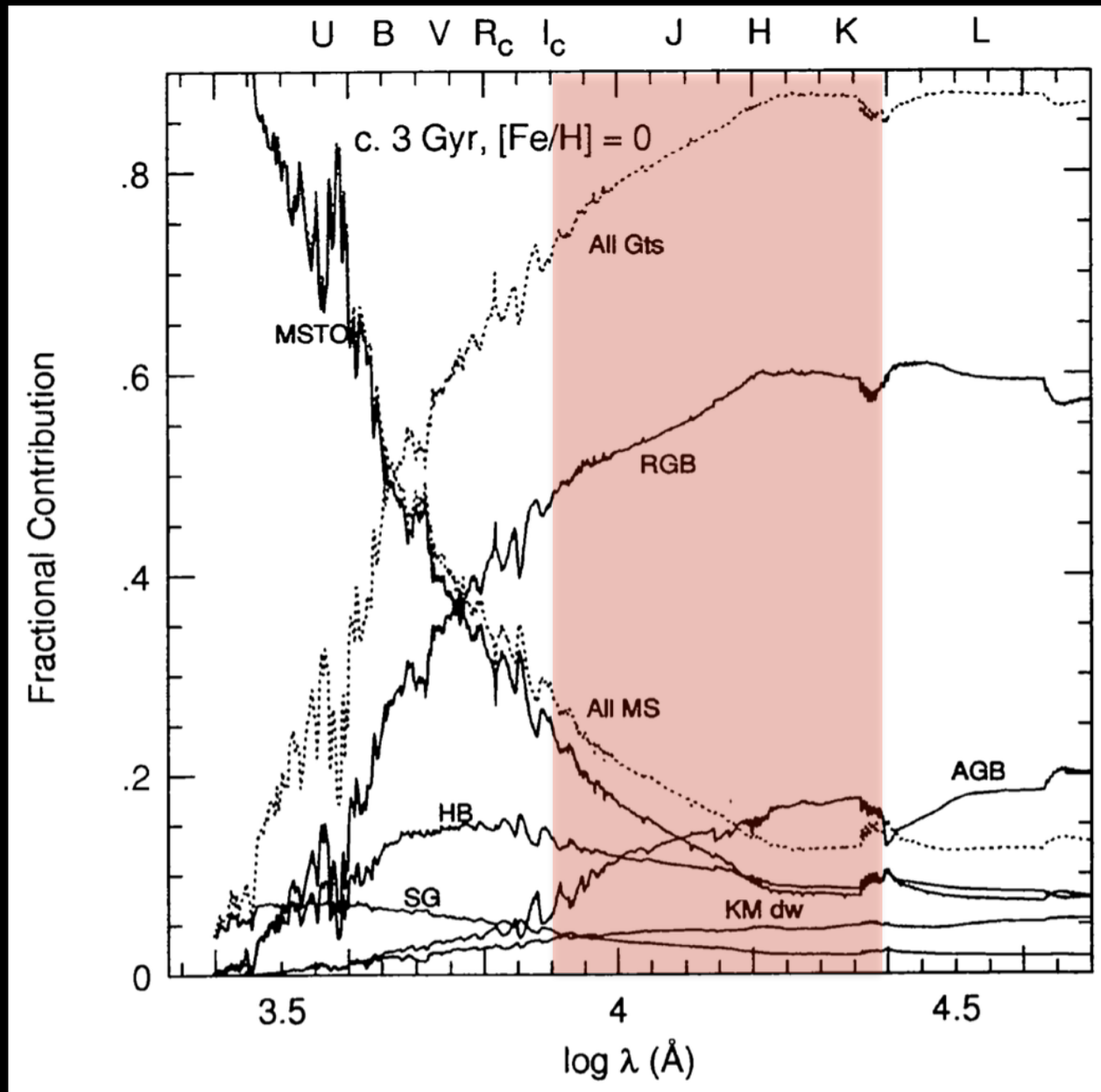
Primary Scientific Questions:

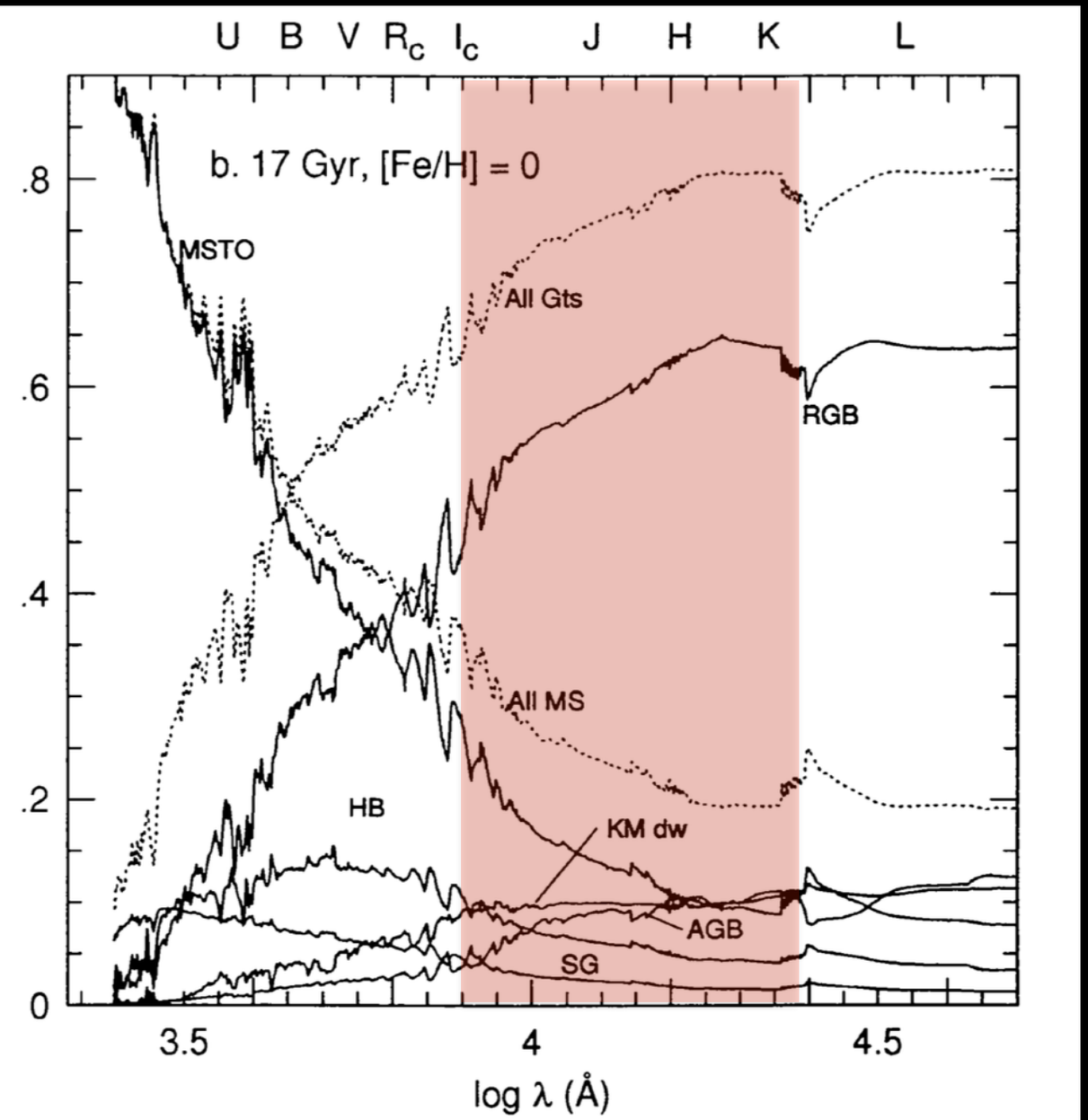
- Does the Initial Mass Function (IMF) vary with galaxy properties?
- Are thermally pulsing AGB (TP-AGB) stars a significant contributor to stellar light in the infrared?



HR Diagram of M55
12 Gyr old Globular Cluster -
Stellar astrophysicist's view
(Credit: Mochejska & Kaluzny)

Relative Stellar Contributions to IR Light

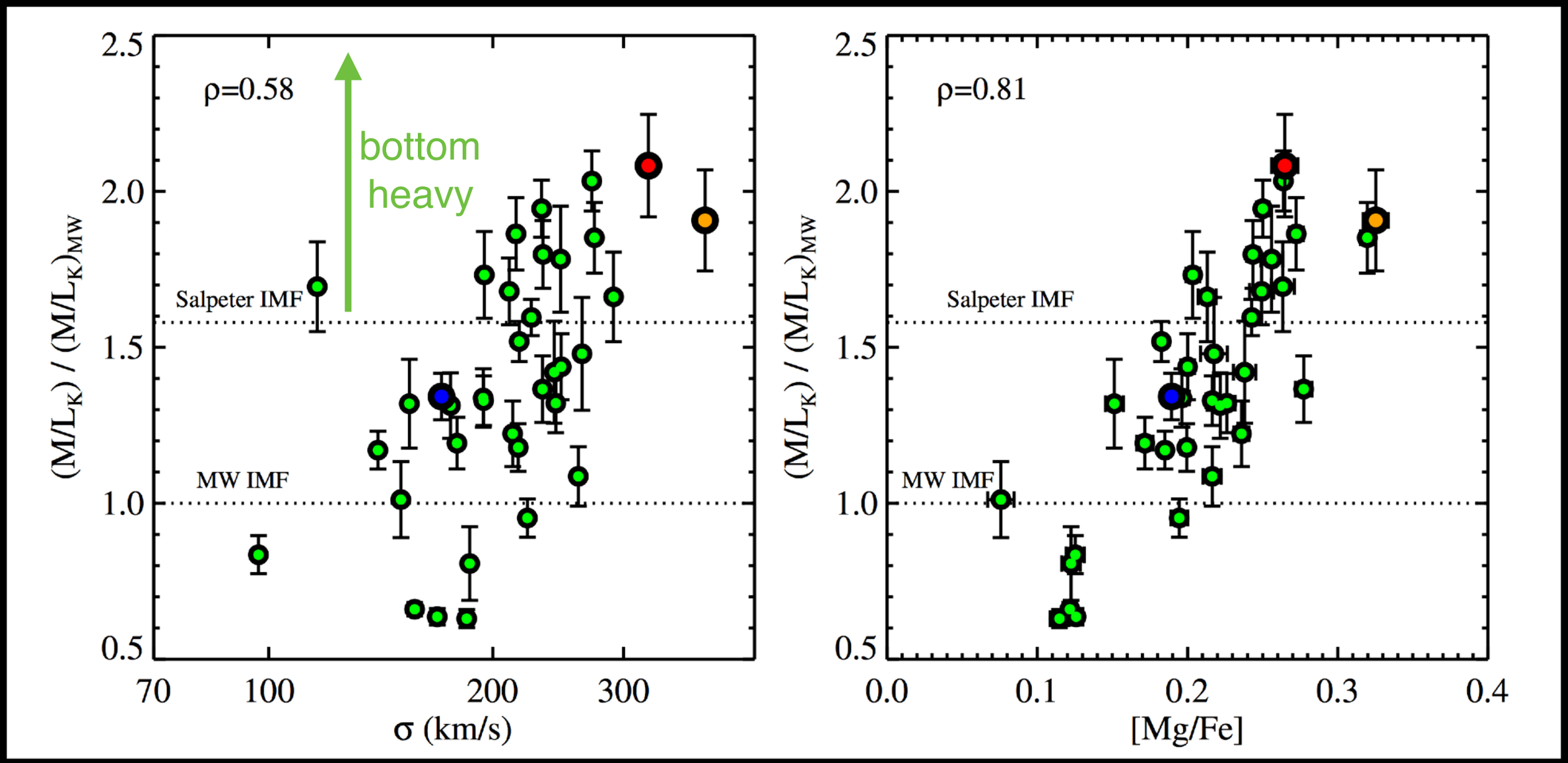




Worthey (1994)

~40-50% RGB ~10-20% other MS dwarfs
~10% KM dwarfs ~10-20% AGB

Stellar IMF from Extragalactic Observations

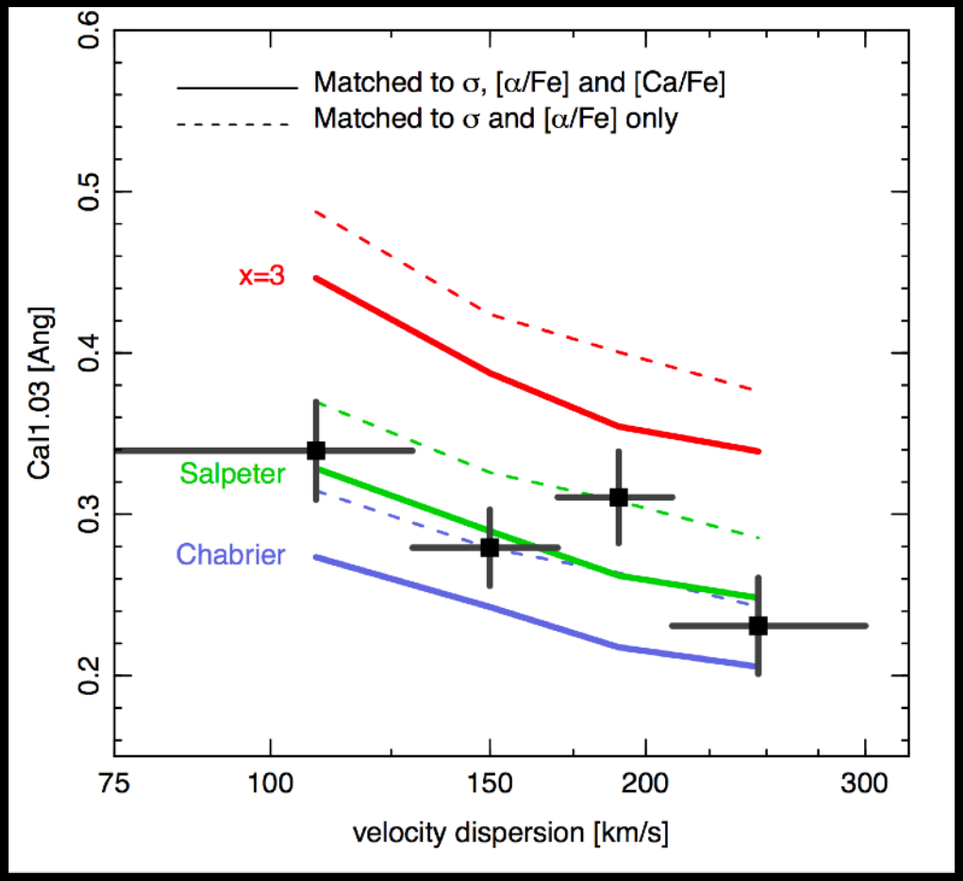


Stellar Population Synthesis (SPS) Analysis Conroy & van Dokkum (2012b)

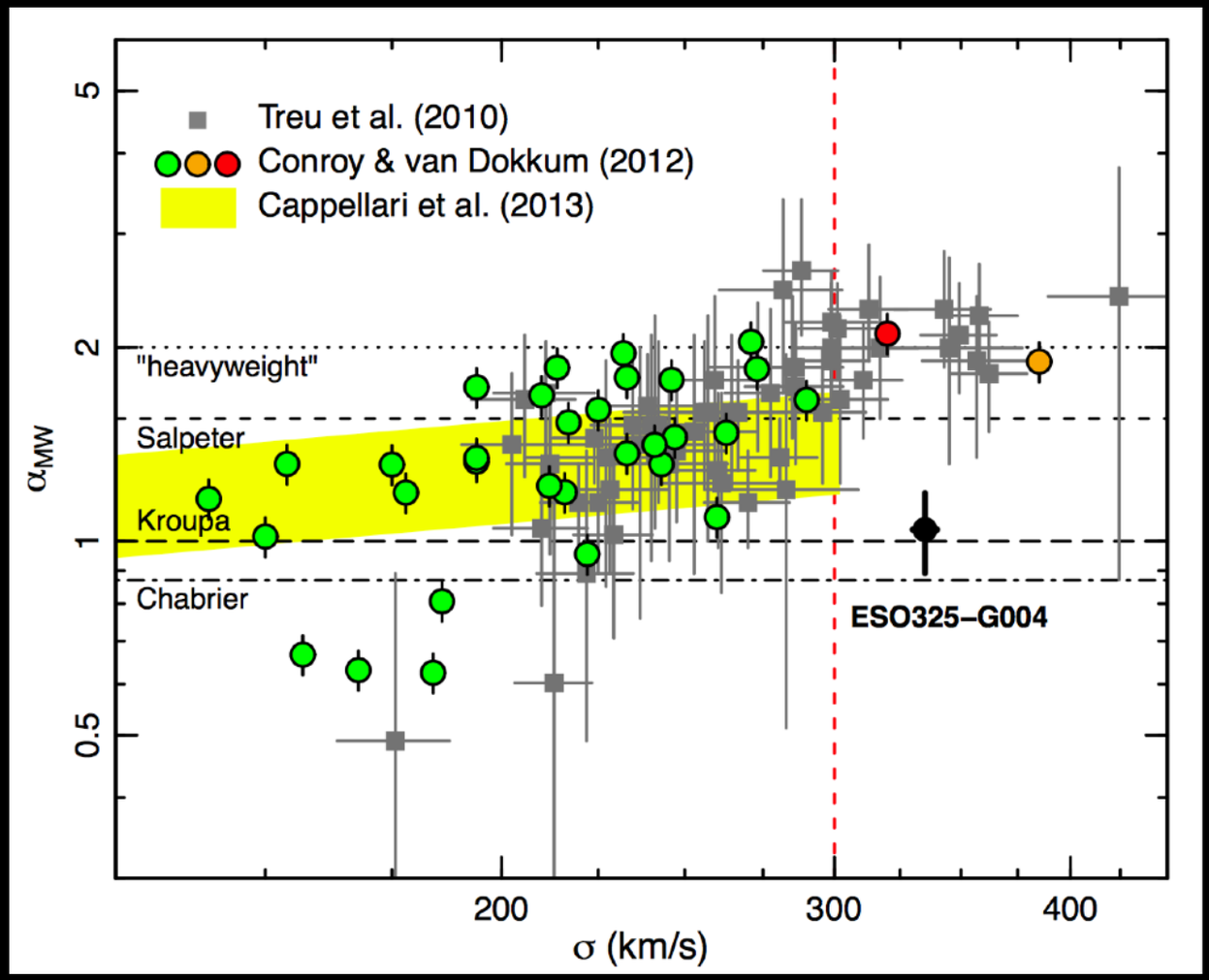
- Corroborated by other SPS works of early types (e.g. Spinnello+12, Martinez-Navarro+2015)
- Bottom-light IMF observed in low mass dwarf spheroidal galaxies (Geha+13)

Stellar IMF from Extragalactic Observations

Not all results of stellar IMF variation in agreement



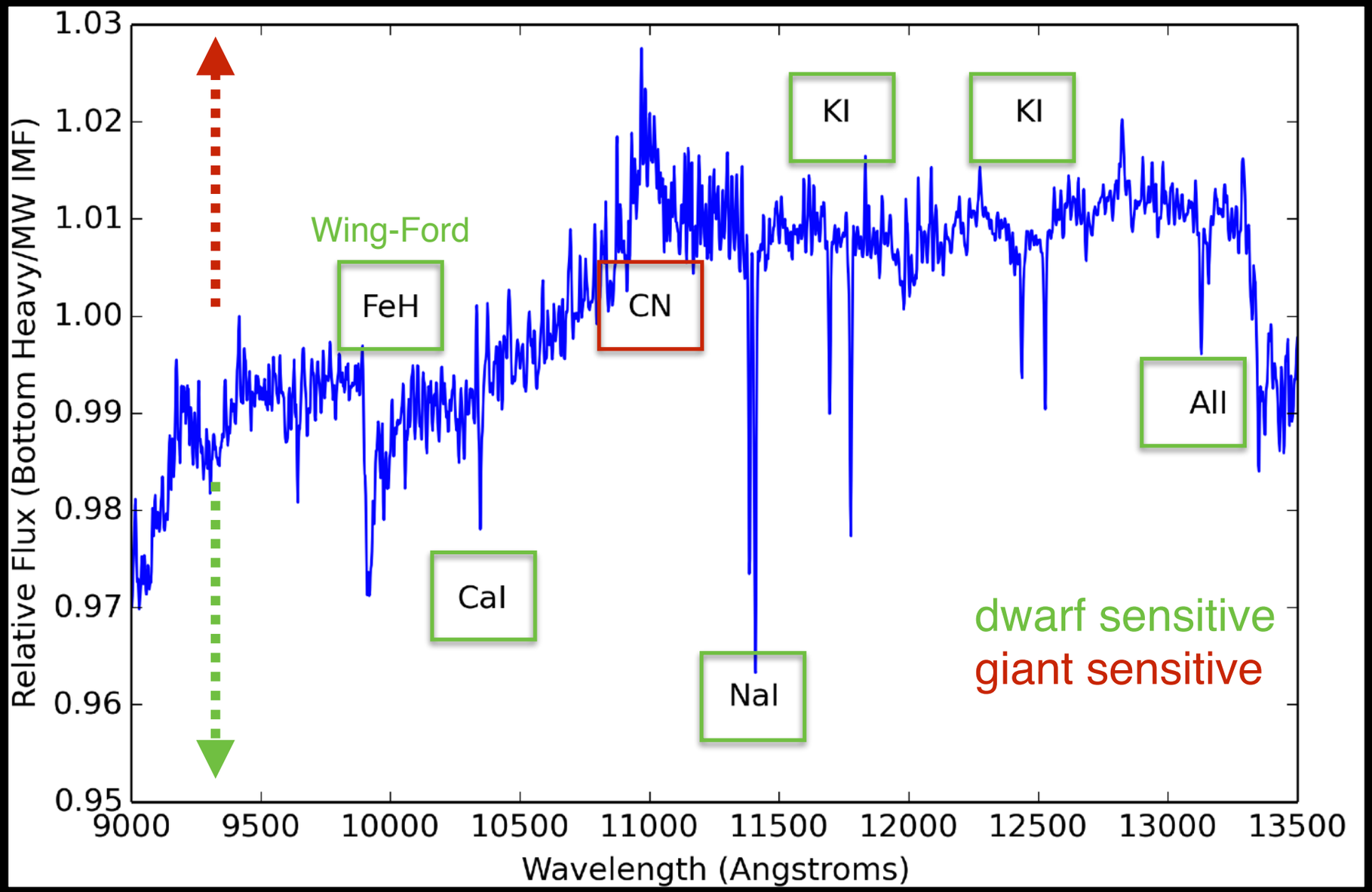
Coma Galaxies Smith et al. (2012)



Lensing Measurement Smith et al. (2013)

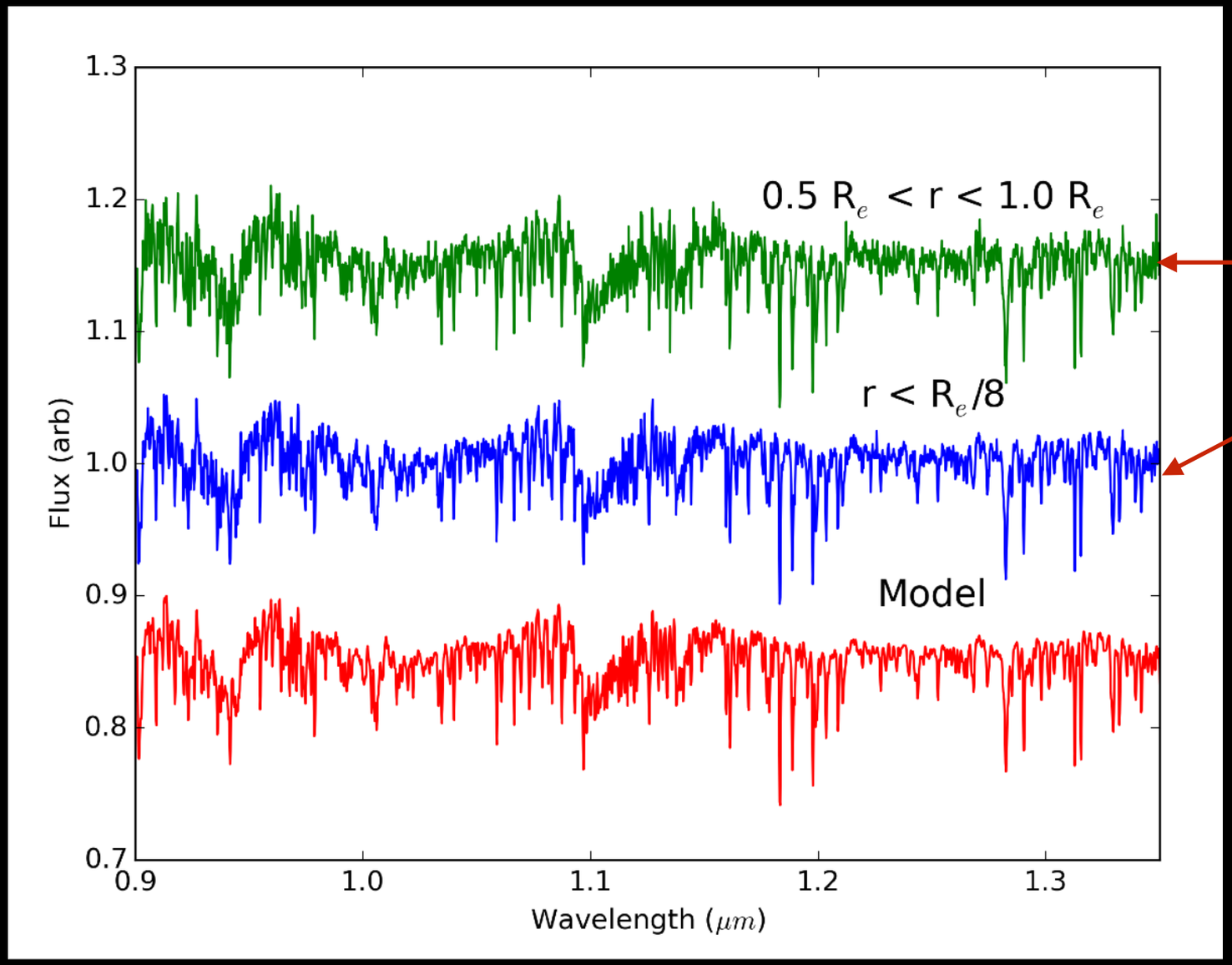
WIFIS Measurements of IMF in Galaxies

Measuring the IMF of Early Types and Spiral Bulges

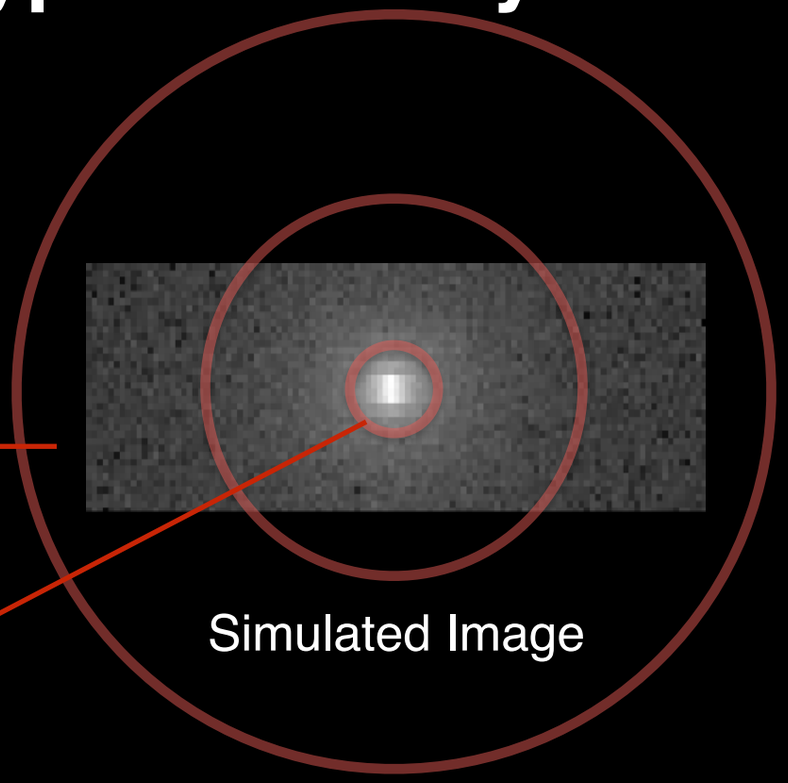


11 Gyr old solar metallicity models from Conroy & van Dokkum 2012a

Simulated Observations of A Typical Galaxy



(Jarvis et al. to be submitted)

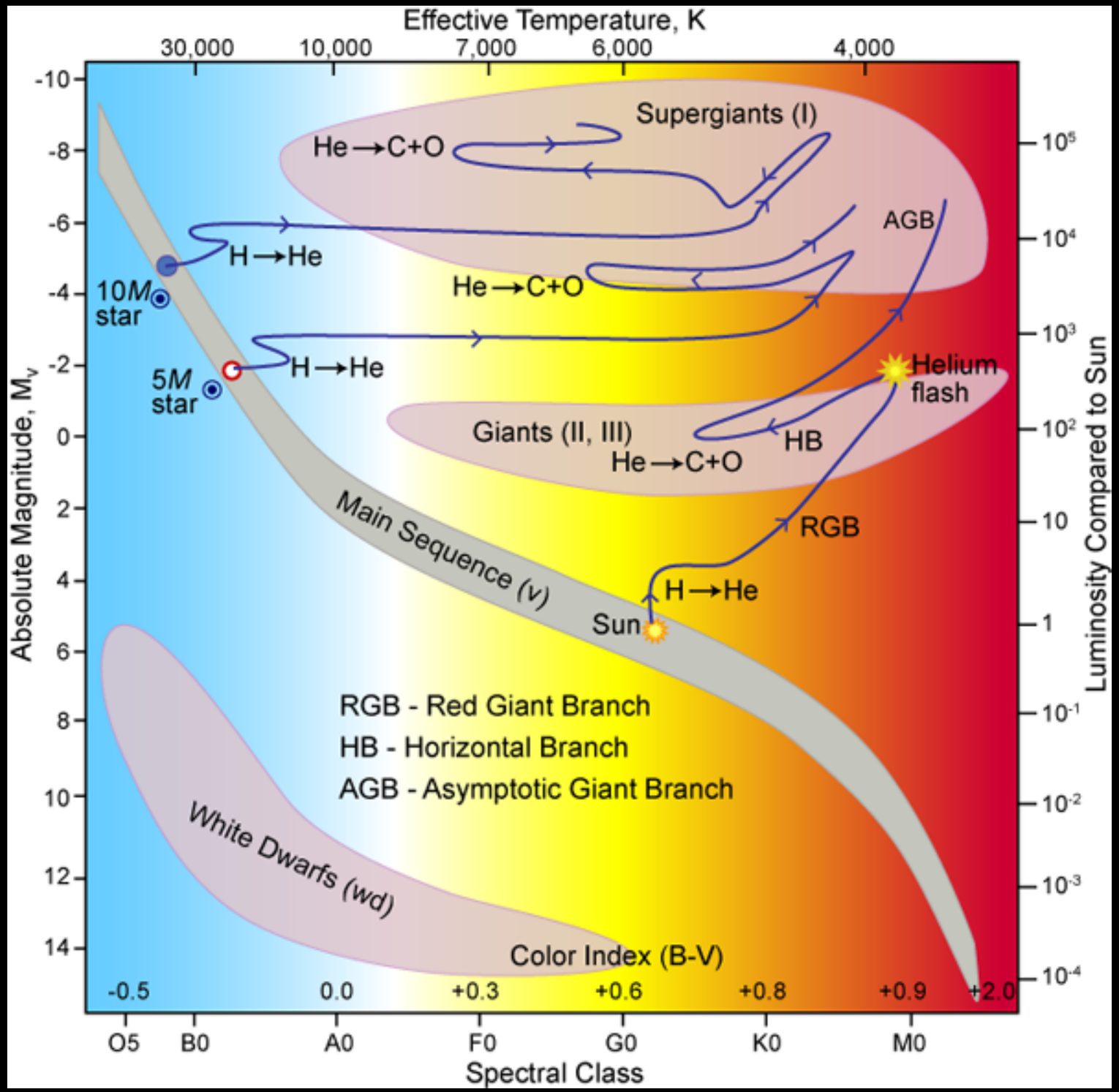


Prototypical Elliptical

- J_{tot} = 10 mag
- R_e = 30” (~10 kpc at 0.02)
- deV profile
- 3 Gyr Chabrier IMF
- $t_{int+overhead}$ = 4 hours

Dominant systematics from sky subtraction and telluric absorption not included

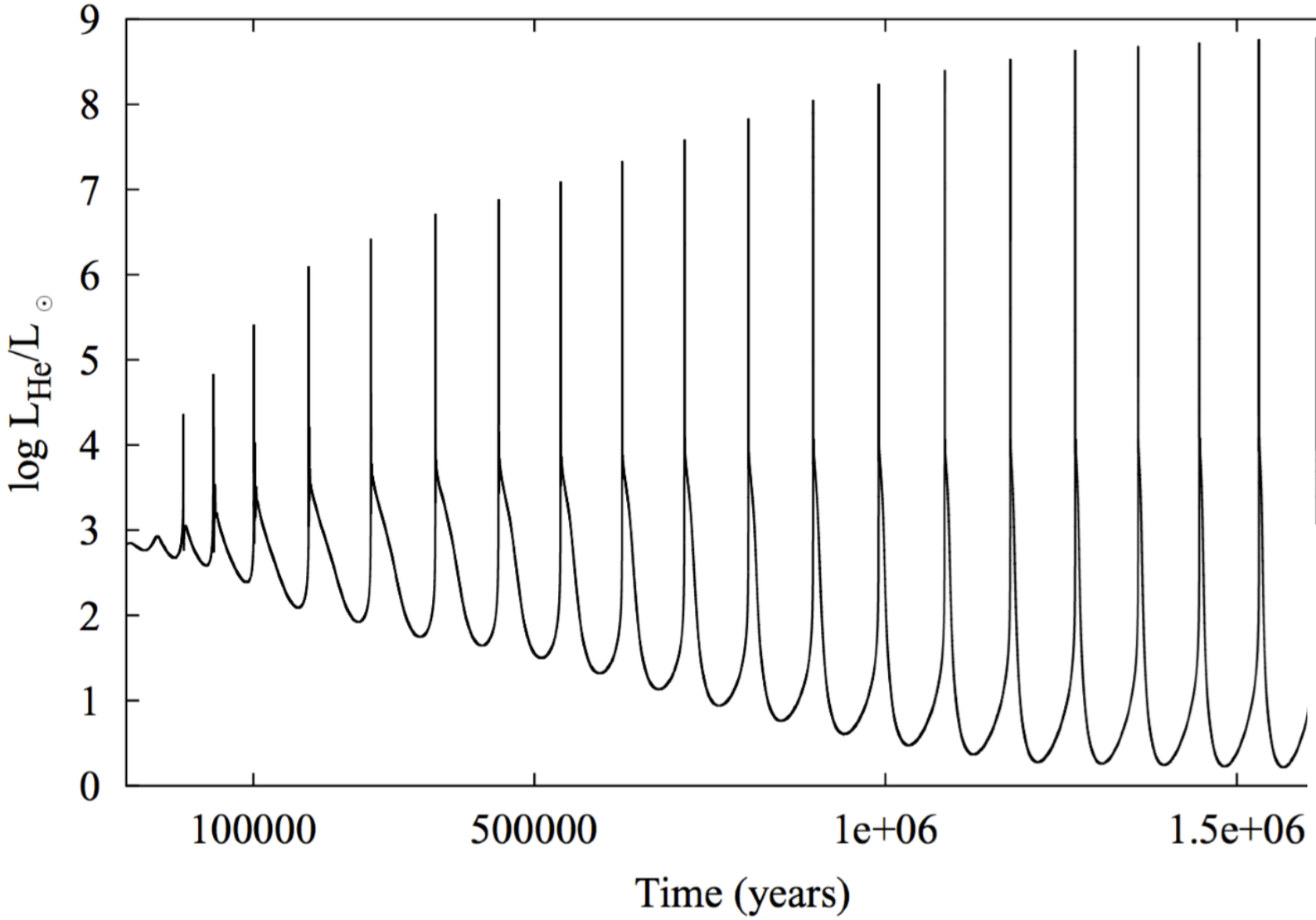
Late Evolution of Low and Intermediate Mass Stars



(Wiescher 2009)

- 0.8-8 $M_\odot$ stars undergo an asymptotic giant branch phase where they exhaust their almost all of their nuclear fuel.
- During the AGB phase, the luminosity of these objects increases several orders of magnitude when they begin to thermally pulsate.

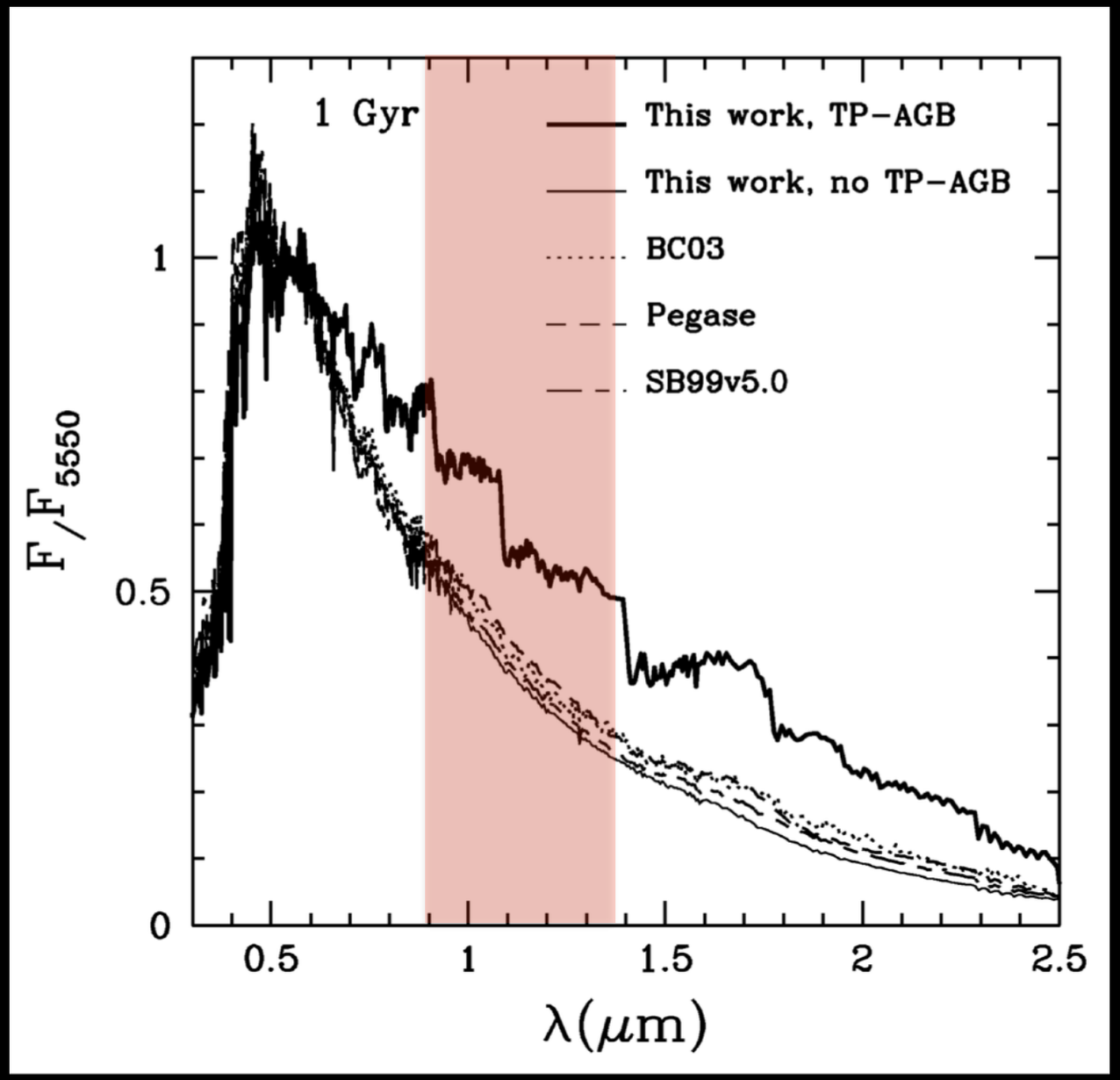
Thermally Pulsating AGB Stars



Helium shell burning luminosity for 3 $M_{\odot}$ in TP-AGB phase (Stancliffe et al. 2004)

Structure of TP-AGB star

Thermally Pulsating AGB Stellar Contribution



Solar Metallicity 1Gyr old Population Model
(Maraston 2005)

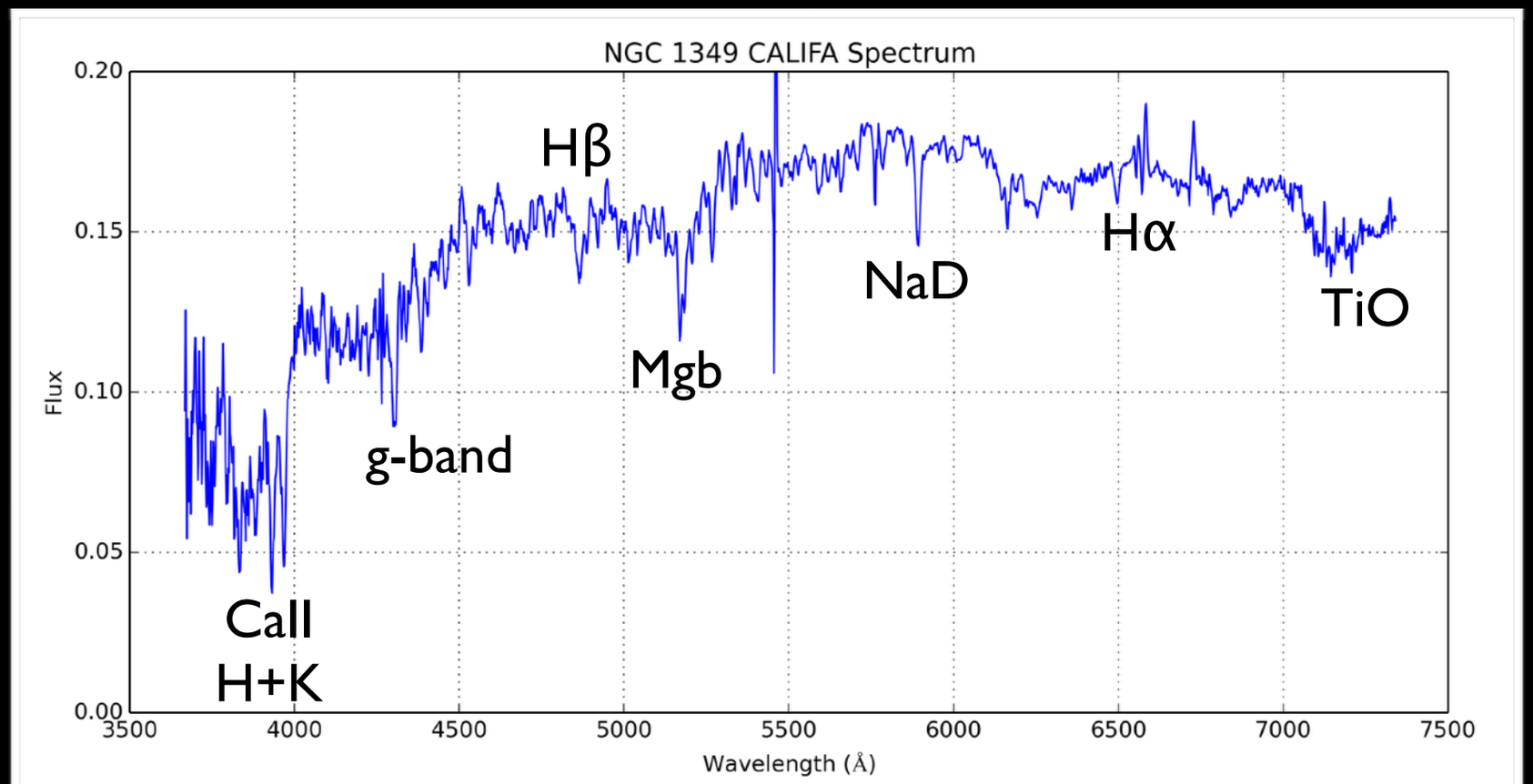
- Previous models neglected their contribution because of the short timescale
- Important contributors for galaxies with stellar ages within 0.2-2 Gyr
- Overestimate stellar mass by factor of 2 when using NIR luminosities

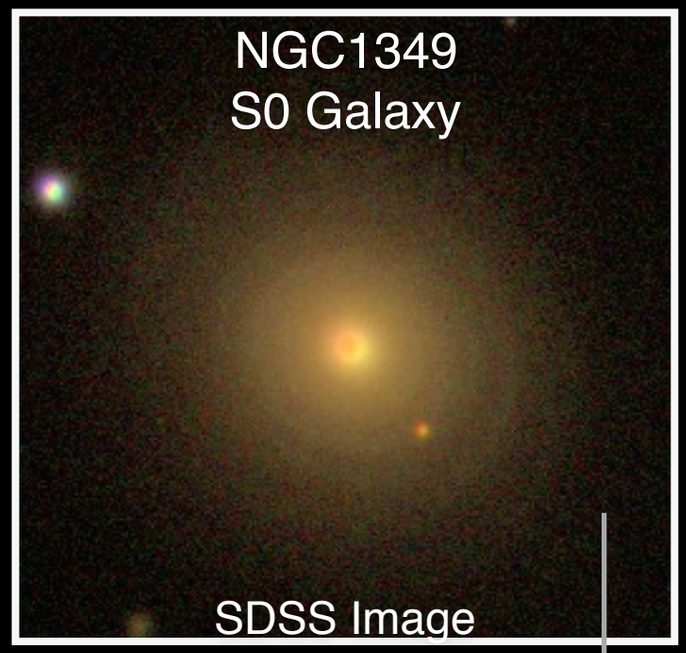
Survey Sample

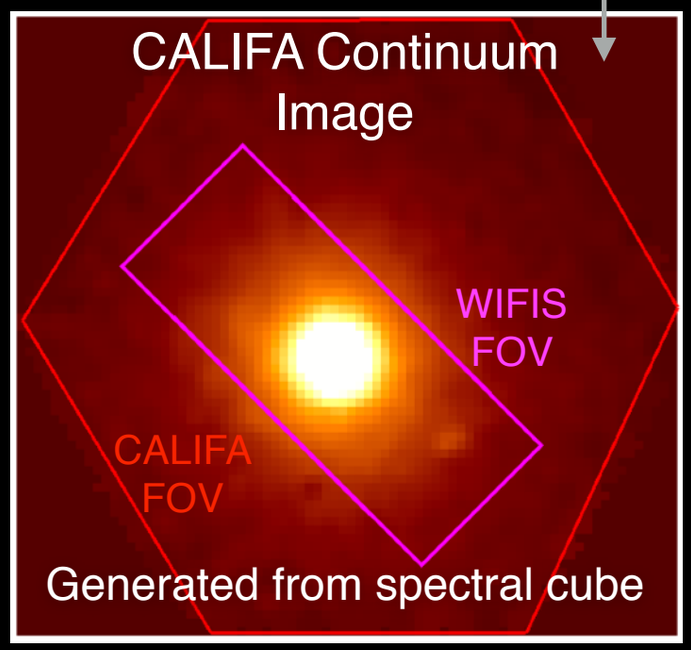
50 nearby elliptical galaxies/spiral bulges

- Broad range of velocity dispersion and metallicity
- Existing optical wide integral field data

10 nearby post-starburst galaxies







Complement optical large-field IFS surveys

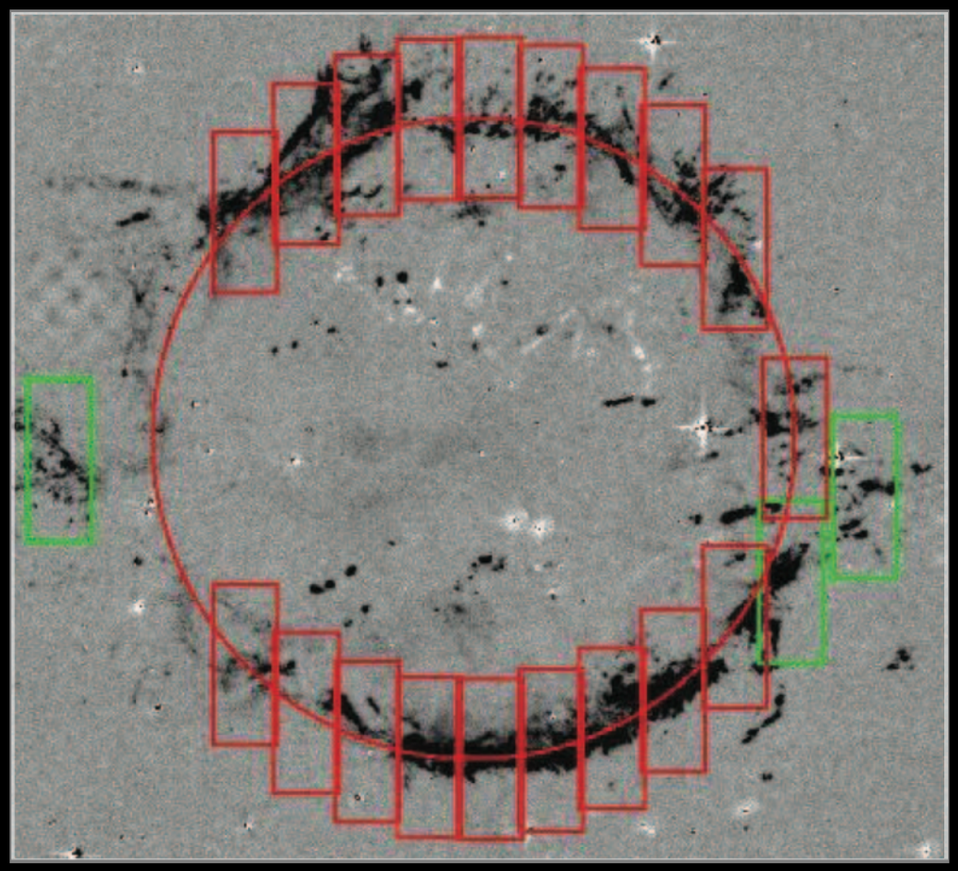
Other WIFIS Scientific Programs

Extragalactic:

- High Mass Star Formation
- Merger Dynamics and Star Formation
- Population Gradients in Spirals
- Bulge - Blackhole Mass Relation

Galactic:

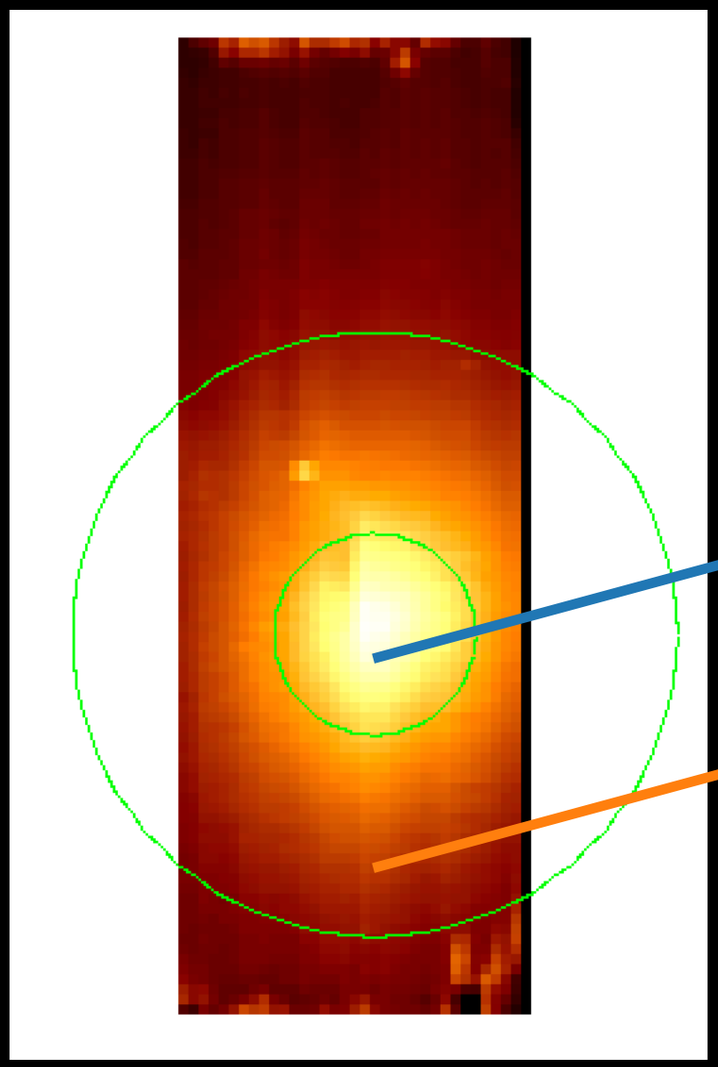
- Nucleosynthesis in Supernovae
- Young Stellar Objects
- Mapping of Galactic Star Forming Regions



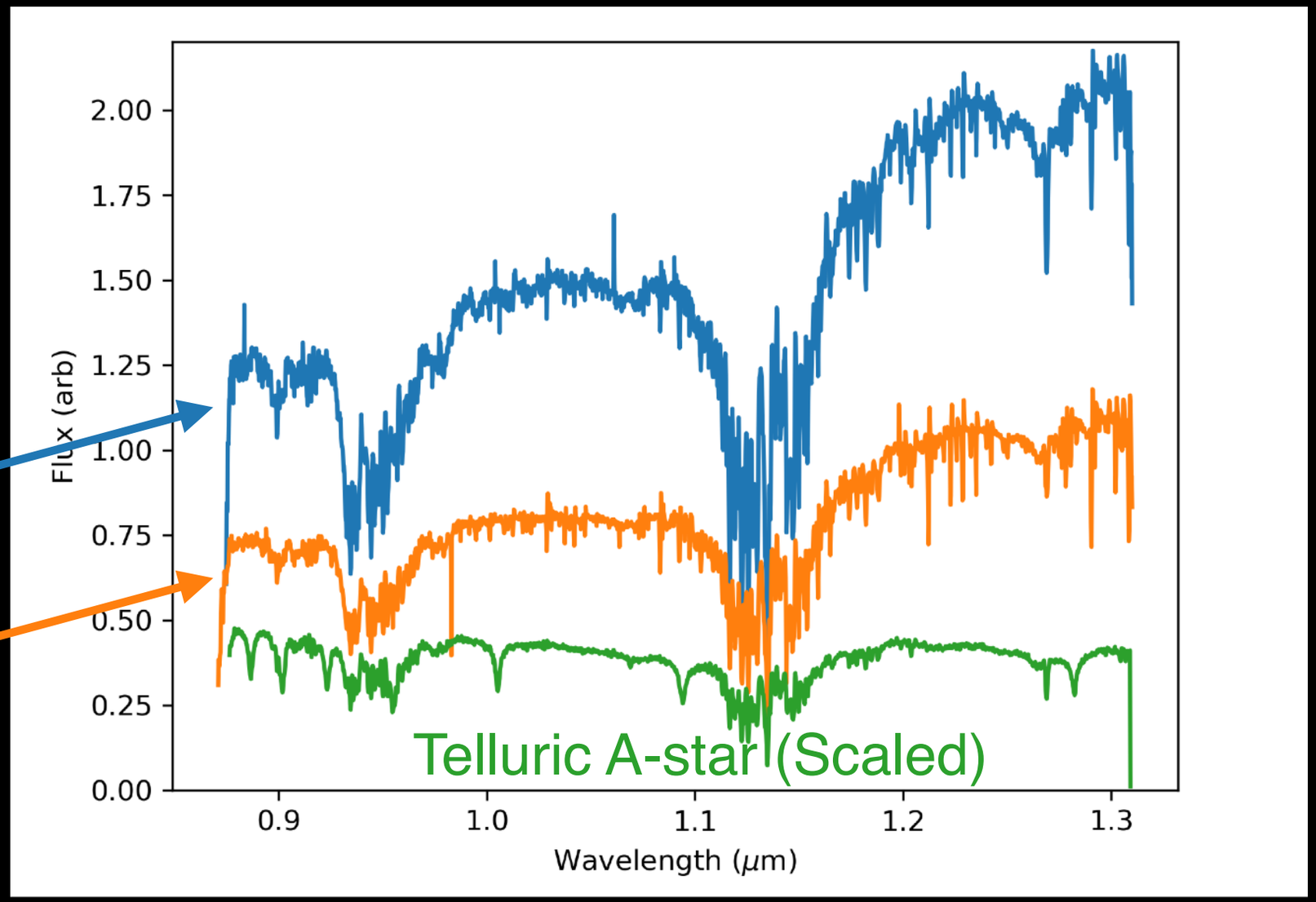
[FeII] 1.64 μm image of Cas A
(Koo et al. in prep)
WIFIS pointings overlaid

Commissioning Results

WIFIS M87 *Commissioning* Results



M87 Continuum Image
(Collapsed cube)

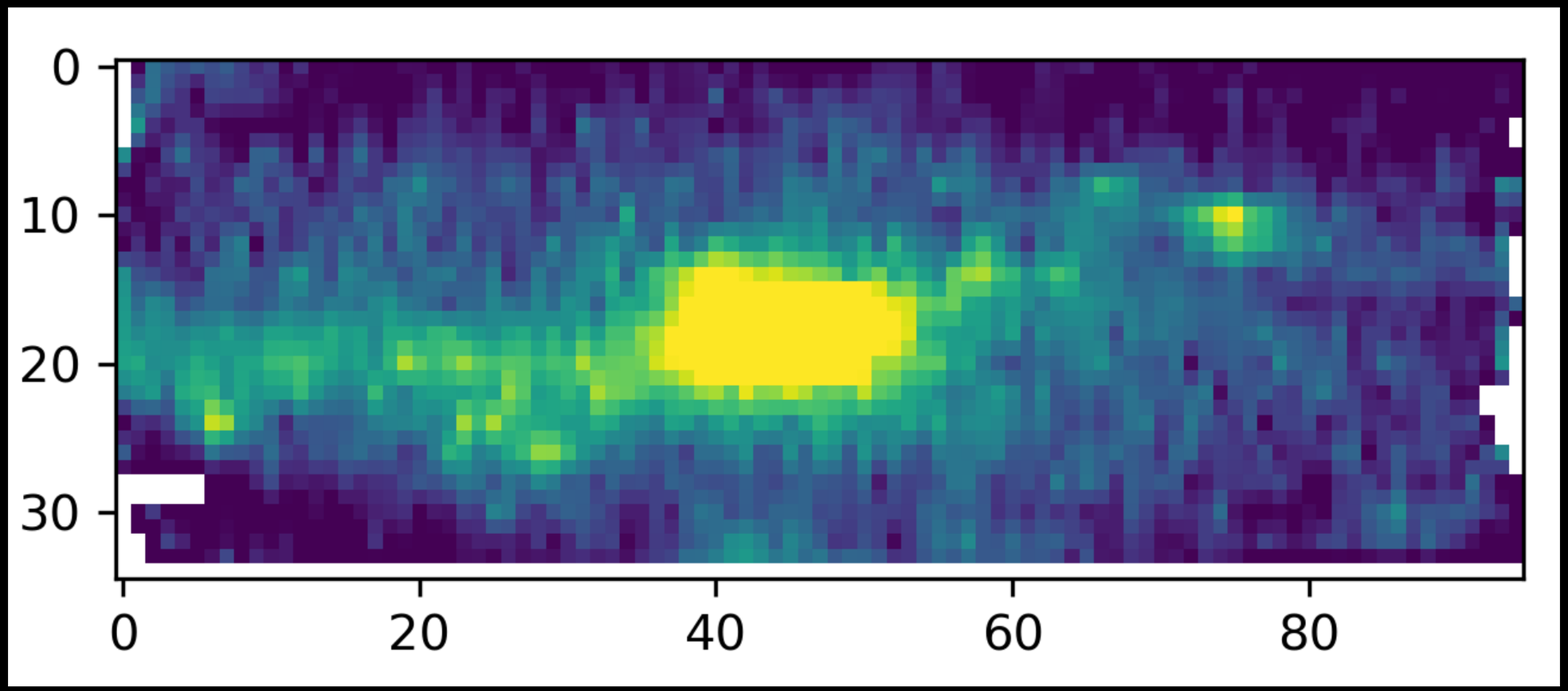


15-Minute On-Source +
15-Minute Off-Source Exposure

Anticipating to spend a few hours per galaxy for survey

Pipeline complete
(Grunhut et al. 2017)

WIFIS NGC7541 *Commissioning* Results

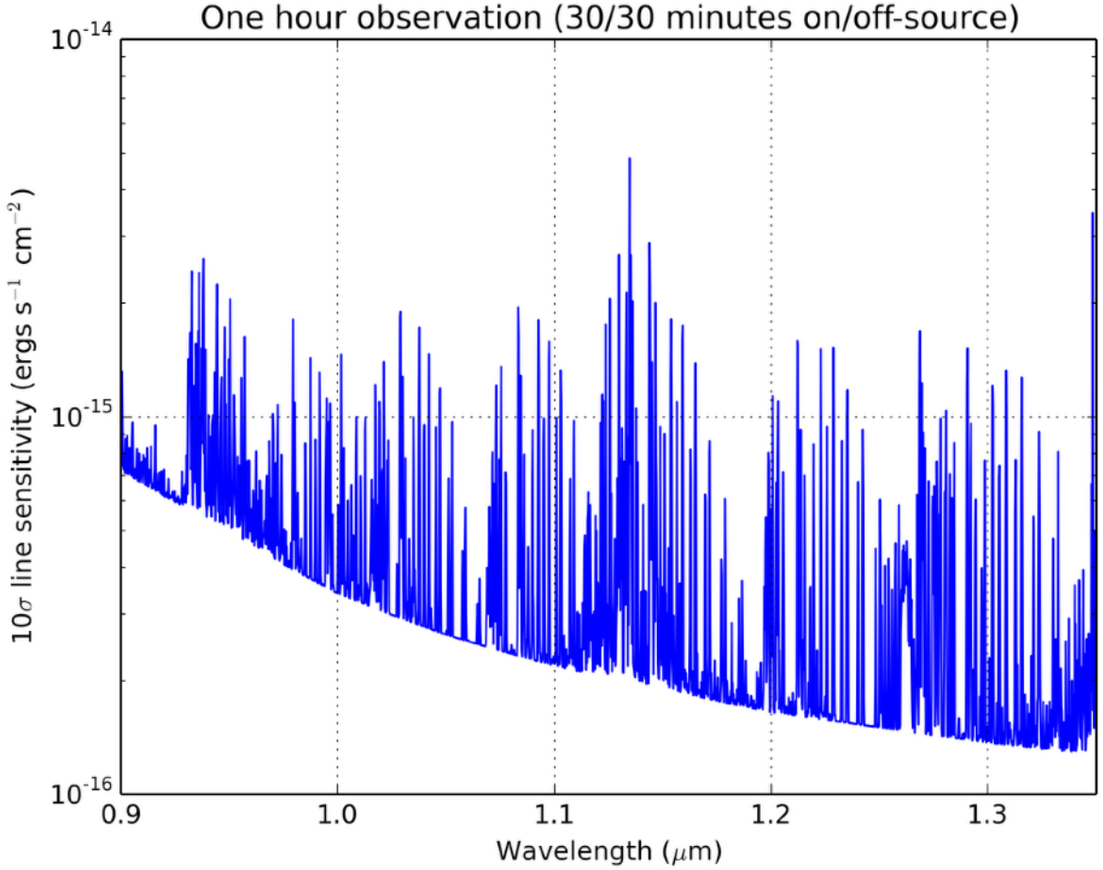


NGC7541 Paβ Image - Starburst Galaxy

60-Minute On-Source +
40-Minute Off-Source Exposure

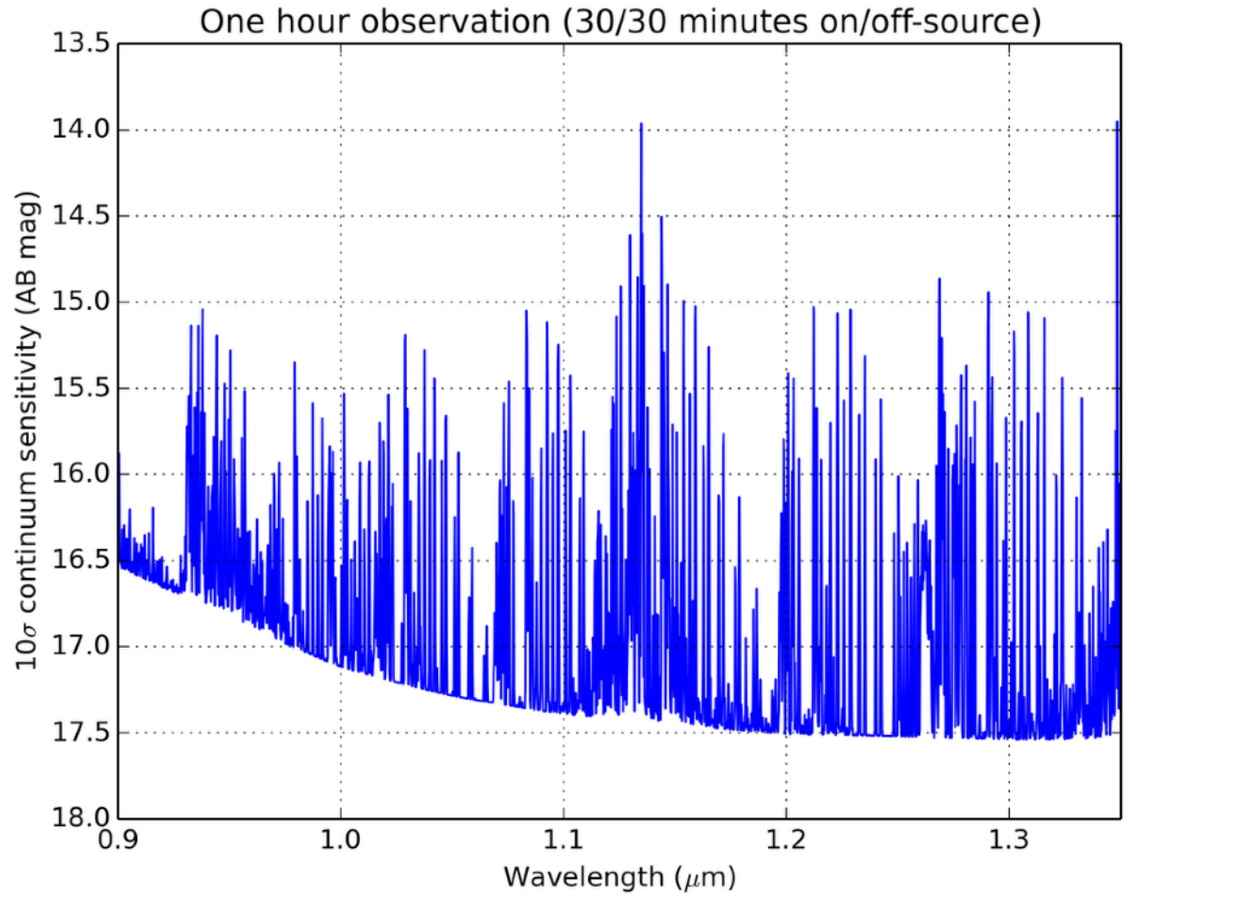
Resolved HII regions

Expected Sensitivity



- Predictions for 30 minutes on source and 30 minutes sky (1 hour observing time)

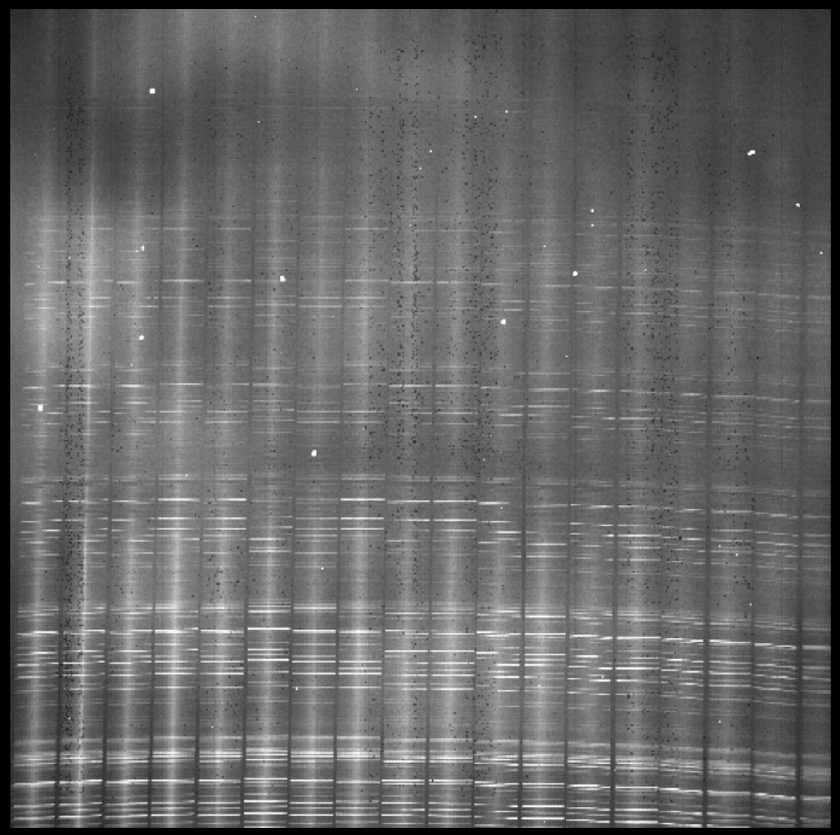
- Still in the process of getting final measurements.
- Current sensitivity is up to 3x worse than predictions



WIFIS Pipeline (Pypline)

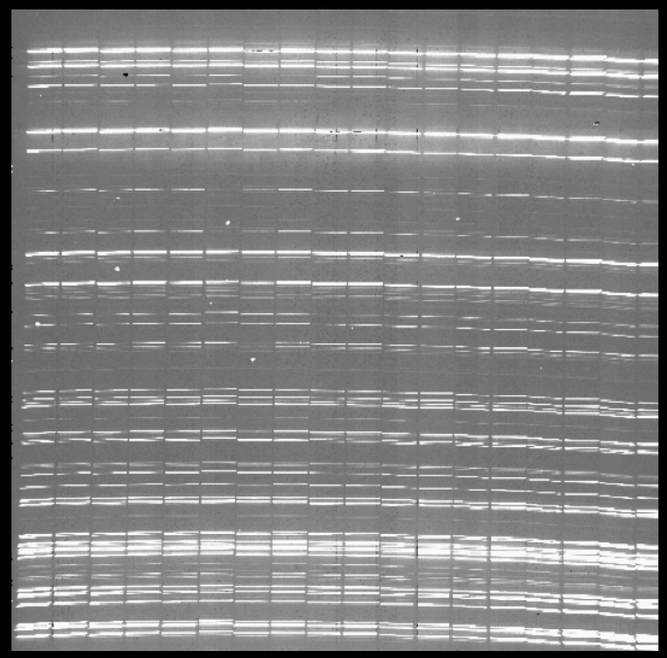
Fully Featured: Raw Data + Calibrations to Spectral Cubes (Python based)

M87



Object + Sky Ramps

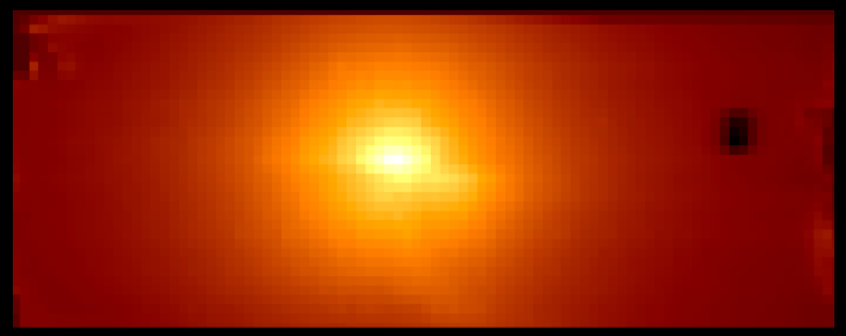
Grunhut et al. 2018

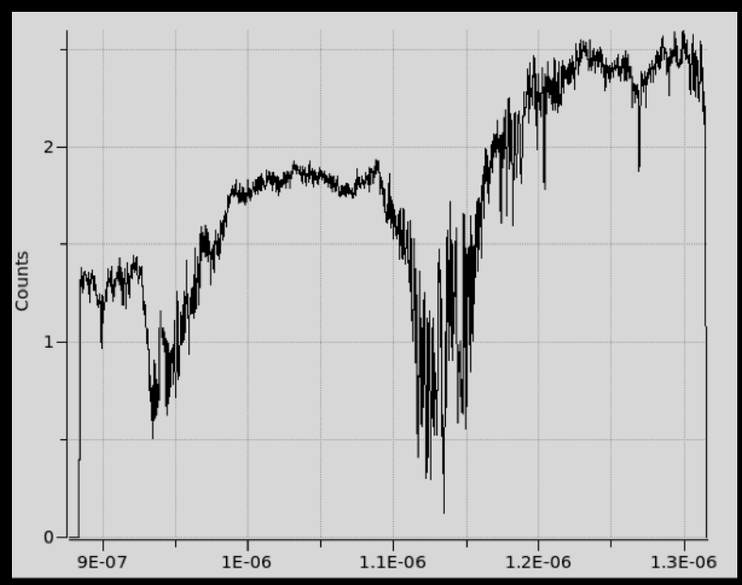


Arcs

Flats

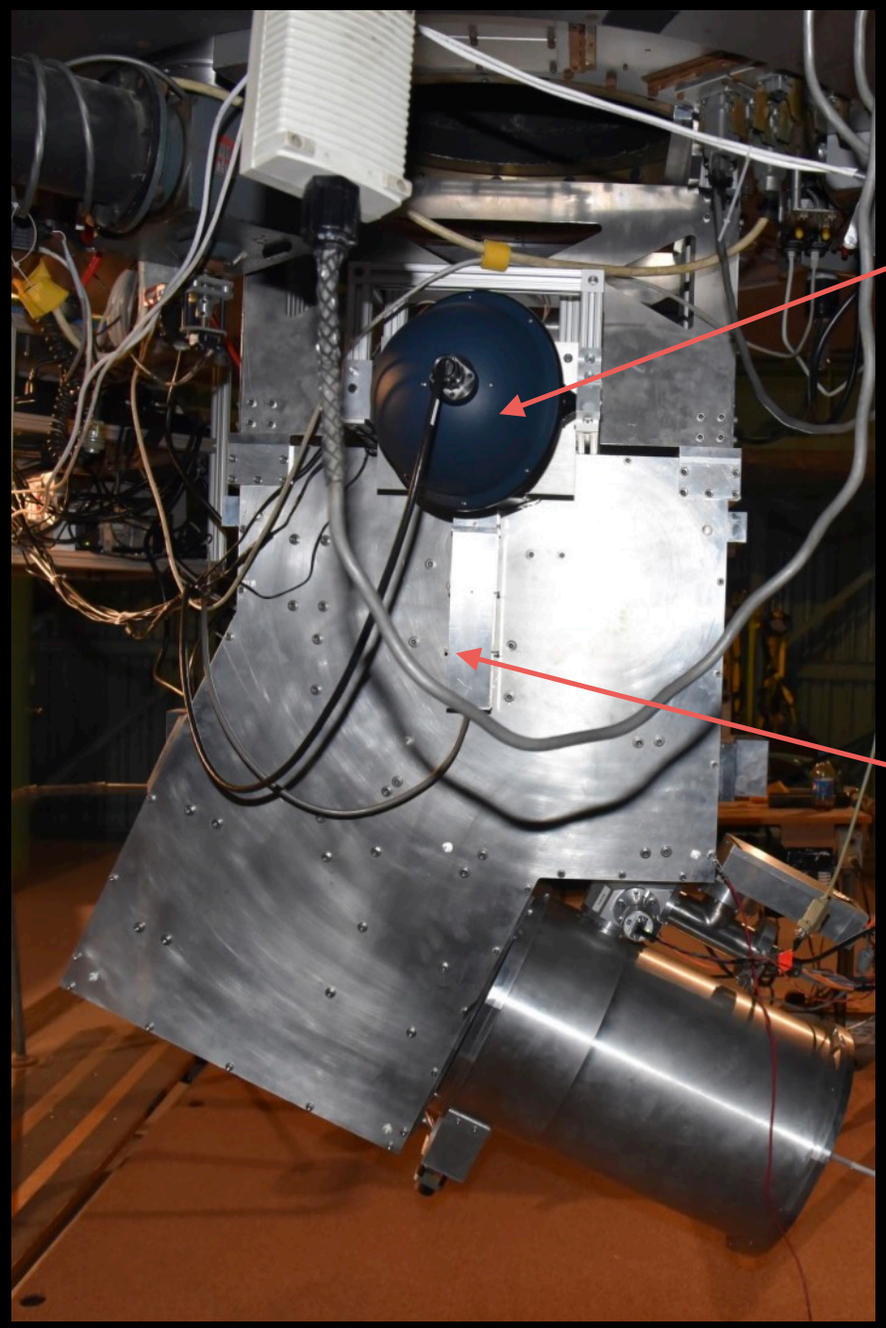
Spectral Cubes





Calibration

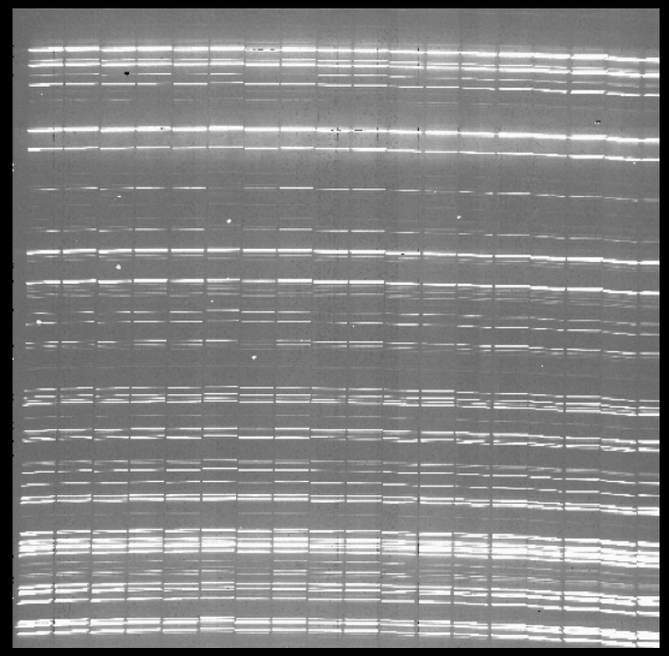
On-instrument Calibration System



Integrating Sphere with Halogen Lamp

Th-Ar Gas Discharge Lamp

Flats



Arcs

WIFIS Pypline Features

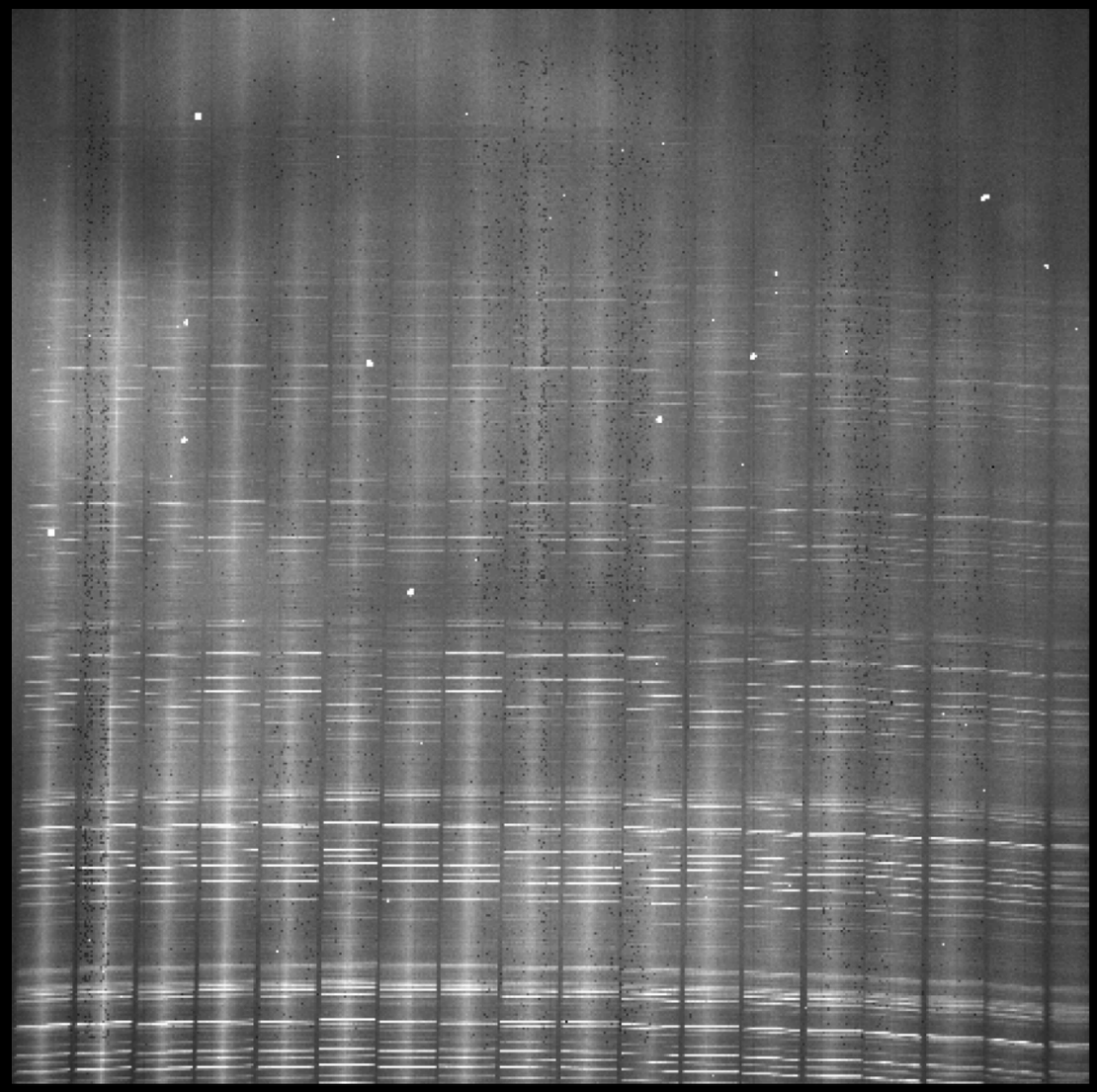
Data Processing:

- **Non-linearity Corrections**
- **Ramp Fitting**
- **Bad Pixel Mapping**
- **Wavelength Solution Fitting**
- **Spatial Reconstruction**

Value-Added Features:

- **Automatic Sky+Background Subtraction**
- **Flexure Compensation**
- **Multi-cube Averaging**

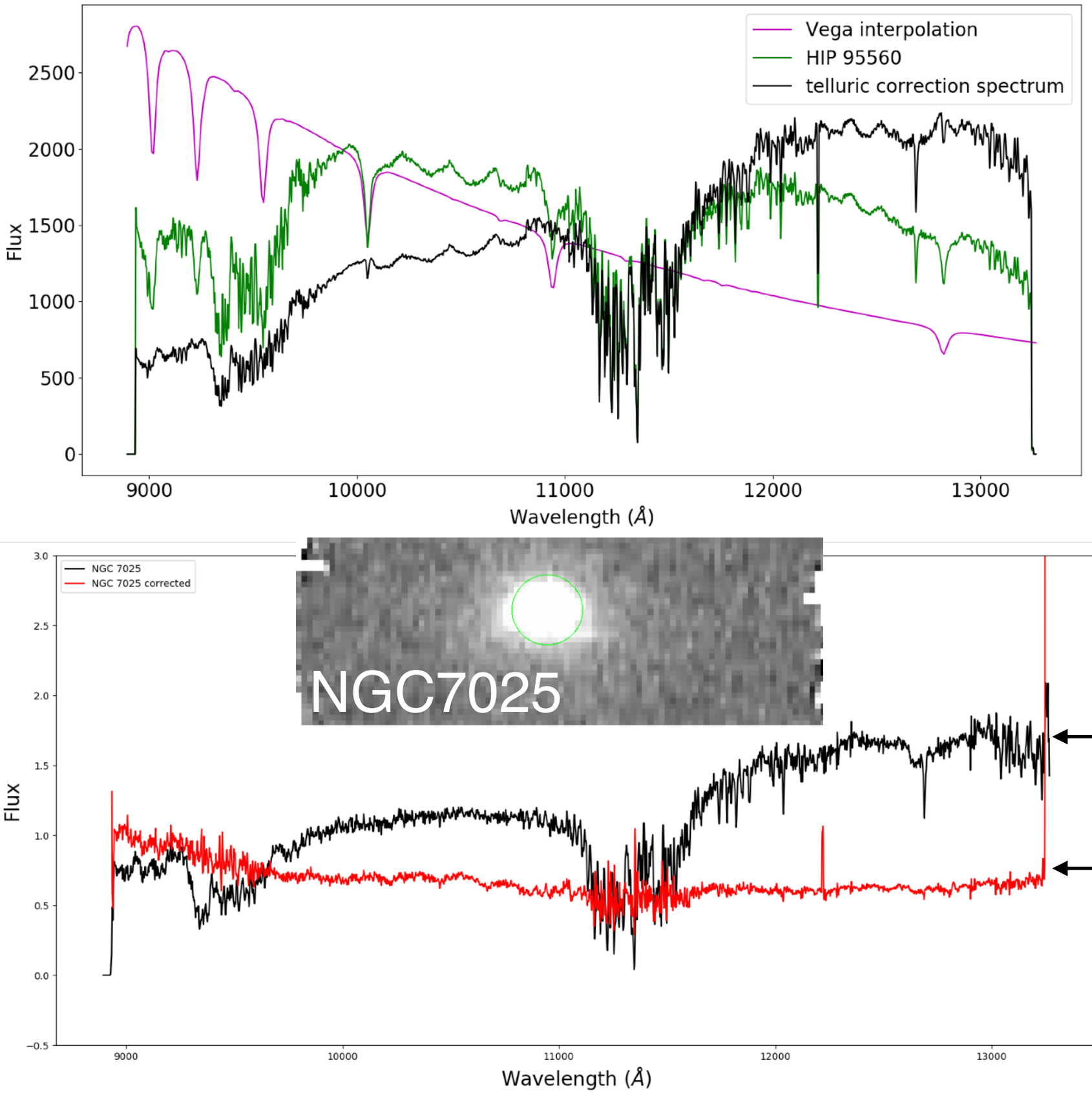
▸ **Telluric Corrections Not Yet Implemented**



High performance (OpenCL+Multiprocessor)

Multi-hour observations reduced in 20 minutes

Telluric Corrections

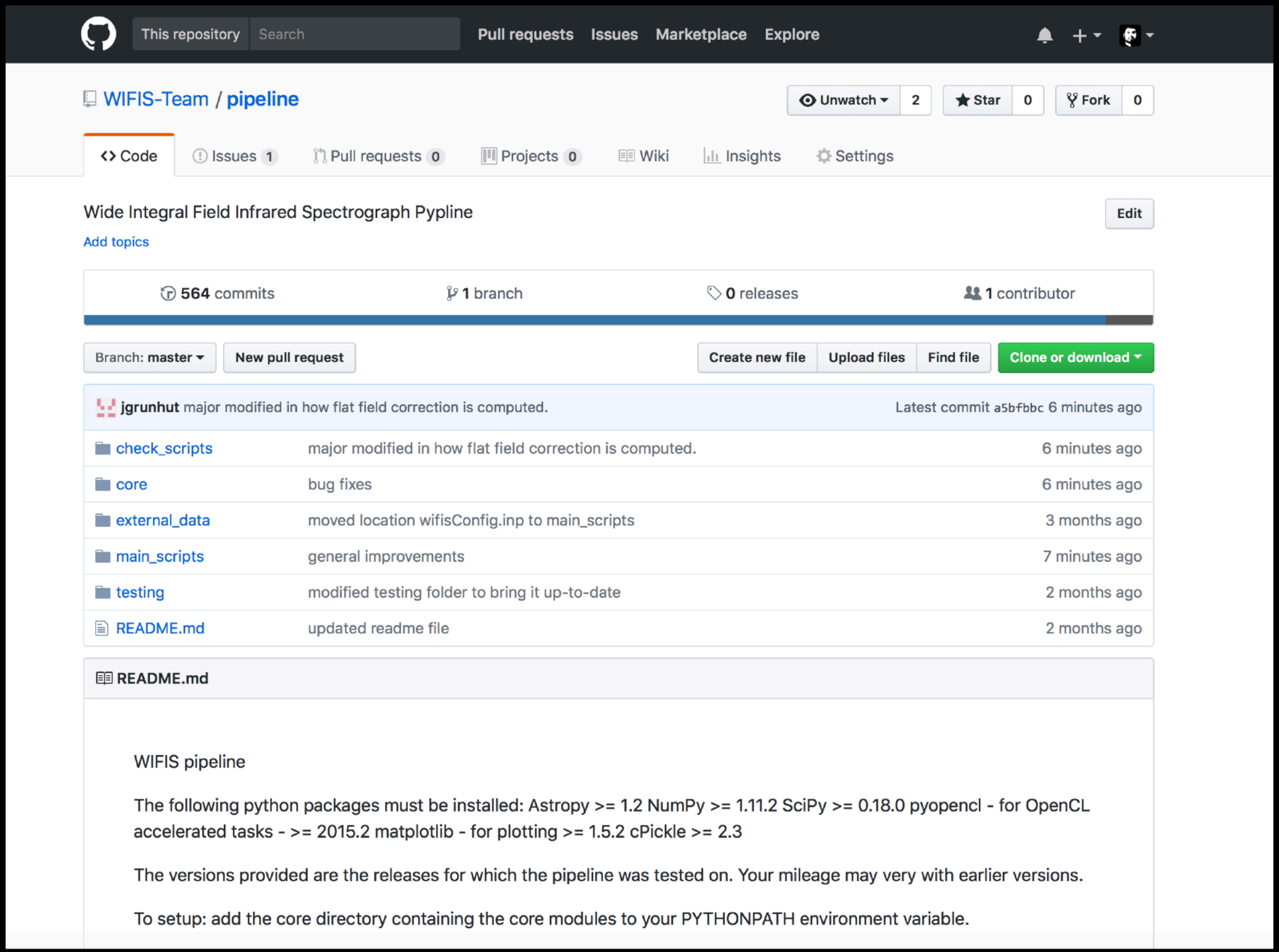


A0V Telluric

Ikape et al. 2018

Demo

M85/M87 Cubes

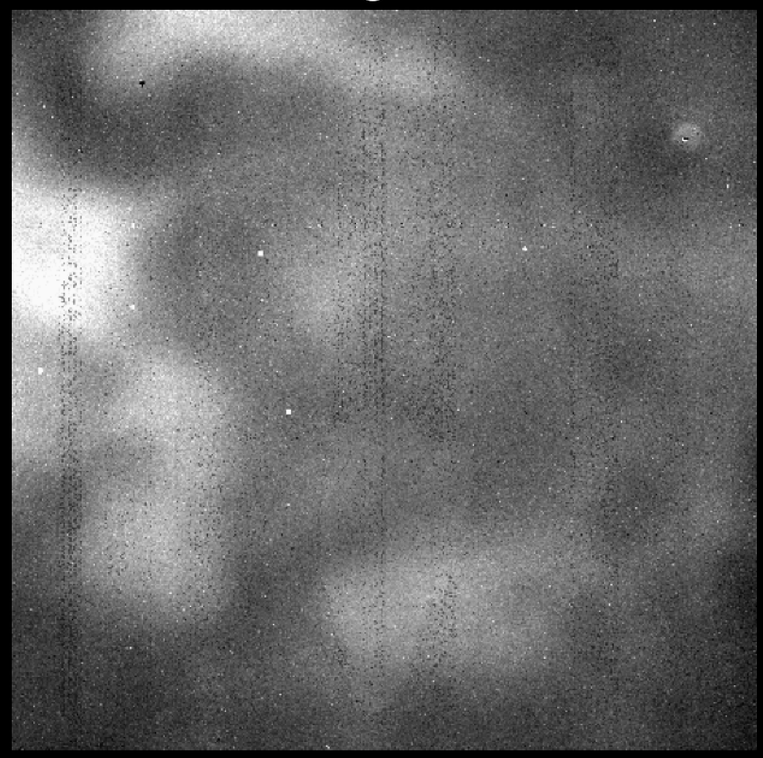


Available on Github: https://github.com/WIFIS-Team/pipeline

Issues to Resolve

- Higher than expected background (~10x)
  - Design Target: < 0.5 e^-/s
- Focus on some slices not very good (~2-3 outer slices)
- Spatial/Spectral flat fielding not perfect
- Pointing flexure needs to be calibrated
- Make instrument more user-friendly
- Observing software still in beta

Residual Thermal Background



Summary

- WIFIS has been commissioned on the 90”
- Performance is generally good and we have a plan to improve it
- Perfectly matched for science cases that require extended source spectroscopy
- We are anticipating that we can offer WIFIS in shared risk mode in the upcoming semester

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