The IFS for WFIRST CGI: Science Requirements to Design

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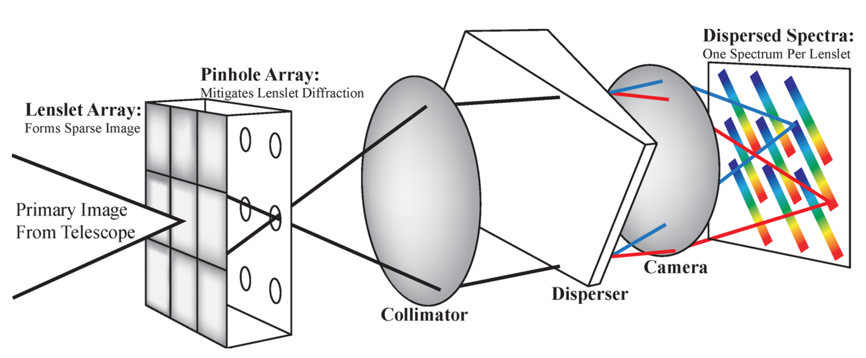
The CGI Flight IFS

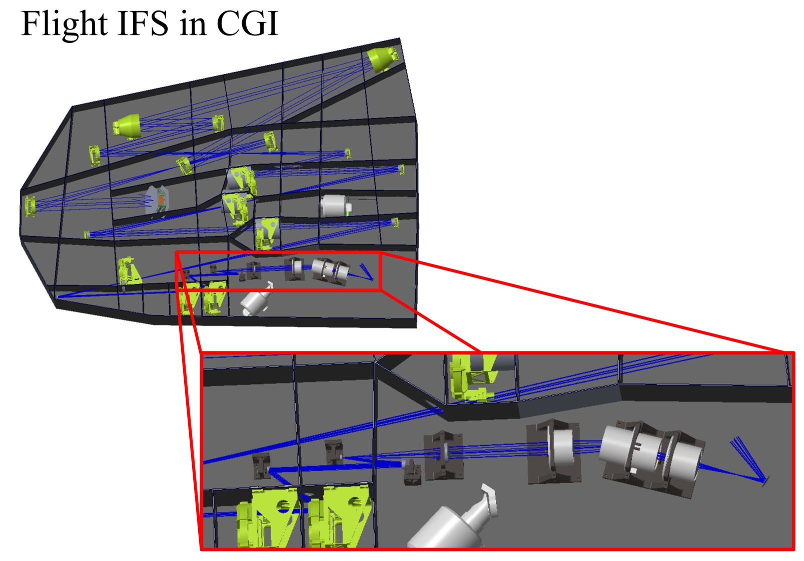
Direct Imaging of exoplanets using a coronagraph has become a major field of research both on the ground and in space. Key to the science of direct imaging is the spectroscopic capabilities of the instrument, our ability to extract spectra, and measure the abundance of molecular species such as Methane. To take these spectra, the WFIRST coronagraph instrument (CGI) uses an integral field spectrograph (IFS), which encodes the spectrum into a two-dimensional image on the detector. This results in more efficient detection and characterization of targets, and the spectral information is critical to achieving detection limits below the speckle floor of the imager. The CGI IFS operates in two18% bands spanning 600nm to 840nm at a nominal spectral resolution of R50. We present the current science and engineering requirements for the IFS design, the instrument design, anticipated performance, and how the calibration is integrated into the focal plane wavefront control algorithms. We also highlight the role of the Prototype Imaging Spectrograph for Coronagraphic Exoplanet Studies (PISCES) at the JPL High Contrast Imaging Testbed to demonstrate performance and validate calibration methodologies for the flight instrument.

General IFS Design:

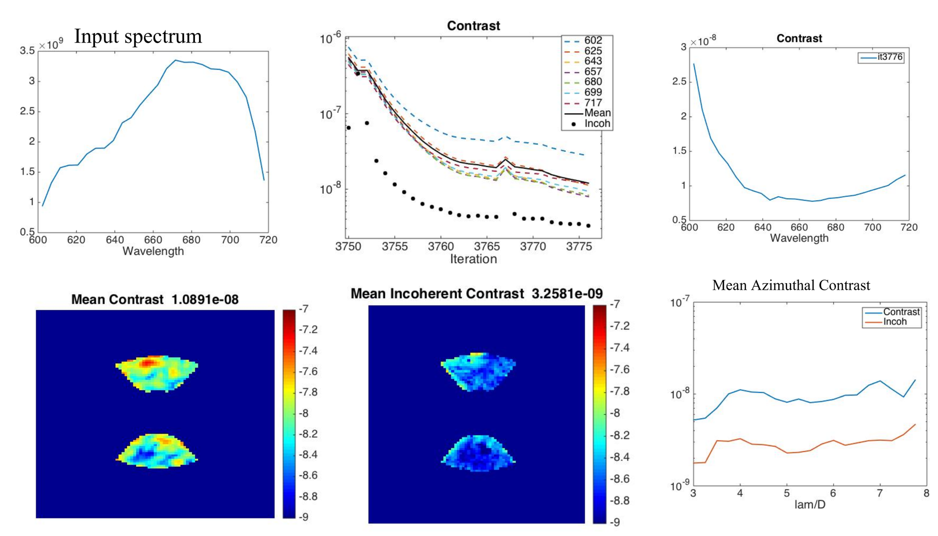
Basic IFS Concept



Flight IFS in CGI



High Contrast Demonstration with PISCES:



- 18% Bandpass, R70, at 660nm
- Score: Two sides, 26 channels, 3-8 lam/D, 65⁰
- Control: Two sides, 7 channels, 2.5-9.5 lam/D, 75⁰
- Using "Optimal" extraction of a 1D gaussian
- Currently working on implementing least-squares extraction
- Working towards higher contrast demonstrations through the next year

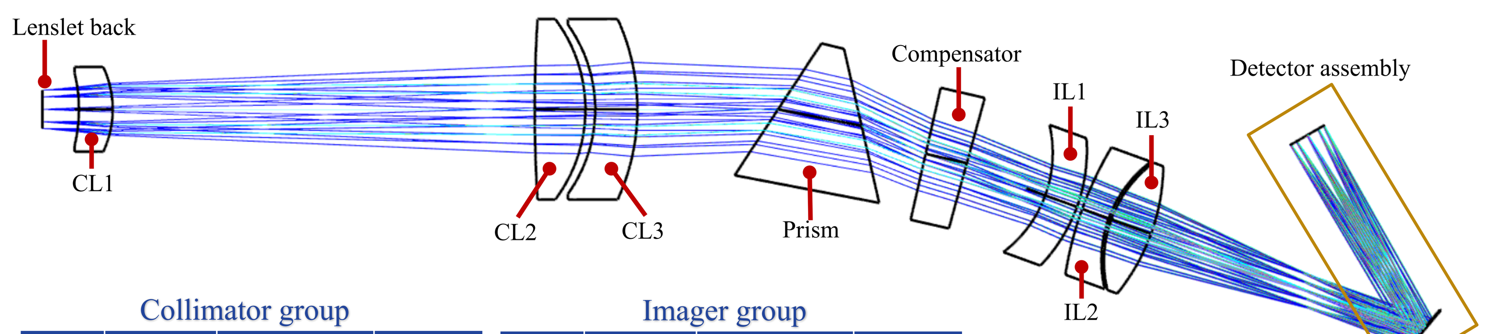
Note: Incoherent Contrast = Unmodulated Field

General Optical Design Specifications:

Phase A IFS Specifications		
# of dispersed pixels	18	18
Lenslet pitch (μm)	174	174
sampling at λ_c	2	2.33
Spectral resolving power	50	50

Baseline Filter Bands	Center	Cut-on	Cut-off	Bandwidth %
CGI Band 1 (Shaped Pupil)	660	600	720	18.2
CGI Band 2 (Shaped Pupil)	770	700	840	18.2
Occulter Band 1	728	656	800	20
Occulter Band 2	910	820	1000	20

- Optical Surfaces are Spherical
- Non-zero deviation design improves optical throughput
- Prism-Compensator pair produce near-constant spectral resolving power from 600nm to 1000nm
- Compact design that minimizes weight
- Final fold mirror is for cosmic ray protection
- Diffraction limited optical quality over full FOV



Collimator group

	R (mm)	Thickness(mm)	Material
CL1 s1	-53.948	12.0	CaF2
CL1 s2	-35.245		
CL2 s1	511.953	18.0	L-FPL51
CL2 s2	-53.069		
CL3 s1	-51.187	15.0	S-LAH79
CL3 s2	-76.331		

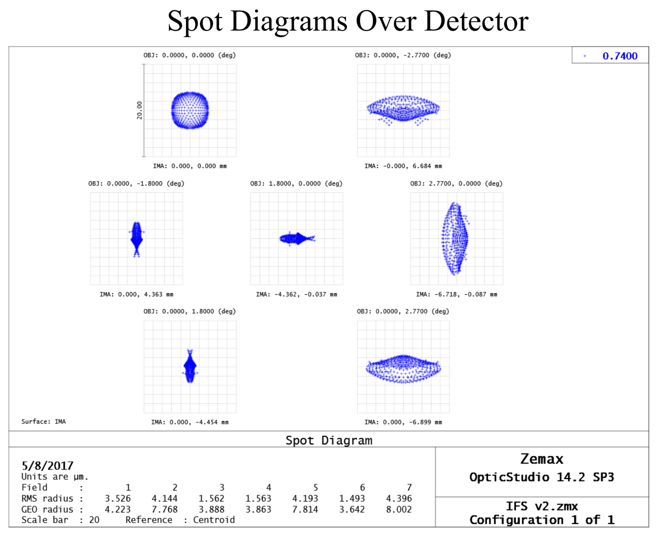
Imager group

	R (mm)	Thickness(mm)	Material
IL1 s1	-44.031	12.0	S-FSL5
IL1 s2	-58.737		
IL2 s1	125.255	10.0	L-BAL43
IL2 s2	43.463		
IL3 s1	43.422	15.0	CaF2
IL3 s2	-72.638		

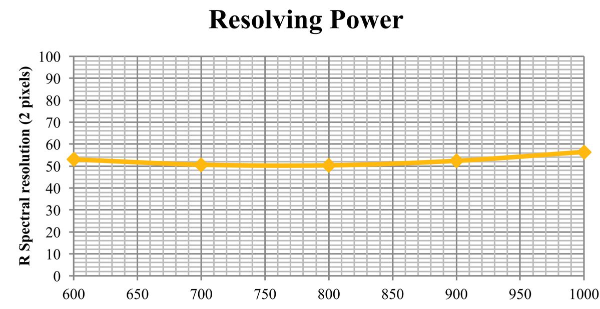
Prism & compensator

	Apex angle (°)	Material
Prism	46.3	F-SILICA
Compensator	2.61	ZnS

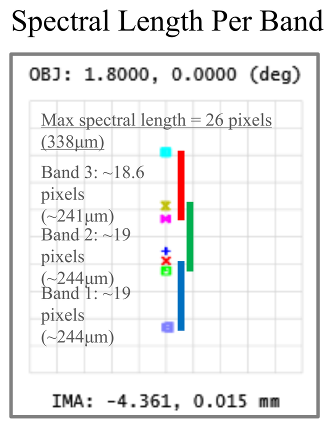
Spot Diagrams Over Detector



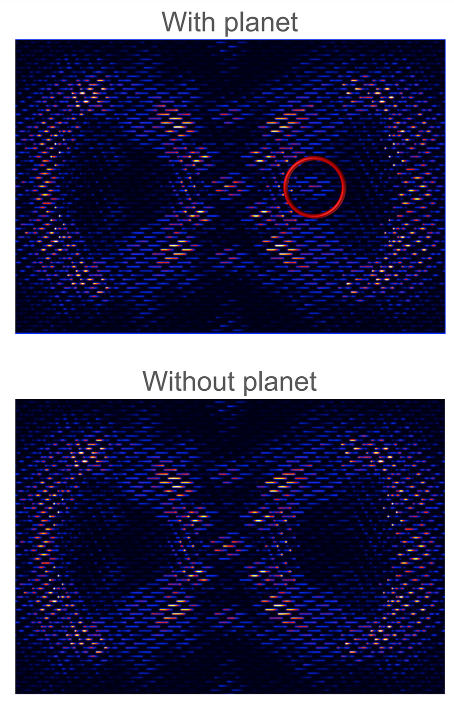
Resolving Power

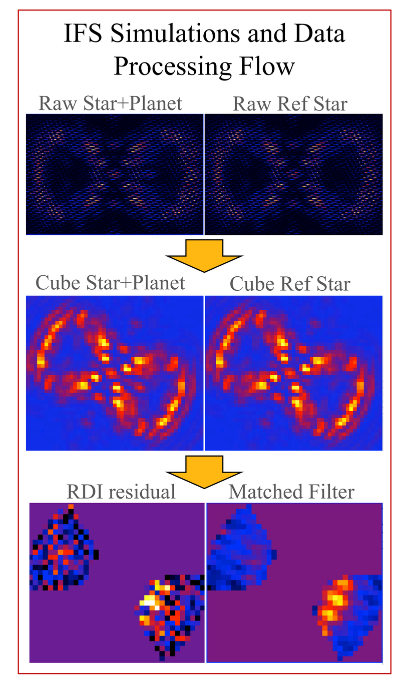


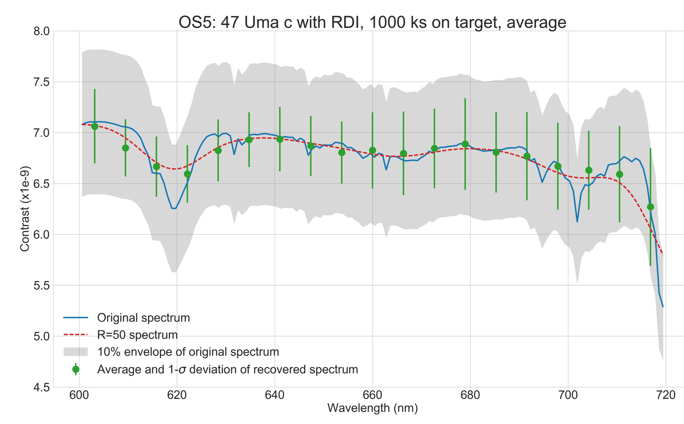
Spectral Length Per Band



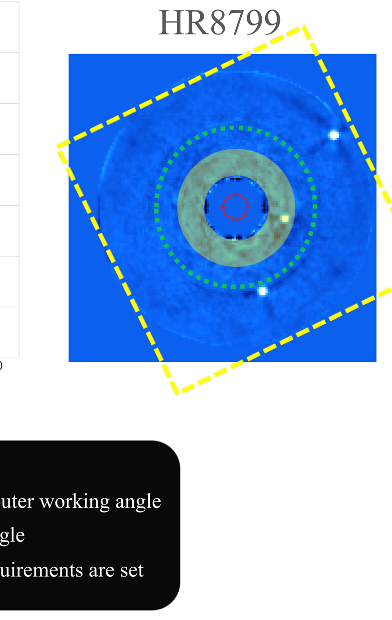
Instrument Simulations:







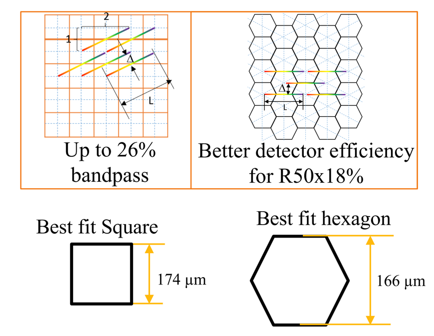
FOV Compared to HR8799

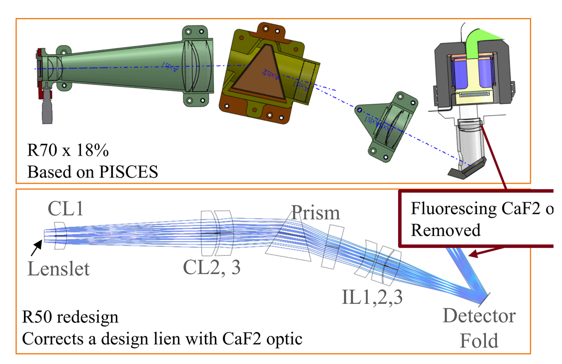


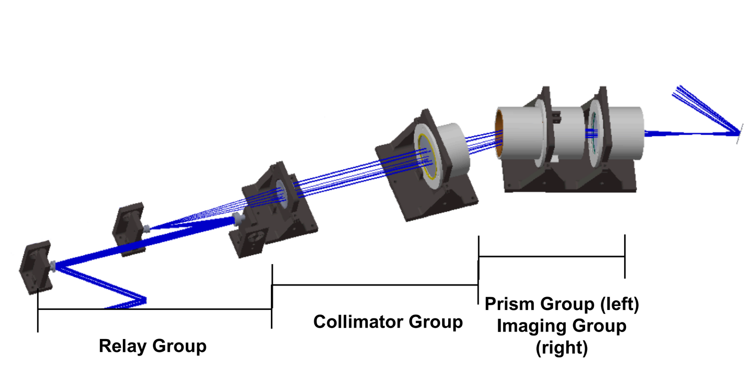
- Baseline differential imaging mode is via reference star subtraction
- Differential images taken and spectra are extracted via template fitting process
- Example spectra on a fiducial target show anticipated performance using Operating Scenario 5 data.
  - Performance will evolve, but steps are now in place to work on new operating scenarios
- Example overlay of the IFS FOV overlaid onto HR8799 to chow detection area

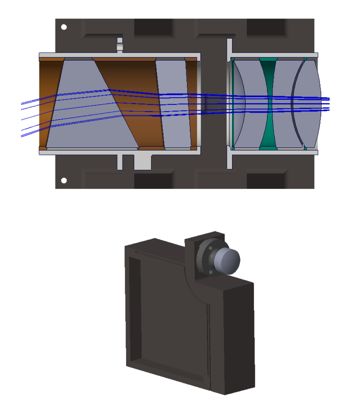
Optomechanical Design and Trades:

- Carried a trade on a reflective design
  Refractive: slightly better image quality, likely cheaper, optomechanics/epoxy bonds more difficult
  Reflective: slightly better throughput, less fluorescence, more mechanically robust, more difficult packing, sensitive tip-tilt
- Lenslet Geometry chosen to most optimally pack detector.
  - Not limited by detector size, but mitigates cosmic ray effects on image
- Requirements driving optomechanics are to keep IFS stable over:
  (a) The course of an exposure → fundamentally drives instrument performance (e.g. image blur)
  (b) The time between recalibration points → drives calibration (e.g. PSF/PSFlet centroid knowledge)
  - Driving Requirement: Non-telecentric image relay feeding lenslet array

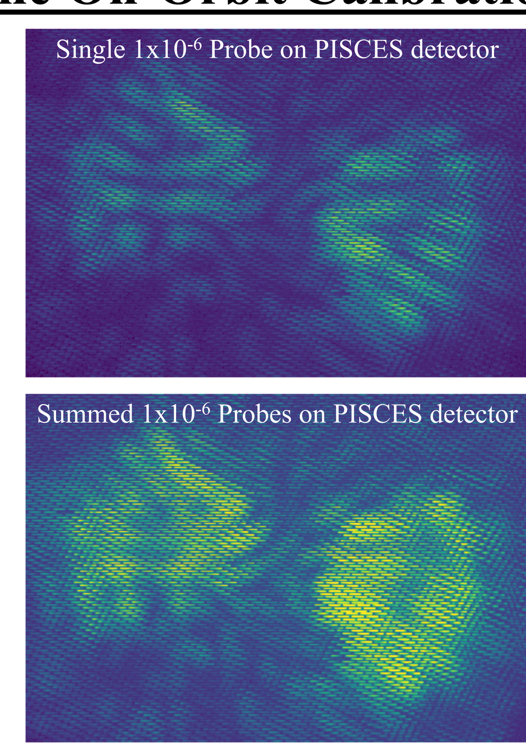




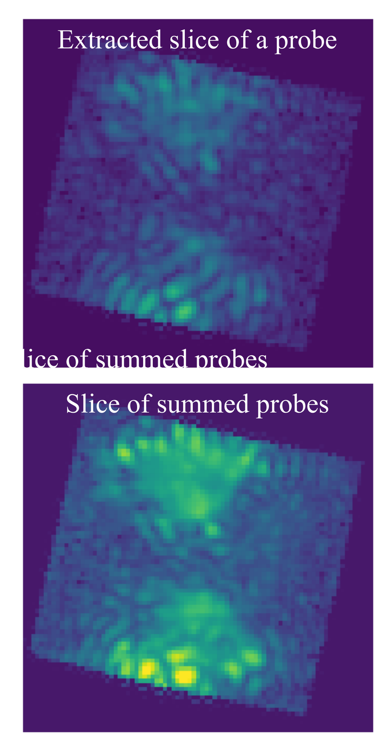


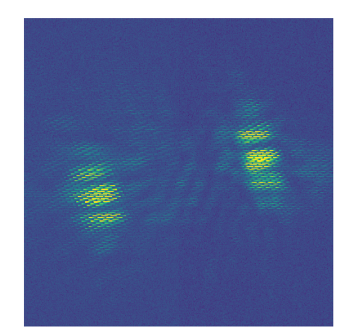


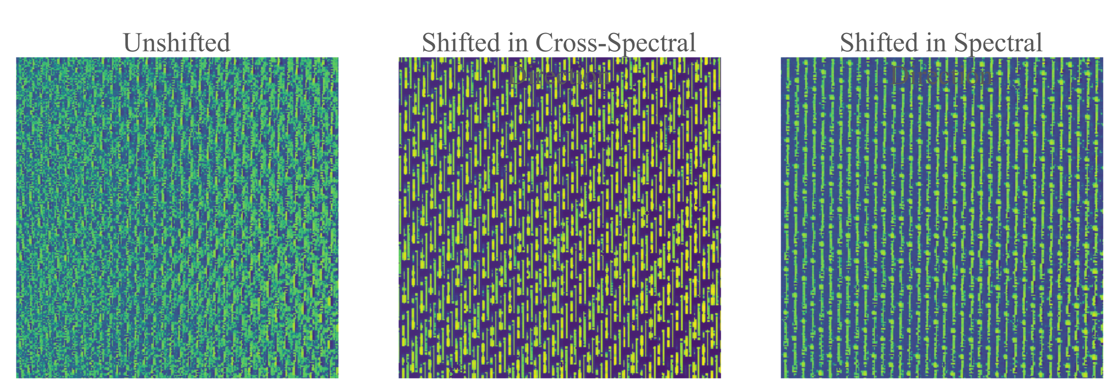
Some On-Orbit Calibration Strategies:



- Example data using PISCES
- Summed probe sets provide a suitable "flat field" for cube calibration.
  - NO telescope repointing would be required
- Open question: can we recalibrate data cube with a broadband flat?
  - Two likely paths forward, both of which should work but not tested yet
  - Testing can be done with PISCES and CHARIS



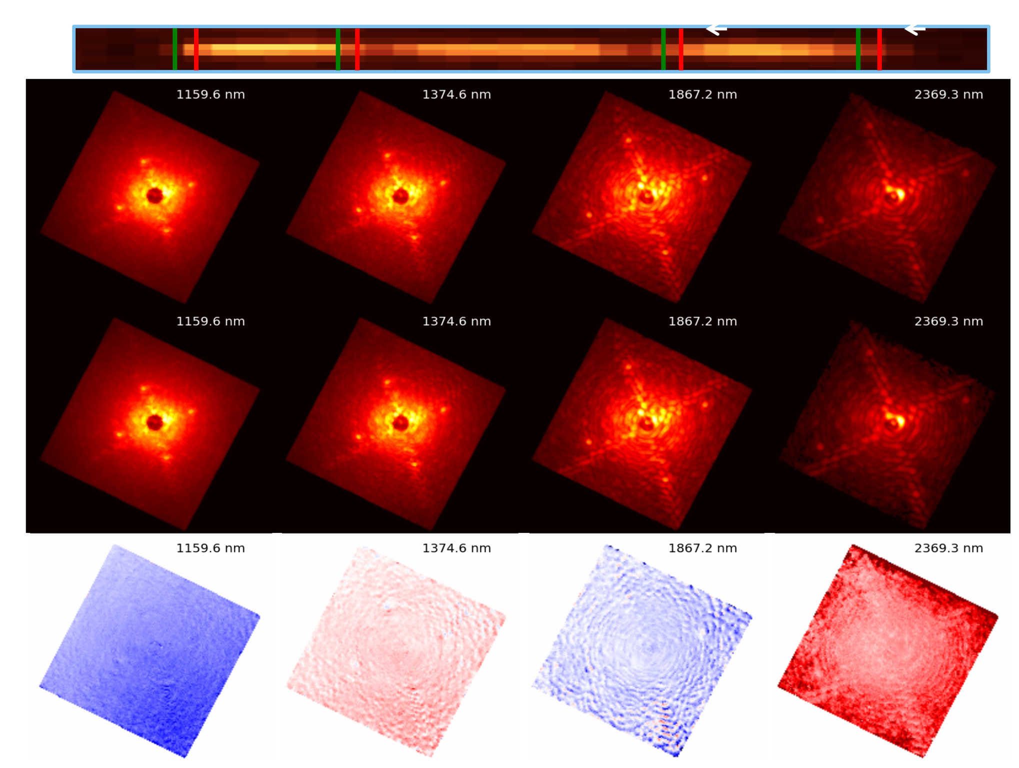




- Shifts in the cross-spectral direction exhibit relatively uniform residuals in spectral direction
- Residuals in the spectral direction exhibit "hot spots" from over/undershoot

- Characteristics in broadband data potentially useful for self-calibration of the IFS cube
  - Makes calibration approach compatible with wavefront control probing

Principal Calibration Error in Spectral Direction



Correct Calibration

Incorrect Calibration

Error