Prototype Imaging Spectrograph for Coronagraphic Exoplanet Studies (PISCES) for WFIRST/AFTA

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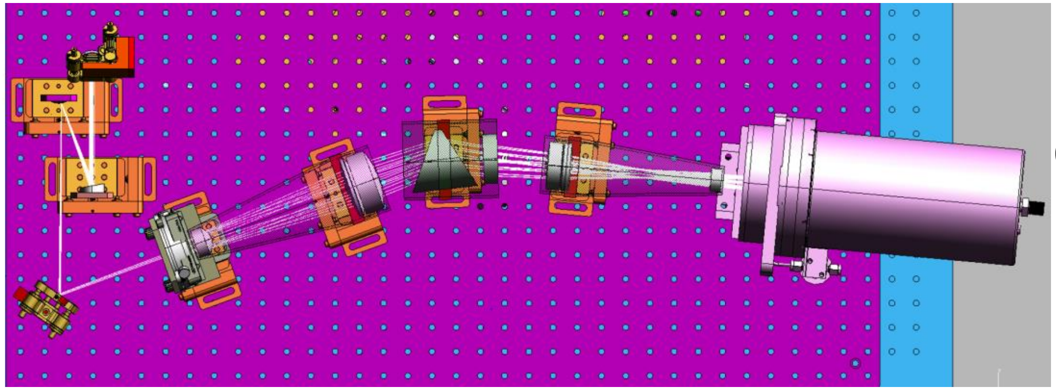
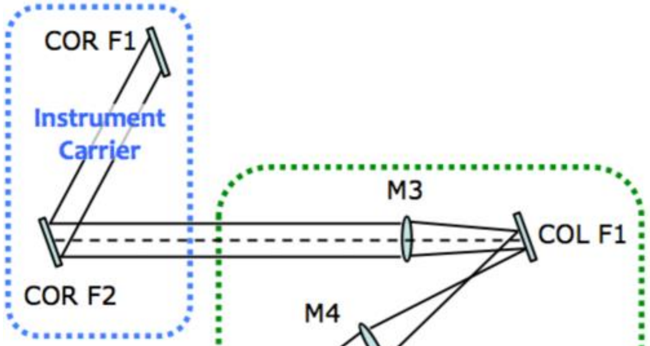
Overview

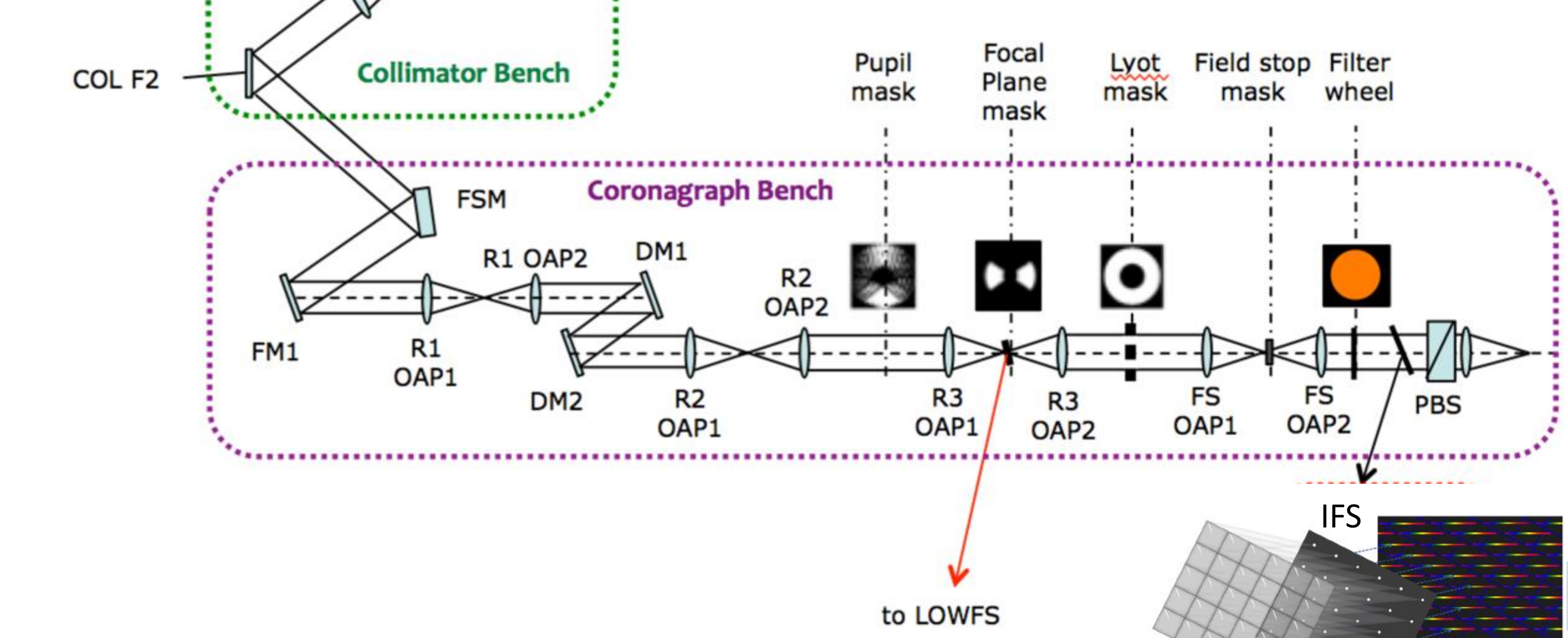
- PISCES in JPL High Contrast Imaging Testbeds
- Comparisons to existing integral field spectrographs
- Selection of a lenslet-based IFS
- Lenslet demonstration and function of mask
- Relay optics and IFS optical design
- Trade off between reflective and refractive optics
- PISCES alignment plan

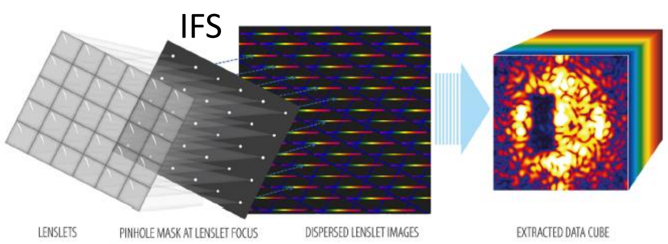
WFIRST Coronagraph and PISCES



Integral Field Spectrometer (IFS)

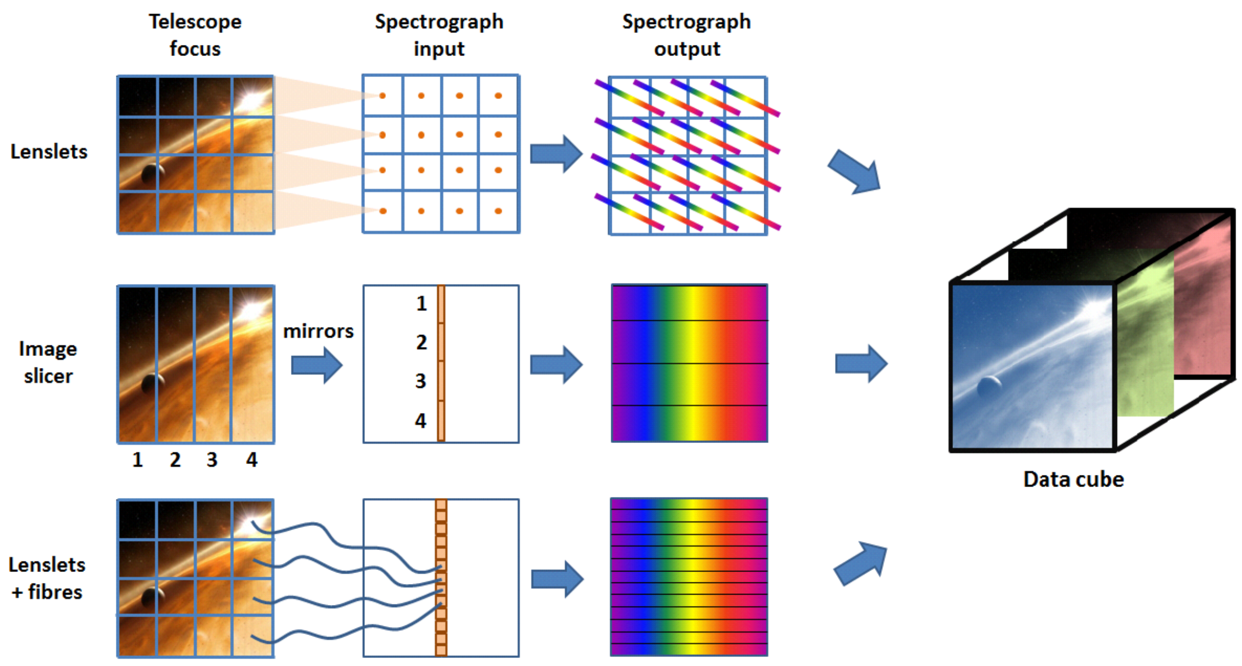






IFS Designs Options

IFS is a spectrometer that provides spectra at each spatial location in a 2D image. No matter which IFS, the goal is the same: to arrange space on the detector such that the spectra do not overlap.



Pro	Con
Simplicity High throughput	Lower detector array usage efficiency
Efficient detector array usage	Scattering loss Additional optics is needed to arrange slicers Difficulty to fabricate high number of slices
Efficient detector array usage	Fiber coupling loss Difficult to align and assemble fibers Fiber material limits wavelength band

Relay & IFS Specification (As-designed)

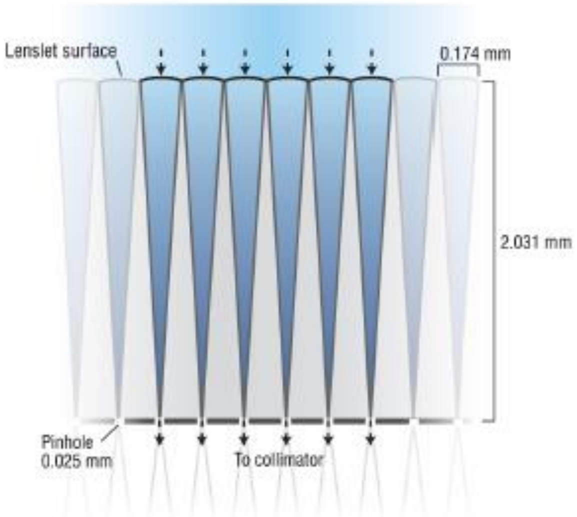
Relay Specifications			
Central wavelength (nm)	660	770	890
λmin (nm)	600	700	810
λmax (nm)	720	840	970
# of dispersed pixels	26	26	26
f/#	870	870	870
Lenslet pitch	174	174	174
Sampling at λ_c	3.3	3.85	4.6
FOV (# of λ_c/D)	22.7	19.5	16.9

IFS Specifications	
Wavelength range (nm)	660
Magnification	1:1
f/#	8
Spectral resolution	R=70±5
Spatial resolution	RMS spot diameter < 13µm
Object size (mm)	13 x 13
Detector	1024 x 1024 with 13 µm pitch

Selection of Lenslet-based IFS for PIECES

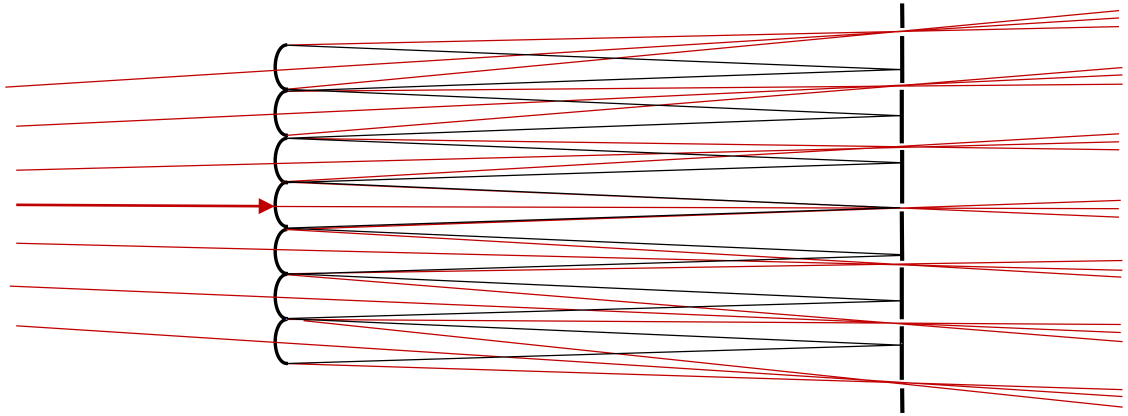
- As mentioned in previous slides, the main advantage of the lenslet IFS is its simplicity and high throughput, the main disadvantage is the low efficiency of using detector pixels.
- For exo-planet coronagraph application, the Field Of Veiw (FOV) is small measured by λ/D, the dispersion (spectral resolution R) is low, so the low pixel efficiency is not a main concern.
- The operation wavelength range is from 600-1000nm. In this wavelength range, lenslet array has a very good transmittance. Besides, the material dispersion in that wavelength range is low enough to have the point spread function (PSF) diffraction limited in the entire wavelength range.
- The combination of lenslet array, pinhole mask, and none tele-centric relay optics design will further increase the coronagraph contrast.

Lenslet Array Design & Demonstration



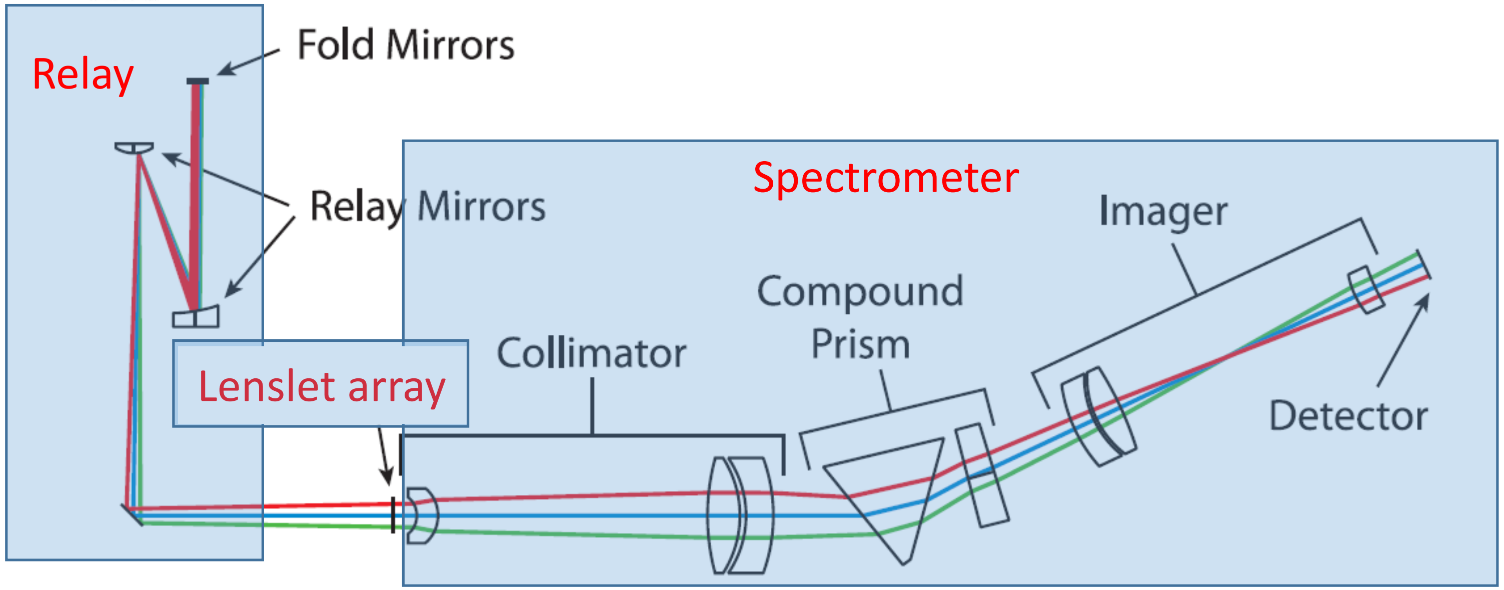
Lenslet Array Specification	
Lenslet size	174µm x 174µm
# of lenslets	76 x 76
F/# in air	8 from side to side
Sampling	0.3 λ/D at 600nm
Spectral channel	26
FOV	25 x 25 λ/D at 600nm 15 x 15 λ/D at 970nm

- The lenslet array we have is basically the same as any other lenslet arrays except the followings:
  1. A pinhole array mask is placed at the focal plane of the lenslet. The focal plane is at the back surface of the lenslet array, which guarantees the stability between lenslet and corresponding pinhole.
  2. The function of the pinhole mask is to prevent the diffraction from lenslet edge to contaminate the PISCES spectra. However, it is also aimed to reduce the speckles of the coronagraph.



In this design, the relay is very non-telecentric, that is, the chief ray angle increases with the increase of the FOV. The pinhole positions are following the chief rays. As a result, the light (red rays) from the planets gets through, but the speckles (black rays) with relative flat wavefront are blocked by the mask.

Optical Design



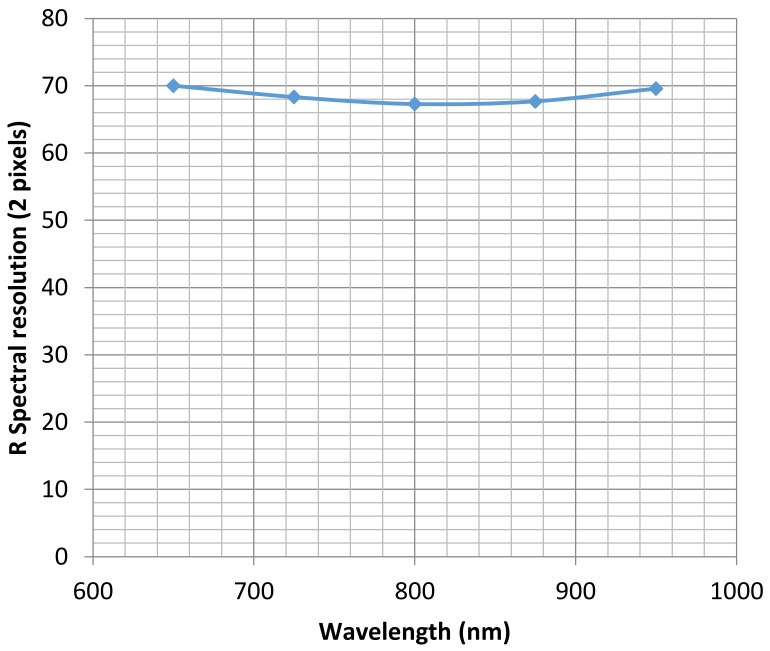
Optical design includes three parts:

1. Relay Optics – to adjust the plate scale to match required FOV into the designed lenslet array. The lenslet array dimension is determined by nλ/D and sampling per λ/D, and the lenslet size is determined by spectral resolution, wavelength range, and the detector pixel size.
2. Lenslet array – to squeeze all light on one lenslet to a tiny spot in order to provide enough space to lay spectra.
3. Spectrometer – IFS spectrometer is similar to regular spectrometers except its multiple pupils. The number of the pupil is equal to the number of lenslets.
4. The spectrometer is consist of a collimator and a imager with a compound prism between them.

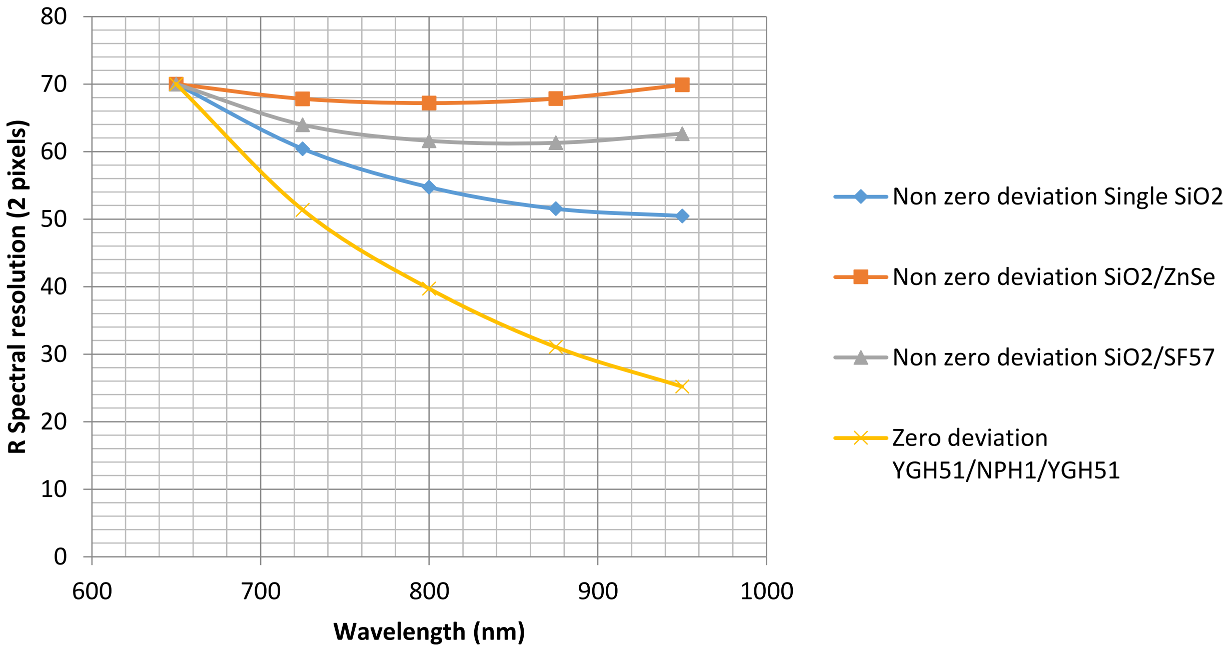
Dispersion Element Selection & Design

- Two most popular dispersive elements in spectrometers are gratings and prisms.
- However, the lenslet IFS prohibits using gratings. The reason is that the unwanted grating orders can't be eliminated from the detector array. They severely contaminate spectra of exo-planet. Therefore, a compound prism is selected as the dispersive element of the IFS spectrometer.
- The design options include single prism and compound prism, zero deviation and non-zero deviation. After a trade-off, the non-zero deviation compound prism is selected for obtaining most uniform spectral resolution across the entire wavelength range.

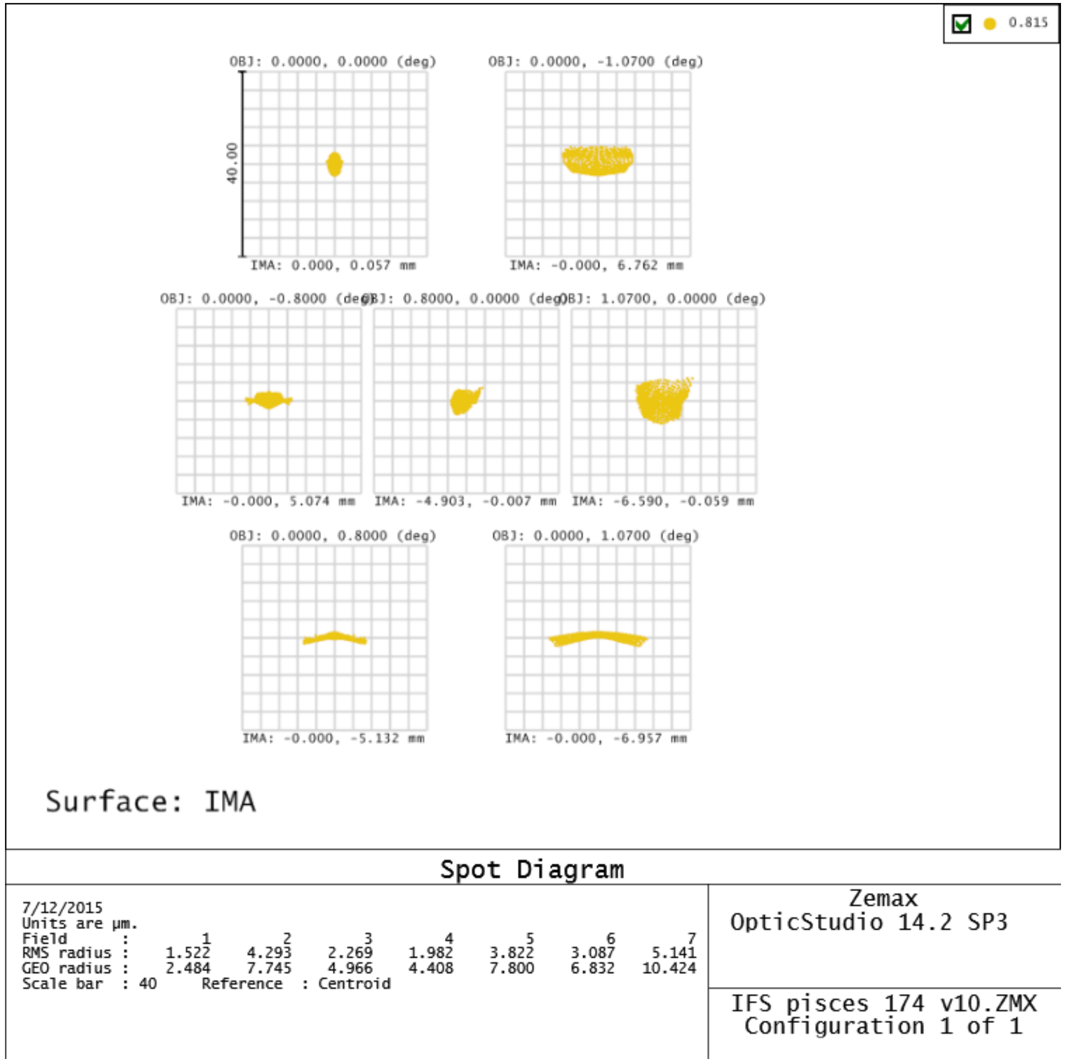
PISCES Spectral Resolution vs Wavelength



Spectral Resolution vs Wavelength For Different Options

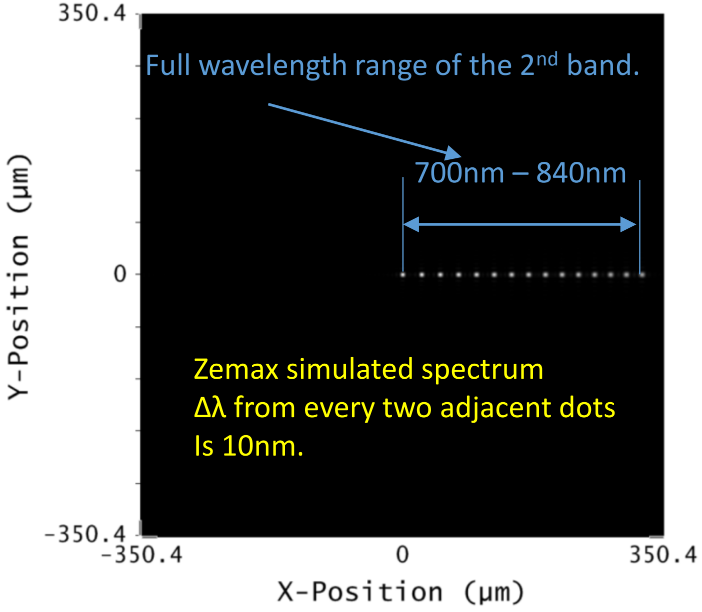


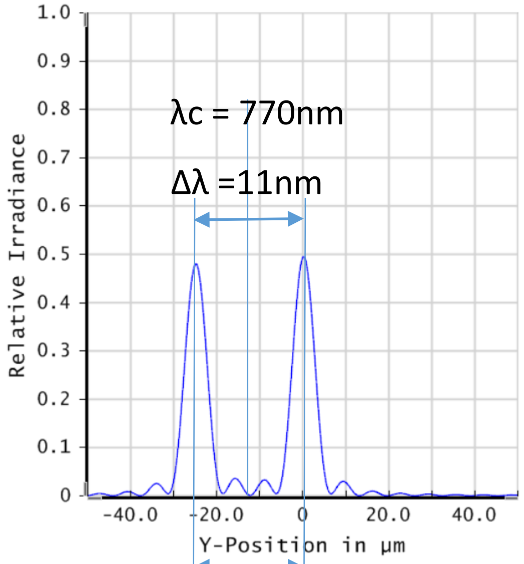
IFS Performance: Spatial and Spectral



Spatial resolution: RMS spot size is less than detector pixel of 13 µm

Note: the result on this page is as-designed.





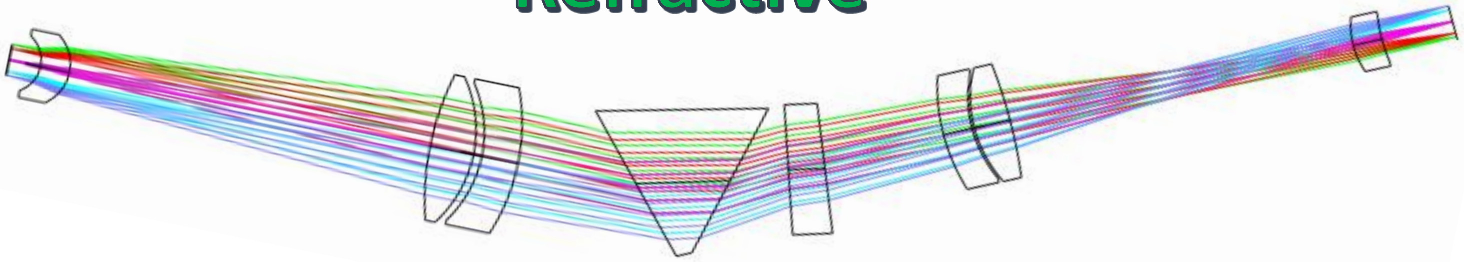
26µm = 2 Det. Pixels

The 2 spectral lines at $R = \lambda c / \Delta\lambda = 70$ is well Separated.

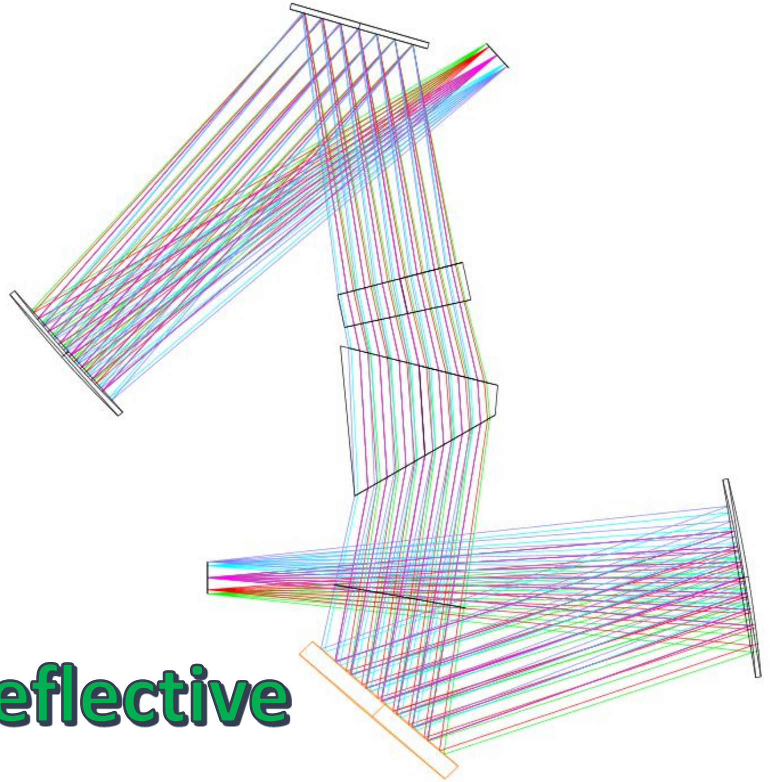
Spectral resolution meets The required R = 70.

Optical Design Trade-off: Refractive vs. Reflective

Refractive



		Pro	Con
Perfor-mance	Spot size	Refractive	Reflective
	Distortion	Reflective	Refractive
	X/Y aspect ratio	Refractive	Reflective
	Throughput	Reflective	Refractive
Volume		Refractive	Reflective
Fabrication		Refractive	Reflective
Alignment		Refractive	Reflective
Cost		Refractive	Reflective



Reflective

Two IFS designs use the same system specification: same f/#, same wavelength range, same effective focal length, and same amount of spectral dispersion.

The envelop of reflective design is ~350 mm x 350 mm.

The envelop for the refractive design is ~610 mm x 120 mm.

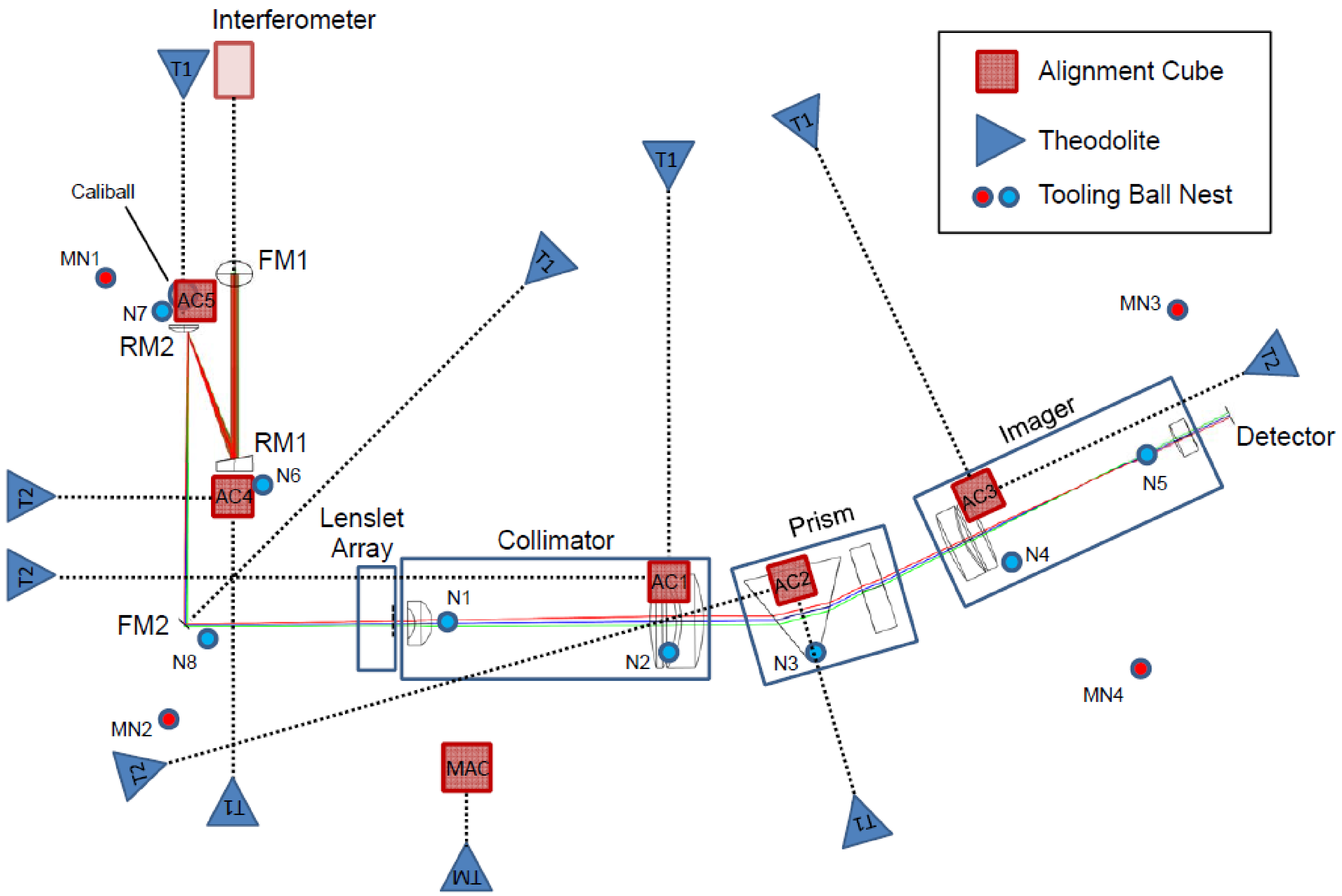
The trade-off above is for PISCES wavelength range (600 nm to 970 nm) only. For UV, mid and far IR, mirrors have to be used.

IFS Alignment Overview

The basic alignment summary is the following:

1. To attach at least one alignment cube and one tooling ball nest to each element and sub-assembly.
2. To use theodolites, alignment telescopes, and Coordinate Measuring Machine (CMM) performing metrology of each element and sub-assembly to obtain the relation between the element and alignment references (cubes and nests).
3. To setup a Zemax alignment model to include the alignment references on all elements and subassemblies. To provide a table with all reference positions in a defined global coordinate.
4. To used metrology tools (theodolites and CMM) aligning each element and sub-assembly to the pre-determined positions.
5. The interferometer will be used to measure the wavefront to verify the alignment at some key intermedium stages.

IFS Alignment Schematic



Prototype Status

- As mentioned in previous slides, the main advantage of the lenslet IFS is its simplicity and high throughput, the main disadvantage is the low efficiency of using detector pixels.
- Optical design was frozen.
- Relay optical elements have been procured and tested. The surface figures meet the specification. Ready for alignment.
- Lenslet array has been procured and tested.
- Spectrometer sub-assemblies, collimator, prism, and imager, have been contracted out to Photon Gear. Estimated delivery date is at the end of August.
- The mechanical design is completed, including the Photon Gear's sub-assemblies.
- Complete alignment plan is in place. Testbed simulator alignment is completed.
- Spectral and radiometric calibration plan is in progress.

Path Forward

1. Evaluate the efficiency of using lenslet array to further compress the speckles.
2. Complete testbed simulator alignment and test.
3. Assemble and test PISCES.
4. Create a calibration plan: both spectral and radiometric.
5. Calibrate PISCES.
6. Deliver PISCES to JPL.