TARdYS : design of an exoplanet hunter for TAO

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OUTLINE

- Motivation
- Project Overview
- Method & Analysis
- Result
- Future work
- Conclusion

EXOPLANET SEARCH

- First discovery in 1995 (Mayor et al, 1995)
- Several observation techniques: Radial velocity, Transits, Astrometry, Timing, Microlensing, Direct Imaging.
- Radial Velocity Measurement proves to be one of the most successful methods
    - Measures Doppler shifts in stellar lines due to gravitational attraction by a nearby planet using **a high resolution spectrograph.**

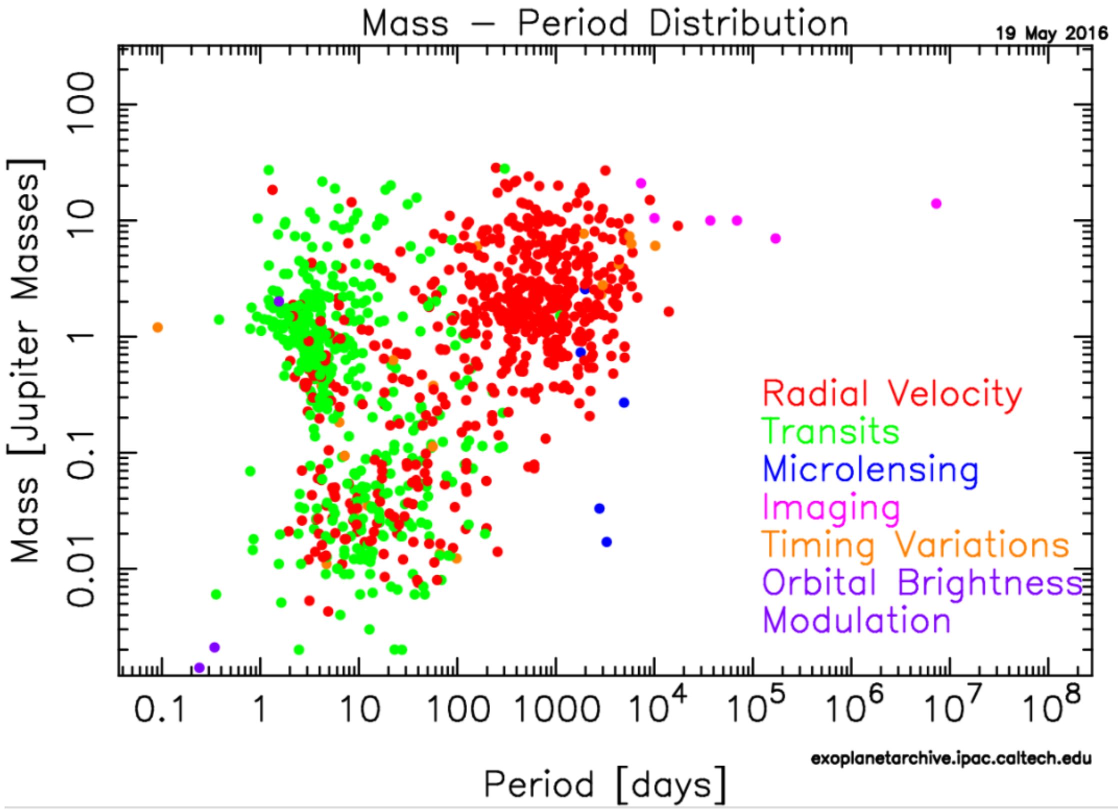
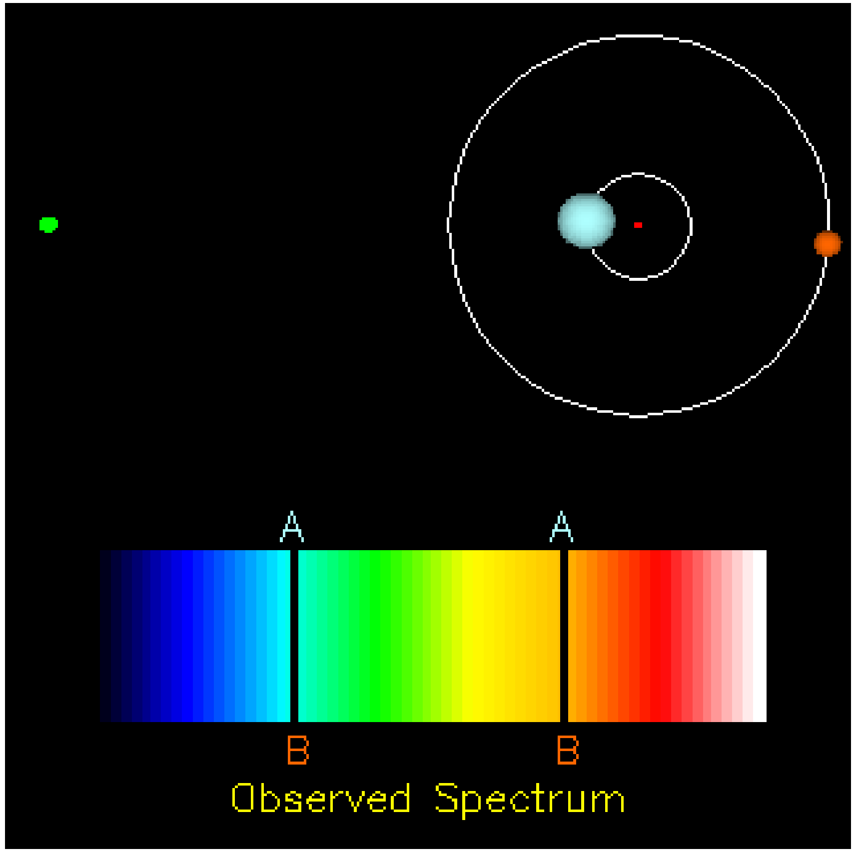
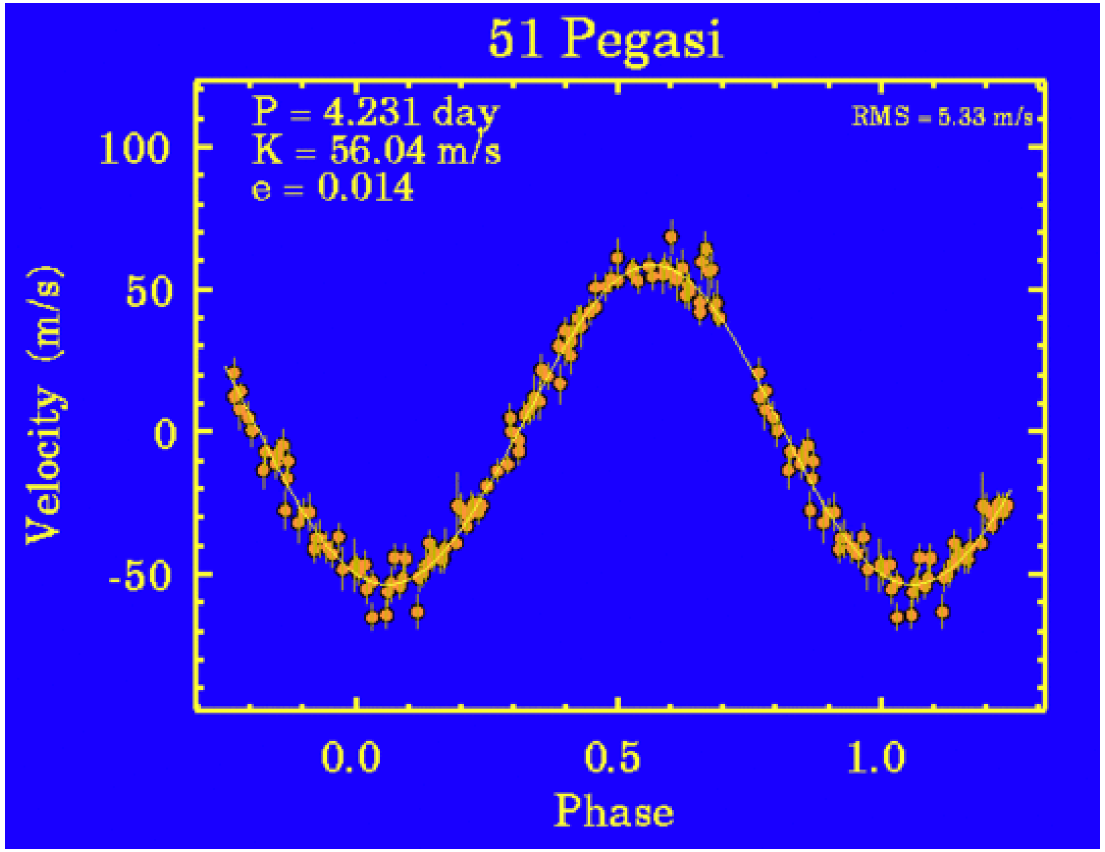


Image NASA: http://exoplanetarchive.ipac.caltech.edu/exoplanetplots/

RADIAL VELOCITY METHOD





$$\frac{v_{\text{rad}}}{c} = \frac{\lambda_{\text{shift}} - \lambda_{\text{rest}}}{\lambda_{\text{rest}}} \Rightarrow \frac{\Delta\lambda}{\lambda} = \frac{1}{R}$$

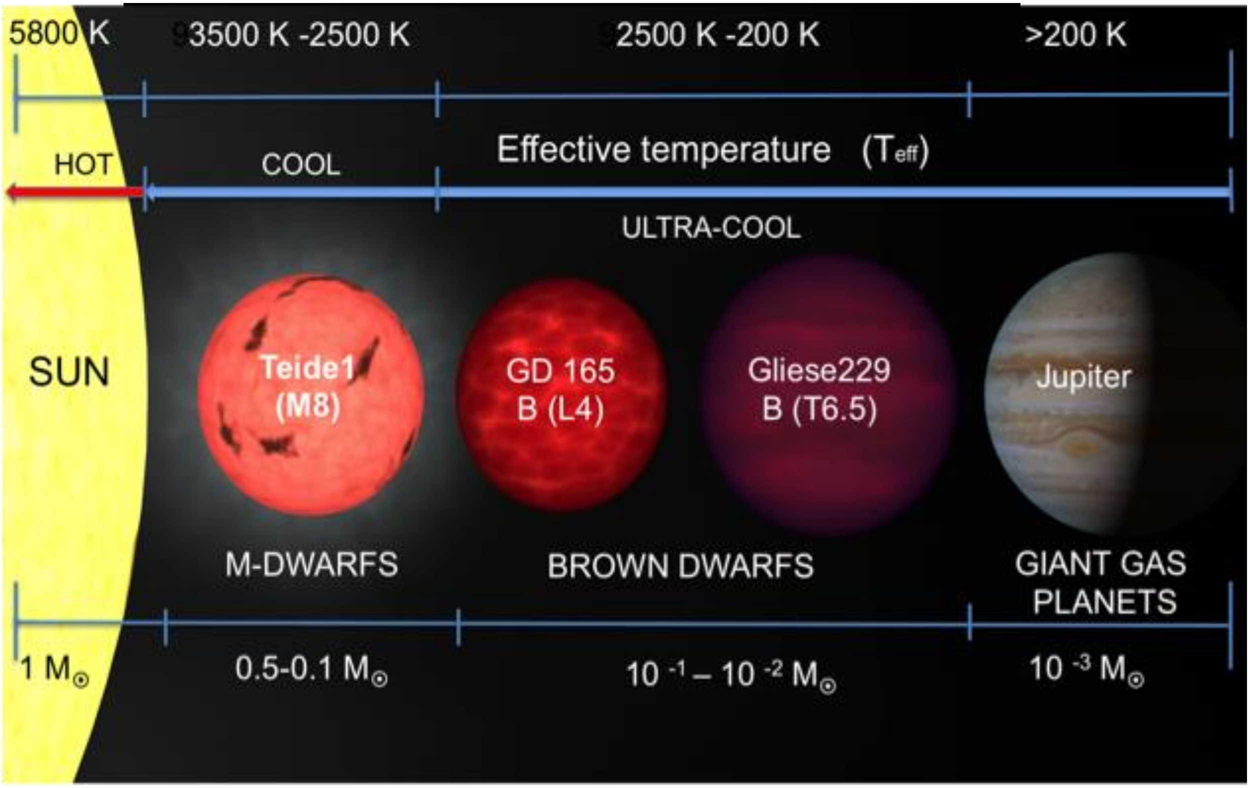
TECHNOLOGICAL MOTIVATION

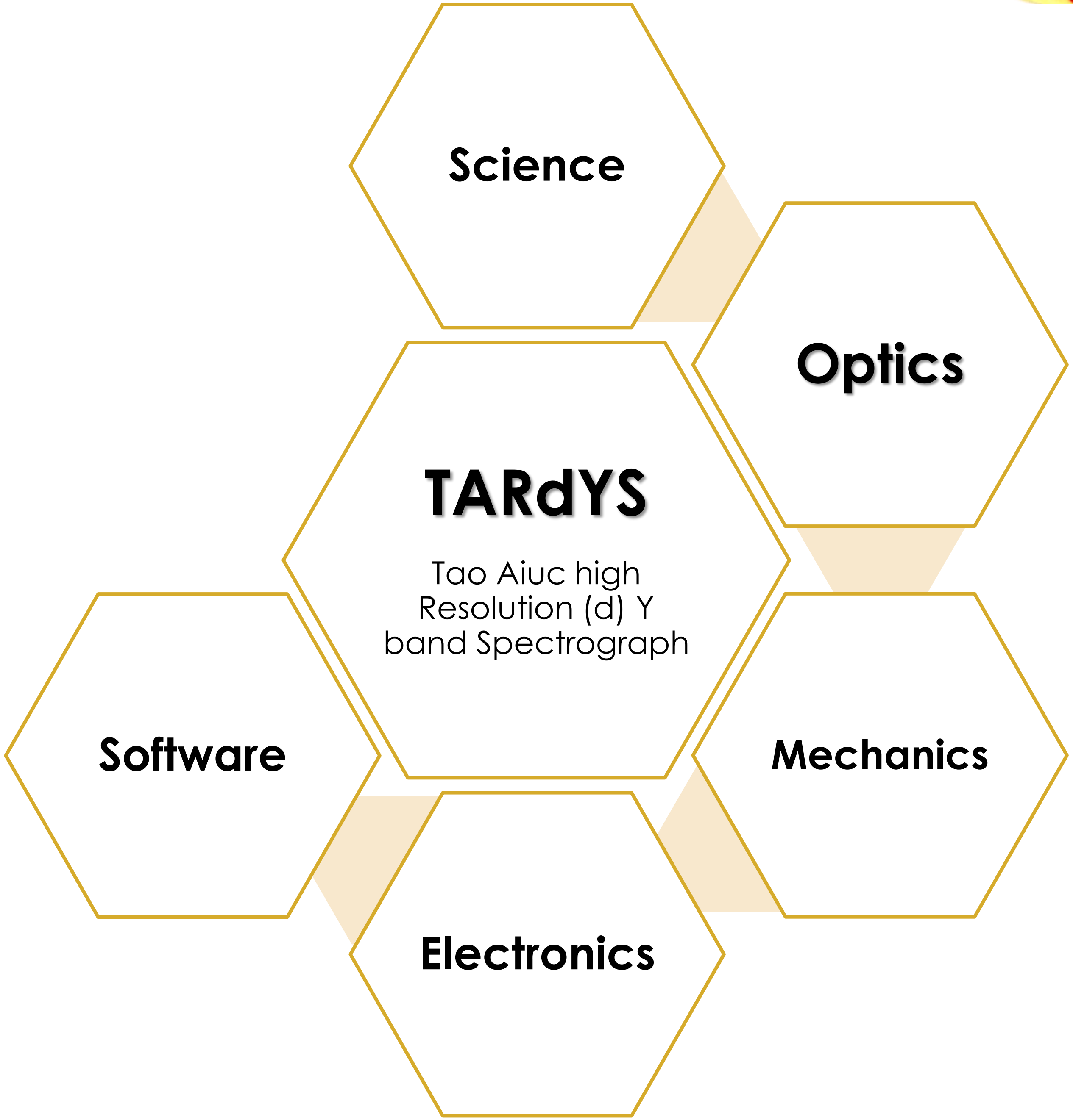
Instrument	Coverage	Resolution	Telescope
NAHUAL	0.9-2.4 µm	R=50,000	GTC 10m
UPF	1-1.75 µm	R=70,000	UKIRT 4m
NIRSPEC	1-5.5 µm	R=25,000	Keck 10m
GIANO	0.9-2.5 µm	R=46,000	TNG 4m
FIRST	1.3-1.8 µm	R=50,000	ARC 3.5m
WINERED	0.9-1.35 µm	R~100,000	??
CARMENES	0.9-1.75 µm	R~80,000	Calar Alto4m
IGRINS	1.5-2.5 µm	R~45,000	McDonald 2.7m
SPIRou	0.98-2.35 µm	R~70,000	CFHT 3.6m
IRD	0.97-1.75 µm	R~70,000	Subaru 8m
HPF	0.85-1.7 µm	R~60,000	HET 10m

Instrument	Coverage	Resolution	Telescope
PHOENIX	1-5 µm	R=70,000	Gemini 8m
CRIRES	1-5 µm	R=100,000	VLT 8m
TARdYS	**0.84-1.12 µm**	**R~66,000**	**TAO 6.5m**

(Pepe et al. Nature, 2014),(Moorwood et al., 2003), (Gennari et al., 2006), (Artigau É. et al. 2014), (Yuk et al., 2010), (Quirrenbach et al., 2014),(Mahadevan et al., 2010), (Tamura M. et al. 2012)

PROJECT OVERVIEW



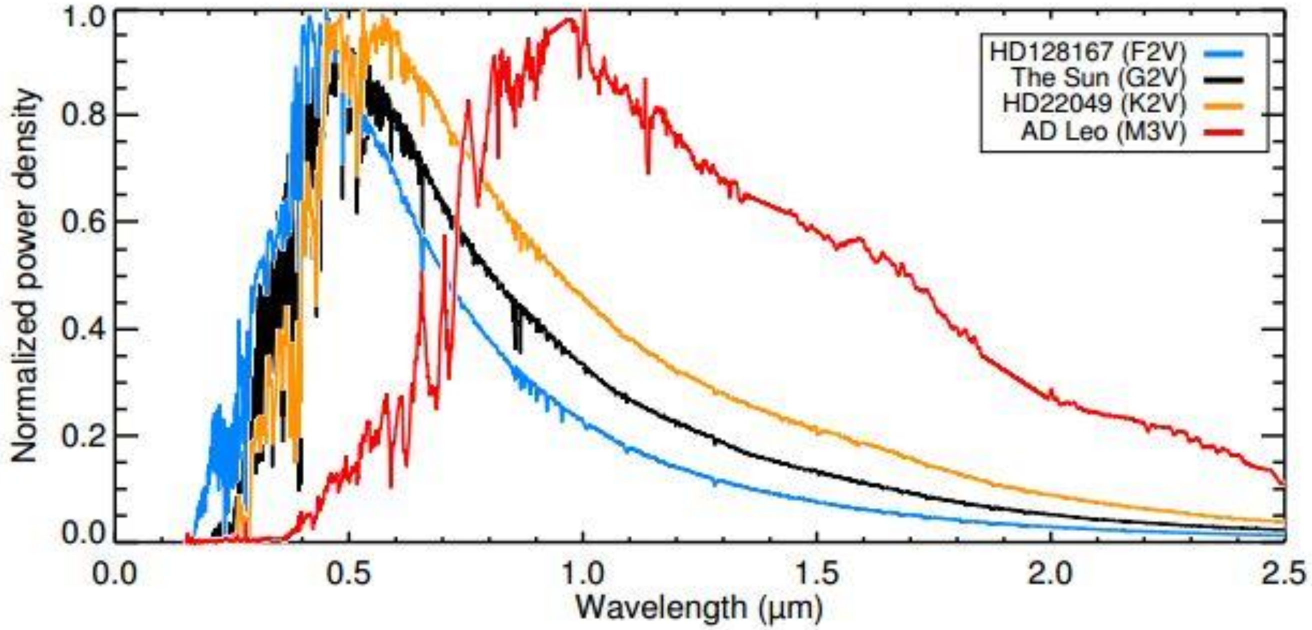


PROJECT OVERVIEW

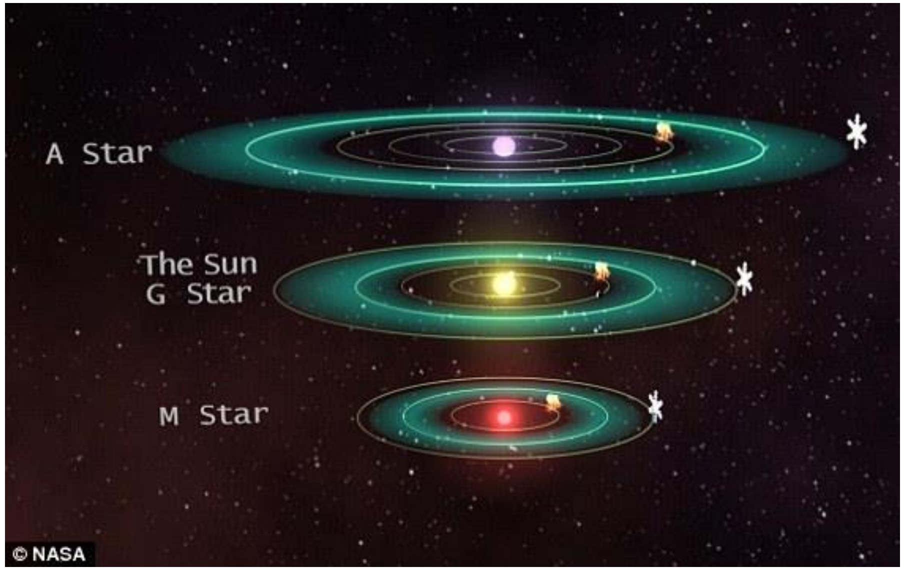
- To detect M-stars in Y band we need resolution of **60,000** (Reiners et al. 2010)

Resolution	S/N				RV precision (m s^{-1})			
	V	*Y*	*J*	*H*	*V*	*Y*	*J*	*H*
Spectral-type M3								
60000	50	100	101	95	3.6	5.7	22.9	10.0
80000	43	86	87	82	2.9	4.4	18.1	8.4
100000	39	77	78	74	2.5	3.8	15.5	7.6
Spectral-type M6								
60000	20	100	114	107	4.7	3.8	11.2	9.7
80000	18	86	99	93	3.7	3.0	8.8	7.8
100000	16	77	88	83	3.2	2.6	7.5	6.9
Spectral-type M9								
60000	12	100	134	128	8.0	2.2	4.6	4.0
80000	10	86	116	111	6.2	1.7	3.5	3.5
100000	9	77	104	99	5.3	1.5	2.9	3.3

Reiners et al. 2010



Shields et al. (2013).



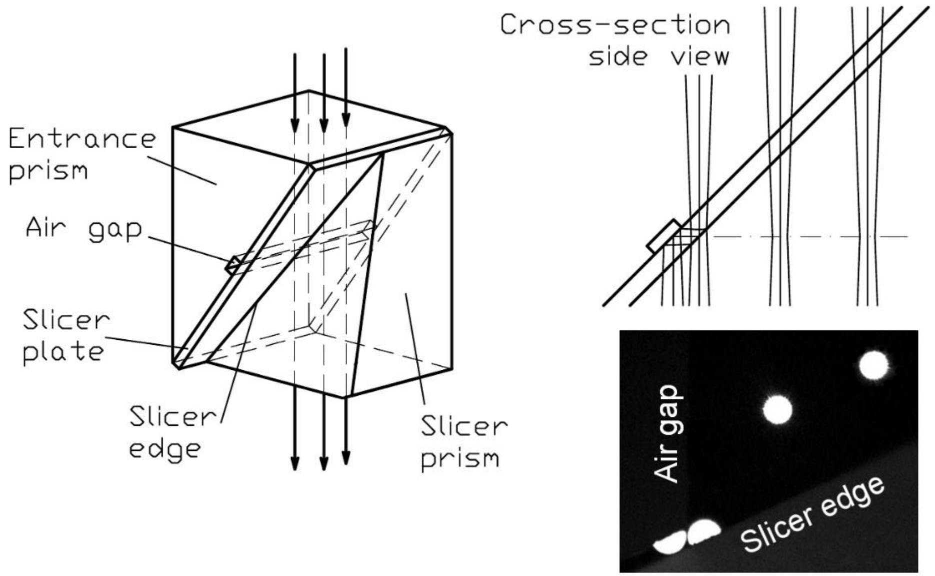
SPECTROGRAPH DESIGN ELEMENTS

- Fiber-feed image slicer
- White Pupil Configuration
- Gratings
- Camera
- Detector
- Wavelength Calibration Source

The main characteristics of TARdYS	
Spectral Resolution	66,000
Spectral Coverage	0.843-1.117 µm
Order	133^{rd}-175th
Detector	Teledyne H1RG; 1kx1k
Spectral Sampling	2 pixels

SPECTROGRAPH DESIGN ELEMENTS

- **Fiber-feed image slicer**
  - Dual fibers (50 μm diameter, f/4)
  - Bowen-Walraven image slicer.
  - Given a suitable distance and angle of its two mirrors, the image slicer creates a two-slice image of a circular fiber containing an astronomical object image.
  - The image slicer works to increase the resolution of the spectrograph to R= 66,000



Raskin, Gert et al. 2011

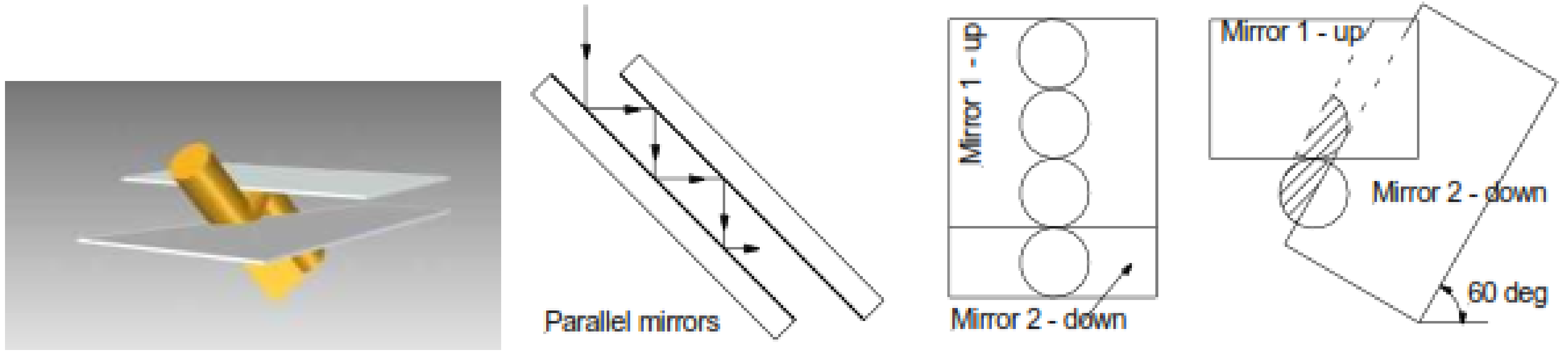
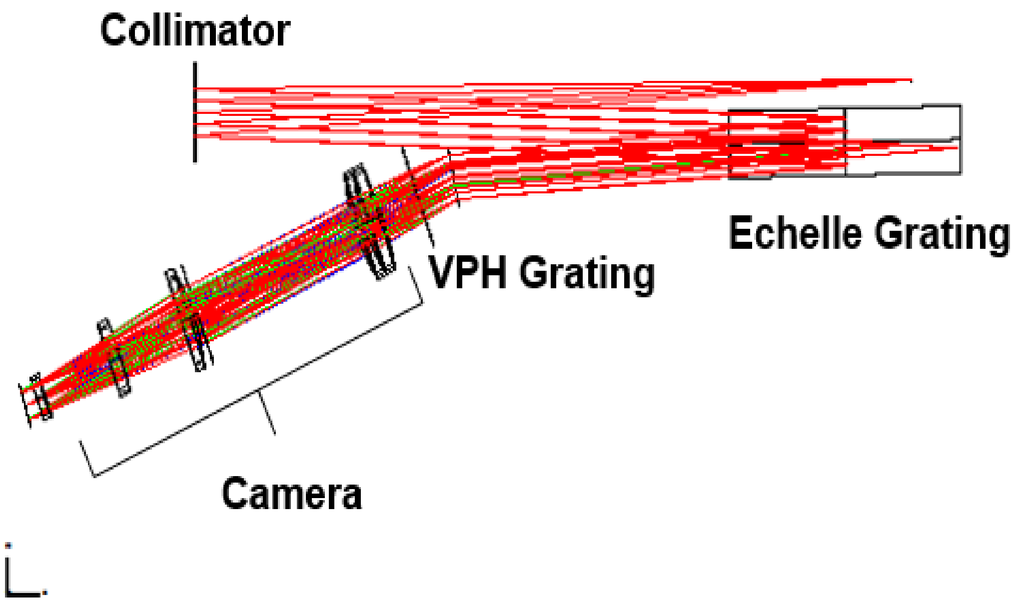


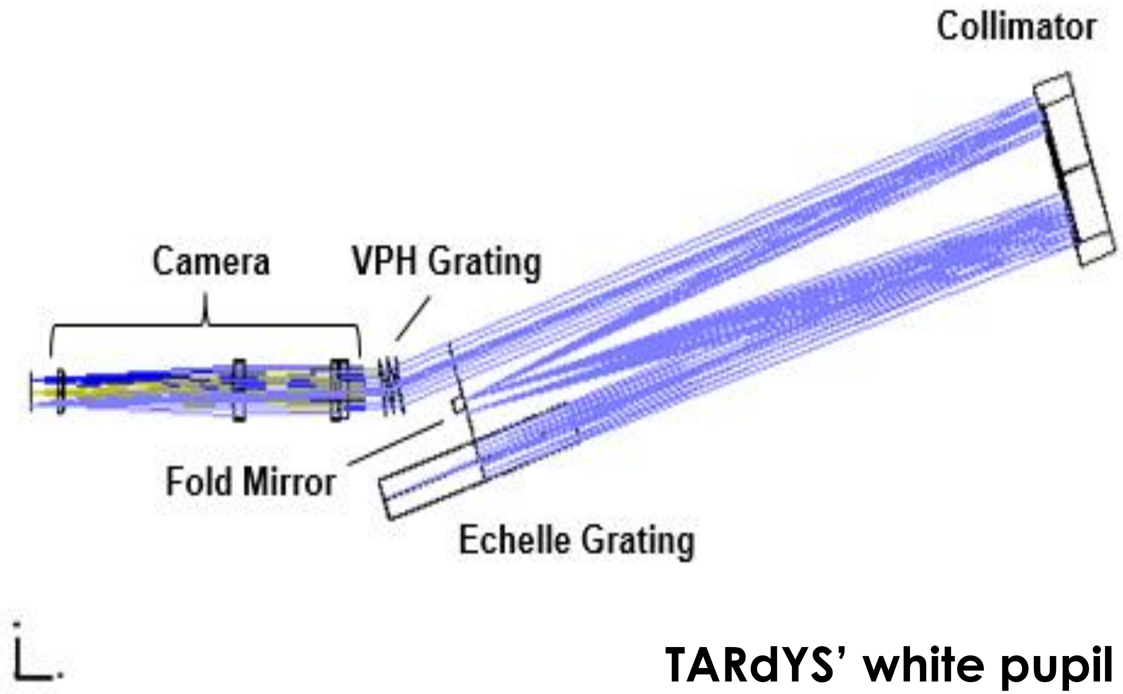
Image Slicer Concept (Gerardo Avila et. al 2012)

SPECTROGRAPH DESIGN

- Spectrograph Configuration



TARdYS' classic

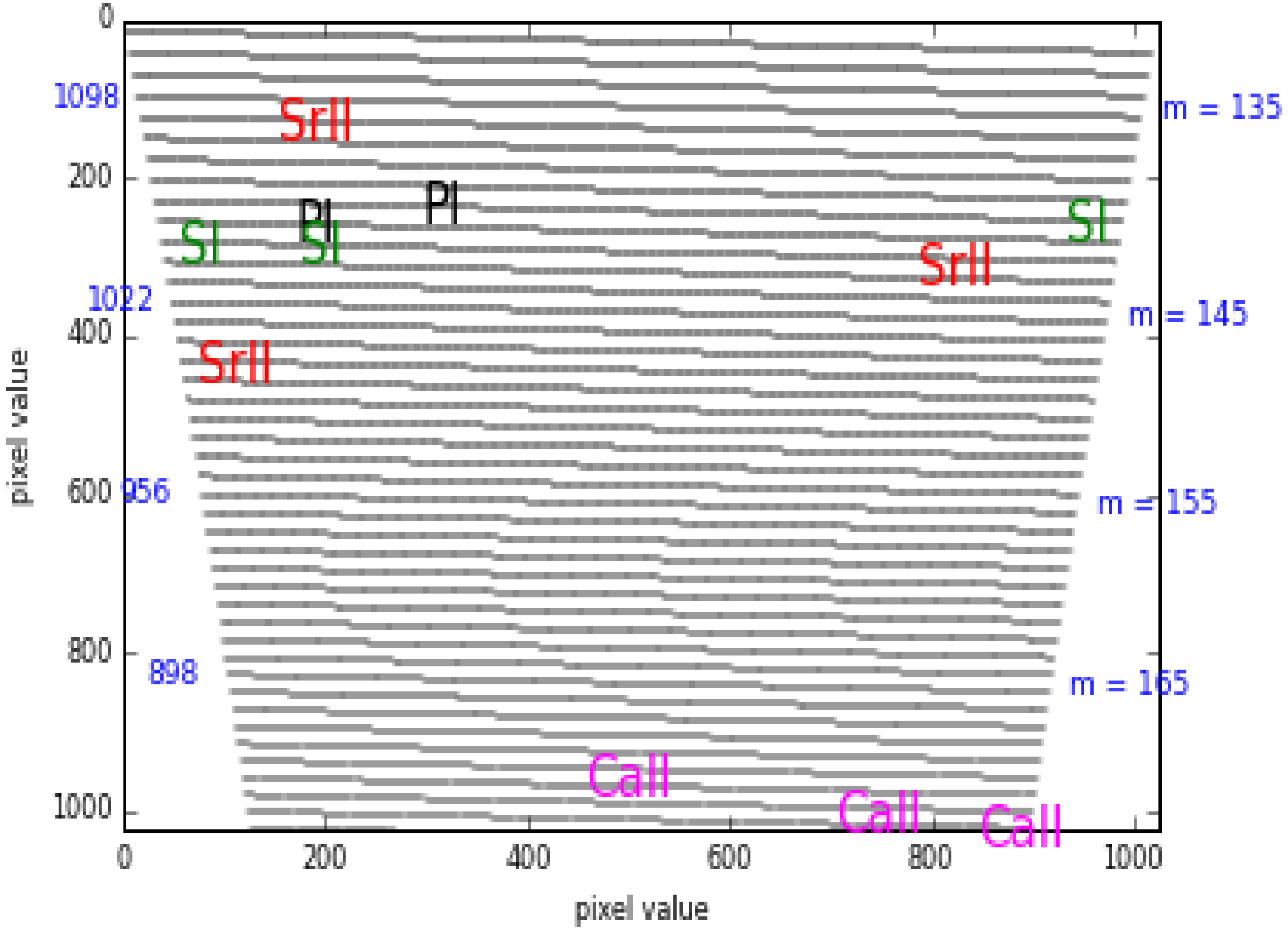


TARdYS' white pupil

SPECTROGRAPH DESIGN ELEMENTS

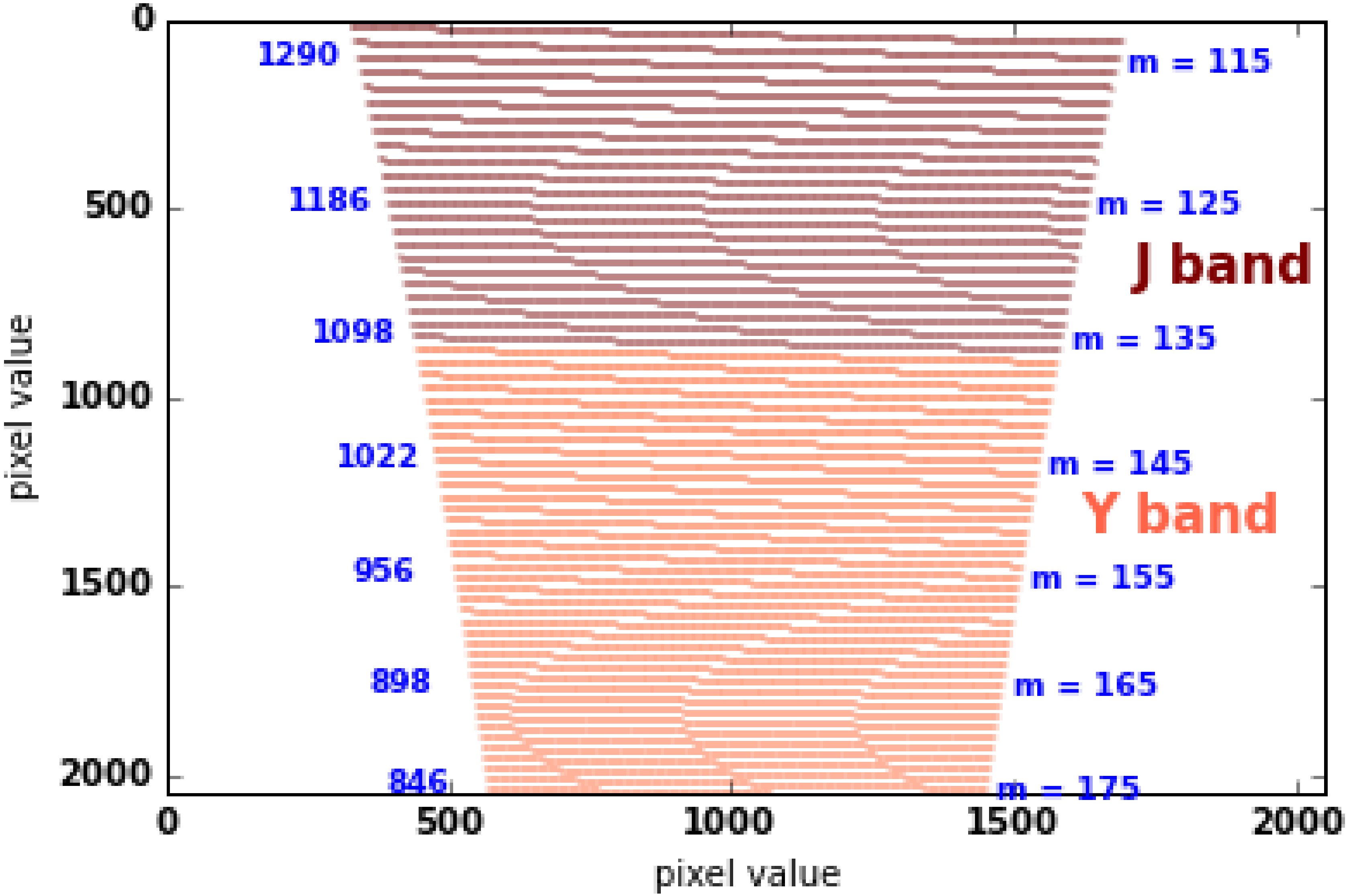
- **Gratings**
  - Echelle 13.33 lines/mm
  - Volume Phase Holographic 333 lines/mm

$$m\lambda = d(\sin i + \sin\theta)$$

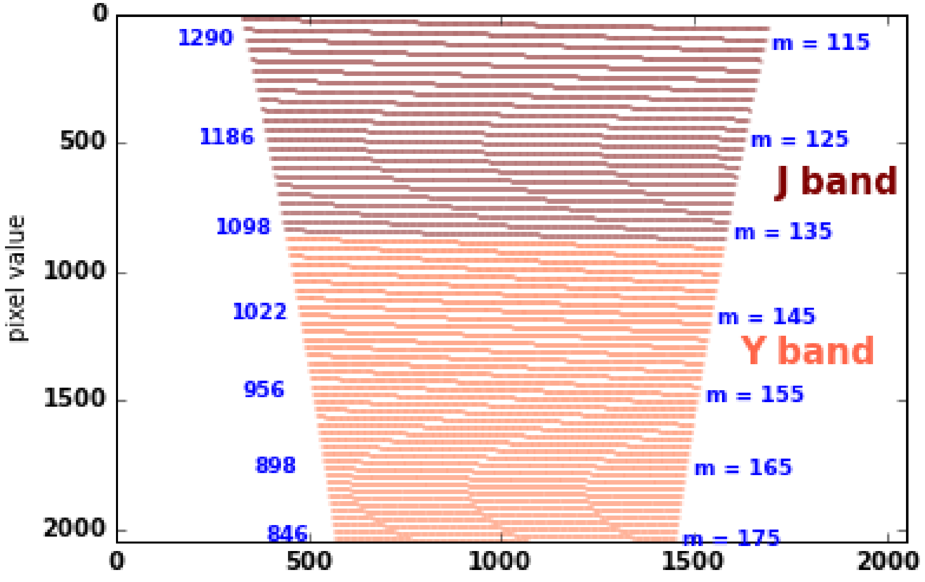


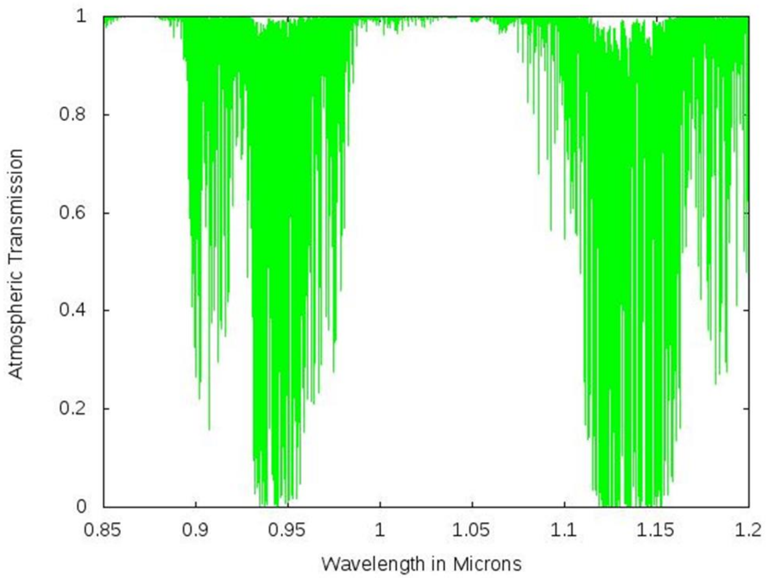
SPECTROGRAPH DESIGN ELEMENTS

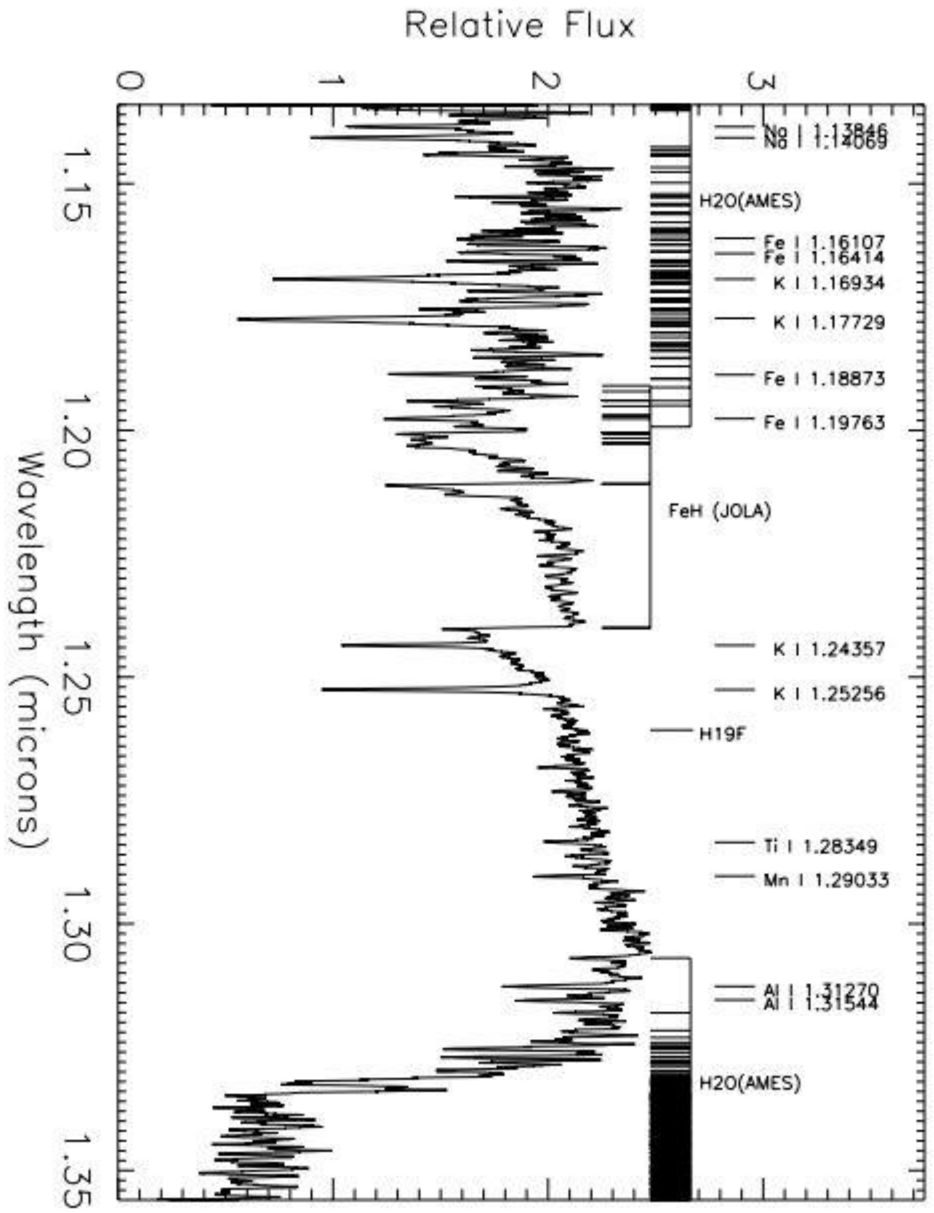
2K Detector



SPECTROGRAPH DESIGN

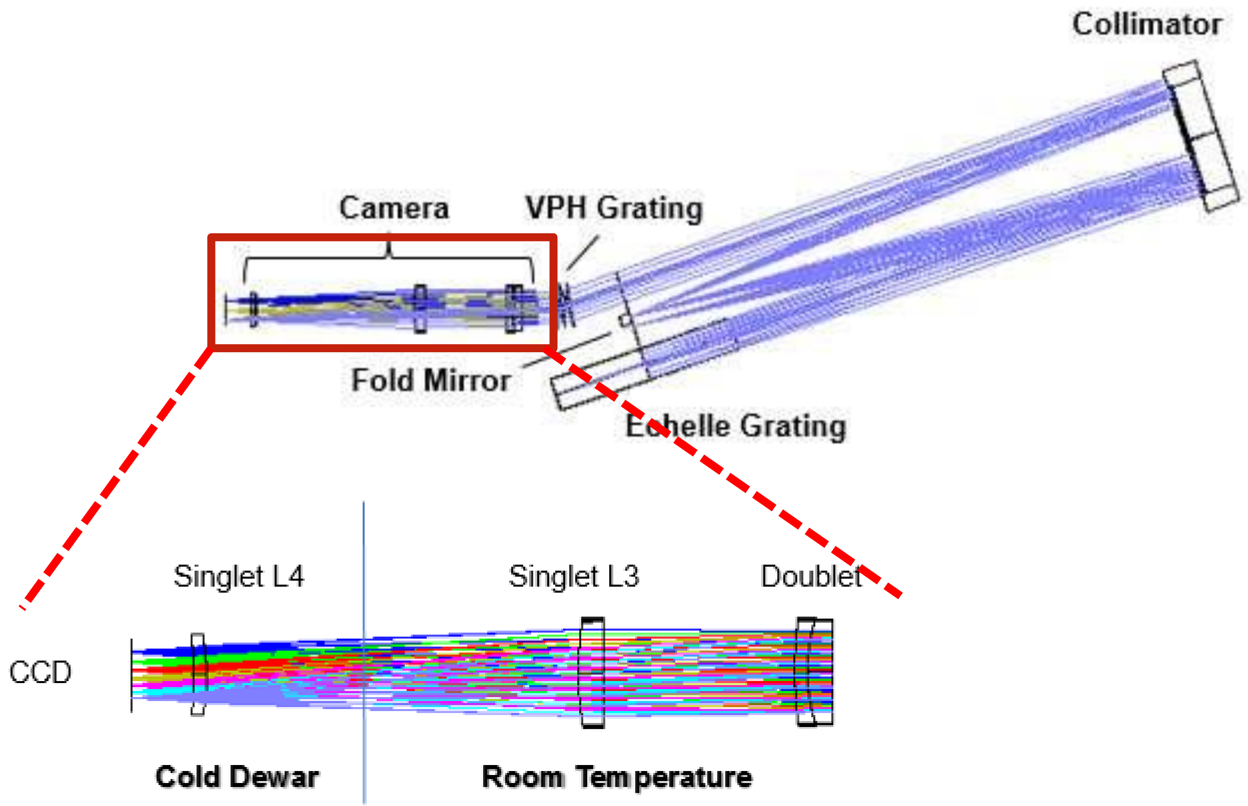


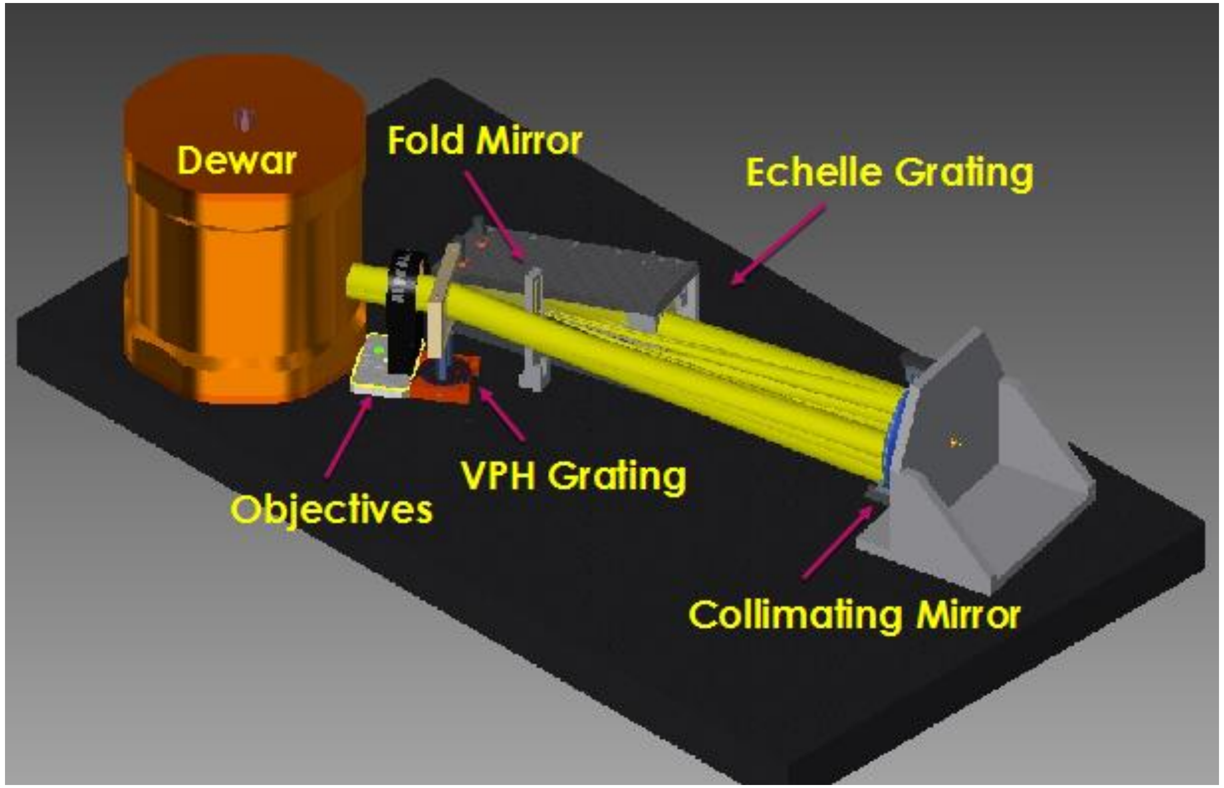




SPECTROGRAPH DESIGN ELEMENTS

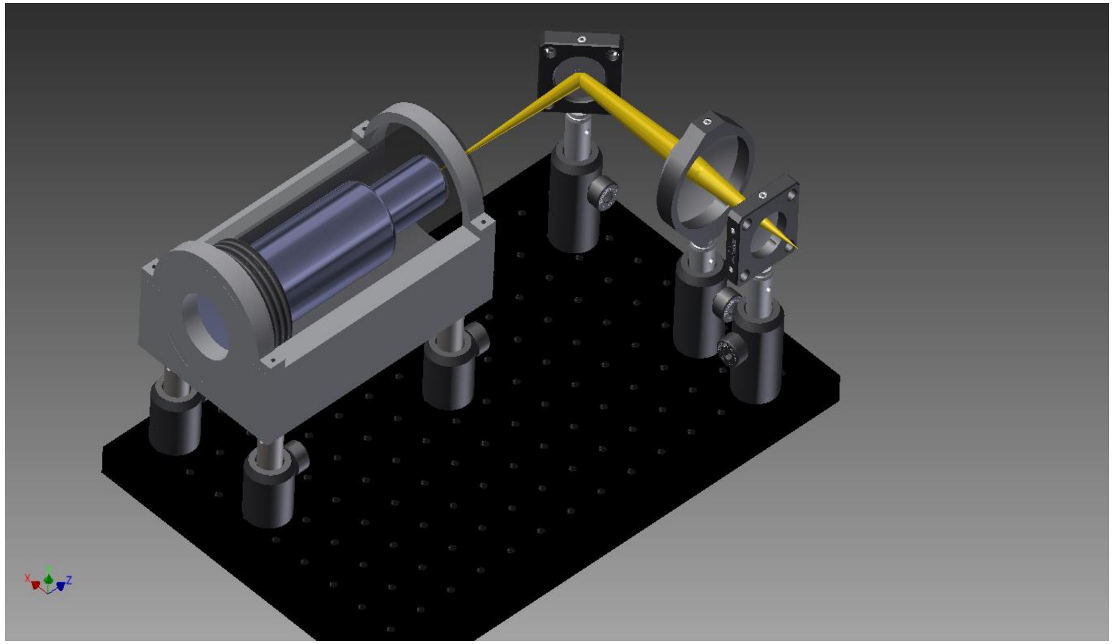
- **Camera**
- **Detector** : Teledyne H1RG; 1kx1k



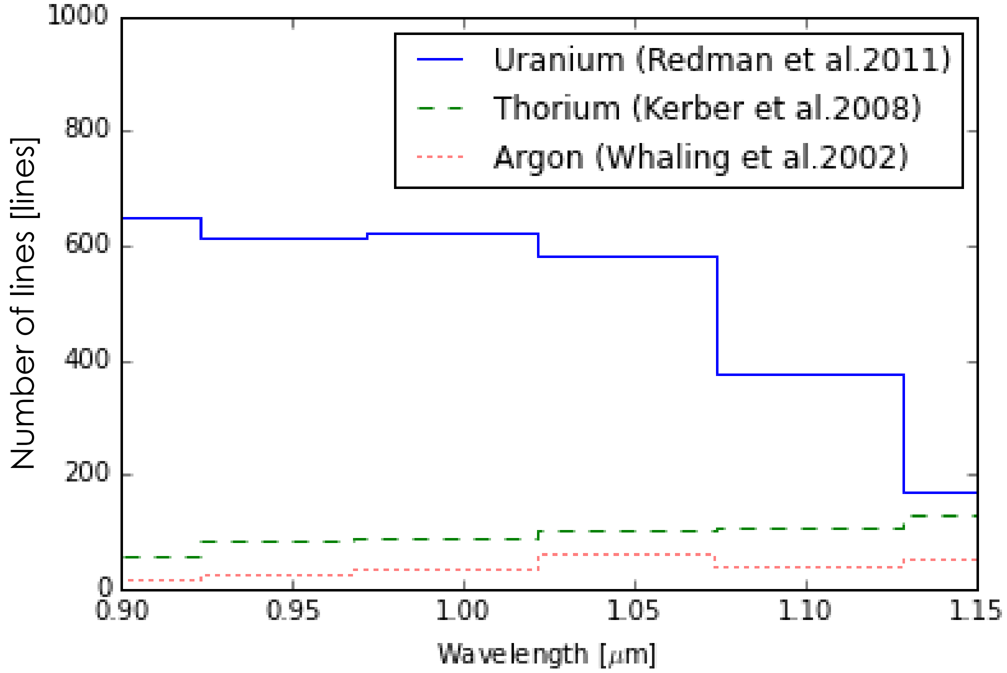


SPECTROGRAPH DESIGN ELEMENTS

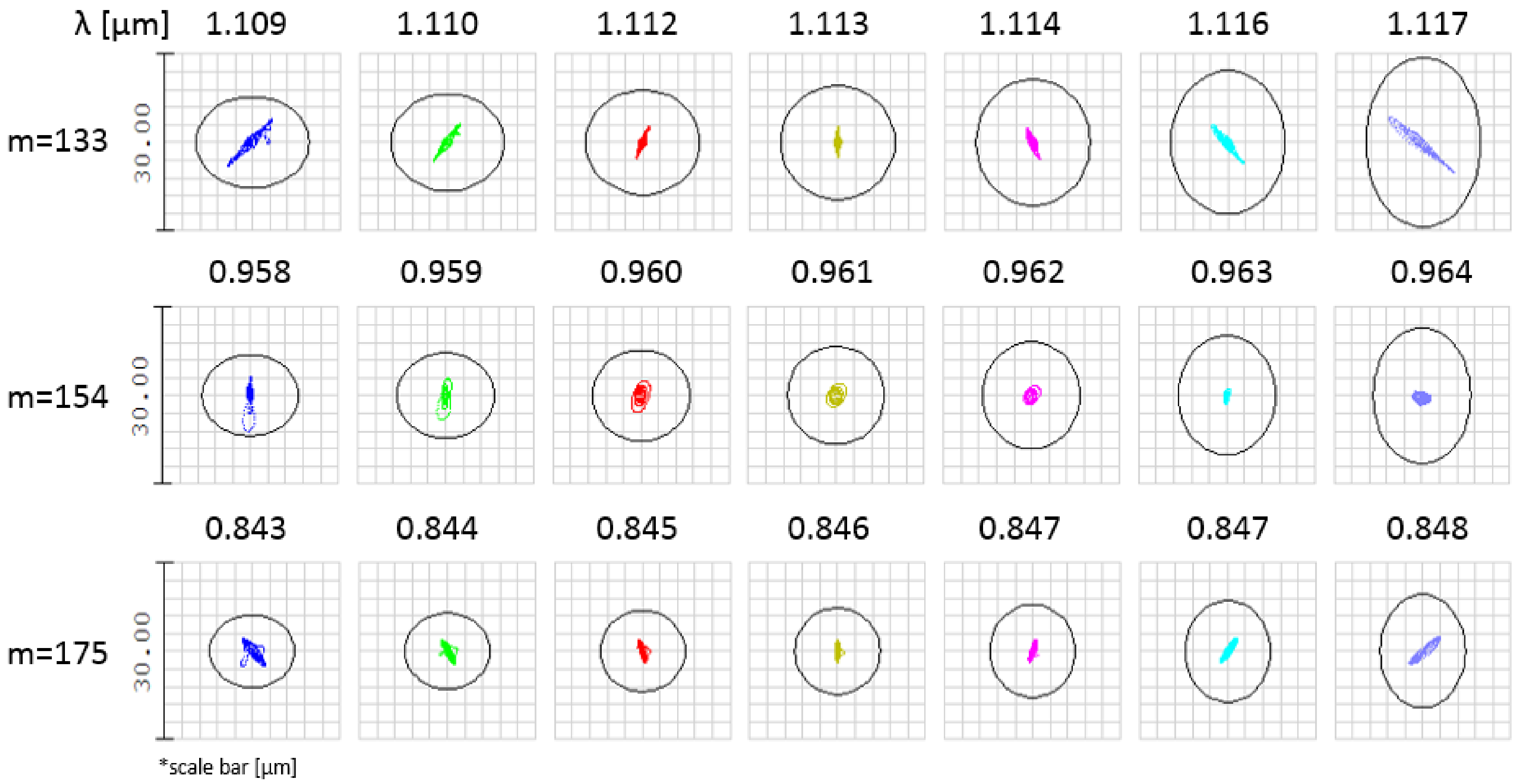
- **Wavelength Calibration Source**
  - Uranium Lamp
  - Fabry-Pérot Etalon (Future plan)



An example how to feed the light from a calibration lamp to the system

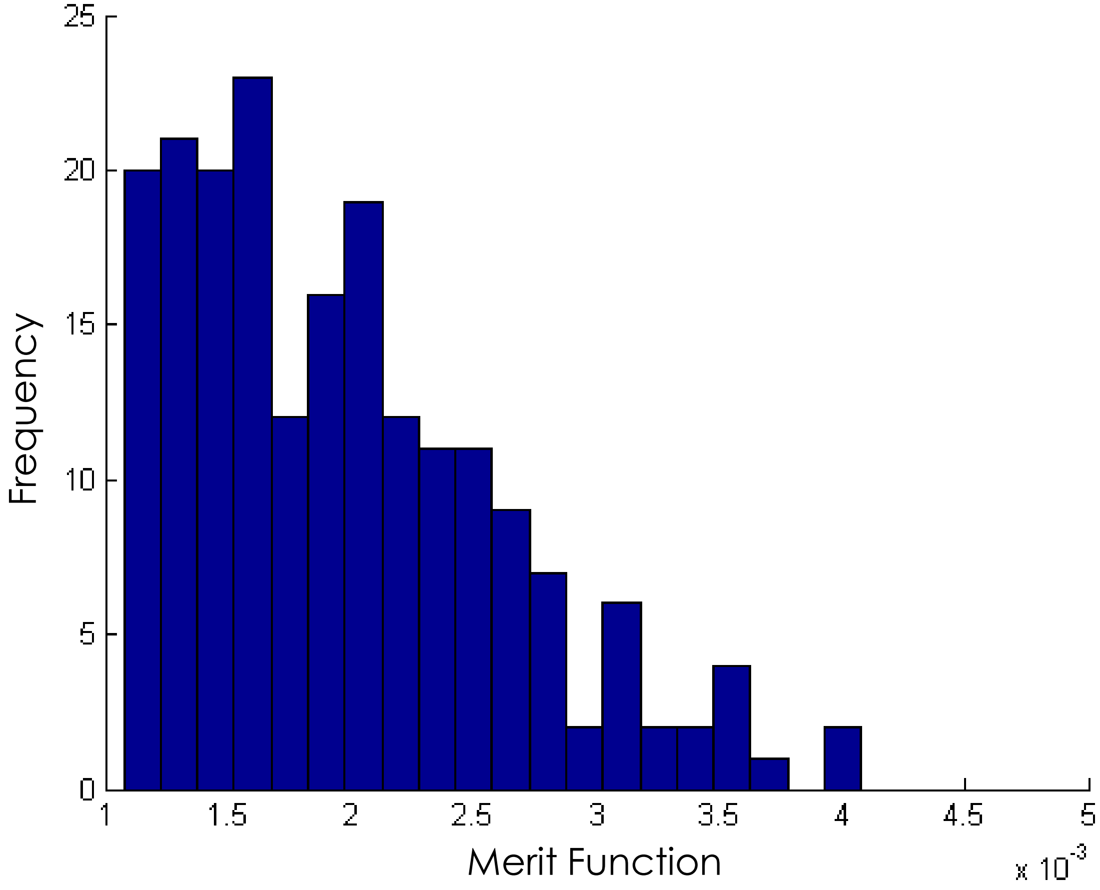


PERFORMANCE : SPOT DIAGRAM



PERFORMANCE : TOLERANCE ANALYSIS

Surface	Criteria	Value
Doublet	Surface radius Center thickness Wedge Irregularity Tilt Decenter	1 fringe ± 0.05 mm ± 0.01 mm ± λ/8 ± 0.2 mm ± 0.2 mm
Group Spacing	Spacing	± 0.05 mm
L3 & L4	Surface radius Center thickness Wedge Irregularity Surface Tilt Surface Decenter Element Tilt Element Decenter	1 fringe ± 0.05 mm ± 0.01 mm ± λ/8 ± 0.1 mm ± 0.05 mm ± 0.2 mm ± 0.2 mm



Histogram shows the merit value of 200 Monte Carlo draws of design meeting the tolerance criteria.

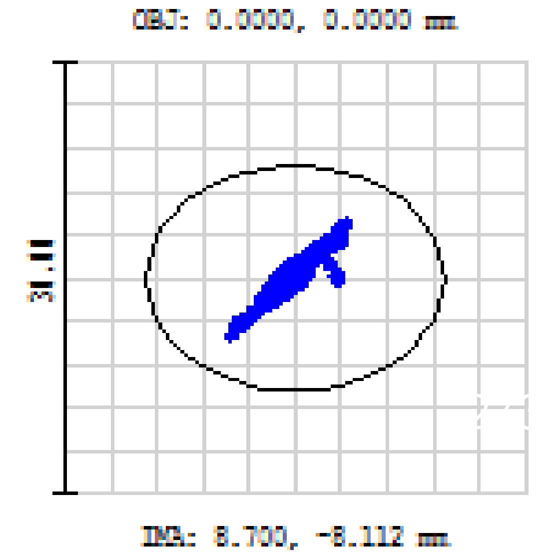
PERFORMANCE : THERMAL ANALYSIS 1/2

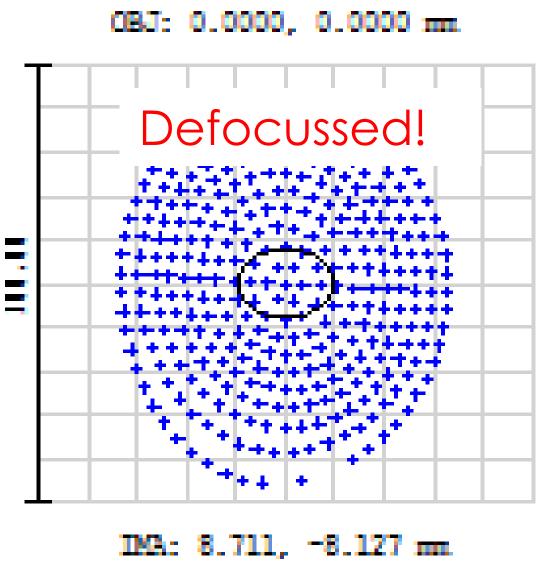
- Operating temperature~ 80K
- Apply reliable refractive index from CHARMS at cryogenic temperature.
- Apply the Sellmeier1 formula in Zemax's glass fitting tool

$$n^2 - 1 = \frac{K_1\lambda^2}{\lambda^2 - L_1} + \frac{K_2\lambda^2}{\lambda^2 - L_2} + \frac{K_3\lambda^2}{\lambda^2 - L_3}$$

wavelength	30 K	40 K	50 K	60 K	80 K	100 K	120 K	160 K	200 K	240 K	275 K	295 K	300 K
0.4 microns	1.46899	1.46902	1.46905	1.46907	1.46912	1.46918	1.46926	1.46948	1.46974	1.47005	1.47036	1.47054	1.47059
0.5 microns	1.46129	1.46131	1.46133	1.46135	1.46140	1.46146	1.46154	1.46175	1.46199	1.46228	1.46257	1.46275	1.46279
0.6 microns	1.45704	1.45706	1.45708	1.45710	1.45715	1.45721	1.45729	1.45748	1.45773	1.45801	1.45829	1.45846	1.45850
0.7 microns	1.45432	1.45433	1.45435	1.45437	1.45442	1.45448	1.45456	1.45475	1.45499	1.45527	1.45554	1.45571	1.45575
0.8 microns	1.45236	1.45237	1.45239	1.45240	1.45245	1.45252	1.45259	1.45278	1.45302	1.45329	1.45356	1.45373	1.45377
0.9 microns	1.45080	1.45081	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.45173	1.45200	1.45216	1.45220
1.0 microns	1.44947	1.44948	1.44950	1.44952	1.44957	1.44963	1.44970	1.44989	1.45012	1.45039	1.45066	1.45082	1.45086
1.2 microns	1.44711	1.44713	1.44714	1.44716	1.44721	1.44727	1.44735	1.44753	1.44776	1.44803	1.44829	1.44845	1.44850
1.5 microns	1.44369	1.44370	1.44372	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.44433	1.44460	1.44486	1.44502	1.44507
1.6 microns	1.44250	1.44251	1.44252	1.44254	1.44259	1.44265	1.44272	1.44291	1.44314	1.44340	1.44367	1.44383	1.44387
1.8 microns	1.43995	1.43996	1.43998	1.44000	1.44004	1.44010	1.44018	1.44036	1.44059	1.44086	1.44112	1.44128	1.44132
2.0 microns	1.43716	1.43717	1.43718	1.43720	1.43725	1.43731	1.43738	1.43757	1.43779	1.43806	1.43833	1.43849	1.43853
2.2 microns	1.43407	1.43408	1.43410	1.43411	1.43416	1.43422	1.43430	1.43448	1.43471	1.43498	1.43524	1.43541	1.43545
2.4 microns	1.43065	1.43067	1.43068	1.43070	1.43074	1.43081	1.43088	1.43107	1.43129	1.43156	1.43183	1.43200	1.43204
2.5 microns	1.42881	1.42882	1.42884	1.42885	1.42890	1.42896	1.42904	1.42922	1.42945	1.42972	1.42999	1.43016	1.43021
2.6 microns	1.42688	1.42688	1.42690	1.42692	1.42696	1.42703	1.42710	1.42729	1.42752	1.42779	1.42806	1.42823	1.42828

Absolute refractive index from CHARMS/NASA





PERFORMANCE : THERMAL ANALYSIS 2/2

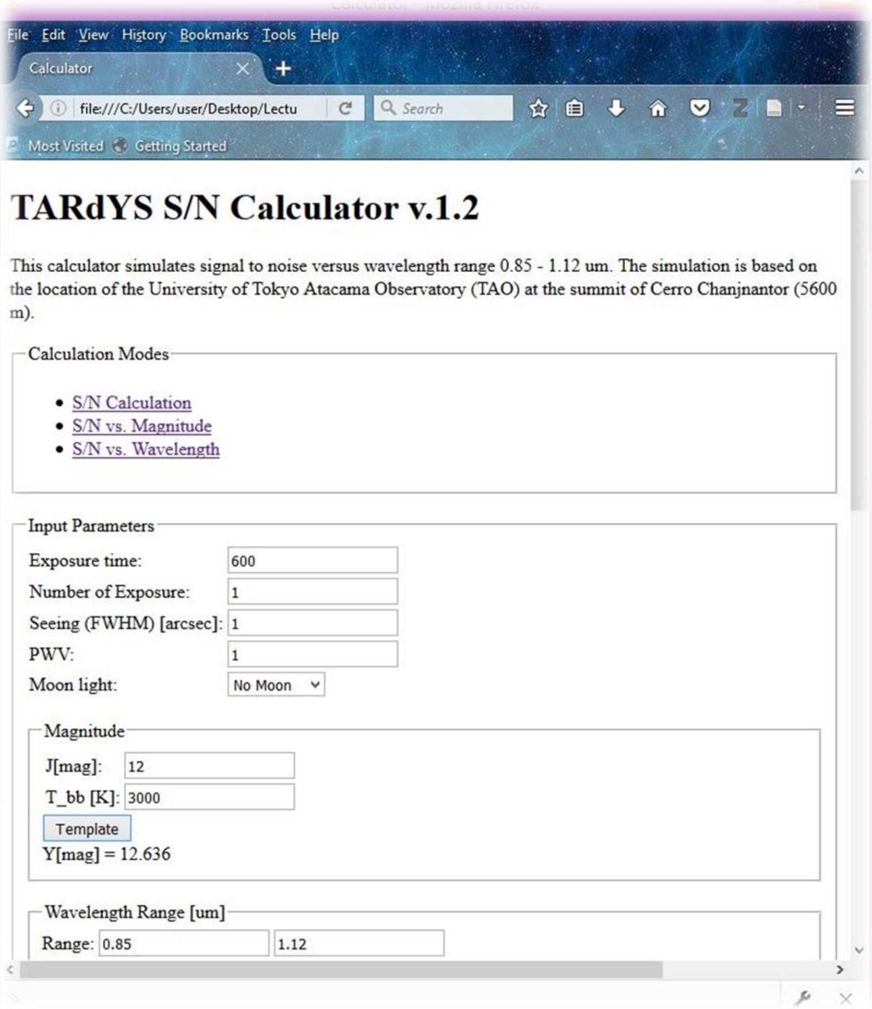
- Operating temperature~ 80K
- Apply reliable refractive index from CHARMS at cryogenic temperature.
- Apply the Sellmeier1 formula in Zemax's glass fitting tool

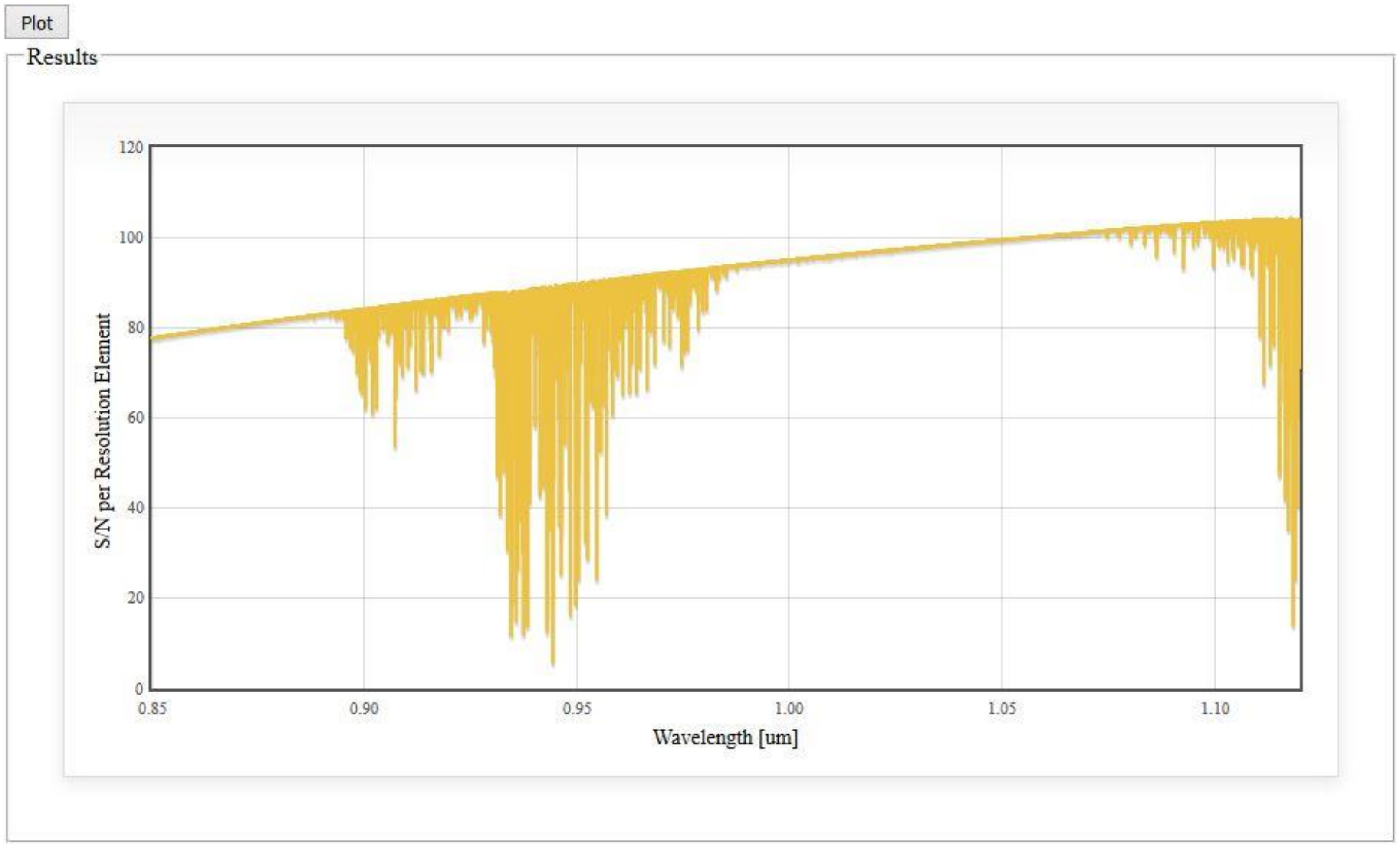
$$n^2 - 1 = \frac{K_1\lambda^2}{\lambda^2 - L_1} + \frac{K_2\lambda^2}{\lambda^2 - L_2} + \frac{K_3\lambda^2}{\lambda^2 - L_3}$$

- Distance adjustment of the last lens needed

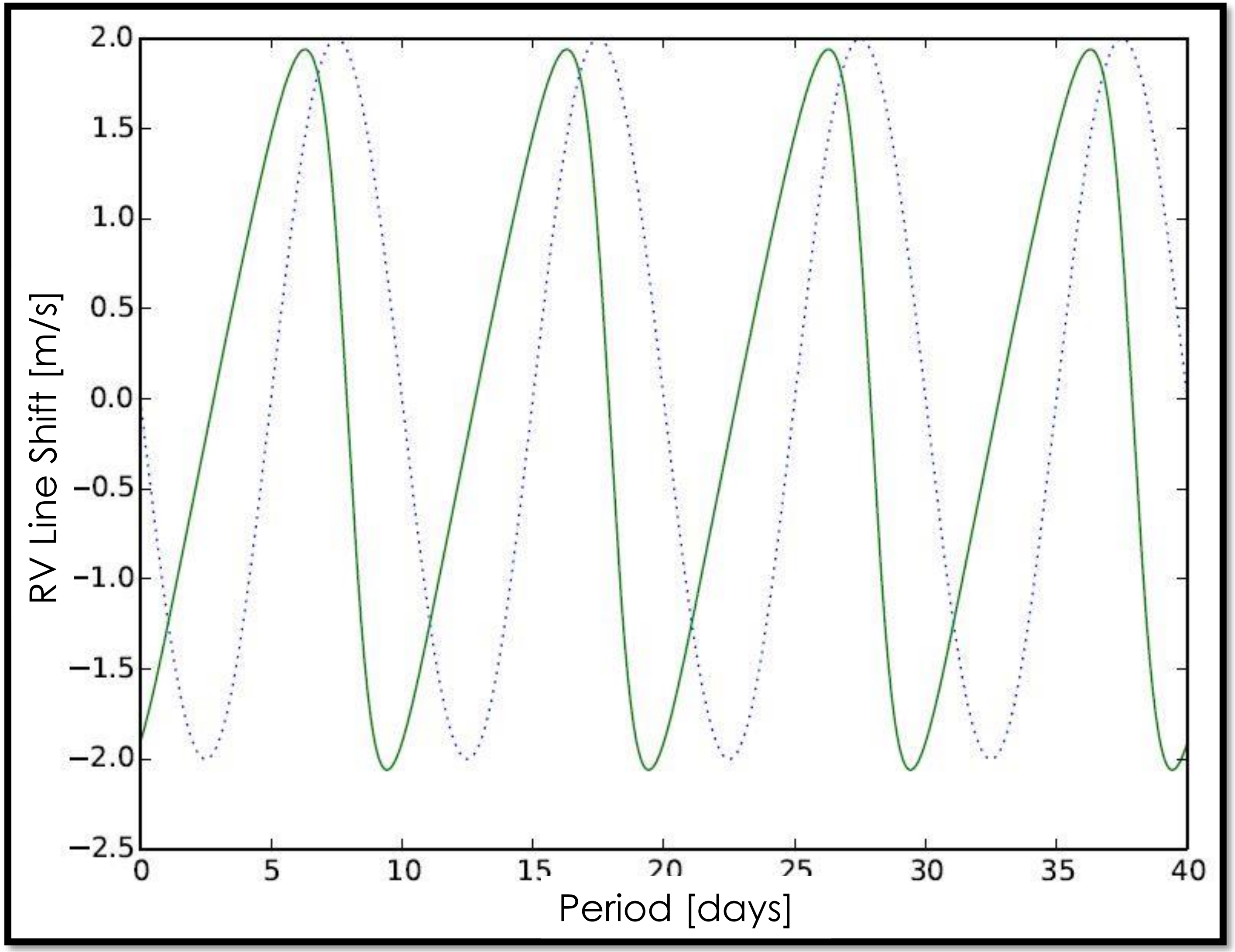
WHAT'S NEXT ?

EXPOSURE TIME CALCULATOR



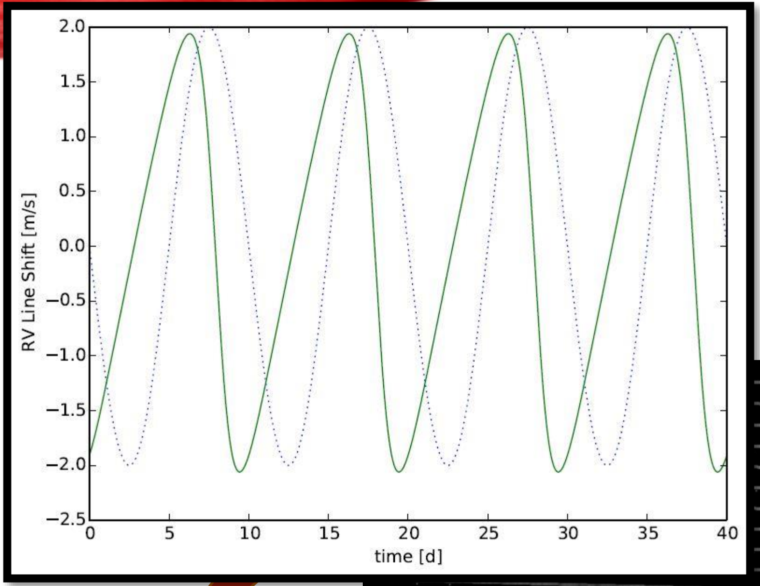


SIMULATION



EXOFIT (Balan et al. 2009) + PyMultinest (Buchner et al. 2014)

SIMULATION


RV Line Shift [m/s]
time [d]
2.0
1.5
1.0
0.5
0.0
−0.5
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−1.5
−2.0
−2.5
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5
10
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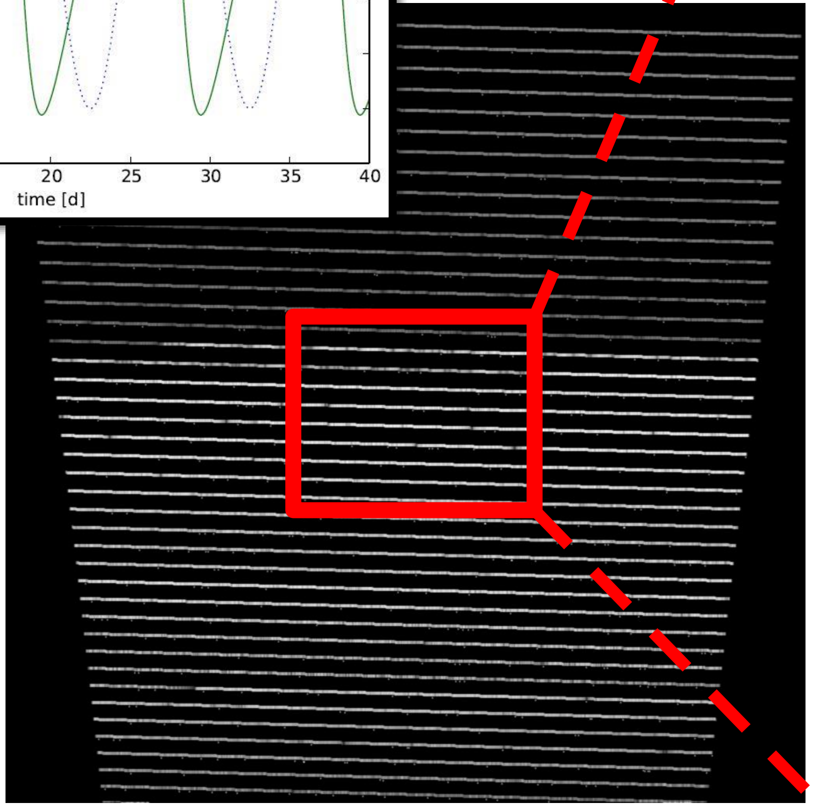
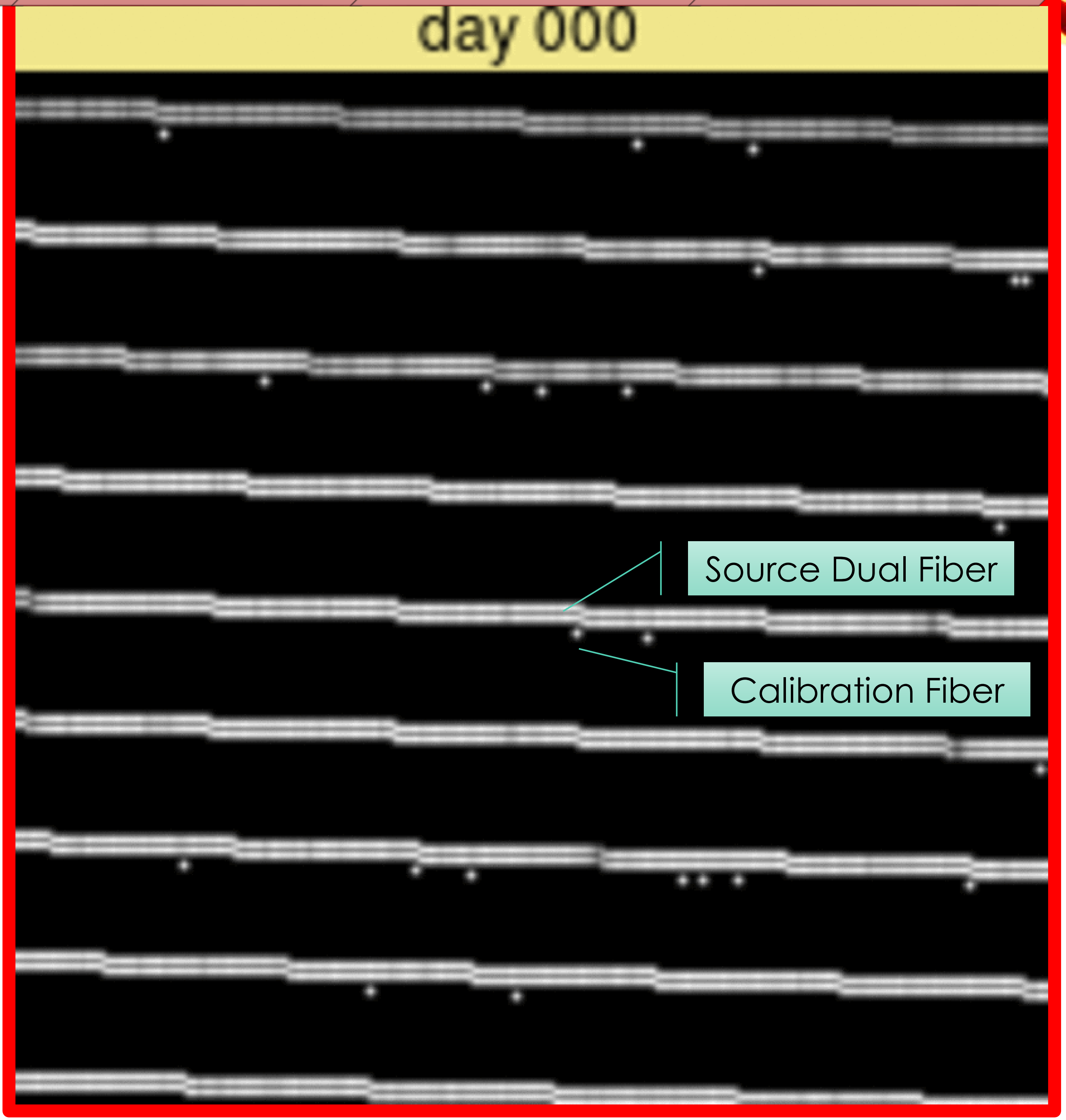
35
40




day 000
Source Dual Fiber
Calibration Fiber

FUTURE WORK

2016

- Finalize Optical Design
- Order Optical Components
- Optomechanical Design & Fabrication

2017

- Alignment
- Lab tests
- Calibration System
- Telescope Interface
- Software

- Commissioning at TAO 6.5 m

SUMMARY

- TARdYS is a fiber-fed infrared echelle spectrograph planned to be installed at the TAO 6.5 meter telescope in Chile.
- The concept design of TARdYS based on the white pupil configuration.
- The tolerance and thermal analysis of the spectrograph's camera predicts diffraction limited performance assuming realistic manufacturing and alignment tolerances.
- The spectrograph is currently under construction in the opto-mechanics phase.
- TARdYS will open up opportunities for high-resolution Y-band infrared spectroscopy including studies of M-dwarfs and searches for their planets.
- Applying a 2K detector will broaden the wavelength coverage and more science cases.