The TAO AIUC high Resolution Y band Spectrograph – TARdYS

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Optical, Mechanical Design, Prototyping

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Mechanical Design

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Detector control

Spectrograph overview

1. Scientific motivation

2. Optical design

3. Laboratory prototype

1. Scientific motivation

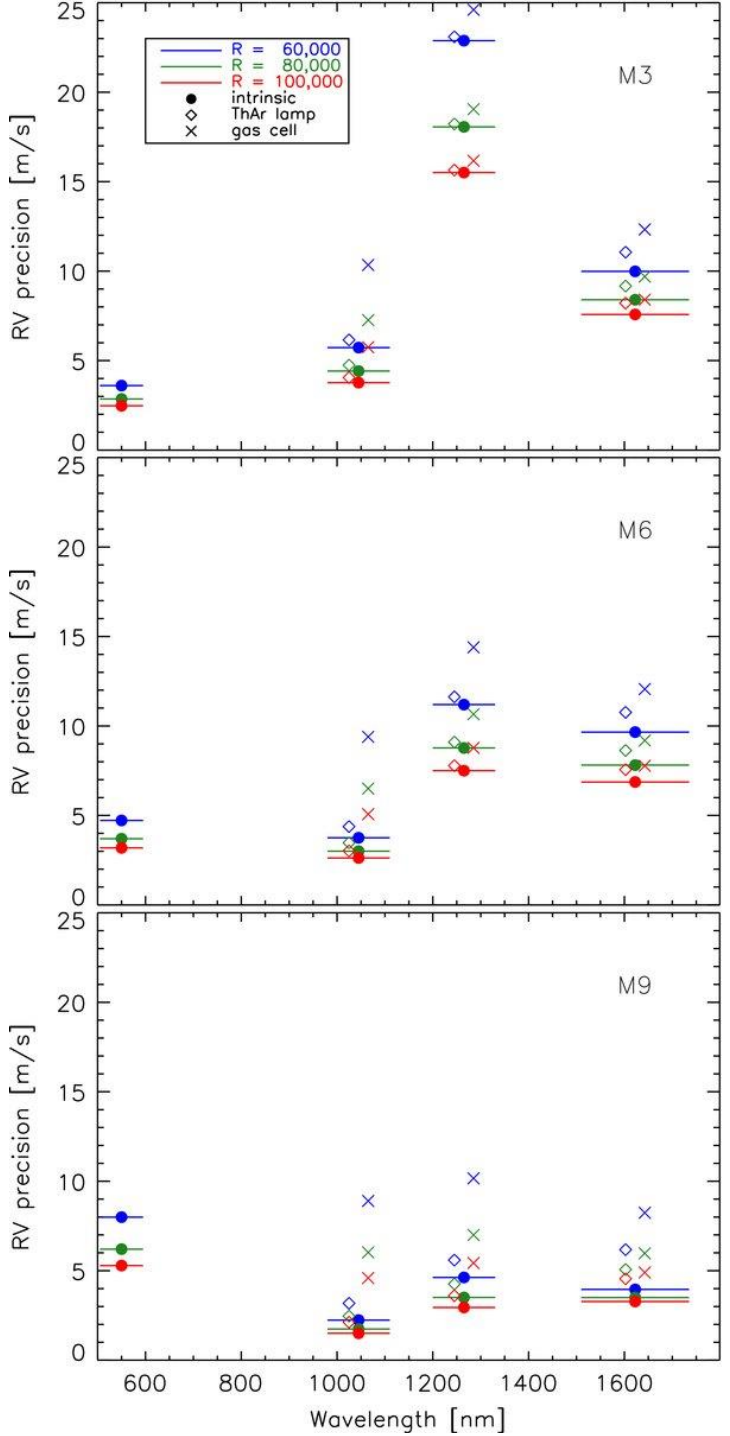
Exoplanet search in low mass stars with:

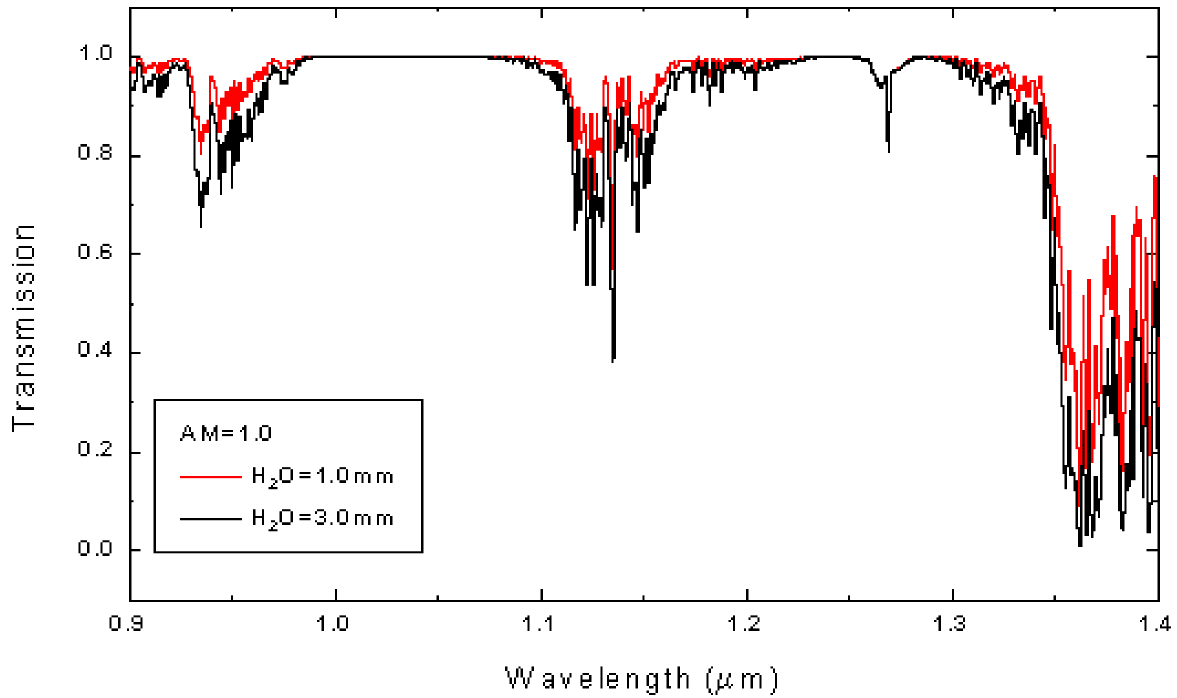
- high spectral resolution
- high RV precision

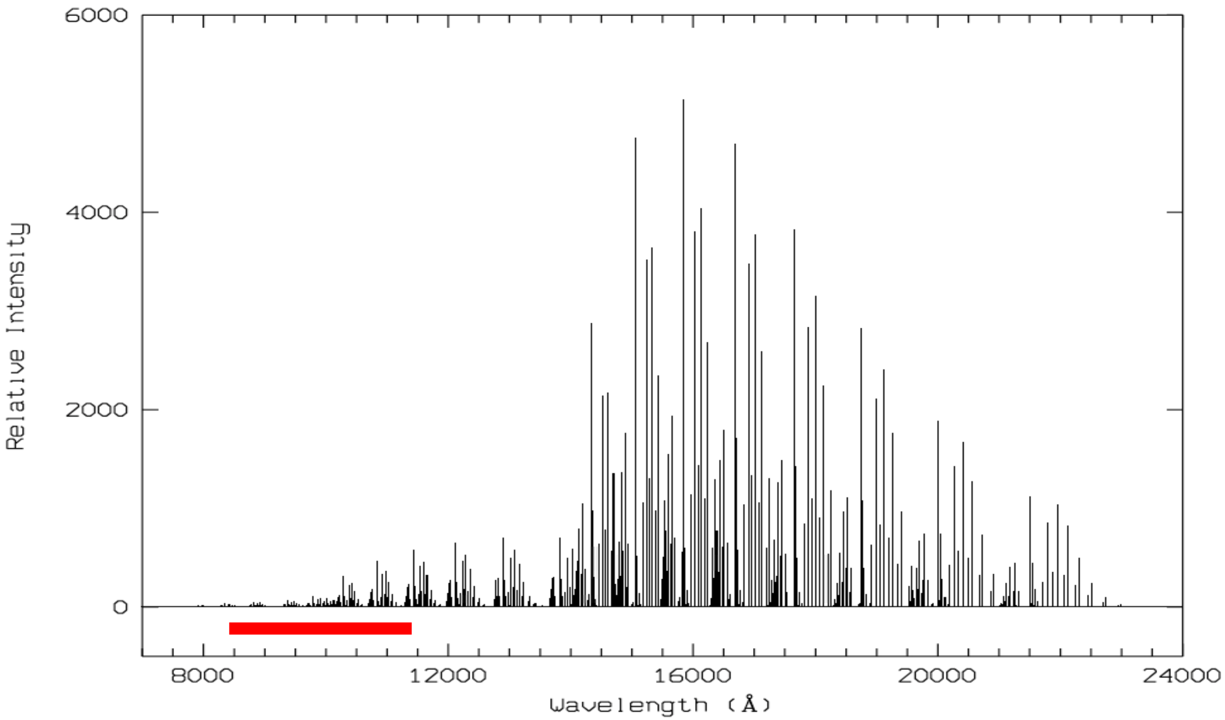
Wavelength-dependent S/N and RV Precision that can be Achieved from Data of this Quality

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







Requirements

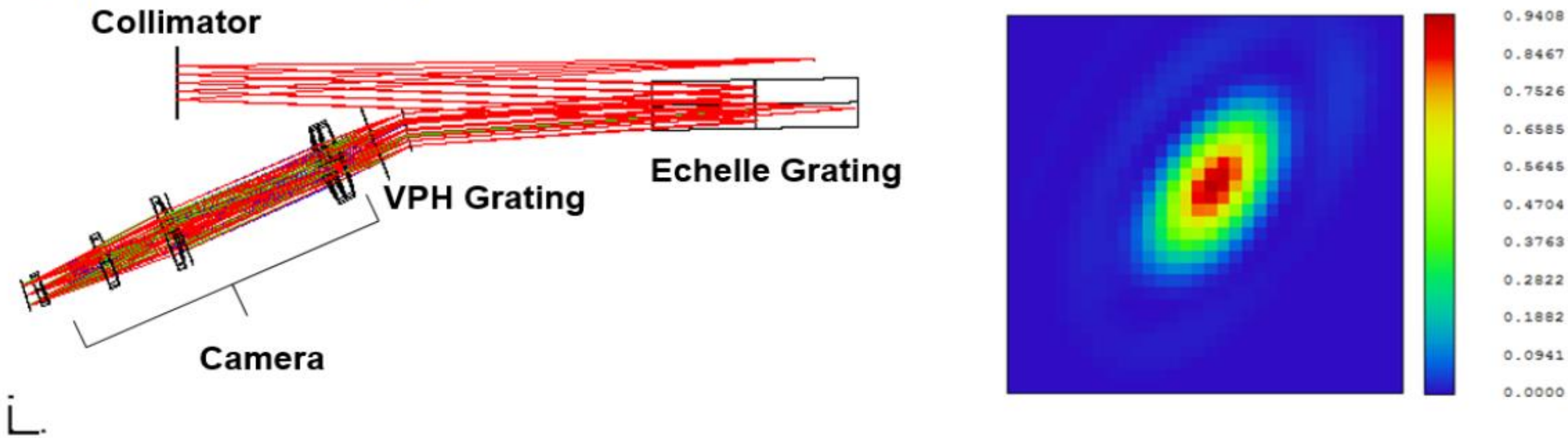
- Y Band
- R > 50.000
- Stability (temperature, pressure and mechanical)

Constraints

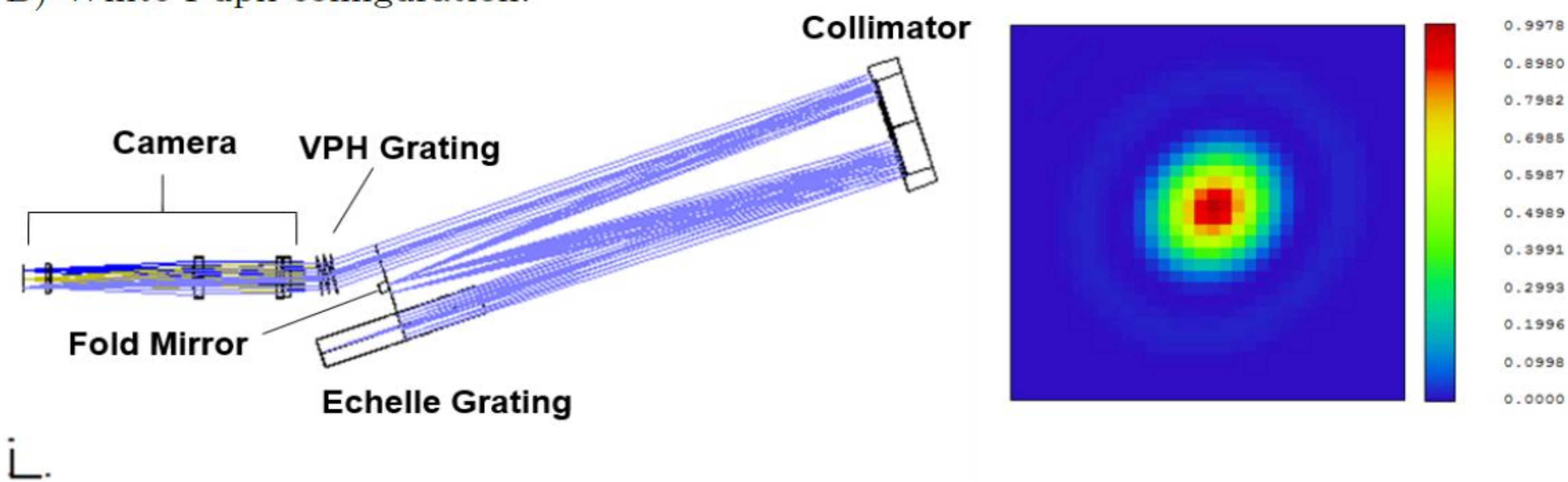
- Cost efficiency (tight budget)
    - 1K Detector
    - Semi cryogenic setup
    - Lamp calibration

2. Optical design

A) quasi-Littrow configuration:



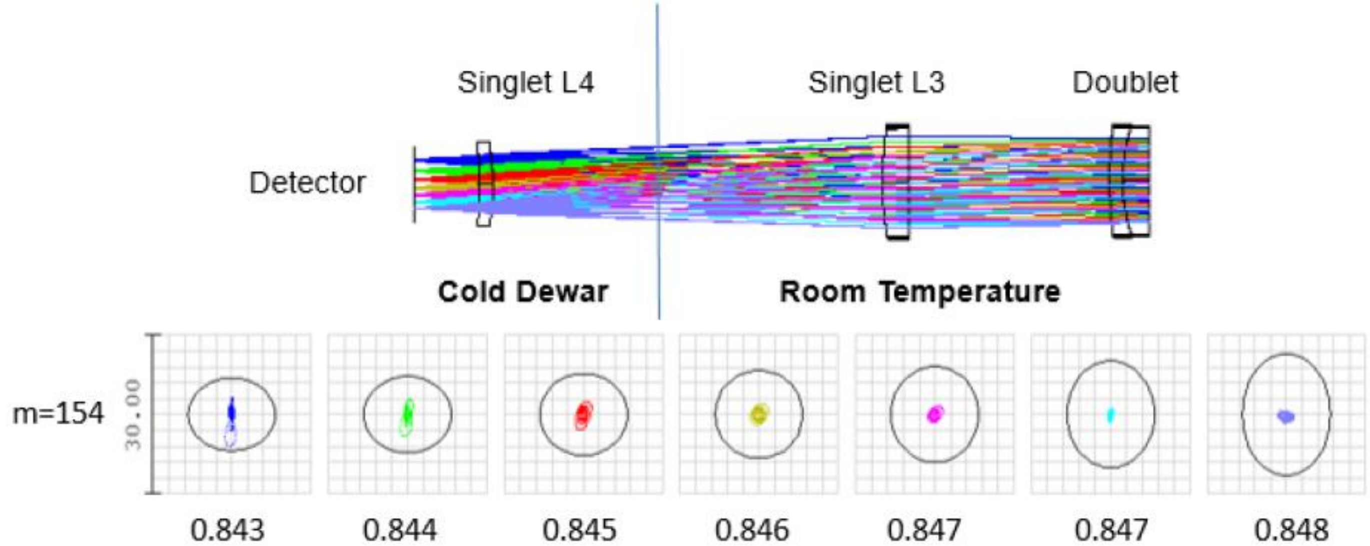
B) White Pupil configuration:



Rukdee et al. 2018 submitted

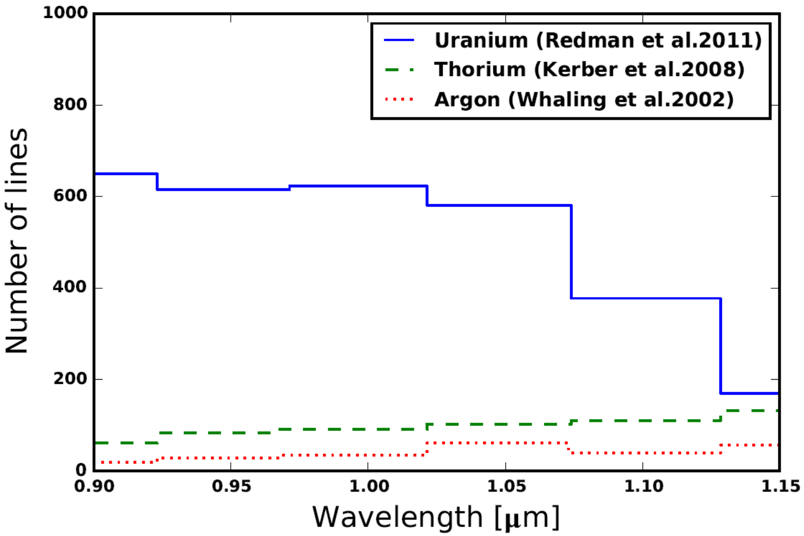
Objective

Semi cryogenic - only first lens inside Dewar



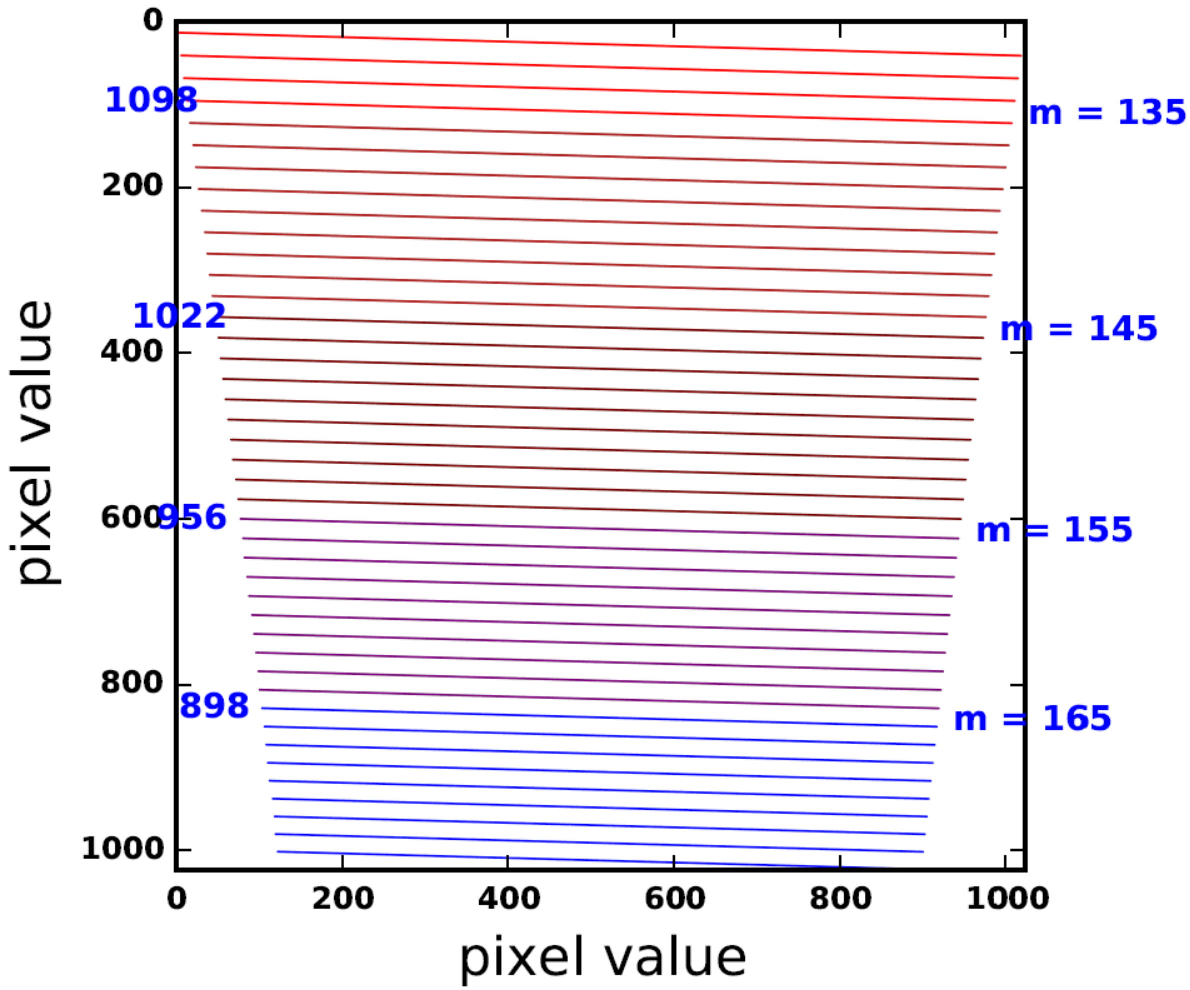
Calibration

- ThAr Lamp → Ur Lamp?



Rukdee et al. 2018 submitted

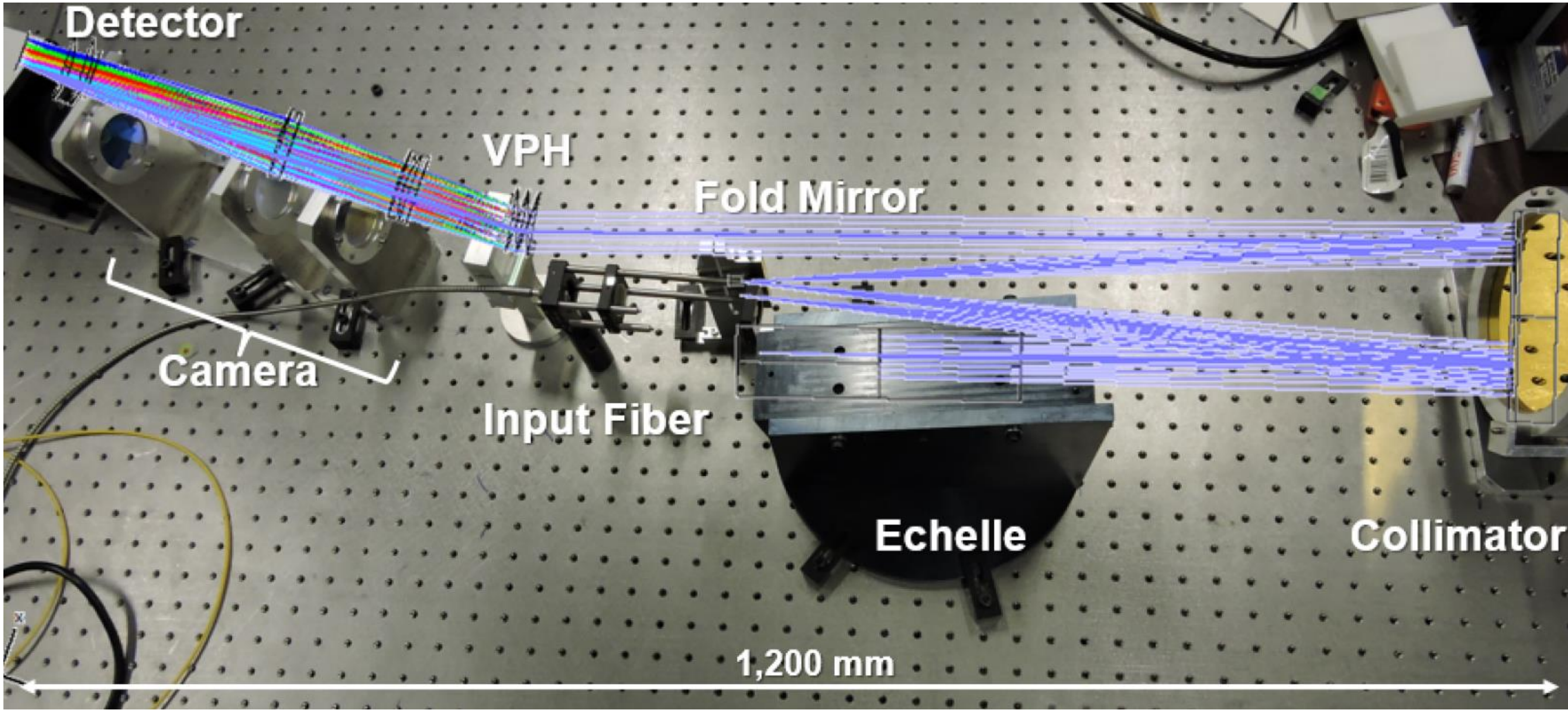
F_{COL} = 550 mm, image slicer, 1K detector → R=60,000, 2 pix sampling



Spectral range: 0.843 – 1.117 μm

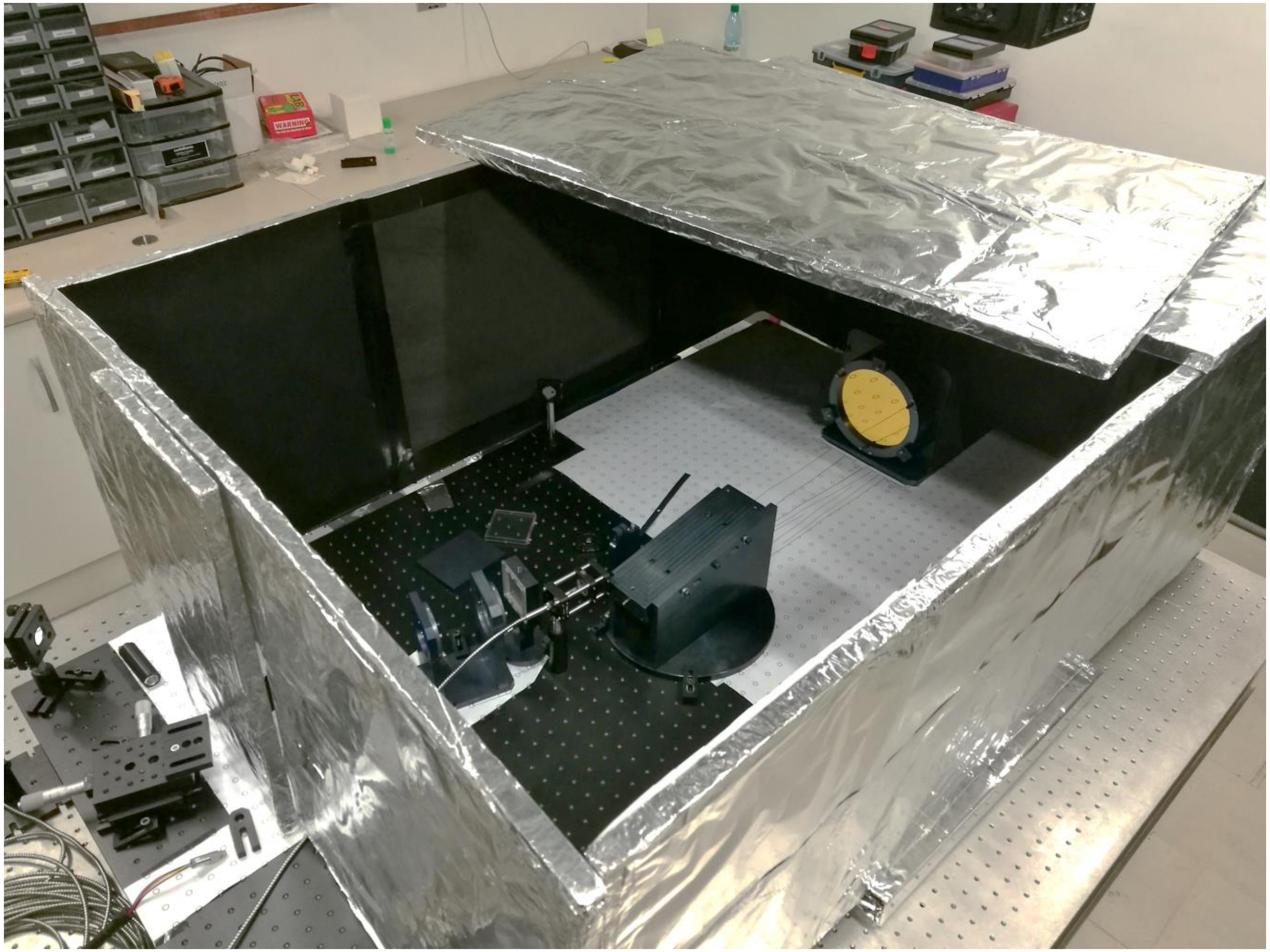
Rukdee et al. 2018 submitted

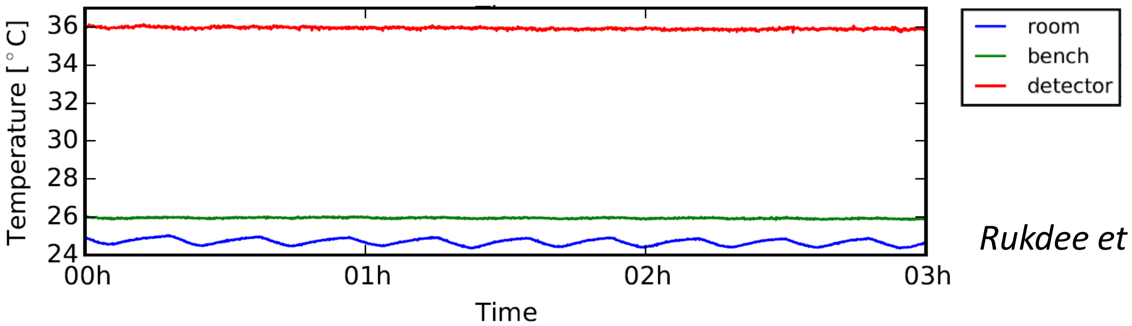
3. Laboratory prototype



Rukdee et al. 2018 submitted

Temperature stability → 0.1K Pressure → Not Yet





Rukdee et al. 2018 submitted

Current challenges

1. Design AO solution

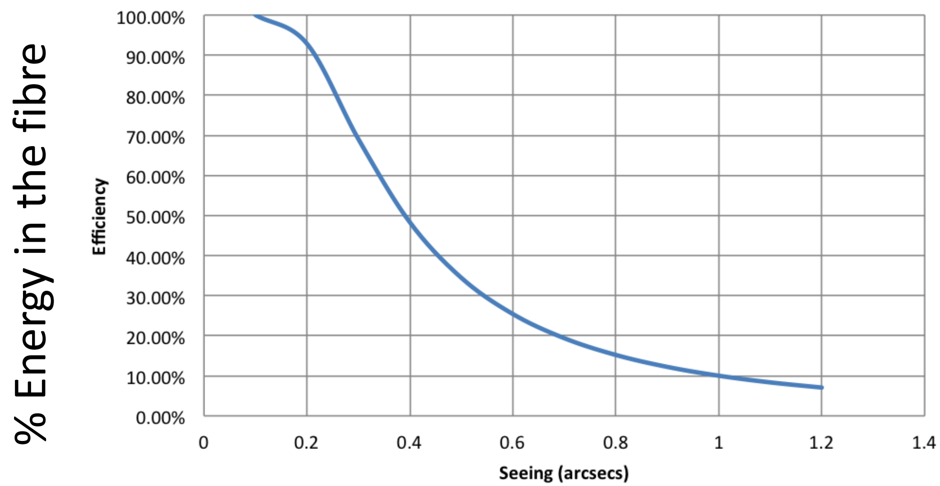
2. Design mechanical interface

3. Choose and acquire scientific detector

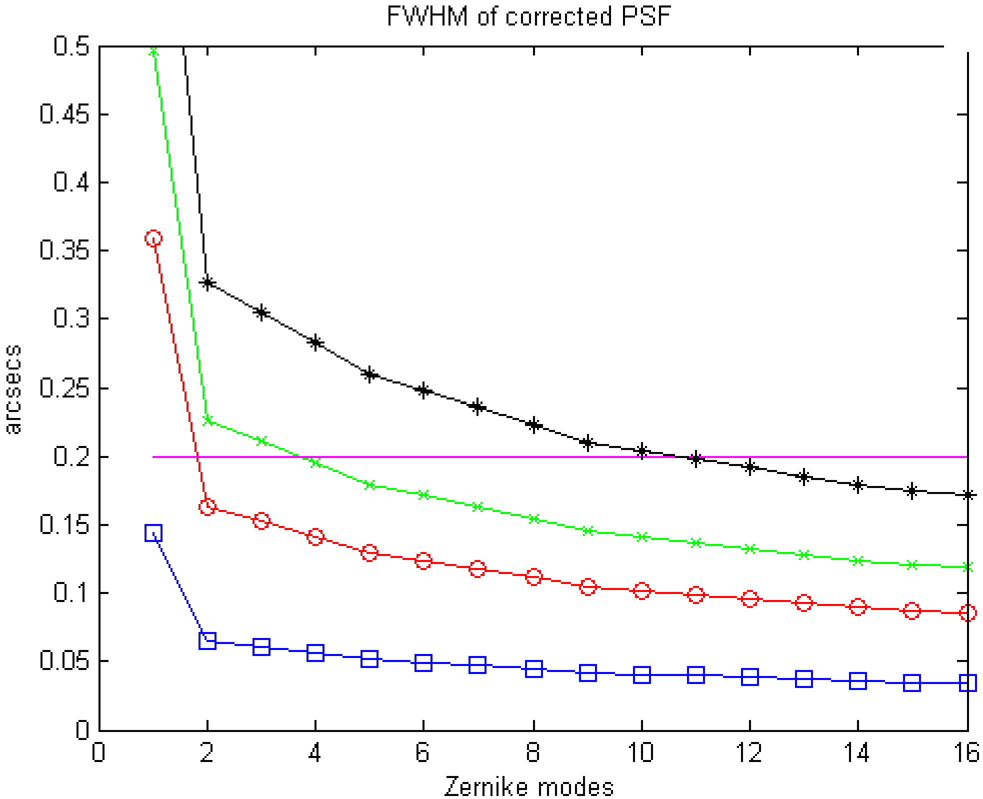
1. Designing AO Solution

What degree of AO correction do we need?

If we corrected in the visible:



PSF



Fiber is 0.4”

Natural Seeing

1.0 arcsec

0.7 arcsec

0.5 arcsec

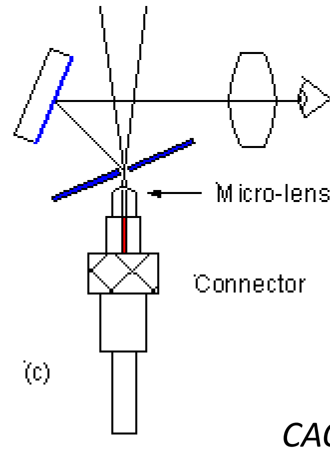
0.2 arcsec

Courtesy A. Guesalaga

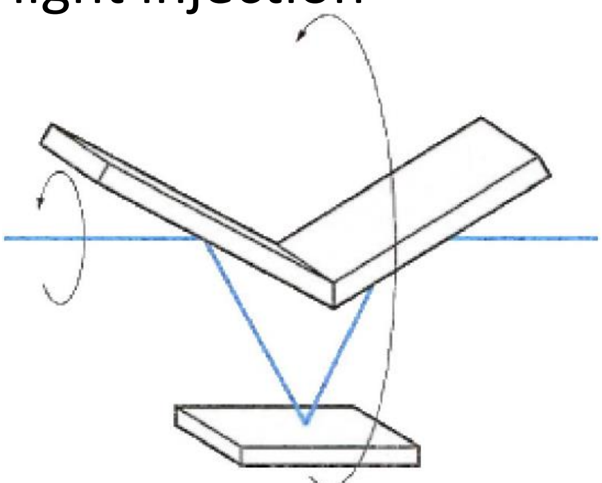
2. Mechanical interface

Must include:

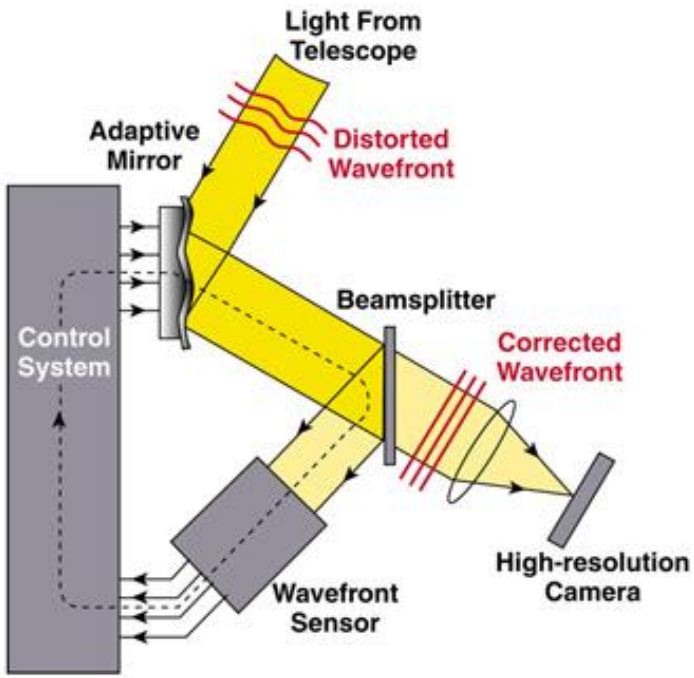
1. Derrotation
2. AO Correction
3. Image acquisition (guiding)
4. Fiber light injection



CAOS Spectroscopy

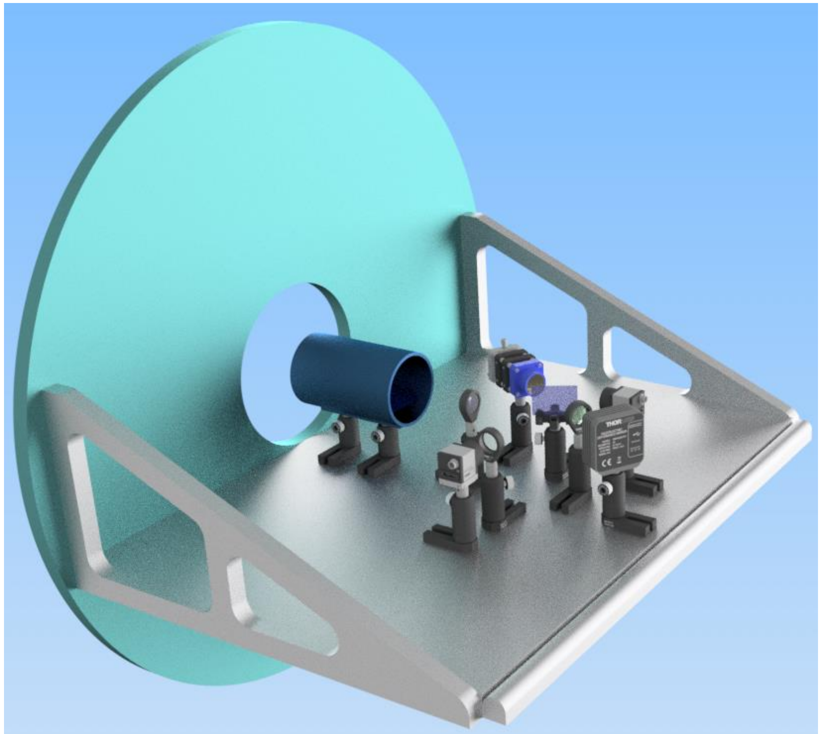


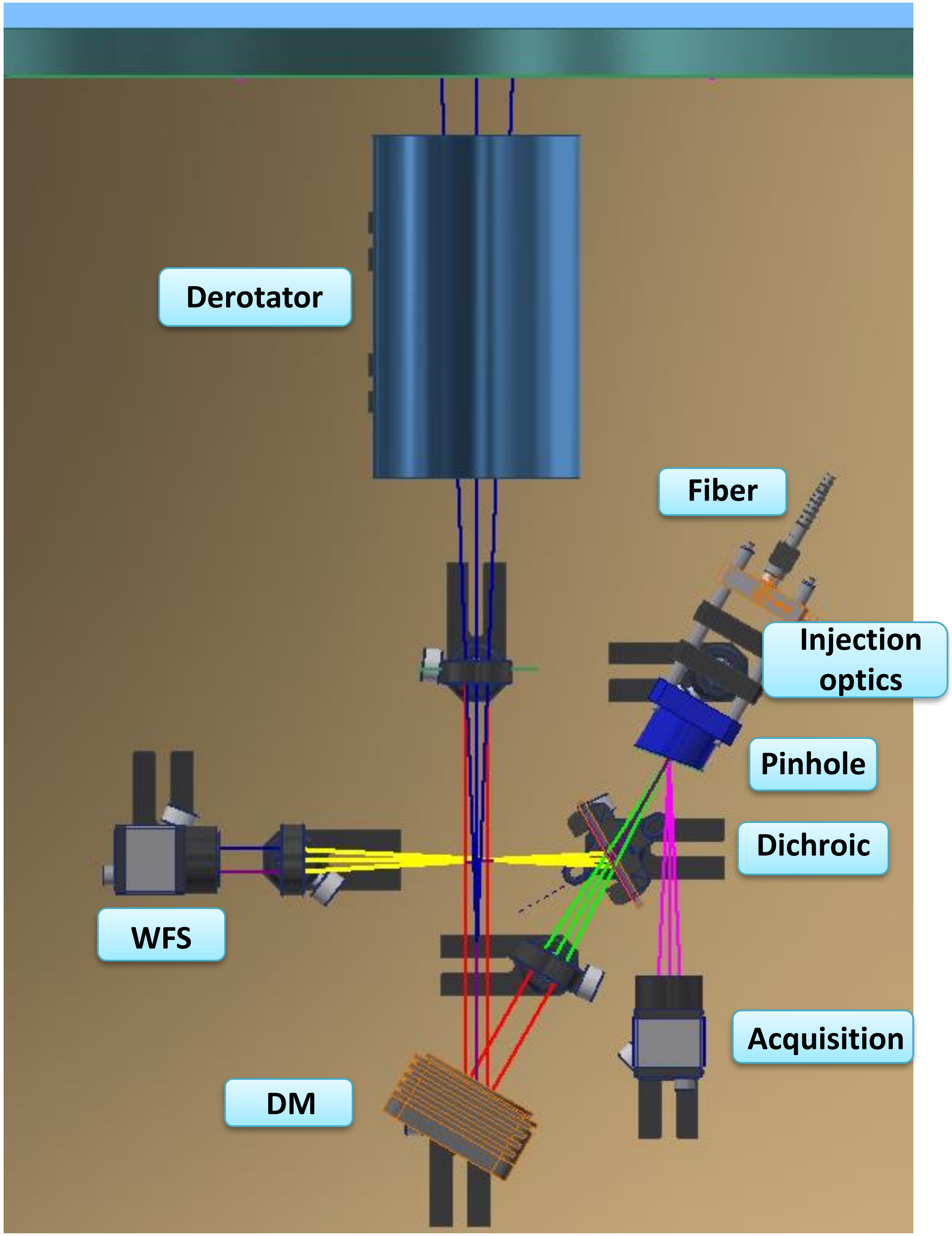
J. Baudet, 2016



Lawrence Livermore National Laboratory and NSF Center for Adaptive Optics.

2. Mechanical interface

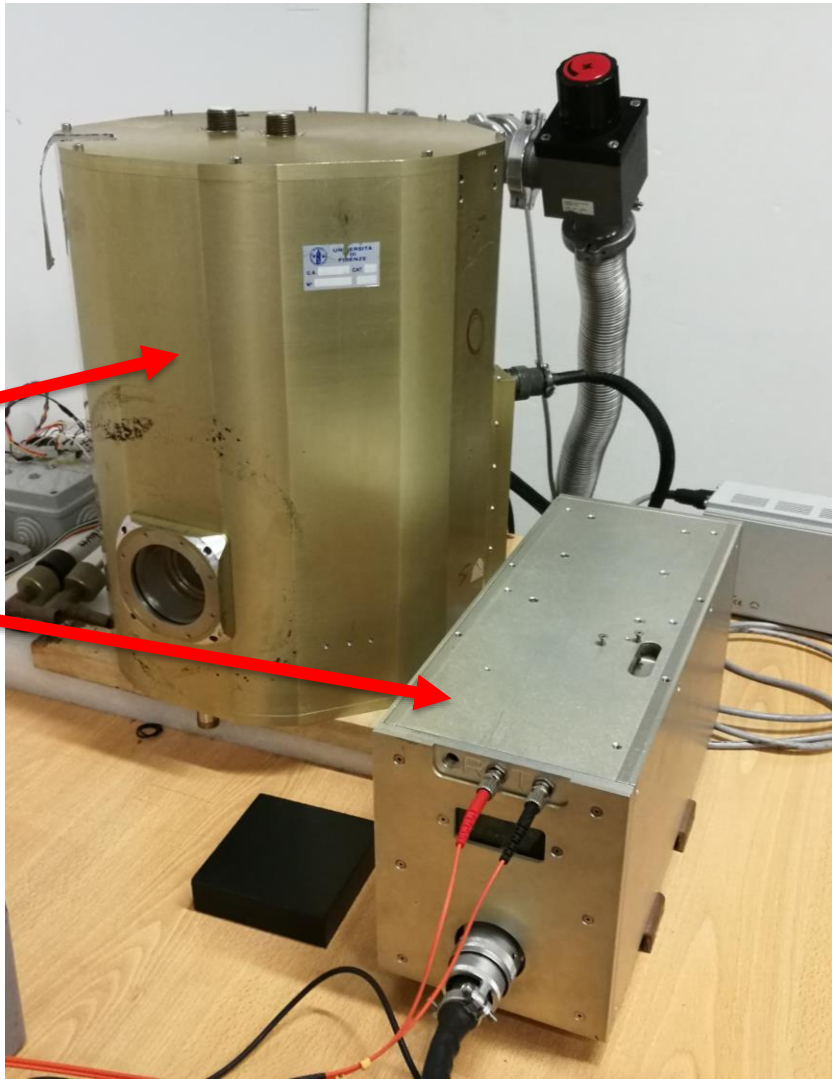




3. Choosing scientific detector

What we currently have: ARNICA

1. NICMOS 3 detector – HgCdTe
   256x256 pixels
   0.9 – 2,5 µm
2. Dewar (vacuum, cooling)
3. SDSU Leach Gen III controller



Scientific detector alternatives

	InGaAs	HgCdTe
Multiplexer	H1RG	H1RG
Spectral Sensitivity [µm]	1.0 – 1.7	0.8 – 2.5
Full Well [e-]	450,000	80,000
Pixel Size [µm]	18	18
Size	1K	1K
RON [e-]	20	15
QE [ph/e-]	0.8	0.9

S. Seshadri, 2007

HgCdTe:
- \+ Widely used, validated
- – More sensitive to thermal noise

InGaAs:
- \+ Less sensitive to thermal noise
- \+ Less expensive
- – Limited scientific use
- – Short wavelength cut-off = 1.0 µm

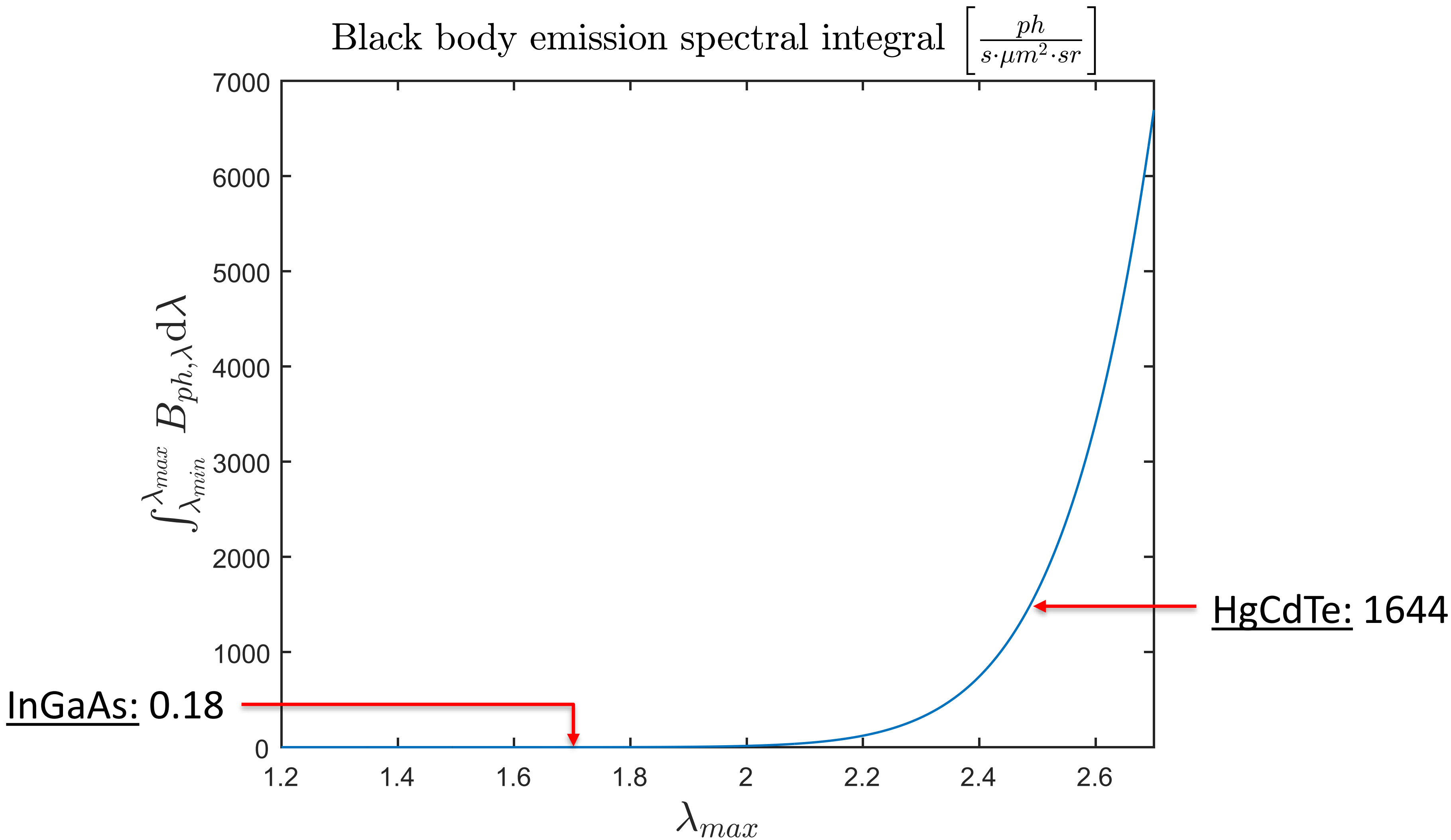
Room Background Emission

Everything outside detector housing (Dewar) emits thermal radiation, at room temperature, which could rapidly saturate detector.

- Modeled as Black Body radiation (Planck's Law).
- Thermal radiation arrives at detector directly, into solid angle equal to detector field of view ($\approx 27°$ for detector + first lens).
- Indirect radiation arrives at detector by reflections (stray light), into a larger than fov solid angle.

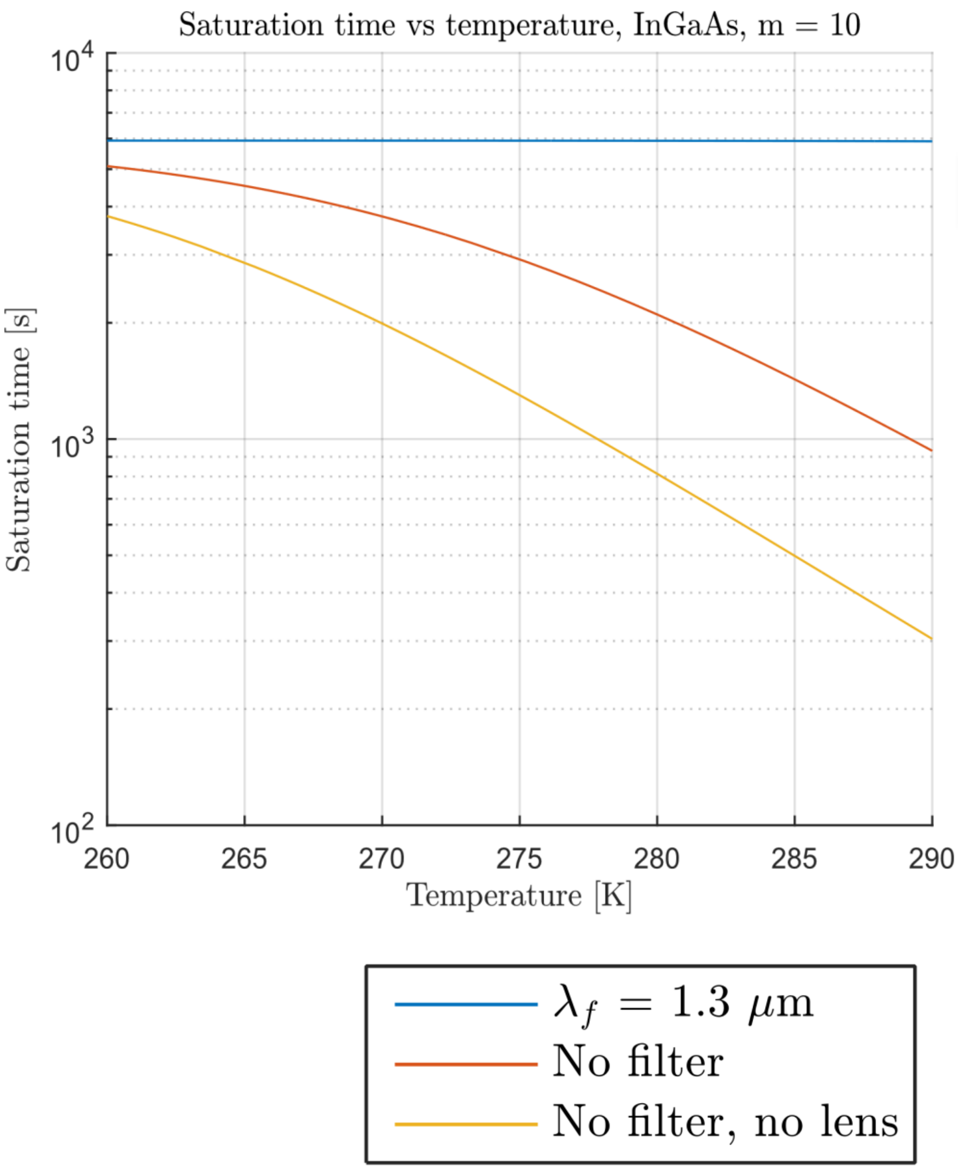
Room Background Emission

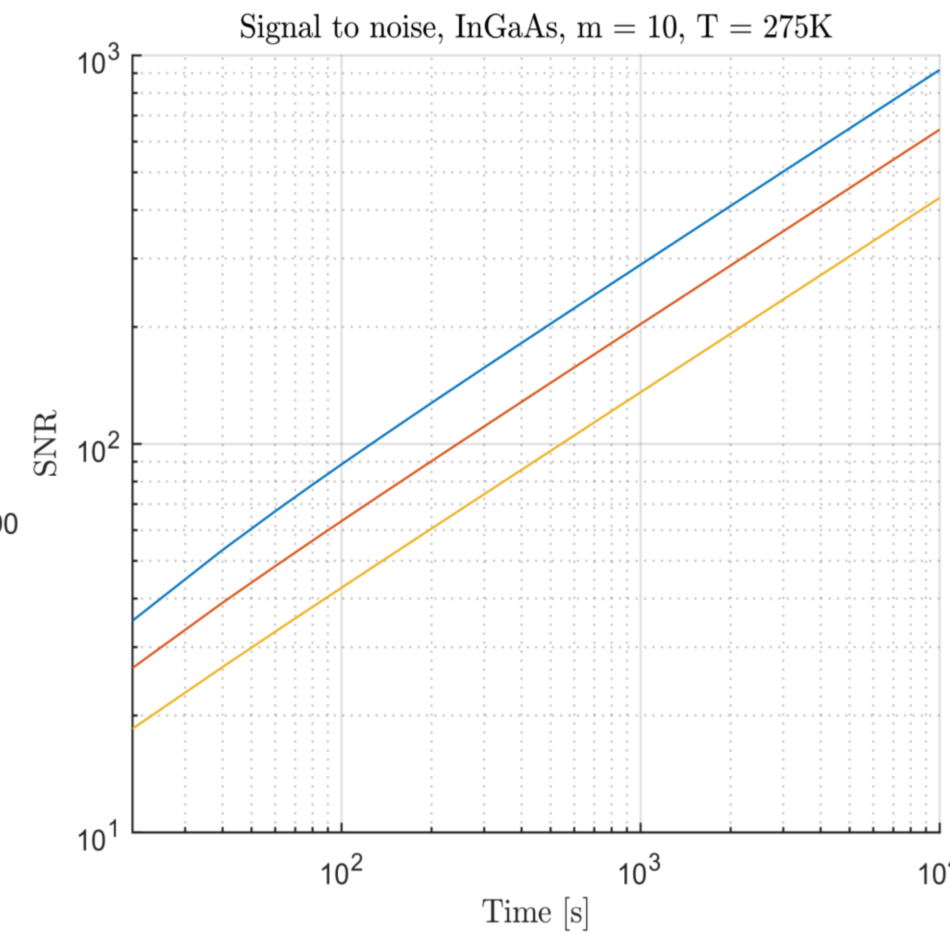
Black body emission at T = 275 K



Room Background Emission - InGaAs

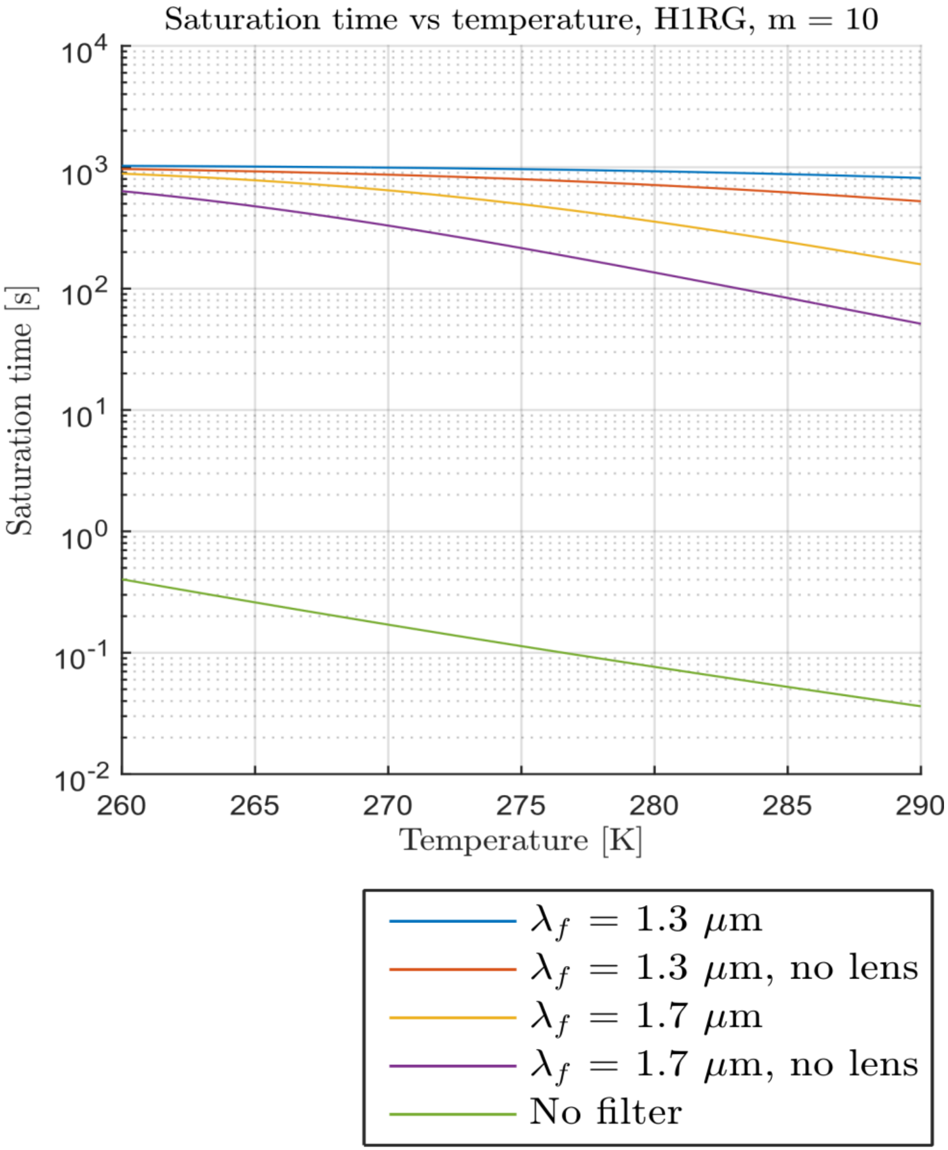
	t_{sat} [s]	SNR ($t_{sat}/2$)
λ_f = 1.3 μm	5900	500
No filter	2900	250
No filter, no lens	1300	110

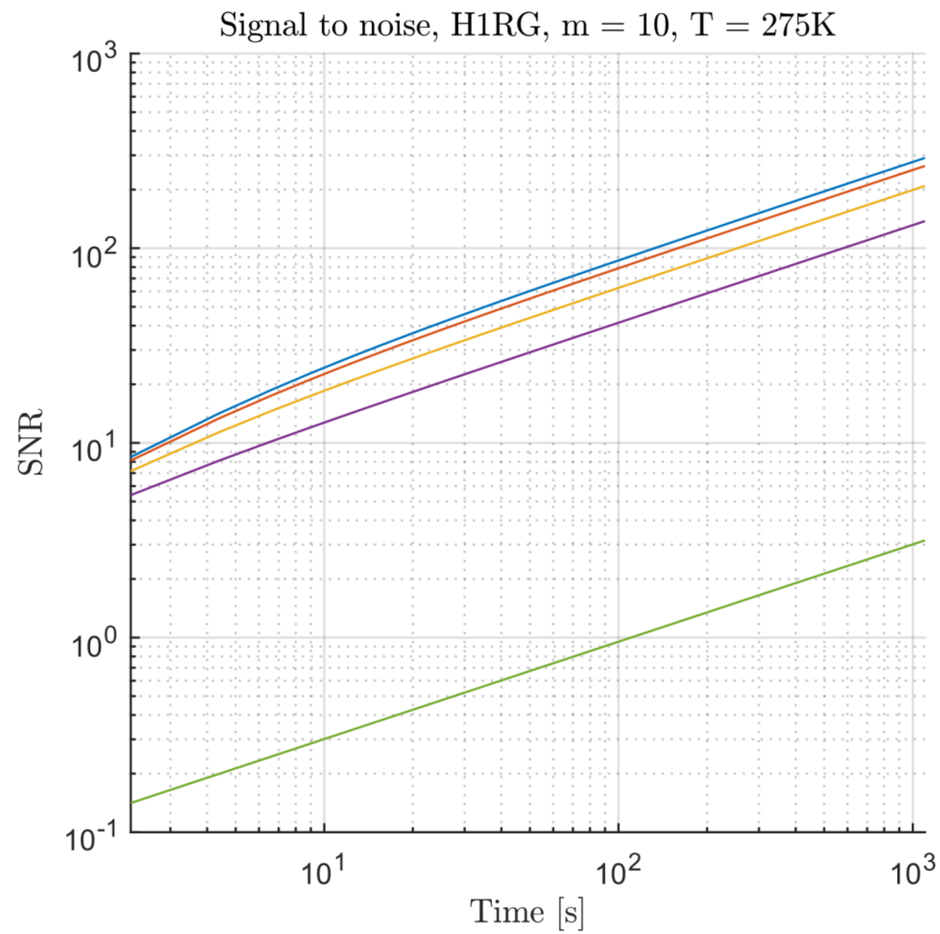




Room Background Emission - HgCdTe

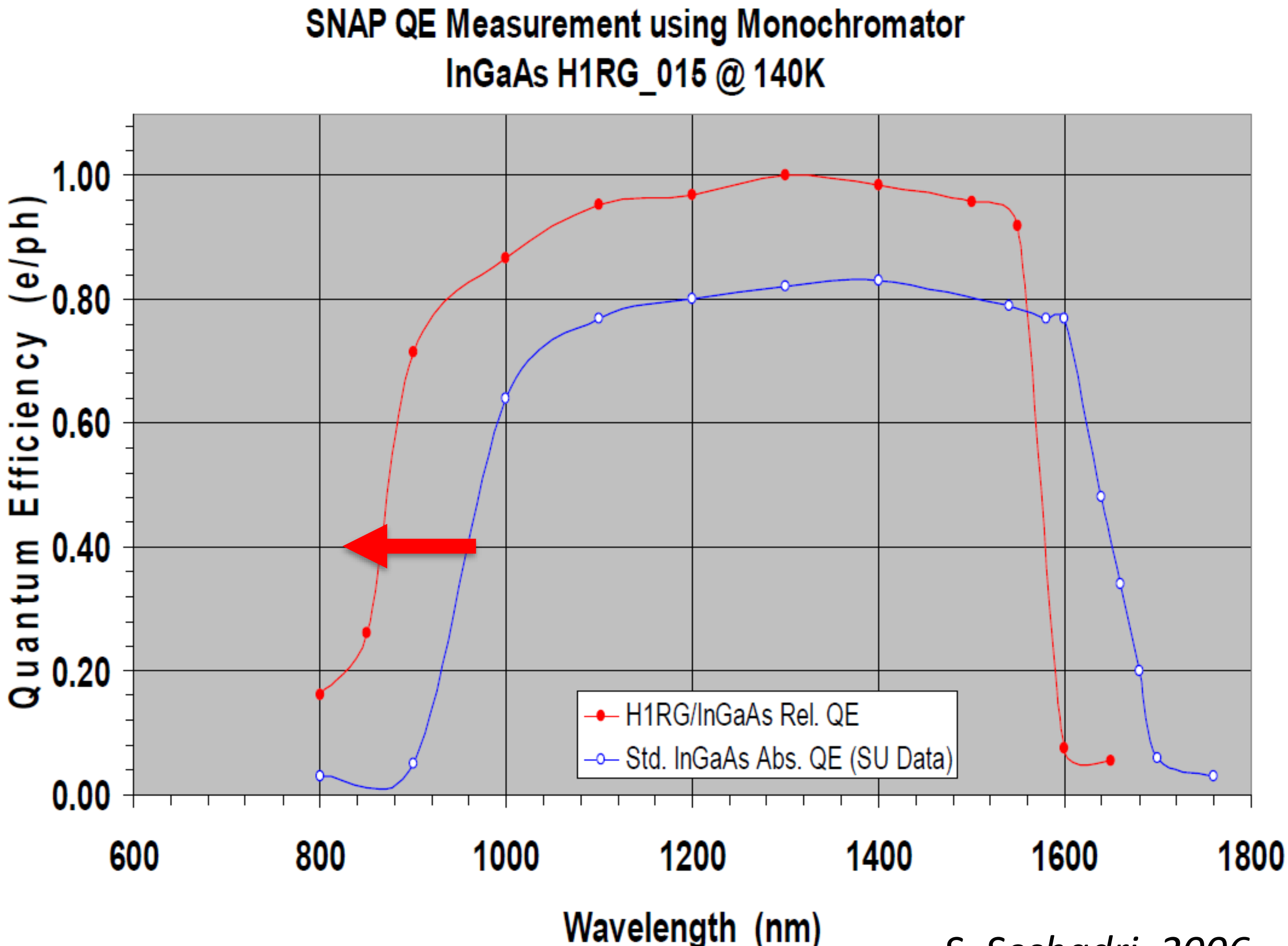
	t_{sat} [s]	SNR ($t_{sat}/2$)
λ_f = **1.3 μm**	960	192
λ_f = **1.3 μm, no lens**	800	160
λ_f = **1.7 μm**	500	100
λ_f = **1.7 μm, no lens**	210	40
No filter	0.1	0.02





InGaAs quantum efficiency

Short wavelength cut-off shift due to cooling



S. Seshadri, 2006

Expected shorter cut-off @80K = 880 nm

Next steps

1. Test cryogenic setup at AIUC, validate Background Emission analysis and characterize filter.
2. Acquire scientific detector, test with control electronics and software.
3. Define AO requirements and design solution.
4. Define derrotator solution.
5. Design fiber injection optics.
6. Adjust mechanical interface design to constraints at TAO’s 6.5m telescope focus and components needed.
7. Design instrument temperature, and specially pressure stability system.

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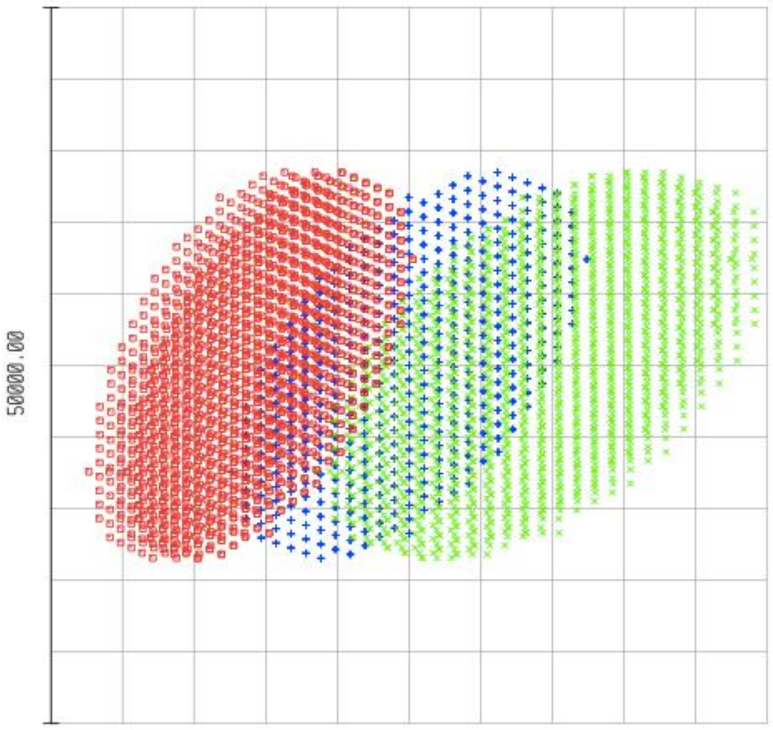
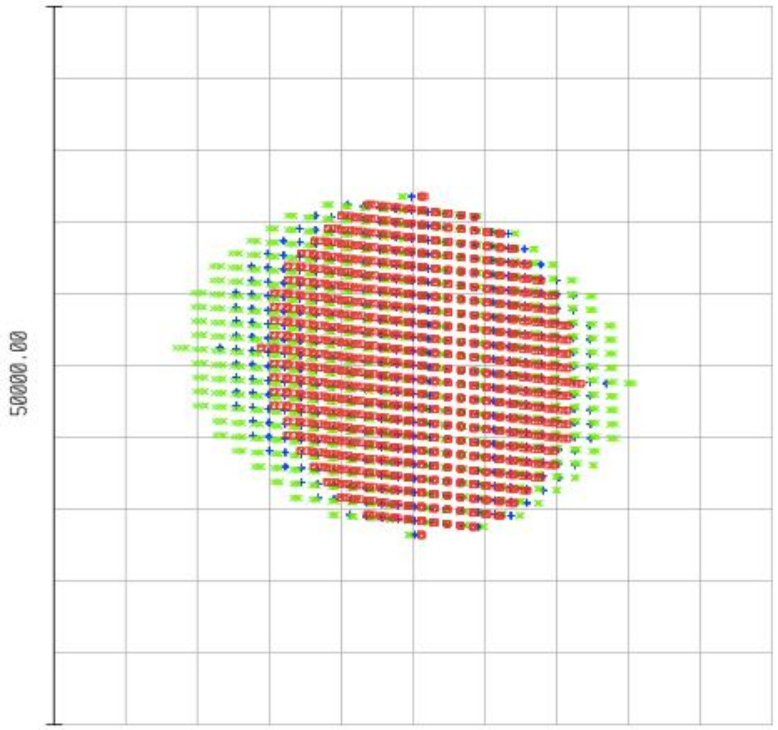
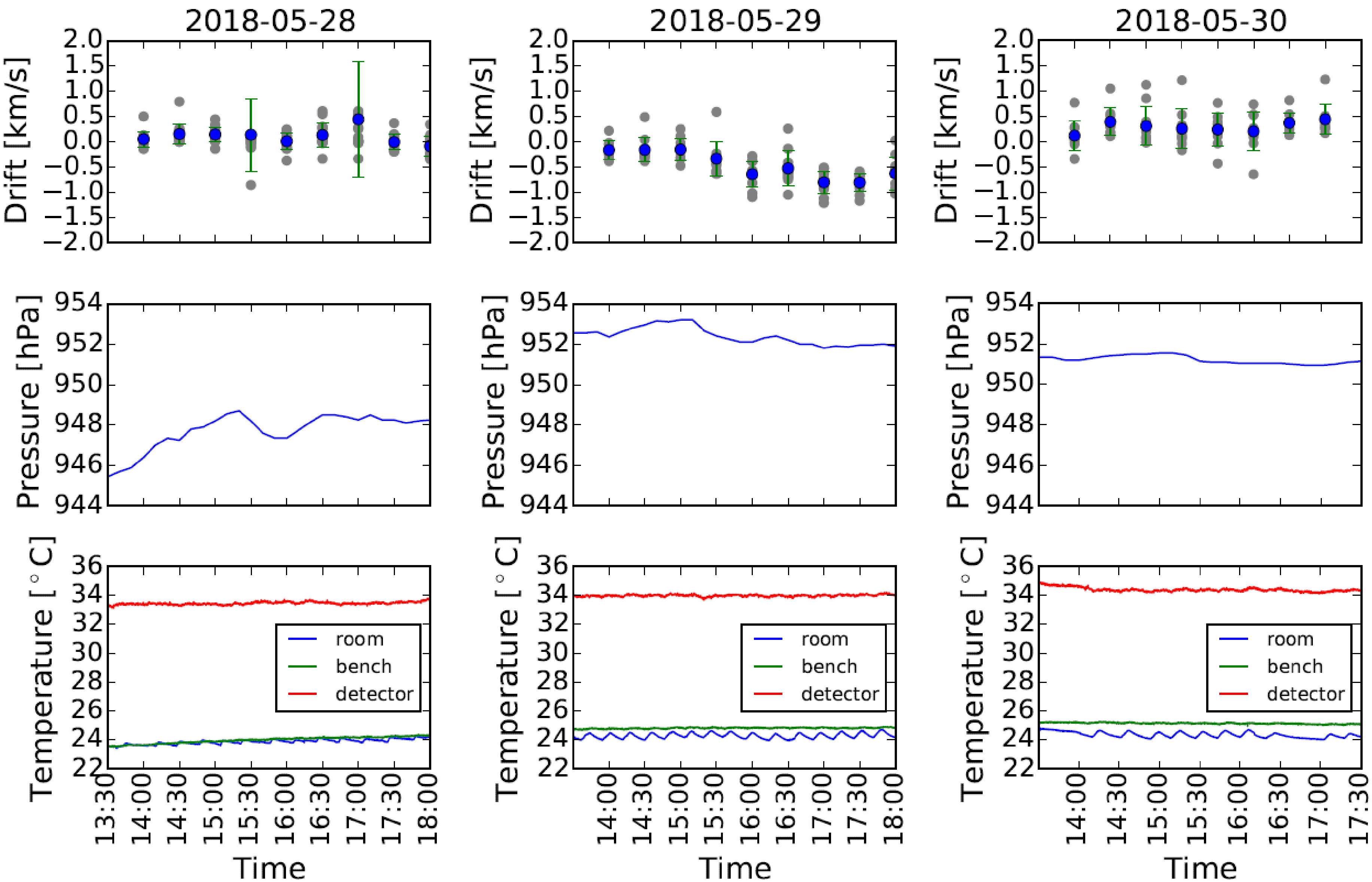
Extra slides

Beam spot diagram at the white pupil





ThAr lamp drift due to temperature and pressure variations



Rukdee et al. 2018 submitted

Background Emission

Thermal flux in photons is calculated as:

$$F_{ph,therm} = F_{ph,therm}^{direct} + F_{ph,therm}^{indirect}$$

$$F_{ph,therm} = a(\tau_{cam}\Omega_{fov} + \epsilon\,\Omega_{indirect}) \cdot \left(\int_{\lambda_{min}}^{\lambda_{filter}} B_{ph,\lambda} \mathrm{d}\lambda + \eta \int_{\lambda_{filter}}^{\lambda_{max}} B_{ph,\lambda} \mathrm{d}\lambda \right)$$

$$\Omega_{indirect} = \Omega_{cut-off} - \Omega_{fov}$$

a : Pixel size

Ω_{fov} : Detector field of view as solid angle

$\Omega_{cut-off}$: Stray light angle of acceptance (greater than fov)

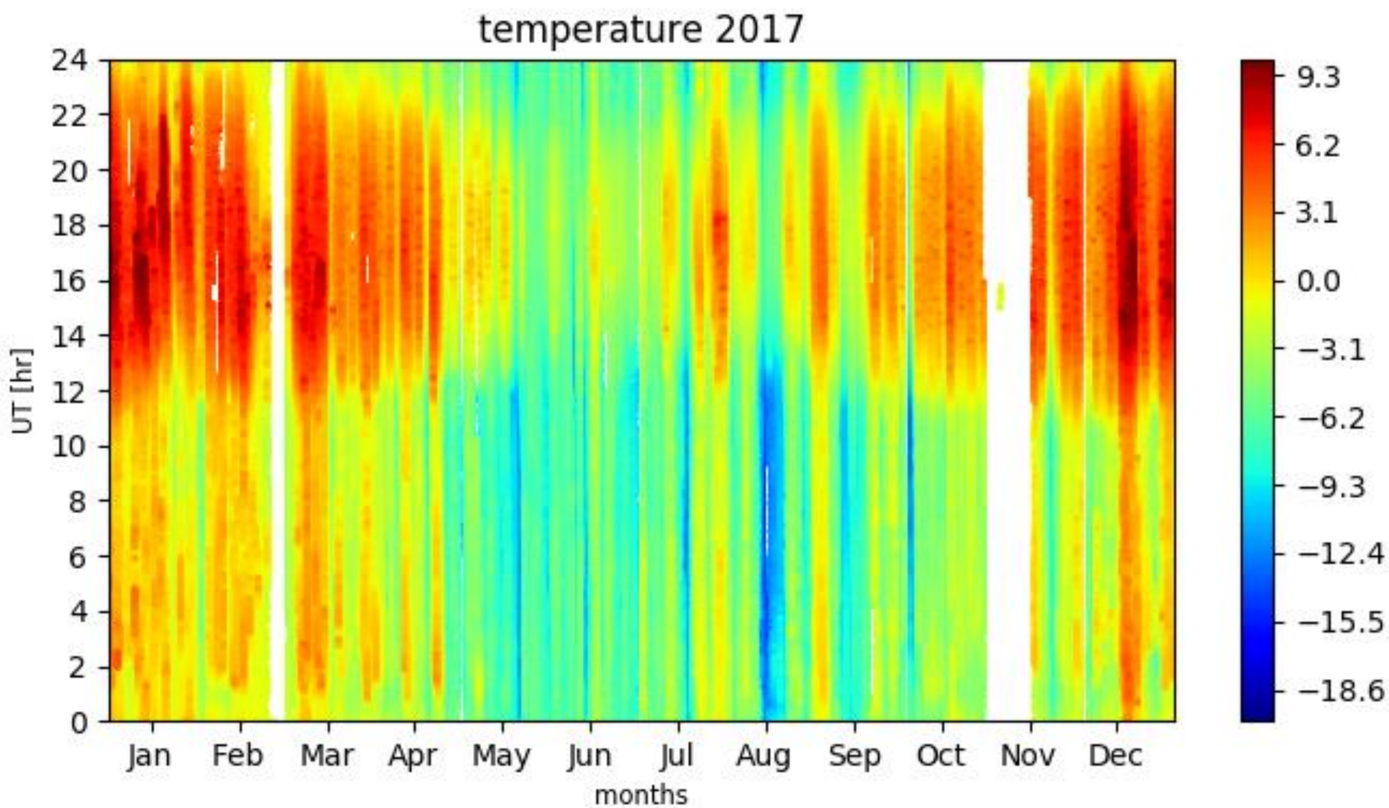
ϵ : Stray light path efficiency

τ_{cam} : Objective efficiency

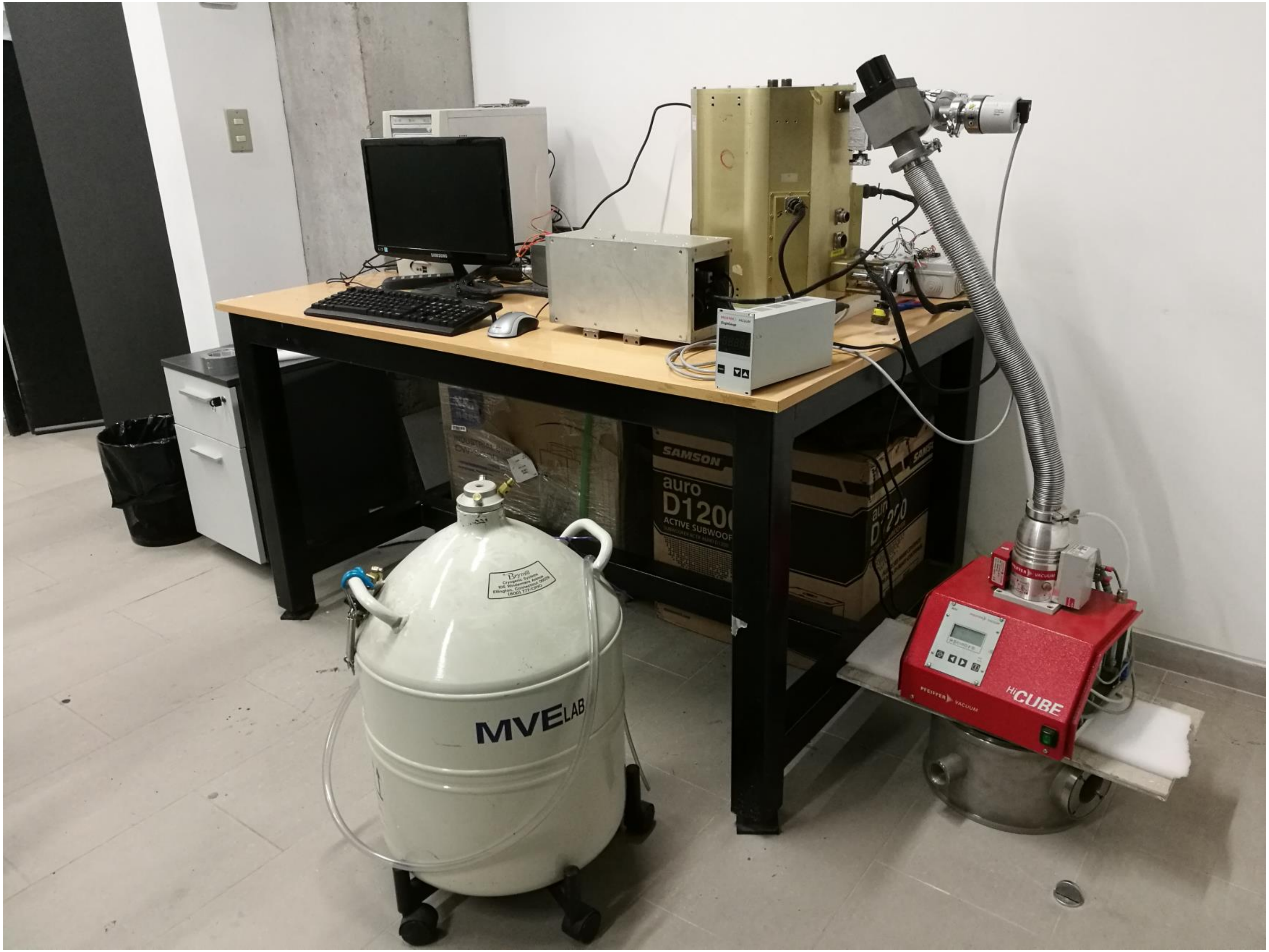
η : Filter rejection band efficiency

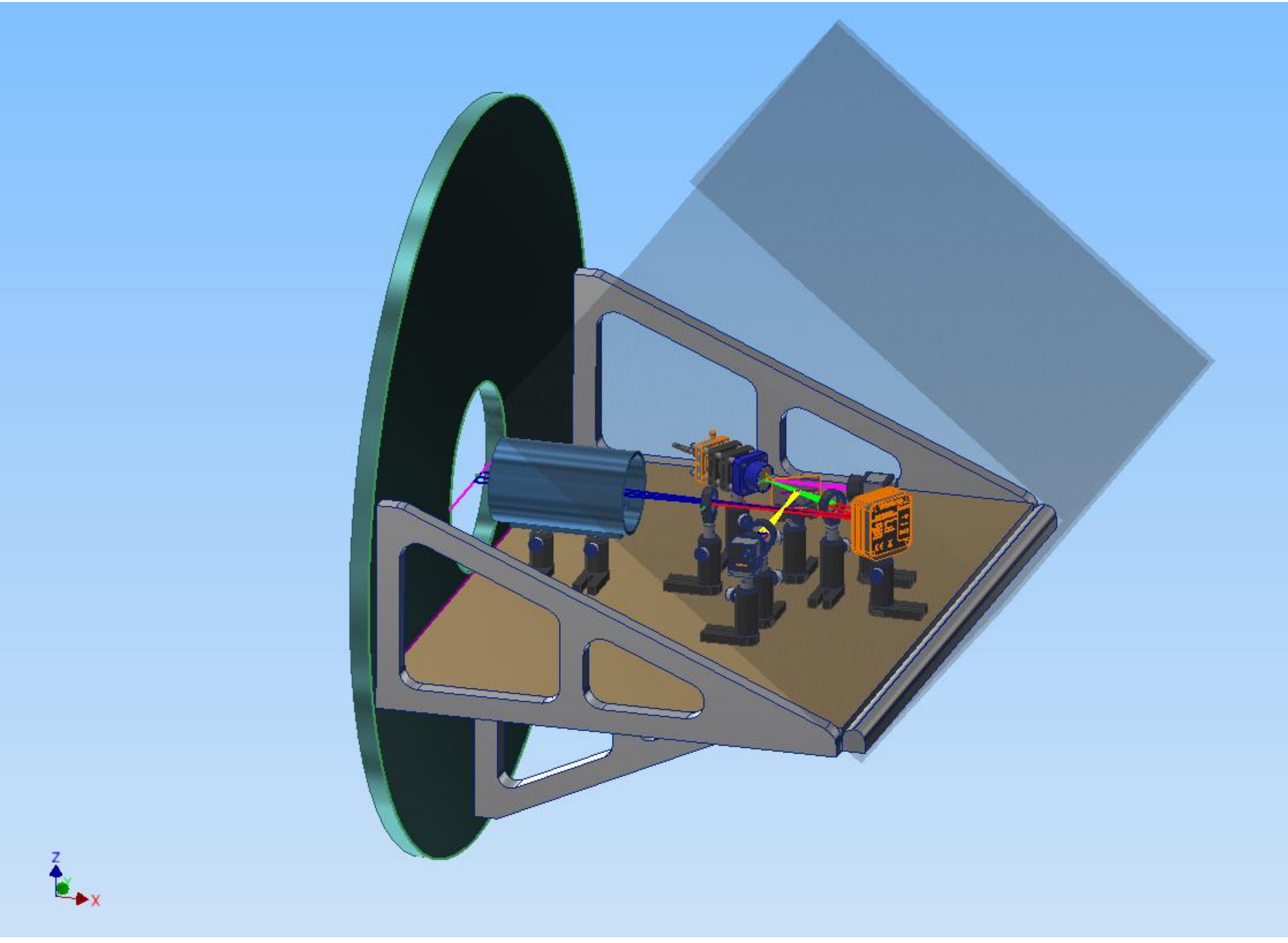
Background Emission

Expected temperatures (°C) at TAO (APEX Weather Monitor)



Laboratory detector setup




Z
Y
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