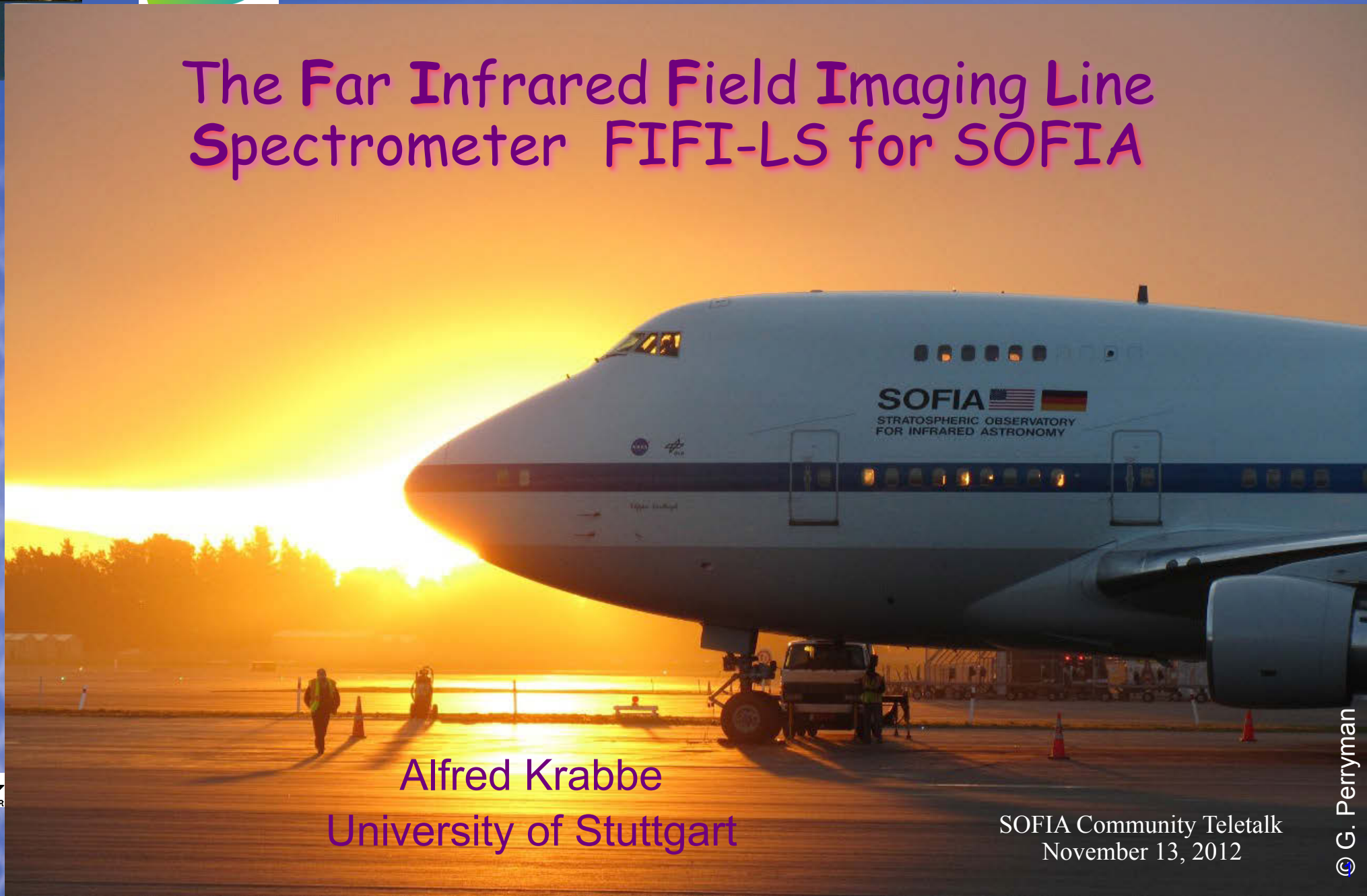
The Far Infrared Field Imaging Line Spectrometer FIFI-LS for SOFIA



Alfred Krabbe
University of Stuttgart

SOFIA Community Teletalk
November 13, 2012

Many Thanks to the FIFI-LS Team

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Thomas Henning	MPIA	Astronomy	CoI
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Walfried Raab	MPE	Mechanics & Design Engineer	
Felix Rebell	IRS	Cryomechanics & Test	PhD
Maureen Savage	USRA	Airworhiness, Documentation	

Topics

- A bit of history …
- Renewed Science & Motivation
- Hardware
  - Imaging Spectroscopy
  - Optics Concept
  - Detector Module
  - Cyro Concept
  - Instrument Control
- Performance
  - FIFI-LS versus PACS
  - Test Results
- Looking ahead …

A bit of History ...

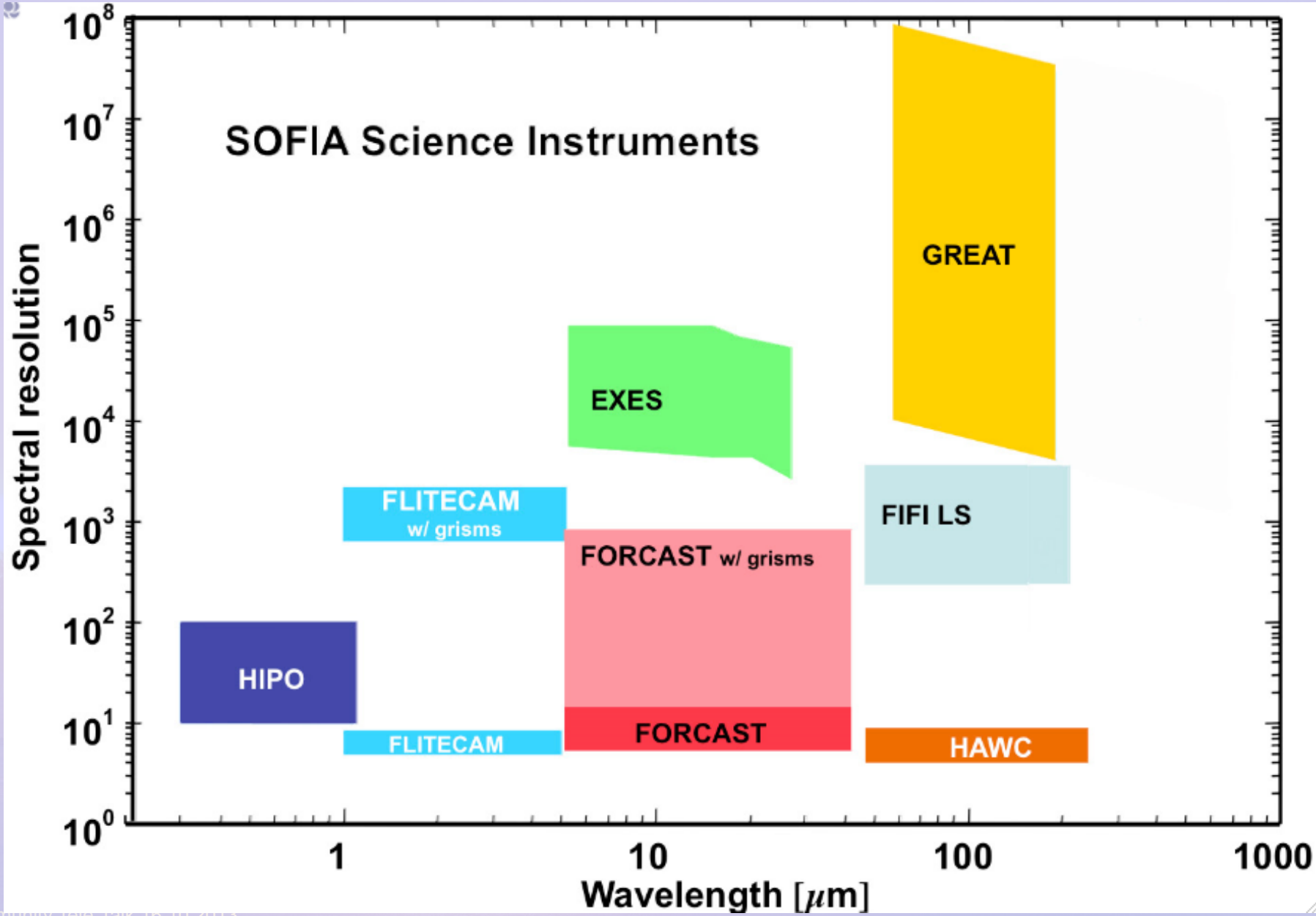
1997	FIFI LS Project Launch at MPE, Garching as PI instrument for SOFIA
2007	Extended Observing Opportunity Program (EOOP) in effect
2009	FIFI LS 80% completed
2010	FIFI LS passed a dedicated NASA Science Review.
	NASA acknowledged to accept FIFI LS as Facility Science Instrument for SOFIA
	IRS (in consultation with USRA) decided to continue FIFI LS as PI instrument
2011	FIFI LS moved to IRS lab in Stuttgart
	FIFI LS successfully passed a dedicated DLR Science Review
2012	DLR Space Agency & University of Stuttgart granted financial support for finishing FIFI LS
	IRS officially took over FIFI LS
	PI-ship transferred from A. Poglitsch to A. Krabbe
	FIFI LS is renamed FIFI-LS
2013	FIFI-LS passed Pre Shipment Review in October

Unique features of FIFI-LS in the post-Herschel Era

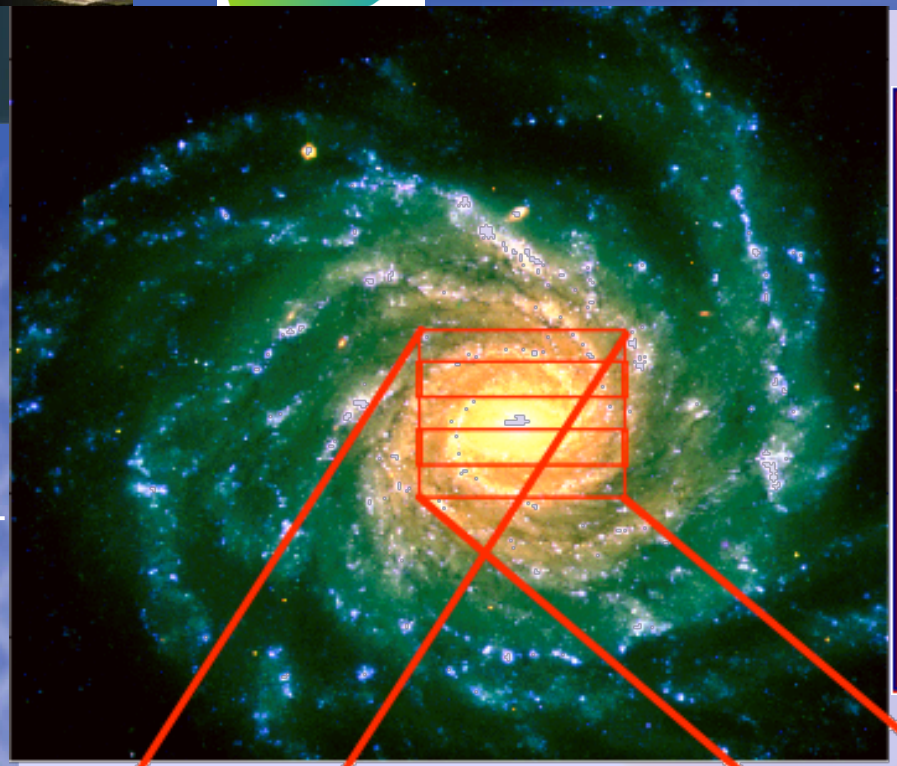
- FIFI-LS enables **reaction to major science discoveries** of Herschel, Planck and WISE, which are presently largely unknown, and none of these satellites is around for follow-up.
- FIFI-LS will be **the galactic and extragalactic spectroscopic workhorse** with SOFIA. FIFI-LS has enough sensitivity to observe a substantial sample of nearby galaxies.
- FIFI-LS has the right combination of wavelength range and spatial resolution to **carry out unique new observations** beyond those possible with Herschel, Spitzer, ISO, and IRAS.
- On extended targets the effective sensitivity of FIFI-LS is only about a factor of 3-5 lower than the PACS spectrometer, mainly due to a **much improved observing efficiency**.
- FIFI-LS will be an important instrument for **transient sources** like novae, supernovae, variable bright AGN and X-ray sources in particular if they are extended (e.g., comets).

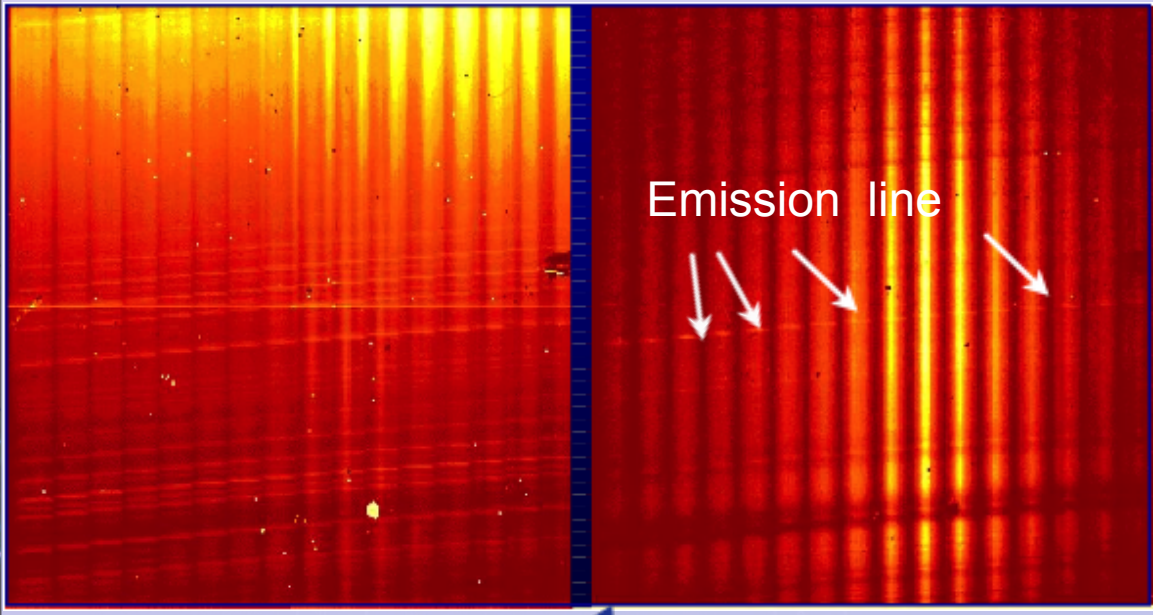
DLR Review 2011

… In conclusion, being convinced of the quality and scientific potential of the FIFI-LS project, the Review Board considers it fully justified and strongly recommends that the DLR continues its support of the FIFI-LS related activities at least at the previous level. …. It is a unique opportunity! …


SOFIA Science Instruments
Spectral resolution
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1
10
100
1000
Wavelength [μm]
GREAT
EXES
FLITECAM
w/ grisms
FIFI LS
FORCAST w/ grisms
HIPO
FLITECAM
FORCAST
HAWC

Field Imaging Spectroscopy



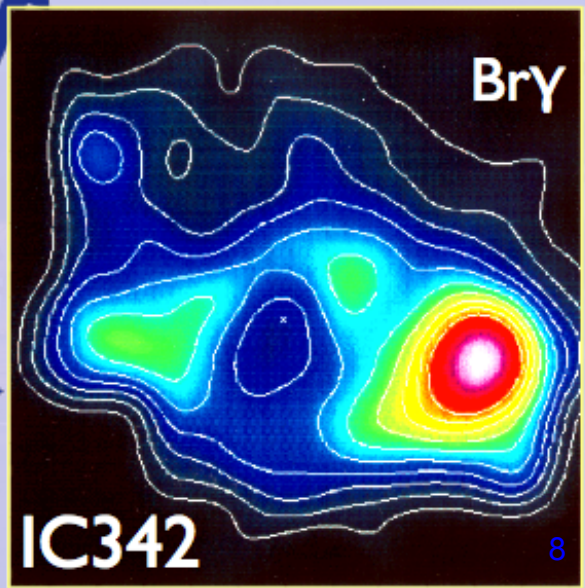


Raw data

Background subtracted

Pseudoslit

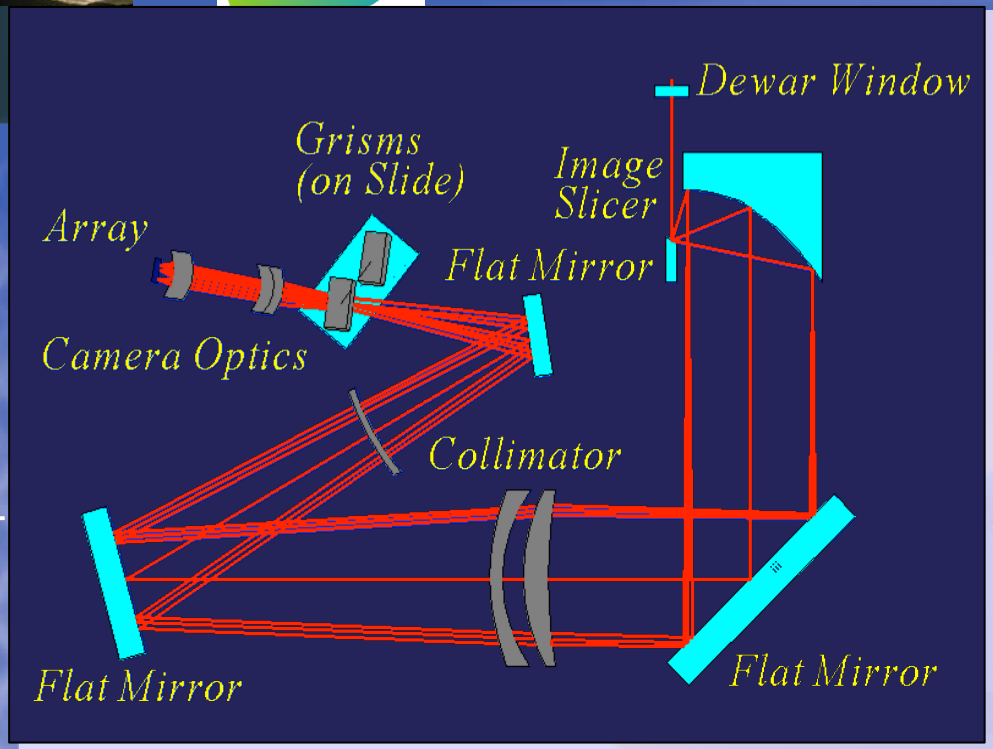
Result

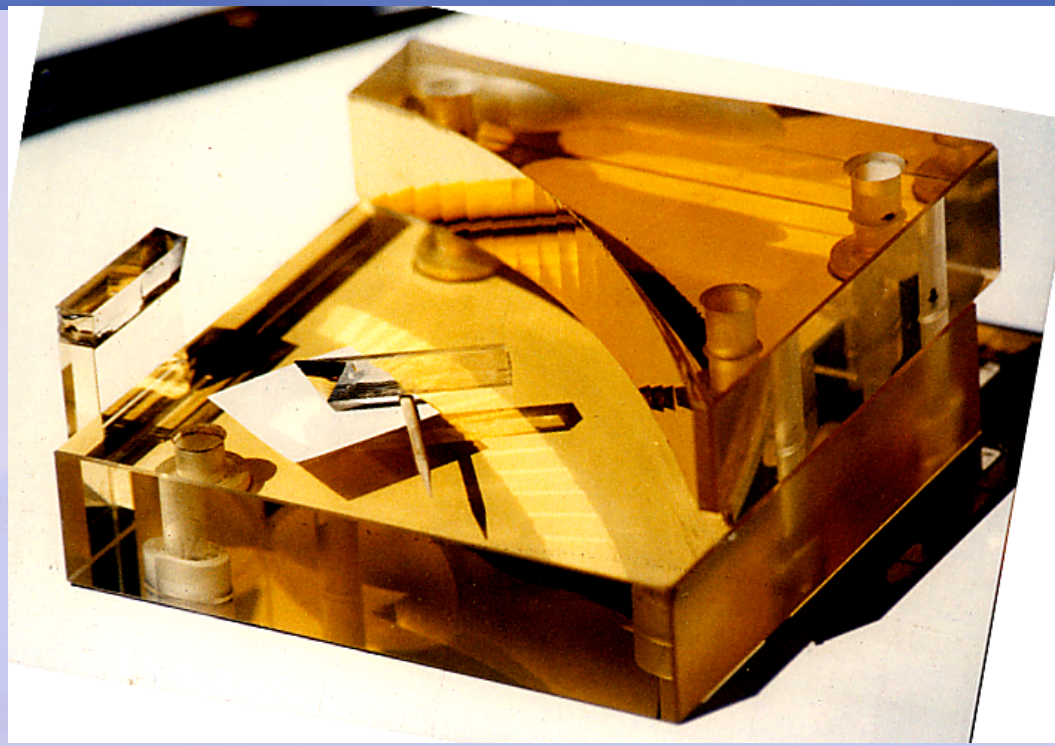


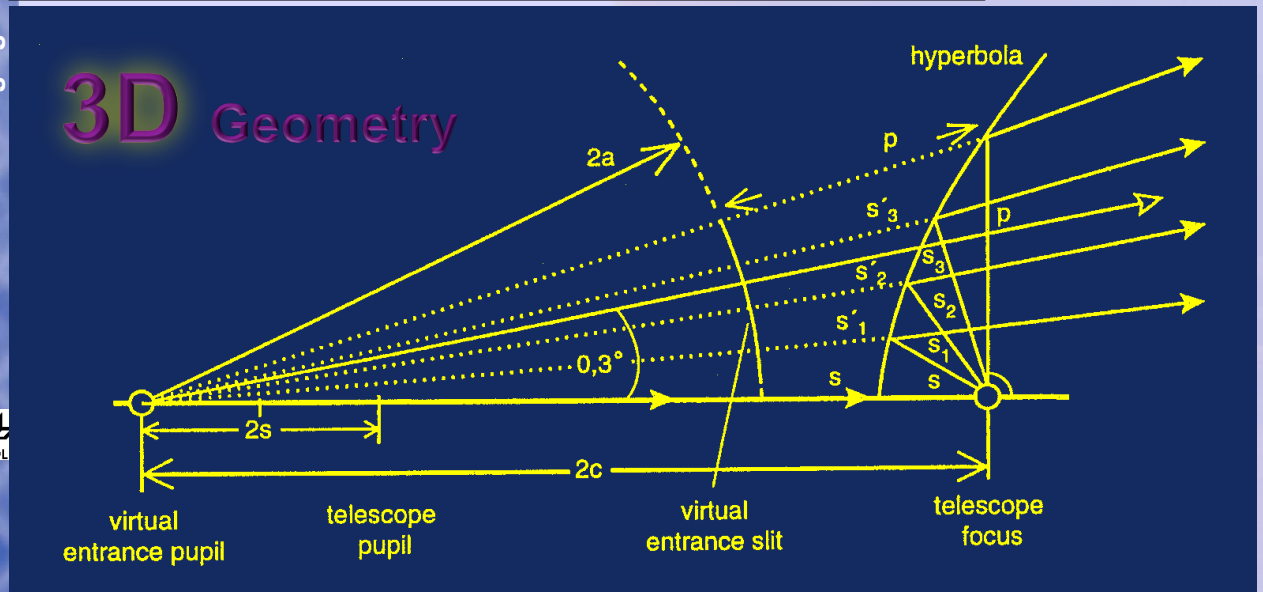
Böker, Krabbe et al. 97

Krabbe et al. 91, 95; Weitzel, Krabbe et al. 96

Field Imaging Far Infrared Line Spectrometer





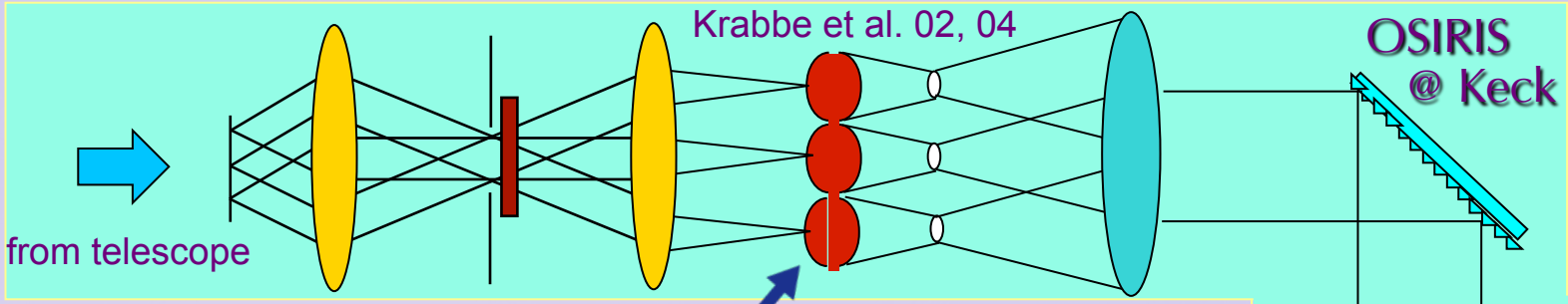


The first astronomical infrared image slicer

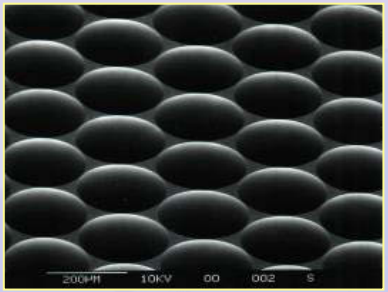
3D instrument

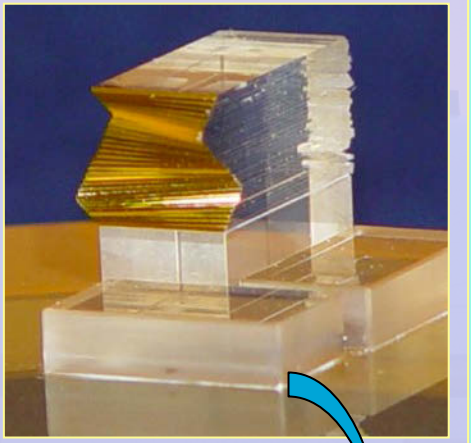
Krabbe et al. 91 & 95
Weitzel, Krabbe et al. 96

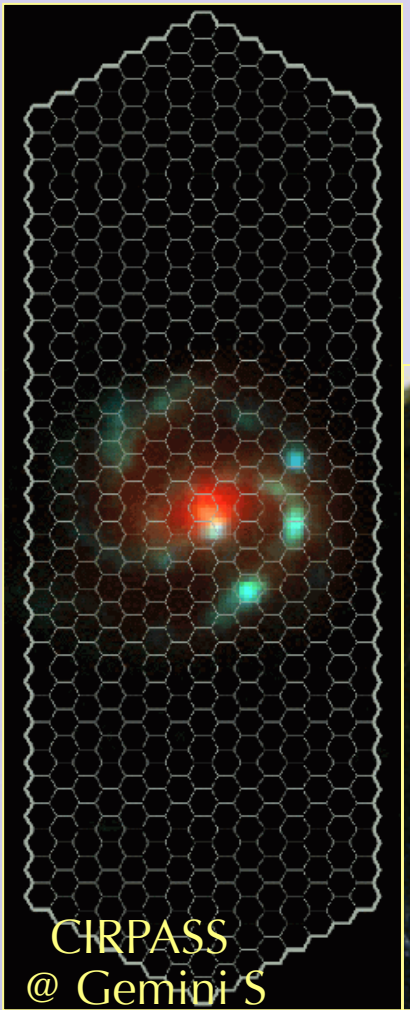
Imaging Spectroscopy

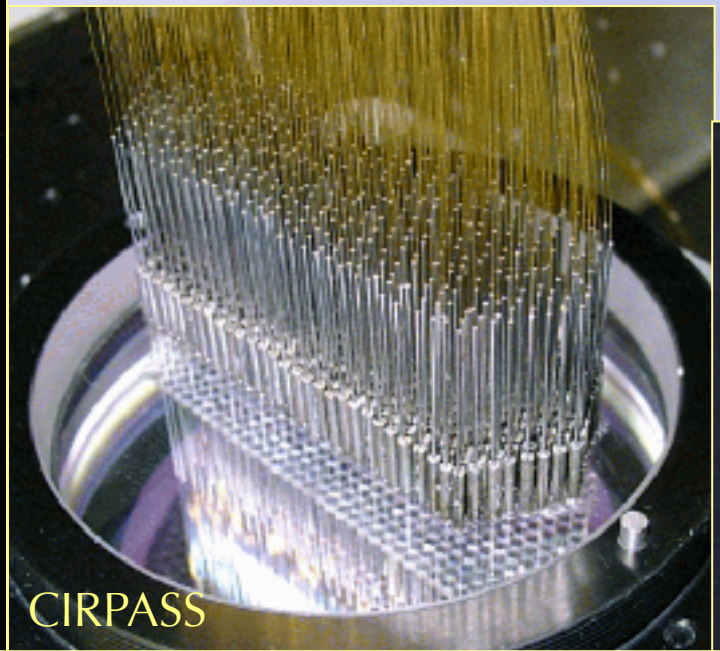


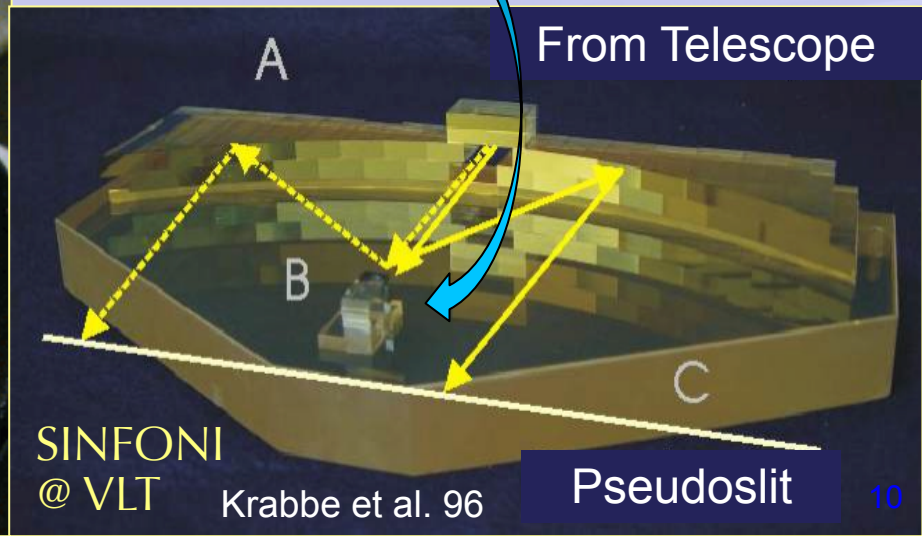
Reimaging
- Fiber bundle
- Microlens array
- Mirror array











Imaging Spectroscopy in the IR : Advantages & Risks

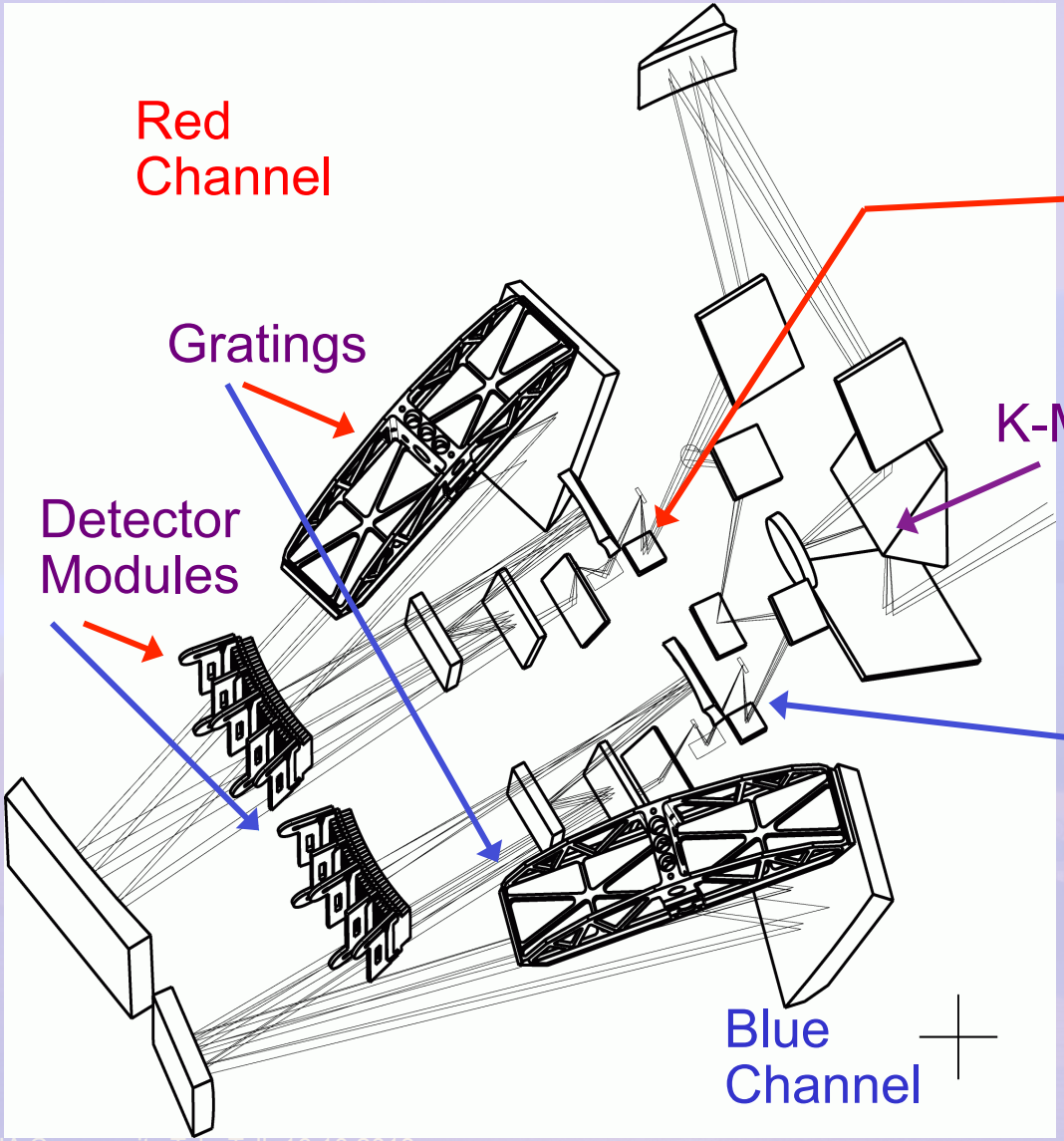
- Full spectral and spatial multiplexing.
- High detector data filling factor.
- Low systematic noise from changing observing conditions:
  E.g., seeing, airmass, telescope tracking.
- Spatial & spectral pixel correlation conserved at all scales.
- Less moving components, lower failure rate.
- Camera modus.
- Peeking up of weak targets and/or line emission targets is much easier compared with a single slit instrument.
- ➡ Observing efficiency increased by a factor of >10 compared with a classical long slit spectrometer

- Bad detector pixel require special attention
- Optical & electronic cross talk may degrade performance
- S/W Effort in data reduction is usually underestimated

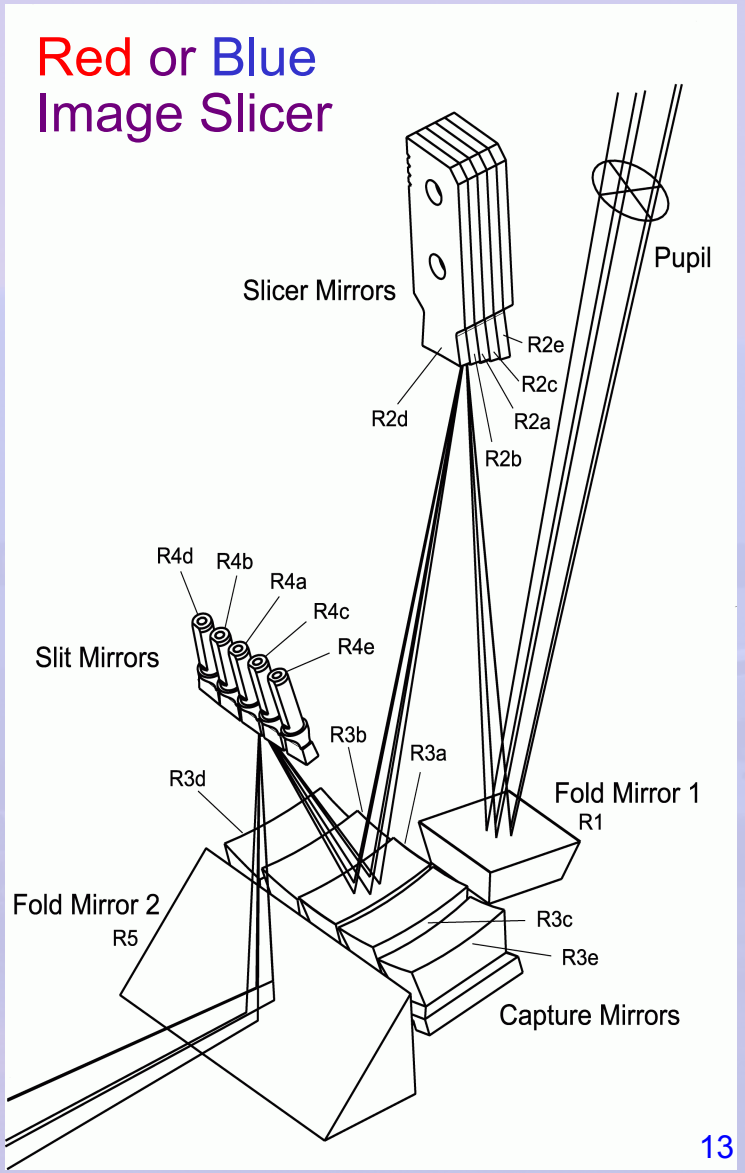
Top level design features of FIFI-LS

- Two Light Paths: For 45 - 110 µm and for 110 - 205 µm simultaneous observations in two bands.
- Simultaneous Spatial Imaging: 30" x 30" and 60" x 60" FOV, for each light path respectively.
- Each field of view resolved with 5 x 5 pixels.
- Good Spectral Resolution: R ~1000-2000 in each band (velocity resolution of 150-300 km/s).
- 16 pixels of spectral resolution: Required to resolve spectral features in, e.g., galaxies.
- Instantaneous Spectral Coverage: of 1500 km/s covers, e.g. the velocity distribution in entire galaxies and provide good baseline coverage on both sides of any spectral line in both bands.
- 3-D Imaging Capability: Simultaneous imaging in both spatial and the spectral domains for all 400 pixels in each band.
- 2 Ge:Ga Photoconductor Arrays: 25x16 pixels each, unstressed & stressed.
- Littrow-Mount Grating Spectrographs: One for each spectrometer, compact design, operating in 1st or 1st/2nd order (for the long and short wavelength bands respectively).

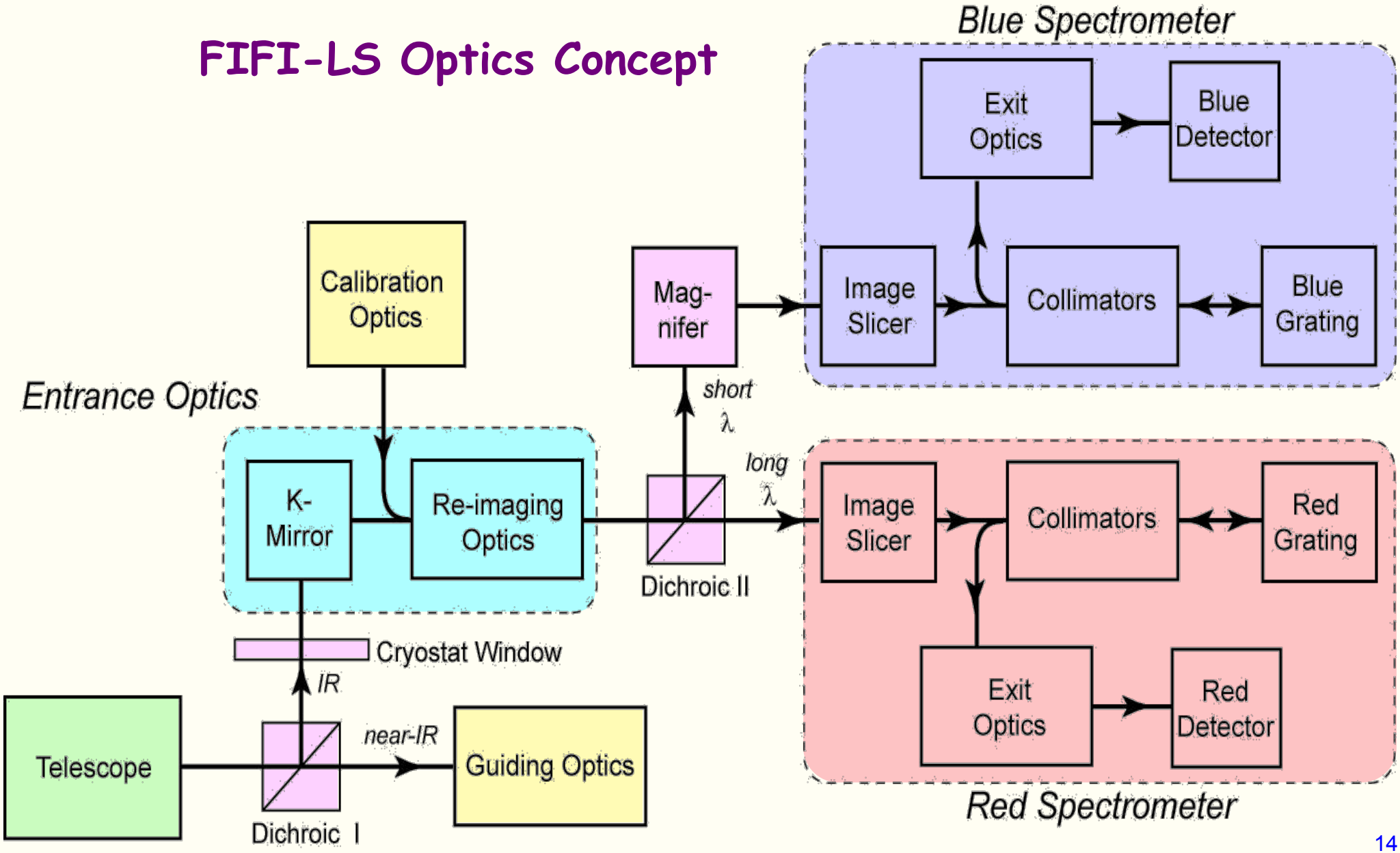
Optical Train



Reimaging Optics

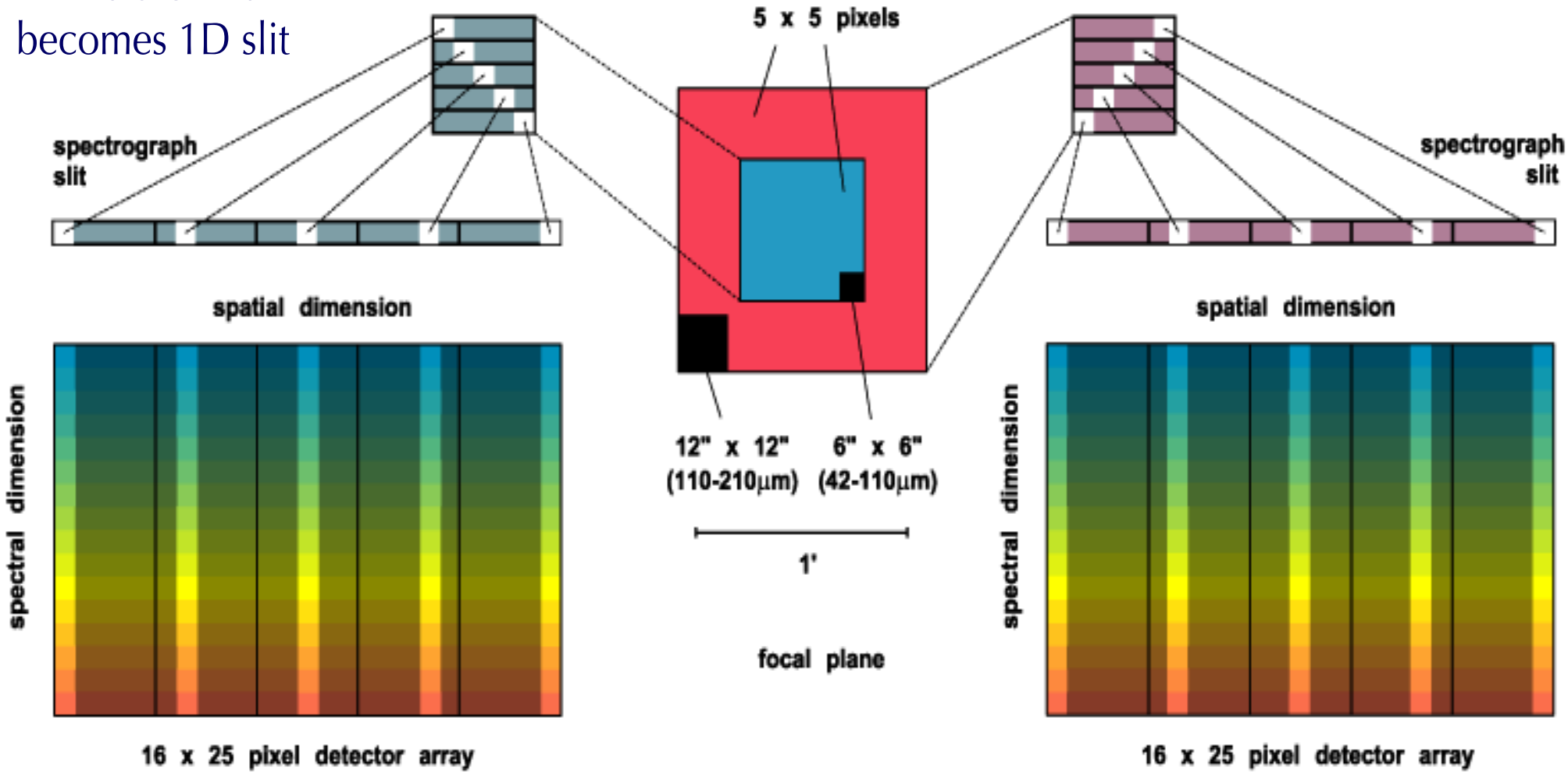


FIFI-LS Optics Concept

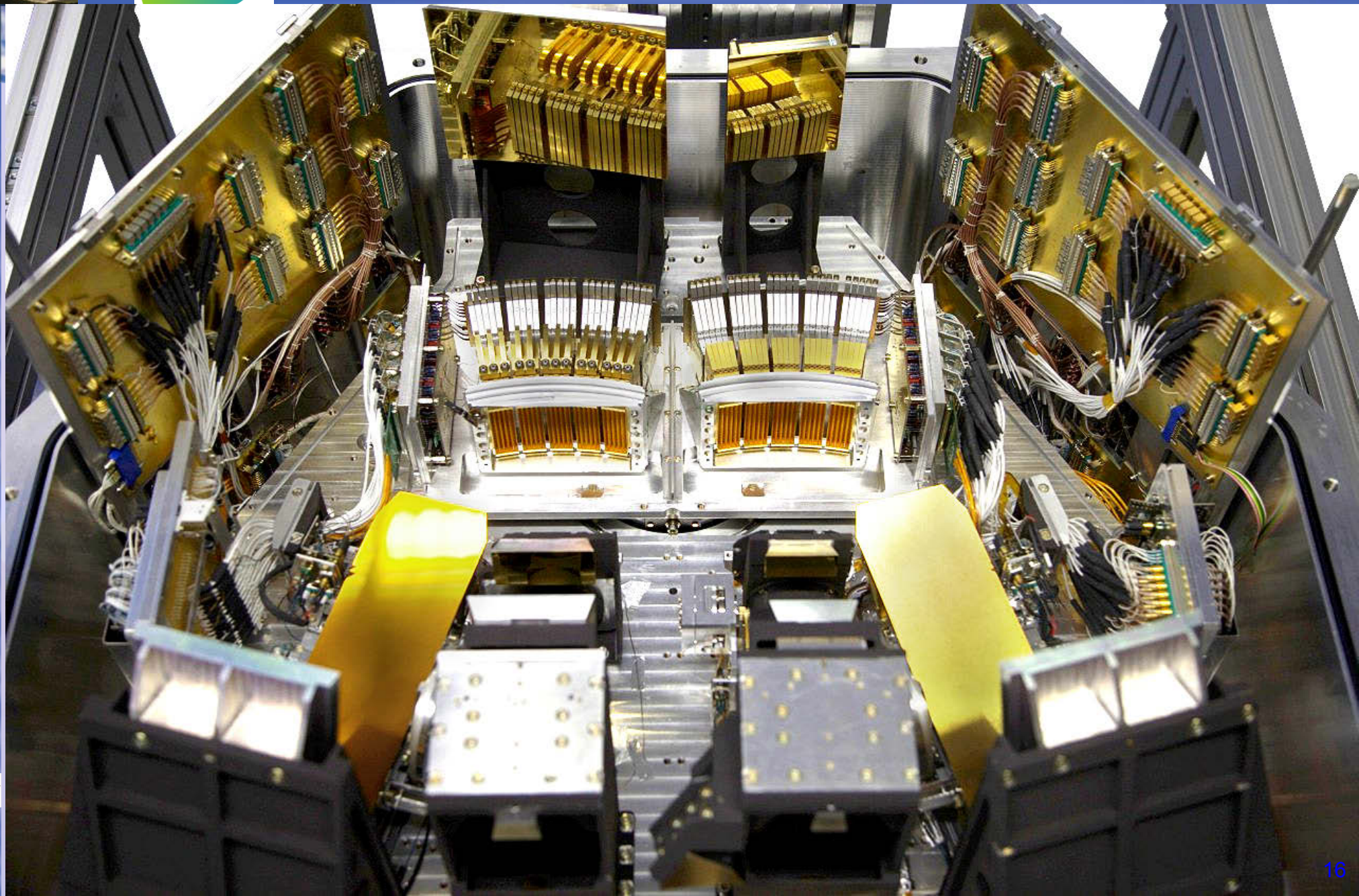


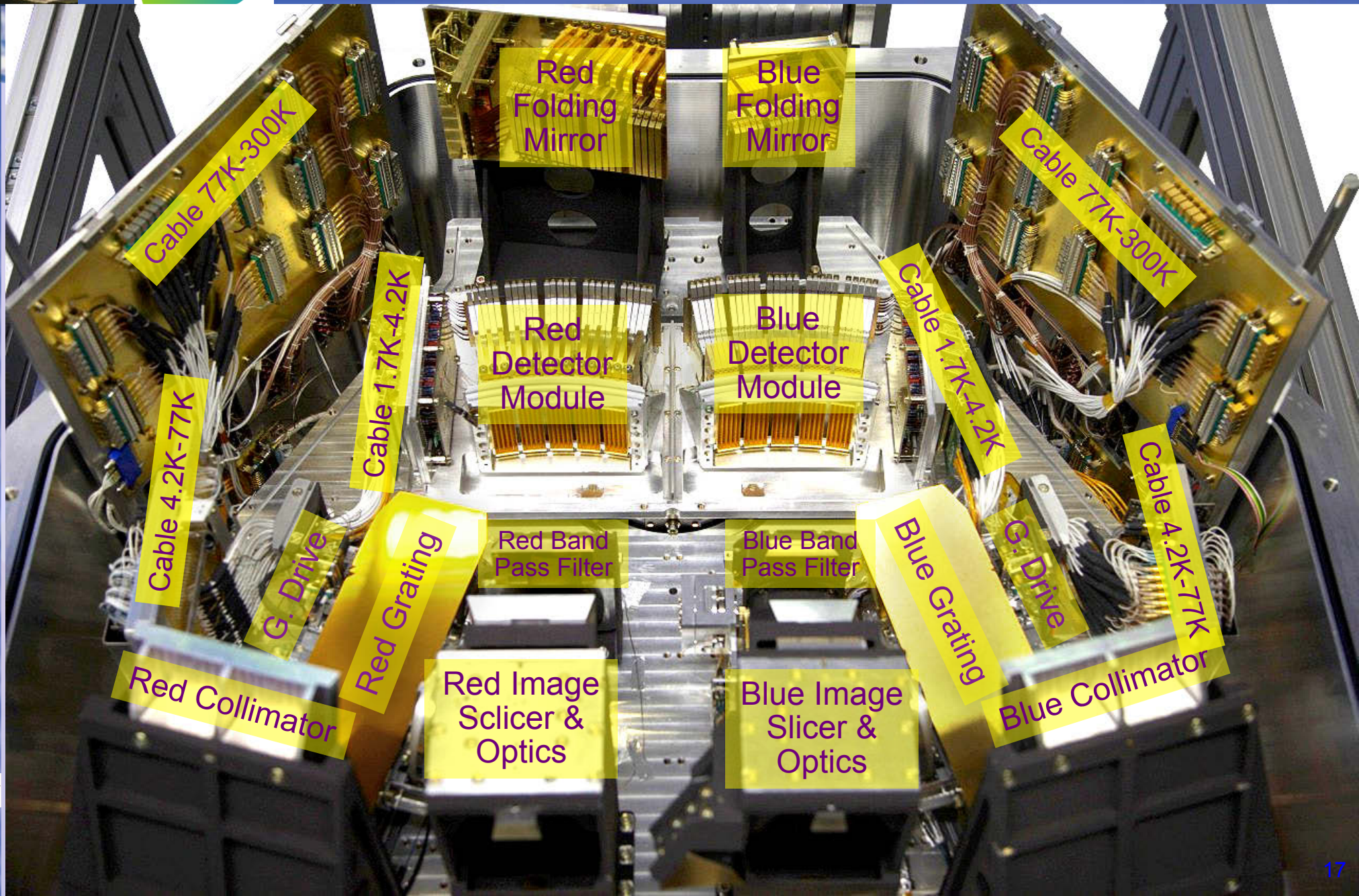
Footprint of Red and Blue channels overlap on sky

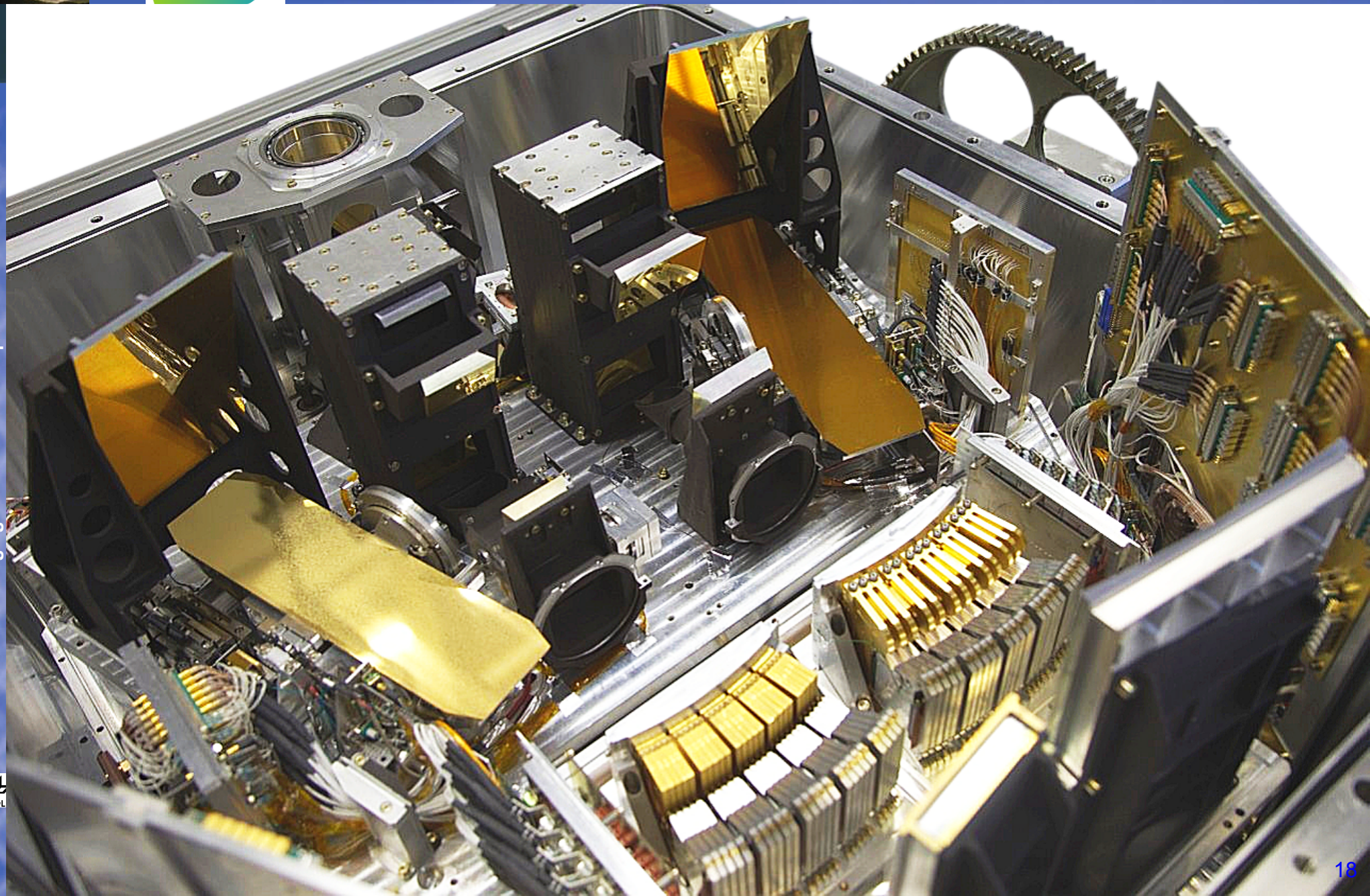
2D field of view becomes 1D slit

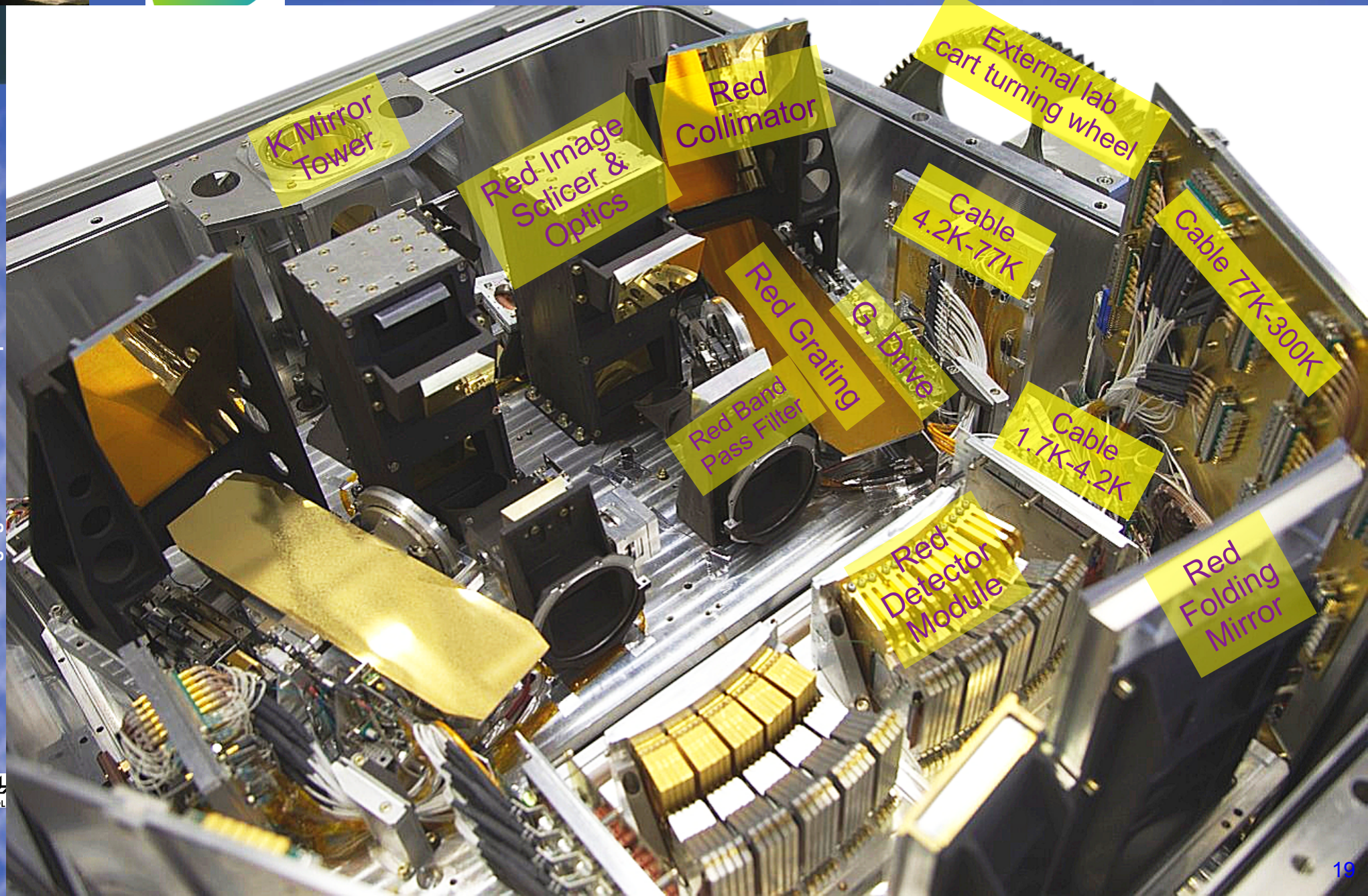


2D detector contains 3D data cube

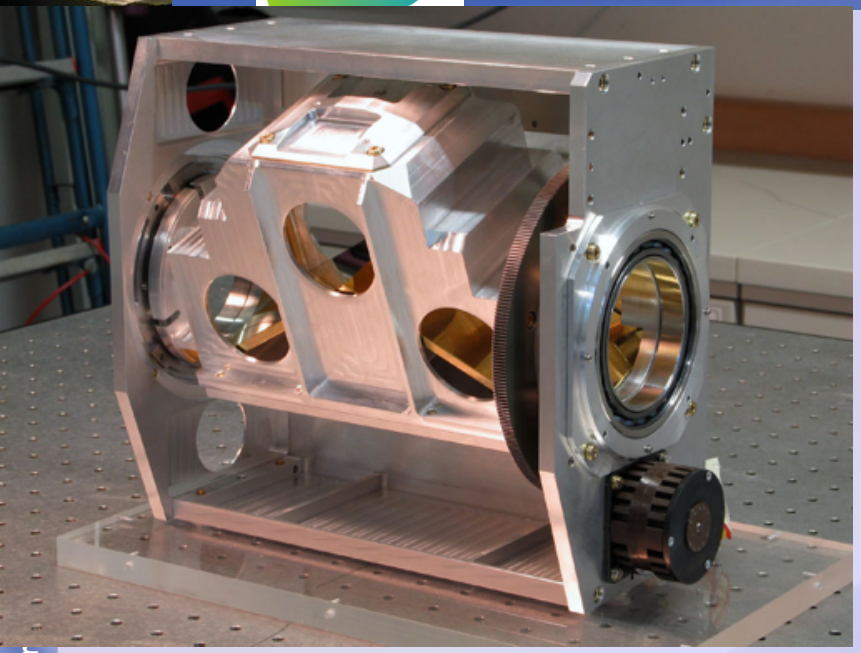


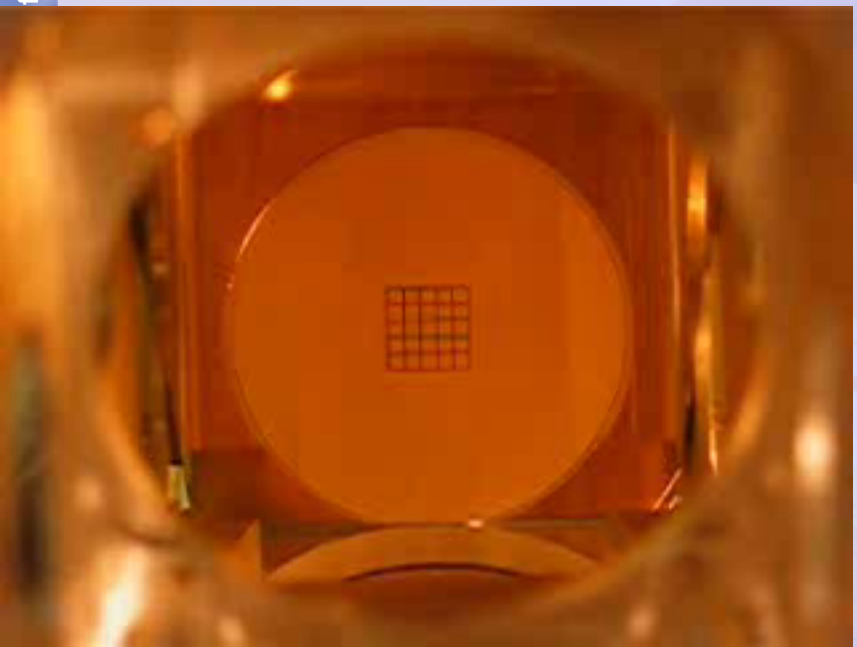

Red Folding Mirror
Blue Folding Mirror
Cable 77K-300K
Cable 77K-300K
Cable 1.7K-4.2K
Cable 1.7K-4.2K
Red Detector Module
Blue Detector Module
Cable 4.2K-77K
Cable 4.2K-77K
G. Drive
G. Drive
Red Grating
Blue Grating
Red Band Pass Filter
Blue Band Pass Filter
Red Collimator
Blue Collimator
Red Image Sclicer & Optics
Blue Image Slicer & Optics

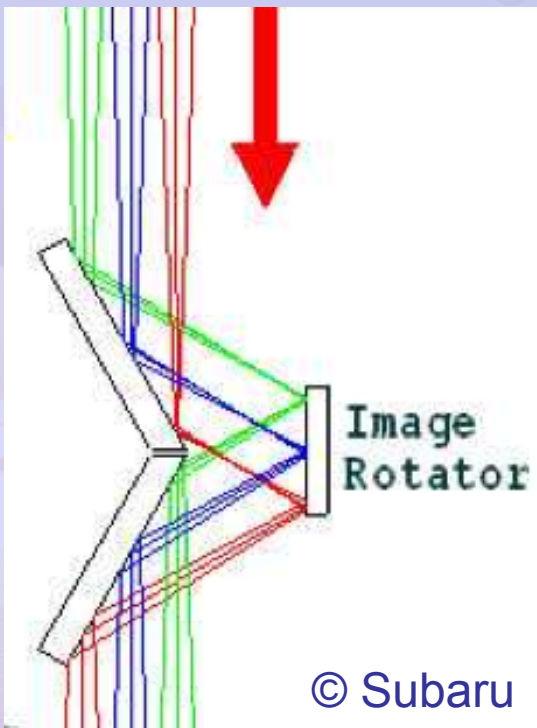



K Mirror Tower
Red Image Sclicer & Optics
Red Collimator
External lab cart turning wheel
Cable 4.2K-77K
Cable 77K-300K
Red Grating
G. Drive
Red Band Pass Filter
Cable 1.7K-4.2K
Red Detector Module
Red Folding Mirror

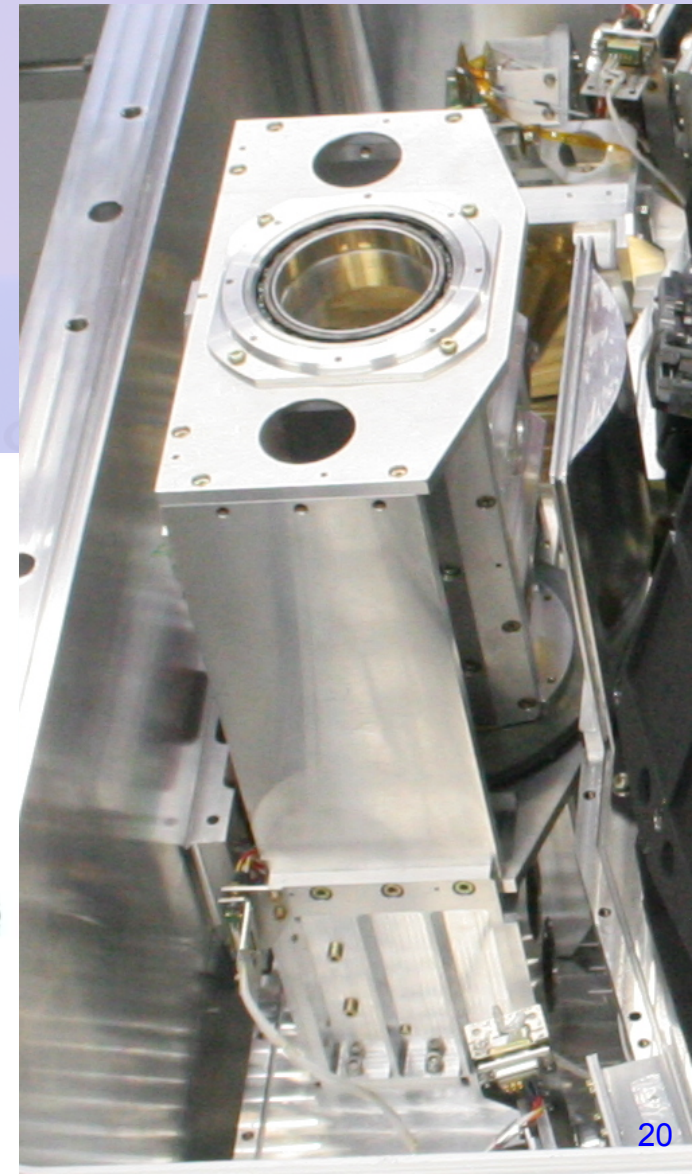
K-Mirror







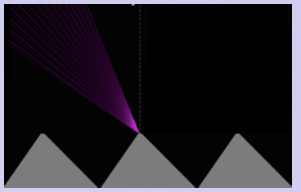
© Subaru

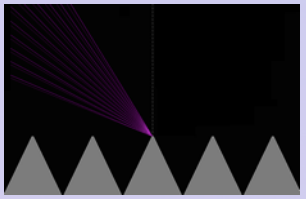


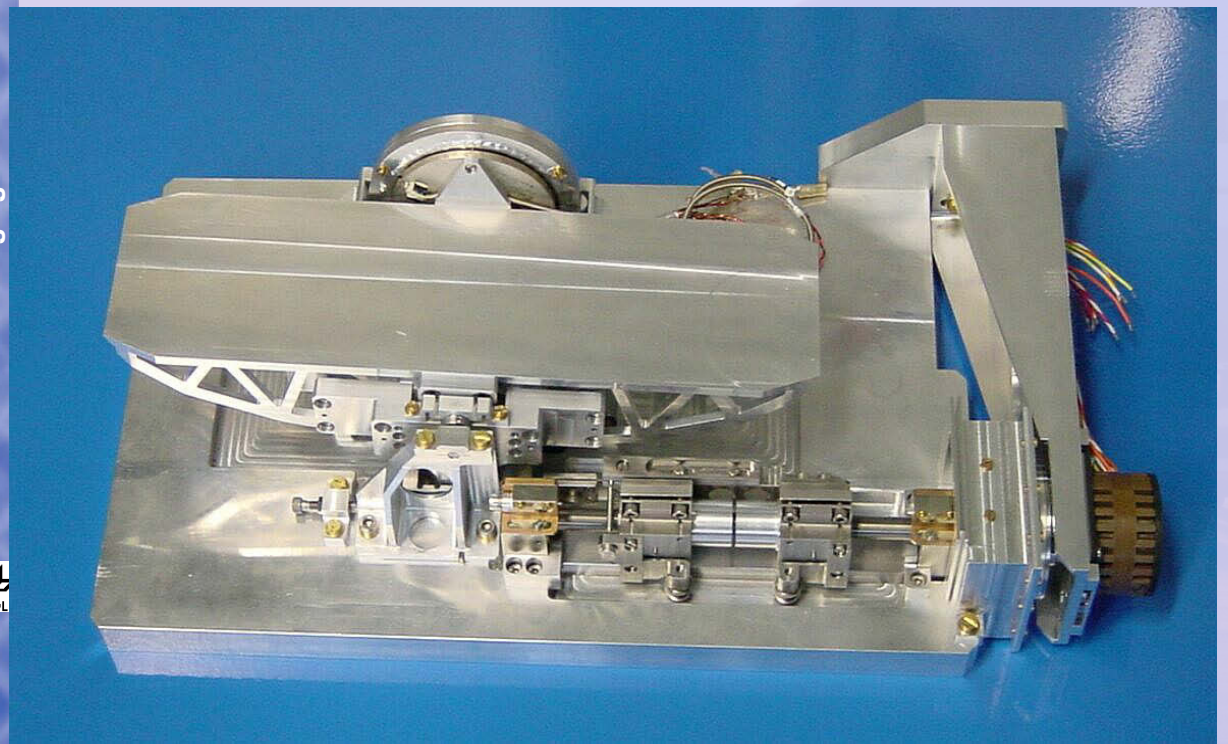
FIFI-LS Gratings

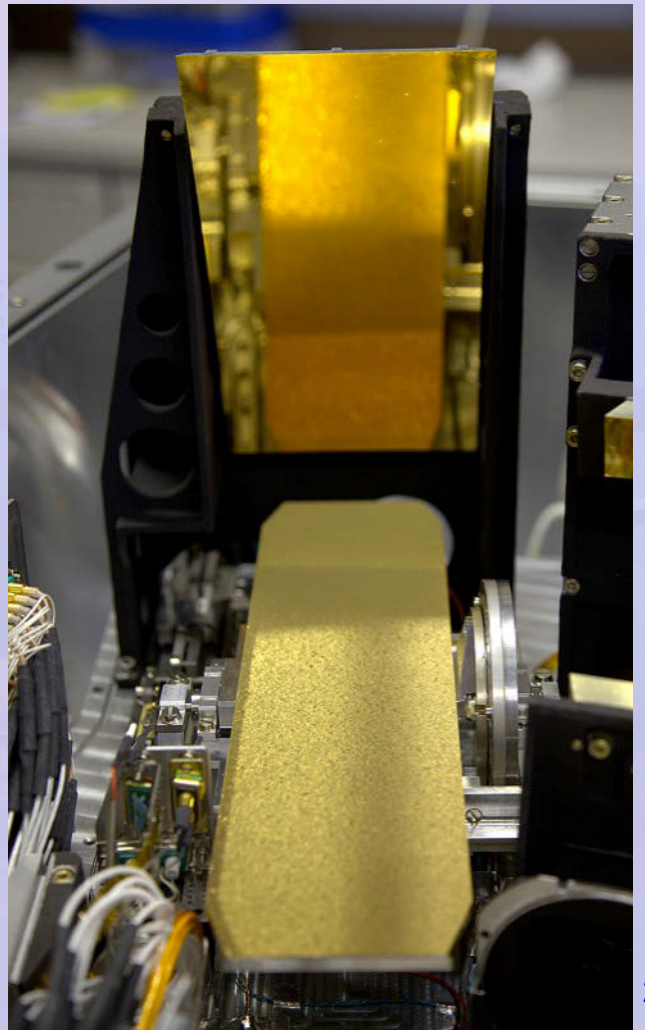
	Red grating	Blue grating
Grove profile	asymmetric	symmetric
Grove scale	8.5/mm	12/mm
# of grooves	~2720	~3840
Grating const.	117.65 µm	83.3 µm
Groove angle	44°	84°
Groove depth	140 µm	42.5 µm

Profiles



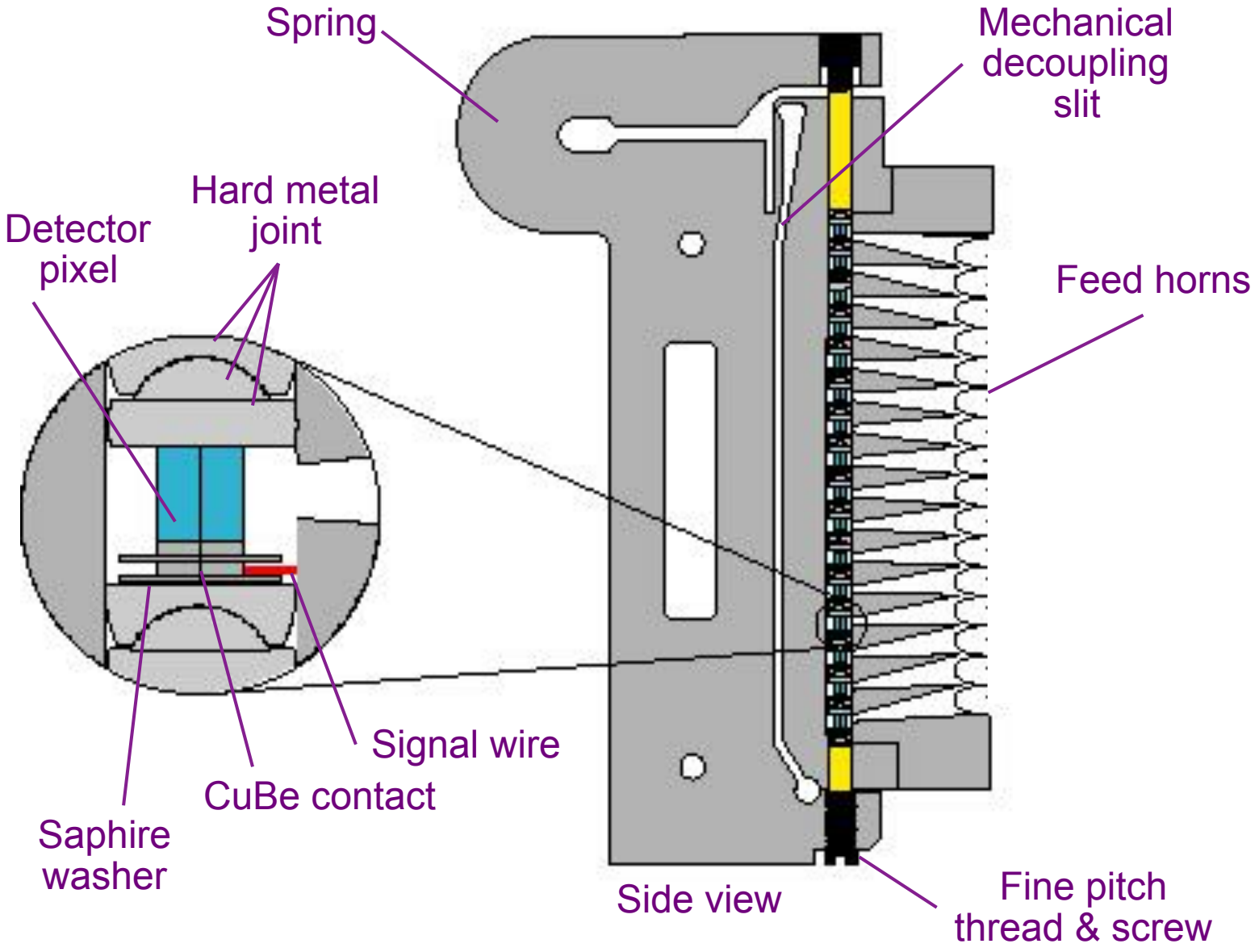


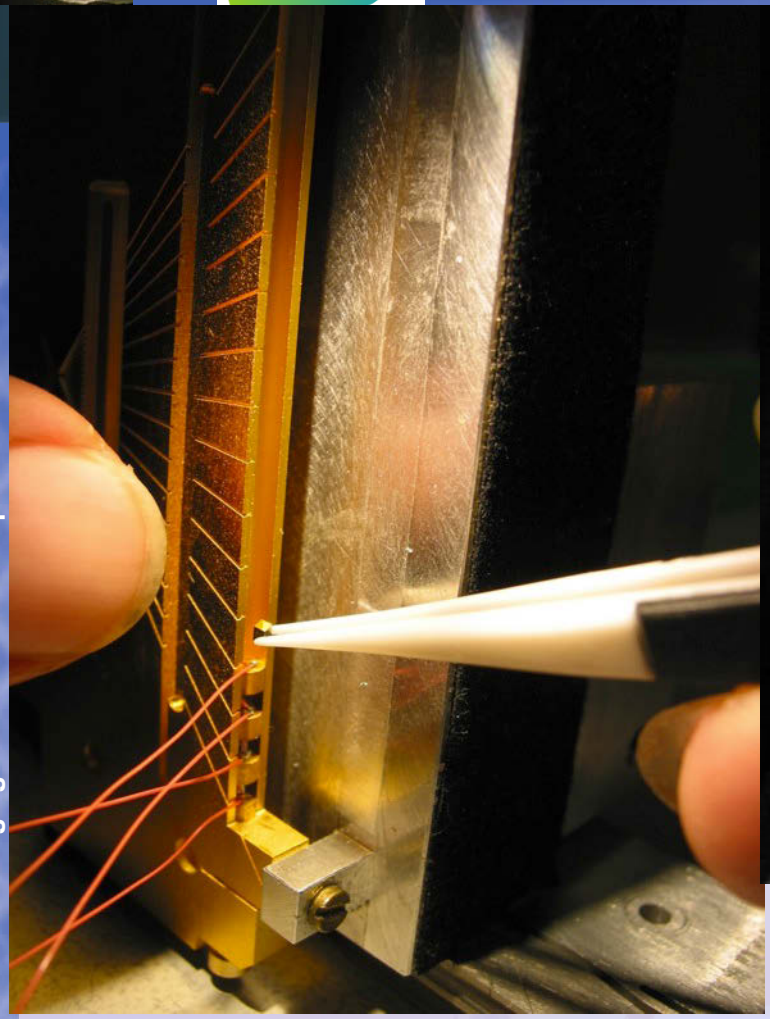


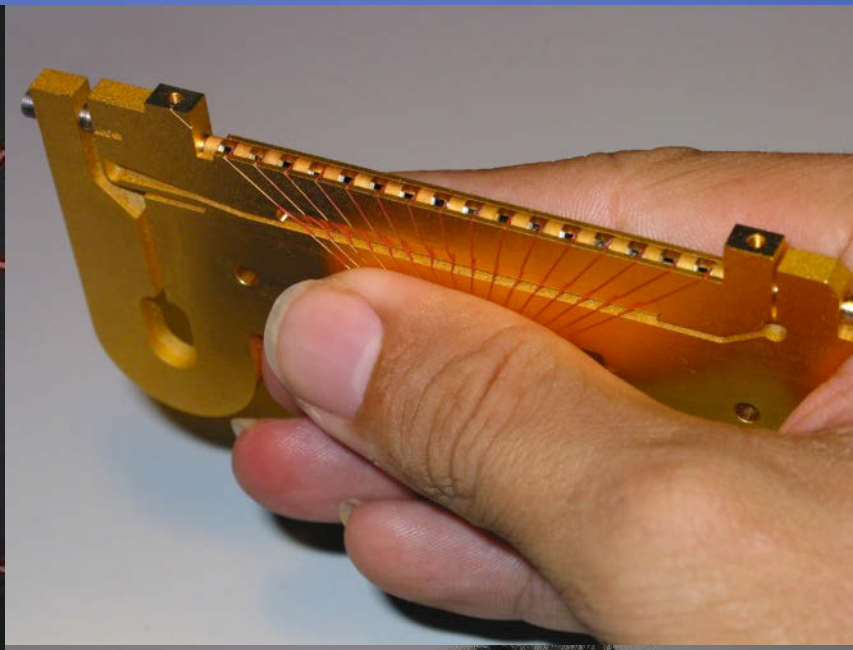


Linear 16-element stressed array (schematic)

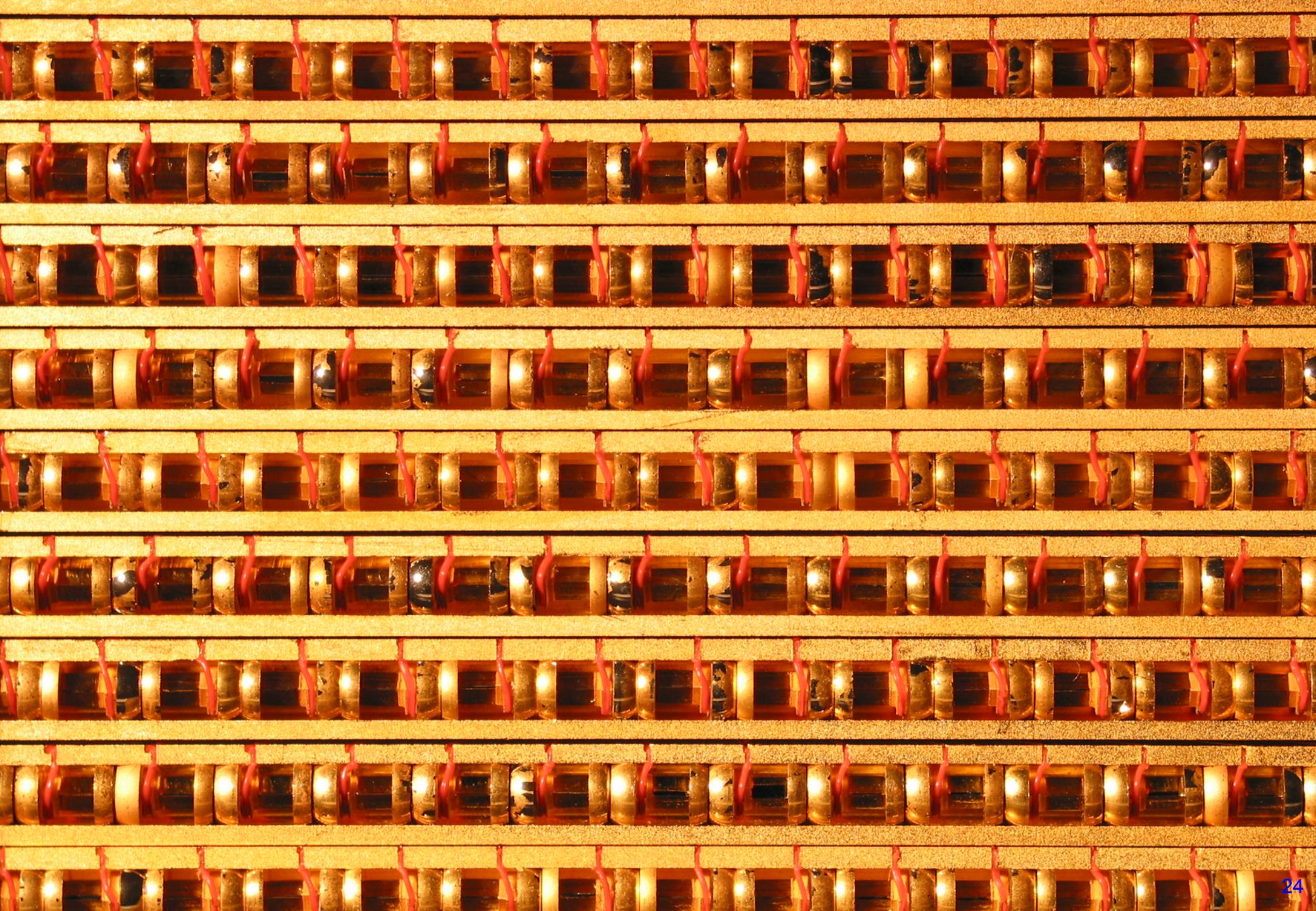
Detectors



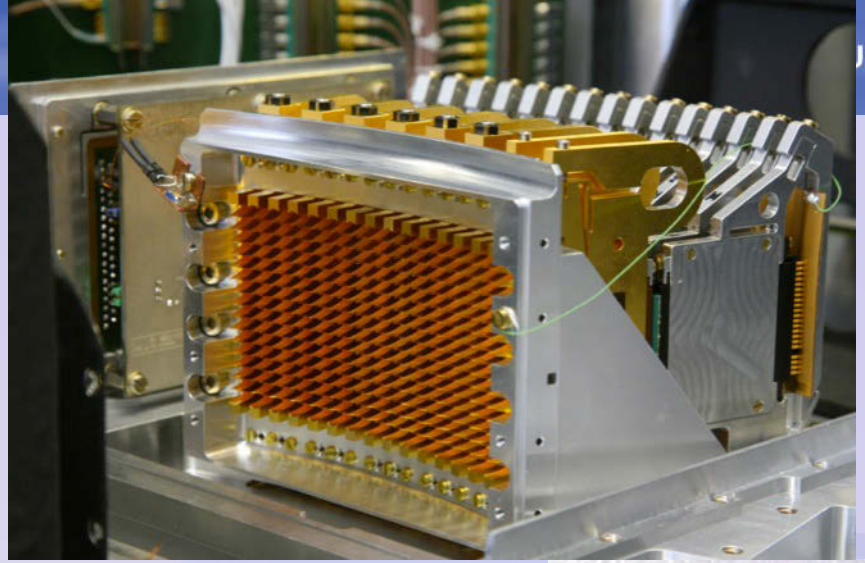




Assembling the detector array by hand: 800 individual pixels

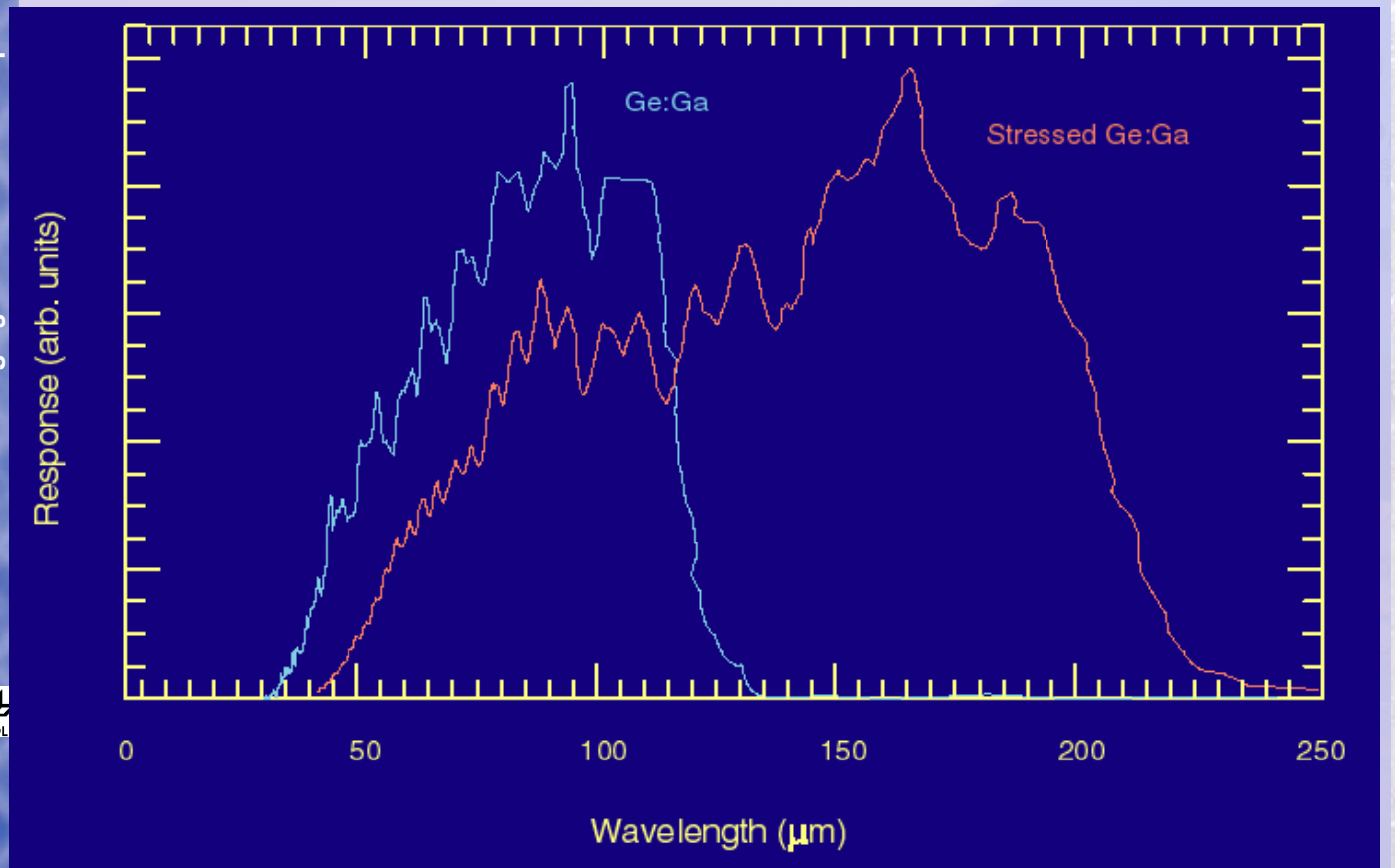


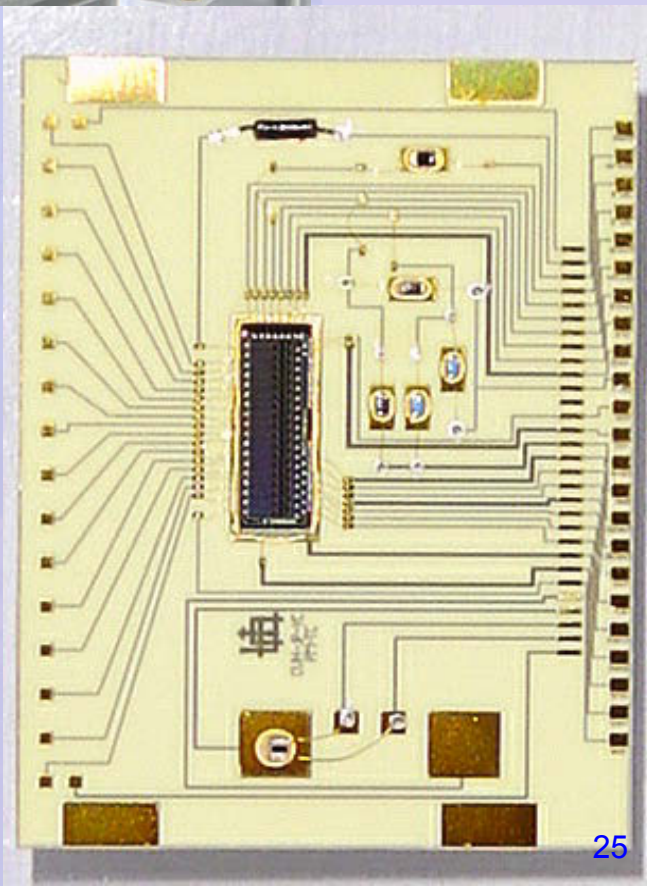
Assembling the detector feed horns and packaging the modules



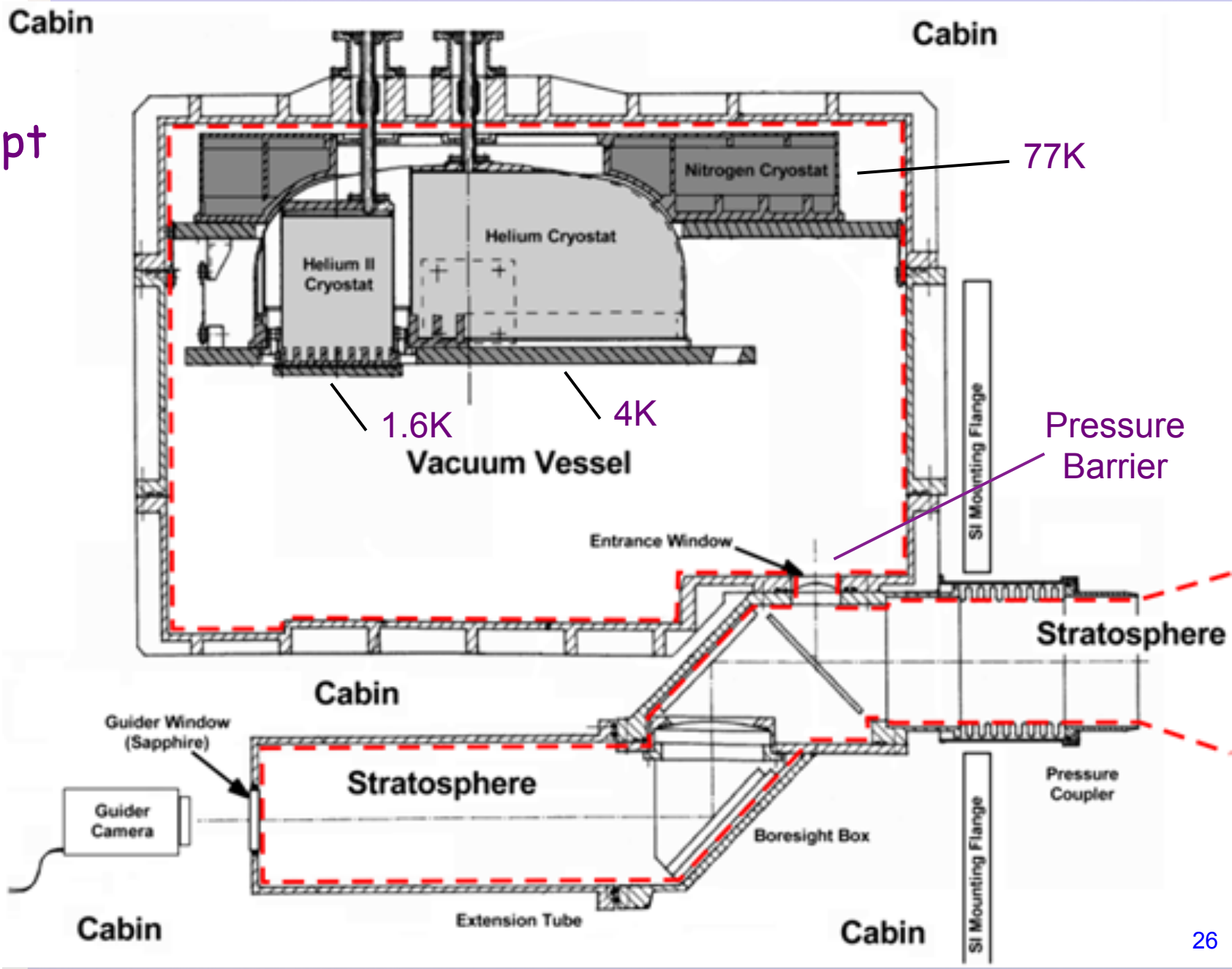
IMEC cold Read-out Electronics

Spectral response of stressed and unstressed Ge:Ga detectors.

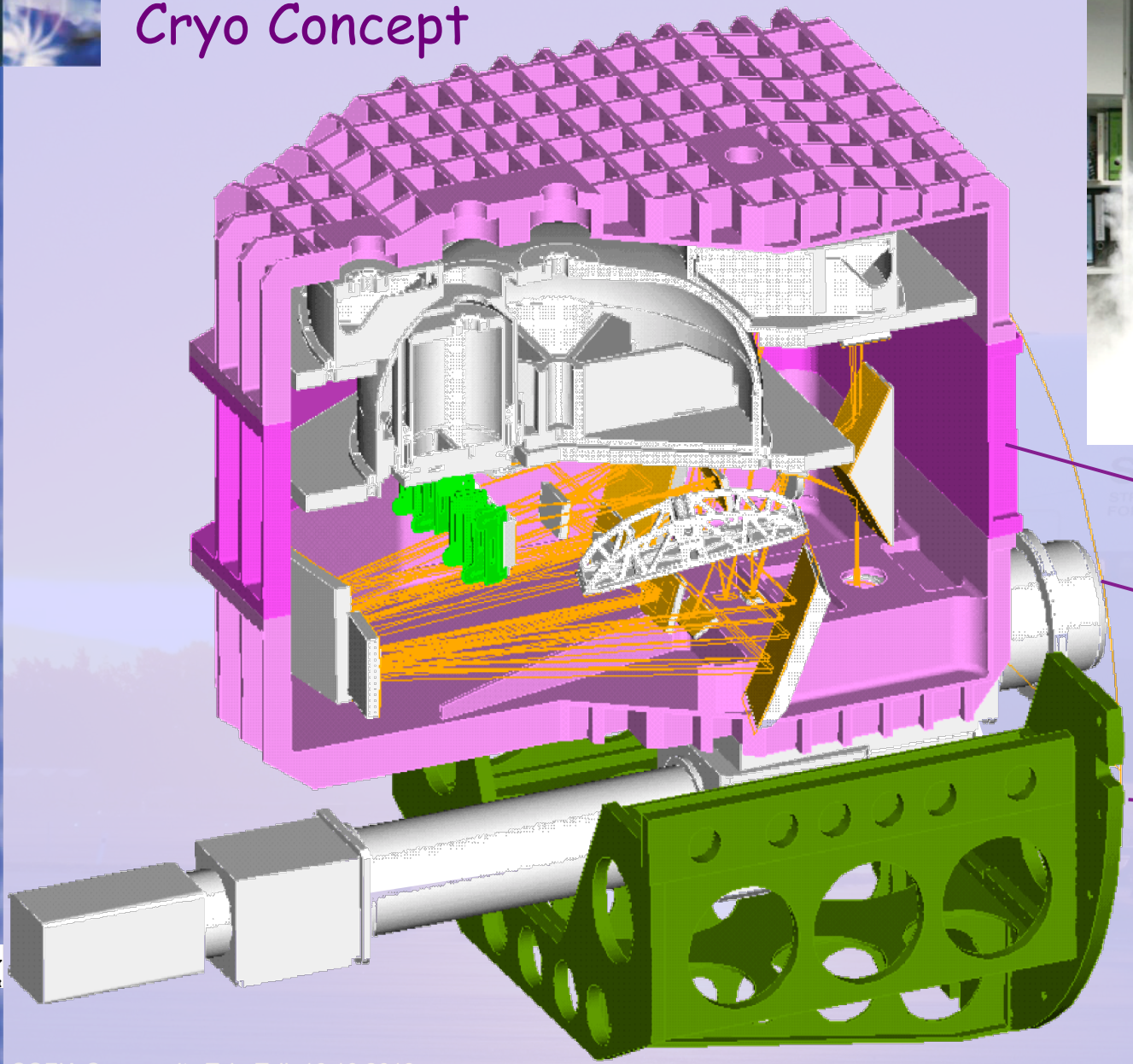


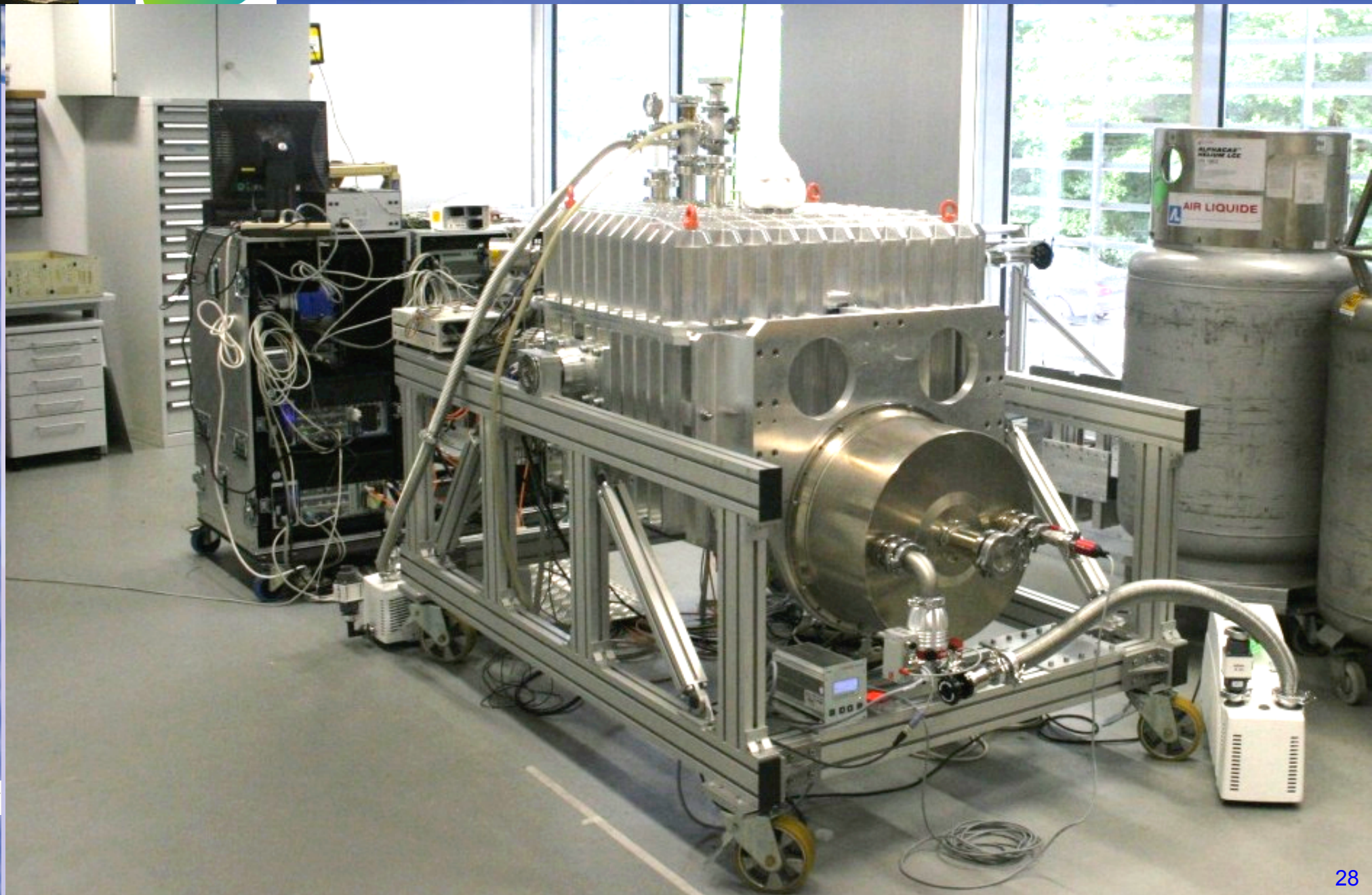


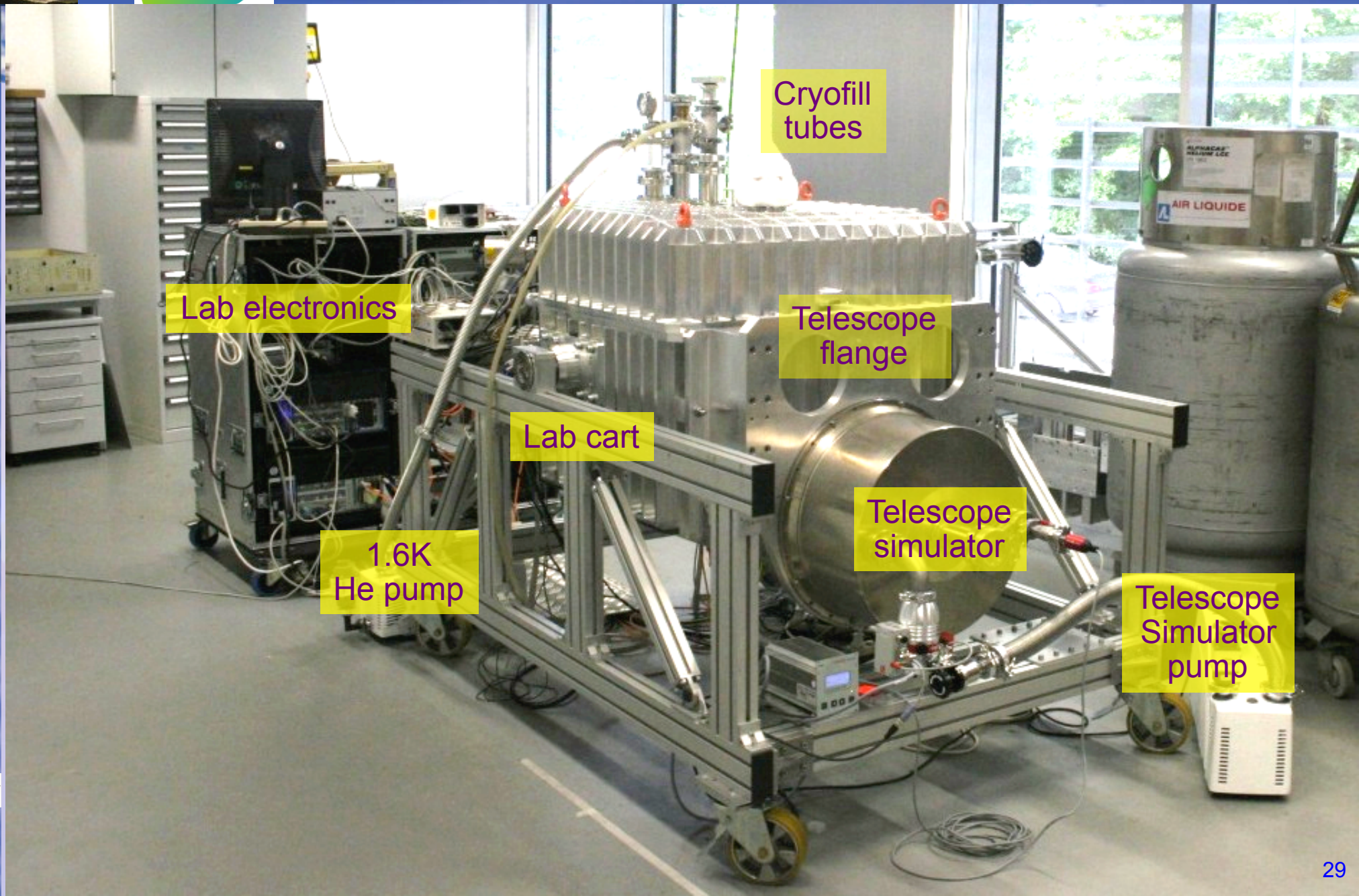
Cryo Concept

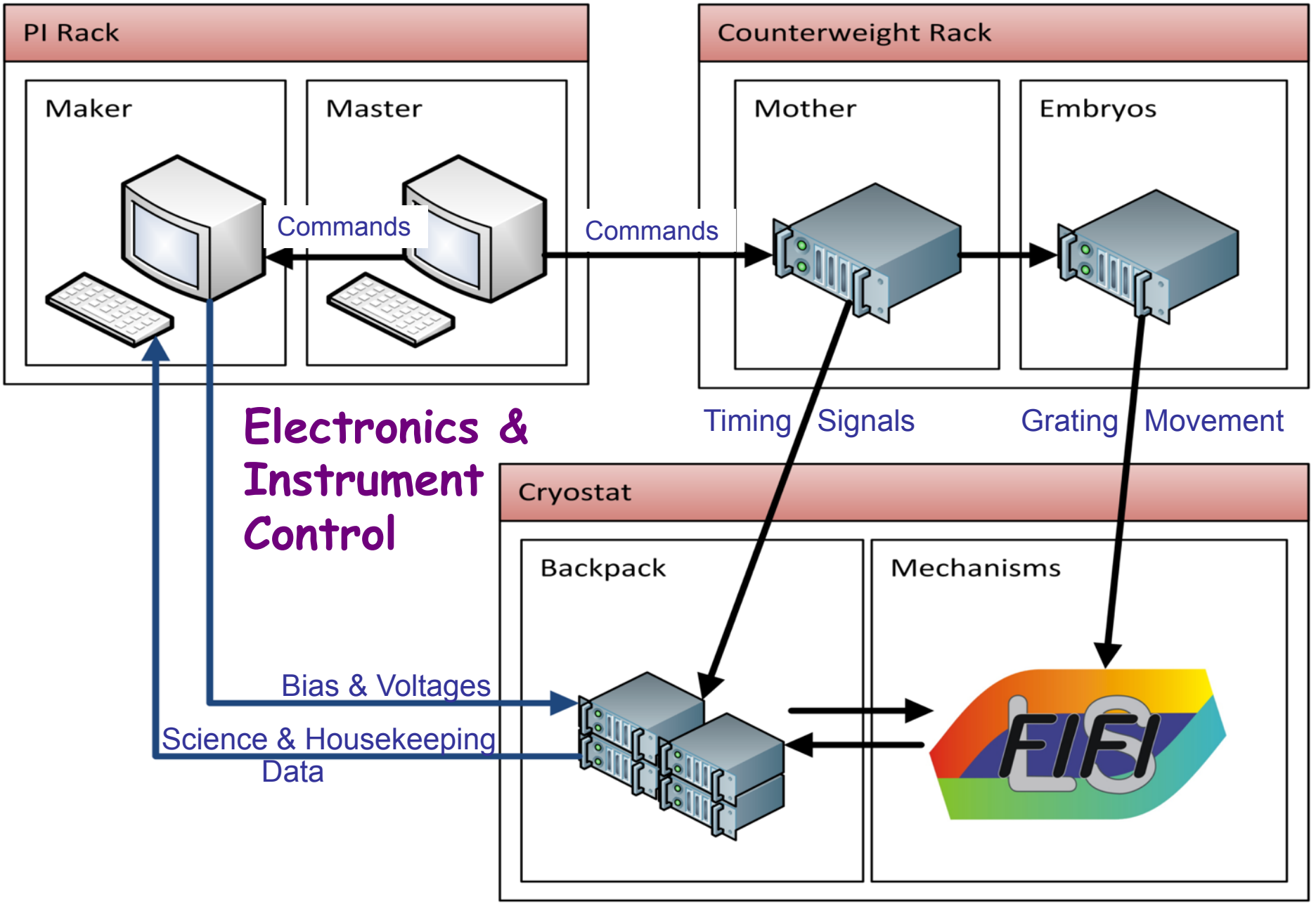


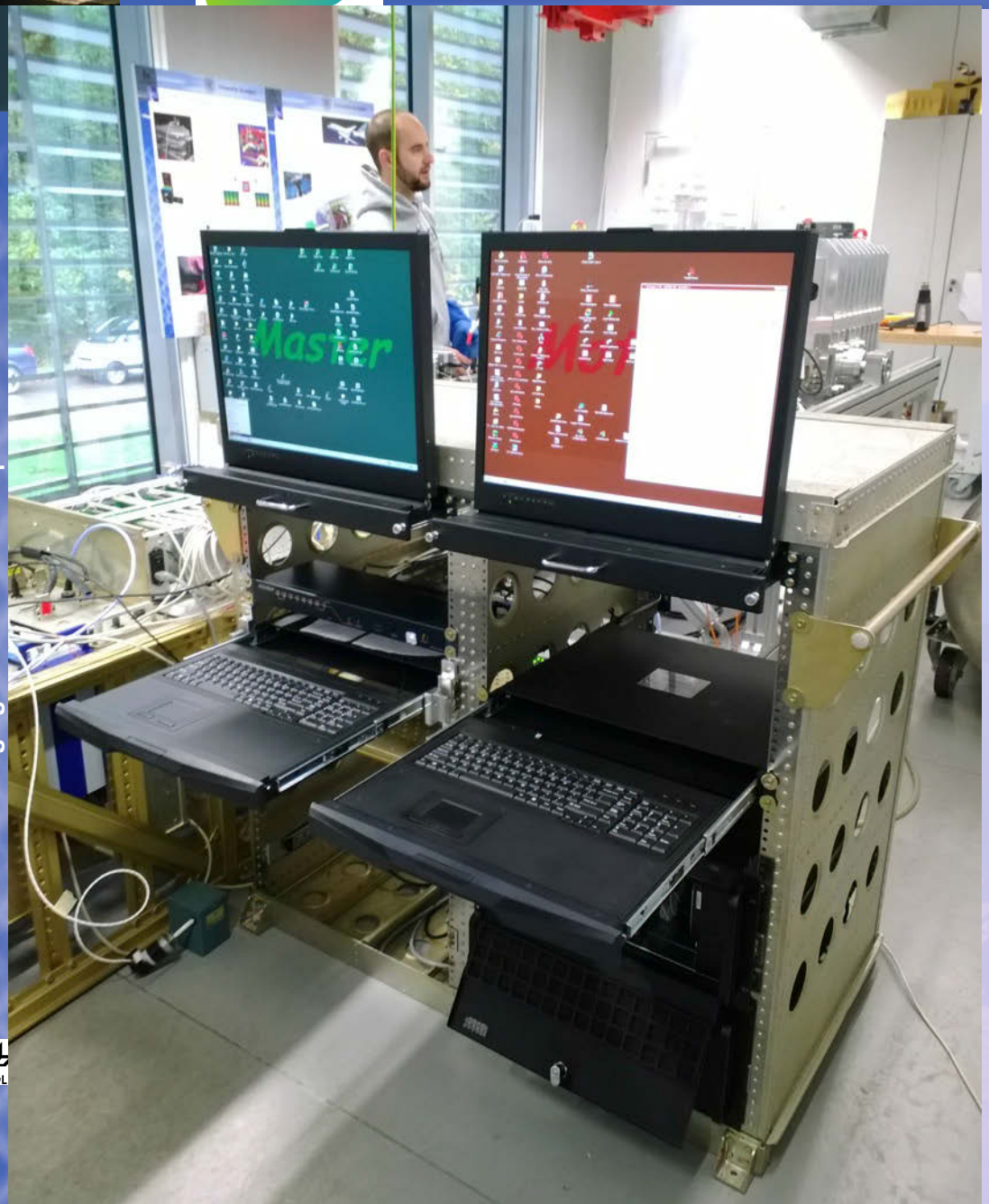
Cryo Concept




AIR LIQUIDE


Cryofill tubes
Lab electronics
Telescope flange
Lab cart
Telescope simulator
1.6K He pump
Telescope Simulator pump
AIR LIQUIDE


PI Rack
Maker
Master
Counterweight Rack
Mother
Embryos
Commands
Commands
Timing Signals
Grating Movement
Electronics & Instrument Control
Cryostat
Backpack
Mechanisms
Bias & Voltages
Science & Housekeeping Data
FIFI



PI Rack

- 2 Terminals with access to all computers and embryos
- Master creates scan schedules and feeds commands (KOSMA)
- Maker records data and adjusts bias voltages

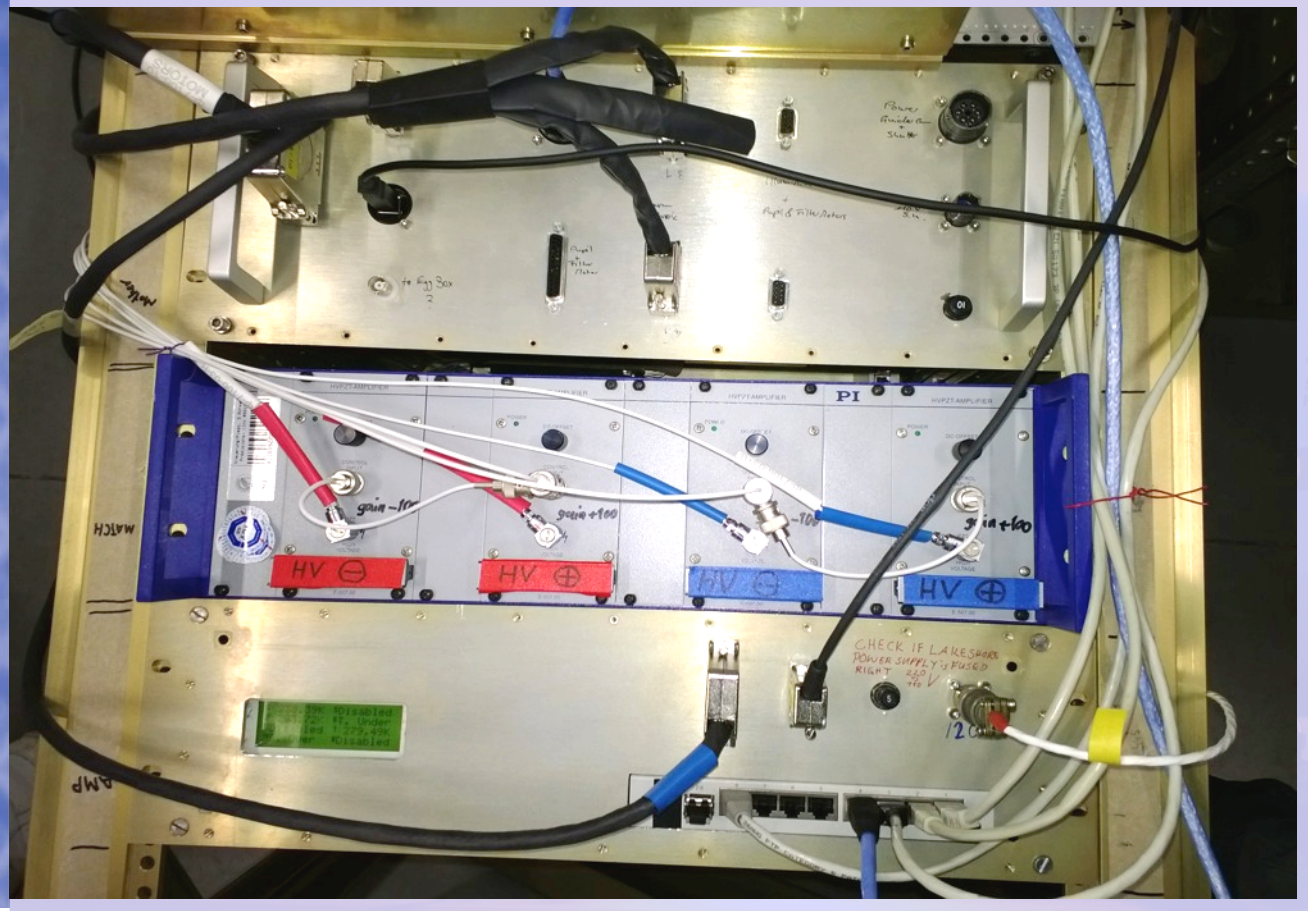
Backpack blue side

Backpack (attached to Cryostat)

- Separated into Red and Blue sides
- Receives Mother commands
- Supplies power to mechanisms
- Reads out data for recording by Maker

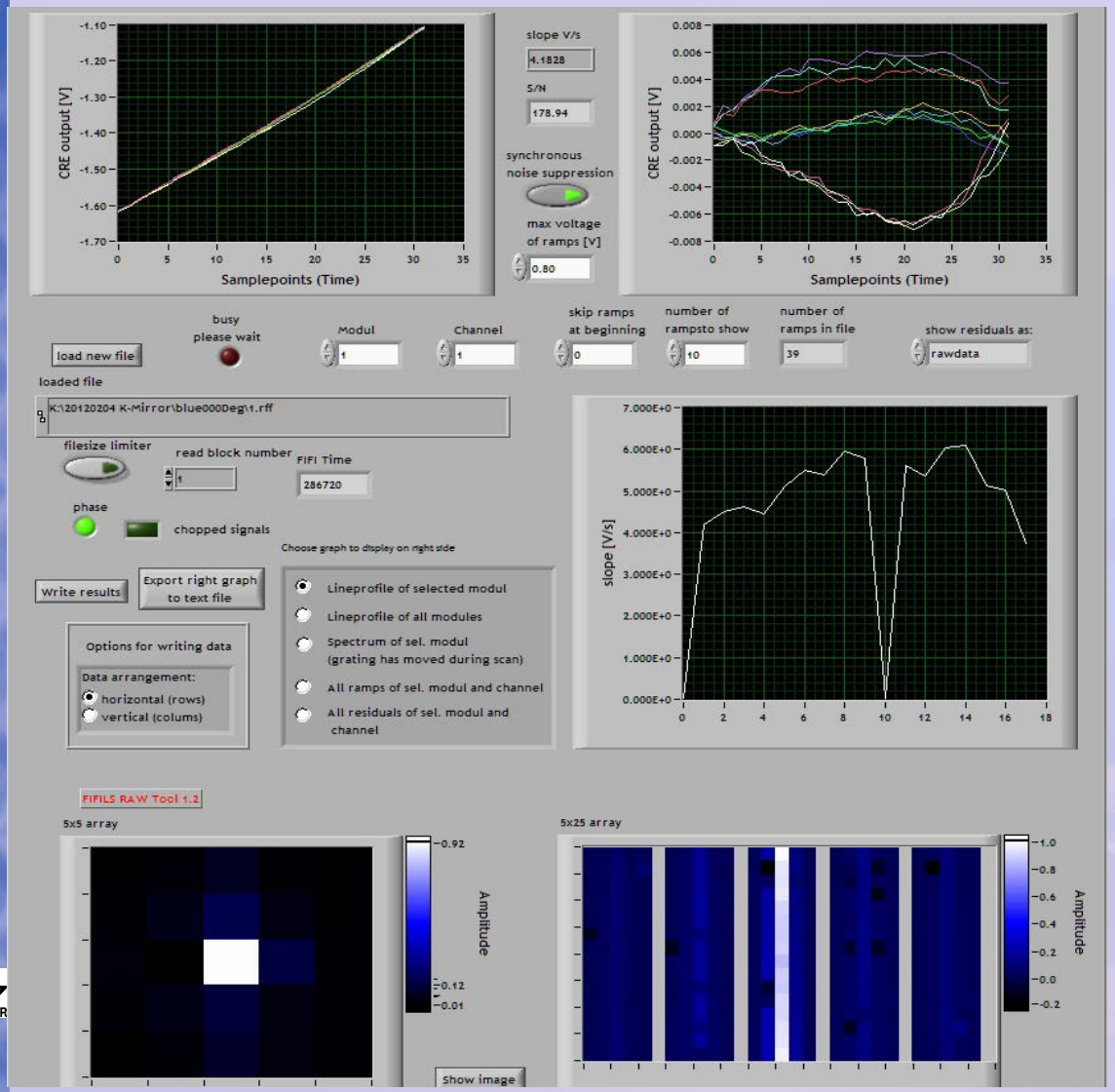
Backpack red side

Counterweight Rack



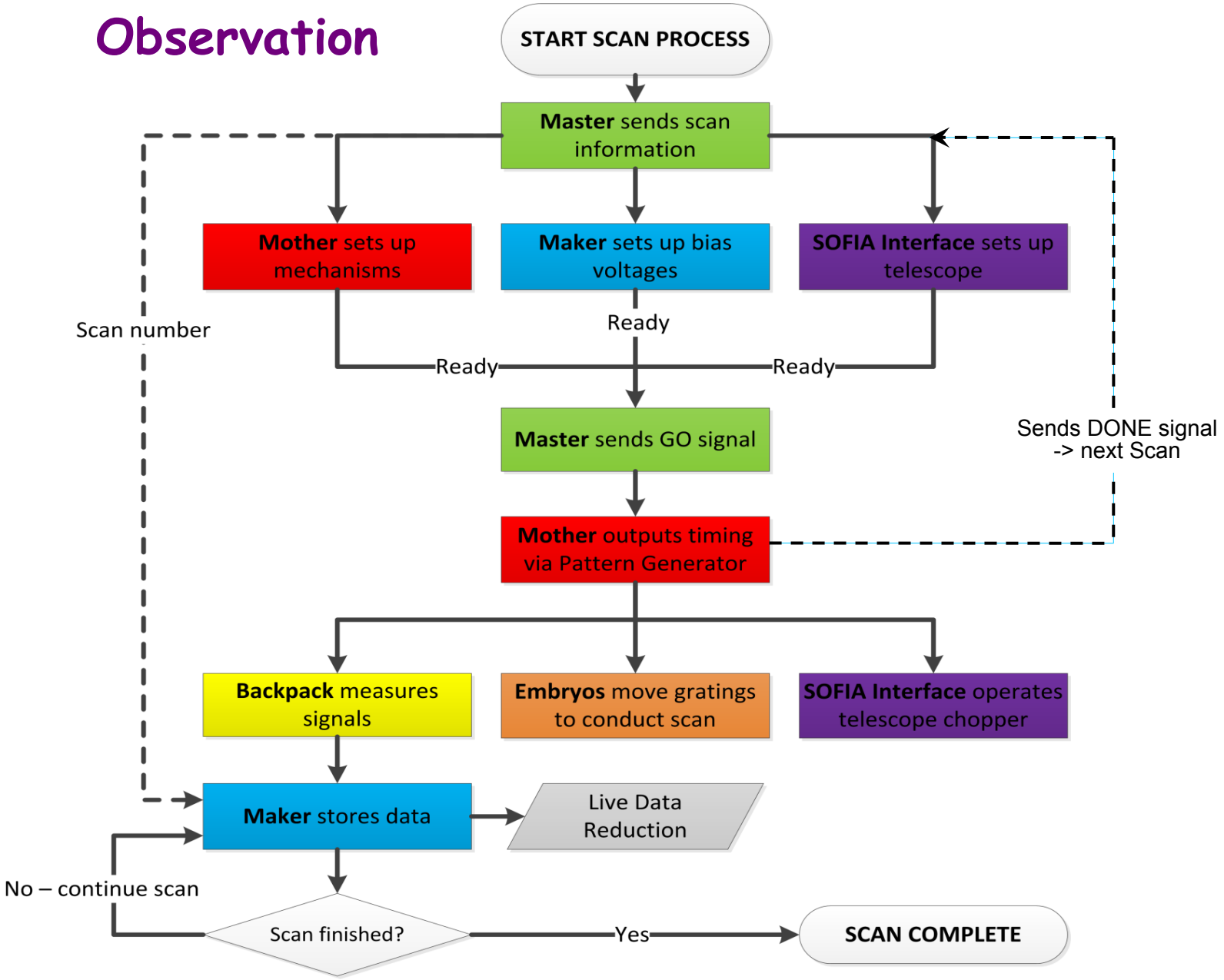
- Houses Mother, Embryos, high voltage power supply and other electronics
- Mother generates timing signal and actuates mechanism movements
- Embryos perform grating movements

Control and Analysis Software



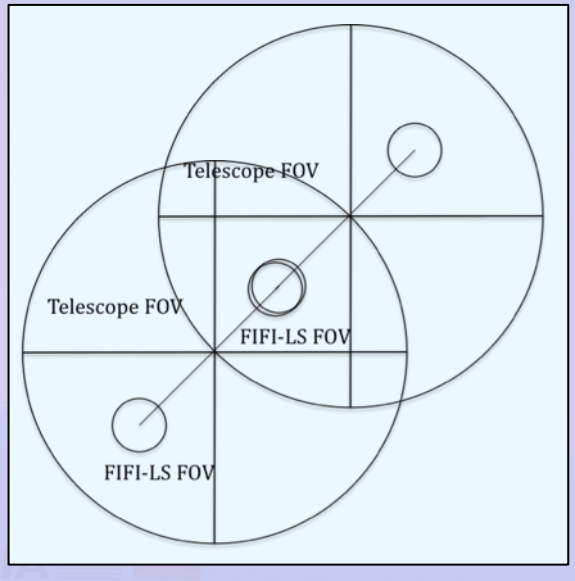
- Dedicated applications and GUIs for
  - Scan and schedule preparation
  - Scan execution
  - Real-time mechanism monitoring
  - Manual movement of components
  - Quick look at data products
  - Telescope simulation
  - And many more...

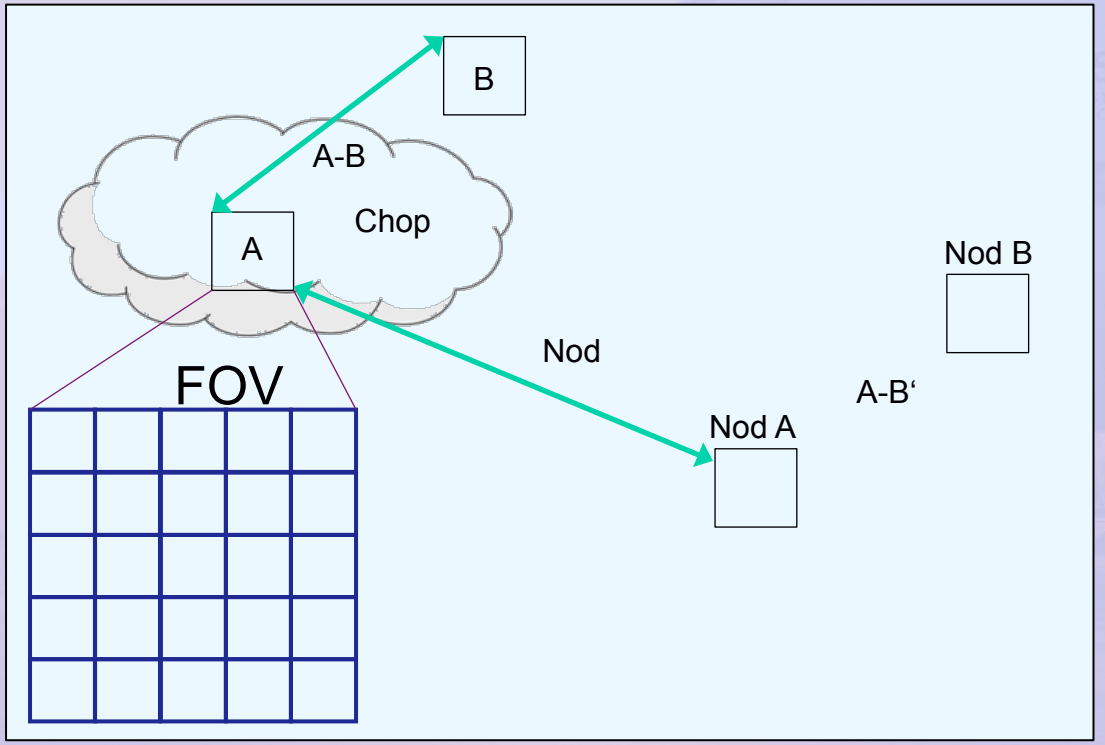
Observation



Observing Modes I

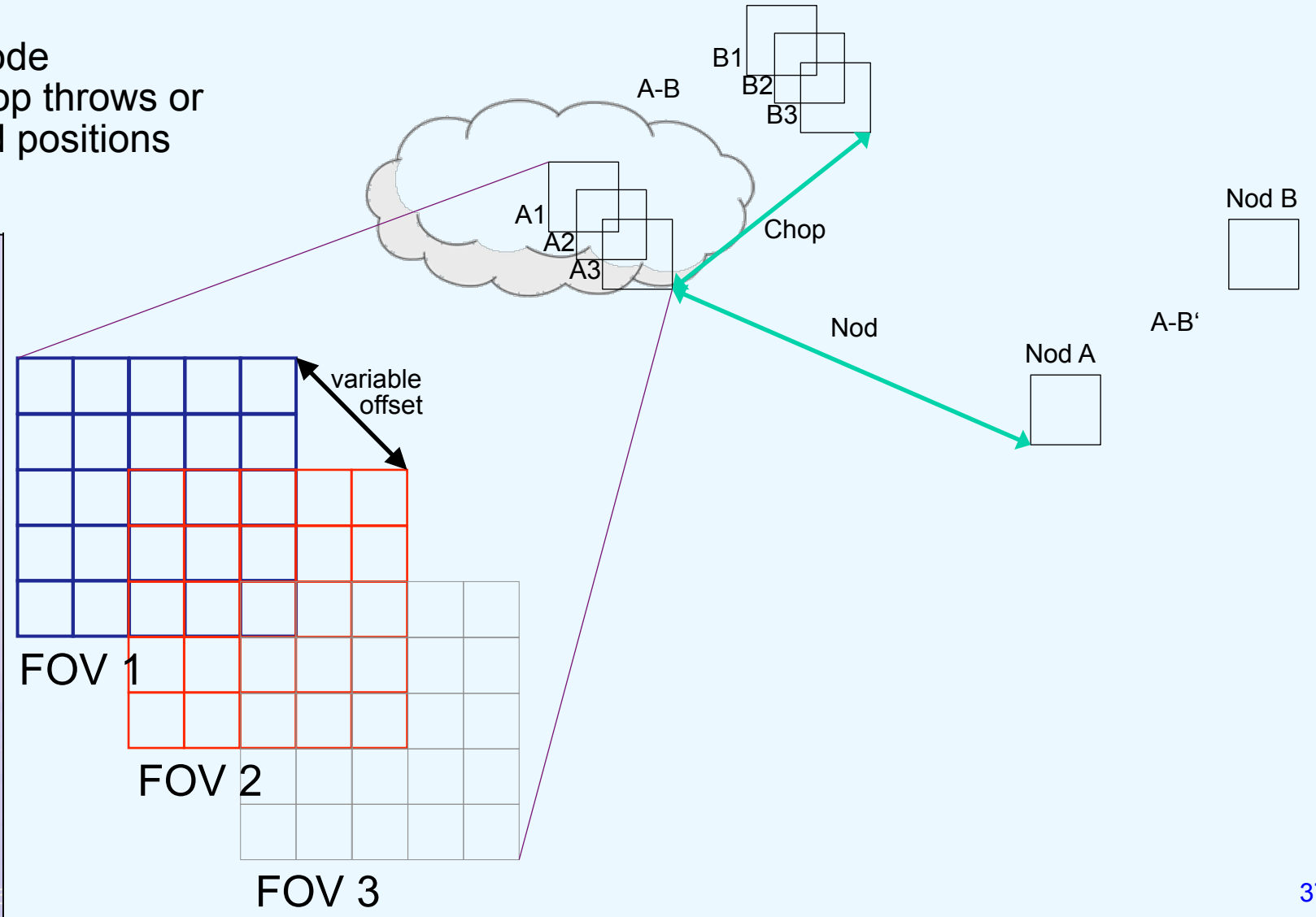
1. Compact Mode
   Beam switch: Symmetric chop & matched nod
2. Extended Mode
   Asymmetric Chop + Off-Nod





Observing Modes II

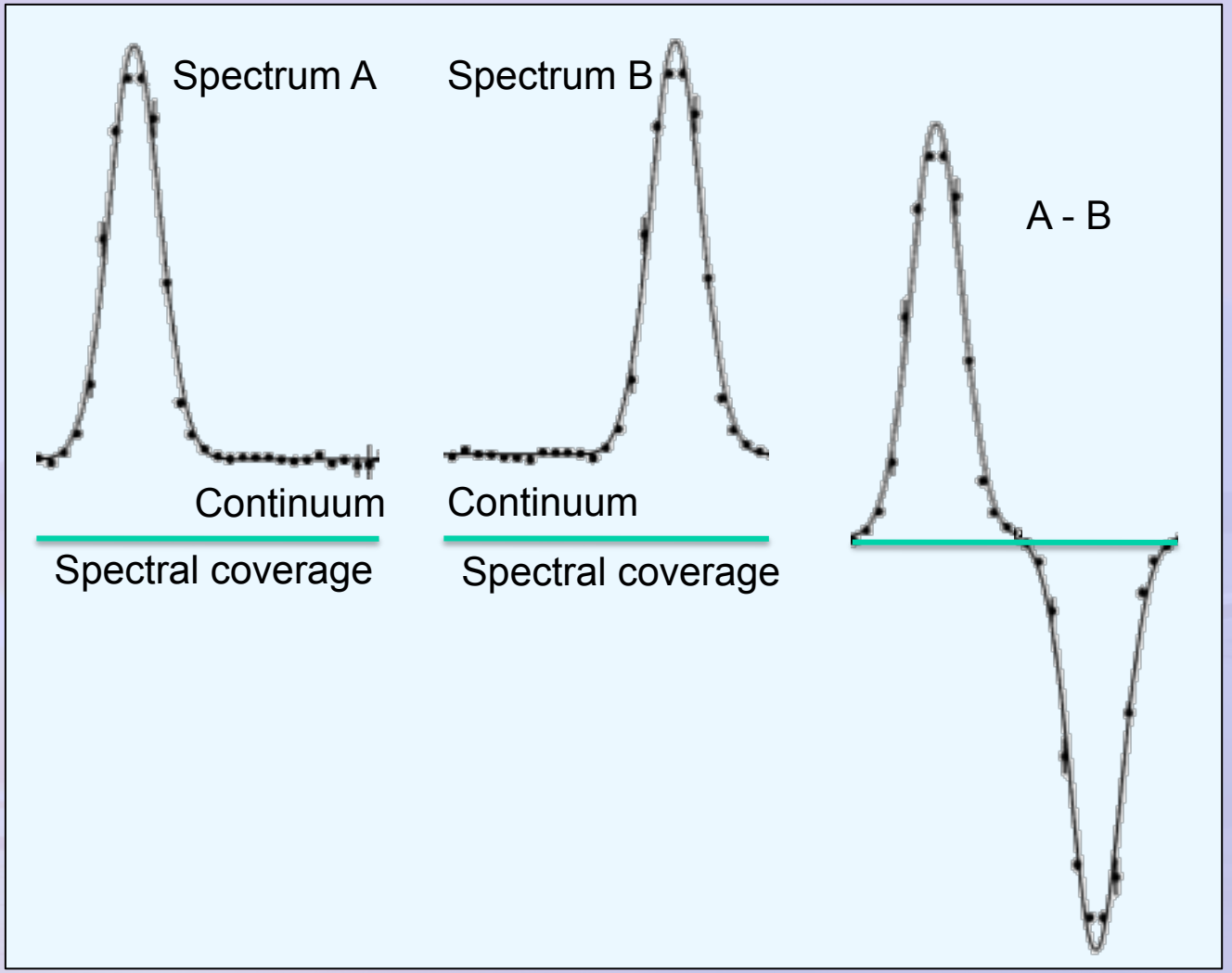
3. Mapping Mode
   Identical chop throws or
   user defined positions



Observing Modes III

4. Spectral differencing
   - **Experimental Mode**
   - Grating chop-nod
   - Discards Continuum
   - May be faster than modes 1-3
5. Spatial Dither Pattern

25	10	11	12	13
24	9	2	3	14
23	8	1	4	15
22	7	6	5	16
21	20	19	18	17



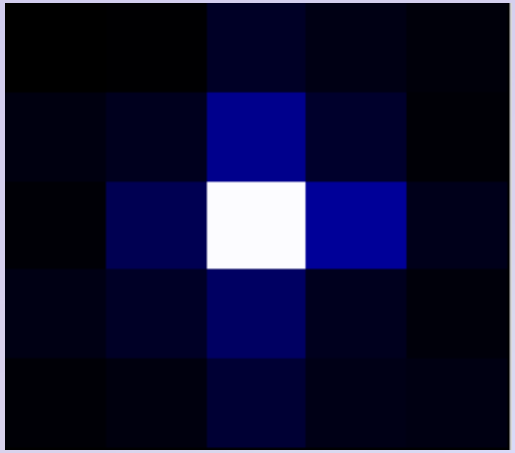
FIFI-LS versus PACS Spectrometer/Herschel

FIFI-LS	PACS
2 gratings	1 grating
blue & red channel independent	blue & red channel coupled
5x5 pixel FOV	5x5 pixel FOV
6”x6” & 12”x12”pixel	9.4”x9.4” pixel
2 channel 16x25 detectors	2 channel 16x25 detectors
42 – 205 µm	50 – 200 µm
shortest observation ~5 sec	shortest observation ~7 min
mapping speed high	mapping speed low
Multiple settings per target	one or few settings per target
upgradable	history

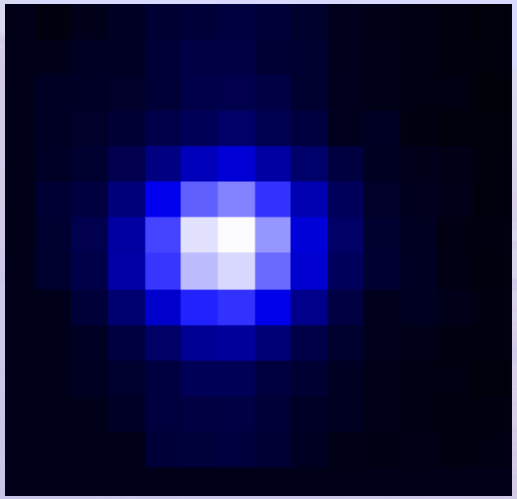
Due to the faster mapping speed and shorter integration times, FIFI-LS is expected to be only 3-5 times less sensitive (and not 8 times) compared with PACS on extended targets.

Performance: Point Spread Function Blue 1st Order

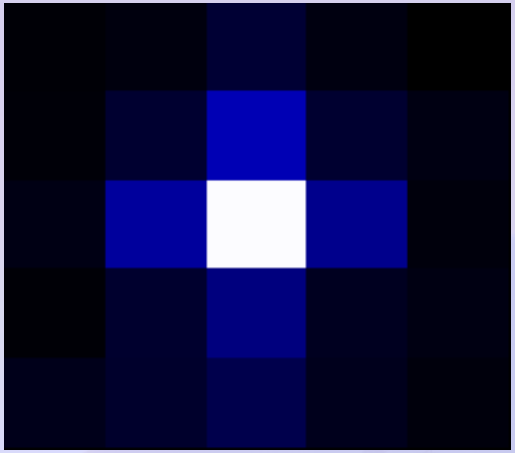
88µm [OIII]



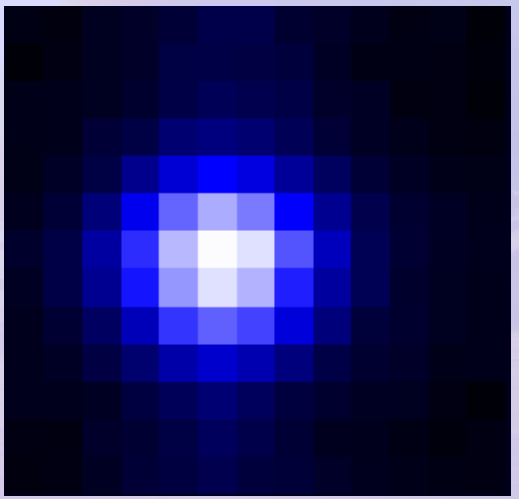
FWHM: 1.44 Pixel
FWHM: 2.55 mm



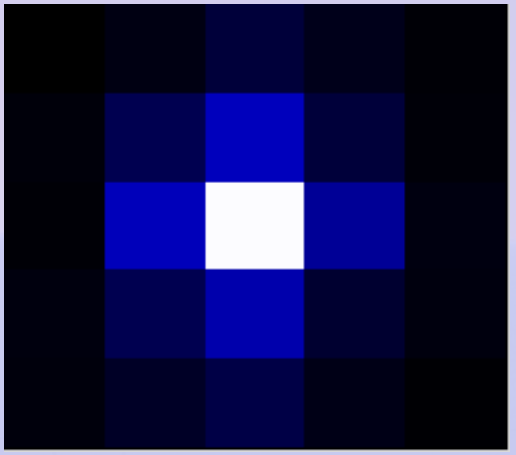
105µm [FeIII]



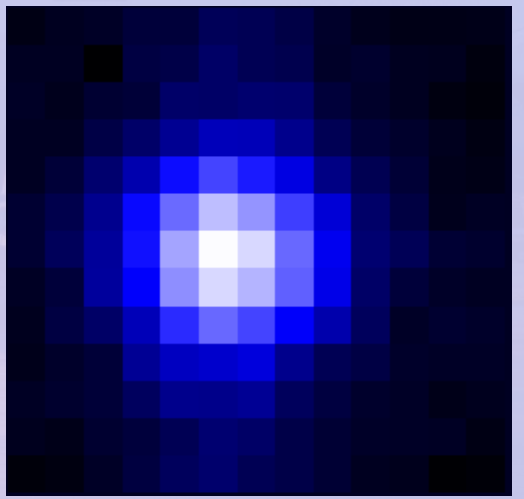
FWHM: 1.60 Pixel
FWHM: 2.83 mm



122µm [NII]



FWHM: 1.68 Pixel
FWHM: 2.98 mm

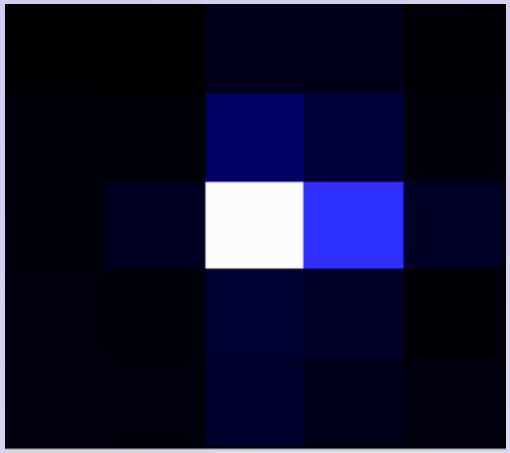


PSF
In
Pixel Space

Nyquist-
Sampled
Beam Maps
in Telescope
Simulator
Coordinates
(Step .6mm)

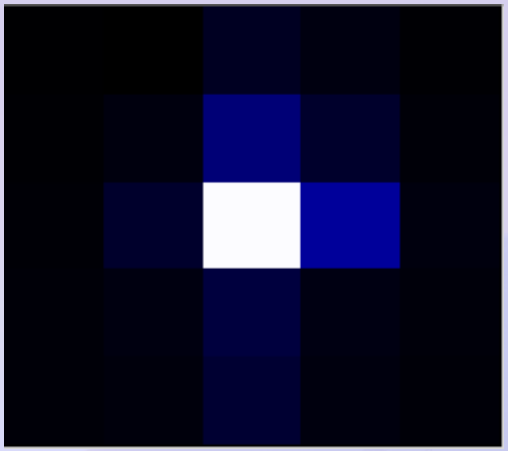
Performance: Point Spread Function Blue 2nd Order

52µm [OIII]



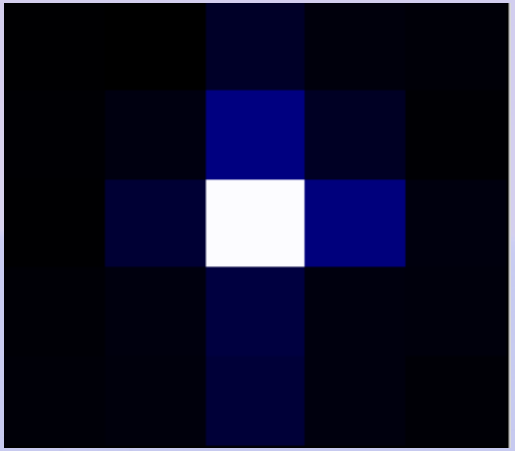
FWHM: 1.60 Pixel
FWHM: 2.84 mm

63µm [OI]



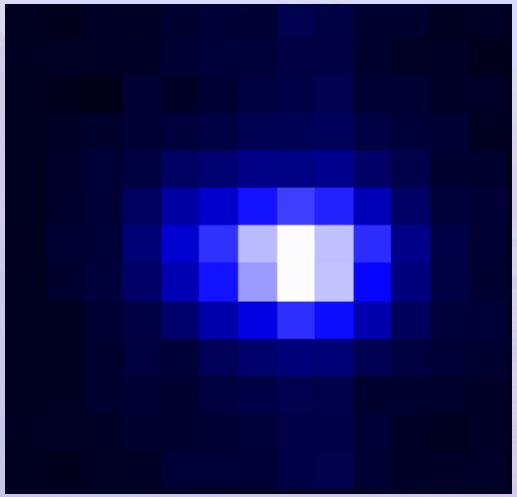
FWHM: 1.25 Pixel
FWHM: 2.21 mm

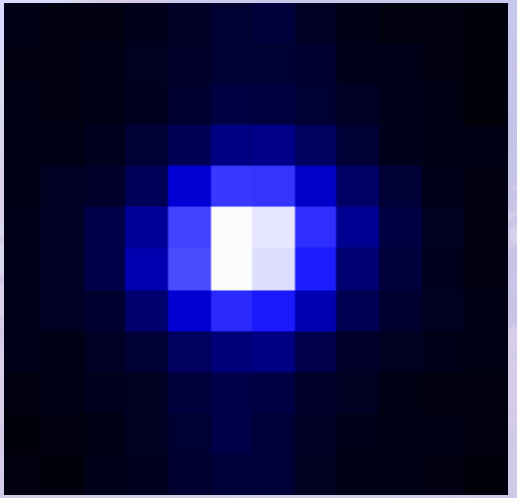
68µm [SiI]

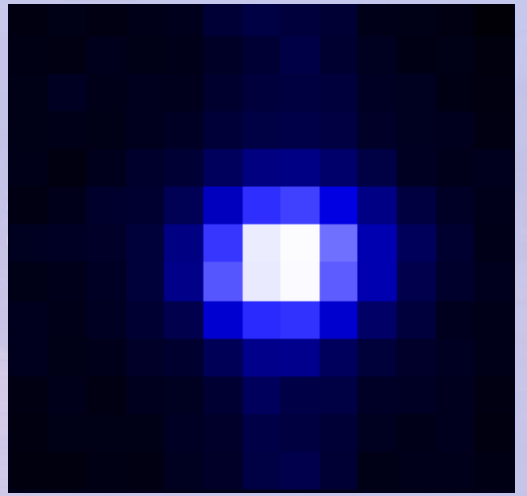


FWHM: 1.28 Pixel
FWHM: 2.26 mm

PSF
In
Pixel Space



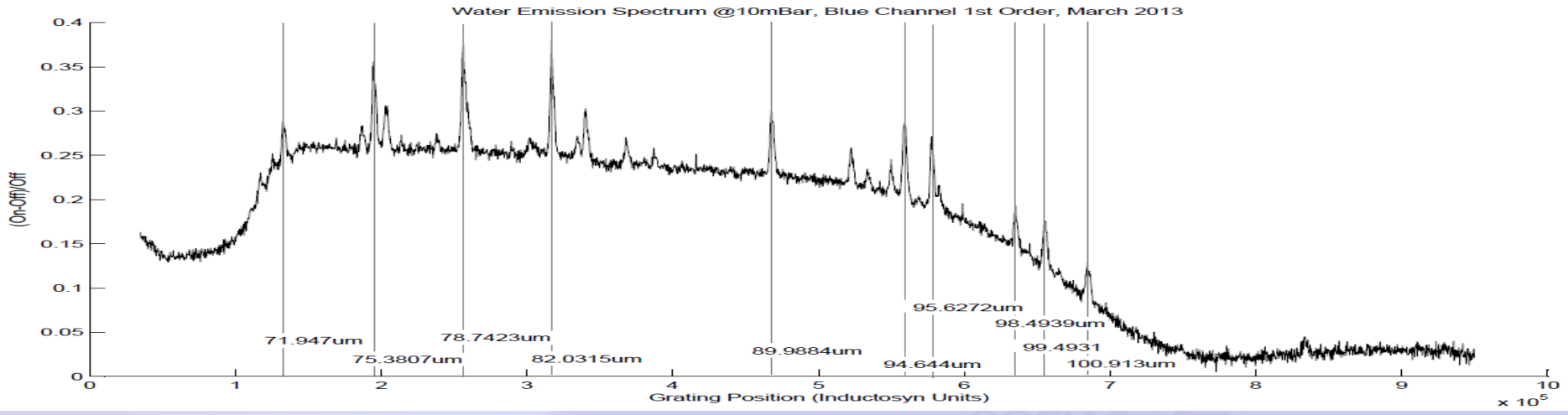




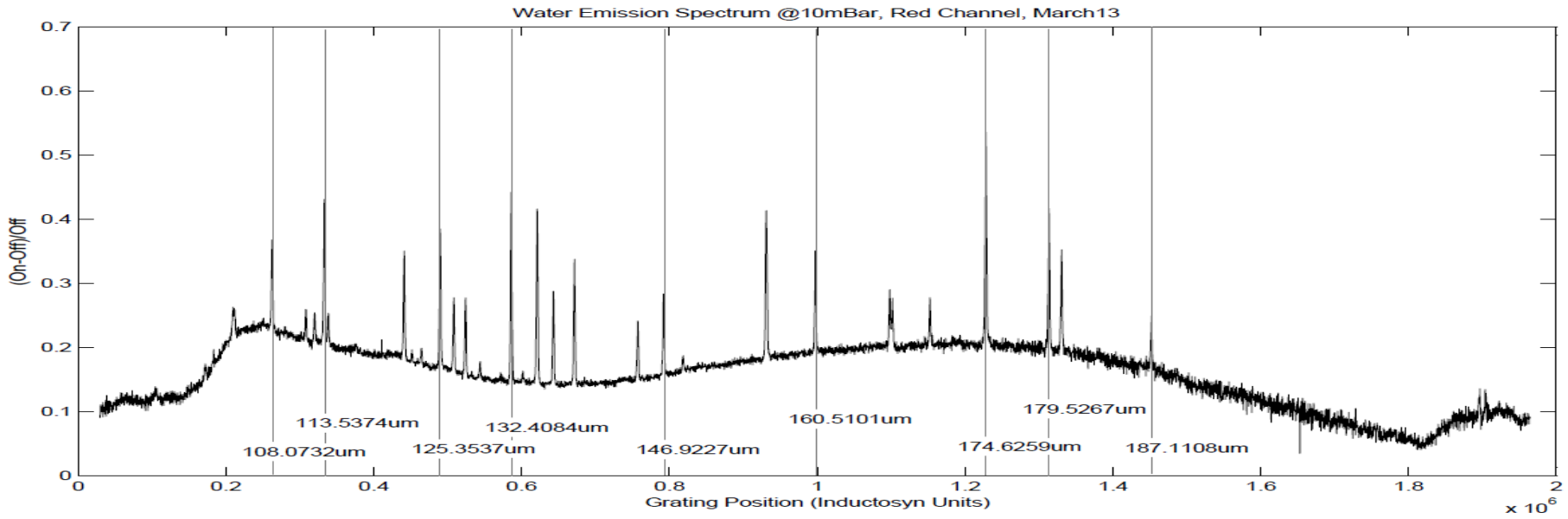
Nyquist-
Sampled
Beam Maps
in Telescope
Simulator
Coordinates
(Step .6mm)

Field Imaging Far Infrared Line Spectrometer

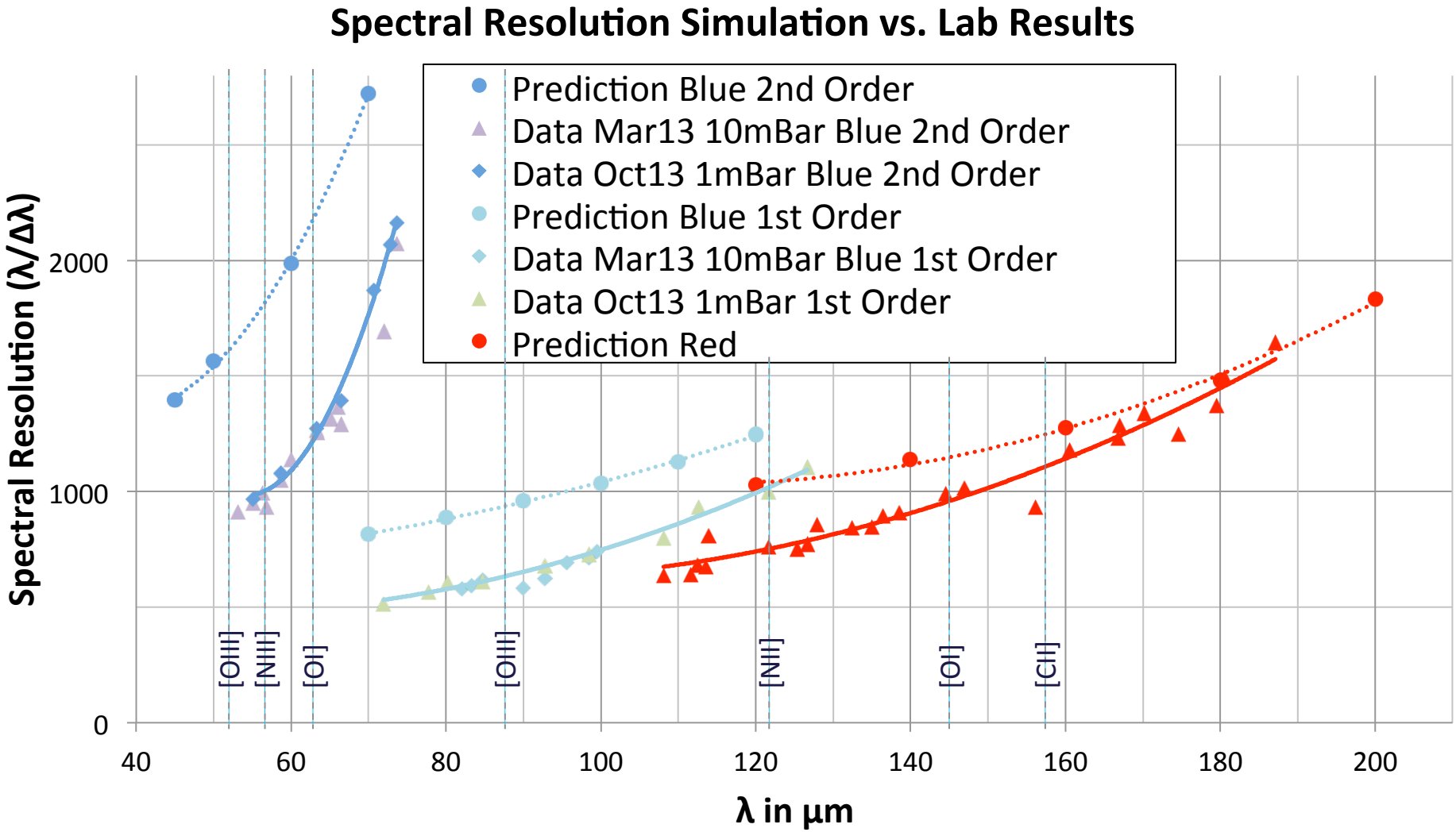
Water Emission Spectrum, Blue 1st Order, Dichroic 105µm



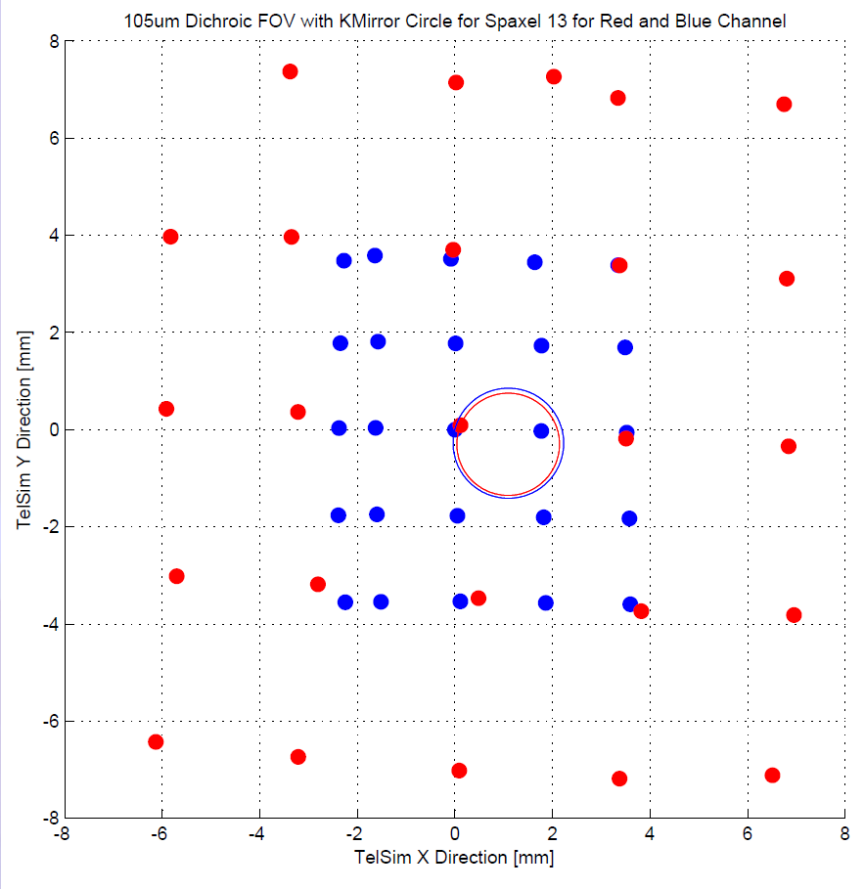
Water Emission Spectrum, Red, Dichroic 105µm



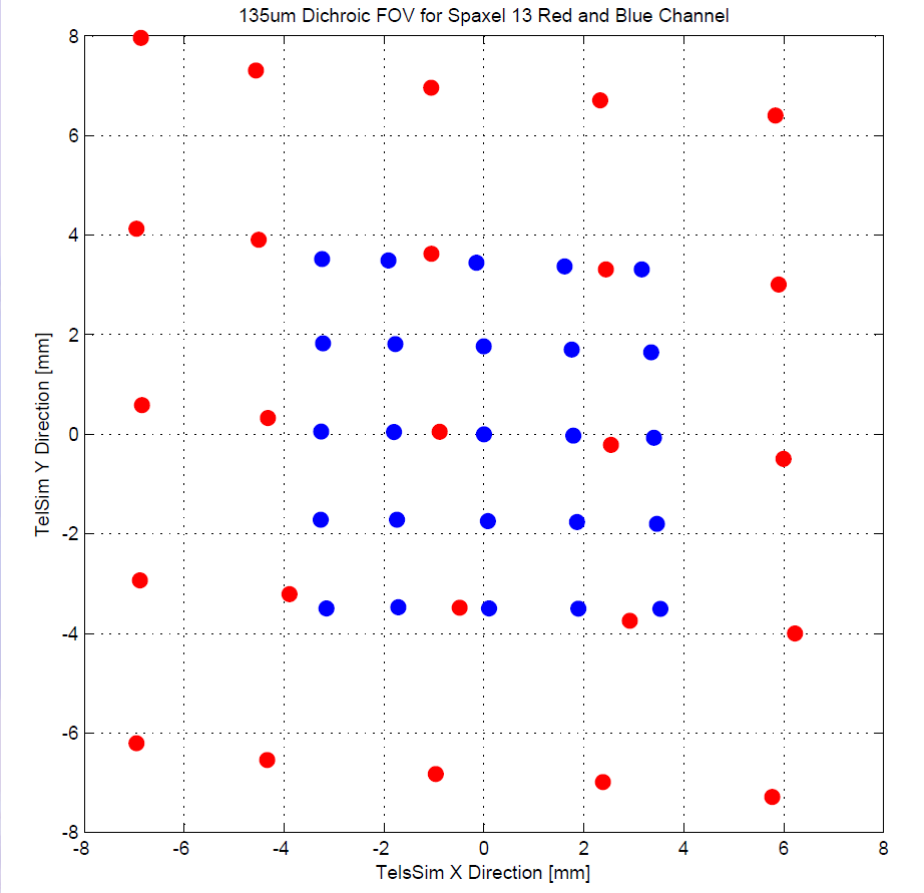
Performance: Spectral Resolution



Performance: Pixel Positions

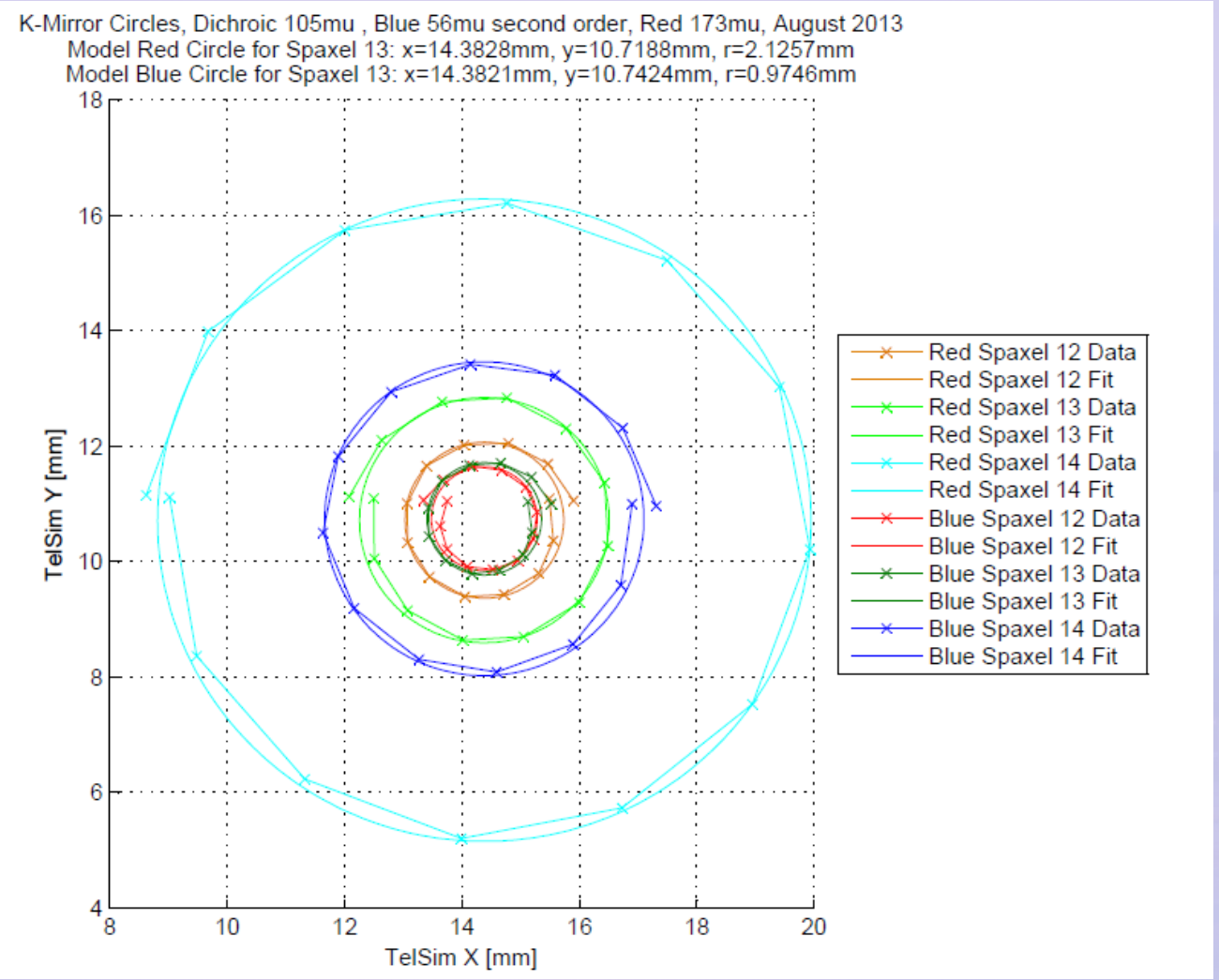


Before realignment



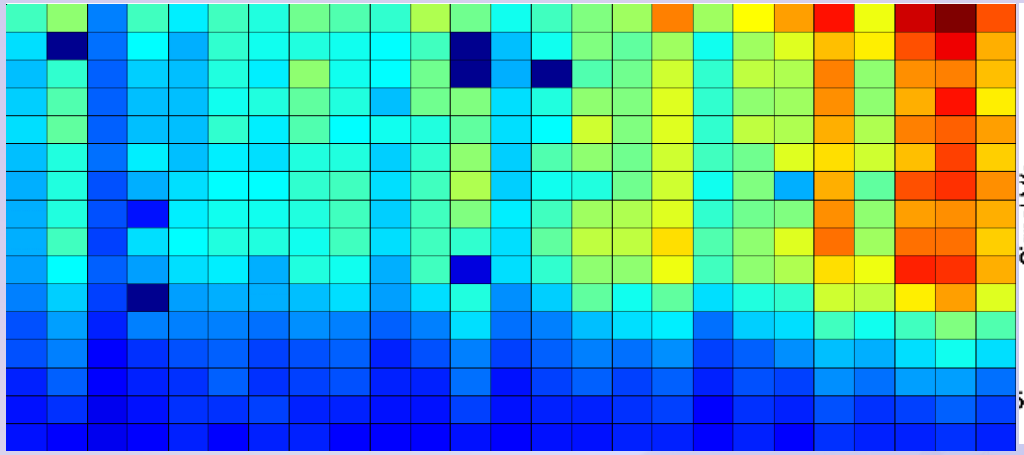
After realignment

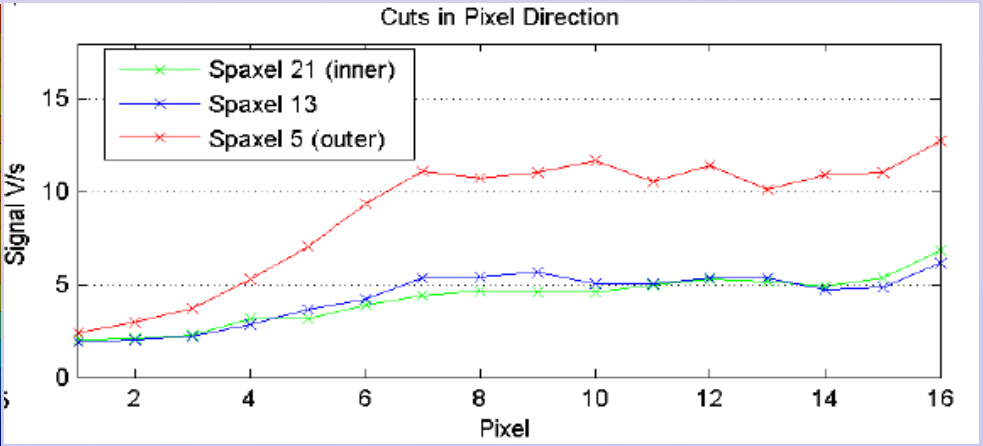
Performance: Boresight Effect of K-Mirror



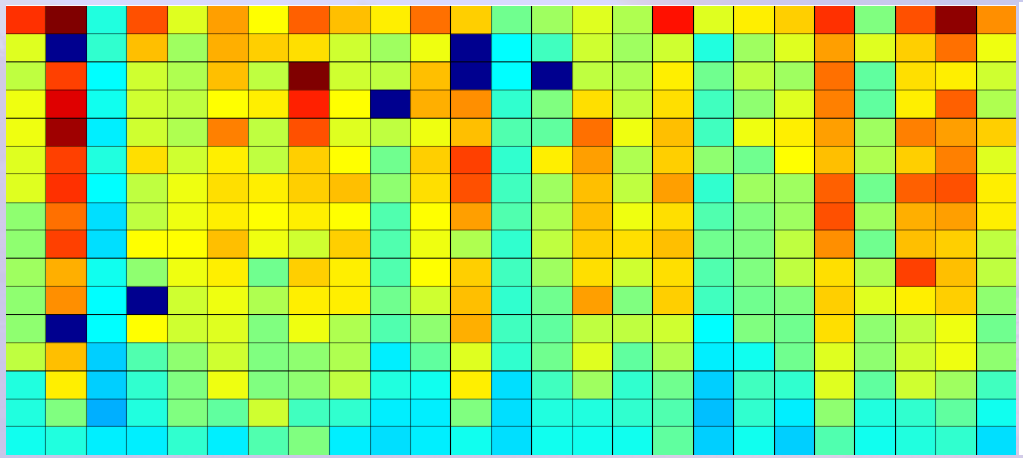
Performance Improvements: Straylight reduction blue channel

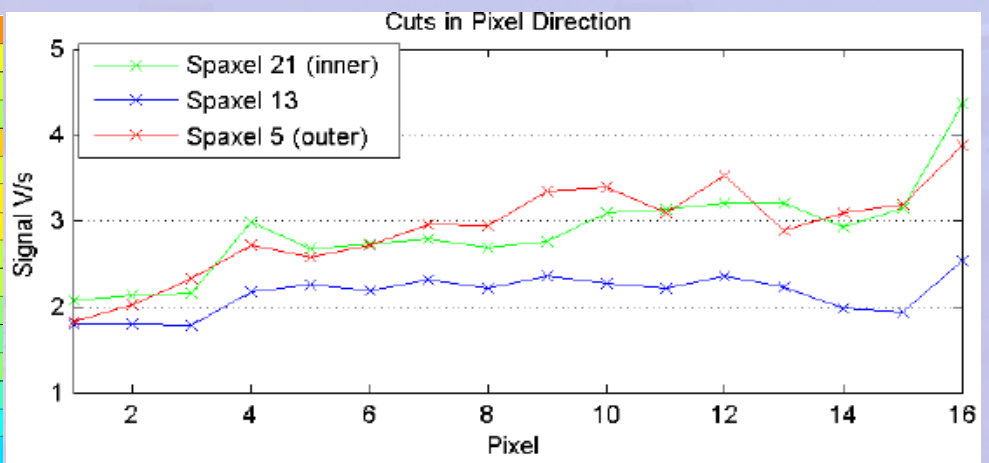
Initial until May 2013:





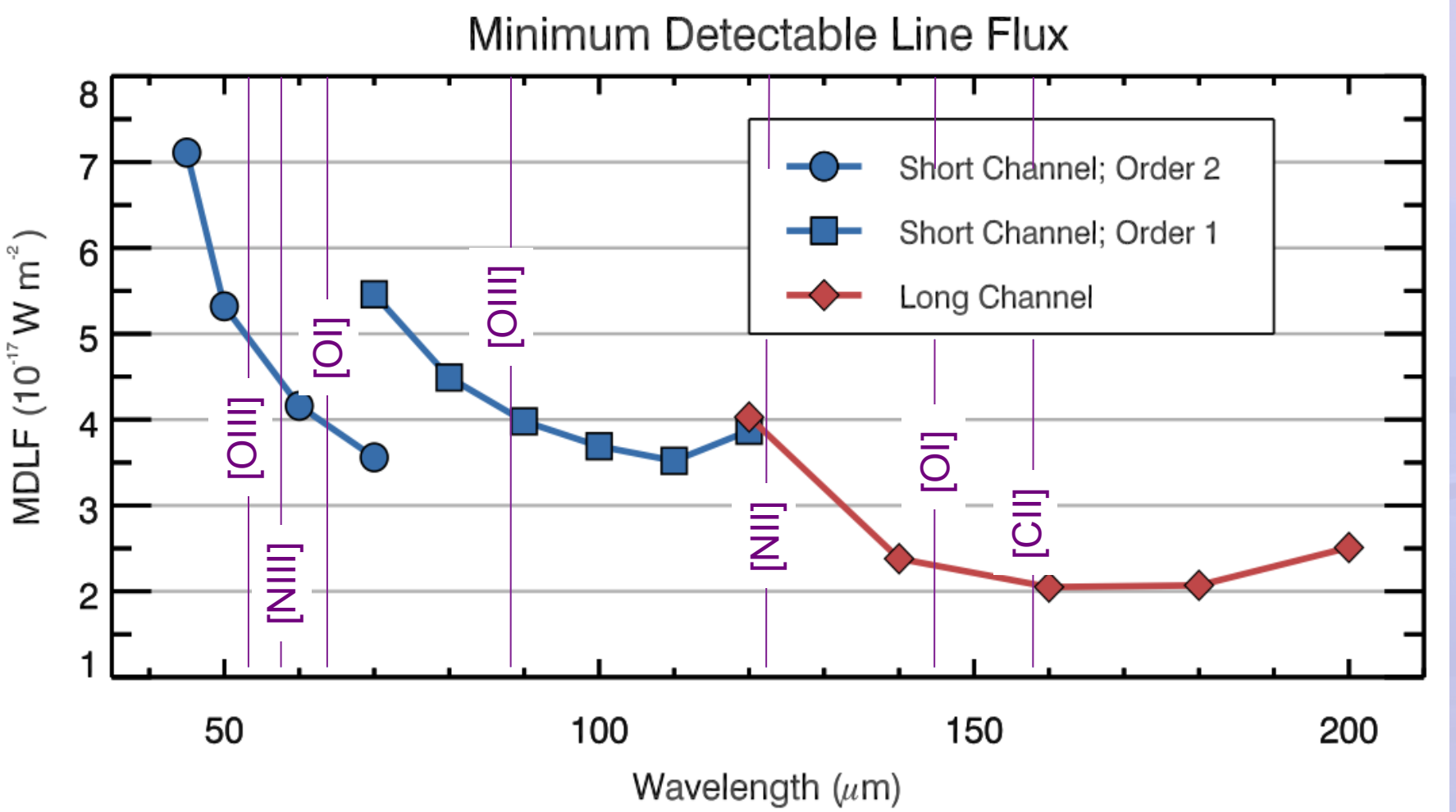
After Installing new Baffle - Signal reduced by factor 3-4





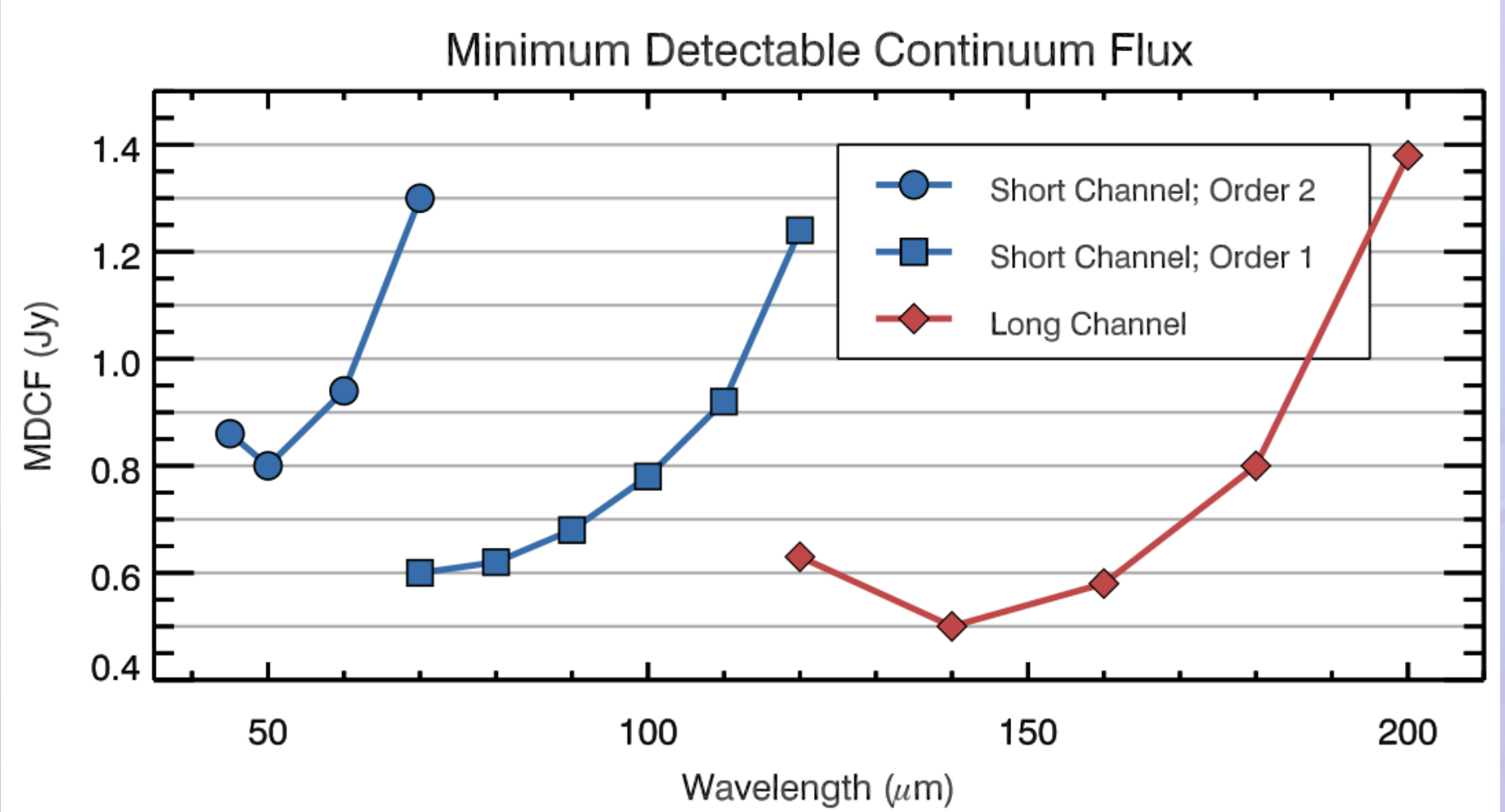
Performance: Expectation

4σ, 15 min on source



Performance: Expectation

4σ, 15 min on source



Looking ahead …

Goal: 2014-03-06

16. Feb	17. Feb	18. Feb	19. Feb	20. Feb	21. Feb	22. Feb
	Presidents Day	OC2A FORCAST	OC2A FORCAST	OC2A FORCAST	OC2A FORCAST	
23. Feb	24. Feb	25. Feb	26. Feb	27. Feb	28. Feb	01. Mrz
	Remove FORCAST	Install FIFI-LS	Install FIFI-LS	Install FIFI-LS	Install FIFI-LS	
02. Mrz	03. Mrz	04. Mrz	05. Mrz	06. Mrz	07. Mrz	08. Mrz
	EMI Line Ops	Line Ops	Line Ops	Engineering Flight	Contingency	
09. Mrz	10. Mrz	11. Mrz	12. Mrz	13. Mrz	14. Mrz	15. Mrz
	FIFI-LS Commissioning Part 1	Contingency	FIFI-LS Commissioning Part 1	Remove FIFI-LS	Install EXES	

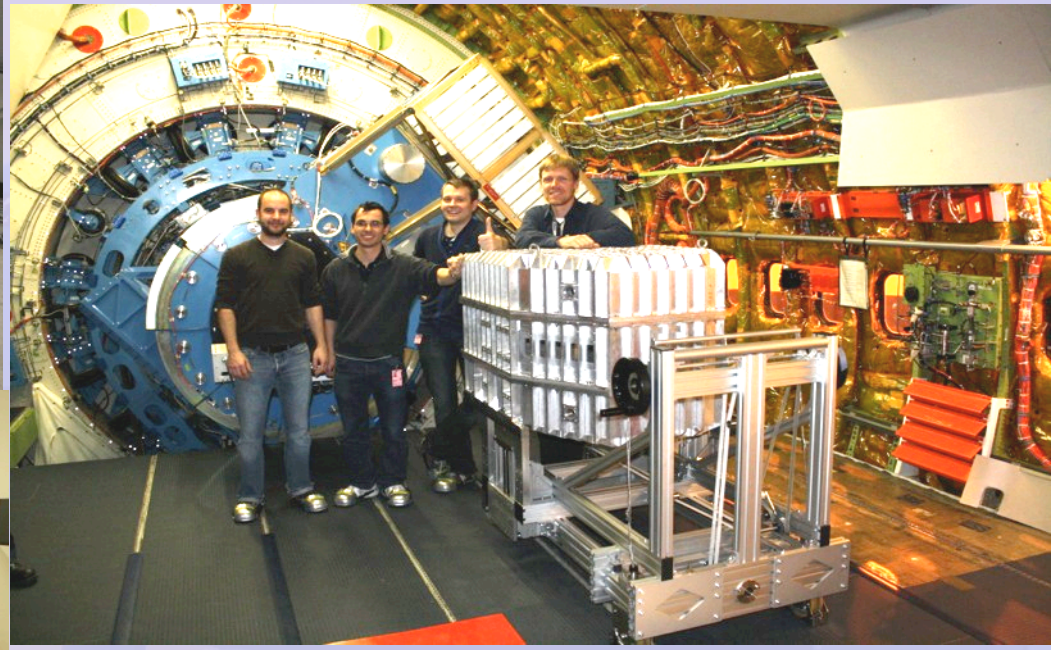
Commissioning timeline II, April 2014

- 2 weeks
- 1 Engineering flight
- 3 Commissioning flights
- 1 Community Science Verification Flight
- 2 days to install (and balance)
- 1 night for line ops

13. Apr	14. Apr	15. Apr	16. Apr	17. Apr	18. Apr	19. Apr
	Remove FLIPO	Install FIFI-LS	Install FIFI-LS	Line Ops	FIFI-LS Commissioning Part 2	
20. Apr	21. Apr	22. Apr	23. Apr	24. Apr	25. Apr	26. Apr
	FIFI-LS Commissioning Part 2	Contingency	FIFI-LS Commissioning Part 2	Contingency	FIFI-LS Commissioning Part 2	
27. Apr	28. Apr	29. Apr	30. Apr	01. Mai	02. Mai	03. Mai
Remove FIFI-LS	Install FORCAST	Install FORCAST	OC2C FORCAST	OC2C FORCAST	OC2C FORCAST	

E. Young: 2012-09-27

Dec. 2012: Maneuver Tests and Fit Checks at DAOF



- Maneuver Test with dummy
- Fit check at the TASS with dummy
- Roll into the aircraft with dummy
- Pressure coupler pump test

Pressure Testing of Essential Containers

Looking ahead …

- 13 Oct. 28/29 Pre Shipment Review passed
- 13 Nov. 11 Shipping on schedule
- 13 Dec. Functional Test @DAOF
- 13 Dec Cold Test @ DAOF
- 14 Jan Fit Check, Cold Test
- 14 Feb SIL
- 14 Mar Commissioning 1
- 14 Apr Commissioning 2, Science Verification Flight
- 14 Fall optional observing flights
- 15 more observing flights
- 15 Summer Transition to FSI

Thank You !