The Brazilian Tunable Filter Imager (BTFI for SOAR)

Claudia Mendes de Oliveira (for the BTFI team)

Collaborating Institutions

- University of São Paulo, Brazil (IAG, Poli)
- INPE
- LNA
- UESC, U. Rio Grande

- Laboratoire d'Astrophysique de Marseille, France (LAM)
  - SESO Etalon controller
- University of Montréal, Canada (LAE)
  - EMCCD controller

SOAR and CTIO

Instrument Team

BTFI project

- **Keith Taylor (USP) – Instrument Scientist and Manager**
- **Rene Laporte (INPE) – Mechanical and Optical Engineer**
- **Denis Andrade (USP) – EE**
- **Ana Molina and Fabio Fialho (USP) - EE**
- **Bruno Quint and Alvaro Calasans (USP) – Instrument Physicists**
- **Renato Severo (Bajé) - Software**
- **Fabricio Ferrari (Rio Grande) – High-level software**
- **Sergio Scarano (USP) - Astronomer**
- **Javier Ramirez Fernandez (Poli/USP) - EE**

Science Team

- Claudia Mendes de Oliveira (USP)
- Henri Plana, Jaqueline Vasconcelos and Adriano Cerqueira (UESC)
- Francisco Jablonski (INPE)
- Laerte Sodré Jr. and João Steiner (IAG/USP)
- François Cuisinier and Denise Goncalves (Obs. Valongo)

Consultants

- Dani Guzman (AstroInventions) – Electronics/Detectors
  - Systems Engineer
- Damien Jones (Prime Optics, Qld) – Optical Design
- Olivier Daigle (U. Montreal) - Detectors
- Sebastien Blais-Ouellette (PhotonEtc) – iBTF physicist
- Jean-Luc Gach (LAM) – Optics/Electronics

The BTFI instrument is in fact two instruments in one:

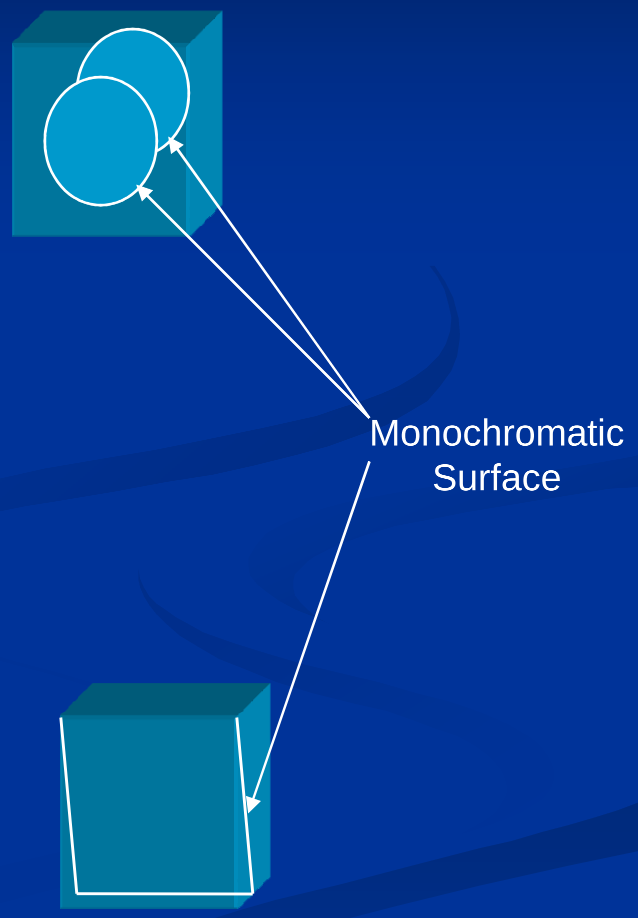
1) A Fabry Perot instrument

   High resolution mode: $2{,}000 < R < 35{,}000$

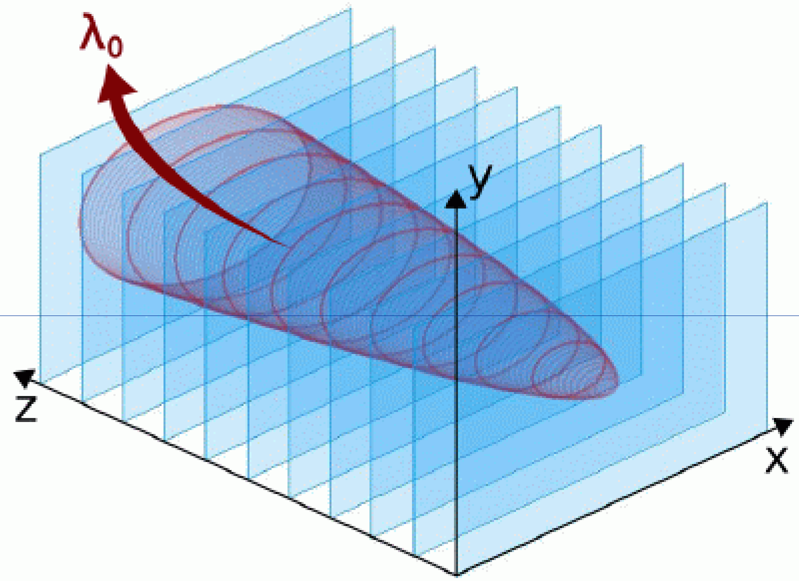
2) An iBTF (Imaging Bragg Tunable Filter)

Hyperspectral Imaging Techniques used in BTFI

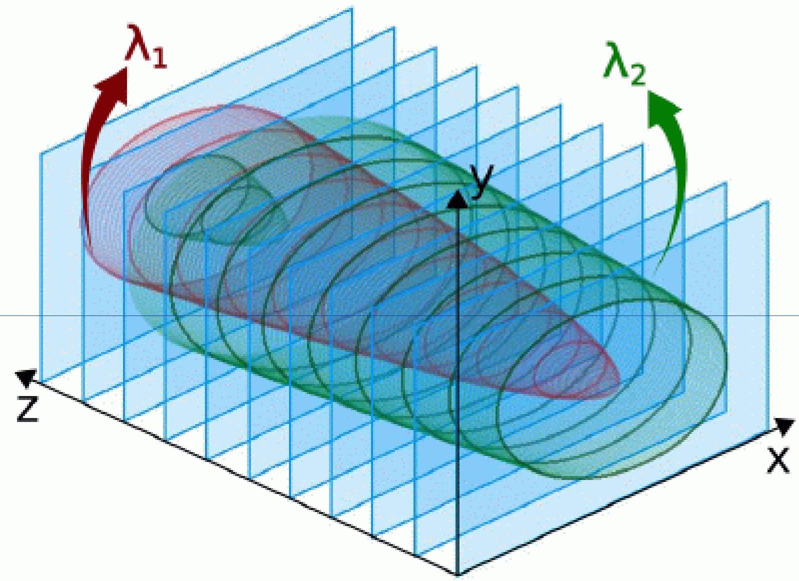
- Fabry Perot (iFP):
  - Complex technology (QI)
  - Easy implementation
  - Parabolic (nested) phase shift
- Imaging Bragg Tunable Filter (iBTF)
  - New technique (VPH gratings)
  - Simple implementation
  - Linear phase shift



Fabry-Pérot - Phase issue



Monochromatic surface within a data-cube.

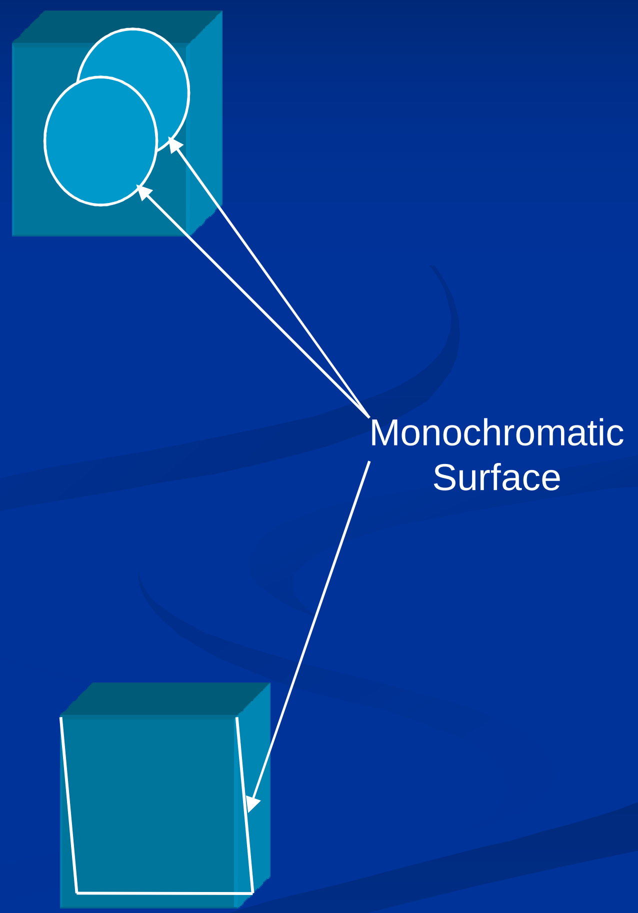


Data-cube containing two monochromatic surfaces.

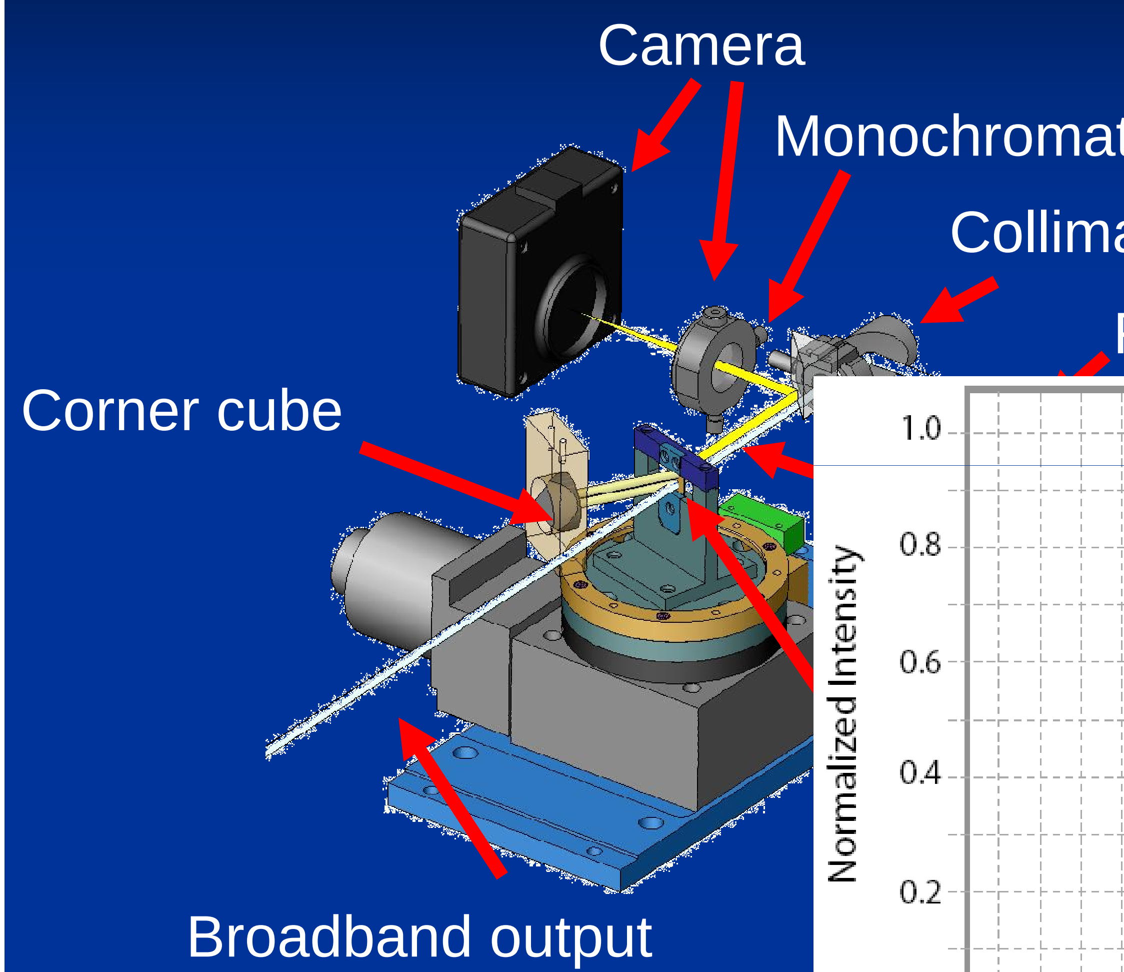
Hyperspectral Imaging Techniques used in BTFI

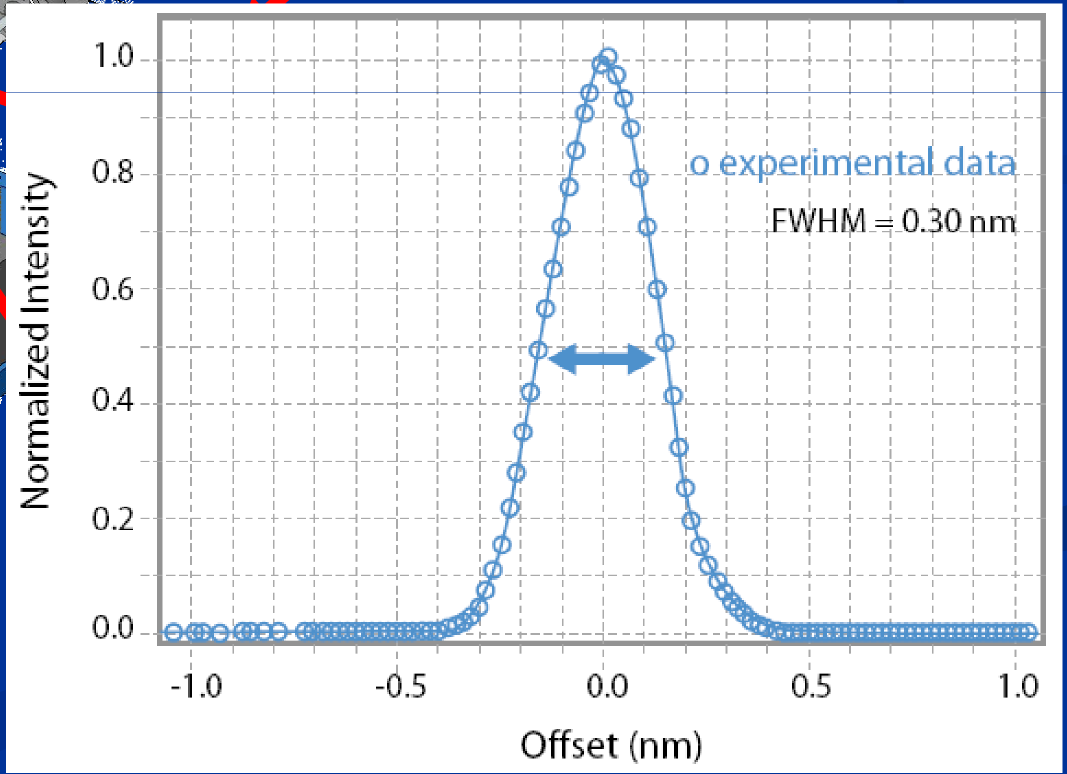
- Fabry Perot (iFP):
  - Complex technology (QI)
  - Easy implementation
  - Parabolic (nested) phase shift

- Imaging Bragg Tunable Filter (iBTF)
  - New technique (VPH gratings)
  - Simple implementation
  - Linear phase shift



The original implementation:





Target Specifications for the SOAR BTFI

- Top-level design performance guidelines for BTFI
  - Wavelength range: 0.4–1.0 **µm**
  - Field of view: ~3’ x 3’ (GLAO & SL)
    - $1{,}600^2$ (16 **µm** pixel) EMCCD (e2v – L3 device)
    - Allows photon counting and rapid-scanned data cubes
  - Spatial sampling: ~0.12 arcsec
  - Spectral resolution: 25-3000 (iBTF) + 2,000-35,000 (FP)

Advantages of BTFI on SOAR

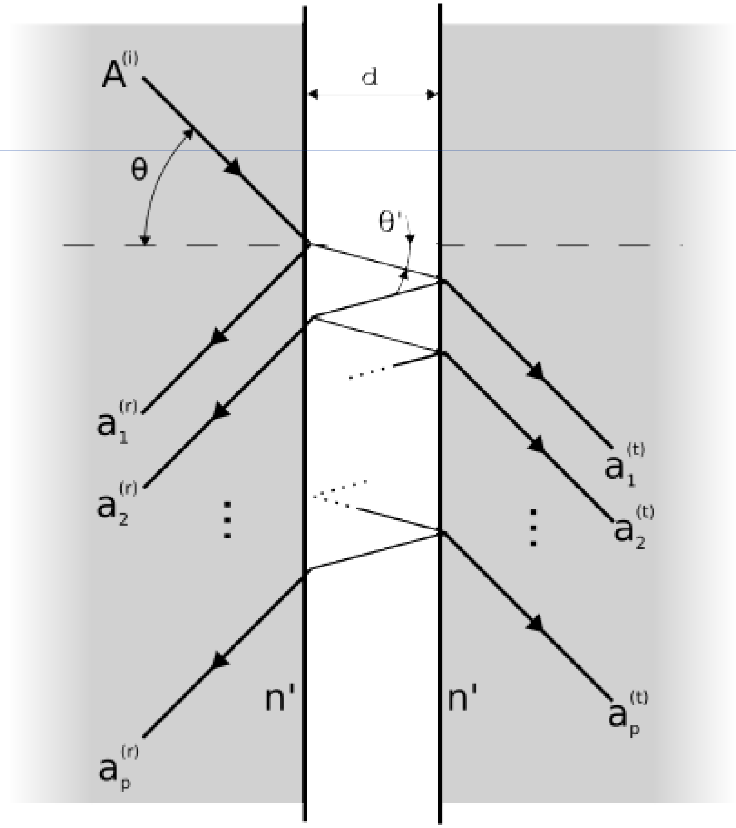
- What is different in this instrument?
  - It combines a Tunable Filter (iBTF) with a FP
    - Large range of resolutions, 25 < R < 35000
  - Capability for correcting for seeing (PSF) and transparency variations
    - Twin camera system (using iBTF's 0th order channel)

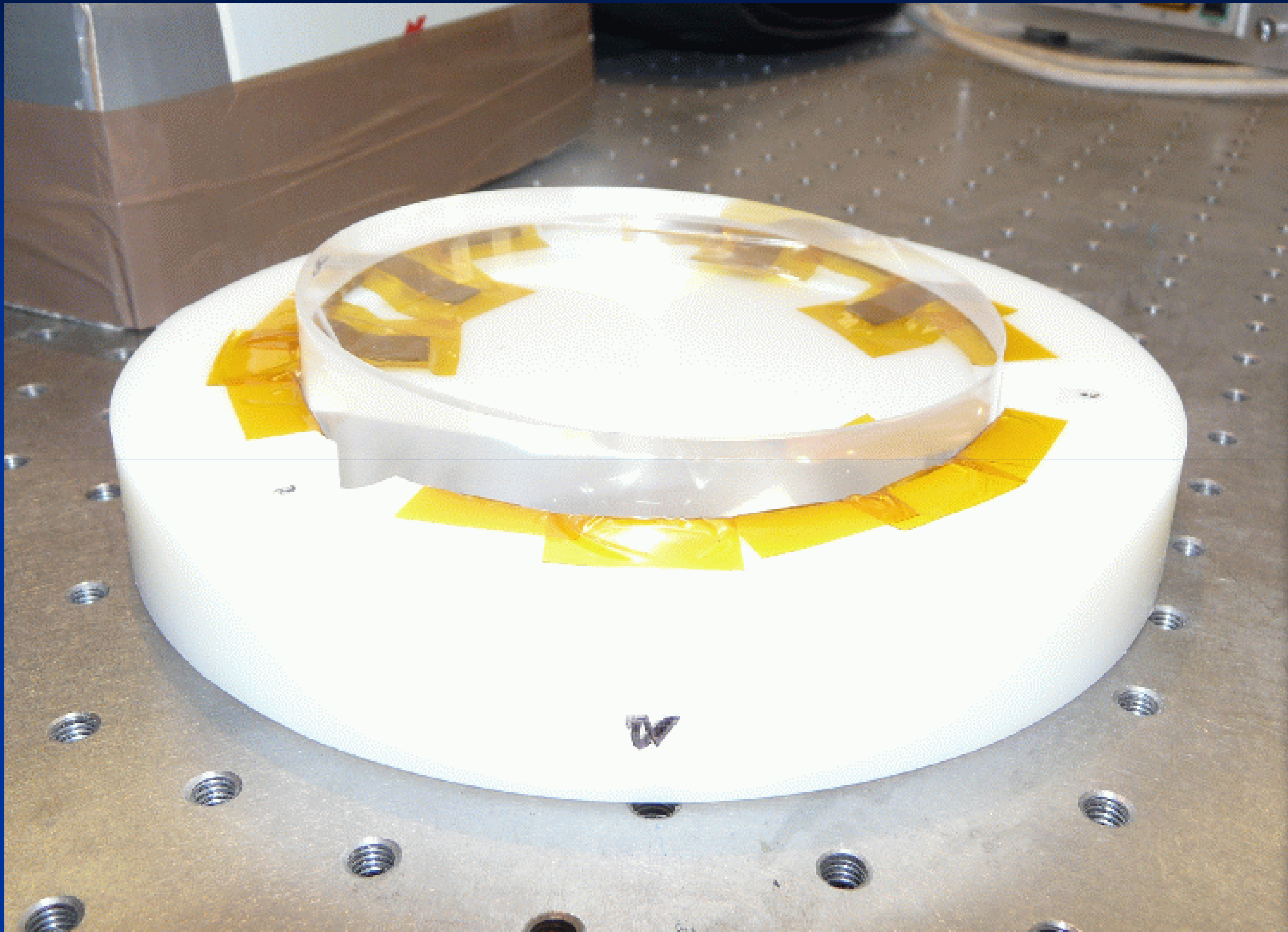
- Use in SAM's GLAO-fed mode:
  - GLAO corrected field: BTFI will be the first of such instrument to work within a GLAO-corrected (3 x 3 arcmin) field.
  - Excellent spatial resolution, not achieved with any other such instrument.
  - Optimal use of SOAR's investment in high spatial resolution.

Tunable Filter Concepts
1. Fabry-Perot (FP)

Fabry-Pérot - Overview

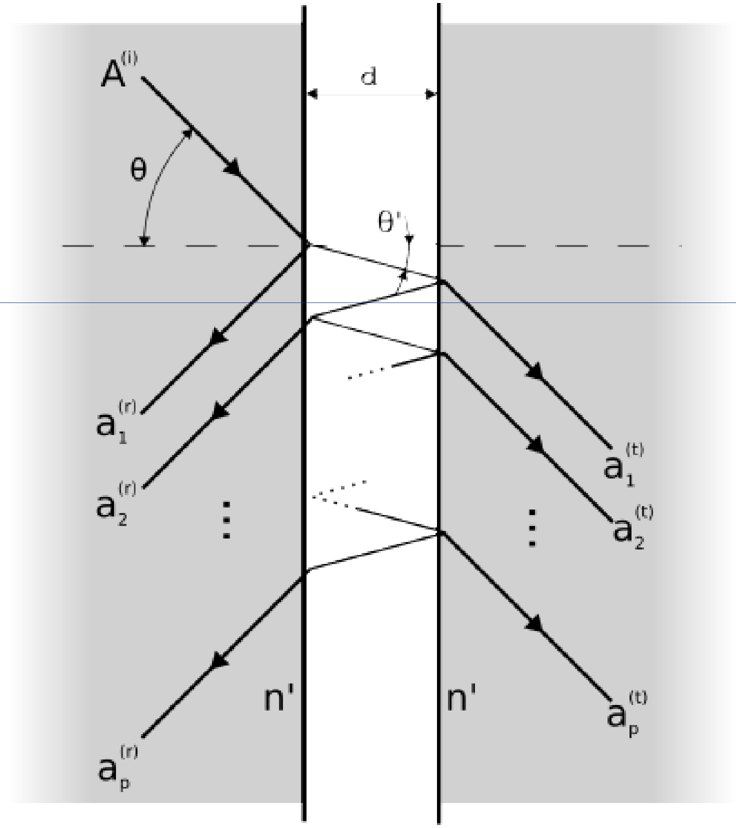
- Two parallel glass plates
- Internal surface with high reflectance
- Interference of a high number of waves
- Interference pattern with axial simmetry (rings)





Fabry-Pérot - Overview

- Two parallel glass plates
- Internal surface with high reflectance
- Interference of a high number of waves
- Interference pattern with axial simmetry (rings)



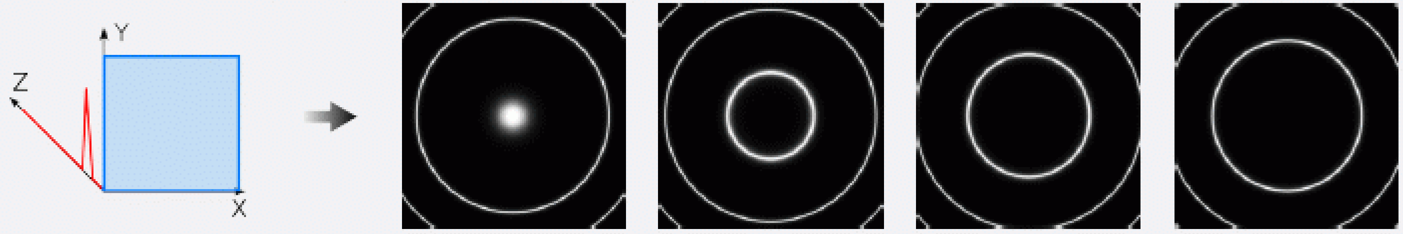
Piezo Actuator

CEDRAT GROUPE

Références	APA 400MML	Unit
Excursion over [-20, +150]V	365	µm
blocked force	189	N
Stiffness in mouvement axis	0.59	N/µm
Mass	56.5	g

Fabry-Pérot - Cubos criados com Illusion

Raw Cube



Spectrum Cube

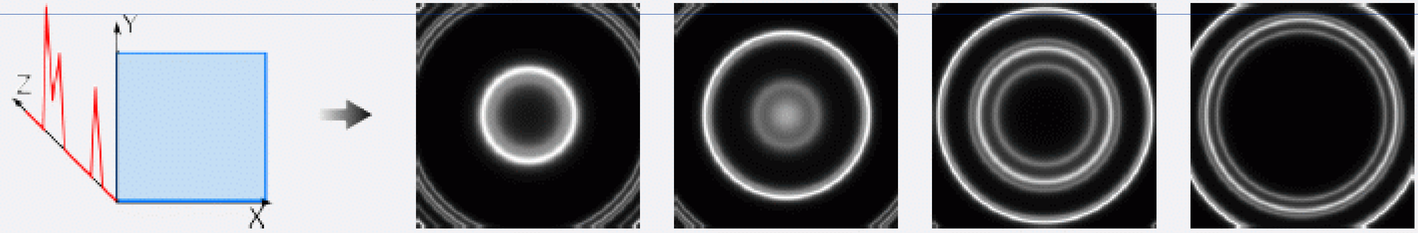
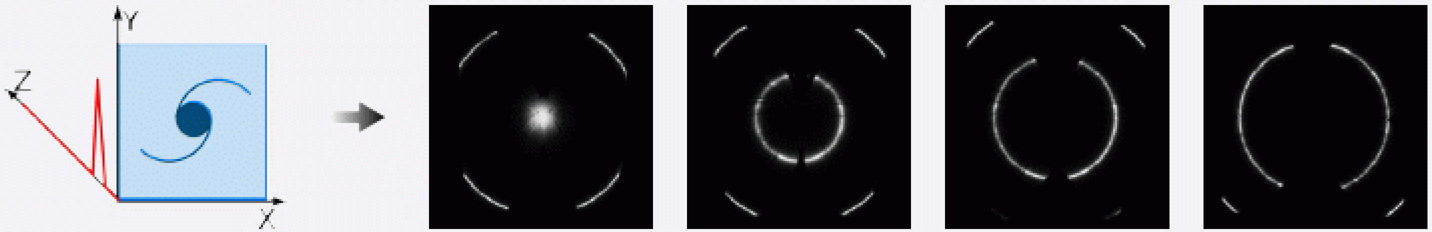
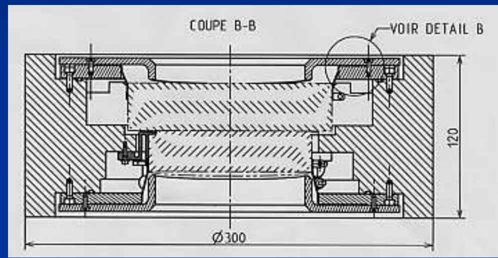


Image Cube

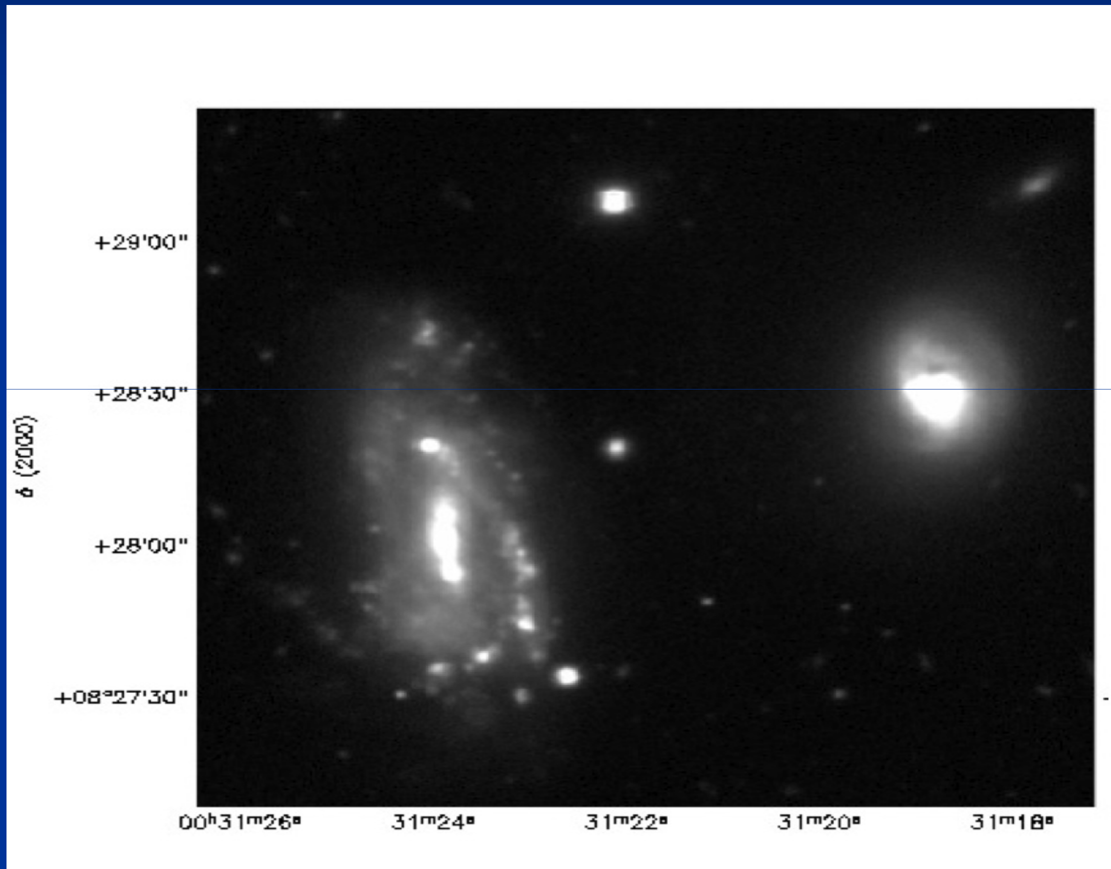


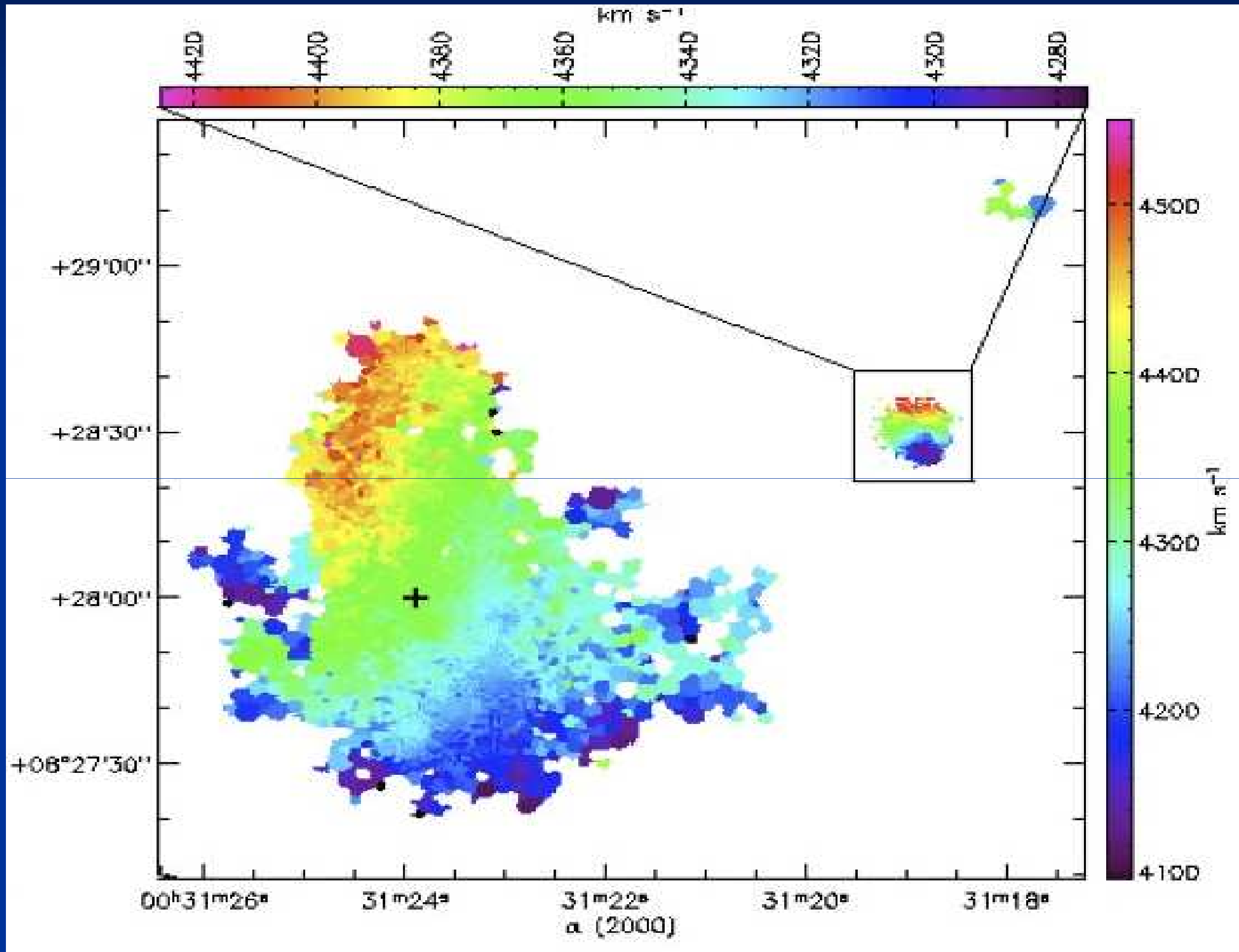
The new SESO etalons



From Jean-Luc Gach (2007)

High resolution arm of BTFI
Velocity fields of extended objects

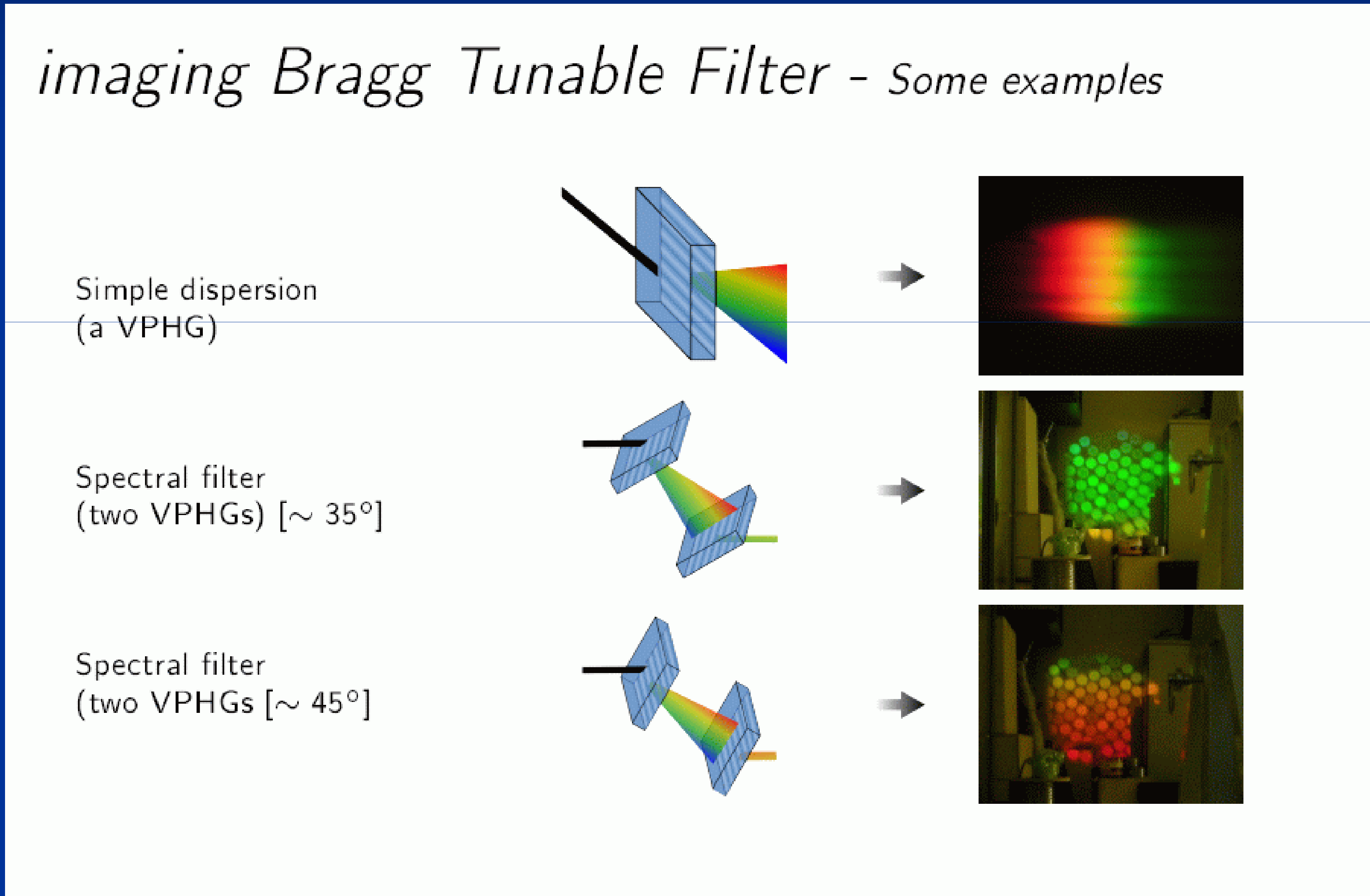




km s⁻¹
4420
4400
4380
4360
4340
4320
4300
4280
+29'00''
+28'30''
+28'00''
+08°27'30''
00ʰ31ᵐ26ˢ
31ᵐ24ˢ
31ᵐ22ˢ
31ᵐ20ˢ
31ᵐ18ˢ
α (2000)
4500
4400
4300
4200
4100
km s⁻¹

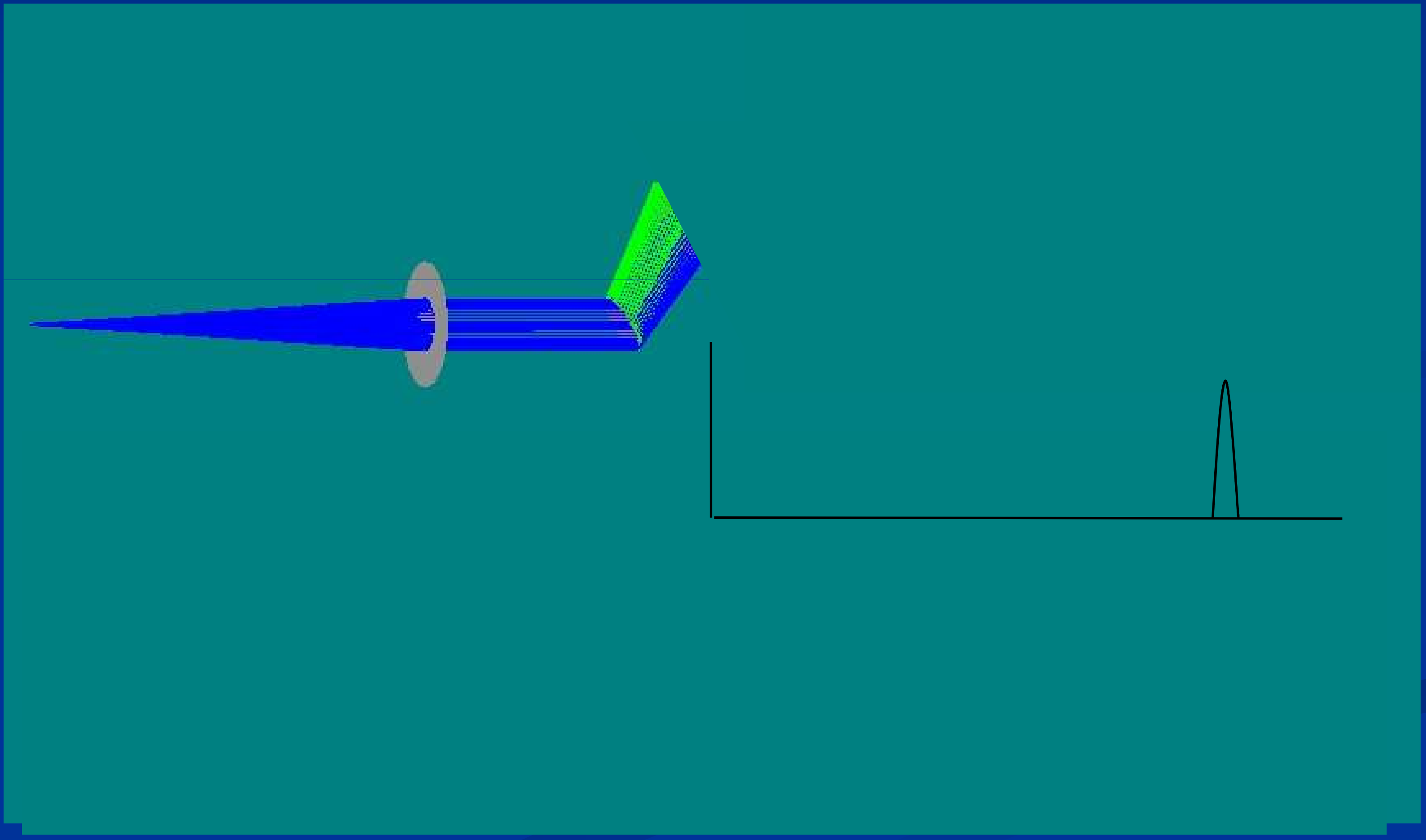
Tunable Filter Concepts

2. Imaging Bragg Tunable Filter (iBTF)



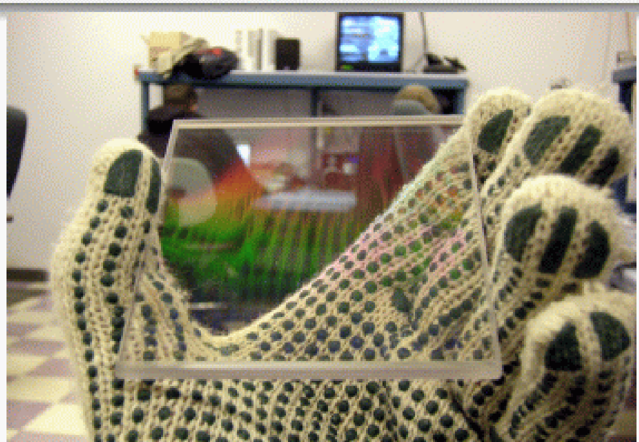
2. Imaging Bragg Tunable Filter (iBTF)

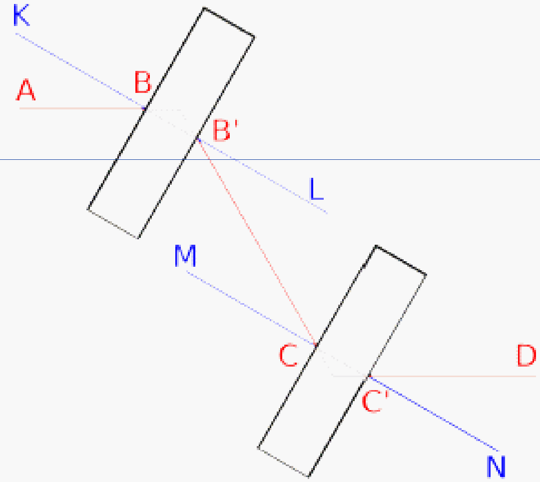
Princípio de funcionamento do iBTF:



imaging Bragg Tunable Filter - General characteristics

- Spectral filter
- Two volume-phase holografic gratings
- The light is dispersed and recombined
- λ is selected by the Bragg condition



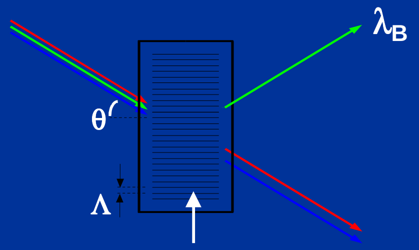


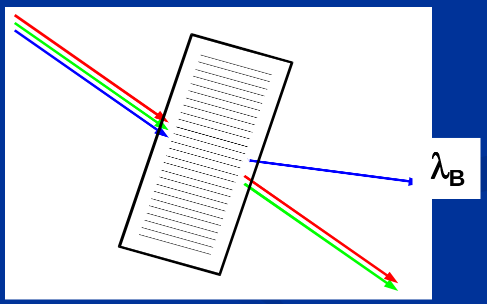
Two parallel VPHGs

VPHs can be used in transmission or reflection

General Facts about Volume Bragg Gratings (VBG)

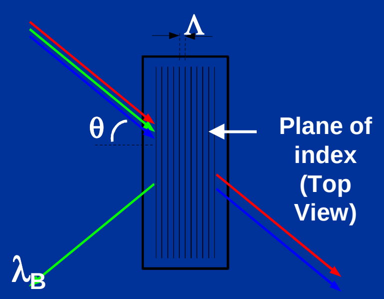
Transmission VBGs

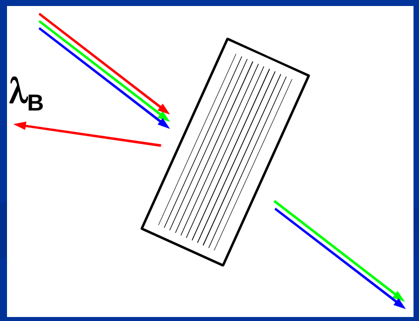




$\lambda_B = 2\,n\,\Lambda \sin(\theta)$

Reflection VBGs



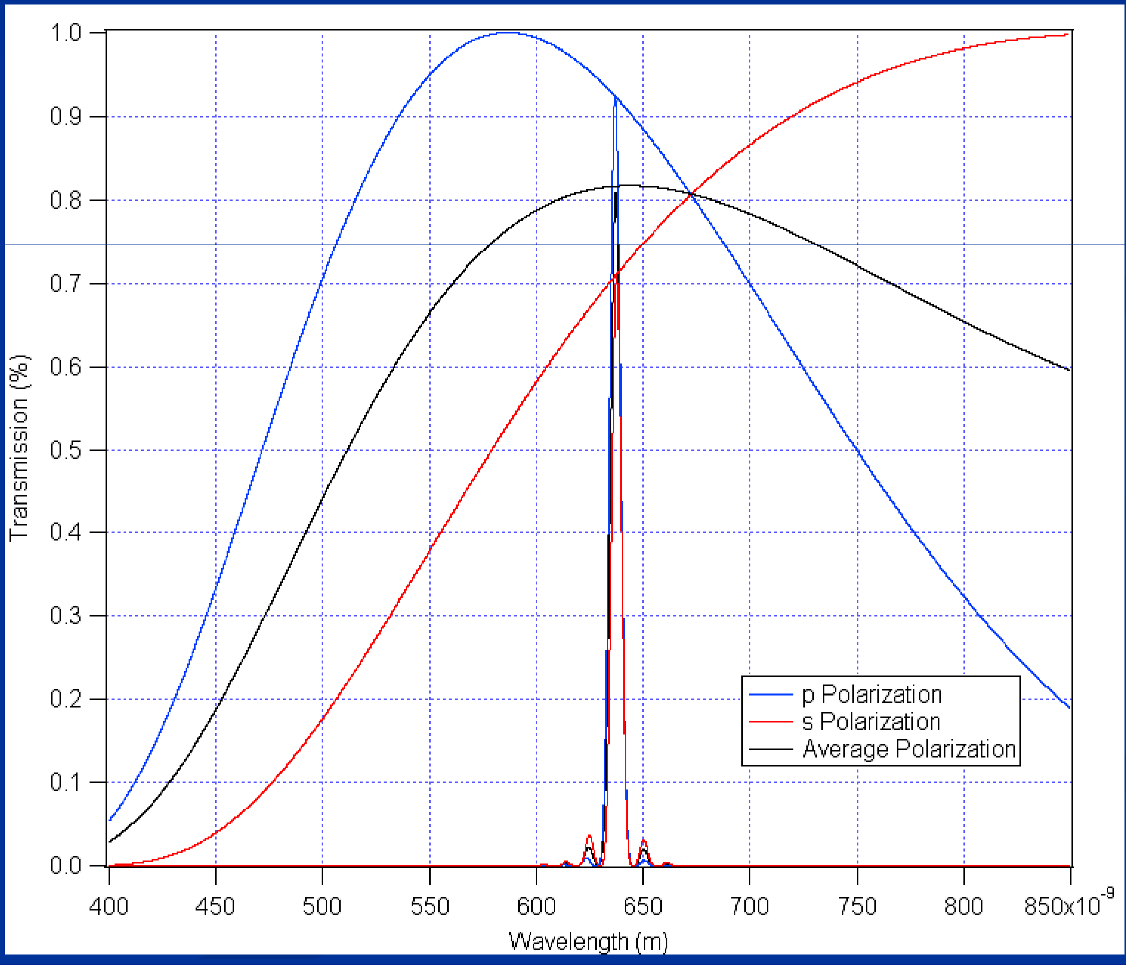


$\lambda_B = 2\,n\,\Lambda \cos(\theta)$

iBTF Transmission (DCG)

R ~100

Tuning$_{25^o\text{-}45^o}$ from λ ~460 to 700nm



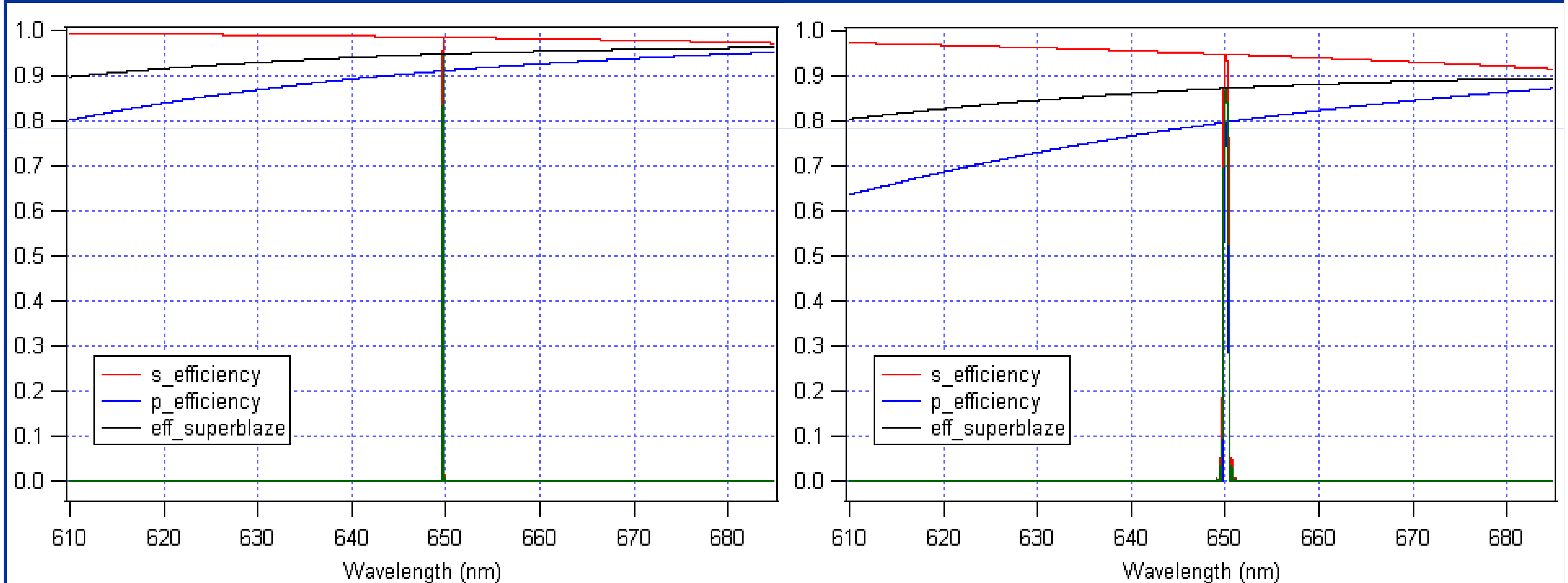
iBTF Reflection (Doped-Glass)

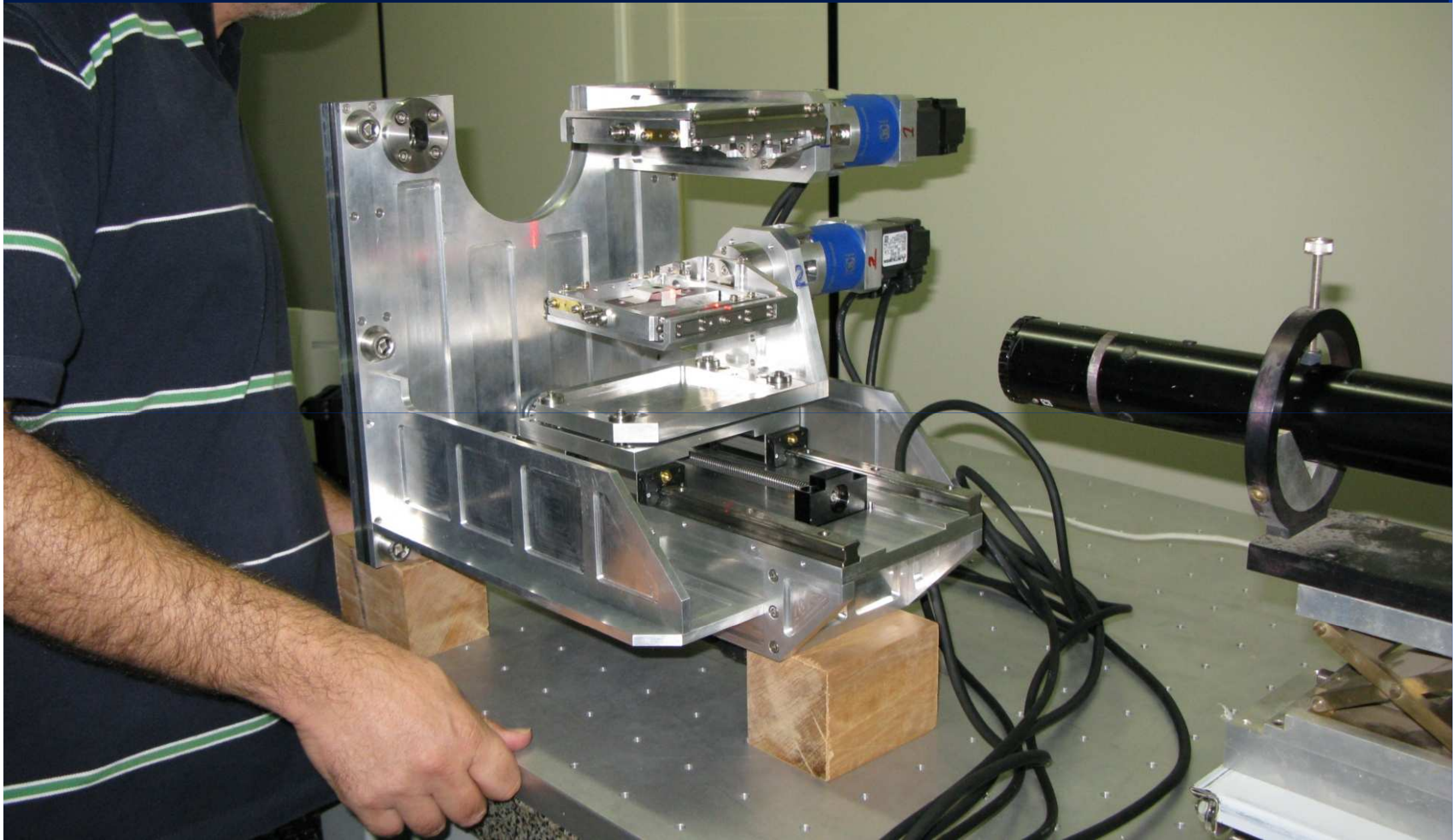
R ~5,400

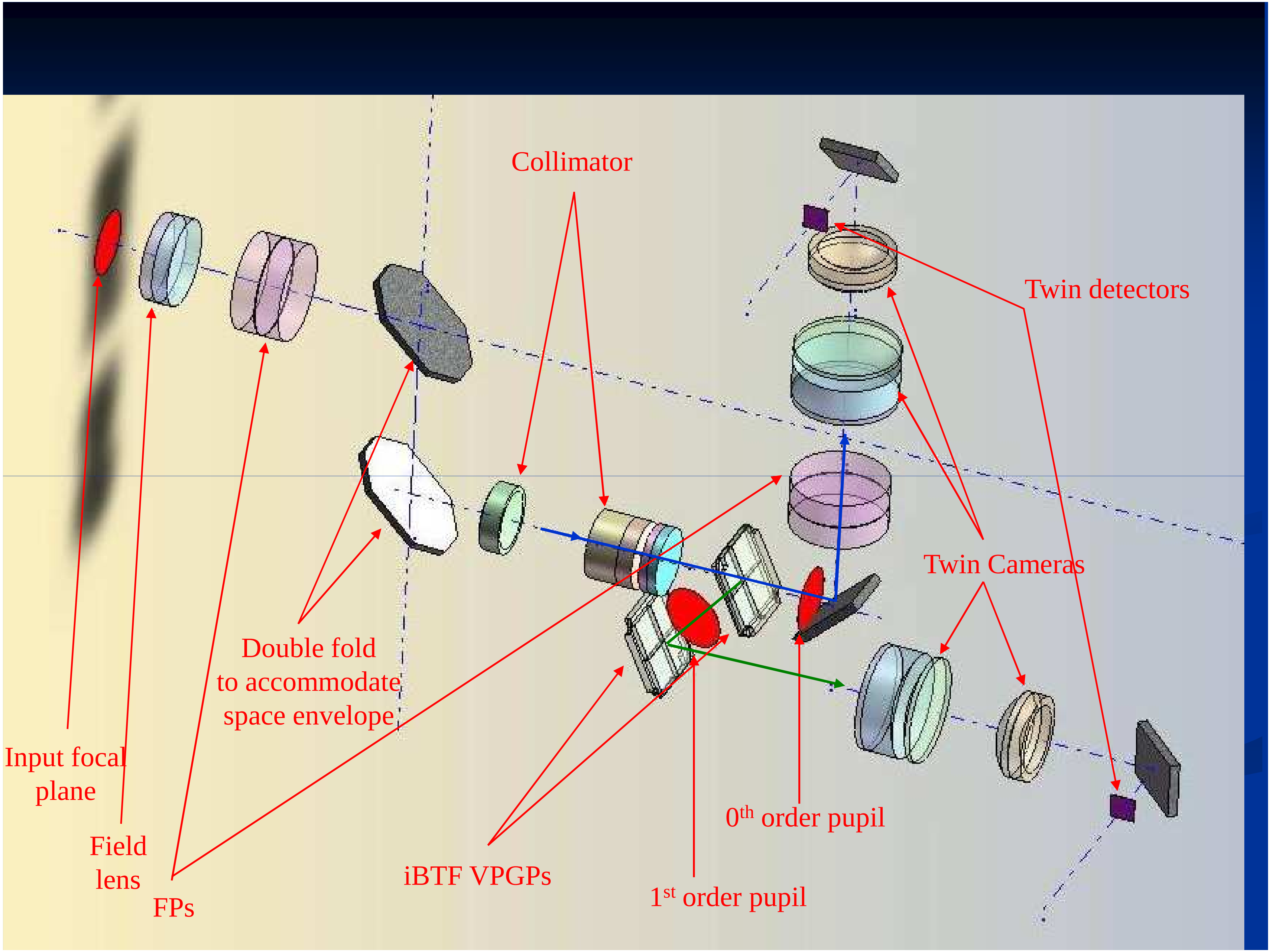
Tuning$_{25^o\text{-}45^o}$ from λ ~620 to 675nm

R ~1,000

Tuning$_{25^o\text{-}45^o}$ from λ ~620 to 675nm







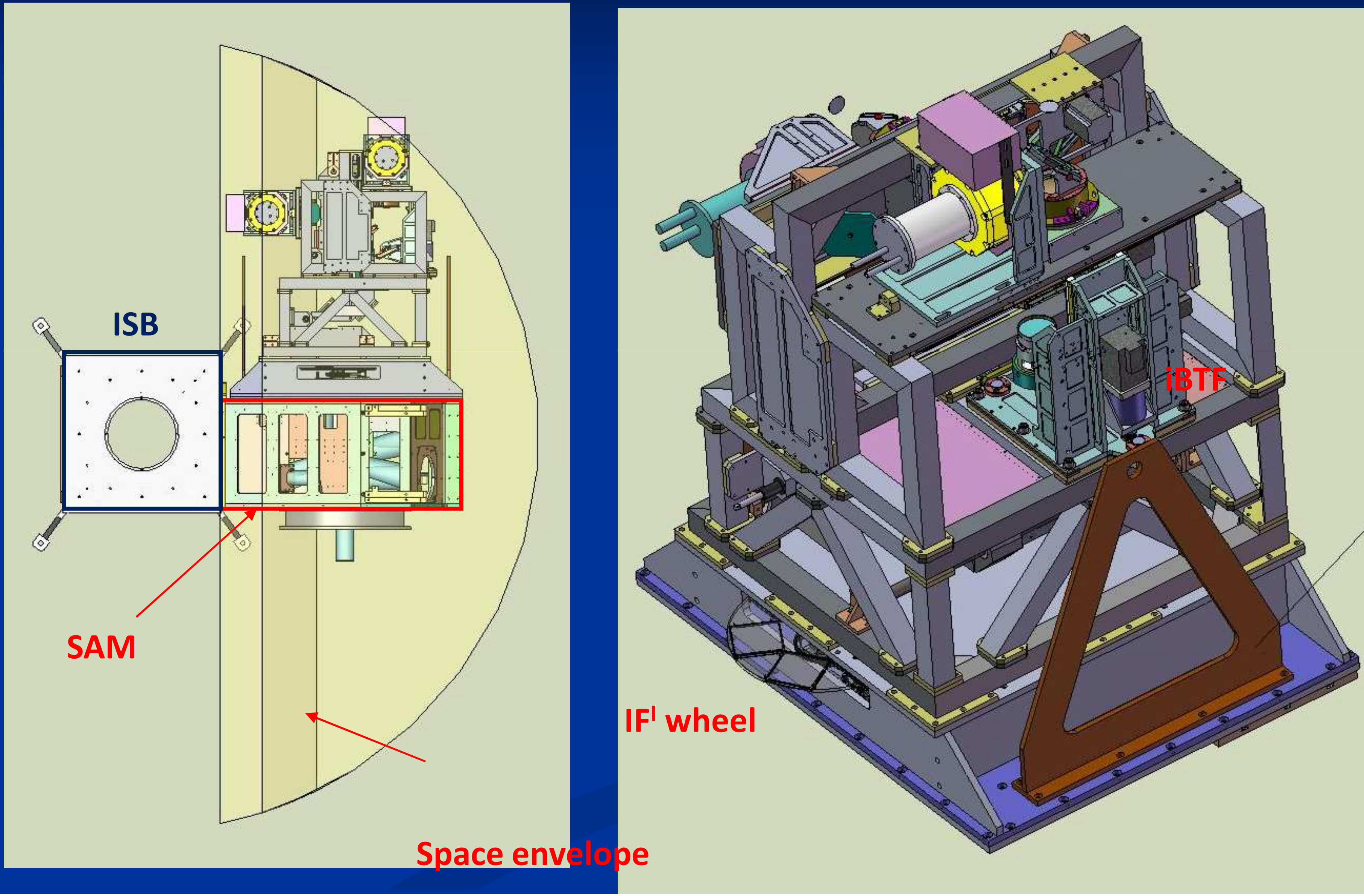
Collimator
Twin detectors
Twin Cameras
Double fold
to accommodate
space envelope
Input focal
plane
Field
lens
FPs
iBTF VPGPs
0th order pupil
1st order pupil

Modes of Operation

Order 1	Order 0
iBTF(Lo-R)	Compl. Channel
iBTF(Lo-R)	FP^P (Hi-R)
Compl. Channel	FP^P (Hi-R)
Compl. Channel	FP^I(Block) . FP^P(Hi-R)

Symultaneous observations with Fabry Perot and iBTF are possible!

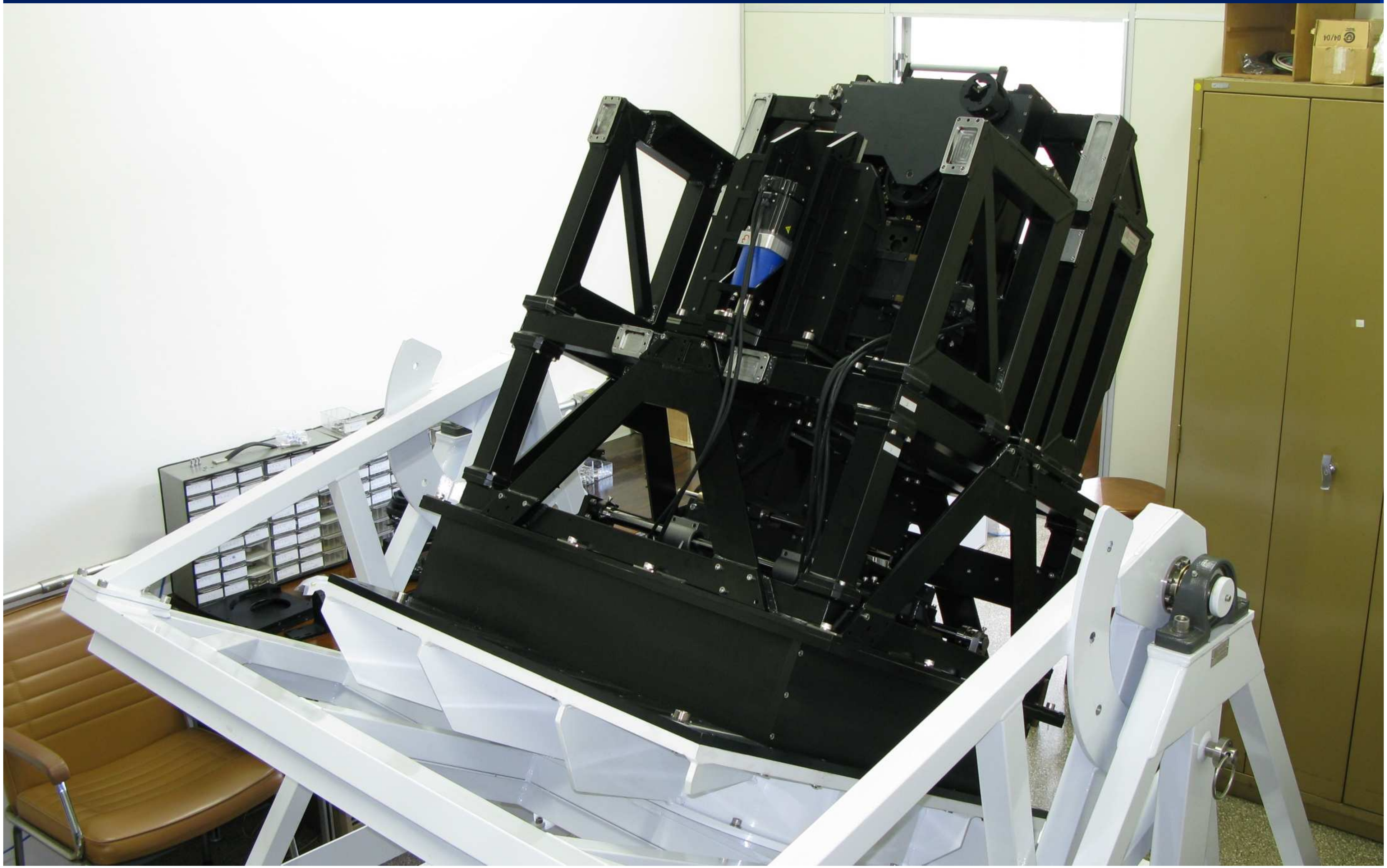
BTFI on SAM



BTFI Milestones

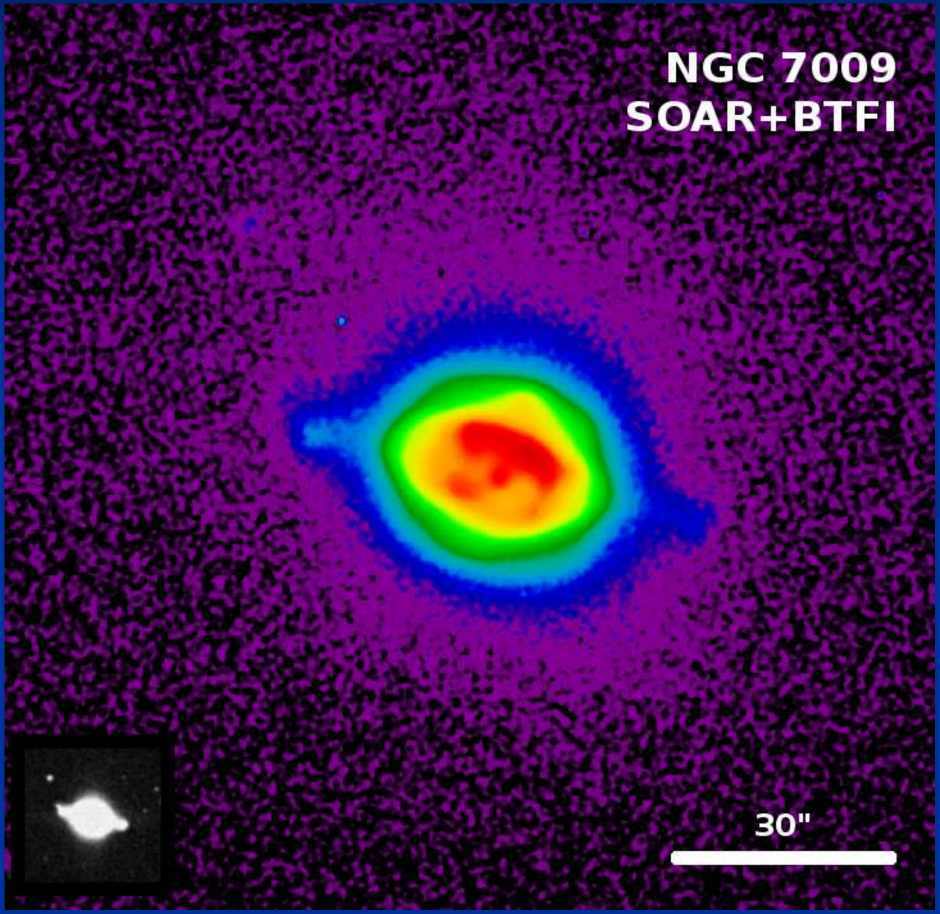
- Feb’07: Start of the project
- July'07: CoDR
- Sep’08: PDR
- Oct’09: Mechanical Integration
- Nov/Dec’09: Electronic Integration
- Mar/April’10: Optical Integration
- May/June'10:   Full Integration and test
- End of June’10: Freighting to SOAR
- End of July’10: Commissioning of iBTF (low resolution mode)

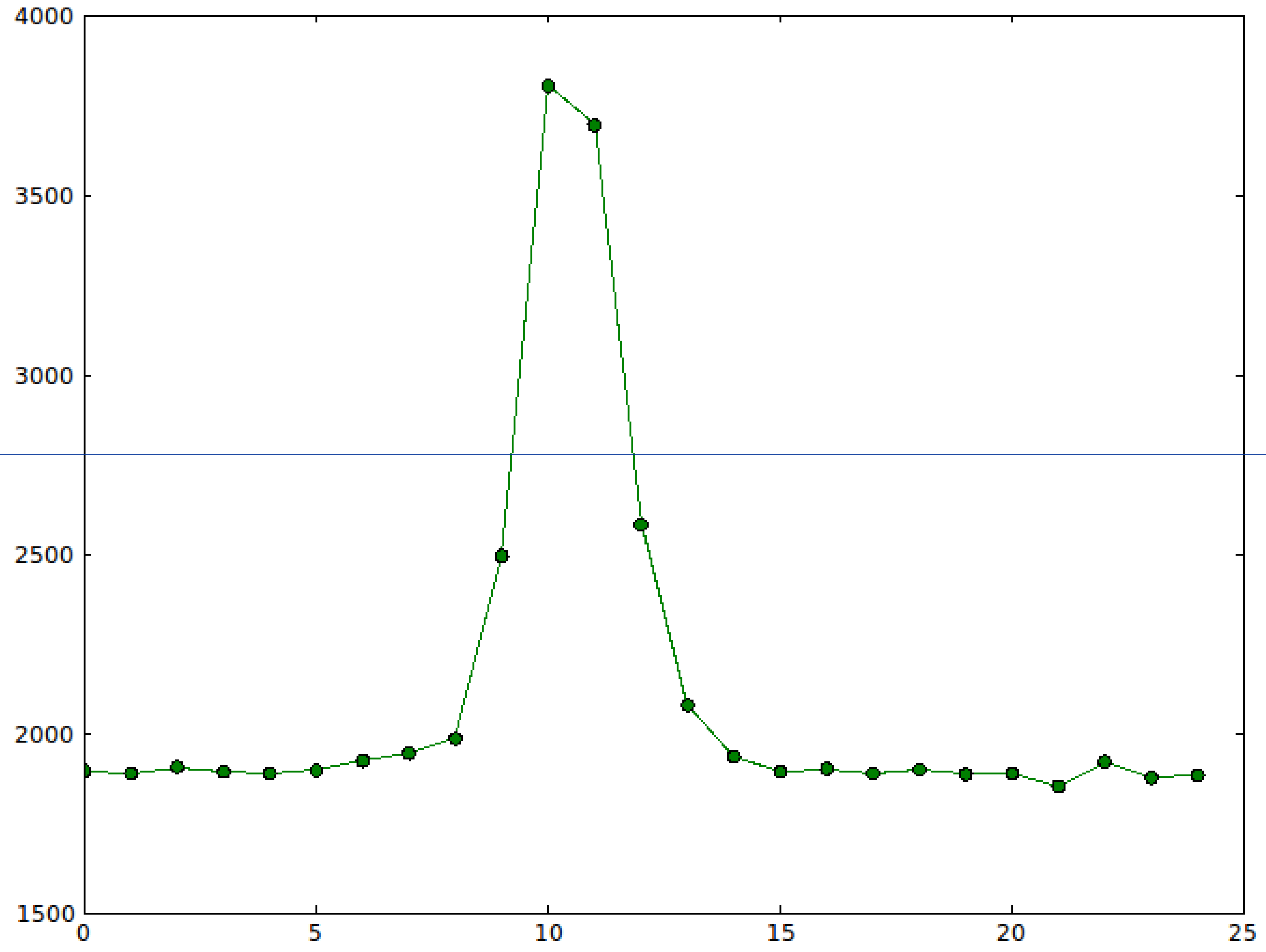
BTFI @ INPE (Sep'09)




MATERIAL SAFETY
DATA SHEETS
12/07/2010 14:40

Test run of BTFI

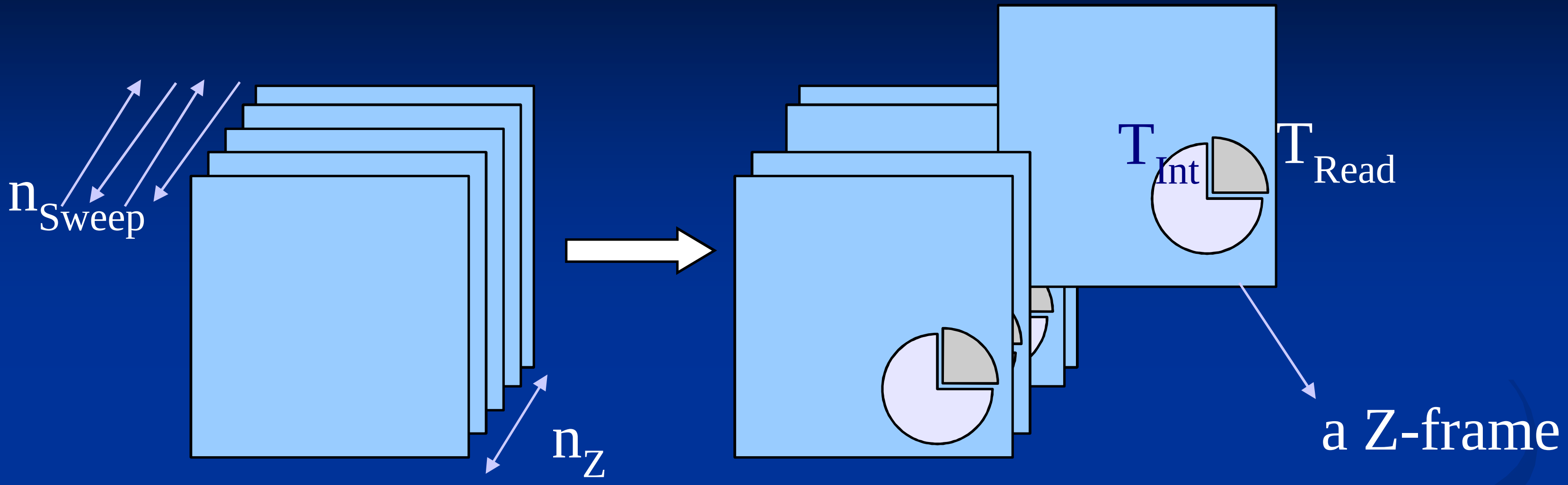



4000
3500
3000
2500
2000
1500
0
5
10
15
20
25

Detectors Issues

- 3 readout modes
  - Classical, slow reads (200kHz)
    - ~3e$^-$ (rms)
  - Amplification mode
    - Analogue, non-photon counting: DQE = QE/2 (Gain-noise)
    - CIC (*important but poorly quantified*) + dark noise
  - Photon counting mode
    - DQE = QE
    - Flux rate <0.1*Frame-rate (typically <0.1Hz/pixel)
      - ⇨ Small dynamic range (non-linearity can be ~corrected, but SNR hit)
    - Trade between CIC + dark noise
- Smaller format EMCCDs had frame-store but ***NOT*** the 1600^2 version:
  - What effect on CIC noise? – seems OK
  - Any other issues? – seems OK (tbc)

Modelled Observational Scenario



$T_{exp} = T_{Int} \cdot n_{Sweep}$

$T_{obs} = (T_{Int} + T_{read}).(n_{Sweep} \cdot n_Z)$

Note:

- $T_{Int} \sim 10*T_{read}$ to reduce duty cycle losses to acceptable level
- For PC: Saturation for flux rate > 0.1 cnts/T_{Int}

⇨ Minimize T_{int} & T_{read} ⇨ Maximize n_{Sweep}

Next steps:

- Test cameras and controllers in Canada (till July)
- Shipping of cameras and controllers to SOAR (Aug)
- Next comissioning run in Sep – first time when we may have both cameras working
- Two FPs have been borrowed, one from AAT and one from U. Of Maryland, for use while the SESO etalons are not ready (R=4500 and R=10000).
- Community use in 2012.
- Implementation of SESO etalons in 2012.
- This is all seeing limited. Implemenation with SAM in 2014.

Funding sources:

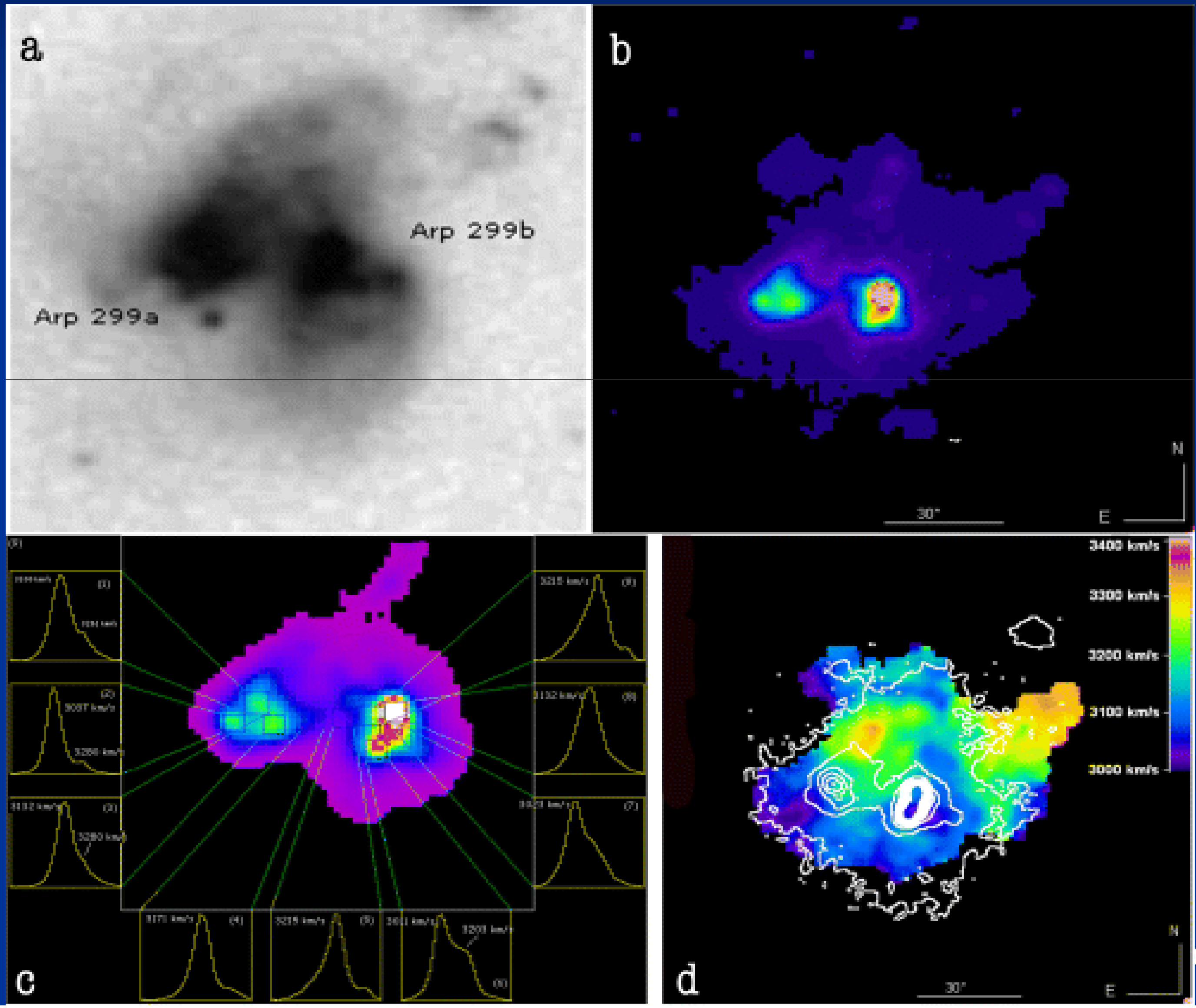
- FAPESP
- CNPq
- INCT-A
- LNA
- Arcus – collaboration Brazil/France

BTFI will allow a variety of scientific projects to be developed

(just a few examples in the following.....)

Velocity fields and metallicity maps of interacting galaxies

2 x 2 arcmin

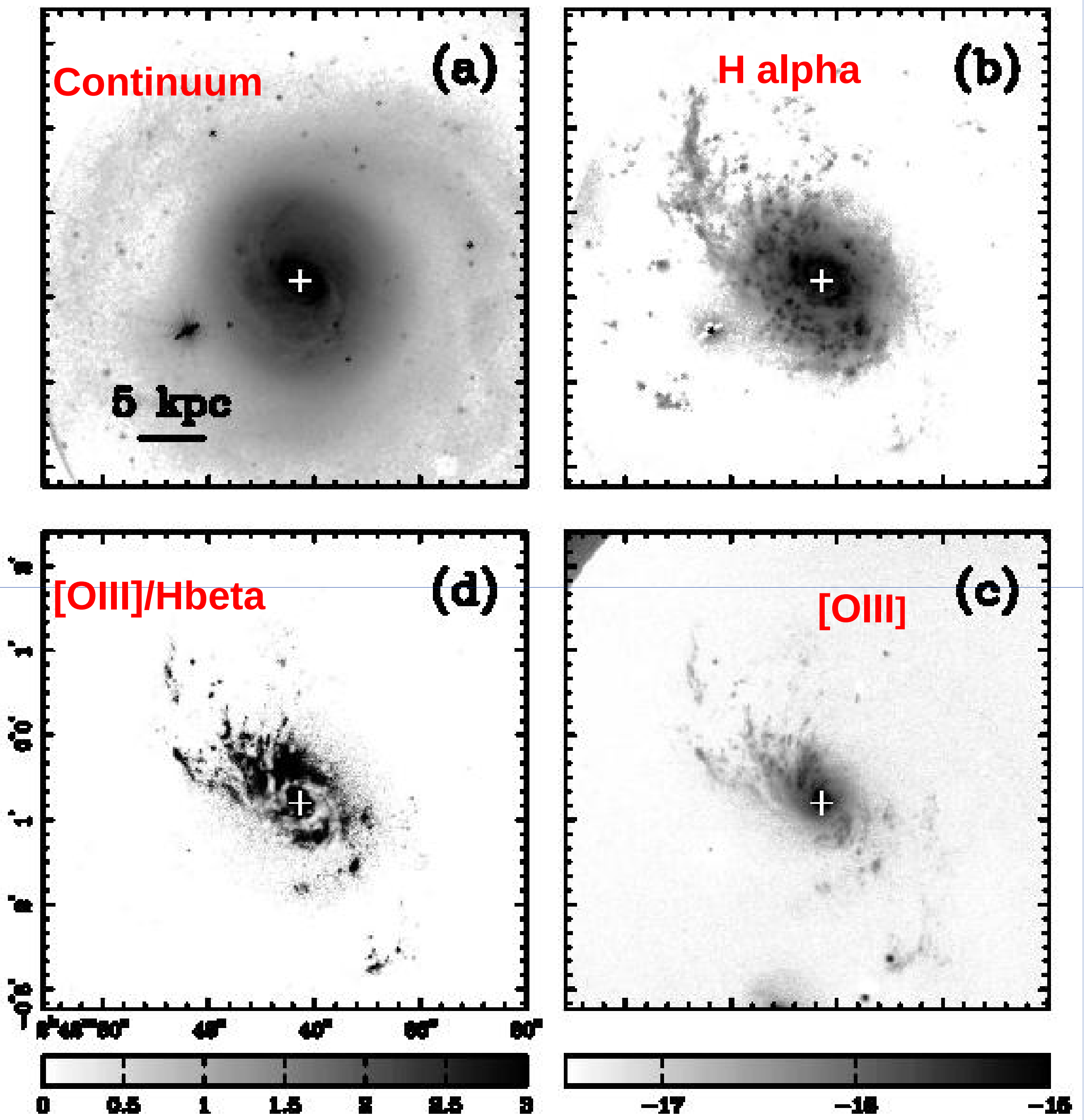


Tunable filter

NGC 1068

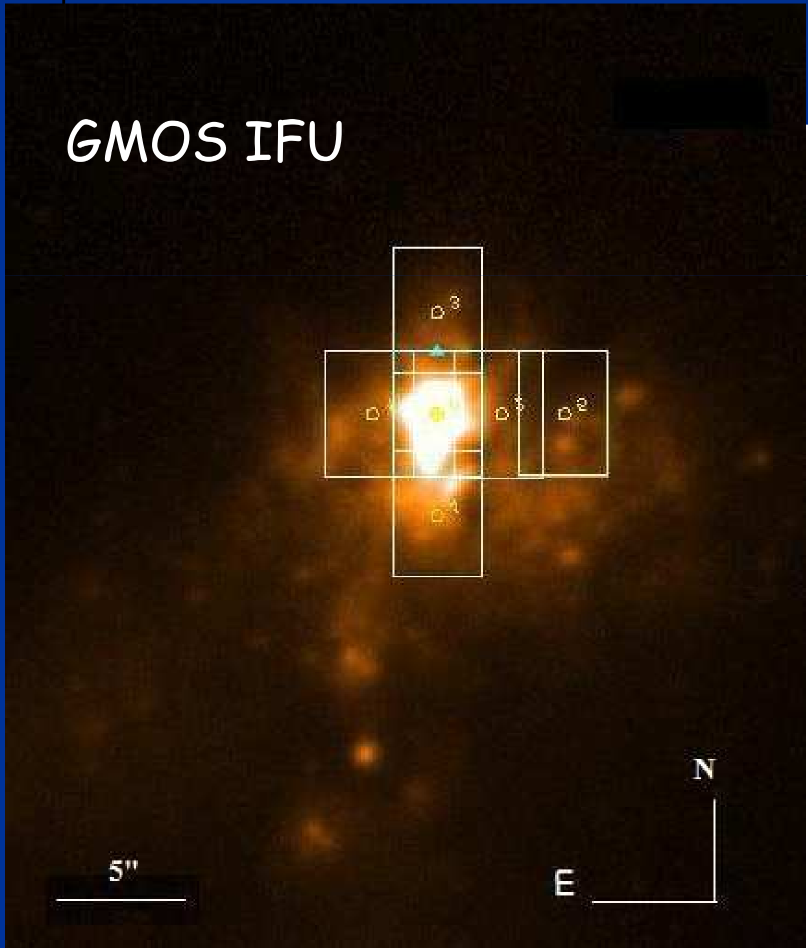
Metallicity gradients in nearby galaxies

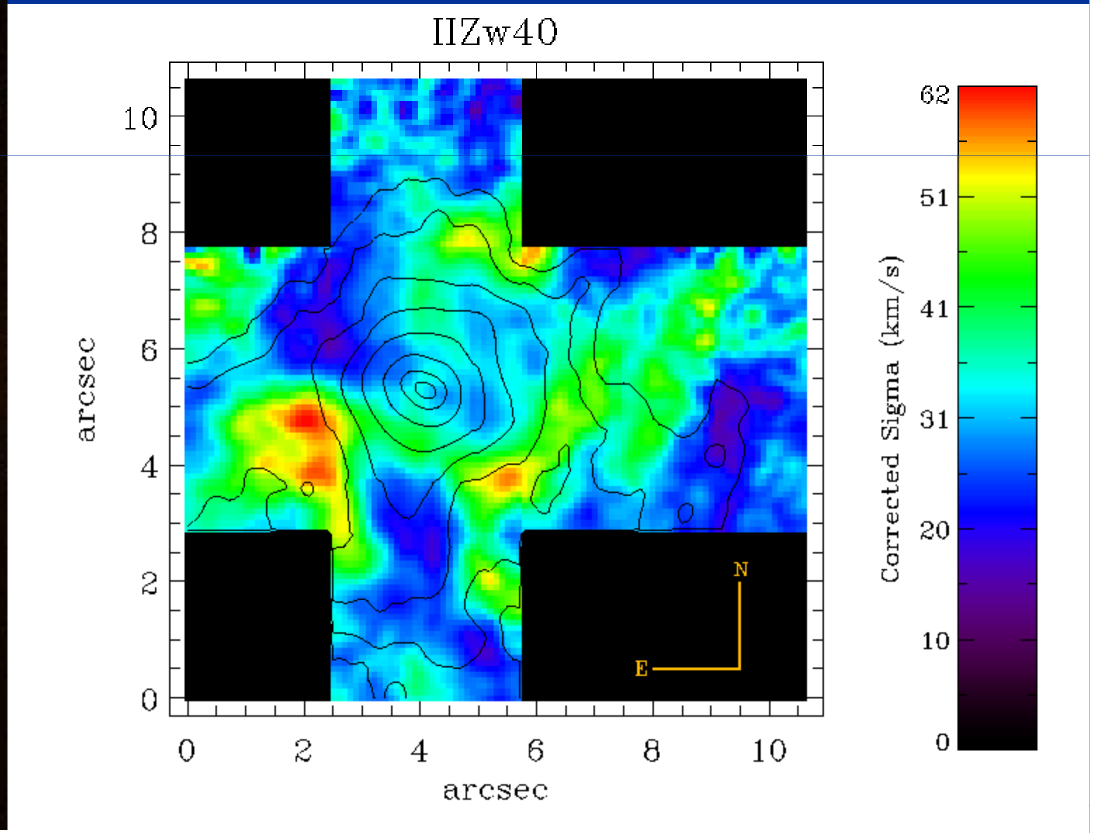
Veilleux et al. 2003



HII Galaxies

* Dwarf galaxies + sites of high SF - motions of GHII regions - high spatial resolution needed.





The centers of active galaxies

Study the nuclear activity of nearby galaxies to understand how mass is transferred from galactic scales down to nuclear scales to feed the supermassive blackhole. Small scale disks in the centers of AGNs have been found . We need to map the streaming motions of gas towards the nucleus, along dusty spiral arms, for a sizeable sample of galaxies.

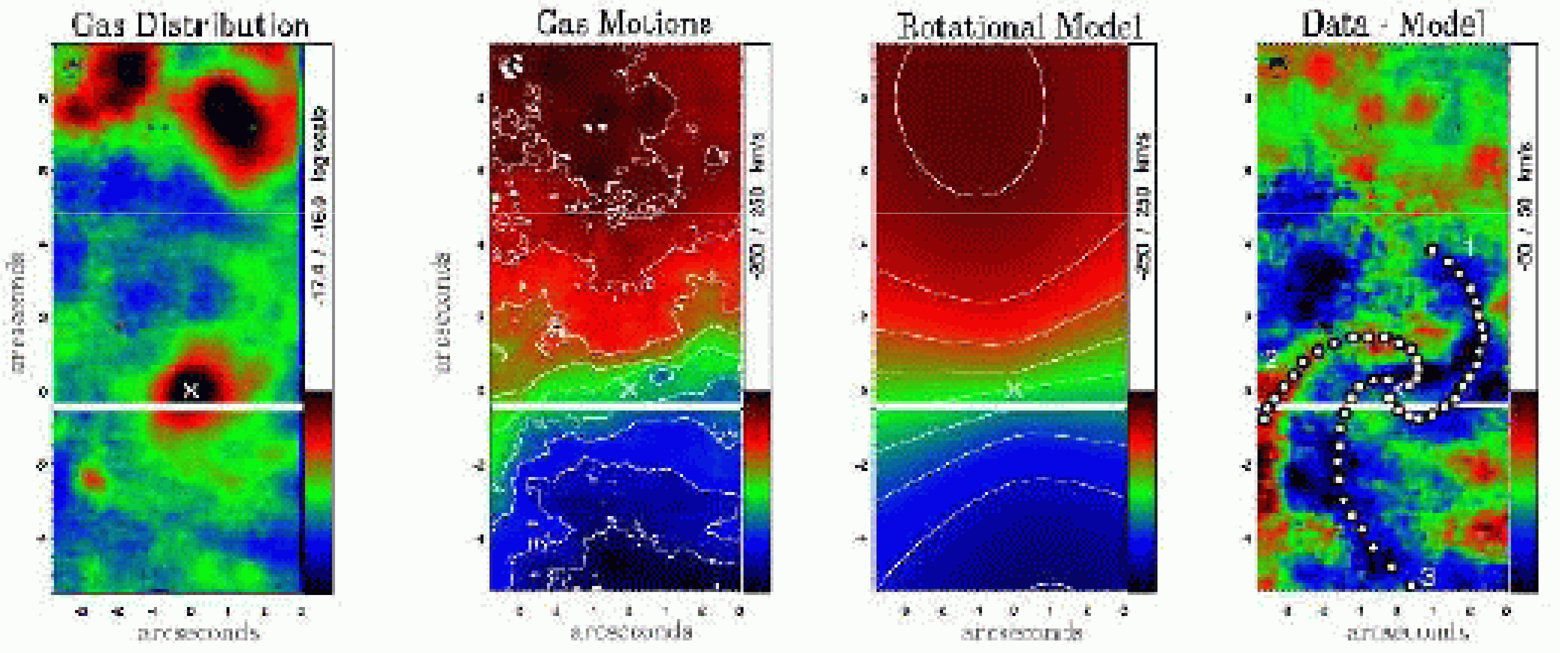
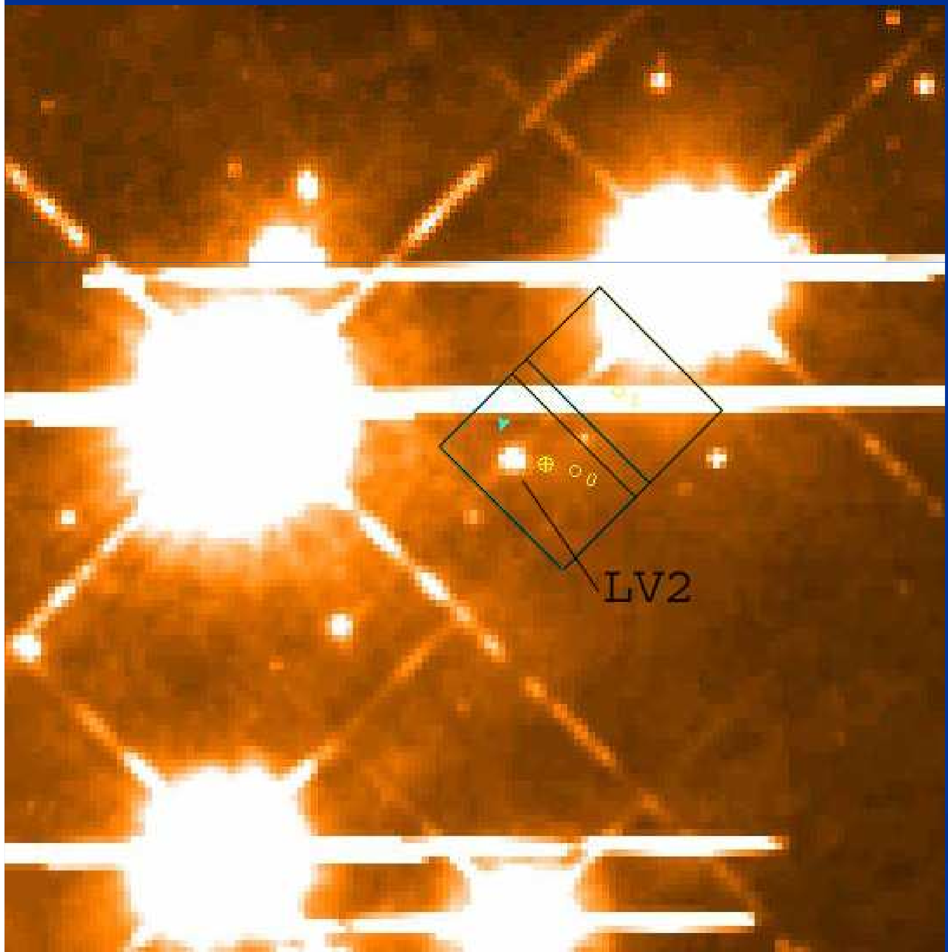
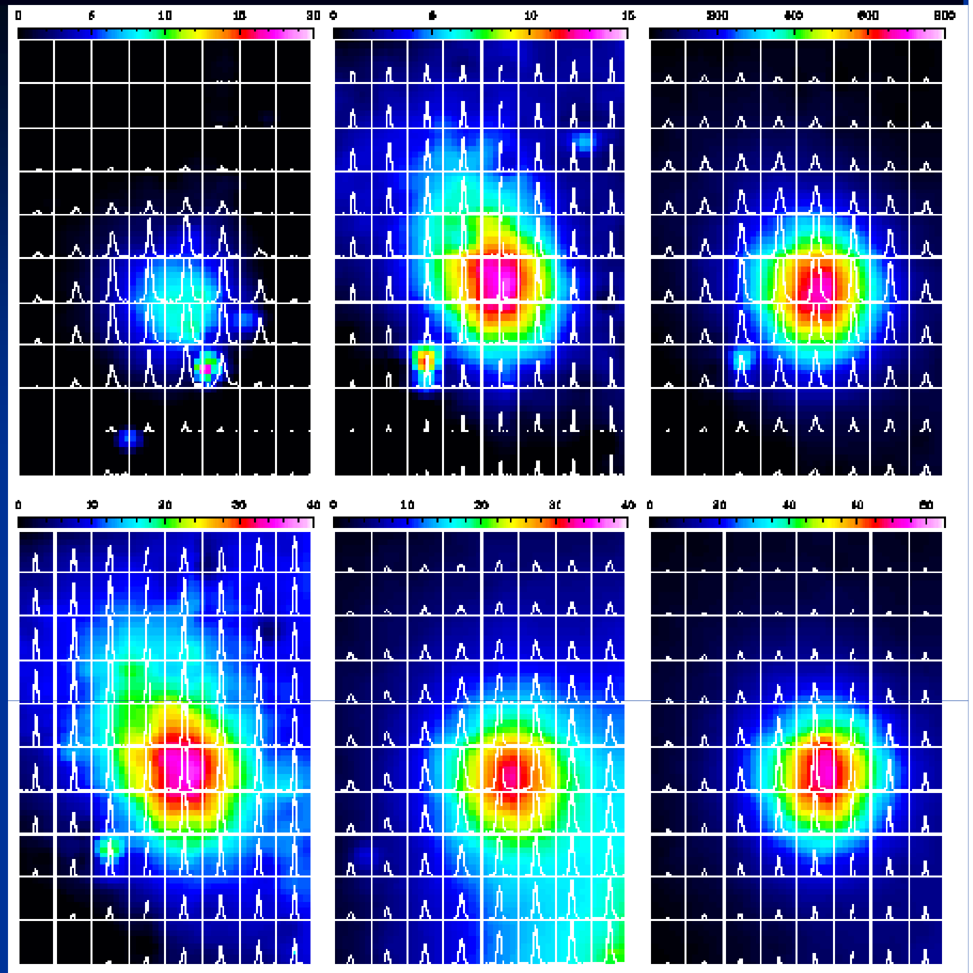


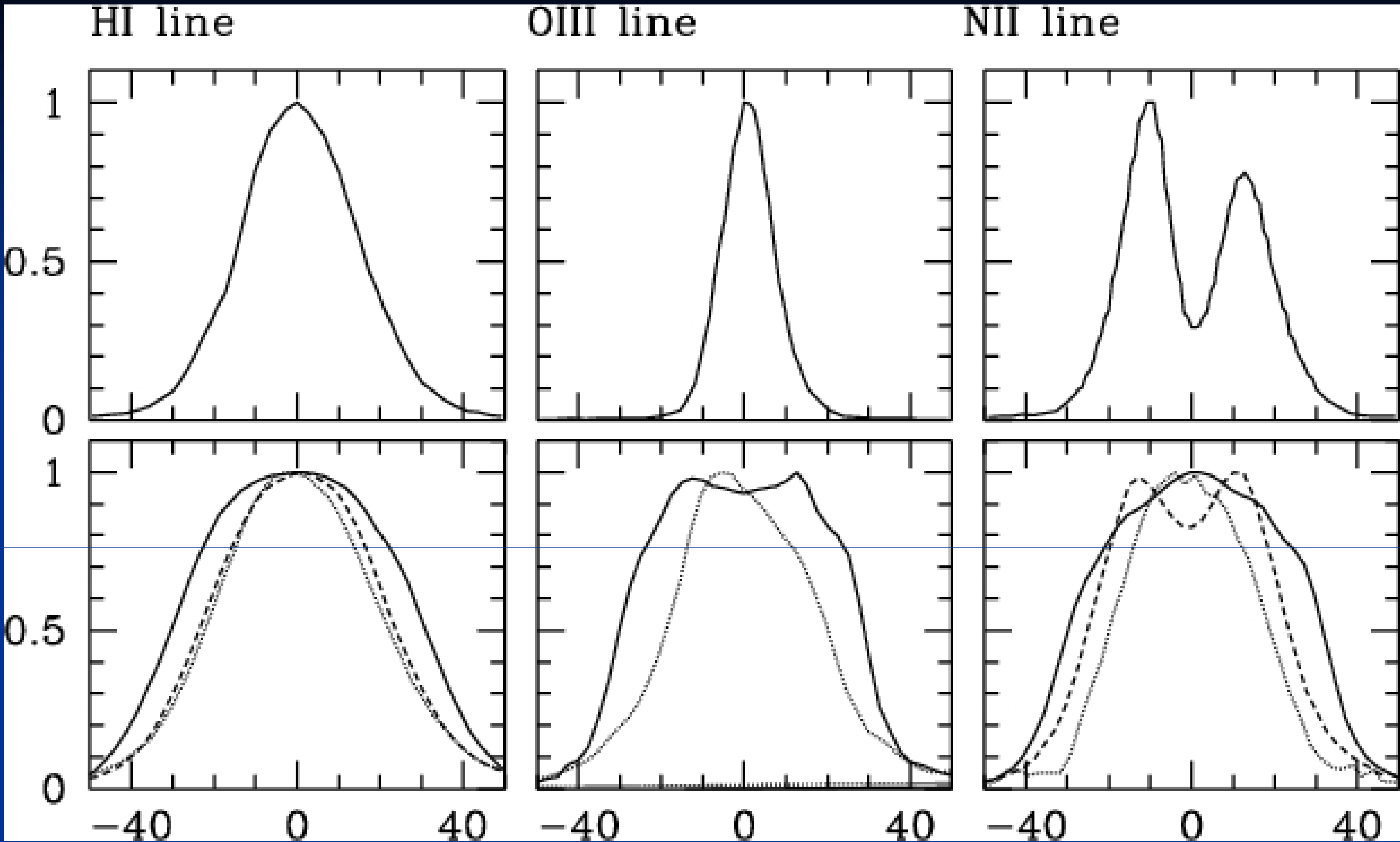
Fig. 2.— GMOS-IFU data results for NGC 1097. From left to right: [NII] flux distribution; radial velocity map derived from the [NII] emission-line; exponential disk velocity field model; and residuals. The spiral features seen in the residual map are delineated by white dots as in Fig. 1(red color indicates redshift and blue color, blueshift). Adapted from Fathi et al. 2006.

LV2 Proplyd GMOS – IFU

Vasconcelos et al. 2005







Comparison between spectral lines of PNG215.2-24.2 (IC418) (upper boxes) and three PN with [WC] central stars (lower boxes, PNG4.9+4.9 (M1-25) – solid line, PNG6.8+4.1 (M3-15)-dotted line, PNG285.4+1.5 (Pe1 -1) – dashed line). The lines of PN with [WC] central stars are much broader.

Need high spectral resolution R= 40000

Obrigada!