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

- 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 (Bajê) - 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
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:

- **Corner cube**
- **Collimator**
- **Monochromatic output**
- **Focal plane**
- **Camera**
- **Broadband output**

**Graph:**
- Normalized intensity vs. offset (nm)
  - FWHM = 0.30 nm
  - Experimental data
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)
  - 1,600² (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 symmetry (rings)
Fabry-Pérot - Overview

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

<table>
<thead>
<tr>
<th>Références</th>
<th>APA 400MML</th>
<th>Unit</th>
</tr>
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<tbody>
<tr>
<td>Excursion over [-20, +150]V</td>
<td>365</td>
<td>µm</td>
</tr>
<tr>
<td>blocked force</td>
<td>189</td>
<td>N</td>
</tr>
<tr>
<td>Stiffness in mouvement axis</td>
<td>0.59</td>
<td>N/µm</td>
</tr>
<tr>
<td>Mass</td>
<td>56.5</td>
<td>g</td>
</tr>
</tbody>
</table>

Jun 19, 2008
**Fabry-Pérot - Cubos criados com Illusion**

**Raw Cube**

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
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**Spectrum Cube**

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<tr>
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**Image Cube**

<table>
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<tr>
<th>X</th>
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<td><img src="image6.png" alt="Image Cube Images" /></td>
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</tbody>
</table>
The new SESO etalons

From Jean-Luc Gach (2007)
High resolution arm of BTFI
Velocity fields of extended objects
Tunable Filter Concepts

2. Imaging Bragg Tunable Filter (iBTF)

*imaging Bragg Tunable Filter* - *some examples*

- Simple dispersion (a VPHG)
- Spectral filter (two VPHGs) [~ 35°]
- Spectral filter (two VPHGs [~ 45°]
2. Imaging Bragg Tunable Filter (iBTF)

Princípio de funcionamento do iBTF:
**imaging Bragg Tunable Filter** - General characteristics

- Spectral filter
- Two volume-phase holographic gratings
- The light is dispersed and recombined
- $\lambda$ 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**

\[ \lambda_B = 2n \Lambda \sin(\theta) \]

**Reflection VBGs**

\[ \lambda_B = 2n \Lambda \cos(\theta) \]
iBTF Transmission (DCG)

$R \sim 100$

Tuning $25^\circ$-45$^\circ$ from $\lambda \sim 460$ to 700nm
iBTF Reflection (Doped-Glass)

**R ~5,400**
Tuning $25^\circ-45^\circ$ from $\lambda$ ~620 to 675nm

**R ~1,000**
Tuning $25^\circ-45^\circ$ from $\lambda$ ~620 to 675nm
Collimator

Twin detectors

Input focal plane

Field lens

FPs

Double fold to accommodate space envelope

iBTF VPGPs

0th order pupil

1st order pupil

Twin Cameras

FPs

0th order pupil

1st order pupil
## Modes of Operation

<table>
<thead>
<tr>
<th>Order 1</th>
<th>Order 0</th>
</tr>
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<tbody>
<tr>
<td>iBTF(Lo-R)</td>
<td>Compl. Channel</td>
</tr>
<tr>
<td>iBTF(Lo-R)</td>
<td>FP(^{P}) (Hi-R)</td>
</tr>
<tr>
<td>Compl. Channel</td>
<td>FP(^{P}) (Hi-R)</td>
</tr>
<tr>
<td>Compl. Channel</td>
<td>FP(^{\Pi})(Block) . FP(^{P})(Hi-R)</td>
</tr>
</tbody>
</table>

Symultaneous observations with Fabry Perot and iBTF are possible!
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)
Test run of BTFI

NGC 7009
SOAR+BTFI
Test run at BTFI on July 27th
Detectors Issues

- 3 readout modes
  - Classical, slow reads (200kHz)
    - $\sim 3e^-$ (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 $< 0.1 \times$ Frame-rate (typically $< 0.1 \text{Hz/pixel}$)
      - Small dynamic range (non-linearity can be $\sim$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

\[ T_{\text{exp}} = T_{\text{Int}} \cdot n_{\text{Sweep}} \]
\[ T_{\text{obs}} = (T_{\text{Int}} + T_{\text{read}}) \cdot (n_{\text{Sweep}} \cdot n_{Z}) \]

Note:
- \( T_{\text{Int}} \sim 10 \times T_{\text{read}} \) to reduce duty cycle losses to acceptable level
- For PC: Saturation for flux rate > 0.1 cnts/T_{\text{Int}}
  \( \Rightarrow \) Minimize \( T_{\text{int}} \) & \( T_{\text{read}} \) \( \Rightarrow \) Maximize \( n_{\text{Sweep}} \)
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. Implementation 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 NGC1097. 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!