The Brazilian Tunable Filter Imager (BTFI for the SOAR Telescope)

Concept Design Review

USP: September 2007

BTFI project

Instrument Team

- Claudia Mendes de Oliveira (USP) - PI
- Keith Taylor (USP) – Instrument Scientist
- Peter Gray (AE Consulting)
- Rene Laporte (INPE) – Optical Engineer
- Mariana Arantes Pereira (USP) – Electronic Engineer
- Luiz Cavalcanti (USP) – Electronic Engineer
- Giseli Ramos (USP) – Software Engineer
- Bruno Correa Quint (USP) – Instrument Physicist

Science Team

- Claudia Mendes de Oliveira (IAG/USP)
- Henri Plana (U.Santa Cruz)
- Laerte Sodré (IAG/USP)
- Chico Jablonski (INPE)
- François Cuisinier (U. Santa Cruz)
- Jaqueline Vasconcelos (U. Santa Cruz)
- Adriano Cerqueira (U. Santa Cruz)
- João Steiner (USP)

Collaborating Institutions

- University of São Paulo (IAG)
- Instituto National de Pesquisas Espacias, Brazil - INPE
- Laboratoire d'Astrophysique de Marseille
  - Jean-Luc Gach
  - Philippe Amram
- Université de Montréal
- Universidade Estadual de Santa Cruz

Consultants/Attendees

- Sebastien Blais-Ouellette (Photonetc) – iBTF
- Cesar de Oliveira (LNA) – Physicist/Management
- Dani Guzman (Durham) – Electronics/Detectors
- Marco Bonati (CTIO) - Software
- Claude Carignan (U.Montreal) – Science
- Olivier Hernandez (U.Montreal) – Science
- Olivier Daigle (U.Montreal) - Detectors

Reviewers

- Claude Carignan (Chair)
- Dani Guzman (Electronics)
- Marco Bonati (Software)
- Peter Gray* (Opto-Mechanics)

* While Peter Gray has acted as a consultant for the BTFI Project, he is also our only currently available, *semi-independent*, opto-mechanical reviewer.

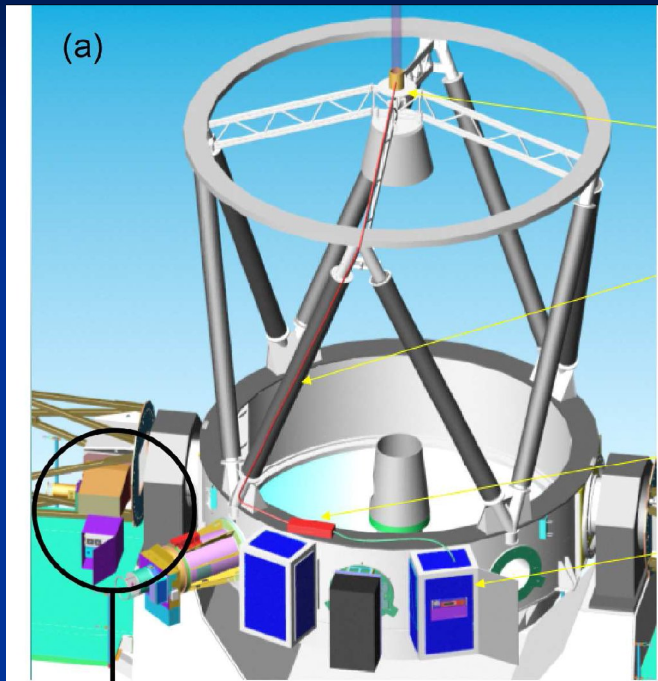
Presentation Overview

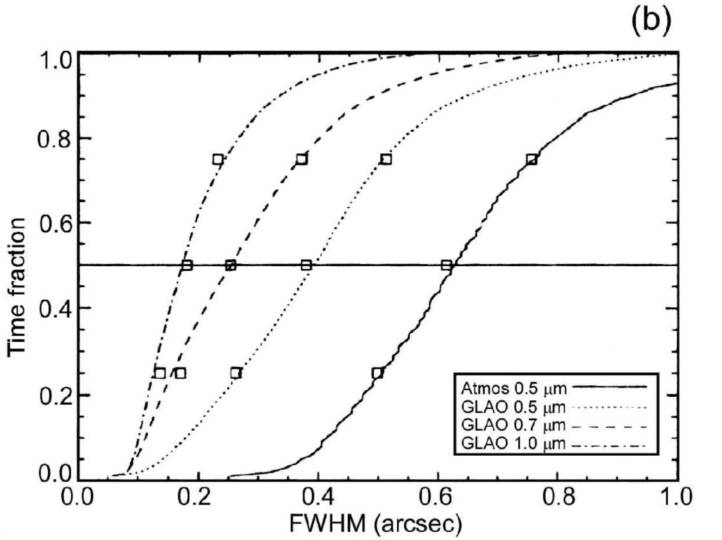
- Science Objectives (Claudia)
- Instrument Overview (Keith)
- Performance modeling (Bruno)
- Instrument Development (Keith)
  - I. Optics, iBTF & FPs
  - II. Opto-mechanical design
- Mechanical Design (Rene)
- Detectors System & Instrument Control (Luiz/Keith)
- Software Systems (Giseli)
- Management (Peter)

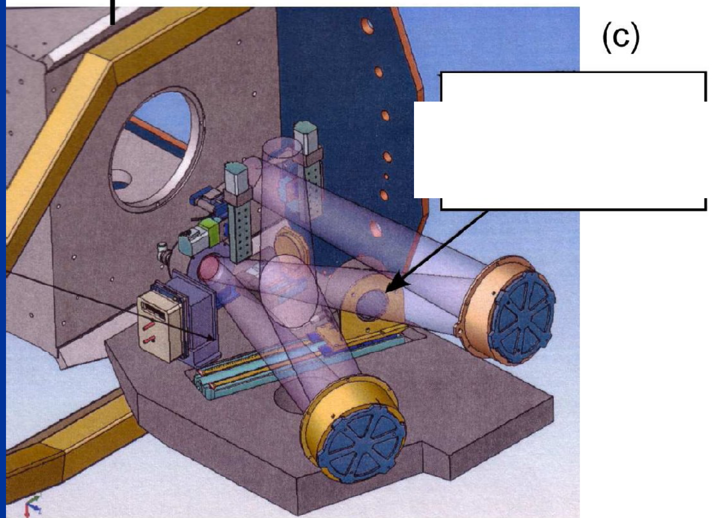
BTFI History

- Kick-off meeting on Dec 14/2006
- Proposal sent to SOAR for a new instrument
- Team core assembled between March-July/2007
- FAPESP funding of Phase I (study) approved in June/2007
- May/2007 - Optical design, first iteration (D. Jones)
- Refinement of design is in progress
- Conceptual design on Sep 24
- New FAPESP funding is sought for phase II, i.e. for the construction phase
- Three-year project

SAM+BTFI concept







SAM = Soar Adaptive Module (GLAO)

Advantages of BTFI on SOAR

- What is different in this instrument? (cf: TAURUS etc)
  - It combines a Tunable Filter with a Fabry Perot (large range of resolutions, $5 < R < 40000$)
  - Capability for correcting for seeing (PSF) and transparency variations (the iBTF concept).

- 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.

SCIENCE

BTFI is a very broadly capable facility instrument

Science Objectives

- FP observations - kinematics of diffuse emission-line objects
- Tunable Filter Observations
- Requirements Summary
  - Type of data to be acquired
  - Wavelength Range
  - Spectral & Spatial Resolution
  - Instrument efficiencies
  - Modes of operation
  - Instrument Status on SOAR
    - Operation, Support & Maintenance

FP high-spectral-resolution mode - Extragalactic projects

- Galaxy interaction and merging to z~0.5
- Evolution of galaxies at medium z (<0.2)
- AGN physics at low and medium redshift
- Internal structure of galaxies, bars, non-circular motions
- Dark matter distributions via kinematics of galaxies
- HII galaxies
- Measuring the mass of black holes in the centers of galaxies from the kinematics of the gas
- PNe in external galaxies

iBTF low-resolution mode extragalactic work

- Photometric redshifts: redshift estimates, star/galaxy classification, galaxy spectral type
- Pre-selection of objects for spectroscopic observations
- Galaxy Evolution: metallicity gradient in nearby galaxies through 2D maps of emission lines:
  - [OII]3727A, Hβ, [OIII]5007A, Hα, [NII].
- Seyfert Galaxies, liners and AGNs, star-forming galaxies in groups and clusters
  - Ionization maps using 2D maps of emission lines and 2D maps of continuum.

FP high-spectral-resolution mode – Galactic/ISM projects

- Kinematics and evolution of planetary nebula
- Physics and kinematics of HH objects and proplyds

iBTF low-spectral-resolution mode – Galactic/ISM projects

- Physics of planetary nebula
- Physics of Novae

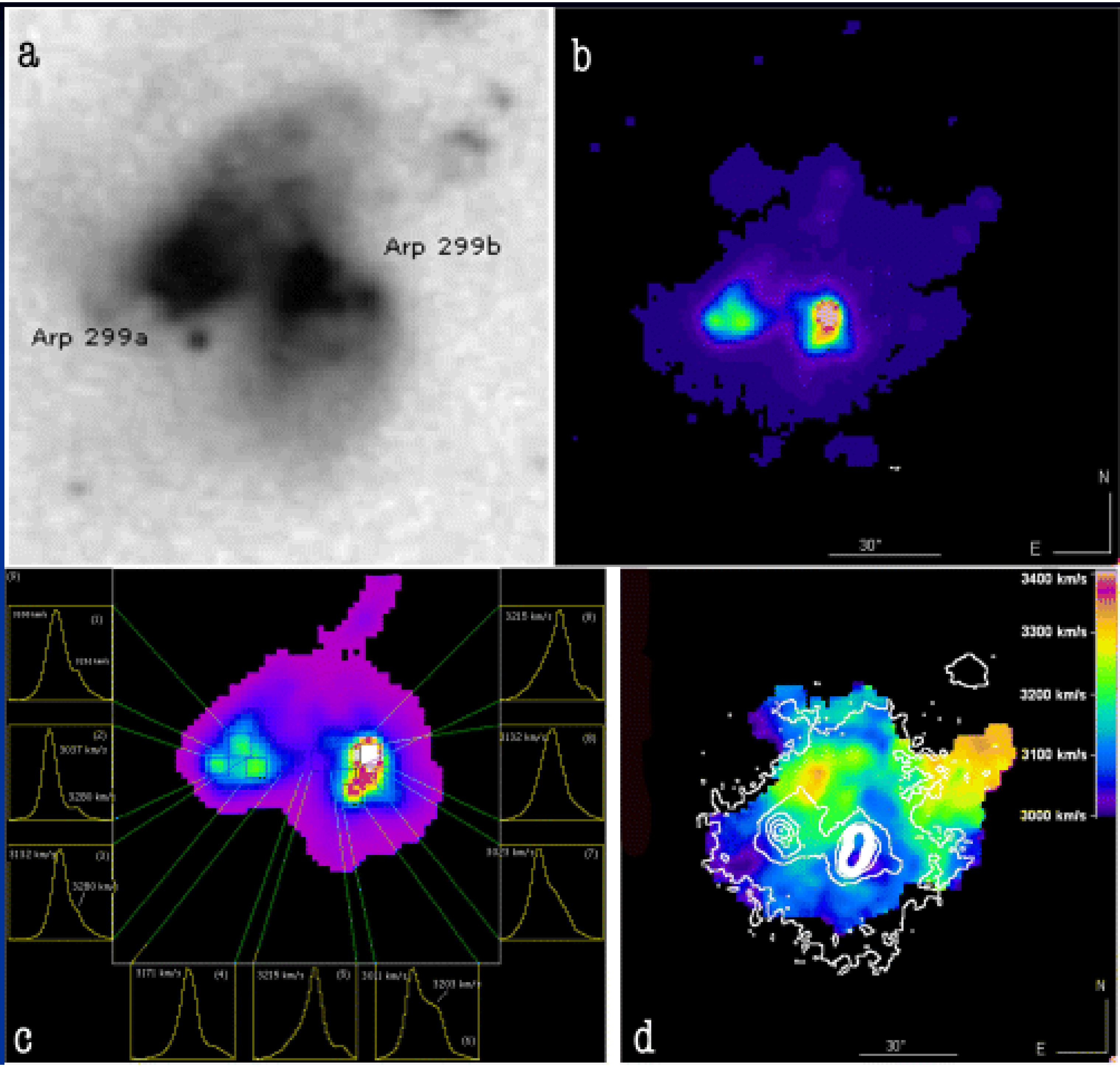
FP for Extragalactic projects

- Environmental Effects

* Galaxy Interactions and merging: Even for bright, z=0 interacting/merging galaxies, present-day FP instruments do not yield good enough spatial resolutions for disentangling the double or multiple components which are often present in these systems.

* At medium redshifts, the gain in spatial resolution will be most important for deriving the kinematics of normal and interacting galaxies.

* Kinematics of pairs, groups and clusters up to z=0.2
Tully-Fisher relation.

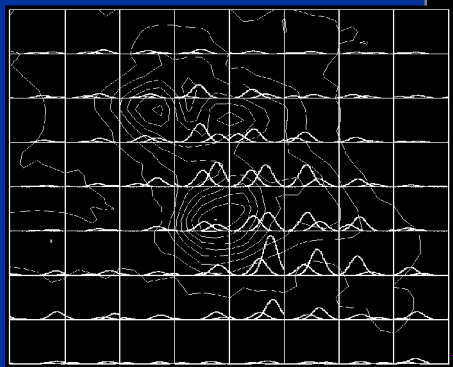

a
Arp 299b
Arp 299a
b
N
30"
E
c
d
3400 km/s
3300 km/s
3200 km/s
3100 km/s
3000 km/s
N
30"
E

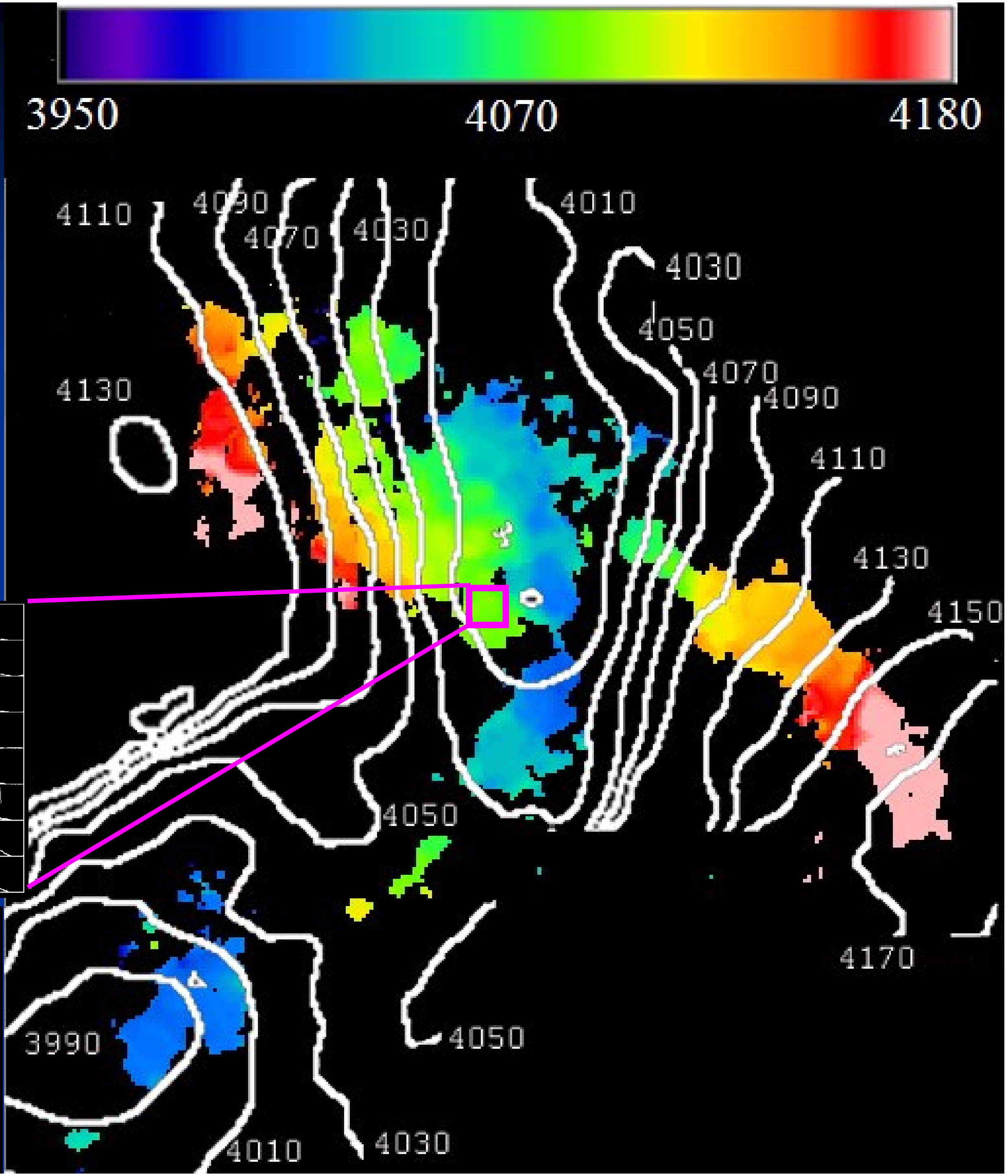
HCG 31

Even @ low redshift

controversy exists on the nature and the history of this system !

- Pre-merging phase or chance alignment ?
- How many components? How many galaxies ?
- TDGs ?



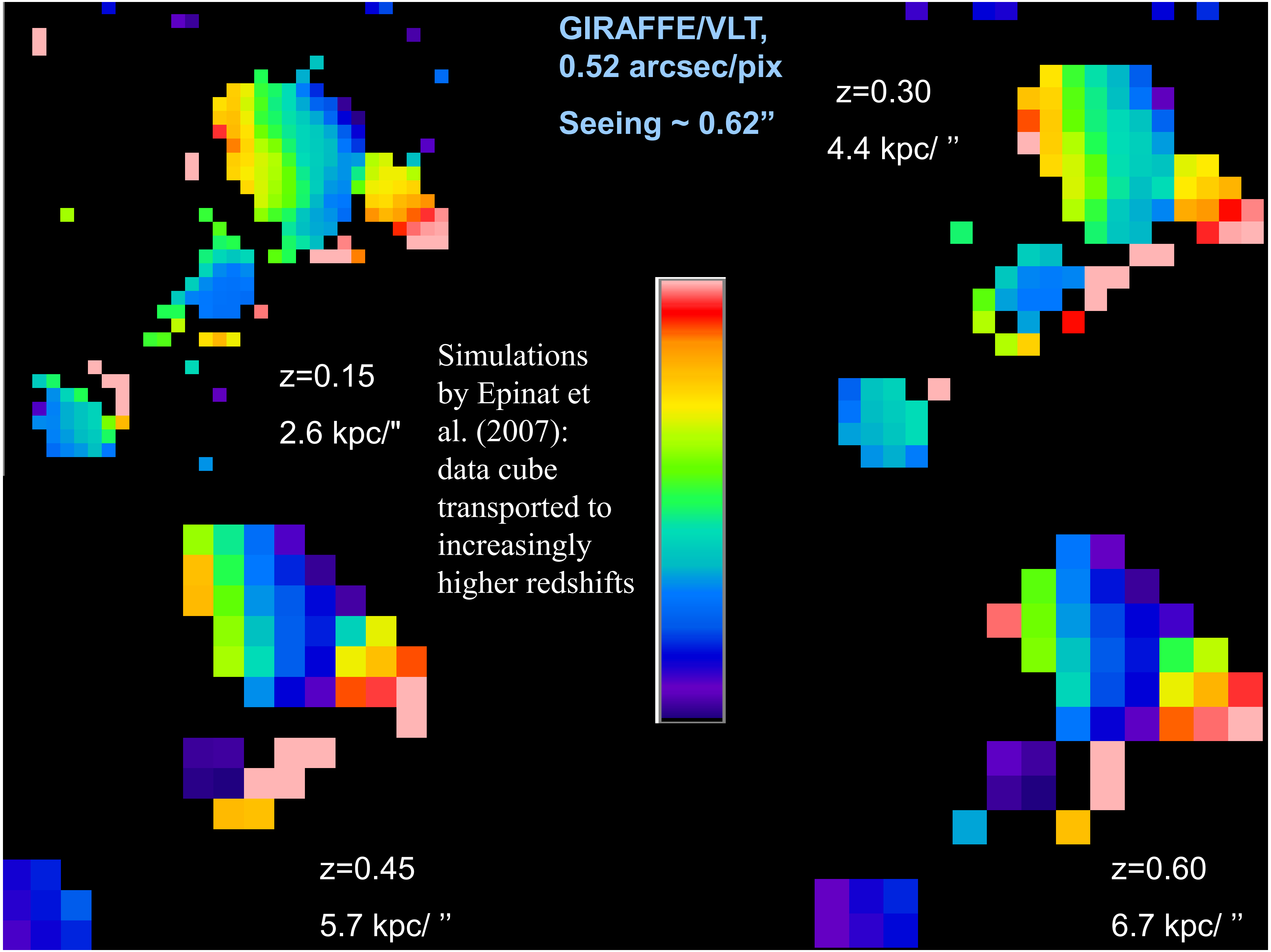


Color Hα velocity Field

(Amram et al. 2004)

White HI isovelocities

(Verdes Montenegro et al 2005)


GIRAFFE/VLT,
0.52 arcsec/pix
Seeing ~ 0.62”
z=0.15
2.6 kpc/"
z=0.30
4.4 kpc/ ”
Simulations by Epinat et al. (2007): data cube transported to increasingly higher redshifts
z=0.45
5.7 kpc/ ”
z=0.60
6.7 kpc/ ”

*Tidal Dwarf Galaxies (TDGs)

- Dwarf galaxies forming on tidal tails
- Kinematics is the best way to study the nature of these objects

  → RCs of TDG candidates have been measured in a few cases but spatial resolution is a crucial issue SAM + BTFI is much better adapted than IFU (px + FOV) for such studies

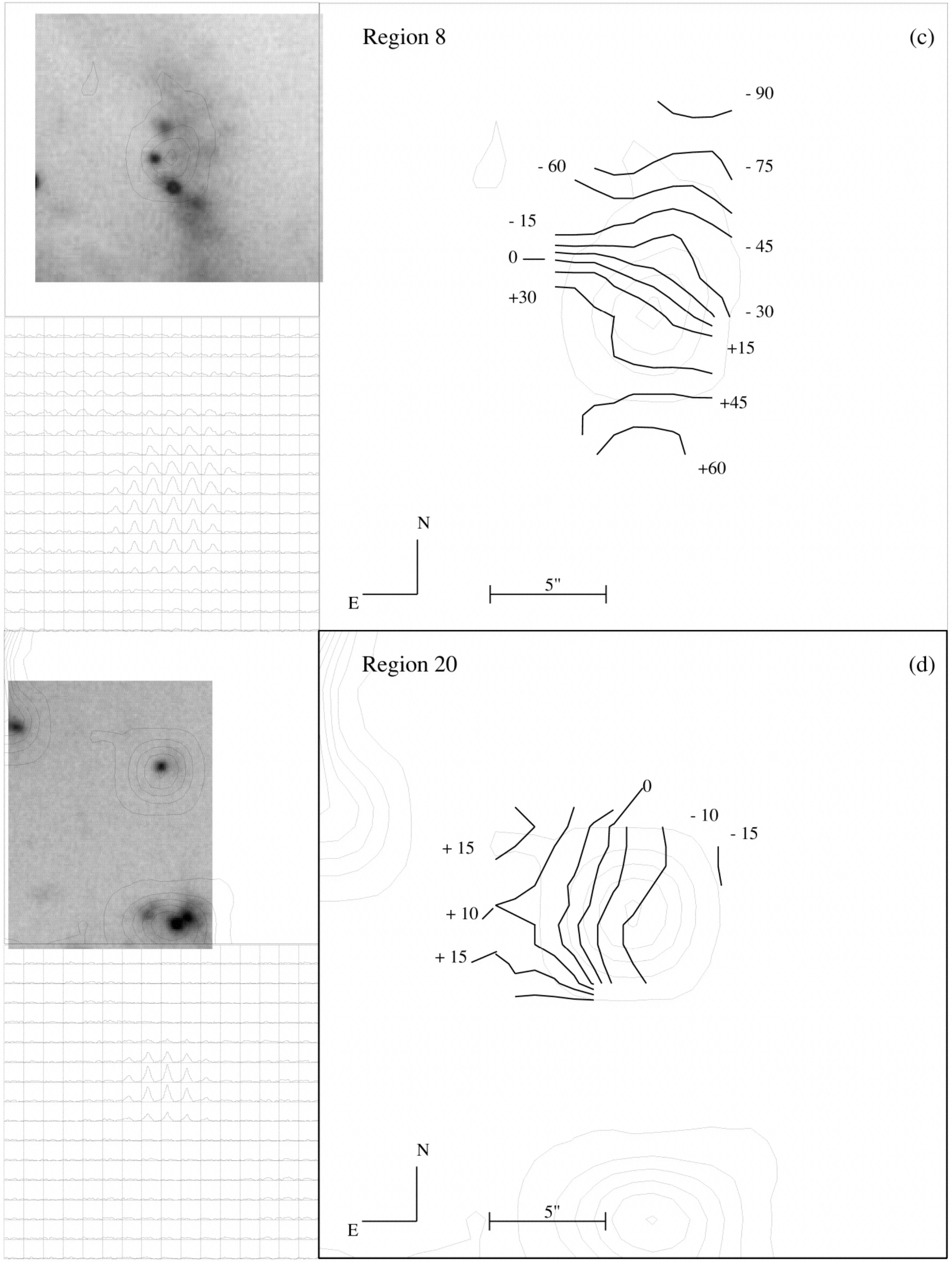
Spectral resolution required: 30000-40000

Tidal dwarf galaxy candidates in Stephan's quintet

Typical amplitudes of the velocity curves are 20-40 km/s

Blobs are very compact, unresolved with a seeing of 1 arcsec

Mendes de Oliveira et al. 2001



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.

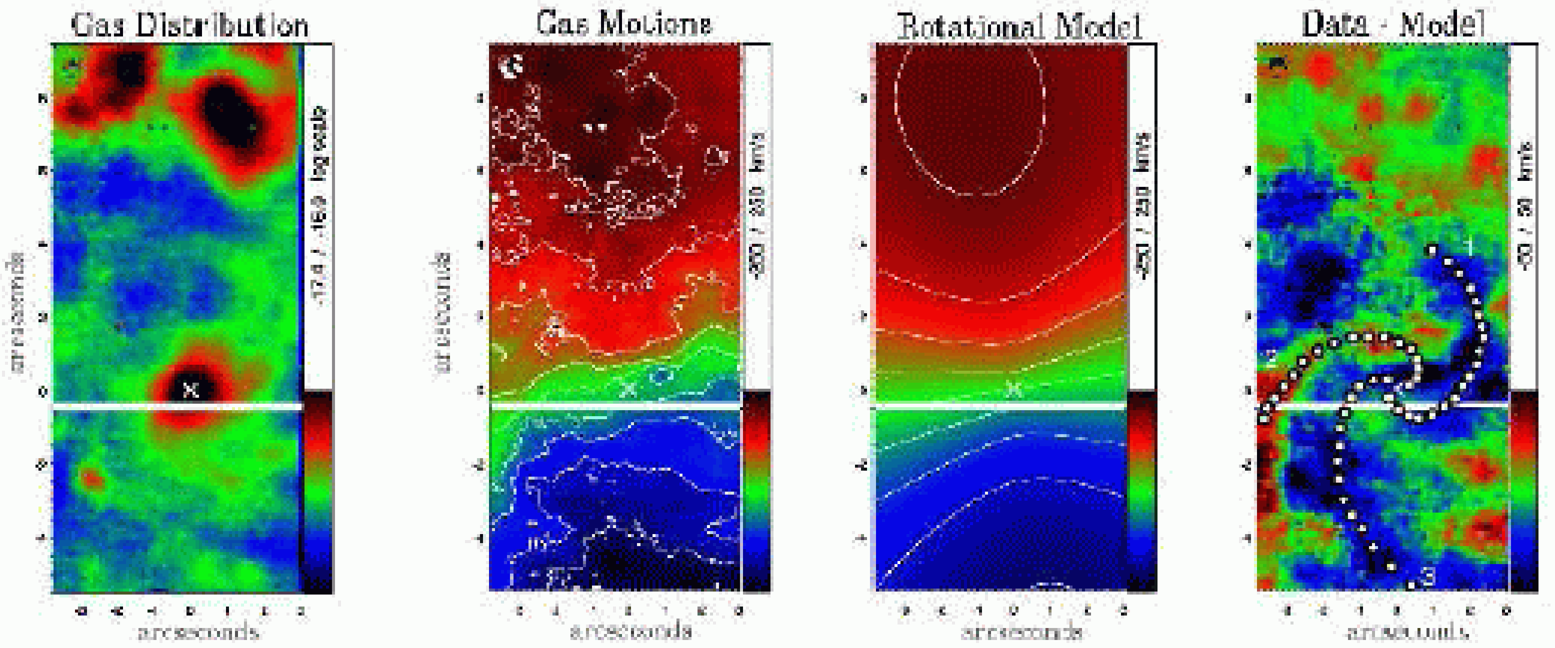
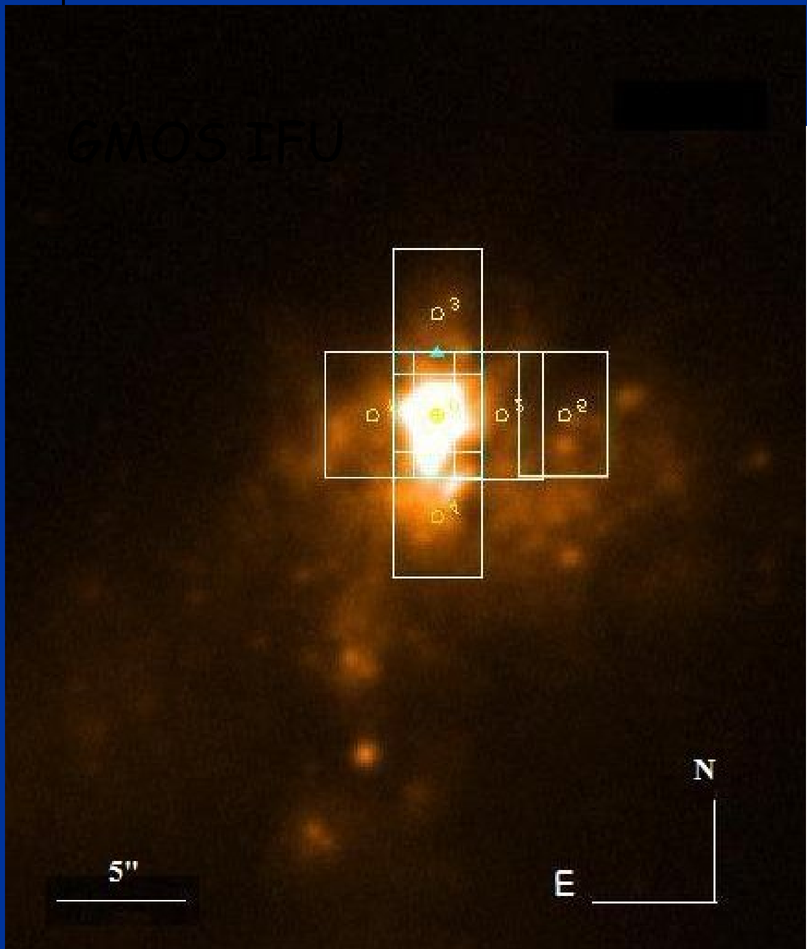


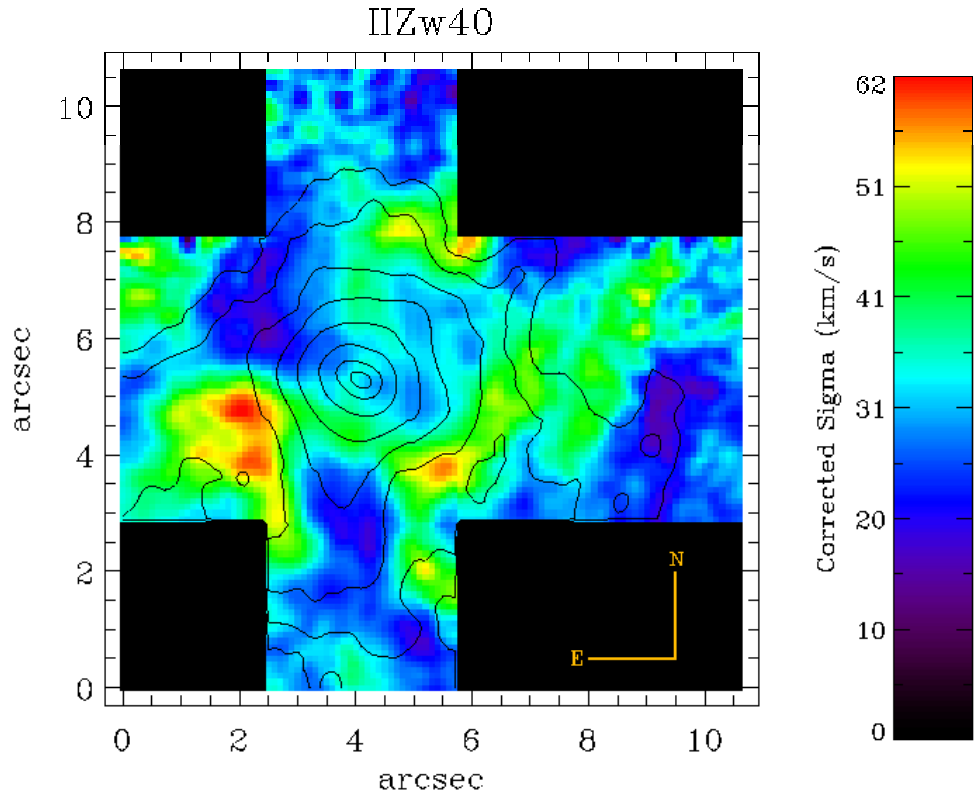
Fig. 2.— GMOS-IFU data results for NGC 1097. From left to right: [NII] flux distribution; radial velocity map derived from the [NII] emission-line; exponential disk velocity field model; and residuals. The spiral features seen in the residual map are delineated by white dots as in Fig. 1(red color indicates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

HII Galaxies

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



Telles et al. 2007



Galactic objects with FP

- Kinematics of Young Stellar Objects

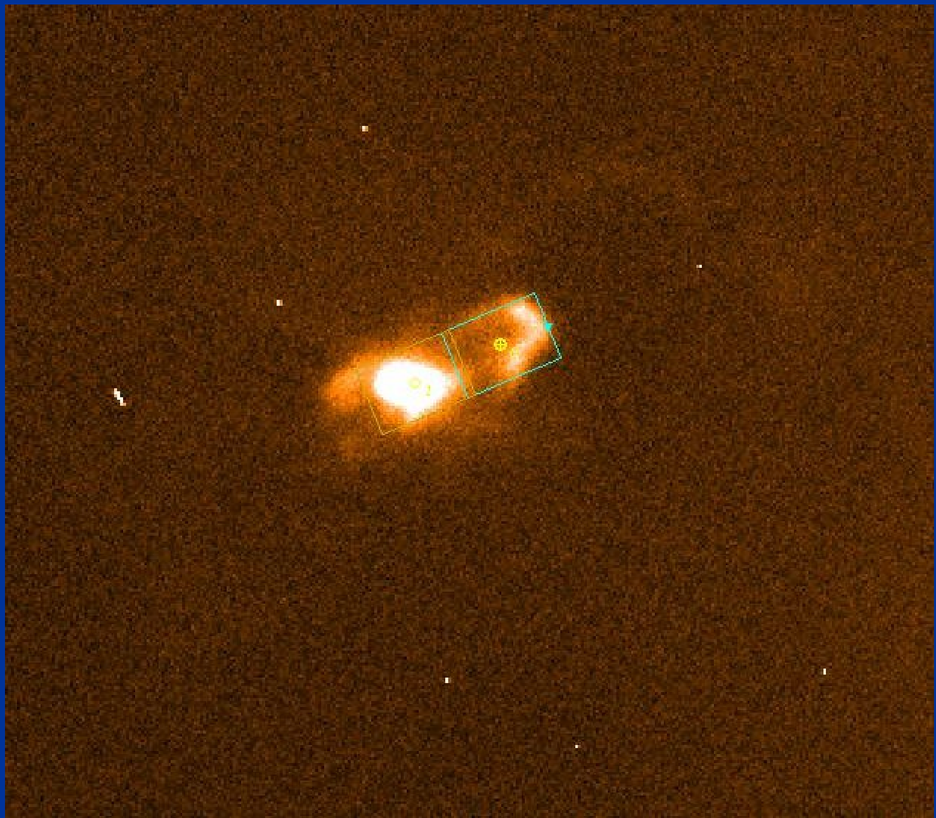
  - Herbig Haro object and jet

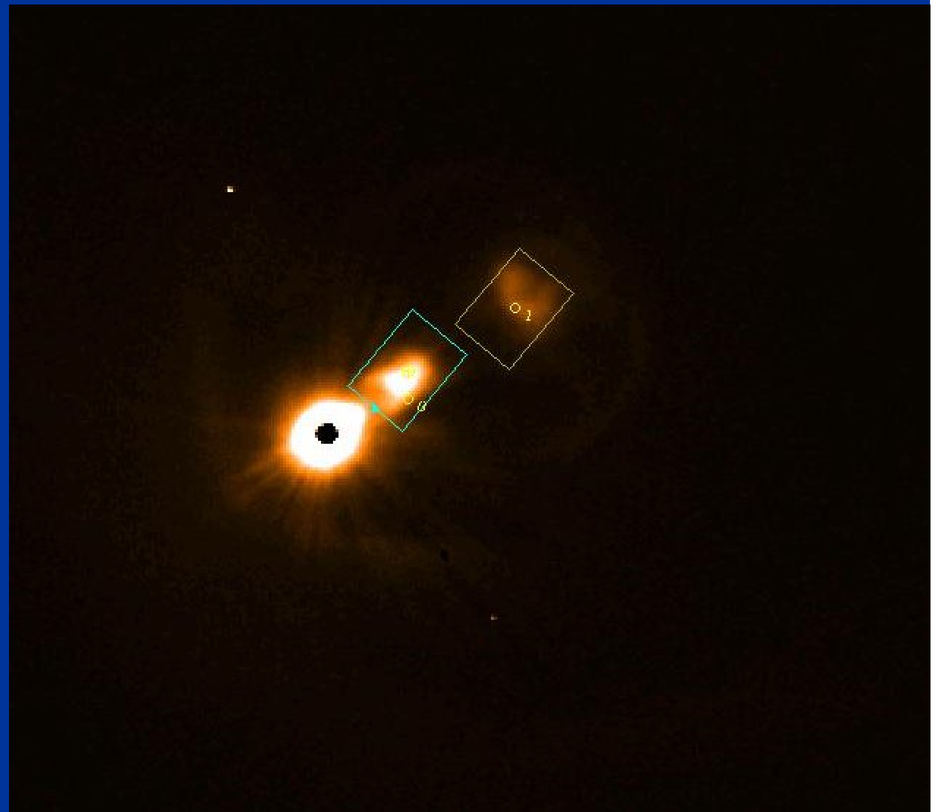
    * Test the magneto-centrifugal model for rotating jet (Baccioti et al. 2002). SAM module + FP solve prb of IFU (FOV and resolution) competitive with HST.

    * Ionization diagram with emission line

  - ProPlyds kinematics – Good use of a SAM's field

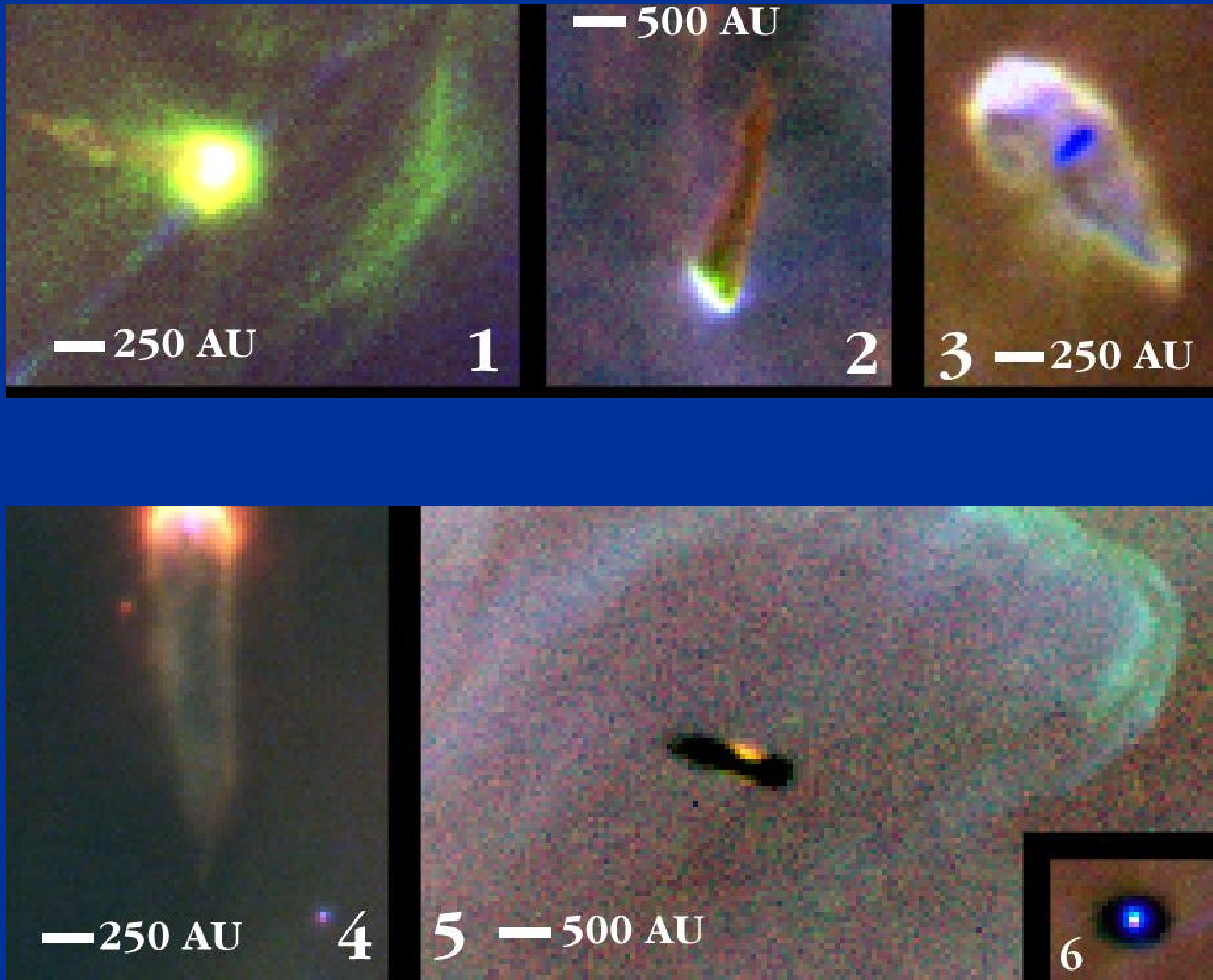
HH 156 - HH158 - GMOS





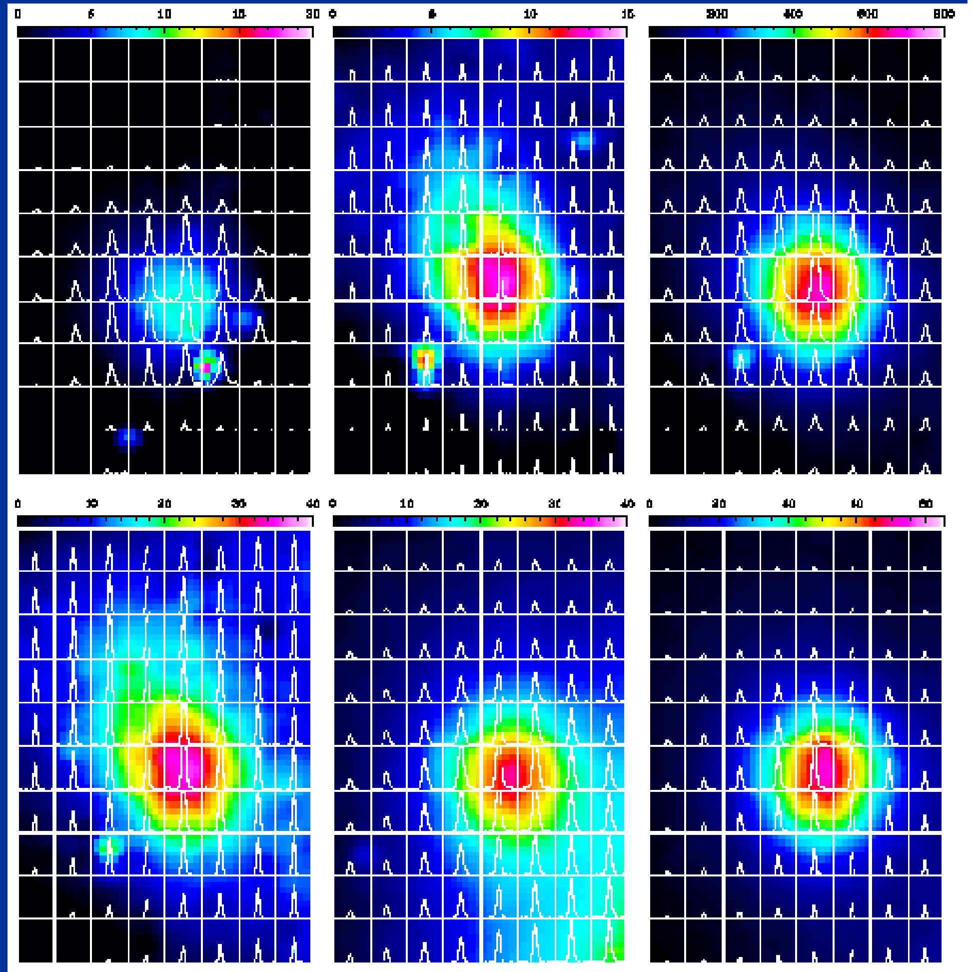
Large scale kinematic structures can be measured, in scales of several arcminutes, from emission lines.

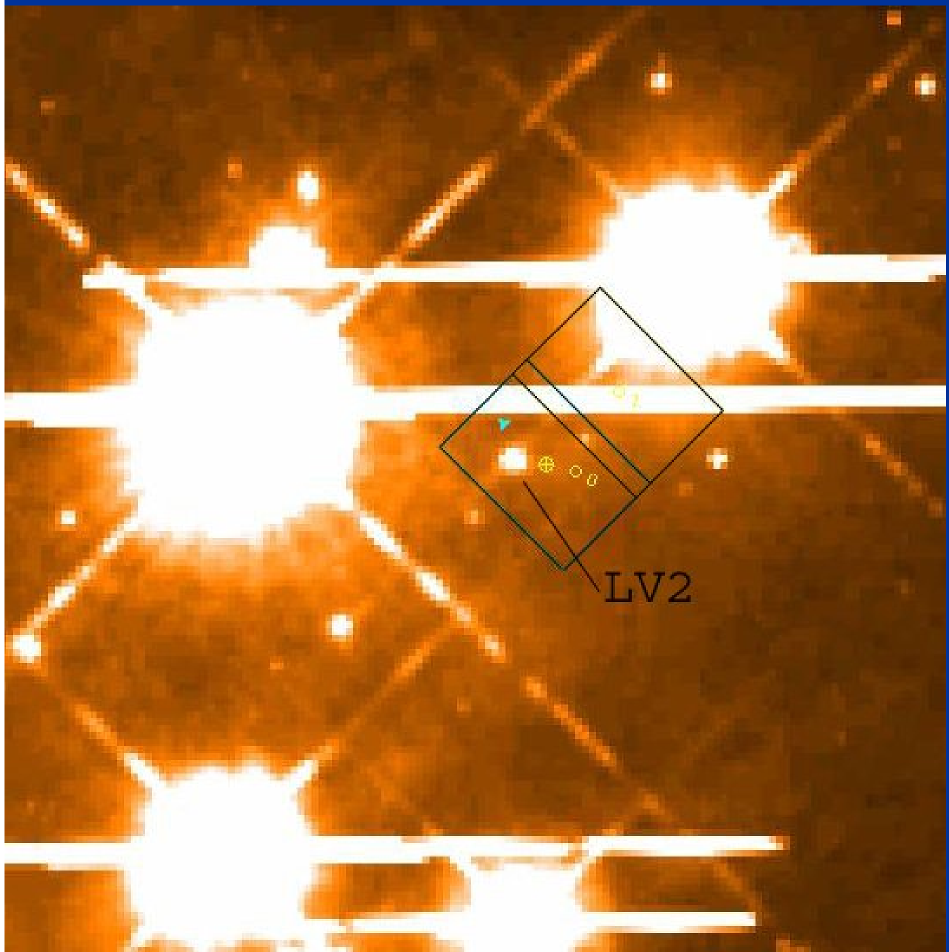
- What are proplyds?
  - YSOs irradiated by external UV radiation: become visible, have photoevaporated flows, irradiated jets, cometary shape
  - They are mostly unresolved emission line objects
  - Churchwell et al (1987) noted they are compact radio sources
  - O´Dell & Wen (1994), O´Dell & Wong (1996) ⇔ found dozens of proplyds with HST
  - ~160 found near the Trapezium cluster, more being discovered in other HII regions.
  - Models for:
    - Ionization Front (Hα, [O I], [N II], etc. emission): Photodissociation and photoionization models by Johnstone et al. 1998, Störzer & Hollenbach 1999, Henney & Arthur 1998)
    - Bow-shock (Hα and [O III] emission): Garcia-Arredondo et al. (2001)
    - Tail: difuse radiation, model by Richling & Yorke (2000) -> however, treatment of a difusion equation


250 AU
1
500 AU
2
3
250 AU
250 AU
4
5
500 AU
6

LV2 Proplyd GMOS – IFU

Vasconcelos et al. 2005





Resolution required: > 7500
High spatial resolution for study of the structure of the proplyd

Emission line profiles for Planetary Nebulae with WR central stars

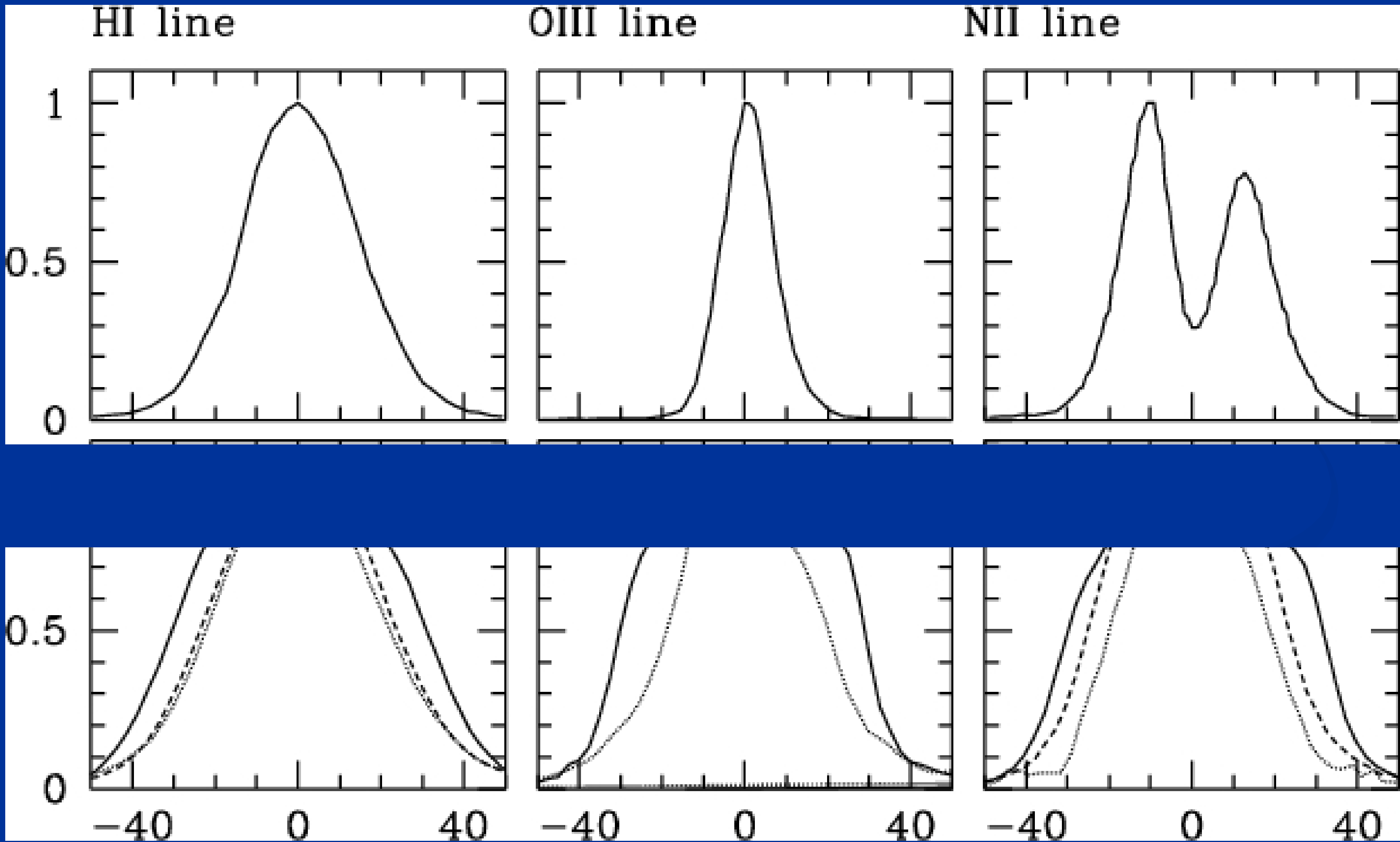
PN central stars spectra generally exhibit a hydrogen rich absorption spectrum.

A few of them (10%) exhibit however broad WR like emission lines, of carbon and helium.

The former is a hydrogen burning shell object while the latter is believed to be in the helium burning shell phase.

These two types have different line profiles. FP observations at R=40000 can provice information on the shapes of the lines over the whole planetary nebulae surface, which will be a crucial constrain for the photoionization modeling of these objects (3D modelling).

R > = 40000 is needed



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

Physics & Kinematics of PNe

- Kinematics gives information on the hydrodynamics of PNe
- Interpretation of expansion velocities
- Combination of 3D Photoionization + high spectral and angular resolution will give us the 3D structure of PNe --> non - sphericity effects ?

iBTF – extragalactic work

- Photometric redshifts: reshift estimates, star/galaxy classification, galaxy spectral type.

Simulations have shown that a large number of narrower bands, say 17 with 150-300Angstrons, perform better in classification and redshift estimation than only a few bands (Wolf et al. 2001).

We would need a band before 4000 break - for nearby galaxies (pushes scientific requirements down to 3700 A)

We would need to go as red as possible (for total wavelength coverage). The atmospheric lines in the red can be avoided.

iBTF - extragalactic work

- Pre-selection of objects for spectroscopic observations.

Search for high-redshift QSO's

Search for Lyman break galaxies

search for any emission line object at a given redshift

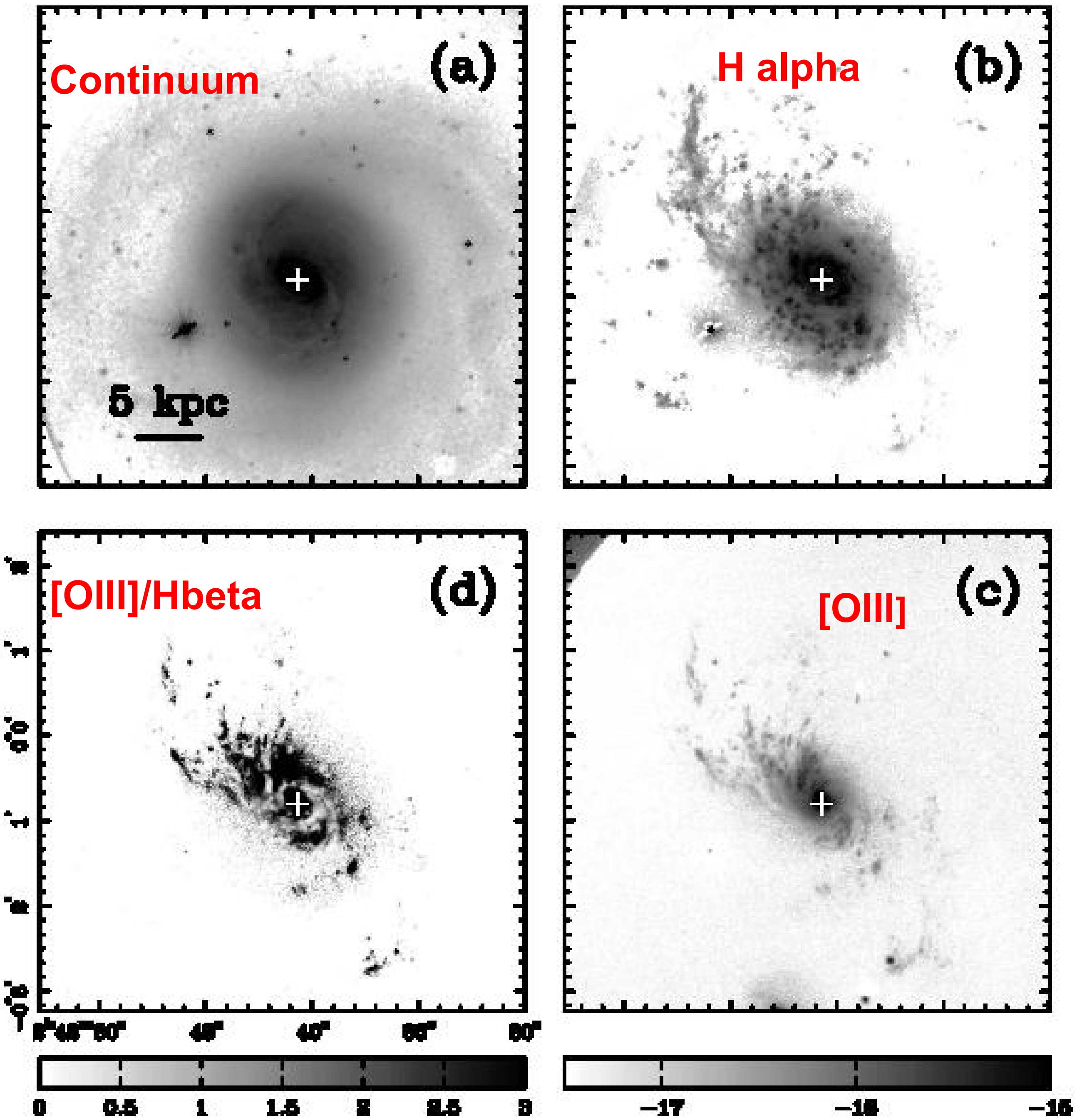
etc,etc,etc

Tunable filter

NGC 1068

Metallicity gradients in nearby galaxies

Veilleux et al. 2003

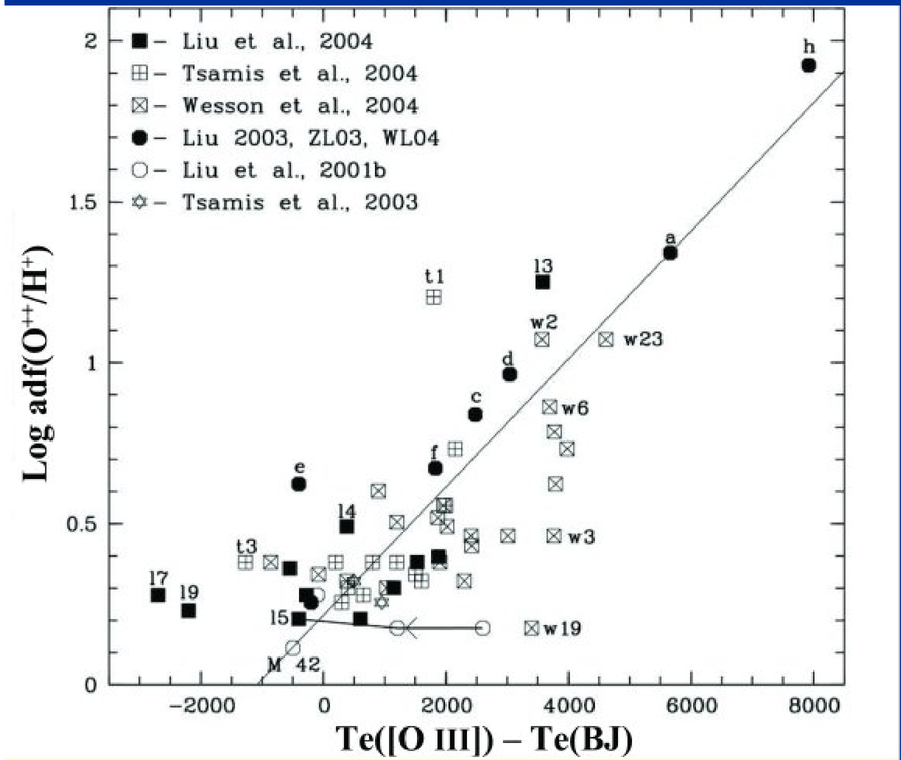


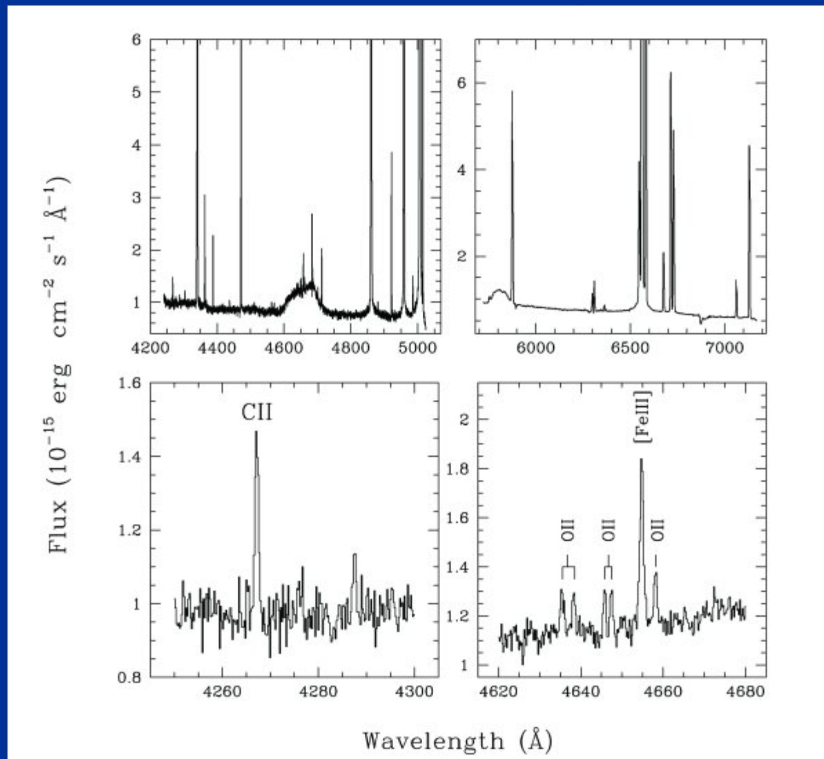
Spatial abundances variations in HII galaxies

- Check if there is a gradient of oxygen abundance in HII galaxies to test scenarios of interstellar medium recycling.
- Use iBTF centered on main emission lines such as Halpha, Hbeta, OIII, OII and NII. Need line at 372.7 microns - absolutely necessary for oxygen abundances determinations.
- Sets science requirement to minimum lambda = 370 microns.

iBTF - Galactic/ISM work

- Measurement of temperatures and abundances for Planetary Nebulae





There are differences from values measured from different lines of hydrogen, helium, or forbidden lines . Ideally one can use the heavy elements recombination lines in PN spectrum for measurements but they are very weak, typically 1% of Hbeta.

Science Requirements

* We require the data output be a datacube

* Wavelength range:

3700 Angstrons

(set by iBTF projects, e.g. oxigen abundances of galaxies and PNs, photometric redshifts).

to 9000 Angstrons

(set by photometric redshift science project)

* Spectral resolution: R = 20 (photometric redshifts, object classification).

  R = 40000 (shapes of lines in PNs, kinematics of TDGs)

* Spatial resolution: 0.24 arcsec (resolve TDG and HII galaxy knots, centers of galaxies and AGNs).

* Instrument efficiency: we must be able to reach $\sim 10^{-17}$ ergs/s/cm^2/arcsec^2 in a 2.5 hour exposure, for a S/N=2 (int.over ~1").

Modes of Operation

Order 1	Order 0
iBTF	complementary channel
iBTF	FP
compl.	FP
FP1+FP2	compl.

Symultaneous observations with Fabry Perot and iBTF are possible!

Science Requirements

REQ-20.00	**SCIENCE**	
REQ-21.01	Wavelength range	370nm > l > 900nm
REQ-21.02	Field of View on Sky	≥ 3 arcmin
REQ-21.03	Spatial Resolution on sky	≤ 0.12 arcsec sampling, resolution ≤ 0.24 arcsec
REQ-21.04	Tunable Filter iBTF λ Resolutions	20 <R < 5,500 (Goal), 20 <R < 3,000 (Acceptable)
REQ-21.05	Use with Two Fabry-Perot Etalons	Ability to observe with either one or two FP etalons in series. FP1 in the diverging beam before the collimator. FP2 in the collimated beam.
REQ-21.06	Fabry-Perot FP1 + Filter λ Resolution	250 < R < 25,000
REQ-21.07	Fabry-Perot FP1 + FP2 + Filter λ Resolution	16,000 < R < 40,000
REQ-21.08	Simultaneous Observation	Ability to observe simulatneously in both FP and iBTF channels with separate identical detectors. Either channel can also be used independently. Possible to image (WHITE) directly onto either detector
REQ-21.09	Modes of Operation	At least four modes of operation: (1) iBTF & WHITE, (2) iBTF & FP2, (3 WHITE & FP2, (4) FP1+FP2 & WHITE
REQ-21.10	Instrument Efficiency	must be able to reach 10^{-17} ergs/sec/cm^2/arcsec^2 in 2.5 hour exposure f a S/N ratio = 2 for 1 arcsec seeing.
REQ-21.11	Overall Average Throughput (SOAR+SAM+Instr+Detect)	≥ 10%
REQ-21.12	Instrumental Average Throughput	≥ 40%
REQ-21.13	Detector Average Efficiency	≥ 60%
REQ-21.14	Instrument Stability	Instrument stability should be stable enough to permit a 1hr observation without requiring realignment or calibration. Long term stability sufficient not need for major recalibration ≤ every 2 days.
REQ-21.15	Output data	Require the output images in data cubes.
REQ-21.16	SOAR Instrument Status	For the first year of operation would be a Visitor Instrument with technic and operational support provided by the instrument. After this period the instrument would become a SOAR instrument supported by observator