The jet-clouds interaction in AGN: a panoramic spectroscopy view.

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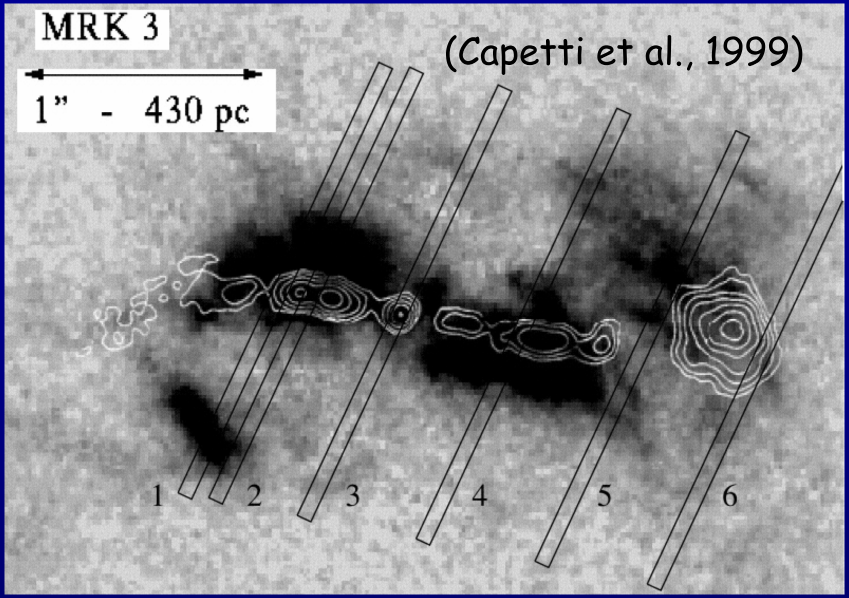
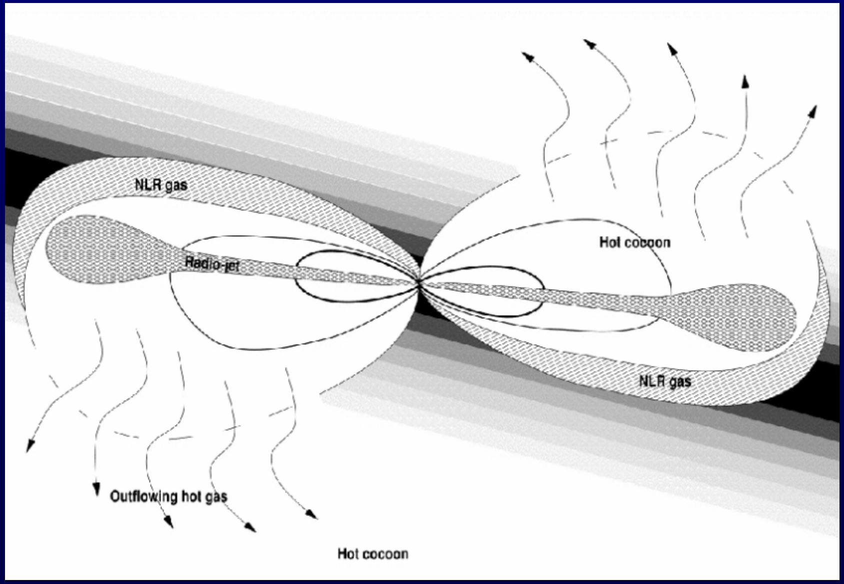
Jet-clouds interaction in Seyfert galaxies

Mrk 3 (HST [OIII] image + radio contours





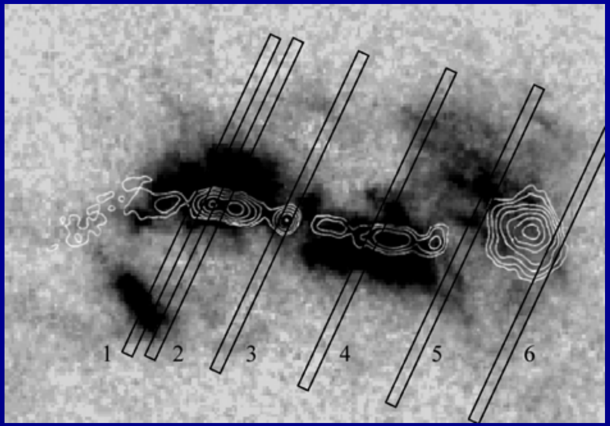
The jets of SyG is extremely hot and diffuse (the free-free and synchrotron radiation are dominate) and observed in radio wavelength . The jet itself is usually not seen at optical and NIR domains.

Despite this many Sy galaxies exhibit narrow line regions (NLR), which are closely associated both morphological and kinematical to the radio emission.

Is it an interaction between the jet material and the interstellar medium (ISM) of the host galaxies?

(Ferruit, 1999; Whittle & Wilson, 2004)

Jet-clouds interaction.



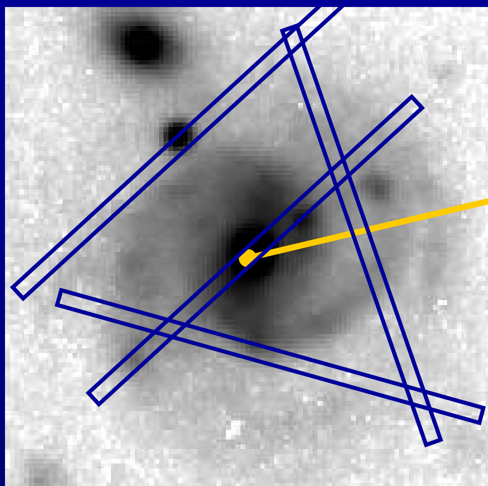
The questions:

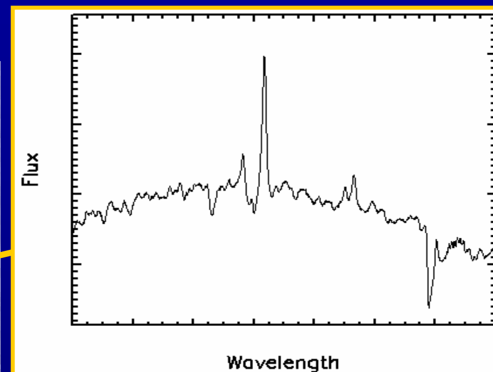
- What are the acceleration mechanisms of the ionized gas?
- What are the roles of shocks and anisotropic radiation?
- What is the nature of morphological structures in NLR?
- What is the evolution of the interaction, the timescale?
- What types of velocity distribution result from the interaction?
- What type of an ionization present in different regions of the objects:
    - only fast shocks?
    - shocks+precursor?
    - domination of the central source?

Direct spectral observations?

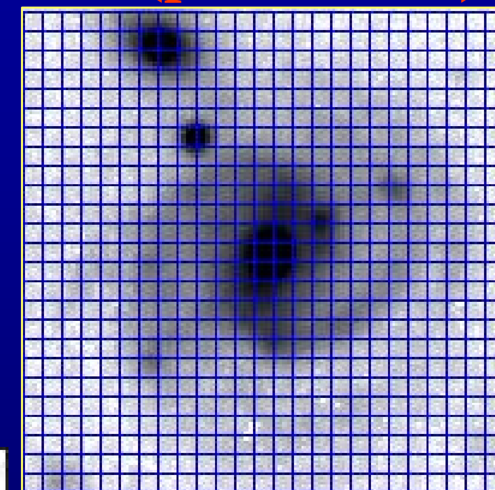
3D versus 1D spectroscopy

1D (long-slit)

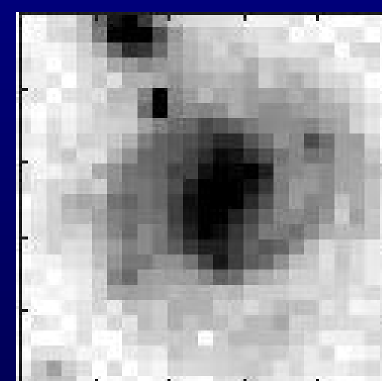




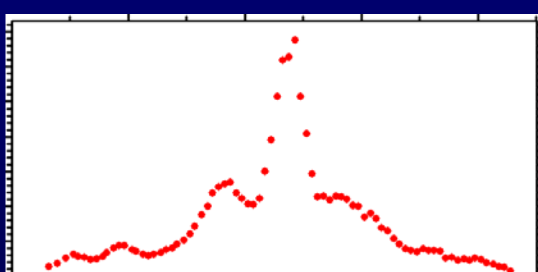
3D (panoramic)



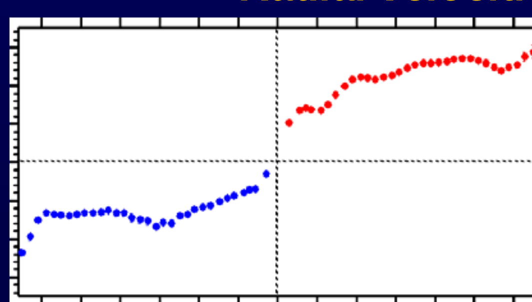
Monochromatic image



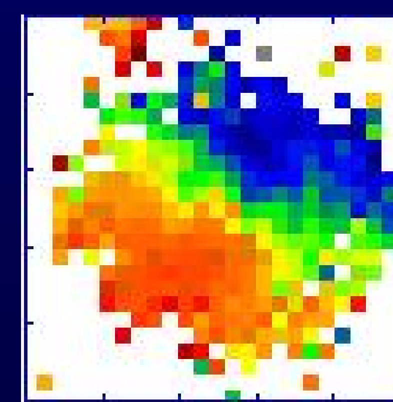
Fluxes in the line



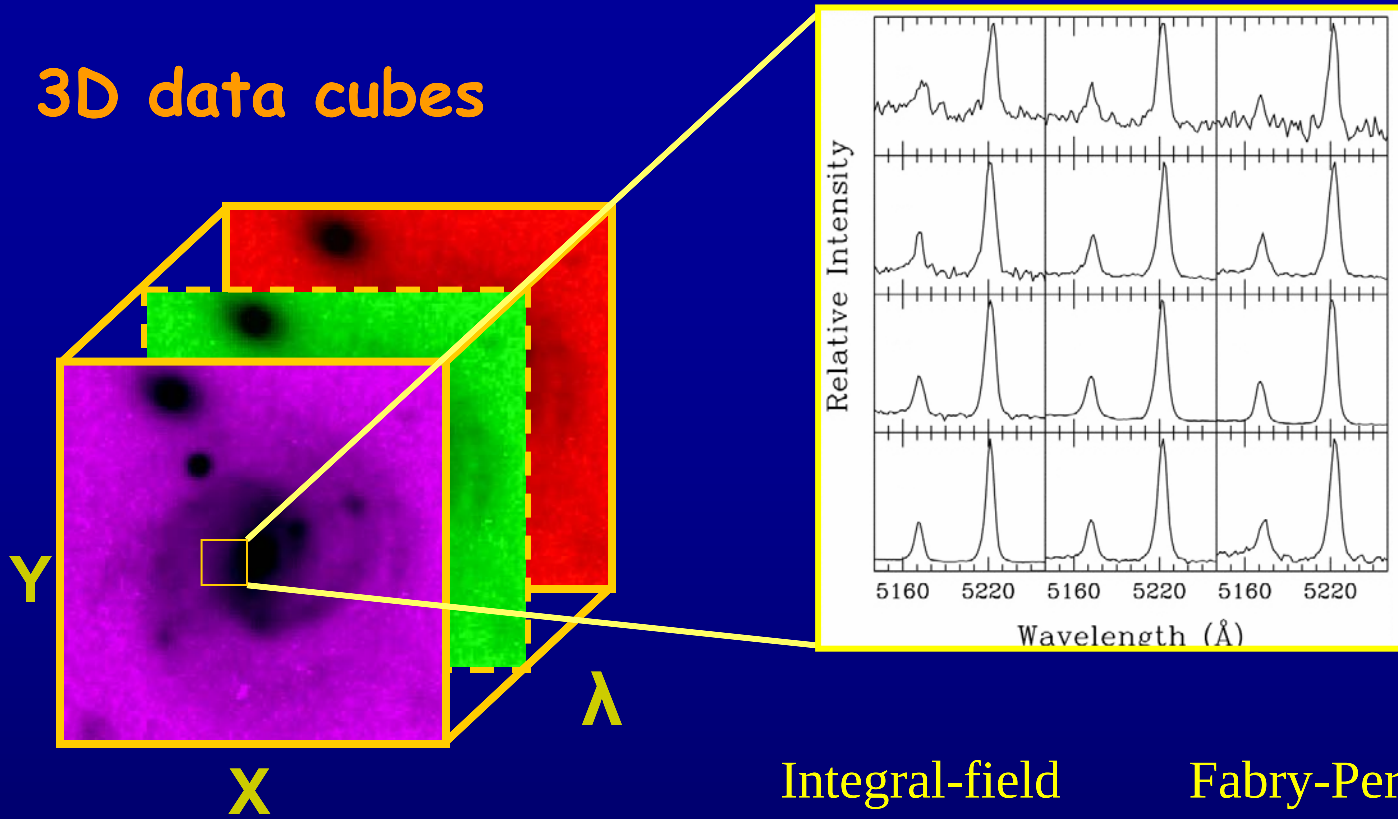
Radial velocities



Velocity field



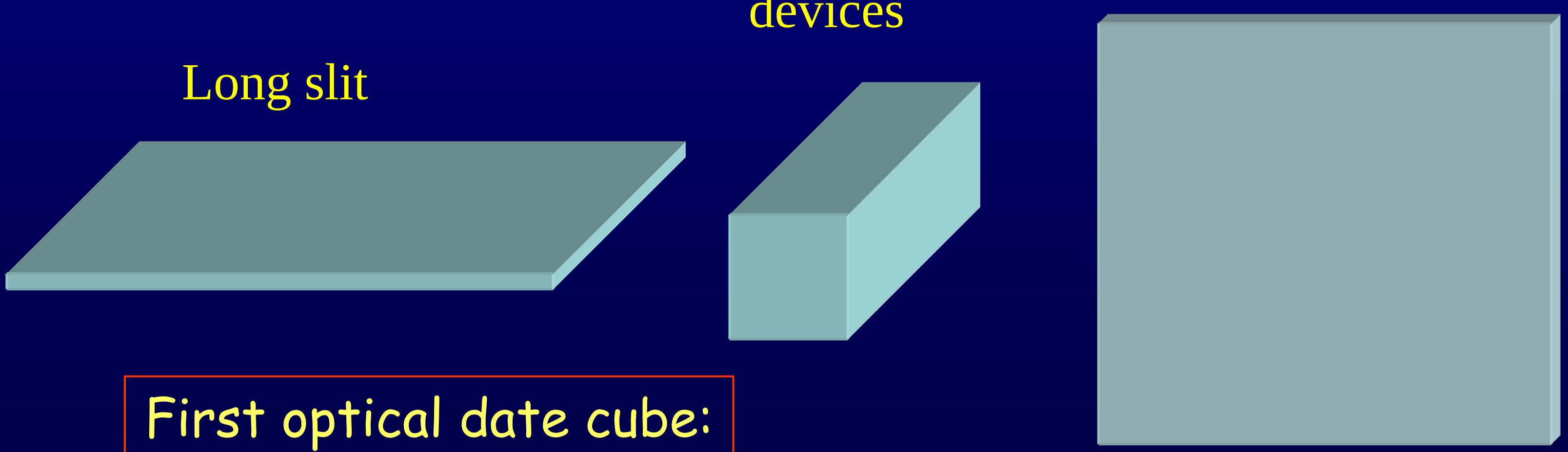
3D data cubes



Long slit

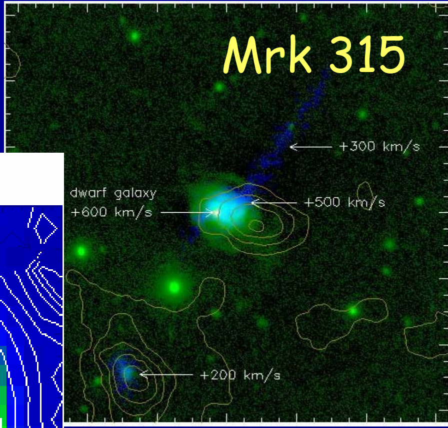
Integral-field devices

Fabry-Perot interferometer

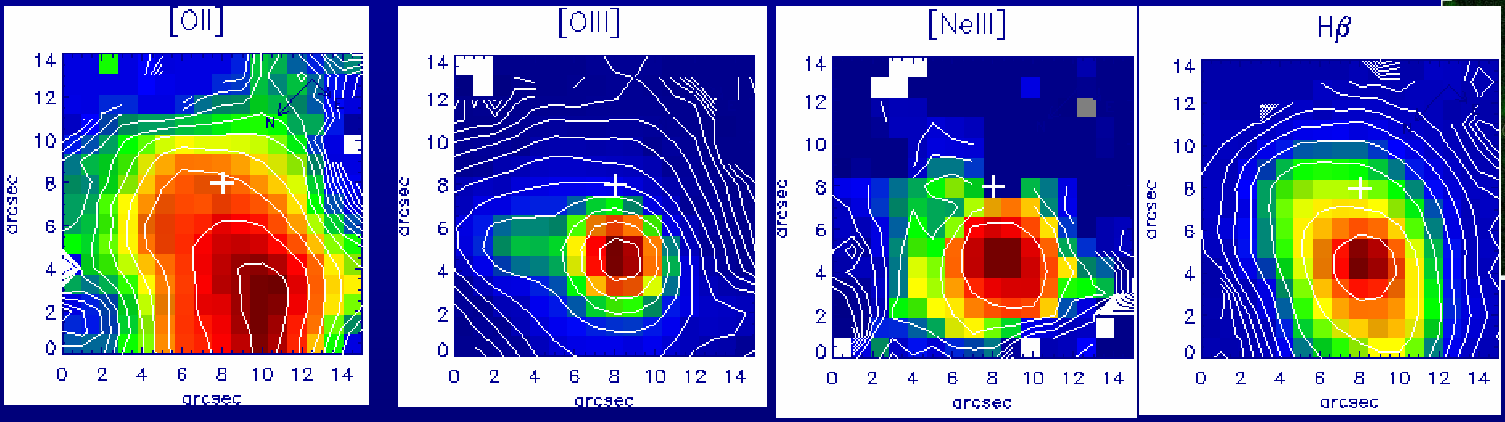


First optical date cube:
Tully (1974)

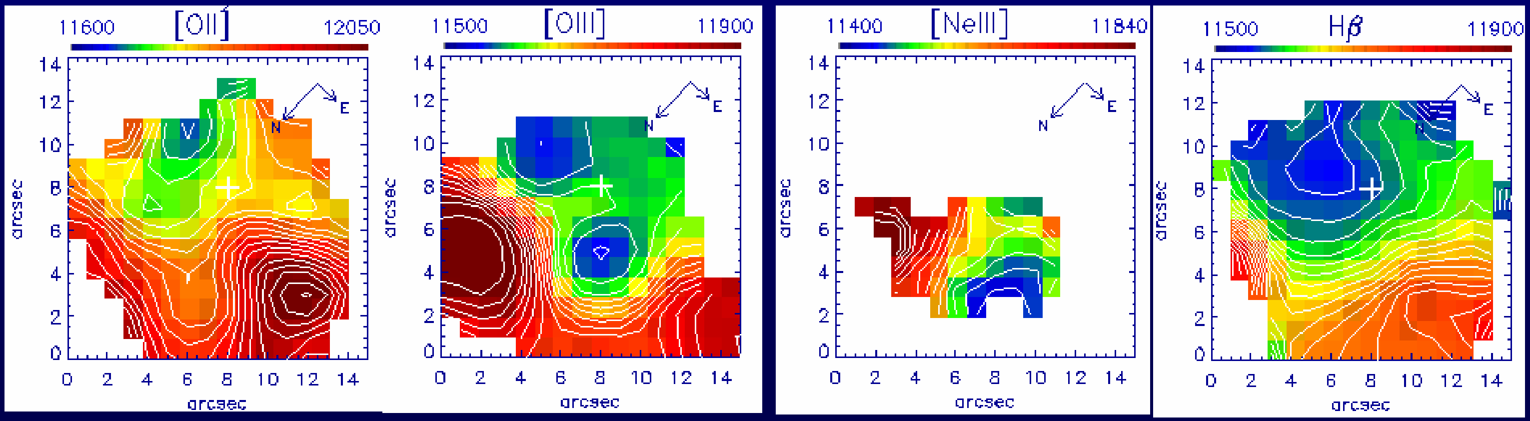
Integral-field spectroscopy in the emission lines.



Differences in the morphology!



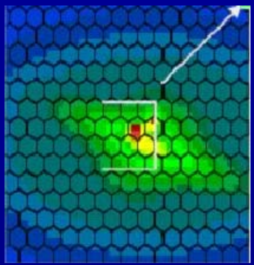
Differences in the line-of-sight kinematics!



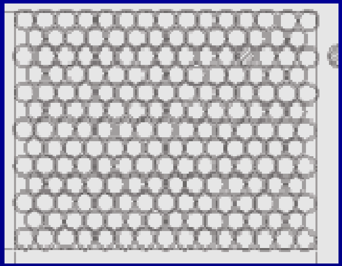
MPFS data/6m telescope: (Ciroi, Afanasiev, Moiseev et al., 2006)

3D spectroscopy of the jets contribution to NLR.

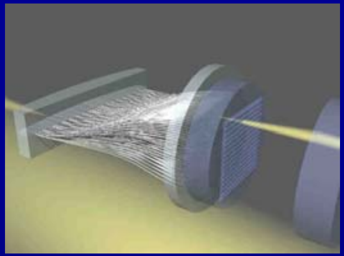
OASIS (3.6m)



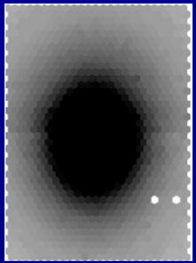
INTEGRAL (4.2m)



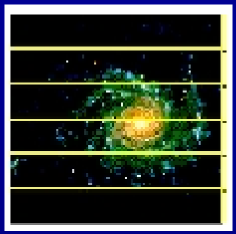
MPFS (6m)



GMOS (8.1m)



SINOFONI (8.2m)

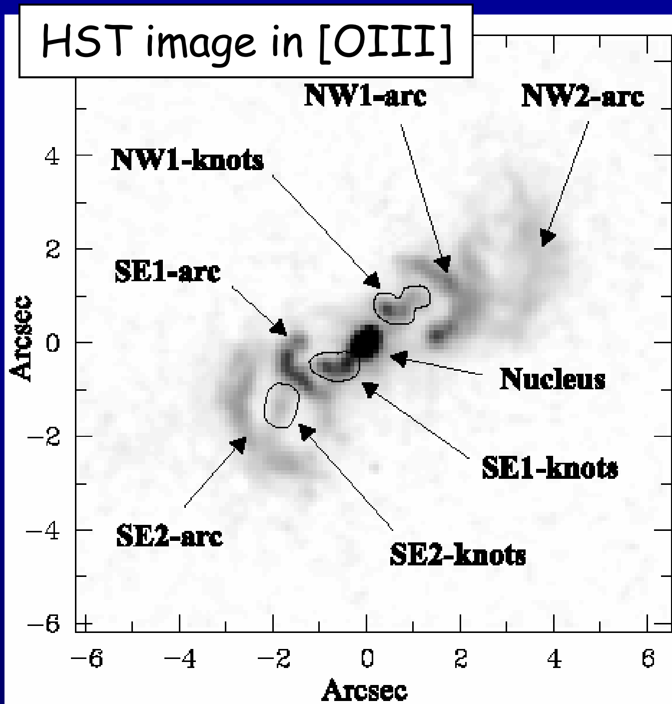


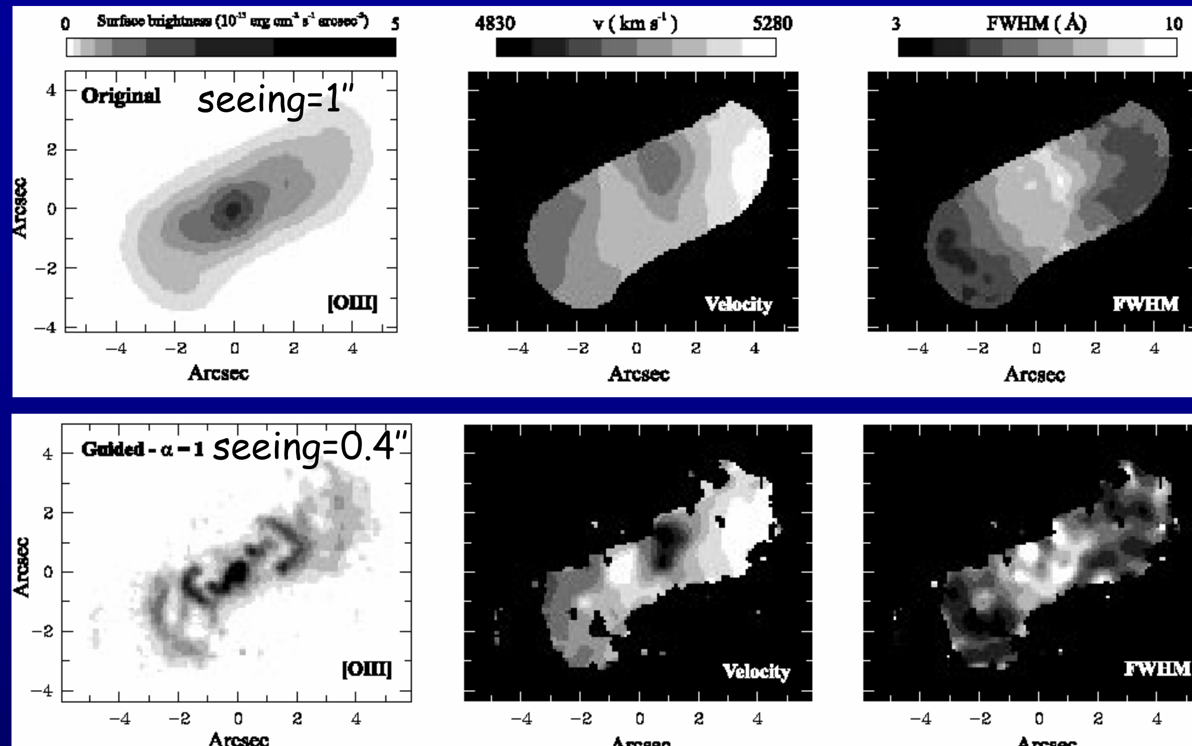
Kyoto 3D (8.3m)

- Kinematically decoupled systems on r<400 pc in NGC 5728 (Schommer et al., 1988; Pecontal et al., 1990)
- TIGER: two-component emission lines profiles associated with two radio lobes in NGC 5929 (Ferruit et al., 1997)
- Kinematics of the ionization cones in NGC 3516 (Veileux et al., 1993), NGC 4258 (Cecil et al., 1992), NGC 5252 (Morse et al., 1998)
- Numerous work about gas stellar/kinematics in SyG and ULIRG (Arribas et al.)
- Bow shocks in NLR of NGC 1068 (Pecontal et al., 1997; Emsellem et al., 2006)
- Bipolar outflow in NGC 1052 (Sugai et al., 2005)

TIGER/CFHT observations: Mrk 573

Ferruit et al. (1999)

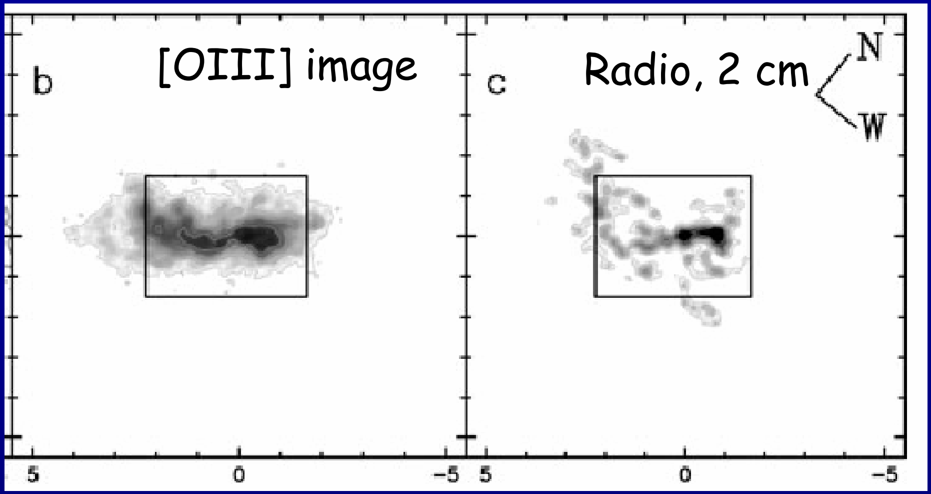




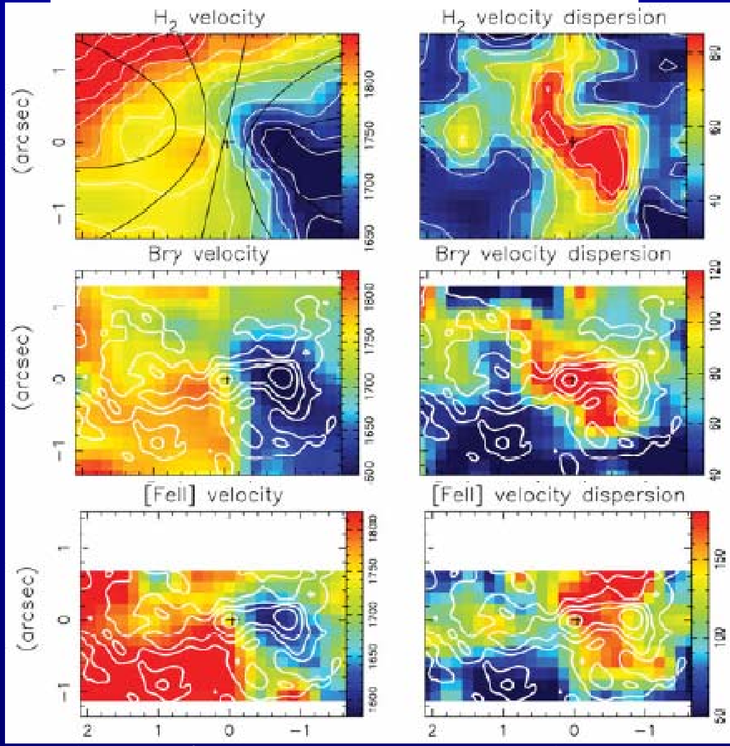
The variation of the ionization parameter and gas density were used to derive the flux of ionizing photons as a function of distance from the nucleus:

- The emission-line knots, associated with the radio knots and the velocity perturbations, probably trace the deflection of the radio jet by clouds.
- The arcs are photoionized by an external source of radiation.
- The fast shocks, possibly associated with the jet/cloud interactions, may provide the required spatially extended source of ionizing photons.

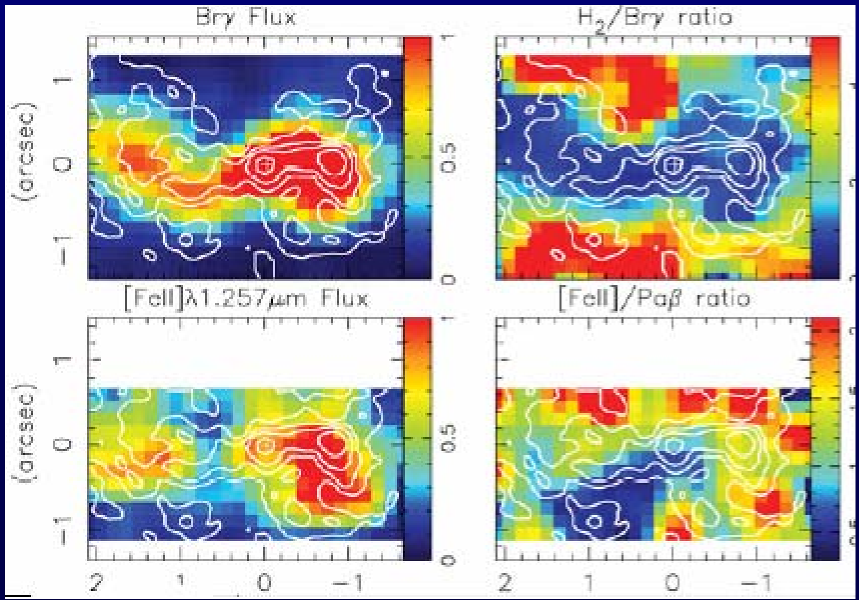
GMOS: ESO 428-G14



Emission line kinematics:



NIR emission line maps:

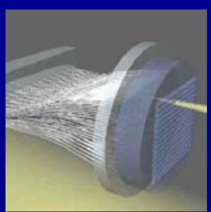


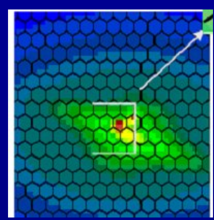
.. find a tight relation between the radio structure and the emission-line flux distributions and kinematics, revealing that the radio jet plays a fundamental role in shaping the NLR but also in the imprint of its kinematics. Blueshifts of up to 400 km/s and velocity dispersions of up to 150 km/s are observed in association with the radio jet..

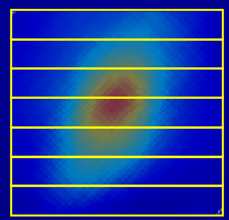
Riffel et al. (2007)

Panoramic (3D) spectroscopy devices: two families.

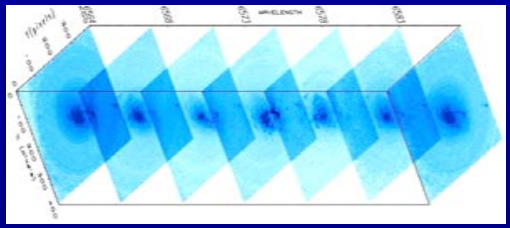
Integral-field spectrographs (lenslets, fibers, slicers...)







Scanning Fabry-Perot interferometers



Field of view

SMALL : 10 – 50 arcsec

LARGE : 100 – 1000 arcsec

Spectral range

LARGE : $\Delta\lambda$ > 100-1000 Å

SMALL : $\Delta\lambda$ < 10-30 Å

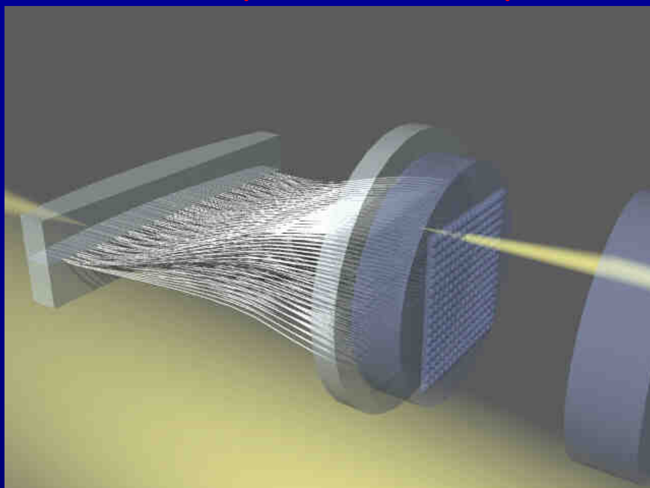
Active galaxies studding:

- Velocity fields in the different emission lines of the ionized gas
- Velocity fields of the stars
- Spectrophotometry in the Balmer and forbbiden emission lines of atoms and ions (Ha, Hβ, [OIII], [SII], [NII]): line ratio diagnostic diagrams

- The kinematics of the ionized gas (velocity field, velocity dispersion maps, line profile analysis) in the single emission lines (Ha, [OIII], etc)

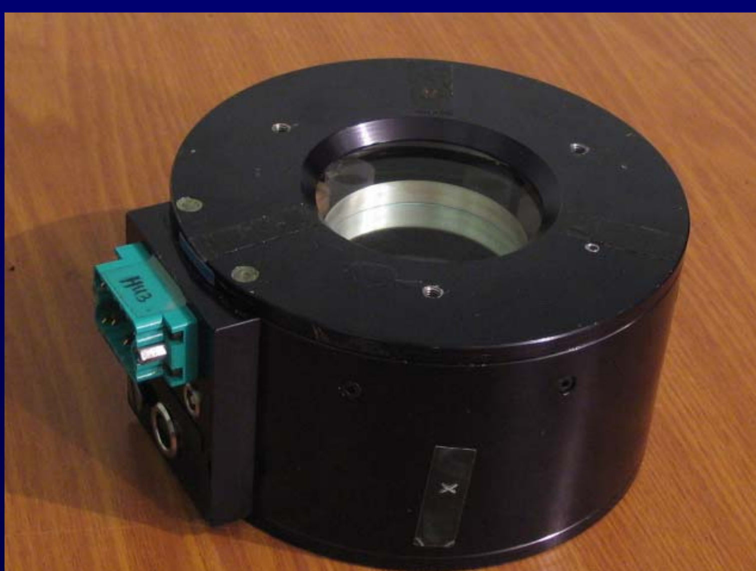
Panoramic spectroscopy on SAO RAS 6-m telescope

Multi Pupil Fiber Spectrograph: lens+fibers



MPFS: Afanasiev et al. (1990, 2001) :
Multilens array: 16x16+16 sky probes
Spatial sampling: 0.5...1 arcsec/lens
Spectral range : 3700-9000 Å
Dispersion: 0.8- 3 Å/px

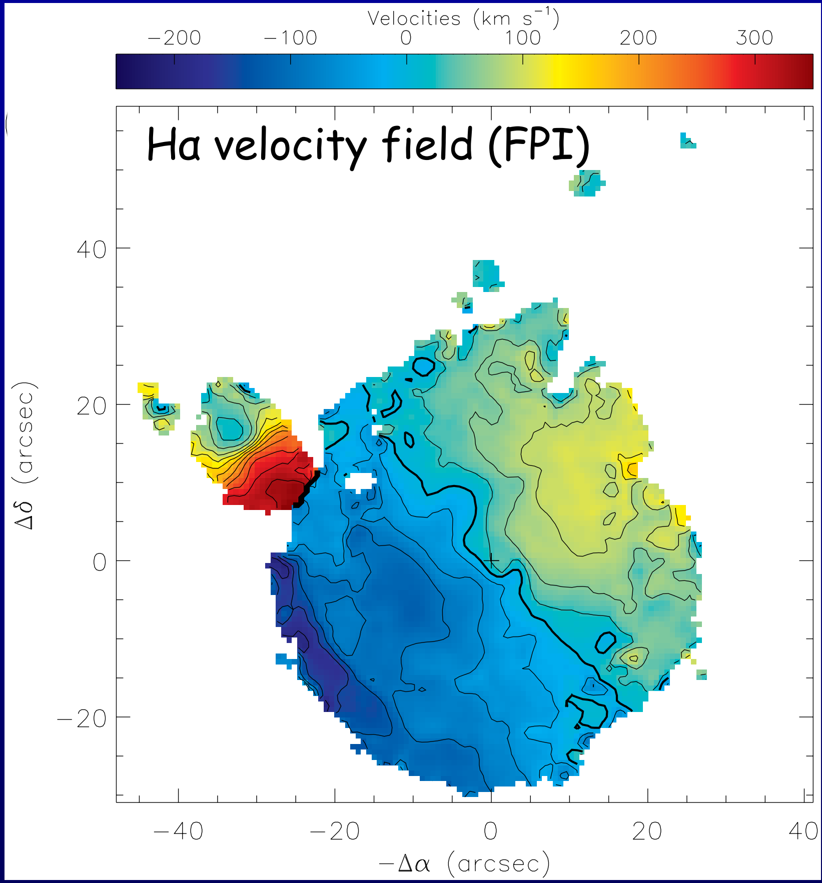
Scanning Fabry-Perot Interferometer



Dodonov et al. (1995), Moiseev (2002):
Field of view: 6 arcmin
Spatial sampling: 0.16...0.70 arcsec
Spectral range : 13-28 Å around Hα,
[OIII]λ5007 and [SII] λ6717 lines
Dispersion: 0.4- 0.9 Å/channel

Mrk 533

Smirnova, Gavrilović, Moiseev, Popović et al. (2007)



Observations (6-m telescope):

- Scanning FPI – kinematics in Hα
- MPFS integral-field data:
  - Ionization state
  - Multicomponent profiles of the emission lines

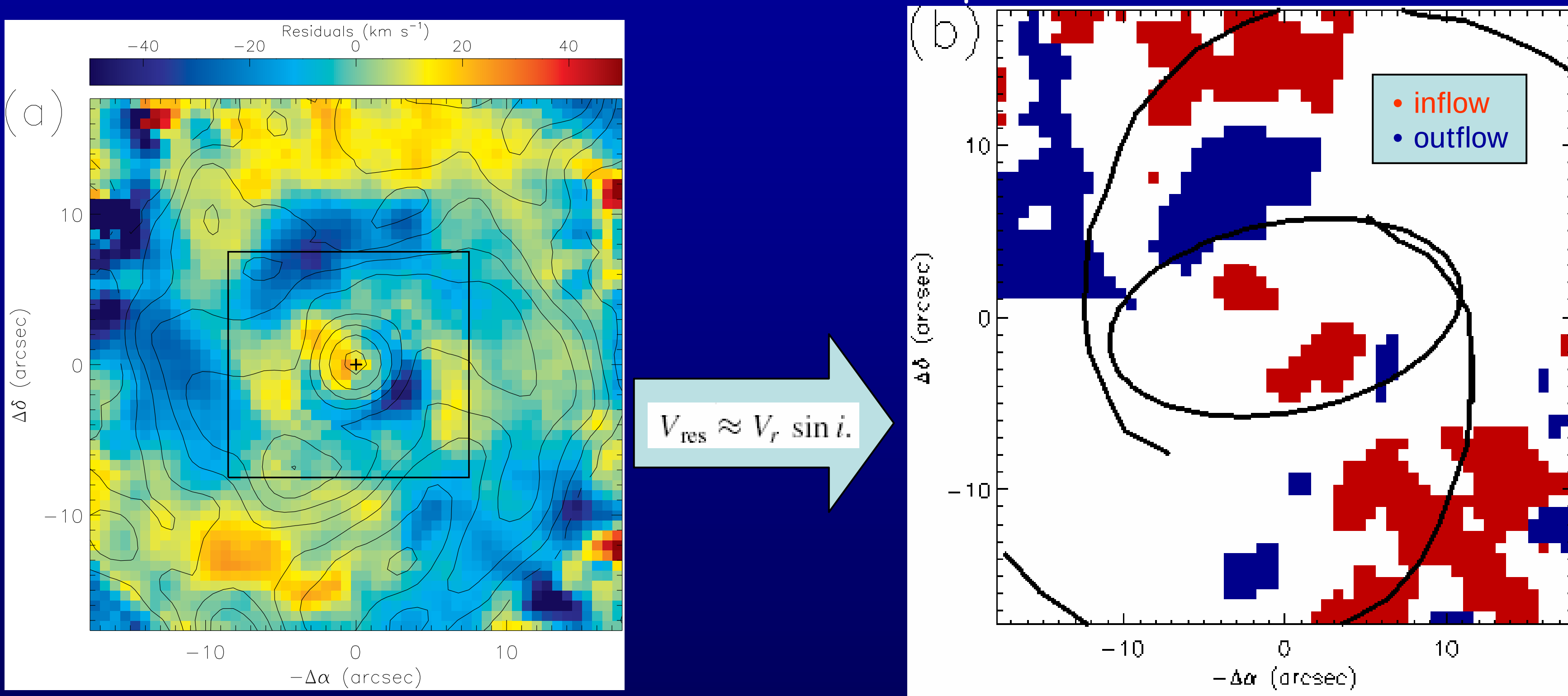
2D fitting of the velocity field:

- Model of rotation
- Warped outer disk + streaming motions triggered by close interaction with the companion

Mrk 533: the perturbations of the ionized gas (FPI)

Residual velocities=observations - model

Map of radial motions

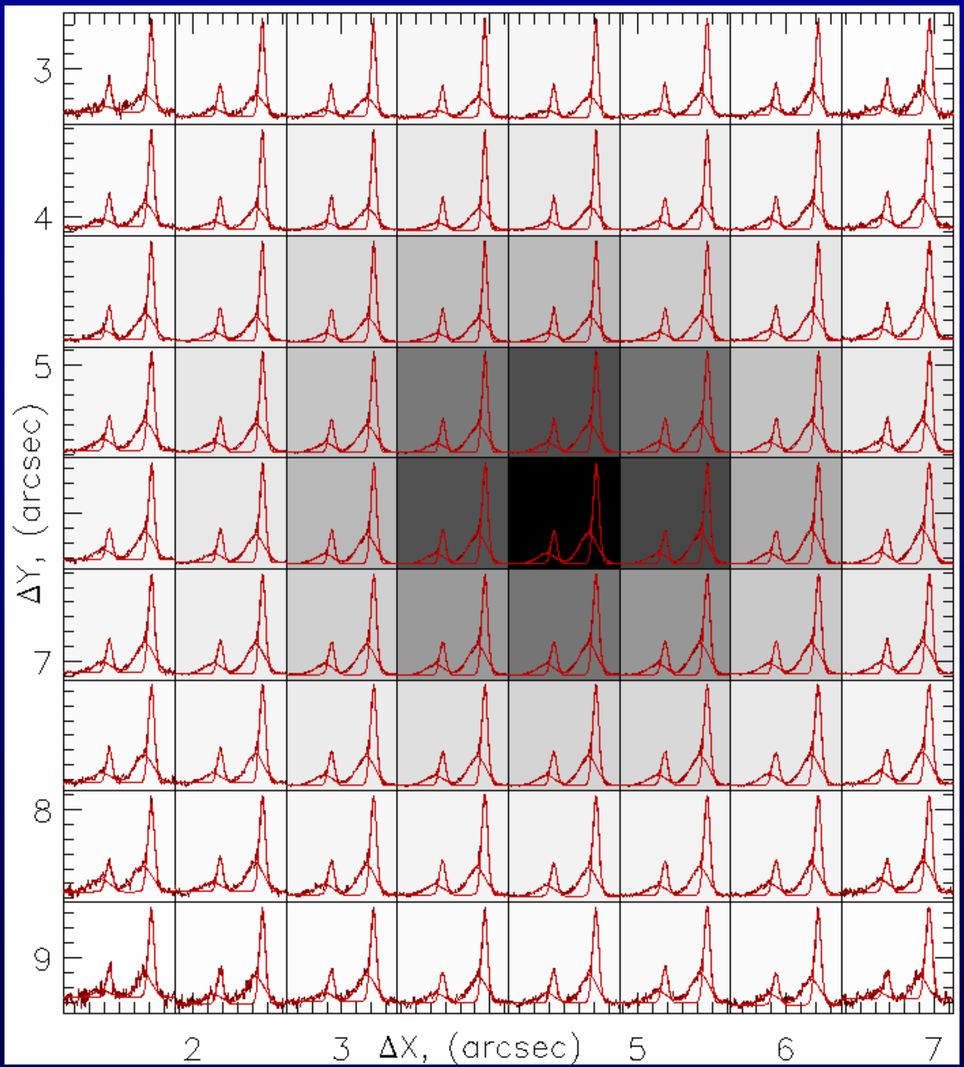


- Streaming inflow/outflow motions along spiral arms

- Circumnuclear outflow along the minor axis with radial velocities 40-90 km/s on r<2 kpc

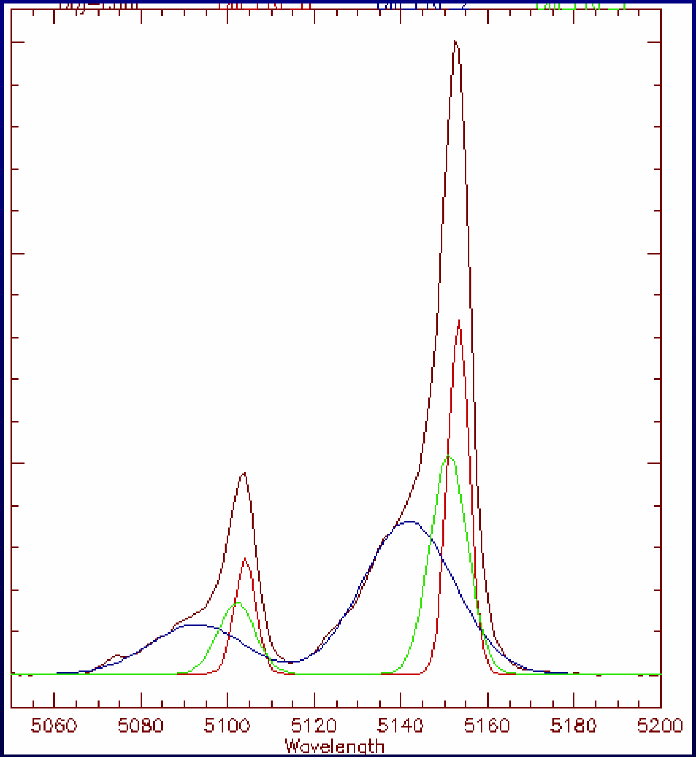
Mrk 533: NLR structure and kinematics (MPFS)

[OIII] multicomponent profiles:



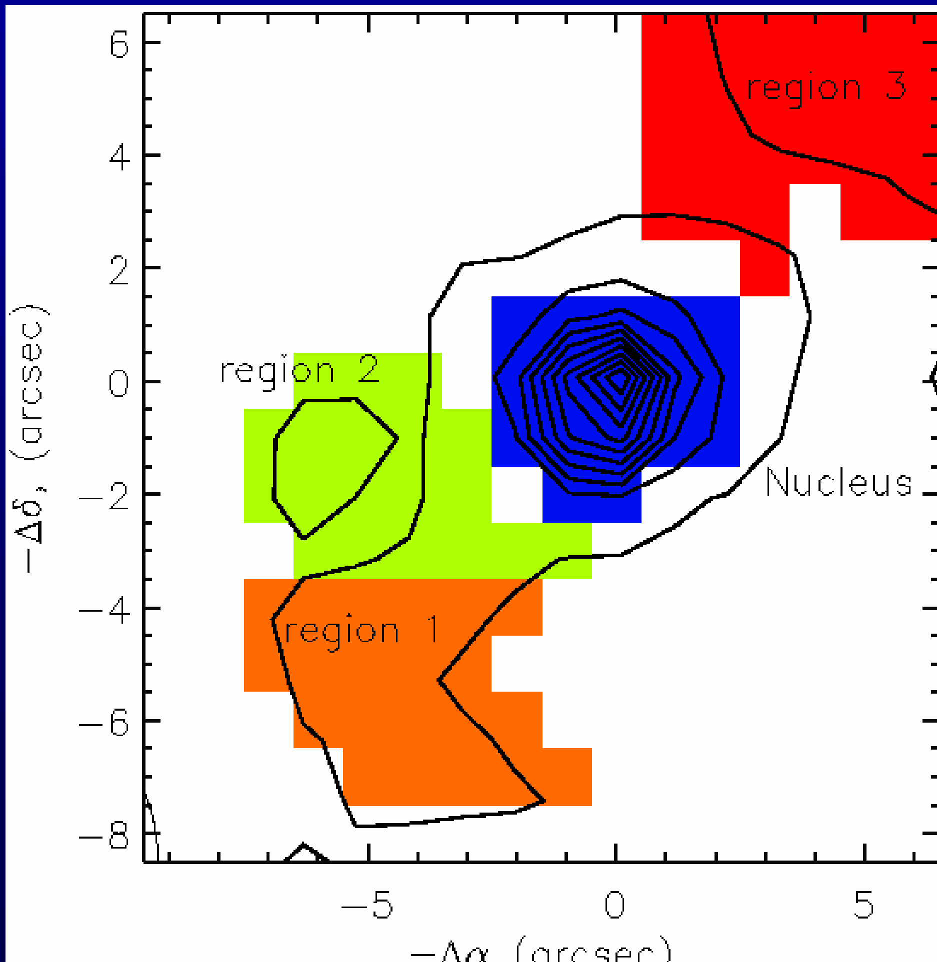
NLR kinematics:

- Blue asymmetry of the emission lines
- 2- or 3- Gaussian components in the [OIII] (complex outflow?)
- The region of this outflow is spatially resolved (r=0.8-1 kpc)

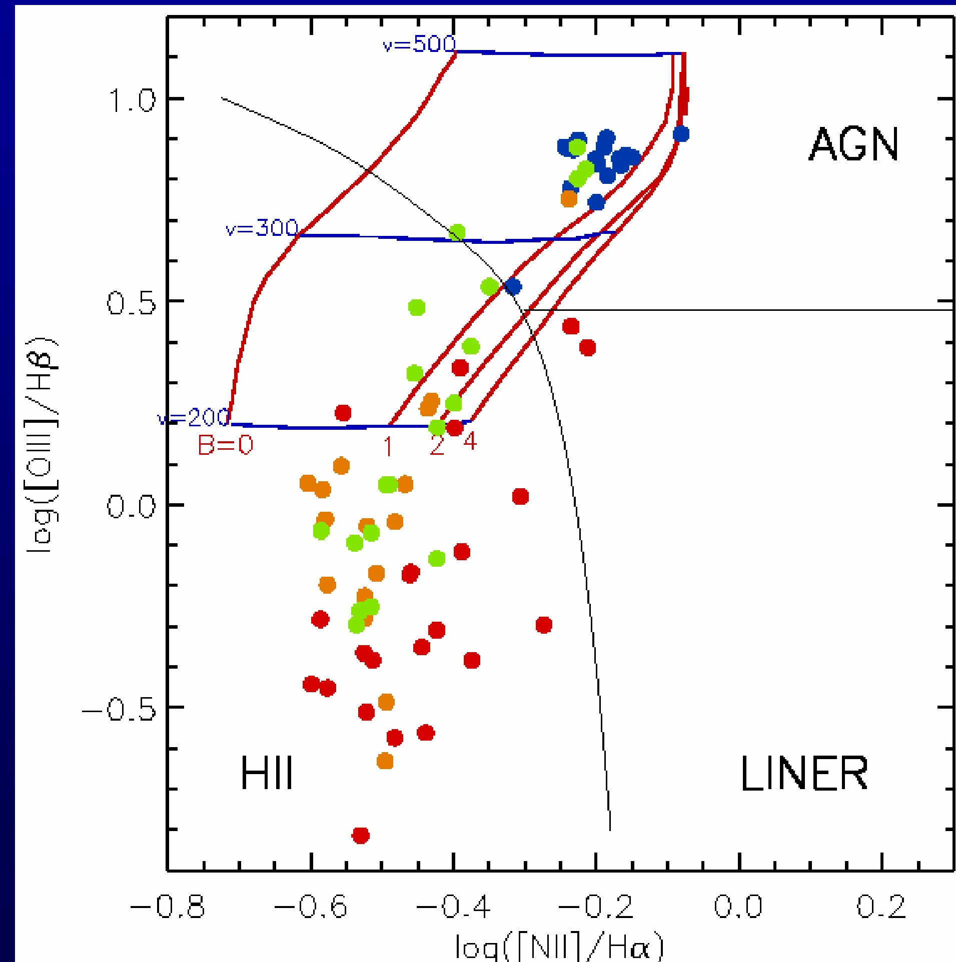


Mrk 533: state of the gas ionization

Regions around nucleus + Ha isophotes



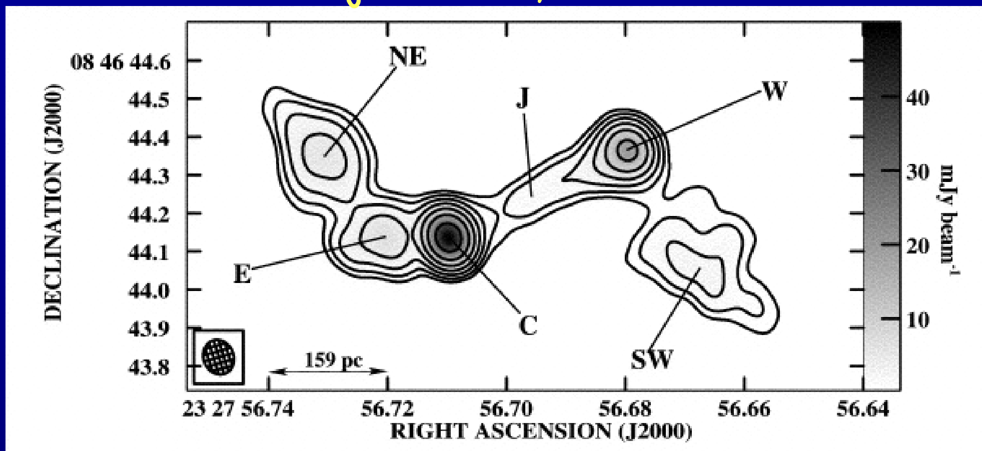
Grid of "shock+precursor" models (Dopita & Sutherland, 1995)

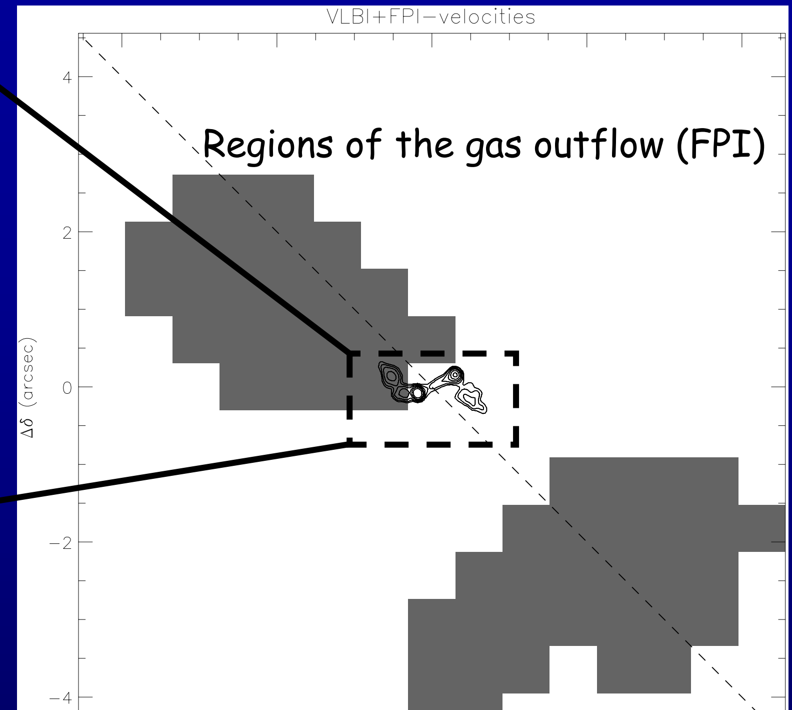


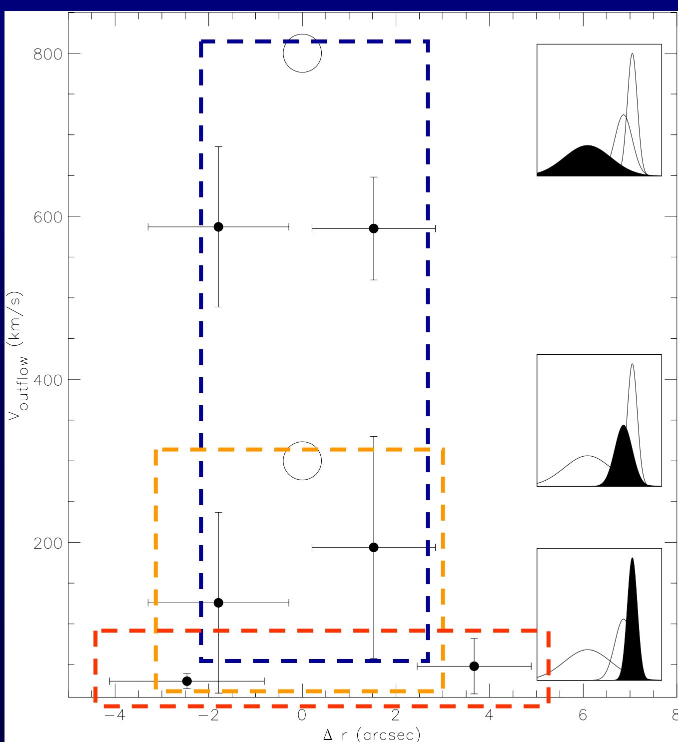
Smirnova, Gavrilović, Moiseev, Popović et al. (2007)

Mrk 533: radio jet and optical outflow

VLBI data: Momjian et al., 2003







There is a stratification in the line-of-sight velocities, the spatial structure of the outflow is slightly resolved .

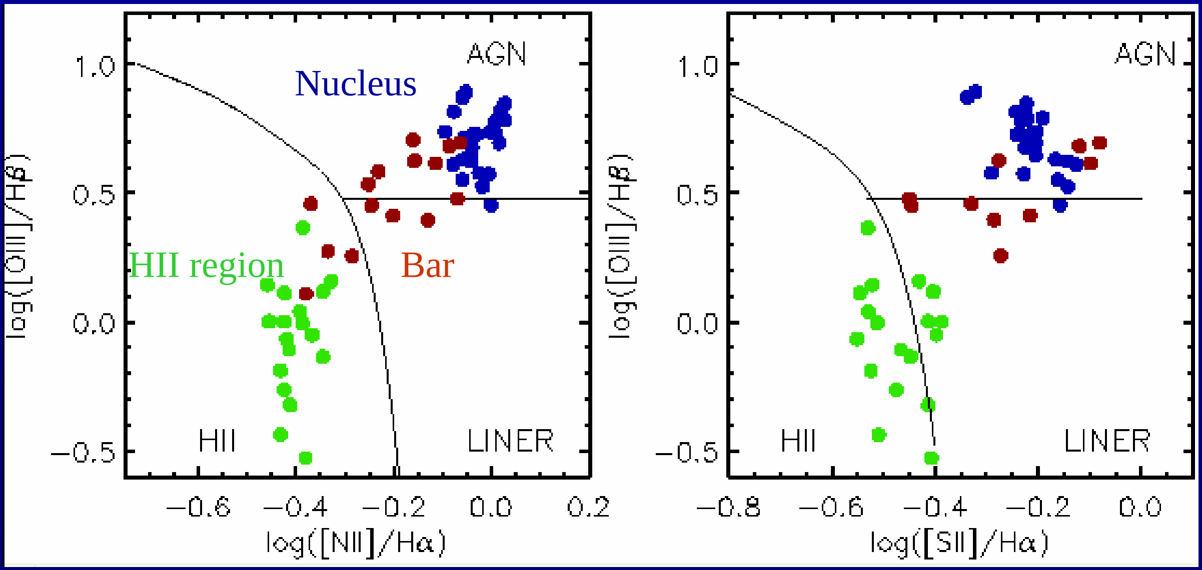
The presence of high-velocity clouds, located close to the passage of the radio jet, shows that the effects of jet-induced shocks are still important in the nuclear regions.

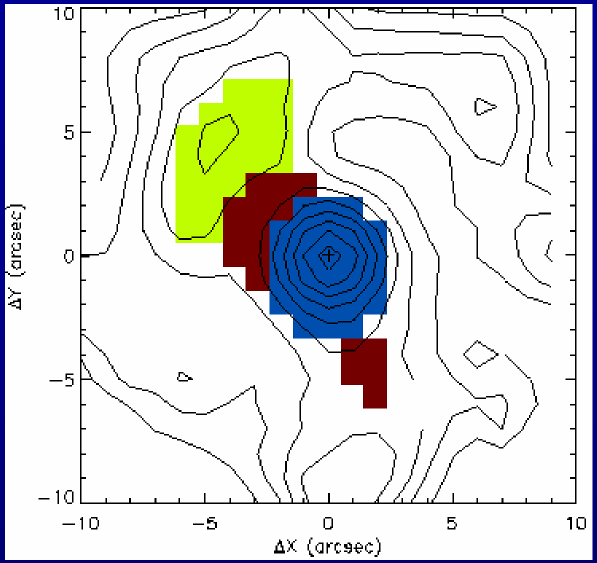
The ionized gas outflows are triggered by the radio jet intrusion in an ambient medium.

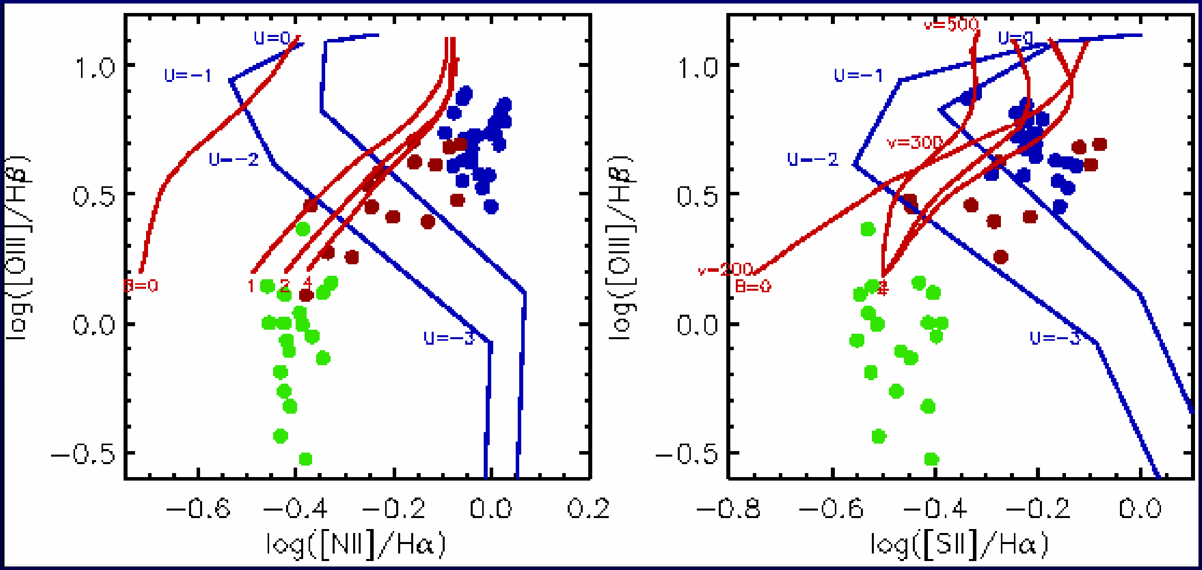
NGC 6104: diagnostic diagrams (MPFS data)

The boundaries were taken from Veilleux & Osterbrock (1987).

The mask + Hα isophotes





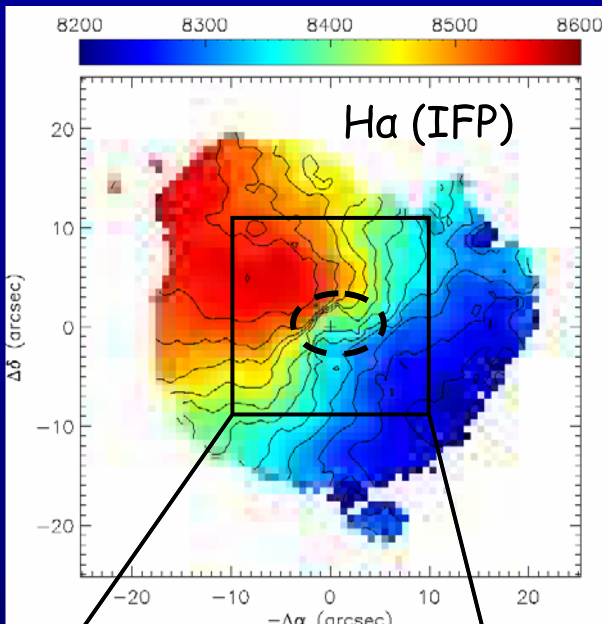


BLUE – AGN optically thick photoionization sequences + realistic dust content

RED - Shock+precursor models (Dopita & Sutherland, 1995)

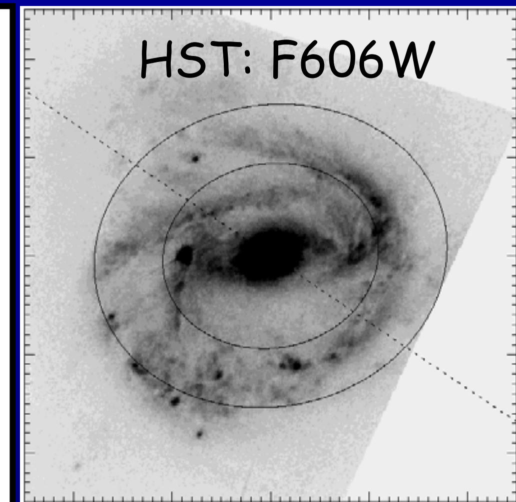
Shock+AGN ionization in the nucleus

NGC 6104: kinematical signatures of the jet

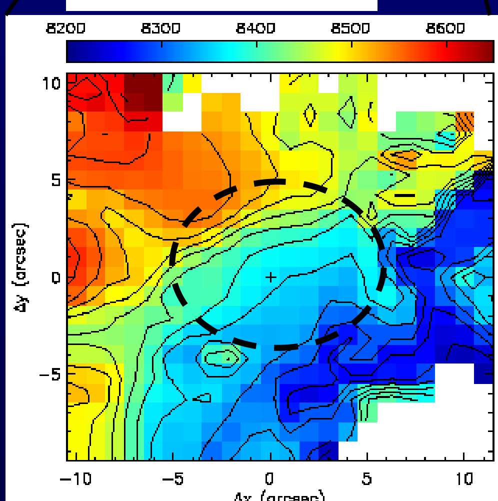


The excess of blue-shifted ionized gas radial velocities in the nucleus:
$V_{outflow}$=30-40 km/s
$R_{outflow}$<1.5 kpc

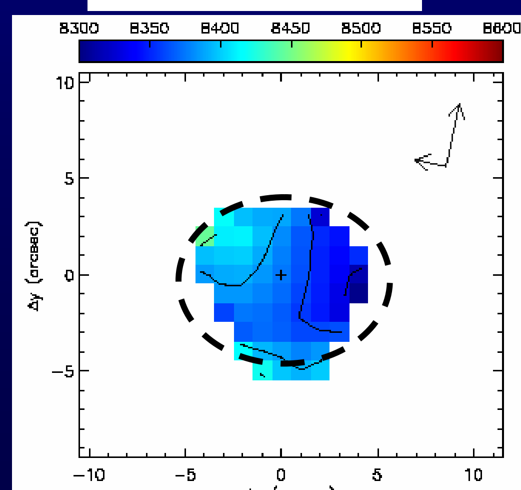
Most of the [OIII] emission apparently originates from the circumnuclear jet and appears the non-circular motions.



[NII] (MPFS)



[OIII] (MPFS)

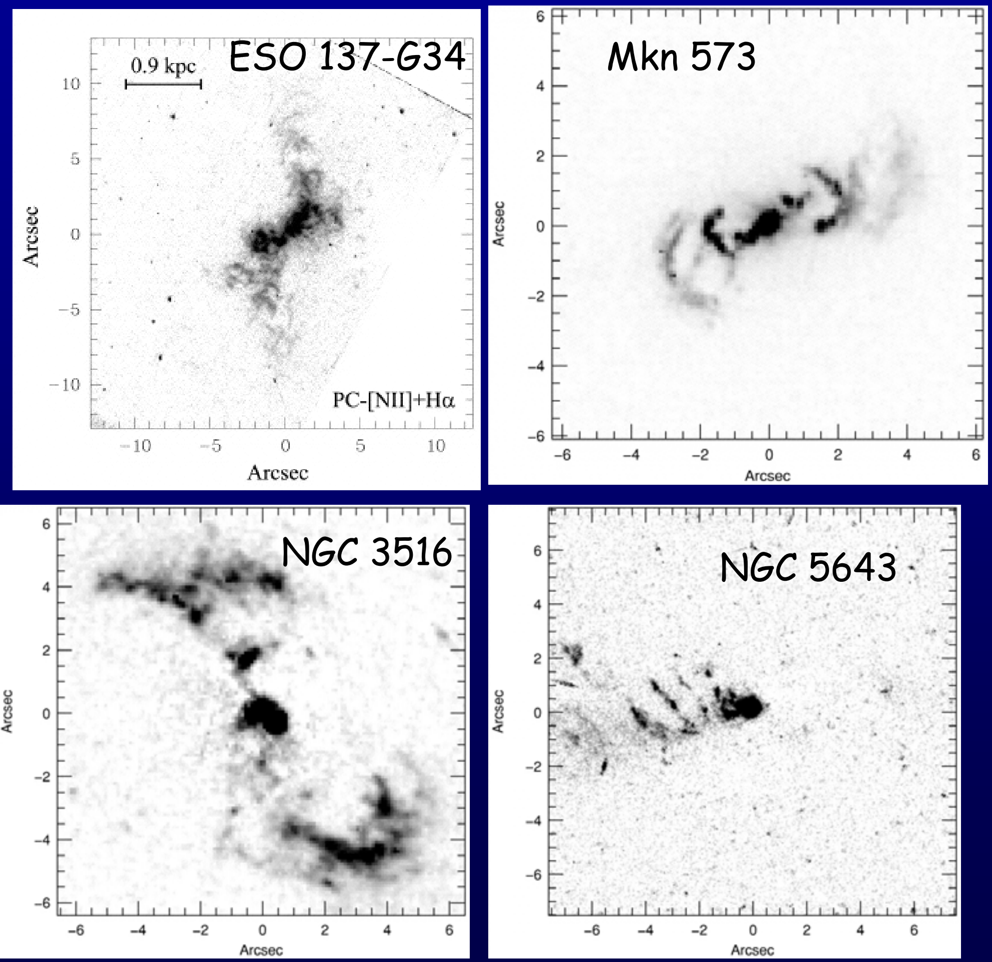


We observed not the high-velocity jet itself emerging from the AGN, but the result of the interaction between the radio jet and interstellar clouds, the formation of an expandin cocoon of hot gas.

Kinematics of AGN with ionization cones

The Seyfert galaxies with a cone-like morphology of Narrow Line Regions.

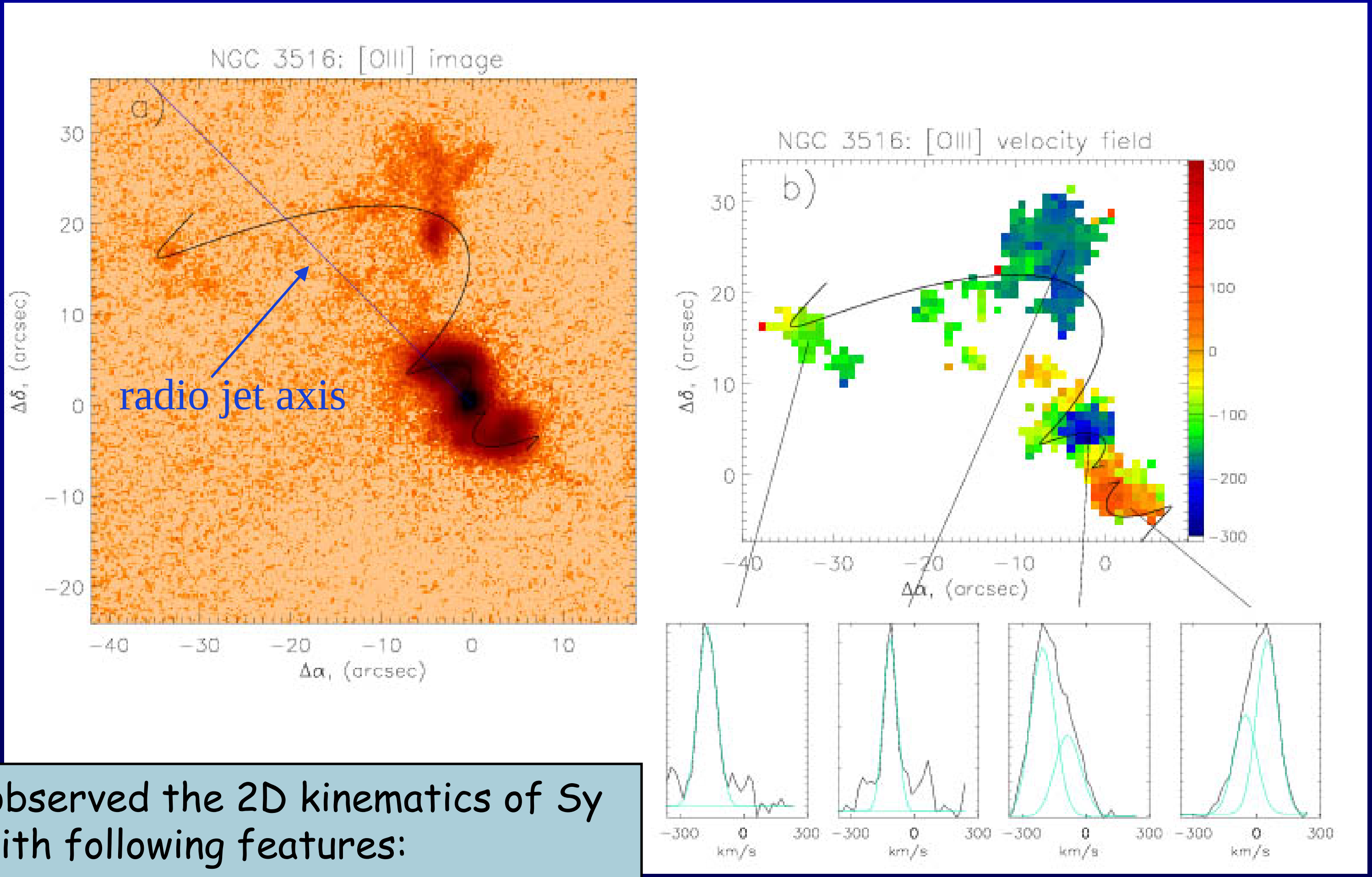
HST emission-line images (*Ferruit et al., 2000; Quillen et al., 1999*):



What is the origin of the regular structures in the NLRs?

- A radio jet preccessing (Veilleux et al., 1993)
- Deflected of the outflow gas toward the galactic disk (Mulchey et al., 1992)
- Systems of inclined disks or merging remains (Morse et al., 1998)
- Shear instability in the boundary layer between the jet/ISM (Falcke et al., 1996; Lobanov et al., 2006)
- Jet + rotating ISM (Lim & Steffen, 2001)
- Other?

Seyfert galaxies with extended NLR: NGC 3516

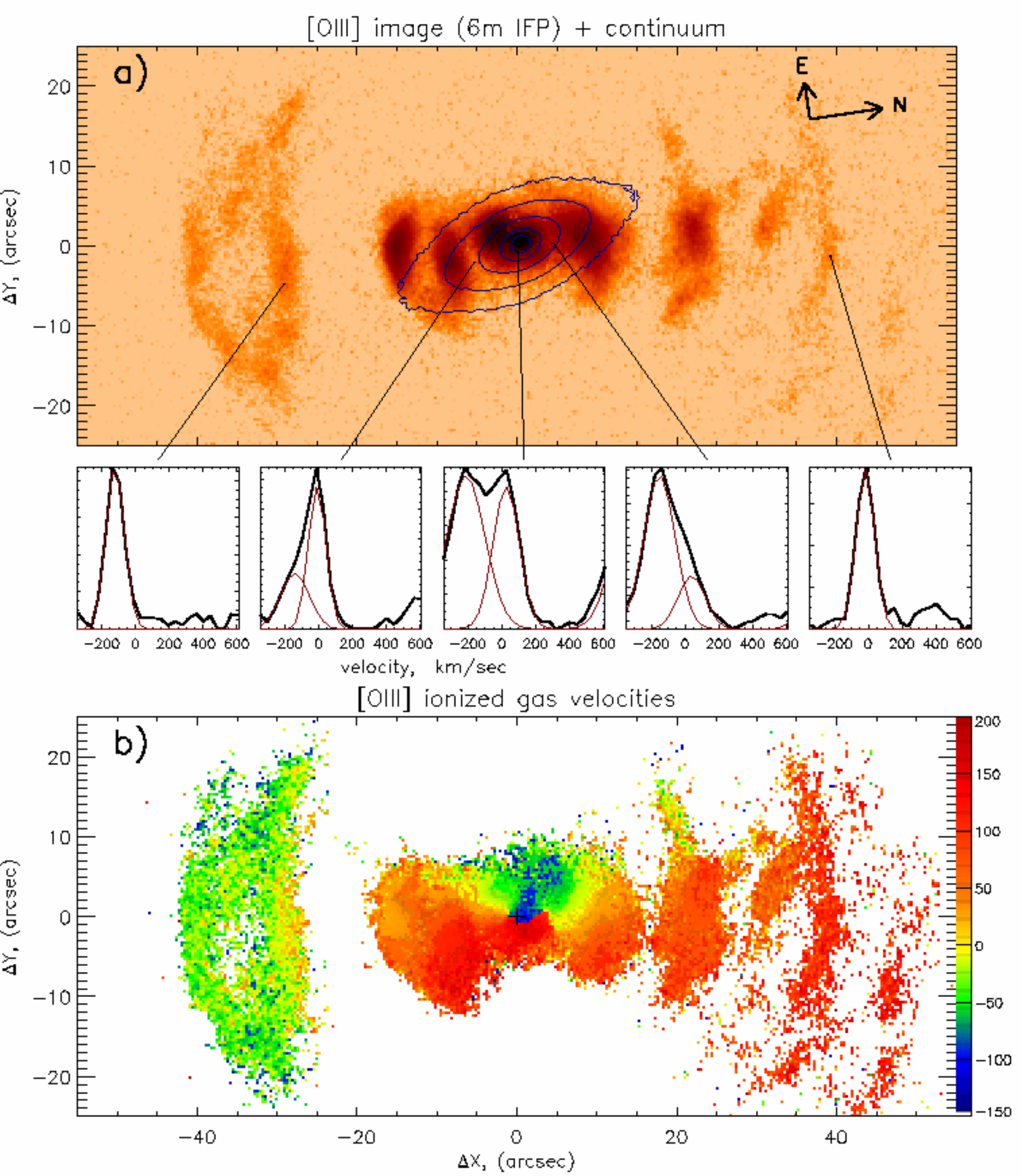


We have observed the 2D kinematics of Sy galaxies with following features:

•a regular Z-shaped pattern of the emission fillaments appears on images
• an elongated radio structure (radio-jet) coincides with the cones axis

FPI observations reveal a double-component structure of the [OIII] emission line profiles
Moiseev et al. (2000)

NGC 5252: emission line structures up to 18 kpc



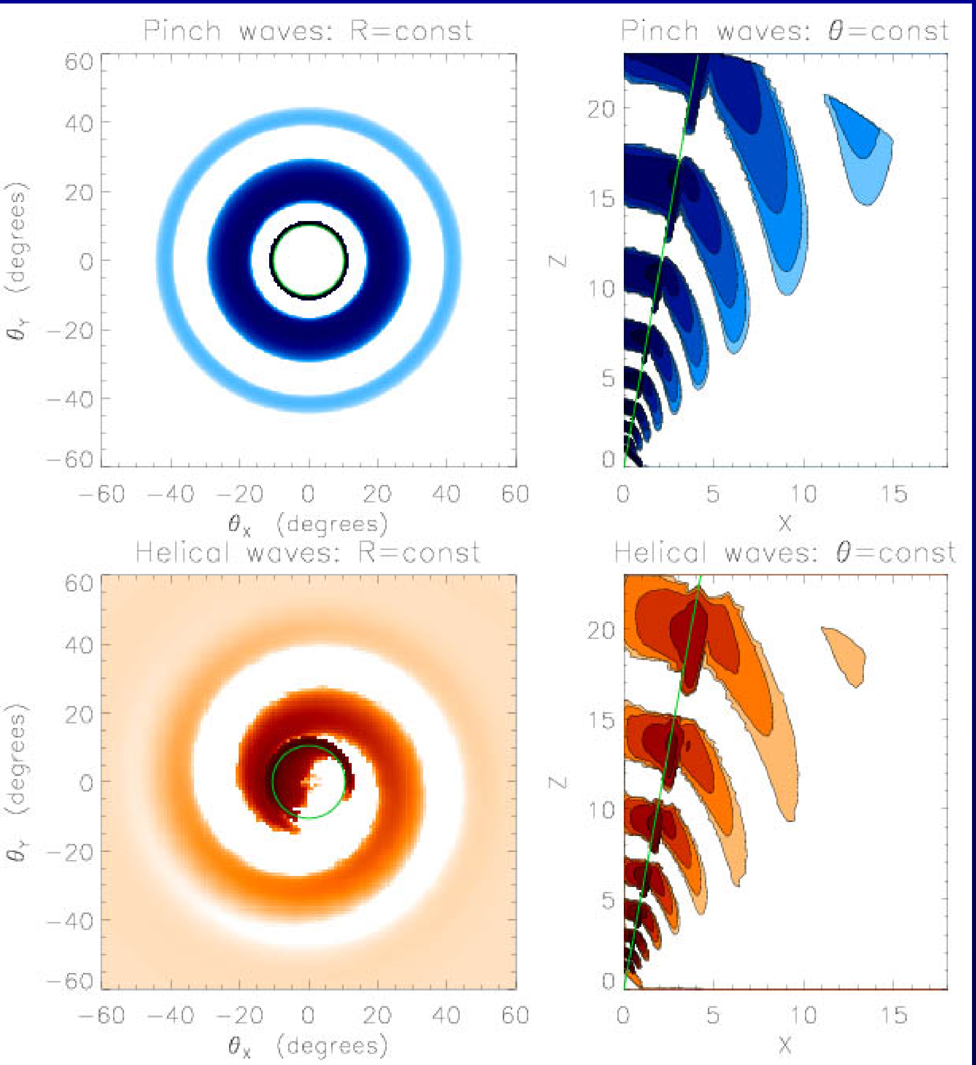
We suggest that filaments in NLRs have a wave origin and generated by the hydrodynamic instabilities on the velocity break between a interstellar medium and a outflowing gas from an AGN.

2D and 3D non-linear hydrodynamical simulations show the axisymmetrical and helical modes of the shock waves are developing and provides the Z-shaped regular emission pattern.

Afanasiev et al. (2007)

The helical and pitch waves: 2D/3D simulations

Afanasiev et al. (2007)



2D and 3D non-linear hydrodynamical simulations show:

- the shock waves penetrate outward from the jet boundaries to the ambient medium.
- pinch (axisymmetrical) and helical modes of the shock waves are developing
- helical waves provides the Z-shaped emission structures which observed in the ionized cones.

Pinch and helical waves in NGC 5252: the superposition.

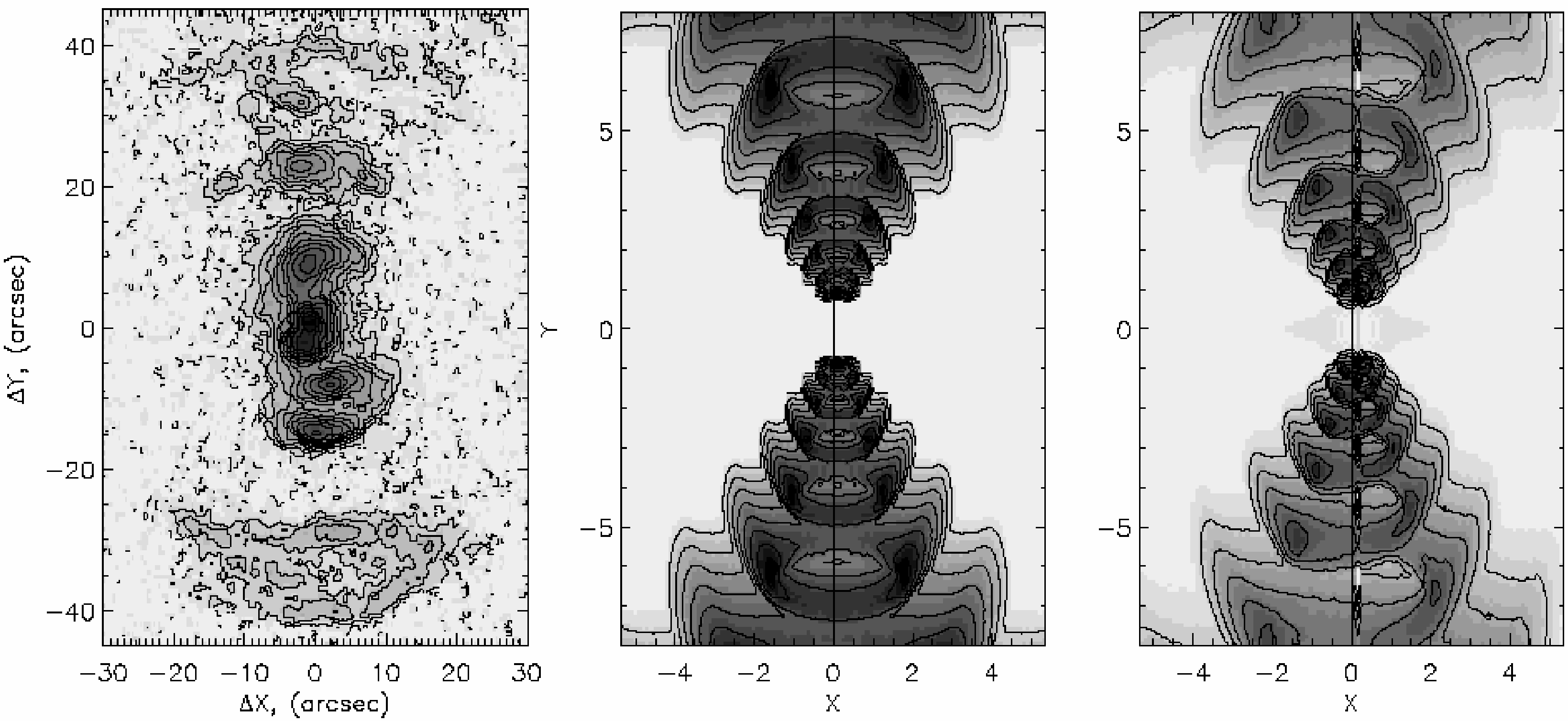
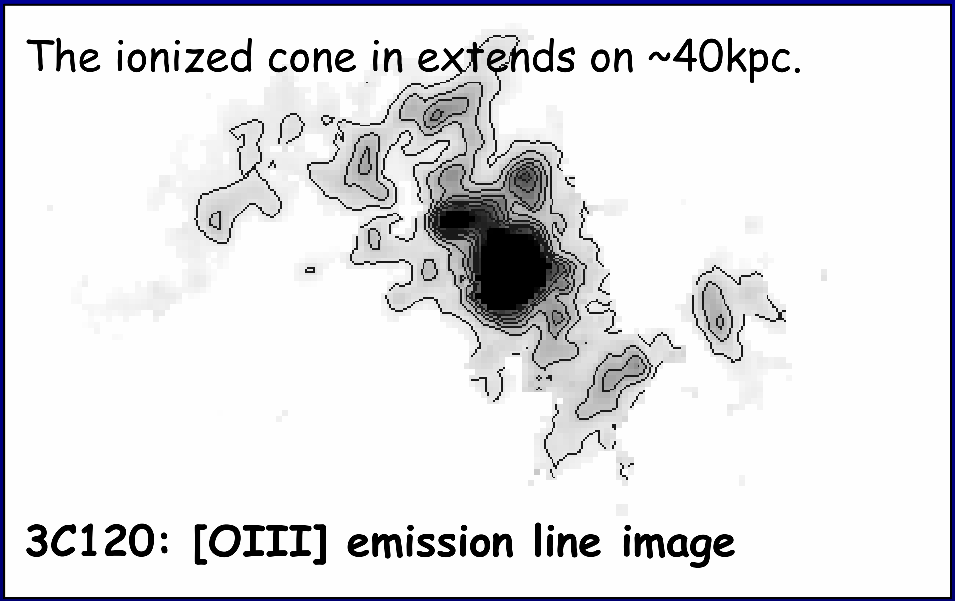
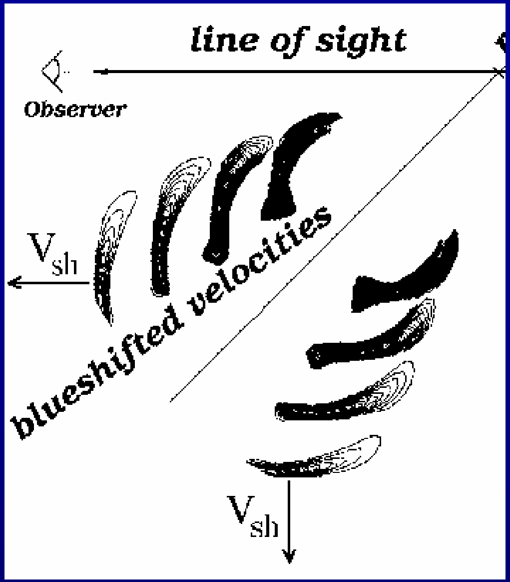


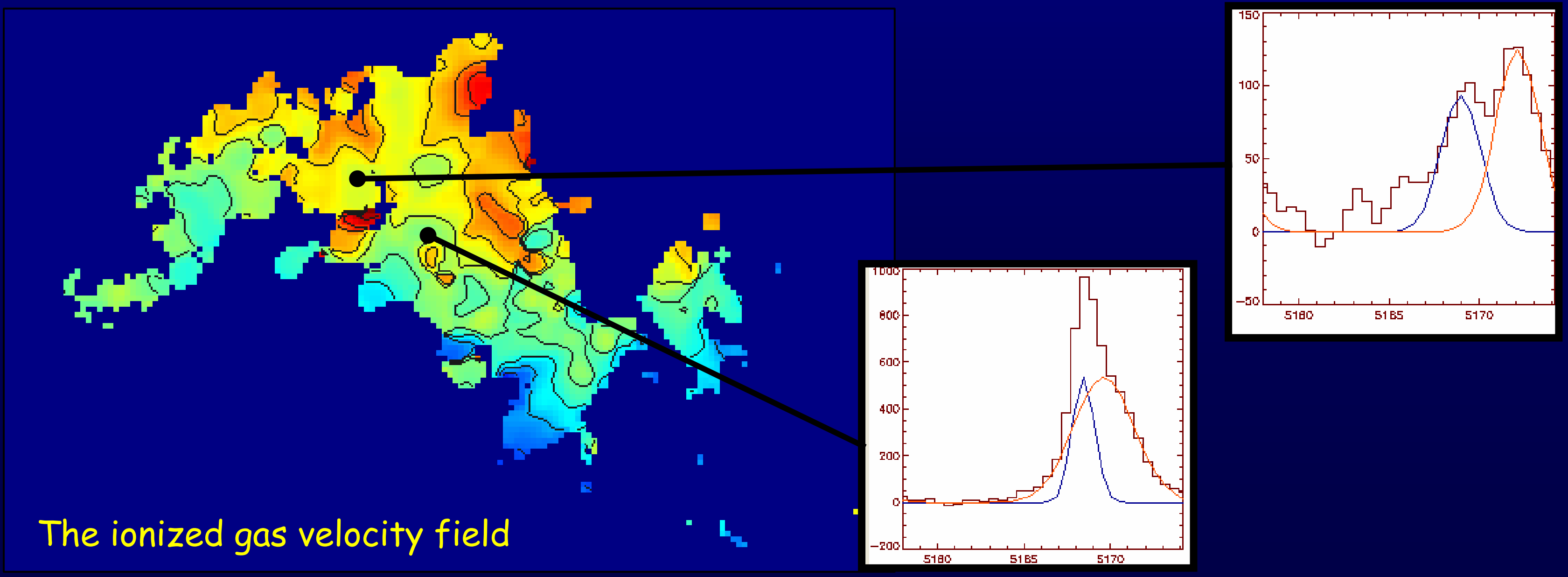
Fig. 13. Left-hand panel: an [OIII]-line contour image of the NGC 5252 galaxy. Central panel: simulated velocity map for the pinch mode ($m = 0$) $i = 60°$. Right-hand panel: simulated luminosity map for the helical mode ($m = 1$) $i = 60°$.

Afanasiev et al. (2007)

Emission filaments in 3C 120: the work in a progress







What is the main problem of the panoramic spectroscopy?

It is not OBSERVATIONS !
It is not a DATA REDUCTION !
(because the spectrographs and software already exist)

It is an INTERPRETATION (includes construction of the models described all observational features and new theoretical predictions)