3D spectroscopy of nuclear and extranuclear regions of nearby AGN

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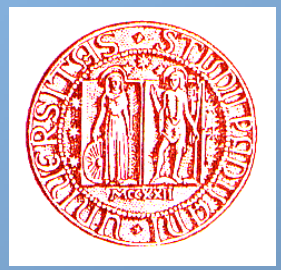


S. Ciroi
F. Di Mille
V. Cracco
L. Vaona

V.L. Afanasiev
S.N. Dodonov
A.V. Moiseev
A.A. Smirnova

Properties of Active Galaxies

High Luminosity of the Nucleus

$L_{AGN} \sim 10^{41} - 10^{47}$ erg s^{-1}

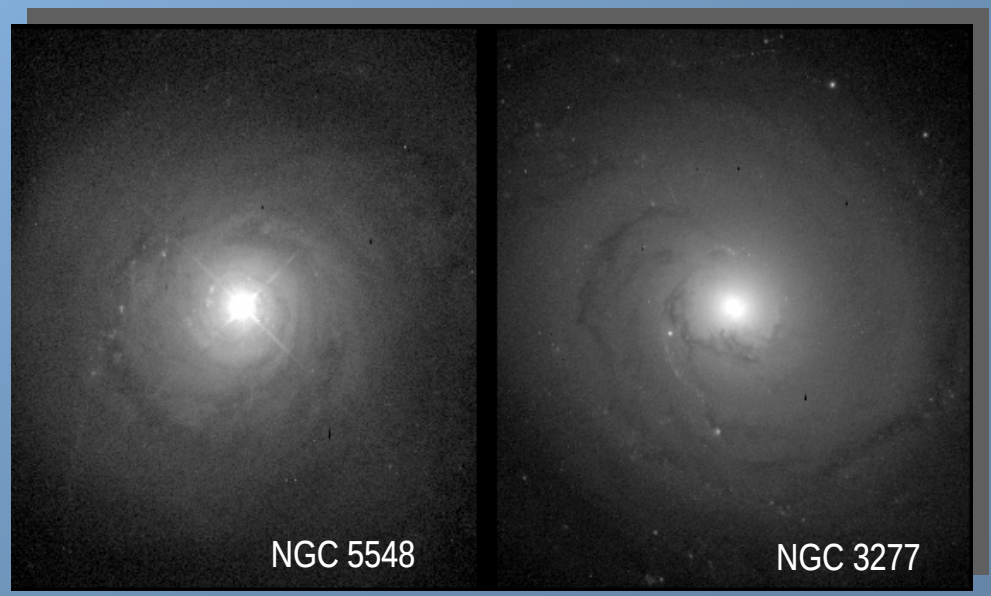
$\sim 10^{8} - 10^{14}\ L_{\odot}$

NORMAL GALAXIES

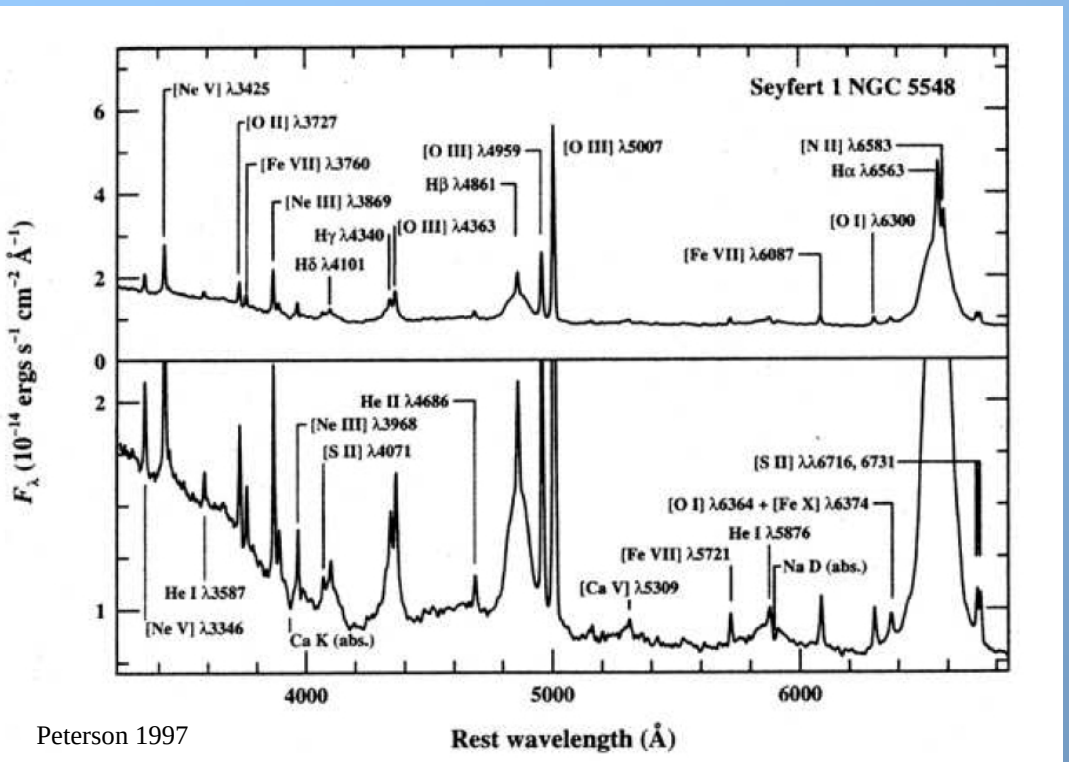
$L_{NUC} \sim 10^{6} - 10^{8}\ L_{\odot}$

$L_{HOST} \sim 10^{9} - 10^{11}\ L_{\odot}$

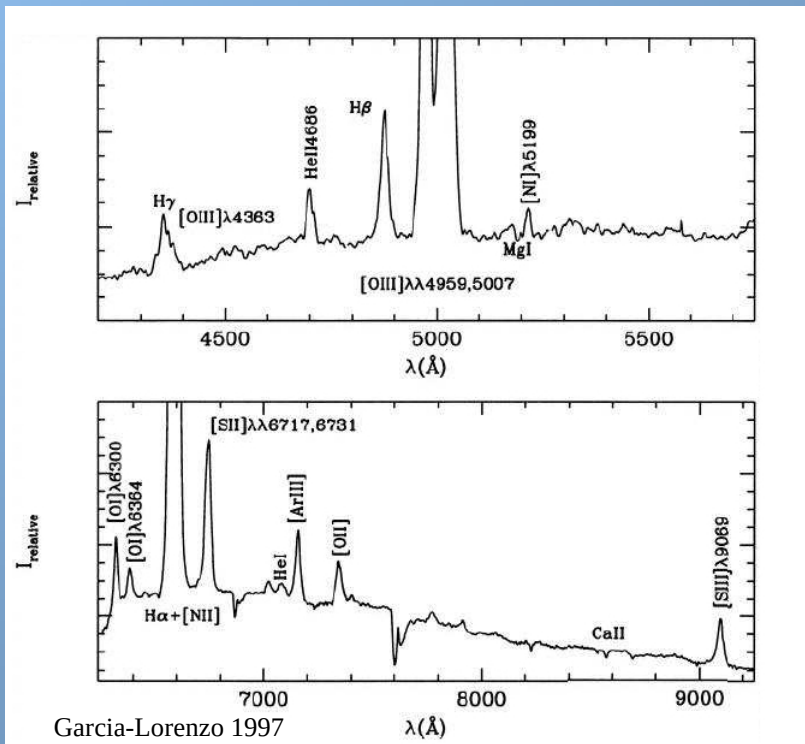
Bright, semistellar Nucleus



Properties of Active Galaxies

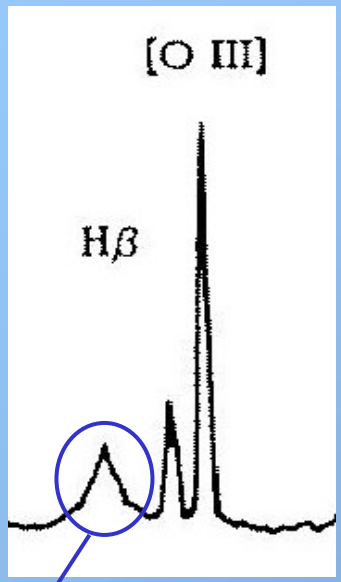


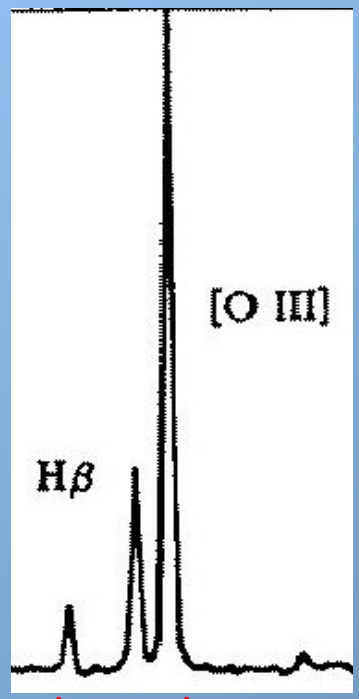
Peterson 1997



Garcia-Lorenzo 1997

High-ionization emission lines in the spectra of the nuclei





Broad Line Region
(BLR)
R~0.1pc

High velocity → FWHM ~ 10^4 km s^{-1}

High electron density :
- No broad [O III] lines
- Broad C III]1909 line

N_e~$10^{9–10}$ cm^{-3}

Narrow Line Region
(NLR)
R~100pc

Low velocity → FWHM ~ 10^3 km s^{-1}

Low electron density : N_e ~ 10^4 cm^{-3}

What do active nuclei hide ?

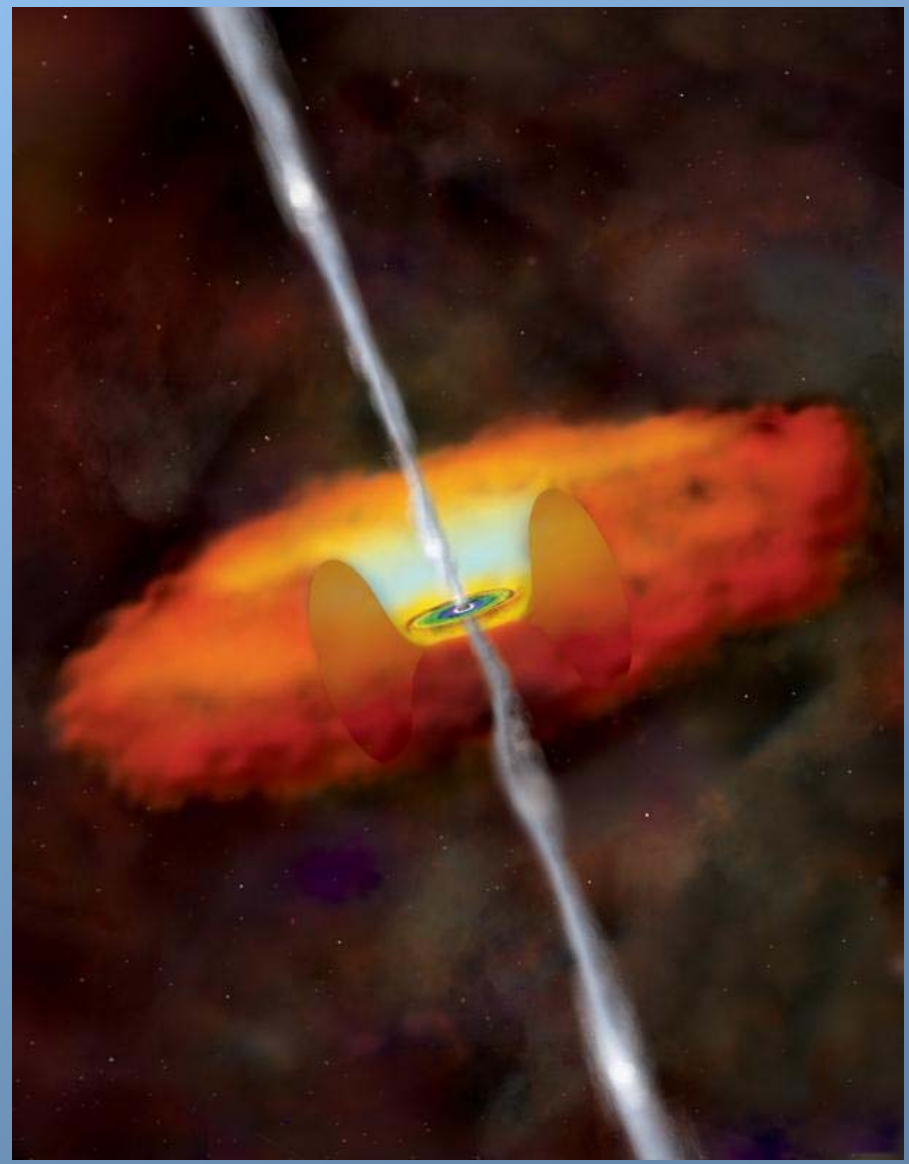
SuperMassive Black-Hole

$M_{SMBH} \sim 10^7 – 10^9\ M_\odot$

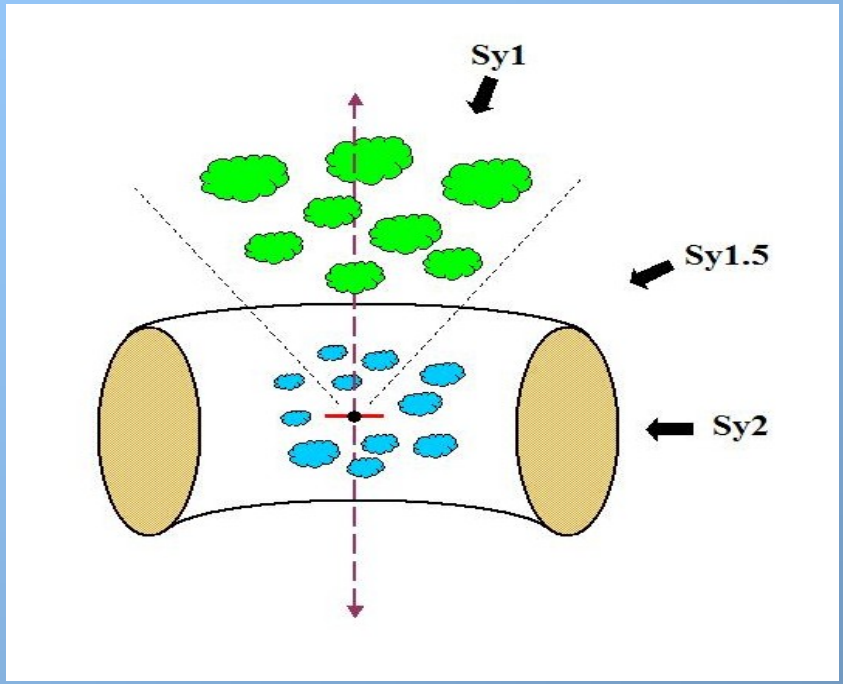
Accretion Rate of matter:

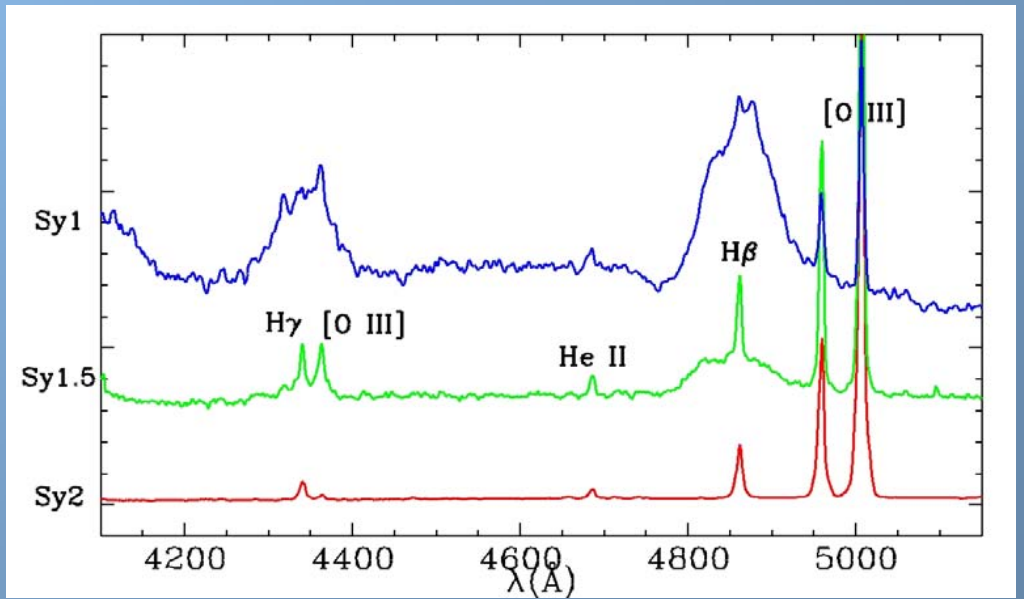
$0.2 - 2.0\ \ M_\odot\ yr^{-1}$

$10^{45} - 10^{46}\ erg\ s^{-1}$



Unified Model





How gas goes down to the Black Hole ?

Possible candidates to explain infall of material on the nucleus are:

- galaxy interactions
- galaxy mergers (major and minor)
- bars
- bars within bars
- turbulence in the interstellar medium
- stellar mass loss
- viscous accretion disks

Results of statistical studies are contradictory.

- Interactions or bars are not more common among AGN compared to non-active galaxies
  (e.g.: Laine et al. 2002,Knapen et al. 2000)

- Other statistical studies did not find a detectable excess of companions around Seyfert galaxies *(e.g.: Sorrentino et al. 2006)*

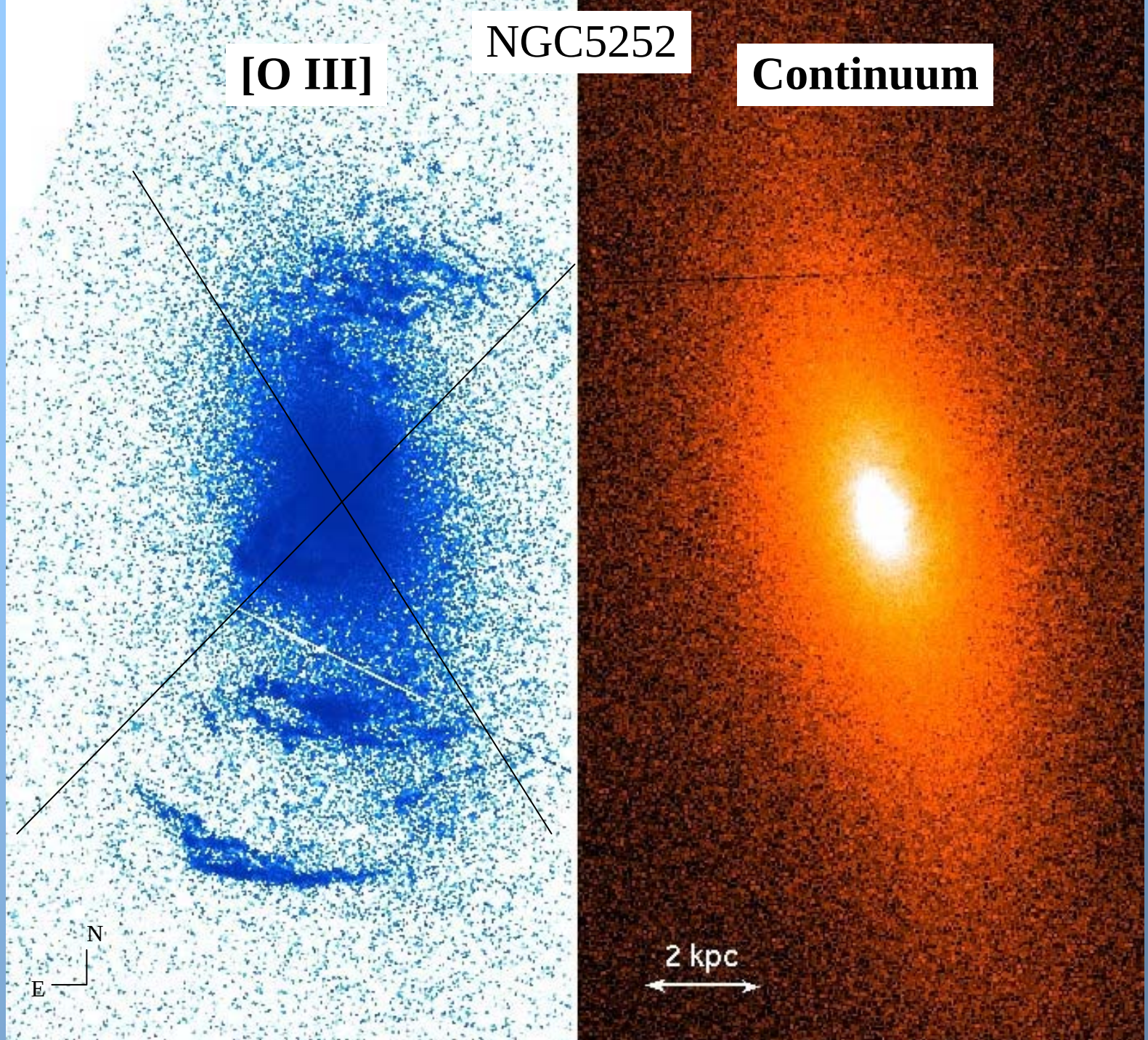
- Nuclear spirals have been observed in a number of normal spiral galaxies without obvious AGN activity
  (e.g.:Martini et al. 2003)

- Several emission line imaging surveys (Pogge1989, Mulchaey et al. 1996, Schmitt et al. 2003) of nearby AGN have shown extended emission line regions (EELR) of size between 0.1 kpc up to several kpc, typically characterized by a high (!) excitation spectrum, photoionized by a thermal and/or nonthermal source.

- These features or part of them have shown in some cases (~20) a conical and/or biconical morphology and an emission line spectrum, photoionized by a nonthermal source, namely by collimated radiation from the nucleus (ENLR).

- The origin of the collimation of the ionizing photons can be:

  1) shadowing of an isotropic non thermal source by a dusty torus;
  2) direct radiation from an intrinsically anisotropic emitter (Wilson et al. 1996).


NGC5252
[O III]
Continuum
N
E
2 kpc

The small number of detected ***ionization cones*** lets open some questions on the origin of the ionized gas within them:

Is this gas simply part of the host galaxy, namely ISM photoionized by the active nucleus ?

Is it material ejected by the nucleus itself and in strong interaction with its beamed radiation?

Is it material acquired from outside through gravitational interaction with companion galaxies or through merging with small galaxies?

Is a toroidal structure always present around an AGN?

It is evident that these questions are also strongly related to the mechanisms, which can switch on activity in the nucleus.

Aims of the project

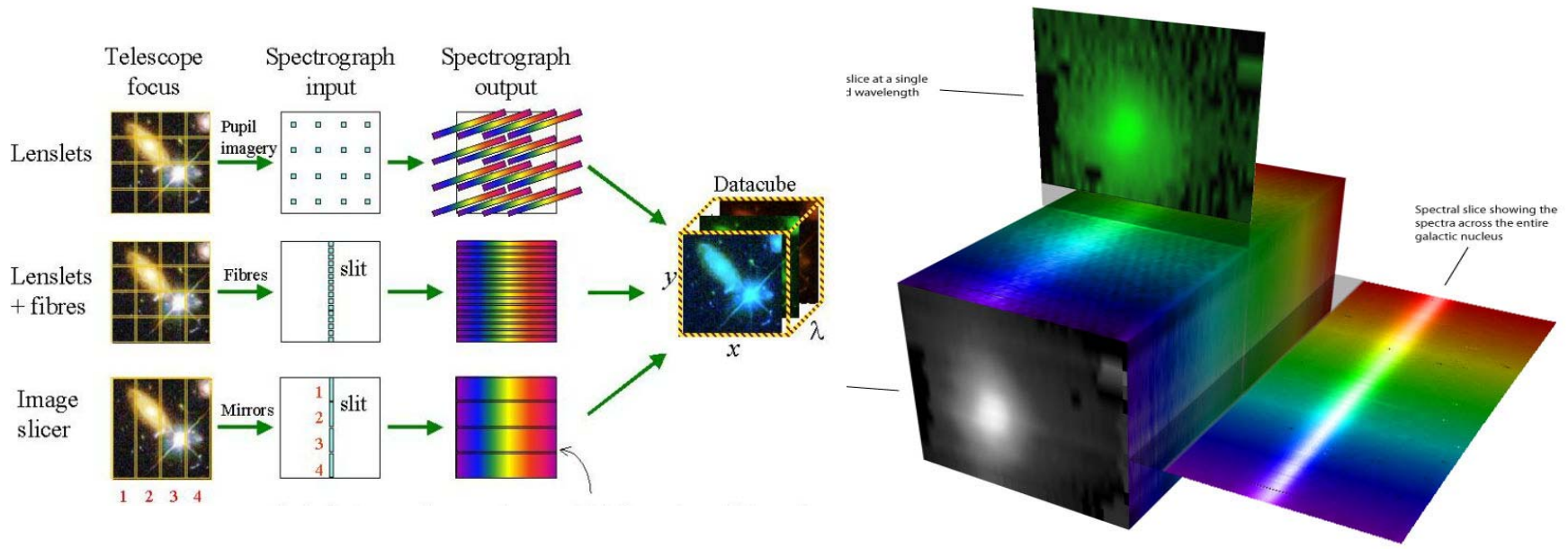
We have then started a program aimed to investigate the physical and dynamical properties of the known ***ionization cones***, using 3D spectroscopy.

In this way we take advantage of the fact that data cubes allow to extract images, taken at the same time, in different spectral ranges isolating continuum or radiation from emission or absorption lines.

In addition, thanks to the performances of 3D spectroscopy, we have also started an investigation of nearby AGN in order to:

- isolate EELR, photoionized by the nucleus;
- identify possible signatures of interaction or merging close to the nuclear regions

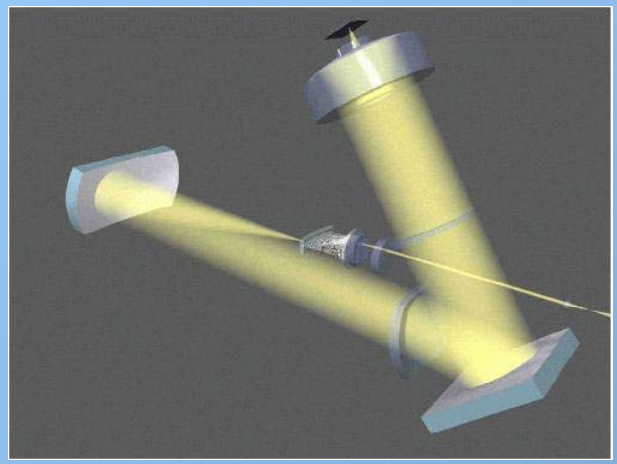
INTEGRAL FIELD SPECTROSCOPY

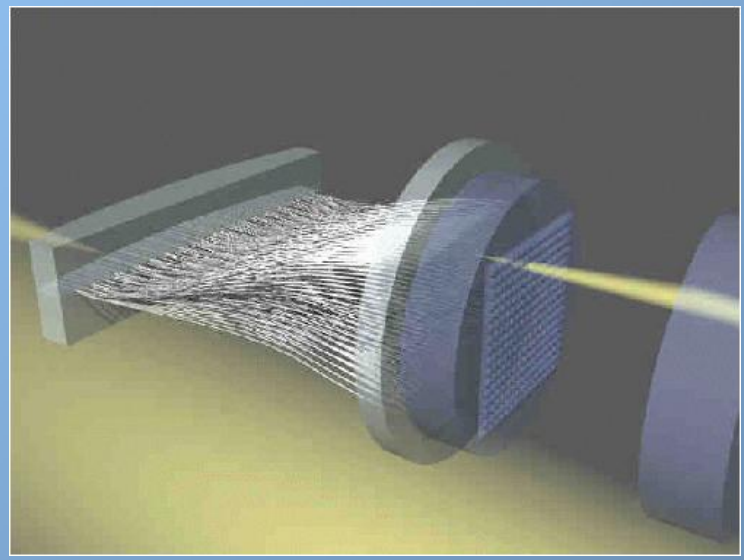


Suitable to study extended objects, star forming regions, PNe or even crowded fields of galaxies

- **3D data (α,δ,λ) instead of 2D with classical long-slit spectrographs**
- **All information recorded simultaneously**

Multi-Pupil Fiber Spectrograph (MPFS)





- **Spatial sampling: 1.0”**
- **Field of view: 16x15 elements**
- **Night-sky: 8 elements @4.5’ from FOV center**
- **Spectral Range: 3600-9600 Å**
- **Dispersion: 7 Å/pix**
- **Grating: 600 g/mm**
- **FWHM: ~ 2.5 pix**
- **CCD: 1k x 1k, 24 μ/pix**

Data and analysis outline

The objects (~20) were extracted from the spectroscopic selected sample of Rafanelli et al.1995

We reconstructed from MPFS spectra:

- Flux maps
- Line of sight velocity distributions
- Stellar kinematics

From emission lines we also calculate:

- Extinction maps
- Mass of the emitting gas
- Emission line ratios

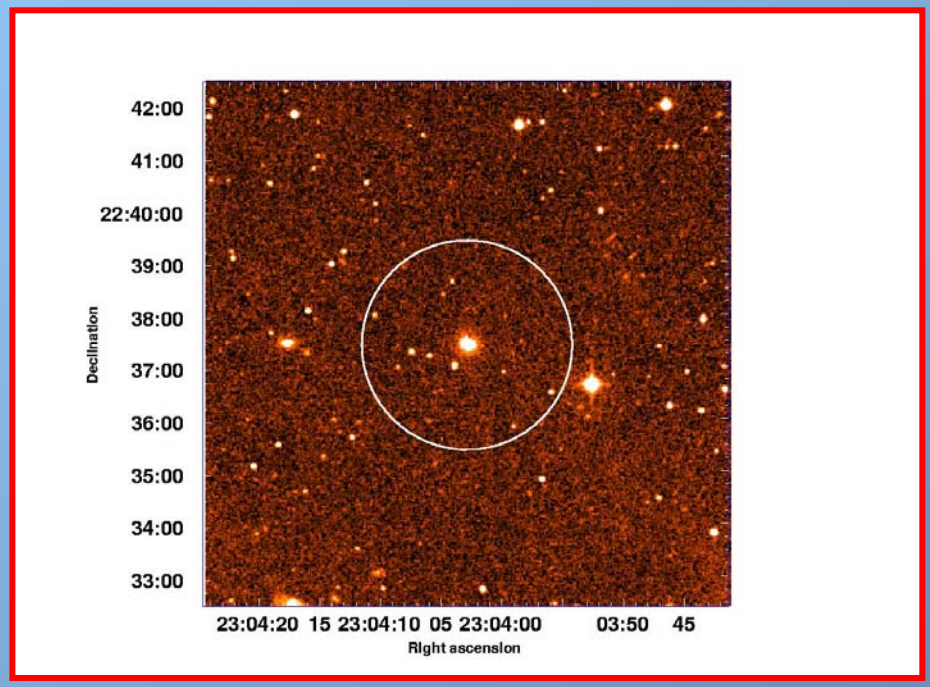
Name	z	Type
Mrk 3	0.01351	S2
Mrk 6	0.01881	S1.5
Mrk 315	0.03887	S1.5
Mrk 1073	0.02334	S2
Mrk 1157	0.01517	S2
NGC 7319	0.02251	S2
IR0450317	0.01581	S2

The physical conditions of the emitting line gas were investigated using photoionization models that we performed using the code Cloudy (Ferland 1997) or shock models taken by the literature.

Global properties of the host galaxies were studied by analyzing broad band images

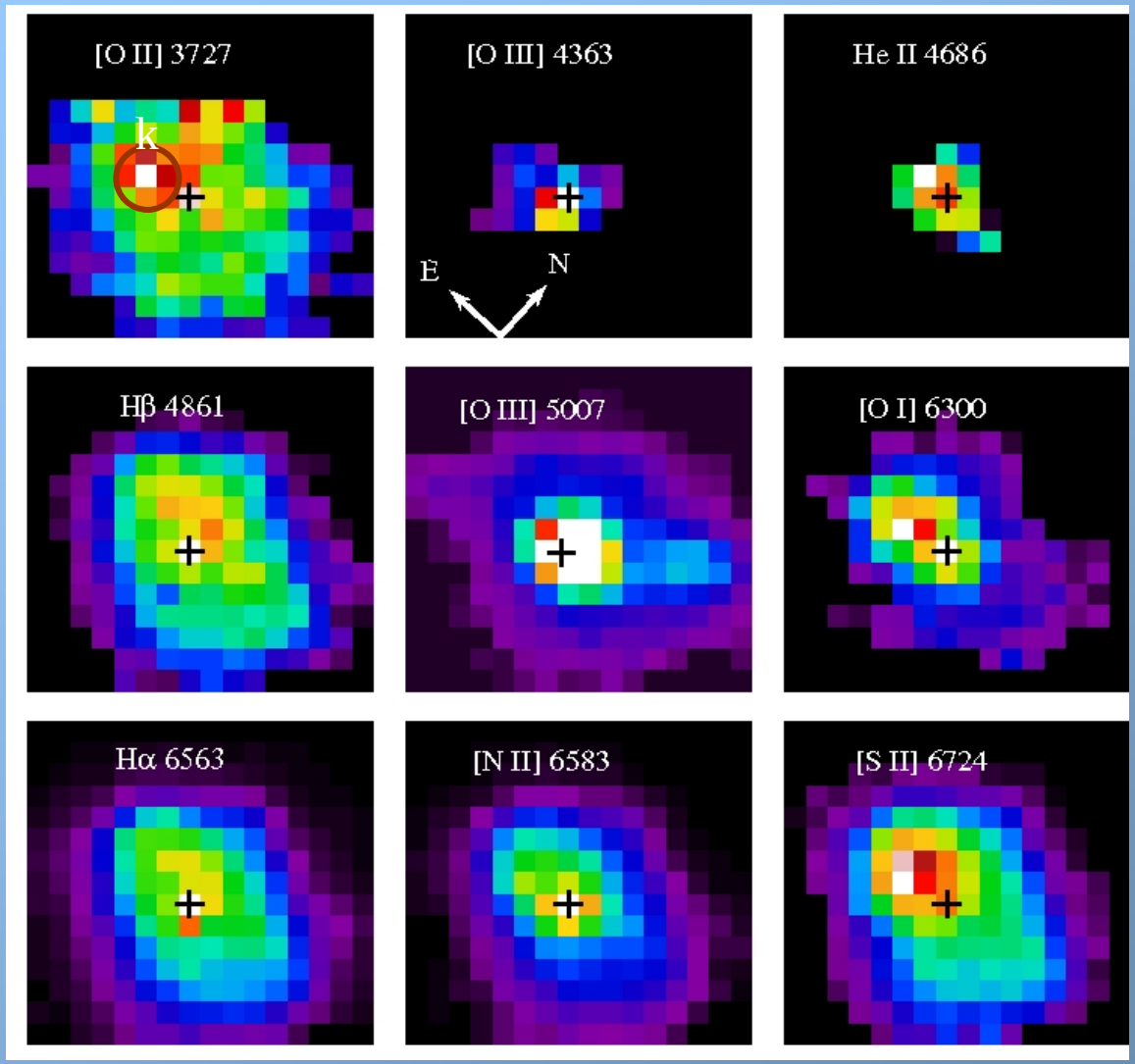
Mrk 315

Seyfert 1.5 at z = 0.0389
Apparently **ISOLATED** and with regular morphology on POSS images, but ….



Deep ground based and HST images revealed the presence of faint tails and a possible secondary nucleus

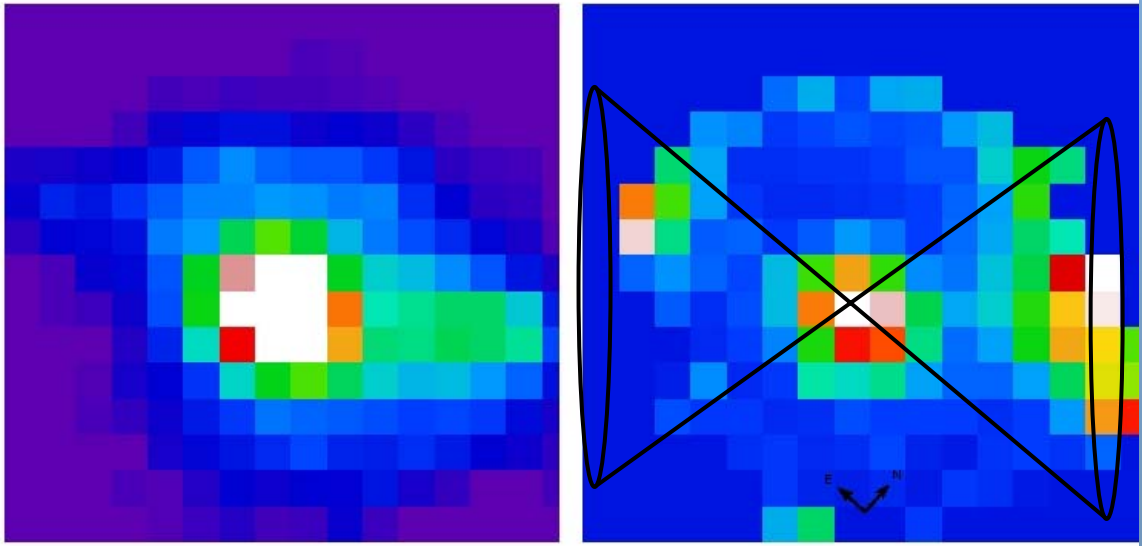
MPFS emission lines maps



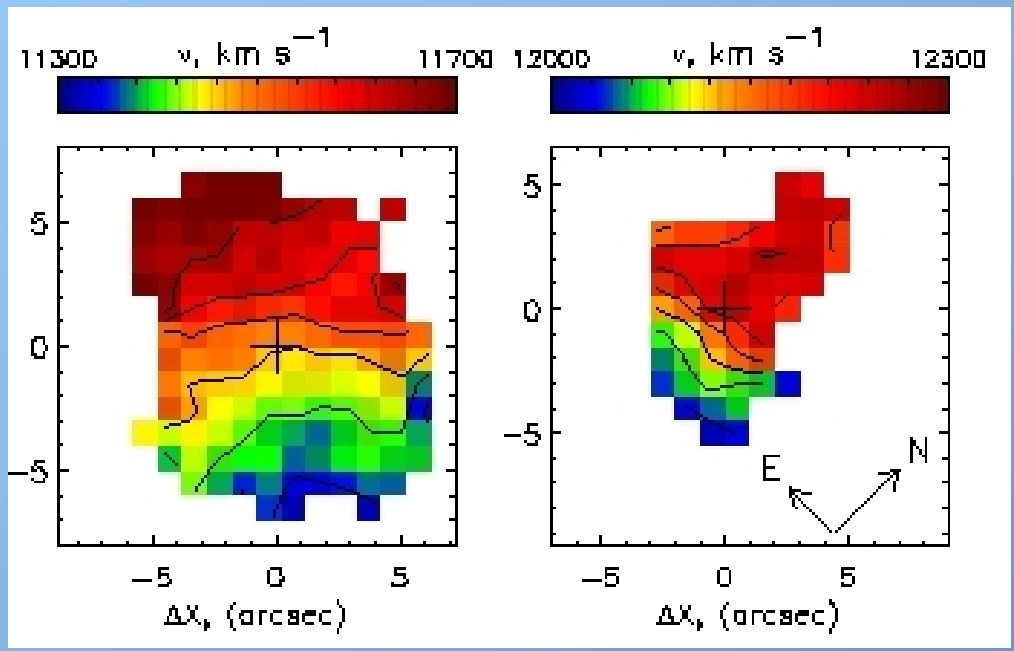
Reconstructed maps of the galaxy for different emission lines in the FOV of the spectrograph (16×15 arcsec). Each pixel corresponds to 1×1 arcsec (0.75 x0.75 kpc)

[O III] λ5007

[O III] / Hβ

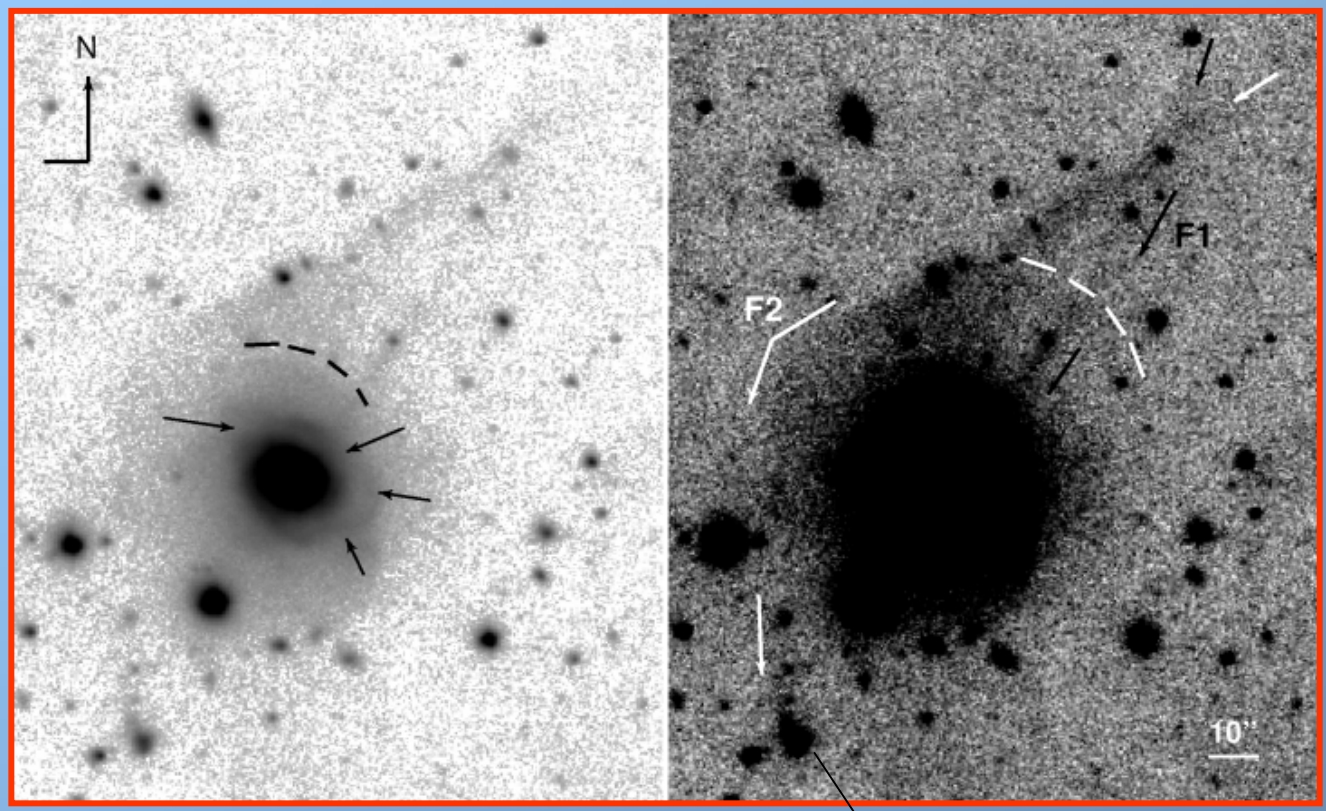


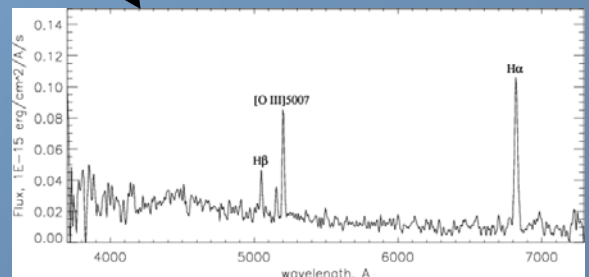
Stellar velocity field



We see 2 stellar components with different kinematics

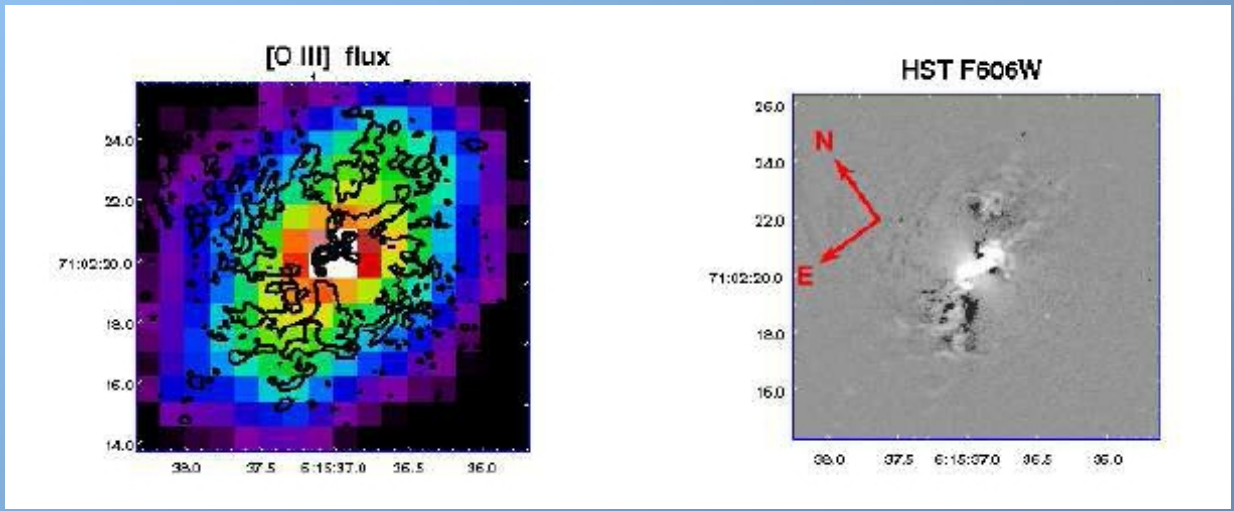
Deep V band image of Mrk 315





Mrk 3

- S0 Seyfert 2 galaxy at z=0.0135
- Broad Line Region detected in polarized light (Schmidt & Miller, 1985)
- HST observations revealed in the inner central 2″ a striking S-shape morphology (Capetti et al. 1995), comprising a large number of resolved knots, embedded in a more extended 8″ ***biconical*** emission line region.



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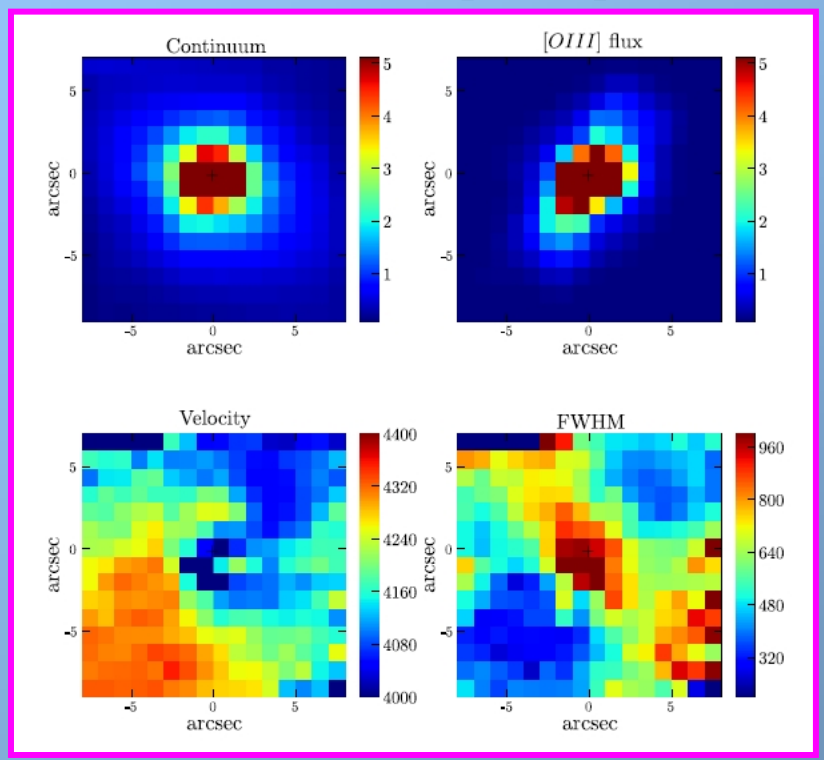
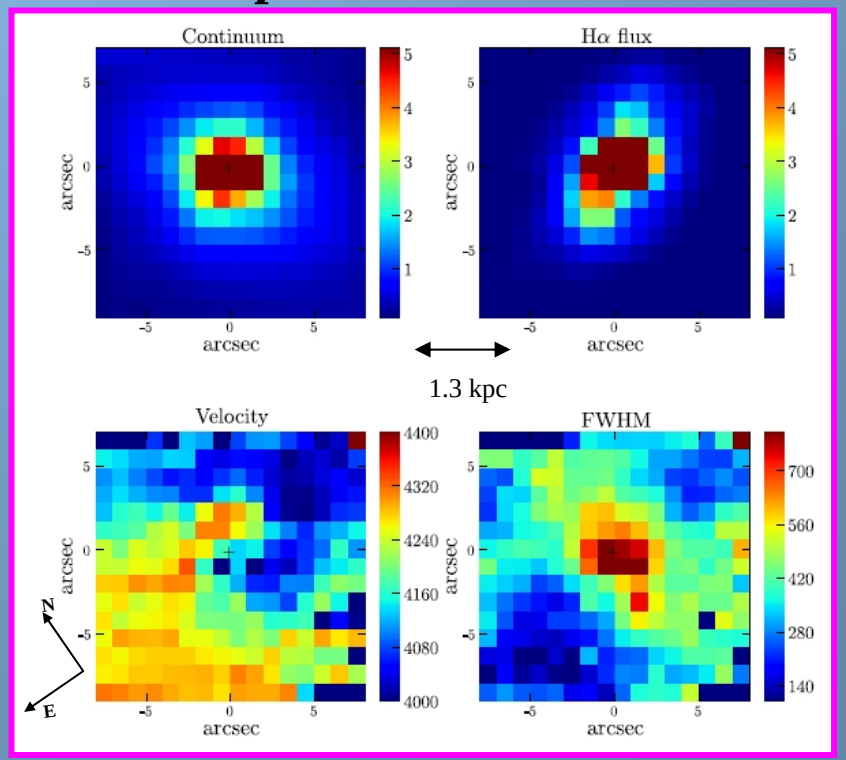
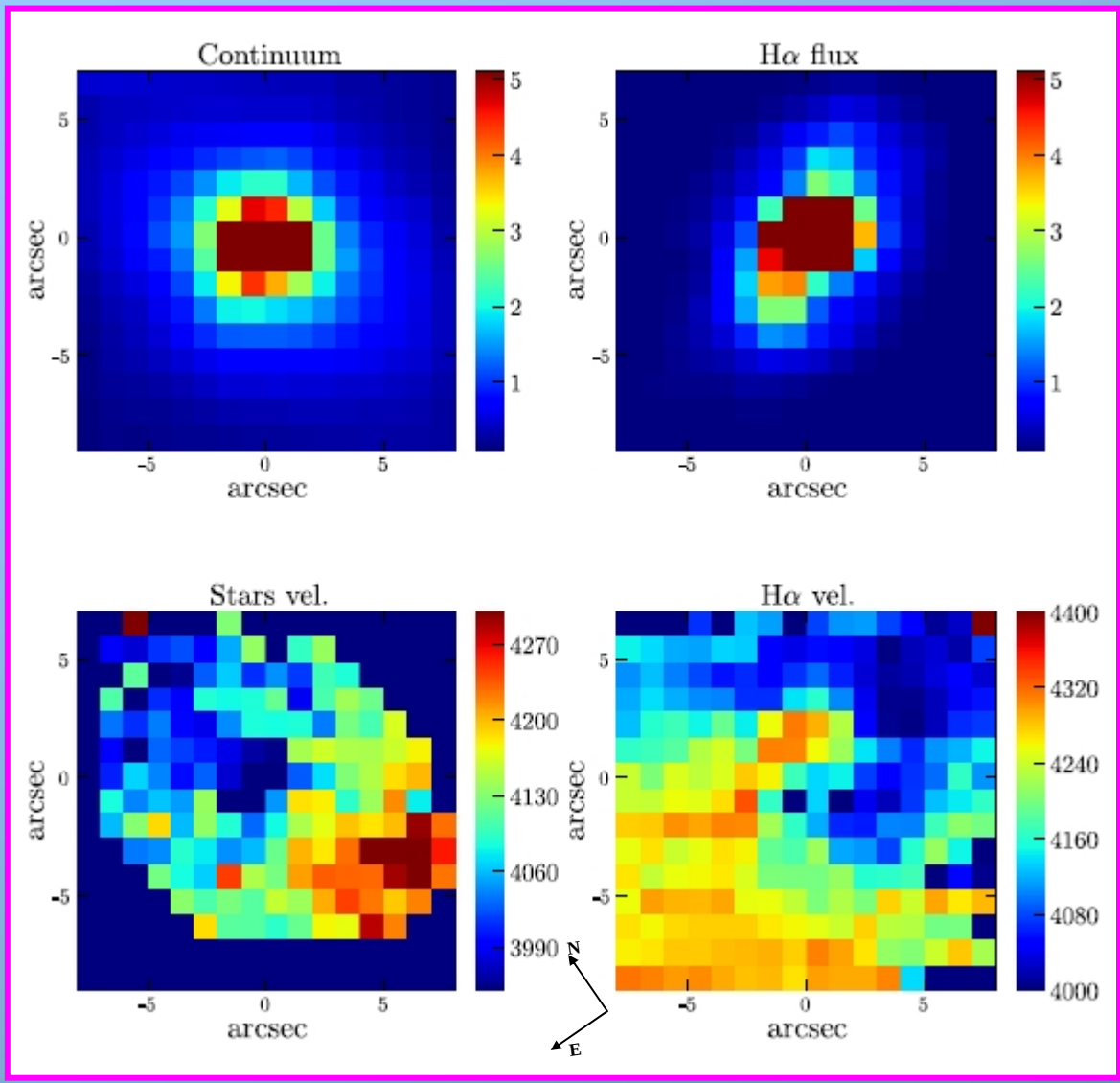
[O III] and Hα reconstructed maps



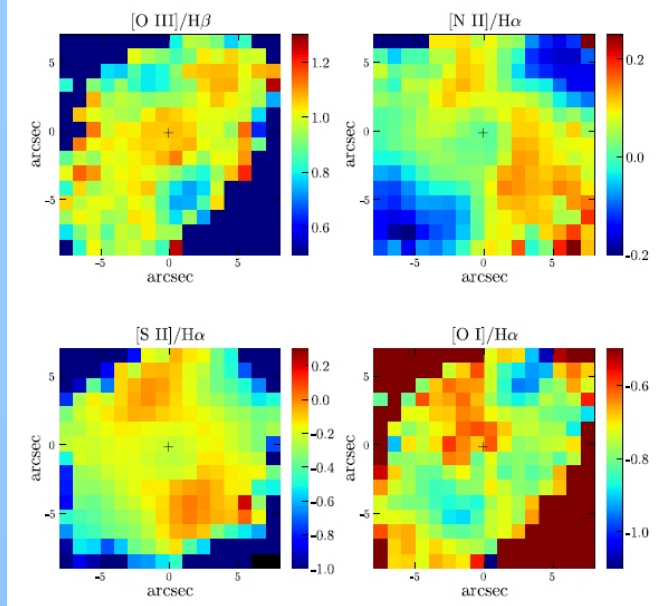


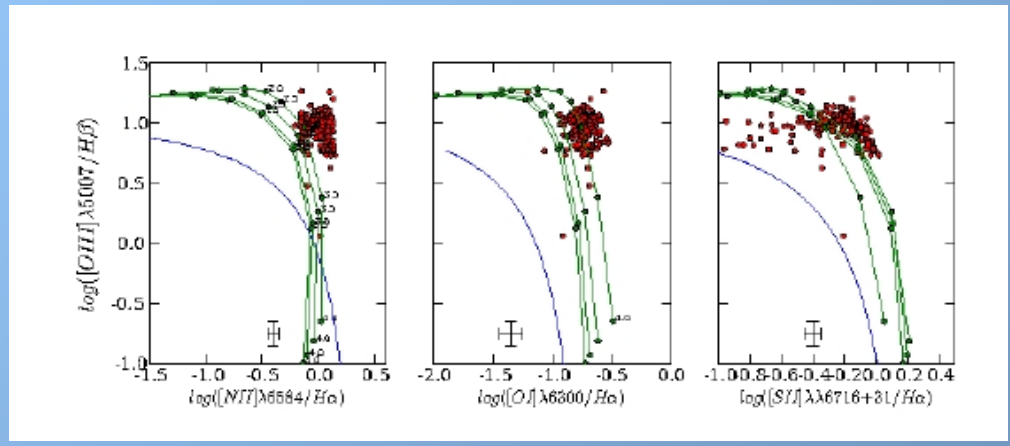
Mrk 3

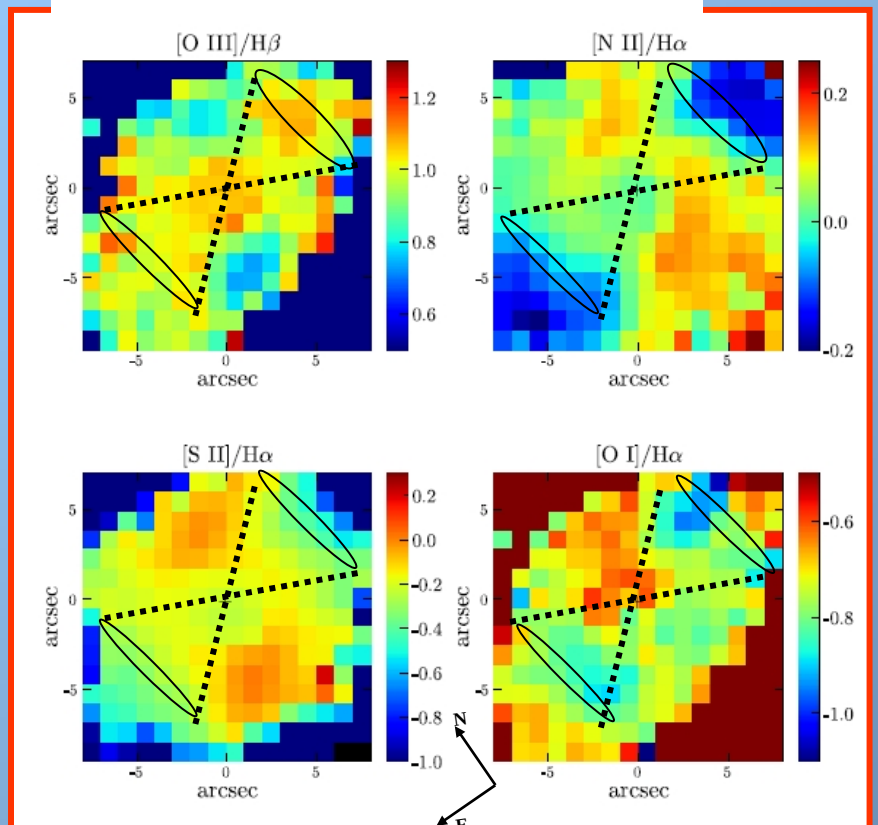


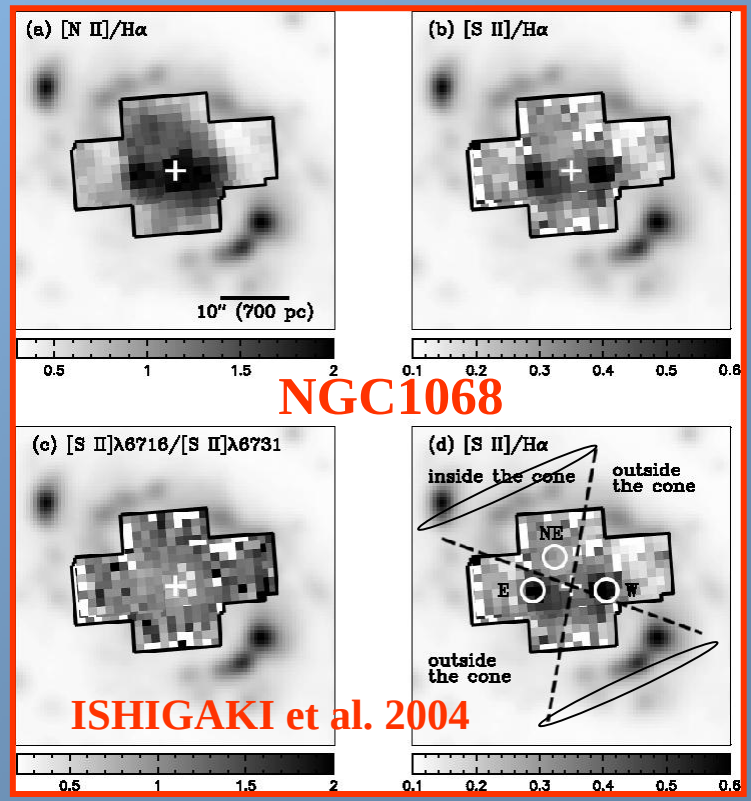
Kinematical decoupling of gas and stars

Mrk 3







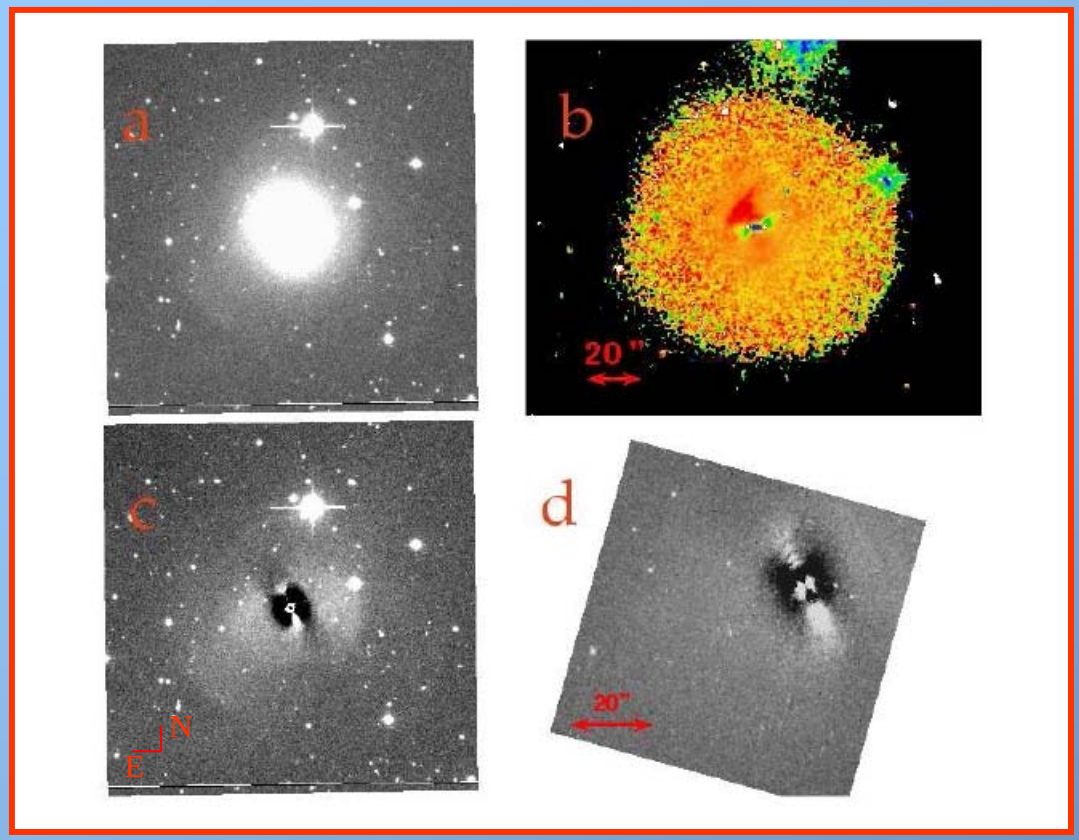


NGC1068

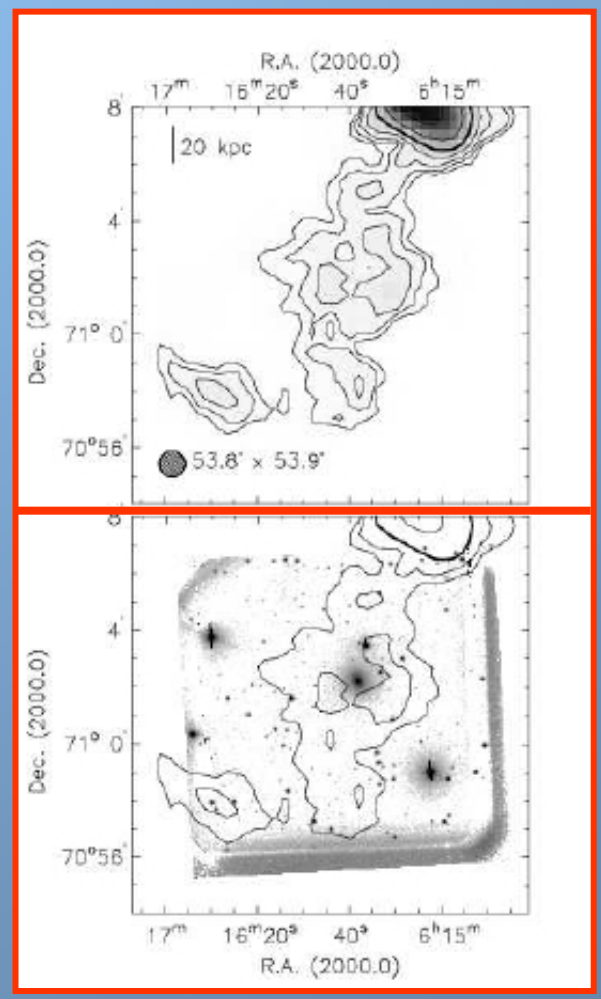
ISHIGAKI et al. 2004

Mrk 3

Host and environment



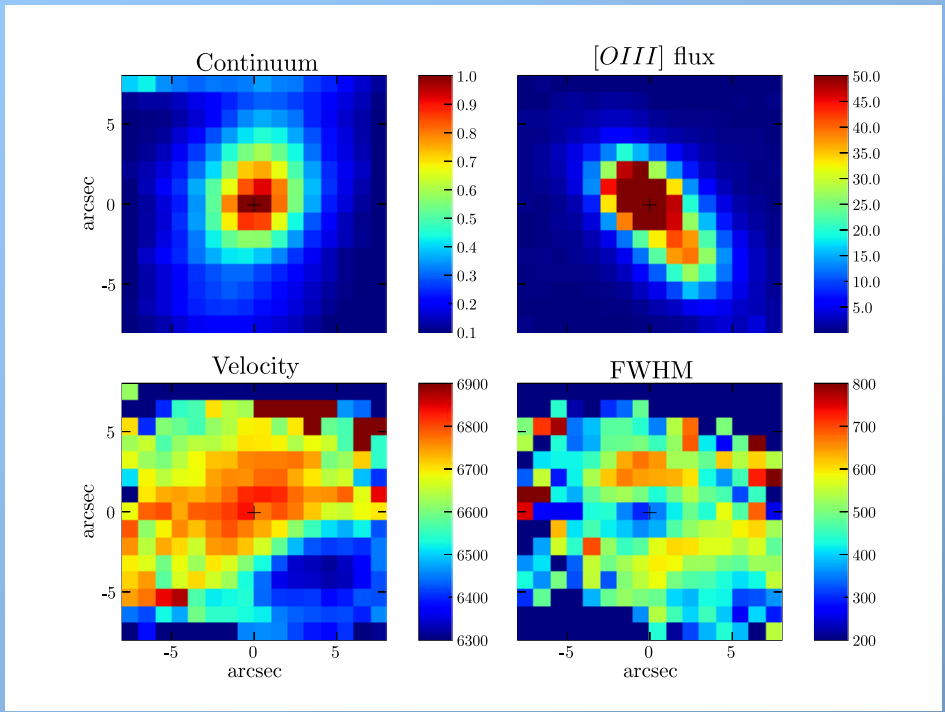
Mkn3 images: a) INT R-band image; b) G-R color image; c)☐GALFIT R-band model residuals; d) GALFIT HST F814W band model residuals

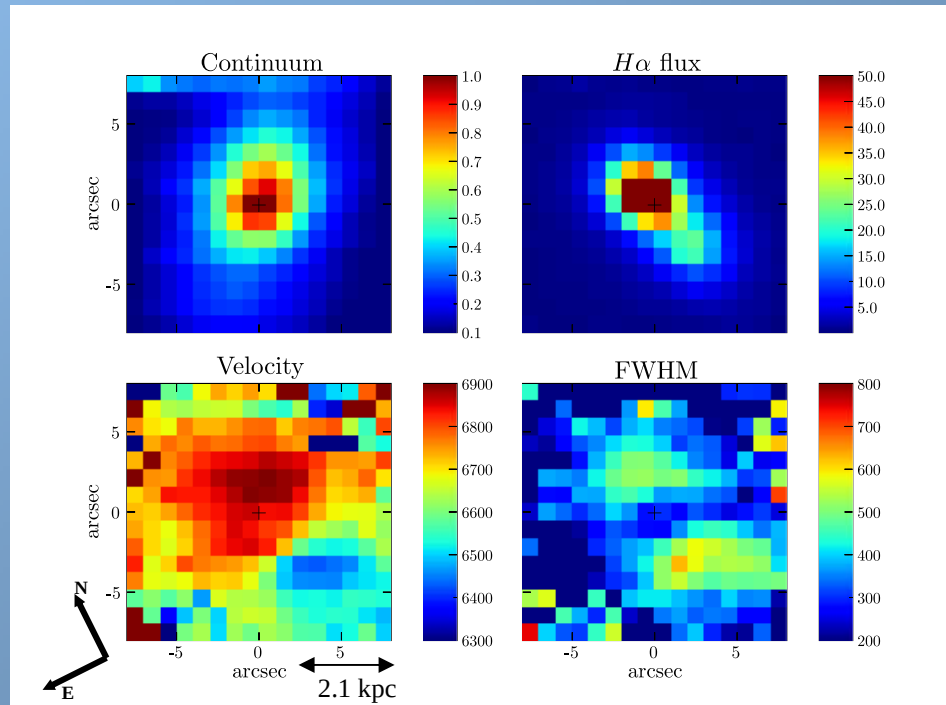


HI maps (Noordermeer et al. 2005)

NGC 7319

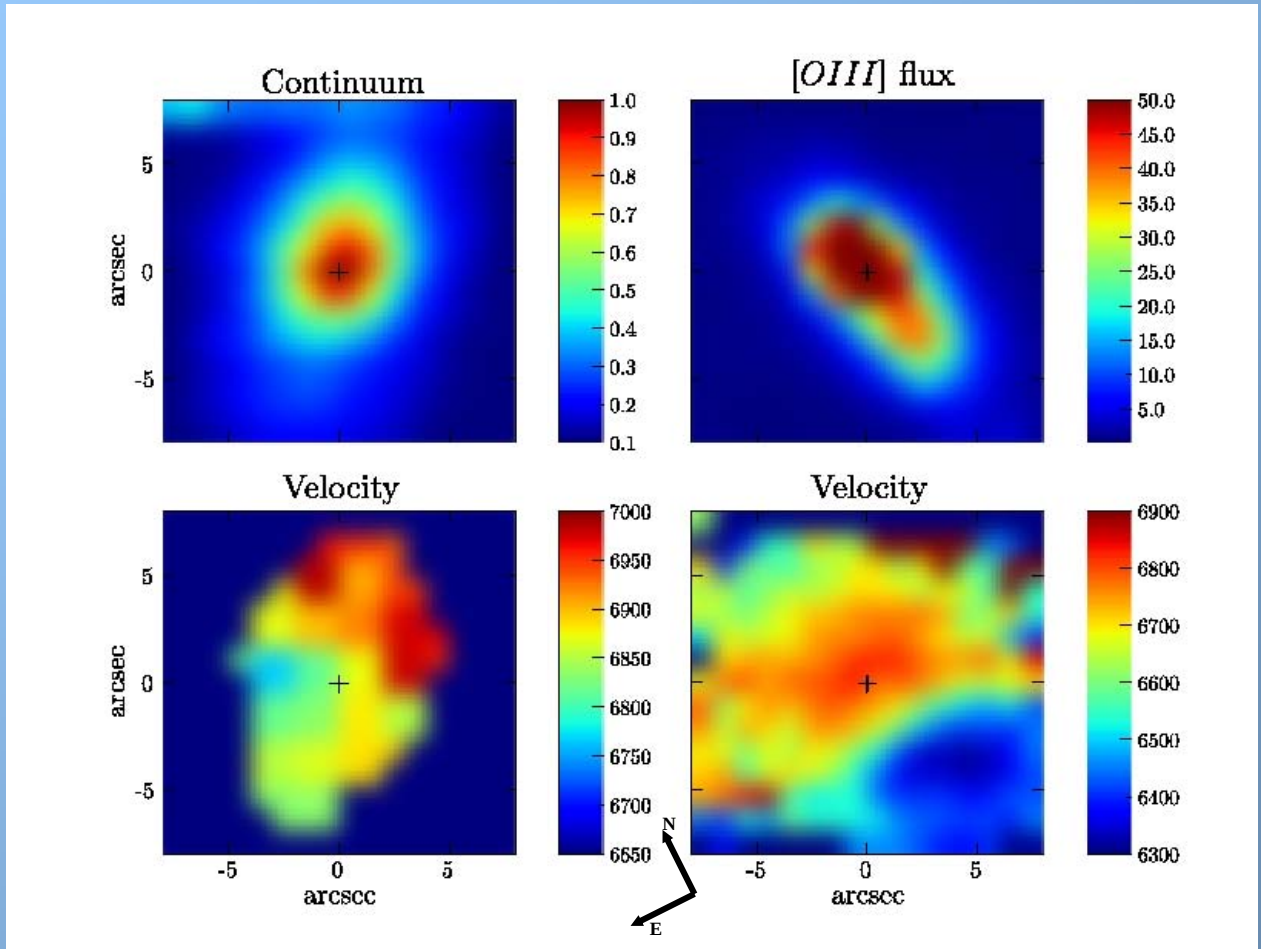
NGC7319 is a SB(pec) galaxy at z= 0.0225 belonging to the compact group of galaxies known as Stephan Quintet





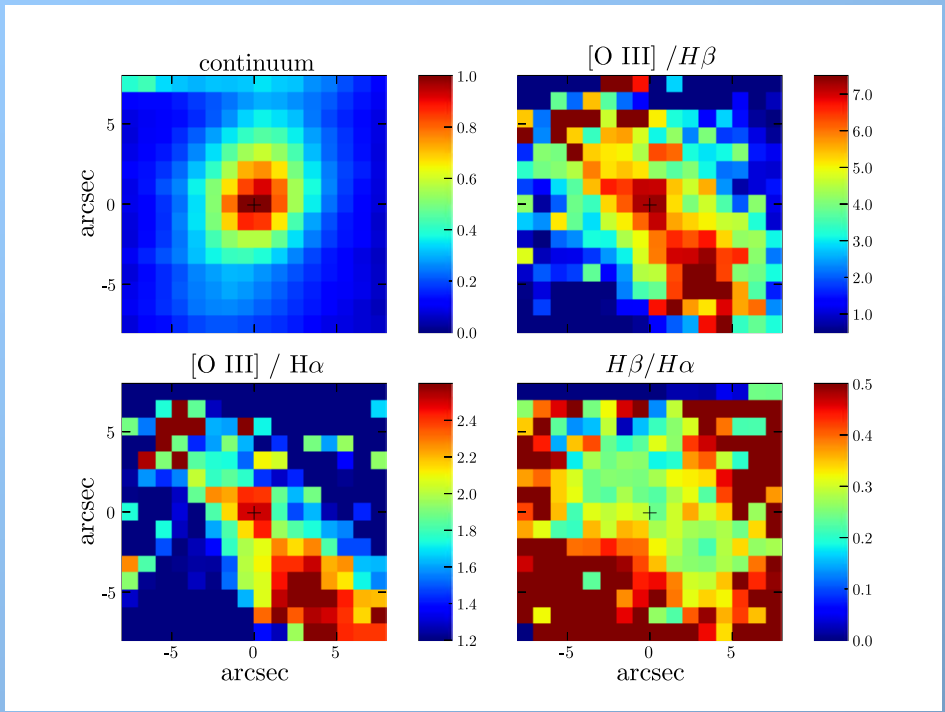
NGC 7319

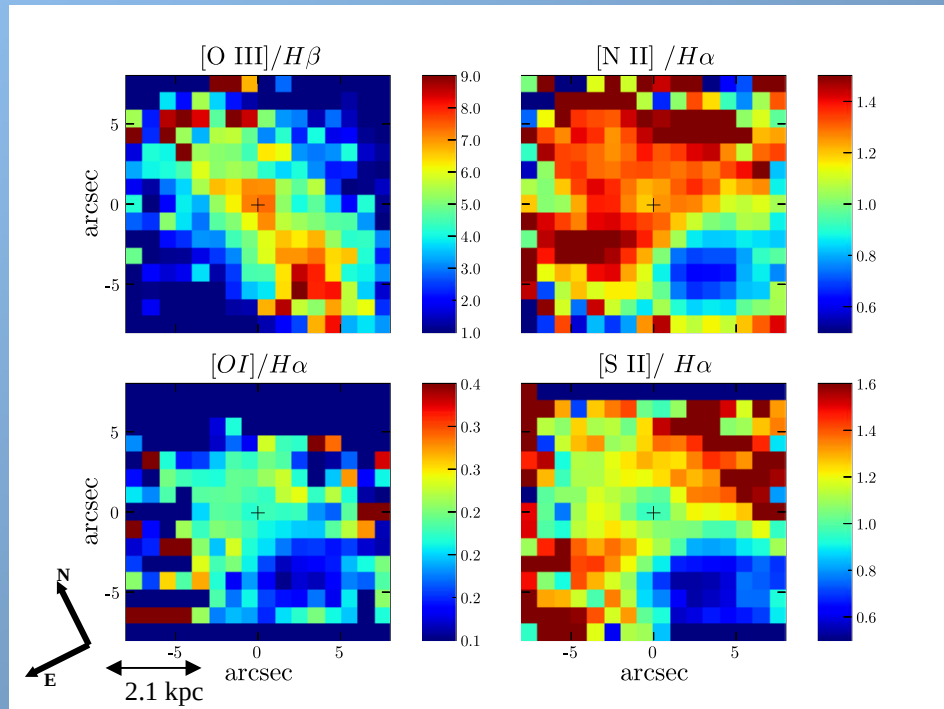
Stellar and gas kinematics



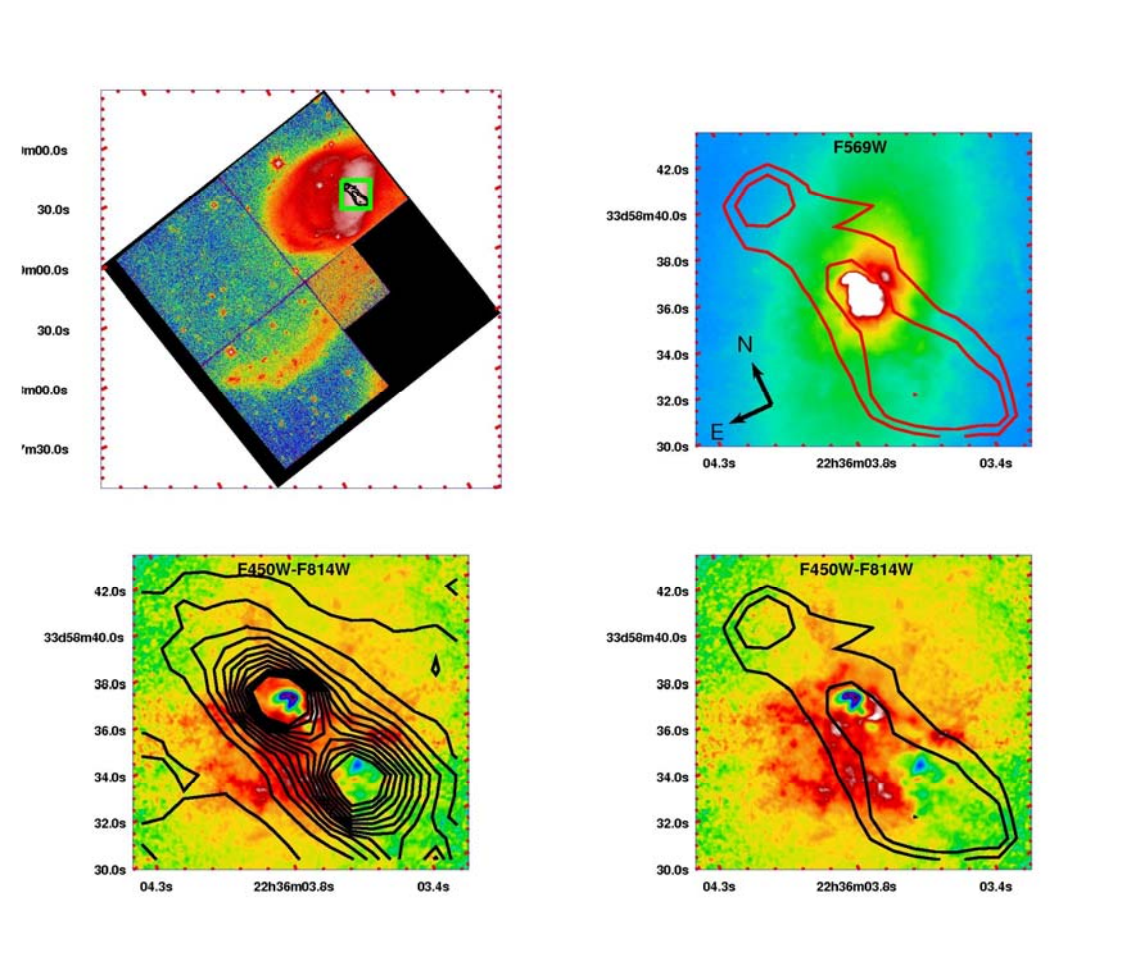
NGC 7319

Flux ratio maps





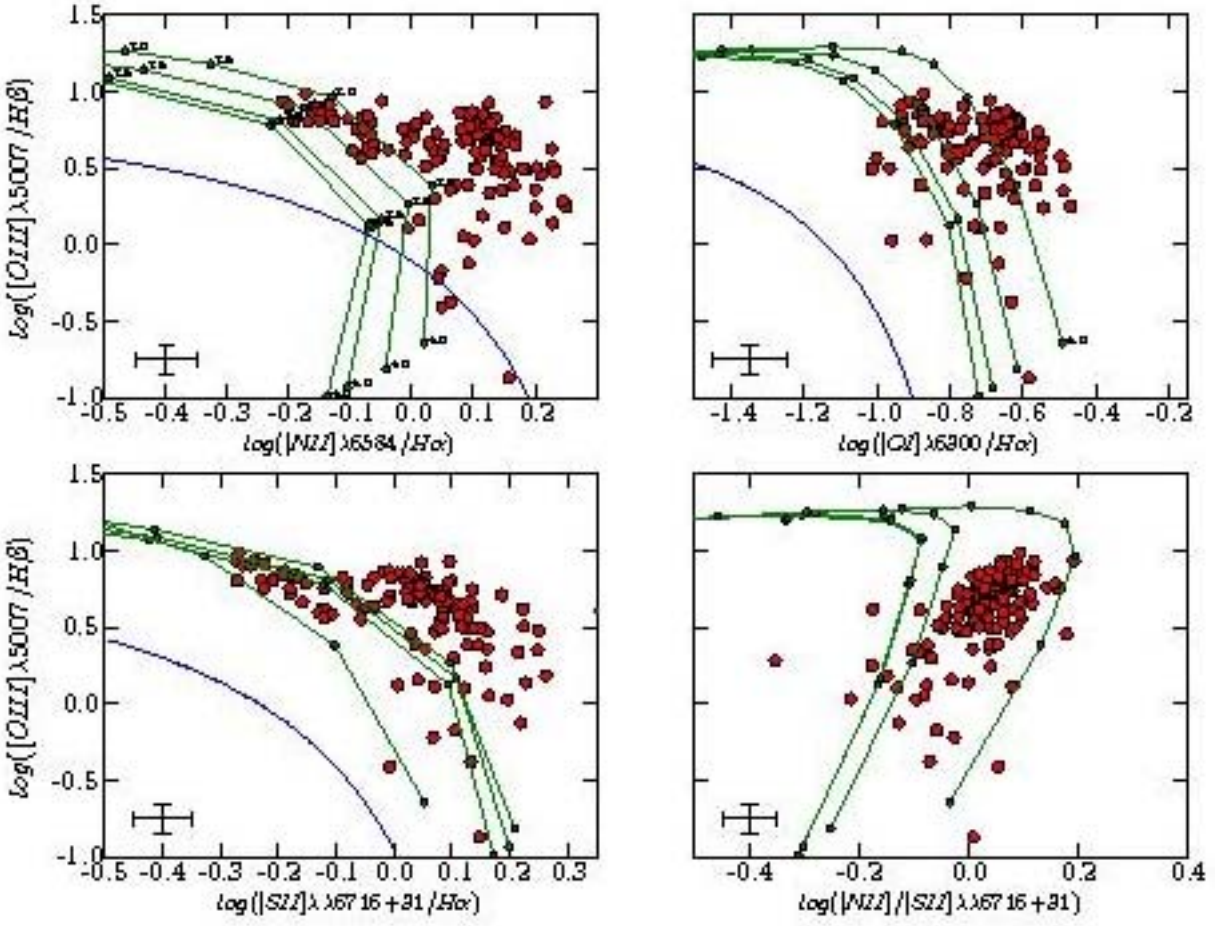
NGC 7319



HST images of NGC7319.
Contours of the [O III]/V ratio are reported in the bottom left image.
Contours of the [O III]/Hα ratio are overlayed to the images on the right side.

NGC 7319

DIAGNOSTIC DIAGRAMS+Cloudy photoionization models



NGC 7319

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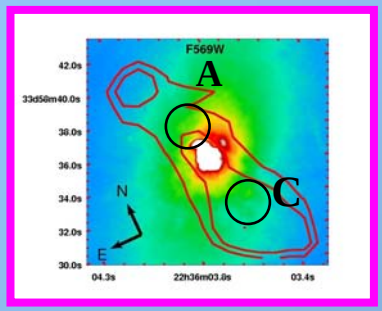

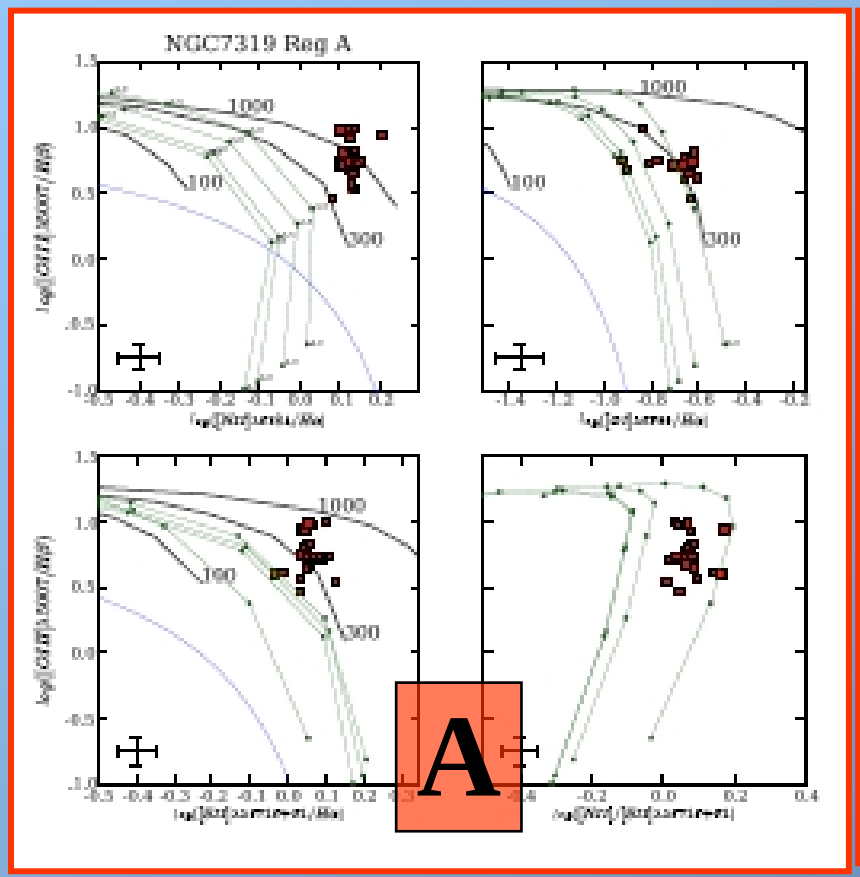

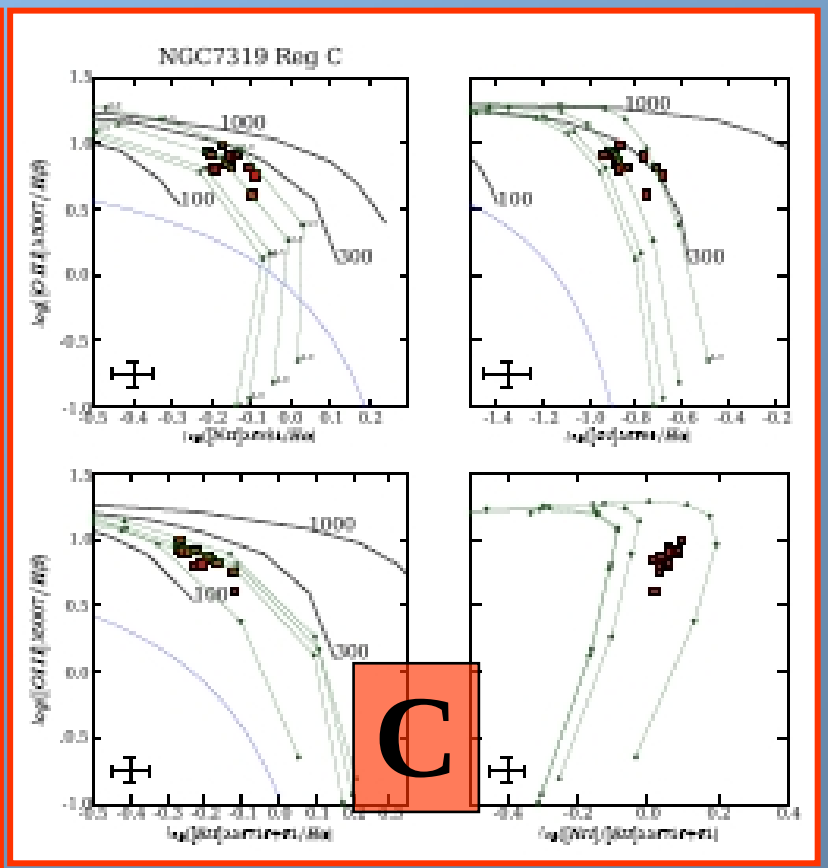

Summary

We have found EELRs photoionized by the nucleus in all three objects we analyzed:

- In all three galaxies a conical emitting region centered on the nucleus has been clearly identified.
- The 2D stellar & gas kinematics reveal complex decoupling of stellar and gaseous motions.
- Signatures of a possible acting merging have been identified in all three objects.

Summary

For **Mrk315** we show that this apparently isolated and undisturbed galaxy has a **secondary nucleus** confirmed by a stellar component kinematically de-coupled from the main galaxy, a **circum-nuclear quasi-ring** with enhanced star formation and other features that indicate a **minor merger** event.

In **NGC7319** we measured for the first time the stellar kinematics of the galaxy revealing a clear **decoupling** of this component with respect of the emission line gas. The ionized gas further shows a large scale **outflow** on one side of the galaxy and the signature of a jet induced **shock** in the other side.

For **Mrk 3** we find a strong decoupling of gas and stars kinematics. The line profiles reveal multiple components in the [O III] lines extended up to 2 kpc scale which suggest the presence of complex radial motions from the active nucleus. From broadband images we also discovered structures resembling **shells** in the outer regions of the galaxy.