

Outflows and Non-Circular Motions in Narrow-Line Regions of Seyfert Galaxies

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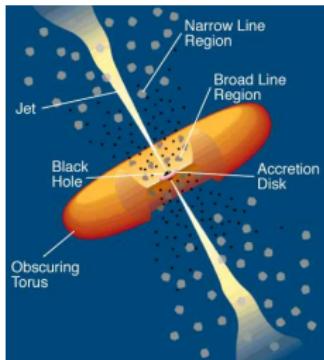
Astronomical Institute ASCR, Prague, Czech Republic

S.F. SÁNCHEZ

Centro Astronómico Hispano Alemán, Calar Alto, Spain

Narrow-Line Regions (NLRs)

Unified Model of AGN



Urry & Padovani (1995)

NLRs: Ionized Gas

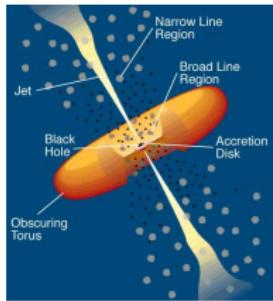
- $T_e \sim 10^4$ K
- $n_e \sim 10^2 - 10^4 \text{ cm}^{-3}$
- Extent: $10^2 - 10^3 \text{ pc}$
- Spatially resolved
- Ionization source: AGN radiation
- Velocities: $10^2 - 10^3 \text{ km s}^{-1}$
- Unconstrained intrinsic structure and kinematics

Seyfert Galaxies:

- Low luminosity AGN ($L \sim 10^{40-43} \text{ erg s}^{-1}$)
- Hosts: S0–Sbc

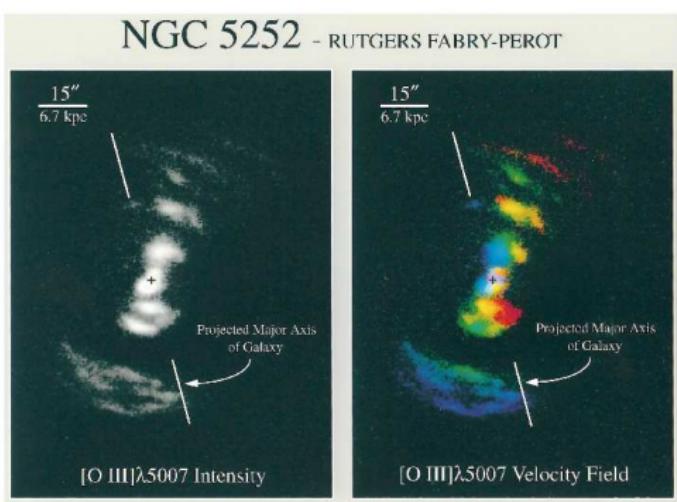
NLR Observations – Motivation

Unified Model of AGN



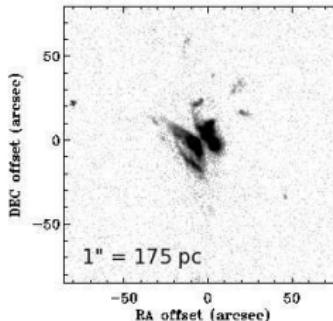
Urry & Padovani (1995)

Irregular Kinematics



Morse et al. (1996)

Optical Imaging (HST)

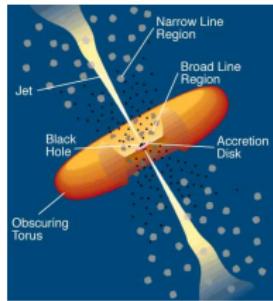


NGC 2992, Allen et al. (1999)

Long-slit spectroscopy insufficient
Efficient 2D spectroscopy necessary

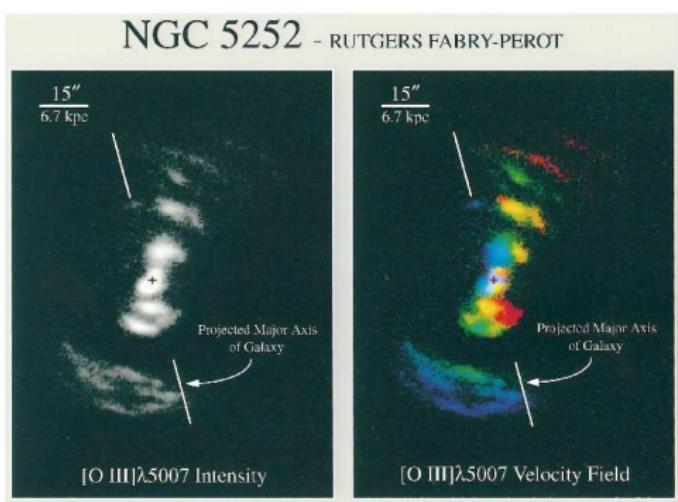
NLR Observations – Motivation

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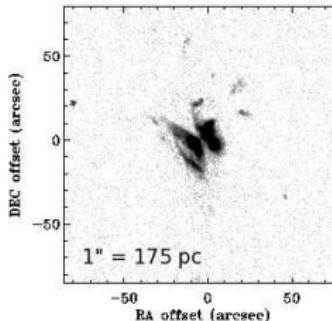
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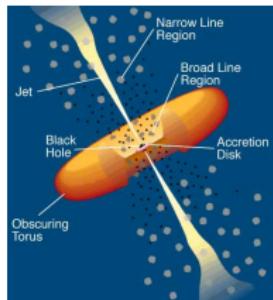


NGC 2992, Allen et al. (1999)

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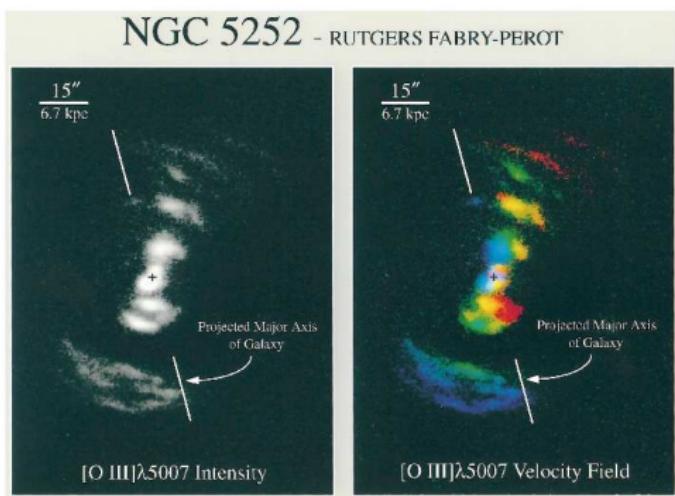
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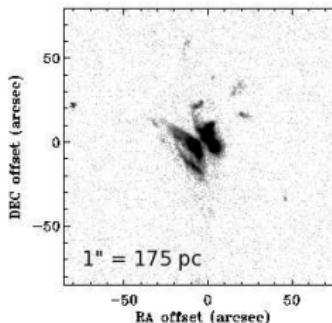
Urry & Padovani (1995)

Irregular Kinematics



Morse et al. (1996)

Optical Imaging (HST)

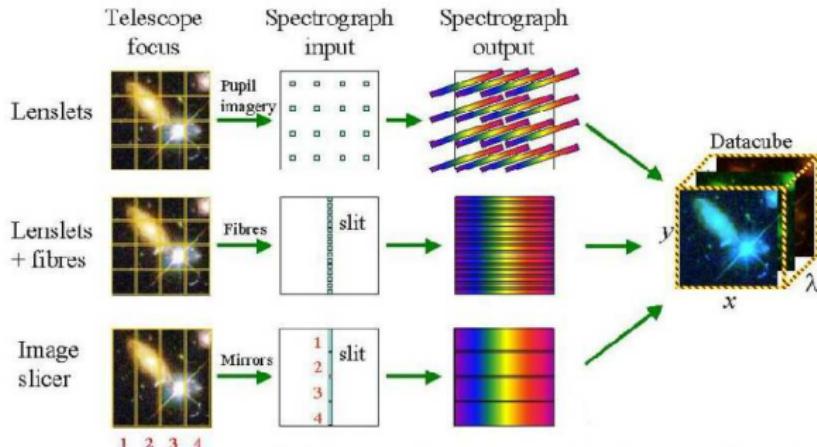


NGC 2992, Allen et al. (1999)

**Long-slit spectroscopy insufficient
Efficient 2D spectroscopy necessary**

Integral-Field Spectroscopy (IFS)

- Spatially resolved spectroscopy
- Simultaneous acquisition of $10^2 - 10^4$ spectra
- Datacube (x, y, λ) → “3D” spectroscopy

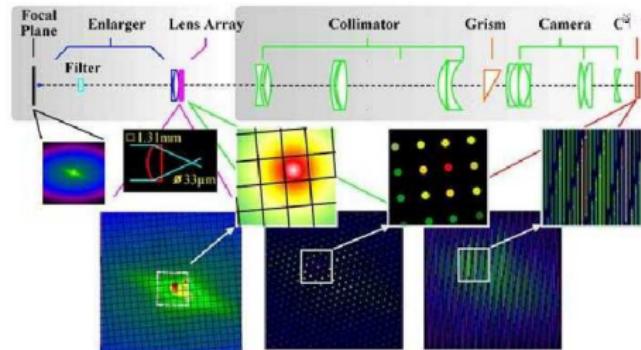


Principles of different integral-field units (IFUs). Credit: University of Durham.

Spectroscopic Data

Optical IFS spectrograph OASIS at 3.6m CFHT (Mauna Kea)

- constructed in CRAL, Lyon
- array of hexagonal lenslets
- 1 000 – 1 600 spectra simultaneously
- spatial sampling $0.27'' - 0.41''$
- spectral sampling $1.92 \text{ \AA} - 1.95 \text{ \AA}$
- field of view (FOV) $10'' \times 8''$ or $15'' \times 12''$



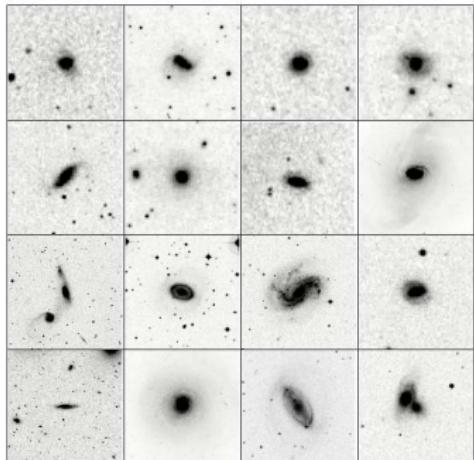
Bacon et al. (2001)

Observed Sample of Seyfert Galaxies

NLRs of 16 nearby Seyfert galaxies observed with OASIS

- 11 Seyferts type 2
- 5 Seyferts type 1
- Redshifts 0.002 – 0.05,
distances 10 Mpc – 220 Mpc
- Two spectral domains
(4700 Å – 5500 Å, 6200 Å – 7000 Å)
- Amount of data: 1000 spectra per
galaxy per spectral domain
- Observations: P. Ferruit et al.

DSS images



Unique Data Set

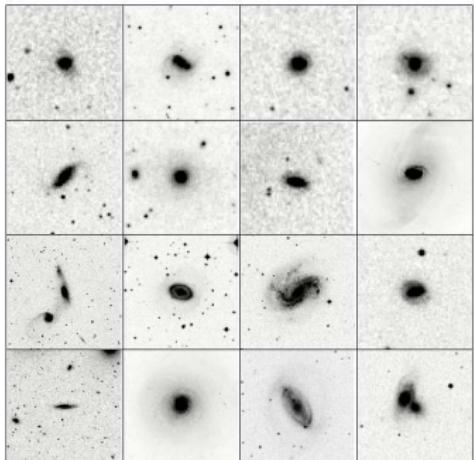
Mrk 34, Mrk79, Mrk 622, Mrk 705,
Mrk 1066, NGC 262, NGC 449, NGC 2273,
NGC 2992, NGC 3081, NGC 4051, NGC 4253,
NGC 4388, NGC 5548, NGC 5728, NGC 5929

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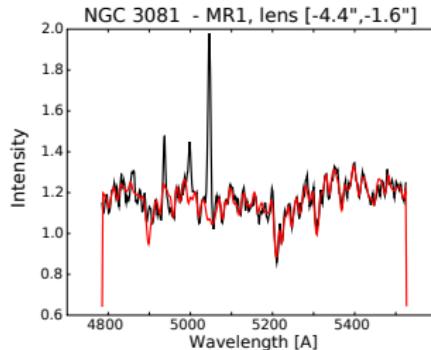
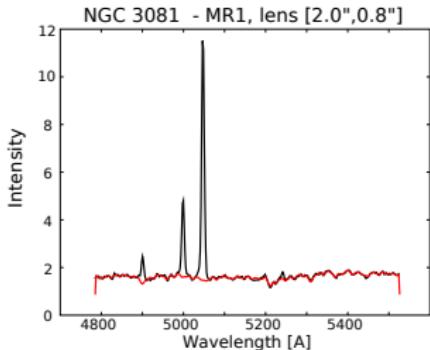


Unique Data Set

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NGC 2992, NGC 3081, NGC 4051, NGC 4253,
NGC 4388, NGC 5548, NGC 5728, NGC 5929

Emission and Absorption Lines

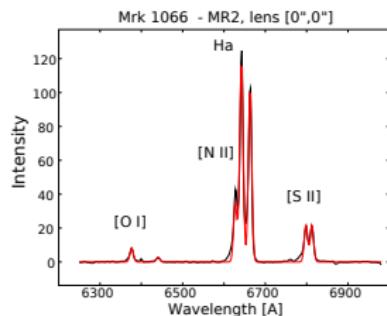
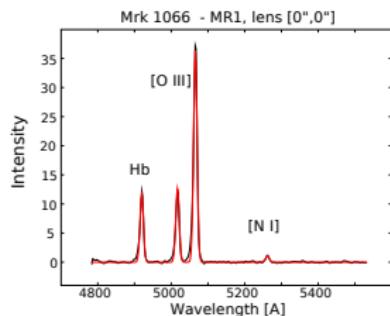
- Absorption: Stellar-population modelling (Bruzual & Charlot 2003)
 - Correction of H lines for underlying absorption
 - Stellar velocities
 - Composition of stellar ages
- Emission lines: Fitting by Gaussian profiles



Intensity units: $10^{-19} \text{ Js}^{-1} \text{ arcsec}^{-2} \text{ m}^{-2} \text{ Å}^{-1}$

Gas Emission Lines

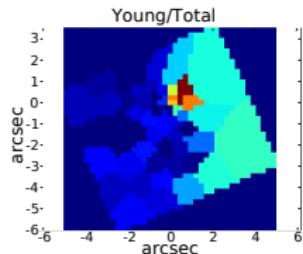
- Recombination lines (Balmer series of H):
 - $H\alpha \lambda 6563 \text{ \AA}$
 - $H\beta \lambda 4861 \text{ \AA}$
- Forbidden lines (collisionally excited):
 - $[\text{O III}] \lambda\lambda 4959, 5007 \text{ \AA}$
 - $[\text{N I}] \lambda\lambda 5198, 5200 \text{ \AA}$
 - $[\text{O I}] \lambda\lambda 6300, 6364 \text{ \AA}$
 - $[\text{N II}] \lambda\lambda 6548, 6583 \text{ \AA}$
 - $[\text{S II}] \lambda\lambda 6717, 6731 \text{ \AA}$



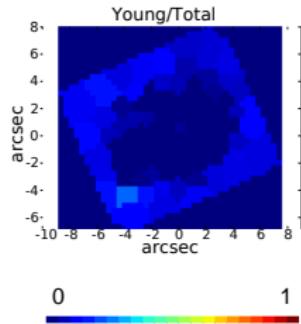
Stellar Populations

Mass Fraction
of Young Stars

NGC 2992

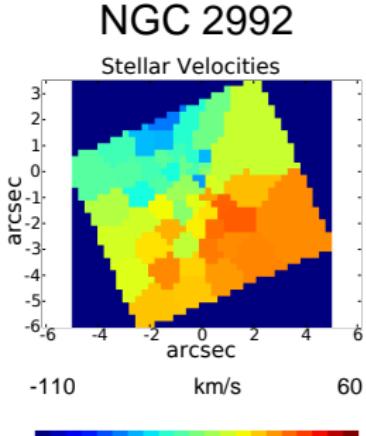


NGC 3081

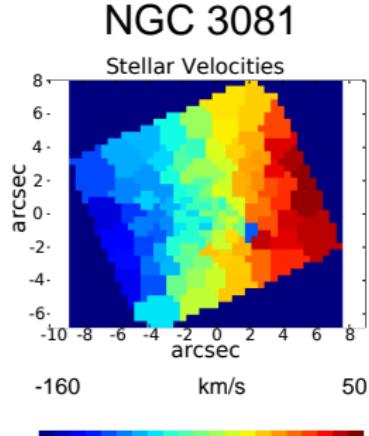


Mean LOS Stellar Velocities

NGC 2992



NGC 3081



$1'' \leftrightarrow 175 \text{ pc}$

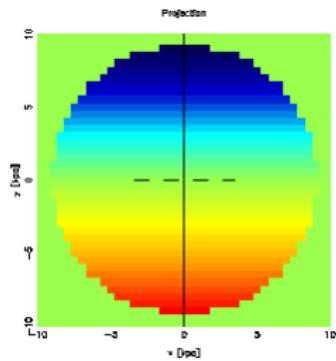
$1'' \leftrightarrow 180 \text{ pc}$

Spatial binning at S/N = 50,
Voronoi tessellation (Cappellari & Copin 2003)

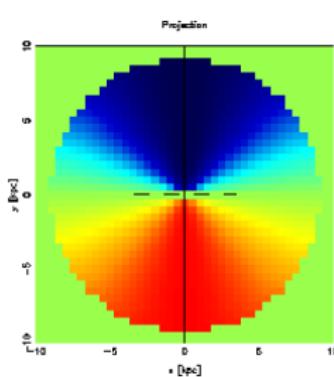
Analytic Velocity Fields – Mean LOS Velocity

Flat disk with circular motion

Linear rotation curve



Flat rotation curve



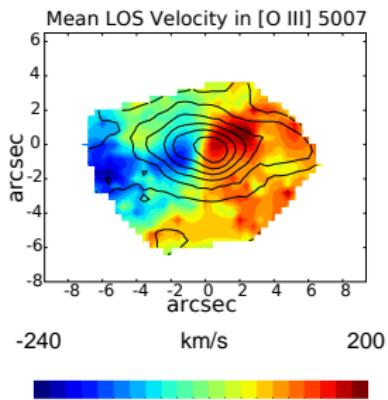
Isovelocity contours:

$$y = \text{const}$$

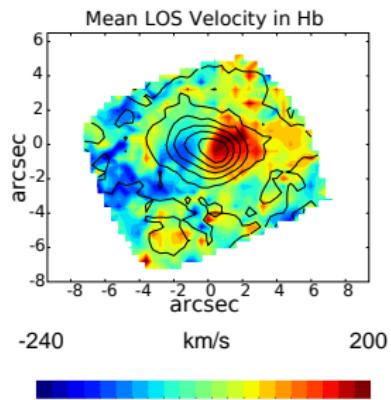
$$|x| = |y| |\cos i| \frac{\sqrt{v_0^2 \sin^2 i - v_i^2}}{|v_i^2|}$$

Stellar and Gas Velocities – NGC 5929

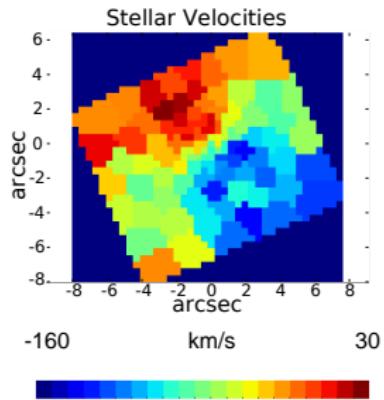
[O III] vel.



H β vel.



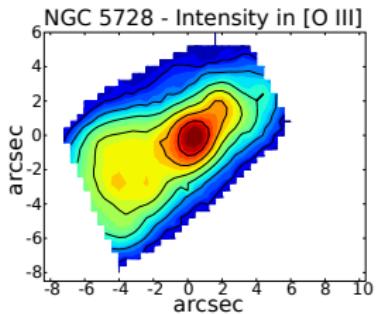
Stellar vel.



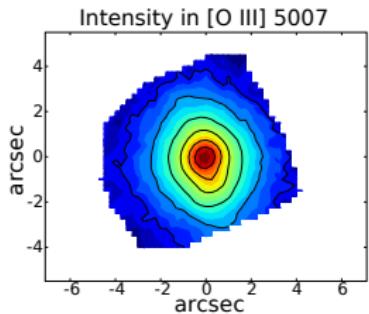
$$1'' \leftrightarrow 170 \text{ pc}$$

NLR Morphologies – [O III]

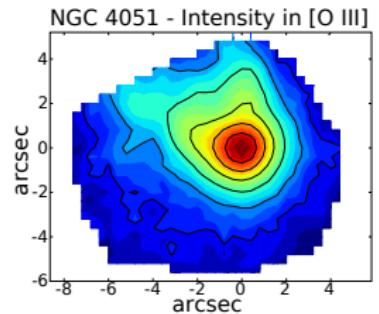
NGC 5728
(Sey 2)



Mrk 348
(Sey 2)



NGC 4051
(NLS1)



2.0

85



1.0

4200



0.8

1900



$1'' \leftrightarrow 200\text{ pc}$

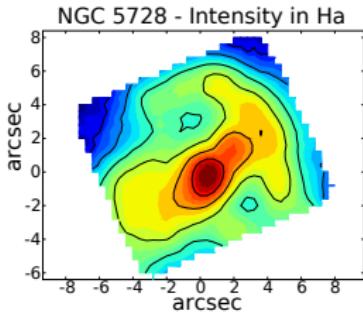
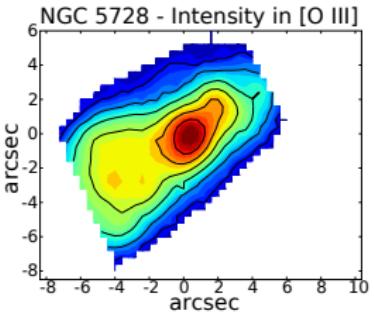
$1'' \leftrightarrow 275\text{ pc}$

$1'' \leftrightarrow 60\text{ pc}$

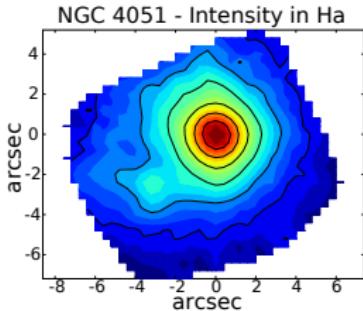
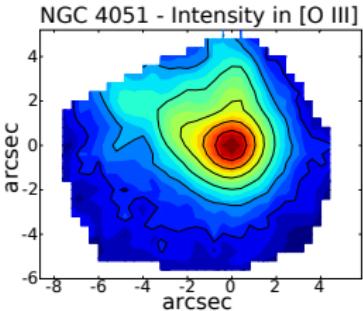
Intensity units: $10^{-19} \text{ Js}^{-1} \text{ arcsec}^{-2} \text{ m}^{-2}$

Misalignments

NGC 5728
[O III] and H α

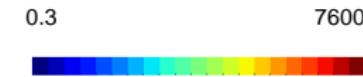
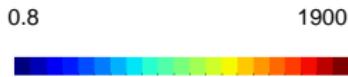


NGC 4051
[O III] and H α



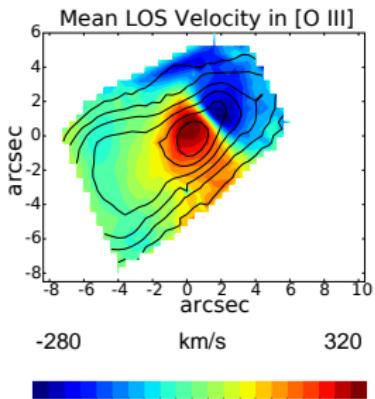
Intensity units:

$10^{-19} \text{ Js}^{-1} \text{ arcsec}^{-2} \text{ m}^{-2} \text{ A}^{-1}$

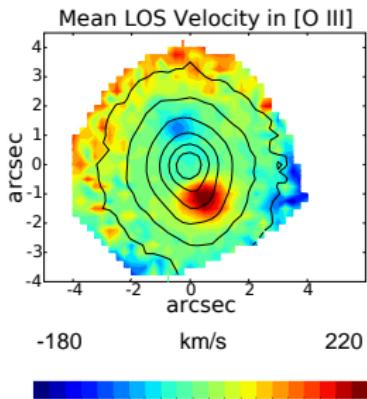


Mean LOS Velocities of Gas

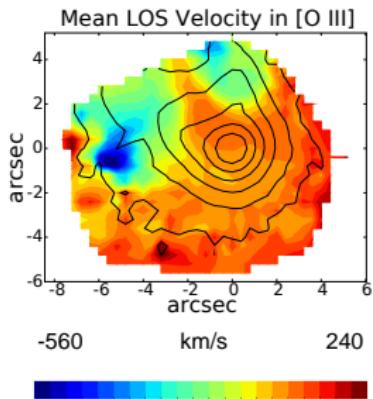
NGC 5728
(Sey 2)



Mrk 348
(Sey 2)



NGC 4051
(NLS1)



$1'' \leftrightarrow 200\text{ pc}$

$1'' \leftrightarrow 275\text{ pc}$

Ring?

$1'' \leftrightarrow 60\text{ pc}$

Radio jet: PA = 50°

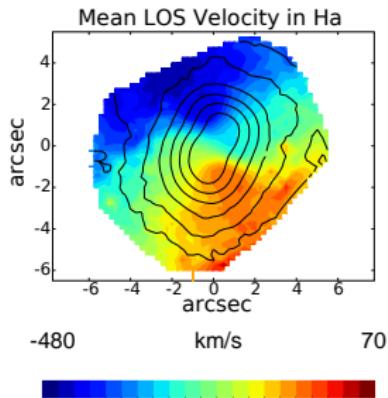
NIR: inflow? (Riffel et al. 2008)

S-shaped Velocity Isocontours ($H\alpha$)

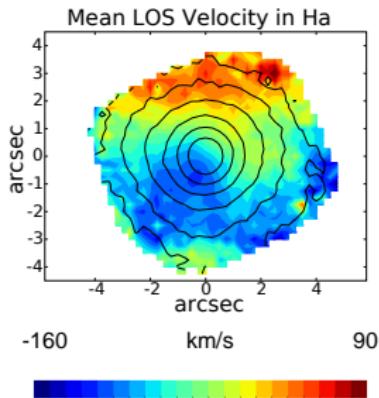
Signatures of non-circular motions due to

- non-axisymmetric potentials (bars, warps, spirals)
- radial flows

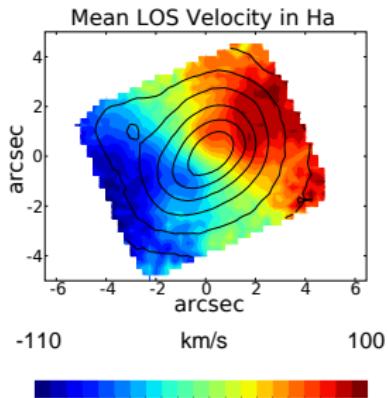
Mrk 34



Mrk 622



Mrk 1066



$$1'' \leftrightarrow 960 \text{ pc}$$

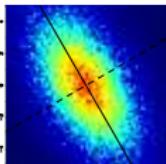
$$1'' \leftrightarrow 460 \text{ pc}$$

$$1'' \leftrightarrow 225 \text{ pc}$$

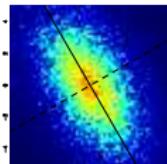
Twisted Isovelocity Contours – Models

Axisymmetric distribution

Stars



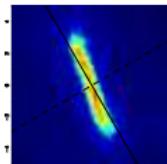
Gas



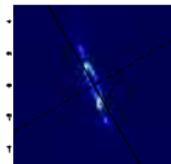
Surf.dens.

Non-axisym. distribution

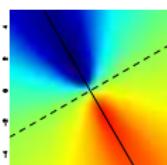
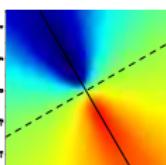
Stars



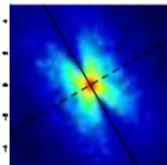
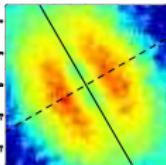
Gas



LOS vel.



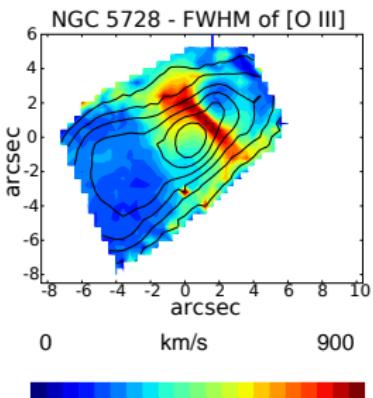
Vel. disp.



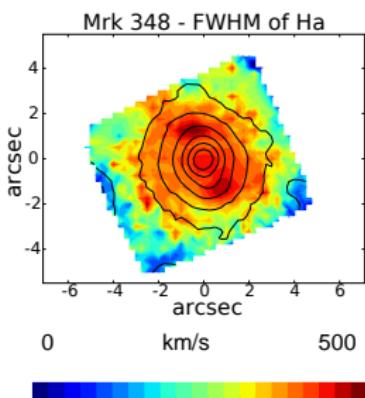
Jungwiert et al. (2003)

LOS Velocity Dispersion

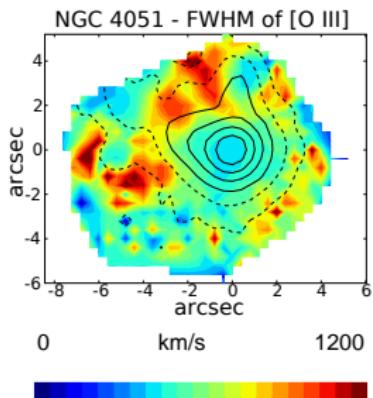
NGC 5728



Mrk 348



NGC 4051

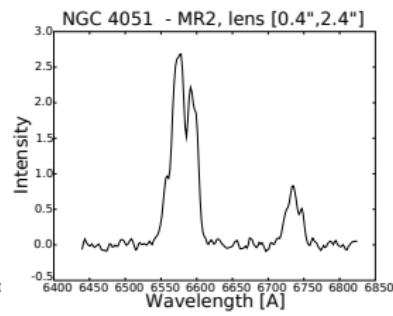
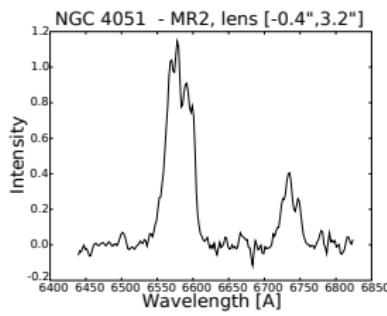
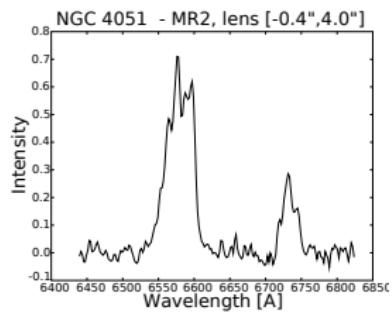
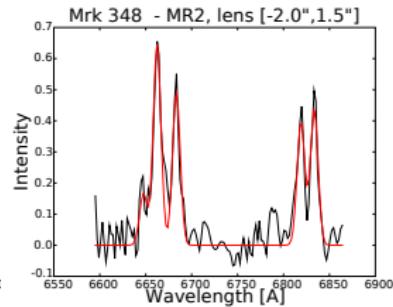
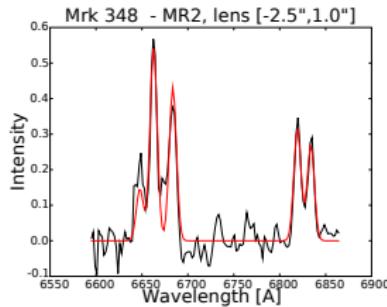
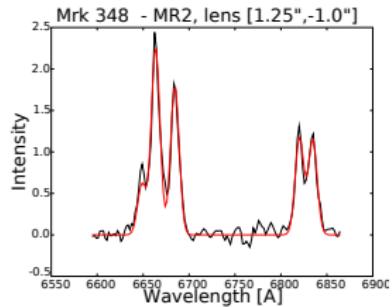


$1'' \leftrightarrow 200\text{ pc}$

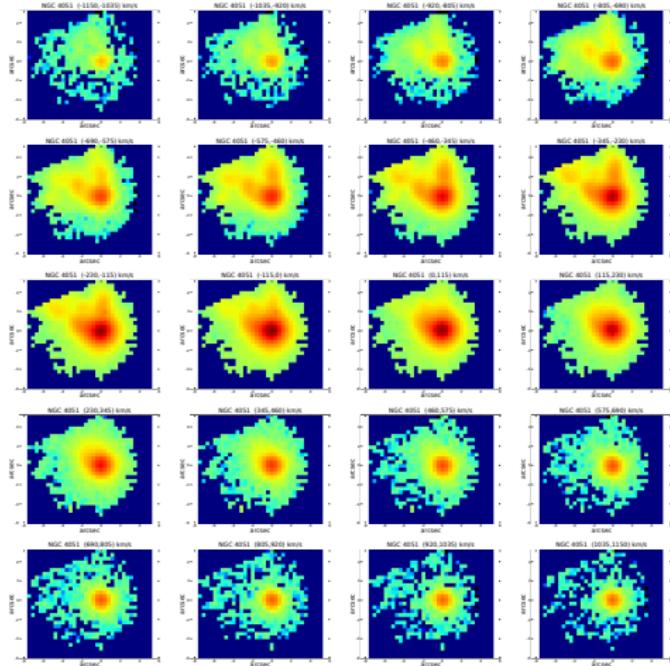
$1'' \leftrightarrow 275\text{ pc}$

$1'' \leftrightarrow 60\text{ pc}$

Multi-Component Line Profiles



Tomography – Velocity Channel Maps – NGC 4051



Future Prospects

Objectives:

- Interpretation of 3D structure of the NLRs
- Dynamics of host galaxies
- Role of NLRs in AGN feeding

Methods:

- Analytic projection models
- Elliptical rings, tilted rings
- Fourier analysis
- N-body models
- Make use of velocity channel maps, p-v diagrams

Summary of Observations

NLR kinematics in 16 nearby Seyfert galaxies (IFU OASIS):

- S-shaped velocity fields found in 80% of Sey 2s
 - Non-axisymmetric potentials? Outflows?
 - Dumas et al. (2007): more S-shapes in active than non-active spiral galaxies
- Outflow mapped in NGC 4051
- Tilted ring detected in Mrk 348
- Emission line splitting in 80% of objects
 - Need detailed line-profile models