Observational overview of AGN feeding

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Credit:Jon Lomberg

Summary

- Introduction: present paradigm – AGN results from feeding of SMBH
- Feeding mechanisms on extragalactic scales →I. Marquez talk!
- Observational constraints: galaxy environment and morphology → I. M talk!
- Feeding mechanisms on hundred of parsecs scales
- Observational constraints: (1) stellar population (2) stellar kinematics (3) distribution of gas and dust in the nuclear region of galaxies; (4) NEW observational constraint: 2D circumnuclear gas kinematics
- Feeding mechanisms on sub-parsec scales: accretion disks
- Observational constraints: spectral signatures
- Conclusions

Introduction

- Present paradigm: Nuclear activity ↔ phase in the life of a galaxy triggered by mass accretion to the nuclear supermassive blackhole (SMBH); bulge growth related to blackhole growth (Magorrian et al. 1998; Ferrarese & Merrit 2000; Tremaine 2002; Marconi & Hunt 2003).

- Origin of AGN fuel and nature of the triggering mechanism: two of the main unsolved questions in AGN research (Martini 2004)

Introduction

Mechanisms for mass accretion triggering/feeding:

(1) galaxy interactions can send gas inwards (Hernquist 1989; Barnes & Hernquist 1992);

(2) non-axisymmetric kpc to hundred pc scale morphologies – e. g. bars – can promote gas inflow from galaxy disk towards the nucleus (e.g. Shlosman 1989, 1990, 1993);

(3) hundred of pc scales gaseous spirals can also send gas to feed the SMBH (Pogge & Martini 2002, Maciejewski 2004);

(4) sub-pc scale (unresolved) accretion disks (e.g. Sakura & Sunyaev 1973; Collin 1990-2000; Narayan 2000s)

Contributions from Debora Dultzin-Hacyan & collabs. related to AGN feeding: effect of the environment on nuclear activity; search for starbursts around AGN; accretion disks signatures: AGN with double-peaked profiles

Feeding on 100 pc scales: stellar population

Theory

• **G**as in its way to the nucleus will most probably form stars

• Perry & Dyson 1985-2000: first to propose an AGN-starburst connections: starburst surrounding SMBH as the source of fuel and broad-line cloudes

• Terlevich & Terlevich, Melnick, Cid Fernandes, Aretxaga and collaborators (1985-1990's): AGN-starburst connection; variability of AGN due to SN explosions, UV- blue light in Seyfert 2 galaxies due to circumnuclear starbursts

•Norman & Scoville 1988: evolution of starburst galaxies to active galactic nuclei

• Collin & Zahn 1999: star formation in accretion disks

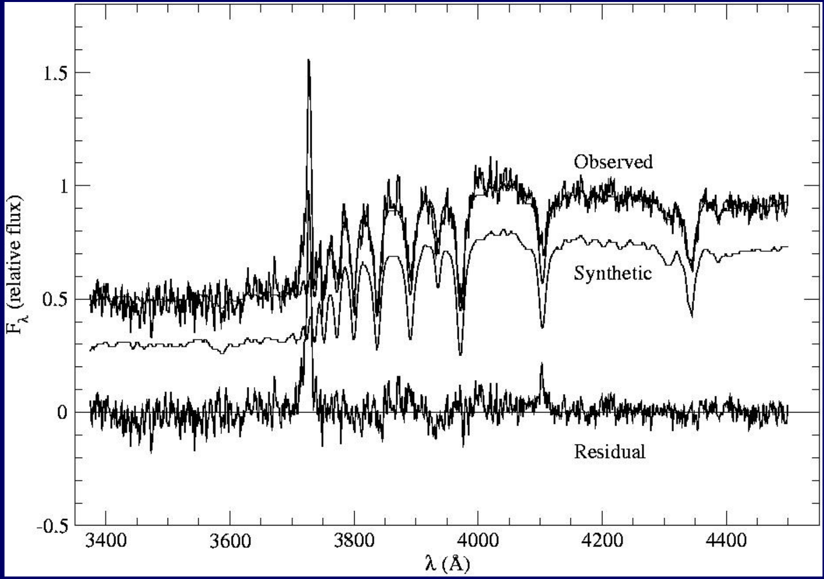
• Wada & Norman 2002: starbursts within obscuring regions surrounding AGN

Feeding on 100 pc scales: stellar population

Observations

Terlevich, Terlevich, Diaz, Aretxaga, Cid Fernandes (1990-1995); Heckman, González Delgado, Leitherer (1995-1998); Nelson & Whittle 1996, Origlia, Oliva & collabs, 1990's: evidences of the presence of young to intermediate age stars in AGN spectra; AGN hosts have lower M/L ratio than non-AGN

Cid Fernandes et al. (1998-2005); Storchi-Bergmann et al. (1998-2001); Schmitt et al. (1999); Raimann et al. (2001-2005); Gonzalez-Delgado et al. (2001-2004): spectral synthesis → excess of young to intermediate age (10^6-10^8yr) stellar population in active galaxies when compared with control sample.



Intermediate age stellar population

Feeding on 100 pc scales: stellar population

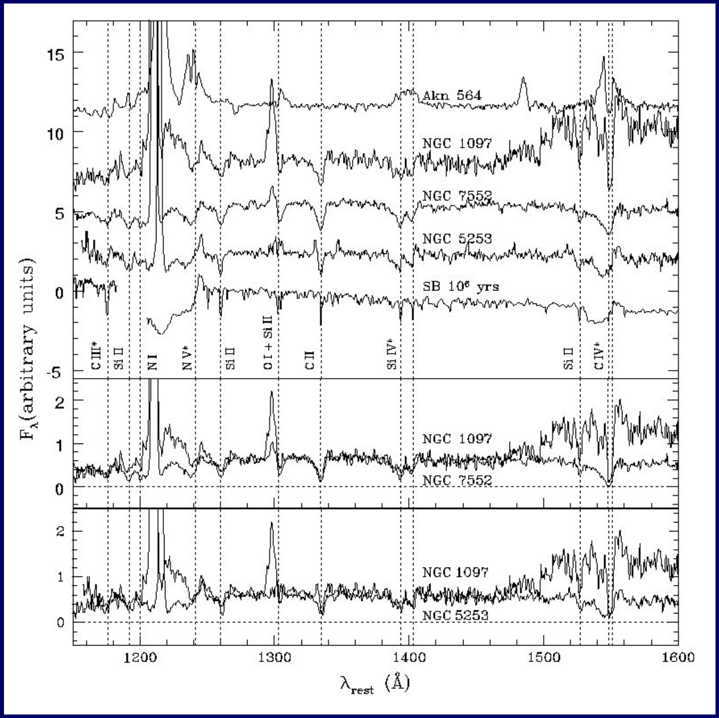
More observations

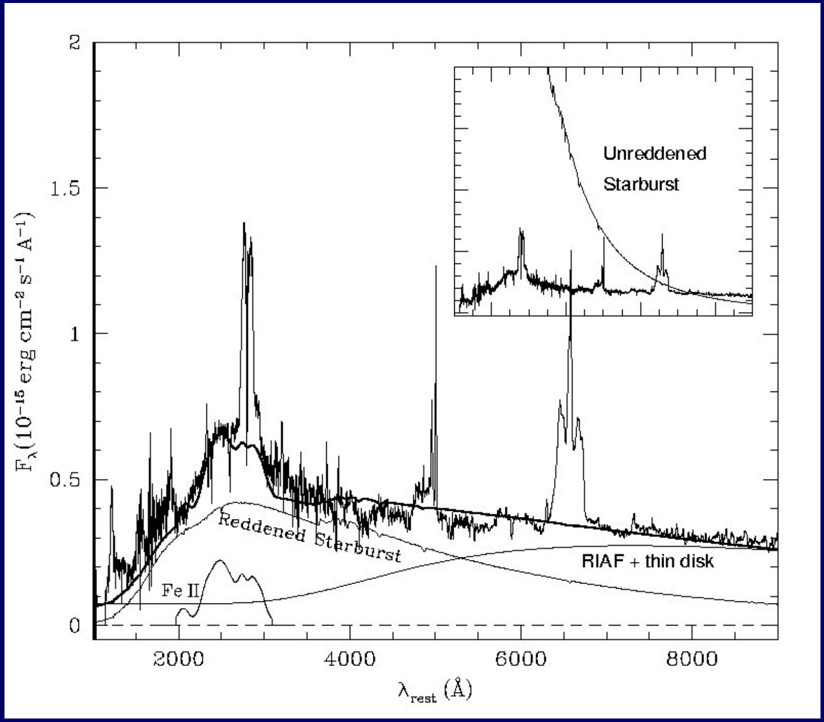
- Dultzin-Hacyan et al. 1988, 1994; Gu, Dultzin-Hacyan et al. 2001: circumnuclear starbursts in Seyfert 2 galaxies
- Stellar populations studies also by Boisson & Joly t~2000
- Kauffmann et al. 2003, SLOAN: most luminous Seyfert galaxies present largest contribution of young stars; less luminous AGN present similar population to non-active galaxies (lower spatial resolution than Cid Fernandes et al.). Also lots of intermediate age (10^8yr) population.
- Canalizzo & Stockton 2000s, Aretxaga et al. 2000s: post-starbursts in radio galaxies and quasar hosts

Feeding on 100 pc scales: stellar population

More observations (high spatial resolution):

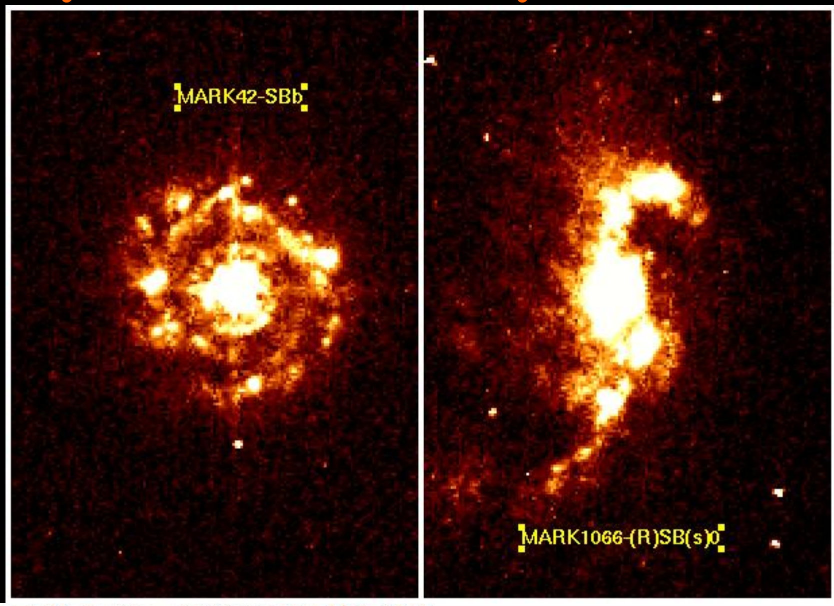
1) Young stars around SgrA* (Genzel and collabs. 2004-2006);
2) Young/intermediate age starbursts within 50pc of nucleus of nearby AGN (Mueller, this conference)
3) Young starburst < 9 pc from NGC1097 nucleus (Storchi-Bergmann et al. 2005):



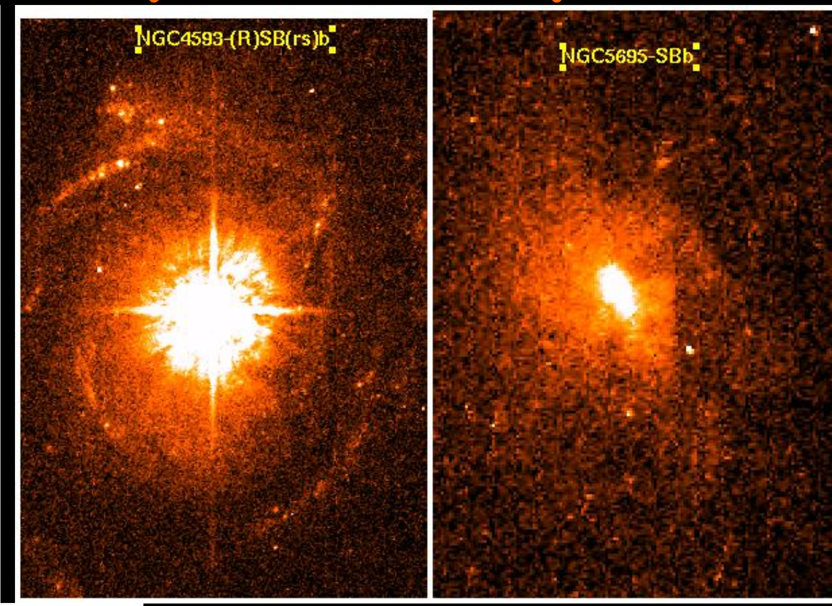


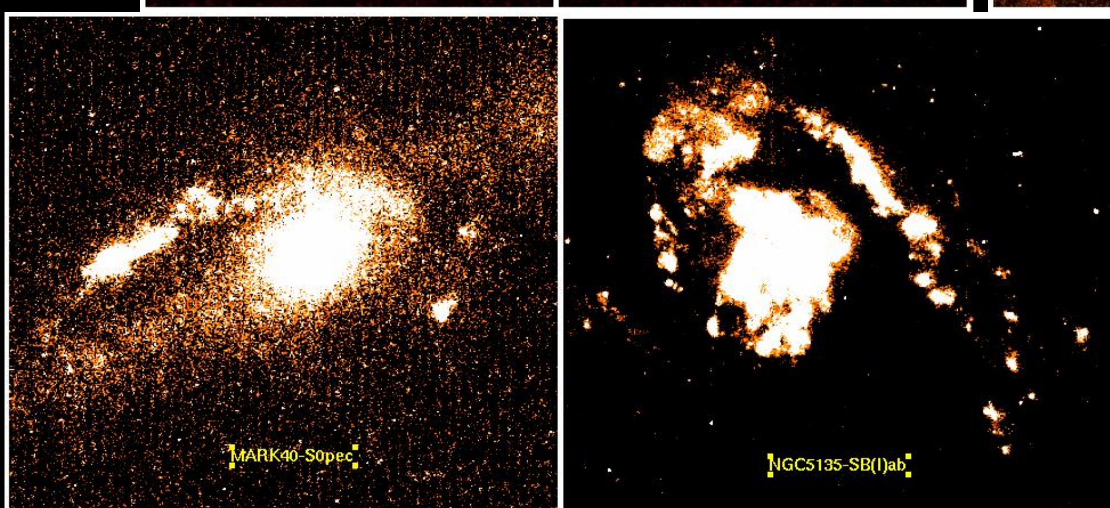
More observations: Marín, Gonzalez Delgado et al. 2007: Atlas of near-UV ACS images of 75 Seyfert galaxies; Spineli, Storchi-Bergmann et al. 2007: Sy1 vs. Sy 2:

Seyfert 1 **Seyfert 2**



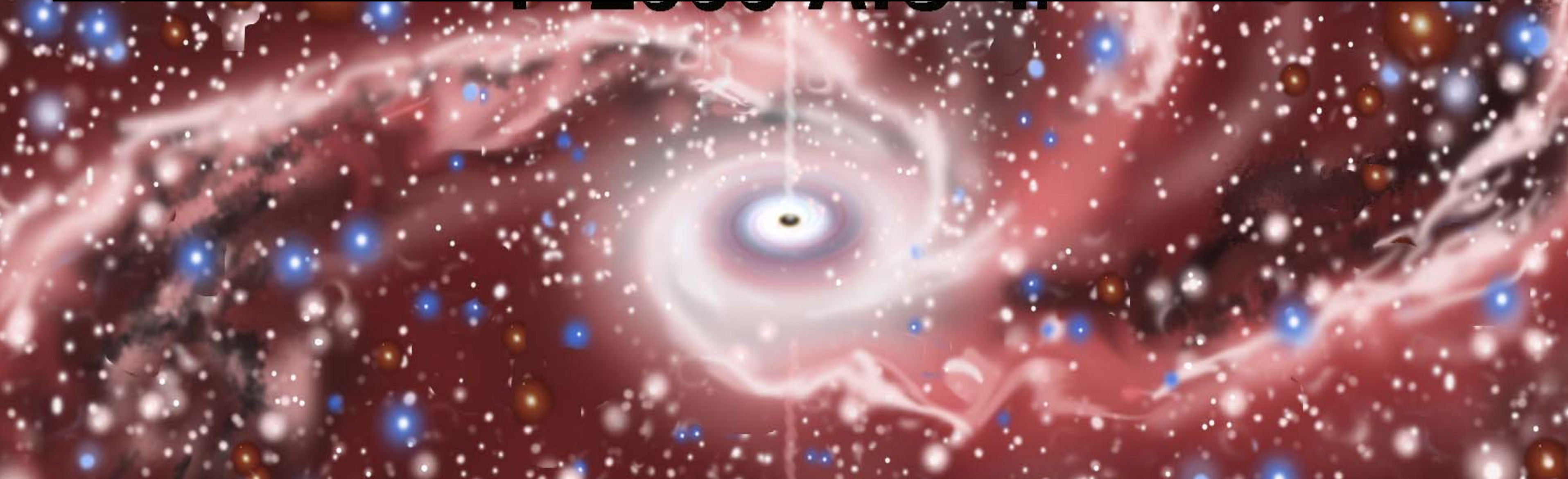
Seyfert 1 **Seyfert 2**





Nature of near-UV light still under investigation: young stellar population or ISM ionized by the AGN?

Feeding on 100 pc scales: morphology



Theory:

• Maciejewski 2004: nuclear (< 1 kpc) gaseous spirals originated as a response to non-axisymmetry in the galactic potential may promote gas inflow up to 0.03 M_{sun} yr^{-1}, enough to feed local Seyfert nuclei.

Feeding on 100 pc scales: morphology

Observations: AGNs have more circumnuclear gas and dust

• Van Dokkum & Franx (1995), HST: radio-loud early-type galaxies have more dust than radio-quiet

• Pogge & Martini, 2002; Martini et al. 2003, HST: Seyfert galaxies present dusty filaments and spirals in the nuclear region

• Xilouris & Papadakis (2002), HST: among early Hubble types, active galaxies present more dust structure than non-active galaxies

• Ferrarese et al. (2006) HST: dust in early-type galaxies; signatures of star formation in most regular/compact dust structures;

• Lauer et al. (2005), HST: dust in early-type galaxies is correlated with nuclear activity

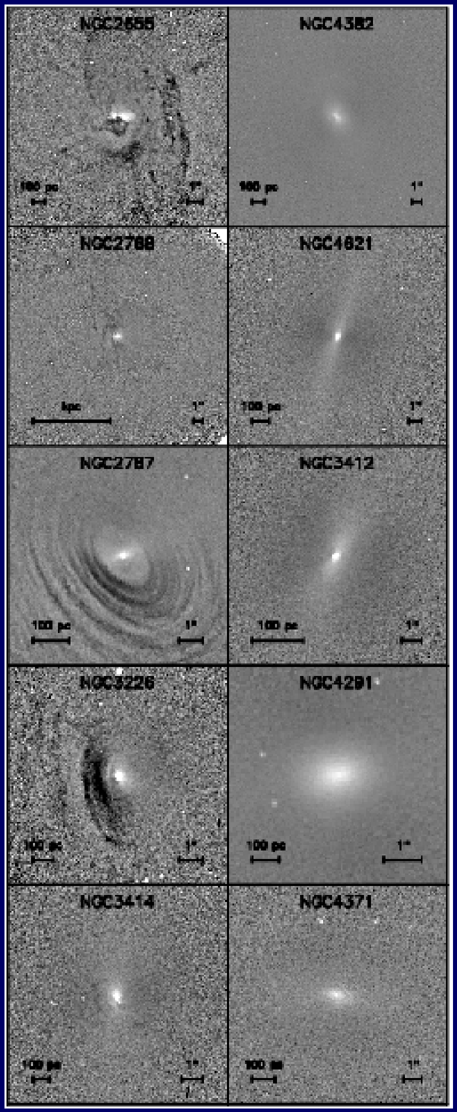
Feeding on 100 pc scales: morphology

More observations:

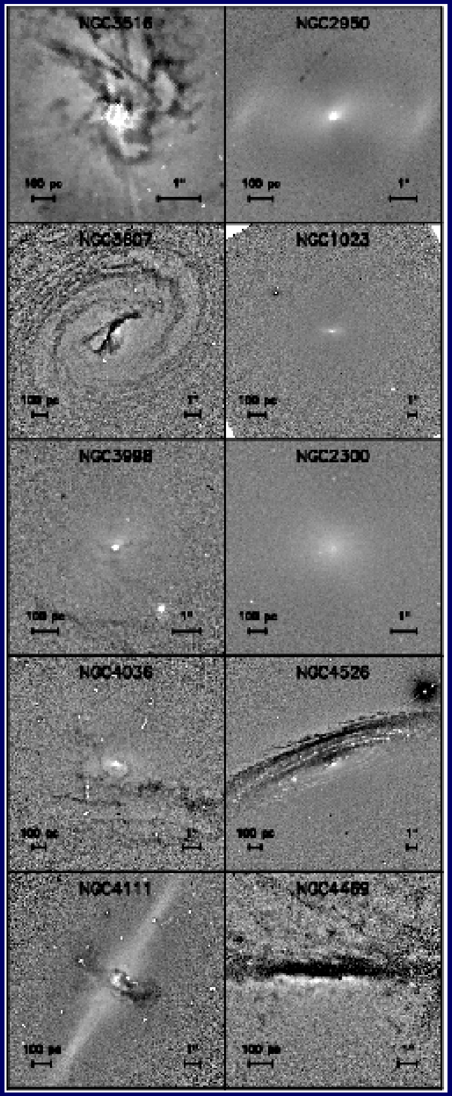
- Prieto et al. 2005: near-IR VLT adaptative optics images of the nuclear region (<300 pc) of LINER/Seyfert 1 galaxy NGC1097 reveal several spiral arms which seem to be channels for gas and dust to reach the SMBH at the nucleus.

- Lopes, Storchi-Bergmann & Martini 2007: found tens of similar structures in HST optical images of the nuclear region of nearby AGN hosts. Technique: structure maps, which enhance the images contrast, of 68 active galaxies and paired control sample of non-active galaxies.

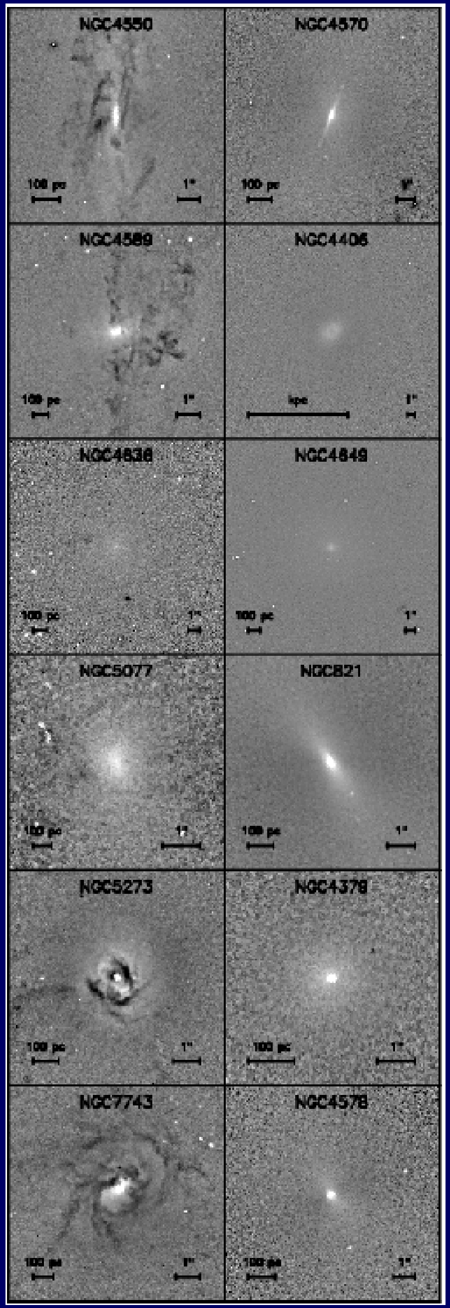
Lopes et al. 2007: Structure maps for 34 early-type galaxies pairs (T<0)



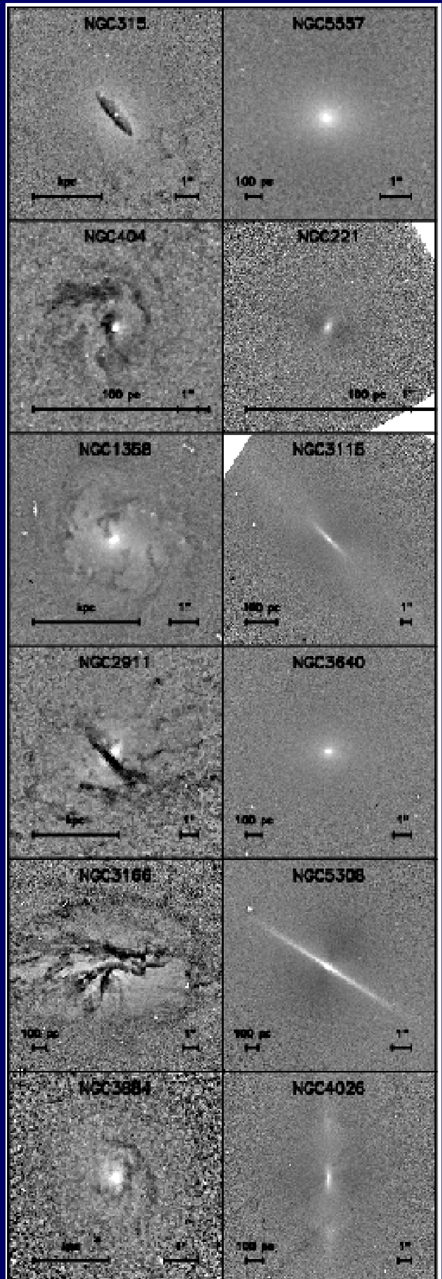
Active Non-active

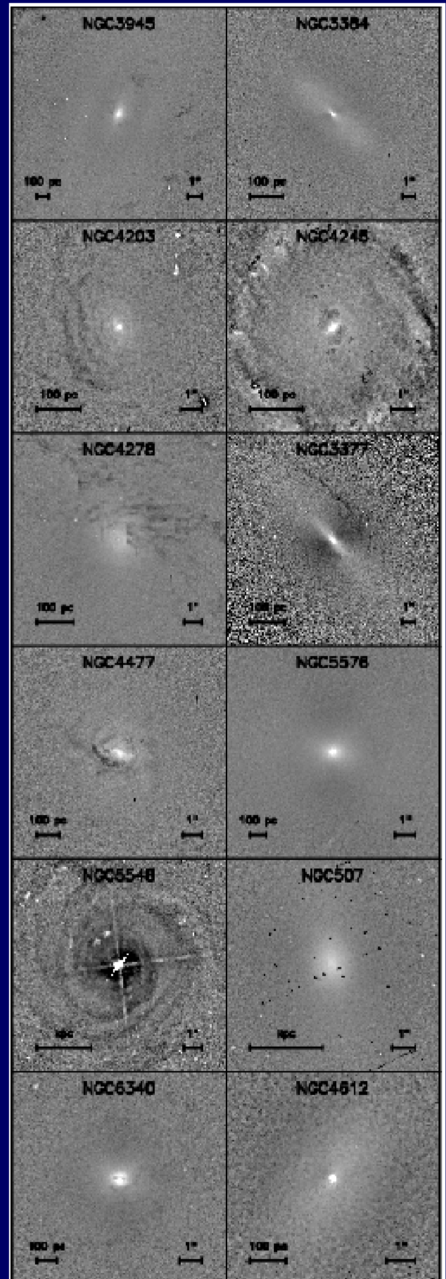


Active Non-active



Active Non-active





Active Non-active Active Non-active

Lopes et al. 2007: Results for 34 early-type pairs:

• Dust structures are more frequent in active than in non-active galaxies (100% vs 27%): feeding material on its way in

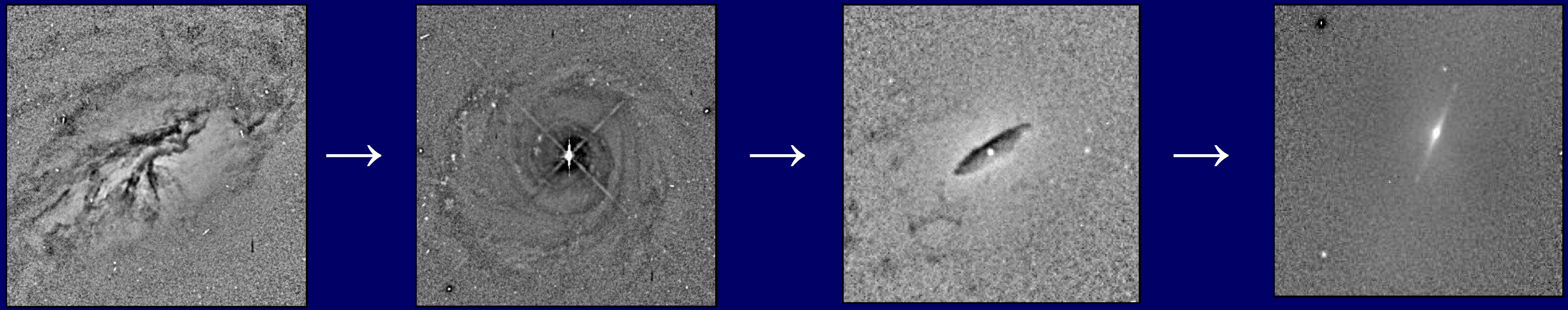
•~50% of non-active galaxies present nuclear stellar disks, absent in active galaxies; may be more, as disks at low inclination are hard to separate from bulge

Lopes et al. 2007: Evolutionary scenario (early-types):

• Dust structure: chaotic ⟶ spiral ⟶ compact disk; suggests evolution, or "settling sequence" (Lauer et al. 2006)

• Presence of stellar disks in non-active galaxies (confirmed by previous works with galaxies in common) ⟶ as host galaxies are matched ⟶ stellar disk may be one more step in the evolutionary sequence:

chaotic dust filaments → spiral → compact dusty disk → stellar disk



Nuclear stellar disk also present in active phase: replenished after each activity cycle and unveiled after accretion of gas and dust

Feeding on 100 pc scales: gas kinematics

Theory

Maciejewski (2004-2006): nuclear spirals as spiral shocks, resulting in streaming motions in the gas at accretion rates needed to power local Active Galactic Nuclei. Kinematic signatures still missing!

Observations

- Peletier, Emsellem, Fathi et al. 2007: SAURON observations of gas kinematics reveal streaming motions due to a bar; not yet many active galaxies

- Storchi-Bergmann, Fathi, Axon, Robinson, Marconi 2006-2007: proposed Gemini IFU observations to look for streaming motions along nuclear spirals in AGN hosts. Sample extracted from Lopes et al. 2007 (structure maps).

- Observational (tricky) constraints: inclination should allow measurement of kinematics, presence of emitting gas, low-activity to avoid too much outflow.

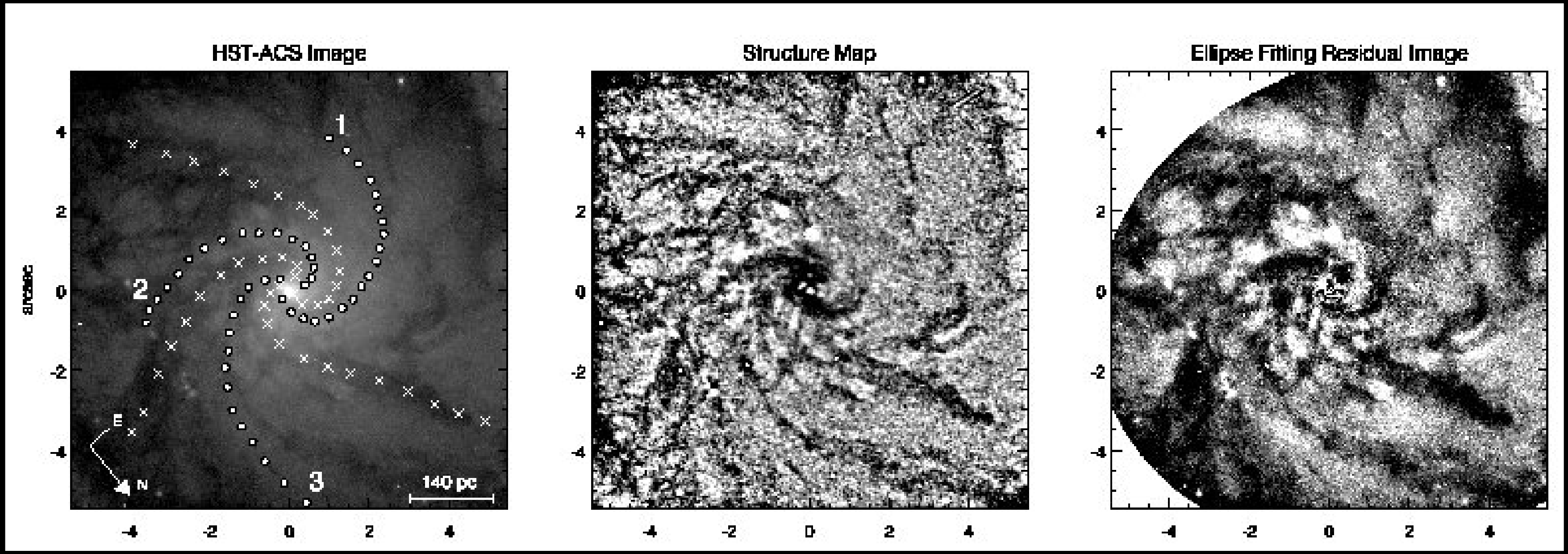
NEW: Already found two cases: NGC1097 and NGC6951

NGC 1097

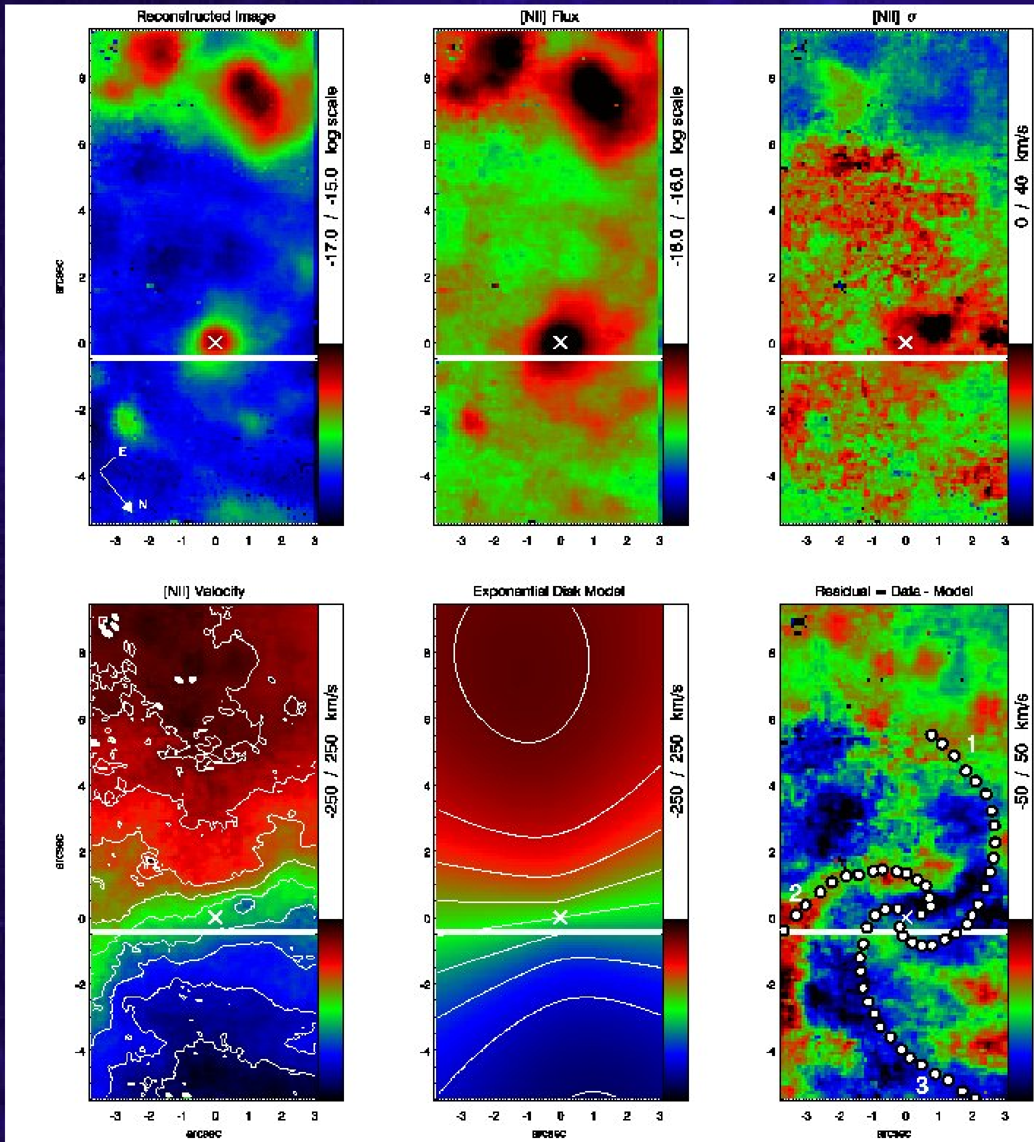
• Luminous (M_B=-21.2) SBb galaxy at 17 Mpc with nuclear ring (700 pc); LLAGN with double-peaked Balmer lines (Storchi-Bergmann et al. 1993-2003)

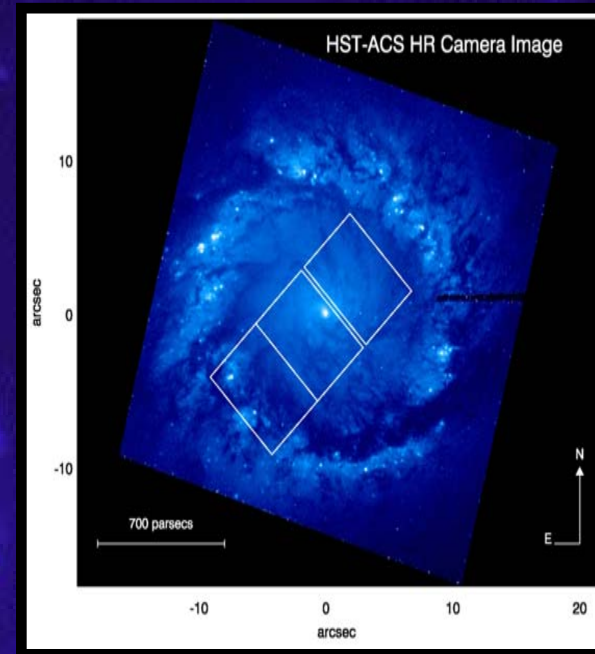
• HST ACS FR656N images of inner 500 pc: gas/dust filaments (Prieto et al. 2005; Fathi et al. 2006)

Fathi et al. 2006:



Fathi et al. 2006: Gemini IFU GMOS spectra of Hα region covering 7″×15″(3 fields; 3000 spectra) →

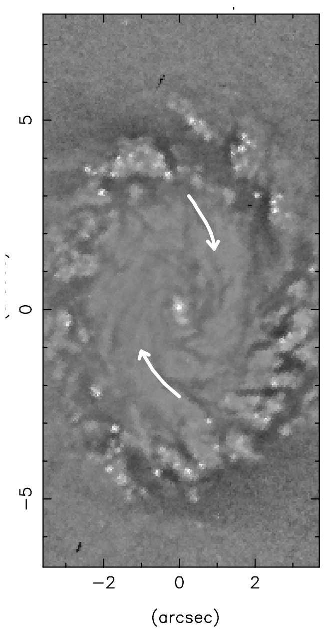




Results:

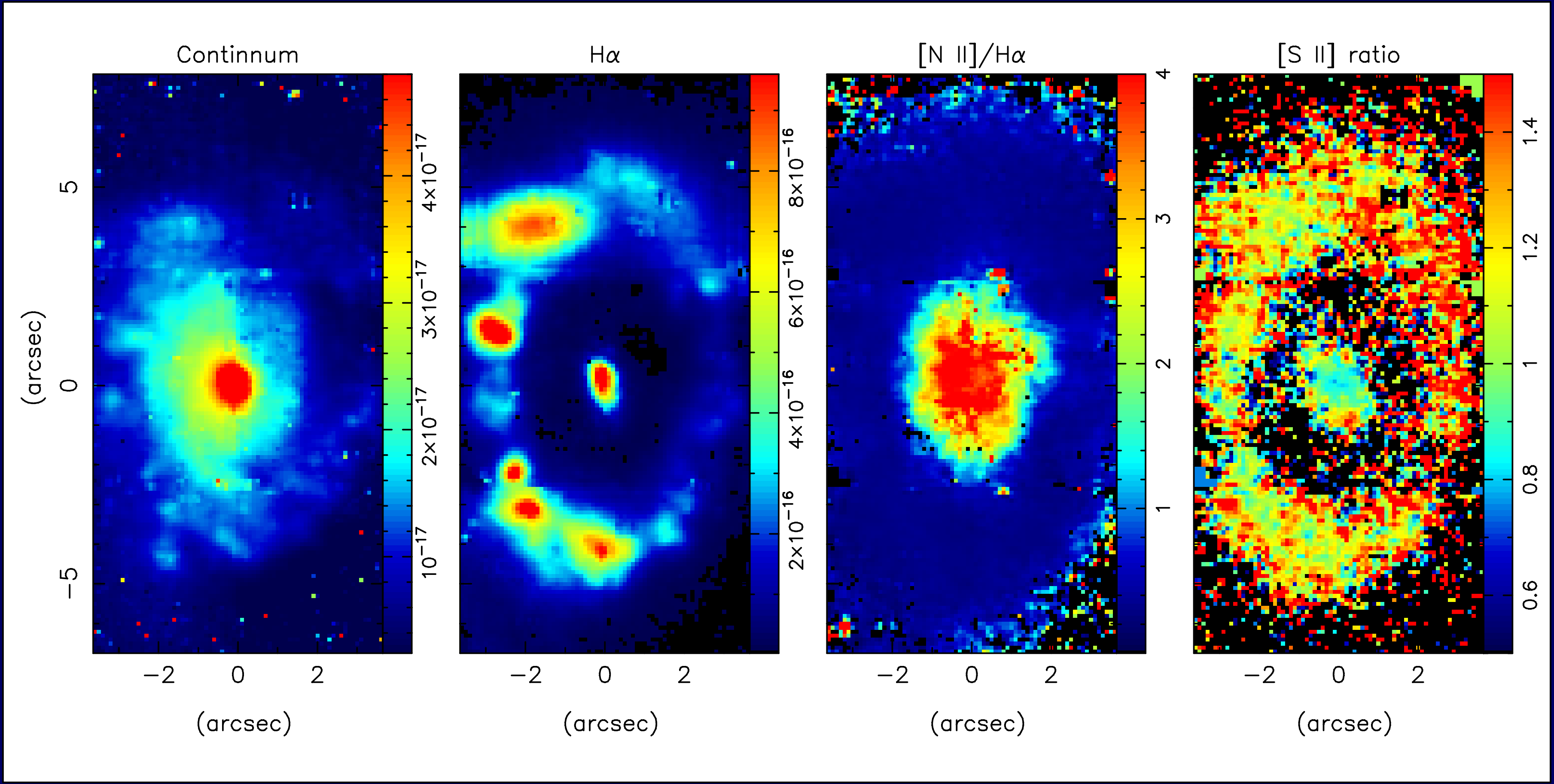
(1) Distorted rotation: residuals relative to circular rotation of ~50 km/s delineate spiral arms (dots); (2) redshifts in the near side, blueshifts in the far side

→ streaming motions along spiral arms towards the nucleus

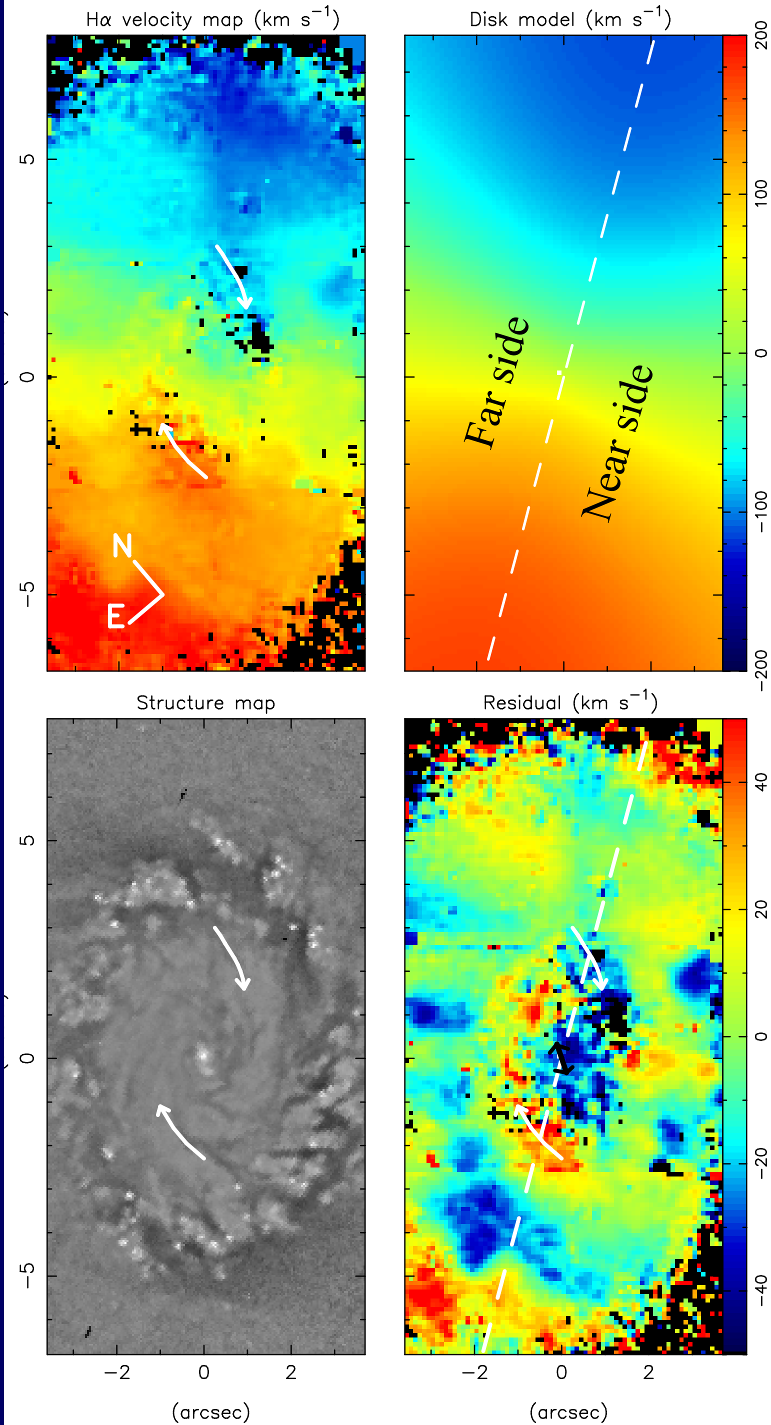


5
0
−5
−2
0
2
(arcsec)

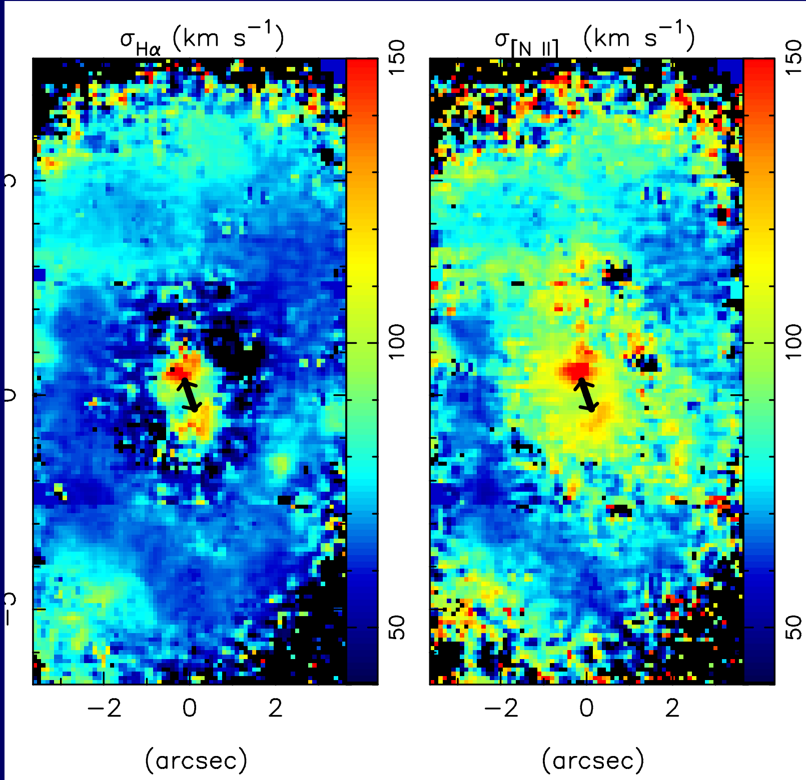
Storchi-Bergmann et al. 2007: NGC 6951 fluxes and line ratios:



Storchi-Bergmann et al. 2007: NGC6951 kinematics



- Streaming motions along nuclear spirals
- Spirals seen in HCN (Krips et al. 2007)
- Residuals include outflow produced by radio jets (Saikia et al. 2002)



Relevance an implications

• First time that streaming motions in nuclear spirals are mapped (previously only on large scale spiral arms: e.g. Visser 1980; Tilanus & Allen 1991; Emsellen, Fathi et al. 2005);

• Nuclear spirals ubiquitous in active galaxies → material in its way in to feed the SMBH (more kinematic studies are being done);

• Timescales: at 50 km/s, gas at ~100 pc from the nucleus will reach the center in a few 10^6 yrs (≡dynamical/free-fall timescale)

• Calculation of mass inflow rate (in ionized gas!):

$$\boxed{\frac{dM}{dt} = \rho \times v \times \sigma \times f \cong 10^{-3} M_{e}\, yr^{-1}}$$

⇒ Of the order of the nuclear accretion rate (derived from AGN luminosity for RIAF structure)

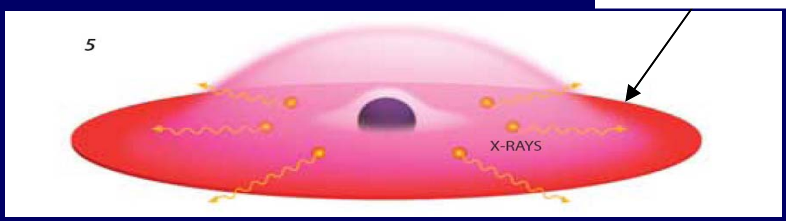
BUT: ionized gas may be only the "tip of the iceberg"; neutral and molecular gas may dominate inflow (nuclear molecular mass ~ 10^7 M_{sun} in NGC6951)

Feeding mechanisms on sub-parsec scales: accretion disks

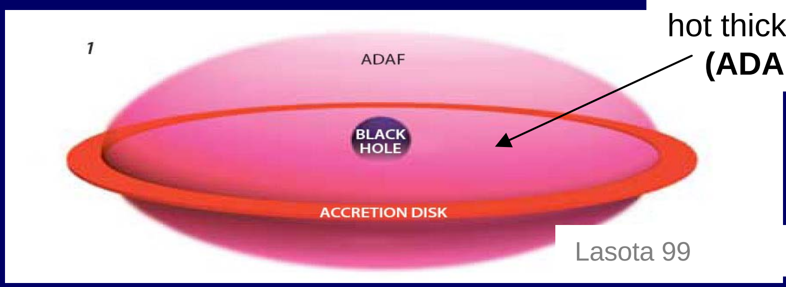
Theory

- Gas flowing toward SMBH has angular momentum ⇒ settles into disk-like structure. Friction (viscosity) allow gas to flow in (Narayan & Quataert 2005;)
- Two main classes of accretion flows (Petrosian, this conference):

cold thin disk



hot thick disk
(ADAF)



Lasota 99

Sakura & Sunyaev 1973, Novikov & Thorne 1973:
Cold, thin disk (T~10^3 K) $\left(L_{\rm rad} \geq 0.1\dot{M}c^2\right)$
High radiative efficiency

Lumious AGN **(e.g. quasars)**

Narayan 1998: Thick, optically thin and hot
(T_i~10^{11} K) $\left(L_{\rm rad} = 0.1\dot{M}c^2\right)$
***Low rad* efic.**

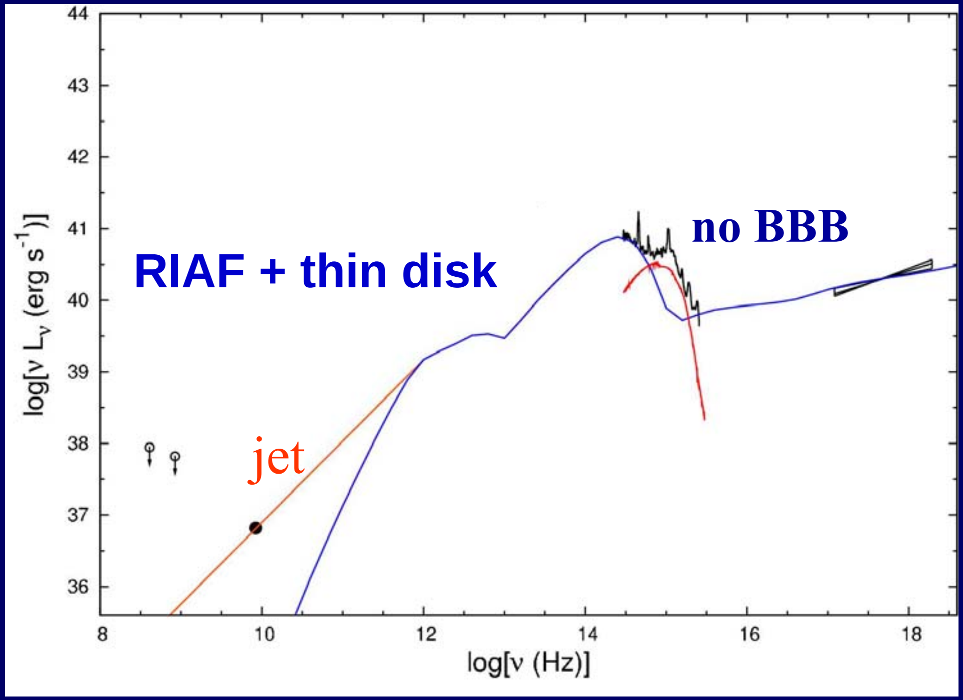
Low-luminosity AGN **(e.g. LINERs)**

Ichimaru 1977, Rees et al. 1982

Feeding mechanisms on sub-parsec scales: accretion disks

Observations

- Quasars and luminous AGN: UV Big Blue Bump (BBB) ↔ thin accretion disks (Blaes 2007)
- Low-lum. AGN: X-ray spectrum and lack of Big Blue Bump ↔ RIAF structure (Yuan 2007)

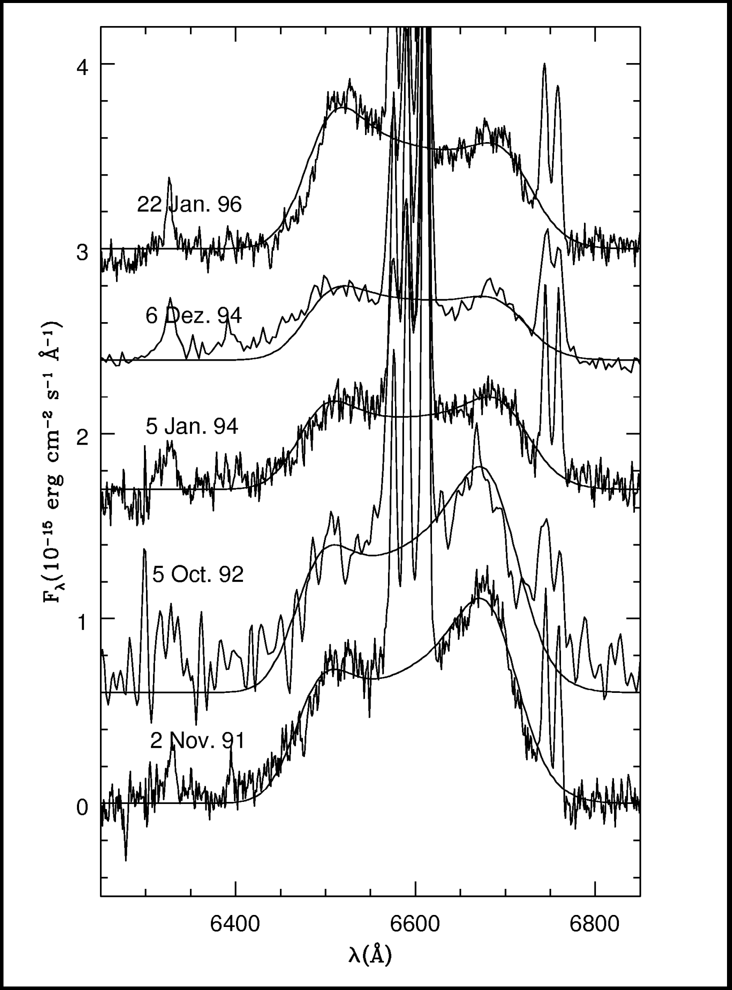


~40% of local galaxies (LINERs) acrete in the RIAF regime (Ho & collabs 2000s)

Feeding mechanisms on sub-parsec scales: accretion disks

Observations

- Kinematic signatures of accretion disks: double-peaked emission-lines, as in cataclismic variables (Chen & Halpern 1989; Eracleous & Halpern 1994 Bower, Shields, Ho, Barth 2000s; Strateva et al. 2003; Storchi-Bergmann et al. 1993-2003; Zhang, Popovic, this conference)
- Alternatively: signature of two BLRs of binary black hole (Zhang, Dultzin-Hacyan et al. 2007)



Storchi-Bergmann et al. 2003

Feeding mechanisms on sub-parsec scales: accretion disks

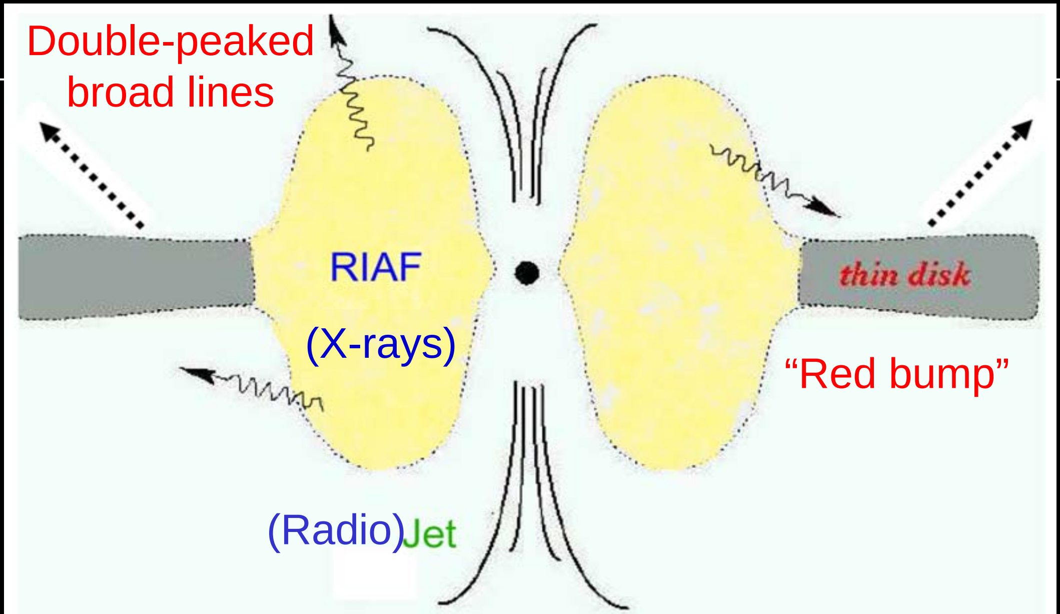
Observations

How to distinguish between accretion disk and binary BLR:

(1) Profile monitoring;

(2) SED: Eracleous 1990-2000's, Nemmen et al. 2006 showed that double-peakers have RIAFs. Necessary to ionize the outer disk and drive the emission-lines?

RIAFs can produce jets (Nemmen et al. 2007)↔radio activity "turned-on" when accretion mode is RIAF



Conclusions: AGN feeding

- Trigger: interactions ⇒ observational signatures still there for AGNs with recent star formation; age of last generation of stars dates the interaction; AGN still there after the signatures of the interaction are gone;
- Mechanisms of inflow: bars? Not obvious association with activity ⇒delay in the onset of activity?
- Nuclear gaseous spirals/filaments: strong correlation with activity→the actual fuel flowing in;
- NEW: kinematic signature of inflow along nuclear spirals; two cases observed so far. Difficulties: inclination, enough ionized gas emission in the nuclear spirals; outflows complicate gas kinematics;
- Accretion flows in the vicinity of the SMBH: dominated by RIAFs in the near Universe (present epoch).