

RADIATIVELY INEFFICIENT ACCRETION DISKS IN LLAGN WHERE TO LOOK FOR THEM

Marco Chiaberge

Space Telescope Science Institute

INAF-IRA

Alessandro Capetti INAF – Torino Observatory

Duccio Macchetto STScI-ESA

Roberto Gilli INAF- Bologna Observatory

Bill Sparks - STScI

1. THE HST VIEW OF LLAGN

**The nuclei of LLRG, Seyferts and LINERS
Where to look for RIAFs**

2. NGC 4565

Are we finally detecting RIAF in the optical?

Accretion disks

- “standard” Shakura-Sunyaev
efficient radiative cooling $\epsilon = L/\dot{M}c^2 \sim 0.1$
geometrically thin, optically thick disks
 $L \ll L_E = 1.3 \times 10^{38} M/M_{\text{sun}} \text{ erg/s}$

Observed in QSO and Seyfert galaxies
SED: Blue bump – IR bump (hot dust)

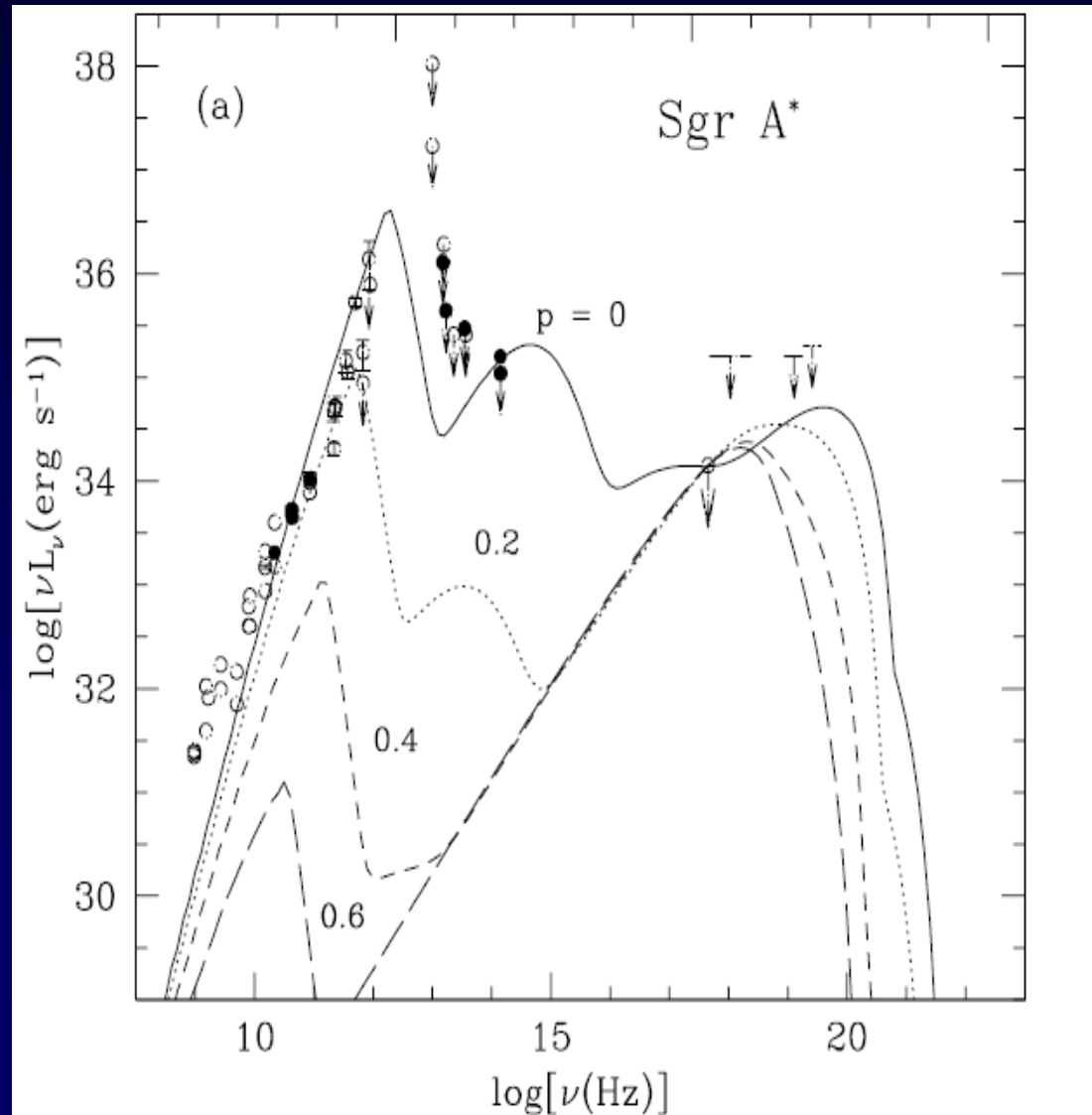
- RIAF (ADAF, CDAF, ADIOS, etc)
 $\dot{m} = \dot{M}c^2/L_E < \dot{m}_{\text{crit}}, \quad \epsilon \ll 0.1$
 $L/L_E \ll 1$
geometrically thick, optically thin

Where can we find them?

SXT?, Galactic center?, **LLAGN?, LLRG?, Seyferts?, LINERs?**

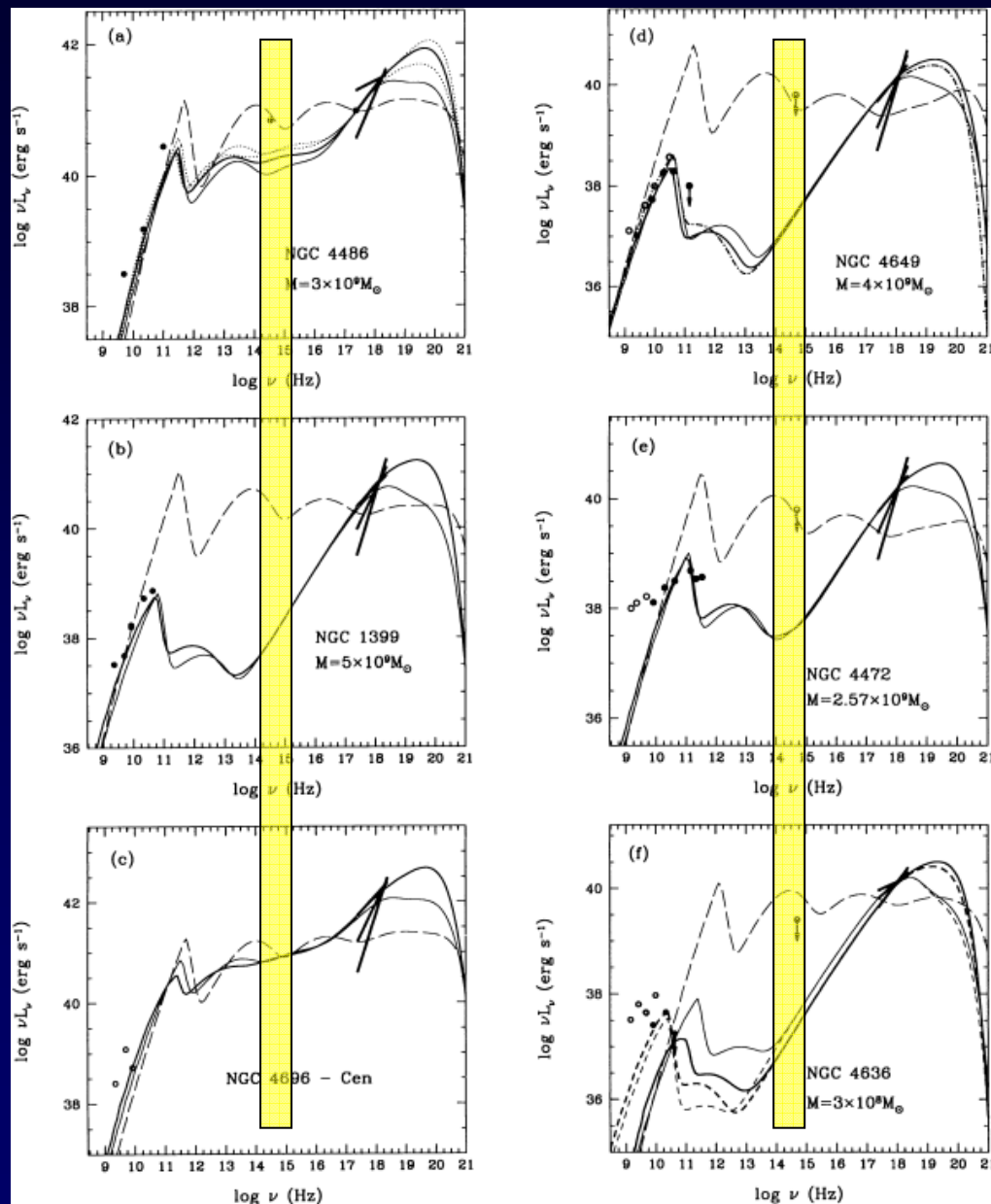
SED: synchrotron peak, IC peak(s), Bremsstrahlung

The Galactic center - ADAF model (with winds)



Quataert & Narayan 1999

SED of elliptical galaxies



Di Matteo et al. 1999

LLAGN

Nearby galaxies with some evidence for AGN activity

Faint compact radio cores

$L(\text{H}\alpha) < 10^{40} \text{ erg s}^{-1}$ (Ho et al. 1997)

Radio quiet

LINERs

Low Ionization Nuclear Emission-line Regions

$[\text{OIII}] / [\text{OII}] < 1$

Seyferts

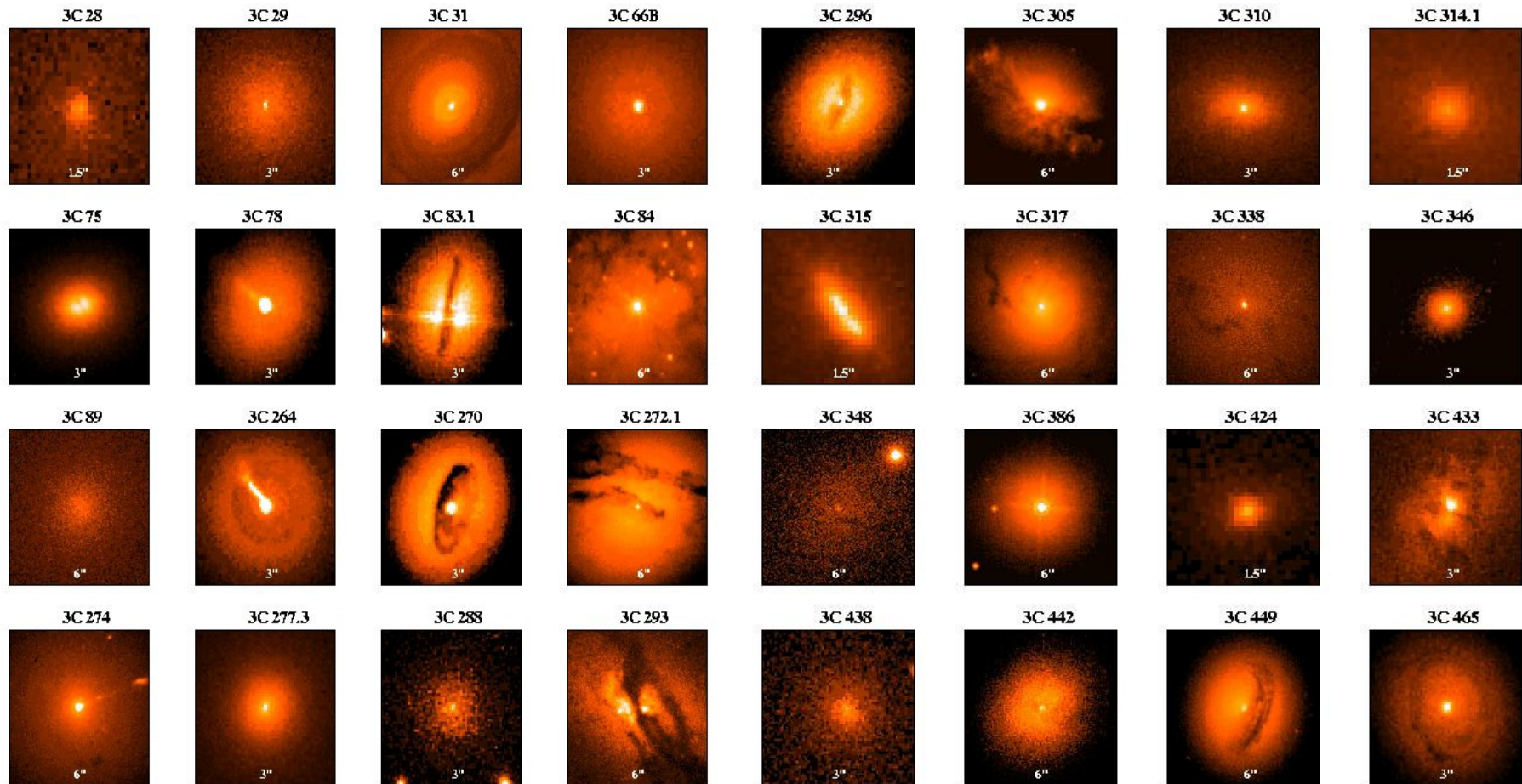
$[\text{OIII}] / [\text{OII}] > 1$

Radio loud

**Low Luminosity
Radio Galaxies (LLRG)
(FR I morphology)**

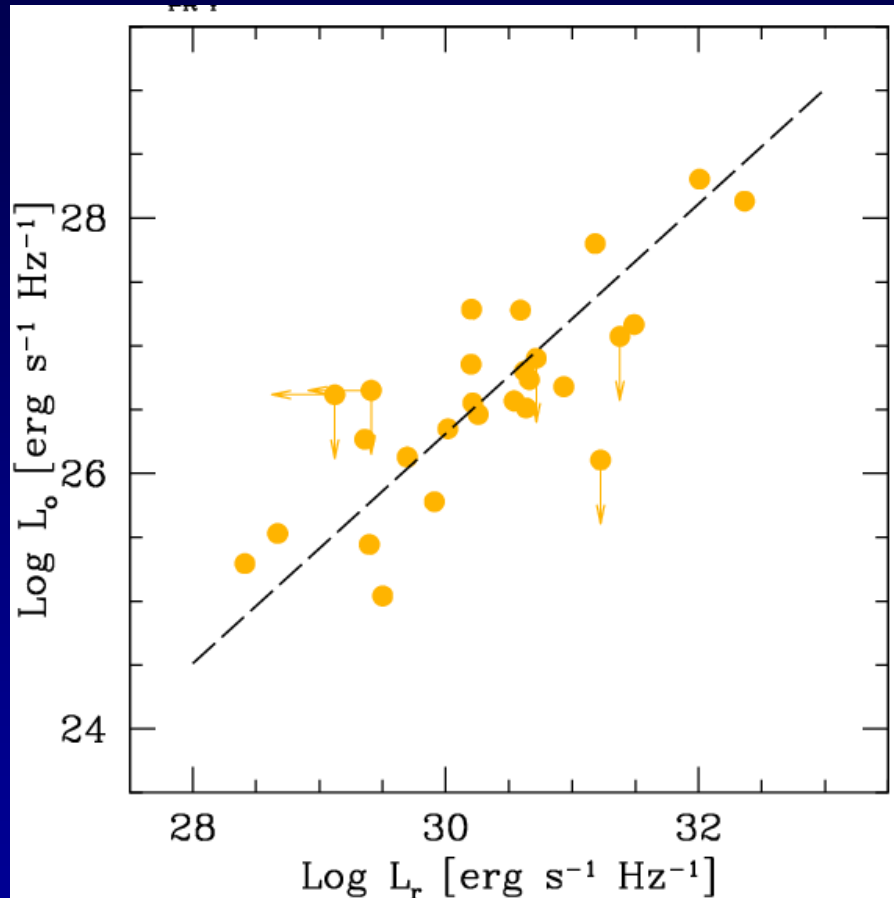
THE HST VIEW of FR I radiogalaxies

Complete sample:
33 objects, 32 with HST R-band observations



The HST/WFPC2 snapshot survey of 3CR radio sources (P.I. Sparks)

THE RADIO-OPTICAL CORE CORRELATION OF FR I NUCLEI



For $M_{\text{BH}} \sim 10^8 M_{\odot}$ the nuclei set the upper limit to the disk luminosity
 $L_{\text{disk}} < 10^{-5} L_{\text{edd}}$

Good candidates to host a RIAF,
but the jet dominates

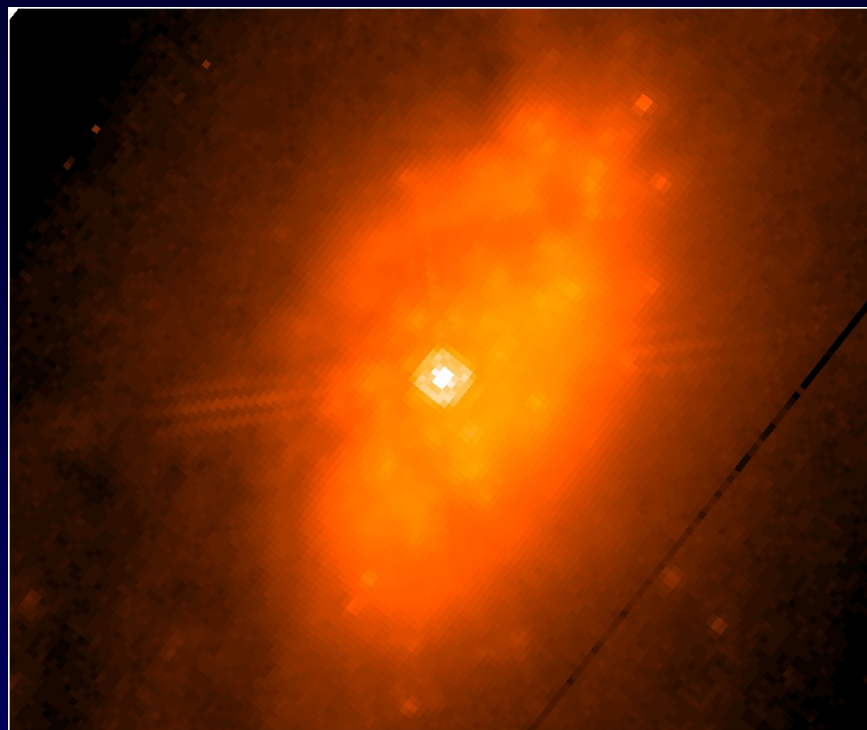
Chiab, Capetti & Celotti 1999, Capetti et al. 2002, Verdoes-Kleijn et al. 2001

NON-THERMAL SYNCHROTRON EMISSION FROM THE BASE OF THE JET

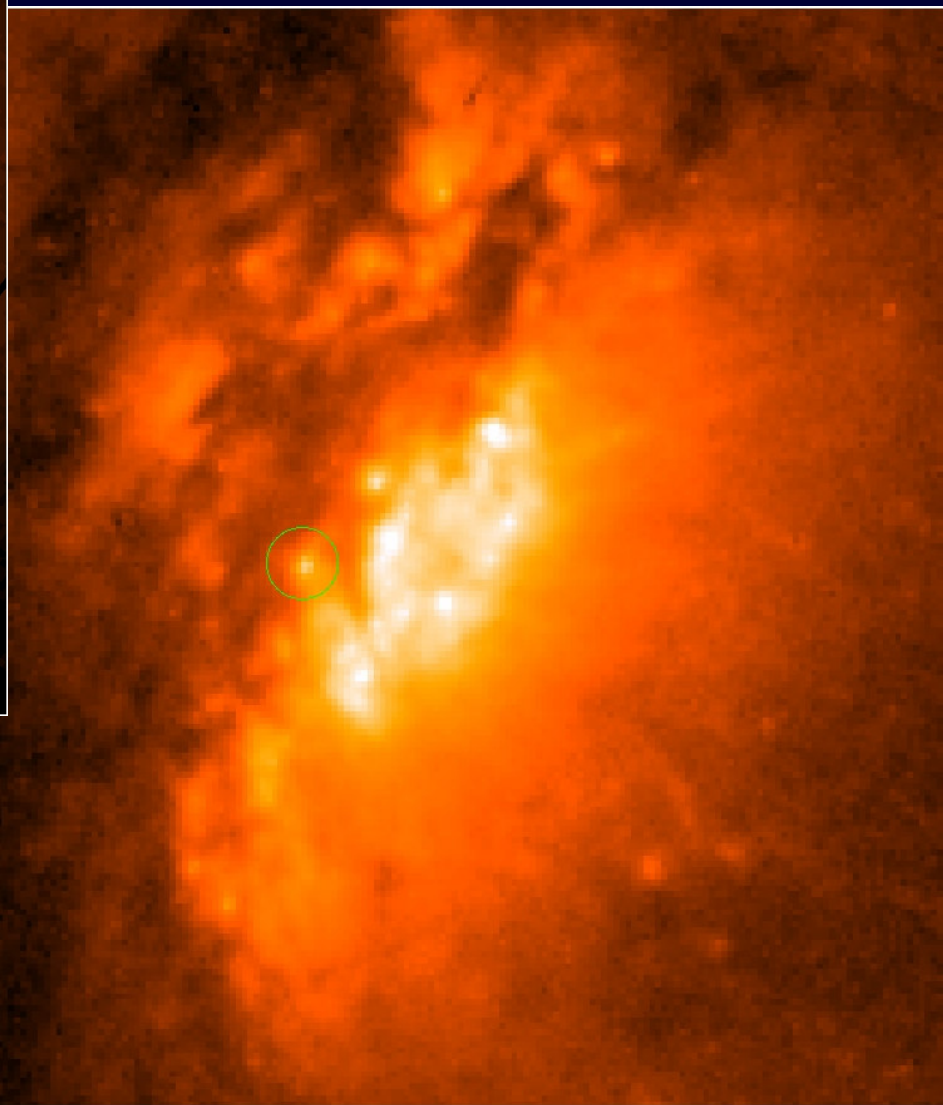
COULD THE DISK BE COMPLETELY OBSCURED?

**Thermal radiation should be reprocessed
by the torus and re-emitted in the infrared**

Seyfert 2 - NGC 7582 - HST



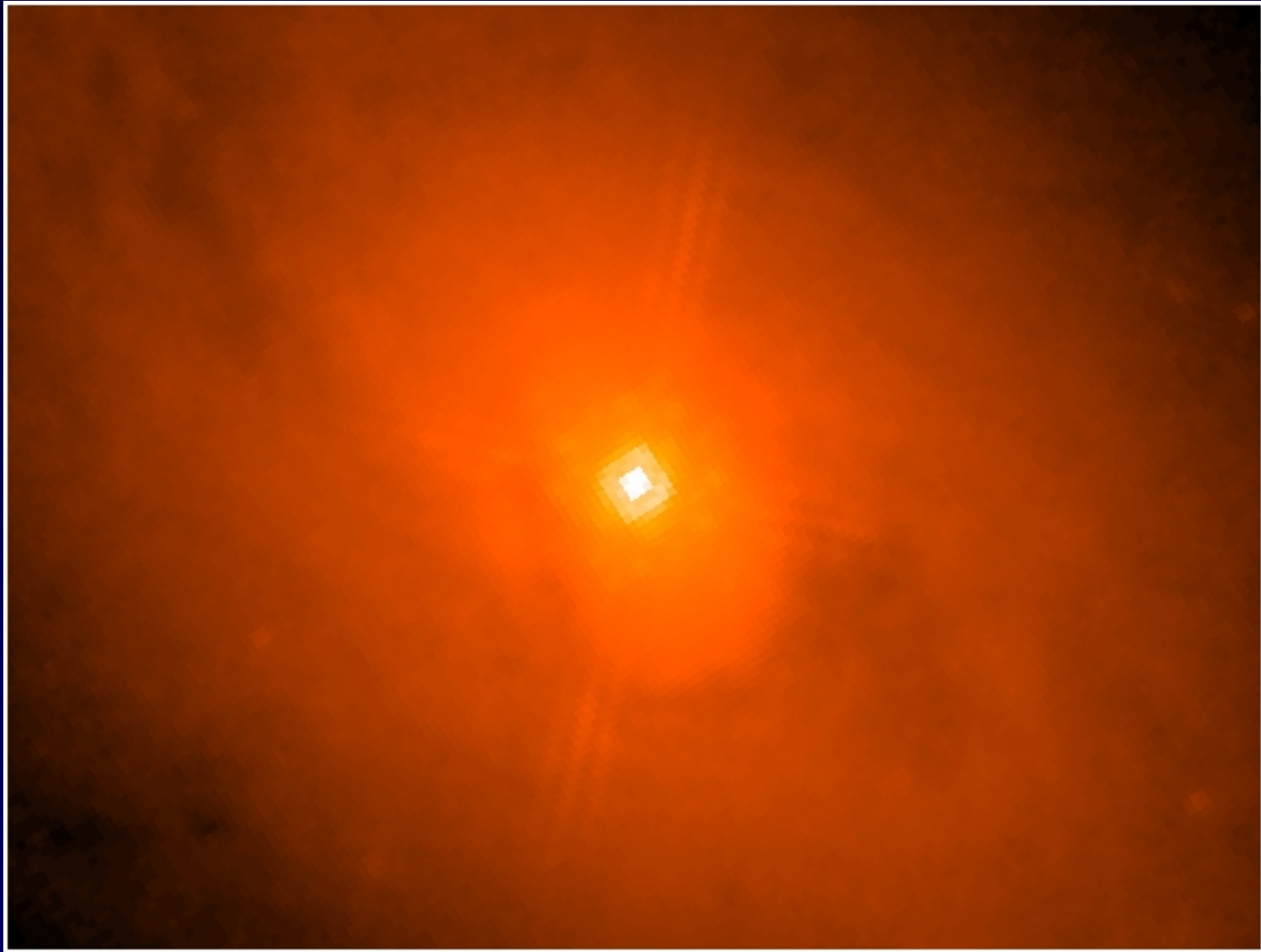
IR 1.6 μm



Optical V band

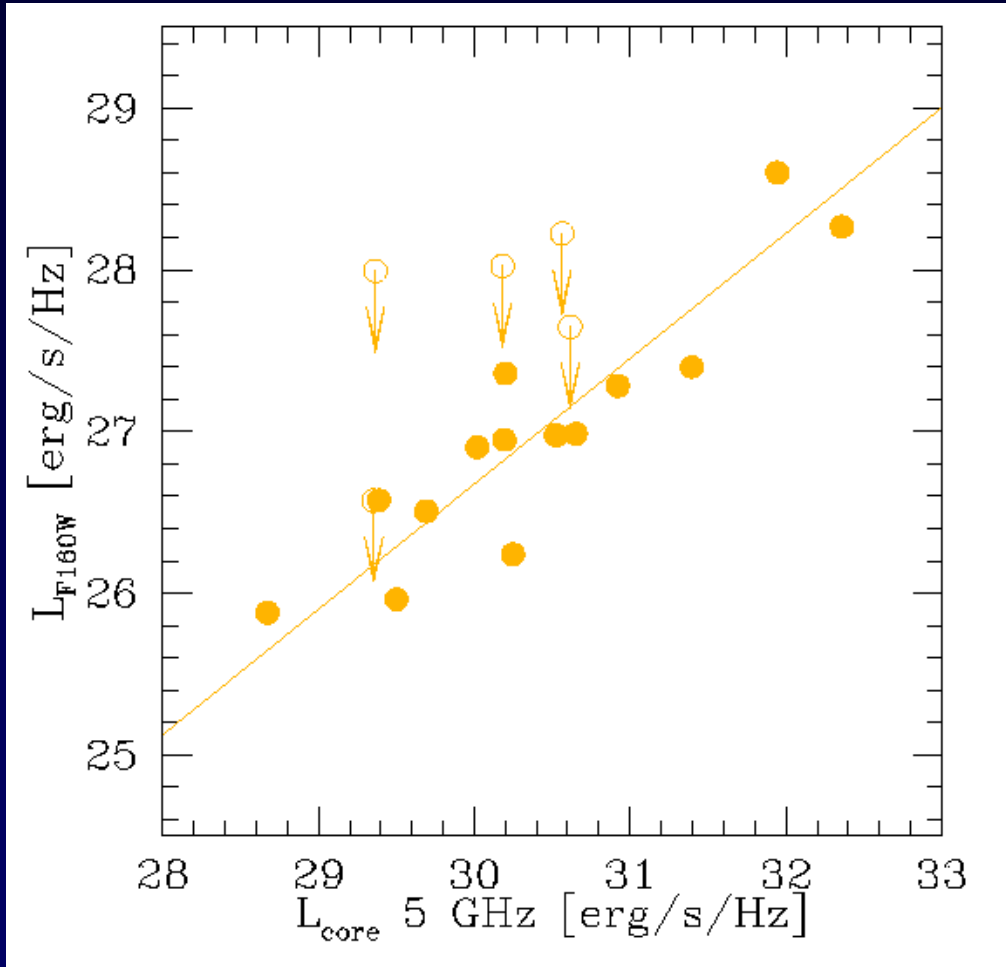
NGC 1068

Compton thick Seyfert 2



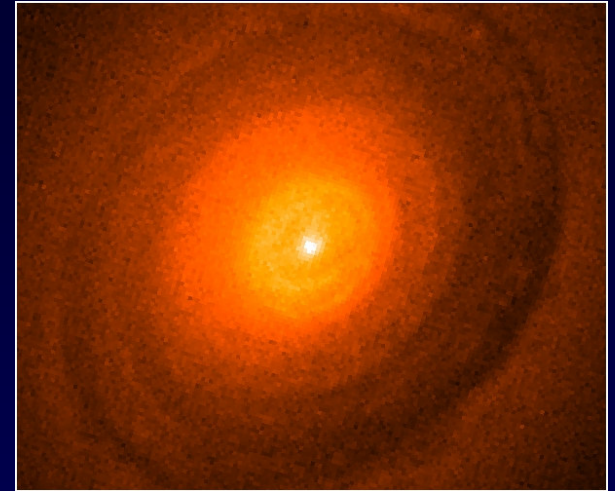
HST NICMOS images of 3CR FRI nuclei

Sparks, Chiab, Macchetto, Capetti,.... et al.



No IR (thermal) excess

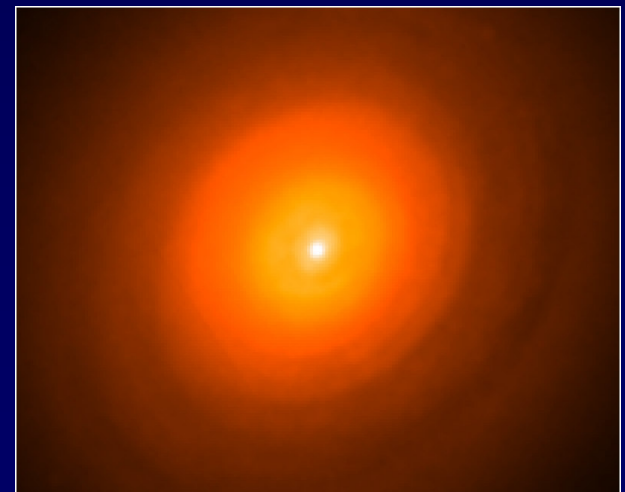
Chiab et al. in prep



WFPC2 Optical

3C31

NICMOS 1.6 μm

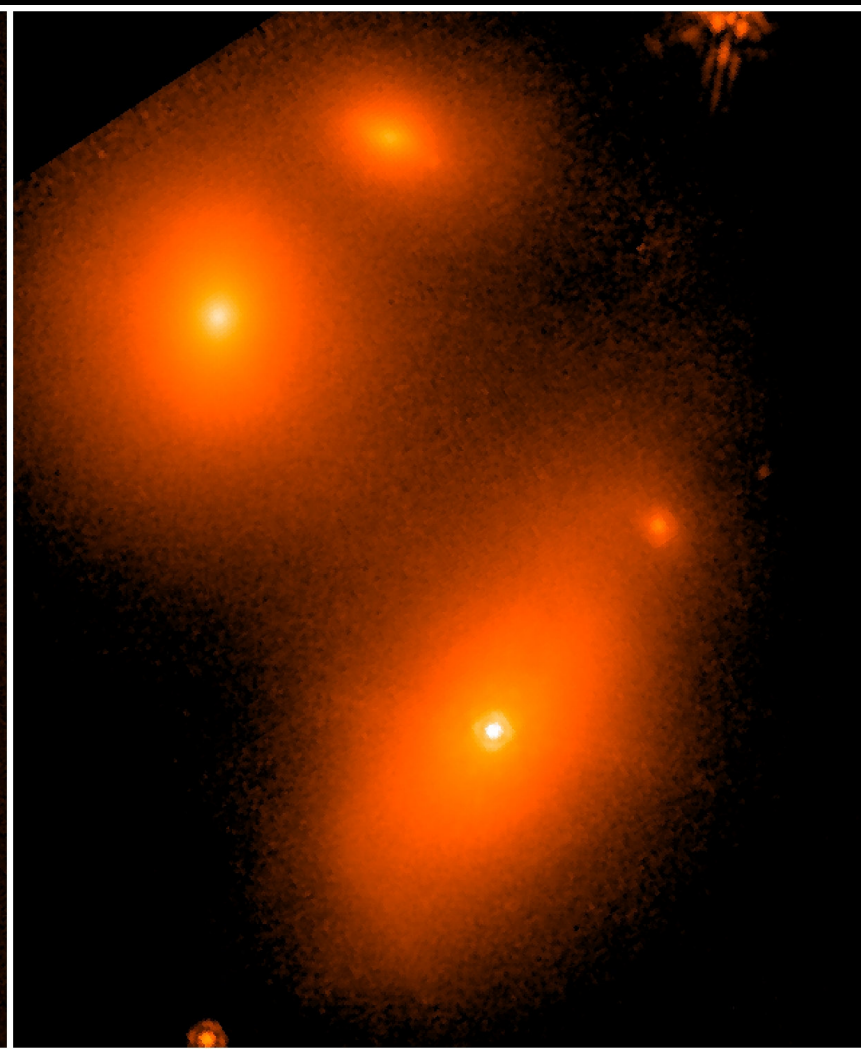


3C 433 $z = 0.059$

Optical R band



Infrared H band



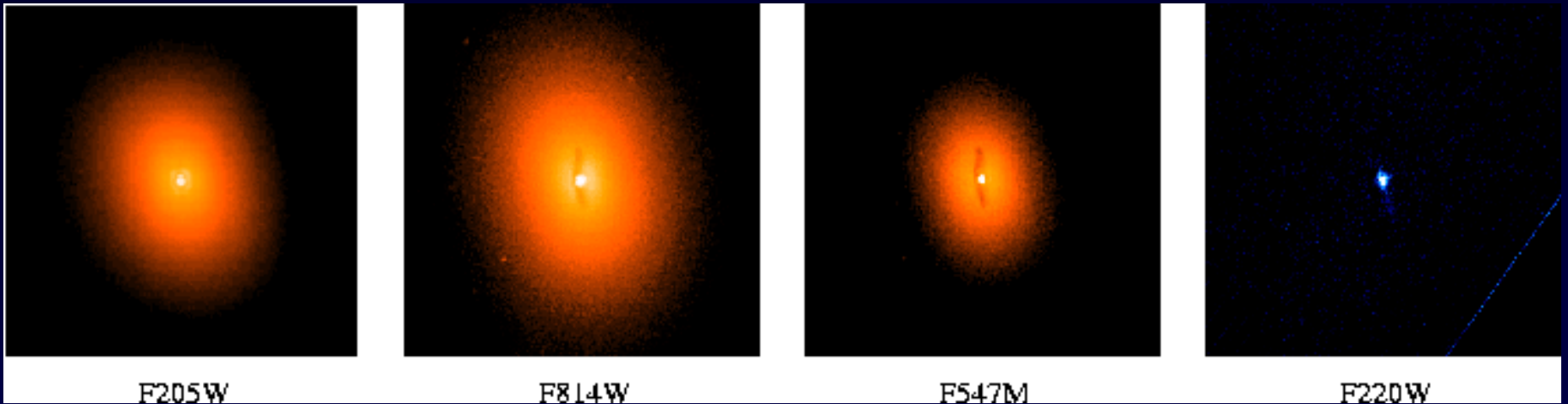
**IR HST observations confirm that low luminosity
radio galaxies (FRI) are unobscured**

They do not host radiatively efficient accretion disks

BUT

**Synchrotron radiation from the jet dominates
(at all wavelengths!!)**

**WHAT ABOUT THE OTHER CLASSES OF LLAGN
IN THE LOCAL UNIVERSE?**

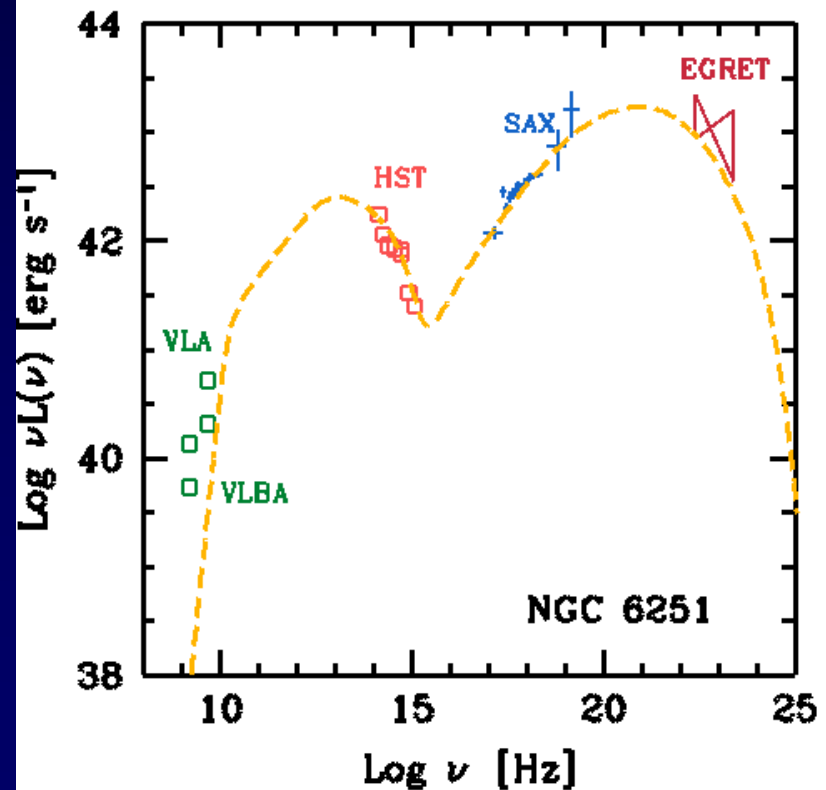


NGC 6251

Synchrotron self-Compton model

Chiaberge, Gilli, Capetti & Macchetto 2003

Grandi et al. 2003



LLAGNs: THE SAMPLE

LINERs

$d < 19$ Mpc from the Palomar
sample of nearby galaxies

21/25 have HST images

SEYFERT 1

data from Ho & Peng 2001

Palomar sample ($d_{\text{med}} = 20$ Mpc)

CfA sample ($d_{\text{med}} = 80$ Mpc)

25/32 have HST images

FR I

radio galaxies from the 3CR catalog

**THE LOCAL AGNs ARE WELL REPRESENTED
BY THESE 3 SAMPLES**

Compact radio cores in LINERs and Seyferts

Unresolved on the mas scale

$$T_B > 10^8 \text{ K}$$

Flat radio spectrum $\alpha \sim 0.0 - 0.6$ ($F_\nu \propto \nu^{-\alpha}$)

The radio cores are variable



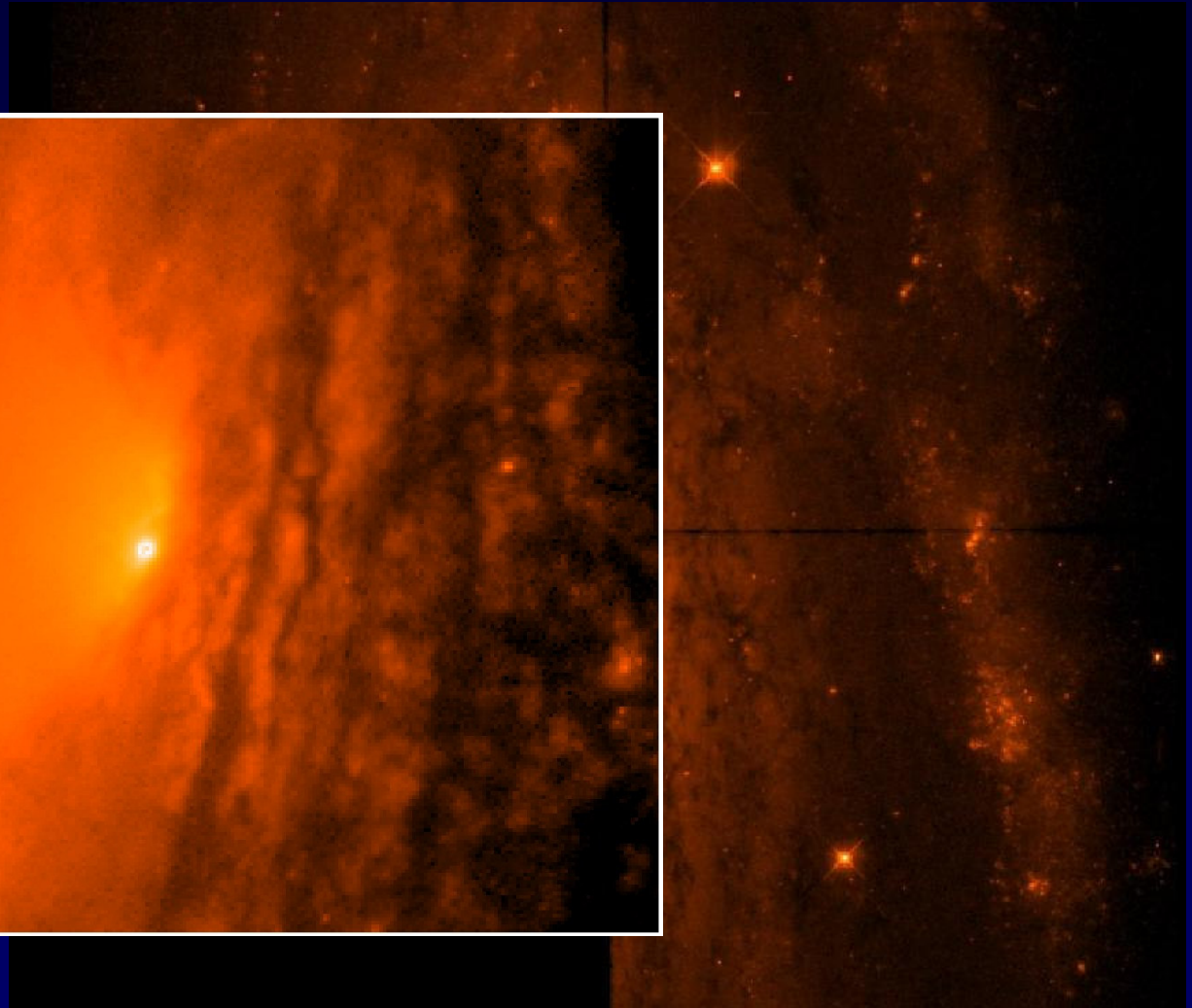
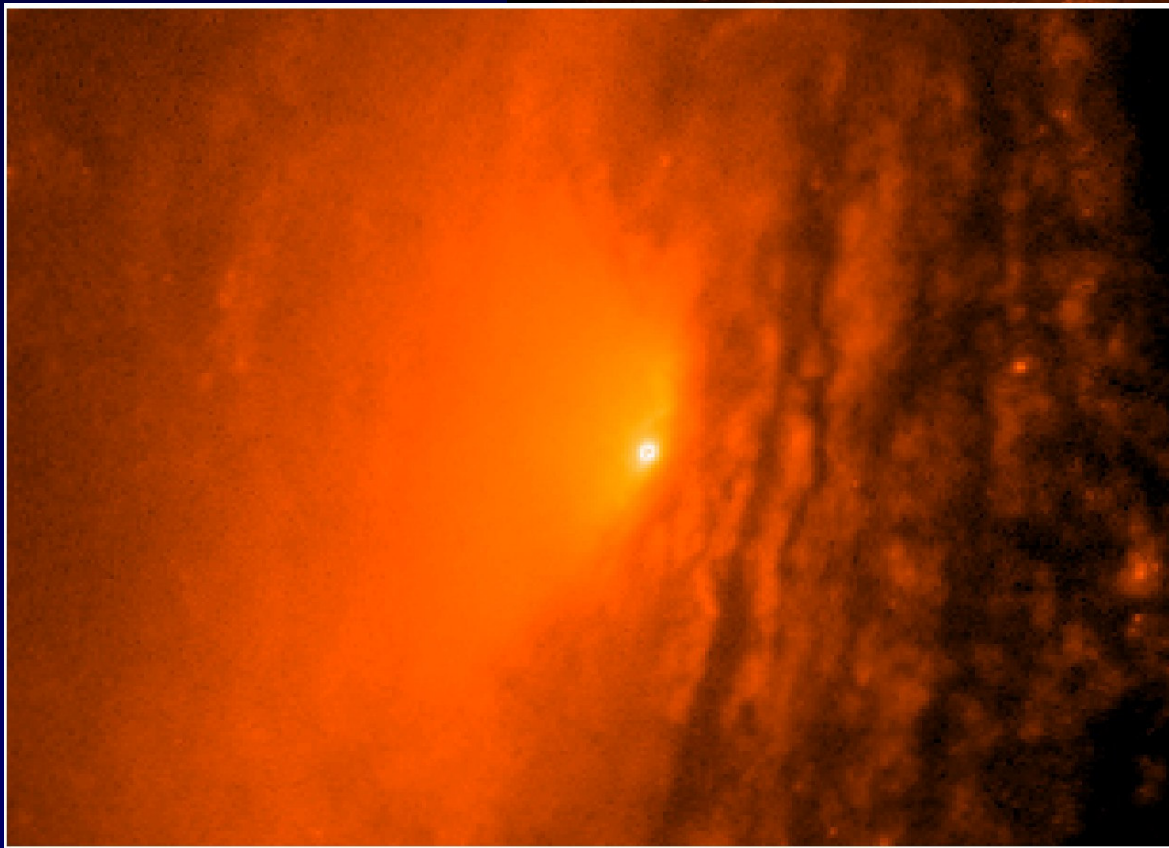
Radio cores are synchrotron emission from a jet

(Nagar et al 2002, Falcke et al. 1999,
Anderson et al. 2004)

SIMILAR TO THE CORES OF RADIO GALAXIES

LLAGN - Seyfert 1 nuclei

NGC 5033 - HST WFPC2 - V band



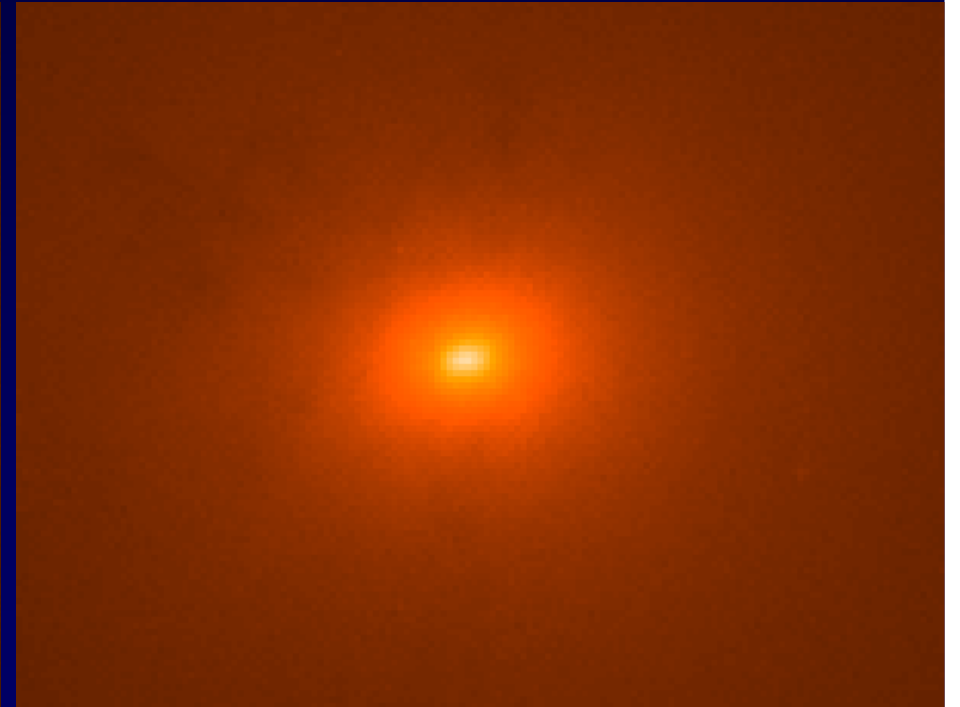
LLAGN - LINER nuclei

NGC 4278 - HST WFPC2- I band



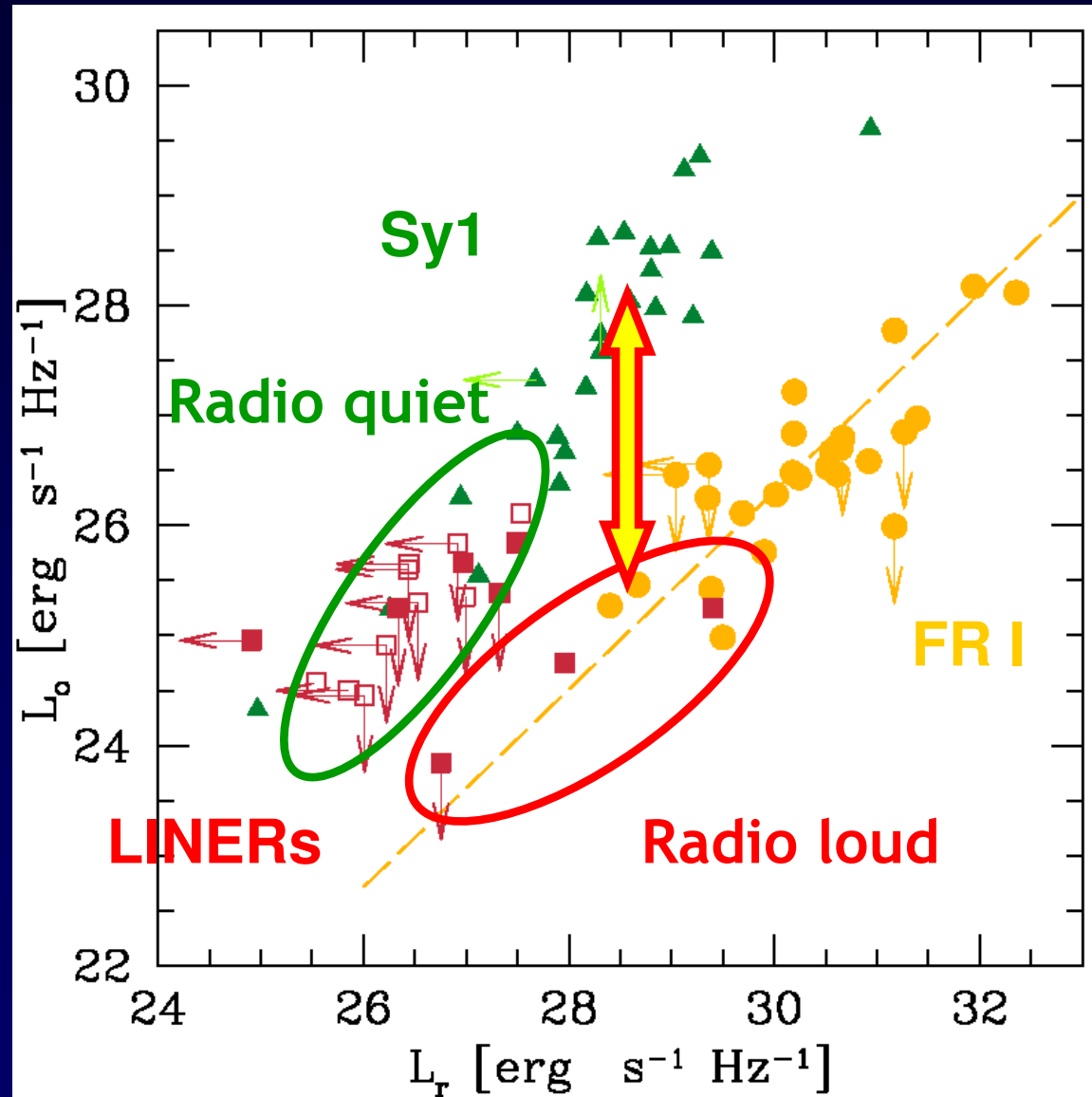
15''

NGC 4589 - HST WFPC2- I band

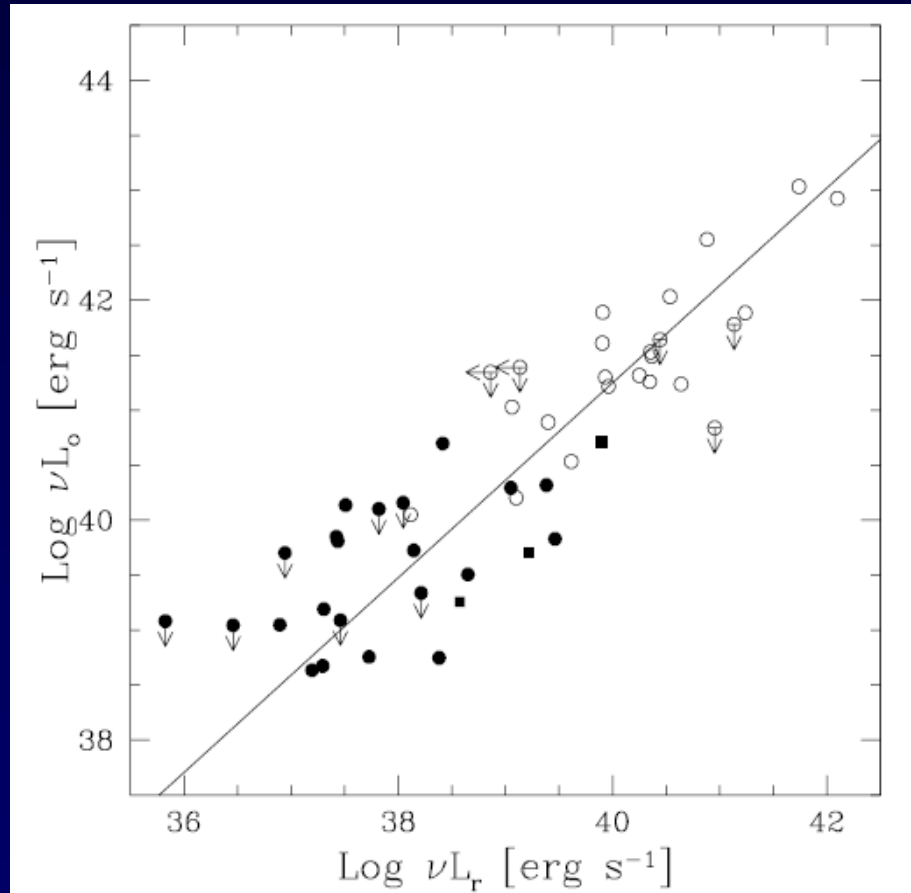


15''

LLAGN IN THE RADIO-OPTICAL PLANE



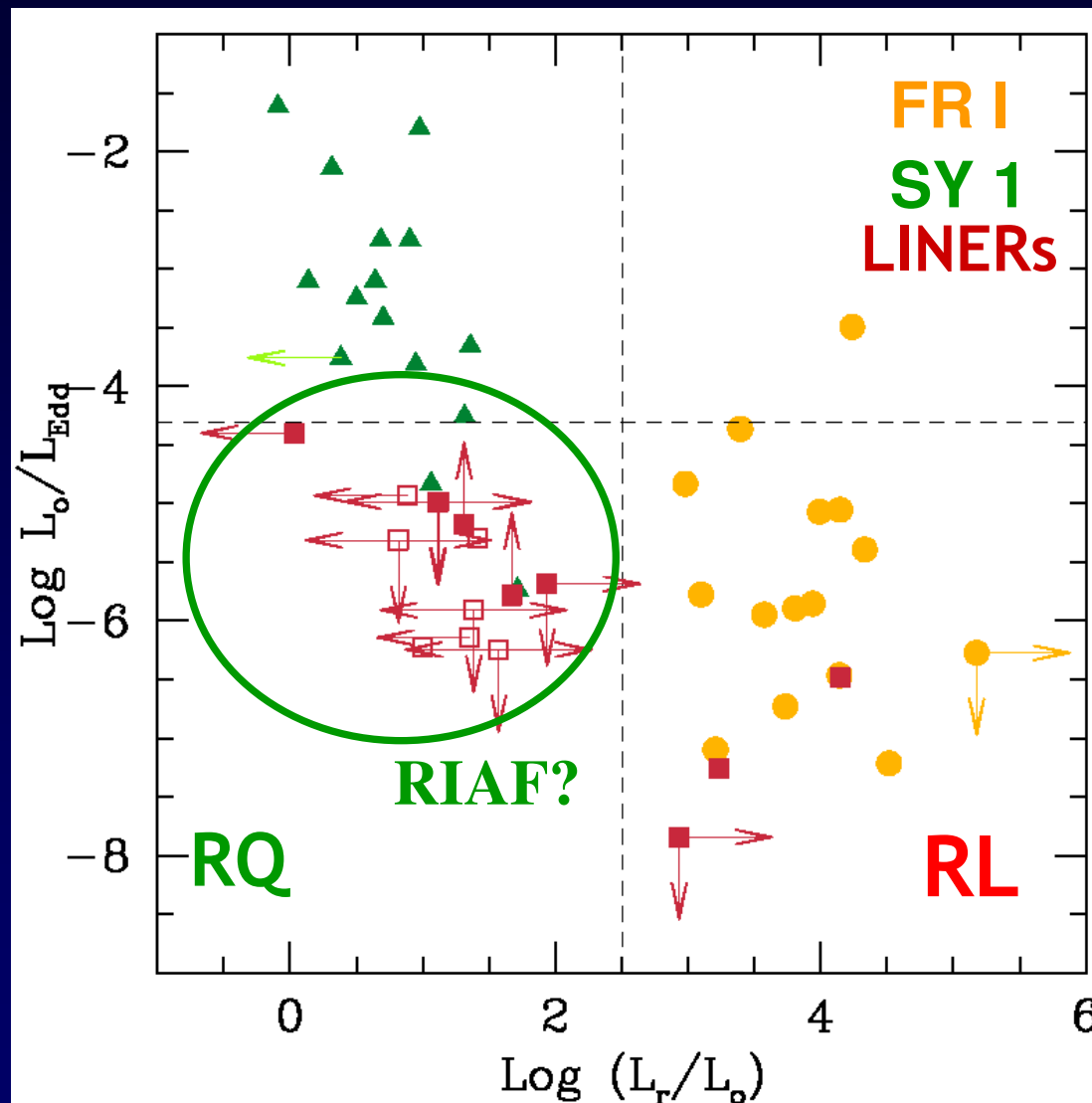
Elliptical galaxies with compact radio emission



Balmaverde & Capetti 2006

ACCRETION EFFICIENCY VS. RADIO LOUDNESS

$$L_{\text{Edd}} = 1.3 \times 10^{38} (M_{\text{BH}}/M_{\odot}) \text{ erg s}^{-1}$$



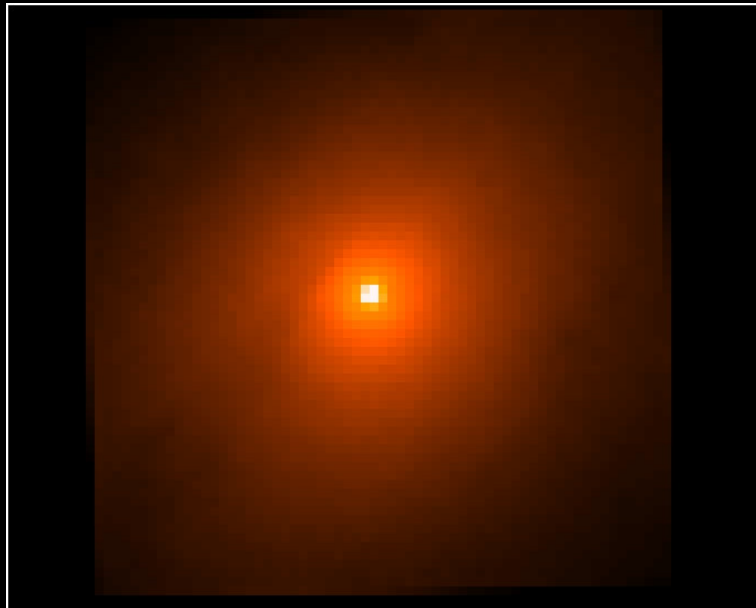
NGC 4565

(Chiab, Gilli, Macchetto & Sparks 2006)

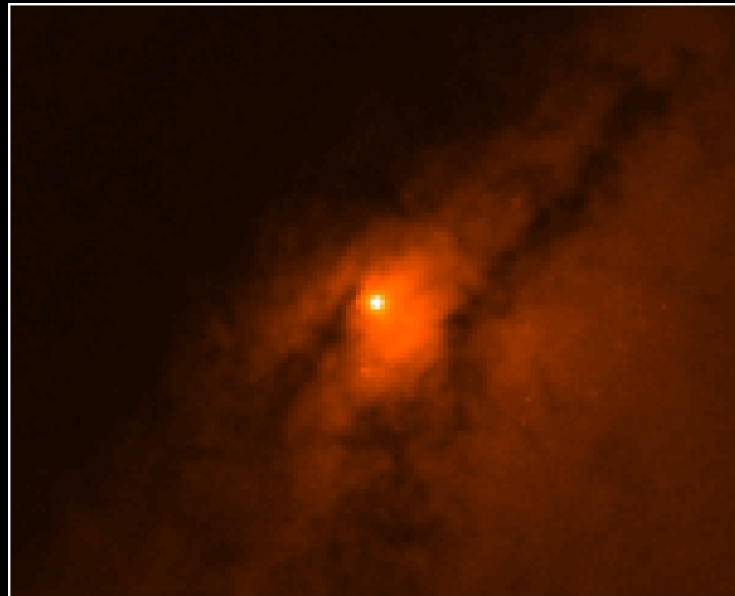
- **Low luminosity Seyfert d= 9.7 Mpc**
- **Included in the Ho et al. 1997 sample (Palomar)**
- **Low absorption in the X-rays $N_{\text{H}} = 2.5 \times 10^{21} \text{ cm}^{-2}$**
- **Only NARROW emission lines (Seyfert 2)**
- **Compact 5GHz radio emission (VLBI)**
- **Flat $\alpha=0.15$ radio spectrum**



IR 1.6 μm

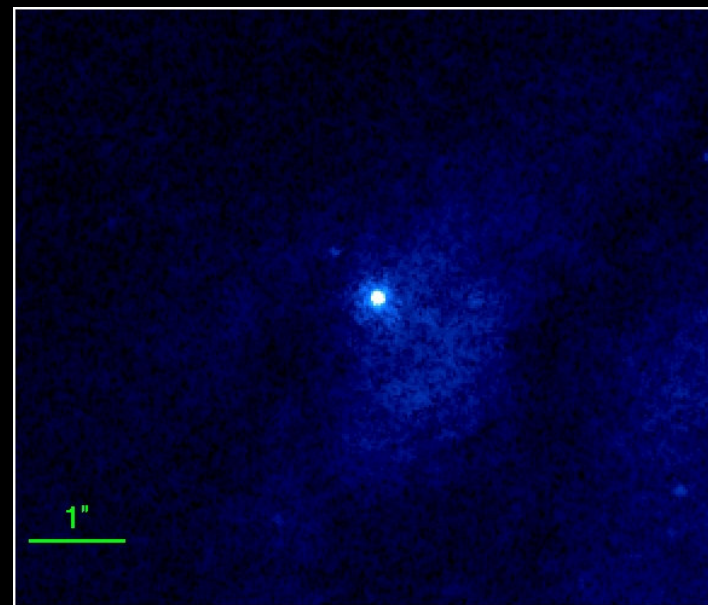


4500 A



**NGC 4565
PICTURE GALLERY**

3300 A



1. What is the origin for absorption?

$$N_{\text{H}} = 2.5 \times 10^{21} \text{ cm}^{-2} \longrightarrow A_{\text{V}} = 1.2$$

NGC 4565 is a spiral galaxy seen almost edge-on $\theta \sim 10^\circ$

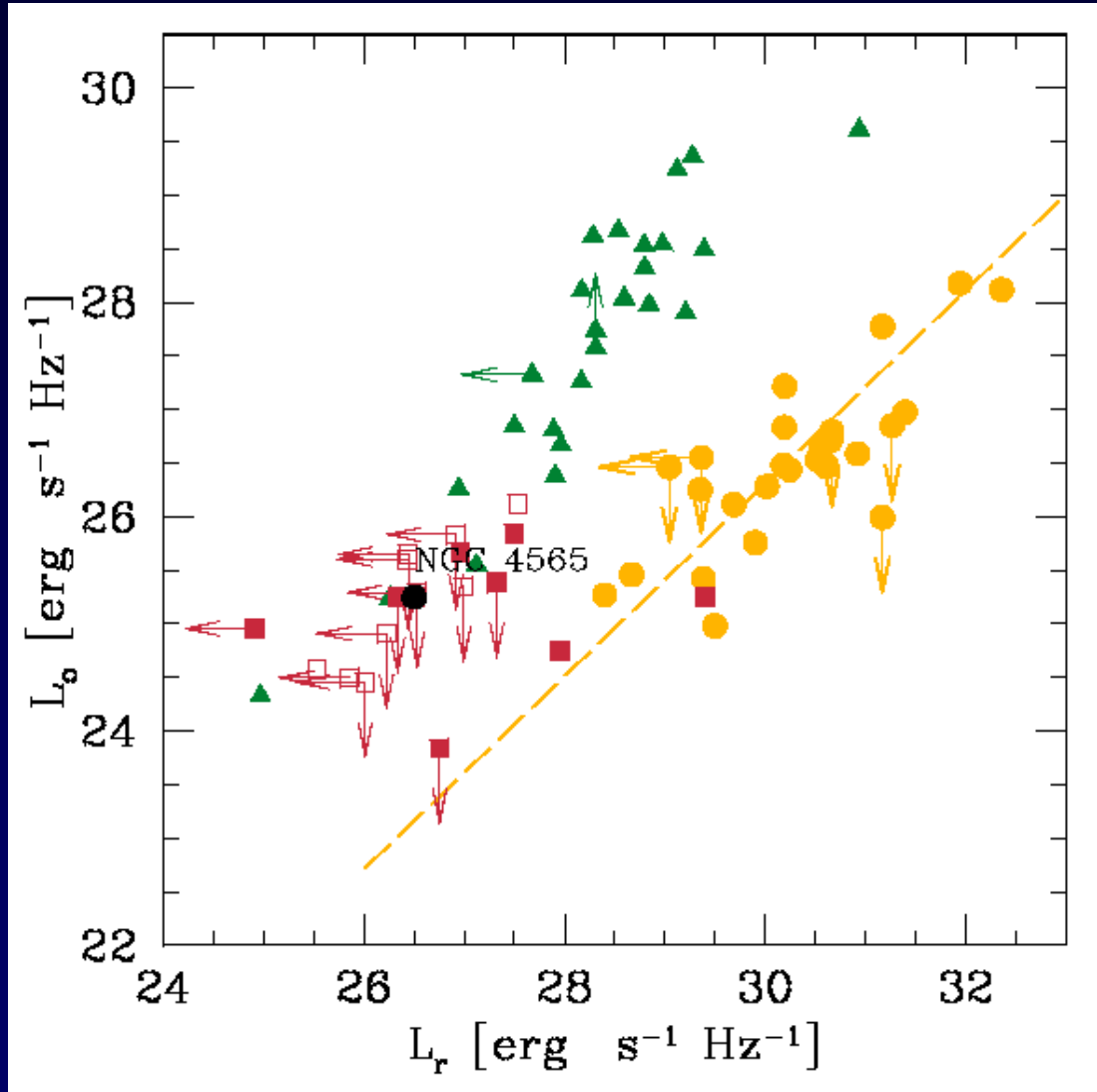
In the Galaxy at $b \sim 10^\circ$ $A_{\text{V}} = 1.0-1.5$



No need for nuclear obscuration

NGC 4565 is an unobscured Seyfert 2

NGC4565 in the radio-optical plane

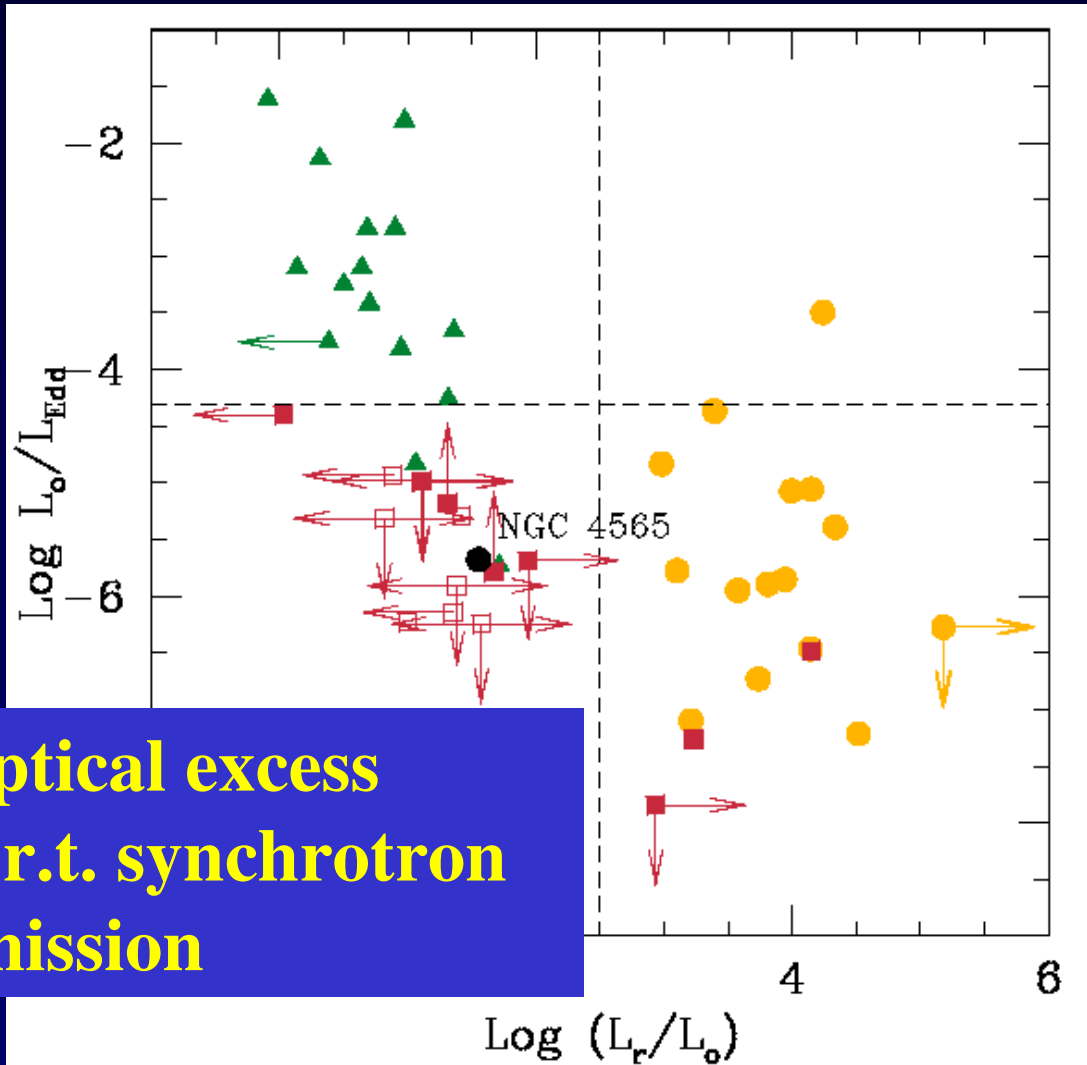


**Optical excess
w.r.t. synchrotron
emission**

**Optical radiation
from the accretion
process**

NGC 4565

BH mass = $2.8 \times 10^7 M_{\text{sun}}$

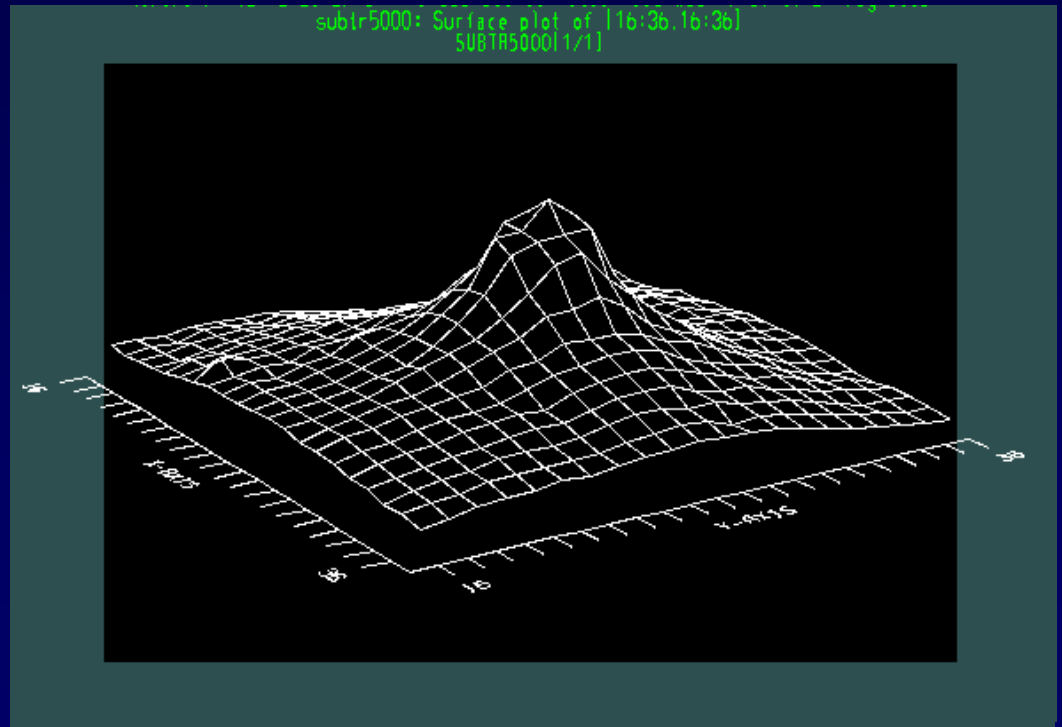
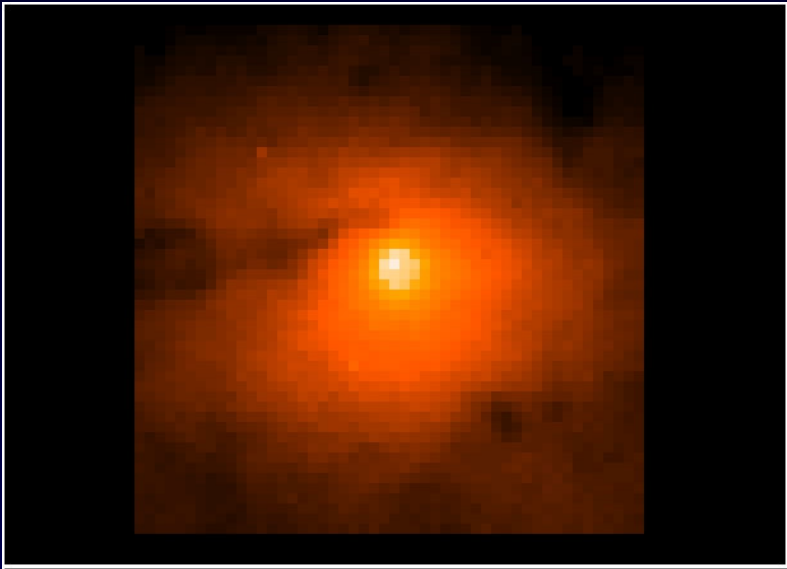


Optical excess
w.r.t. synchrotron
emission

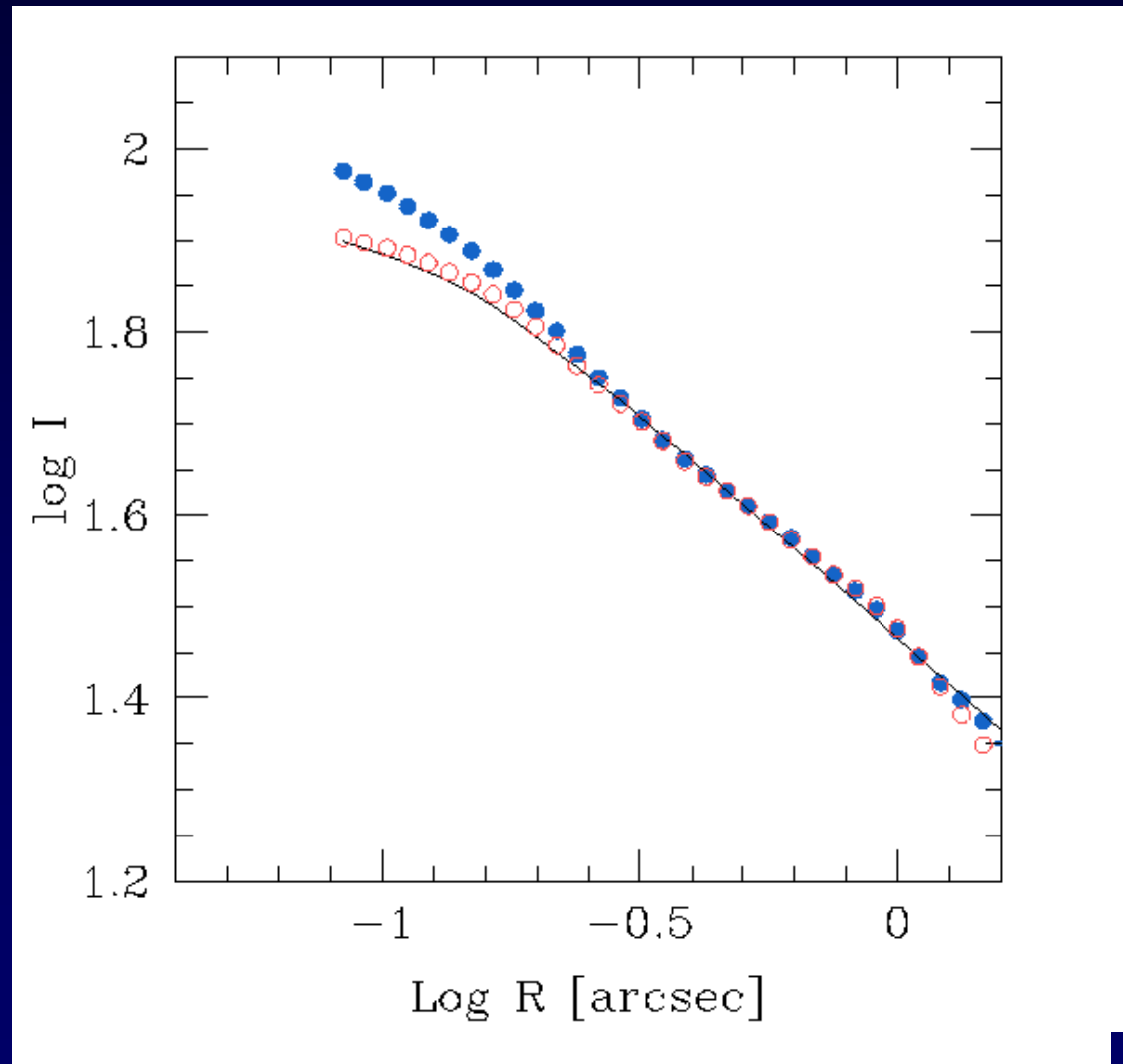
Low L/L_{ed}



low radiative efficiency
and/or
low accretion rate



NUCLEAR RADIAL BRIGHTNESS PROFILES

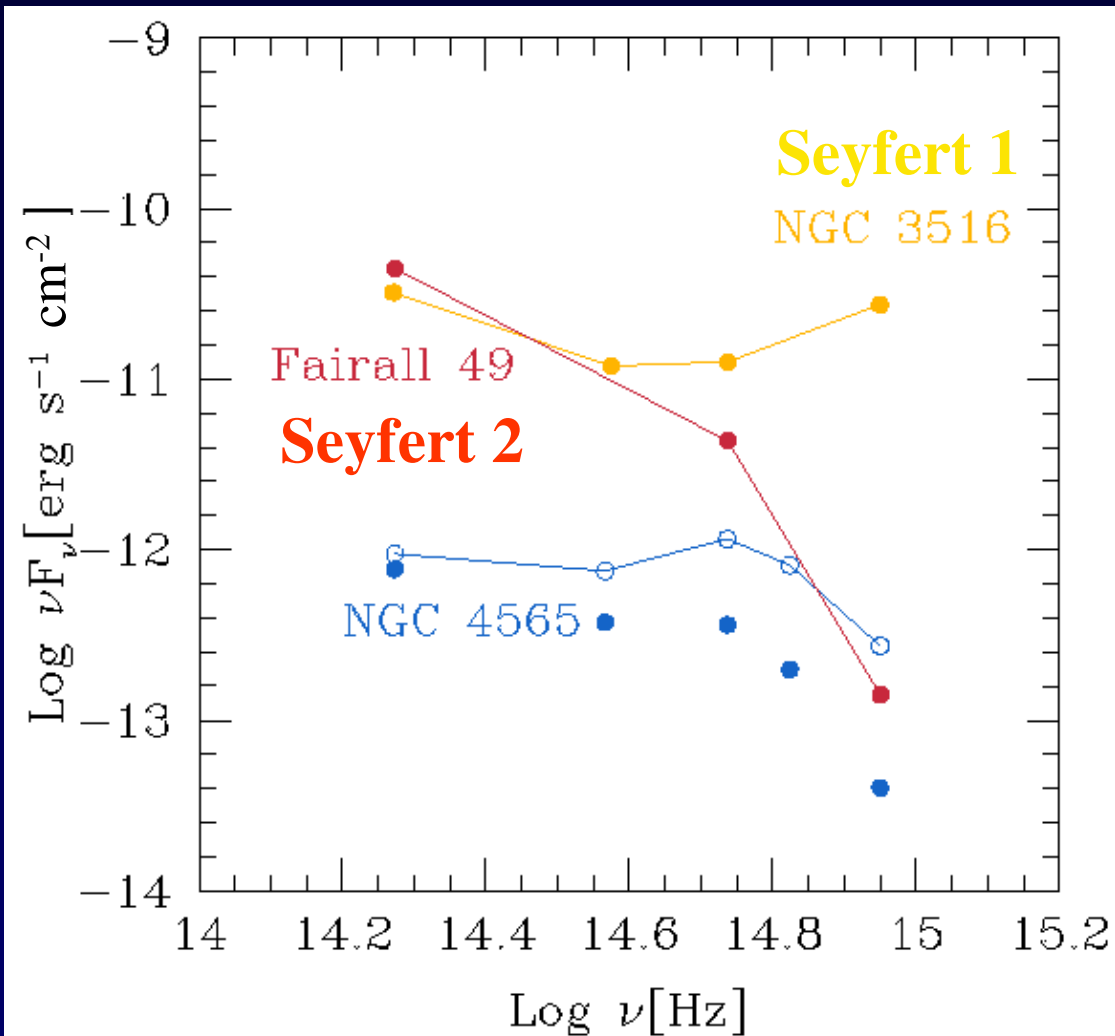


OBSERVED

PSF SUBTRACTED

POWER-LAW
SIMULATED PROFILE

SED OF NGC 4565 COMPARED TO OTHER SEYFERT GALAXIES

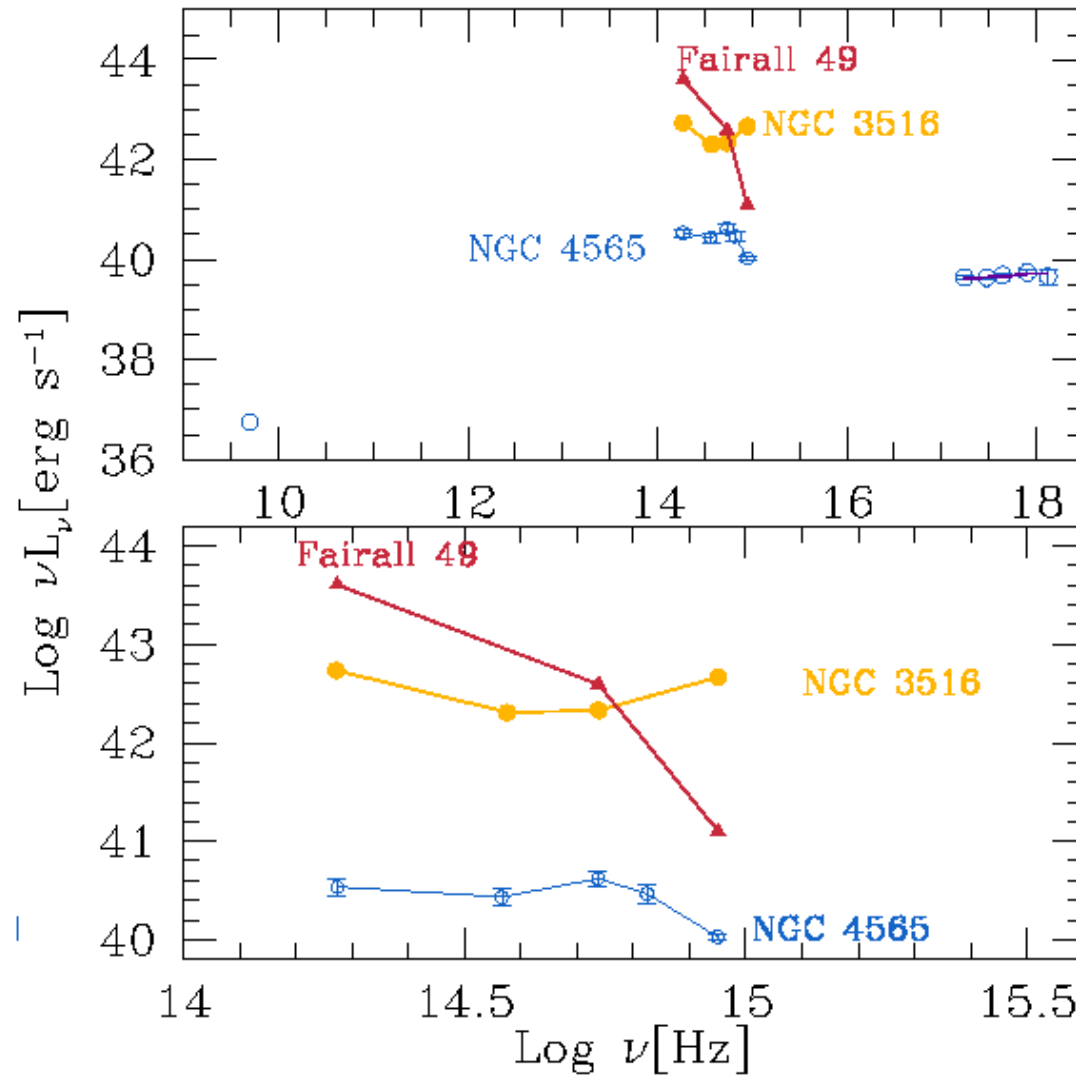


The SED is unusual

No IR thermal excess

No blue bump

OVERALL SED OF NGC4565



$$L_{\text{bol}} \sim L_{\text{opt}}$$

X-ray data (Chandra)

Absorbed power law

$$\Gamma = 1.9 \pm 0.2$$

$$N_{\text{H}} = (2.5 \pm 0.6) \times 10^{21} \text{ cm}^{-2}$$

CONCLUSIONS

1. WE CONFIRM THAT FRI RADIO GALAXIES ARE UNABSORBED BUT, IF THEY HOST A RIAF, WE CAN'T DETECT IT BECAUSE THE JET DOMINATES

2. WE SHOULD SEARCH FOR RIAFs AMONG LLAGN WITH **RADIO QUIET NUCLEI** (SEYFERT AND LINERS)
IN HOW MANY OBJECTS CAN WE DETECT THEM?

3. IN NGC 4565 WE ARE MOST LIKELY OBSERVING (FOR THE FIRST TIME?) AN ADAF-LIKE ACCRETION PROCESS IN THE OPTICAL

4. NGC4565 IS AN “UNOBSCURED” SY2
unobscured Sy2 do exist

NGC 3998

Ptak et al 2004

