AGN, MASSIVE BLACK HOLES, ACCRETION AND EJECTION

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cf. proceedings of the XXth Blois symposium, May 2008

THE CONTEXT

DICHOTOMY BETWEEN STRONG AND WEAK ACCRETORS

DICHOTOMY RADIO LOUD / RADIO QUIET OBJECTS
AND JETS / WINDS

CONCLUSION

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DICHOTOMY BETWEEN RADIO-LOUD AND RADIO-QUIET OBJECTS AND JETS VERSUS WINDS

CONCLUSION

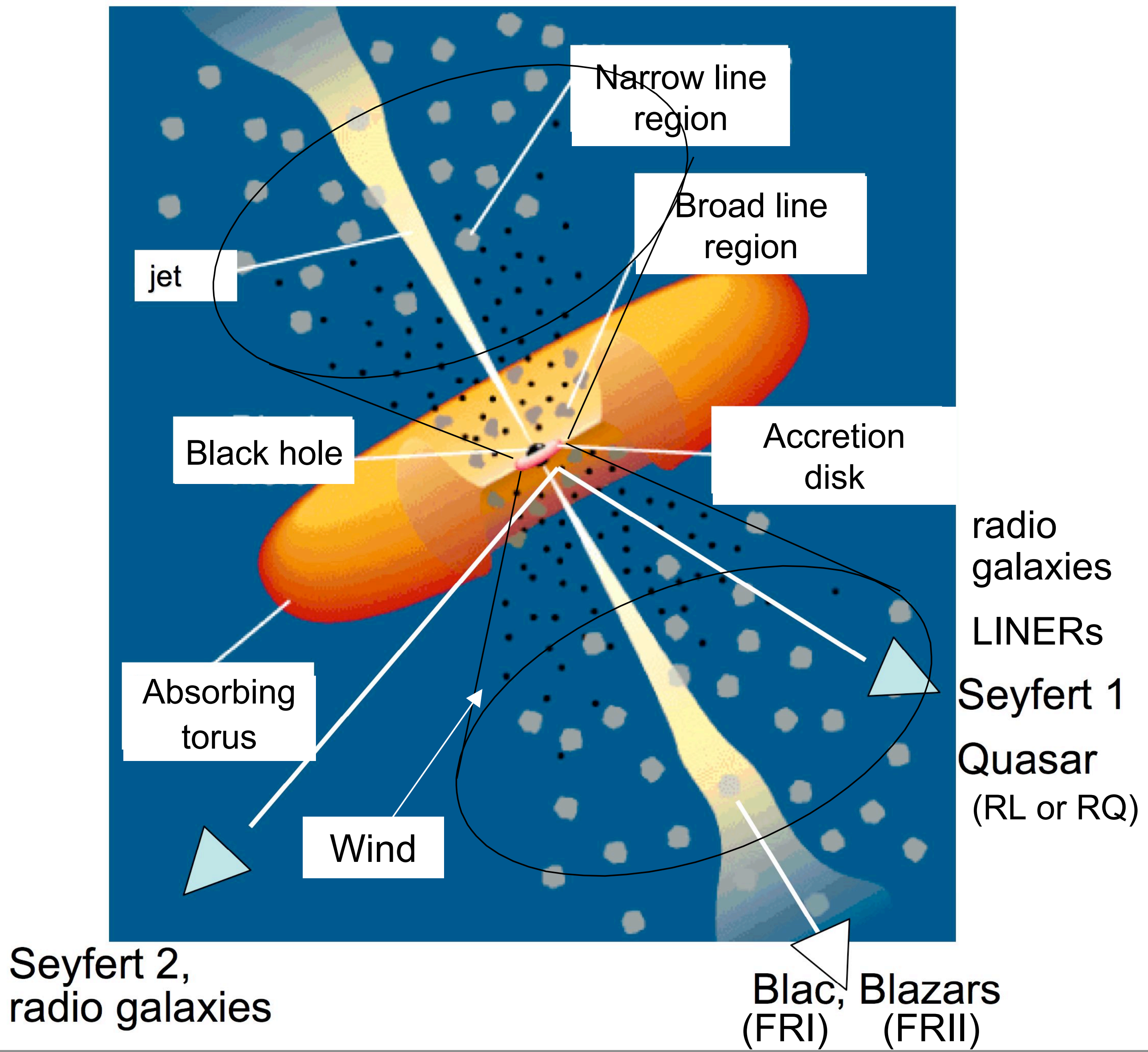
RECALL OF SOME WELL-KNOWN FACTS

1. Active Galactic Nuclei: from quasars ($L=10^{46-48}$ erg/s) to Seyfert galaxies ($L=10^{43-46}$ erg/s), and Low Luminosity AGN (LLAGN, $L=10^{40-43}$ erg/s)

2. Power derived from accretion onto a supermassive black hole

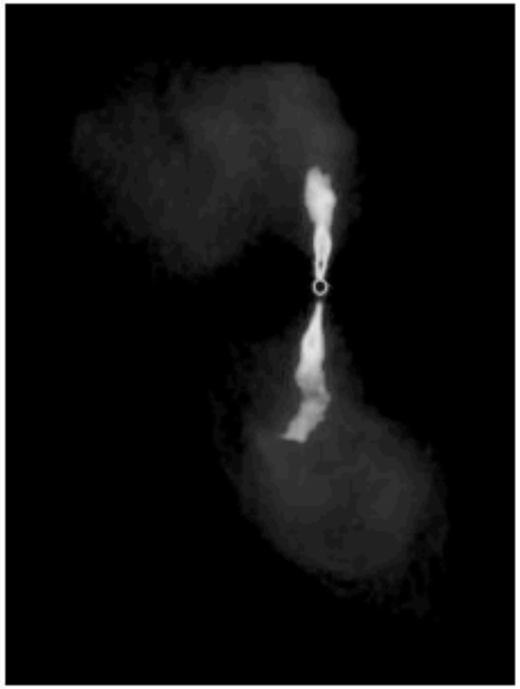
3. A massive BH is present in ALL NUCLEI of galaxy, M(BH) from 10^5 to 10^{10} $M_{\odot}$, M(BH) ~ M(Bulge)/1000

4. « Unified Scheme »


Narrow line region
Broad line region
jet
Black hole
Accretion disk
Absorbing torus
Wind
radio galaxies
LINERs
Seyfert 1
Quasar
(RL or RQ)
Seyfert 2,
radio galaxies
Blac, Blazars
(FRI) (FRII)

Radio-galaxies

FR I and Blac



MILLIONS OF LIGHT-YEARS

FR II and RLQ

LOW POWER

$L_{178} \sim< 2 \times 10^{26}$ W Hz $^{-1}$

HIGH POWER

$L_{178} >\sim 2 \times 10^{26}$ W Hz $^{-1}$

SOME FIDUCIAL VALUES

gravitational radius: $R_G = \frac{GM}{c^2}$ $= 1.5\ 10^{13}\ M_8$ cm ~10^{-5} pc

Eddington luminosity $L_{\mathrm{Eddington}} = \frac{4\pi c G M m}{\sigma_T}$.

$= 1.3\ 10^{46}\ M_8$ erg/s

bolometric luminosity $L_{bol} = \varepsilon \dot{M} c^2$

where $\dot{M}$ is the accretion rate

ε: rmaximum radiation efficiency of mass-energy conversion

$\varepsilon = 0.057$ for a Schwarzschild BH, R(ISCO)=6Rg
$\varepsilon = 0.3$ for a maximally rotating Kerr BH, R(ISCO)~1Rg

$$\dot{M} = \frac{\varepsilon}{0.1} L_{46}\ 0.6\ \mathrm{M_o/yr}$$

HOW TO FUEL BLACK HOLES?

The angular momentum $(GMR)^{1/2}$ must be transported outward!

1. At large distances (≥ 100pc)

Major and minor mergers (quasars)

Tidal interactions between galaxies (luminous Seyfert)

Bars, bars within bars, nonaxisymmetric potentials (weak Seyfert)

Dynamical friction of molecular clouds (LLAGN)…

2. At small distances (<1pc)

« ACCRETION DISKS »

local turbulent viscosity (MRI, possibly)

or global transport of AM via an organized magnetic field?

3. At intermediate distances

12.12.08

Still unknown! Gravitational instability?

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CONSLUSION

In local Universe

Luminous AGN : ~ 1% of all galaxies

Low Luminosity AGN : ~ 40% of all galaxies

The remainder 60%: dormant BHs

ACCRETION DISKS:

INFLUENCE OF THE ACCRETION RATE

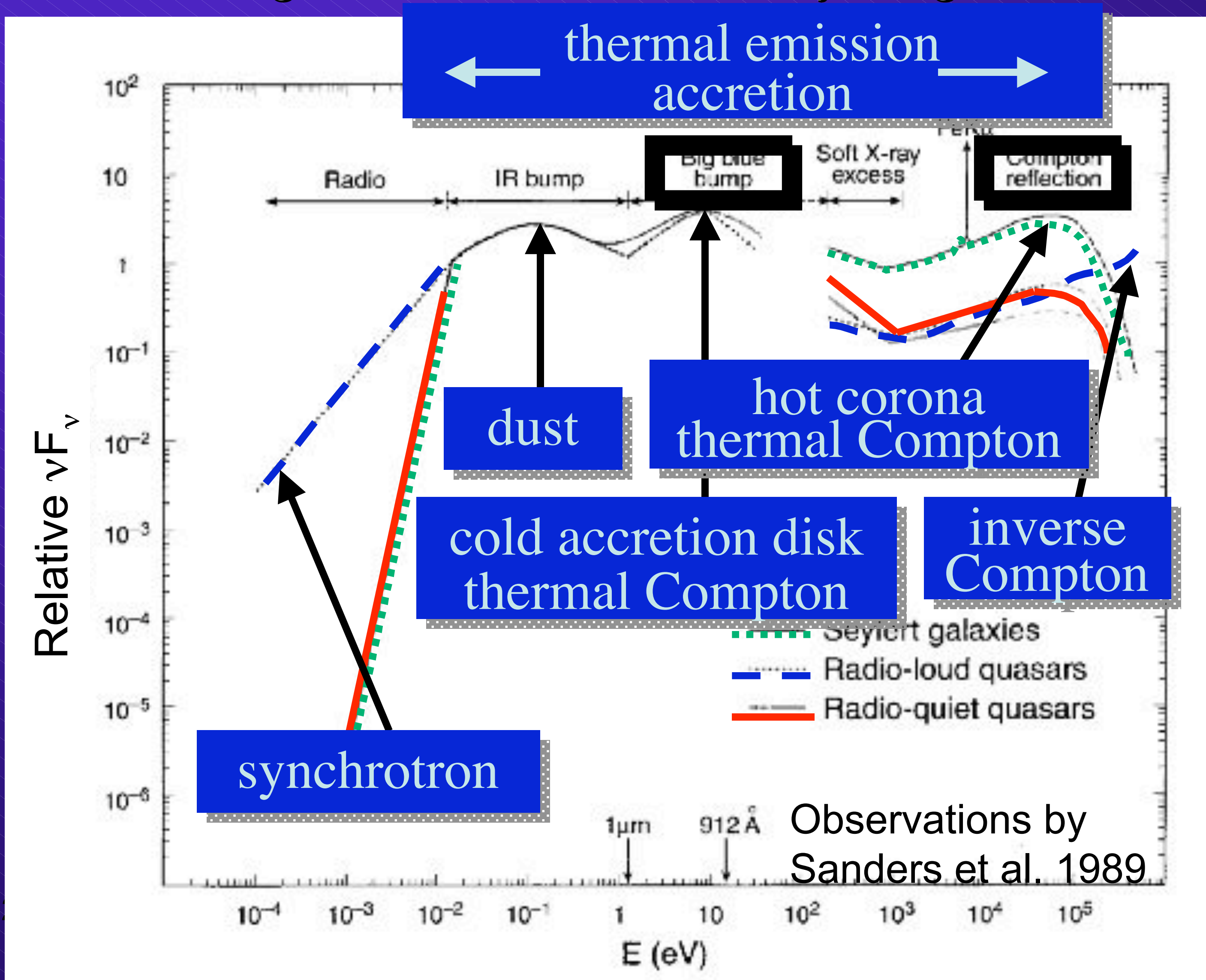
$$\dot{m} = \dot{M}/\dot{M}_{crit}, \; with \; \dot{M}_{crit} = L_{Edd}/c^2$$

$$\dot{m} < .001: \; weak \; accretors$$

$$\dot{m} > .01: \; strong \; accretors$$

A. STRONG ACCRETORS

Spectral distribution of Seyfert and RQQ,
no radio or gamma radiation, everything is thermal!



Observations by
Sanders et al. 1989

I. $0.1 < \dot{m} < 3$

Thin disks, H/R <<0.1, optically thick, emit the « Big Blue Bump »

Seyfert

II. $3 < \dot{m} < 10$

« slim » disks, H/R ~0.1, optically thick, radiation pressure, emit the « Big Blue Bump »

Quasars, Narrow Line Seyfert 1 (NLS1s)

III. $10 < \dot{m}$

« Thick » disks, H/R~1, optically thick, radiation pressure, emit soft X-rays, ***photons cannot escape, thus*** $\varepsilon << 0.1$

$$L/L_{Edd} \sim 1 << \dot{m}$$

Some low mass NLS1s (10^{6-7}Mo), in growing process

CONTROVERSY ABOUT THICK DISKS

Do these boulimic accretors exist?

MHD simulations seems to show that if $\dot{m}$ >> 10 at large distance,

strong outflows are expelled at smaller distance,

and the ***accretion rate on the BH remains limited***

at the Eddington value.

A model for high accretors

Flaring corona
Compton-
cooled
by UV
photons

Disk heated by
gravitational
release
AND X-rays

B. WEAK ACCRETORS

$$\dot{m} \leq 0.001$$

Optically thin, geometrically thick, hot (relativistic) disks, emitting mainly radio and X-rays,

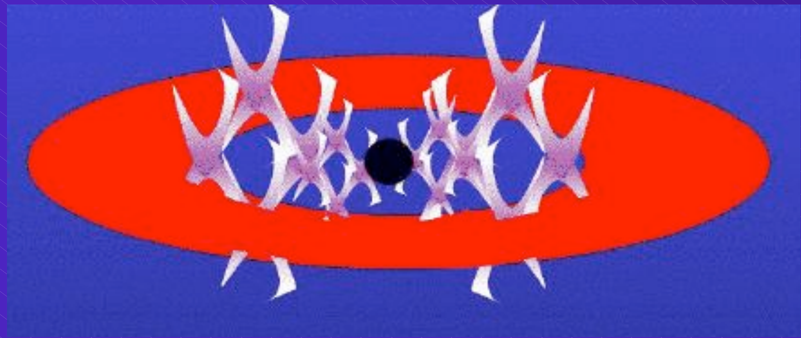
Gas falls into the BH before radiating, thus $\varepsilon \ll 1$

$$L / L_{Edd} \ll \dot{m}$$

LLAGN, radio galaxies FRI (M87, CenA...),

Galactic Center

A model for weak accretors: flaring corona, and suppression of the inner regions of accretion disk



CONTROVERSY ABOUT THESE DISKS

Which model for these anorexic accretors?

ADAF, ADIOS, CDAF… RIAF

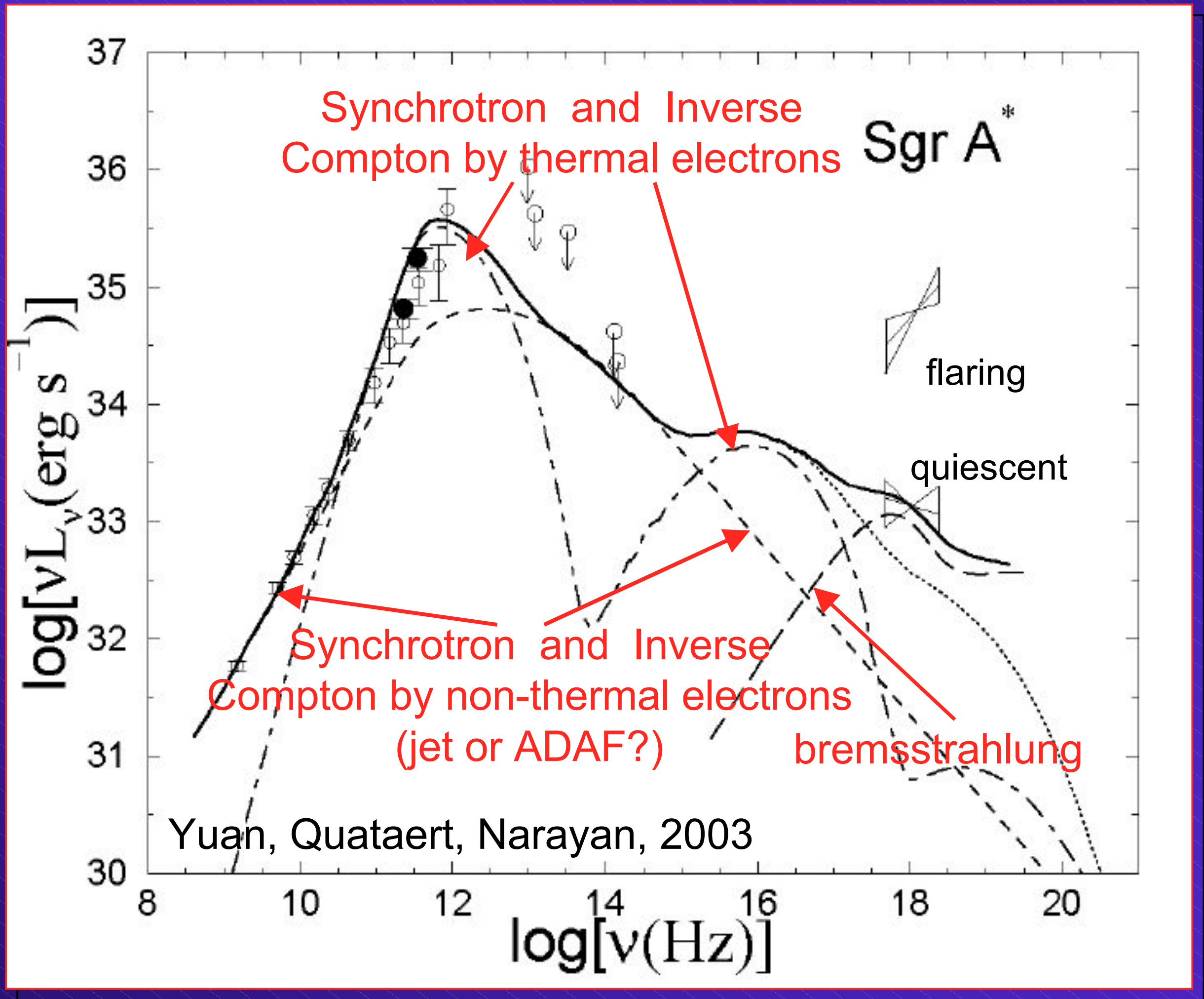
Is there also a jet?

Are "cold accretion disks" completely absent?

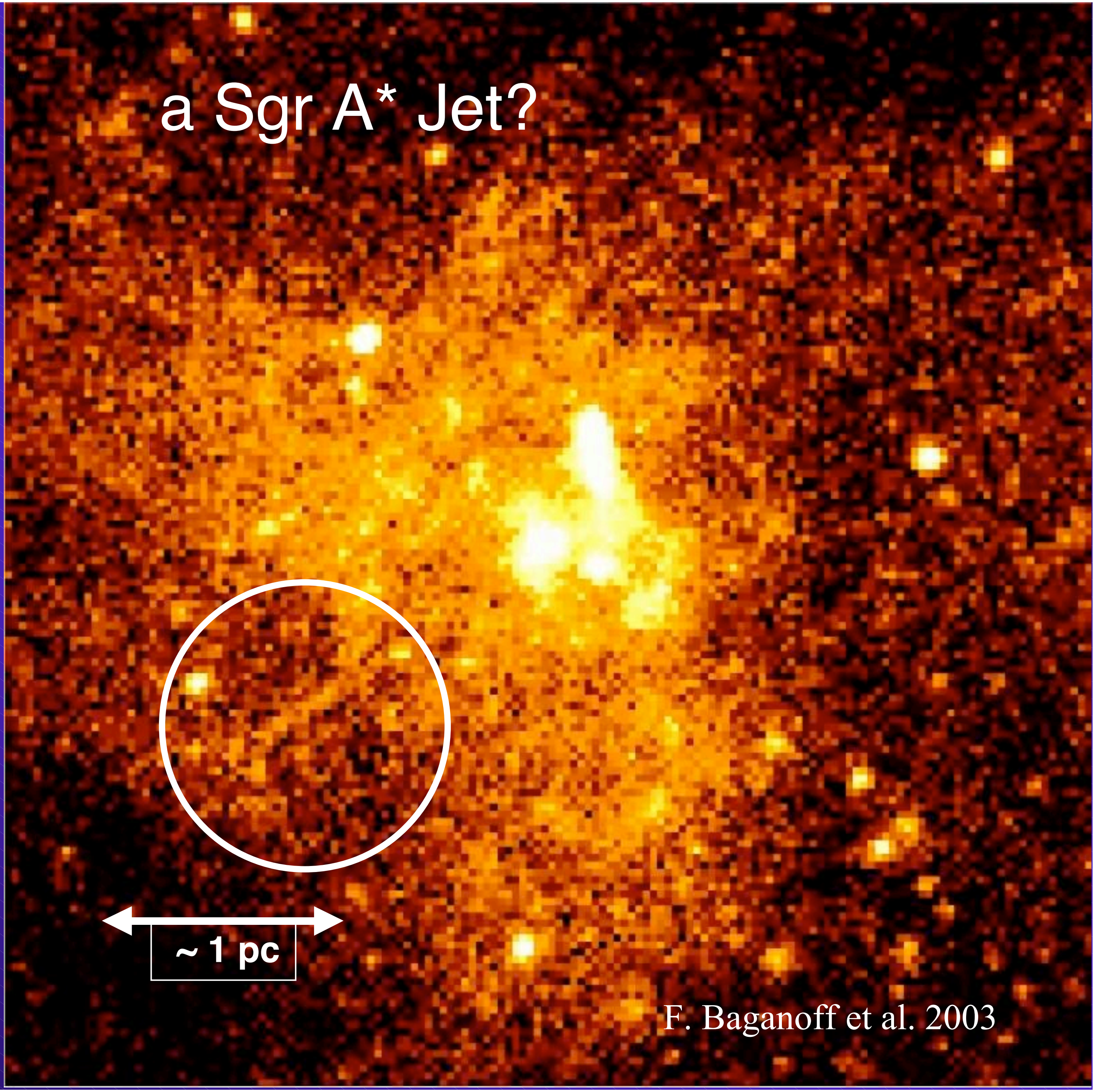
ADAF+JET FOR A « QUIESCENT » BH: THE GALACTIC CENTER

measured $\dot{M}$~3 10^{-6} M_o /yr ⟹ L (for ε ~0.1) should be ~ 10^{41} erg/s

BUT measured L~ 10^{36} erg/s ⟹ L/L_{Edd} ~ 3 10^{-9}, ε ~ 10^{-6}

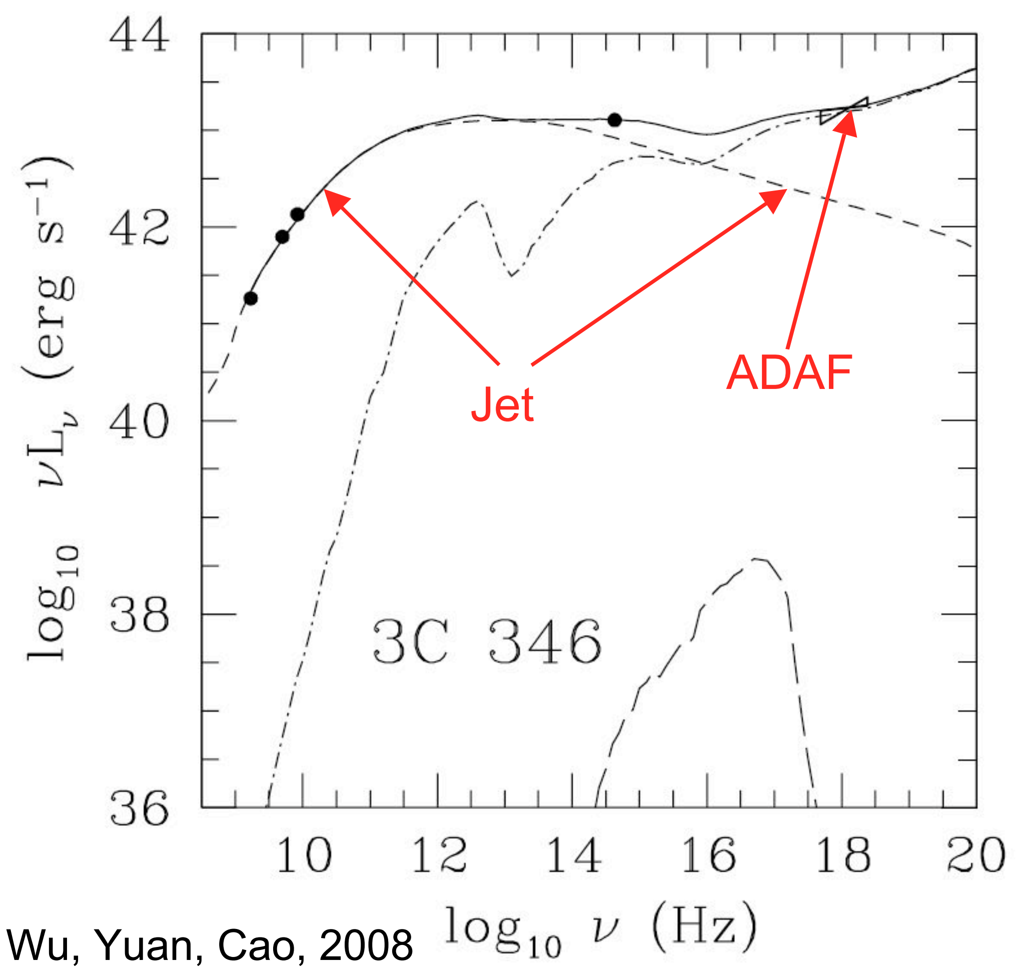


a Sgr A* Jet?



ADAF+JET MODEL FOR THE CORE OF A FRI GALAXY

$L/L_{Edd} \sim 3\ 10^{-4}$



Wu, Yuan, Cao, 2008

CONCLUSION:

WEAK ACCRETORS ARE RADIATIVELY INEFFICIENT

↓

THEY MUST PRODUCE OUTFLOWS TO EVACUATE THEIR ENERGY

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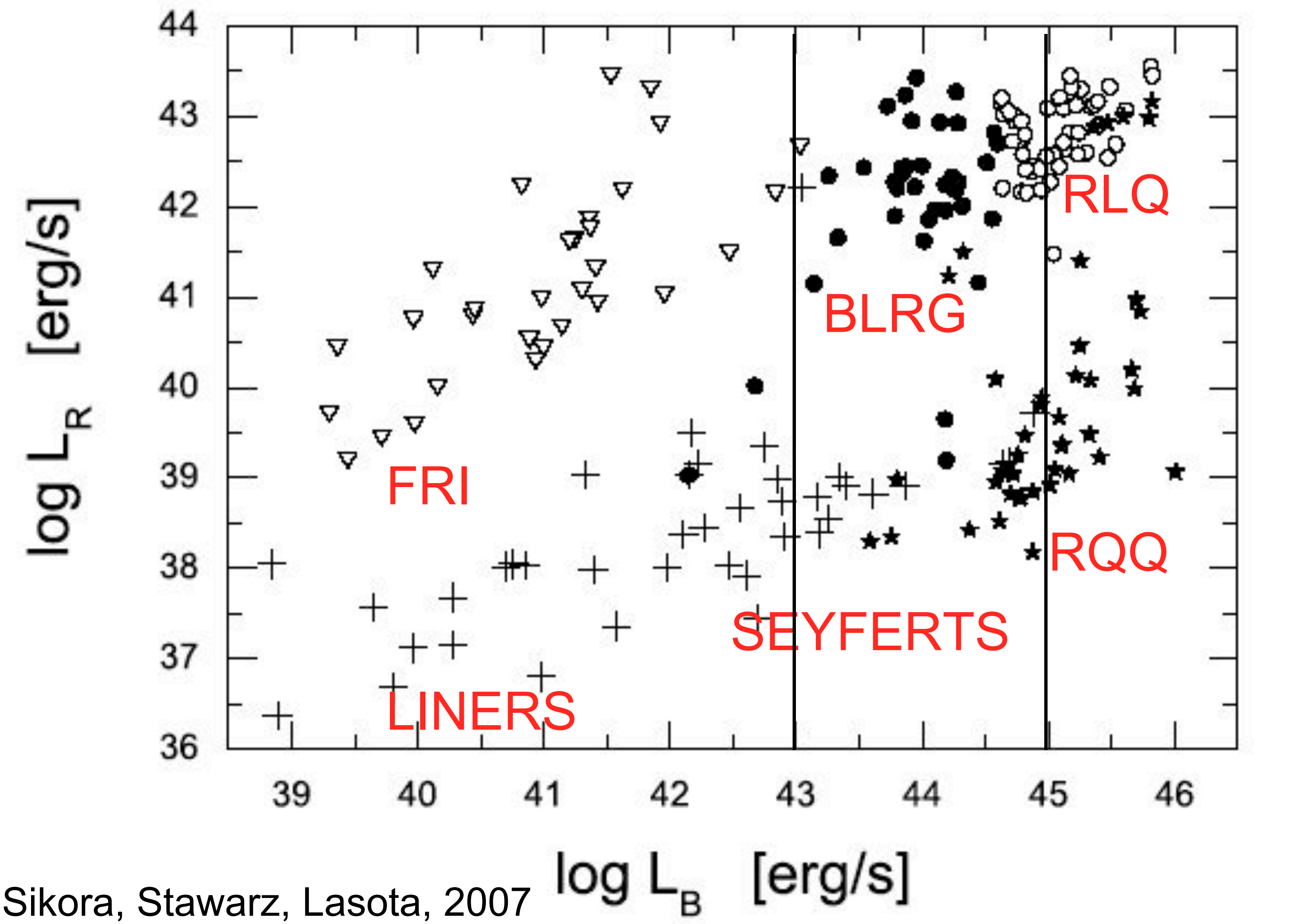
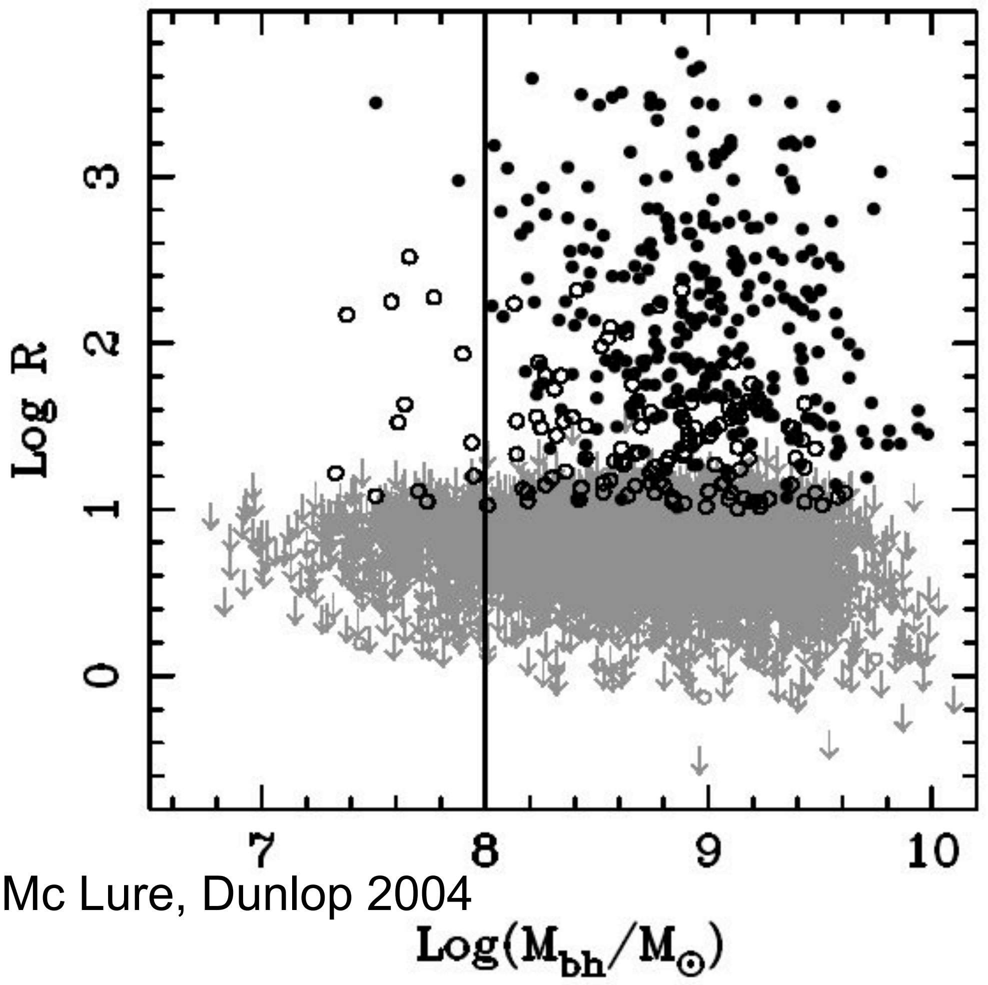
AGN are divided in « Radio Loud » (RL) and « Radio Quiet » (RQ)



Sikora, Stawarz, Lasota, 2007

With a complete sample of quasars (SDSS)

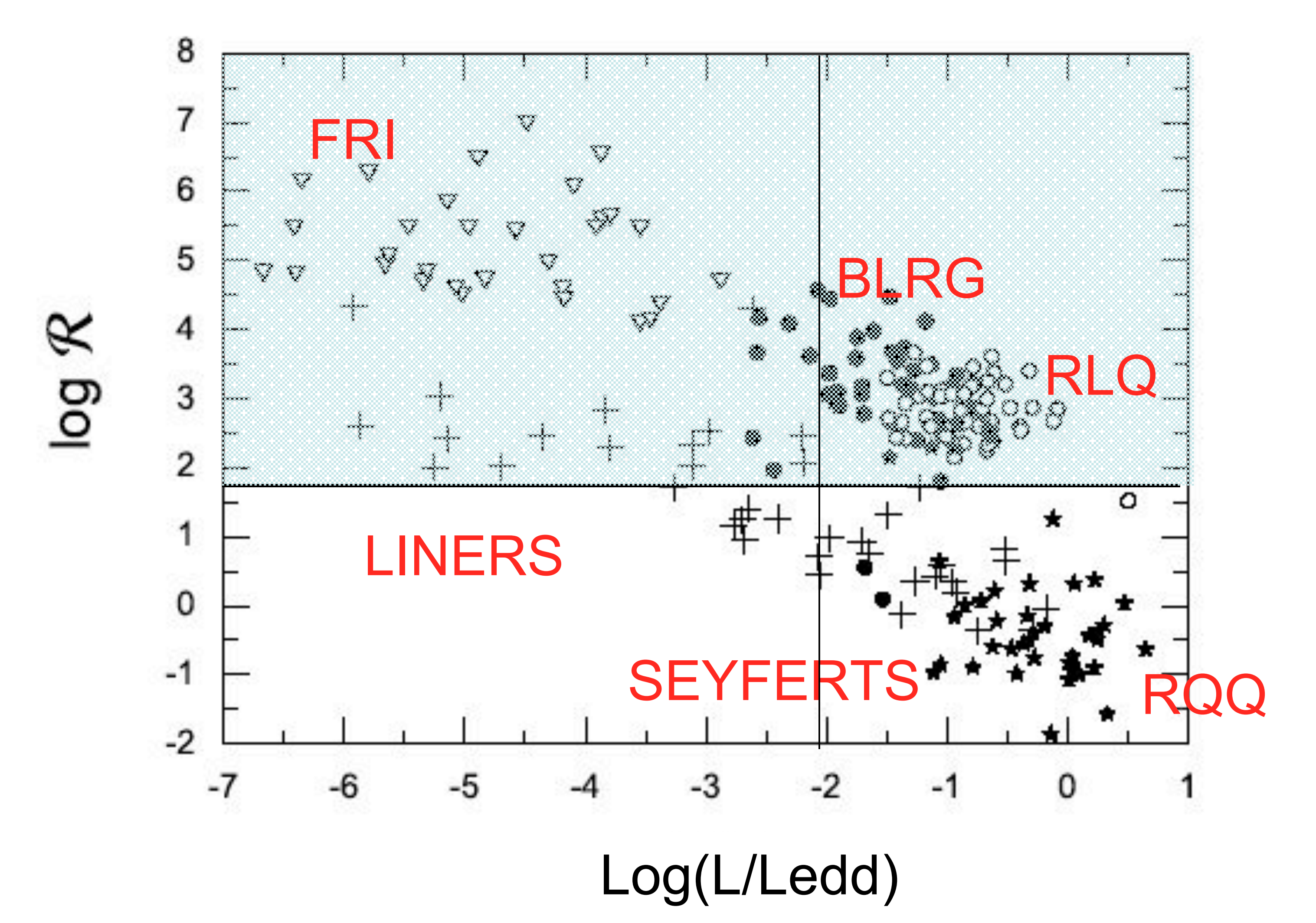


Mc Lure, Dunlop 2004

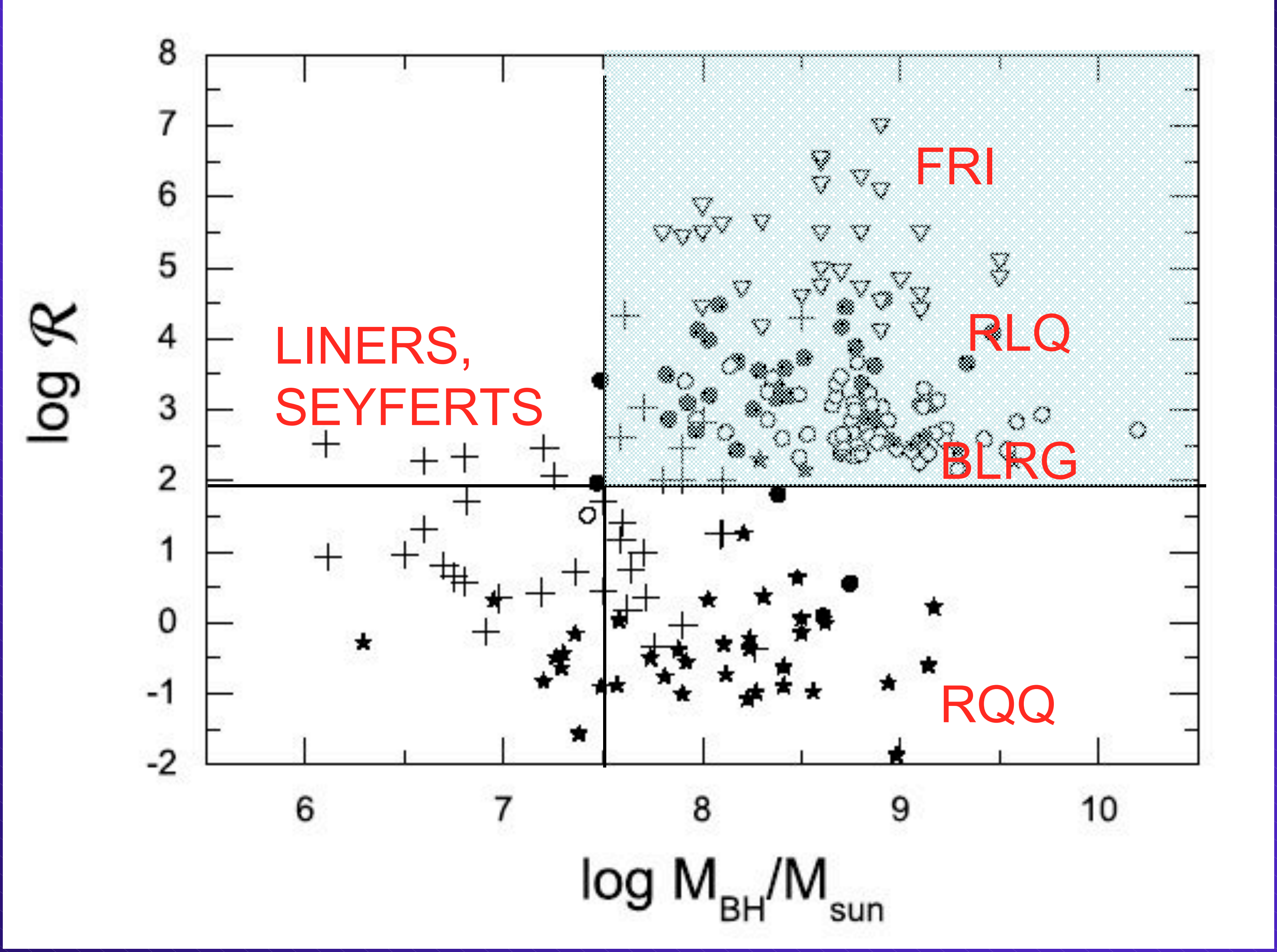
$\mathcal{R}$ = Lradio(5GHz) / Lopt

RLQs are less than 10% of RQQs

RADIO LOUDNESS DEPENDS ON THE EDDINGTON FACTOR



RADIO LOUDNESS DEPENDS ON M(BH)



I. HIGH LUMINOSITY AGN

DIFFERENCES BETWEEN RL AND RQ objects

1. Locally RL are exclusively in elliptical galaxies,

RQ in spiral galaxies

2. RLs are associated with non-thermal relativistic collimated jets,

RQs seem associated with thermal non-collimated winds

(detected by Broad Absorption Lines and X-ray absorbers)

3. Several more subtile properties, not understood

(i.e. intense FeII lines only in RQs)

WHY?

JETS VERSUS WINDS

OBSERVATIONS

Jets are launched at R ≤ 1000 Rg (VLBI)

Winds are launched at R ≥ 10000Rg

Jets have relativistic bulk velocities and are made of relativistic particles

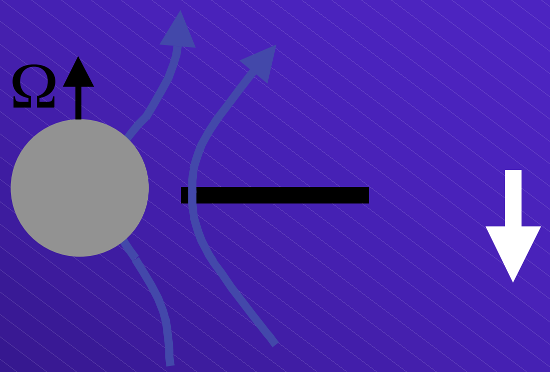
Winds have velocities from few hundreds km/s to c/10 and consist of warm (10^{5-6} K) thermal gas

JET DRIVING MECHANISM

Magnetic field is indispensable to explain extended jet acceleration:

1. Centrifugally driven flow from the disk

2. Extraction of the rotational energy of the BH:
field connects the BH to the disk
(Blandford-Znajek, 1977)



Jets might be linked with the spin of the BH

BLACK HOLE SPIN

Measured by dimensionless angular momentum
$a = J/Jmax = cJ/GM^2$

1. Even RQ AGN have spinning BH (FeK line)

2. Cosmological evolution of AGN requires large fraction of spinning BHs (mass-conversion efficiency must be > 0.06)

3. Power of the jet must increase with *a*

4. It is expected that *a* increases with accretion AND with merger of two BHs

5. BHs increase with galaxy bulges, and a fraction of elliptical galaxies (large bulges) are due to the merger of spirals

↓

Elliptical galaxies favor high spin, therefore jets

But it does not explain all:
Other mechanisms must be at work

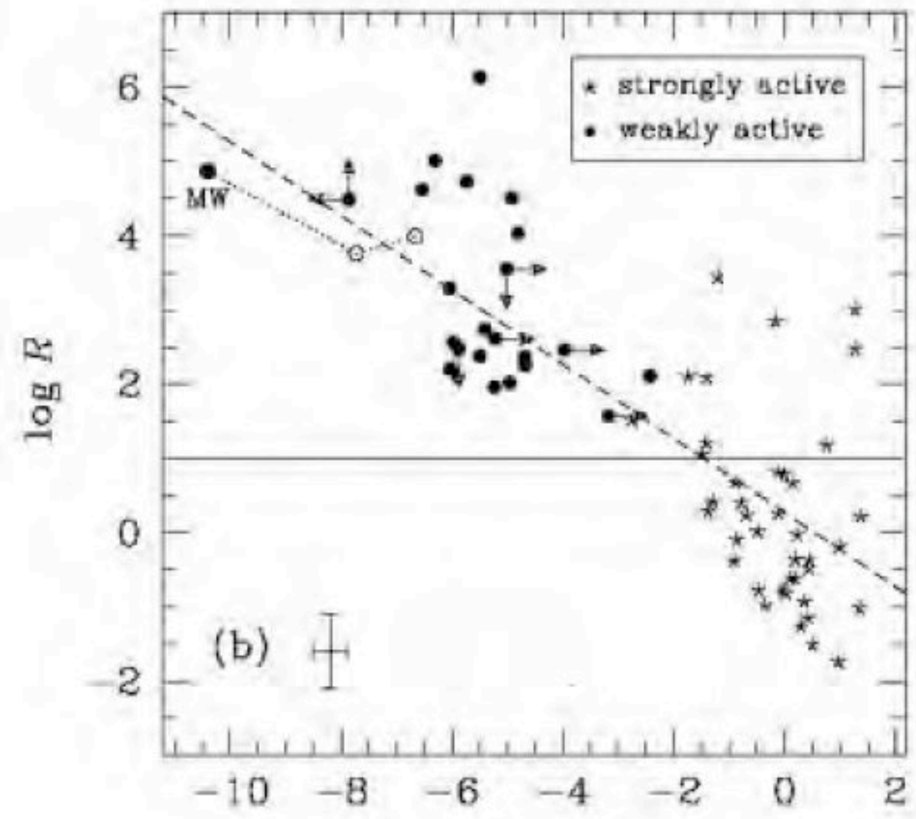
1. Environnement can play a role:*spiral galaxies contain cold gas, ellipticals contain and are surrounded by hot gas*

2. Geometry of the inner disk can play a role: *thick or thin*

3. Density profile of the circumnuclear regions can play a role: *cusp or core*

etc… etc…

II. LOW LUMINOSITY AGN
DO THEY HAVE JETS? YES!



Ho, 2002

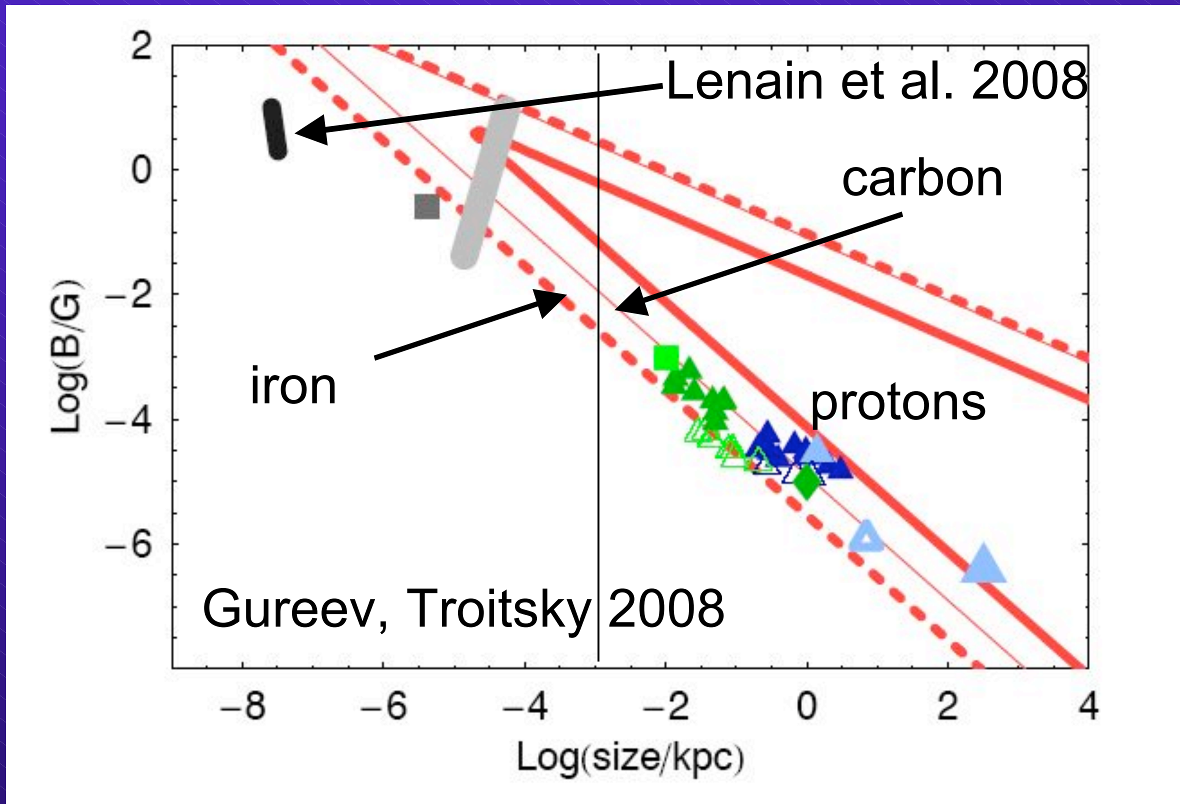
Log(L/Ledd)

Compact jet structure with flat spectra observed in 40% of LLAGN

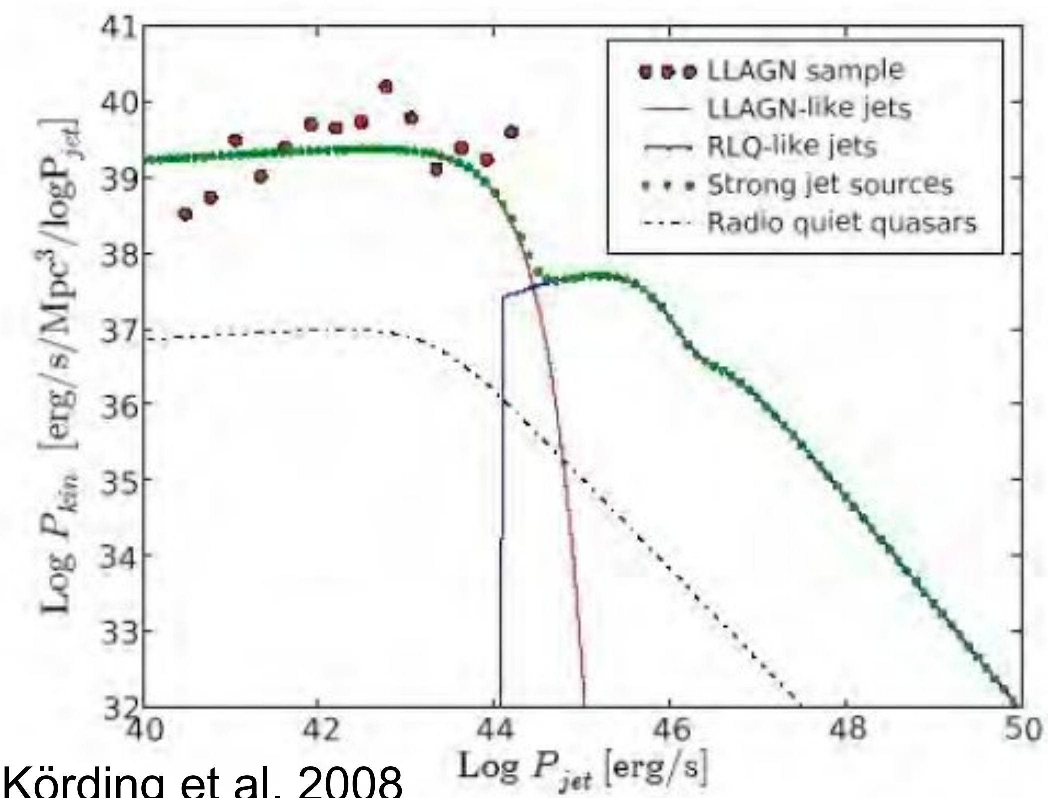
In FRI radio-galaxies, pc-jets can be as powerful as kpc jets ! Example: Centaurus A

Evans et al. 2004

Component	1 keV X-Ray Flux Density (μJy)	Radio Flux Density (Jy) (frequency)
Kiloparsec-scale jet...............................	0.22 ± 0.01	0.74 ± 0.12 (8.4 GHz)
Second power law/parsec-scale jet.......	3.31	5 (4.8 GHz)

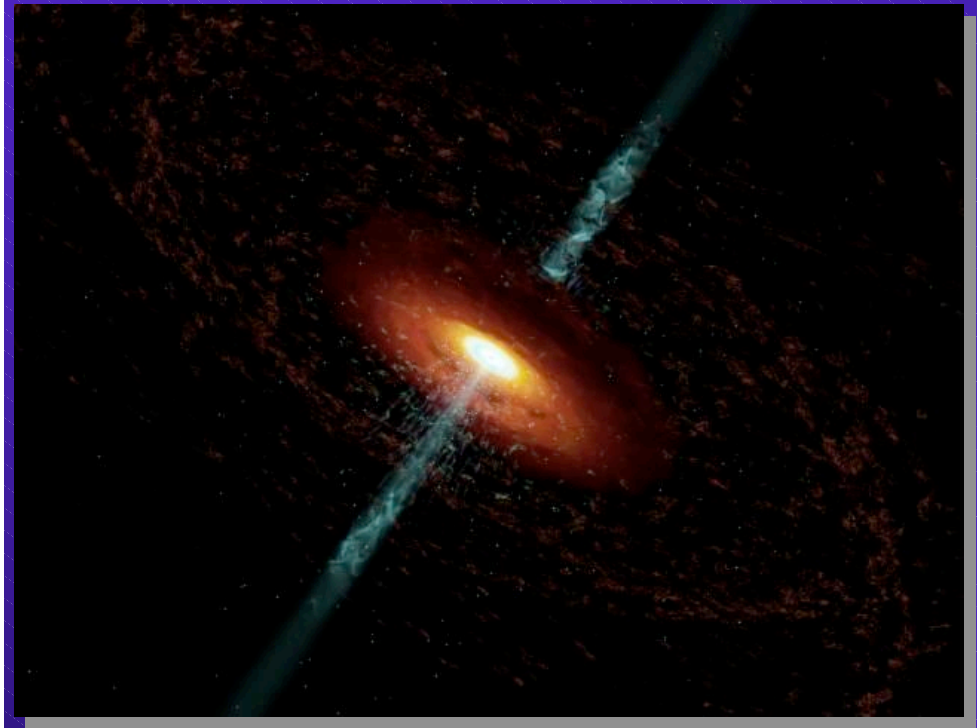


The kinetic luminosity of jets at z=0 is dominated by LLAGN



Körding et al. 2008

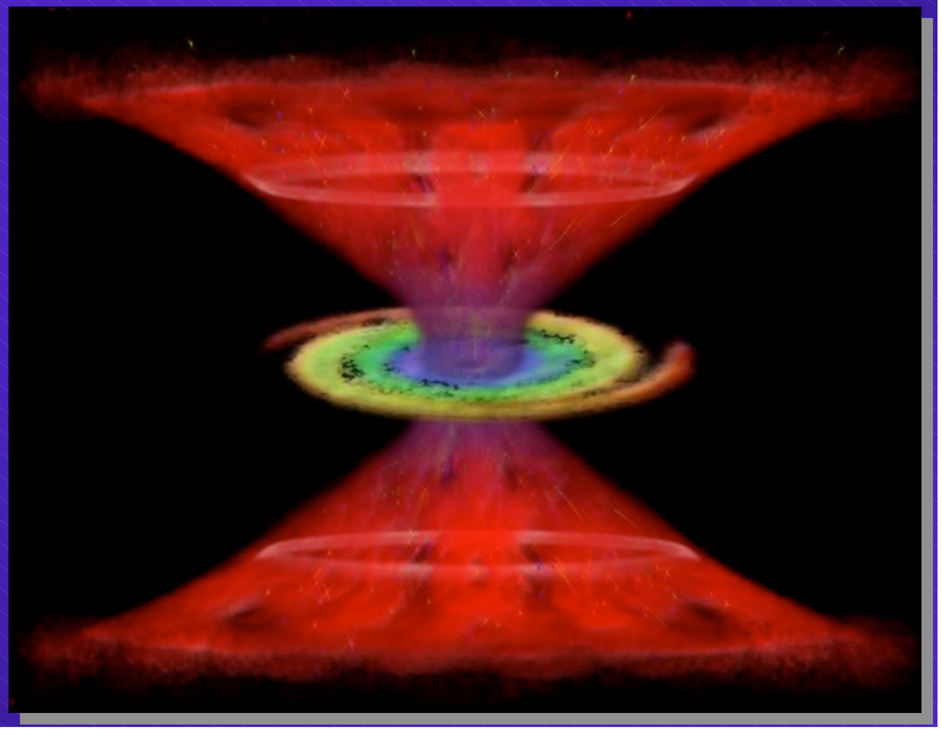
FINALLY IS THE SOLUTION THIS ONE?



Radio Loud AGN

and LLAGN

Radio Quiet AGN



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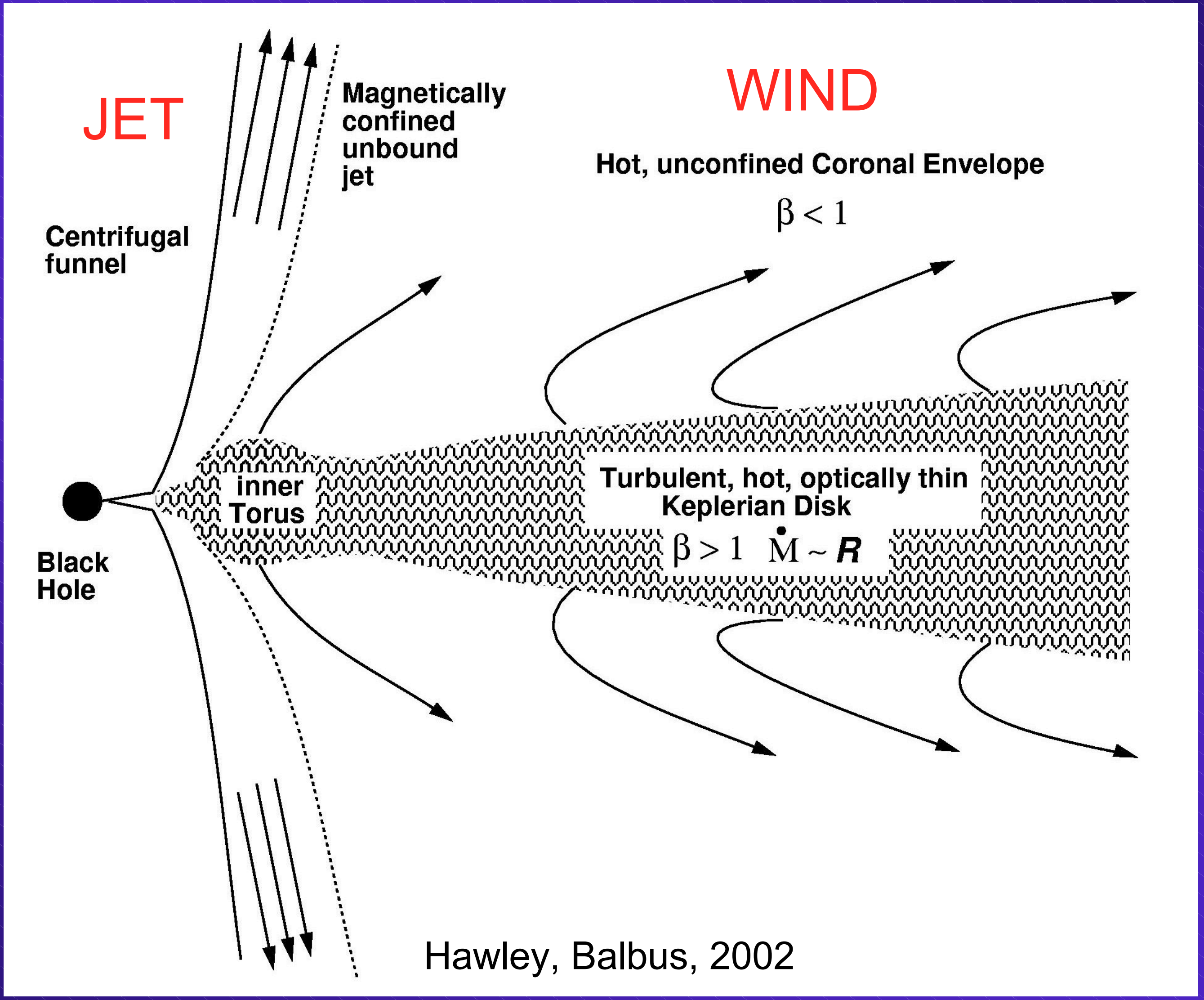
OR IS IT THIS ONE?



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With variable wind/jet luminosity ratio

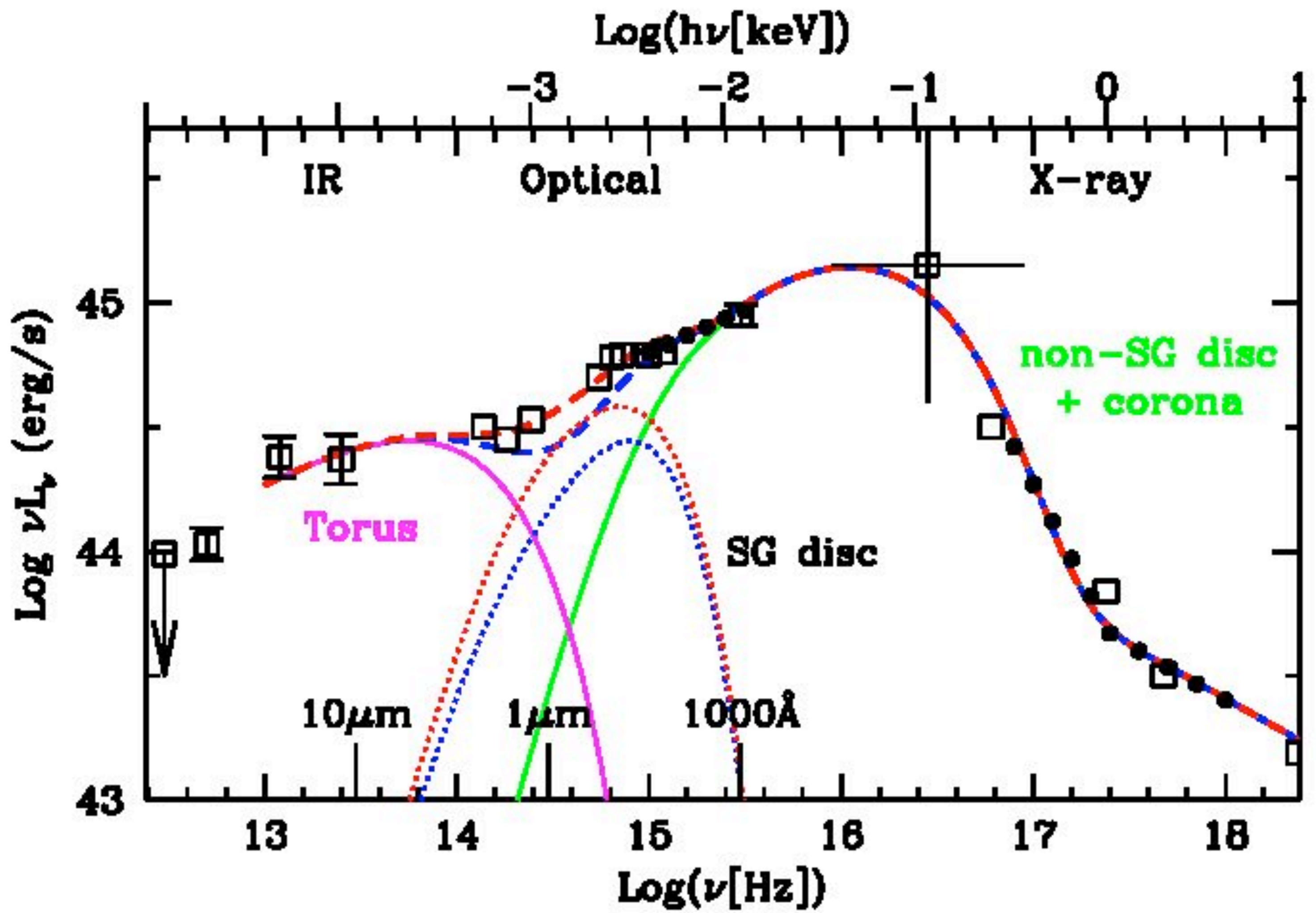
CONCLUSION

1. BAD NEWS: Only a small proportion of AGN have relativistic jets at the kpc scale and non-thermal radiation

2. GOOD NEWS: In low luminosity AGN (and basically all galaxies), there are probably jets/winds close to the central BH, and they carry much more kinetic energy than the radiation

3. Little is understood concerning the dichotomy between radio-loud and radio-quiet objects

An exemple of a strong accretor (Ton S 180) modeled by a thick disk, $M(BH)=6\ 10^6\ M_o$, m=60



[1] Kawaguchi, Piérens, Huré, 2003

Caution: one defines sometimes

$$\dot{M}_{Edd} = L_{Edd}/\varepsilon c^2, \; which \;\; gives \;\; \dot{M}_{Edd} = \dot{M}_{crit}/10 \;\; for \; \varepsilon = 0.1$$

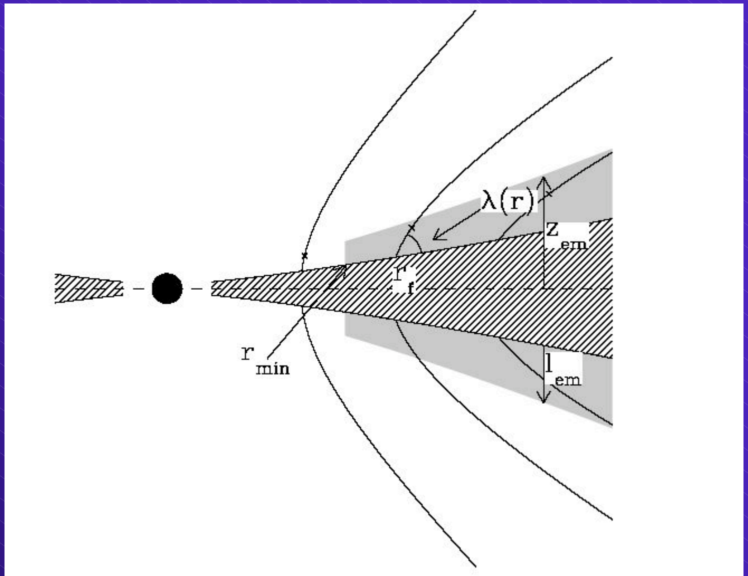
Wind driving mechanism

-radiation pressure driven from the disk

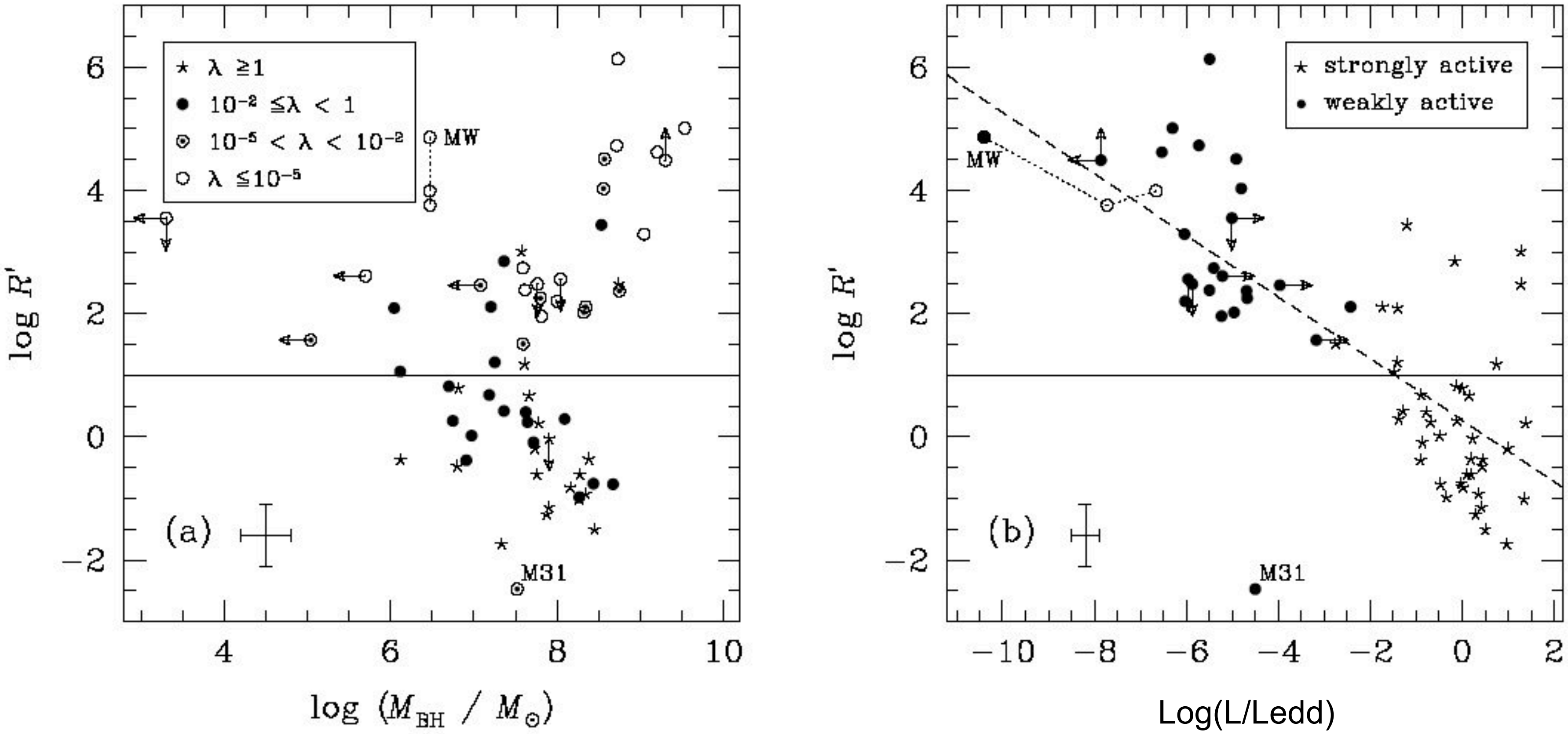
but « shielding » of the central source necessary

-centrifugally driven from disks threated by an open magnetic field

- thermally or hydrodynamically driven from the hot corona



sketch of a disk wind, centrifugally and/or radiatively accelerated



λ ≥1
10⁻² ≤λ < 1
10⁻⁵ < λ < 10⁻²
λ ≤10⁻⁵
MW
M31
(a)
log R′
log (M_BH / M_⊙)
strongly active
weakly active
(b)
Log(L/Ledd)

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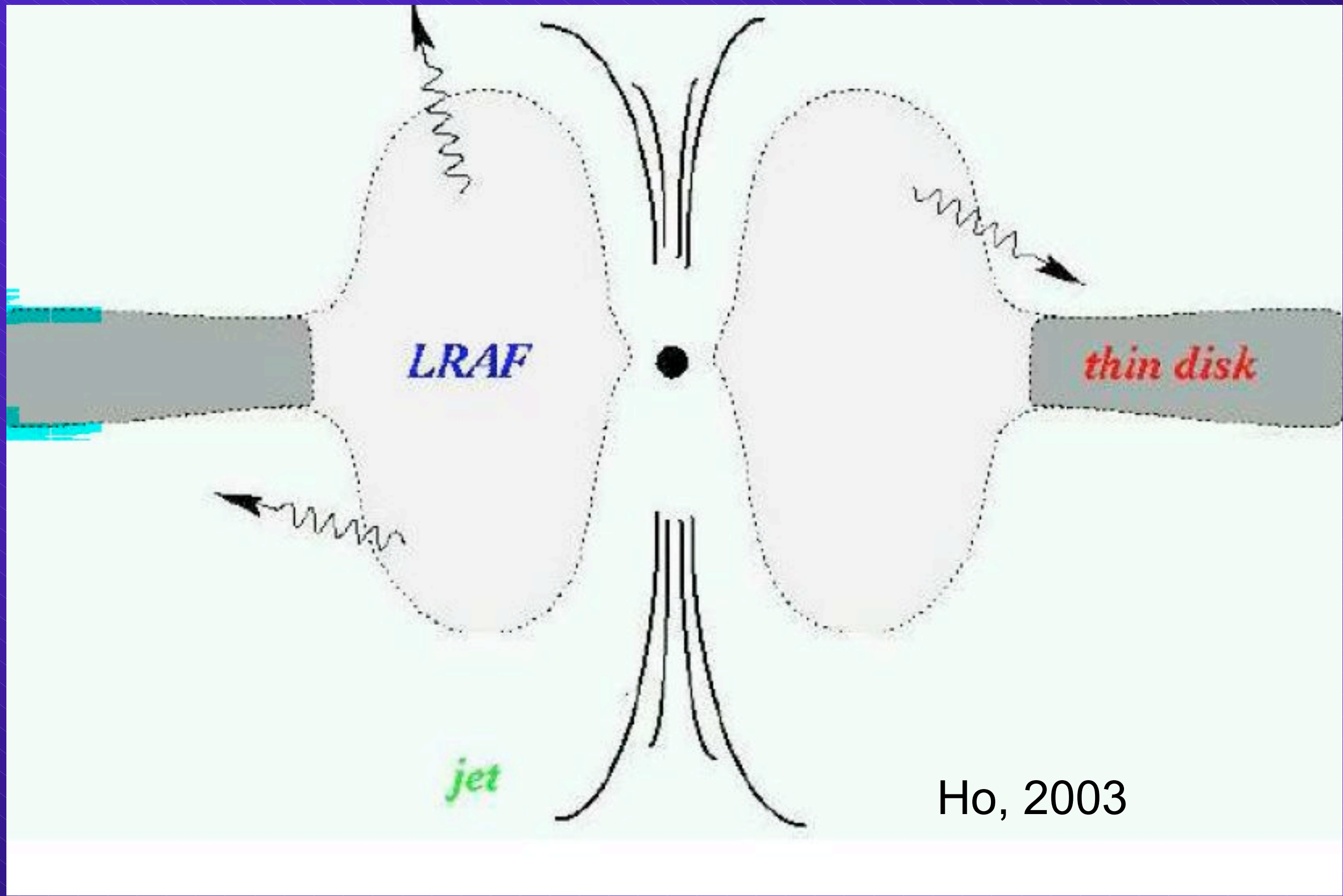
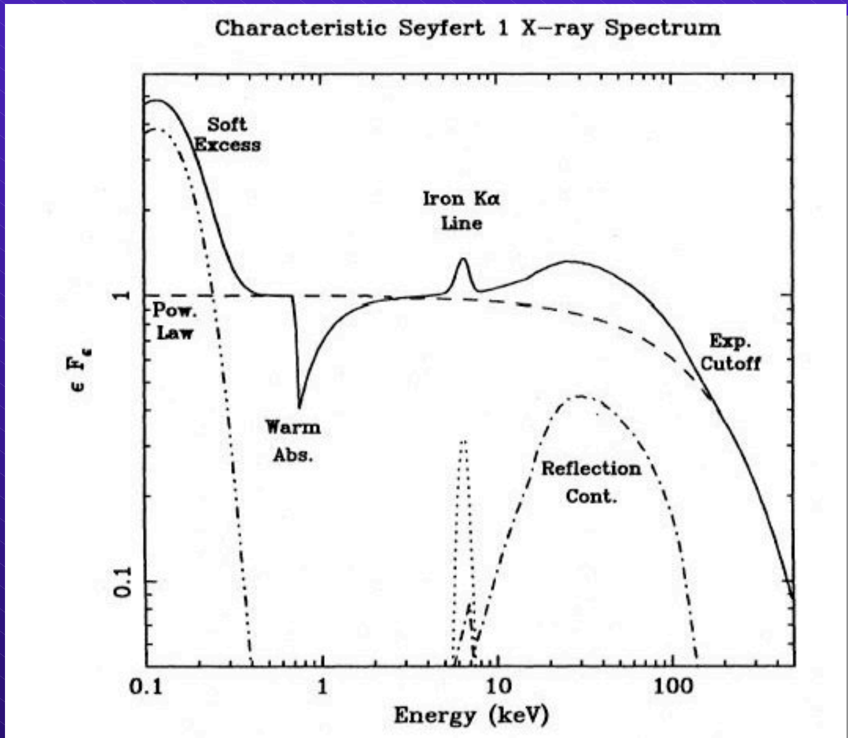
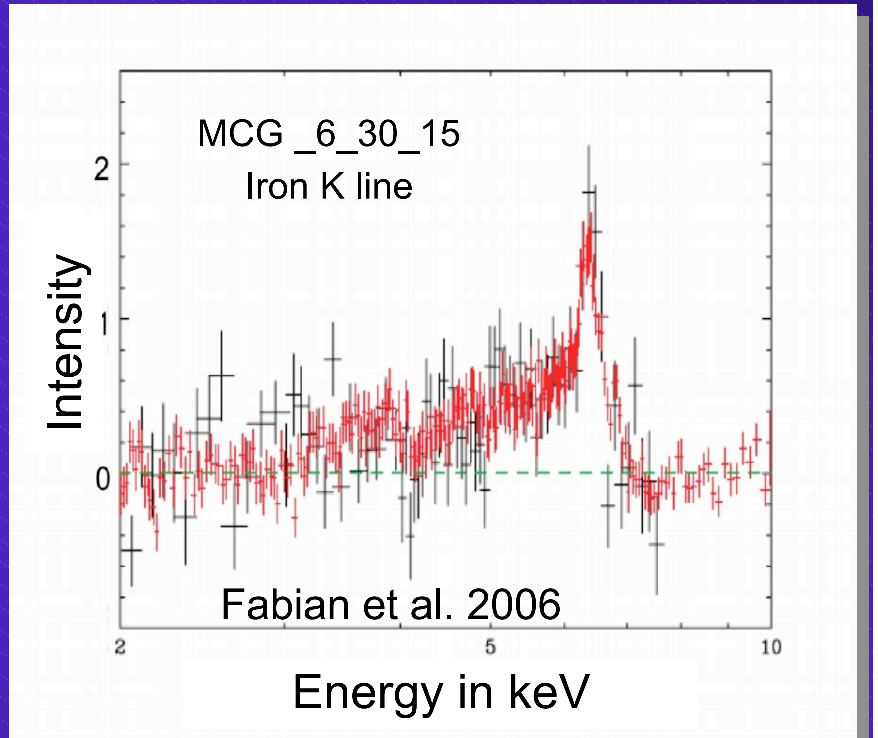

LRAF
thin disk
jet
Ho, 2003

NO HARD X-RAYS ARE EXPECTED FROM THESE DISKS
BUT

proof of the presence of a hot medium emitting the hard X-rays whose emission is « reflected » by the disk





Relativistic profile of FeK ⟹ the disk extends down to ~10Rg, and sometimes to ~1Rg ⟹ ISCO of a rapidly spinning BH