The AGN / host galaxy connection in nearby galaxies.

A new view of the origin of the radio-quiet / radio-loud dichotomy?

Alessandro Capetti & Barbara Balmaverde
(Observatory of Torino – Italy)

The radio-quiet / radio-loud dichotomy

Radio-quiet AGN are hosted preferentially by late-type galaxies, but they are found also in early-type galaxies. Radio-loud AGN are only hosted by early type.

It has been proposed that radio-loud galaxies are associated to the most massive black holes, but there is a large overlap in MBH between the two classes. Other parameters must be important.

We here re-explore the classical issue of the host-galaxy/AGN connection taking advantage of both theoretical progresses (e.g. the link between galaxies and supermassive black holes) as well as of the substantial advances in the telescopes capabilites using high resolution HST and Chandra data.

The AGN / host galaxy connection in nearby galaxies.

We must look at the nearby Universe to be able to see and study in detail the properties of both AGN and host galaxies.
Early type galaxies are the crucial class of objects in which RL and RQ coexist.

The starting point of the project.

Radio surveys of two volume limited samples of nearby early tpye galaxies (Wrobel 1989, Sadler 1989; V < 3000 km/s, $m_B < 14$, radio flux limit = 1 mJy). Radio data boost the fraction of AGN with respect to purely optically selected samples.

The samples (North + South):

216 + 116 = 332 S0 and E galaxies.

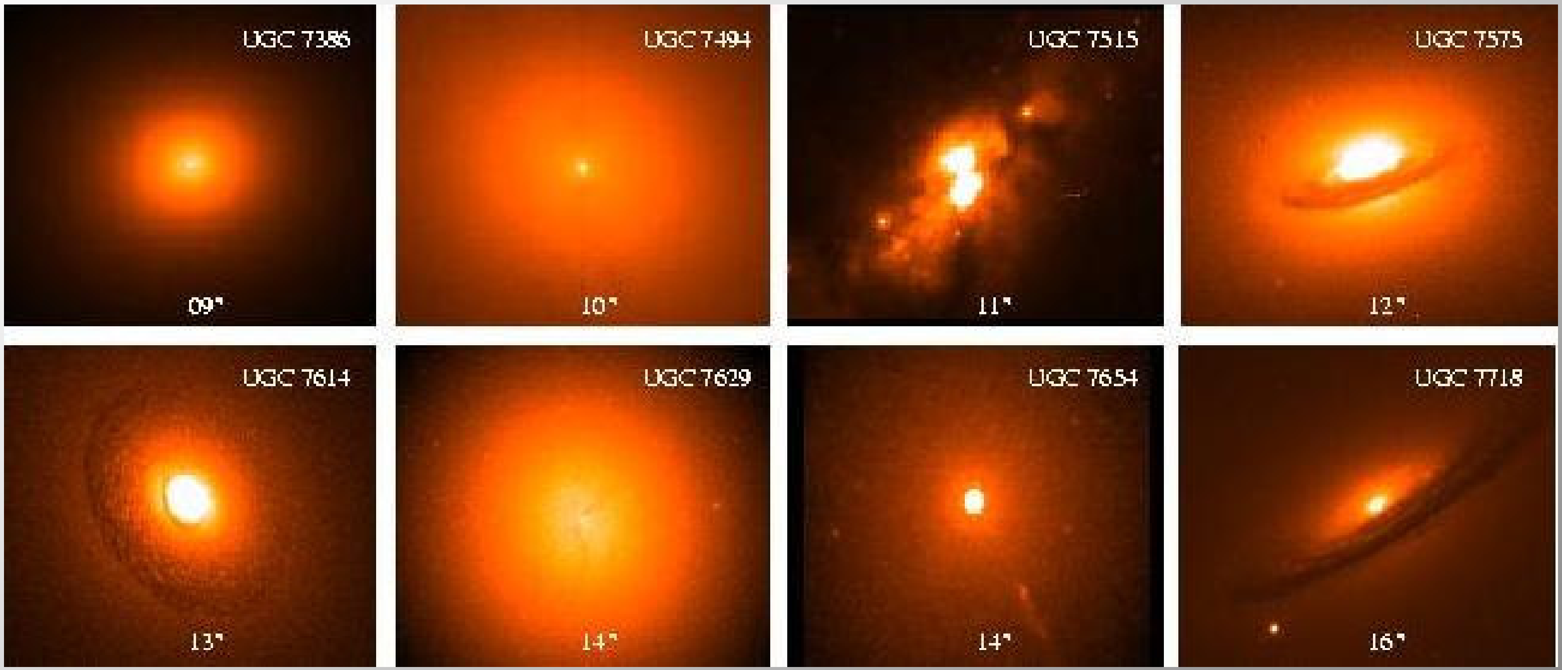
67 + 51 = 118 detected at 5 GHz above 1 mJy

Archival data available:

HST images : 48 + 17 = 65 galaxies, 55 % of the radio detected objects.

Chandra data: 28 + 7 = 35 galaxies, 30 % of the radio sources.

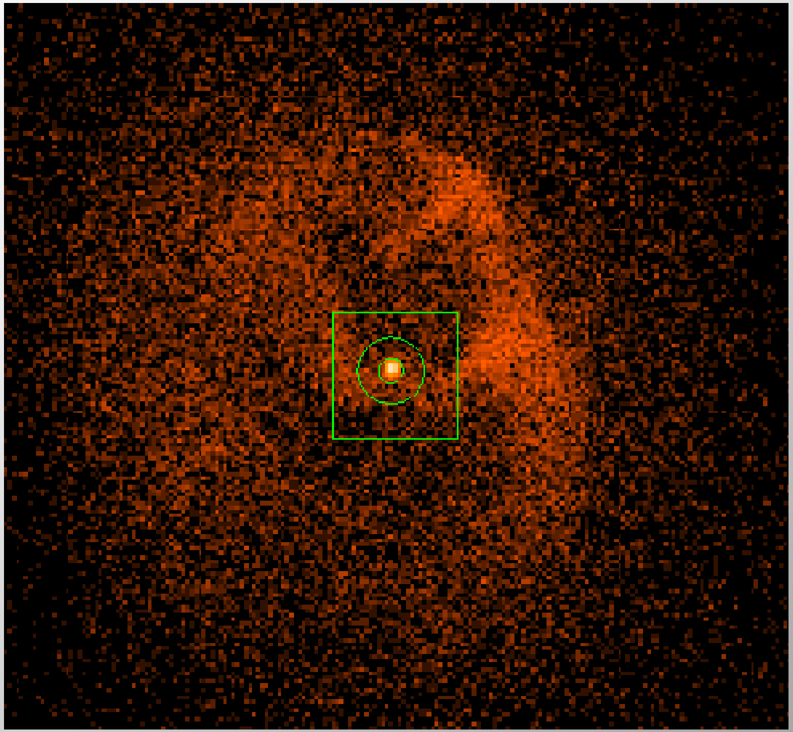
Results from HST observations: I

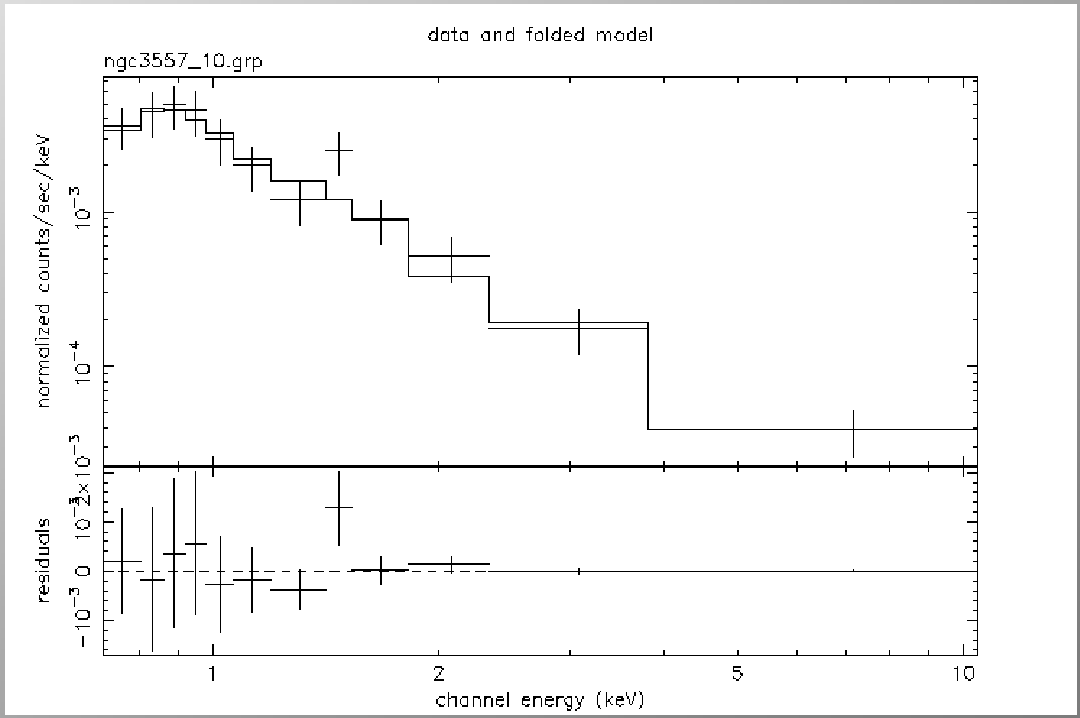


HST reveals the presence of optical nuclei in most galaxies, crucial to properly define the radio-loudness parameter.

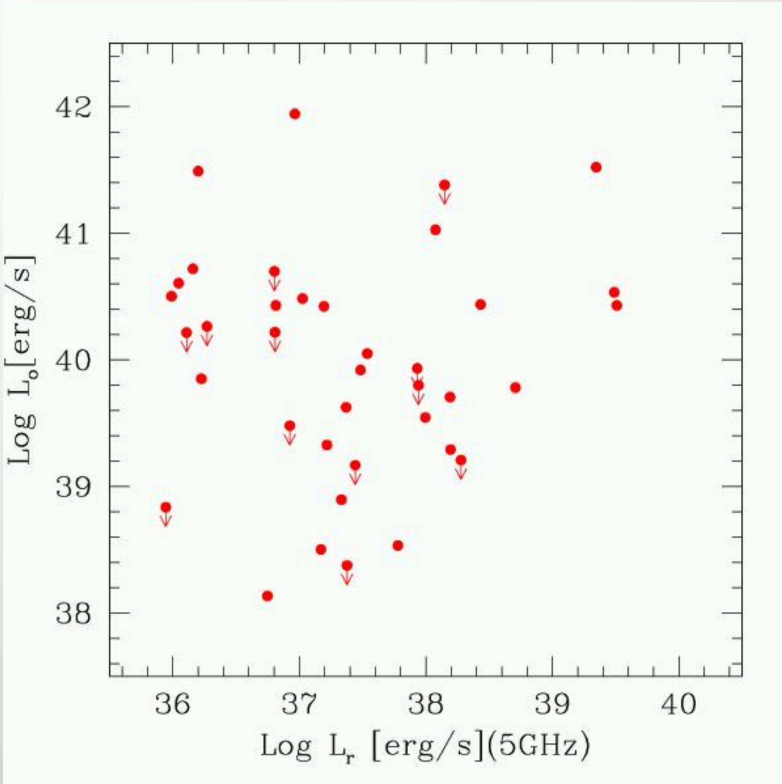
Results from Chandra observations

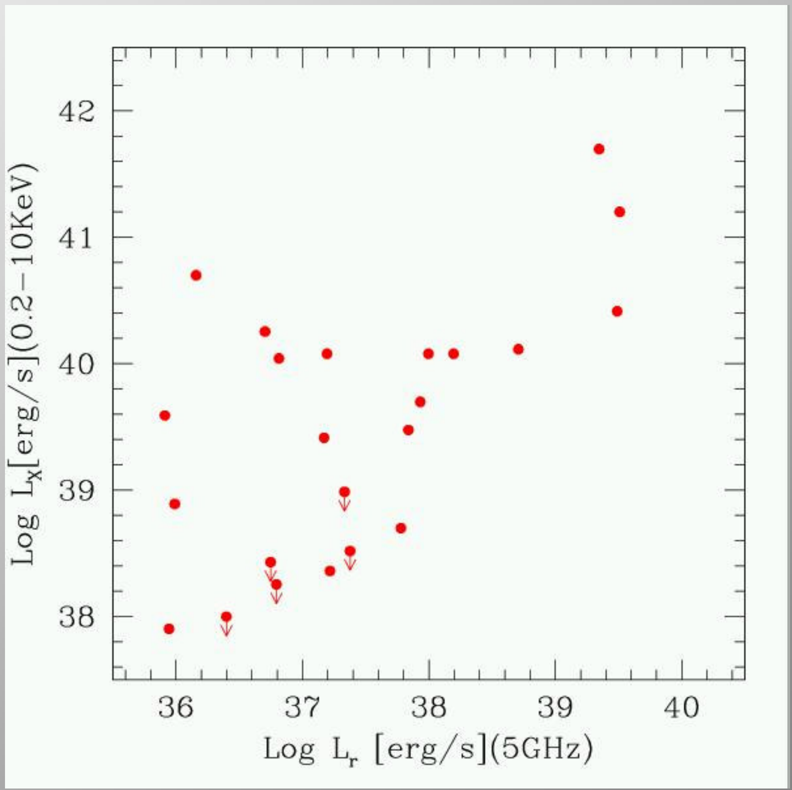
Most galaxies have a nuclear component with a power law spectrum in the X-ray. This provides us with a different measure of RL/RQ based on the X-ray.





The nuclear diagnostic diagrams





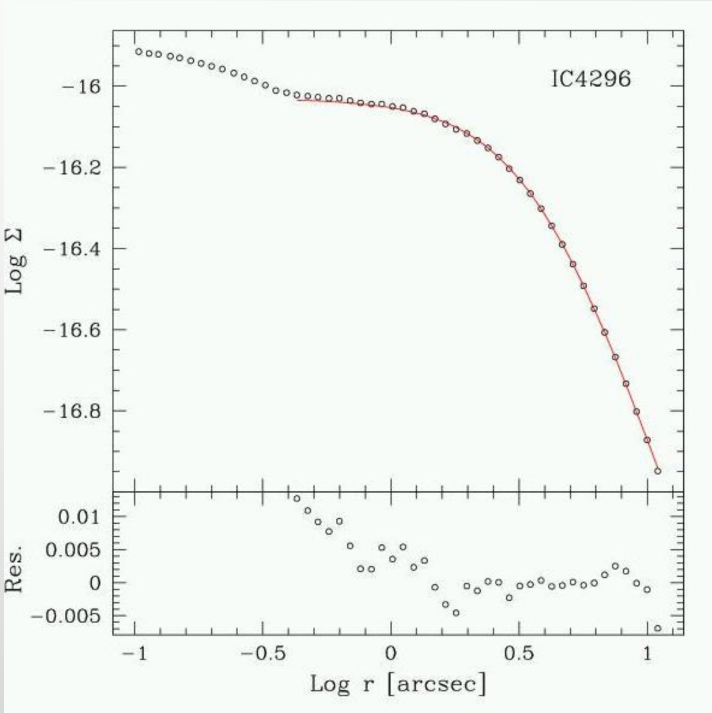
As expected, a very large range of radio-loudness parameters, from R = 1 to R =10^4

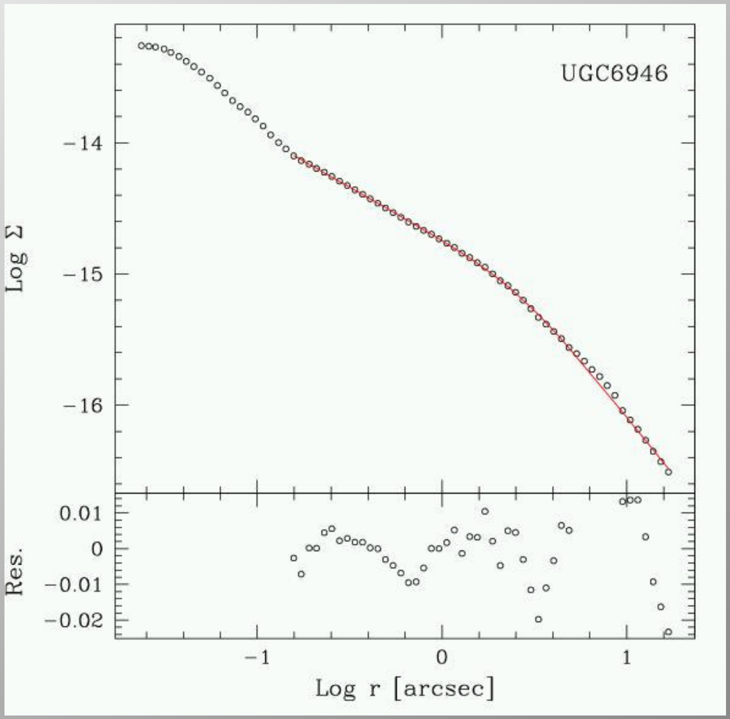
… but,, looking more closely at the host galaxies properties a different picture emerges…

Early type galaxies can be separated into core and power-law galaxies on the basis of the logarithmic slope γ of the nuclear profile at the center.

Core galaxies have $\gamma < 0.3$, power-law have $\gamma > 0.5$

Results from HST observations: II

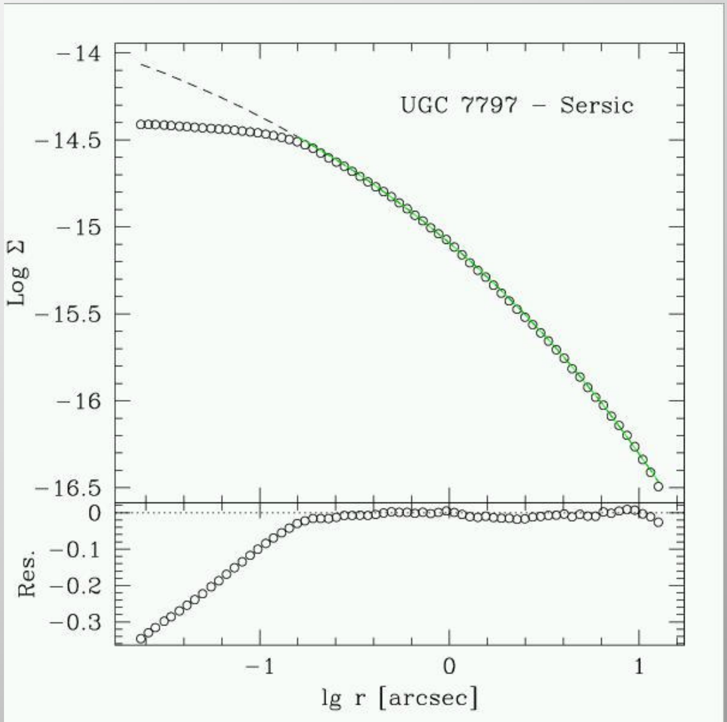


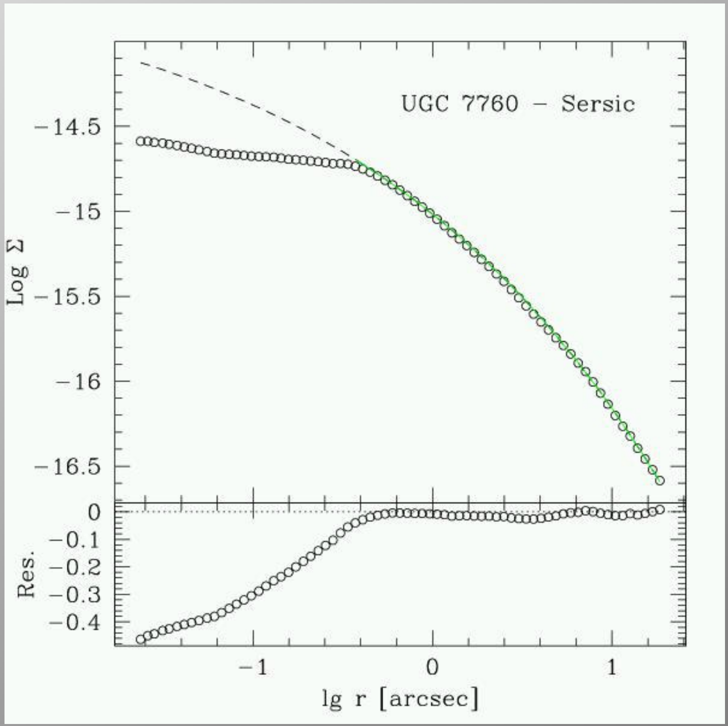


The brightness profile of most galaxies can be described with a double power-law (Nukers). The central slope is the crucial parameter.

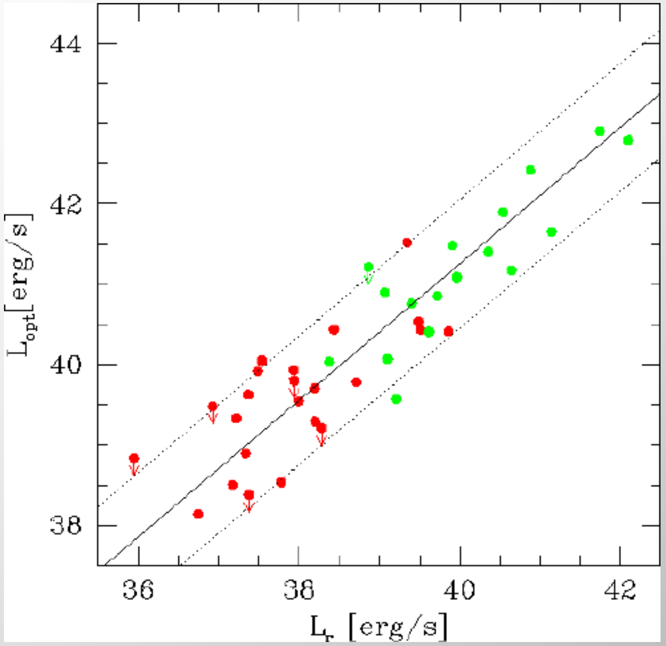
A critical analysis of the Nukers scheme

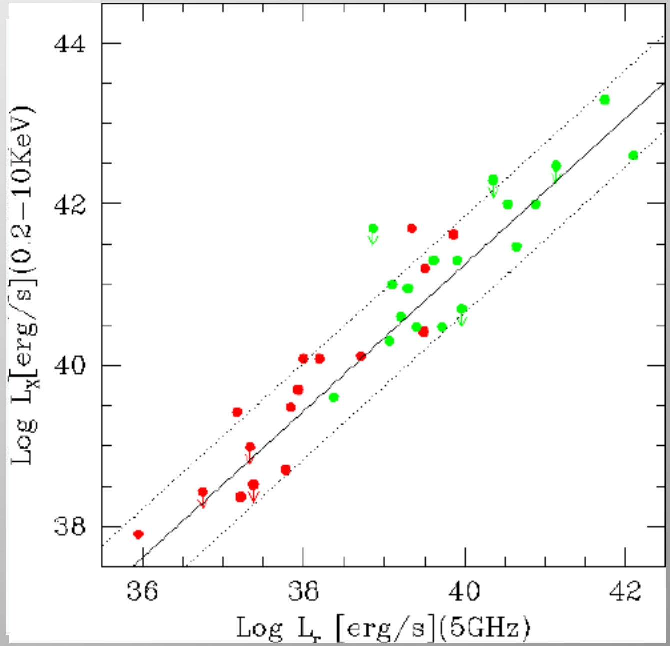
Graham and Co. challenged the definition of core and power-law galaxies proposed by the Nukers, arguing that a Sersic law profile provides a better description of early type galaxies.
They define: power-law = Sersic fit, core = inner deficit from Sersic law.
We checked that for our targets the two definitions provide the same classification.





Core galaxies only:



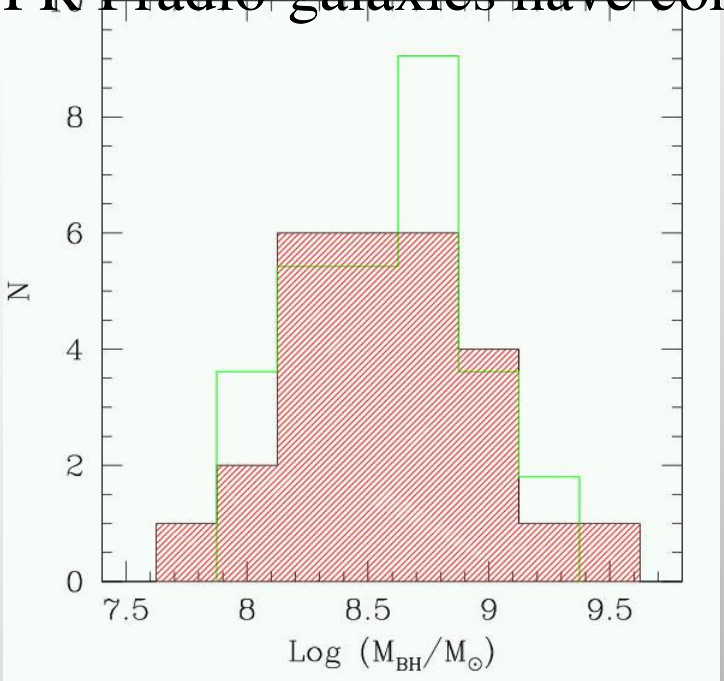


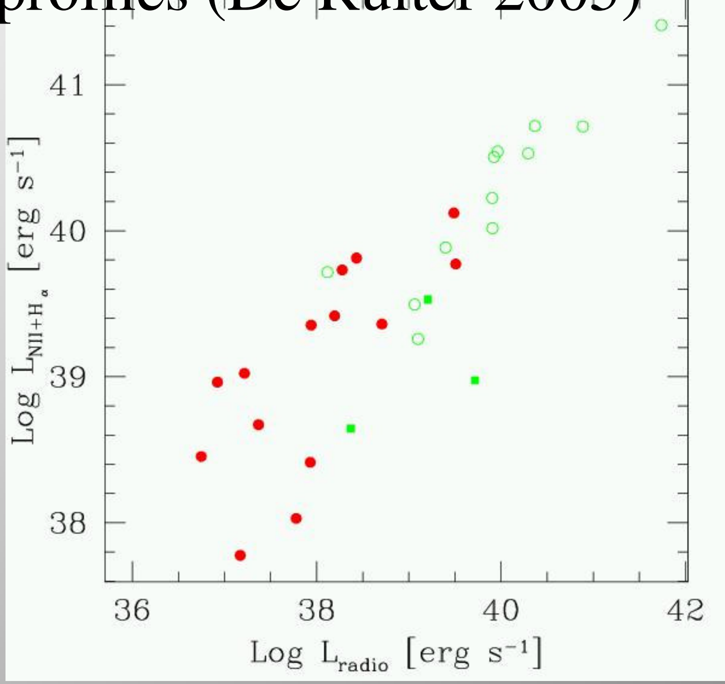
They are all radio-loud nuclei, with <R> =1000.

They follow the same relations of the 'bright' 3C/FRI radio-galaxies (green dots), with luminosities up to a factor 1000 lower, with very small dispersion (only a factor of 2 in the X-ray/radio correlation).

Core galaxies vs. FR I radio-galaxies

FR I radio-galaxies have core profiles (De Ruiter 2005)





… same distribution of black hole masses

… same radio line-luminosity relation

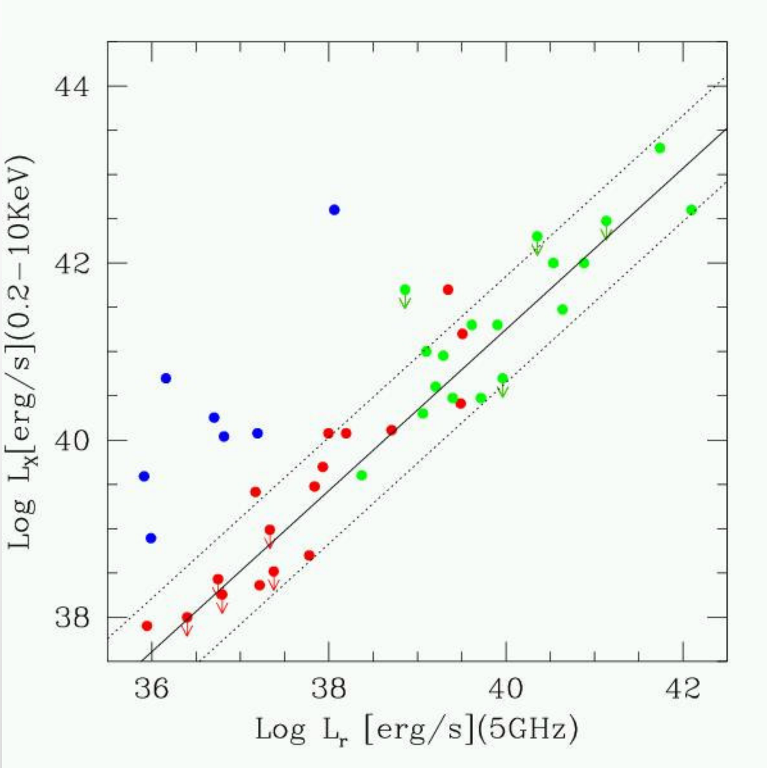
All 13 CG with "diagnostic" classification are LINERs, as FRI. At least 17 have radio jets or lobes.

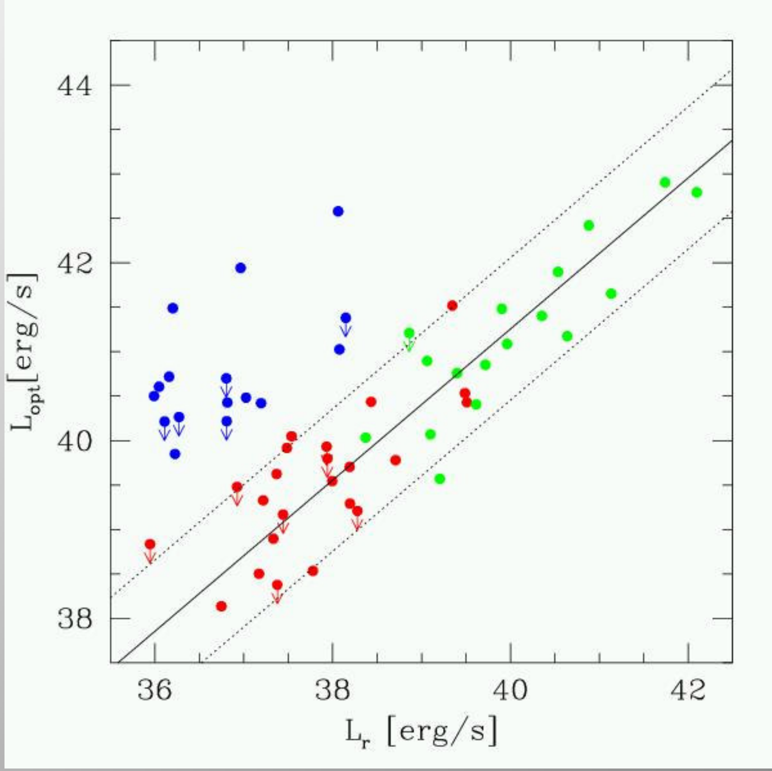
FRI and core galaxies differ only for the level of nuclear activity.

FRI form the "high luminosity" end of the core galaxies population.

Is there a miniature radio-galaxy in every "core galaxy"?

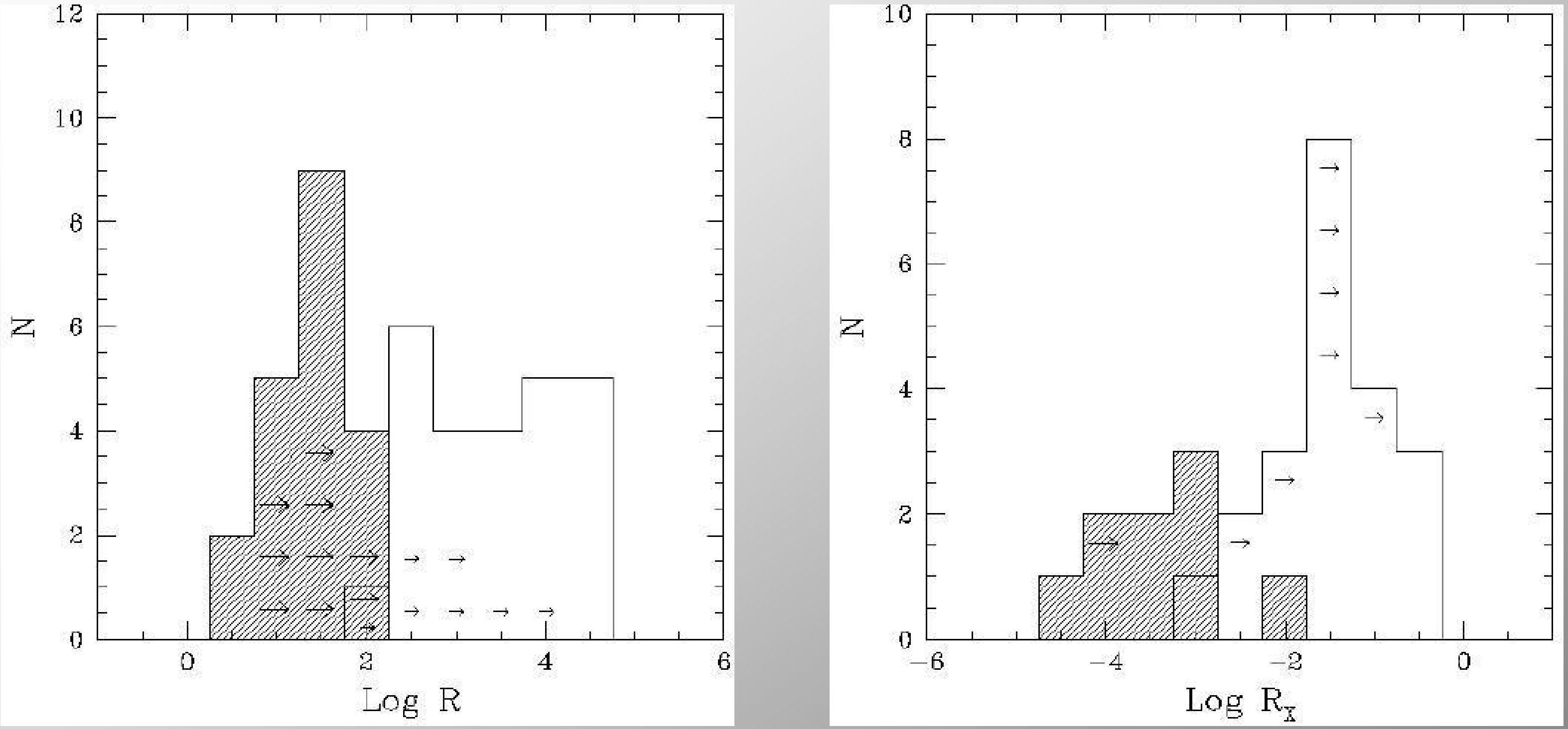
Power law galaxies





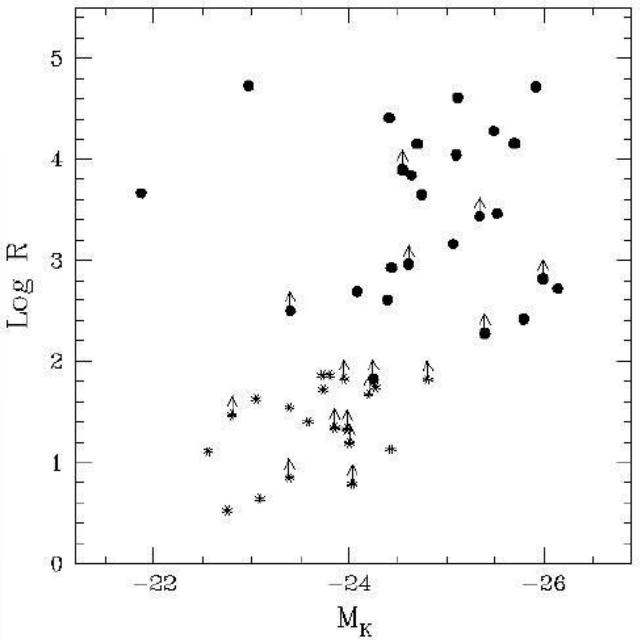
AGN associated to "power-law" early type galaxies (blue dots) are located above the correlations defined by core-galaxies, by an average factor of 100. They are all low luminosity radio-quiet AGN with a large deficit of radio-emission at a given optical luminosity from core-galaxies.

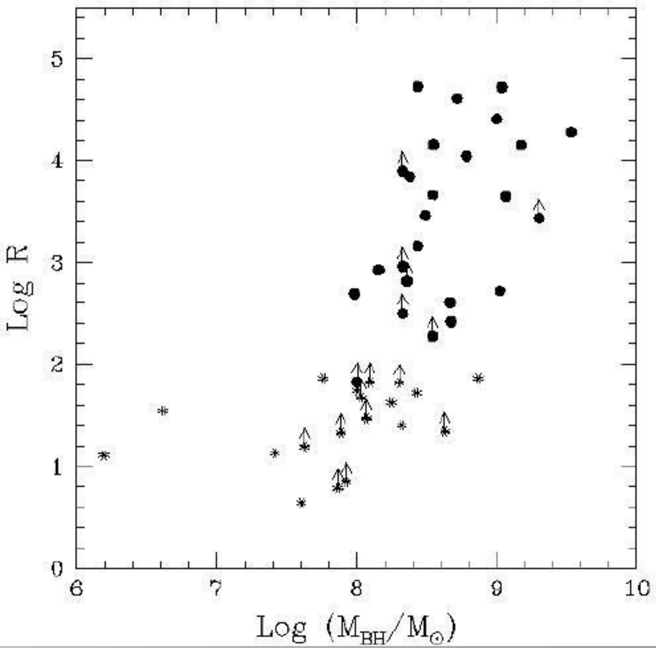
A radio-quiet/radio-loud bimodality in nearby early type galaxies

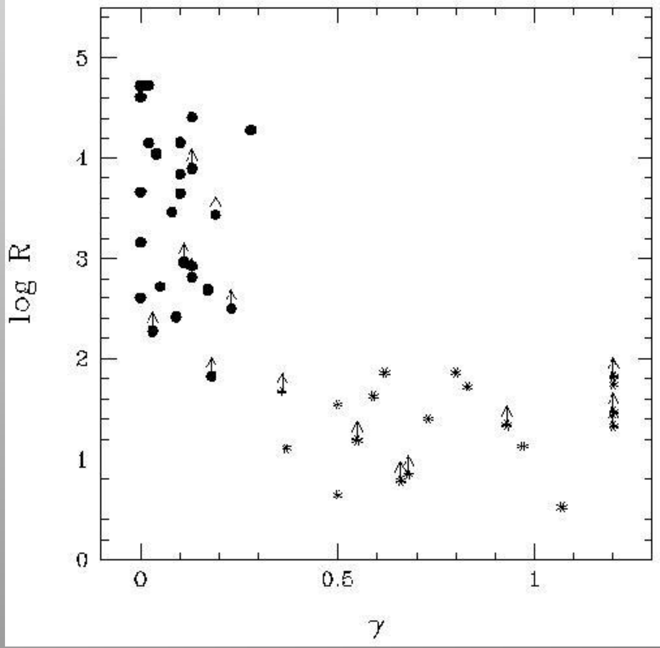


AGN in early type galaxies have a bimodal distribution of radio-loudness corresponding to "core" and "power-law" hosts.
Not simply related to the BH mass, only a factor of 2.5 larger for "cores".

A radio-quiet/radio-loud bimodality in nearby early type galaxies







The bimodal distribution of radio-loudness does not correspond to a threshold in host luminosity or Blackhole mass. They differ only statistically.

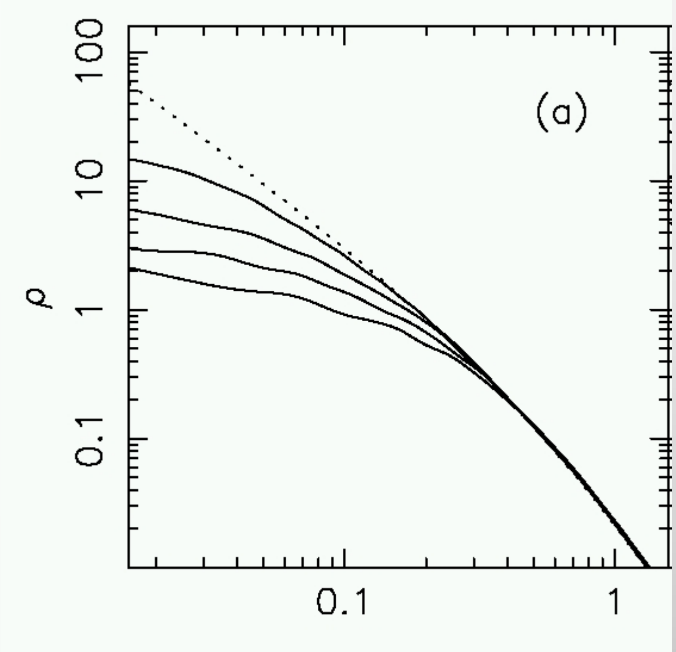
Only the brightness profile provides a full separation.

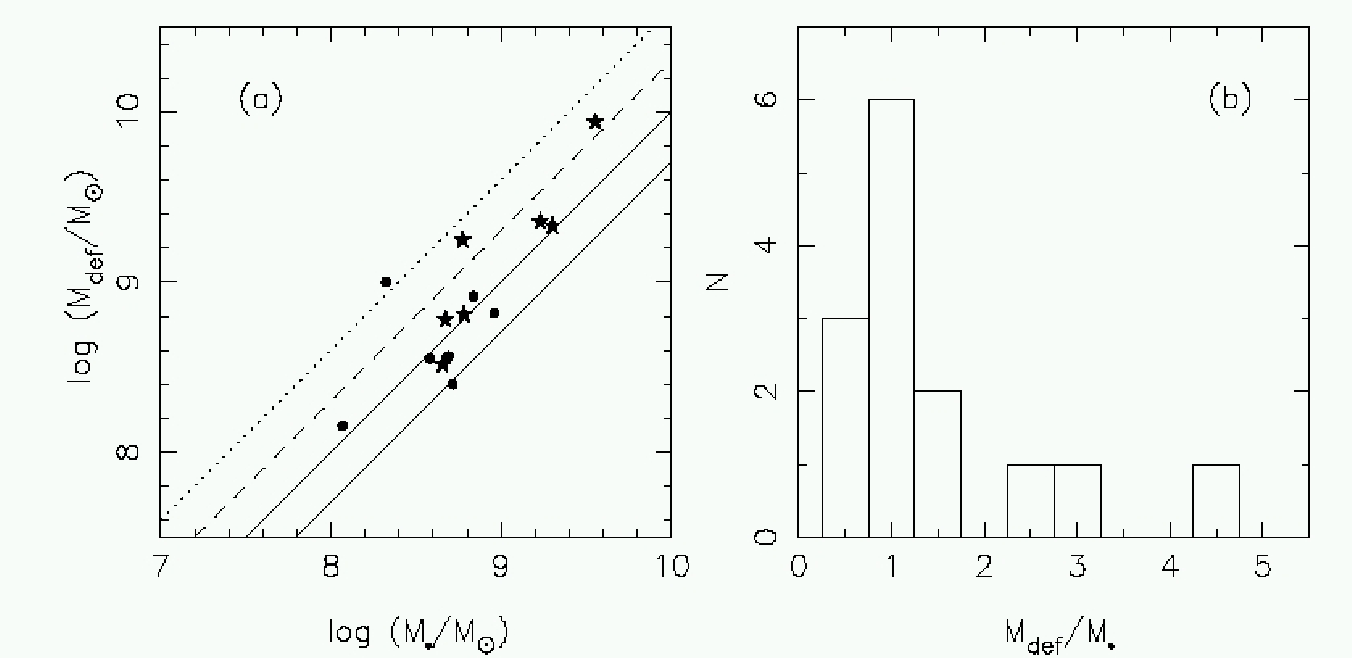
A possible interpretation.

Core galaxies form from a merger of two massive galaxies of similar mass. The flat brightness profile is explained with the stellar heating due to a system of binary black holes.
On the other hand, it has been suggested that radio-loud AGN are associated to a rapidly rotating black-hole (Wilson and Colbert 95), resulting from the coalescence of two large BHs from which the energy necessary to launch the relativistic jet can be extracted.

Power-law galaxies (and spirals) form from a chain of minor mergers, with small mass satellites hosting small BH (or no BH at all?). A different nuclear configuration which corresponds to a different AGN flavour.

Results from numerical simulatations.

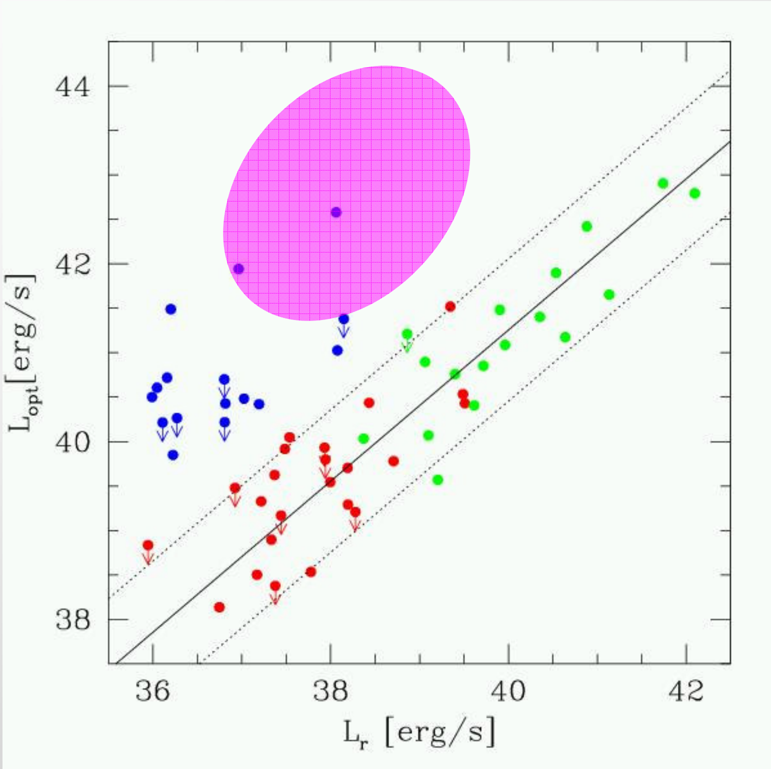


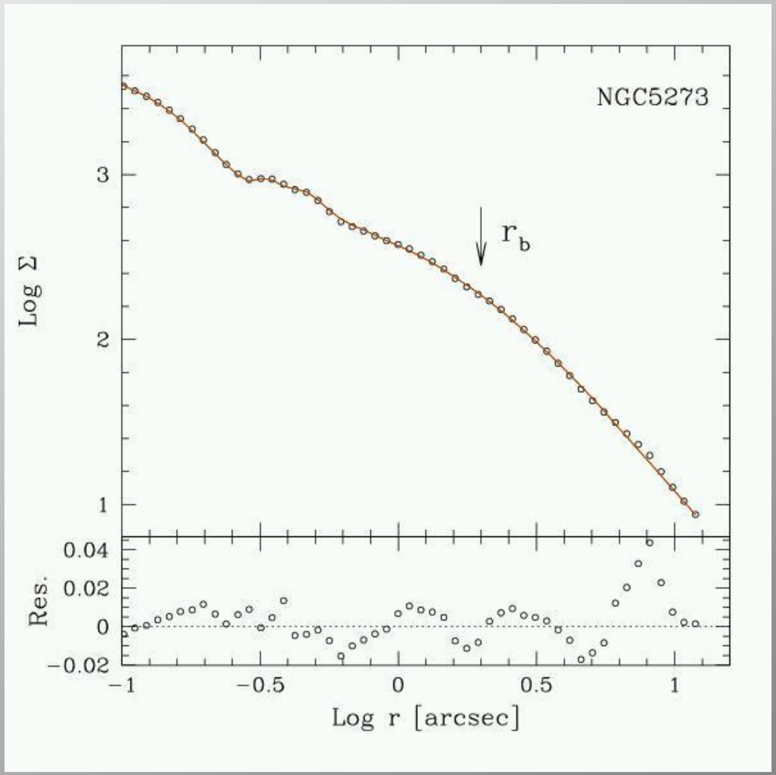


Numerical simulations (Merritt 2006) allow us to calibrate the mass deficit in core galaxies: $M_{def} \sim 0.5\ N\ M_{BH}$ where N is the number of mergers. Comparisons with observations sets N to 1 – (a few) mergers for CoreG. The bimodal distribution of radio-loudness might be driven by the value of N, which is N = 0 for power-laws, ≥ 1 for core-galaxies.

Extension to higher luminosity.

Do Seyfert galaxies have a power law profile?





Analysis of a sample of 51 nearby Seyfert 2 hosted by early type galaxies with NICMOS observations confirms that this is indeed the case.

Conclusions

The dichotomy between radio-loud and radio-quiet AGN corresponds bi-univocally to the dichotomy in the brightness profile of the host galaxy.

Note: spiral galaxies have bulges that can be described as power law (or Sersic) and do not host radio loud AGN, but only Seyferts and LINERs.

The galaxy's morphology is set by its formation history, via mergers.

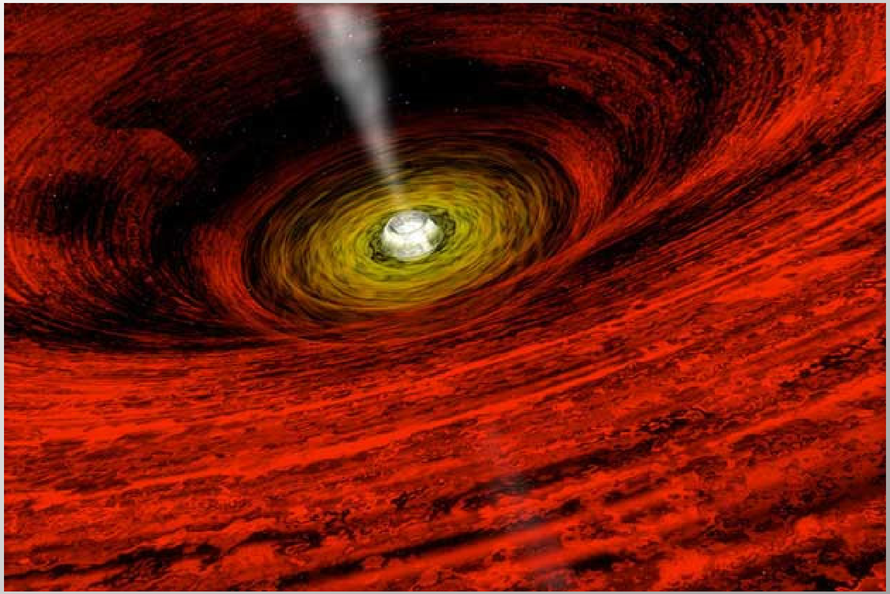
The AGN flavour is determined by the same process.

The crucial parameter appear to be the number of mergers (leading to a BH binary) occurred after the formation of the galaxy.

ACTIVE GALACTIC NUCLEI

Nuclear activity is observed in a significant number of galaxies, a fraction as high as 30% for low luminosity AGN in the local Universe. It is now clear that the light from the AGN is the result of the radiation released by gas in accretion onto the supermassivie black holes which are hosted by all massive galaxies.

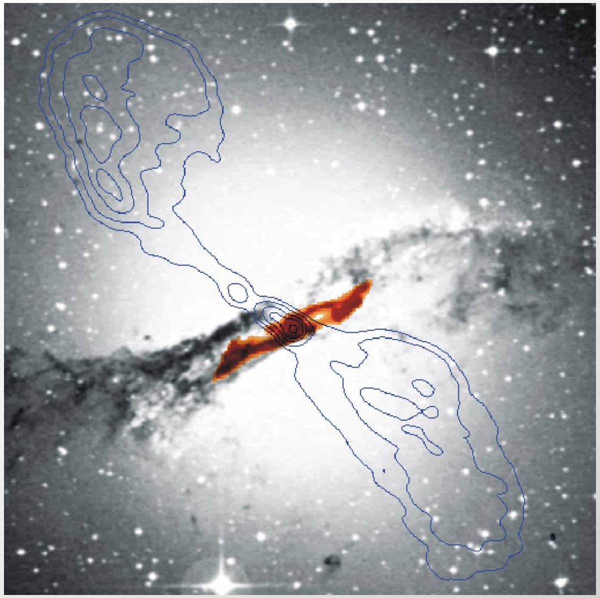
The newly discovered connection between black holes and galaxies makes the study of AGN a crucial ingredient to understand galaxies formation and evolution.



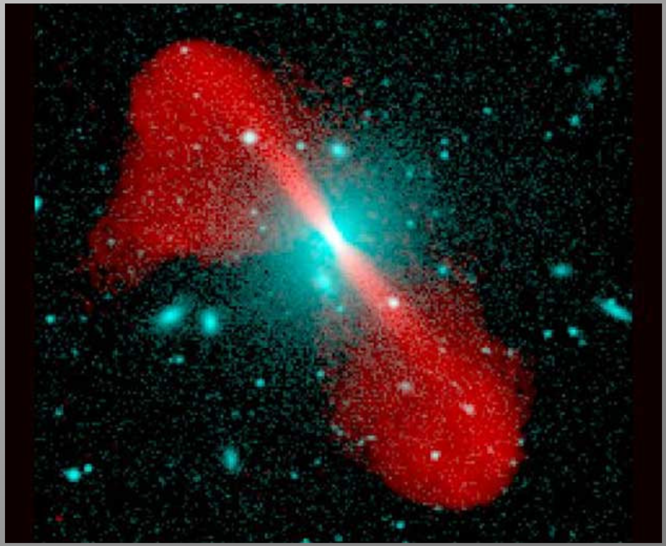
An AGN can present itself in an infinite variety of manifestations, probably depending on a large set of parameters (e.g. black hole mass and spin) and environments (e.g. host galaxy and accretion rate), all this further complicated by evolution.

The role of most parameters on the AGN properties is still largely not understood.

The radio-loud / radio-quiet dichotomy



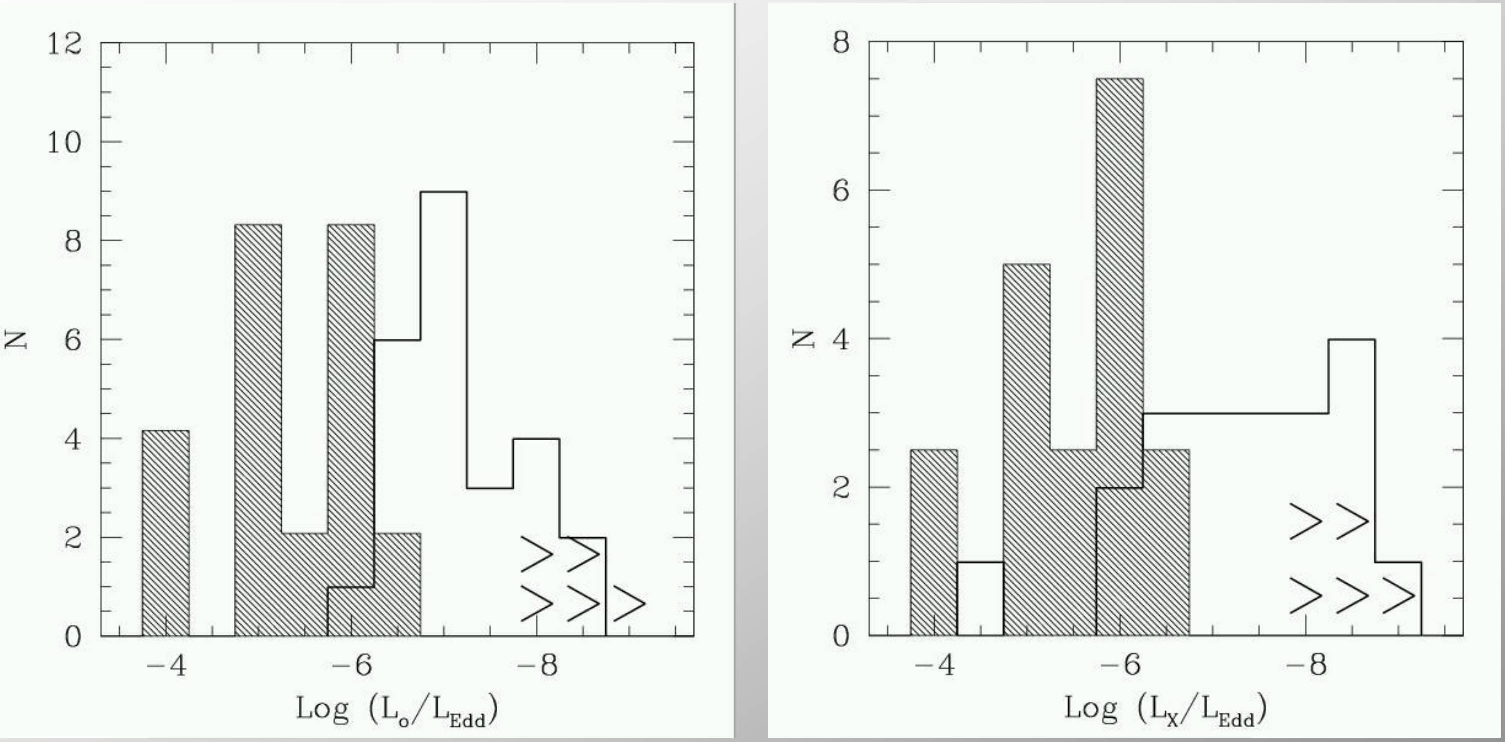
Among the many differences distinguishing AGN one of the best known and studied effect is the presence of two populations of AGN, which can be separated on the basis of their radio luminosity with respect to the light emitted in the optical band.



The dichotomy can be parametrized numerically, with a threshold of $L_r/L_o = 10$, but in most cases radio-loud AGN can be recognized by the presence of very extended radio-structures clearly associated to large scale jets.

Why only about 10% of the AGN produce jets?

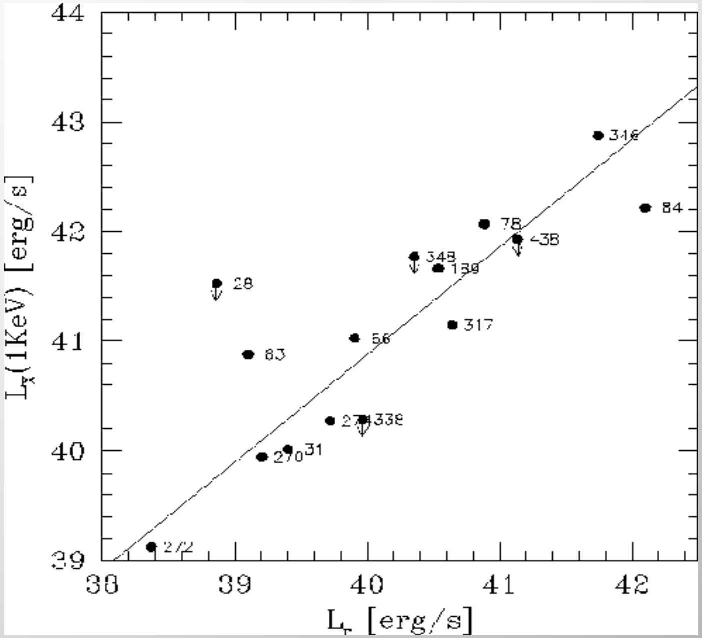
Limits on the "radiative accretion" in core galaxies

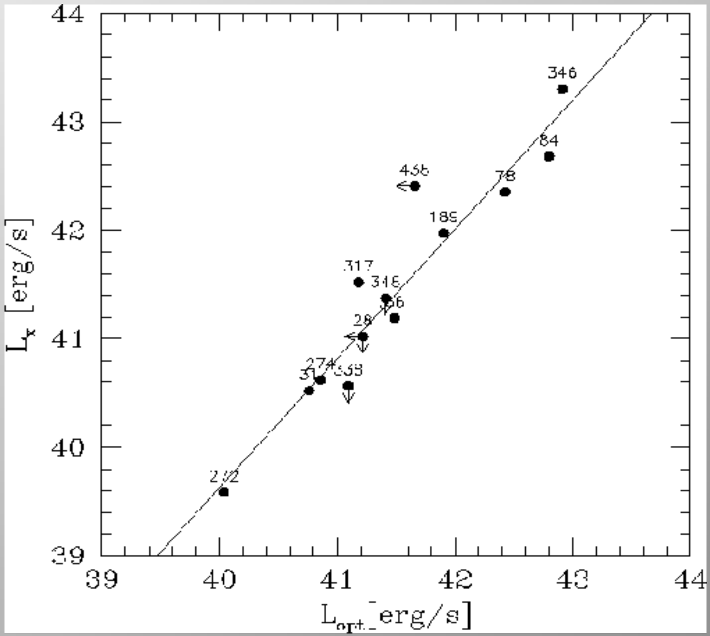


Nuclei of FRI and core galaxies set limits (upper limits?) to any radiative manifestation of the accretion process with values as low as $10^{-8:-9}$ L_{Edd}.

Even in an ADAF scenario it probably requires that most of the gas within the Bondi radius escapes without reaching the innermost regions.

A step backward: the nuclear properties of low-luminosity radio-galaxies





Nuclei in LLRG show strong correlations between the luminosity in the radio, optical and X-ray bands, suggestive of a common origin, most likely non thermal emission from the base of their relativistic jets.

LLRG nuclei are highly polarized (3-15 %) supporting the interpretation of synchrotron emission. It appears that the same scheme applies to early type core-galaxies.