# Radio Jet Energetics in ``Normal'' Galaxies: The Not-So-Silent Majority

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# Active vs. Normal Galaxies (continuum)

- ….the artist formerly known as Prince….
- focus on weakly accreting black holes in galaxies formerly known as “NORMAL” galaxies (now so-called LLAGNs)
- Nuclear luminosities in LLAGNs are at least ~100 times weaker than `classical AGNs (and the weakest SDSS AGNs)
- So weak that its not clear whether LLAGNs are powered by (or even have) an accreting black hole.

Obscuration, contrast of weak nucleus to underlying galaxy,
non-uniqueness of AGN origin, are all significant problems

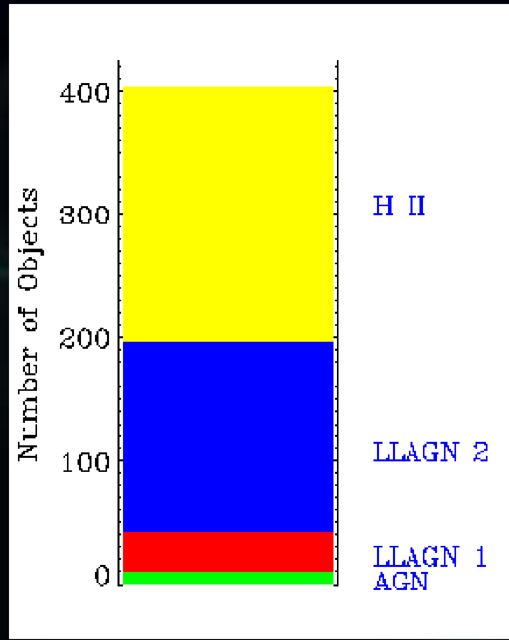
# Why should we (you) care?

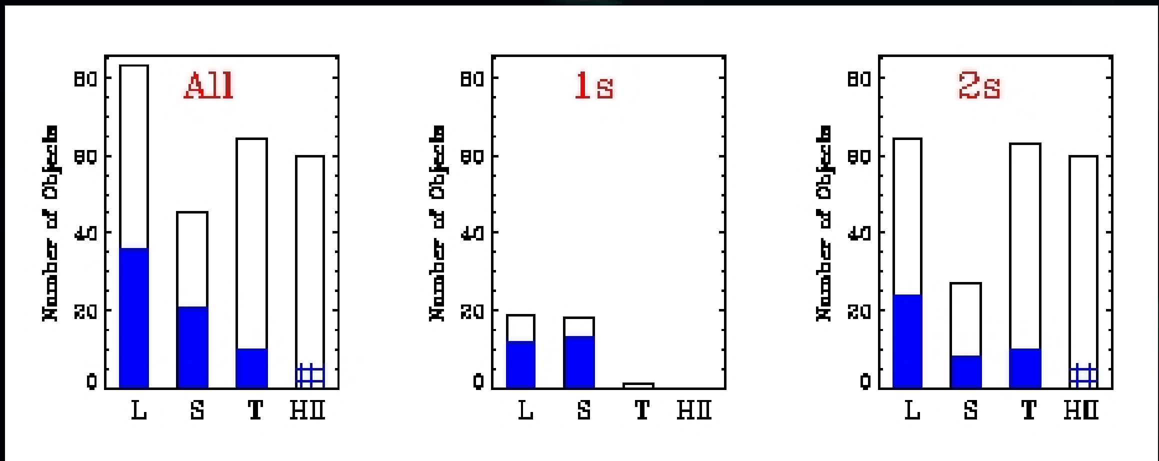
(Especially since its almost dinner time)

- Ubiquitity of supermassive black holes (jury?)
  - Tracking down Quasar Relics (why are they dead?)
  - `hidden' accretion can account for much of black hole growth
  - Coeval evolution of Galaxy plus black hole
- New accretion mechanisms
  - Matter starved? Or Radiatively inefficient accretion?
- Extension to population at higher redshifts

# The Palomar Sample

- 480 northern bright galaxies (B$_T$ < 12.5 mag)
  - two `classical' AGNs: NGC 1275, NGC 4151
- Radio arguably the best AGN tracer:




Nagar et al., A&A, 2002, and in prep
Filho et al. 2002 and in prep.
Ulvestad & Ho 2002

197 LLAGNs
193 observed in the radio
68 have compact radio cores.
VLA A-array:
Frequency: 15 GHz,
resolution : 150 mas
(15pc at D(median) =18 Mpc)

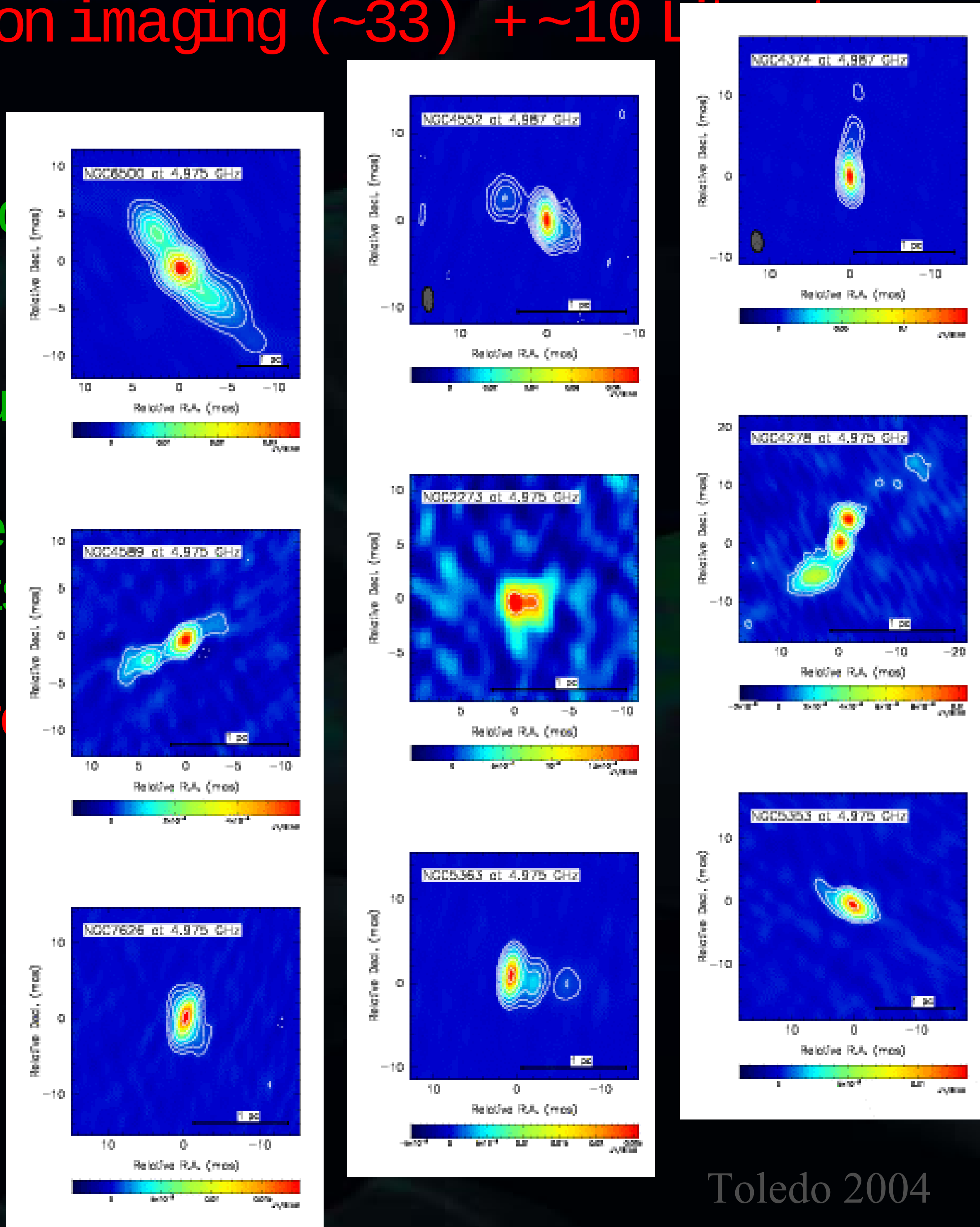
# Follow -up mas-resolution imaging (~33) + ~10 L

100% detection rate of
mas-scale (sub-parsec) rad

Implied $T_b > 10^8$ Kelvin
Thermal emission ruled ou

Radio cores with the highe
compact fluxes have jets

I.e. Confirmed AGN natur
the VLA-detected nuclei




Falcke et al. '01
Nagar et al. '02,'04

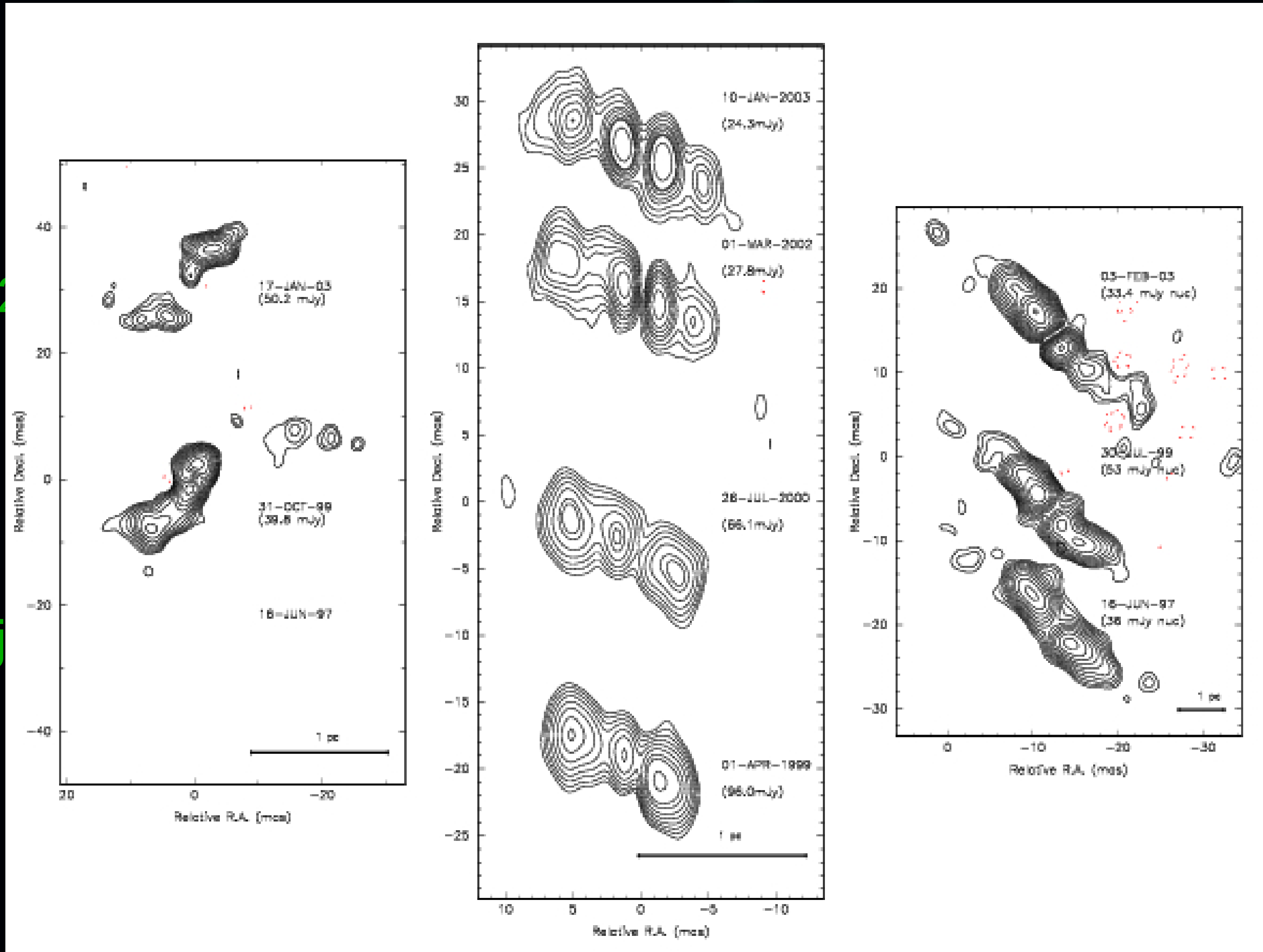
# Sub-relativistic `knots' and ?relativistic? plasma flows

NGC 4278:
~ 0.1c

NGC 4552:
0.09c, 0.14c, 0.2

NGC 6500:
~ 0.1-- 0.2c

Possibly helical j




Nagar et al., in prep

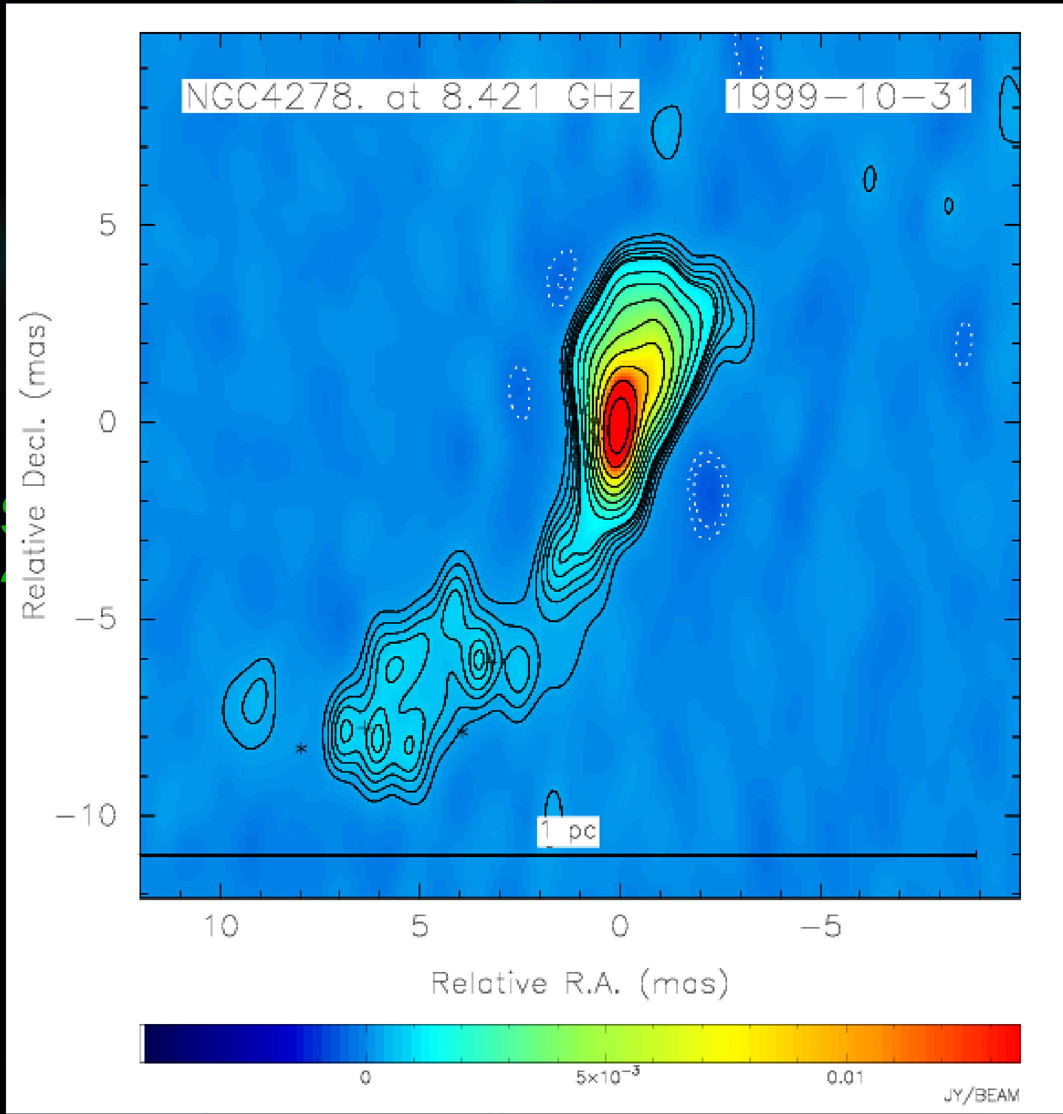
NGC 4278 NGC 4552 NGC 6500

# NGC4278 : `tight' relativistic jet?

Distance: 9.7 Mpc:
1mas = 0.05 pc

Two assymmetric jets

Multiple >90 degree bends
-- Jet – BLR interaction
-- helical jet?




Nagar et al., in prep.

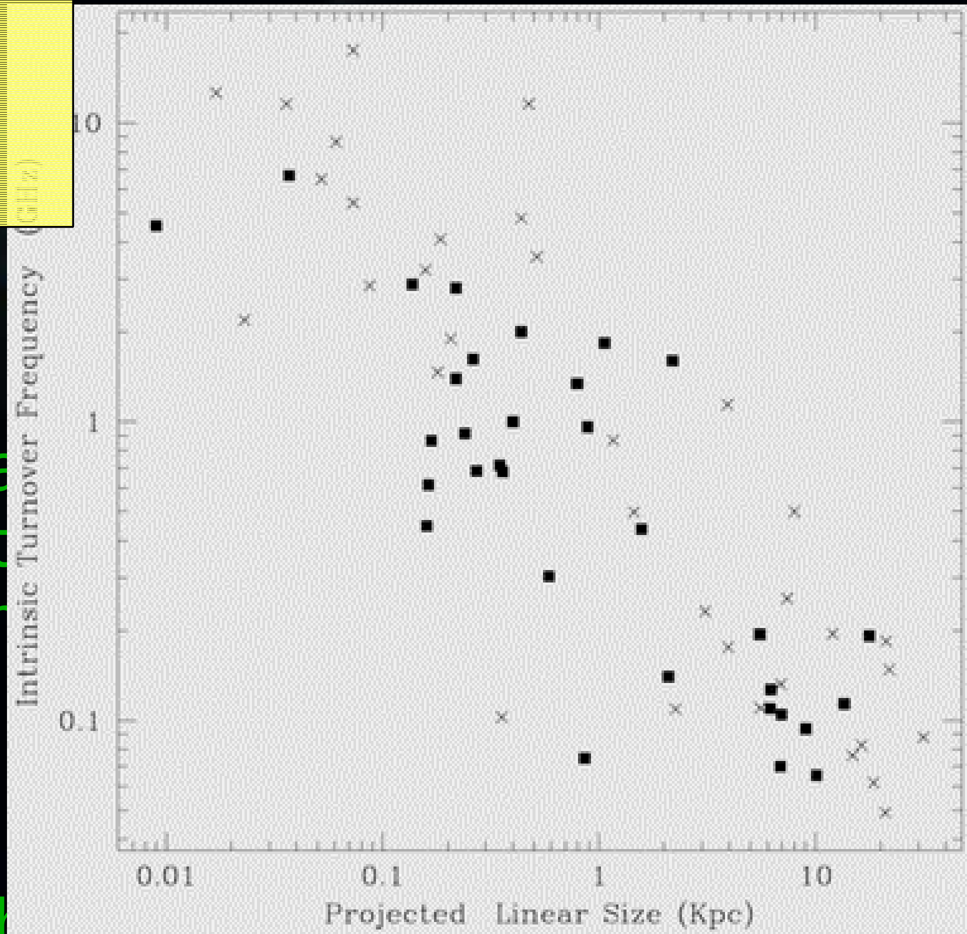
# Gigahertz Peaked Sources in LLAGNs?

Peak in the 1-20 GHz range
weak X-ray sources
compact-symmetric or core-jet.

LLAGNs : sub-parsec extents a
1-20 Ghz peaks would place t
at the extreme GPS population

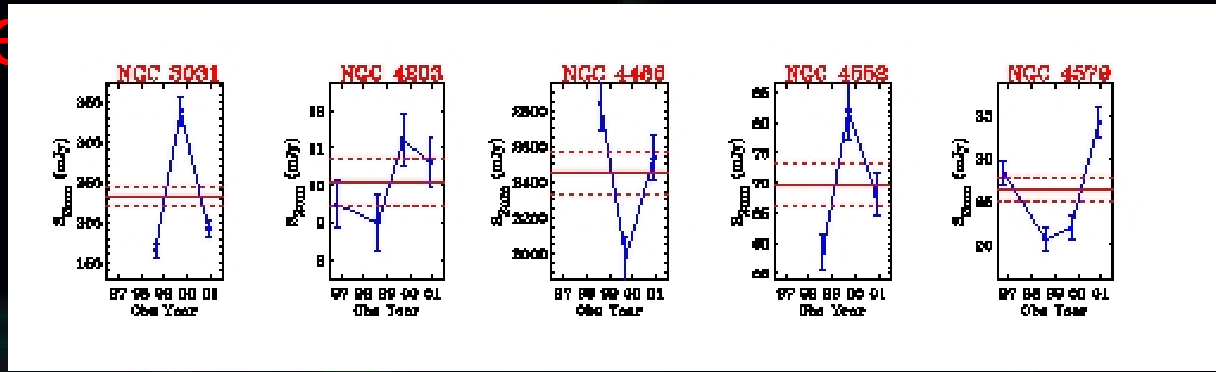
Young or frustrated?

Extreme GPS : single ejection changes spectrum.




O'Dea 1998

# Other AGN propertie

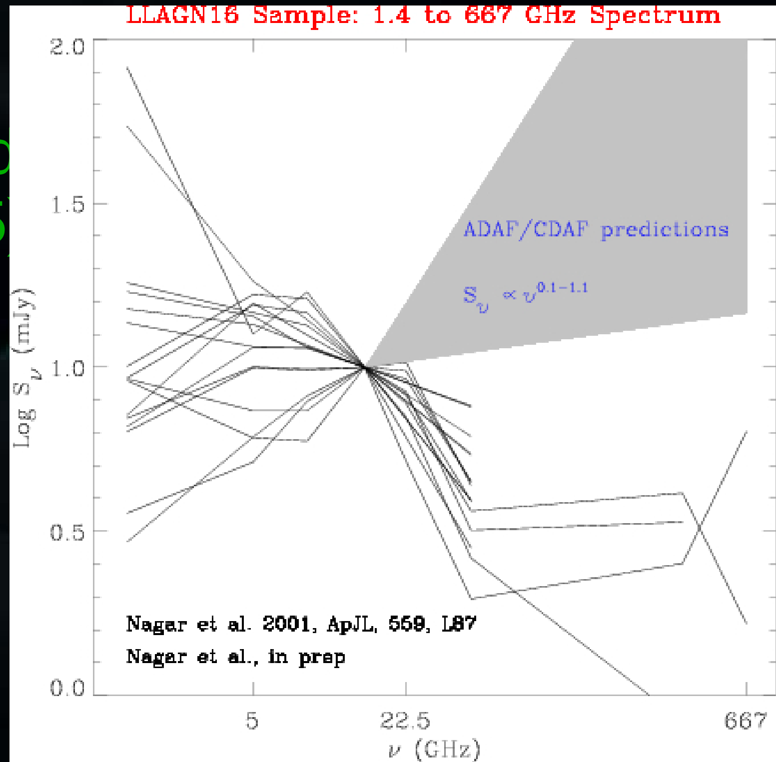



10 --50% variability over ~1yr timescales

Nagar et al., A&A, 2002

Coordinated HST-UV and radio variability campaign recently completed
UV variability common! (Maoz et al. 05

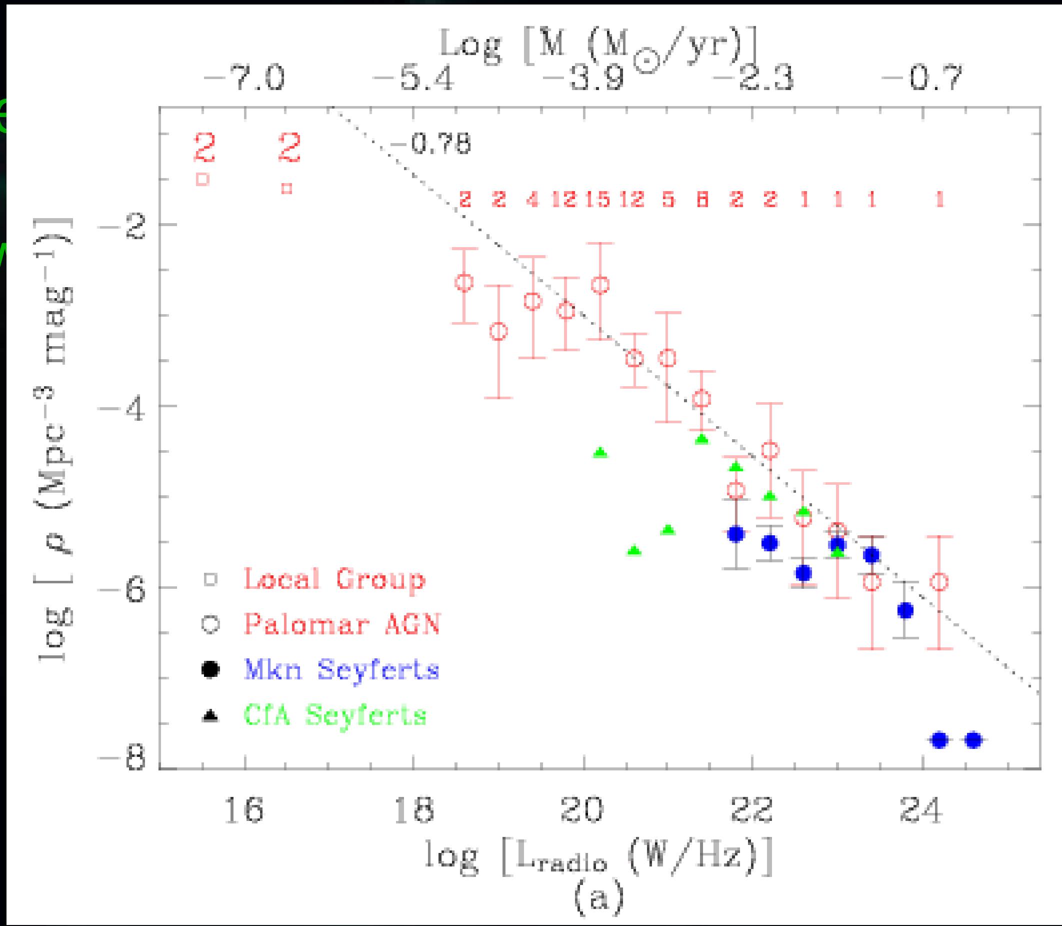
Flat radiospectrum: jets, not RIAFs



# Palomar sample RLF: the Not-so-silent Majority

Smooth connection to Mrk Seyfe

Suggestion of flattening at $10^{19}$ W



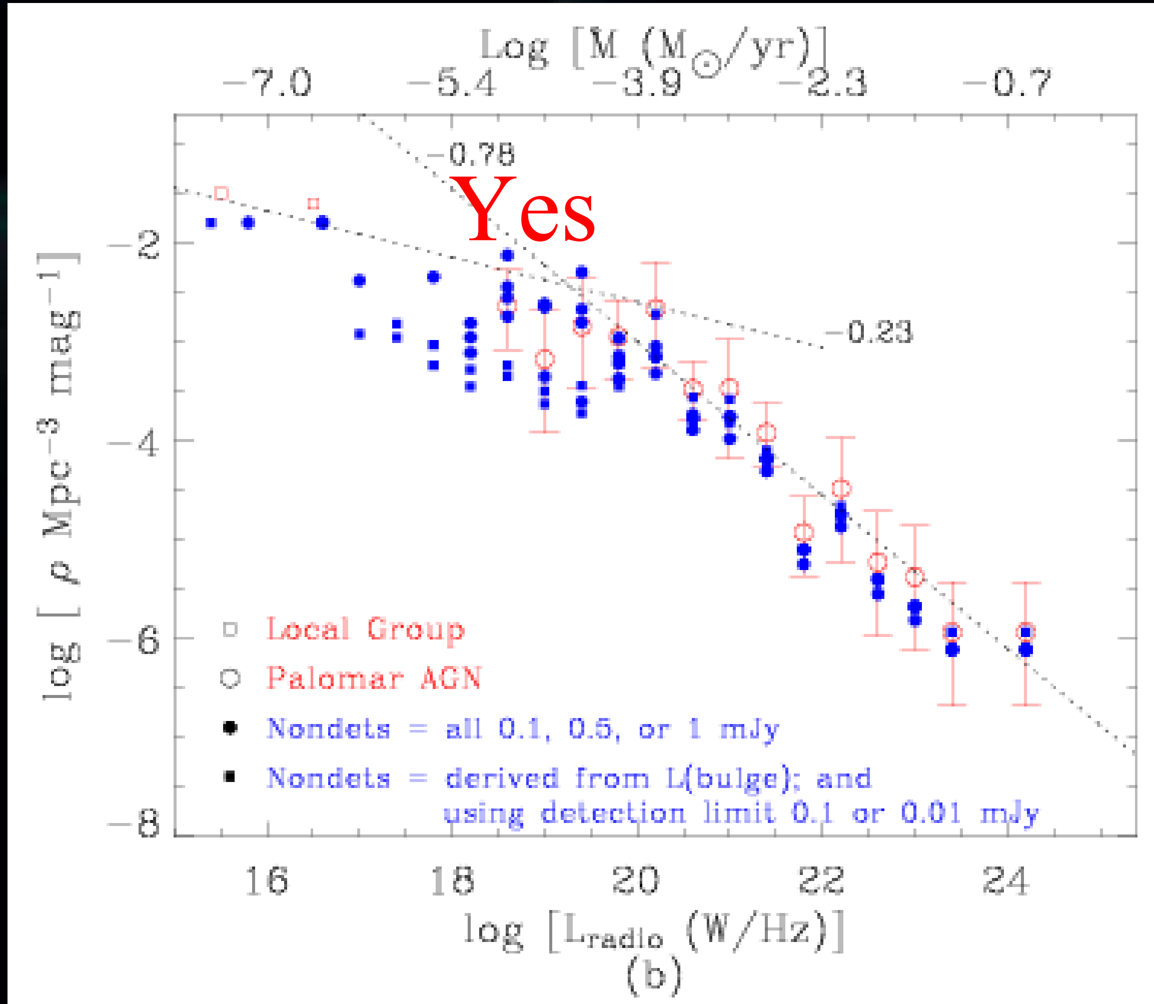

Nagar et al., (2005)
(Mrk RLF: Meurs & Wilson 1984
CfA RLF : calculated by Ulvestad & Ho 2001
using data from Kukula et al.

# Is the RLF break real?

Red squares: Local group RLF

Blue squares: 1, 0.5 or 0.1 mJy

Blue circles: from L(bulge)



# Imaging the shadow of a black hole - potential targets
(also the jet-collimation region)

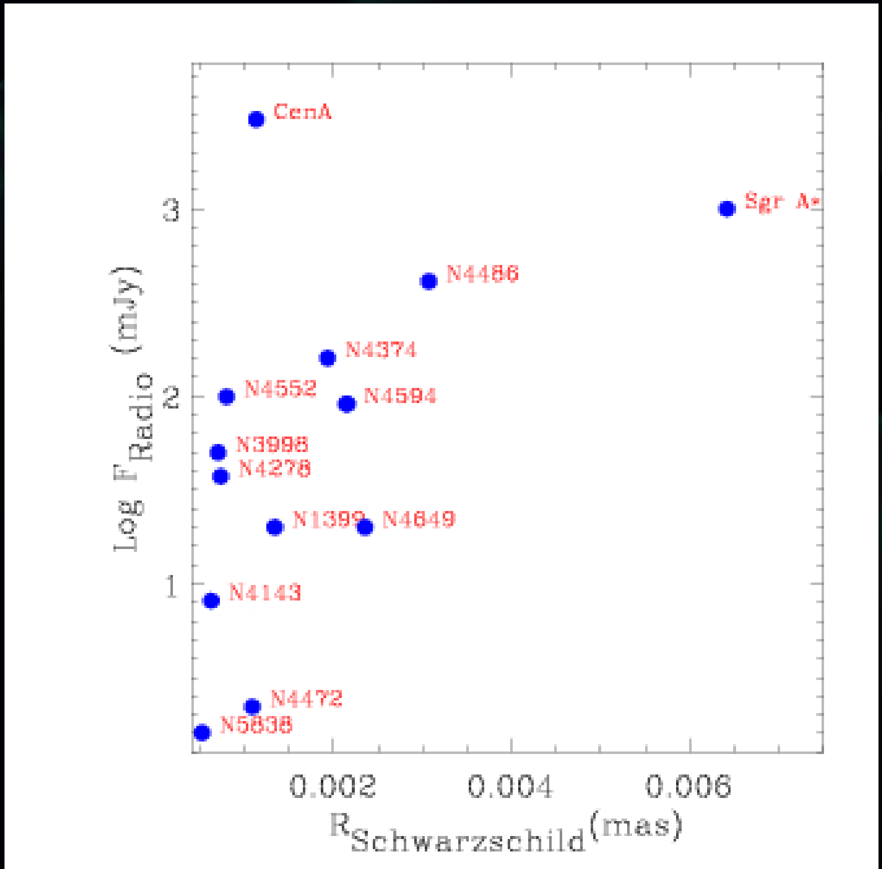
VSOP:
- 0.1 mas @ 6cm

VLBA:
- 0.32 mas @ 7 mm
- 0.15 mas @ 3 mm

SKA:
- up to 20 Ghz
- sensitivity: 50 nano-Jy

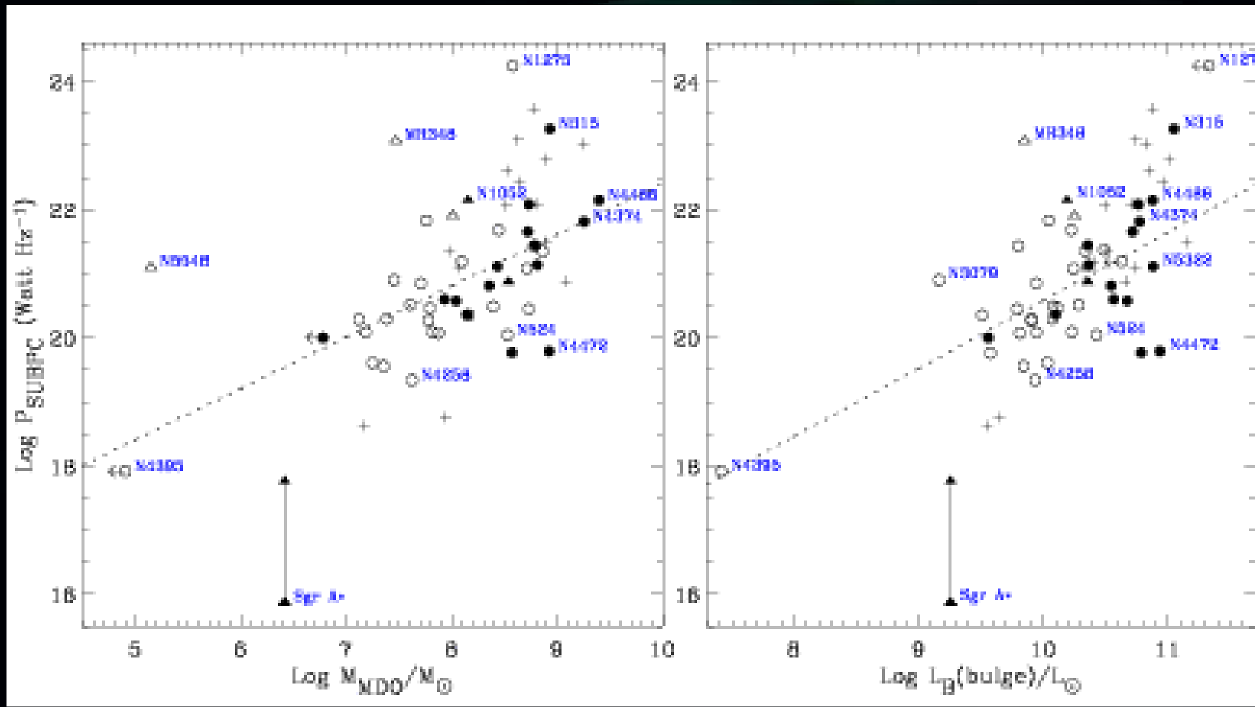
ALMA: 10 mas

mm-VLBI



# Radio Power and Galaxy/Black Hole Mass

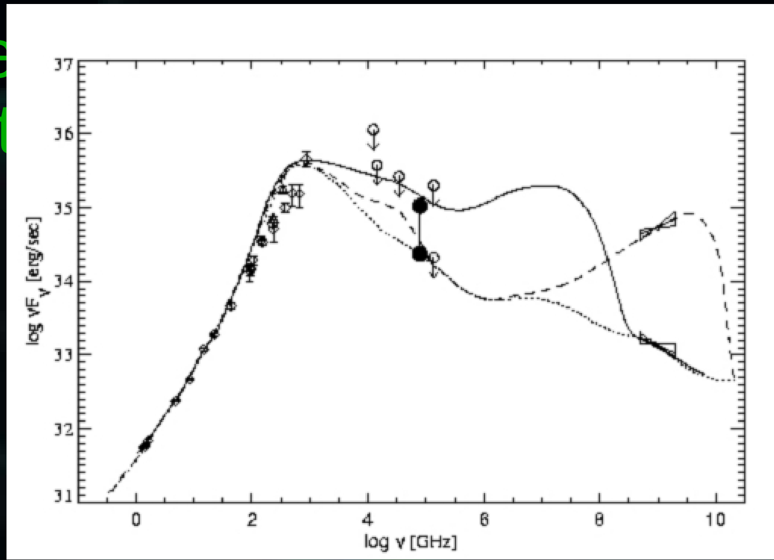
Only Sub-Parsec Radio Measurements




Nagar et al. 2005

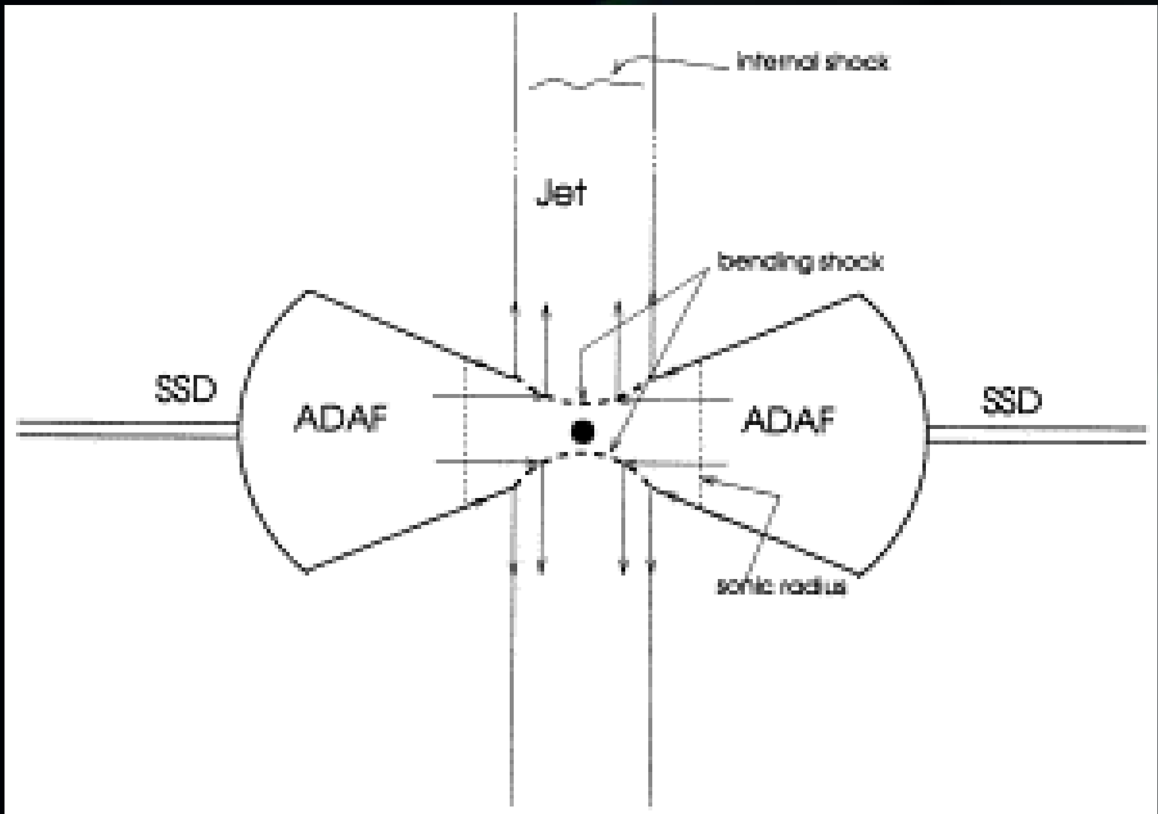
# Jet model: Sgr A*, NGC 4258, LLAGNs

`Bending shock' produces power-law ele
distribution. Synchrotron and SSC from t
electrons give IR and X-ray emission.




Yuan et al. 2003

Internal shocks in
produce the radio



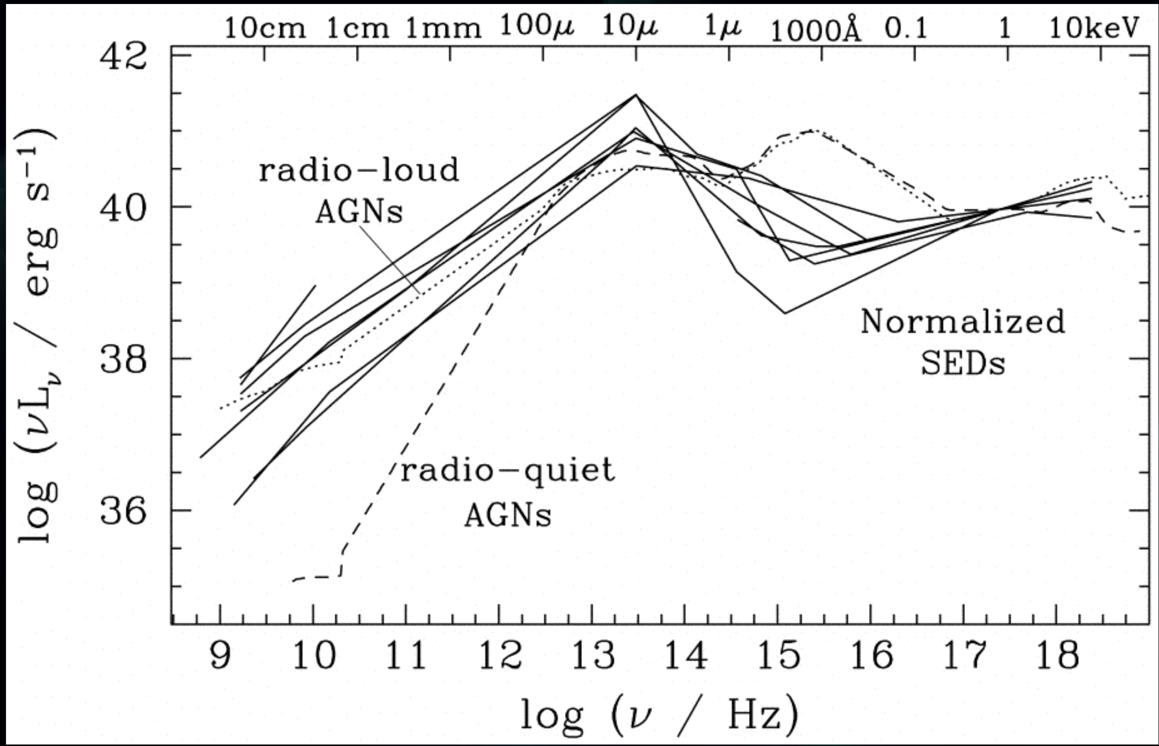

Yuan et al. 2002,2003

# Spectral Energy Density (SED) of (famous) LLAGNs

No big blue bump.

radio loud.

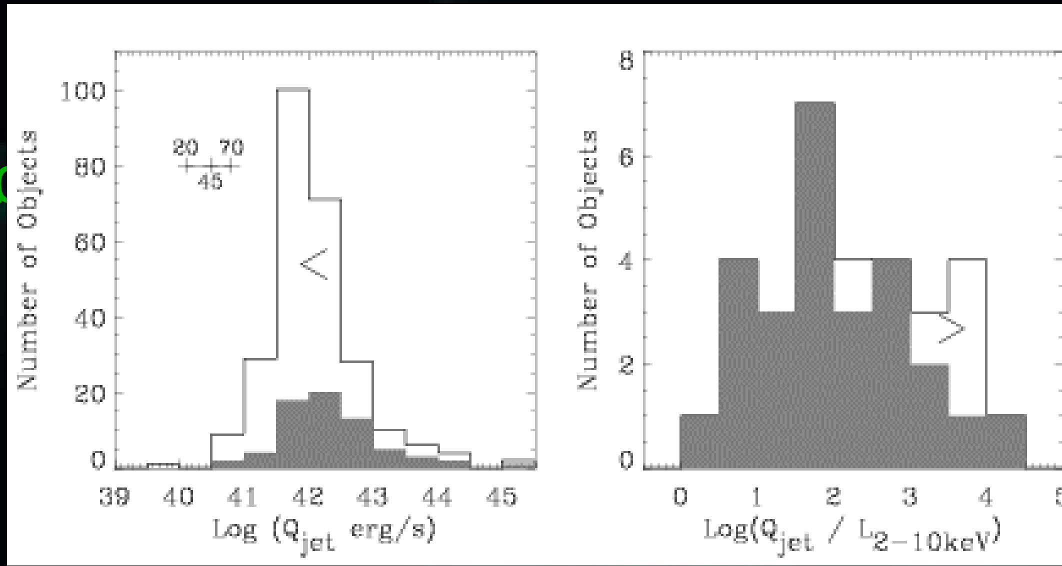
X-ray dominates.
- or does it?

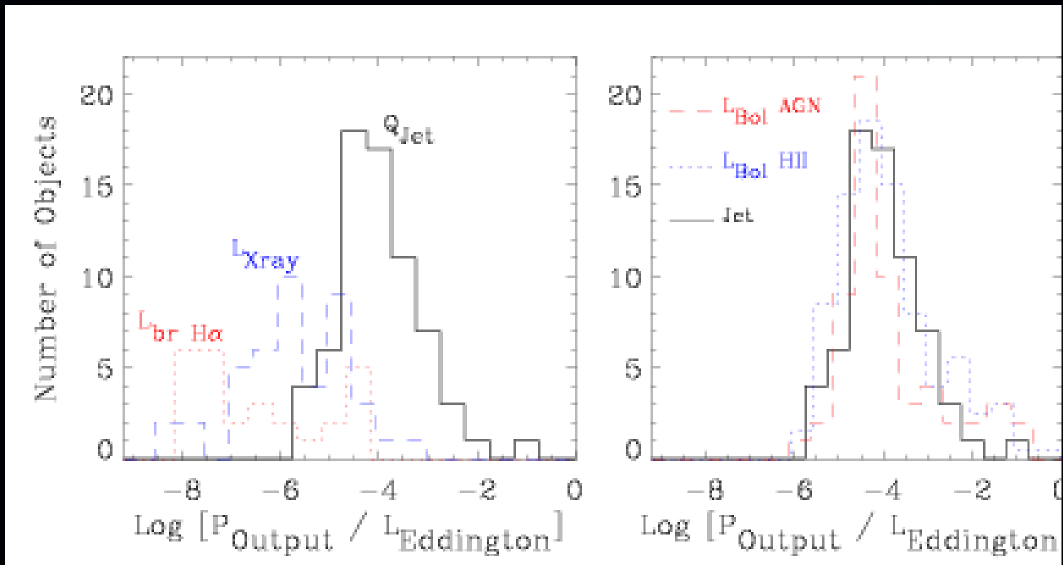


# Jet Model: $Q_{jet}$ dominates X-ray (and Bolometric) Outpu

$L_{bol}$ 3 – 15 $L_{X\text{-}ray}$

Jet could carry away a signific
fraction of accretion power.



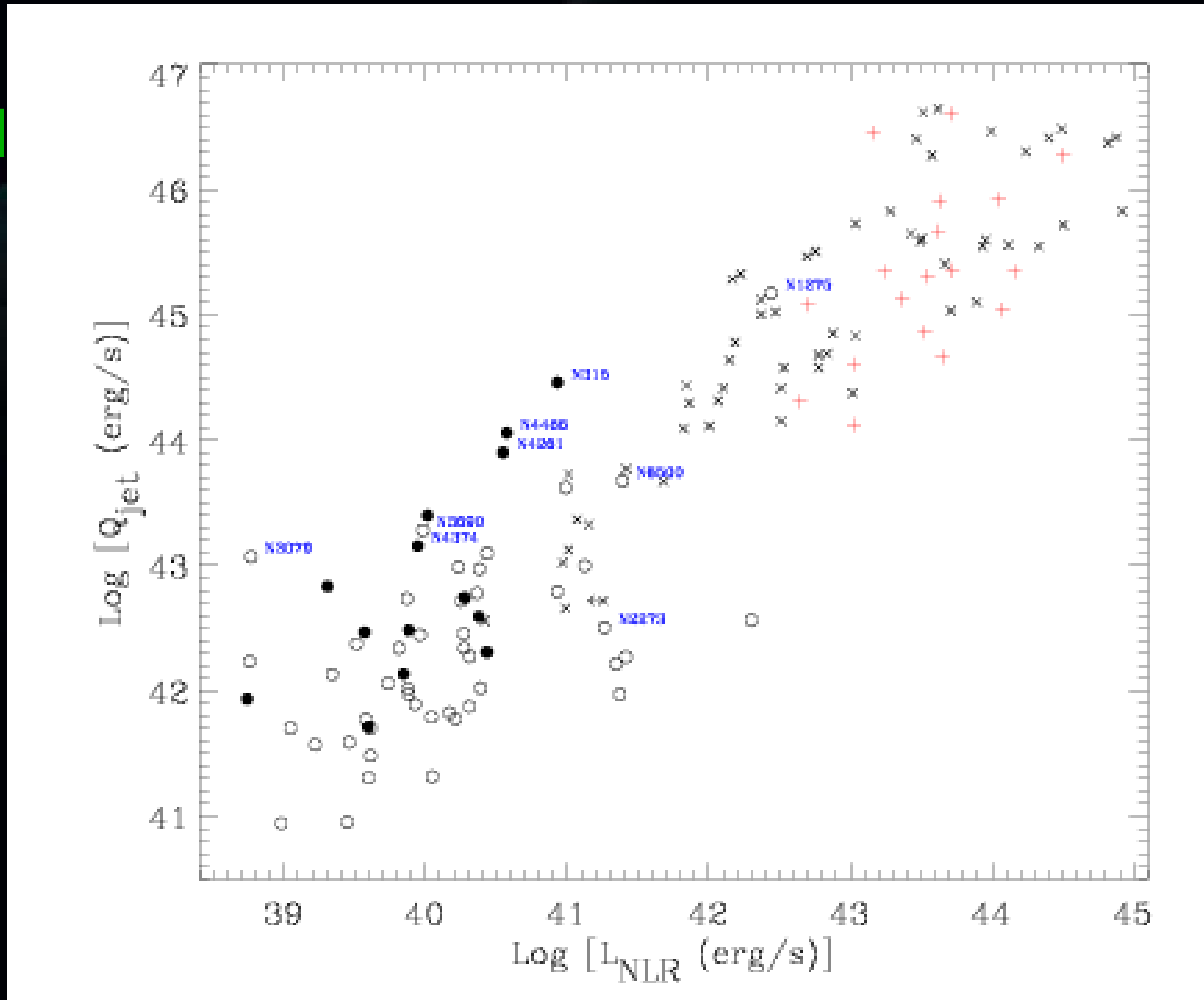

Nagar et al. 2005

# Jet Model ($Q_{jet}$): LLAGNs and AGNs in common scalin

Rawlings & Saunders
(blue crosses; measured

Celotti & Fabian
(red crosses; jet model)

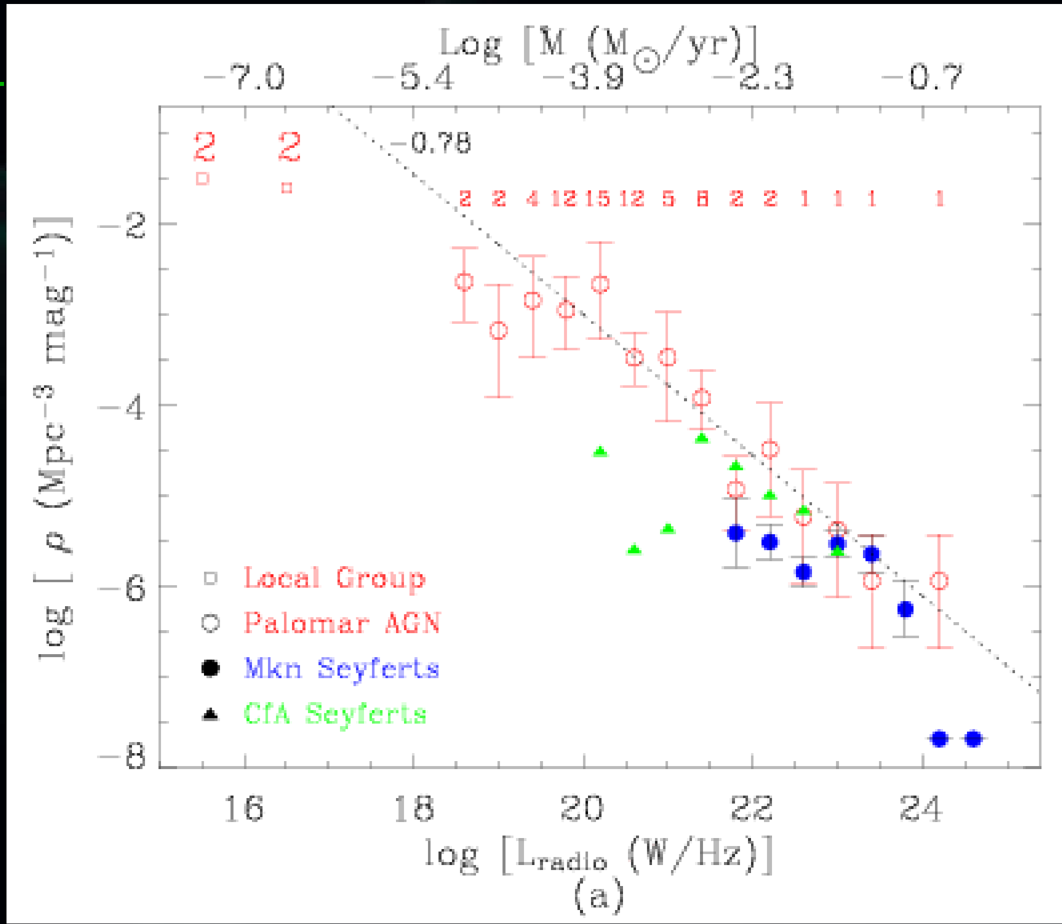
Palomar LLAGNs
(circles; filled=elliptical)



# Palomar sample RLF: the Not-so-silent Majority

Accretion rates down to 10 -

RLF break at $10^{-5}$




Nagar et al., (2005)

# Jet Model ($Q_{jet}$): LLAGN Jets and Galaxy Energetics

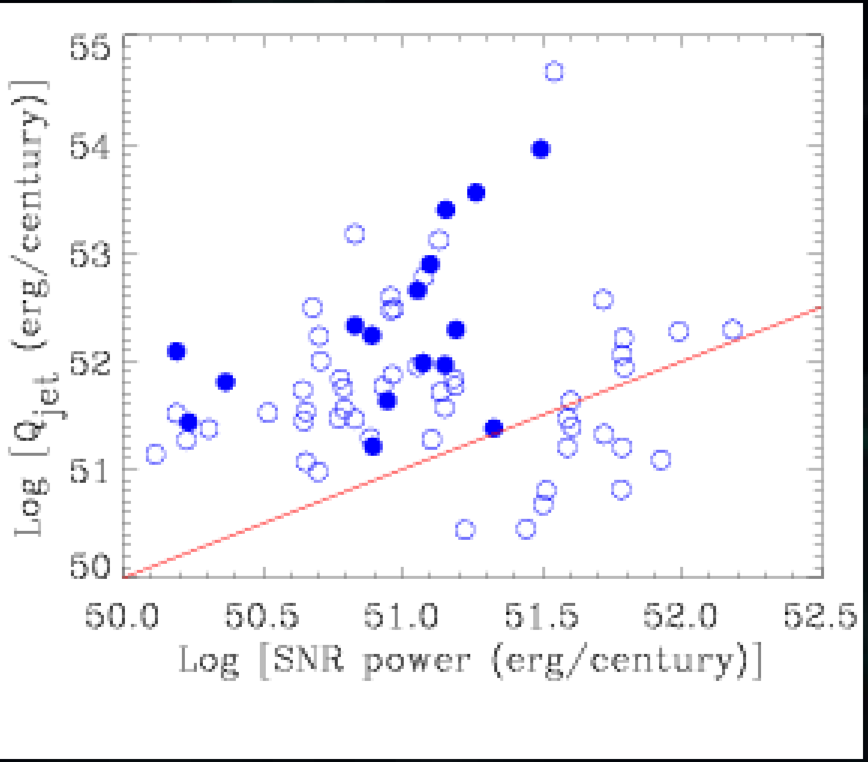
Other important input to galaxy energetics are SN type I and II

For a 100% duty cycle, the LLAGN jets dominate SNR power output

Jet energy dumping is nuclear; mo closely tied to accretion feedback

e.g. Ostriker, Binney - coeval evolu

feedback regulates black hole growth



# The high-z potent

SKA:

50 – 100 times VLA

VLBI mode:

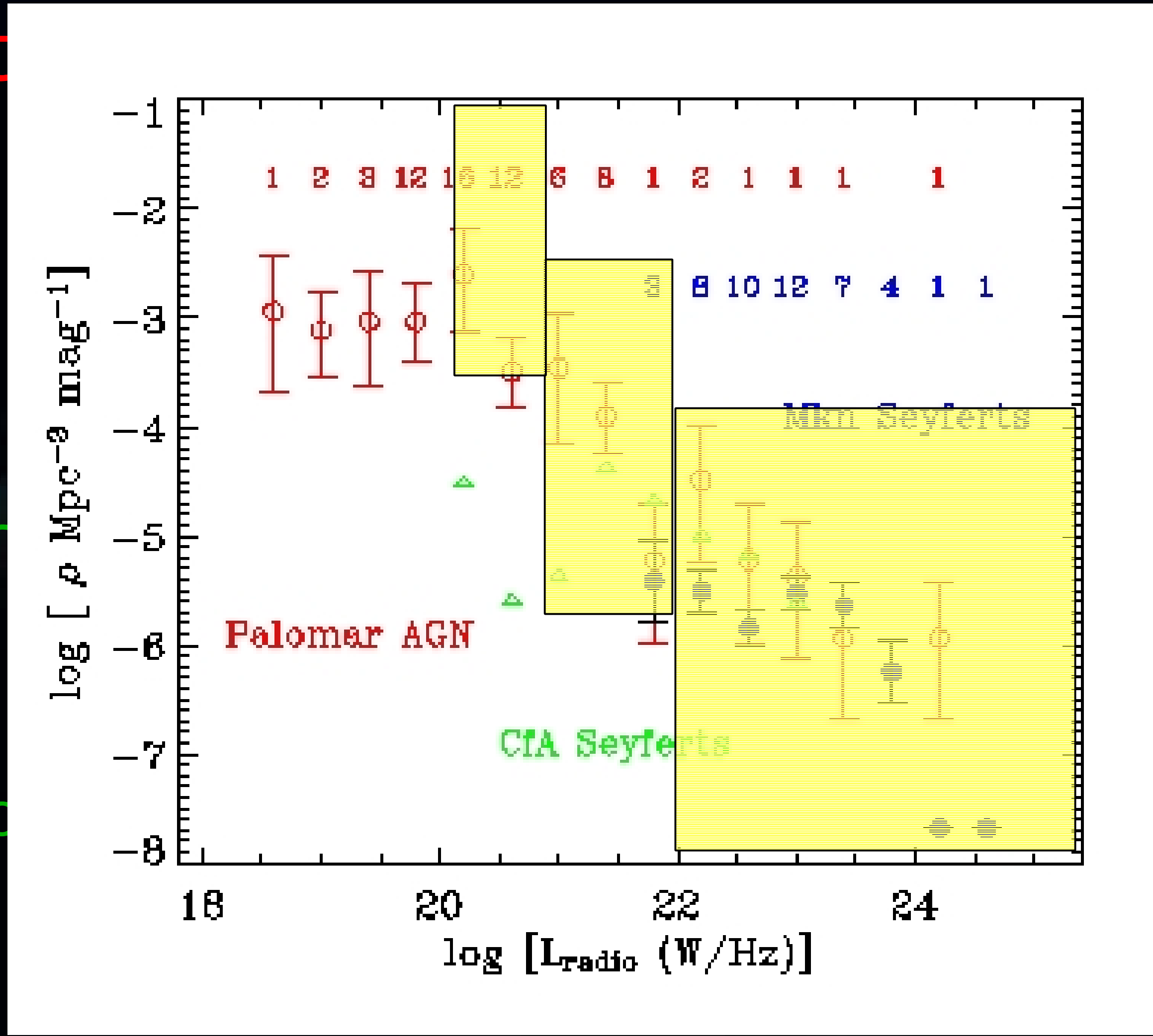
1hr, 7 sigma: 15 micr

i.e. Sgr A* at 2.5Mpc

high b/w mode:

1hr, 7 sigma: 1.5 micro

i.e. Sgr A* at 8 Mpc




Z= .1 .2 1.0

Radio Luminosity Function

# Summary I – a happening backyard

- > 25% of all nearby bright galaxies have detectable accreting black holes; these are preferentially in `type 1s' and massive ellipticals.
- Milli-Jy radio population; but not a silent majority
- Radio emission dominated by jets in the well studied objects
- Relativistic plasma motion and sub-relativistic radio knots in the best studied LLAGNs: beaming could be a factor
- Compact, absorbed sources: many similarities to GPSs
- Jet + RAIF model the most consistent so far (but also most free parameters)

# Summary II – a little physics

- Highly sub-Eddington but jets could account for significant (dominant?) fraction of accretion power in LLAGNs
- Jets significant player in galaxy energetics even in LLAGNs
- Jet – BLR interactions
- Spectacular resolution: jet physics and black hole laboratories.
- Can push to higher – z with new instruments, but this sample will remain highly unique (even in the SDSS, or later SKA, era)