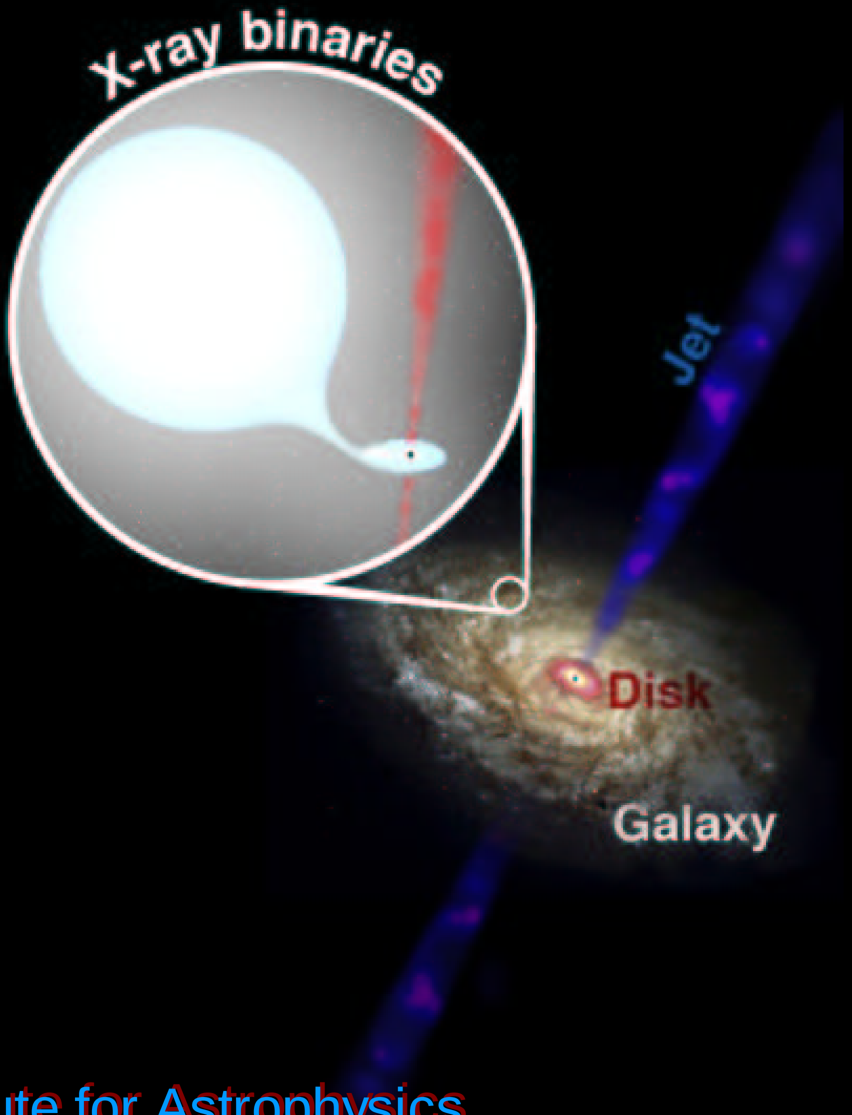
Baby beams and jumbo jets:

investigating the relation between microqusars and AGNs



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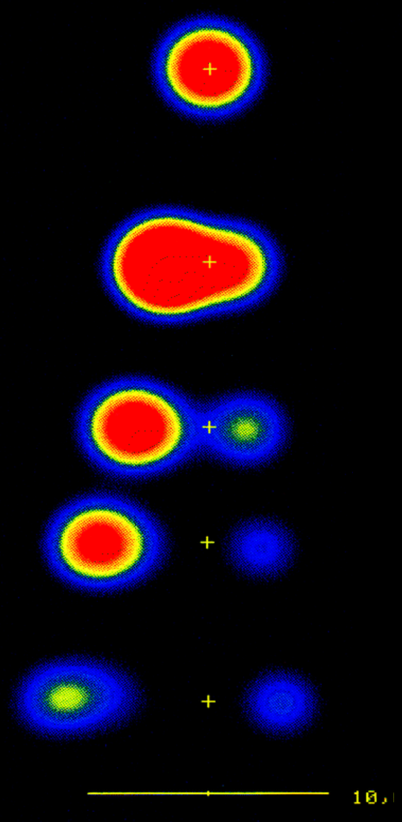
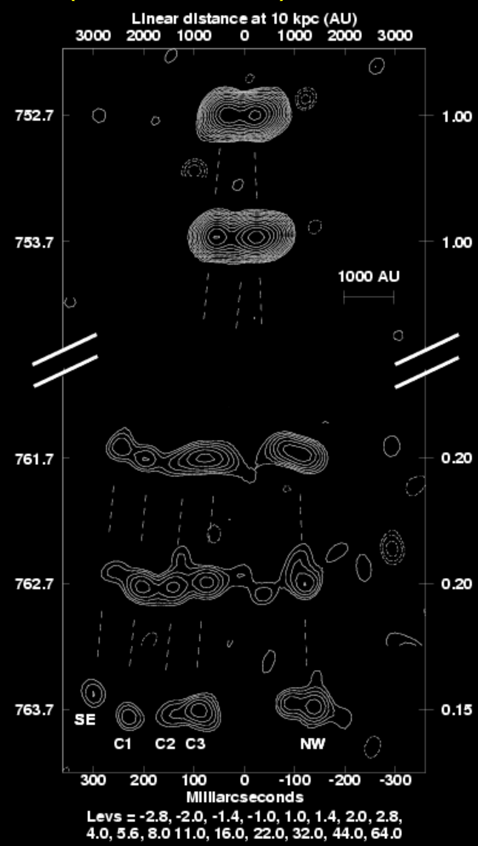
at Max-Planck-Institute for Astrophysics

Similar morphologies

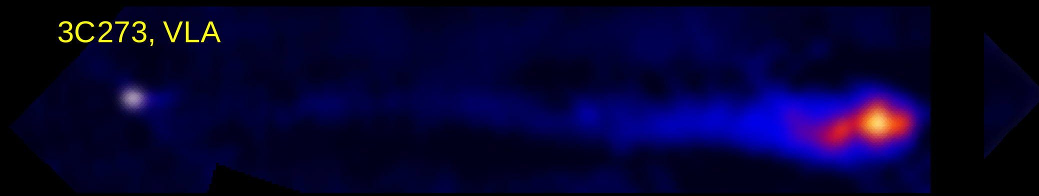
GRS 1915+105, VLBA (Mirabel et al. 94)



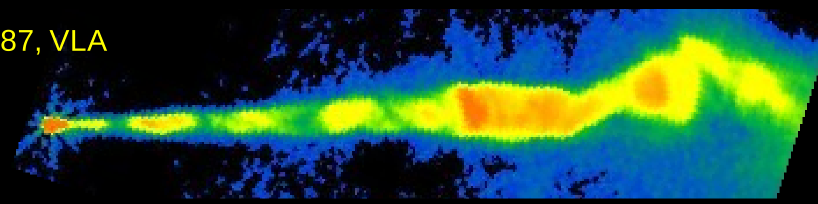
GRS 1915+105, MERLIN
(Fender et al. 99)



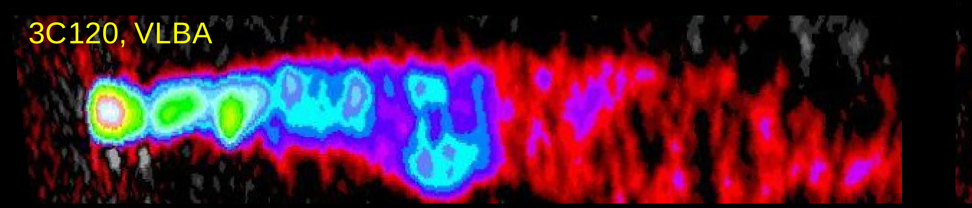
3C273, VLA



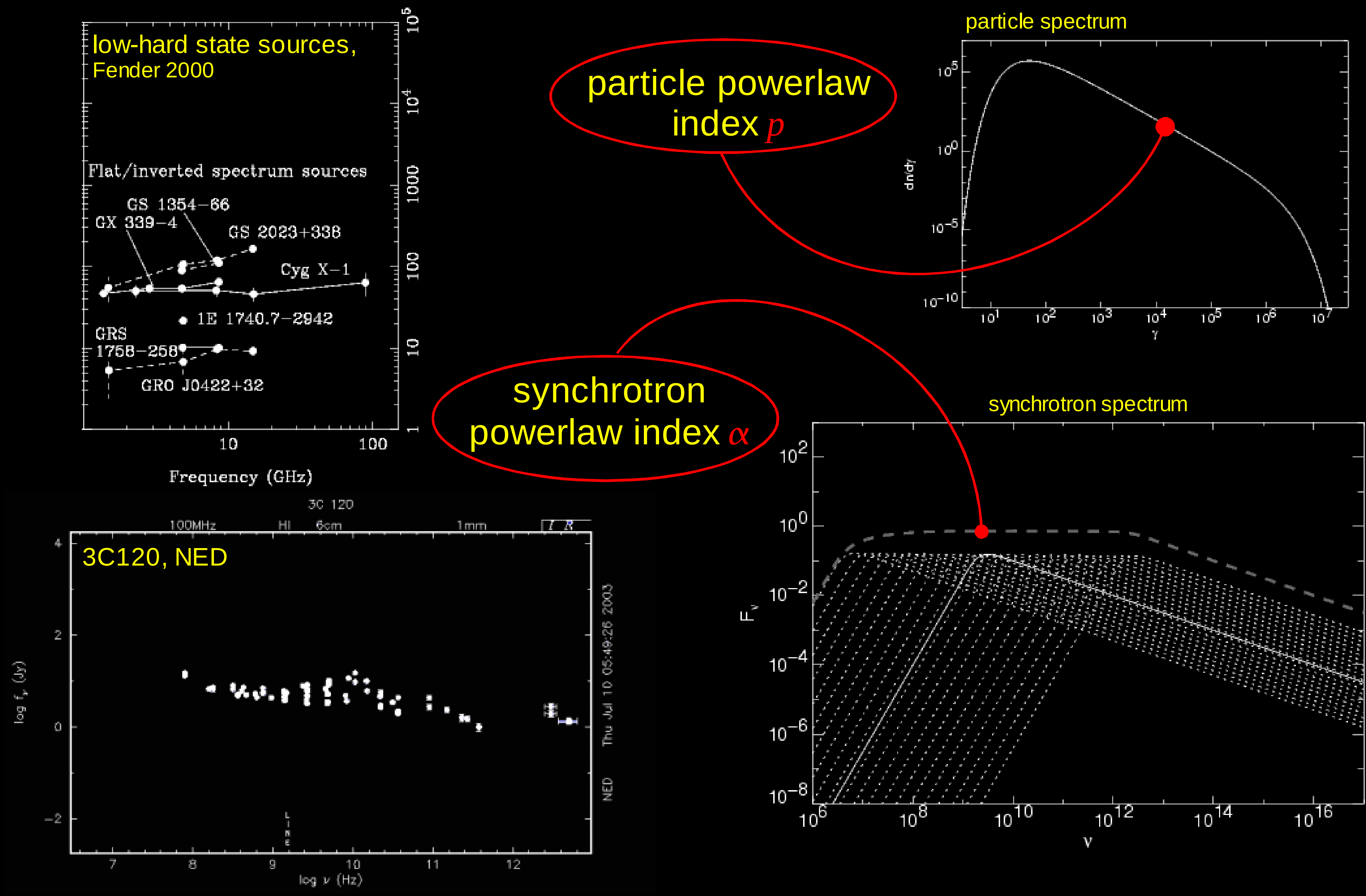
M87, VLA



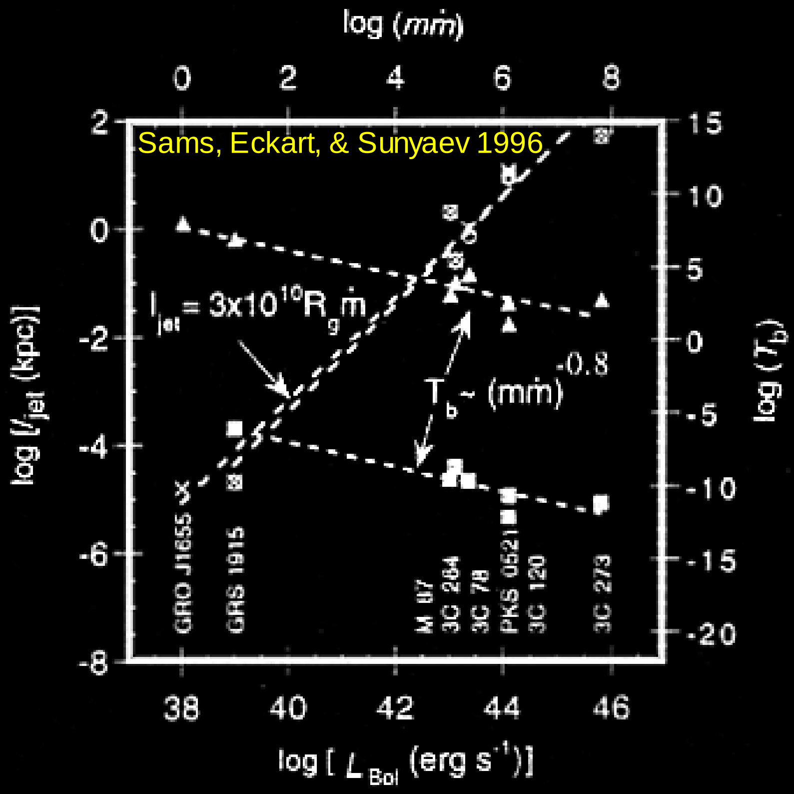
3C120, VLBA



Flat nuclear spectra



AGNs are more radio loud than microquasars



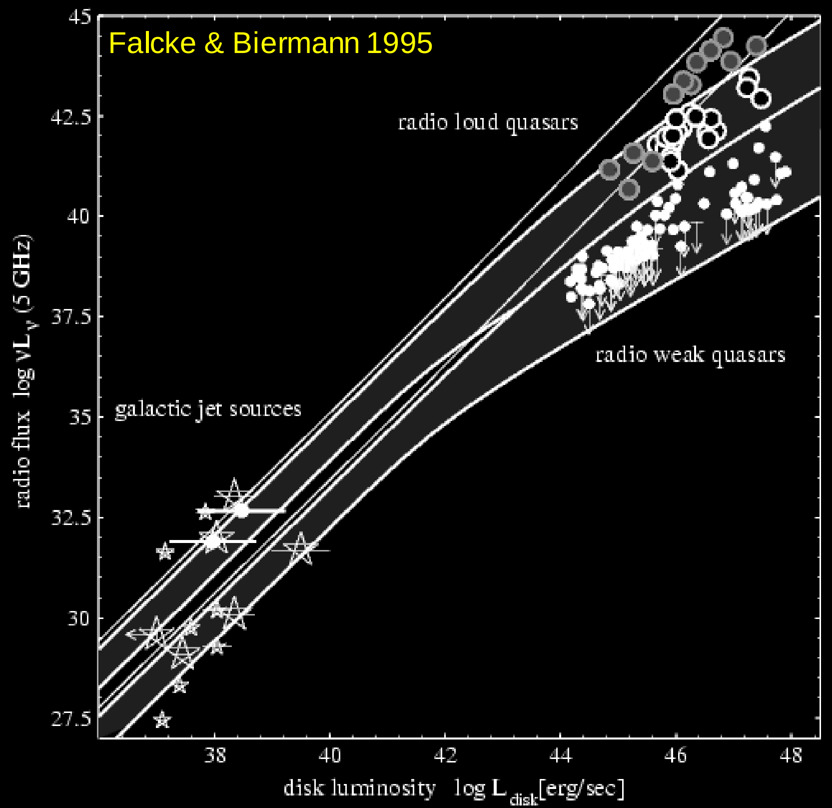
Opt. thin jets:

$T_{\rm b} \propto \dot{M}^{-0.76}$

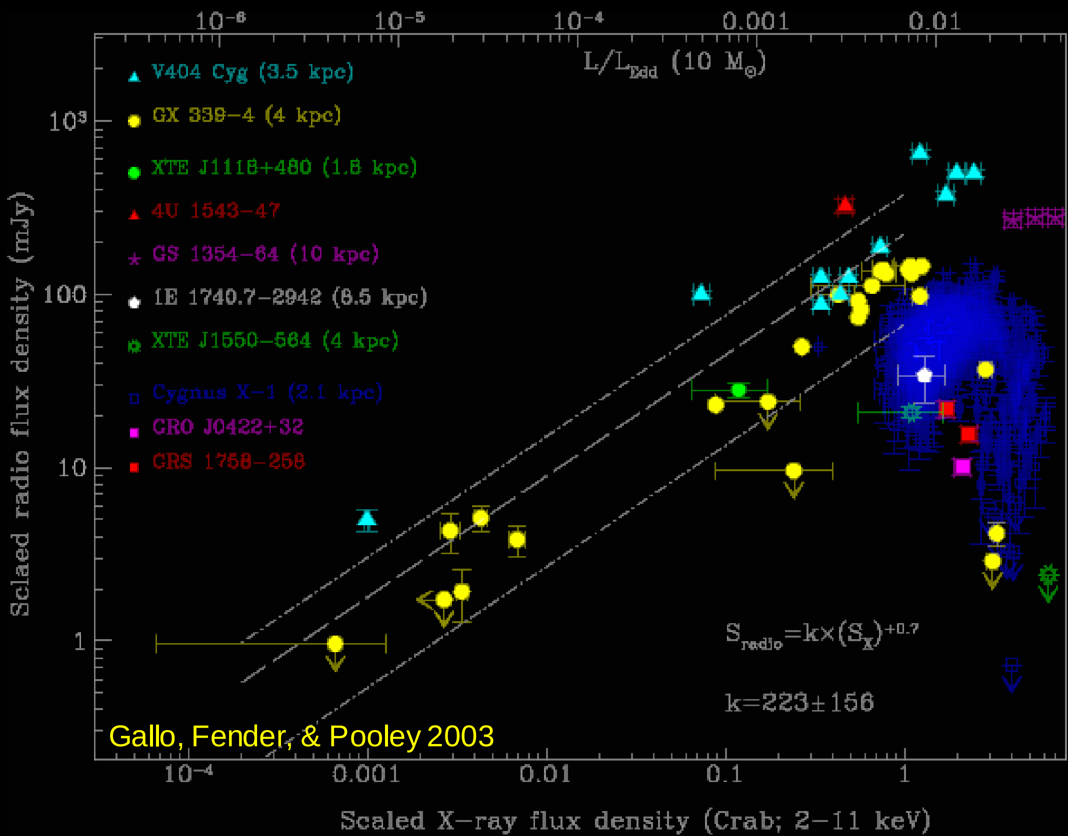
$L_{\rm r} \propto \dot{M}^{1.24}$

Flat core emission:

$L_{\rm r} \propto \dot{M}^{1.45}$



Accretion rate correlation



Black holes in Galactic X-ray binaries:

- X-ray radio correlation in low/hard state

$$F_{\text{radio}} \propto F_{\text{x-ray}}^{0.7}$$

Comparing AGNs and microquasars

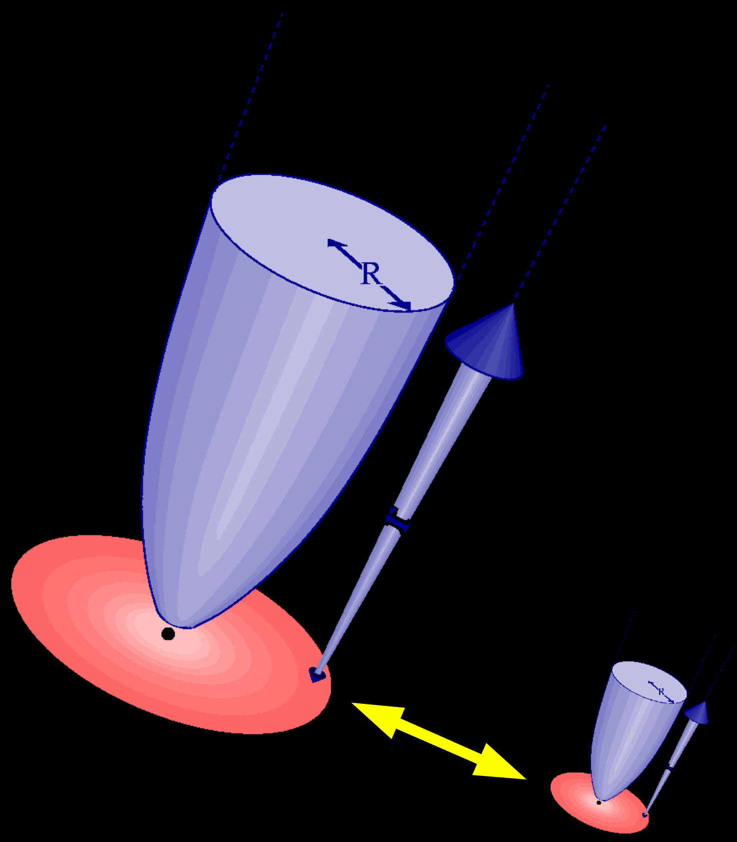
motivation:

- jets ↔ accretion
- jets from compact objects are relativistic
- morphologies: AGN & microquasars very similar
- spectra: AGN & microquasars very similar
- flat spectrum core emission: no messy ISM-interactions

questions:

- what produces radio loudness differences?
- are jets really similar at heart?
- disentangle dependence of flux on different parameters ($M_{\mathrm{BH}}, \dot{m}, \vartheta_{\mathrm{LOS}}, a$)

The scale invariance Ansatz



parameters governing inner disk:

- black hole mass M
- accretion rate $\dot{m} = \dot{M} / \dot{M}_{Edd}$

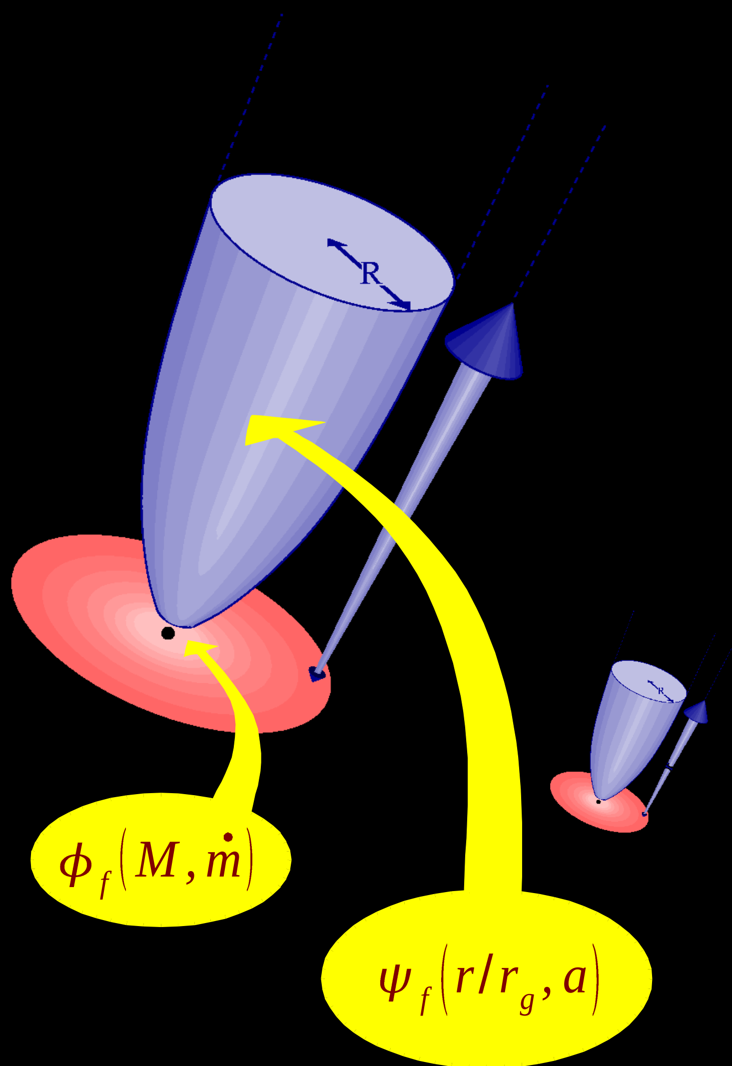
(black hole spin a ?)

Jet launched in the inner disk

⇒ inner jet goverened by: $M, \dot{m}$

(black hole spin a ?)

The scale invariance Ansatz



Universal process of jet formation:

$\updownarrow$

no qualitative difference for different M

$\updownarrow$

Jets are <u>*scale invariant*</u>

$\updownarrow$

only one scale: r_g

$\updownarrow$

similarity variable: $\chi = r/r_g$

$\updownarrow$

write any quantity f as

$$f(M, \dot{m}, a, r) = \phi_f(M, \dot{m})\, \psi_f(r/r_g, a)$$
$$= \phi_f(M, \dot{m})\, \psi_f(\chi, a)$$

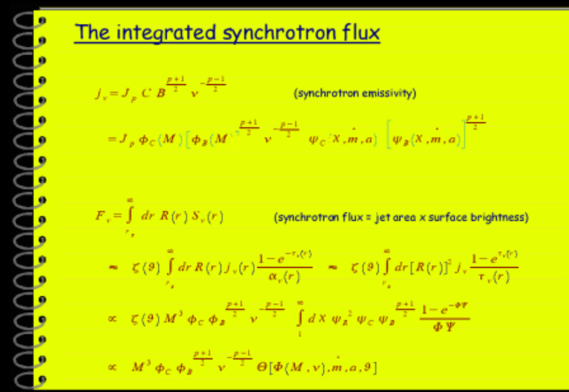
Synchrotron emission from the core:

scale invariance:

$$f(M,\dot{m},a,r)=\phi_f(M,\dot{m})\,\psi_f\left(r/r_g,a\right)$$

+

synchrotron theory:


The integrated synchrotron flux

$$j_\nu = J_p\, C\, B^{\frac{p+1}{2}}\,\nu^{-\frac{p-1}{2}} \qquad \text{(synchrotron emissivity)}$$

$$= J_p\,\phi_C(M)\left[\phi_B(M)\right]^{\frac{p+1}{2}}\nu^{-\frac{p-1}{2}}\,\psi_C(X,\dot{m},a)\left[\psi_B(X,\dot{m},a)\right]^{\frac{p+1}{2}}$$

$$F_\nu = \int_{r_0}^{\infty} dr\, R(r)\, S_\nu(r) \qquad \text{(synchrotron flux = jet area x surface brightness)}$$

$$\approx \zeta(\vartheta)\int_{r_0}^{\infty} dr\, R(r)\, j_\nu(r)\frac{1-e^{-\tau_\nu(r)}}{\alpha_\nu(r)} \approx \zeta(\vartheta)\int_{r_0}^{\infty} dr\left[R(r)\right]^2 j_\nu\frac{1-e^{\tau_\nu(r)}}{\tau_\nu(r)}$$

$$\propto \zeta(\vartheta)\, M^3\,\phi_C\,\phi_B^{\frac{p+1}{2}}\,\nu^{-\frac{p-1}{2}}\int_1^{\infty} dX\,\psi_R^2\,\psi_C\,\psi_B^{\frac{p+1}{2}}\frac{1-e^{-\Phi\Psi}}{\Phi\Psi}$$

$$\propto M^3\,\phi_C\,\phi_B^{\frac{p+1}{2}}\,\nu^{-\frac{p-1}{2}}\,\Theta\left[\Phi(M,\nu),\dot{m},a,\vartheta\right]$$

=

Scaling of core radio flux with mass:

$$\frac{\partial\ln(F_\nu)}{\partial\ln(M)} = \frac{2p+13+2\alpha}{p+4} + \frac{\partial\ln(\phi_B)}{\partial\ln(M)}\left(\frac{2p+3+\alpha p+2\alpha}{p+4}\right) + \frac{\partial\ln(\phi_C)}{\partial\ln(M)}\left(\frac{5+2\alpha}{p+4}\right) \equiv \xi_M$$

$$\Rightarrow \qquad F_\nu \propto M^{\xi_M}$$

NOTE: al model dependence absorbed into observables α and p

radio-mass dependence

$$F_\nu \propto M^{\xi_M}$$

$disk\ \ mode:$	B^2	ξ_M	
$ADAF$	$\frac{\dot{m}}{M}$	$\frac{17}{12}-\frac{\alpha}{3}$	$\sim 1.42-0.33\alpha$
$rad.\ press.$	M^{-1}	$\frac{17}{12}-\frac{\alpha}{3}$	$\sim 1.42-0.33\alpha$
$gas\ press.$	$\dot{m}^{\frac{17}{20}} M^{-\frac{9}{10}}$	$\frac{187-32\alpha}{120}$	$\sim 1.56-0.27\alpha$
$W_{jet} \propto W_{disk}$	$\frac{\dot{m}}{M}$	$\frac{17}{12}-\frac{\alpha}{3}$	$\sim 1.42-0.33\alpha$

result: $F_\nu \sim M^{1.42-0.33\alpha}$ ⇨ AGNs are more radio loud!

radio-accretion rate dependence

$$F_\nu \propto \dot{m}^{\xi_{\dot{m}}}$$

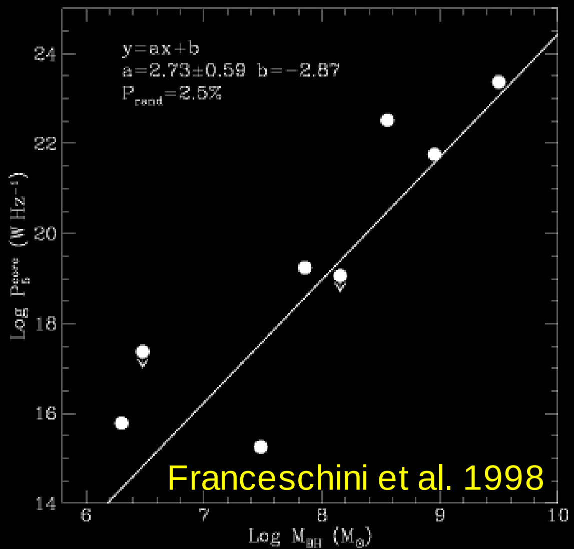
disk mode:	B^2	$\xi_{\dot{m}}$	
ADAF	$\frac{\dot{m}}{M}$	$\frac{17}{12}+\frac{2\alpha}{3}$	$\sim 1.42+0.66\alpha$
rad. press.	M^{-1}	0	0
gas press.	$\dot{m}^{\frac{17}{20}} M^{-\frac{9}{10}}$	$\left(\frac{17}{12}+\frac{2\alpha}{3}\right)\frac{17}{20}$	$\sim 1.2+0.56\alpha$
$W_{jet} \propto W_{disk}$	$\frac{\dot{m}}{M}$	$\frac{17}{12}+\frac{2\alpha}{3}$	$\sim 1.42+0.66\alpha$

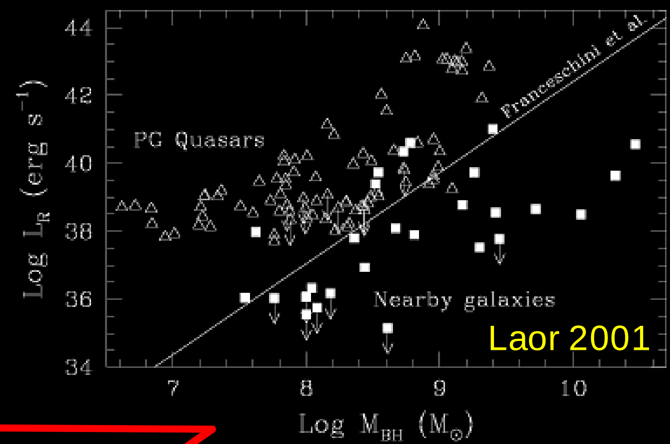
for inefficient accretion:

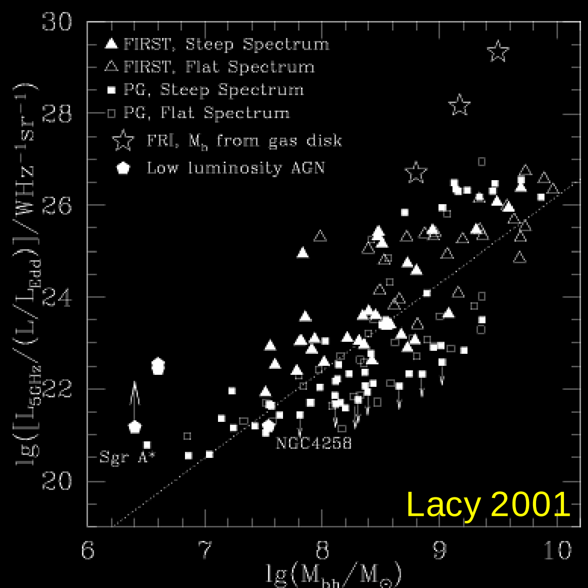
$$F_\nu \sim \left(\dot{m}\right)^{1.42+0.66\alpha} \propto L_x^{0.71+0.34\alpha}$$

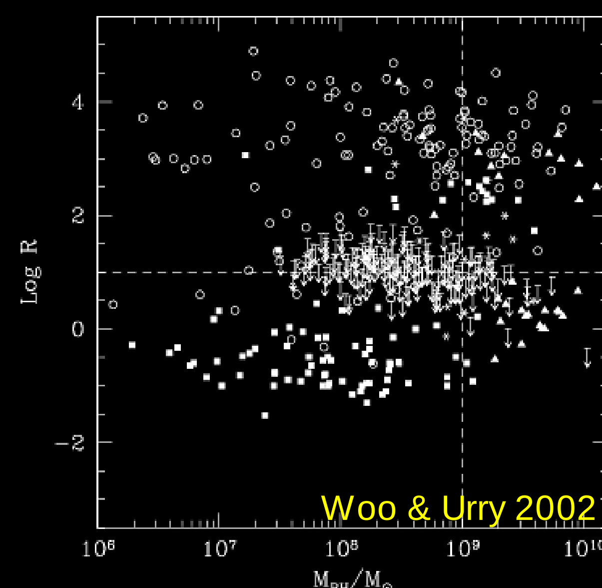
A fundamental plane of black hole activity

- past searches: no clear radio-mass correlation









A fundamental plane of black hole activity

- past searches: no clear radio-mass correlation

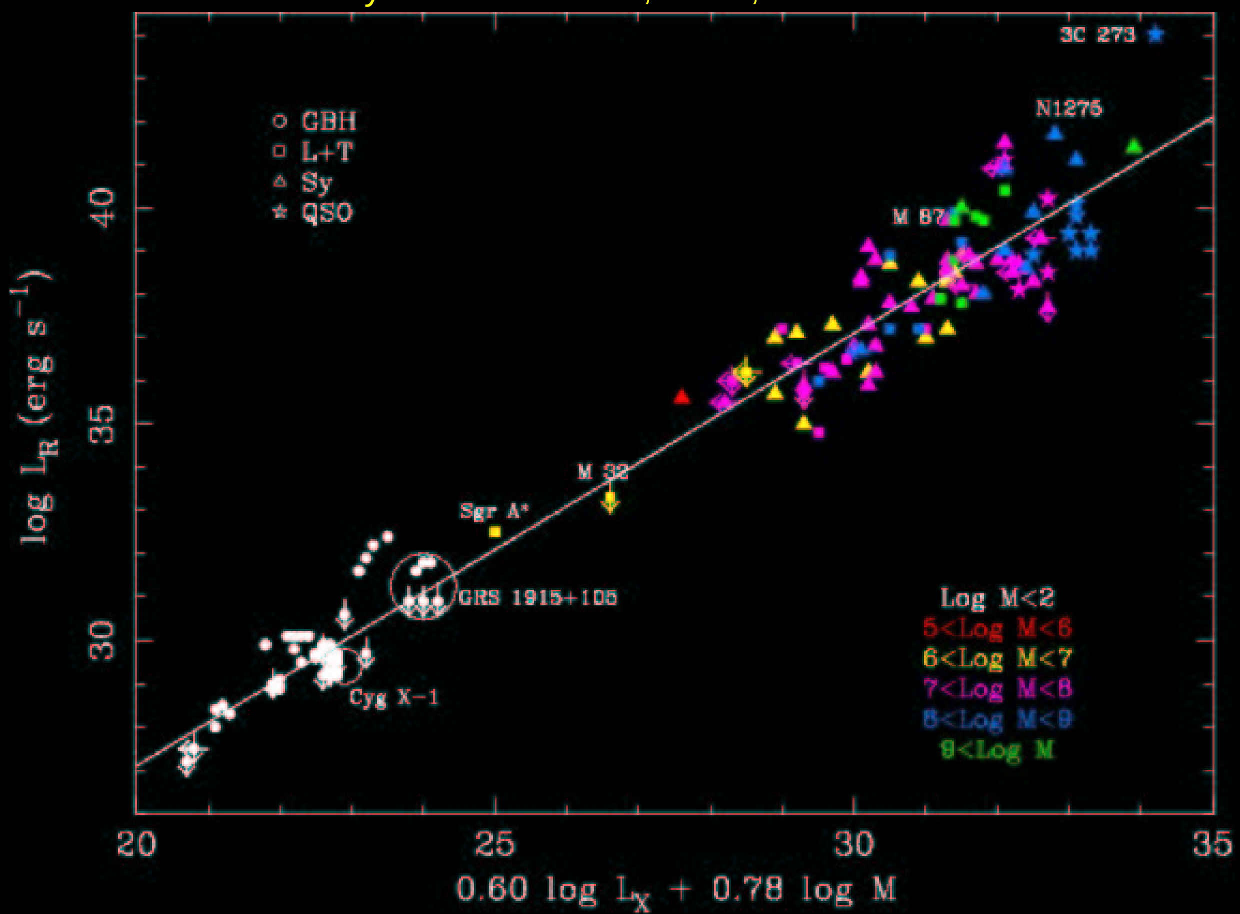
- should consider:
  mass **and** accretion rate

- 2-10 keV X-ray as
  proxy of inner disk

- Sample: ~100 AGNs
  60 XRB observations
  with measured masses:

- radio correlates with
  mass **AND** X-rays

Radio vs. X-ray & Mass: Merloni, Heinz, & DiMatteo 2003



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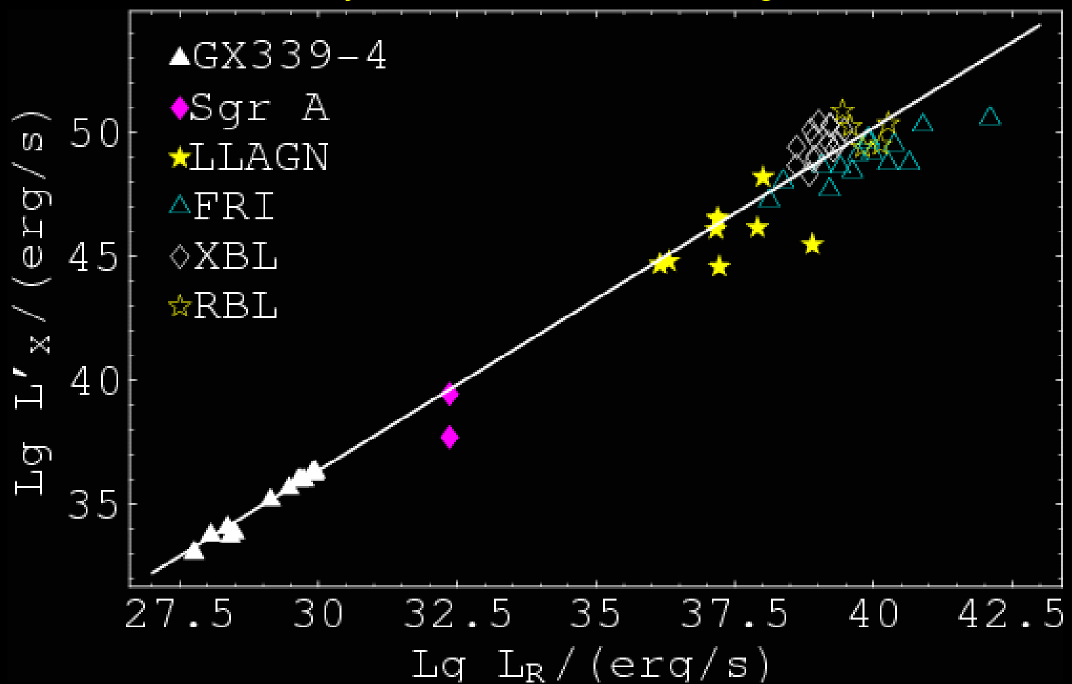
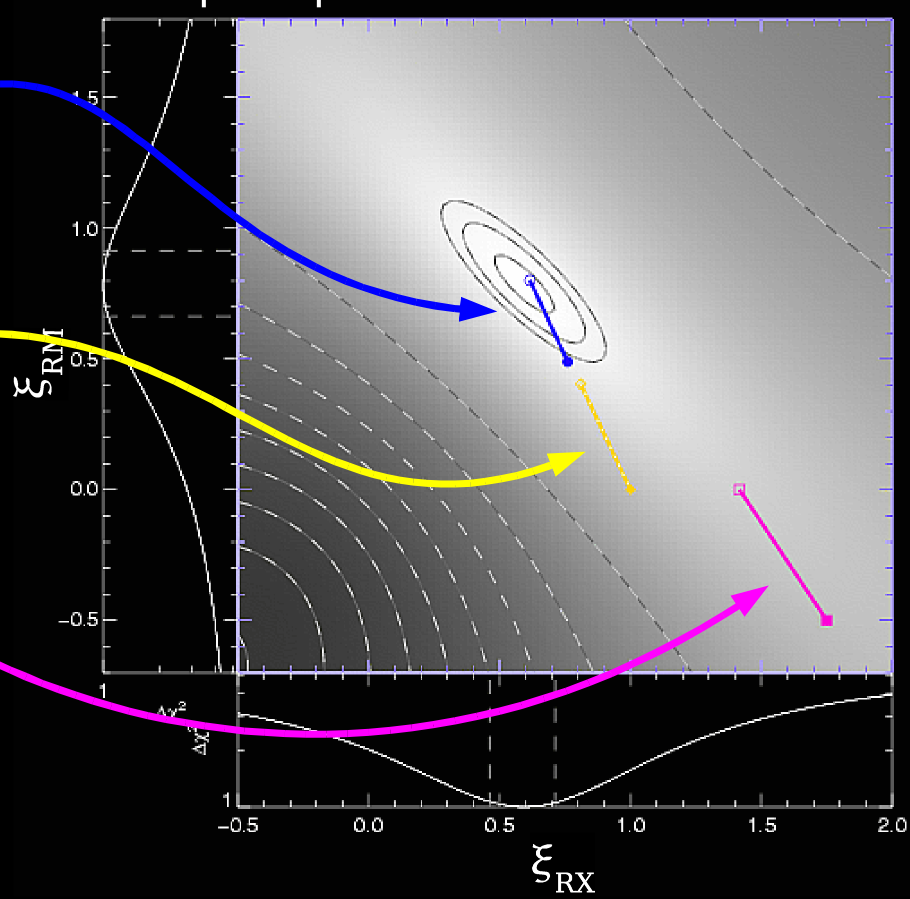
Radio vs. X-ray & Mass: Falcke, Koerding, & Markoff 2003



A fundamental plane of black hole activity

- plane equation: $\log L_R = 0.78 \log M + 0.6 \log L_x + 7.33$
- scatter: $\sigma \sim 0.9$
- consistent with inefficient accr.
- marg. consistent with jet X-rays
- inconsistent with efficient accr.
- scatter: beaming weak

Chisquare plot of correlation coefficients



Conclusions:

- Scale invariant jets: robust scaling relations, independent of model

$$F_\nu \propto M^{\xi_M} \dot{m}^{\xi_{\dot{m}}} \sim M^{1.42-0.33\alpha} \dot{m}^{1.42+0.66\alpha}$$

- Measuring correlations: test accretion physics

- Observational test finds: fundamental plane of radio-mass-x-rays

$$L_r \propto M^{0.78} L_x^{0.6}$$

- consistent with inefficient accretion ($L_x \propto \dot{m}^{2.3}$),
  marginally consistent with jet X-rays,
  inconsistent with efficient accretion ($L_x \propto \dot{m}$)