Radio Quiet AGN at high radio frequencies: jet or accretion disk corona?

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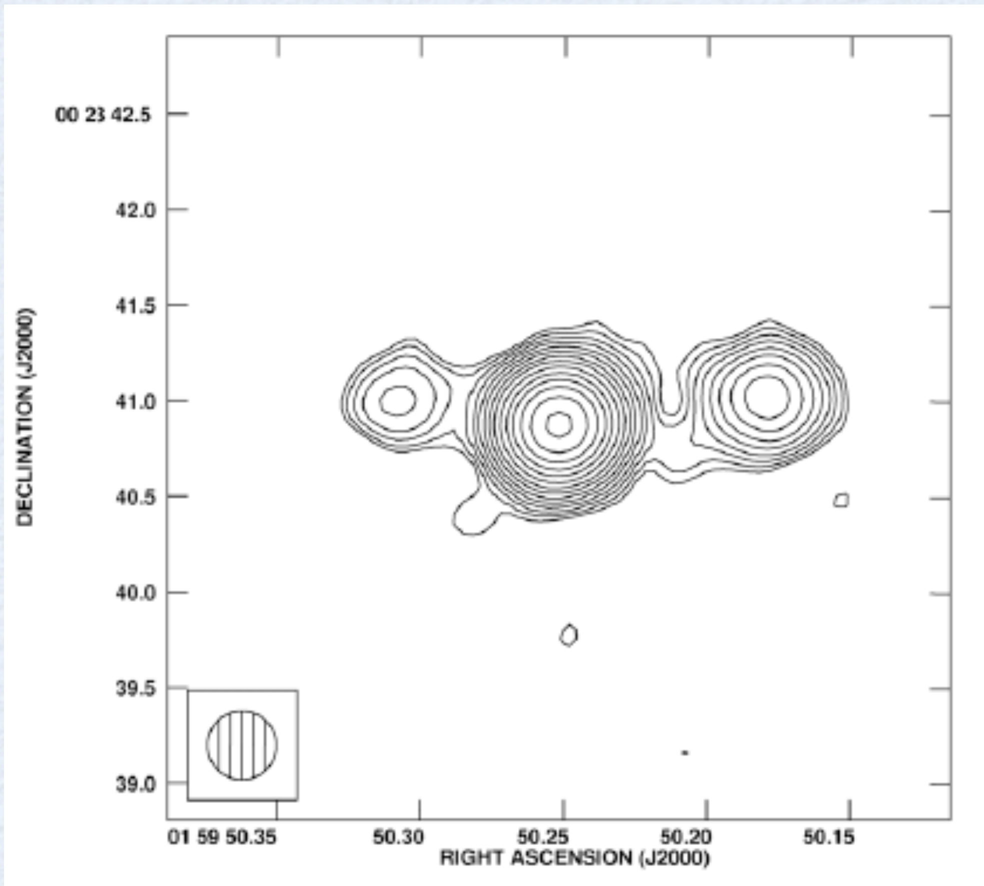
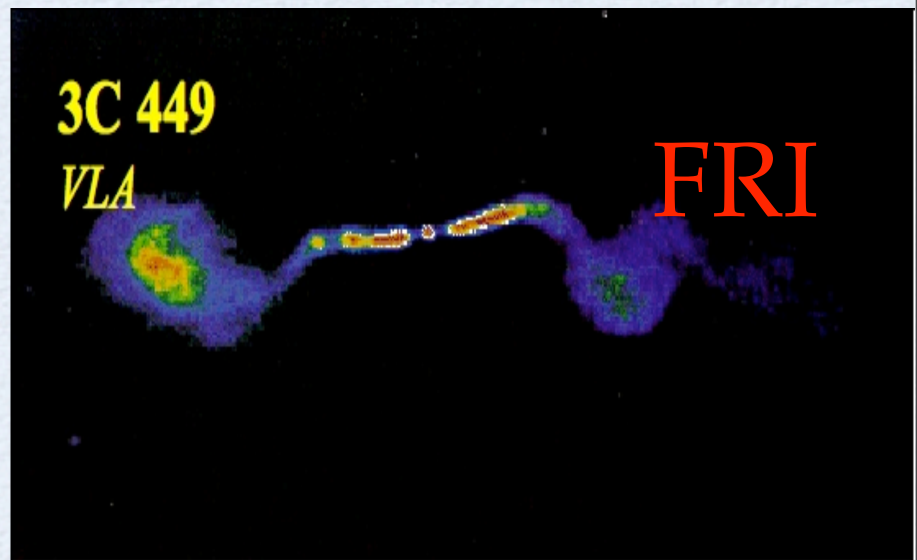
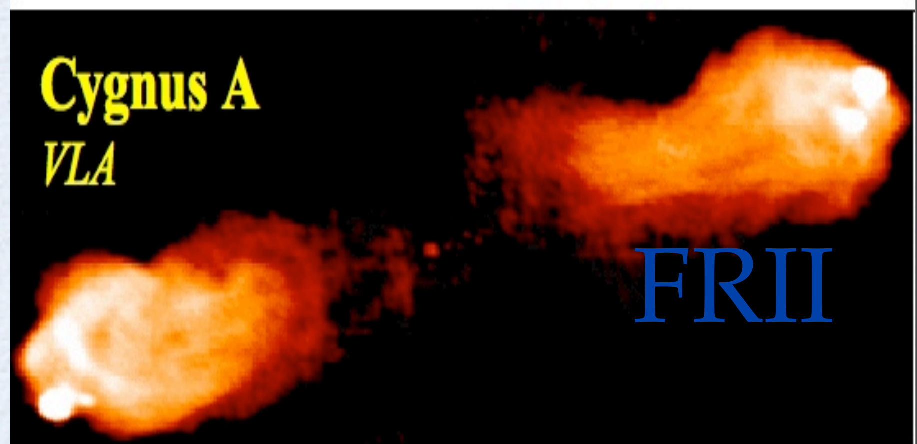
local radio-emitting population

Starburst galaxy *Radio Quiet AGN* *Radio Loud AGN*







L_{radio} (erg/s)

30 32 34 36 38 40 42 44

Origin of radio emission

- Star formation ⇒ young stellar pop
- Jet⇒ synchrotron for RL AGN
- RQ AGN:

- ~10^3 weaker than in RLQ, some show extended jets
- some show high radio brightness T → hot non-thermal electrons
- Unresolved with VLA → Smaller than ~1 kpc.
- Unresolved with VLBI → Smaller than ~1 pc
- Variable on months timescale → Smaller than ~0.1pc

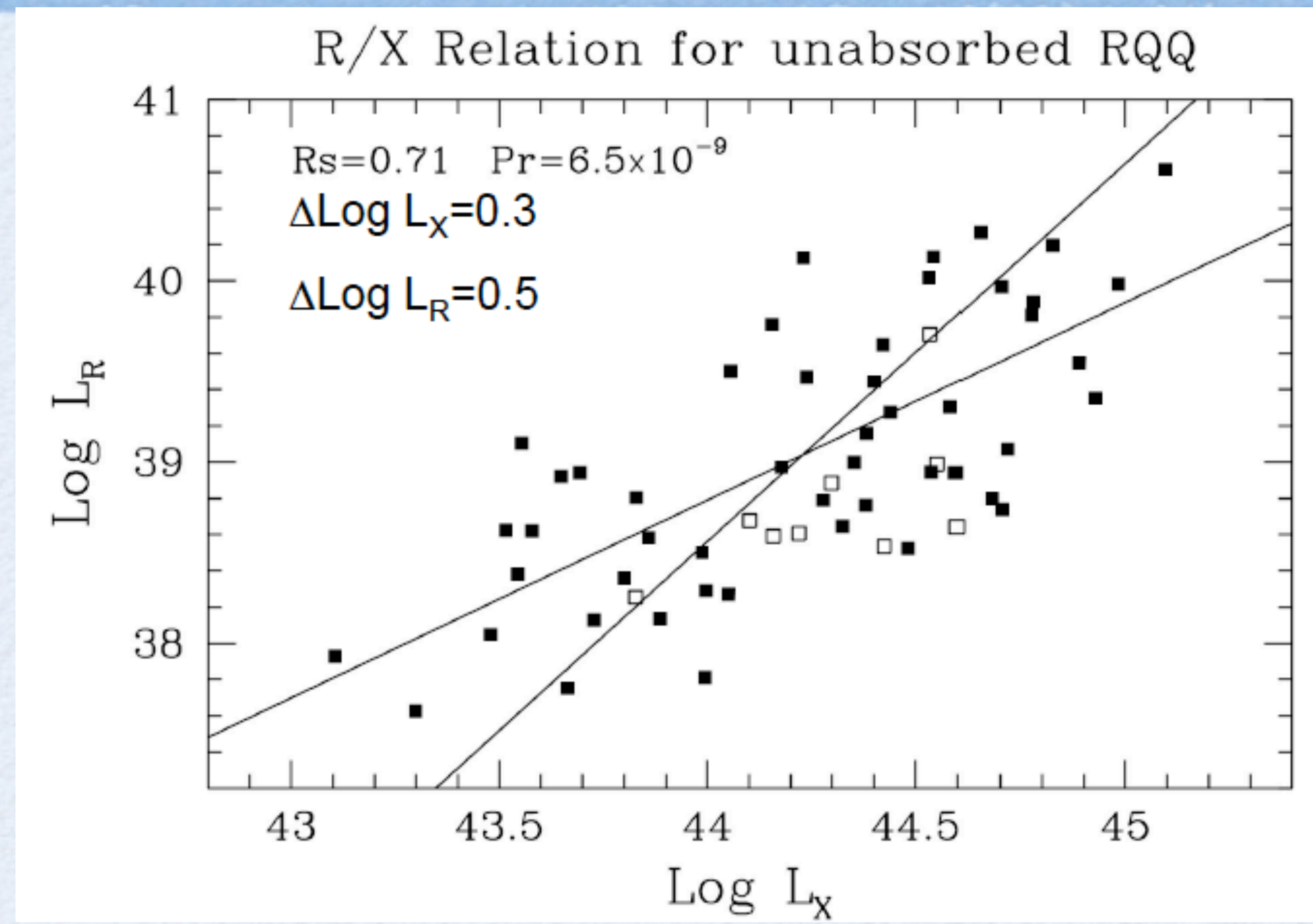
→ a scaled-down version of relativistic jet??

But, there is a clue for a different origin....

Radio / X-ray Relation

Laor & Behar (2008) found that the RQQ from the Palomar-Green quasar sample show the following relation:

$L_R / L_X \approx 10^{-5}$



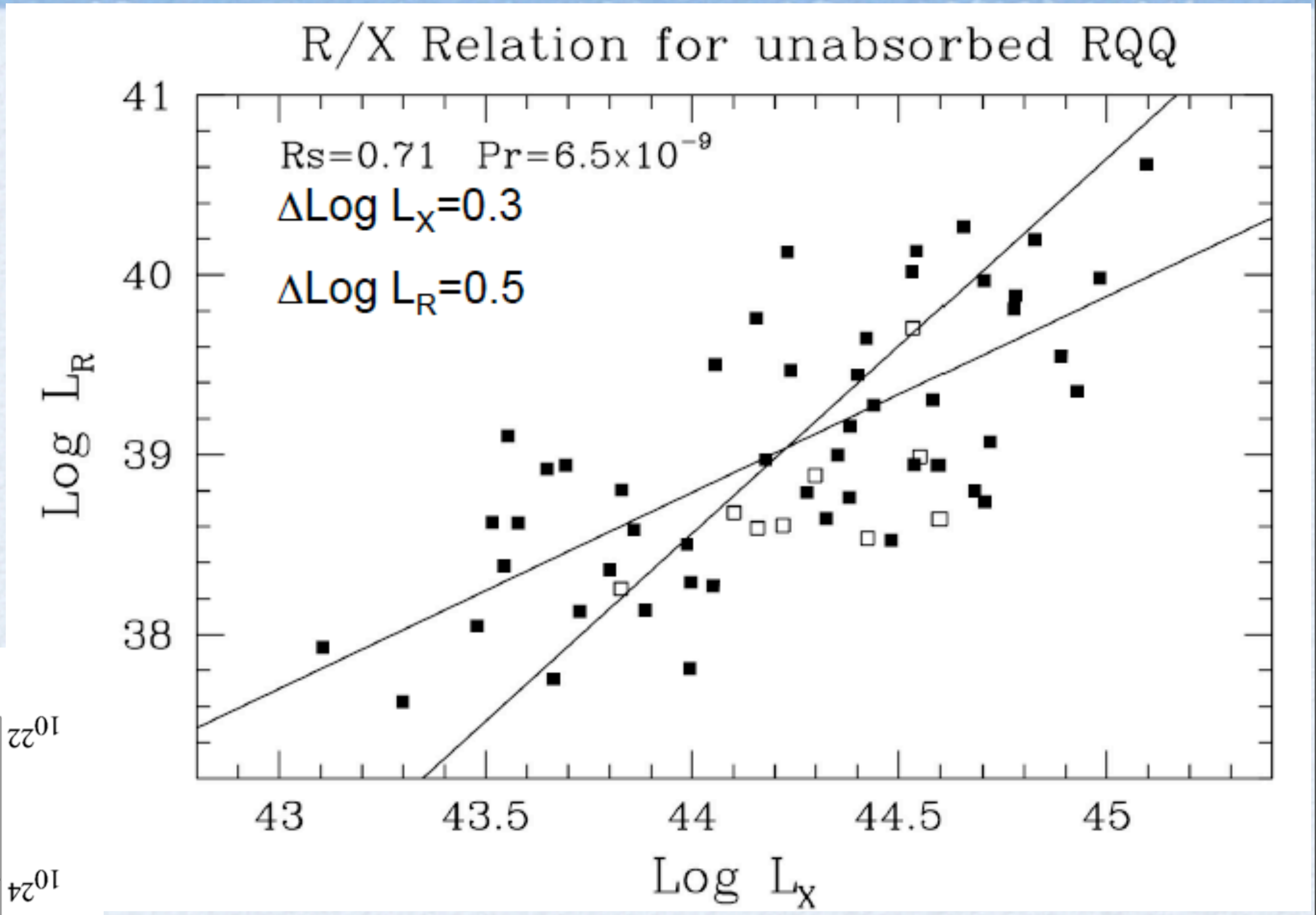
•X-rays are not relativistically beamed

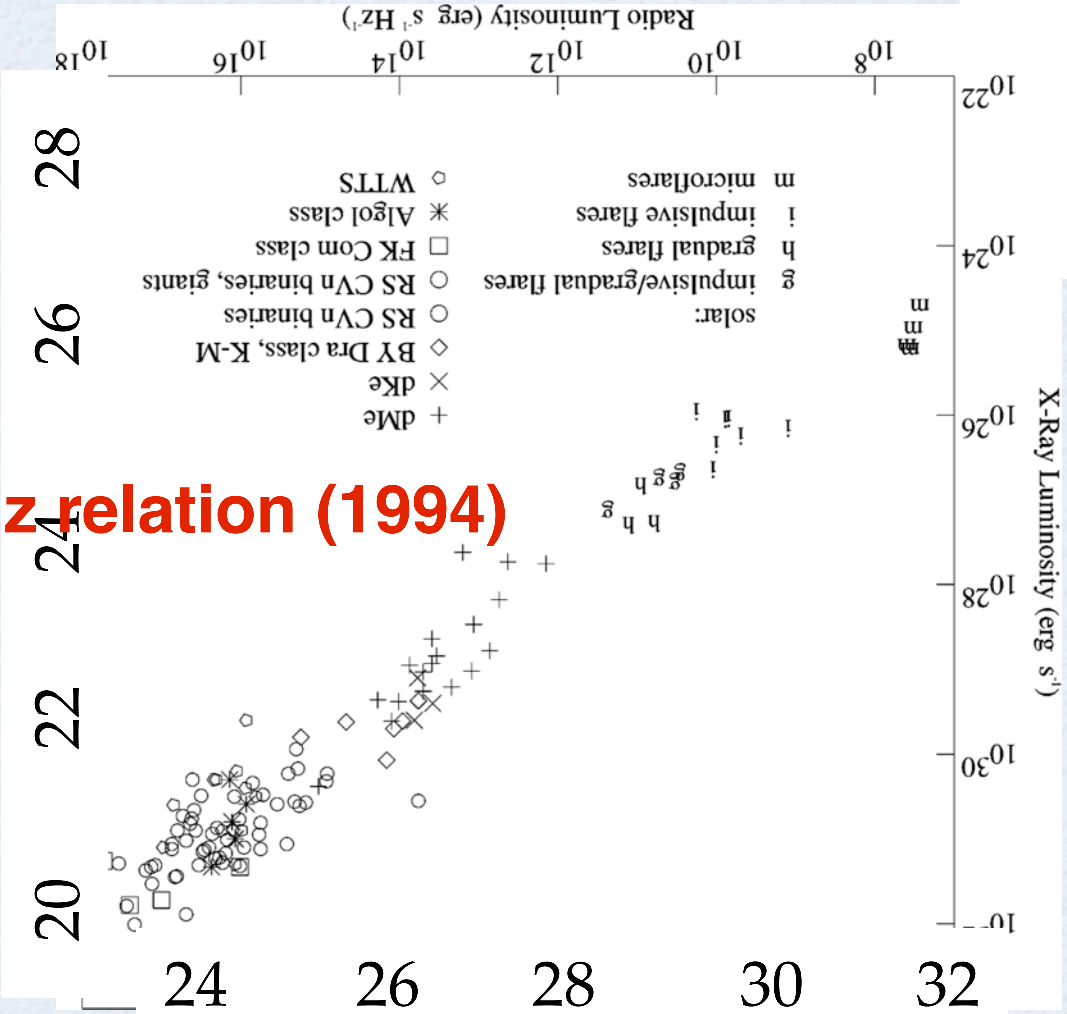
→ Radio emission in RQQ is also unbeamed.

If radio is from a jet, the jet must be slow.

•X-rays most likely from a hot corona.

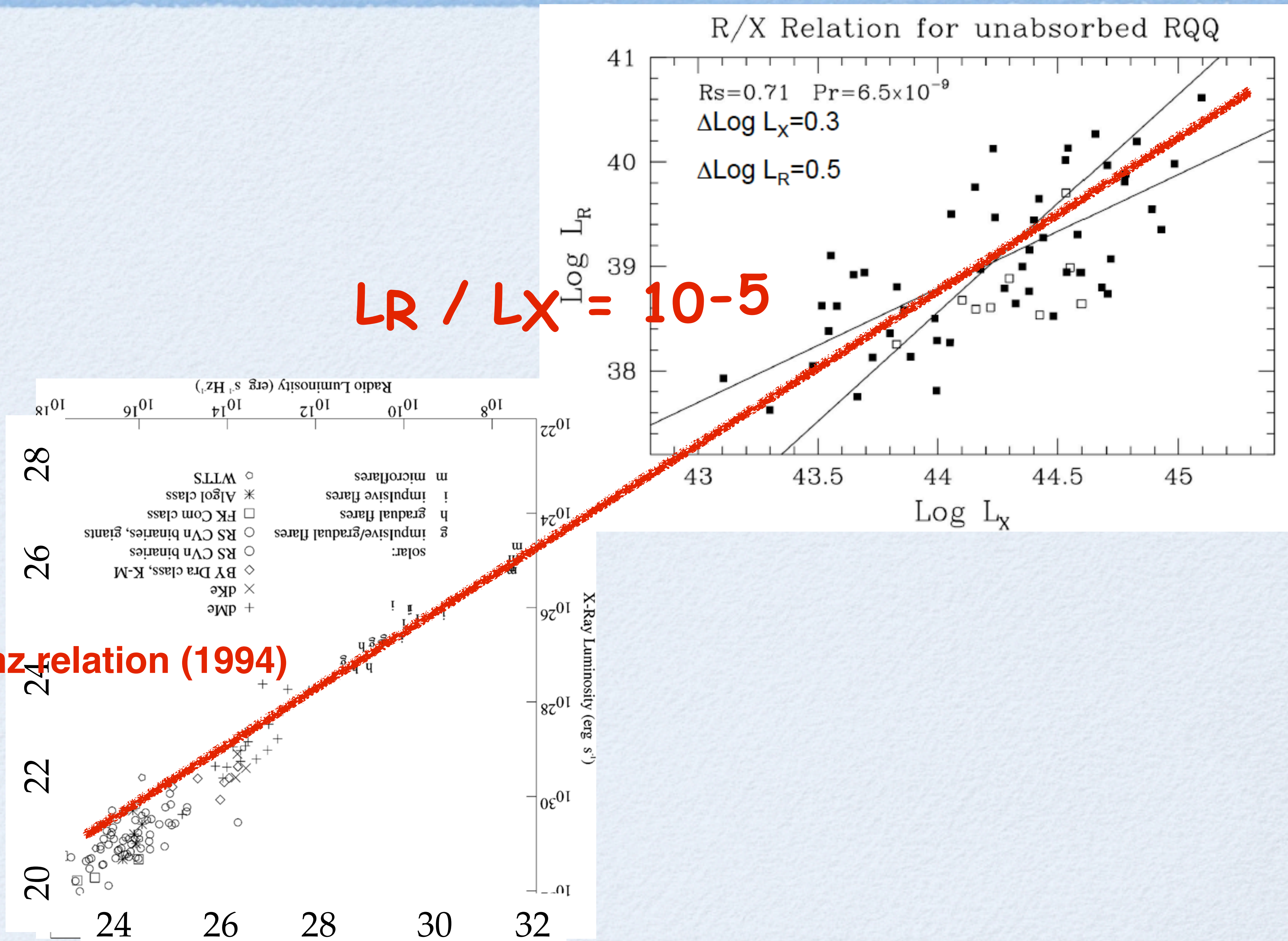
Radio / X-ray Relation





Güdel & Benz relation (1994)

Radio / X-ray Relation



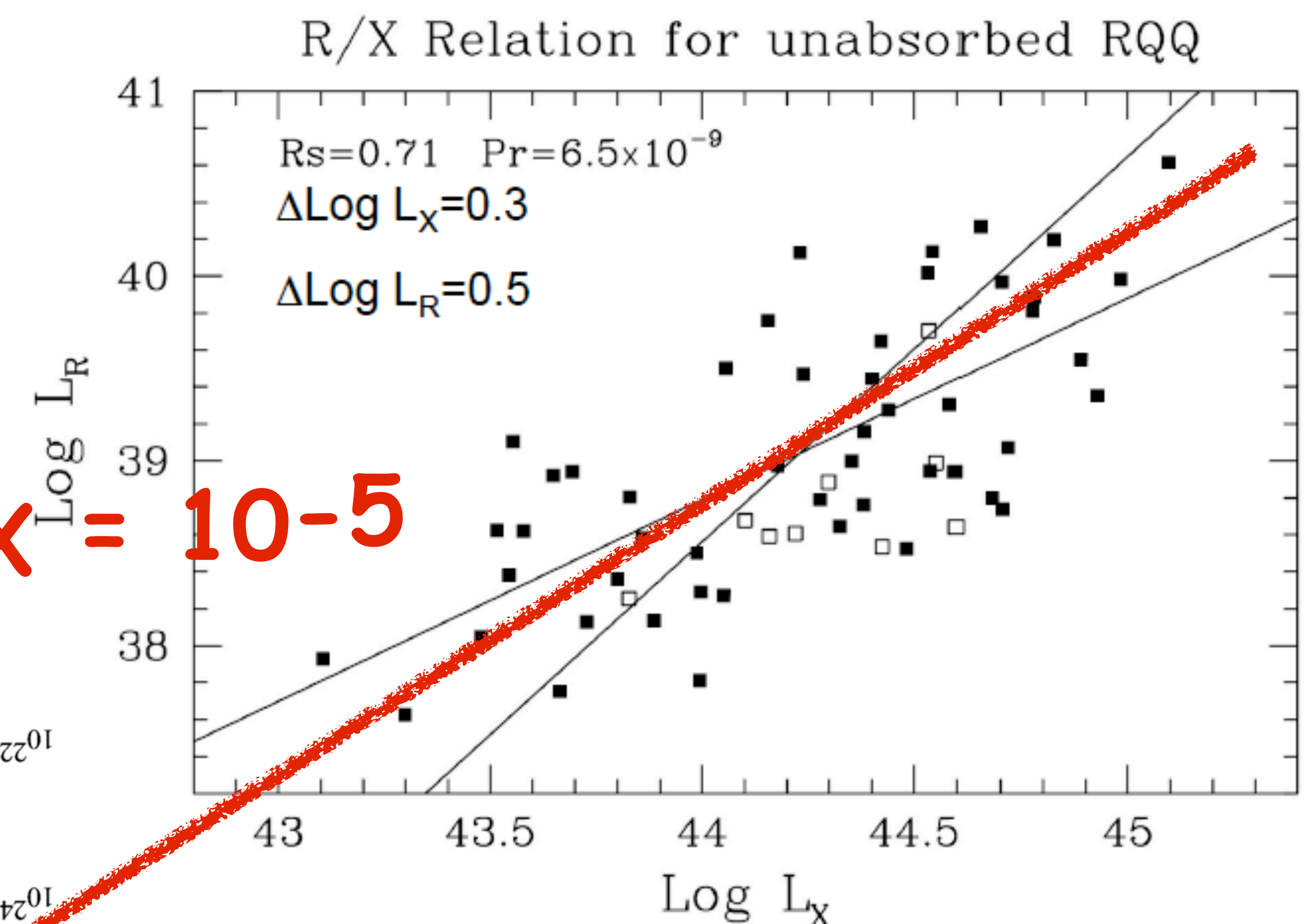
Radio / X-ray Relation

Stellar coronae ~ 10^{6-7} K : $L_R / L_X \approx 10^{-5}$

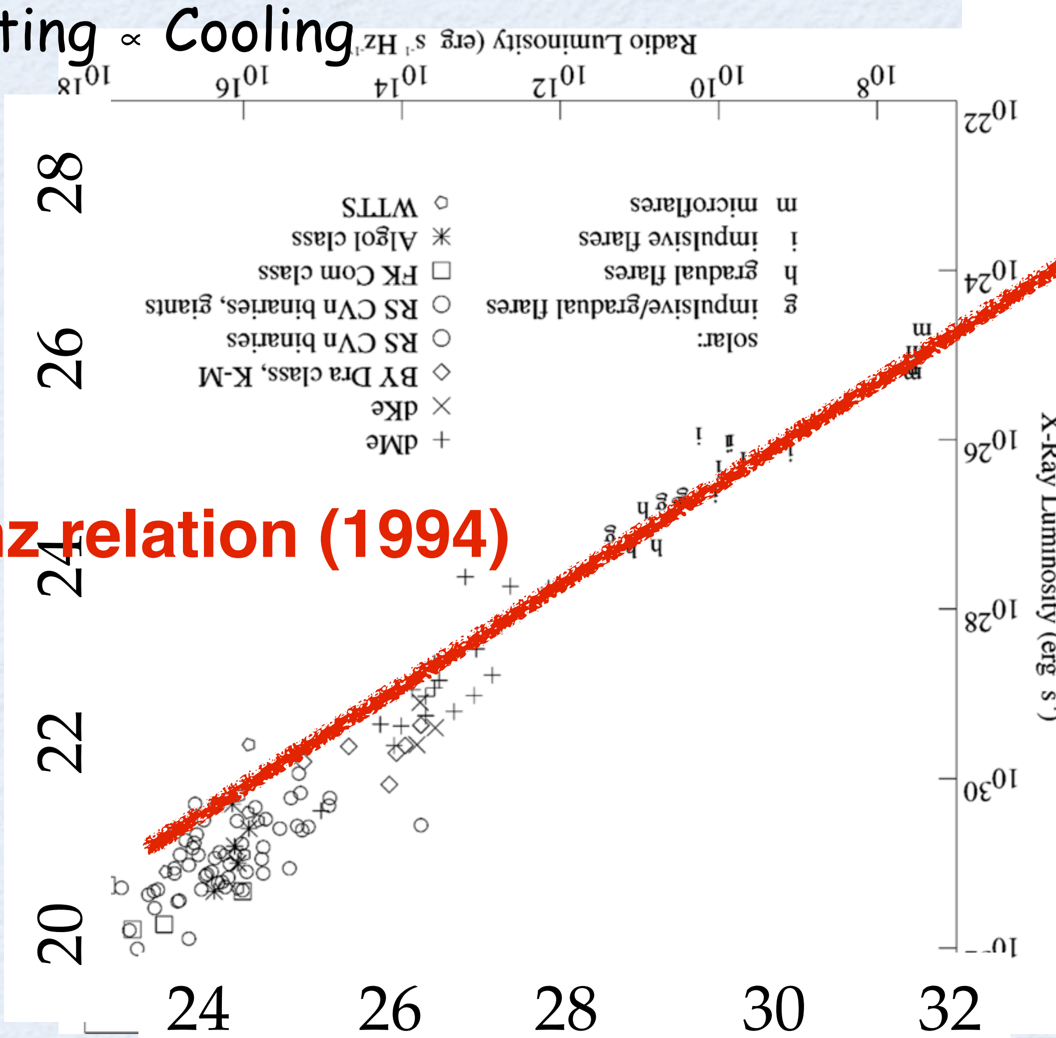
Coronae are magnetically heated.
B^2 is converted to accelerated particles (reconnection) → synchrotron emission.

Particles deposit their energy, heating the corona, and releasing hot coronal gas → X-ray emission

$L_R \propto L_X$ → Heating ∝ Cooling



$L_R / L_X = 10^{-5}$



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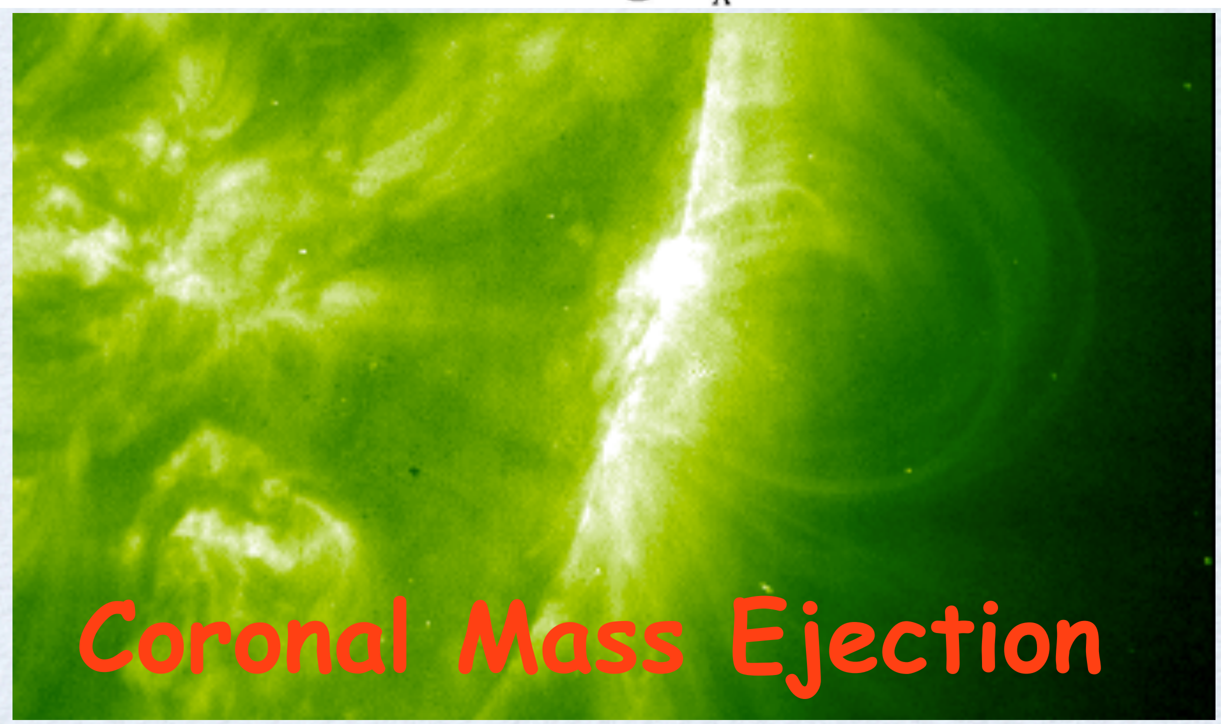
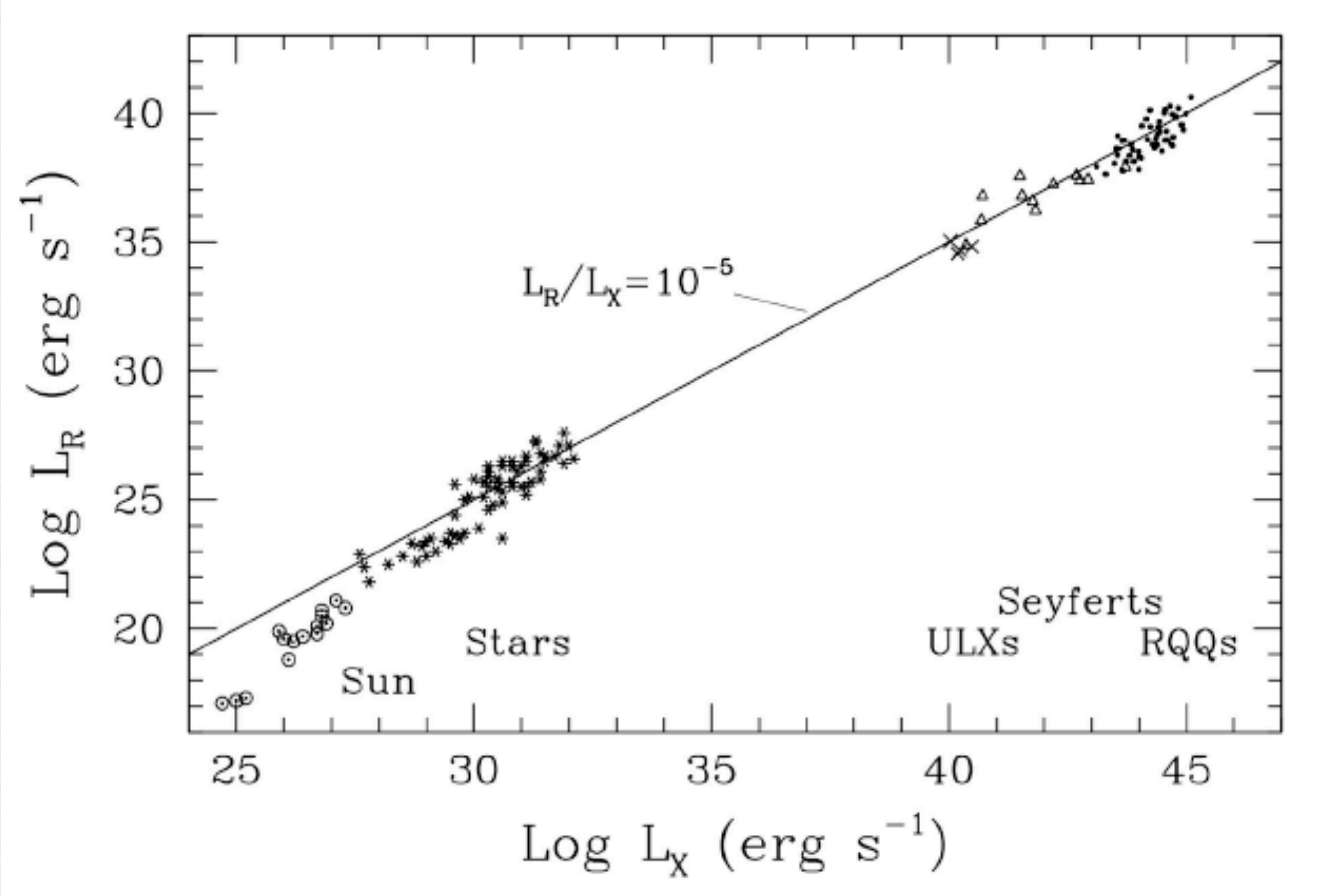


Coronally active stars vs RQ AGN



Does radio emission in radio quiet AGN also originate in a magnetically heated corona?

STELLAR - AGN CORONA

Why should similar physics apply to stellar and AGN coronae?

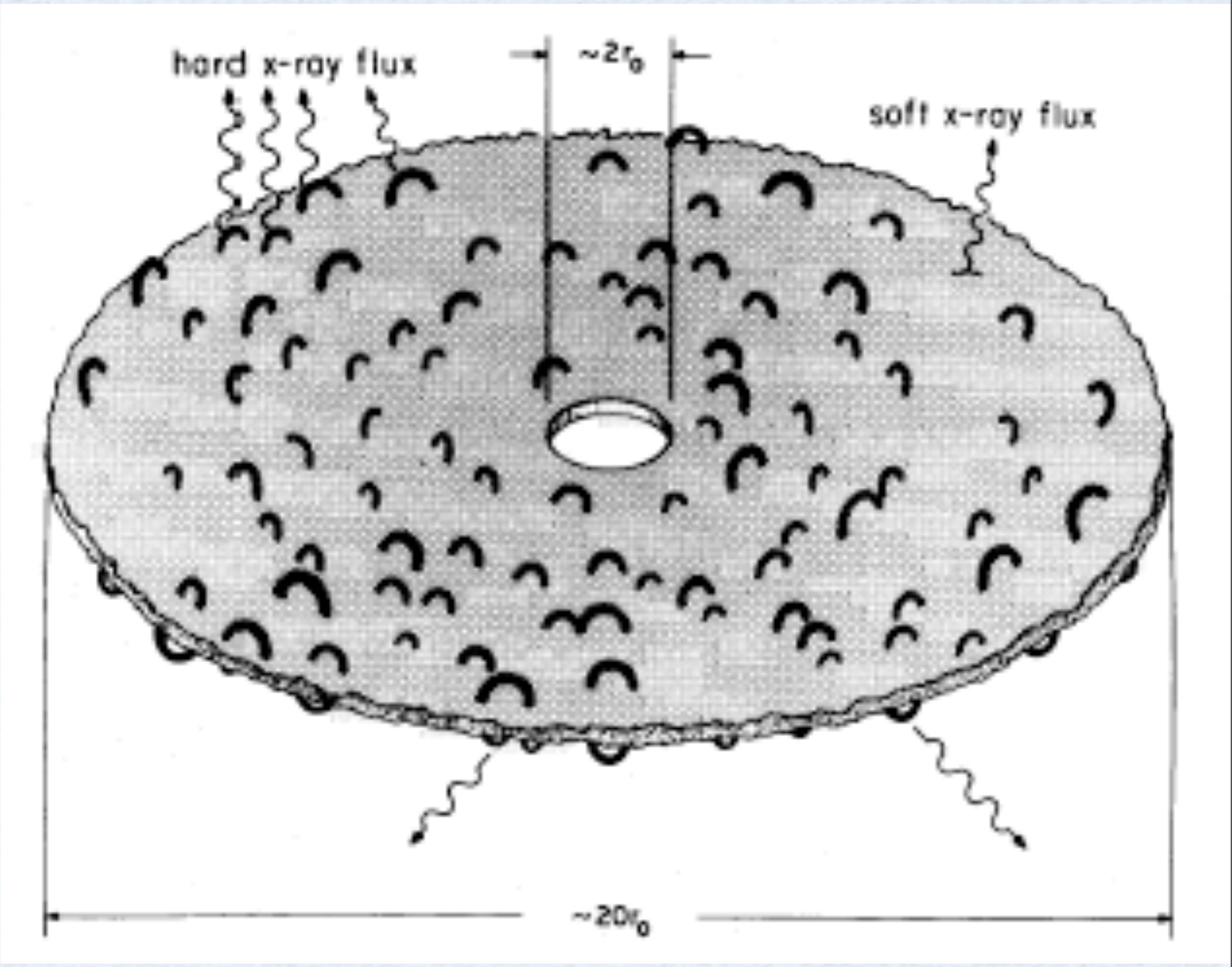
- UV disk: T ~ 5 x 10^4 K
- $L_{X\text{-}AGN} \sim 10^{13} L_{X\text{-}☆}$

$R_{AGN\text{-}X} \sim 10^{15}$cm (light day), $V_{AGN\text{-}X} \sim 10^{45}$cm^3

0.01 - 0.1 $R_{☆\text{-}X}{}^3 \sim 10^{31-33}$cm^3 ~ 10^{-13} $V_{AGN\text{-}X}$

$B_{eq\text{-}AGN}{}^2 \sim L_{X\text{-}AGN} / V_{X\text{-}AGN} \sim B_{eq\text{-}☆}{}^2$

Since the X-ray emission originates from the disk coronae, which are magnetically heated, the radio emission from RQ AGN also derive from coronal activity?



Galeev, Rosner & Vaiana 1979

Magnetically heated coronae in accretion disks
(but no mention of observable radio emission)

How can this interpretation be tested?

Neupert effect

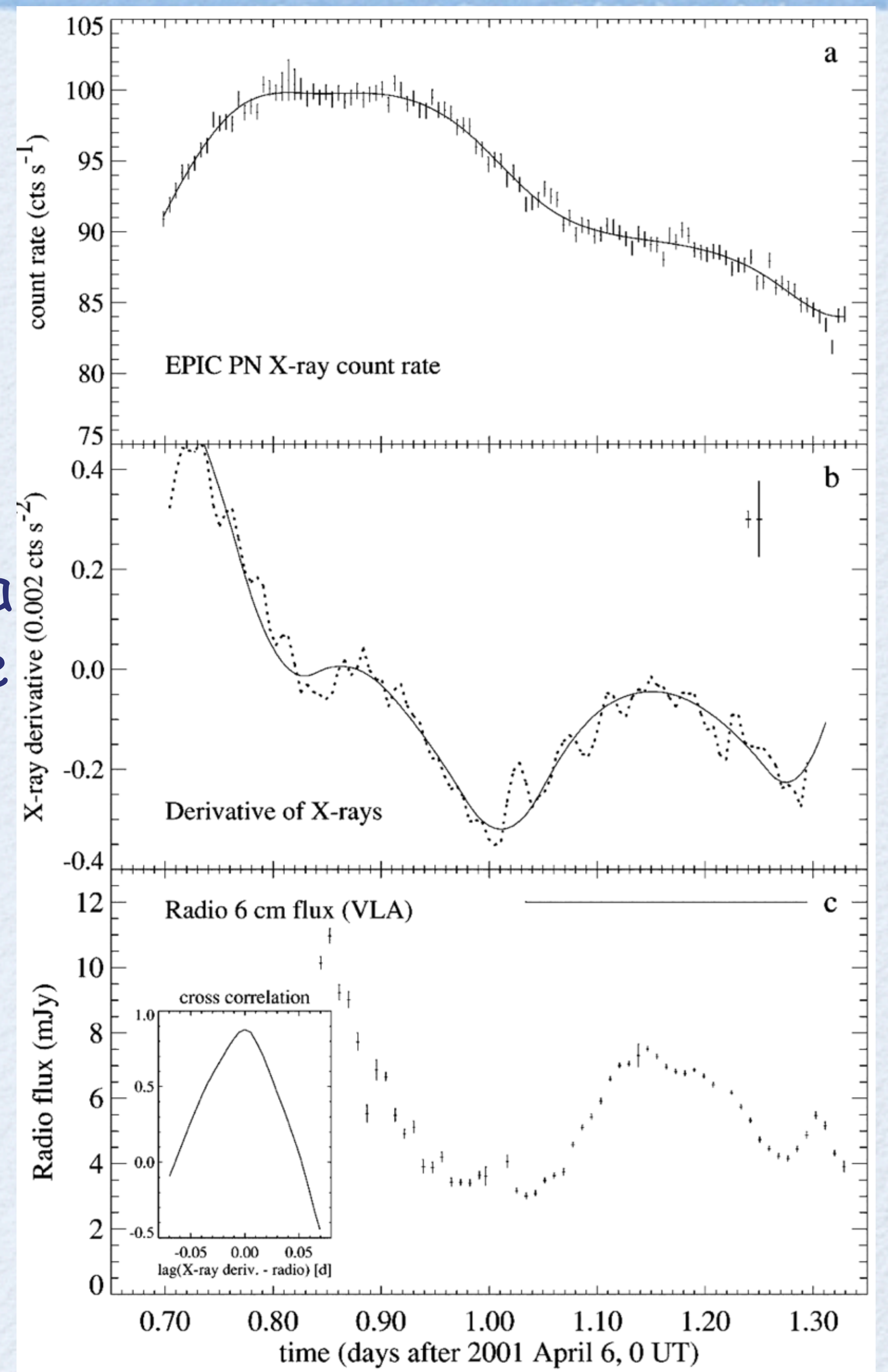
When a radio flare is followed by an X-ray flare with the relation

$dL_x / dt \propto L_r$ (Güdel 2002)

A magnetic reconnection event in the corona produces a synchrotron spike and then raise the coronal X-ray emission

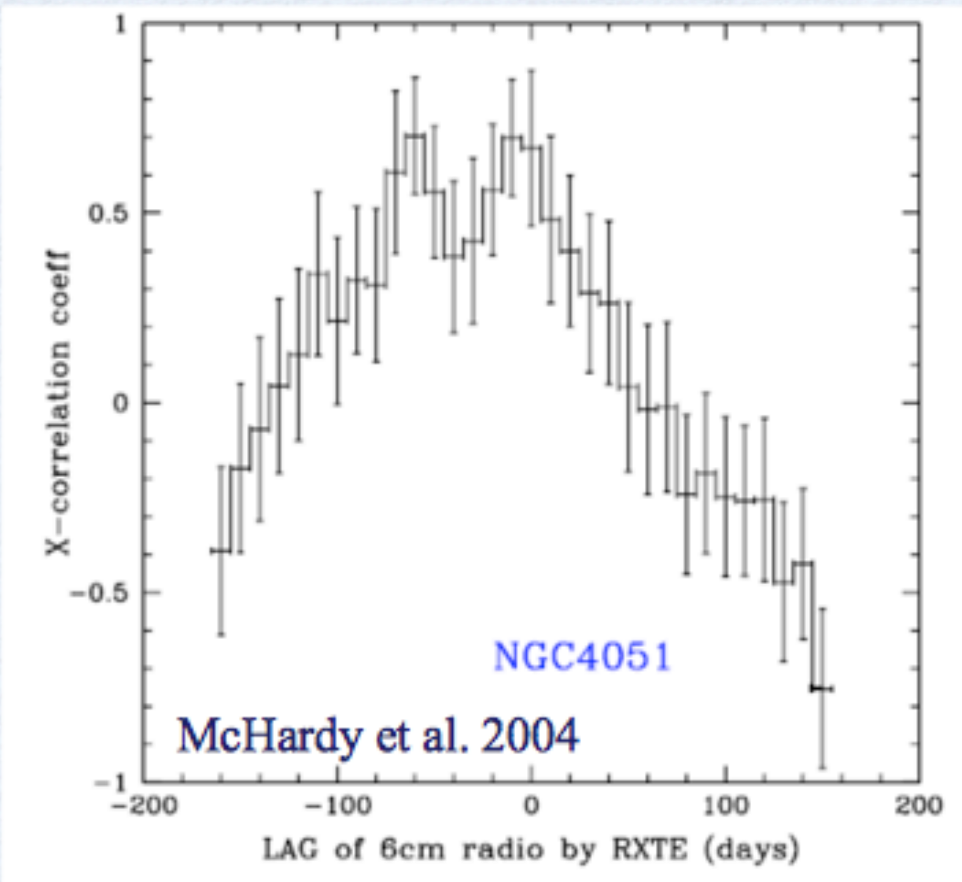
A corona could launch coronal mass ejections (CMEs) that feed the extended radio-sphere.

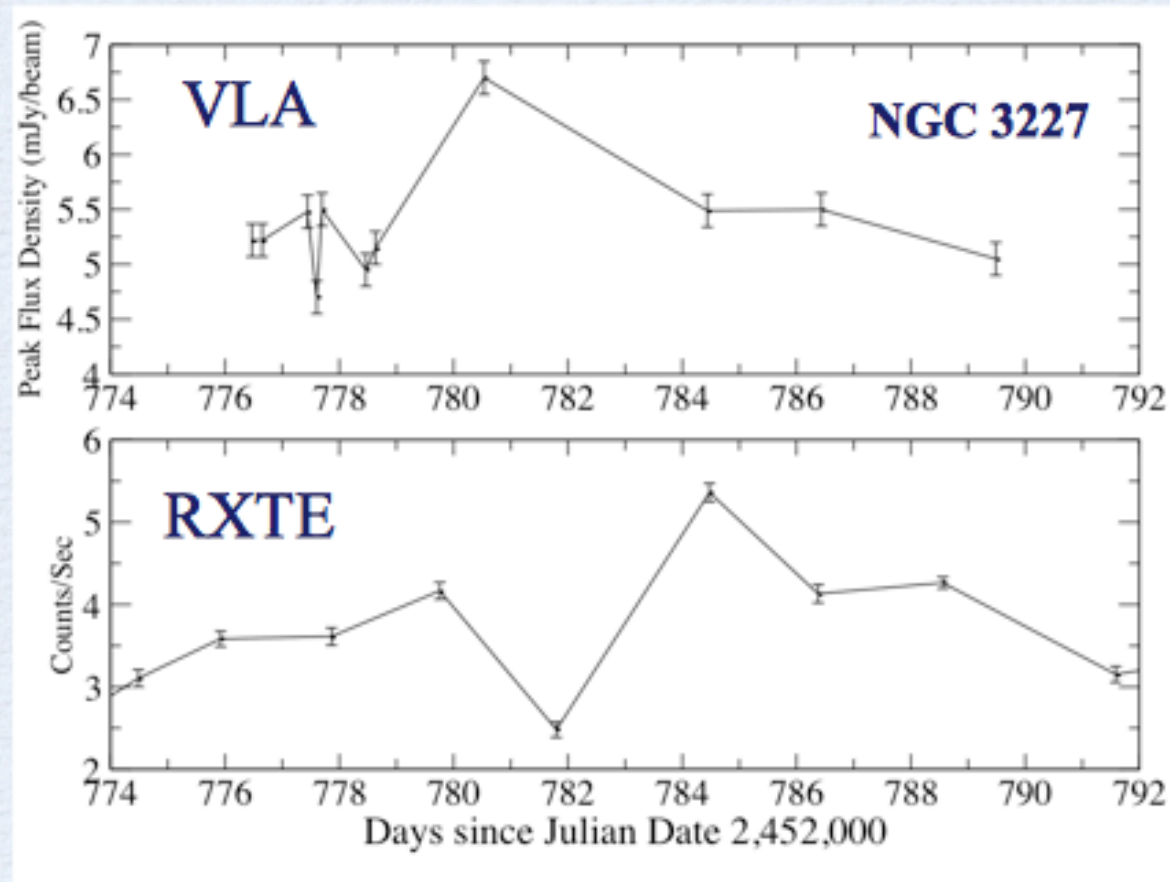
→ simultaneous radio/X-ray monitoring



Radio/X-ray monitoring

- X-ray-radio correlated variability
  - VLA with RXTE





- Clearly, more monitoring is needed

at high radio frequencies..

- Synchrotron self absorbed source, radio sphere:

$$R_{ssa} = 0.1 \left(\frac{\nu L_\nu}{10^{40} \text{erg s}^{-1}}\right)^{1/2} \left(\frac{B_\perp}{\text{Gauss}}\right)^{1/4} \left(\frac{\nu}{5\text{GHz}}\right)^{-7/4} \text{pc}$$

- If B ~ 1/R, we saw $R_{ssa} \sim L^{1/2} / \nu \sim \nu^{-1}$. To observe radio sizes comparable to X-ray coronal sizes ~100 times smaller, we need to observe at (assuming L_ν = const.) at ν= 100 GHz, which should reveal a 20 times smaller source
- absorption decreases with frequency $a_\nu \sim \nu^{-(p+4)/2}$
- Variability increase $\sim \nu^{5/4}$: at variability time scale at 95 GHz is expected tobe about 40 times shorter than that at 5 GHz

Radio Observations at 95 GHz

- Sample of local bright Seyferts
- radio compact and relatively bright in radio (> a few mJy)
- X-ray monitored and higly variable

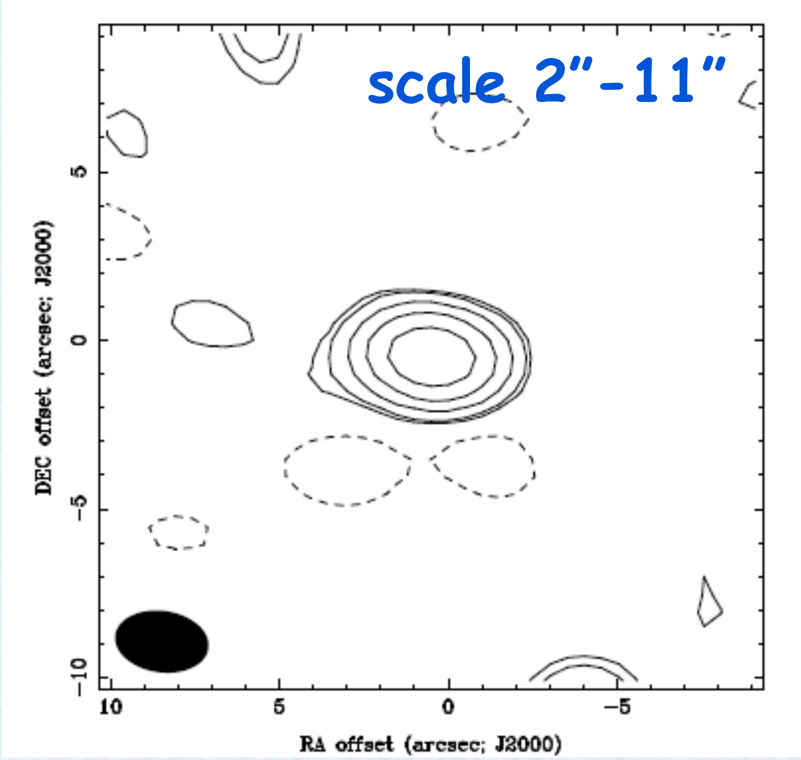
Object	D_{Lum}
MR 2251-178	289.1
NGC 3783	42.2
NGC 5506	26.8
NGC 7469	71.2
ARK 564	108.4
NGC 3227	16.7
MRK 766	75.0
NGC 5548	56.3

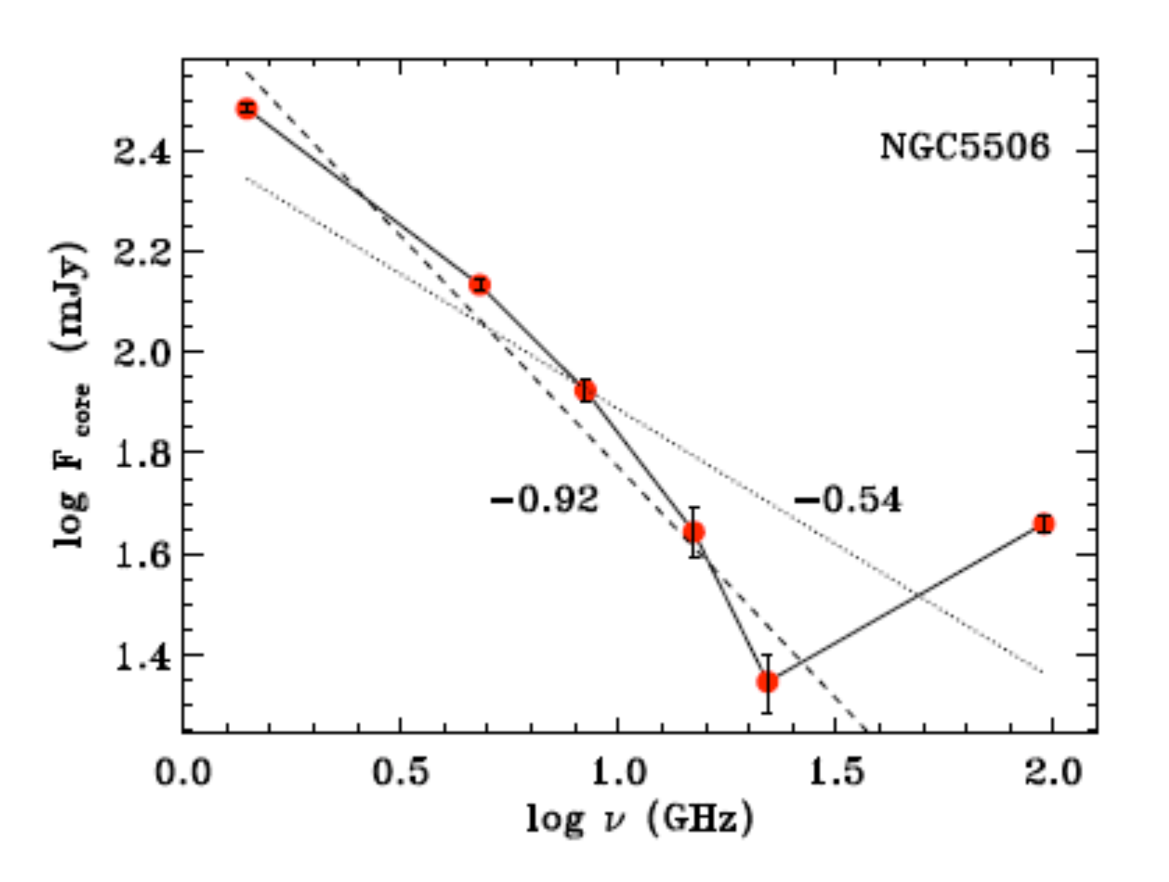
CARMA
Combined Array for Research in Millimeter-Wave Astronomy

Australia Telescope Compact Array

Detections at 95 Ghz

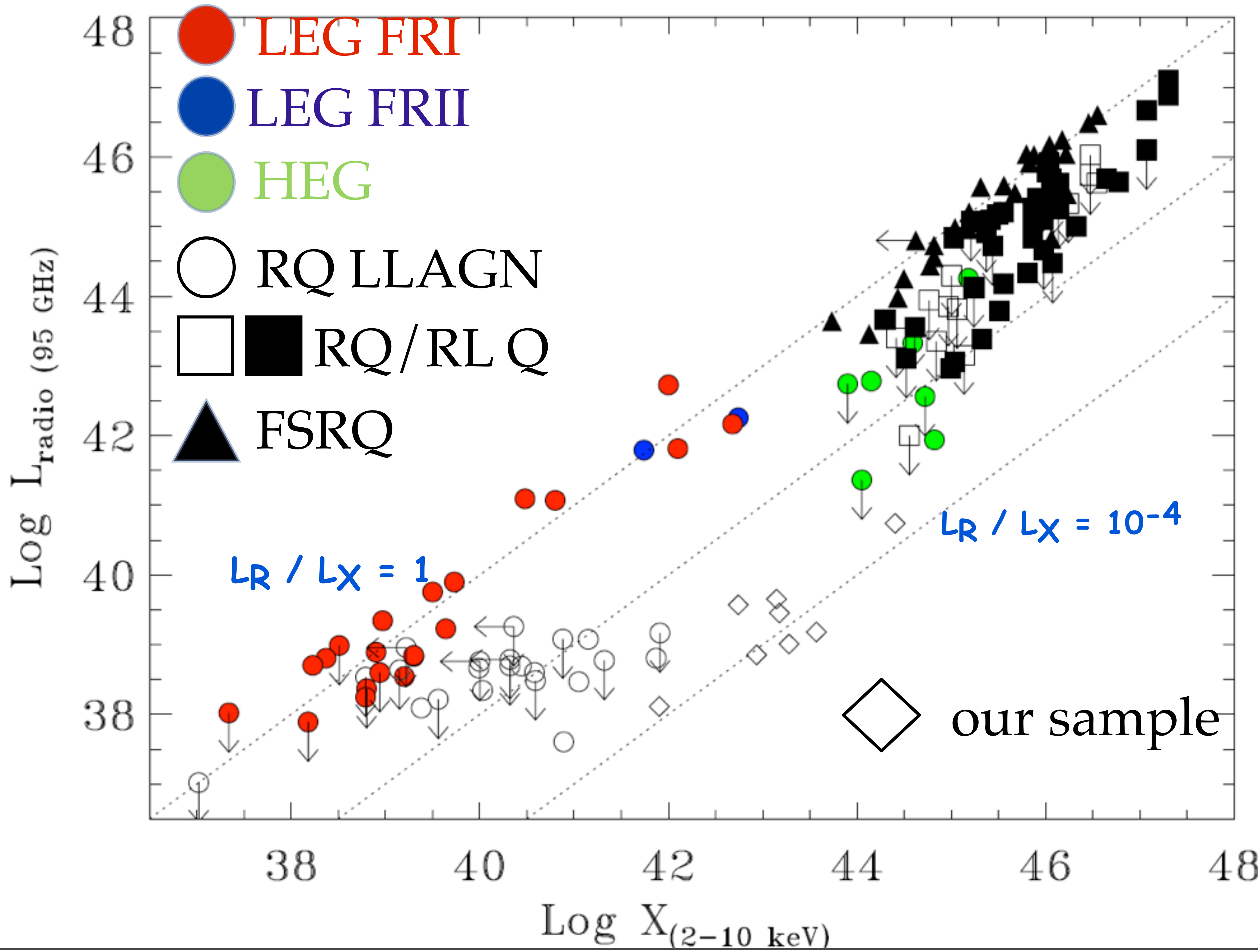
Object	95 GHz Flux (mJy)	$L_{95\ GHz}$ (erg/s)	L_X (erg/s)	R_{pc}
MR 2251-178	5.8±0.3	40.74	44.40	0.0018
NGC 3783	22.3±0.8	39.65	43.15	0.0019
NGC 5506	45.7±2.0	39.57	42.74	0.0019
NGC 7469	4.95±0.16	39.46	43.18	0.0019
ARK 564	1.14±0.19	39.18	43.57	0.0019
NGC 3227	4.1±0.24	38.11	41.90	0.0020
MRK 766	1.98±0.17	39.01	43.28	0.0019
NGC 5548	1.6±0.3	38.85	42.93	0.0019





- ☐ NO dust/star formation
- ☑ radio core from a jet
- ☑ submillimeter-bump due to ADAF
- ☑ accretion disk corona?

L_{95GHz} - L_X plane



Behar, Baldi, Laor et al in preparation

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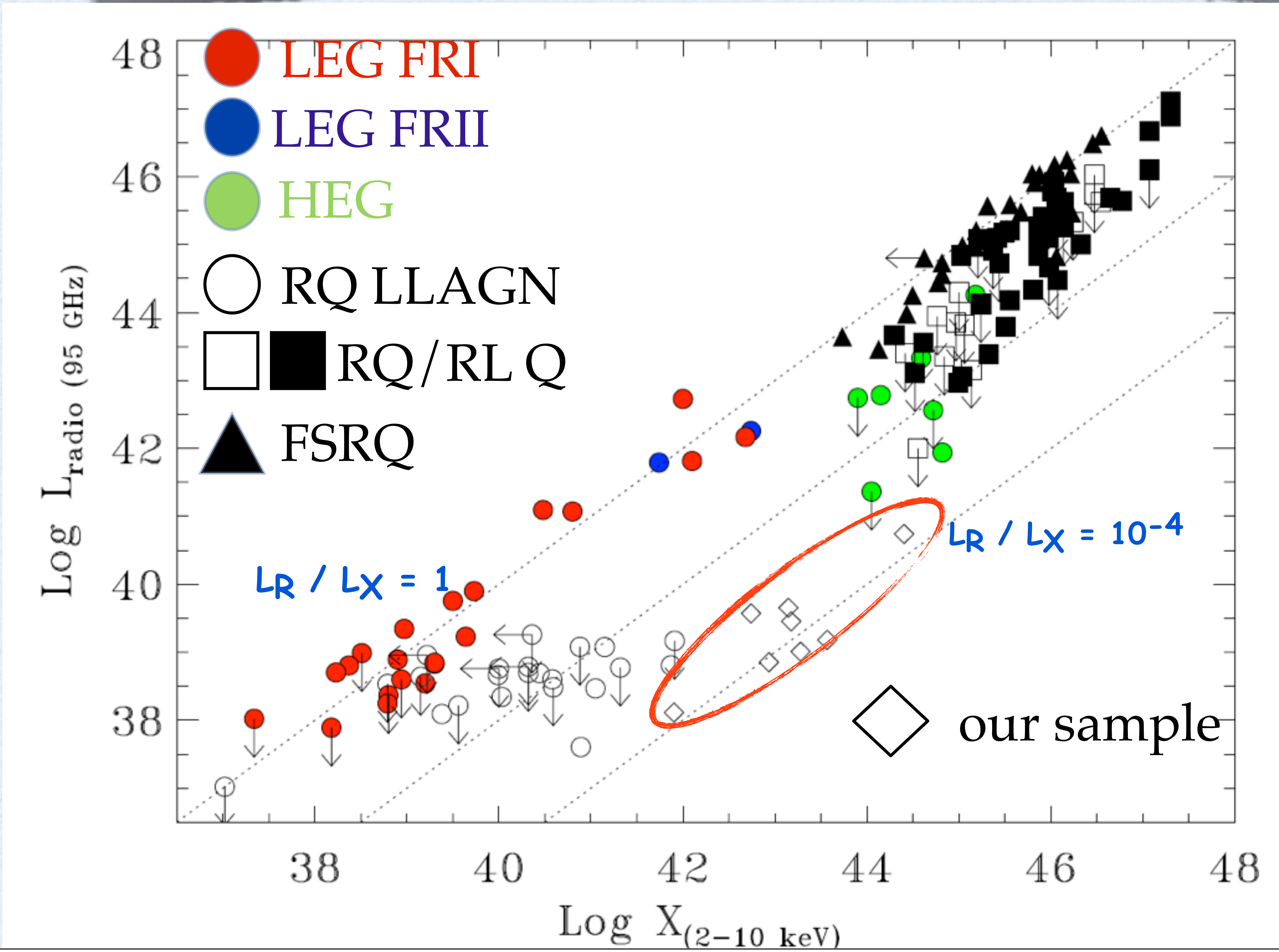

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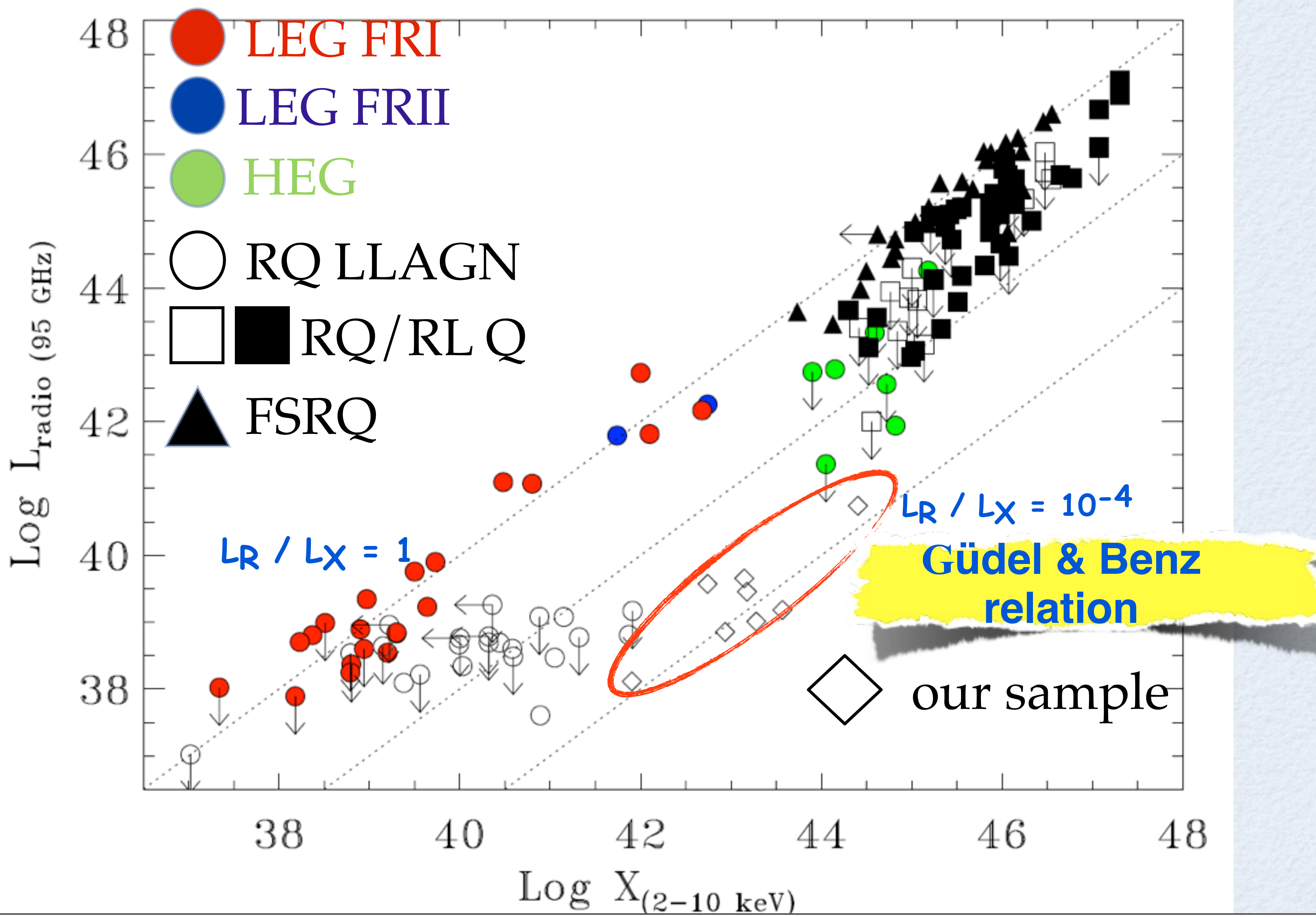

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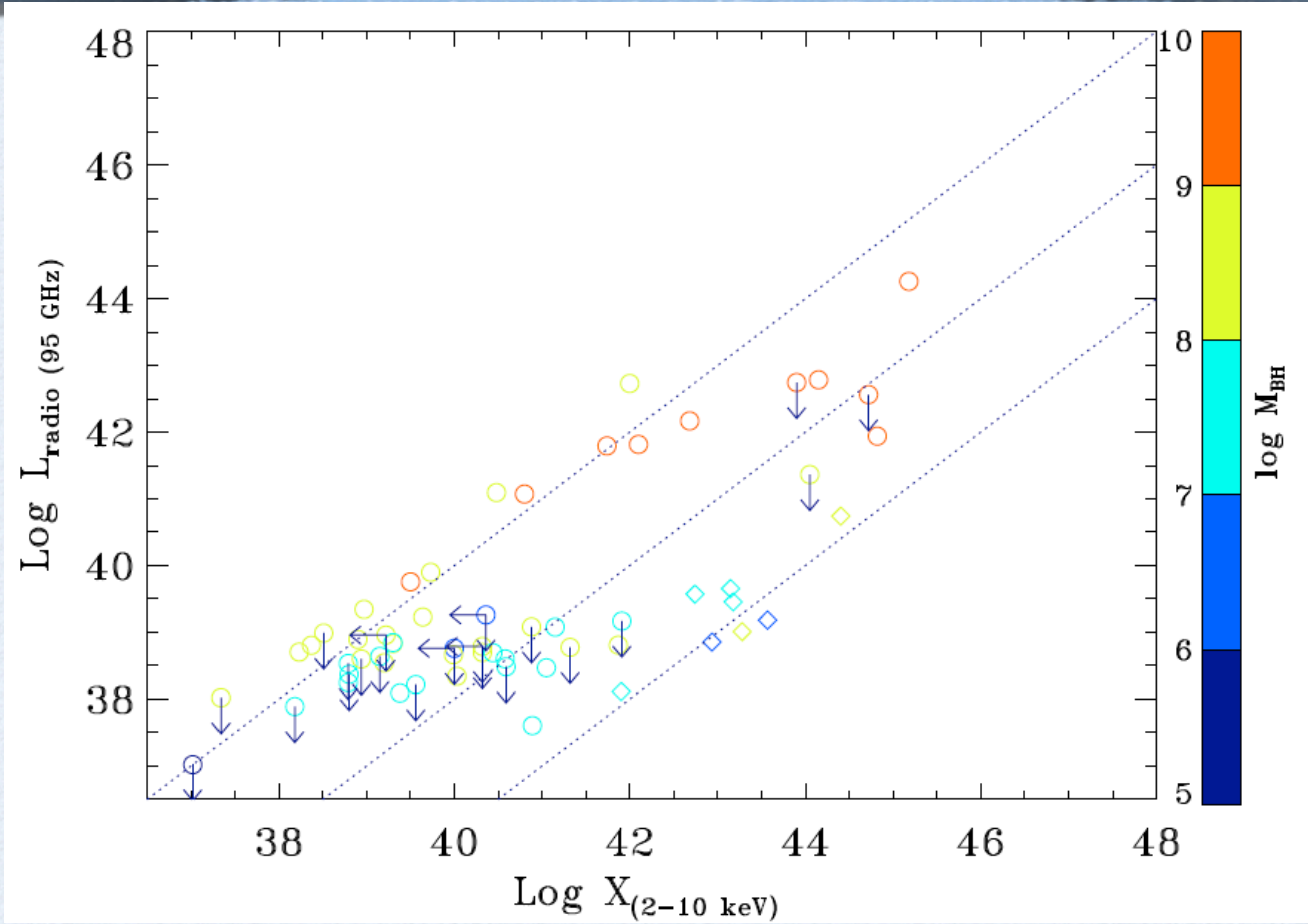
L_{95GHz} - L_X plane (M_{BH})



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At high GHz, when the jet component fades away, other componets emerges: ADAF and coronal emission

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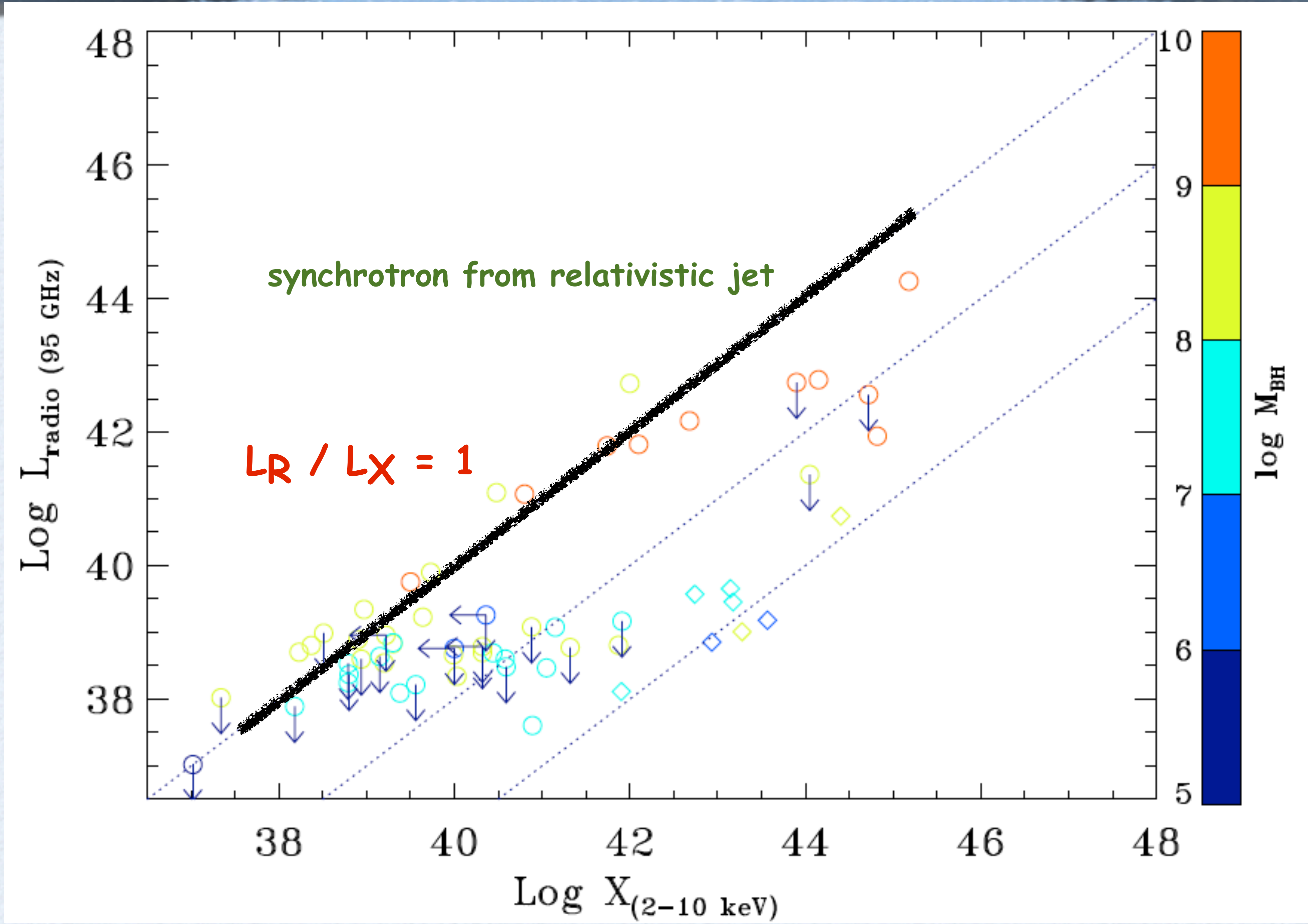

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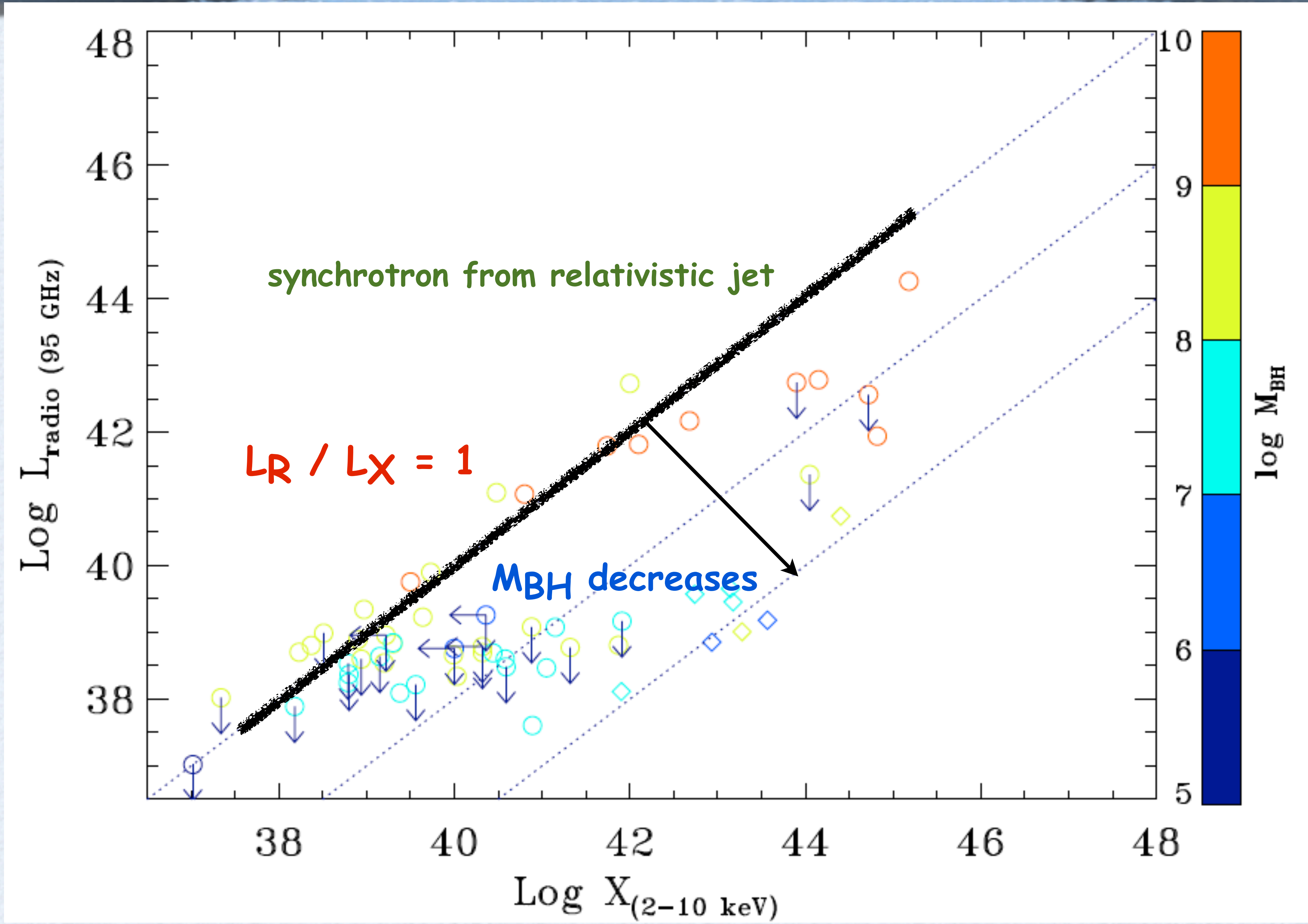

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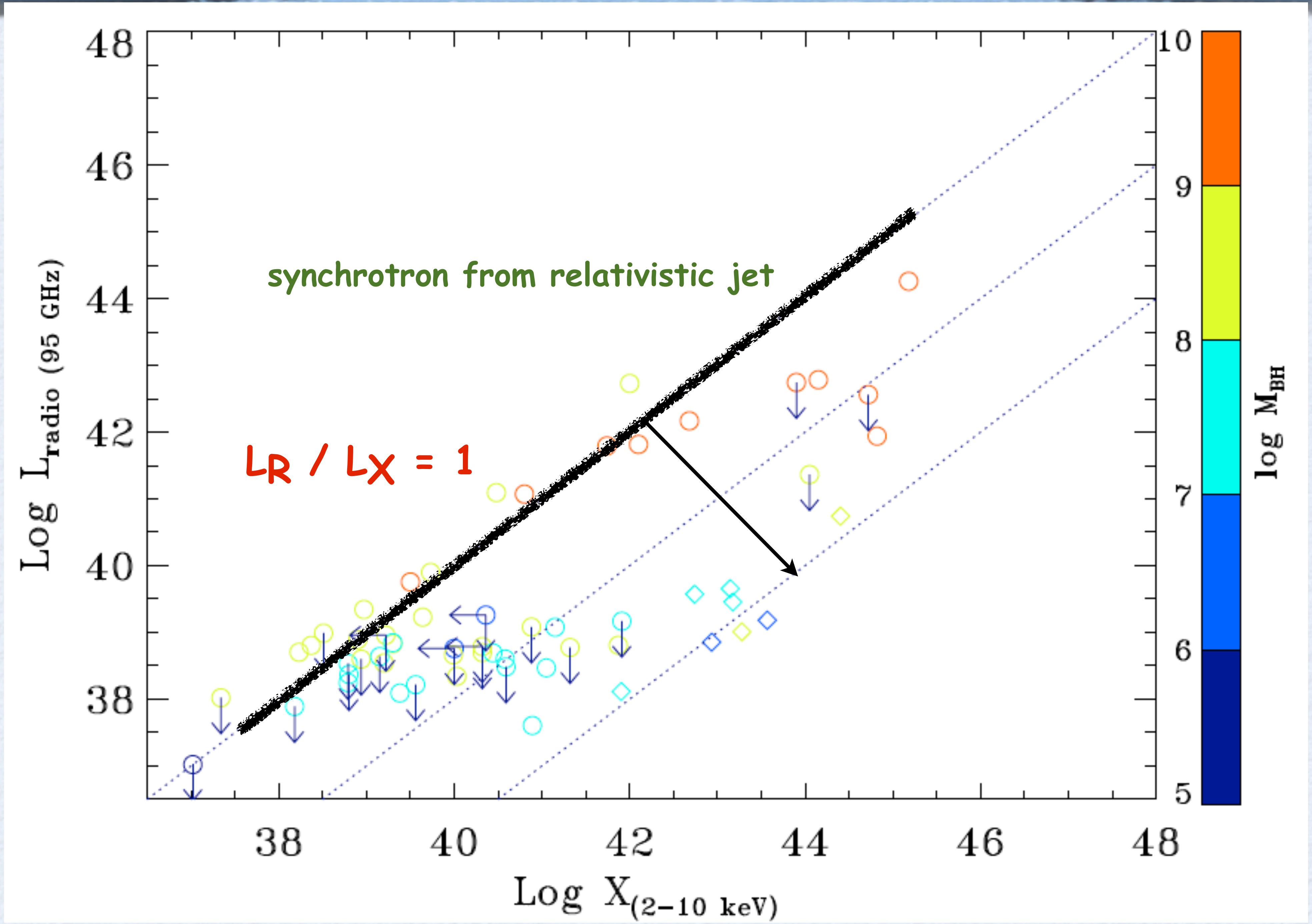

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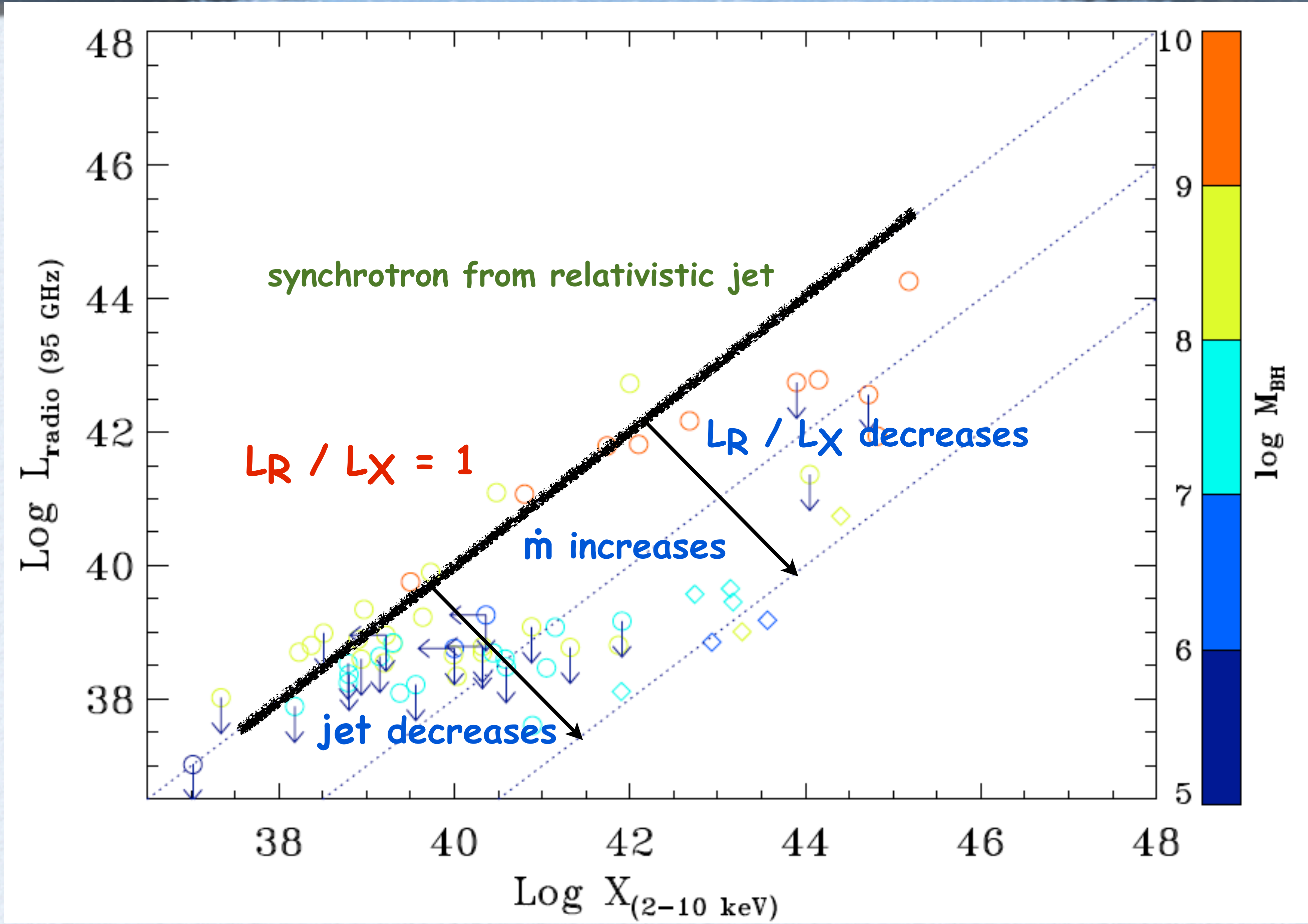

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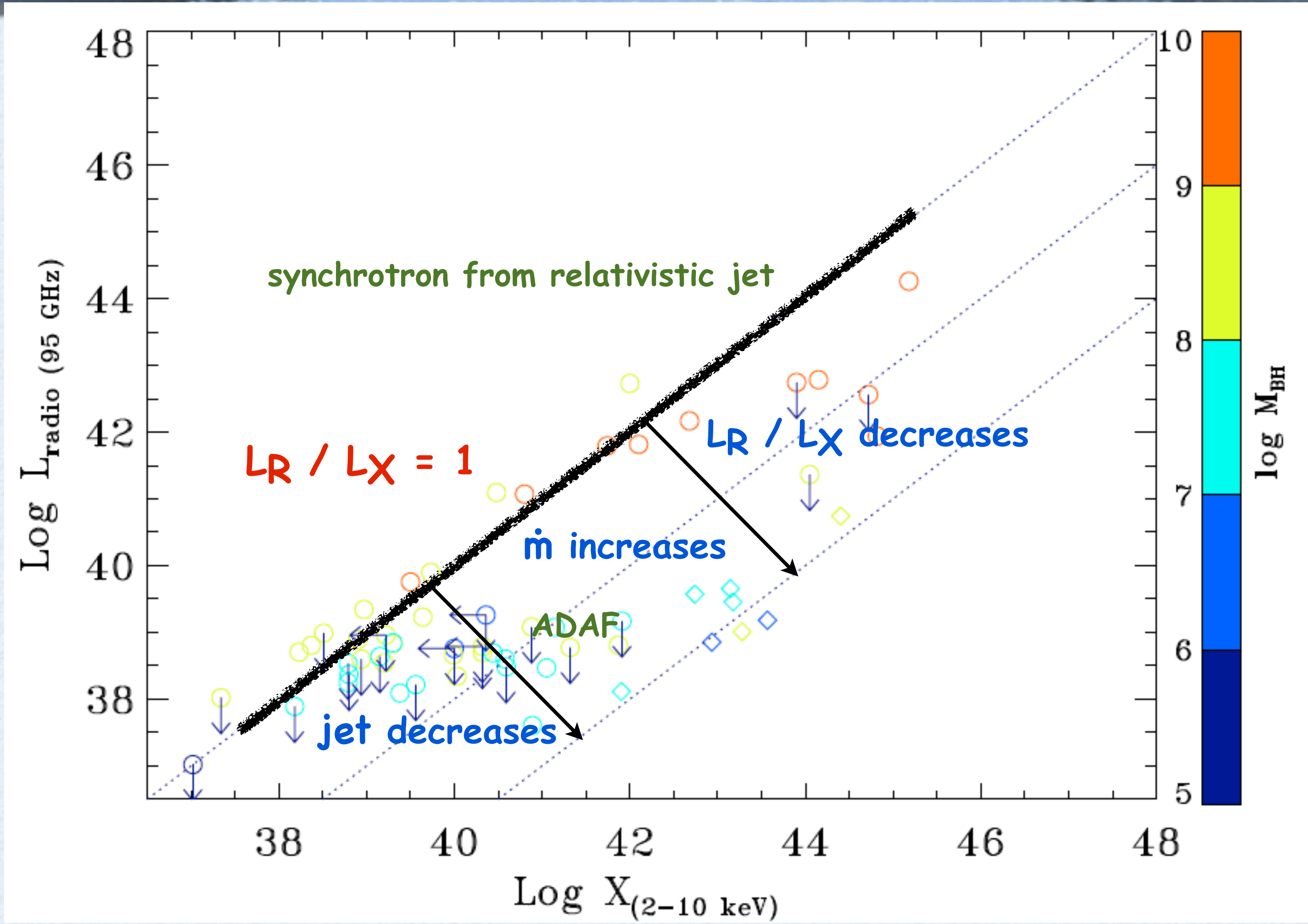

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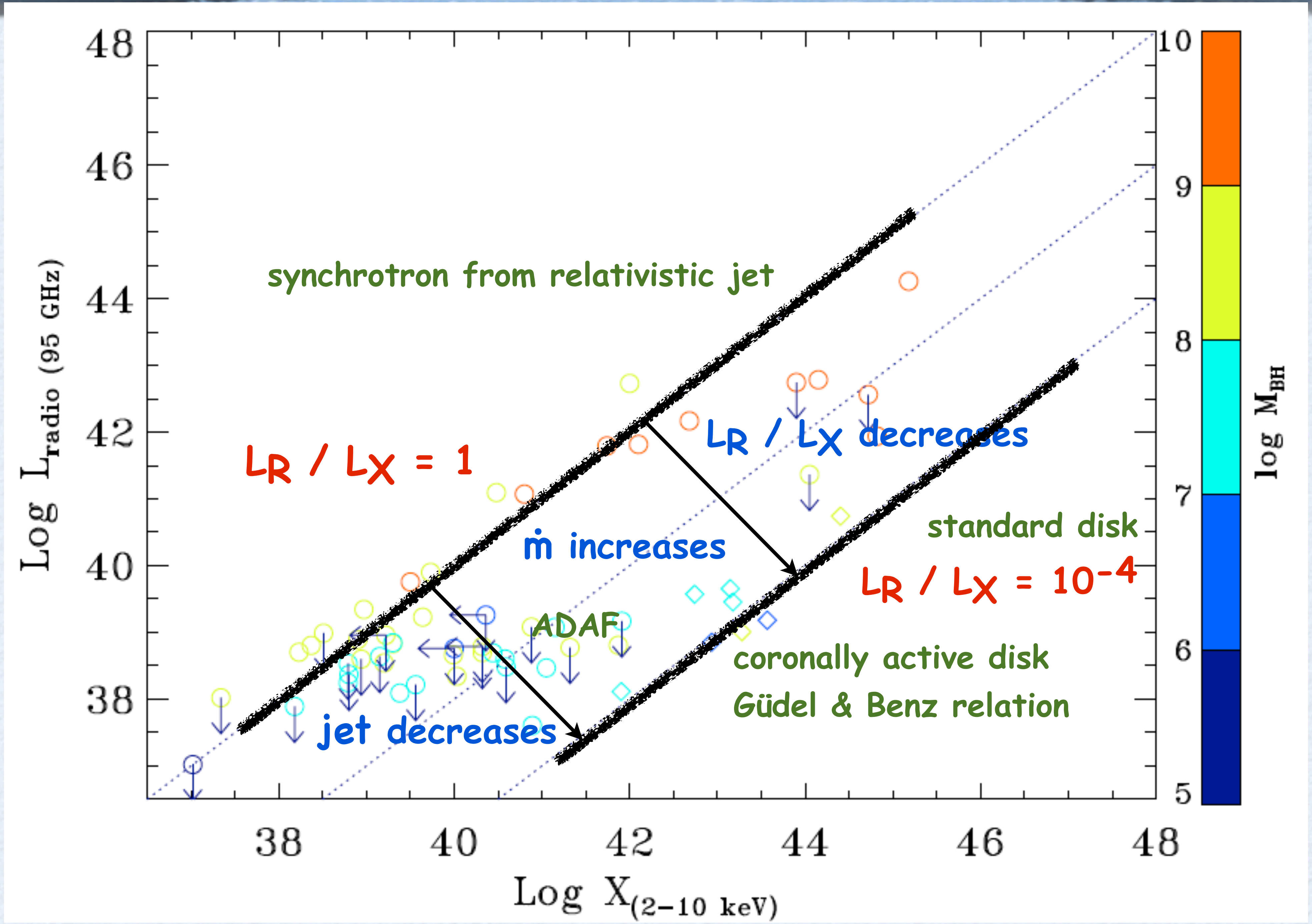

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At high GHz, when the jet component fades away, other componets emerges: ADAF and coronal emission

Summary & Conclusions

- X-ray in AGN produced in the accretion disk corona:

L_R/L_X (stellar coronae) ~ 10^{-5} ~ L_R/L_X (RQ AGN)

→ Radio emission in RQ AGN may also originate in the accretion disk corona: coronal mass ejections (CMEs) that feed the extended radio-sphere.

- At mm-wavlengths different component (jet, ADAF/corona) can coexist and the relative contribution depends on the BH mass and the accretion properties.

- Better simultaneous radio/X-ray monitoring is required to further explore this hypothesis.

- Observations at higher frequencies not easily accessible (but soon, e.g. ALMA) will be able to test this conjecture


Thank you