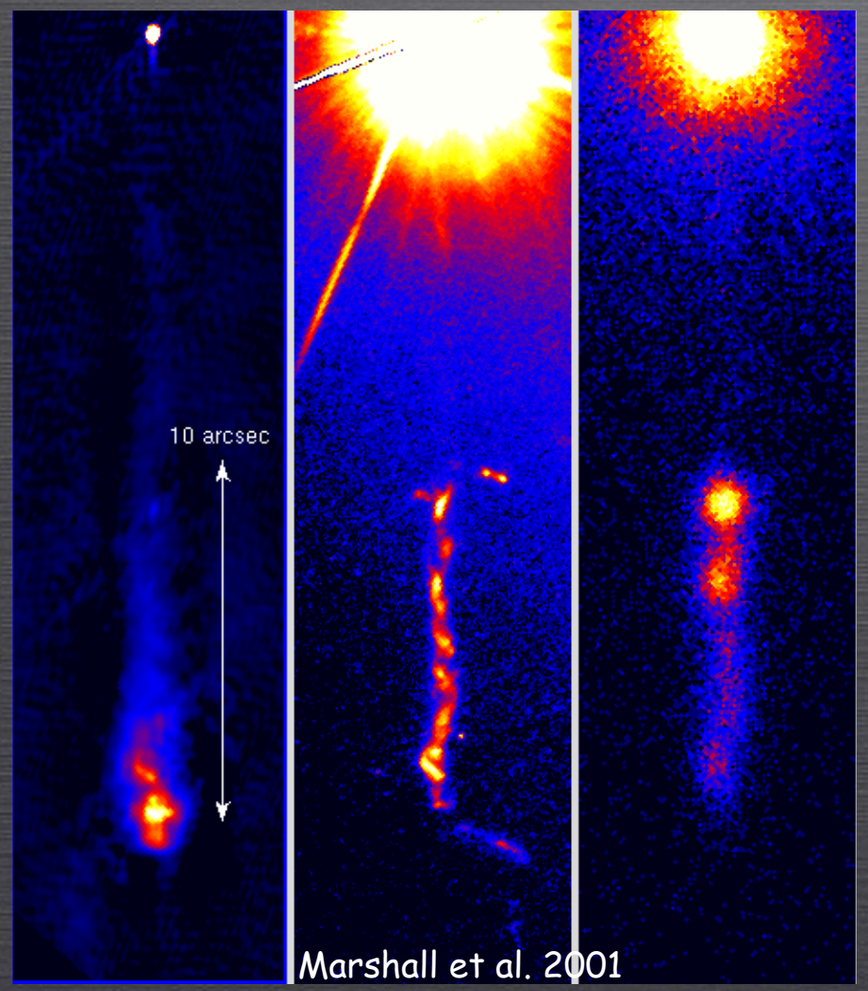
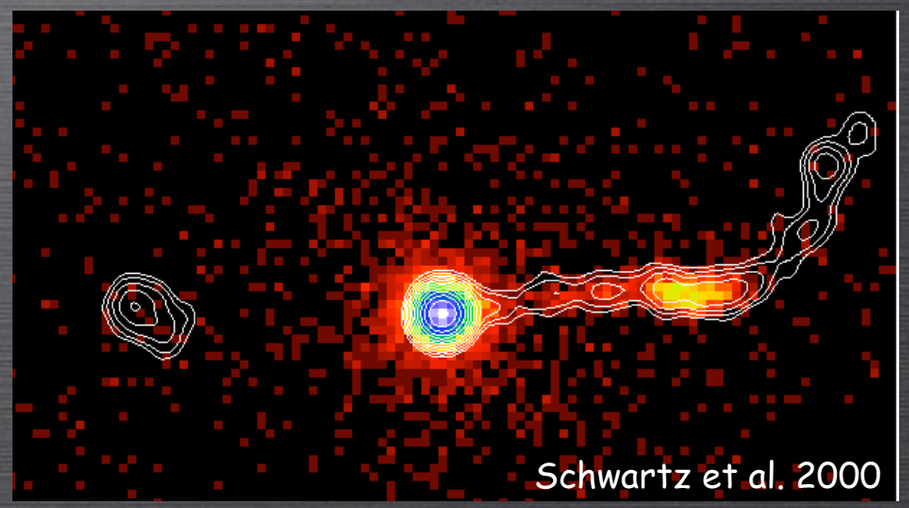
X-ray Imaging of a Complete Sample of FR II Quasar Jets

Herman L. Marshall (MIT Kavli Inst.)
D. Schwartz, D. Worrall, M. Birkinshaw (SAO)
J. Gelbord, E. Perlman, L. Godfrey, J. Lovell



Marshall et al. 2001


Schwartz et al. 2000

CXC

Not Time for a Nap!

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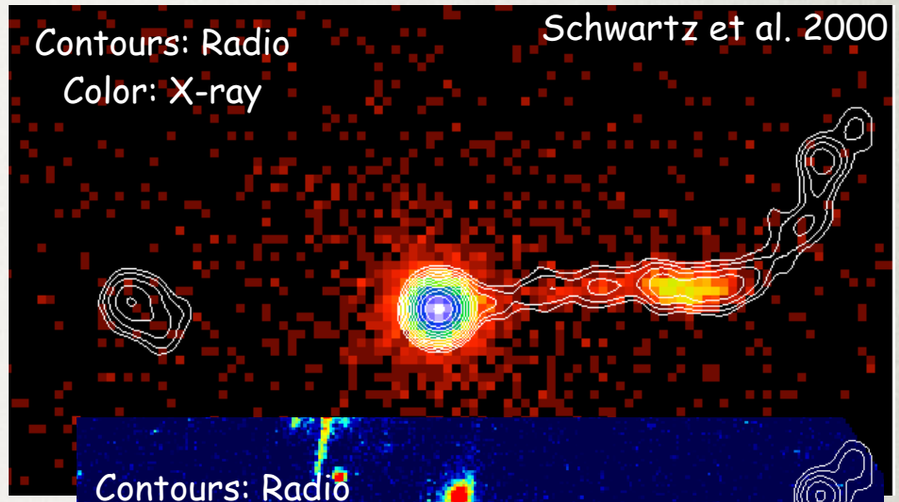
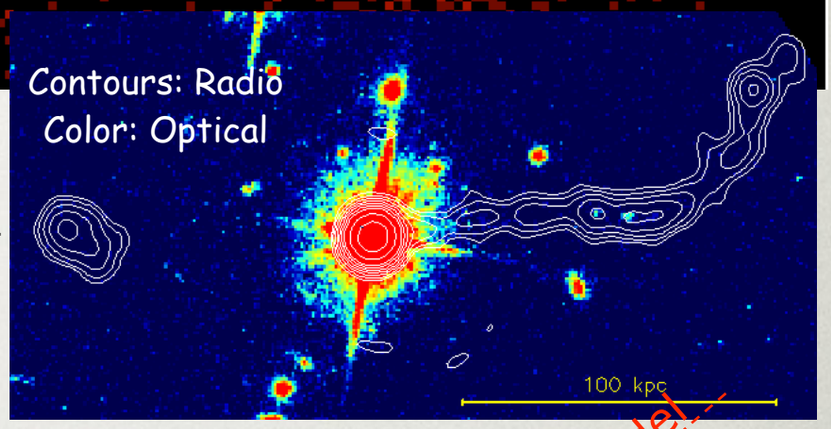
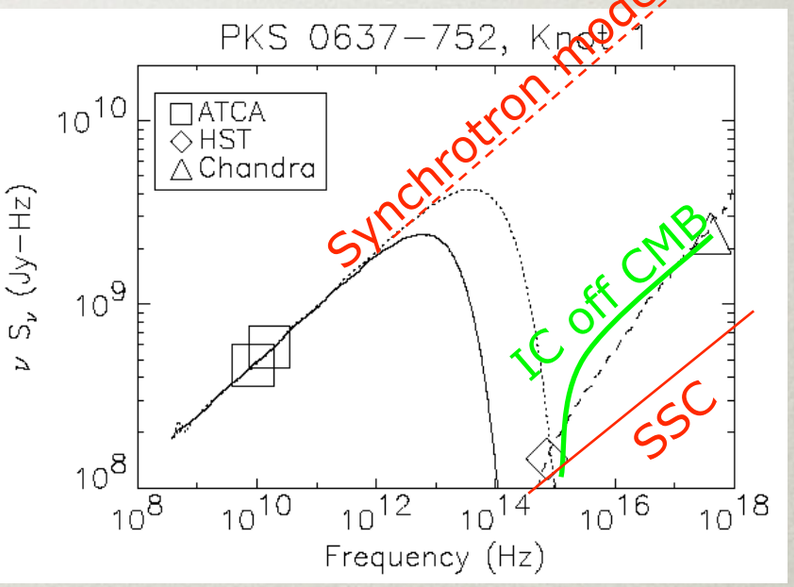
First Chandra Jet

- Observed for focussing
- Jet flux is 7% of core flux
  - 3C 273: 0.5% in jet
- Optical jet emission is weak
  - Rules out simple synchrotron
  - Rules out SSC
- Inverse Compton of CMB
  - Jet is 10° to line of sight
  - Bulk $\Gamma \sim 15$
  - Γ, θ like pc scale VLBI







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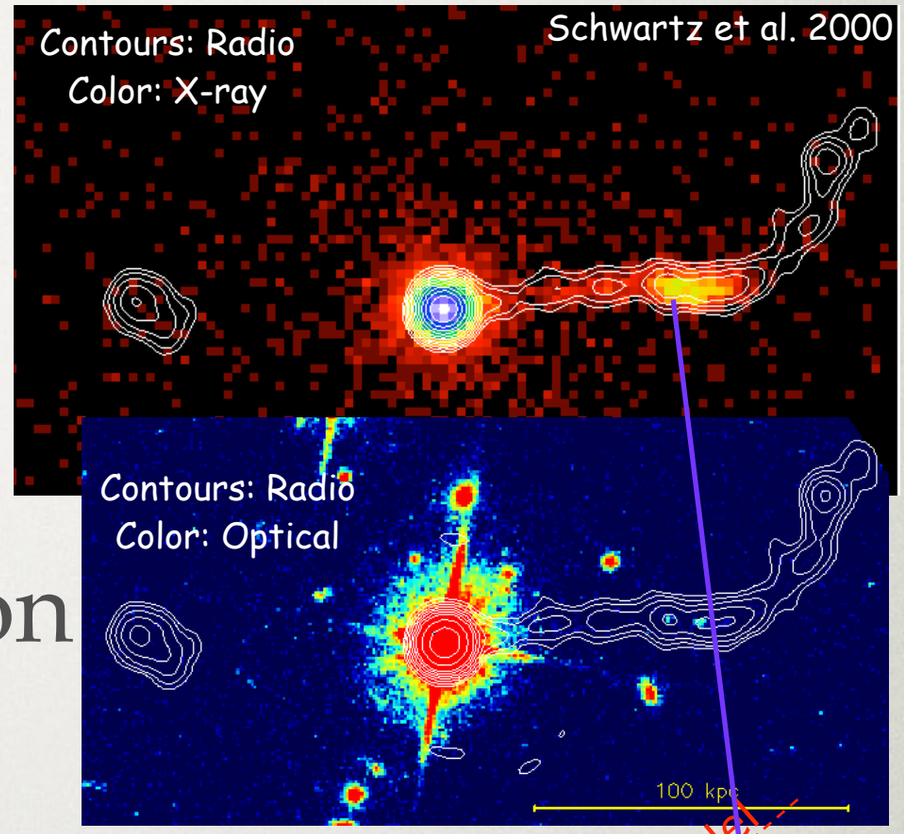

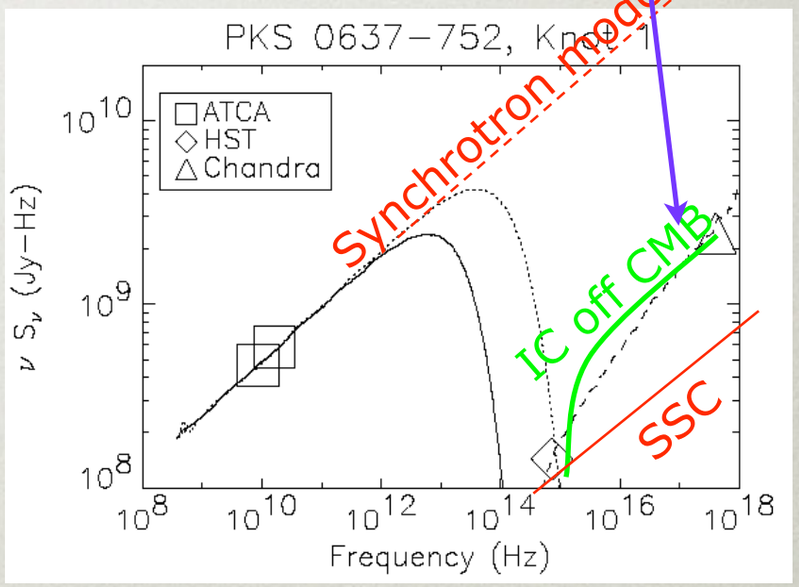

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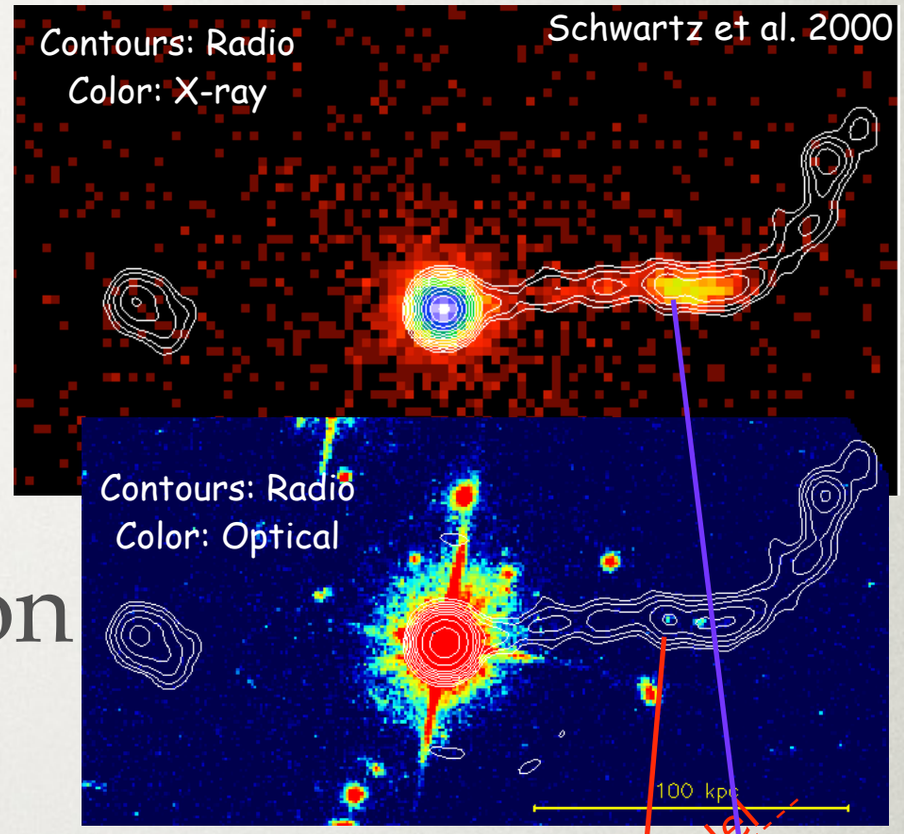
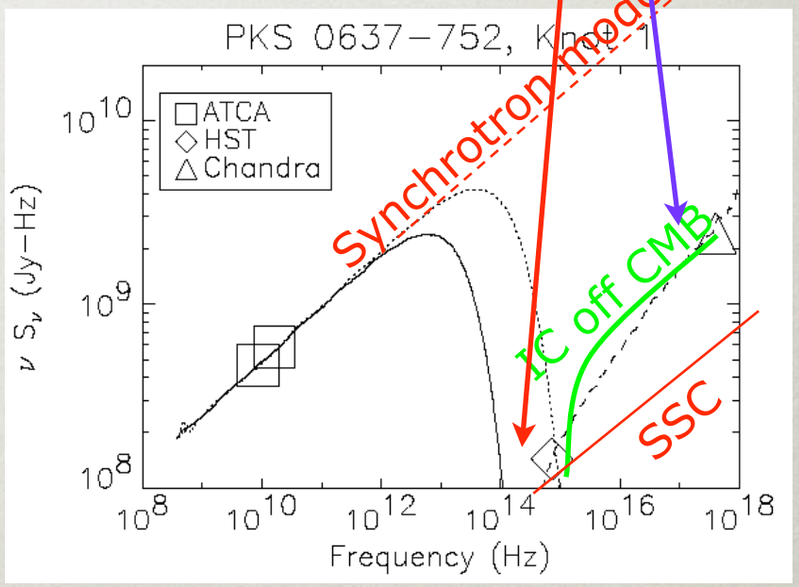




IC-CMB Method

- See Dermer '95, Tavecchio+ '00, Celotti+ '01
- Based on blazar core modeling
  - superluminal motion --> high Γ, small θ
  - Doppler factor $\delta = 1/(\Gamma[1 - \beta\cos\theta])$ is large
- Estimate B'_{me} in jet frame
  - based on B_{me} in observed frame $B'_{me} = B_{me}/\delta$
  - B_{me} depends (weakly) on L_r, V of a jet knot
- Assume L_X is iC from CMB:

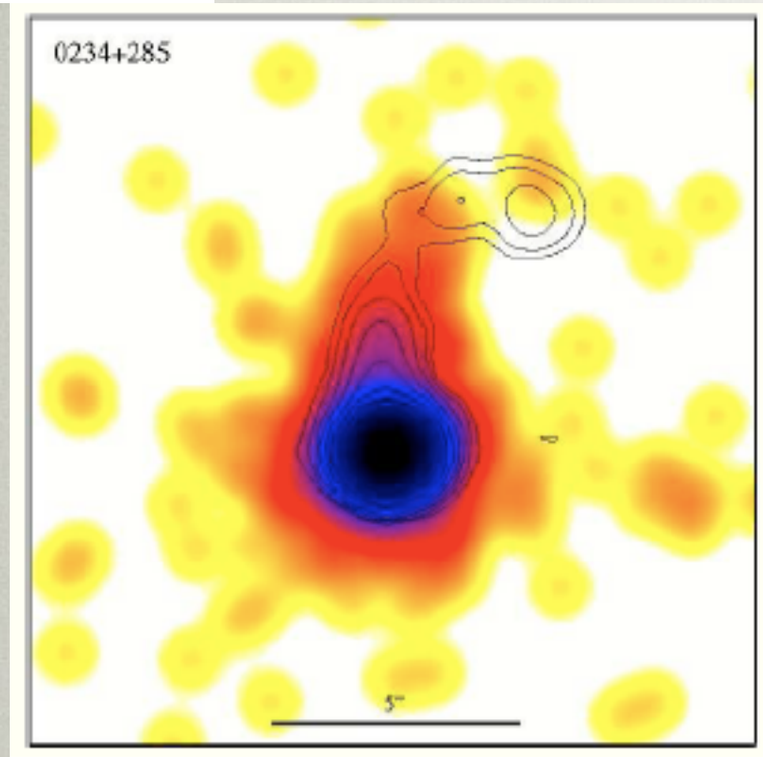
$$\frac{L_S}{L_{IC}} = \frac{\nu_r S_r}{\nu_x S_x} = \frac{u_B}{u_\nu} \qquad u_B = \frac{B^2}{8\pi} = a[(1+z)T]^4\Gamma^2\frac{L_S}{L_{IC}} \approxeq aT^4(1+z)^4\delta^2\frac{\nu_r S_r}{\nu_x S_x}$$

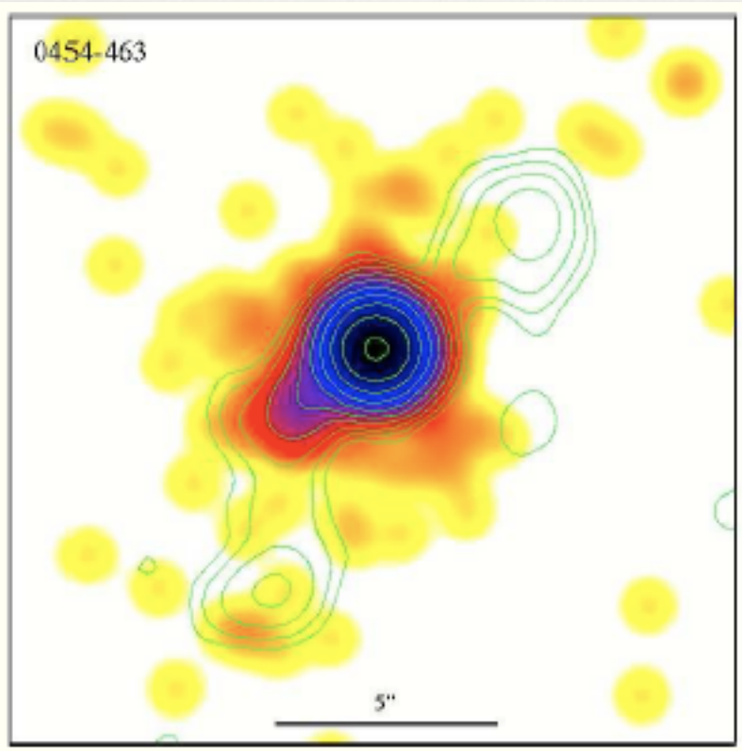
- Match B to B'_{me}, giving δ from observables

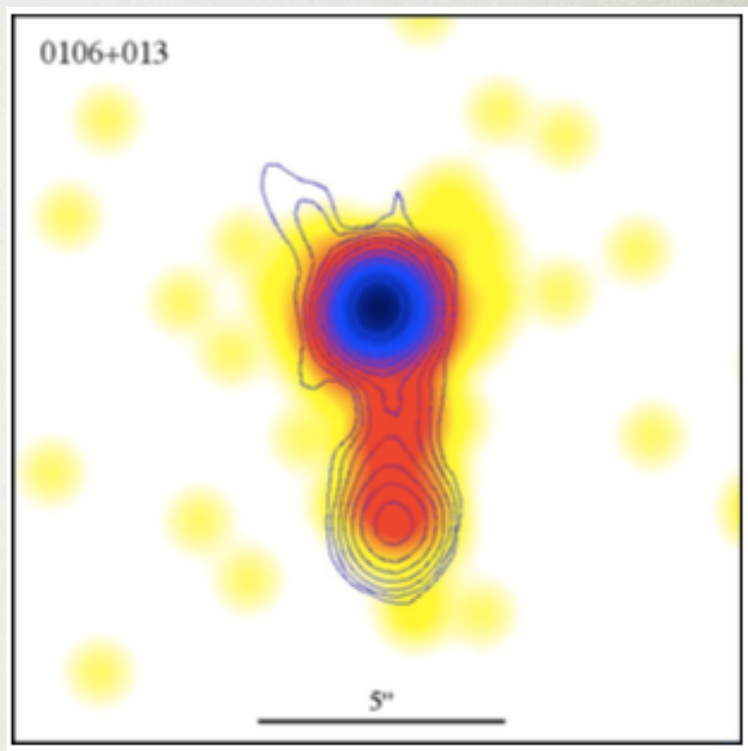
Chandra Jet Surveys

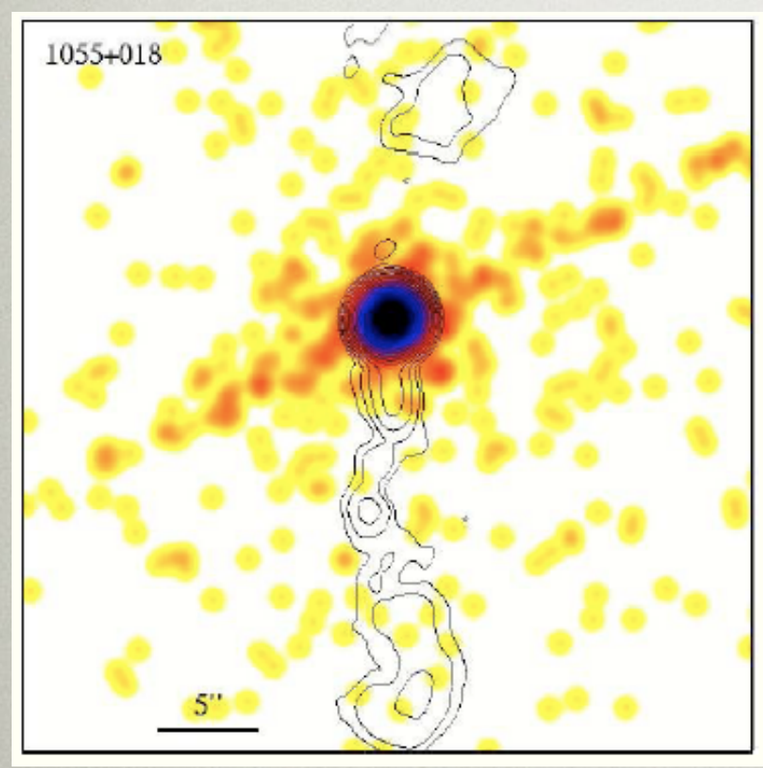
- Select FSRQs from VLA, ATCA maps
- Sambruna+ 2004: 17 sources, 10 ks each
- Marshall+ 2005, 2011, & in prep.
  - 56 sources, 5 ks ea., flux-limited subset
  - Chandra followup for 5, HST for many
- Hogan+ 2011 — MOJAVE sources
  - 10 new observations, flux limited sample of 27
  - Kharb+ 2013: followup of 2 sources
  - Stanley+ 2015: followup of 3 w/ Hybrid morph.
- Results: jets detected in 60-75% of samples

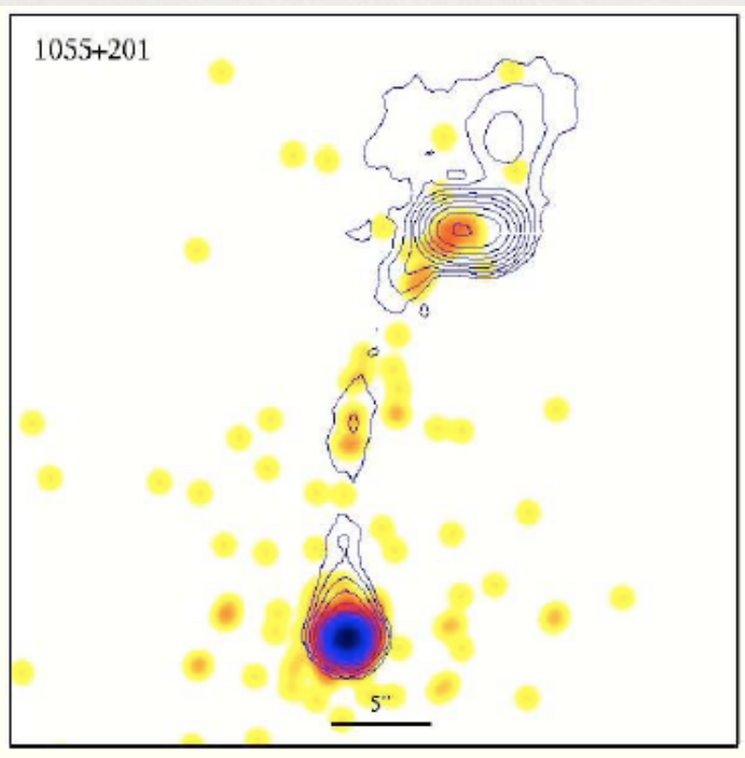
X-ray & Radio Imaging

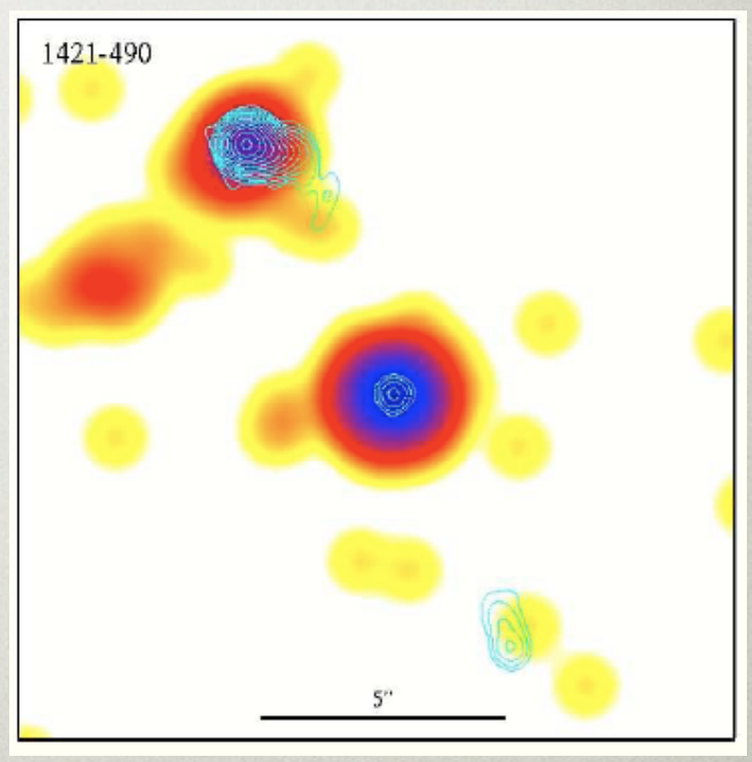




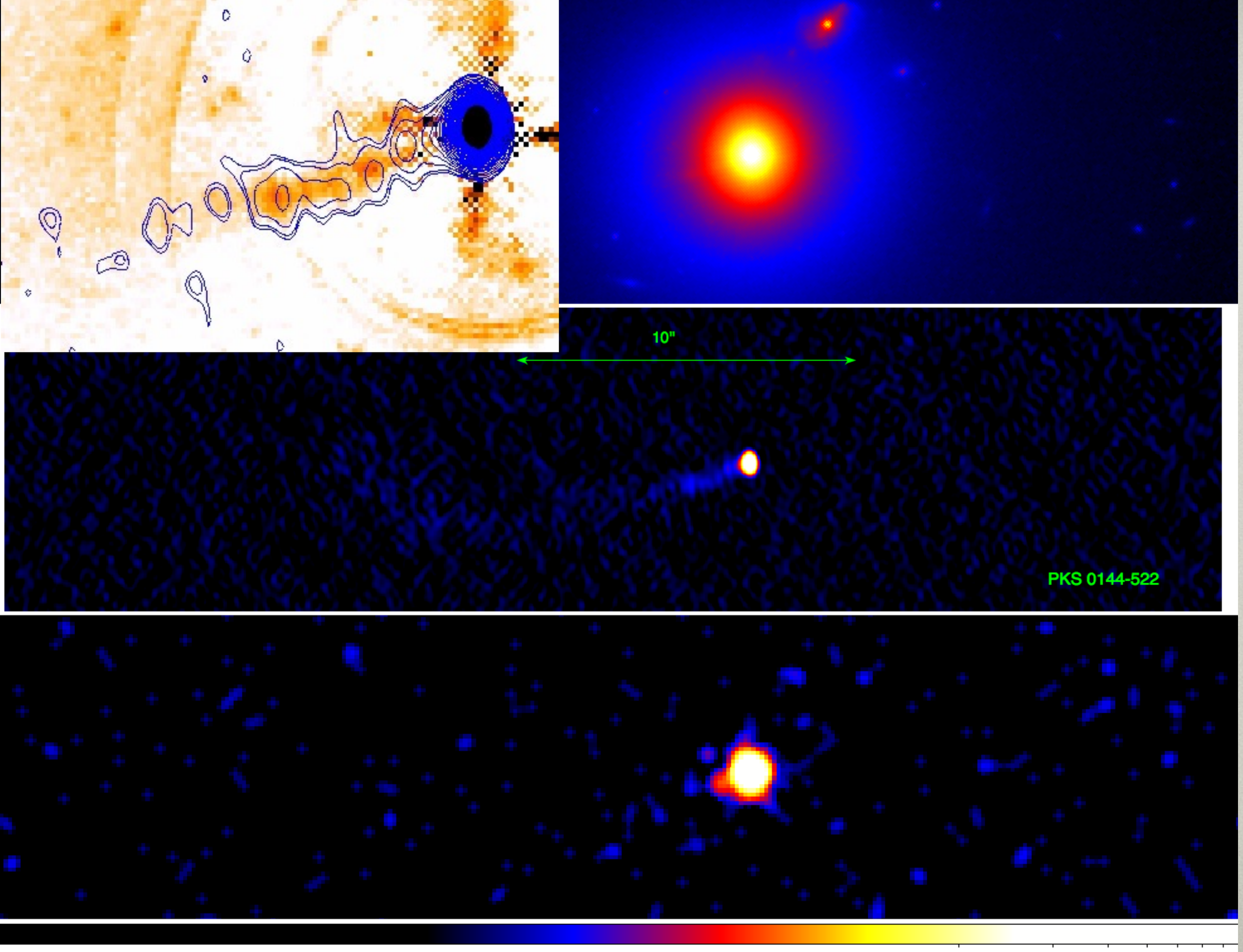






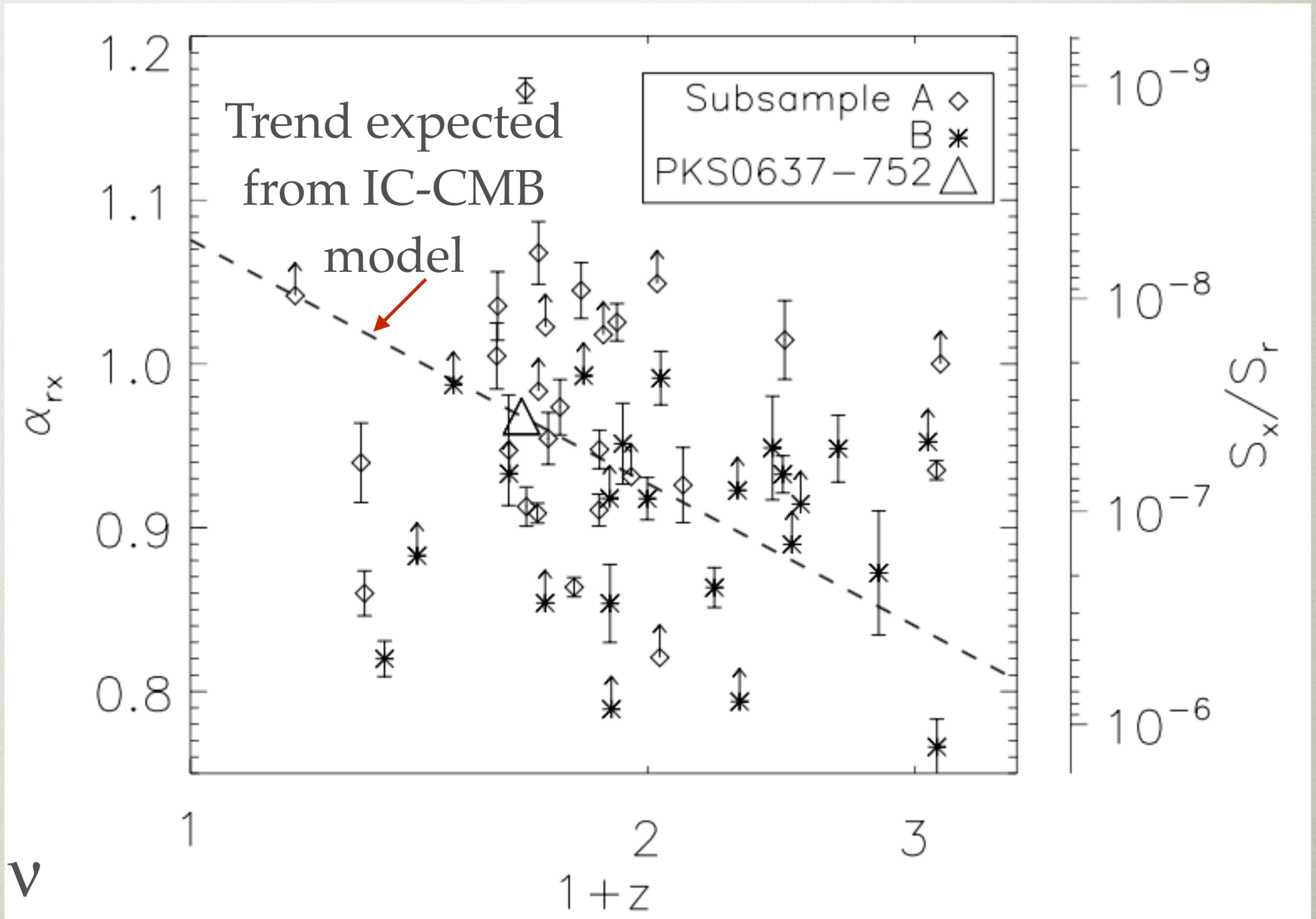


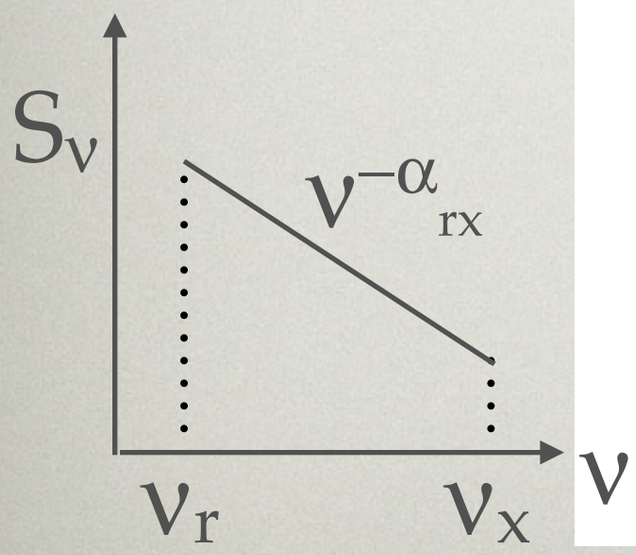
0208-512 (green contours = 0.6GHz)
0229+131 (blue contours = 1.4GHz)
0234+285 (black contours = 4.8GHz)
0413-210 (black contours = 4.8GHz)
0454-463 (green contours = 0.6GHz)
0745+241 (black contours = 4.8GHz)
0820+225 (blue contours)
0920-397 (green contours = 0.6GHz)
0923+392 (blue contours = 1.4GHz)
0903-573 (green contours = 0.6GHz)
1030-357 (green contours = 0.6GHz) (black contours = 4.8GHz)
1046-409 (green contours = 0.6GHz)
1040+123 (blue contours = 1.4GHz)
1055+018 (blue contours)
1116-462 (green contours = 0.6GHz)
1145-676 (green contours = 0.6GHz)
1202-262 (green contours = 0.6GHz)
1251-713 (green contours = 0.6GHz) (red contours = 2.5 x RMS noise)
1258-321 (green contours = 0.6GHz)
1343-601 (green contours = 0.6GHz) (red contours = 2 x RMS noise)
1354+195 (blue contours)
1424-418 (green contours = 0.6GHz)
1641+399 (blue contours = 1.4GHz)
1642+690 (blue contours = 1.4GHz)
1655-776 (green contours = 0.6GHz)
1655+077 (blue contours = 1.4GHz)
1828+487 (black contours = 4.8GHz)
1928+738 (blue contours)
2101-490 (green contours = 0.6GHz)
2123-463 (green contours = 0.6GHz)
2251+158 (black contours = 4.8GHz)
2255-282 (blue contours = 1.4GHz)
2326-477 (green contours = 0.6GHz)
1421-490
1055+201 (blue contours)


10"
PKS 0144-522
0.02
0.04
0.06
0.08
0.1
0.12
0.14

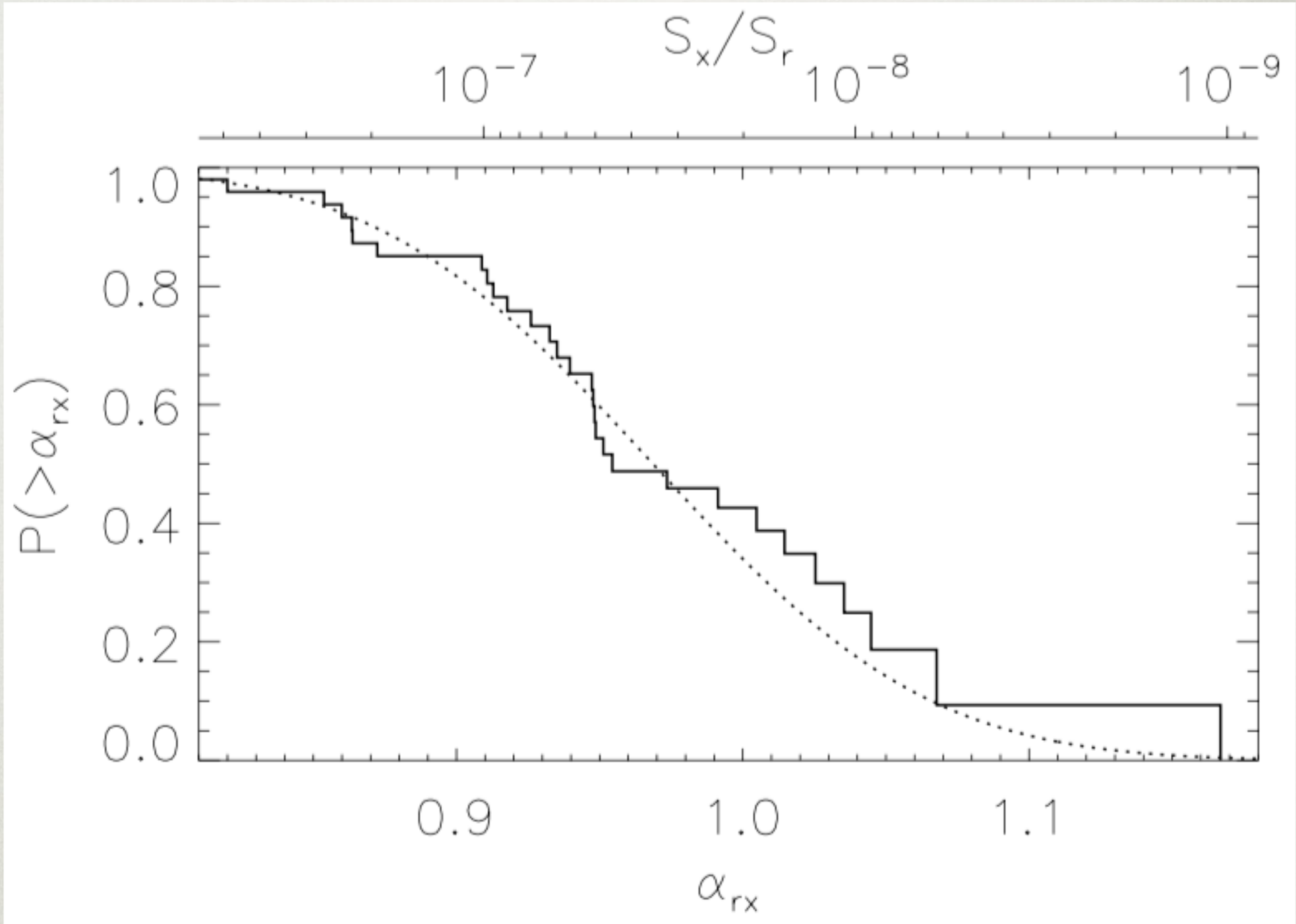
Summary of Sample

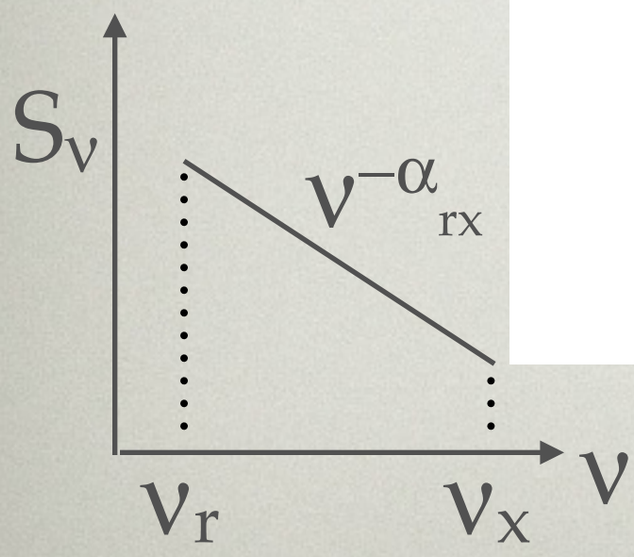
- Many X-ray bright jets found in 5 ks each!





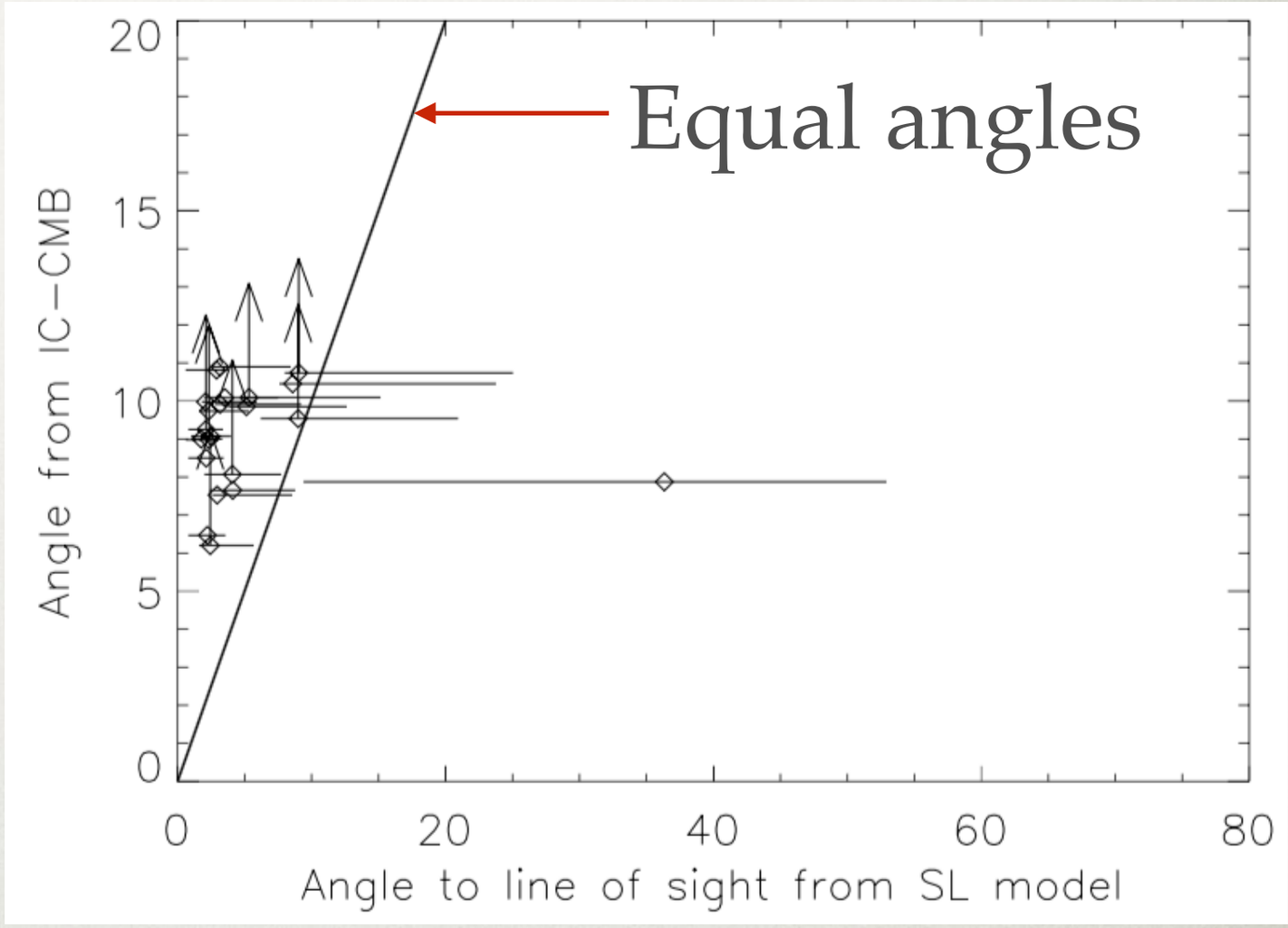
Broad Sx/Sr distribution





VLBI v. IC-CMB

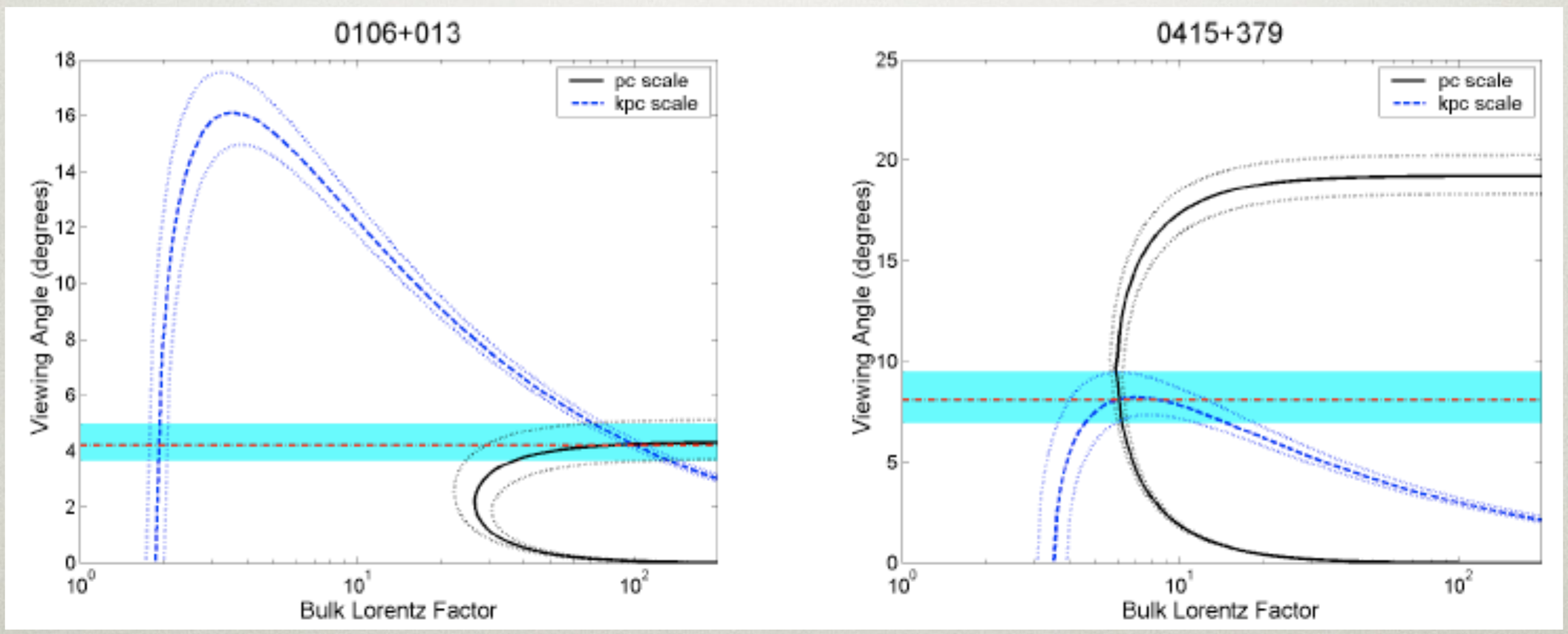
- Angles predicted for kpc scales
- Set $\theta_{pc} = \beta_{app}/2$
- Set $\Gamma_{kpc} = \Gamma_{pc}$
- Use PA differences to limit prediction from superluminal model at 90% conf.



—> Either jets bend or decelerate (cf. Hogan+ ‘11)

Mojave Survey
(Hogan+ 2011)

- Sample from MOJAVE list
- VLBI: pc-scale jet motion
- Chandra survey: IC-CMB model constraints
  - Jets likely bend by few degrees from pc to kpc
  - Deceleration is most likely



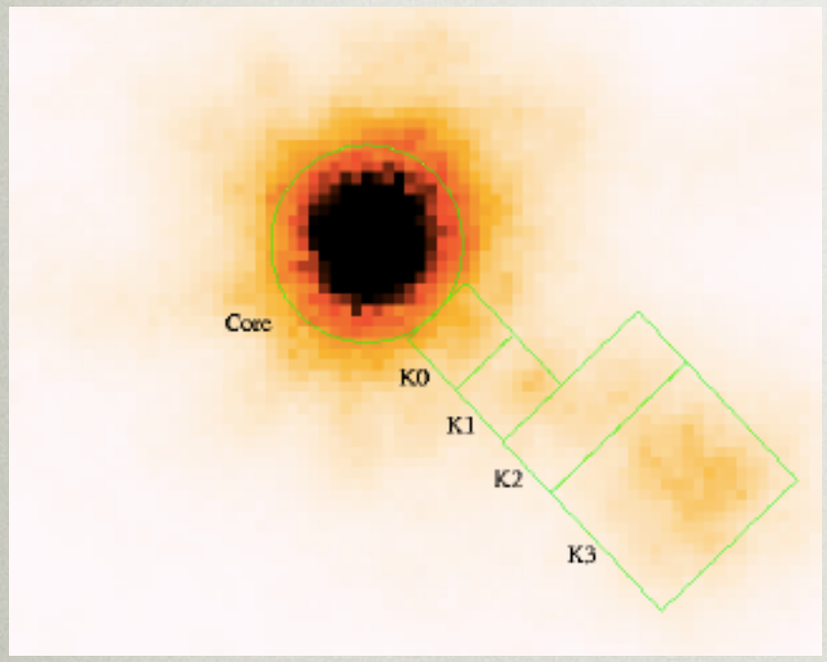
Survey Conclusions

- Detected jets/hotspots in 60% of sample
  - Flux (A) and morphology (B) selection are similar
- Distribution of α_{rx} is very broad
  - In iC-CMB, ratio depends on $B^{1+\alpha}\,(1+z)^{3+\alpha_r}$
  - Shape is independent of z or A/B subsample
    - —> Variance is intrinsic to population
- Fitting $(1+z)^a$ gives $a = 0.9 \pm 0.9$
  - iC-CMB is ruled out at 99.5% conf., for $\alpha_r > 0.5$
- Angles to line of sight: jets bend or decelerate
- Caveats: need knot fluxes, eliminate hotspots

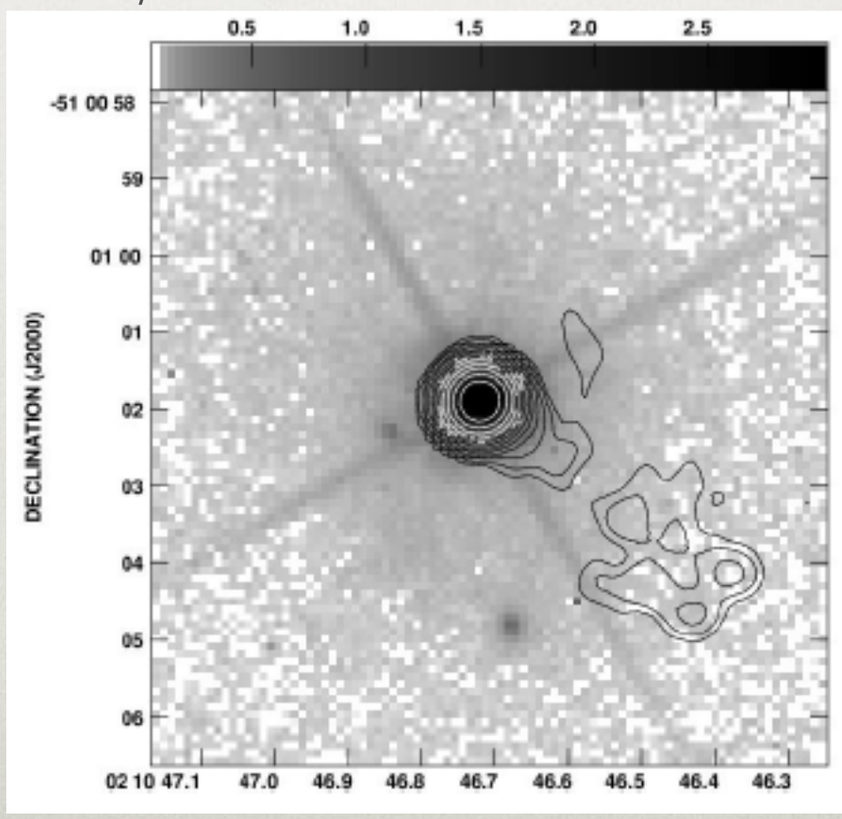
Survey Follow-up: PKS 0208

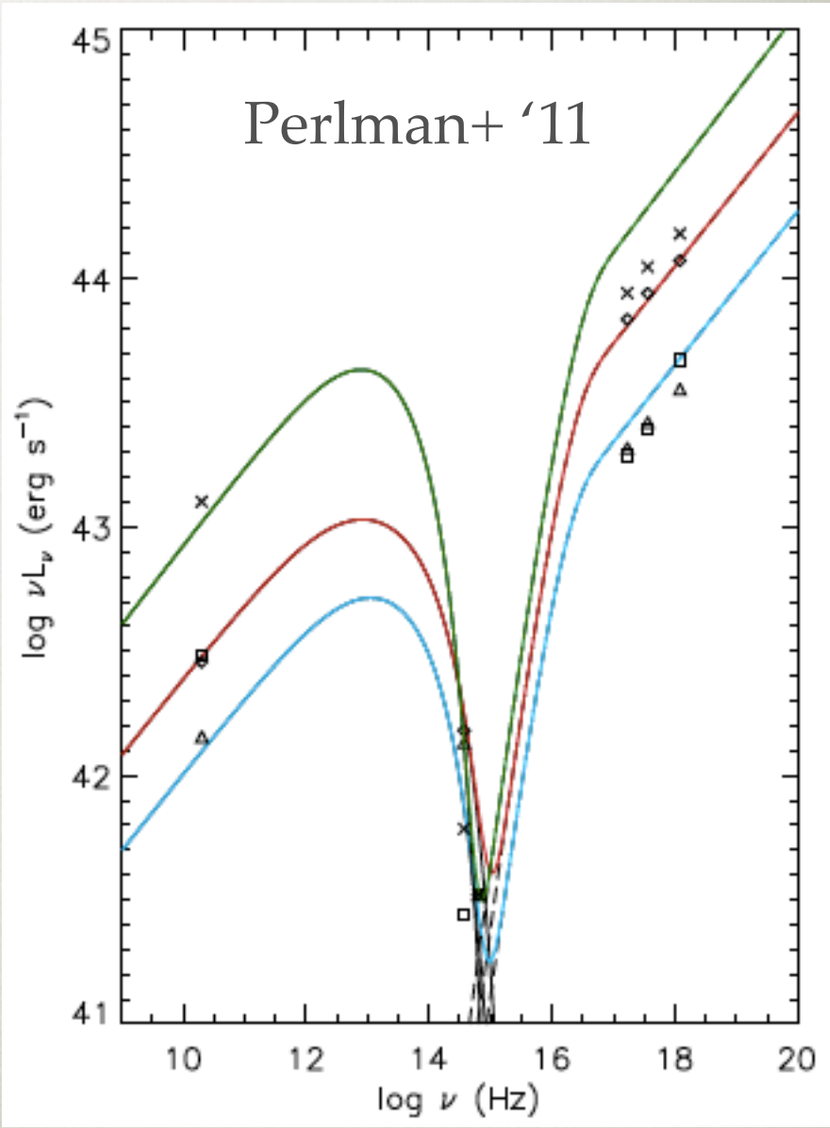
- Define knots with deep Chandra image
- Two HST bands obtained
- iC-CMB: $\delta = 10$, dropping to 7

Chandra

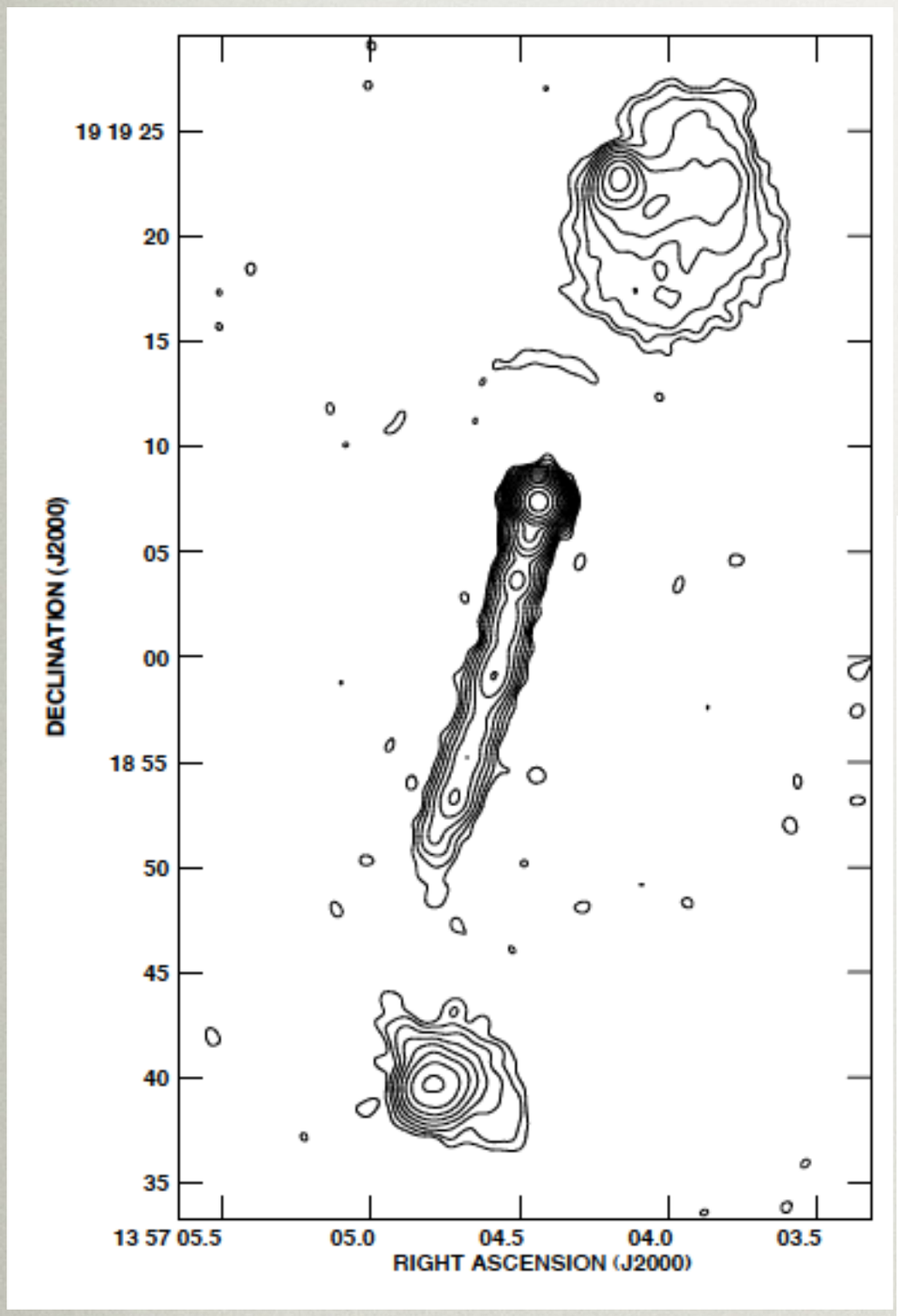


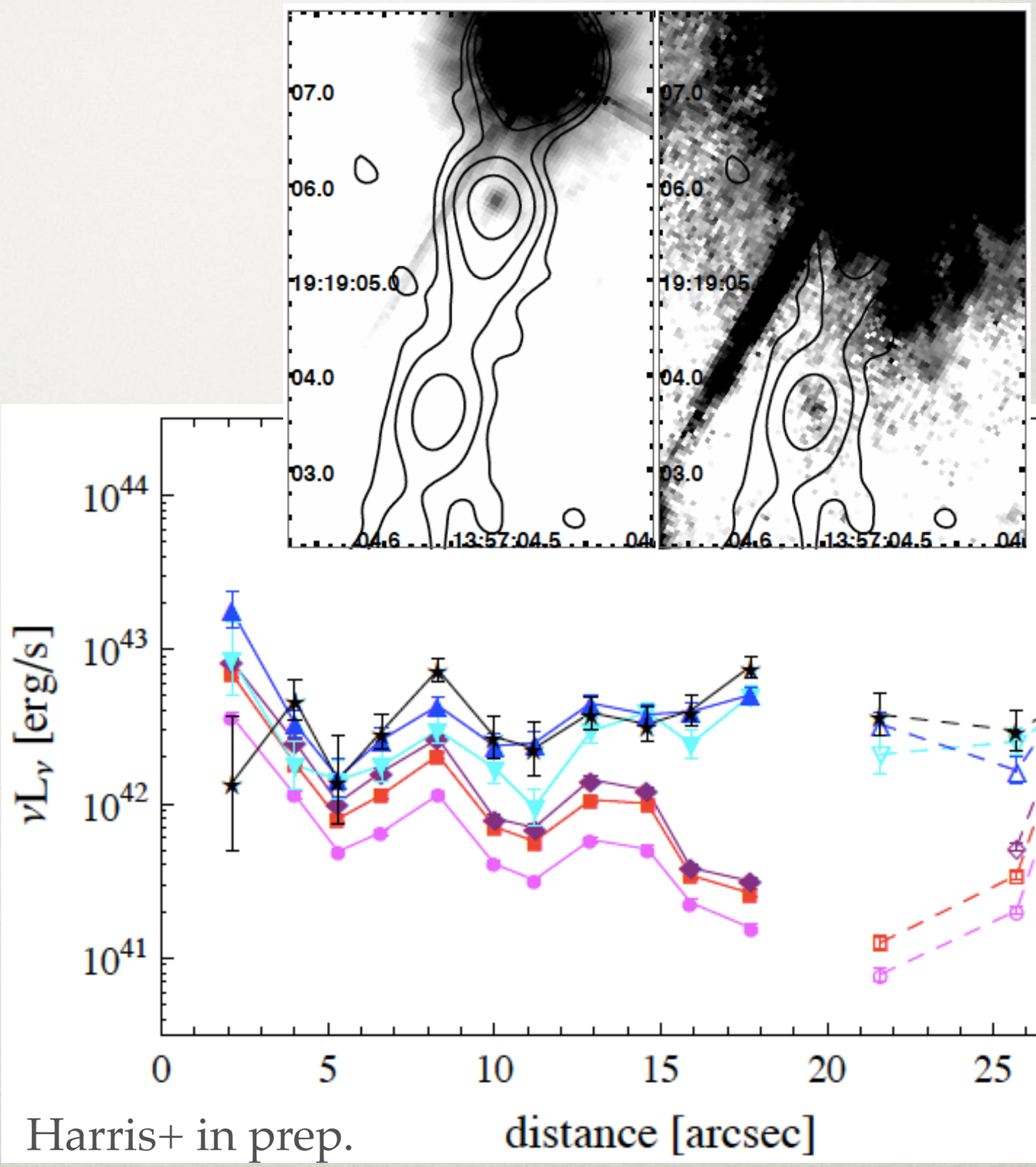
HST / ATCA





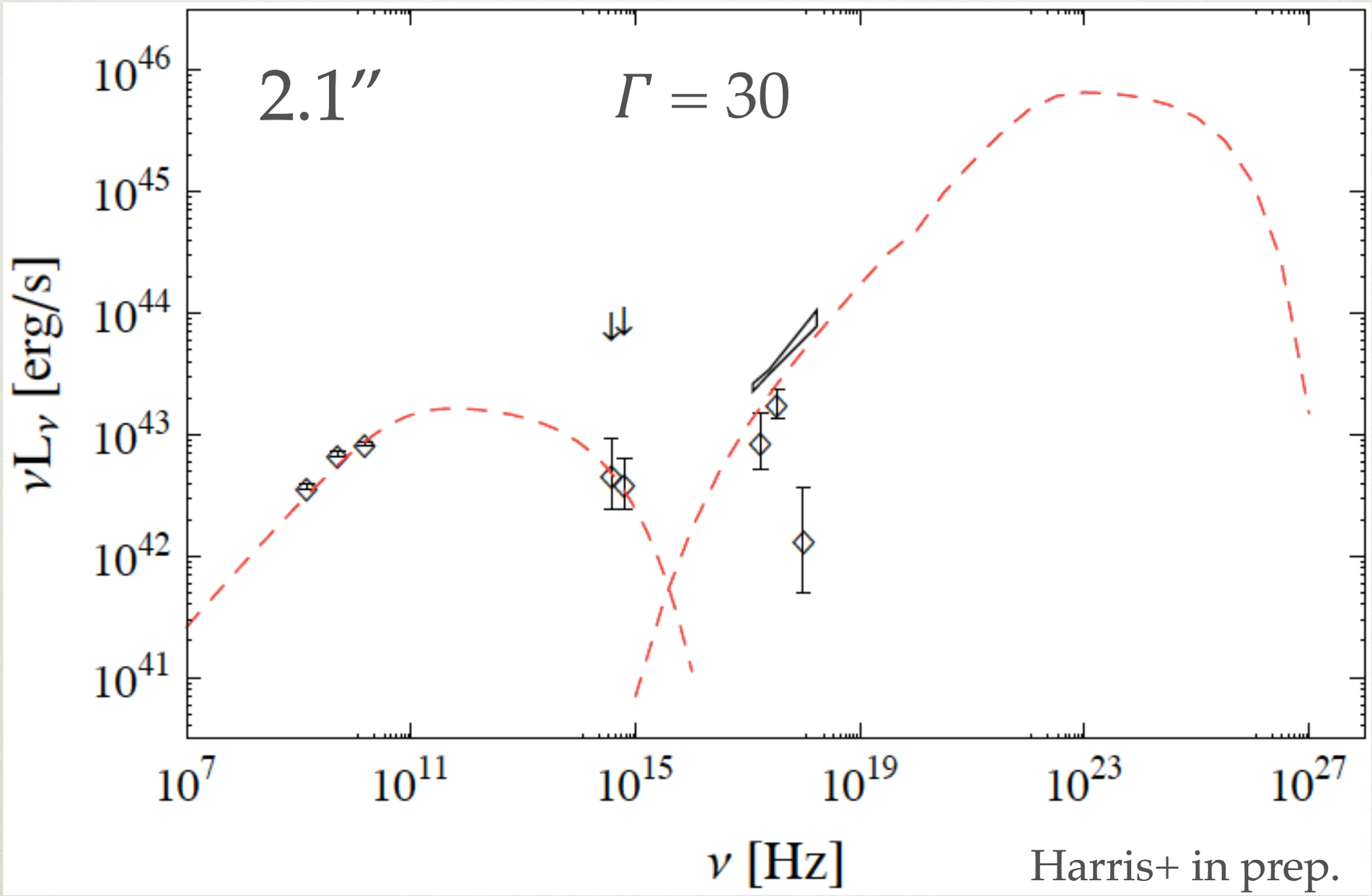
Detail: 4C 19.44





Harris+ in prep.

Detailed SEDs: 4C 19.44



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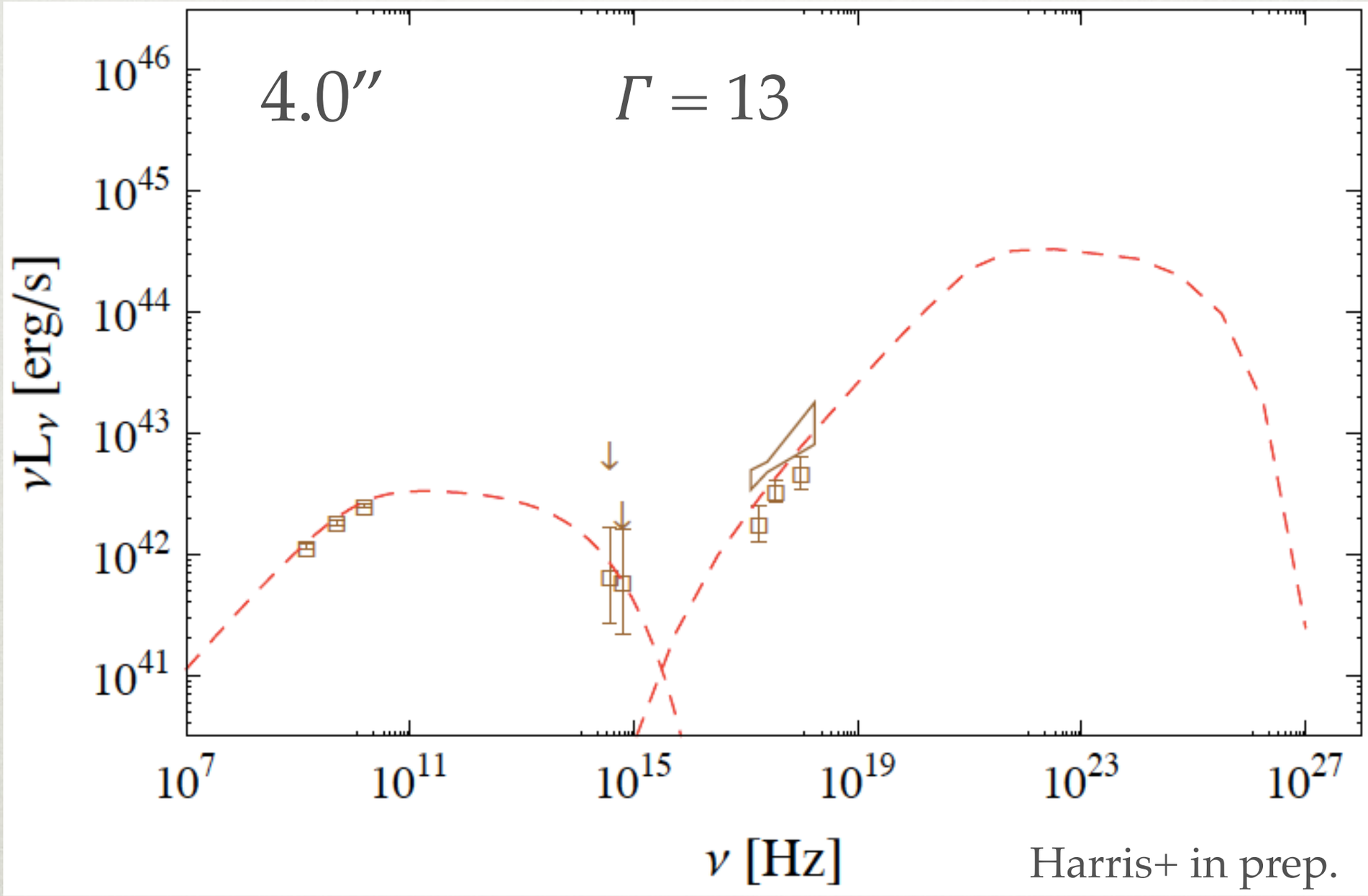

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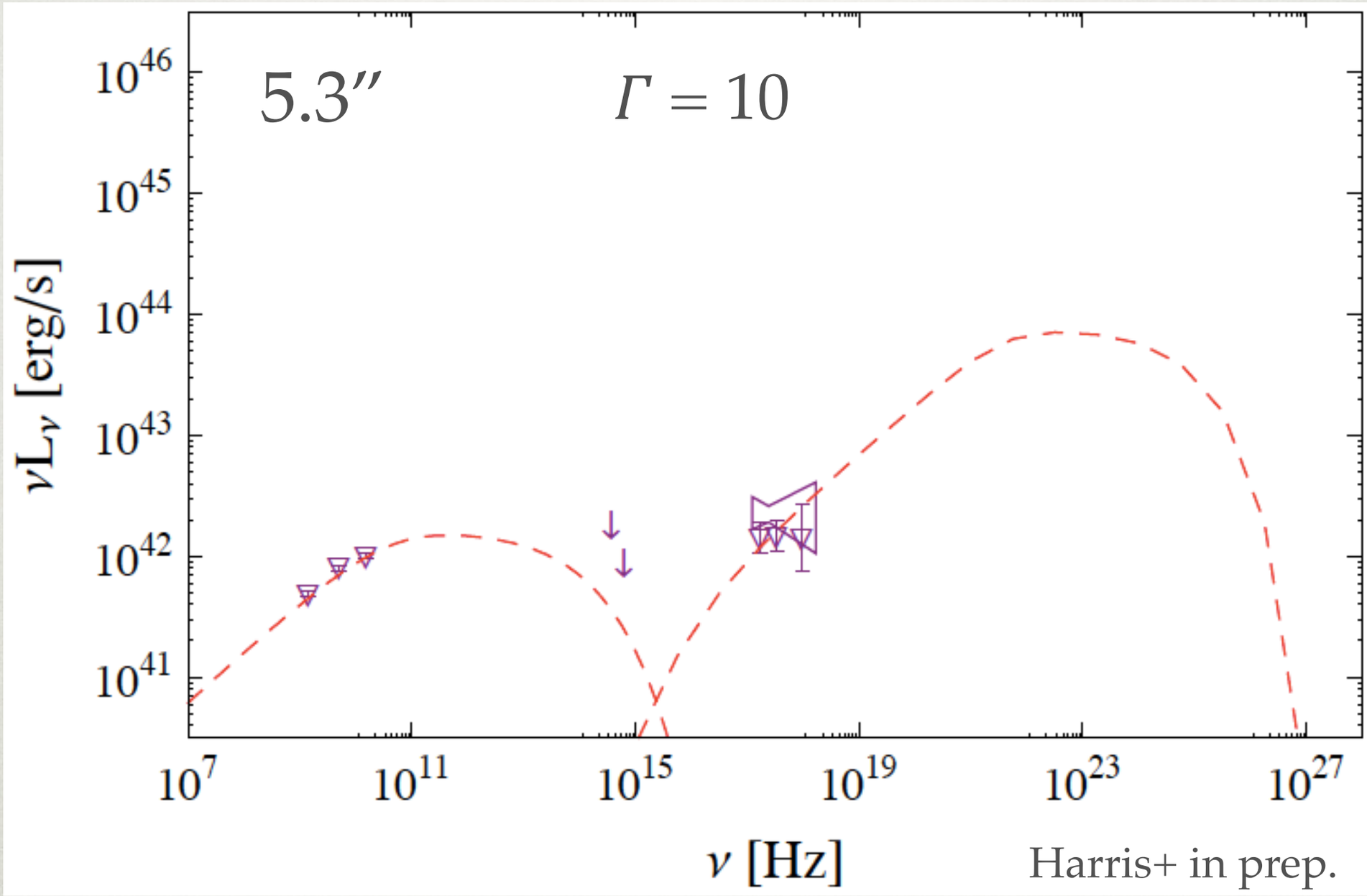

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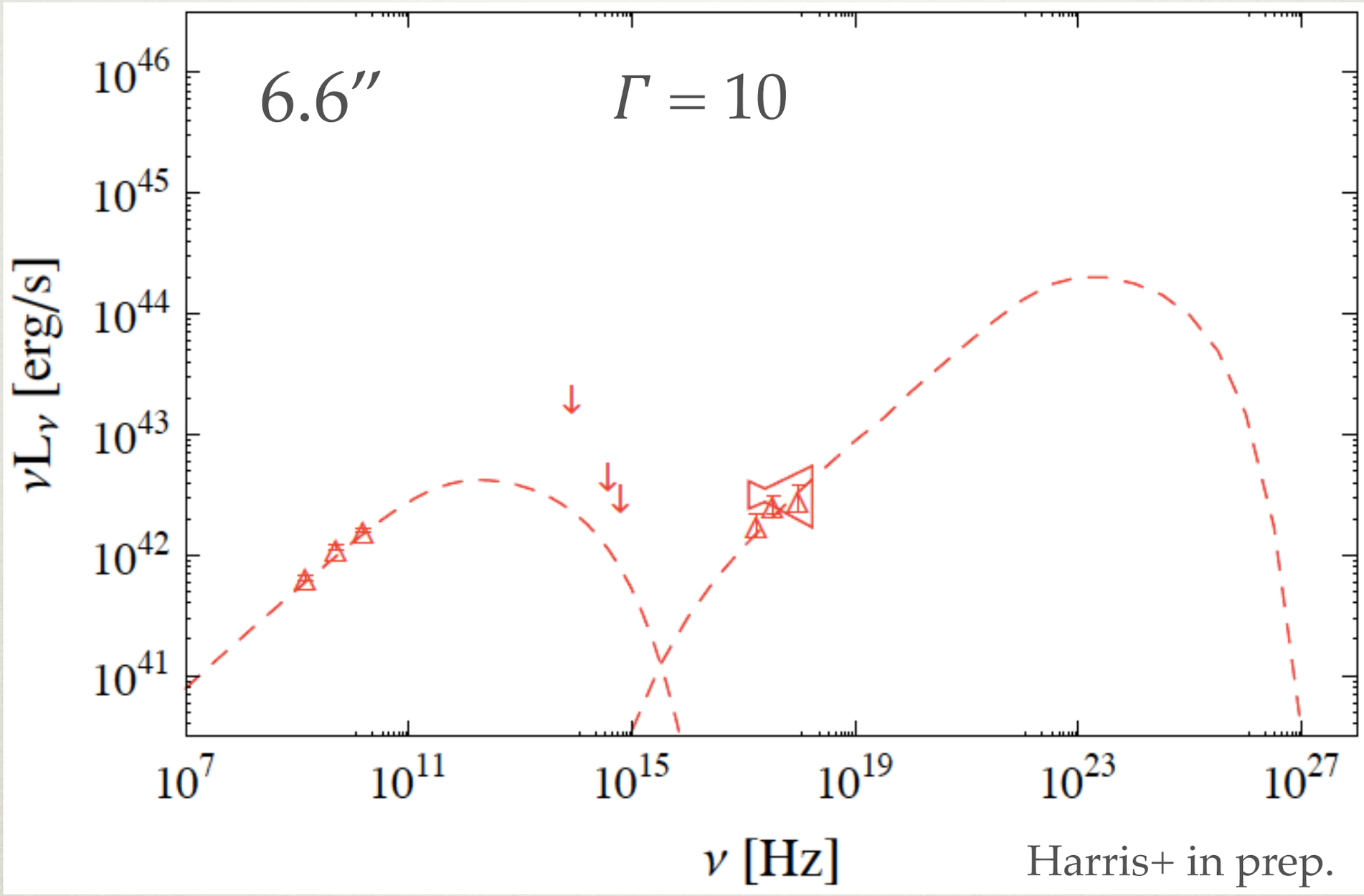

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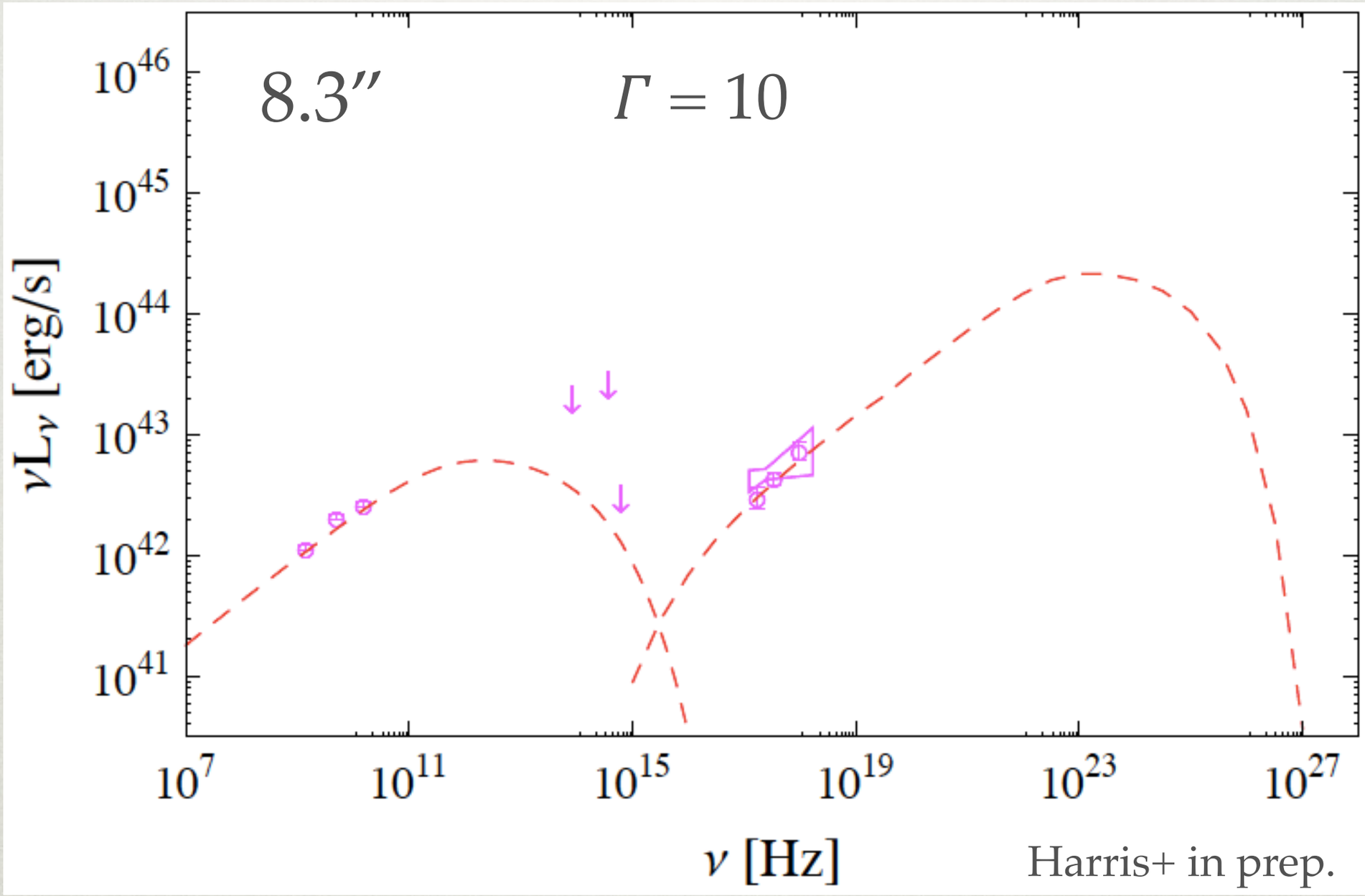

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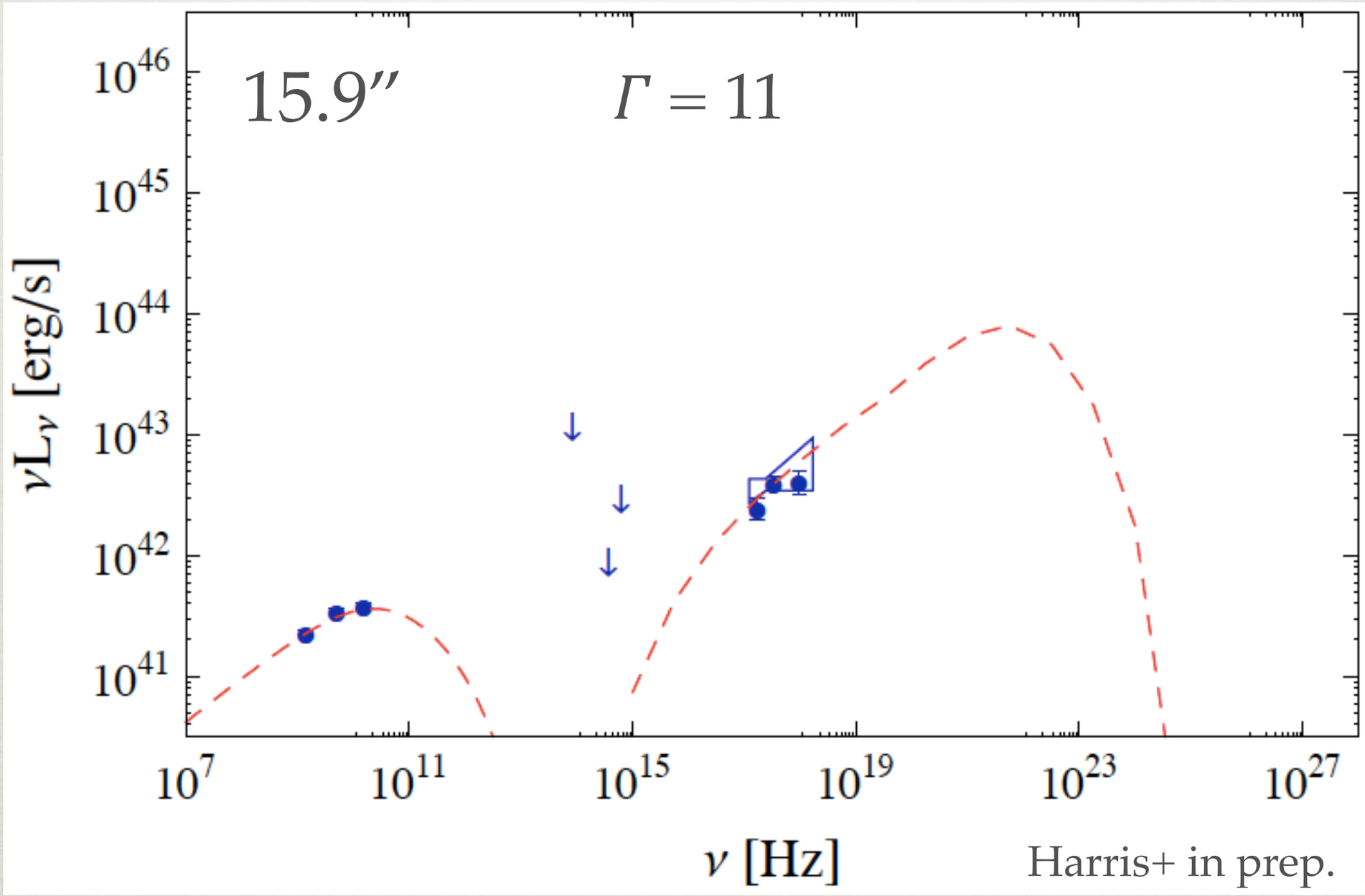
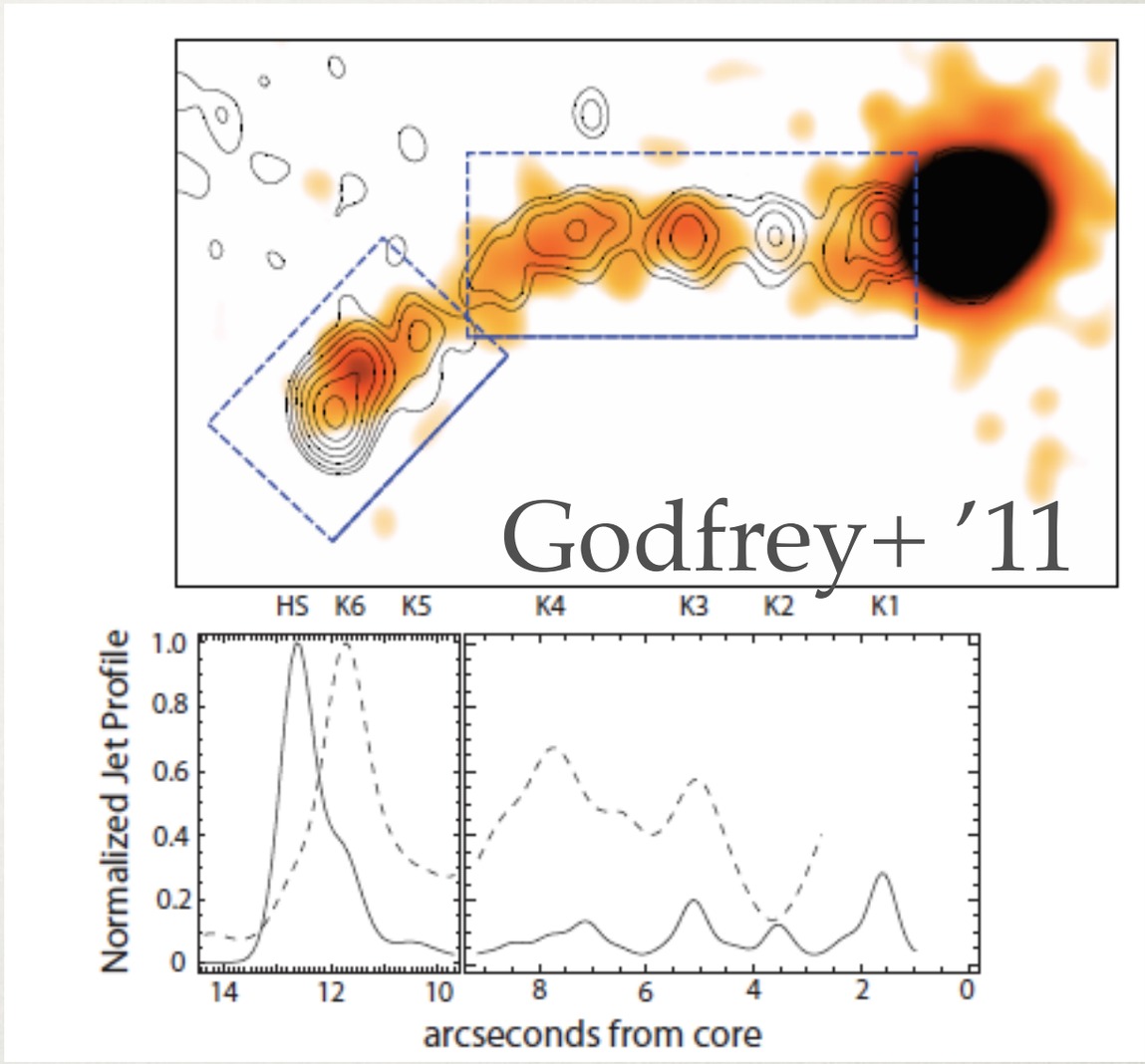
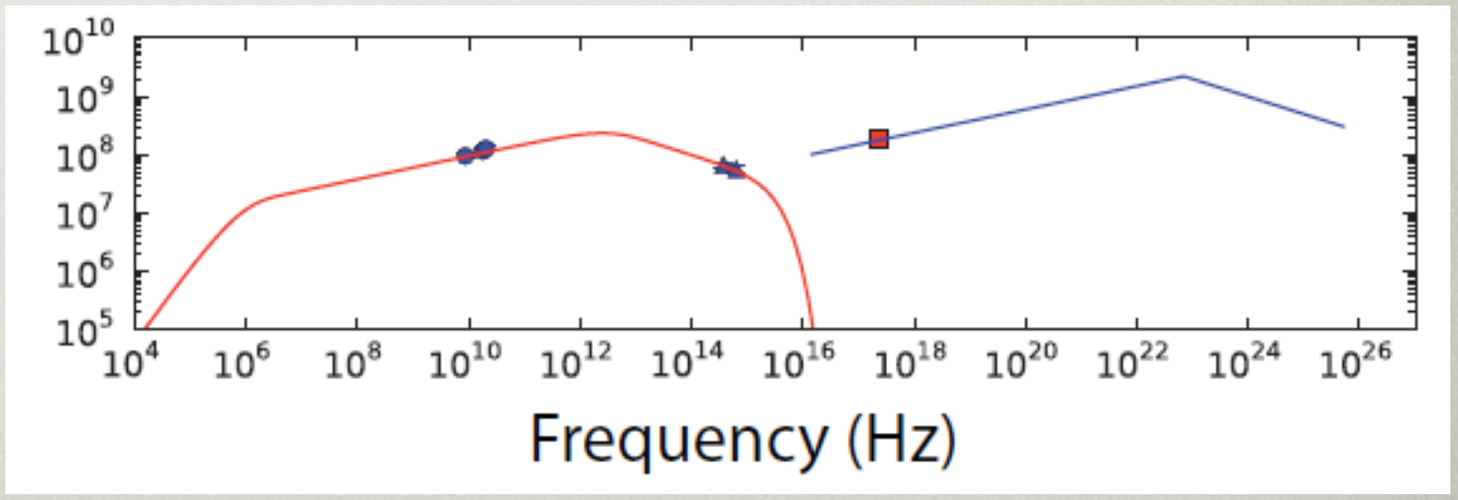


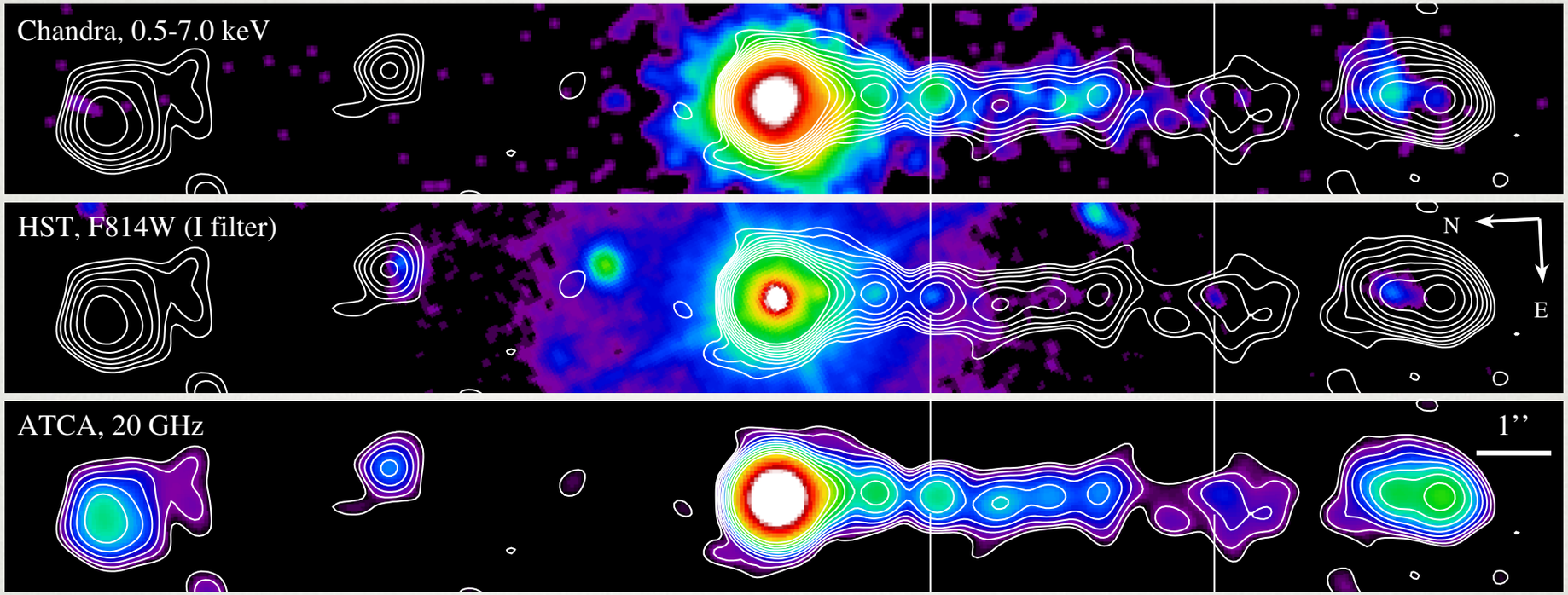
Detail: PKS 2101

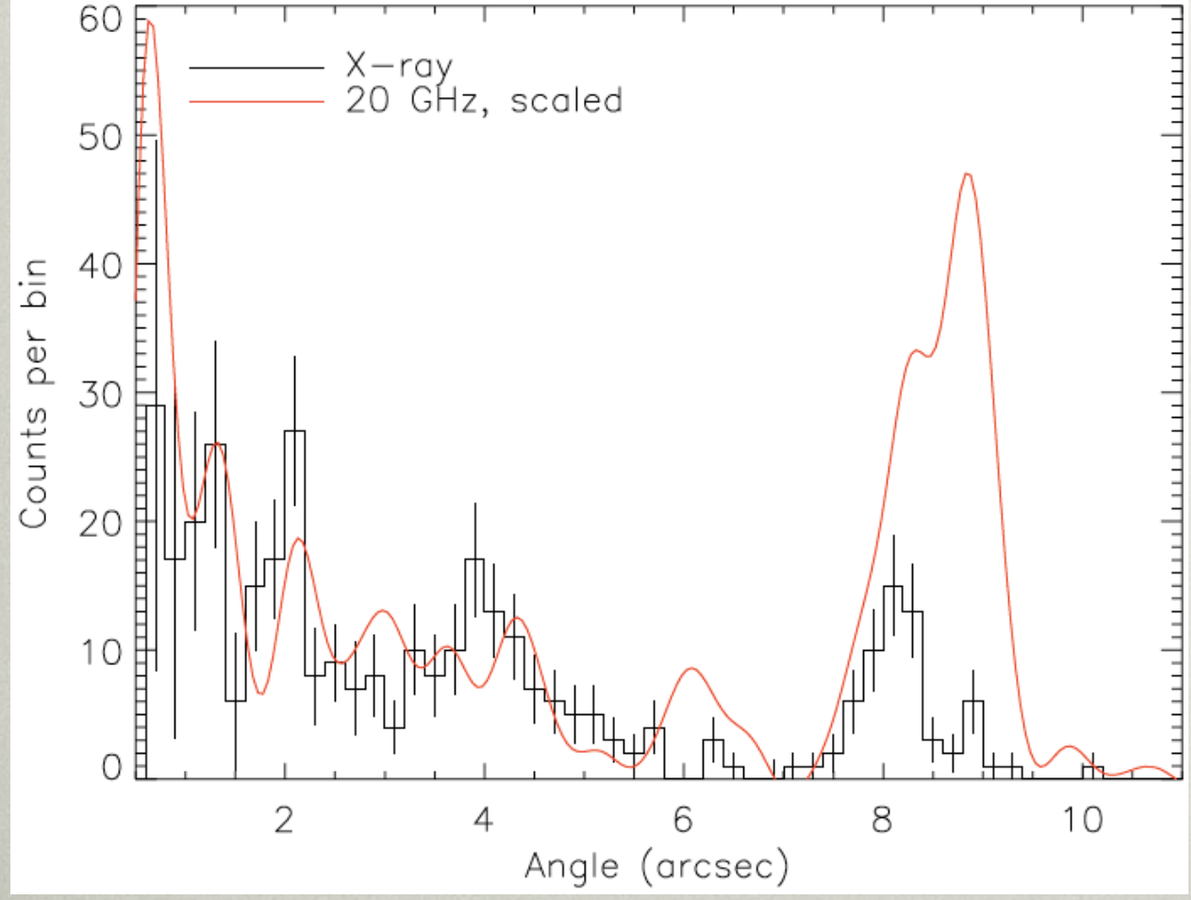
- iC-CMB: $\delta = 6$, past bend

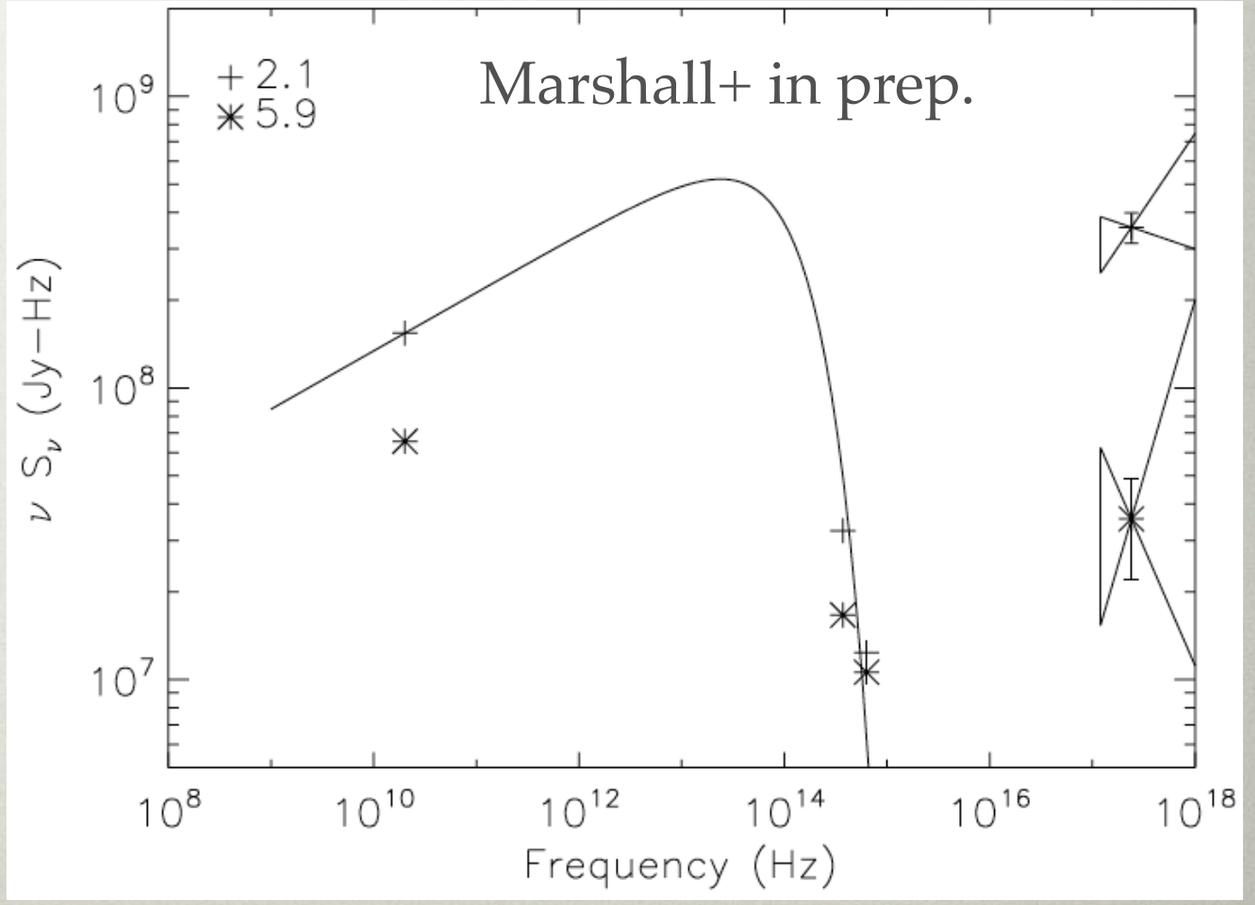




Detail: PKS 0920







Summary

- Chandra surveys: X-rays in 60% of FSRQ jets
- Distribution of S_x/S_r is very broad
- iC-CMB models work superficially, fail details
  - Expected trend of α_{rx} is not found
  - Pc- to kpc-scale deceleration (also Hogan+)
  - α_r and α_x do not match in 3C 273 (Jester+)
  - low GeV flux: $\Gamma < 9$ (Georganopoulos & Meyer)
  - UV polarization indicates synchrotron (Cara+)
  - soon: proper motion tests of 3C 273, others (Meyer+)
- Spine-sheath model?
- Need: X-ray followups, X-ray polarimetry!

Leroy says: Thanks for your Attention!

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