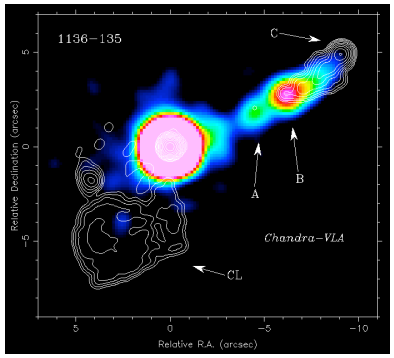
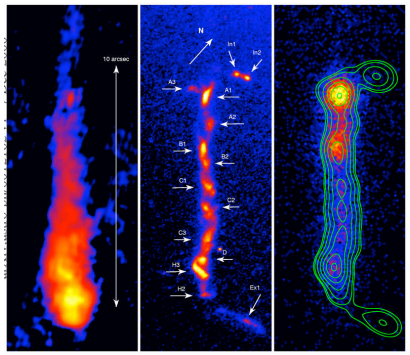
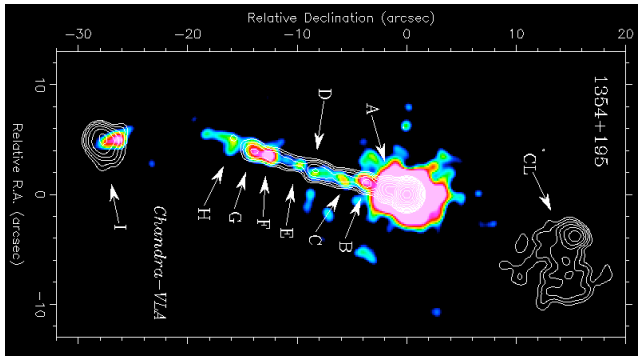






Missing Υ-rays from kpc-scale AGN Jets

A Test of the IC/CMB Model

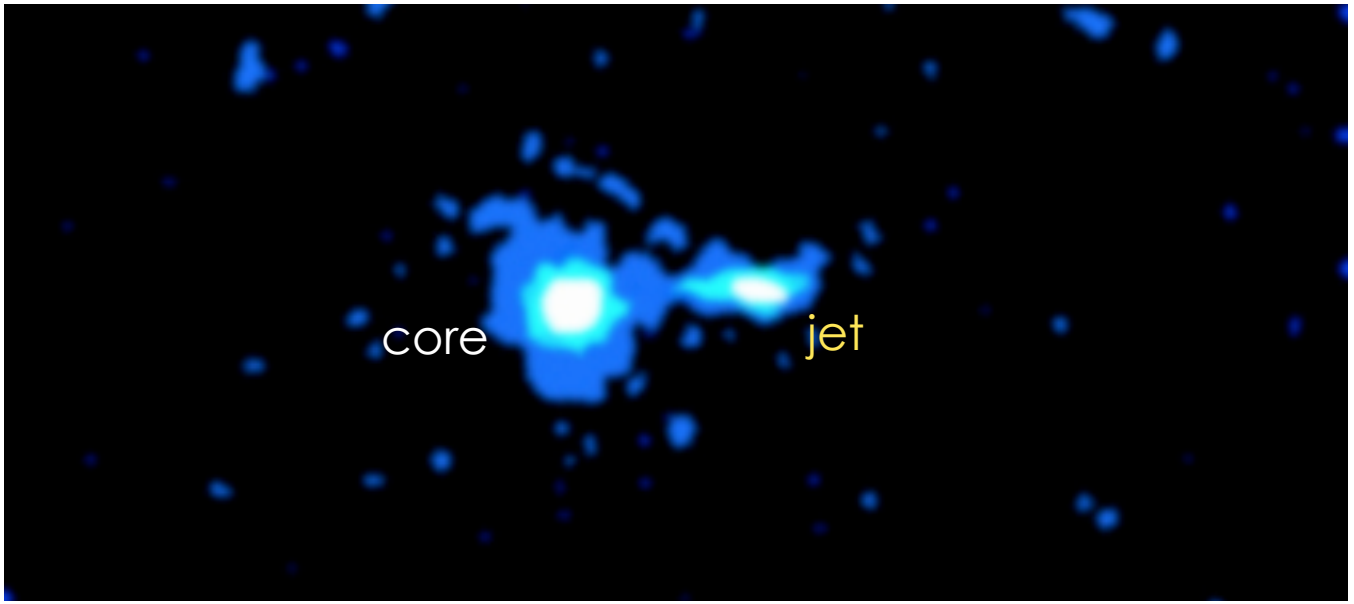
Eileen Meyer
Space Telescope Science Institute

5th International Fermi Symposium
Nagoya, Japan
22 October 2014

Collaborators:
Markos Georganopoulos (UMBC), Eric Perlman (FIT), Bill Sparks (STScI), John Biretta (STScI), Marco Chiaberge (STScI), Aneta Siemiginowska (CfA), Leith Godfrey (ASTRON)

July 1999: The Chandra X-ray Observatory is Launched

August 1999: Chandra discovers the extended kpc-scale jet of PKS 0637-752 during orbital activation and checkout phase

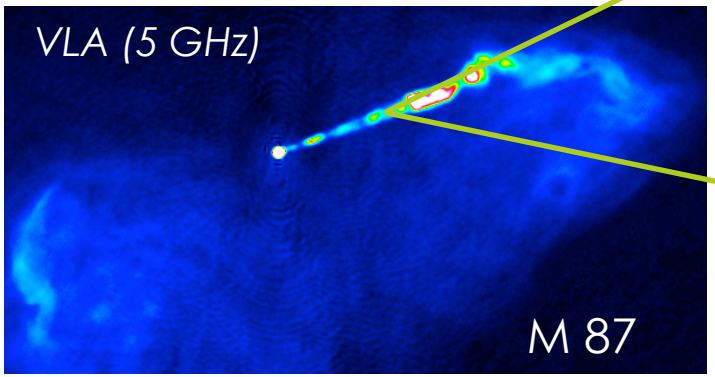


Chartas+ 2000, Schwartz+ 2000

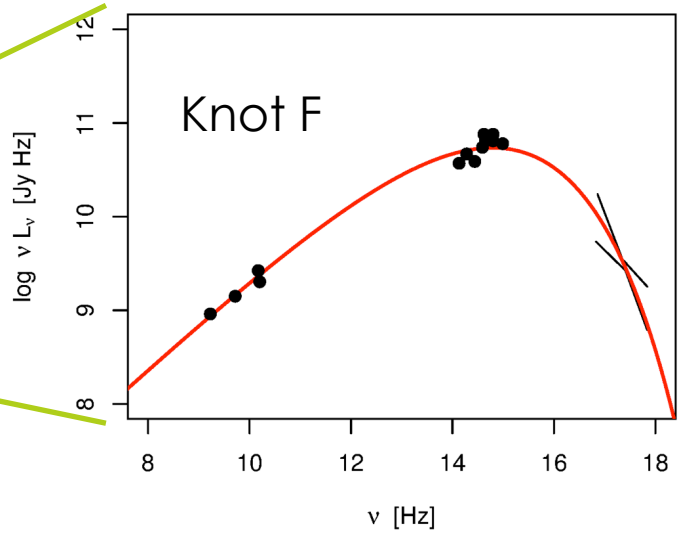
The Quasar Surprise!

Low-power, FR I type jets:

Single radio-optical-Xray spectrum

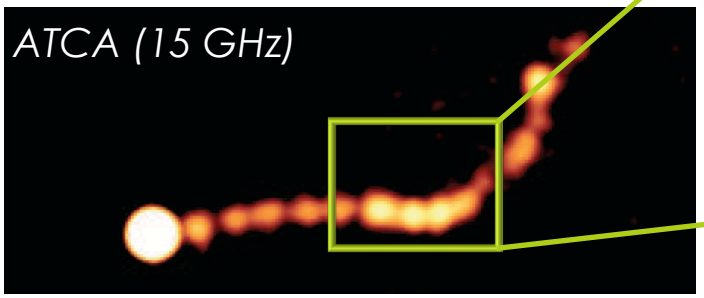


Wilson & Yang 2002

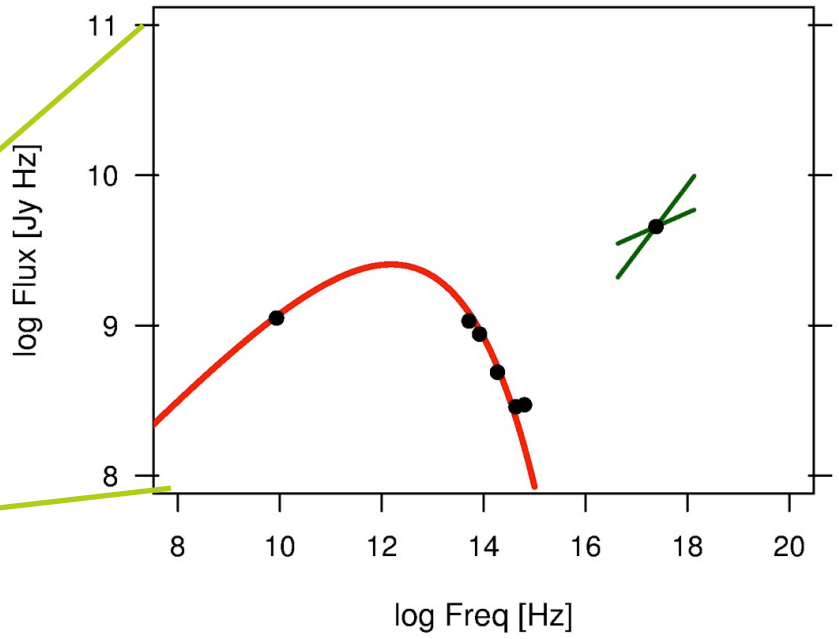


Powerful, "Quasar" Jets like PKS 0637-752:

Anomalously High X-rays



Mehta+ 2009



Godfrey+ 2012

Why is this problem important? (Spoiler Slide!)

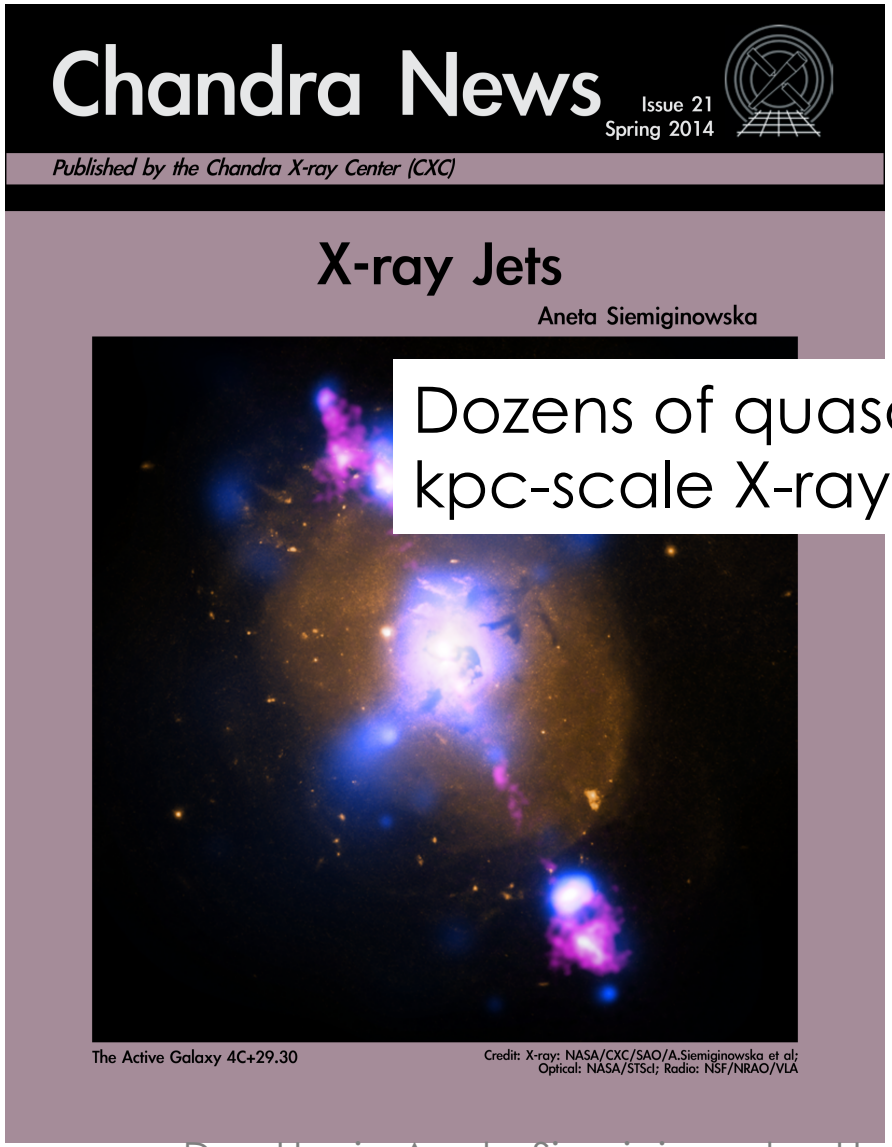
- Because we don't know the speed, particle makeup, energy, and momentum of these jets
- This ignorance is partly why "AGN heating" in galaxy evolution is very ad-hoc and poorly understood – we cannot quantify it without knowing some of the above

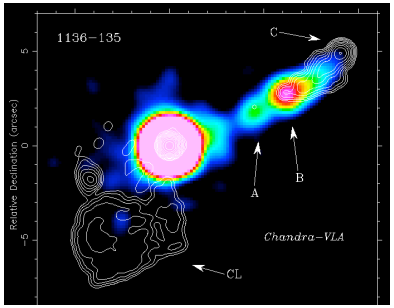
<u>To explain the X-rays in Quasar Jets, we come down to two models:</u>

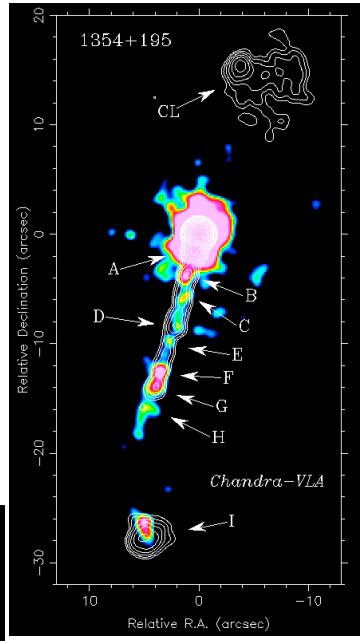
MODEL 1 – Requires **very powerful jets** (near or super-Eddington) which are narrow "pencil beams", **highly relativistic on the kpc scale.** Total (4π integrated) emission on the kpc scale is much lower than what you get from the core

MODEL 2 – Suggests **low-power jets** that nonetheless are **highly efficient multi-TeV particle accelerators.** Jets are slow on kpc scales, and kpc-scale radiative output may rival or exceed the core emission, with implications for blazar heating.

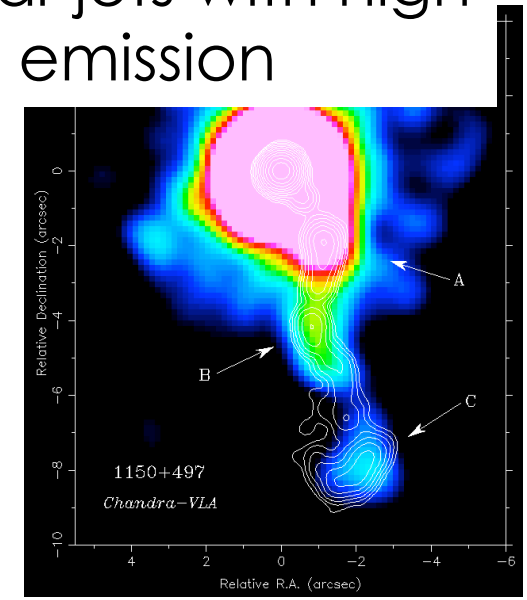
Anomalously Bright Quasar Jets: One of Chandra's major discoveries, and an ongoing **mystery.**

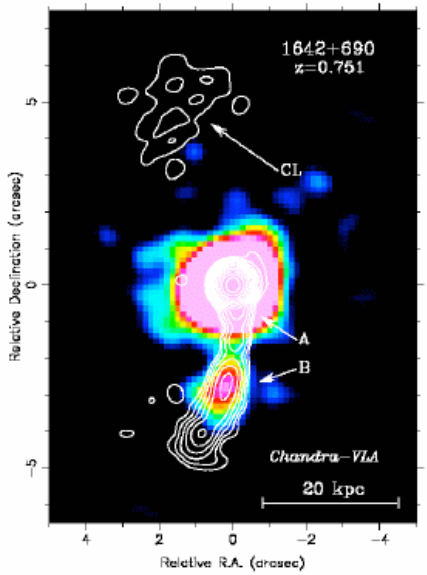




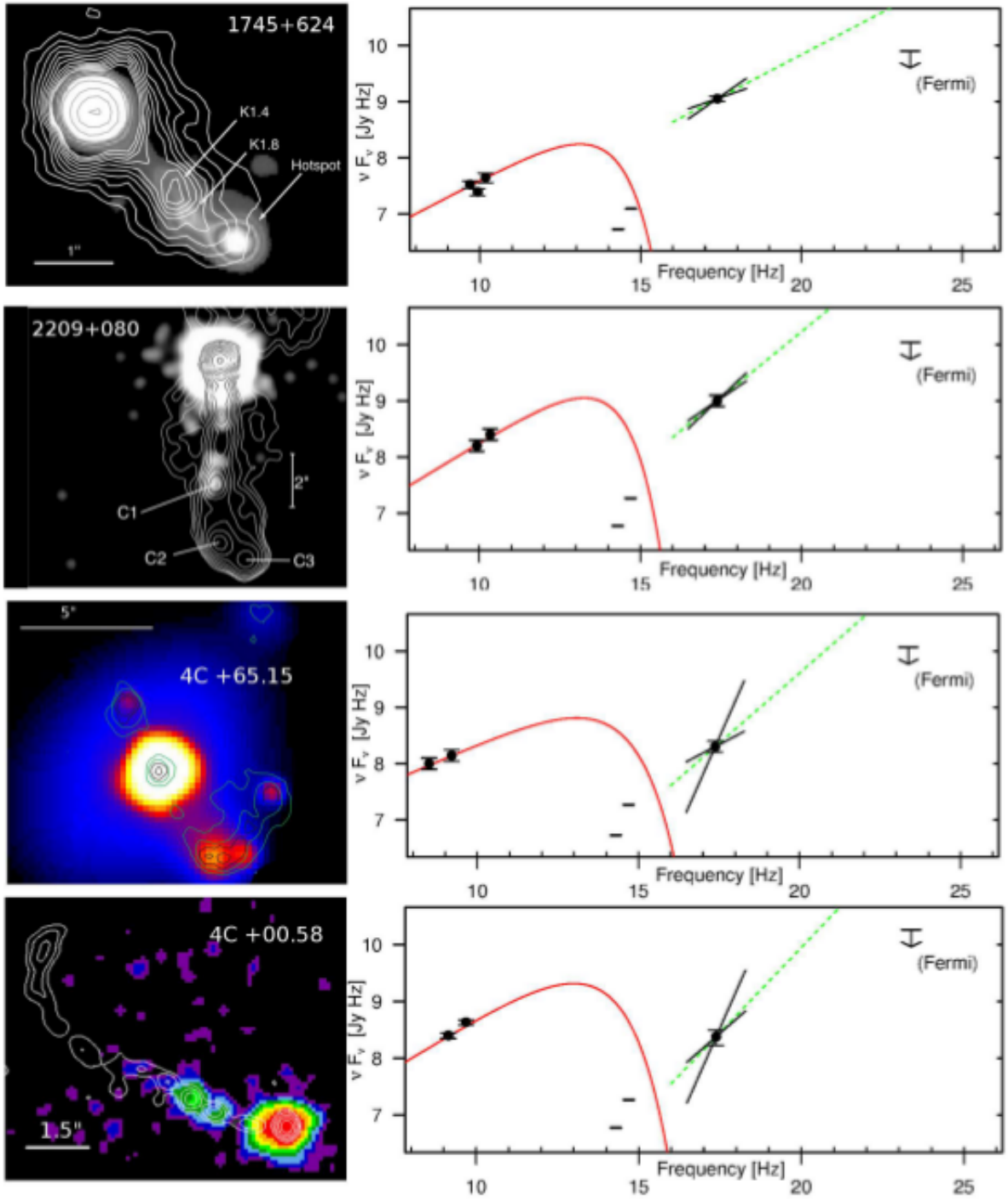


Dozens of quasar jets with high kpc-scale X-ray emission





Dan Harris, Aneta Siemiginowska, Herman Marshall & Others


1745+624
K1.4
K1.8
Hotspot
1"
2209+080
C1
C2
C3
2"
5"
4C +65.15
4C +00.58
1.5"
ν F_ν [Jy Hz]
Frequency [Hz]
10
9
8
7
15
20
25
(Fermi)

What is the Origin of the X-rays…

… and what can it tell us about Jet Physics?

Synchrotron Radiation

- Leptonic: second electron energy distribution

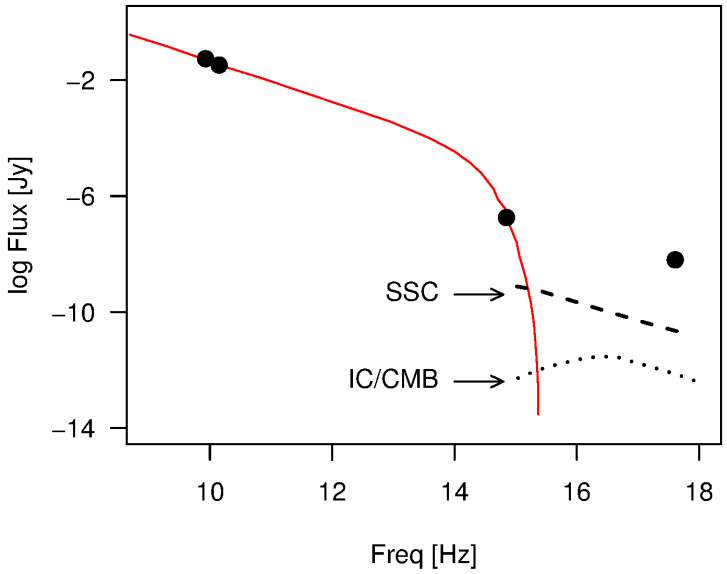
  [Jester+ 2006;Uchiyama+ 2006; Hardcastle 2006]

- Hadronic Models [Aharonian+ 2002]

Inverse Compton Upscattering

- Synchrotron Self-Compton
- "External" Compton with the CMB photon field (aka "IC/CMB")

<u>BOTH possible IC models were ruled out in the original case of PKS 0637</u>



Chartas+ 2000

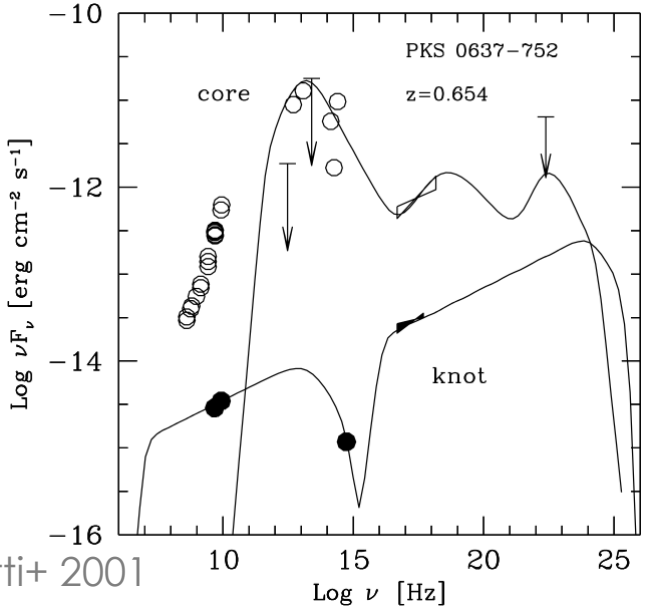
Quasar Jets are frequently observed to be highly relativistic on sub-parsec scales probed by VLBI with Γ=10-50

But Radio surveys have long suggested that on kiloparsec scales the jet is only mildly relativistic with Γ=1.2-1.5

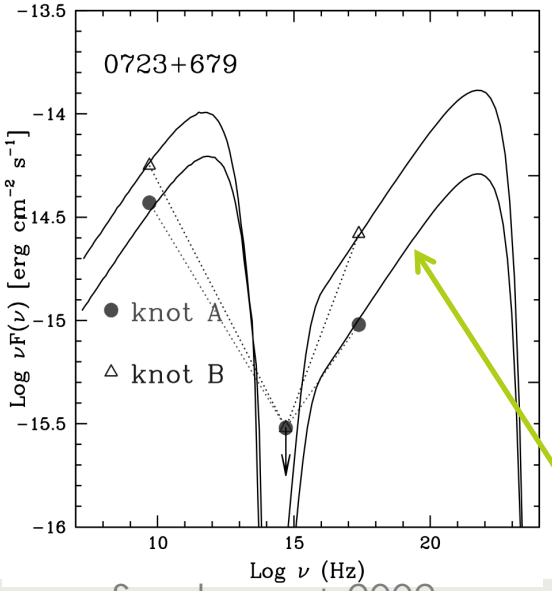
[e.g., Arshakian & Longair 2004]

However, if you assume that powerful quasar jets remain highly relativistic on kpc scales, then IC/CMB works.

[Celotti+ 2001, Tavecchio+2000]

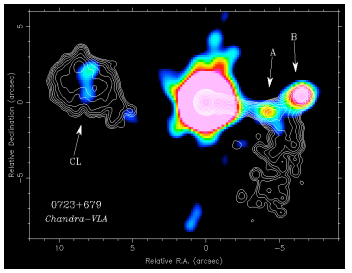


Celotti+ 2001



Sambruna+ 2002

PKS 0723+679

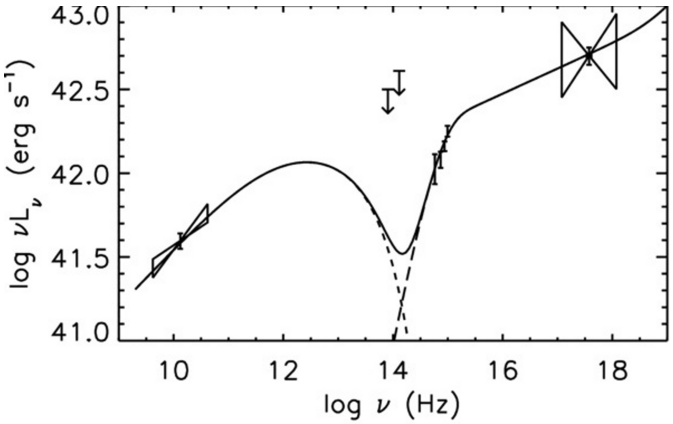


Working IC/CMB model assuming fast jet

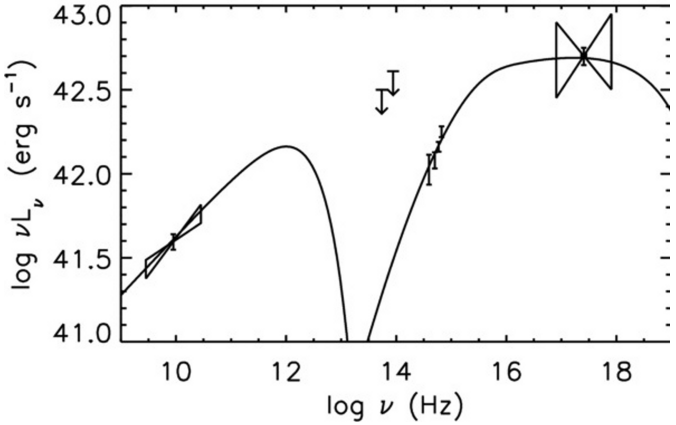
The Essential Problem.

IC/CMB requires near or super-Eddington jets in some cases, and small beaming angle implies longer jets than observed.
→ In many cases the IC/CMB fit is an "uncomfortable" one

We cannot definitively show that IC/CMB or synchrotron is a better mechanism based on SED fits.



PKS 1136-135, IC/CMB Model



PKS 1136-135, synchrotron Model

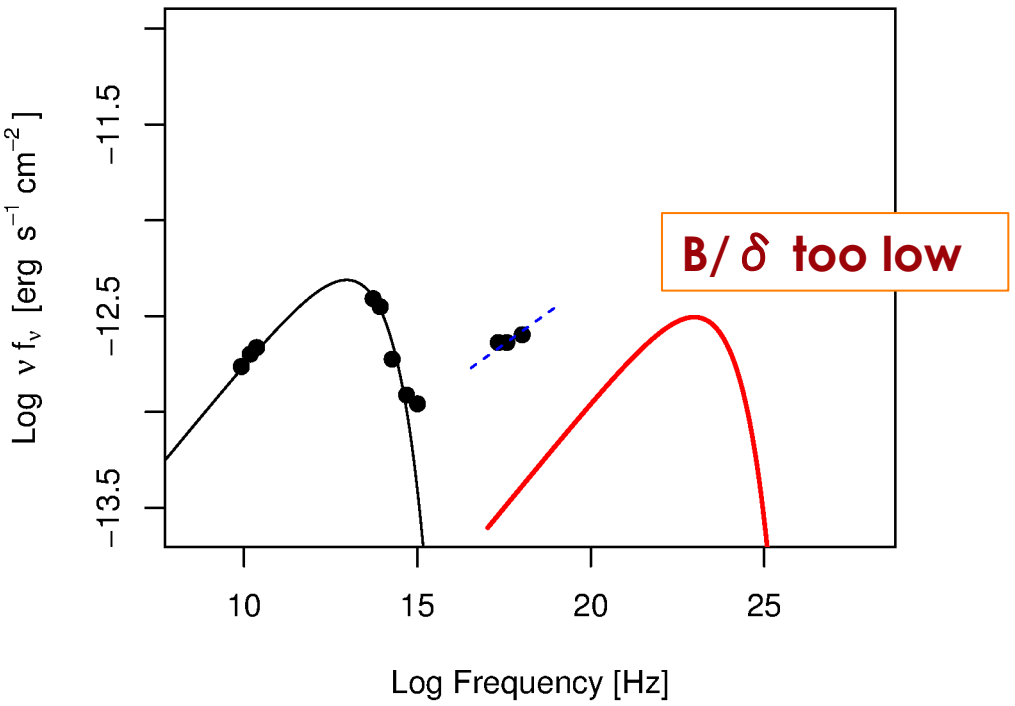
[Cara+ 2013 – Showing that X-rays of PKS 1136-135 are synchrotron due to high UV polarization]

The Test: How to Rule out IC/CMB

[Georganopoulos+ 2006]

The IC Component is a copy of the synchrotron, shifted in frequency and luminosity.

That shift is parameterized ONLY by B/ δ , <u>no other free parameters.</u>



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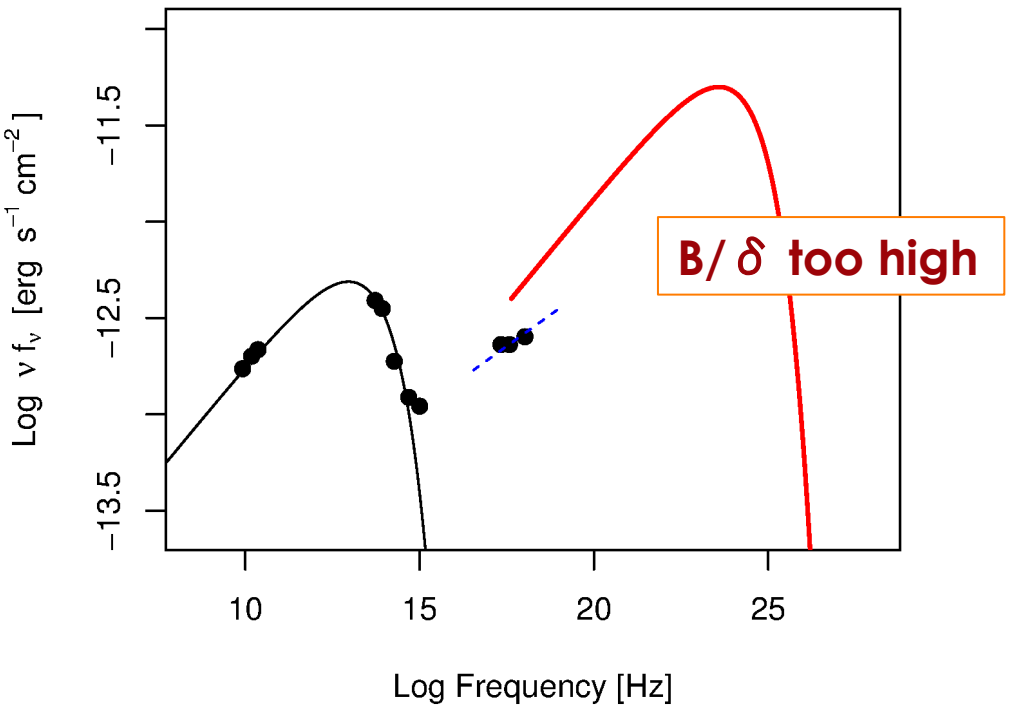

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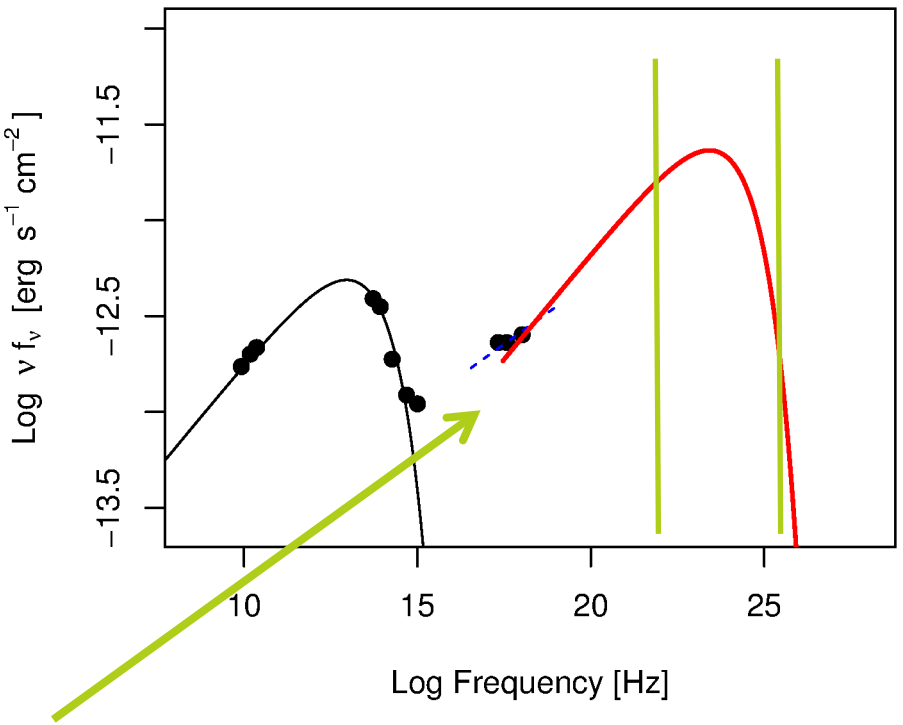
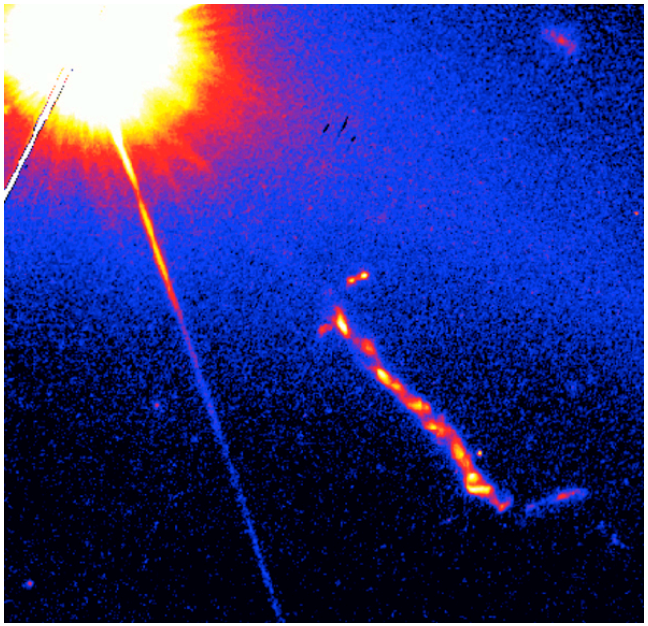


Getting the X-rays just right means fixing B/ δ **and consequently implies a high level of gamma-ray emission which should be detectable with Fermi**

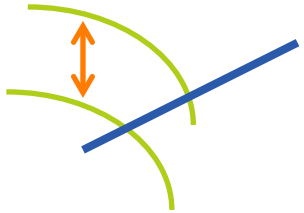
Case 1: 3C 273



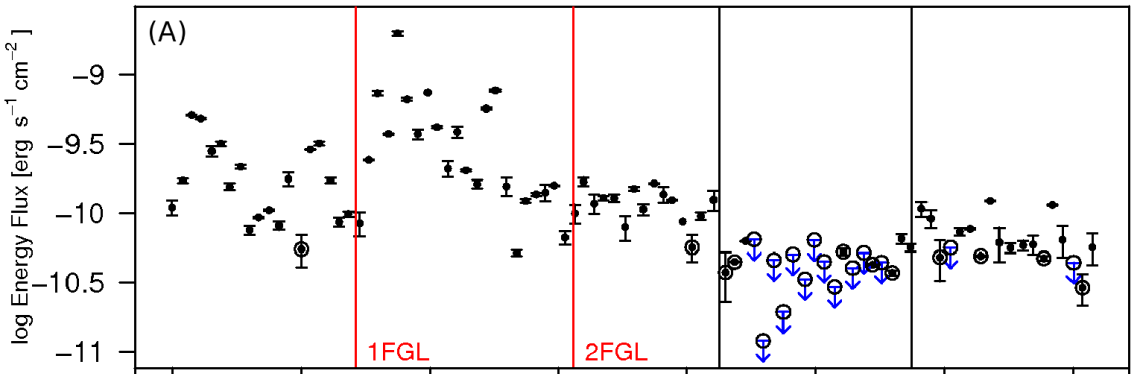
Resolution Issue: From core to end of the jet is ~ 24" - even the 68% PSF at 3 GeV is >10x this scale (few tenths of a degree)

However:

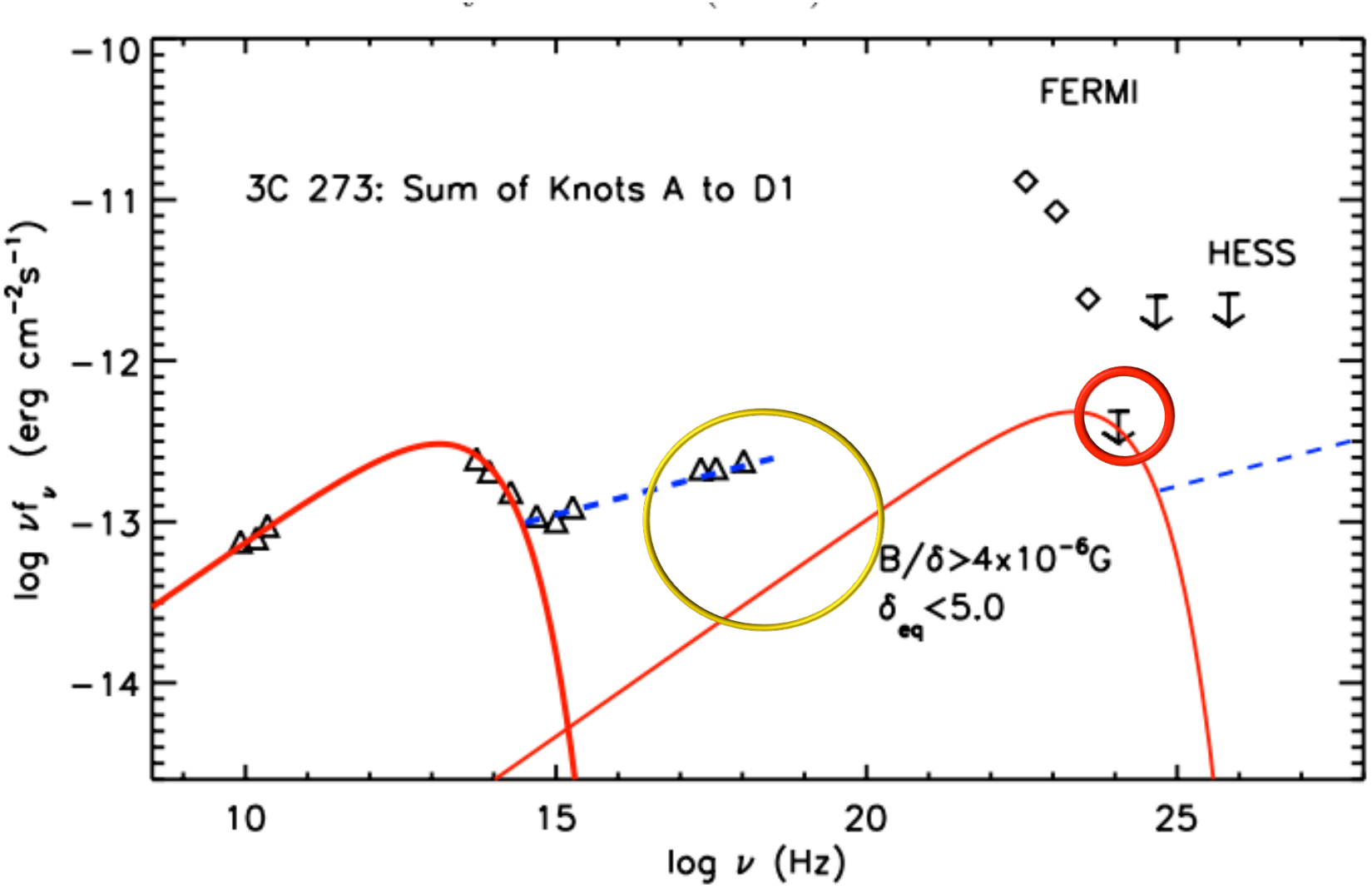
- IC/CMB emission of the 3C273 should be quite **hard and completely non-variable**.
- The core is known to be soft (Γ ~2.7), and **variable**.



We can thus stack the parts of the 3C 273 lightcurve when the blazar is low to get the lowest upper limit, which applies to both the core + the jet.

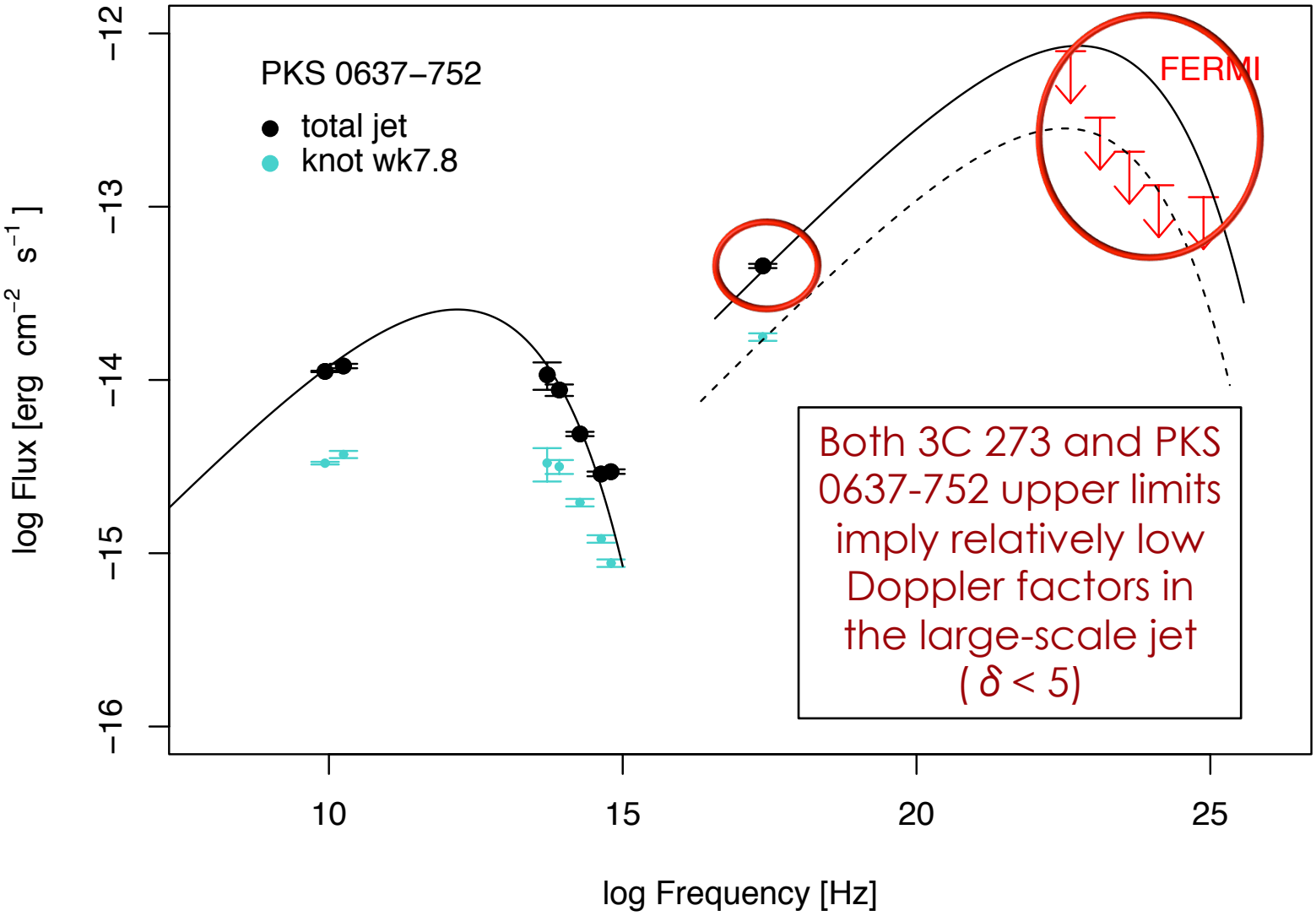


Case 1: 3C 273
IC/CMB is ruled out as the source of the X-rays.



Meyer & Georganopoulos 2014 ApJ 780, 27

Case 2: PKS 0637-752



Meyer+, in prep.

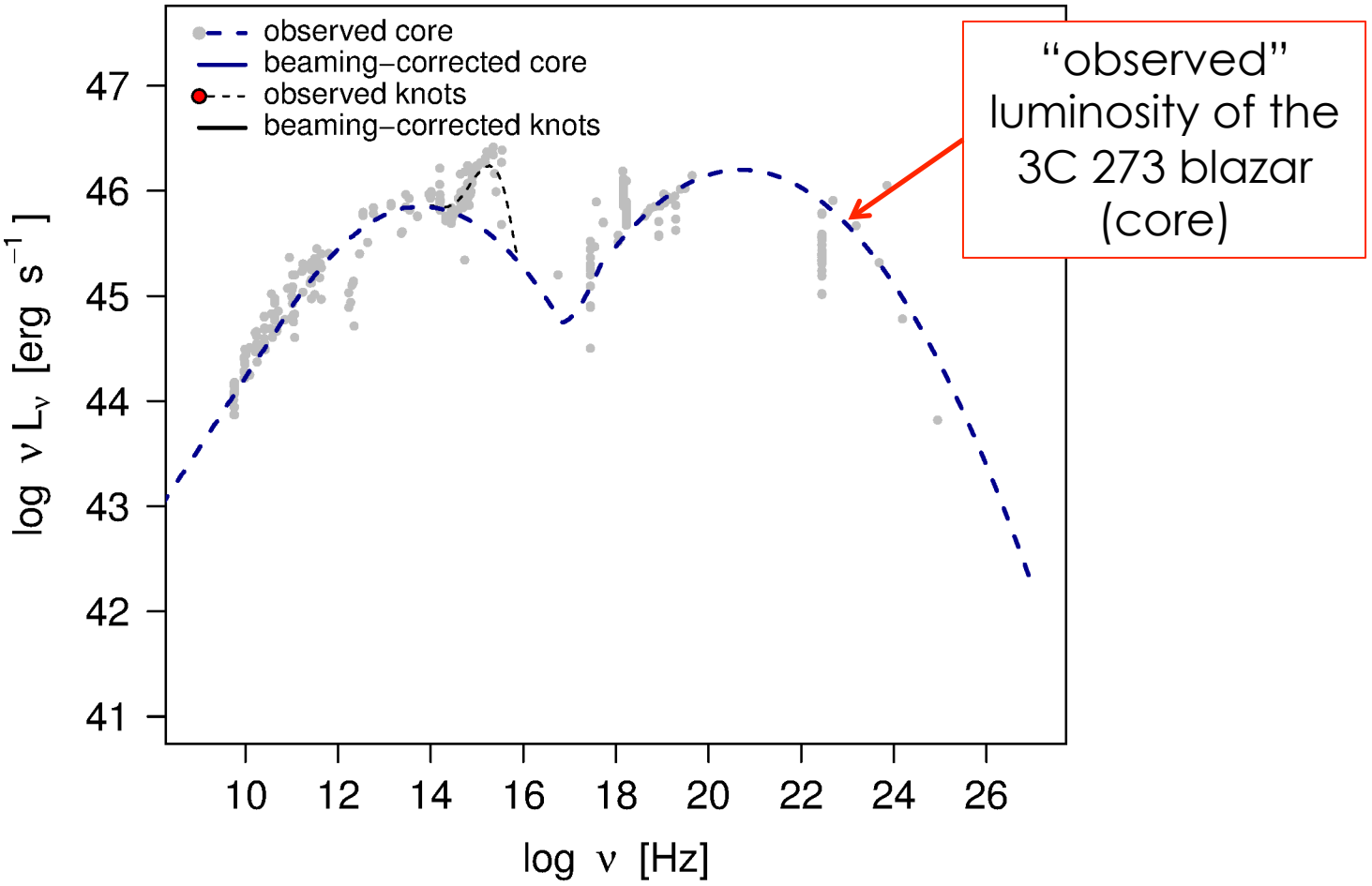
Understanding **Jet Physics** on Large Scales

- **What are the speeds of jets on the kpc scale?**
  - Proper Motions with VLA, HST can only probe jets within ~500 Mpc, but do give upper limits on δ
    (e.g., M87, 3C 273, 3C 264, 3C 346 as part of HST program)
  - However, detection of IC/CMB with Fermi is possible for a number of jets in the next 5-10 years (3C 273 is #1 target) → **fix B/ δ**
  - **Can start to put tight constraints on B, equipartition**

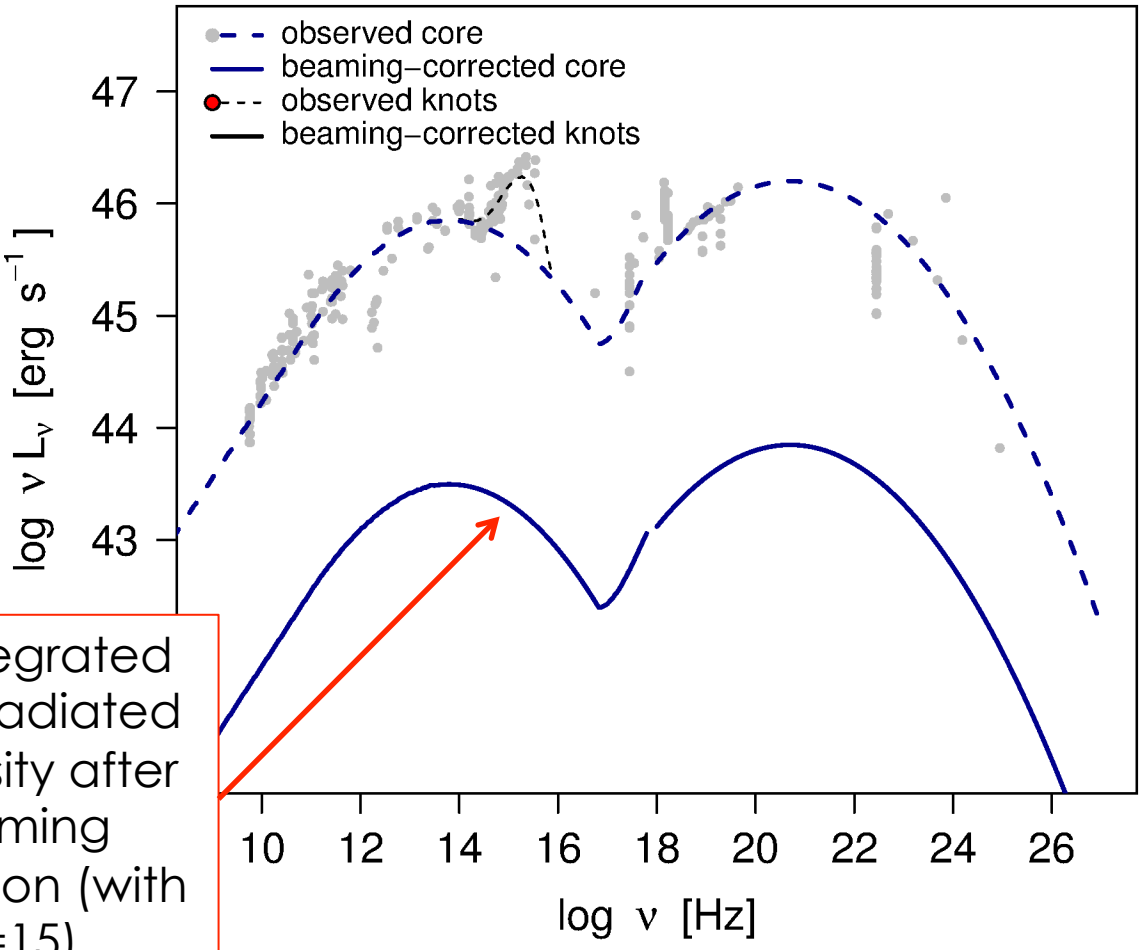
- **A new Requirement of Jet Models**
  - What mechanism can produce extremely efficient, multi-TeV particle acceleration to produce the second component?
  - Jets must be "slow" on kpc scales

- **Ongoing work**
  - Fermi has a lot to contribute: high-E limits go down as 1/time
  - We can continue to rule out IC/CMB X-rays in more and different jets, but also possibly detect the IC/CMB emission *that must be there at some level.*

Understanding **Jet Impact** on Environment

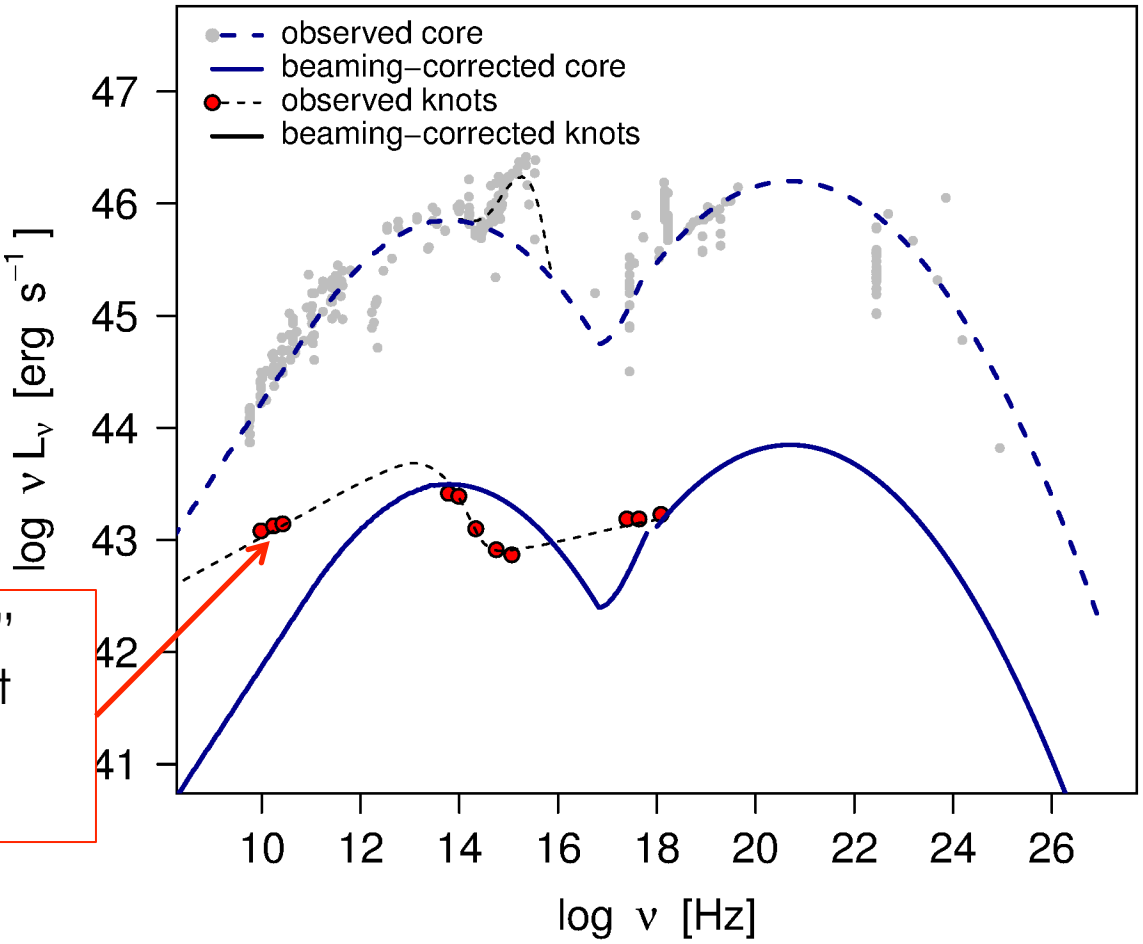


Understanding **Jet Impact** on Environment



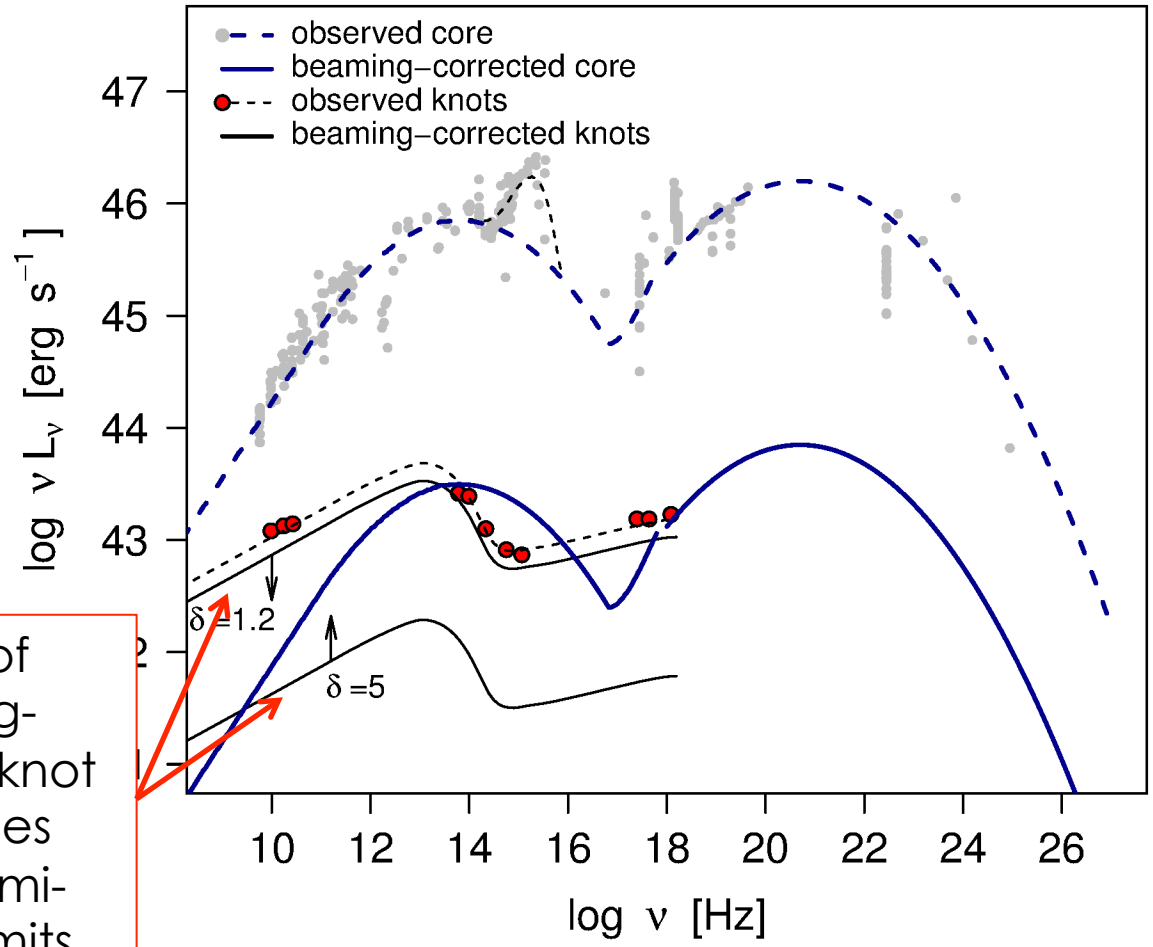
4π-integrated "true" radiated luminosity after beaming correction (with $\delta = 15$)

Understanding **Jet Impact** on Environment



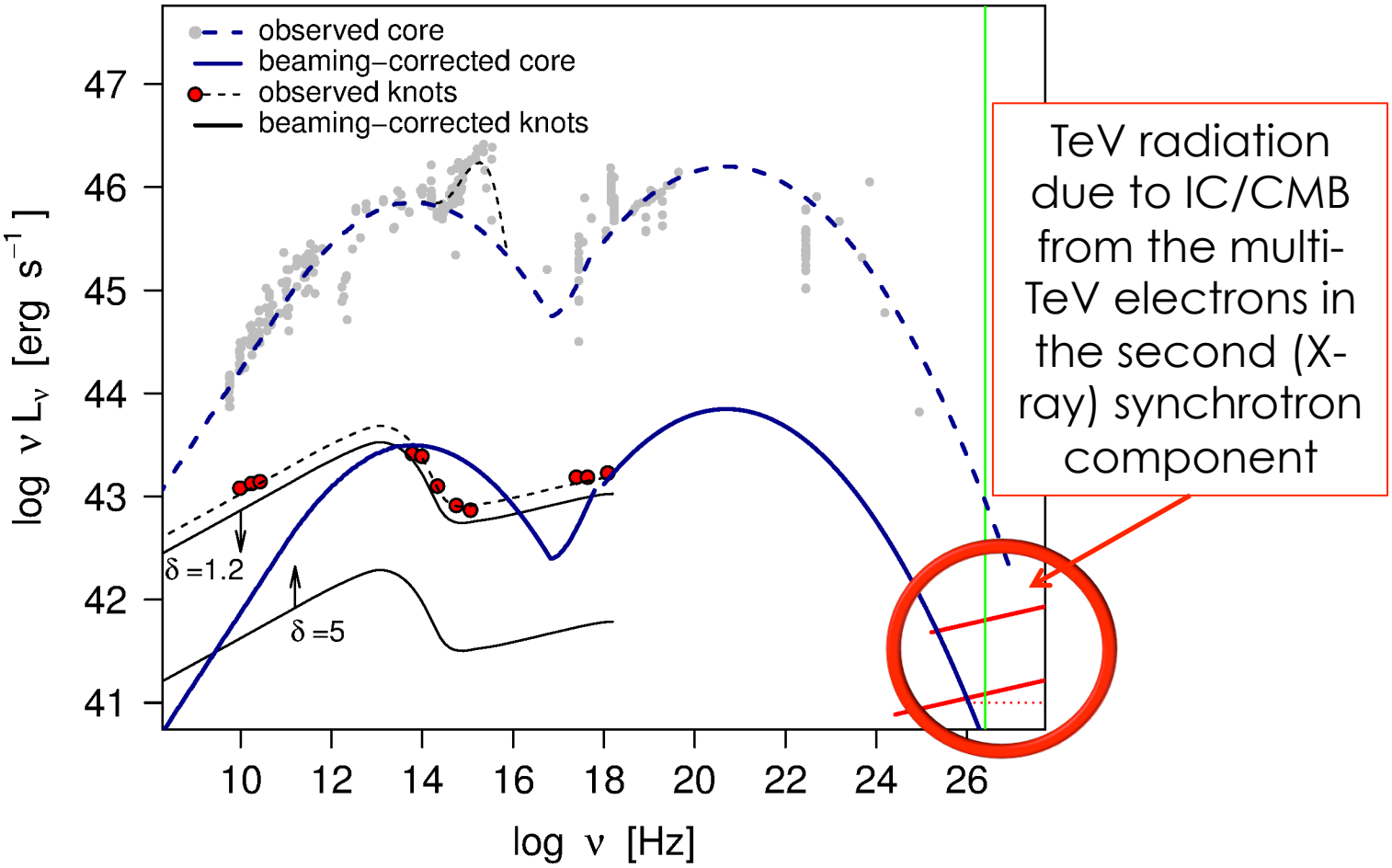
"observed" 3C273 knot Luminosity (total)

Understanding **Jet Impact** on Environment



Range of beaming-corrected knot luminosities within Fermi-derived limits

Understanding **Jet Impact** on Environment



Large-scale jet may dominate blazar in total output at TeV energies
For 3C 273, δ =2-5 implies IC/CMB from the X-ray synchrotron spectrum well above the integrated TeV luminosity from BL Lacs (~ 10^{41} erg/s)

Conclusions

The IC/CMB model has been **ruled out in 3 cases** as the mechanism for the high X-ray fluxes of some quasar jets.

We instead favor synchrotron models, but the origin is unknown (and hadronic models are not ruled out) – this suggests less powerful jets, but also a **far greater radiative output on kpc scales,** including dominant TeV emission. This may have far-reaching impact from reionization to heating in galaxy evolution.

An extremely important contribution of Fermi all-sky monitoring will be to continue the search for the IC/CMB emission from powerful quasars, as **IC/CMB detection enables direct measurement of B/ δ .**

When combined with proper-motion studies we can "solve" the system, unambiguously determining important physical parameters (angle, Lorentz factors, Doppler factor, Magnetic Field) **– look for proper motion results on 3C 273 in 2015 (HST observations in cycle 21)**