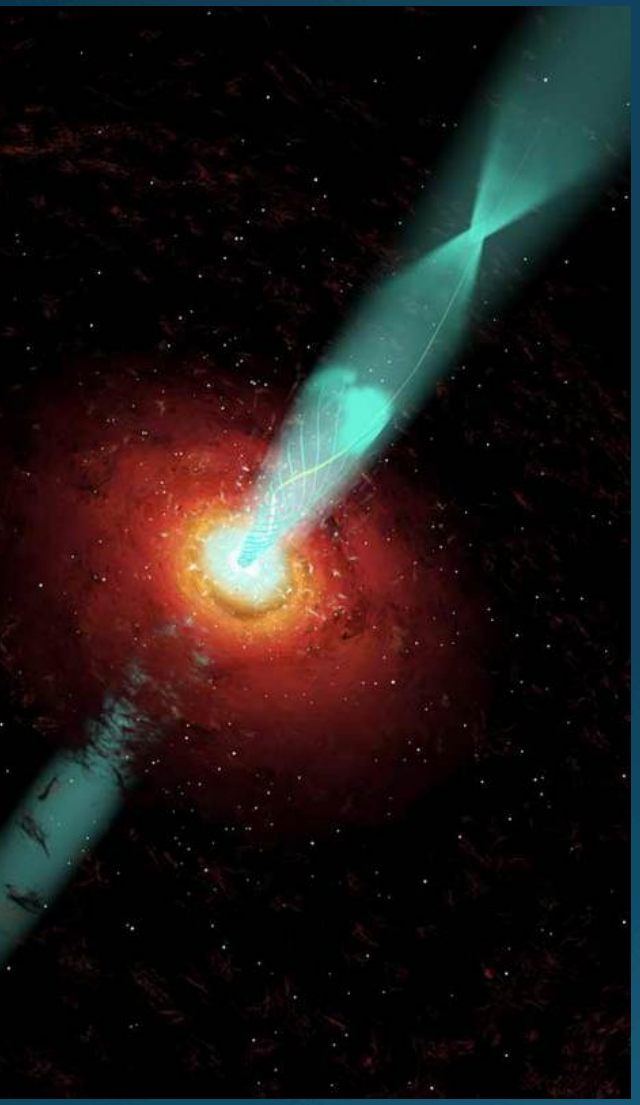

A Multi-wavelength Campaign to test the Inverse Compton model for Large-Scale-Jets

Eileen Meyer
Assistant Professor
University of Maryland, Baltimore County

Sixth Fermi Symposium
Washington, DC November 11, 2011

Collaborators

Markos Georganopoulos, UMBC
Bill Sparks, STScI
Eric Perlman, FIT
Aneta Siemiginowska, CfA
Keith Godfrey, ASTRON
Tim Lovell, U. Tasmania

Some History: The Rise of the Inverse Compton Model for X-rays from Large-Scale Jets

July 1999: Chandra X-ray Observatory Launched

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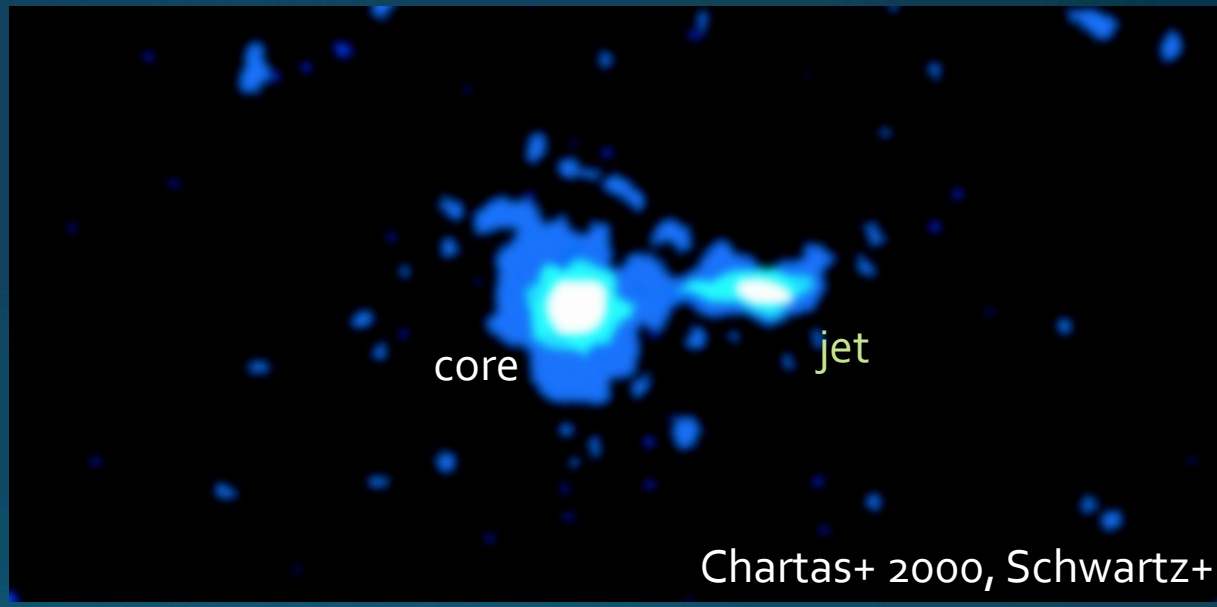
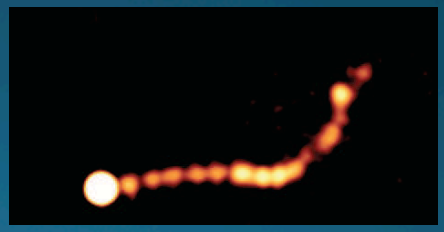


Chartas+ 2000, Schwartz+



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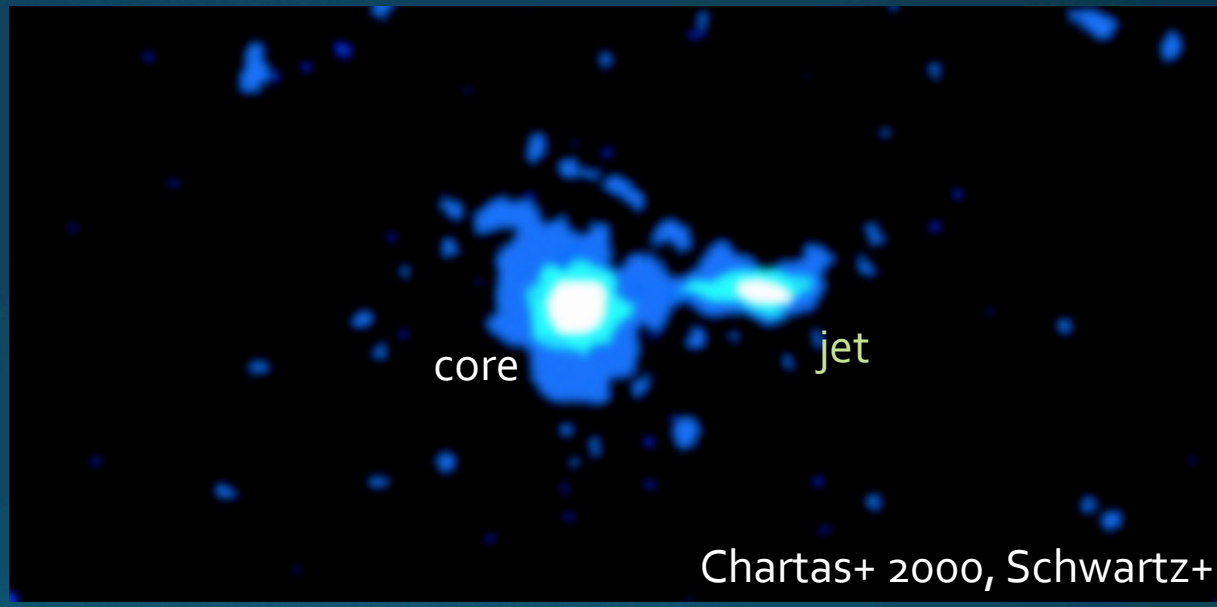
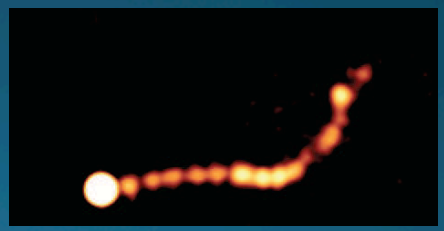


Chartas+ 2000, Schwartz+

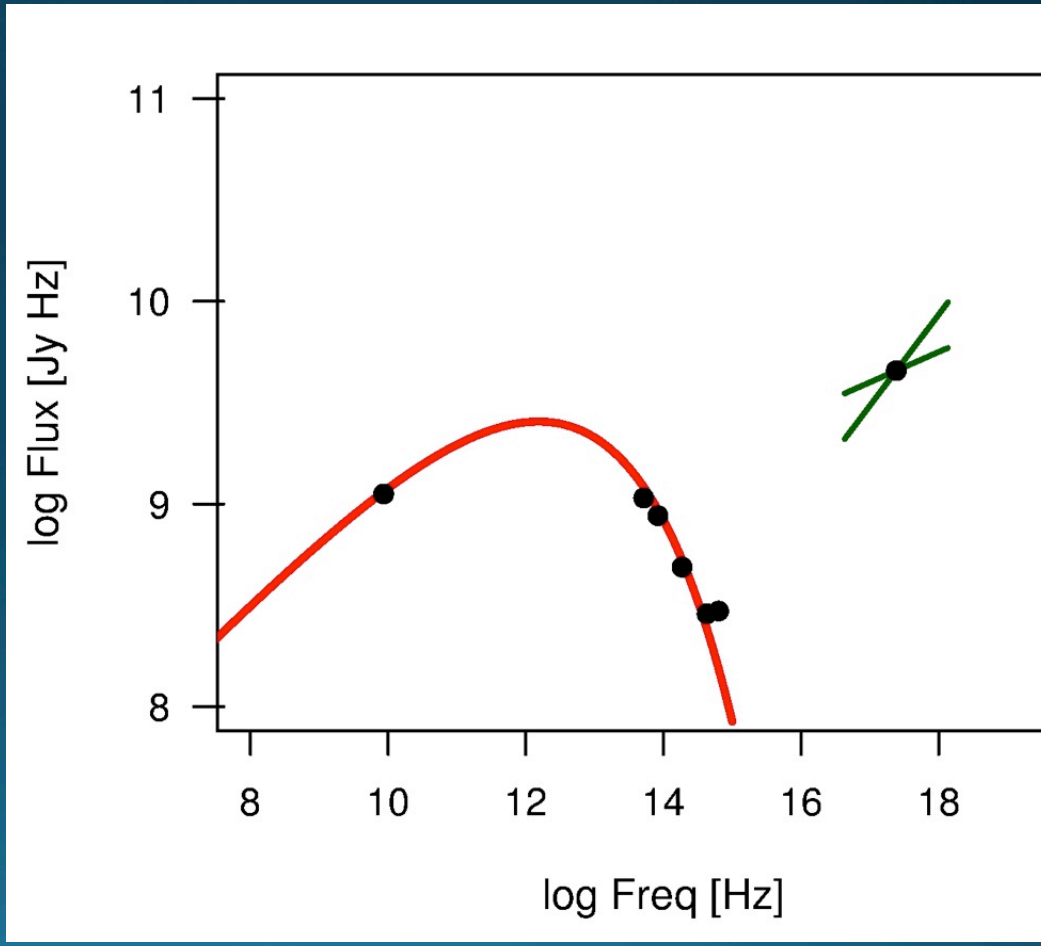
Jet was expected to be 10-100 times fainter.



Some History: The Rise of the Inverse Compton Model for X-rays from Large-Scale Jets

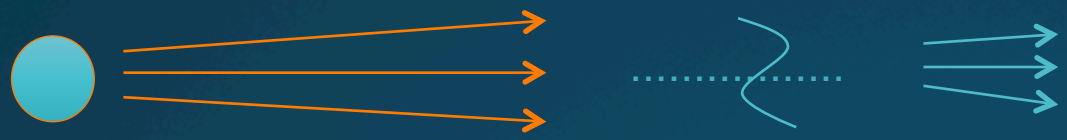
September/October 2000: Chartas et al. & Schwartz et al. discovery & discussion papers on PKS 0637-752 manage to rule out:

- Thermal Bremstrahlung (electron density required far too high)
- Synchrotron self-compton (requires a "gross departure from equipartition)
- Inverse Compton off the CMB (off by orders of magnitude)
- A Single Synchrotron Spectrum
- A second, co-spatial synchrotron spectrum was considered, but deemed unlikely because no known reason for it, and co-spatial with first synchrotron component!



Some History: The Rise of the Inverse Compton Model for X-rays from Large-Scale Jets

November 2000: Tavecchio et al. and **February 2001:** Celotti et al.: is it IC/CMB after all?



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

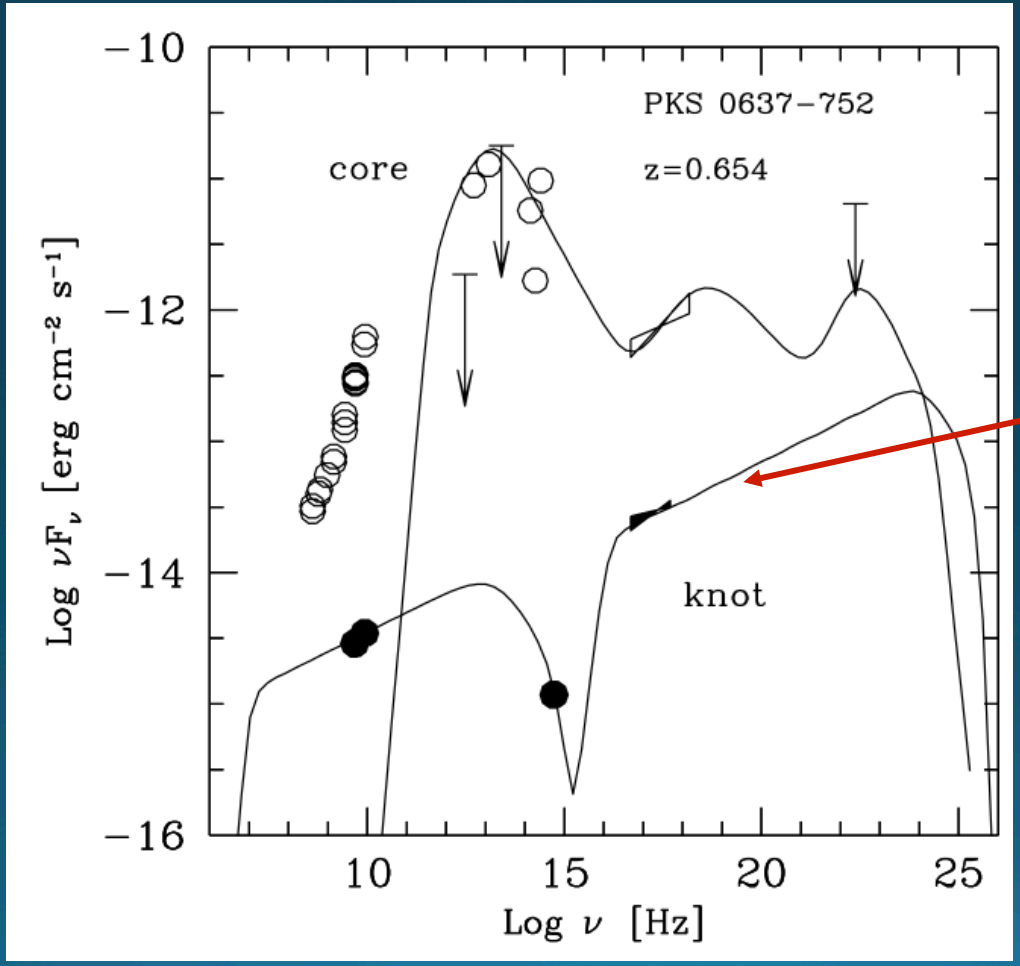
But Radio surveys have long suggested that on kiloparsec scales the jet is only mildly relativistic withΓ=1.2-1.5 [e.g., Arshakian & Longair 2004]

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

Some History: The Rise of the Inverse Compton Model for X-rays from Large-Scale Jets

elotti et al 2001:

you simply take Γ~15, he increased beaming llows the IC/CMB to natch the observed X-ays without any other najorly contrived ssumptions.



Working IC/CMB model for the kno of PKS 0637-752

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

andra News Issue 21 Spring 2014

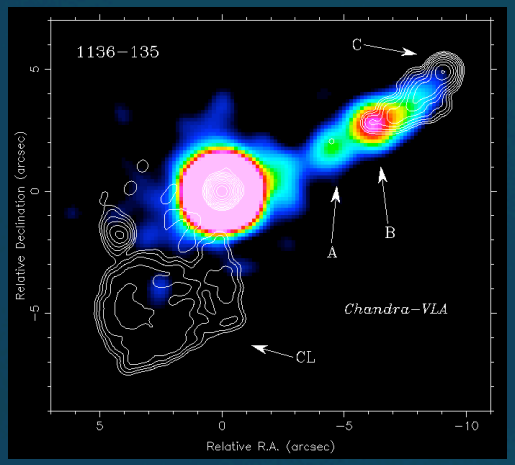
the Chandra X-ray Center (CXC)

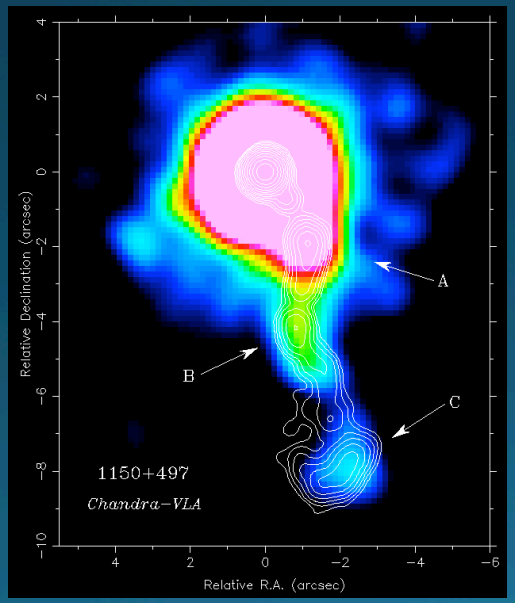
X-ray Jets

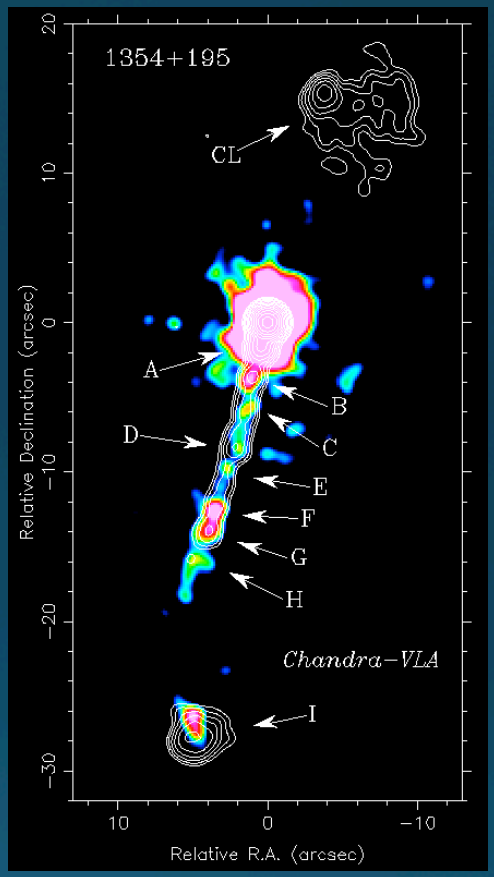
Aneta Siemiginowska

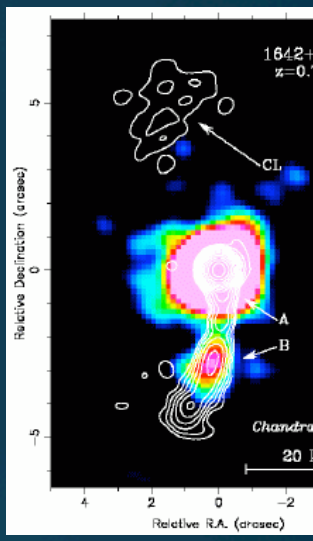
Galaxy 4C+29.30

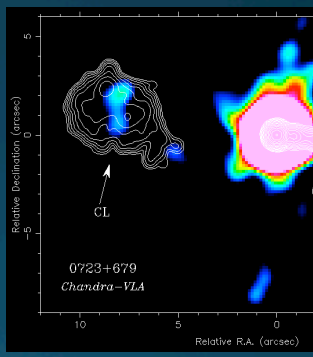
Credit: X-ray: NASA/CXC/SAO/A.Siemiginowska et al; Optical: NASA/STScI; Radio: NSF/NRAO/VLA











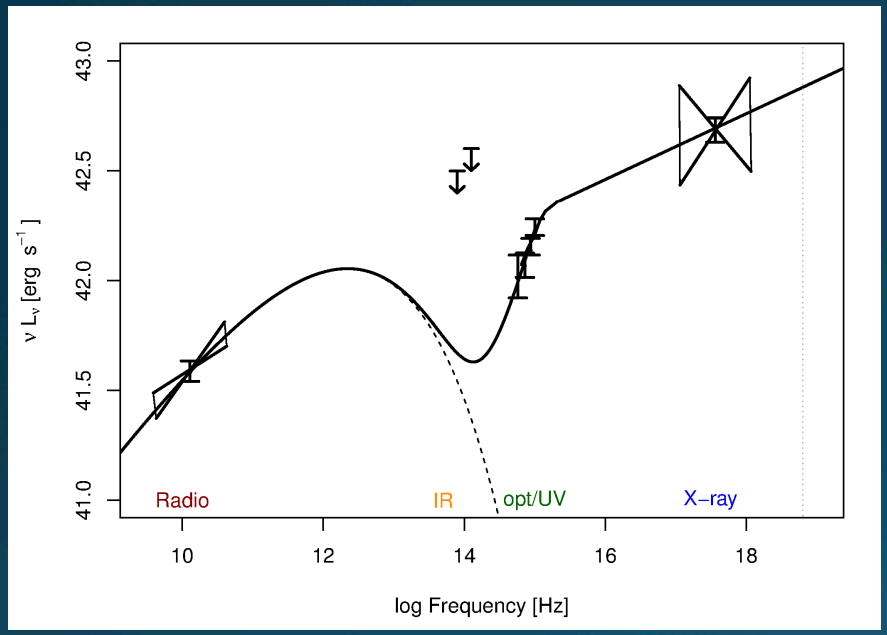
Several dozen now discovered (see review Harris & Krawczynski 2006, Also papers by Marshall, Sambruna, Jorstad & Marscher, K Godfrey, Siemiginowska, and many more.

Doubts about the IC/CMB model

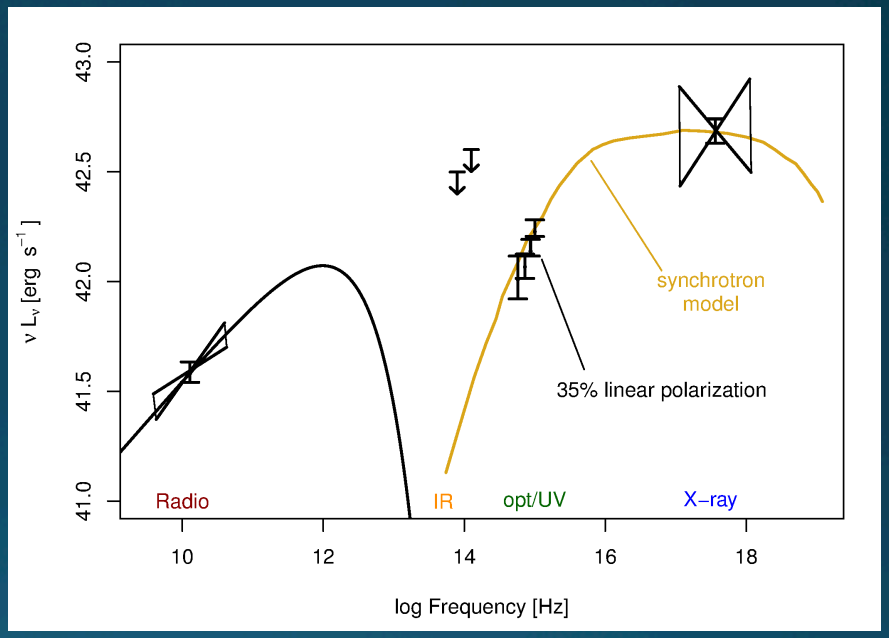
- IC/CMB only works with deceleration (Georganopoulos & Kazanas 2004, Hardcastle 2006)
- IC/CMB requires near or super-Eddington jets in some cases
- Small beaming angle sometimes implies jet lengths > 1 Mpc (longer than the very longest in the plane of the sky)
- In many cases the IC/CMB fit is an "uncomfortable" one
- Jester 2006, Uchiyama 2006, Hardcastle 2006: All suggest (leptonic) synchrotron models very much alive
- Hadronic models also a rather under-explored possibility (Aharonian 2002)

The Essential Problem

Second-synchrotron and IC/CMB fit radio-optical-Xray equally well.



PKS 1136-135, IC/CMB Model



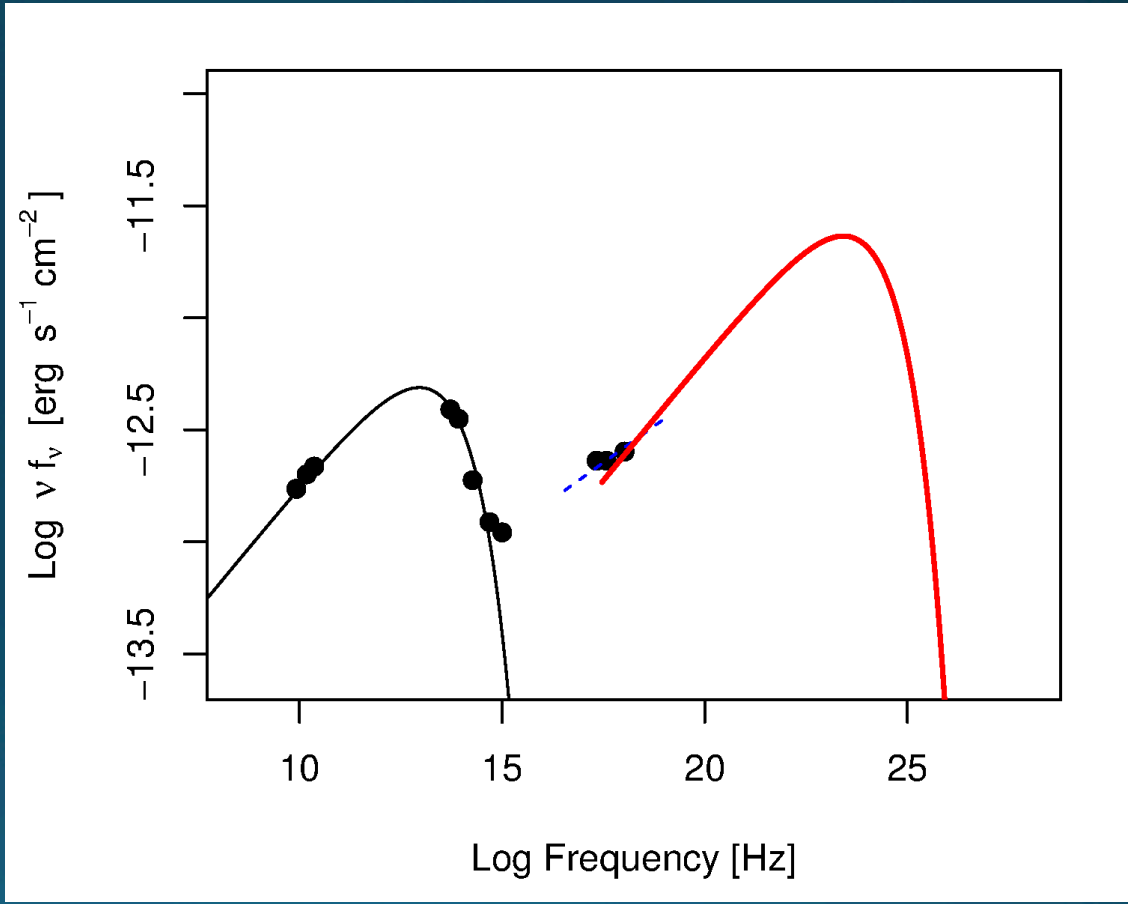
PKS 1136-135, synchrotron Model

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

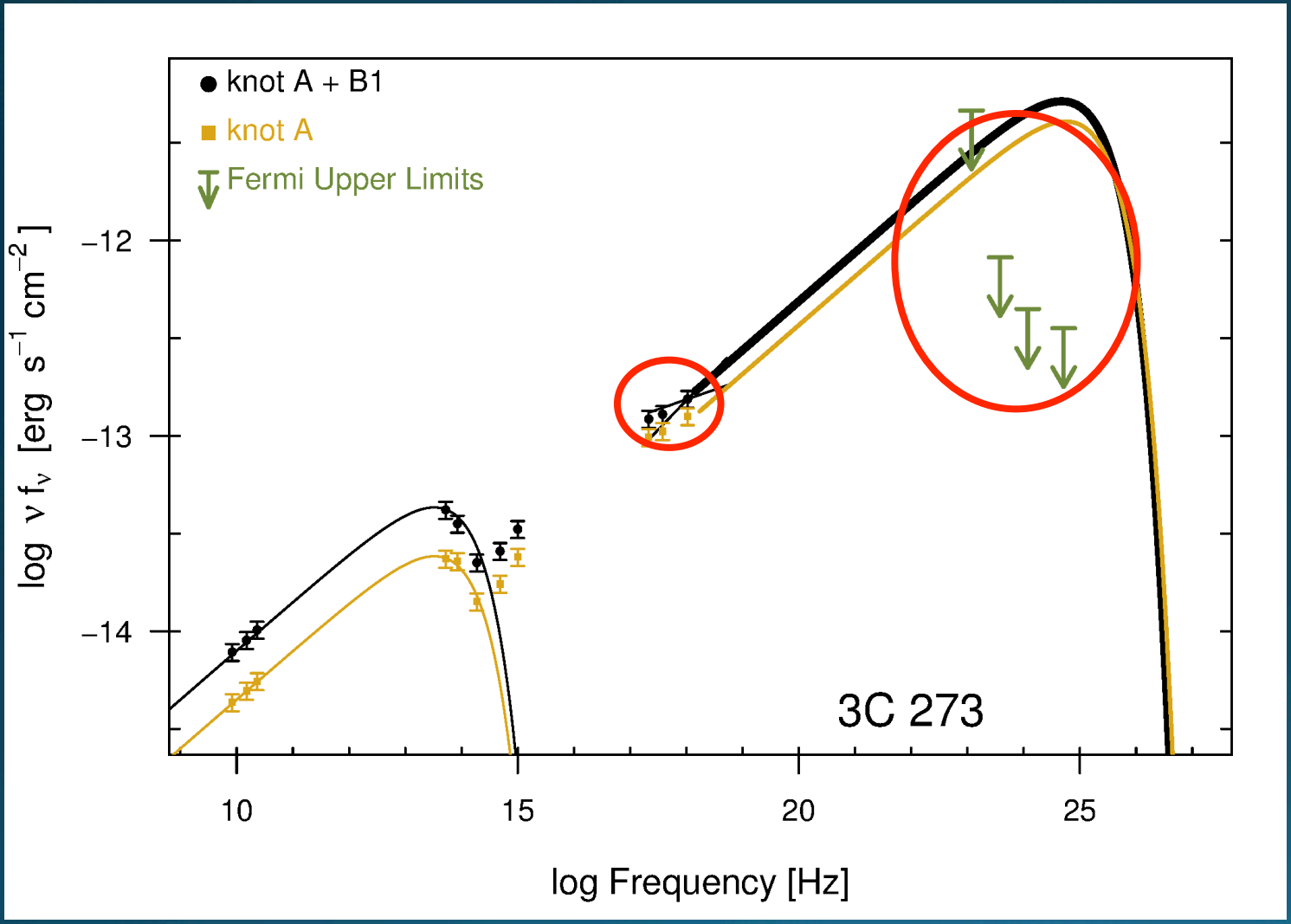
The IC Component is a copy of the synchrotron, shifted in frequency and luminosity.

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



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

The case of 3C 273

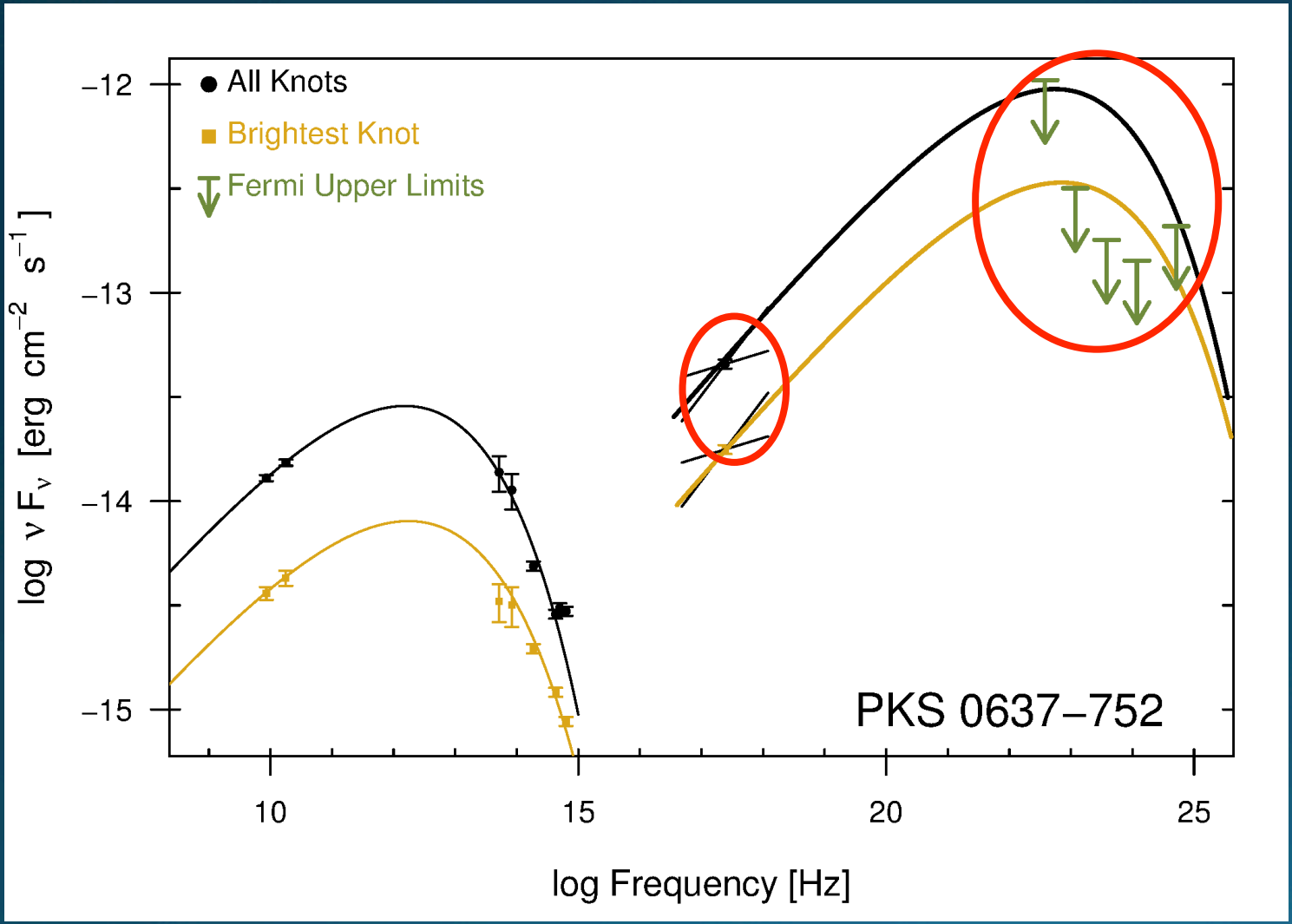


IC/CMB clearly ruled out at the > 99.99% level

You cannot satisfy producing the X-rays and the gamma-ray limits.

Meyer & Georganopoulos 2014 ApJ 780, 27

The case of PKS 0637-752



IC/CMB is now ruled out at the > 99.99% level for the original jet for which the model was first proposed!

(Meyer et al. 2015 ApJ 805 154)

Take-away #1: The IC/CMB Model is in trouble.

IC/CMB has been conclusively ruled out by lack of gamma-rays on 2 sources
(Meyer & Georganopoulos 2014, Meyer et al., 2015)

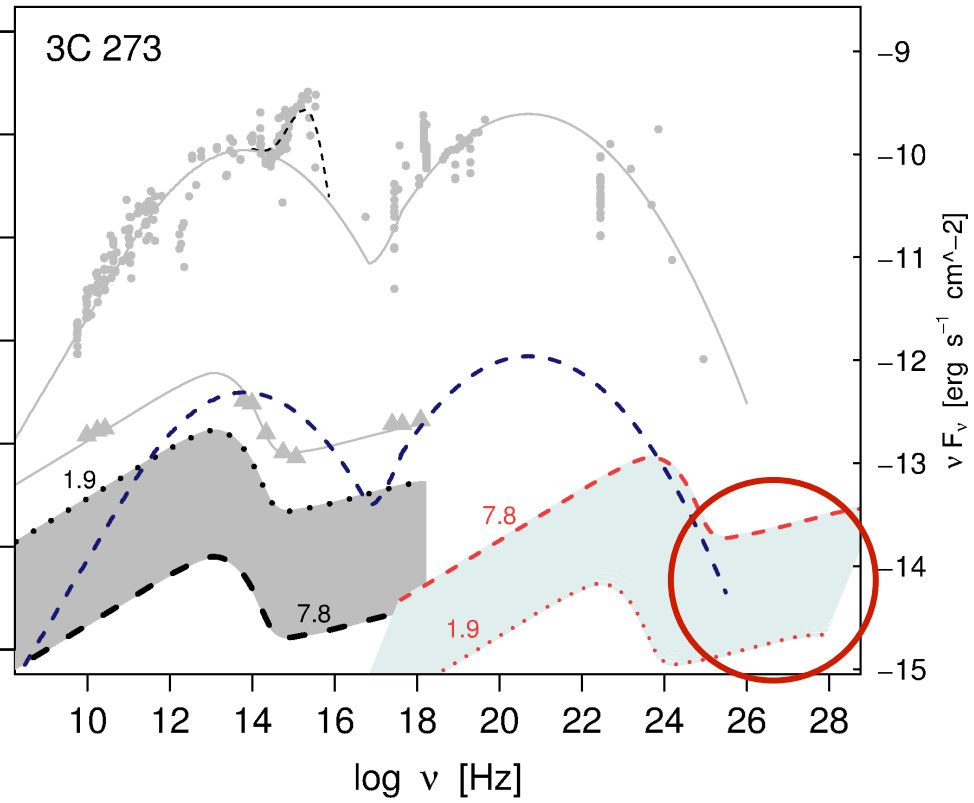
IC/CMB has also been ruled out by lack of proper motions In 3C 273
(Meyer et al., 2015, submitted)

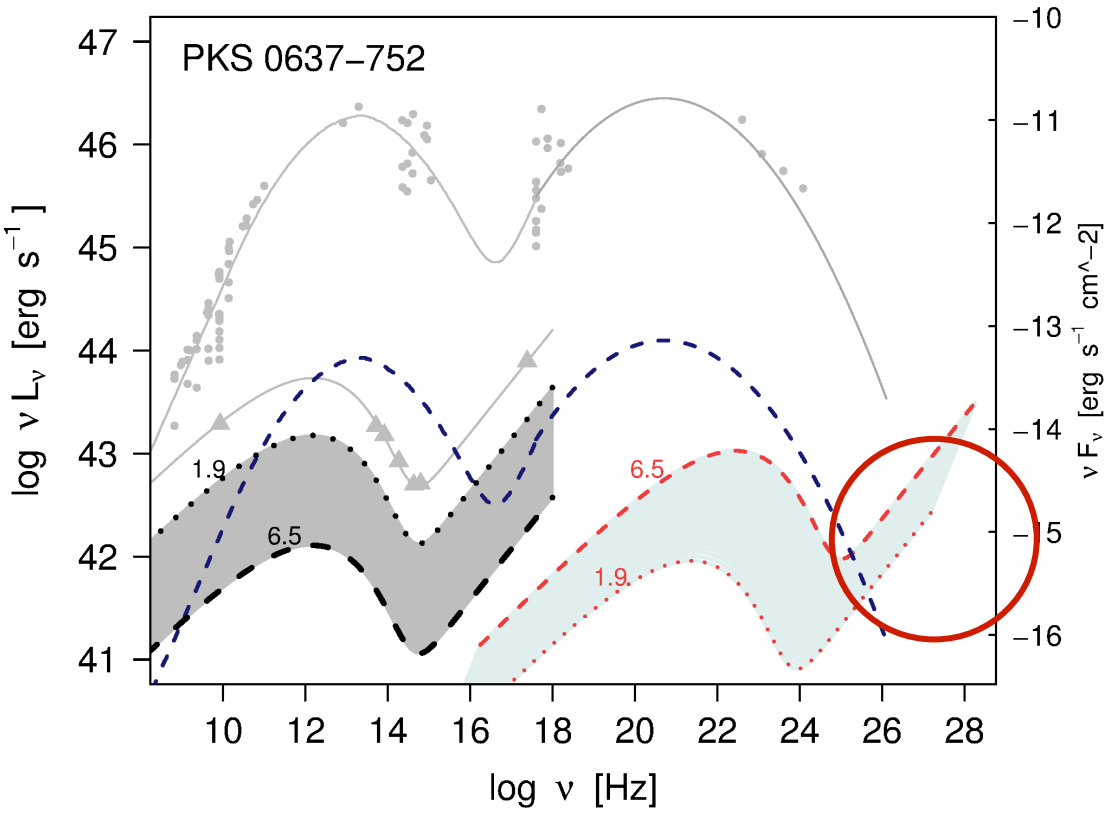
IC/CMB has been ruled out in a third case because the second component is hi
polarized (35%, unexpected since the CMB has low polarization)
(Cara et al., 2013)

Take-away #2: The only alternative is a second synchrotron component

Theorists: what is this and why is it there?

onsolation Prize: Slow Jets = TeV Emission

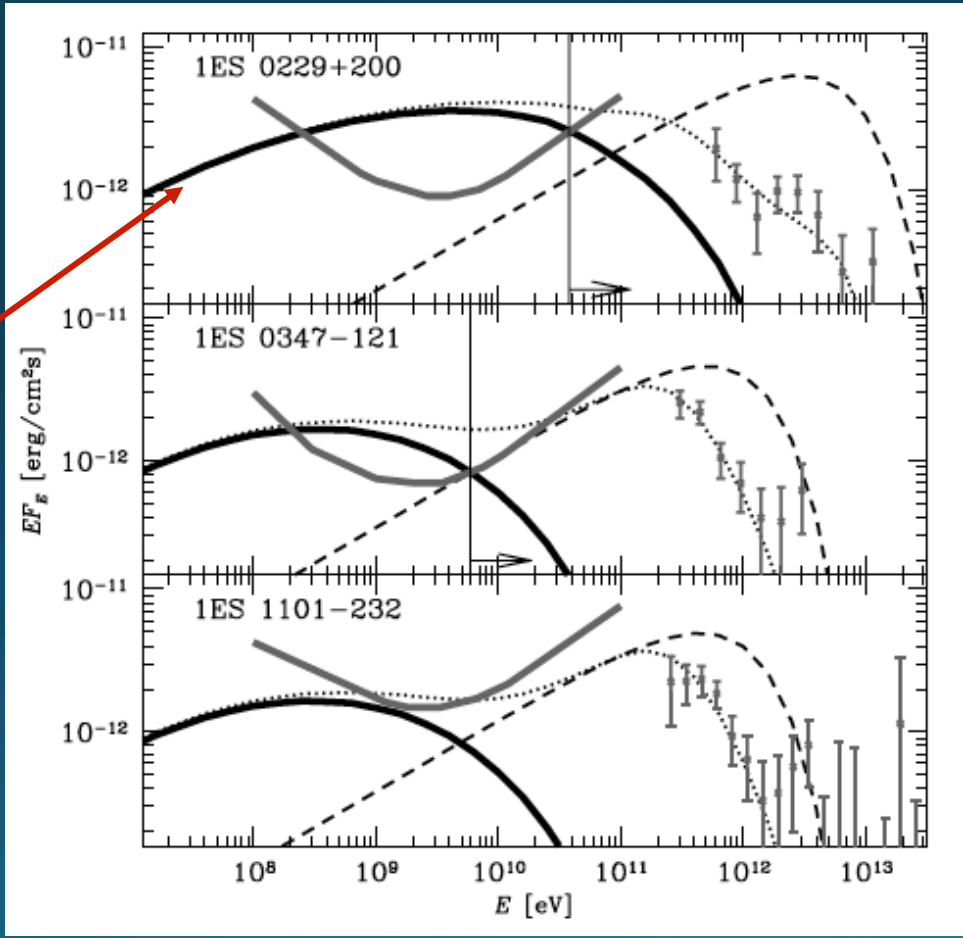




Both 3C 273 and PKS 0637-752 already have predicted IC/CMB TeV emission which is far above the isotropic output of a ‘typical’ TeV Blazar.

- TeV Heating (recent work by C Pfrommer, A Broderick, P Chang)
  - Motivated in part by the lack of the expected GeV 'halo' around TeV blazars from pair cascades (e.g. Nevonov & Vovk 2010, Aleksic 2010, H.E.S.S 2014)

Fermi limits rule out expected signature



Nevonov & Vovk (2010)

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  - An alternative is plasma beam instabilities (Broderick 2012)
  - May also explain missing dwarf satellites compared to simulations (leads to suppression of dwarfs) , alleviates need for a very differently evolved population, may also explain inverted IGM temperature-density profile at low densities (Chang 2012).

Take-aways

1. IC/CMB is not the cause of the anomalously high X-rays in 3C 273, PKS 0637-752, and PKS 1136-135
2. I think it likely that this will turn out to be true for most of our anomalous X-ray sources (maybe not at high z?)
3. We still have a mystery: what is the source of the second synchrotron component? Why does it appear co-spatial? Why does it (usually) decrease as you go down the jet? → theorists!
4. Kpc-scale jets are not, after all, super-fast. They are mildly relativistic (one-sided jets, hotspots are also somewhat beamed)

Take-aways

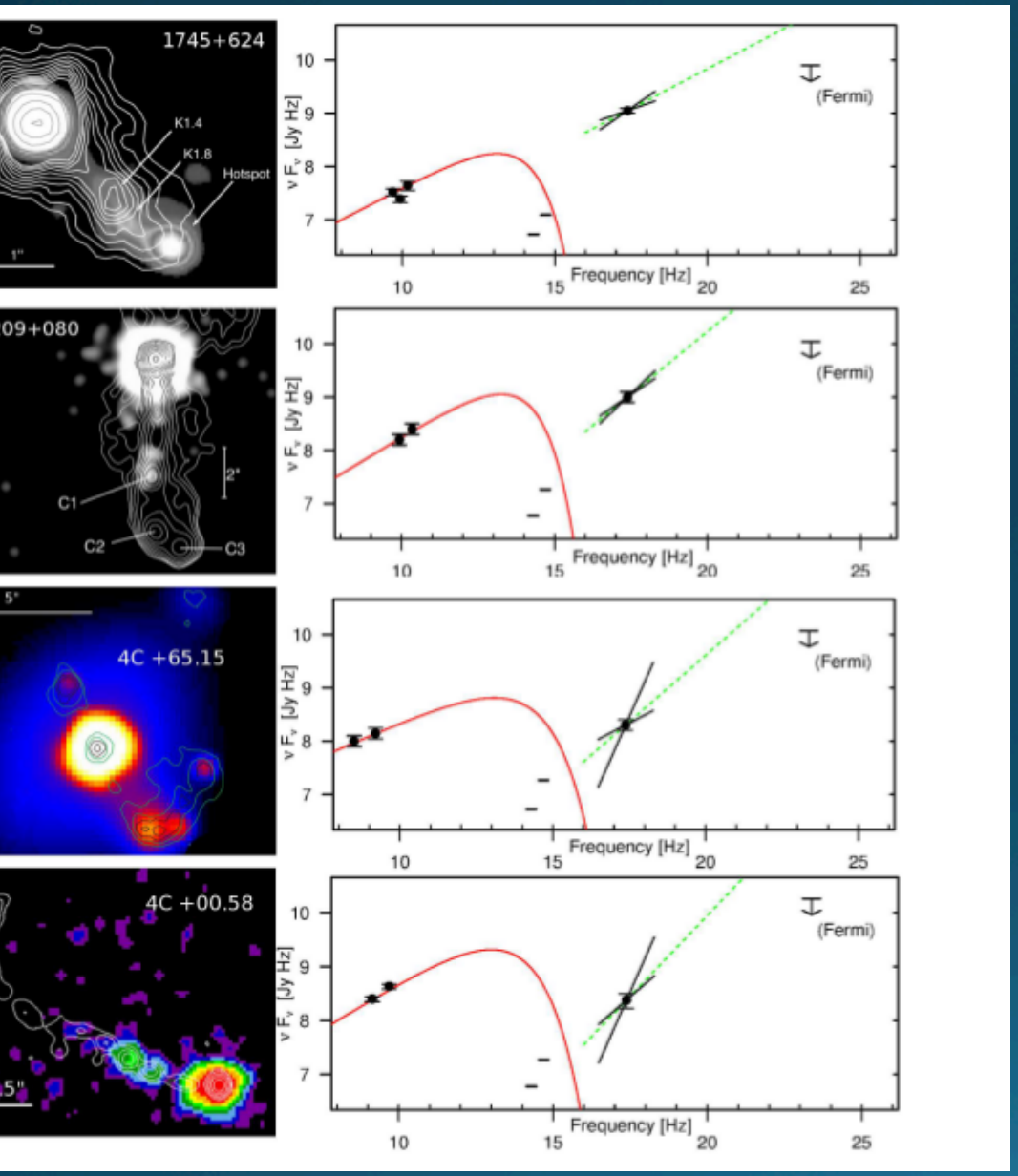
5. Prediction: Fermi will detect IC/CMB before the 10 year mission is up. It must be there at some level even if it doesn't produce the X-rays. This gives us a direct measurement of B/δ

6. The synchrotron X-rays should give us lots of TeV emission, almost certainly more than 'TeV blazar's in total luminosity. This may turn out to be Really Important.

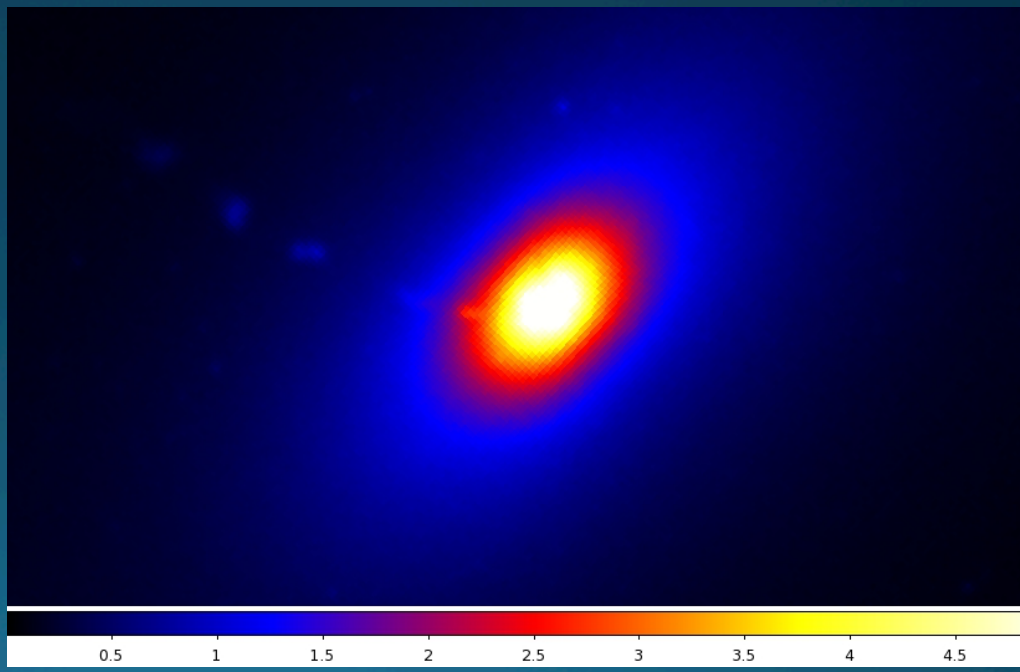
7. Prediction: Either Fermi or CTA will finally detect this component, ultimate proof that the X-rays are synchrotron.

Follow-up & Current Work

- New data on 8 sources + archival effort on about 2 dozen total jets should give us a good test of IC/CMB overall with Fermi
- Variability study for Chandra X-ray jets: variability not expected in IC/CMB
- Ongoing look for the TeV 'upturn' at the highest Fermi energies to confirm synchrotron origin of X-rays
- Population study of Anomalous X-ray Jets to estimate TeV heating potential (initial idea paper should be out in a few months, until then see Meyer et al., 2015).

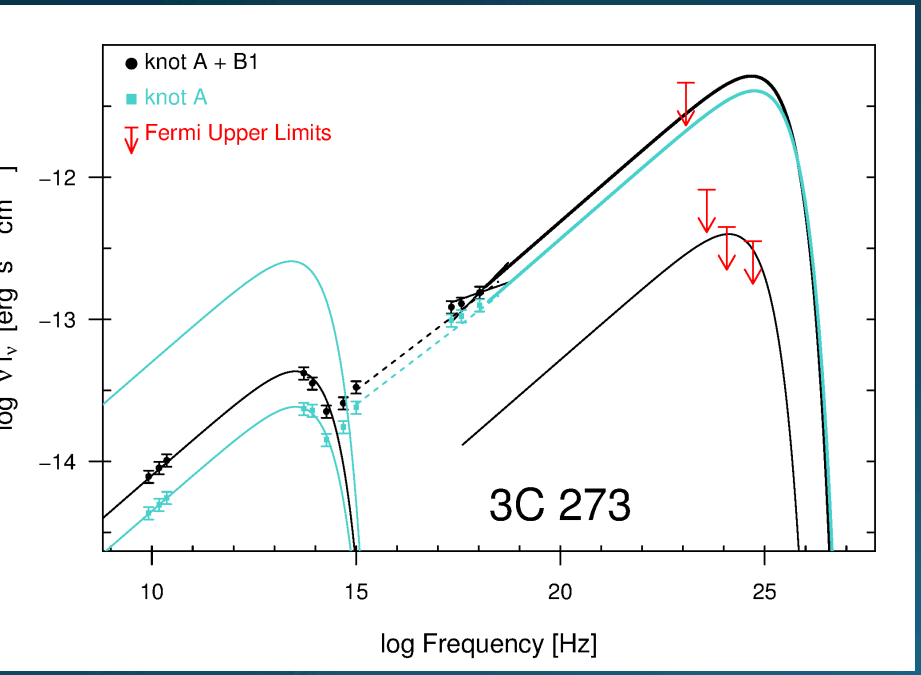


What is next? We will be using t
Fermi test on at least 8 more jets
year (new Chandra and HST
observations)



Limits on Doppler factor/Magnetic Field

Fermi observations not only rule out IC/CMB X-rays, they put limits on the Doppler beaming factor of jets on kpc scales.

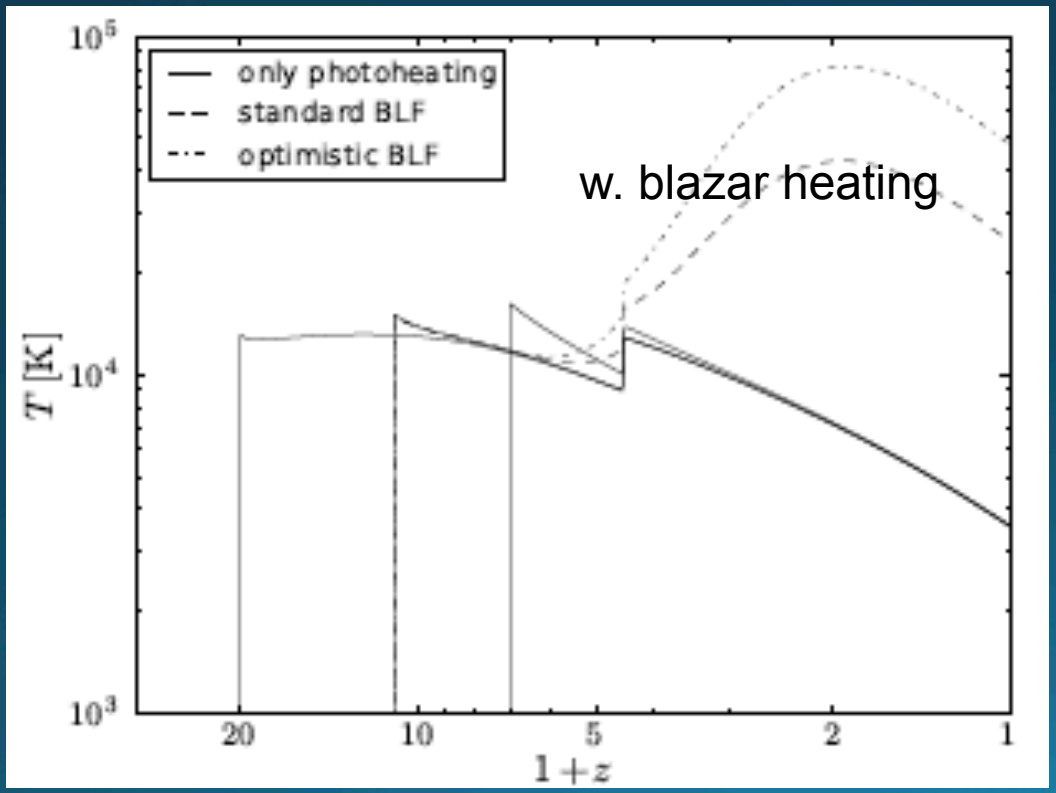


Assuming equipartition fields, $\delta < 7.8$ in 3C 273 (based solely on knots A and B1)

For PKS 0637-752, $\delta < 6.5$

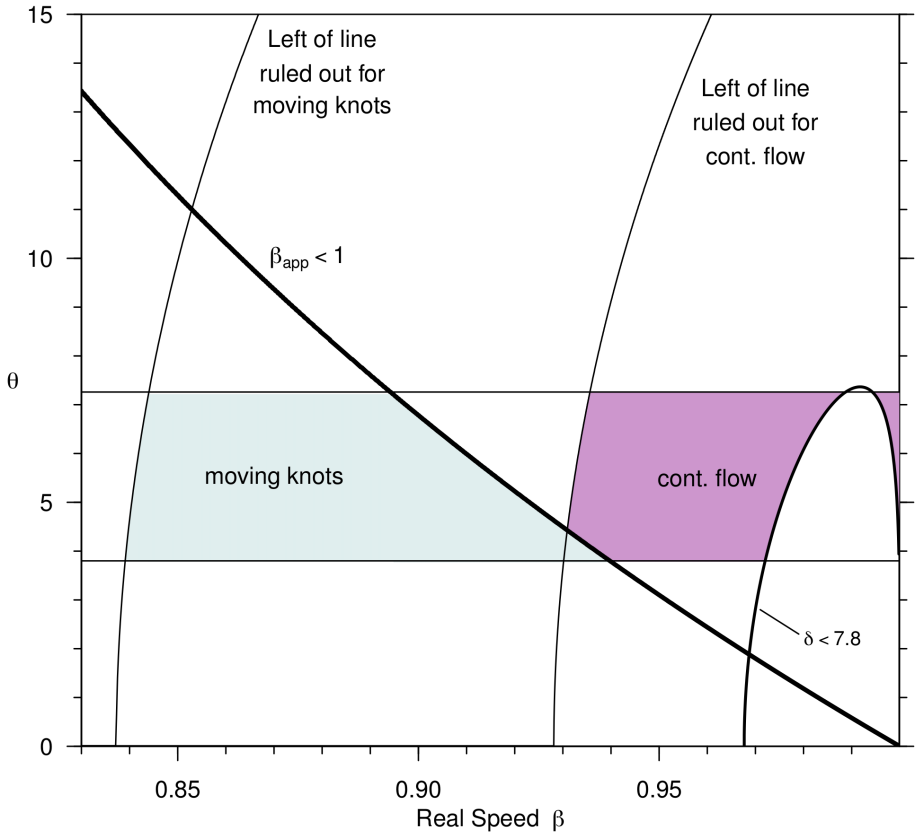
TeV Heating

- Issues that could be solved by Jet Heating:
  - Inverted temperature-density relation in under-dense regions of the IGM



PC, Broderick & Pfrommer (201

3C 273 another way



The colored zones at left give the remaining 'allowed' zones given the following constraints:

Bapp = 15 c on parsec-scale (Lister et al 2009)
Jet length < 1 Mpc
Bapp < 1c on kpc scale