Prospects for Large-Scale Jets with Lynx

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From Chandra to Lynx | Cambridge, MA | 8-10 August 2017

Jets from AGN

“After all these years and all these conferences on jets, we still don’t know what jets are made of or how they work.”

– Dan Harris (Proceedings of the IAU, 2015)

Jets from AGN

They are not well-understood systems:

- Particle Content (electron/positron? Proton content pre-/post-entrainment?)

- Speeds, Lifetimes, Duty Cycles (do all AGN go through Jet Cycles?)

- Connect of the Jet to the black hole – mass, accretion mode, rate (What makes an AGN radio-loud? An FR class I or II?)

- What explains the huge range in morphology, jet power?

- Particle Acceleration Mechanism?

- Total Energetics?

Jets from AGN

Beyond Jets (The Bigger Picture):

Cosmological Probes

- High-z blazars trace massive BH growth at very early times

- Low/moderate-z radio lobes can be used to measure the Extragalactic Background Light

Role in Structure Formation/Galaxy Evolution

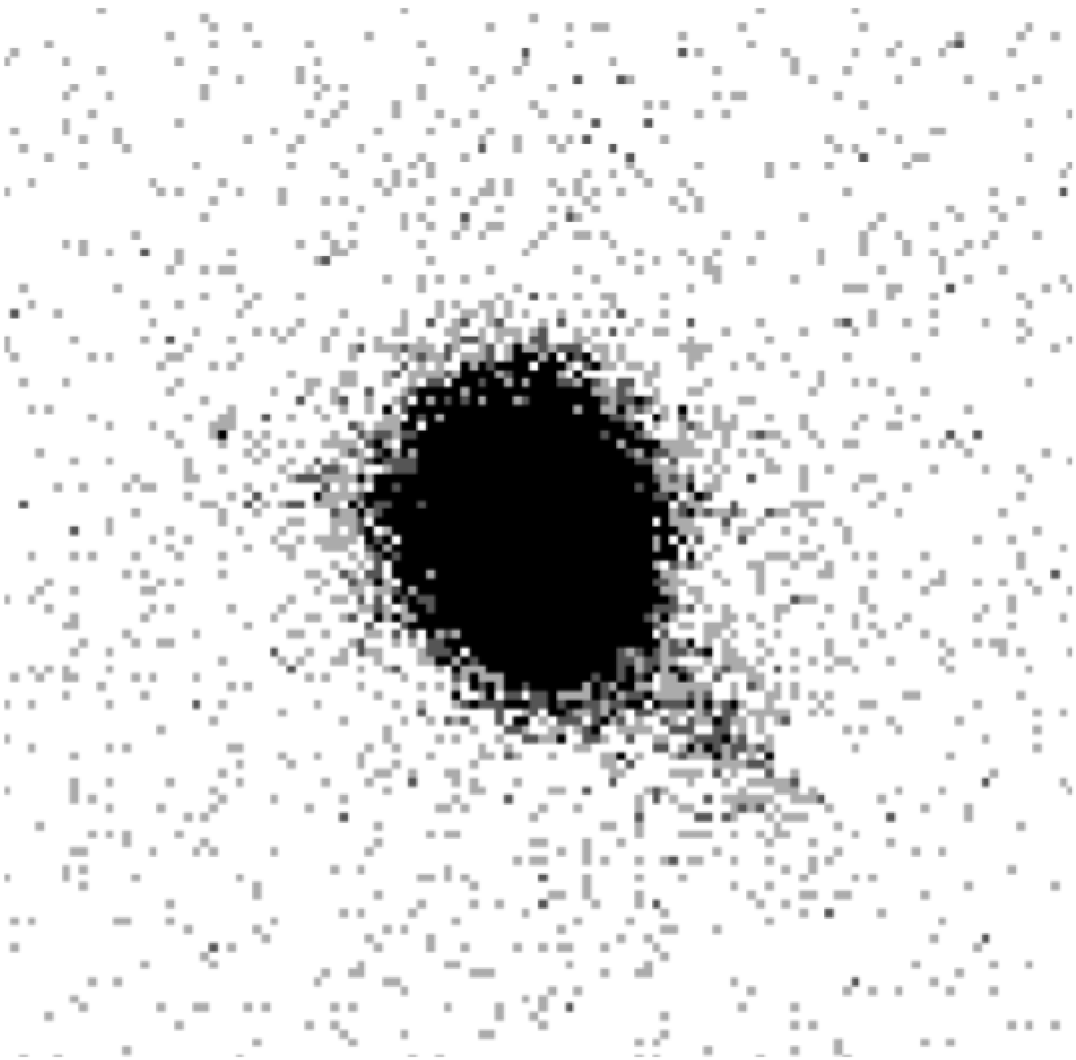
- Reionization?

- Slow the rate of Star Formation (Nesvadba et al., 2008; Page et al., 2012)

- Heating of cluster gas (McNamara & Nulsen, 2007)

- Heating of galaxy-scale gas (Lehnert et al., 2011; Guillard et al., 2012)

The Chandra Revolution



3C 273, ROSAT HRI
(17 ks, Roser et al., 2000)

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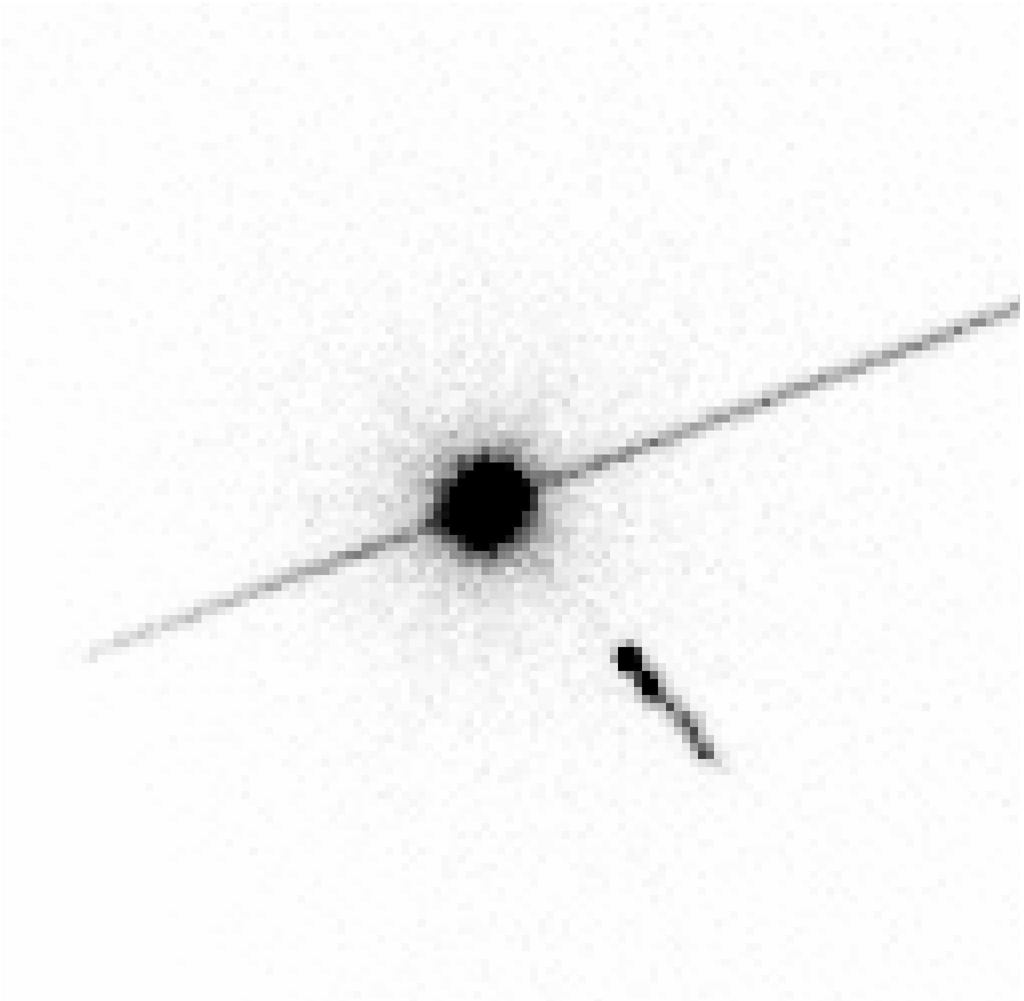

3C 273, Chandra
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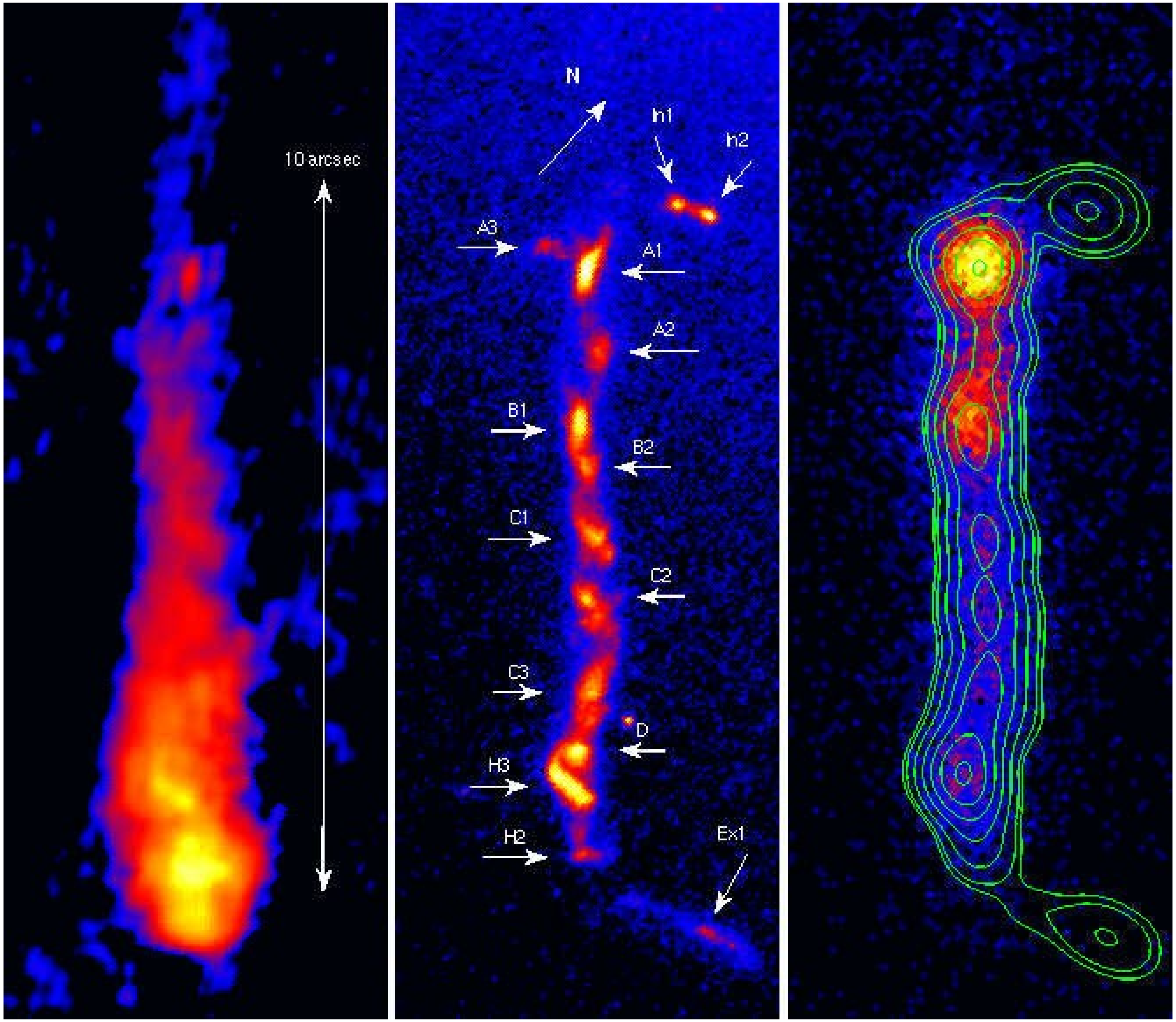
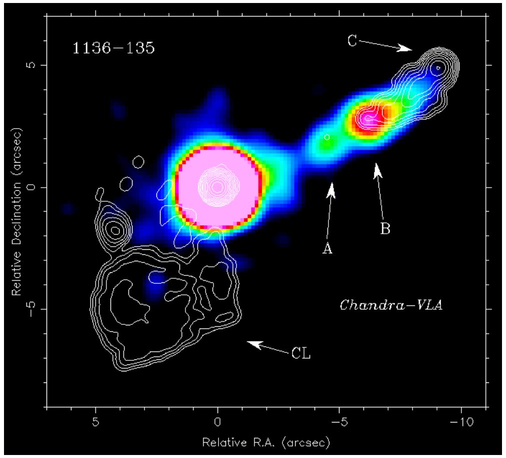
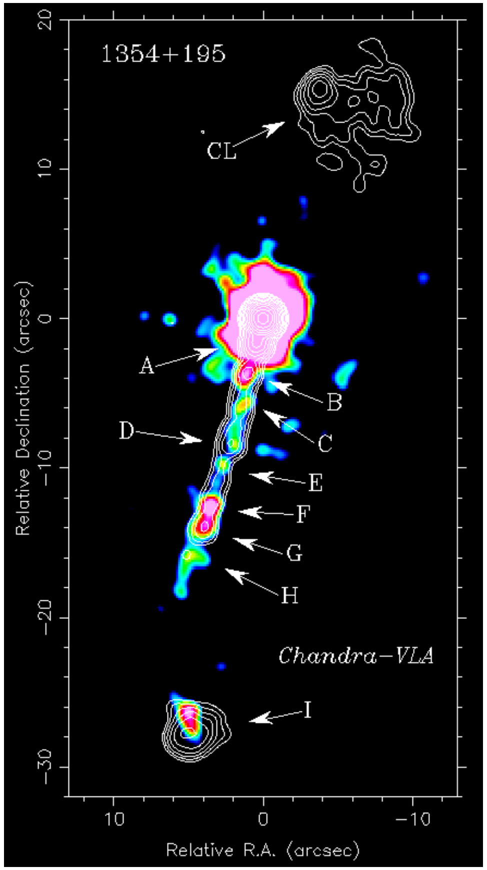
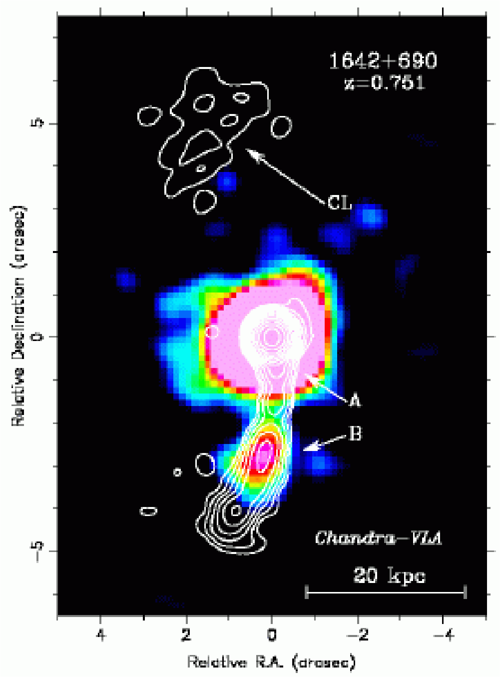


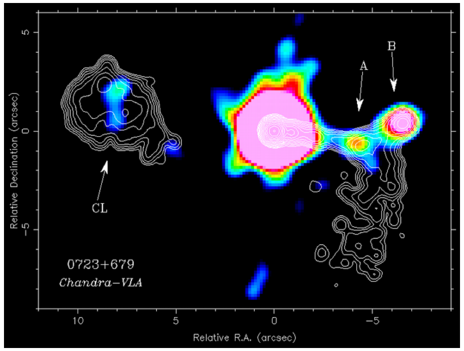
3C 273 (Herman Marshall)

The Chandra Revolution

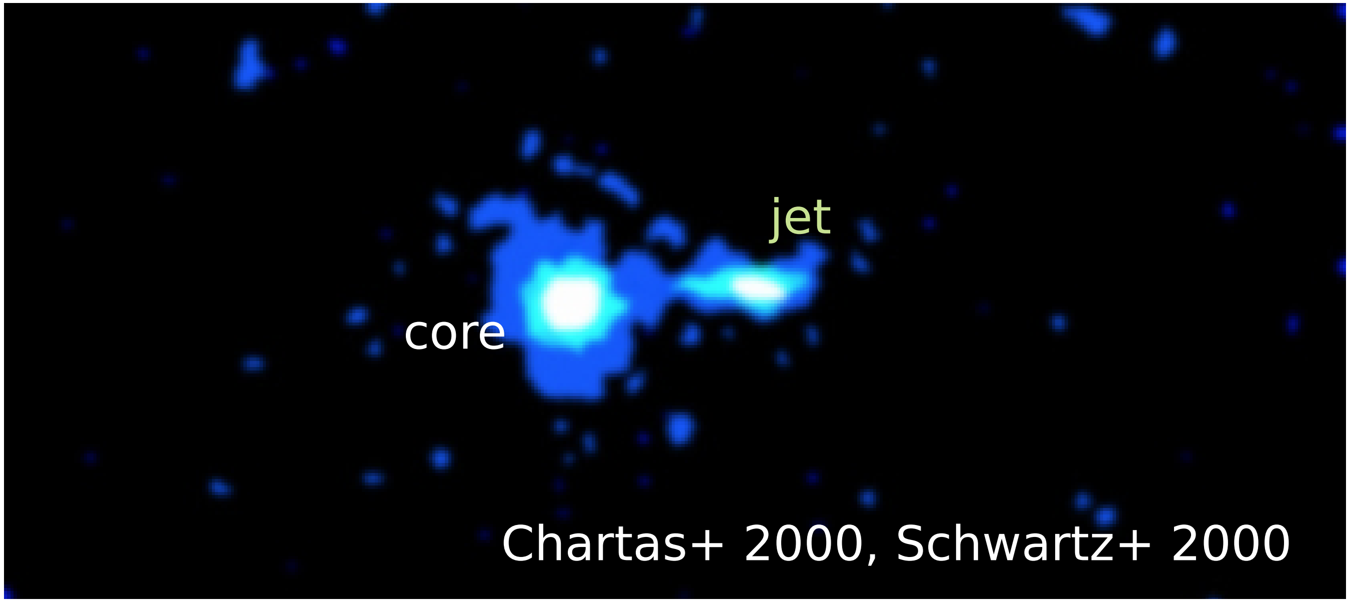






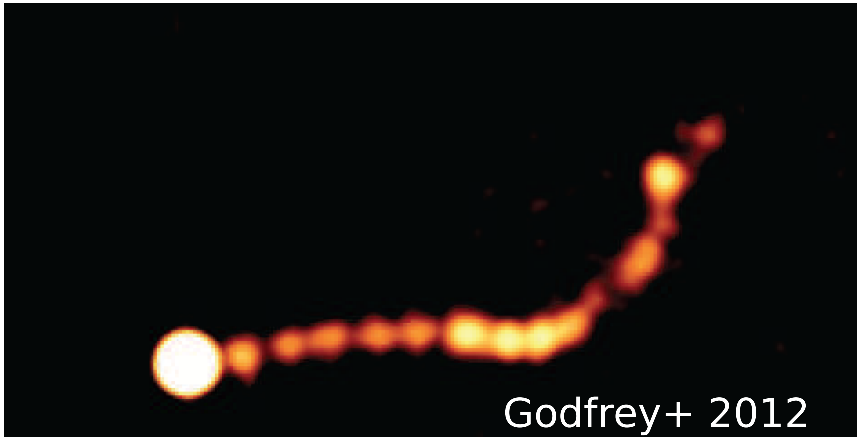


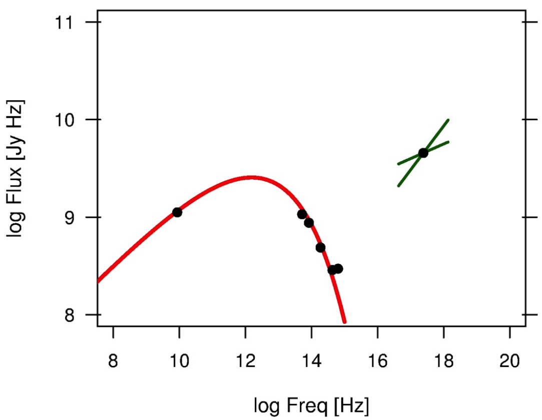
The Chandra Discovery - ‘Anomalous Jets’



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

The Chandra Discovery - ‘Anomalous Jets’





Two Alternative Models are mainly discussed:

(1) The X-rays are produced by upscattered CMB photons by a highly relativistic large-scale jet *(The IC/CMB model)*

(2) The X-rays are synchrotron emission produced by a second population of electrons *(The second synchrotron model)*

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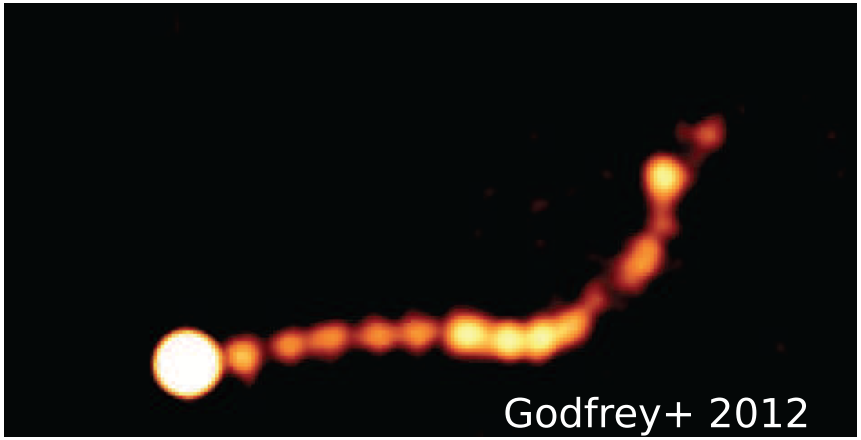

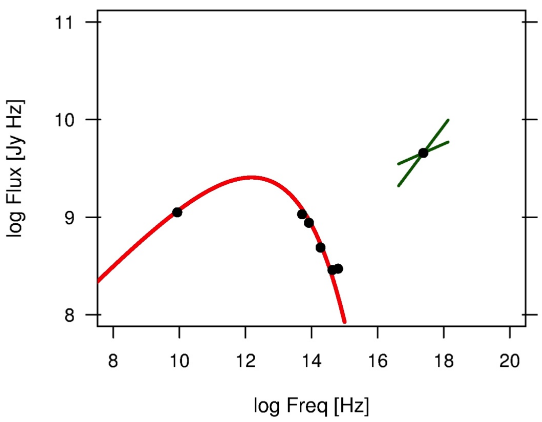

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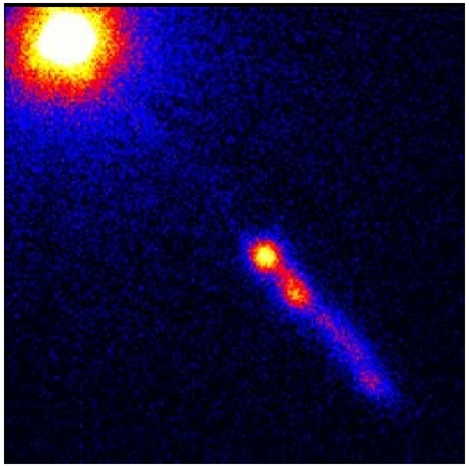
(3) Hadronic Models?

The Chandra Discovery - 'Anomalous Jets'

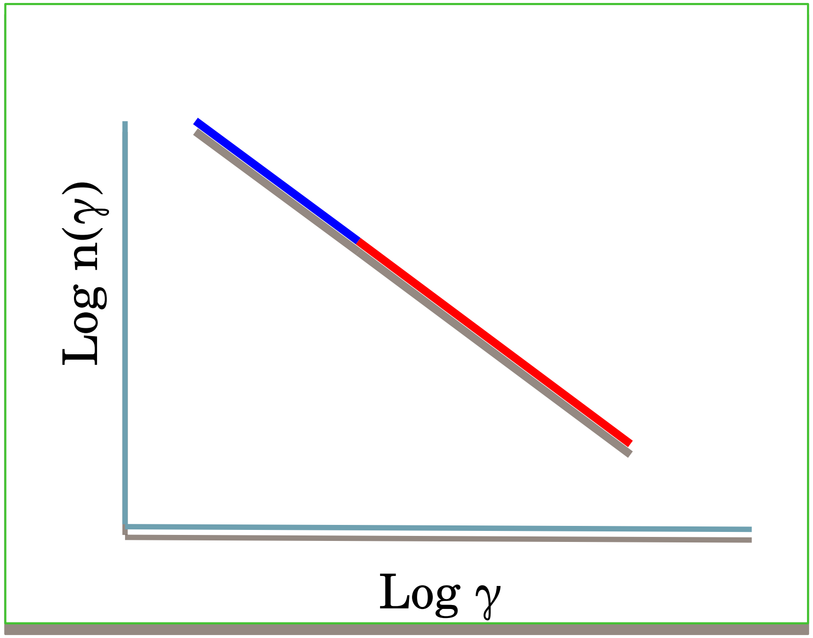
*These are **very** physically different interpretations!*



IC/CMB:

The electrons corresponding to the X-rays are VERY LOW ENERGY.

Requires extending the EED down to very low gamma (γ~1-100 compared to γ~few 10^3 required by the radio).



The EED is a powerlaw, extending (blue line) to low γ pushes your energy requirements to *Eddington-magnitude values.*

You also need pretty extreme Doppler boosting, which requires BOTH small angles and high bulk Γ.

e.g., bulk Γ=10 @ 100 kpc from the core!
e.g., jet lengths of > 1 Mpc due to small θ

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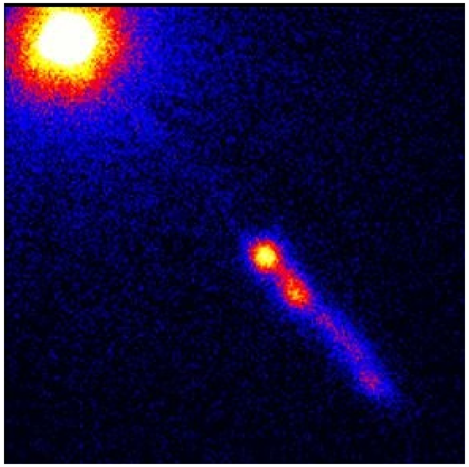
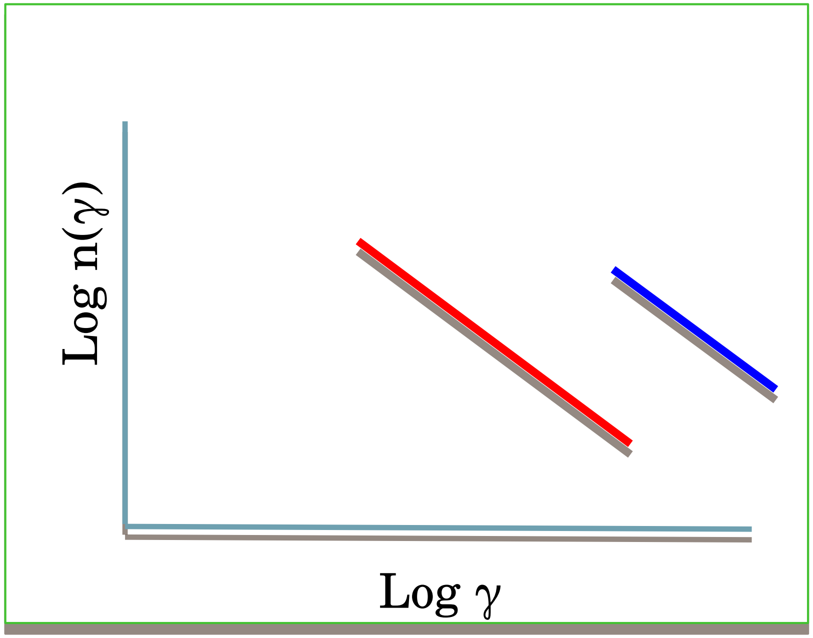


second-synchrotron

Opposite: electrons giving X-rays must be accelerated in situ to multi-TeV energies!

But synchrotron is a much more efficient processes, so energies required are well below Eddington.



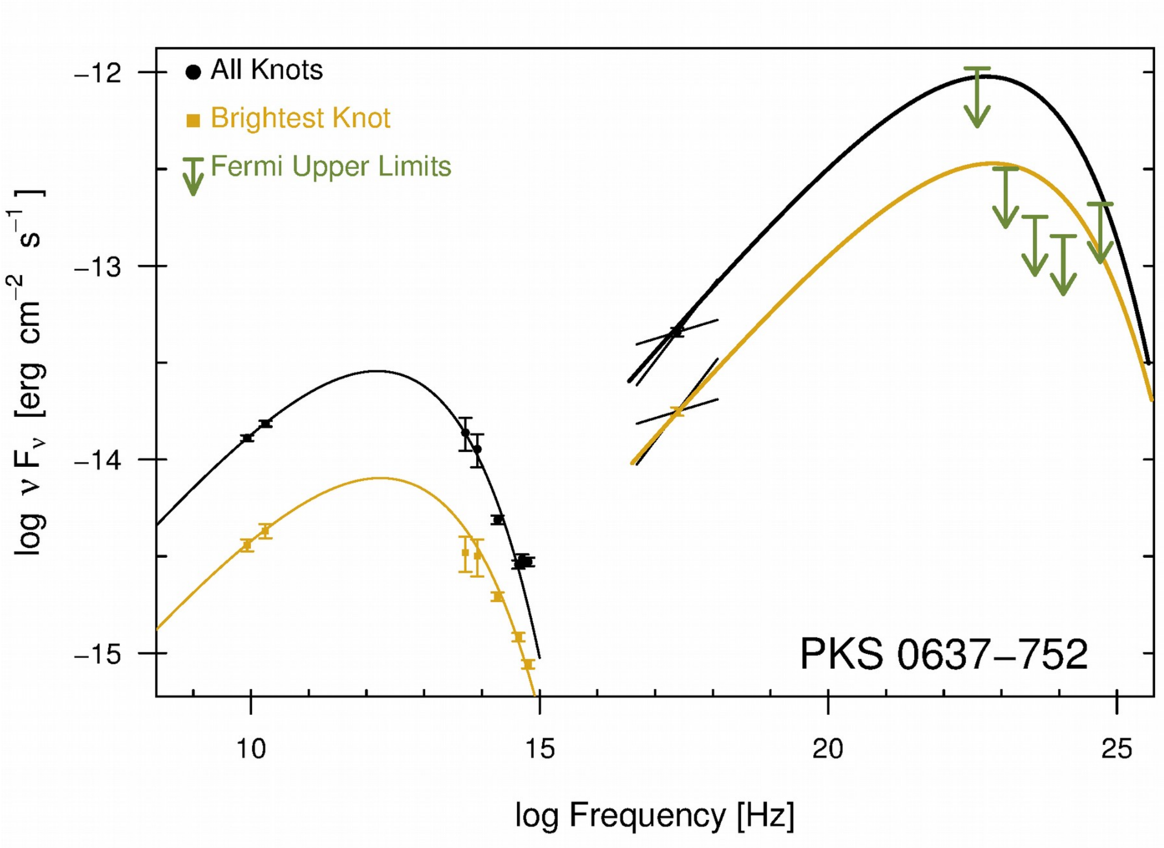
You also don’t need to be extremely Doppler boosted – mildly relativistic flows are fine (Γ of 2-3).

Solving this question is critical to understanding particle acceleration in jets, the particle content of jets, the total energy carried.

If you want to understand jet feedback, we need to answer this fundamental mystery, which was raised by Chandra.

Has it been resolved?

Chandra got us into this mess, can Fermi get us out?



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

See: Meyer et al., (2014) ApJ 780 L27
Meyer et al., (2015) ApJ 805, 154
Meyer et al., (2017) ApJ 835, 2
Breiding et al., (2017), submitted

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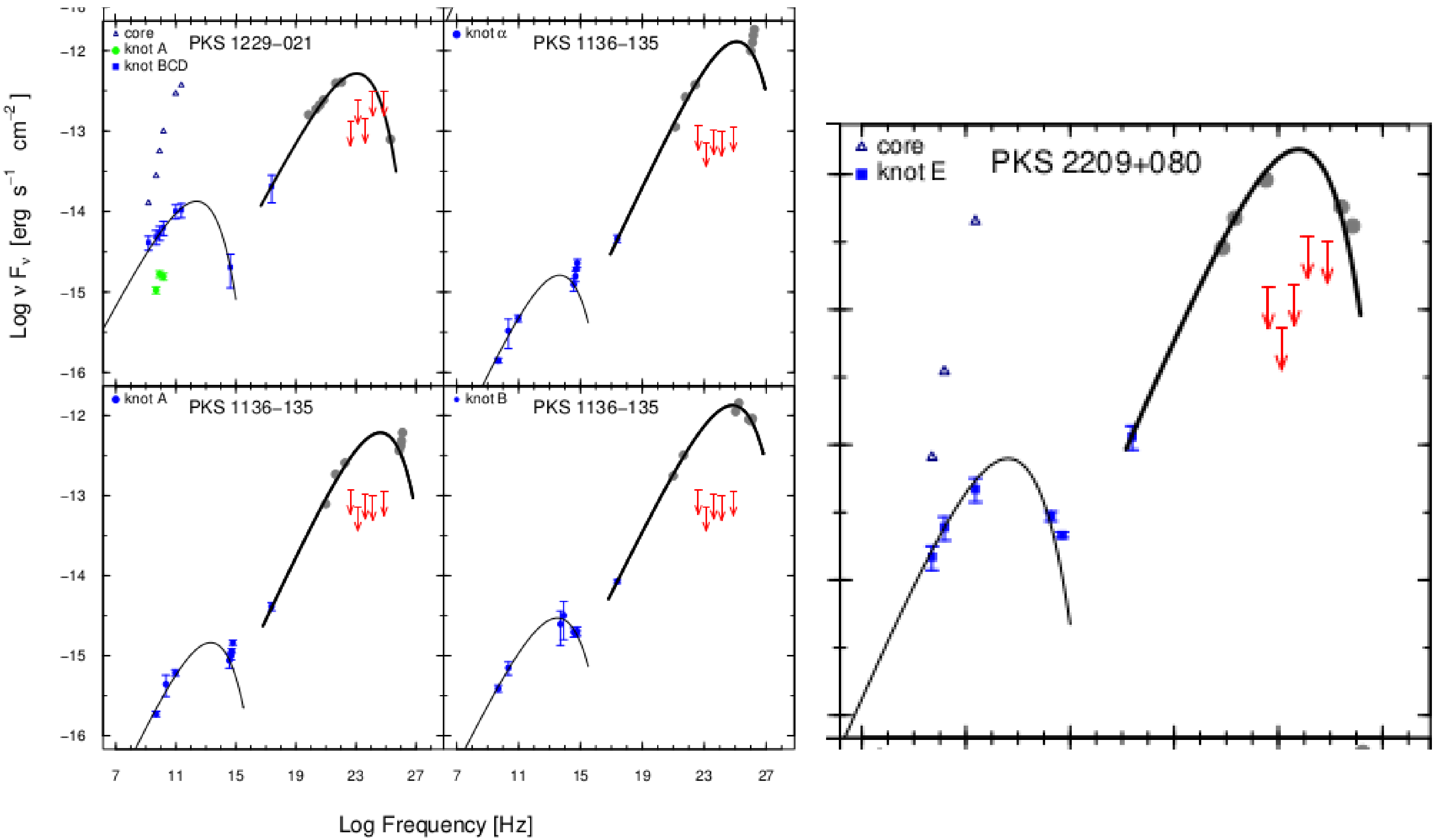

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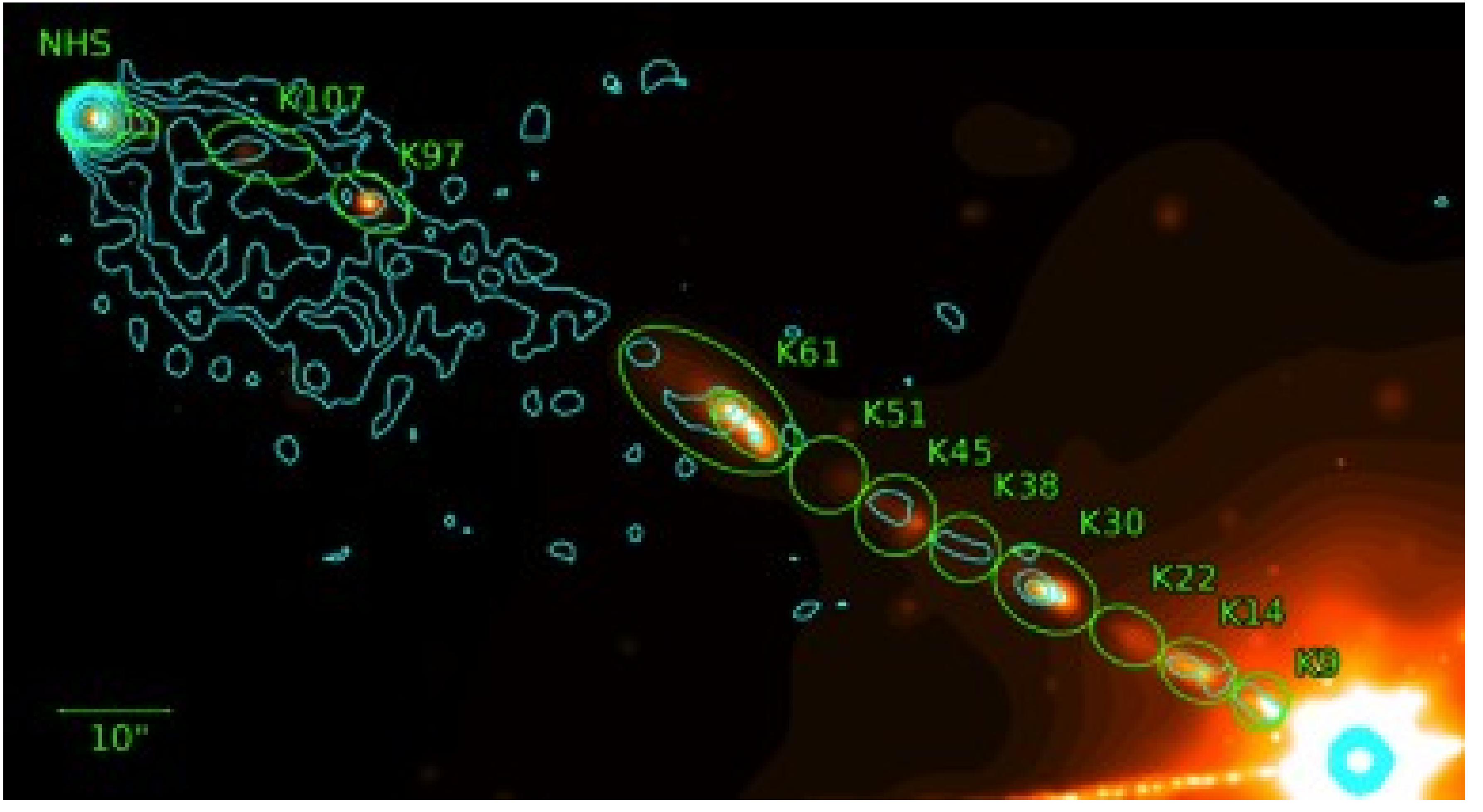
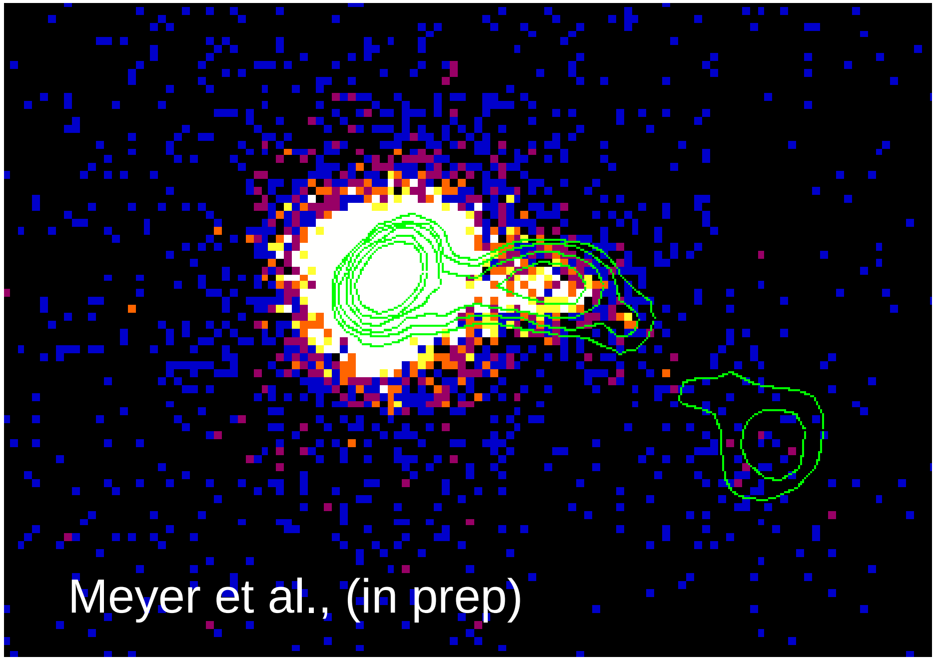


3C 111: X-ray knots peak upstream the radio knots
(Clautice et al. 2016).

Ok, the Truth This Time



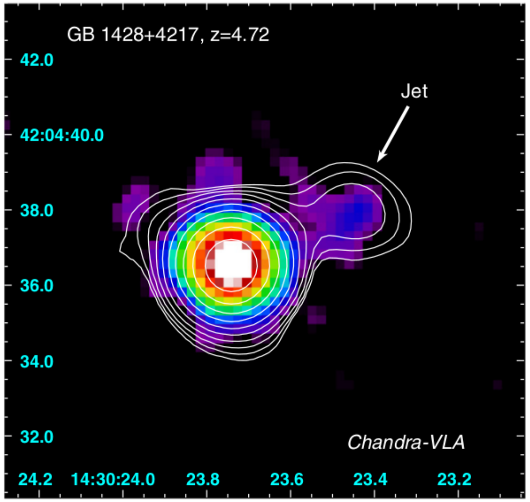
This is PKS 1229-021, a relatively "good case" from our sample of anomalous jets. Combined 120 ks.

I cannot get a spectrum for any of these jet components.

Most knot detections are just a handful of counts.

This is especially a problem as we try to go to high redshift.

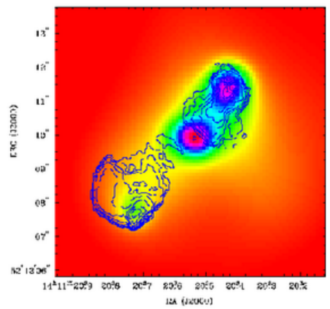
GB 1428+4217 (z=4.72) detected with only 20 counts in 10 ks (Cheung et al., 2012).



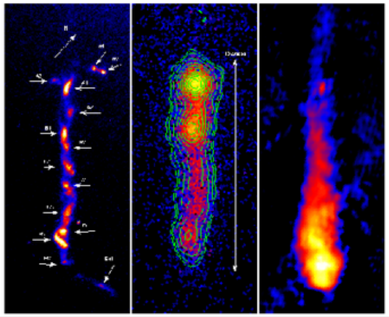
From Chandra to Lynx

Chandra has detected over 100 extragalactic jets.

XJET: X-RAY EMISSION FROM EXTRAGALACTIC RADIO JETS



3C 295: False color Chandra overlayed with radio contours



3C 273: HST, Chandra, and Merlin (Marshall *et al.*)

MOTIVATION

This website is meant to serve as a clearing house for radio galaxies and quasars for which X-ray emission has been detected which is associated with radio jets, i.e. knots and hotspots. As resources permit, we will also provide downloadable fits images for public use. If you would like to donate a fits image, have a new example to add to the list, or find erroneous or incomplete information, please email D. Harris

Chandra Flux Maps for Downloading
Index of FITS images
Image Policy
Image doc template (for image submission).

RADIO SOURCES WITH JET RELATED X-RAY EMISSION

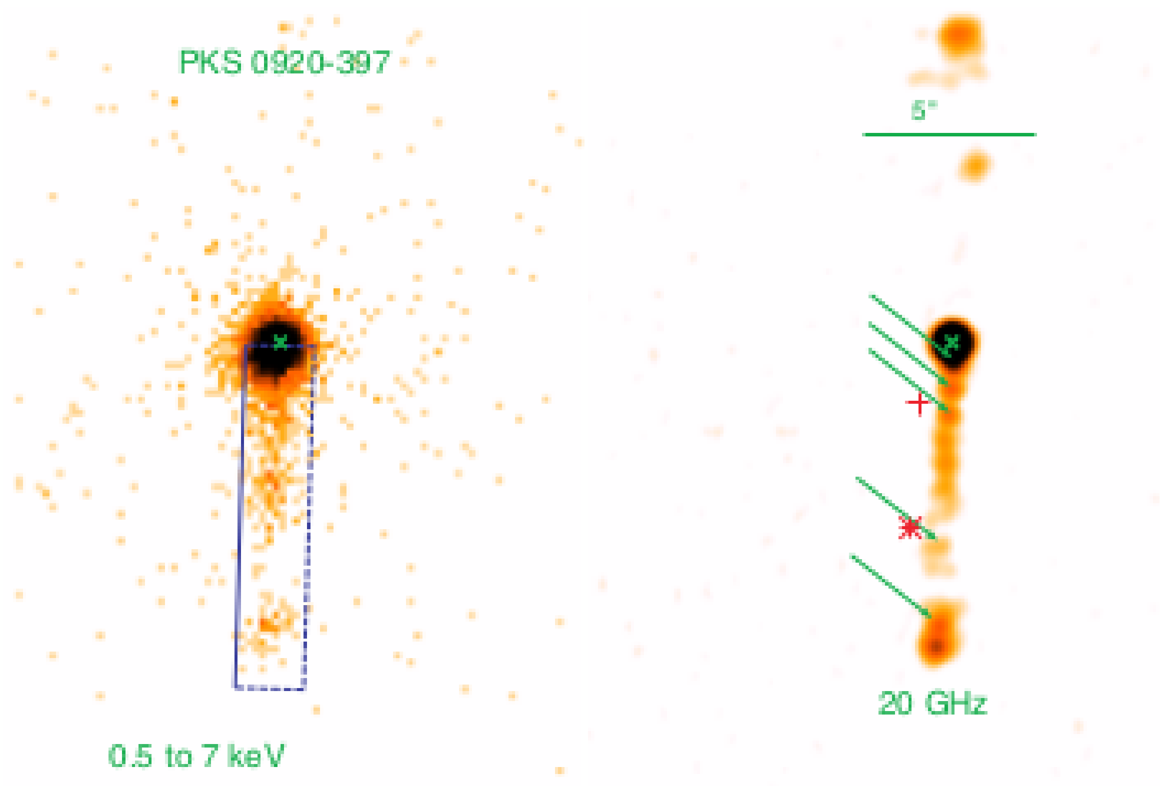
Generic Name	R.A. (J2000) hh:mm:ss.s	Dec. (J2000) dd:mm:ss.s	z	Class	X-ray Features	Assoc. optical	Assoc. radio	PA w.r.t core	Dist. (H=71) (Mpc)	kpc/" (H=71)
3C6.1	00:16:31.1	+79:16:49.9	0.8404	FRII RG	both HS	?	yes	N, S	5342	7.6
3C9	00:20:25.2	+15:40:54.7	2.012	LDQ	jet, CL	?	yes	SE, NW	15,850	8.5
3C15	00:37:04.1	-01:09:08.5	0.0730	FRI RG	knot, lobes	yes	yes	-30	326	1.4
3C17	00:38:20.5	-02:07:40.7	0.22	FR2 RG	knot	yes	yes	SE	1081	3.5
NGC315	00:57:48.9	+30:21:08.8	0.0165	FRI RG	inner jet knots	?	same as X-ray	NW	70.6	0.33
3C31	01:07:24.9	+32:25:45.0	0.0167	FRI RG	inner 8" jet	yes	jet	-20	71.4	0.34

https://hea-www.harvard.edu/XJET/

From Chandra to Lynx

Chandra has detected over 100 extragalactic jets.

However, the vast majority of them have very poor spectral information due to low count rates.



Schwartz et al., 2010

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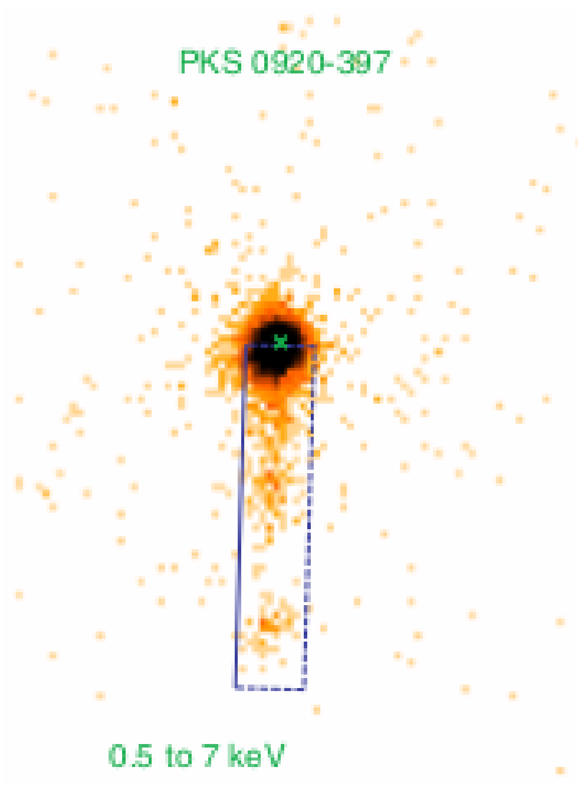
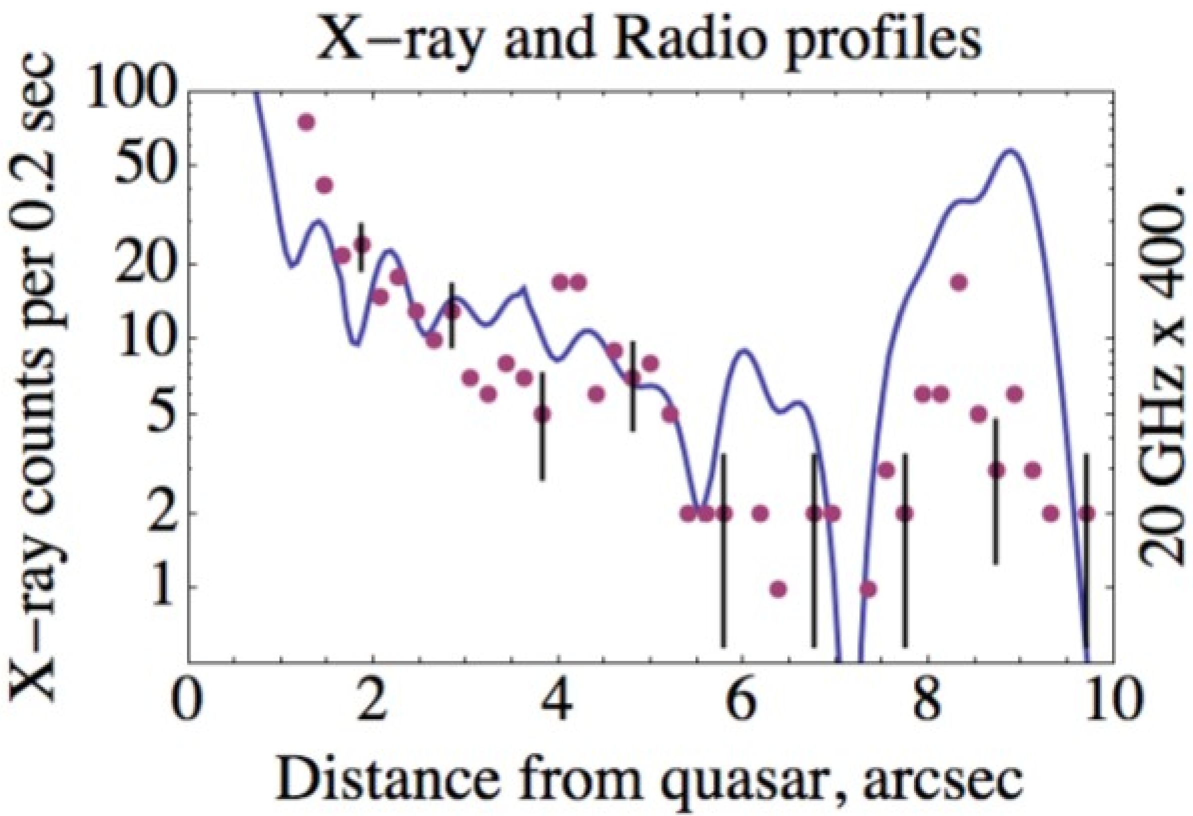


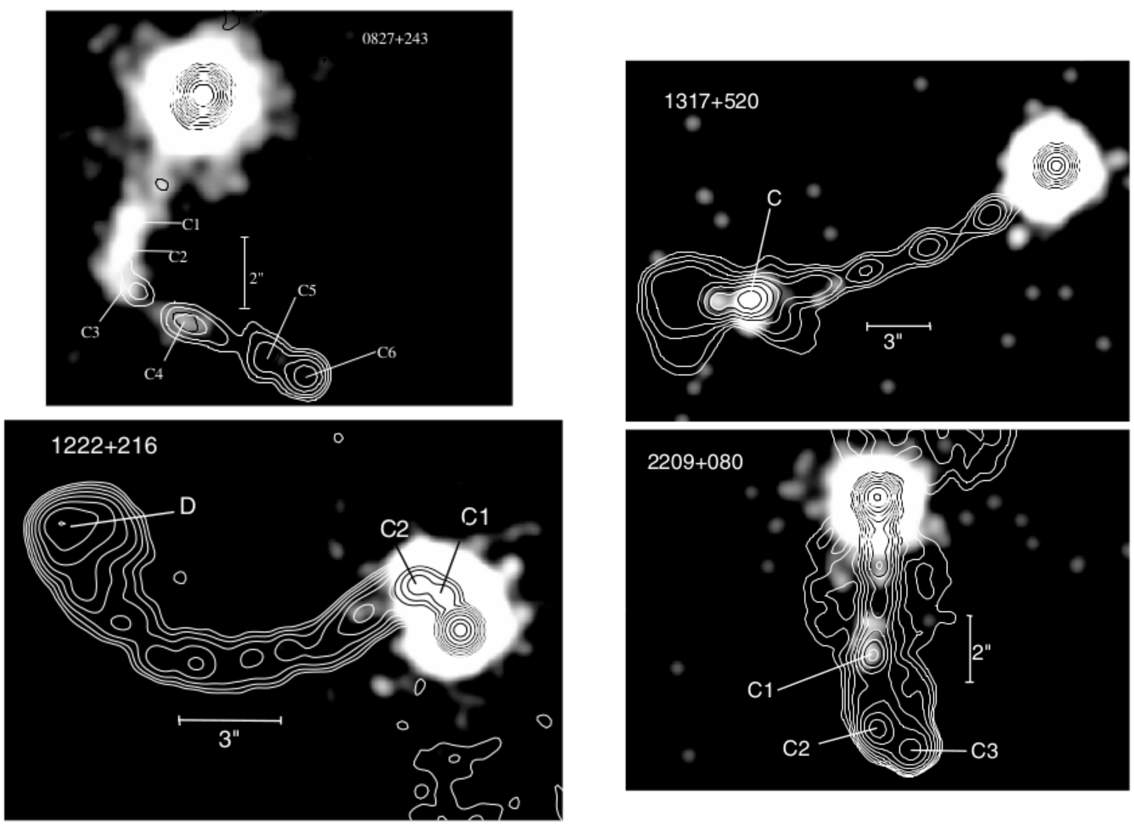


From Chandra to Lynx

Chandra has detected over 100 extragalactic jets.

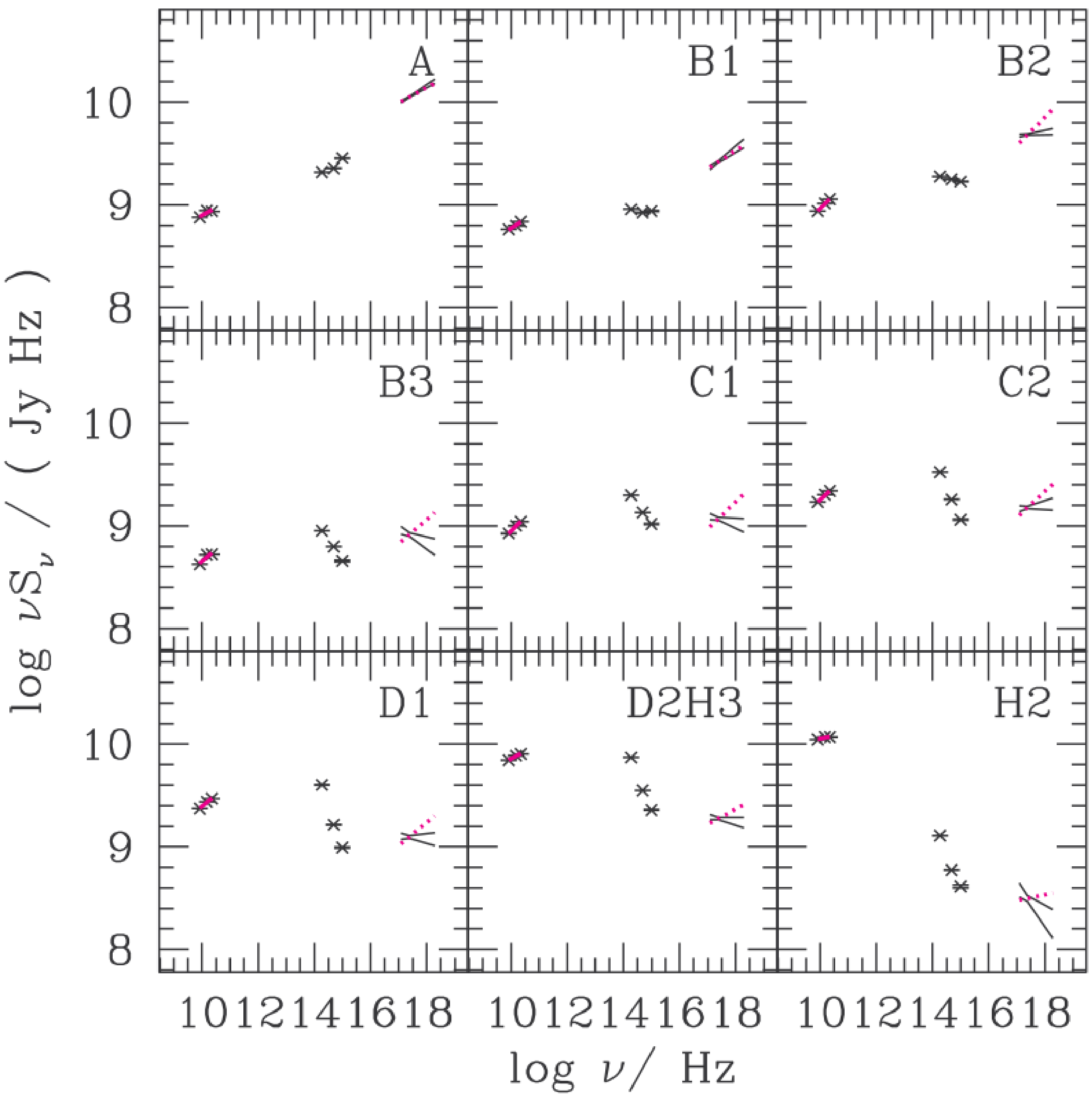
Worse: A significant fraction of the jets Chandra has looked at do not show up at all. (About 40% in the 3C surveys)

Even then, not all parts of the jet are detected – most are hotspot detections.



← Here, a ‘successful’ Chandra study of four jets (Jorstad et al., 2006). Note that most of the jet lies undetected.
(18 ks exposures)

What we can do with Lynx

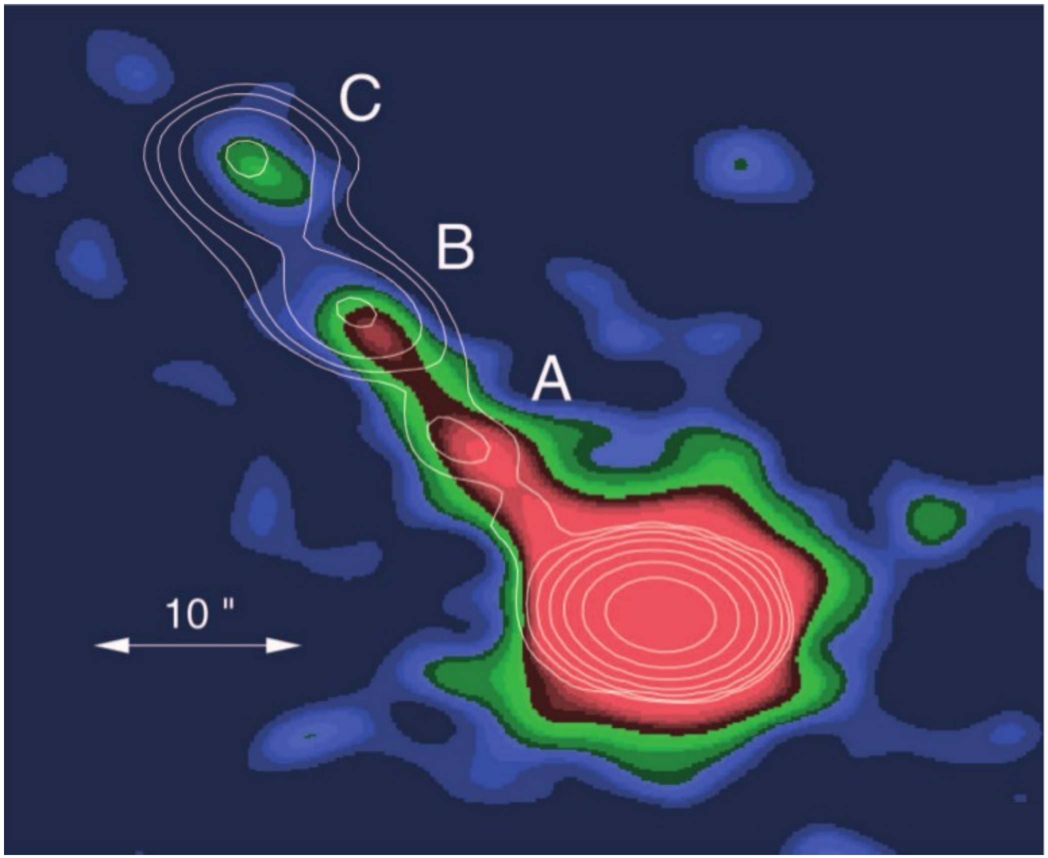


Large population studies of well-characterized sources:

(1) measuring spectral evolution along the jet as it extends out into the host

(Jester et al., 2006)

What we can do with Lynx



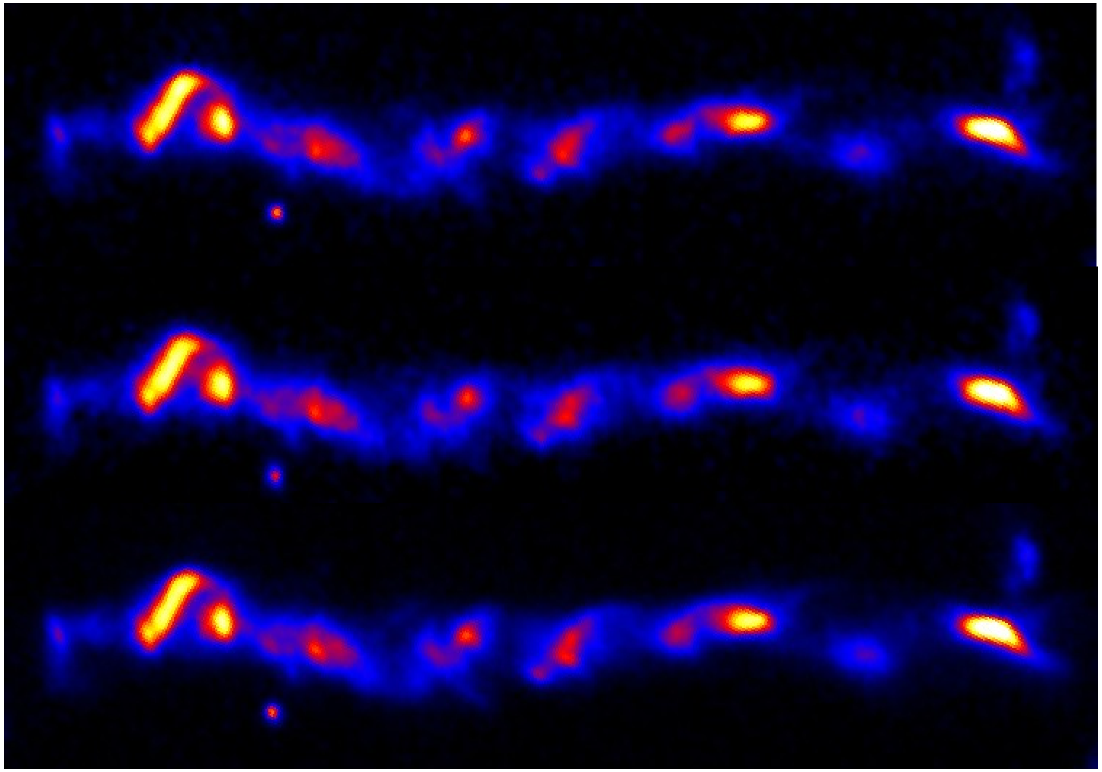
PKS 1127-145 (Siemiginowska et al., 2002)
Z=1.187

Large population studies of well-characterized sources:

(2) offsets between radio, optical, X-ray

[here spatial resolution is key]

What we can do with Lynx



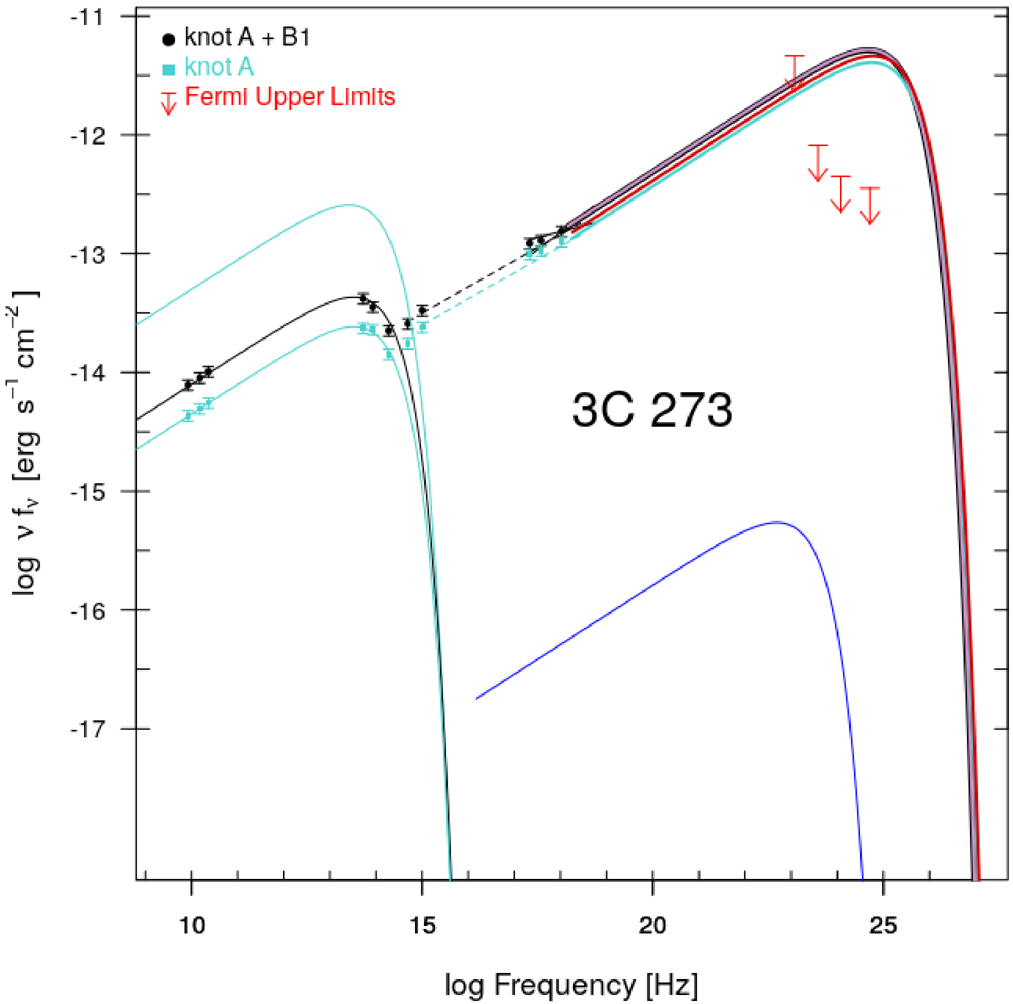
HST Proper Motions study of 3C 273
Meyer et al., 2016

Large population studies of well-characterized sources:

(3) long-term proper motions?

[here spatial resolution is key]

From Chandra to Lynx



A Back-of-the-Envelope Calculation:

Take 3C 273 radio synchrotron spectrum, assume a doppler factor of 1.5 (basically absolute minimum beaming) for the mandatory IC/CMB process as an absolute minimum X-ray flux.

1 keV log nFn flux is about -16.5

Applying a point-source sensitivity 100x better than Chandra, we could see such a source at a redshift of about 0.3.

For a more reasonable (we think delta of 2-3, this goes out to z~1)

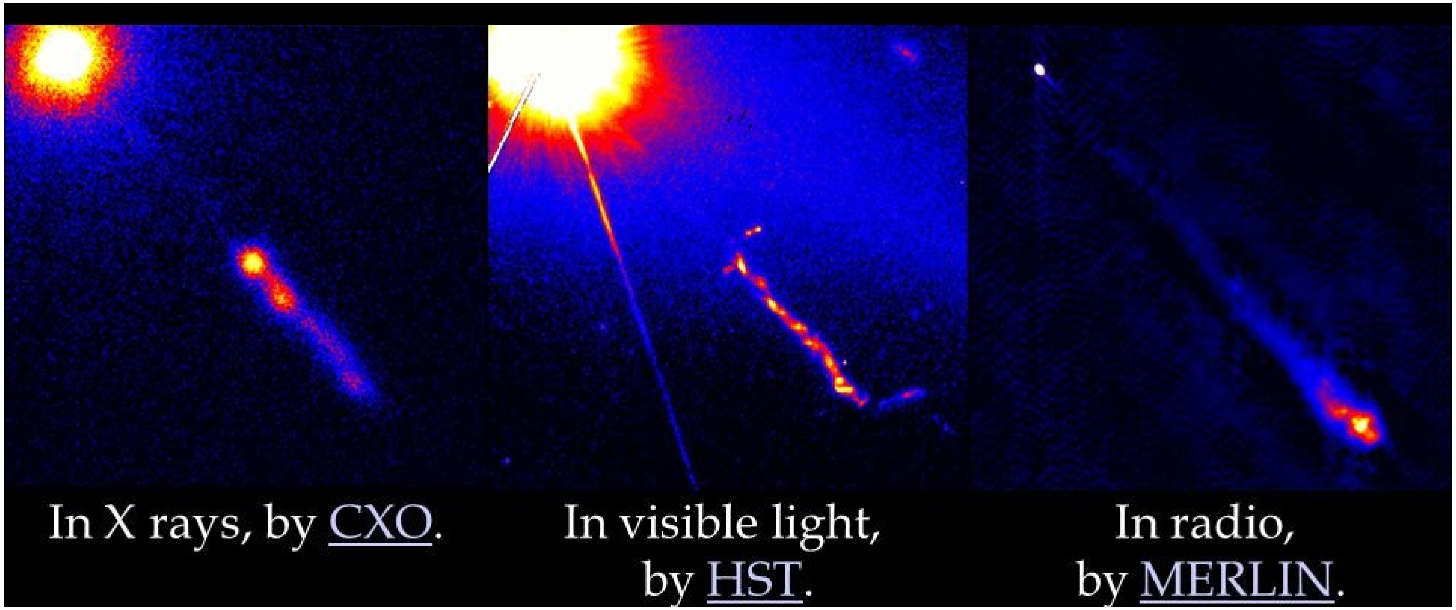
Pushing the Limits of Lynx?

FOV – not generally important (especially at high z) – though see lobe study discussed next

Sensitivity – 100x Chandra will result in major discoveries

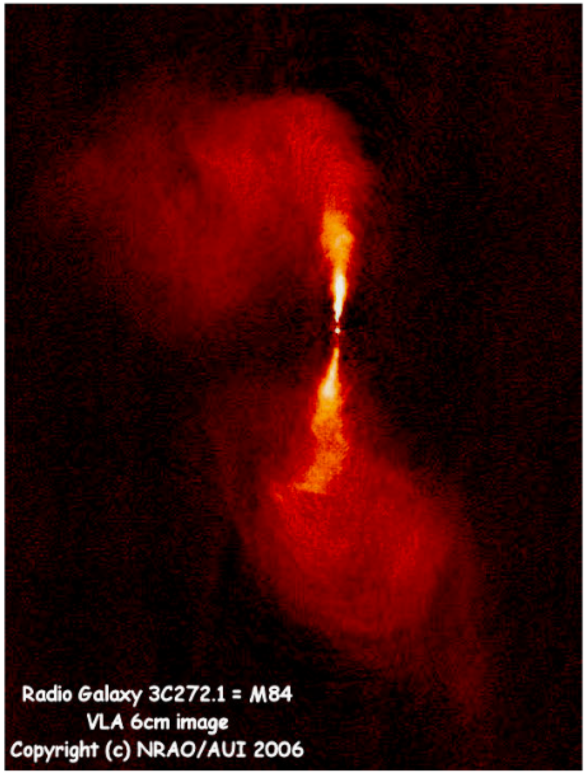
Resolution – Ideally, as close as possible to match HST/JWST/WFIRST (0.05”).

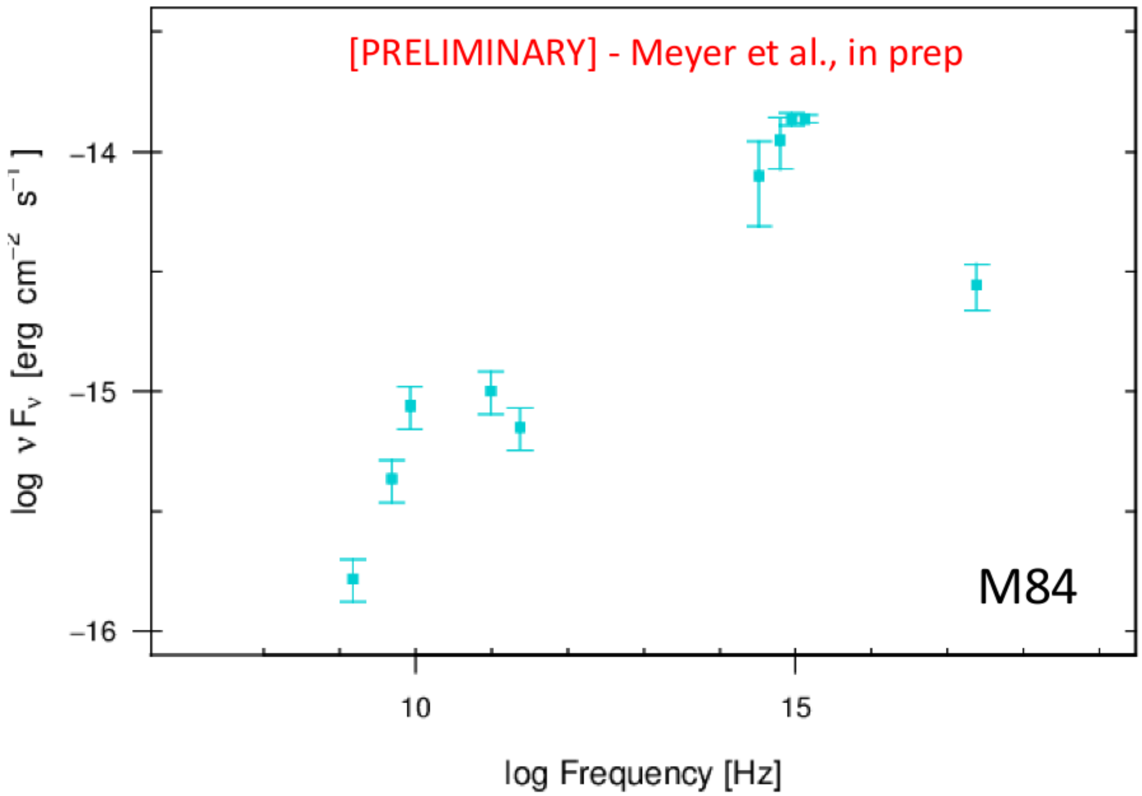
Important for *radio/X-ray offsets* which are almost certainly there but undetectable due to larger PSF of Chandra, detecting *high-redshift jets,* and potentially, *proper motions.*



In which things get more confusing…

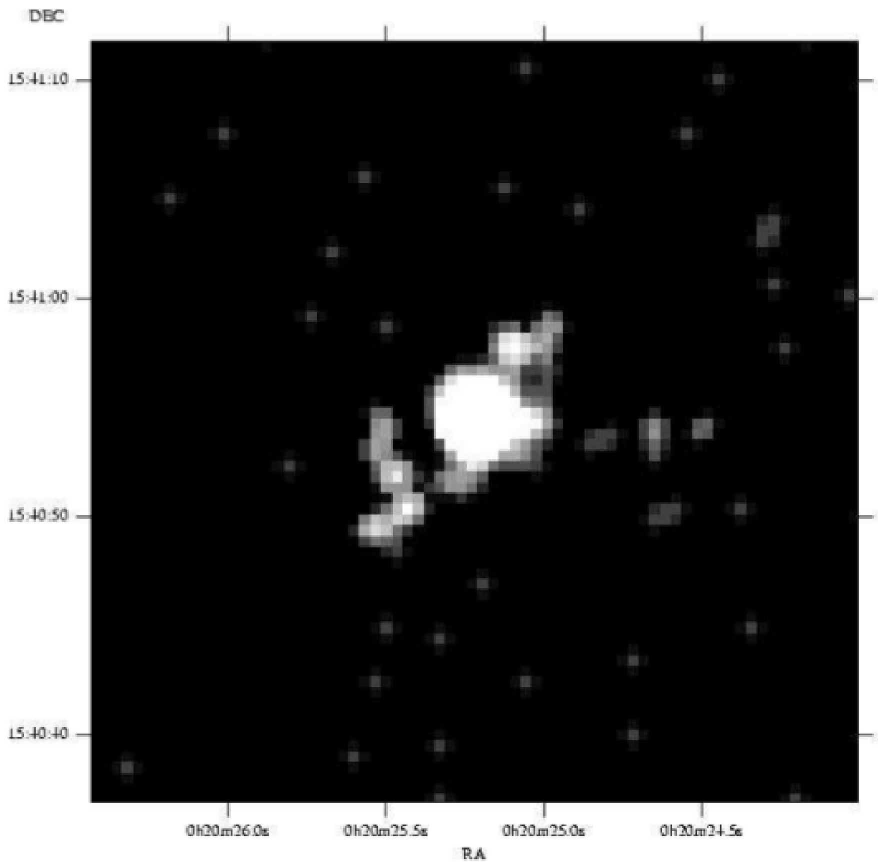
Extrapolation over a couple of orders of magnitude is not advised.

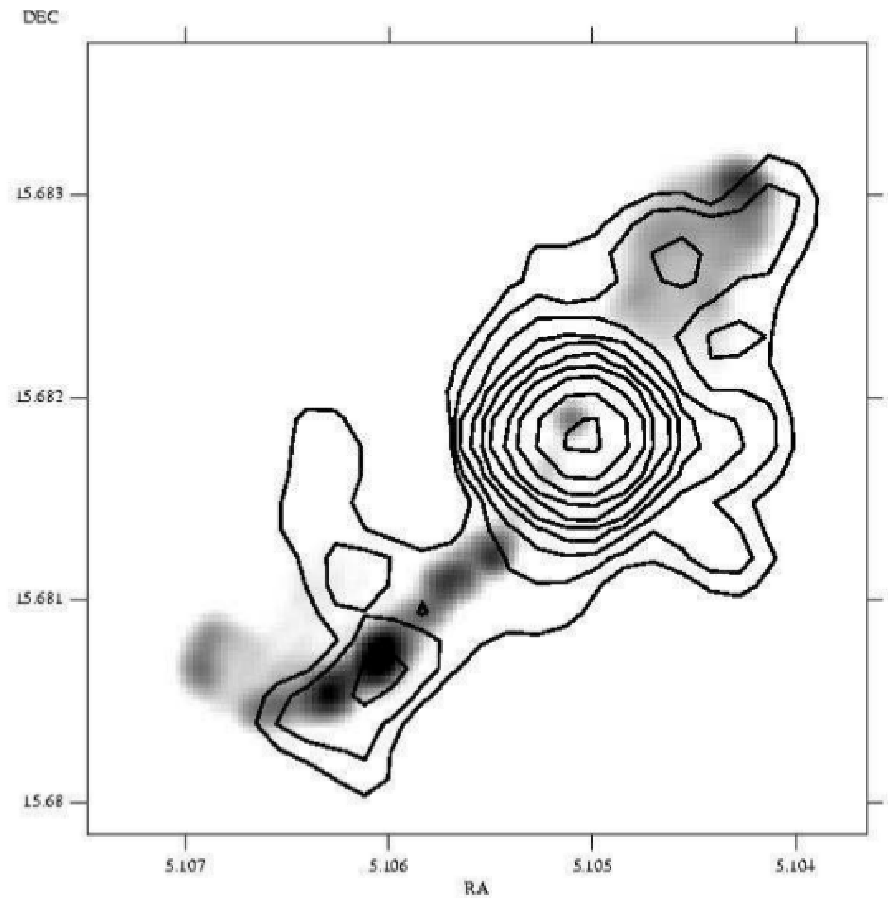




(Things you should never say in science: "Why bother to look? We know what we'll find")

What if it's not the jet we're seeing?





3C 9 – A source with potential thermal signatures of shocked gas around the jet. Poor statistics prevents discrimination between models (Fabian+ 2003)

Giant Radio Lobes

Open Questions:

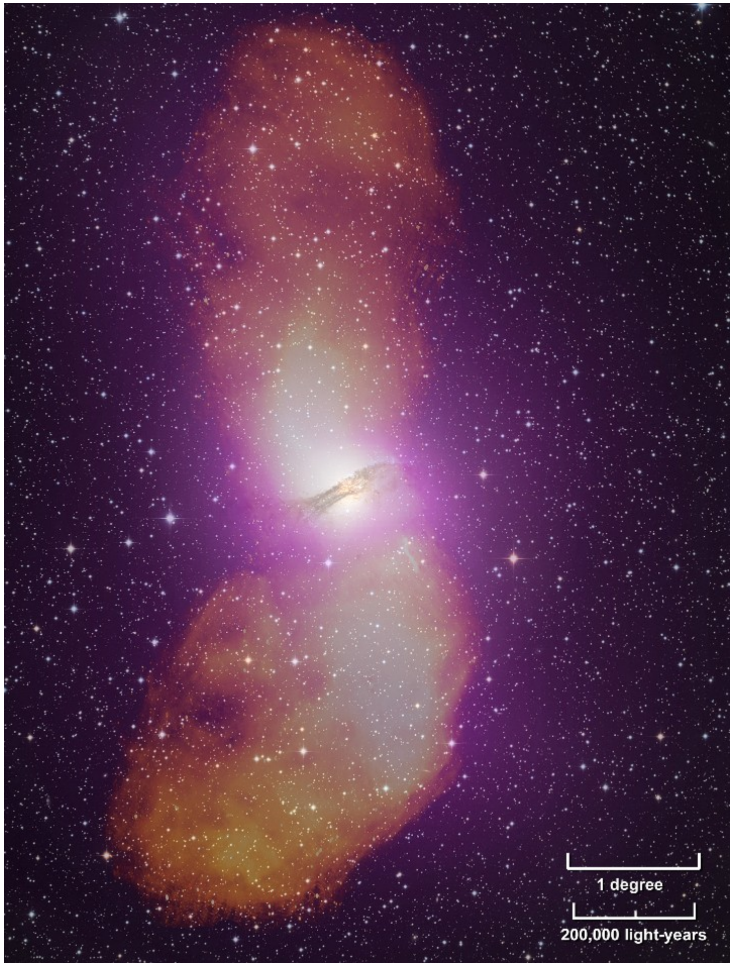
(1)Particle Content

(2)Total energetics (how far out of equipartition are we?)

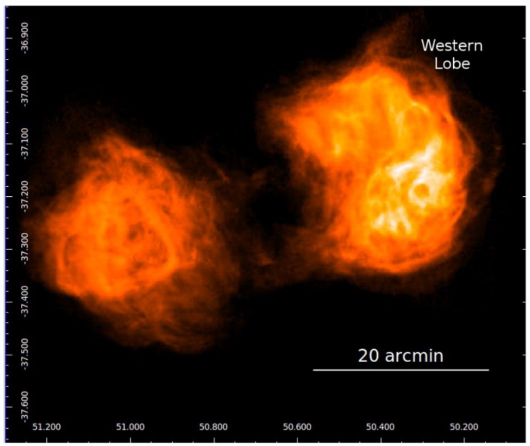
(3)Exactly how energy is transferred to ICM

Lots of work on this subject:

Hardcastle, Croston, Ineson, Inoue & others



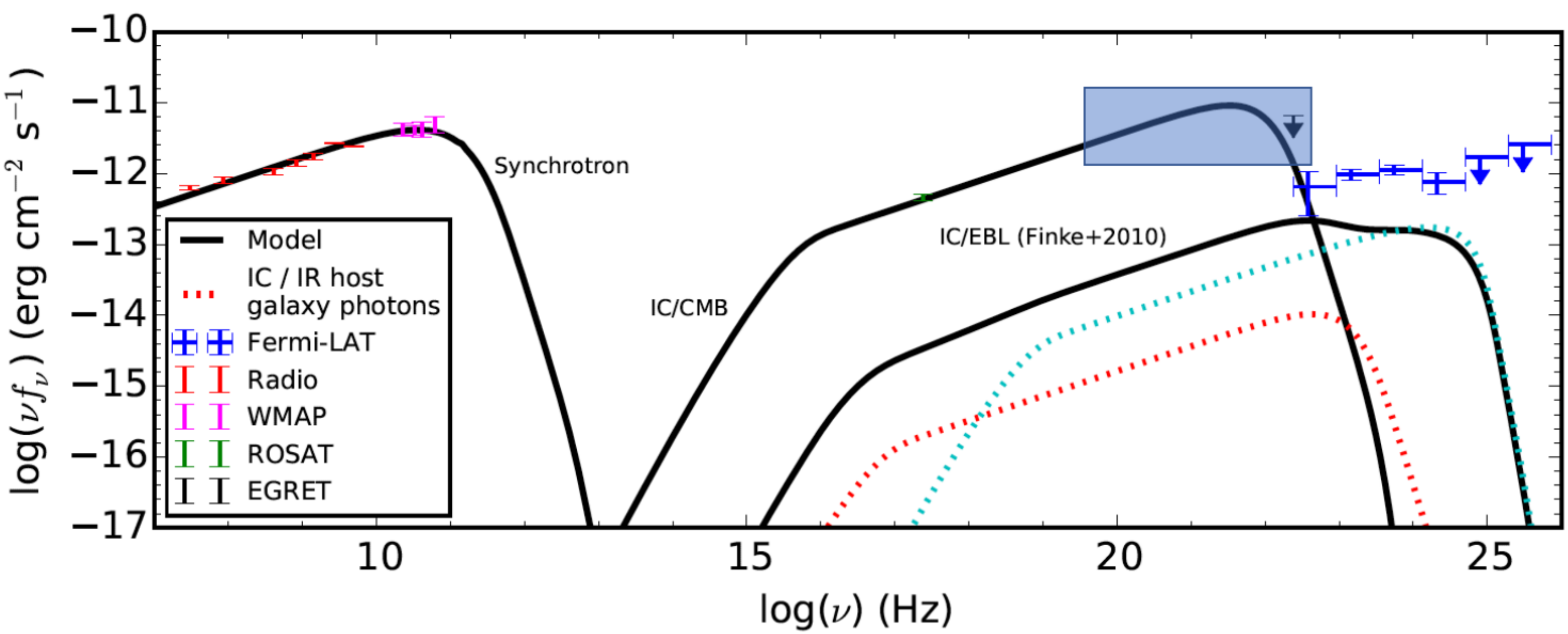
Using Giant Radio Lobes to study the EBL



The case of Fornax A

Need complete MW coverage of the lobes, but X-rays are critical to set the normalization of the IC/CMB & thus the magnetic field.

Large FOV and improved sensitivity will make this a very important science case as we will be able to reach higher redshift sources.



Ackermann+ 2016 (Fermi Collab.)

Summary

Chandra has brought about a true revolution in high-energy studies of jets.

Lynx will do this again, bringing us from dozens of well-characterized sources to hundreds if not **thousands**, including many at high redshift.

Key technological needs are increased sensitivity (we are photon-starved) and high-angular resolution (in ideal world, matching JWST/HST).