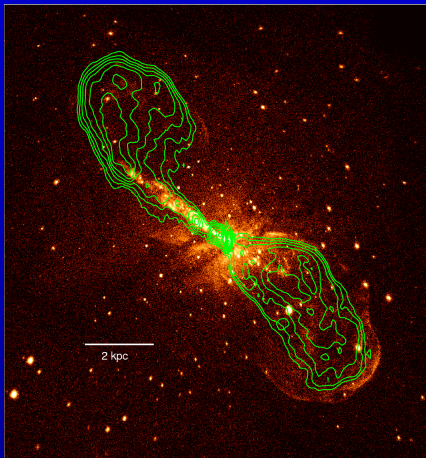
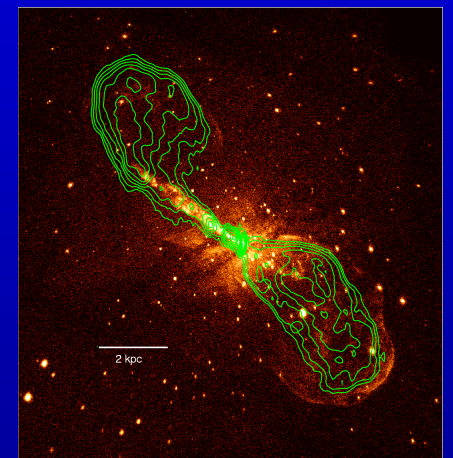


The Physics of Extragalactic X-ray Jets with the IXO



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Why are extragalactic jets of broad interest?

- Their momentum & heat input → affect state of external medium & its ability to cool and form stars.
- They accelerate electrons to high energies → if same happens to heavies the acceleration sites of VHE cosmic rays are localized.

Cavities → integrated power over long times.

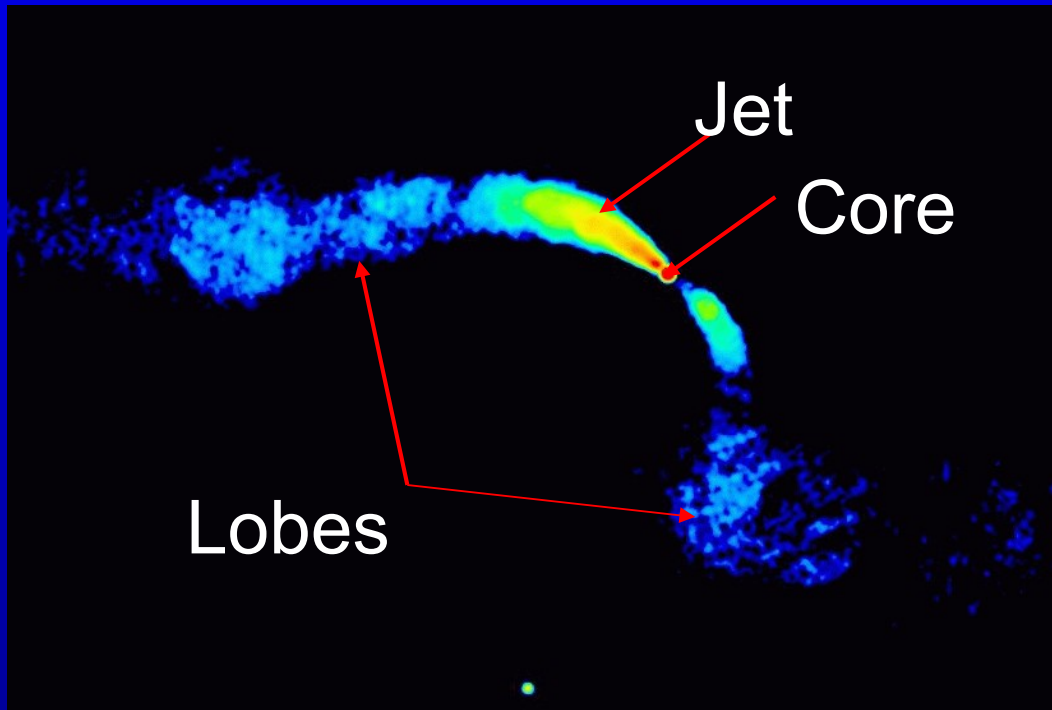
Need to understand energy processes involving jets → duty cycles, triggering, powers, relationship to BH mass

Several issues unlikely to be solved before IXO. Will use e.g., dynamical measurements. Nonthermal spectra as function of position.

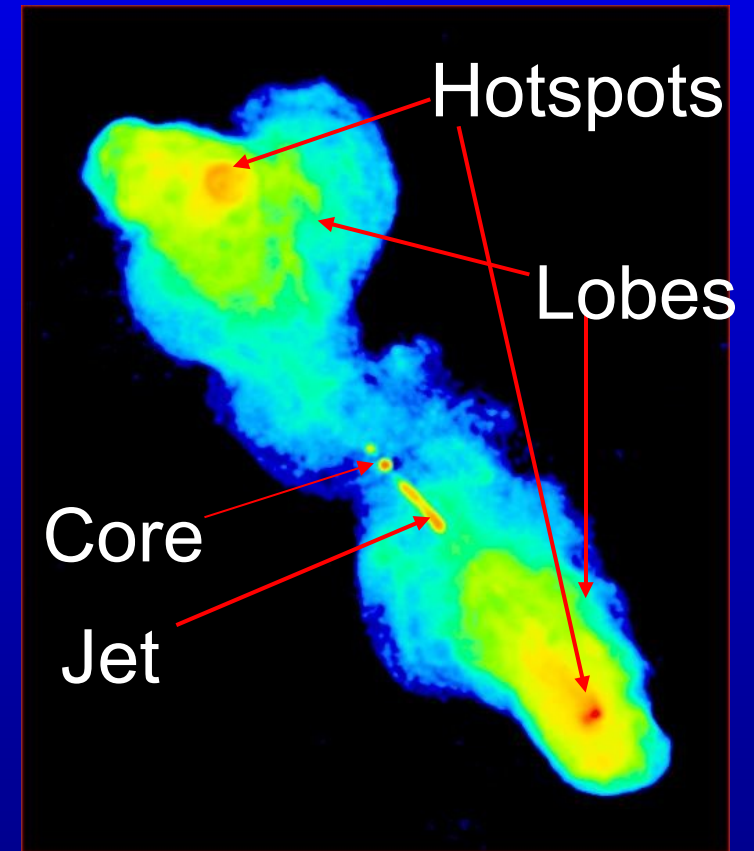
Momentum transfer and heating observed so far is mainly a gentle process. Large total energies, but low energy densities and rates of deposition.

Sources of relatively low jet power seen to participate.

Low-power FRI



High-power FR II



But peak in luminosity density, $L N(L)$, is at FRI/
FR II transition.

→ Peak of jet kinematic power

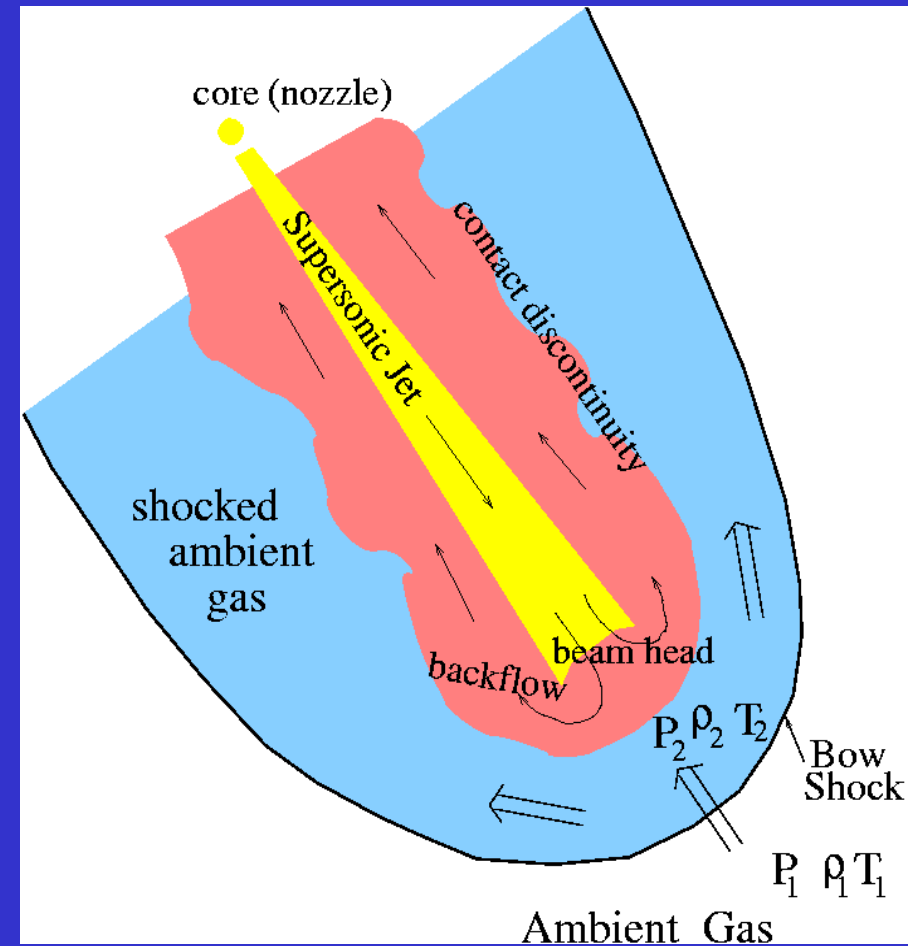
Expect FRIIs to be supersonic wrt external gas and drive a bow shock. Jump conditions (e.g. Spitzer 1978):

$$\rho_2 / \rho_1 = 4M^2 / (M^2 + 3)$$

$$T_2 / T_1 = (5M^2 - 1)(M^2 + 3) / 16M^2$$

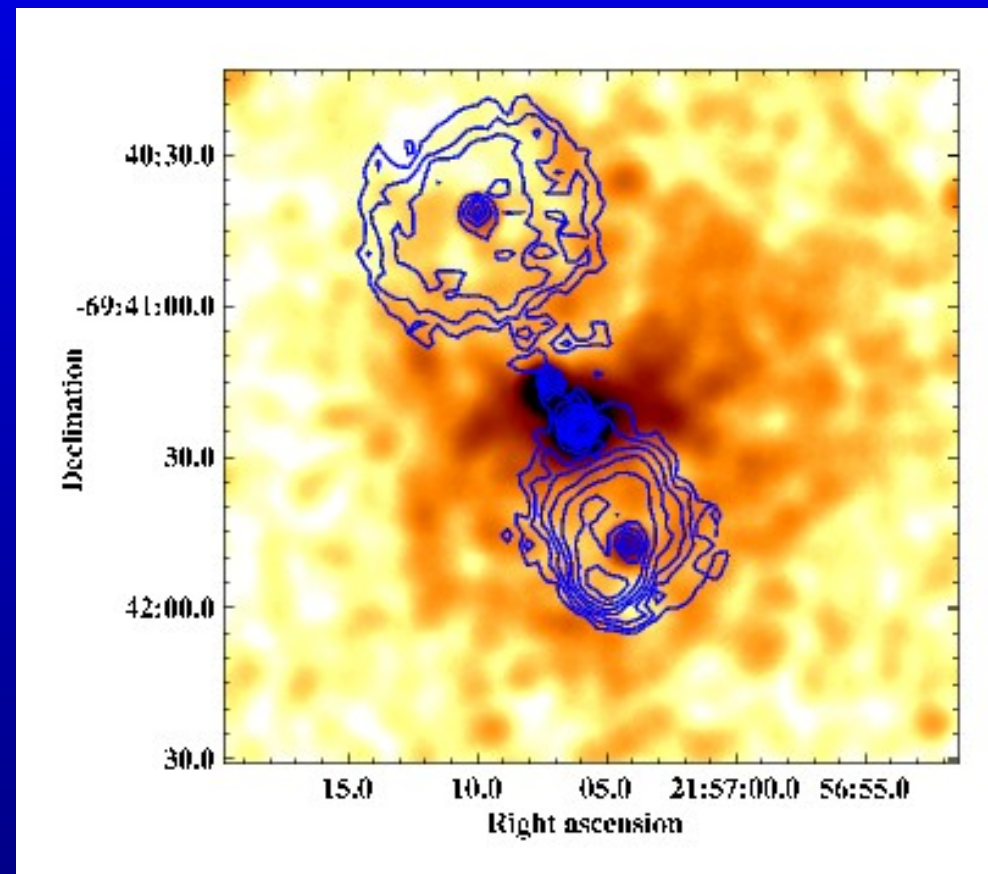
where M is the Mach number.

Combined with flow dynamics will test validity of the model and probe jet composition.



Evidence of cavities in FRIIs from Chandra,
But IXO sensitivity needed to
probe outer regions.

Shocked regions currently
difficult to see, probably
due to being relatively
small volume compared with
unshocked gas



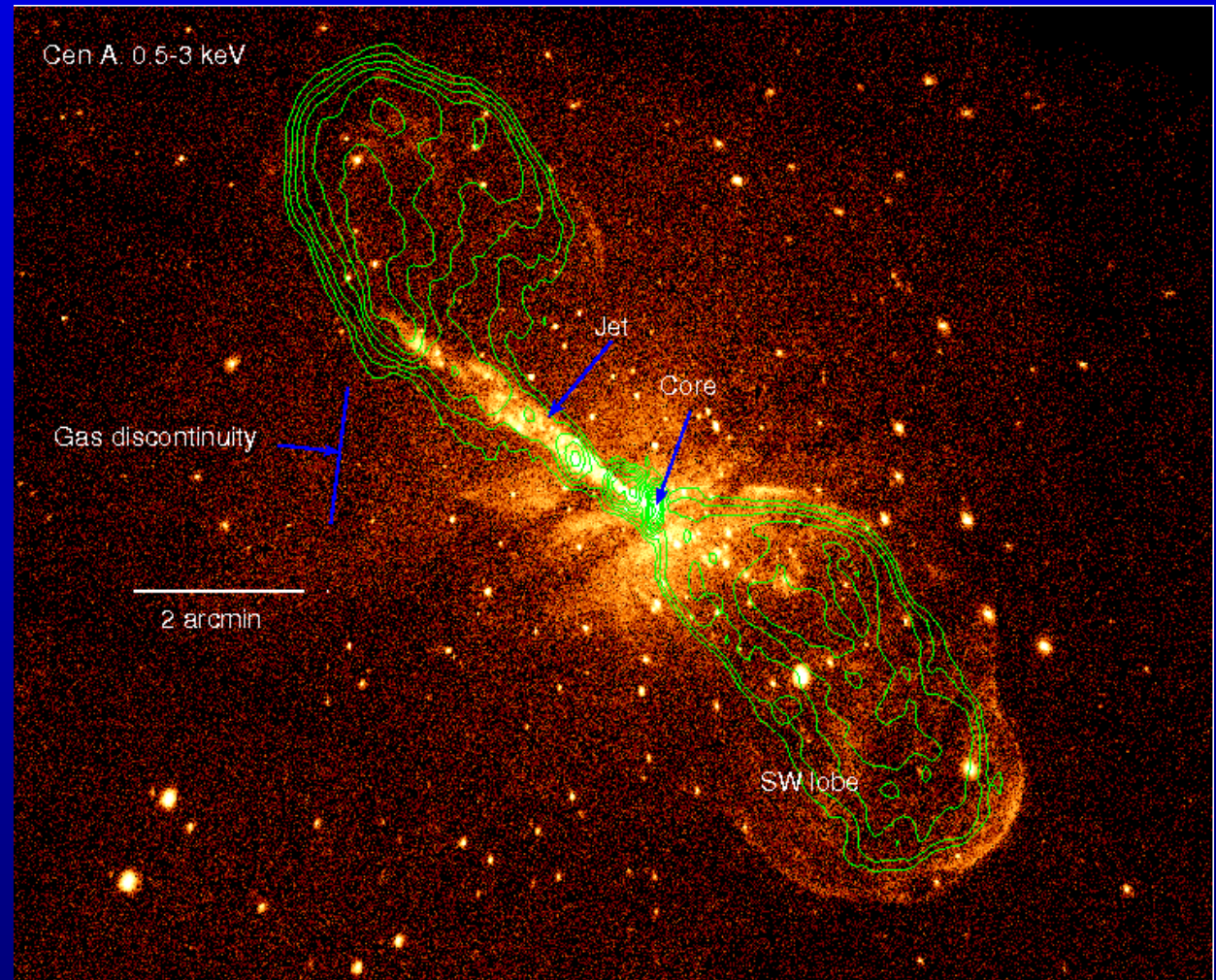
Young et al. 2005

Best example of strong shock is from inner (young) lobes of an FRI

Thermal
Doppler-shift
measurements
will be possible
with IXO.

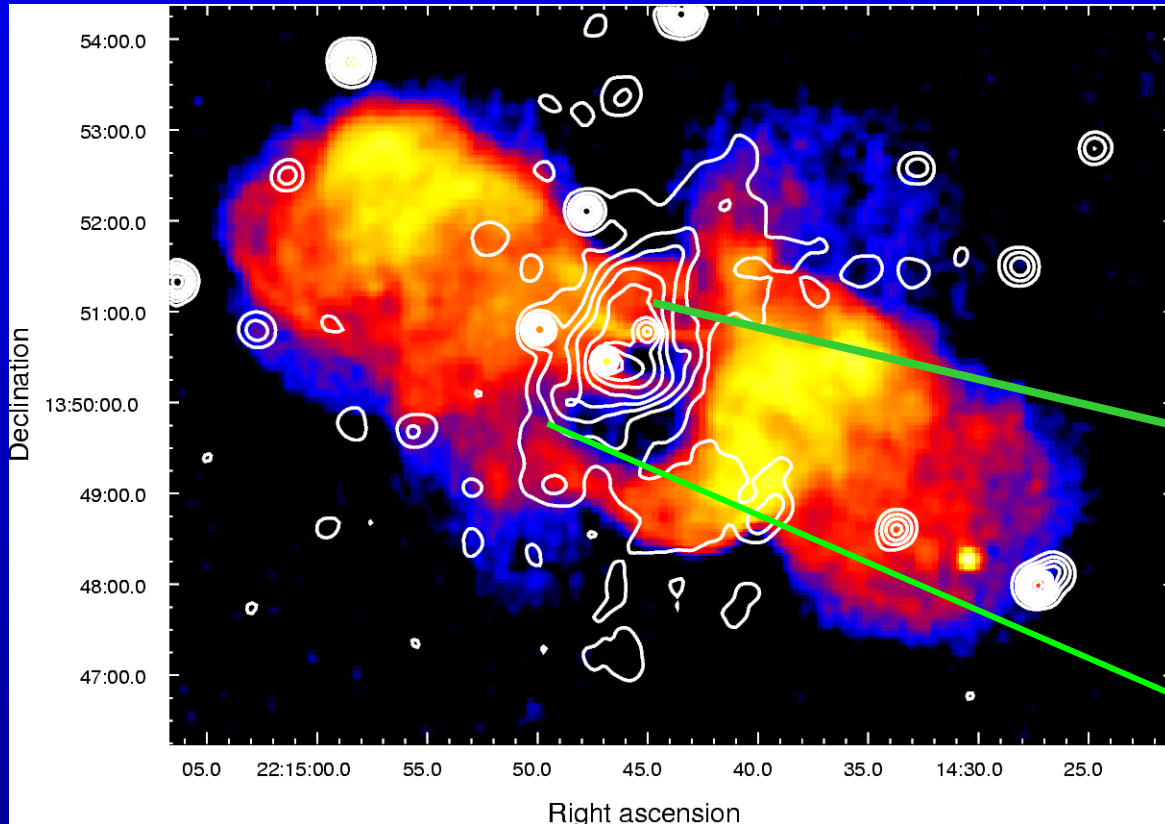
Kraft et al. 2003,
+ Cen-A VLP papers in
prep.

Cen A



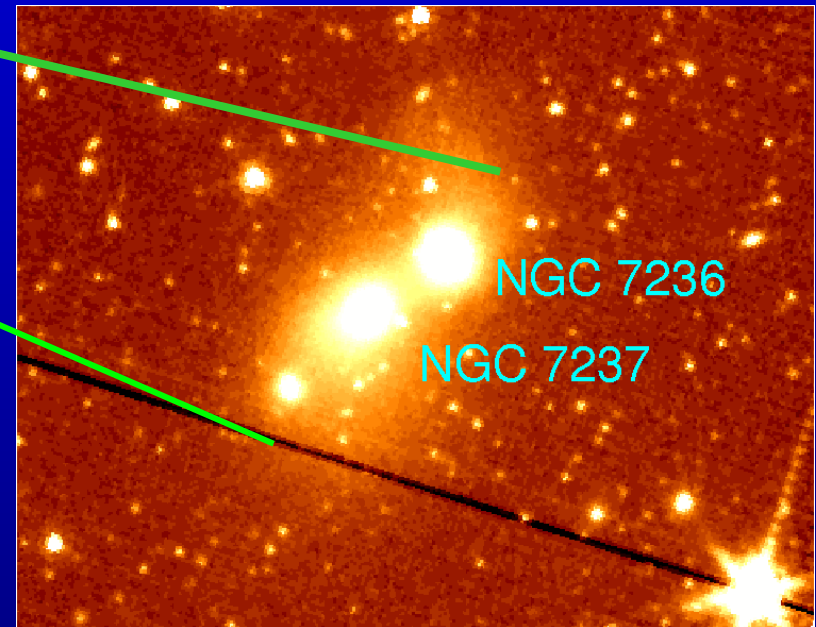
3C 442A

Dynamical: Merger gas causing old radio lobes to separate



Chandra contours on radio colour

Worrall et al. 2007



Spitzer 4.5 μ m

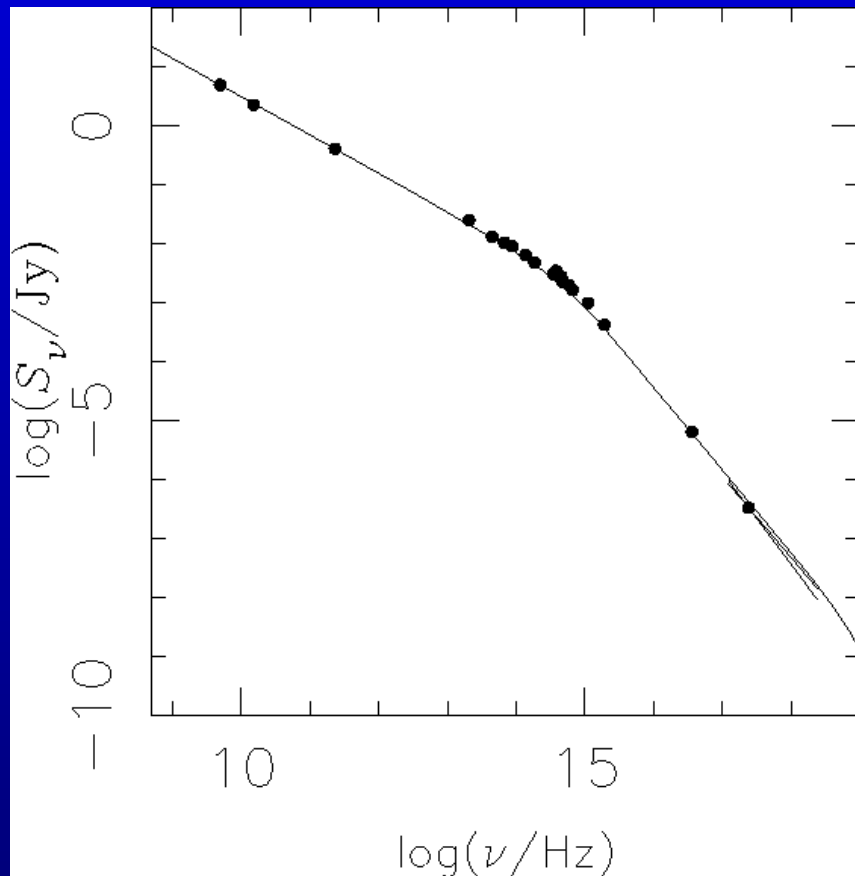
As well as heating surrounding gas, jet kinetic energy goes into internal energy. Some fraction will be non-thermal energy → particle acceleration.

Particle composition, and the locations and processes of particle acceleration currently uncertain.

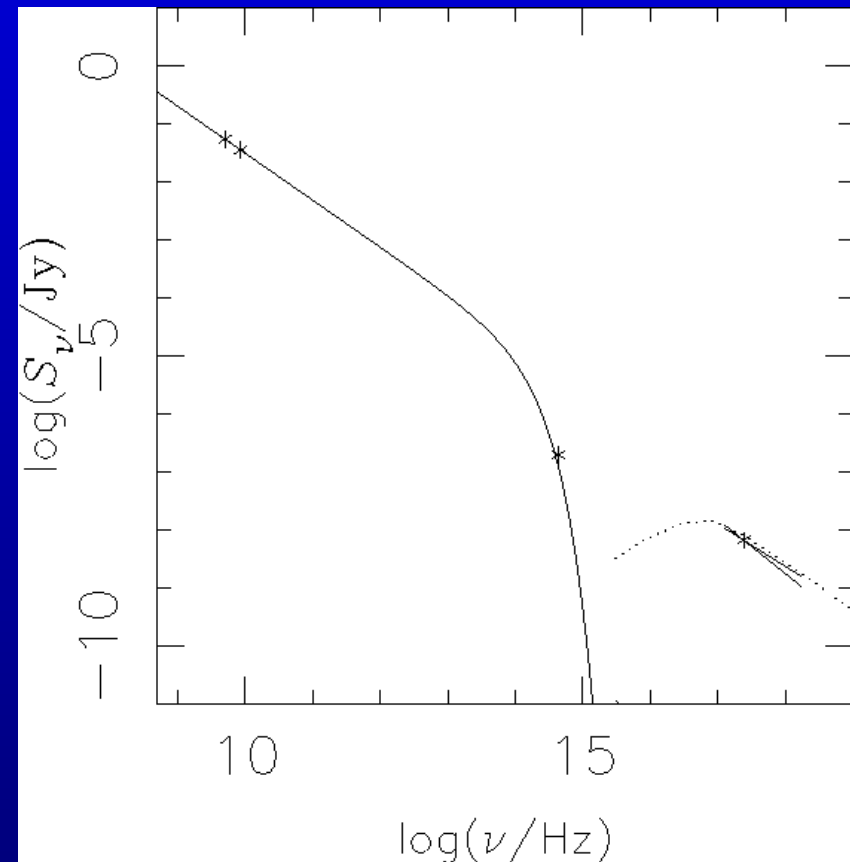
Known for a long time that relativistic heavies can solve pressure imbalances in FRIs (now also supported by prevalence of cluster cavities). Heavies likely energy carrier in FRIIs.

Synchrotron X-rays require in-situ particle acceleration in FRIs. Less clear for FRIIs (return to that later)

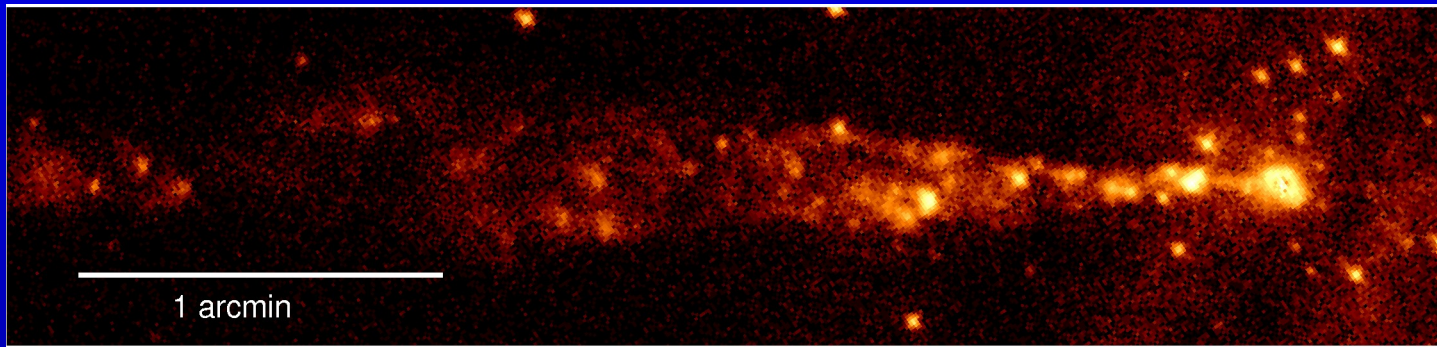
M87 - FRI



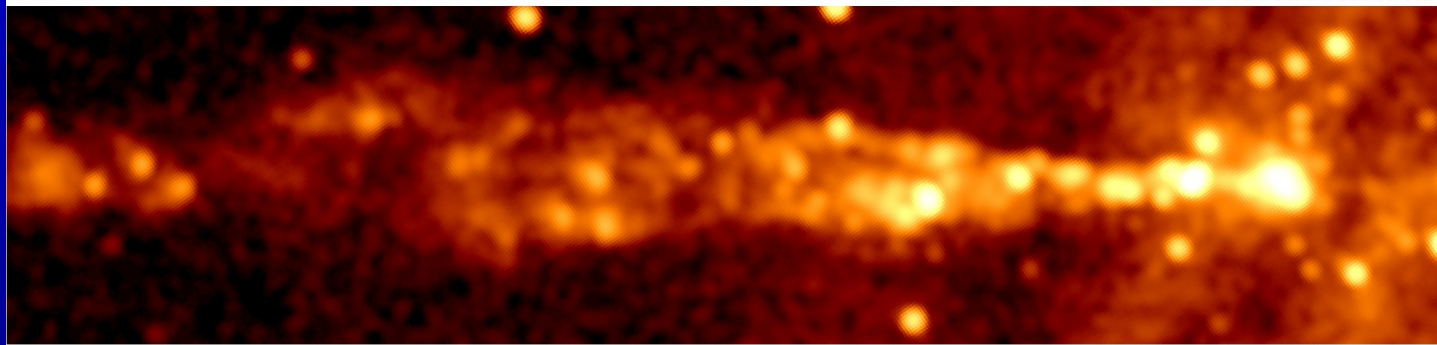
PKS 0637-752 - FRII



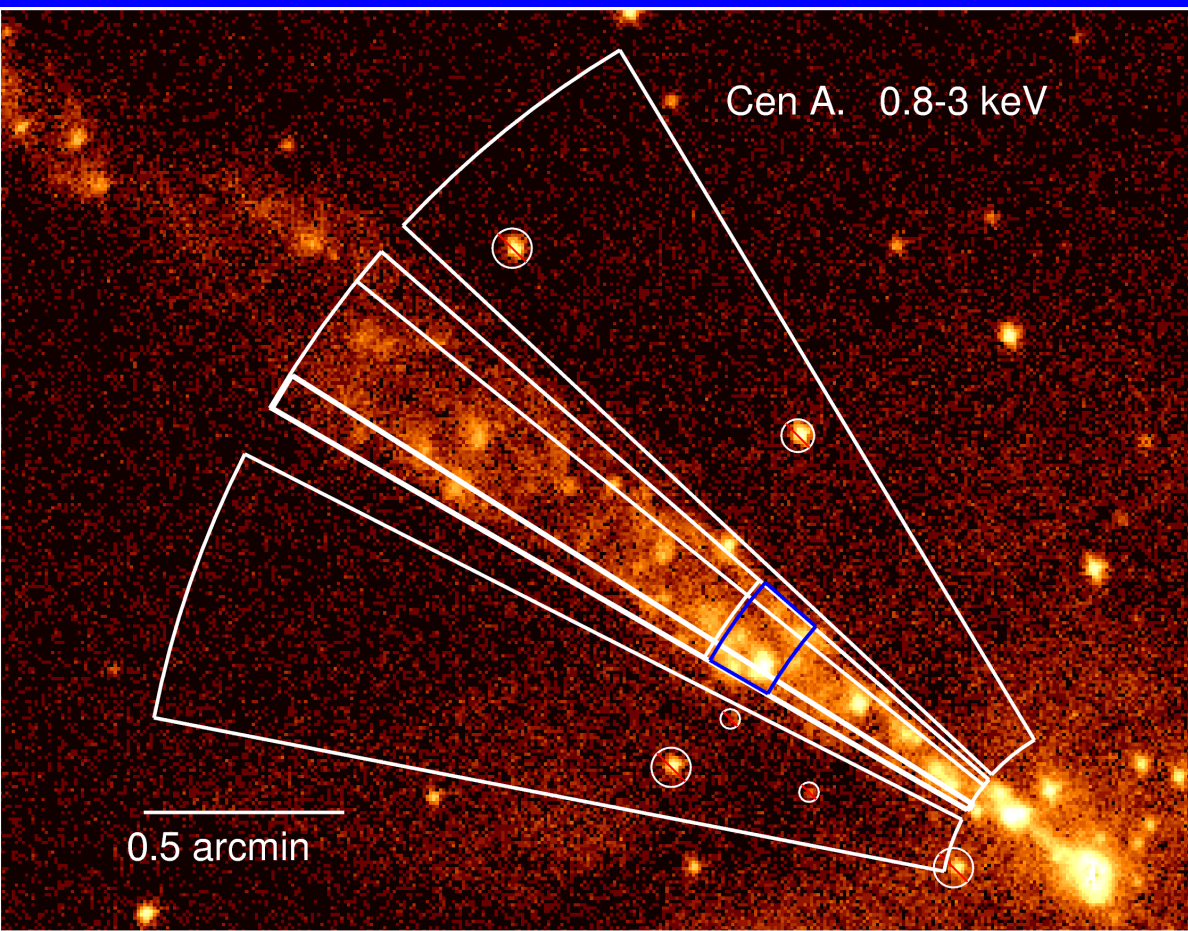
Cen A



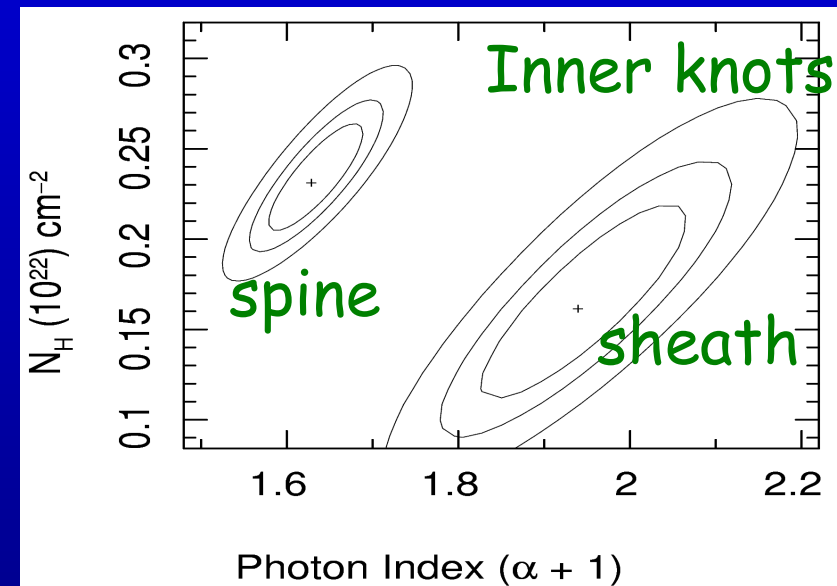
Chandra



IXO
resolution



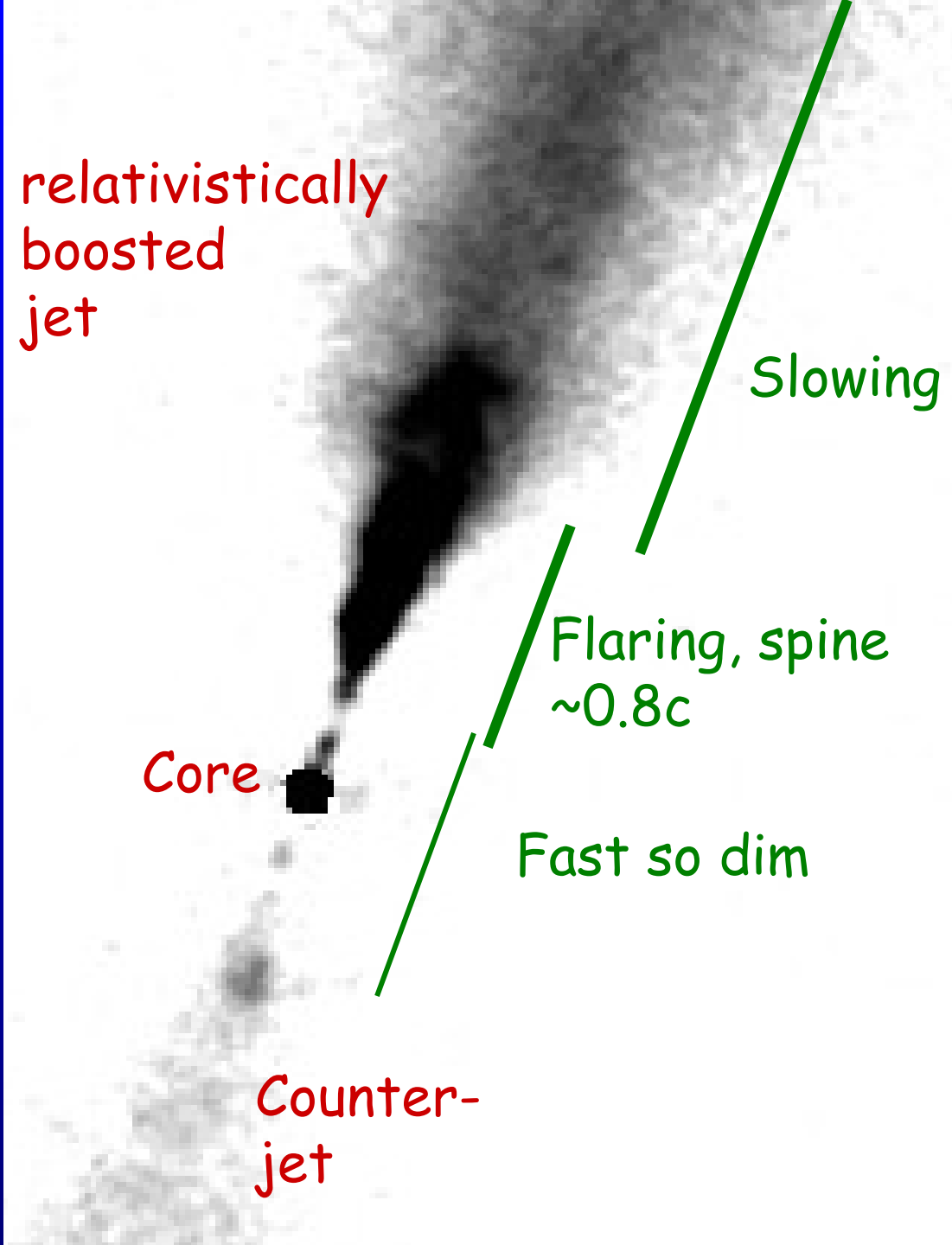
Knot spectra different between
jet middle and edge \rightarrow differences
in jet **speed**, density, composition



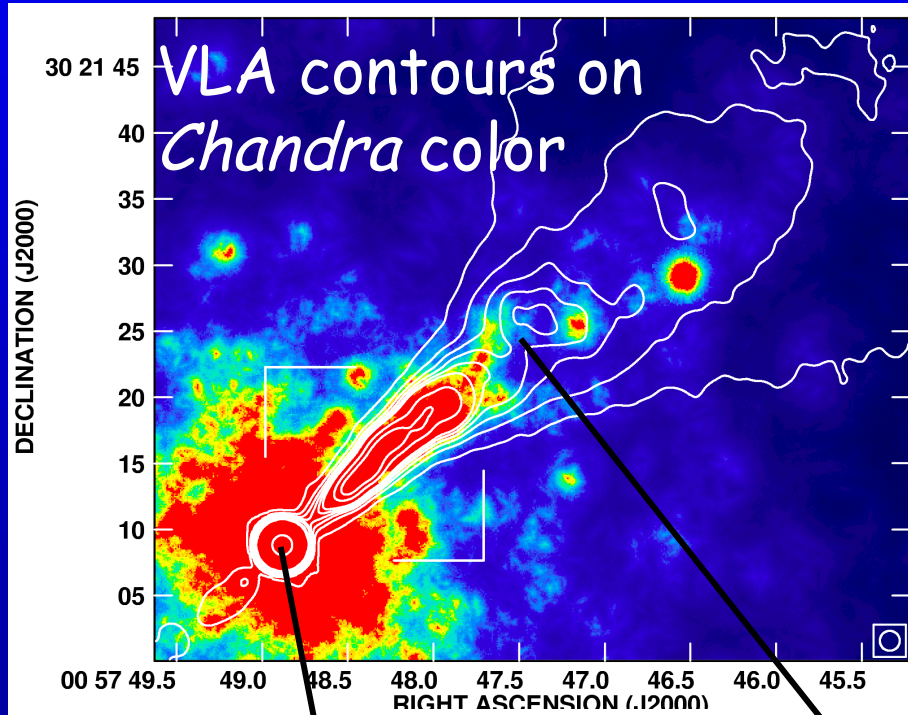
Worrall et al. 2008

Existing radio evidence
that FRIs have transverse
velocity structure.

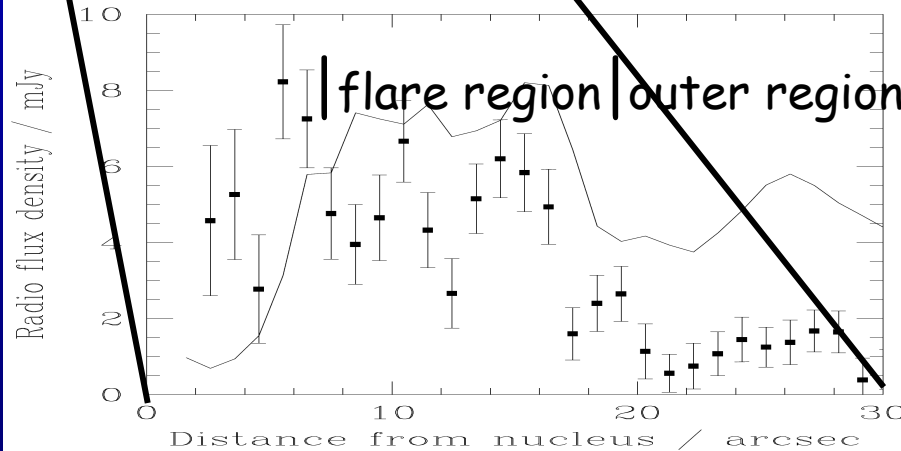
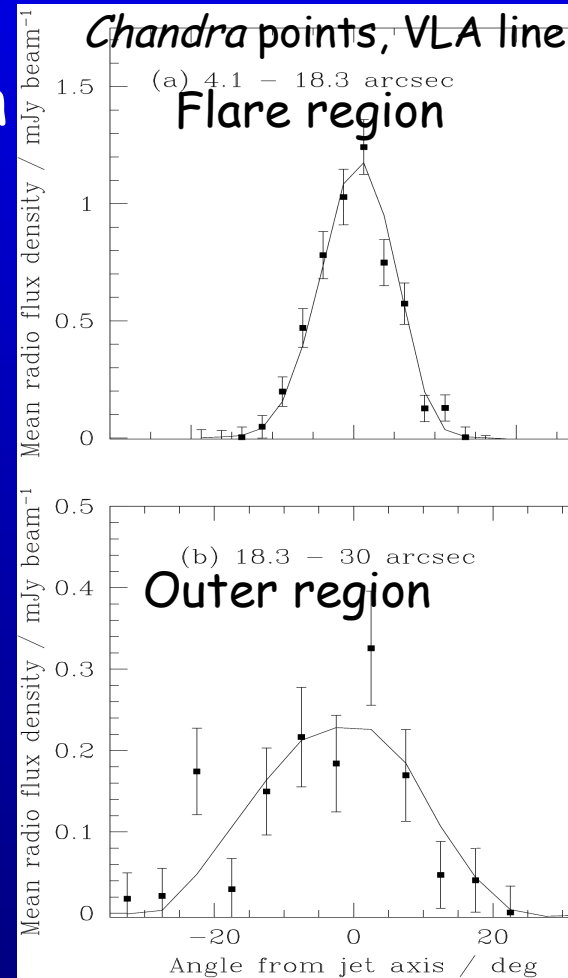
In straight 2-sided jets the
kinematics can be inferred
from the radio intensity and
polarization structures,
e.g., 3C 31
Laing & Bridle 2002



IXO sensitivity essential for spatially-resolved spectroscopy in the larger population

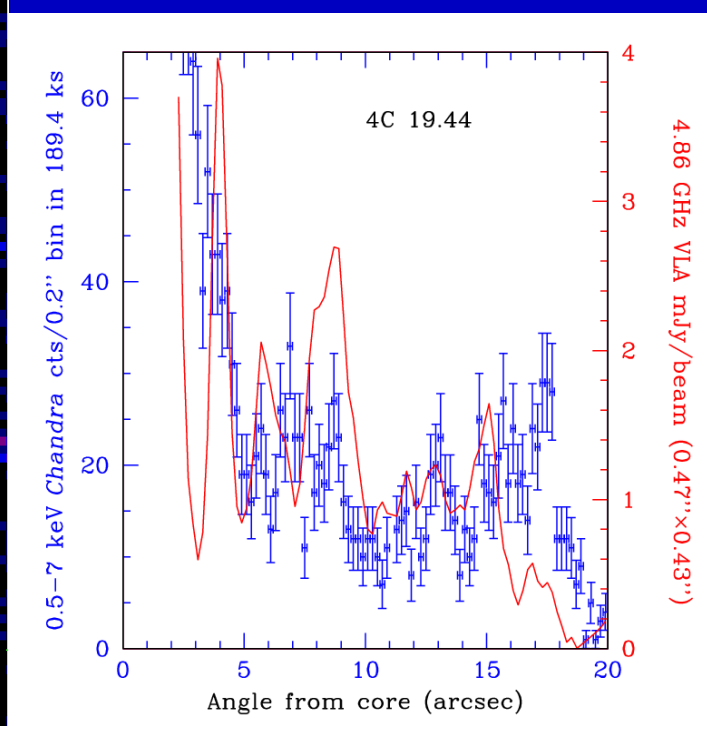
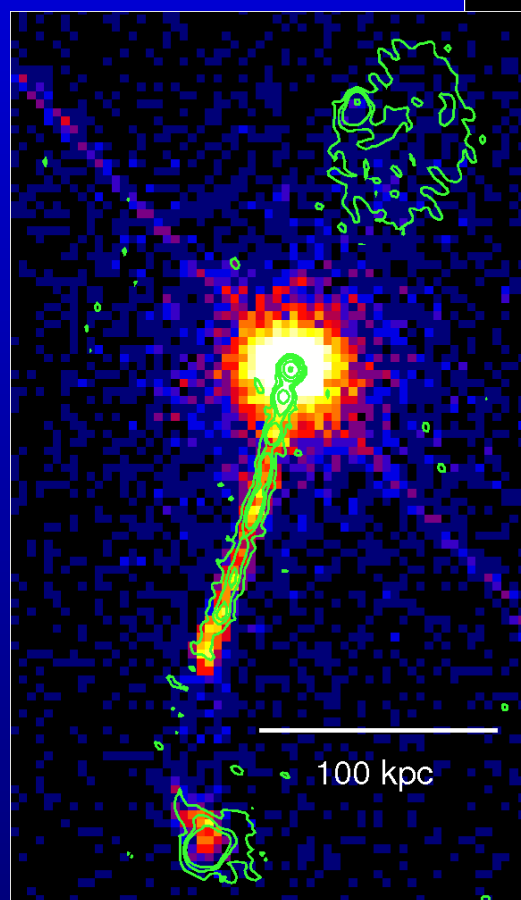
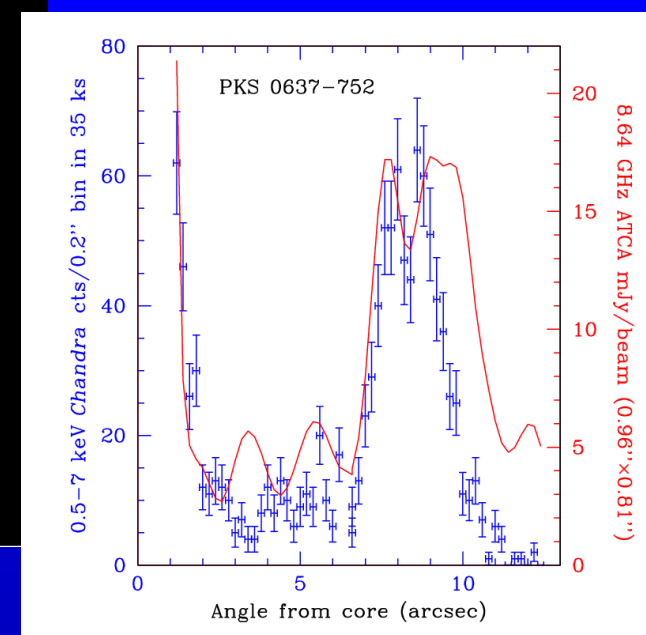
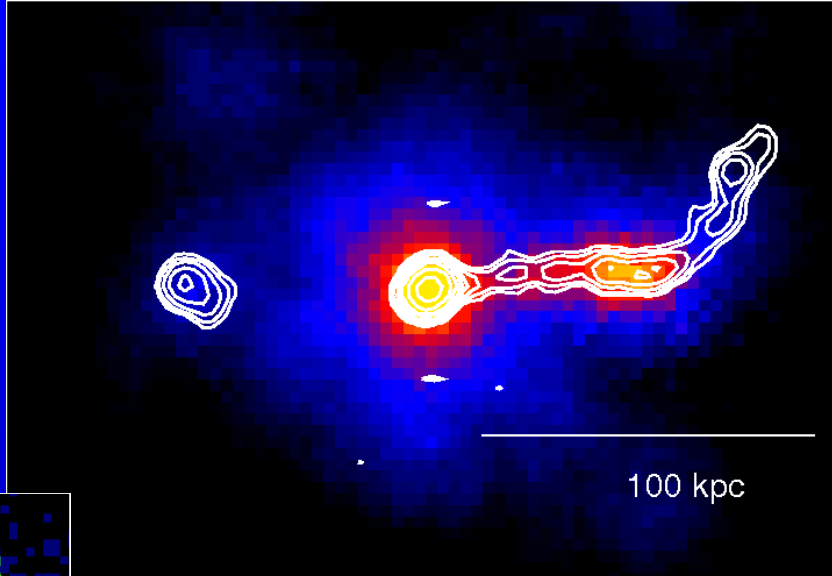


Particle acceleration throughout diffuse jet out to 30" (10 kpc)



NGC 315

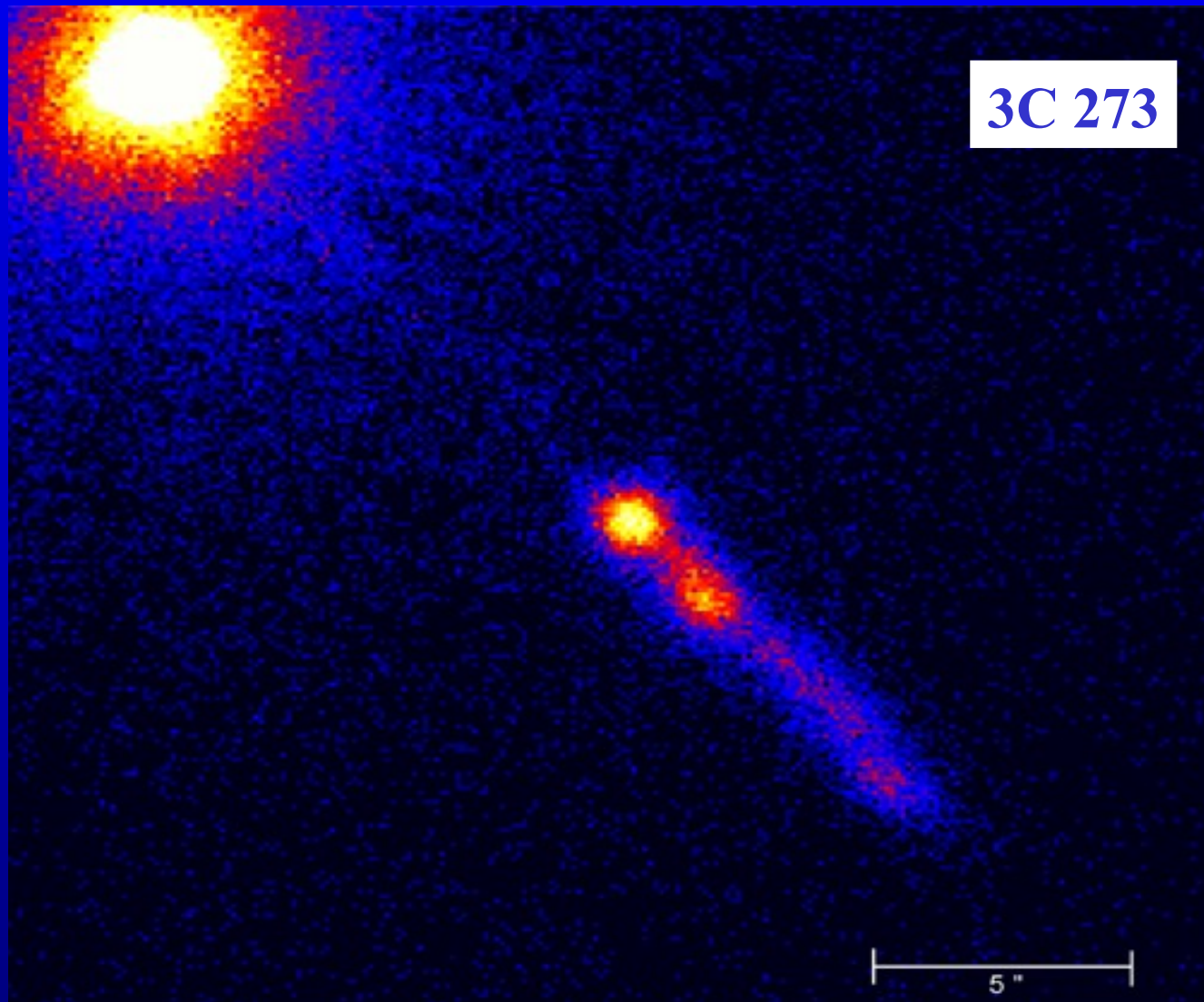
Worrall et al. 2007



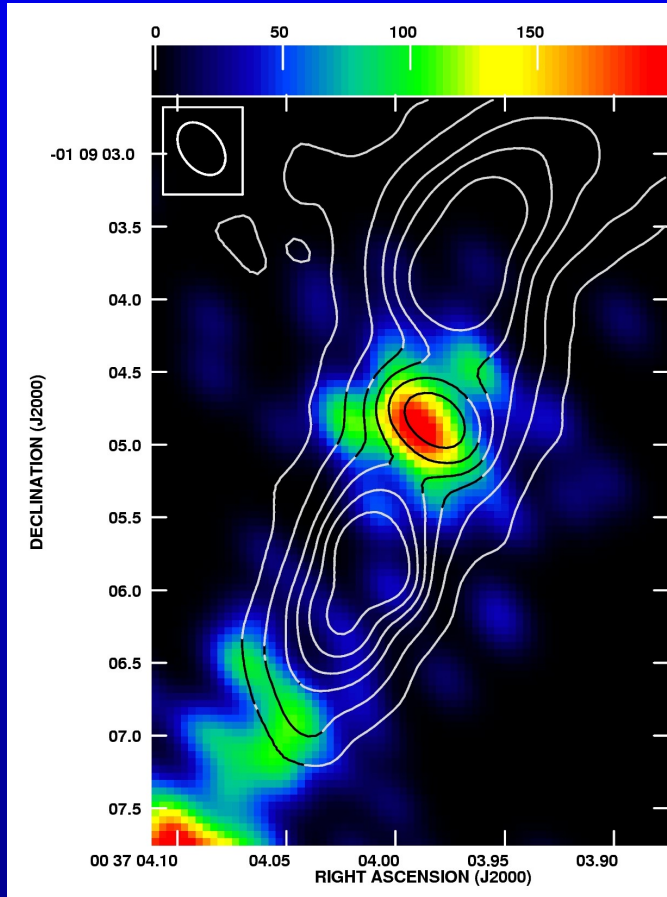
High-power jets: low-energy or high-energy electrons responsible for X-rays?

Sensitive polarization observations would tell us

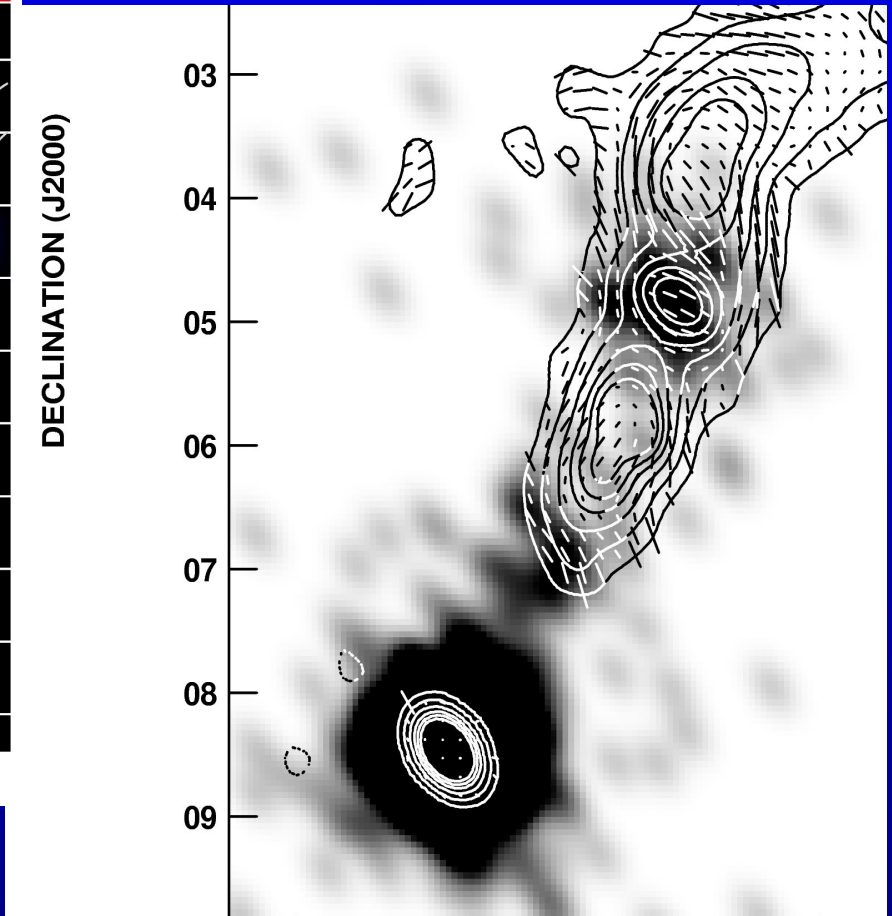
A prime candidate



Transverse magnetic fields in radio and optical polarization often seen roughly where X-rays bright. X-ray polarization?



Chandra image, radio contours



plus radio polarization B vectors

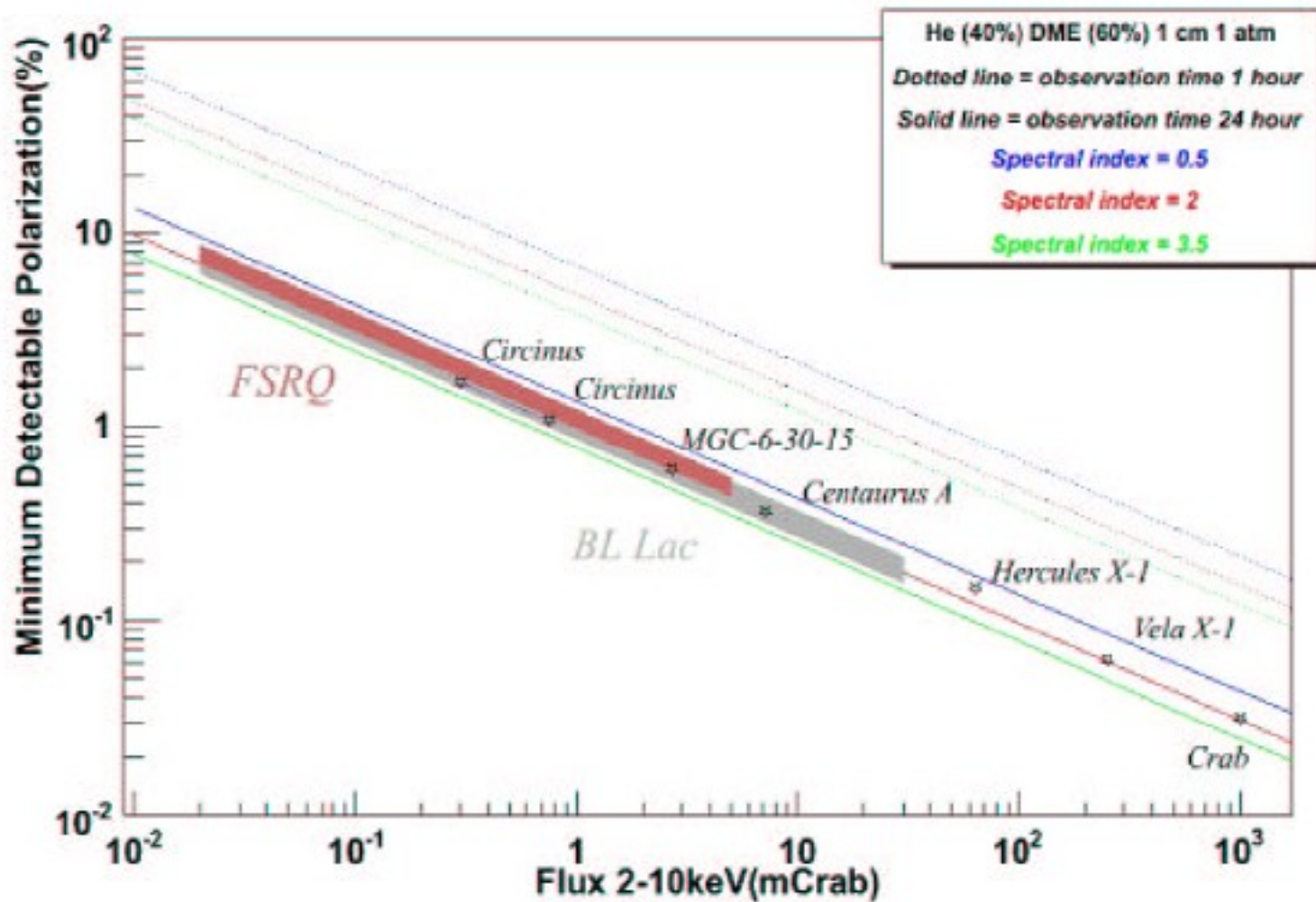
Summary

- Momentum & heat input from jets affect the external medium & its ability to form stars.
- Jets accelerate particles to high energy.

Need to understand the physics of the jets themselves → duty cycle, triggering, range of powers, relationship to BH mass..

IXO will have what it takes

- Sensitivity (spatially resolved spectroscopy)
- Spatial resolution
- Spectral resolution (dynamics)
- Polarimetry?
- FOV



Bellazzini et al 2006