The Curious Radio Streak in Abell 2256

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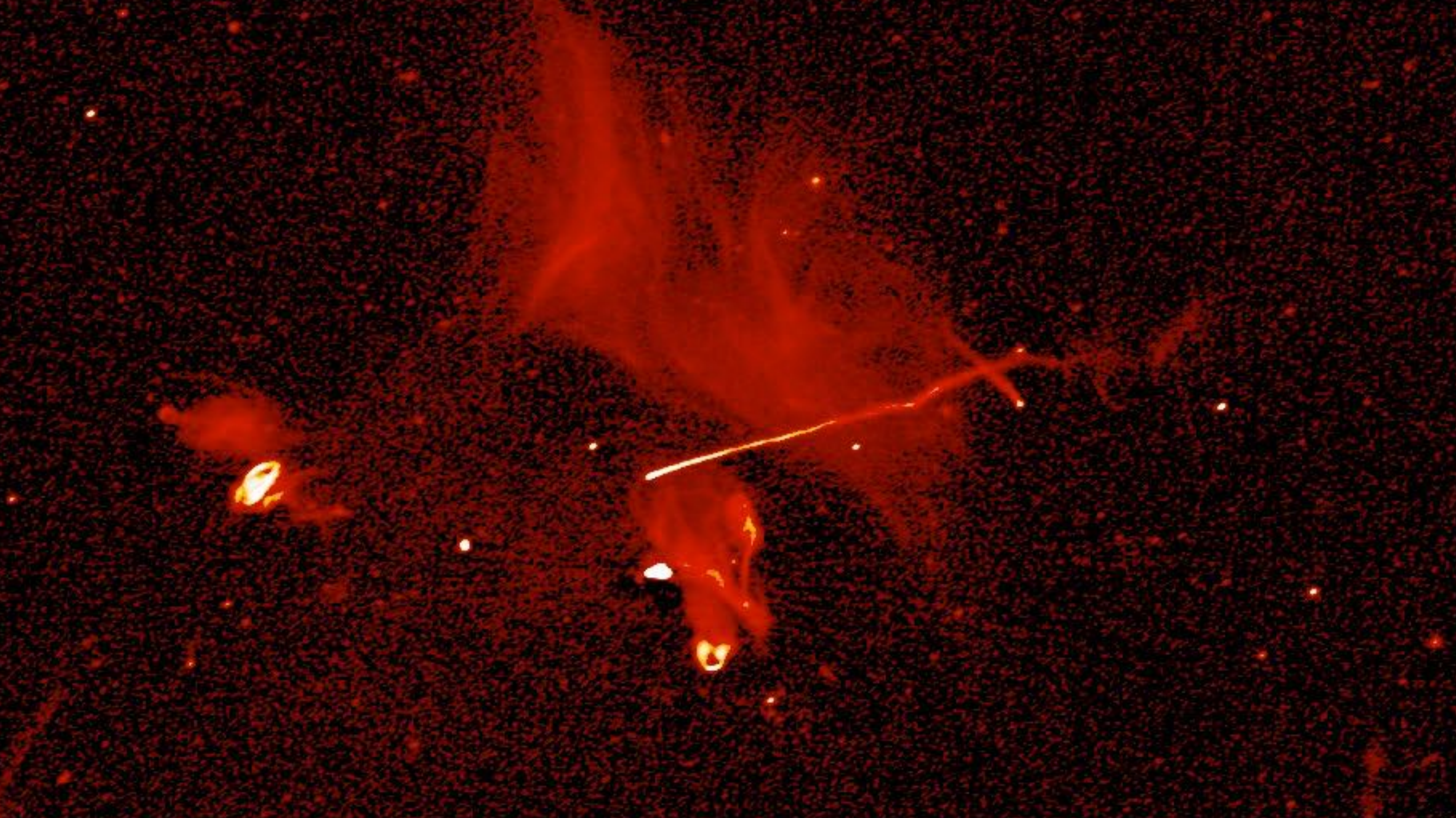
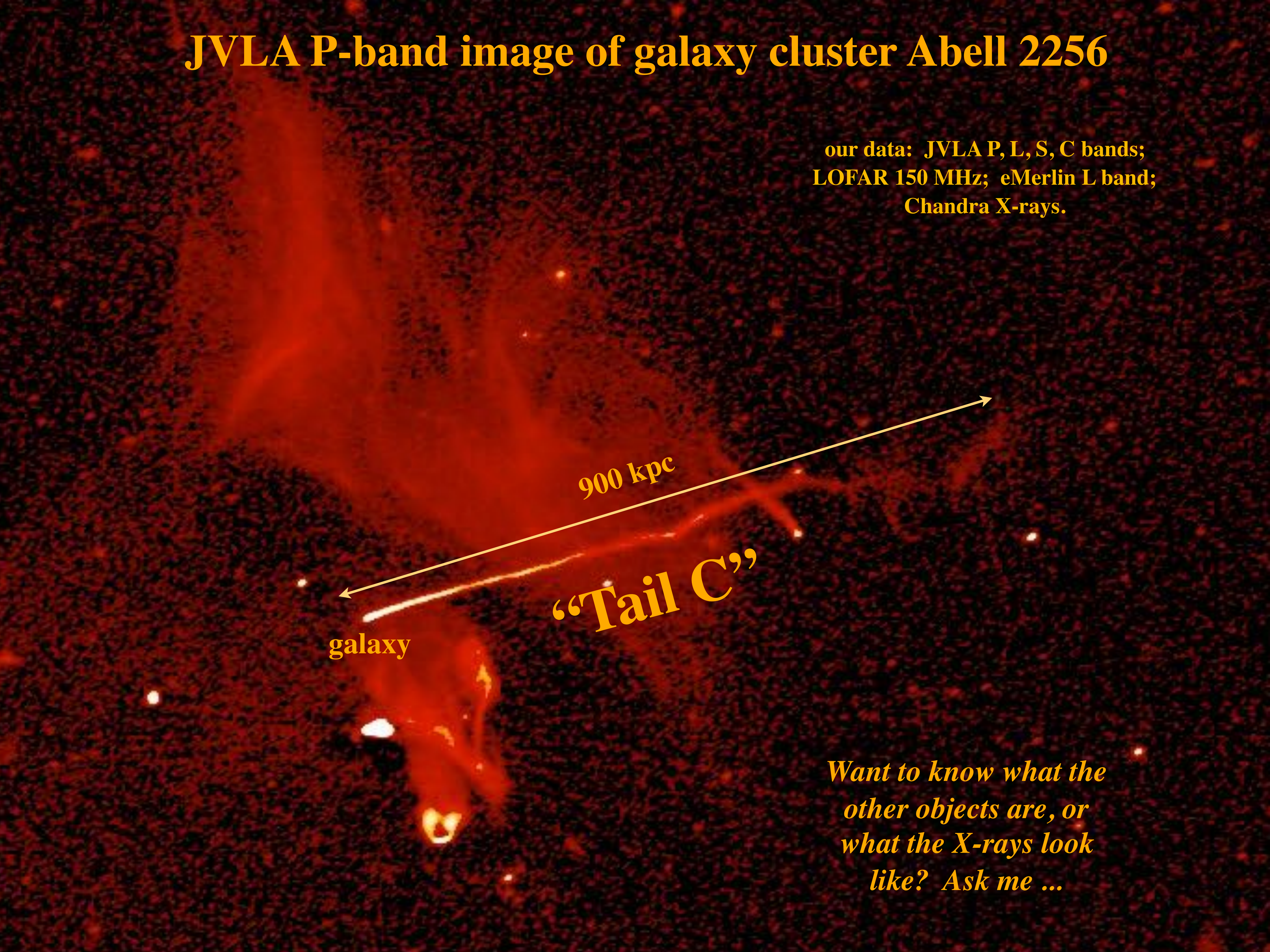
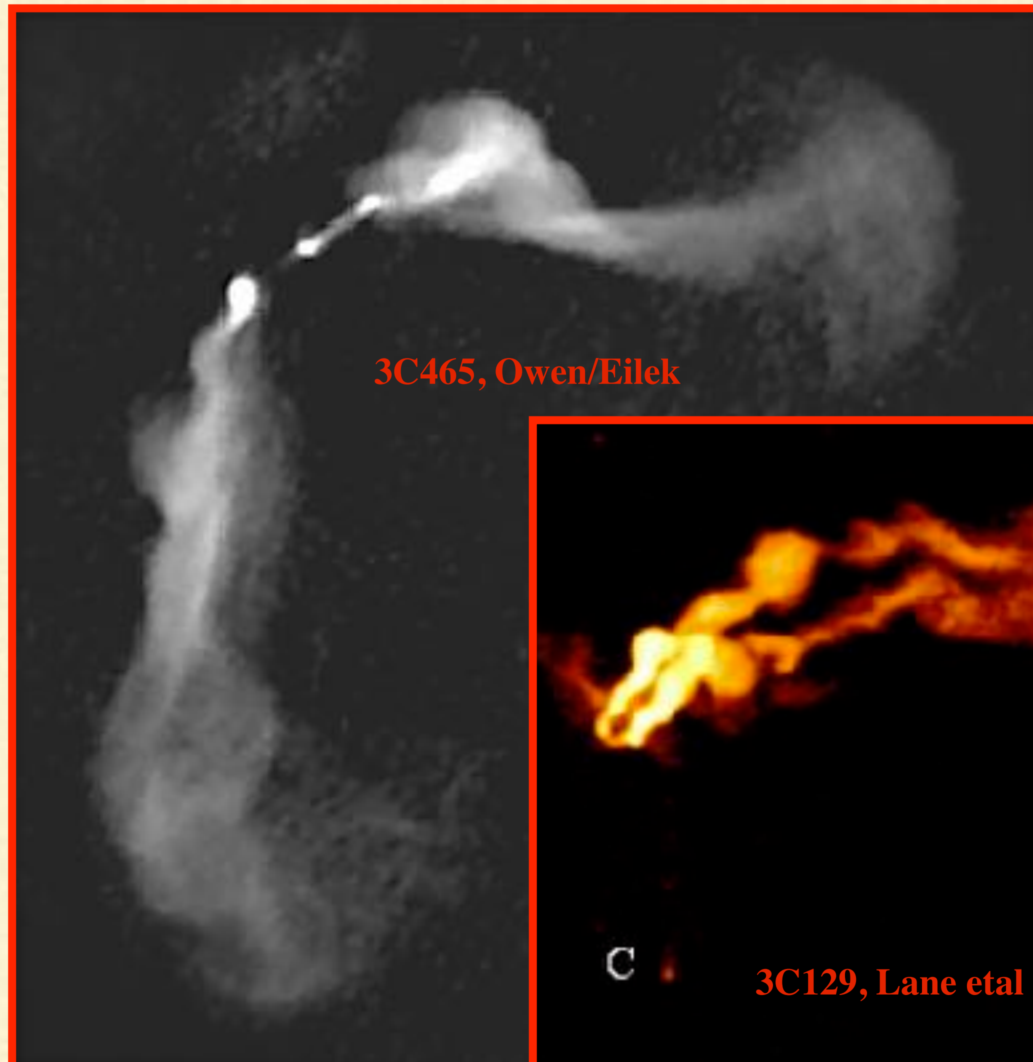
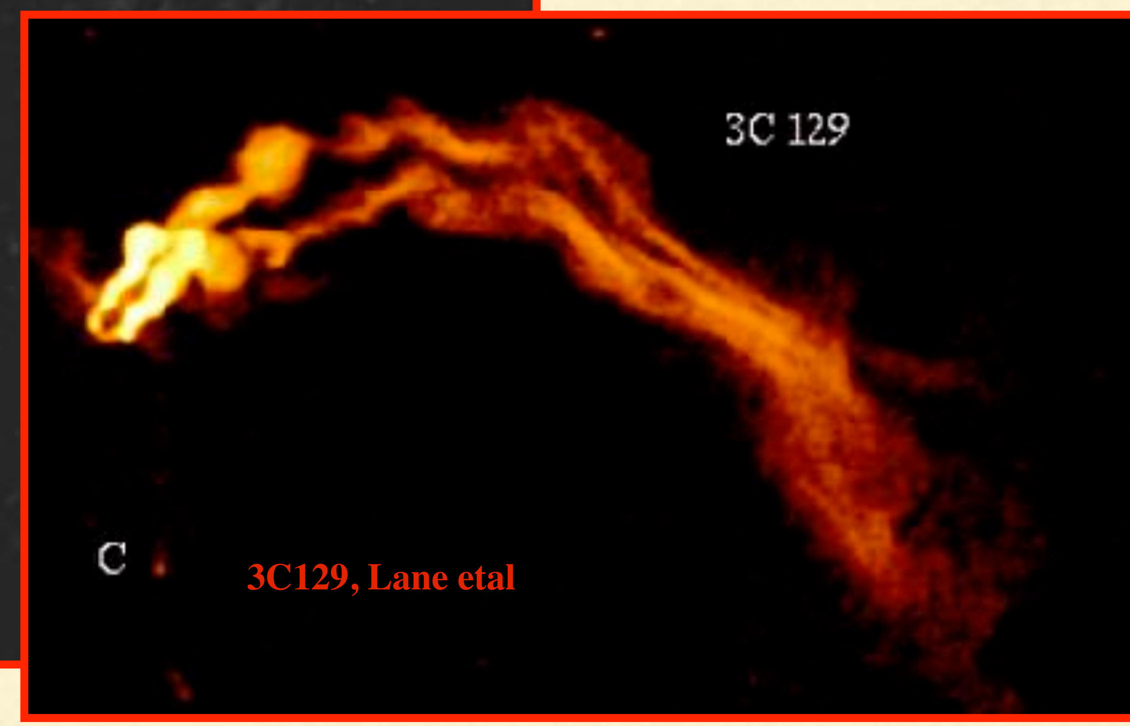


with thanks to M. Mao, R. van Weeren, S. Bhatnagar, E. Greisen, U. Rao


JVLA P-band image of galaxy cluster Abell 2256
our data: JVLA P, L, S, C bands;
LOFAR 150 MHz; eMerlin L band;
Chandra X-rays.
900 kpc
"Tail C"
galaxy
Want to know what the
other objects are, or
what the X-rays look
like? Ask me ...

Radio galaxies 101: double jets from AGN can be ...





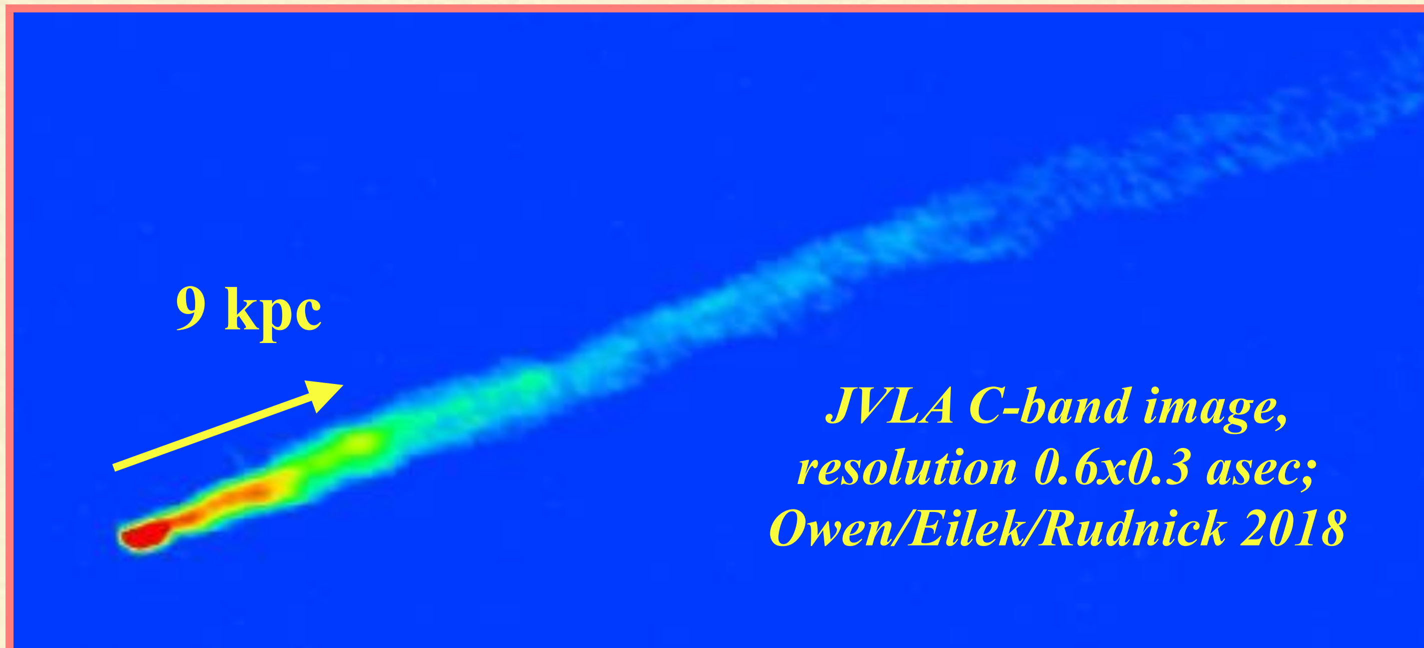
straight ; **somewhat bent ;**

or very bent ("Narrow-Angle Tail")

At first, I (like everyone else) assumed Tail C is an extreme Narrow-Angle Tail; but we were all WRONG !

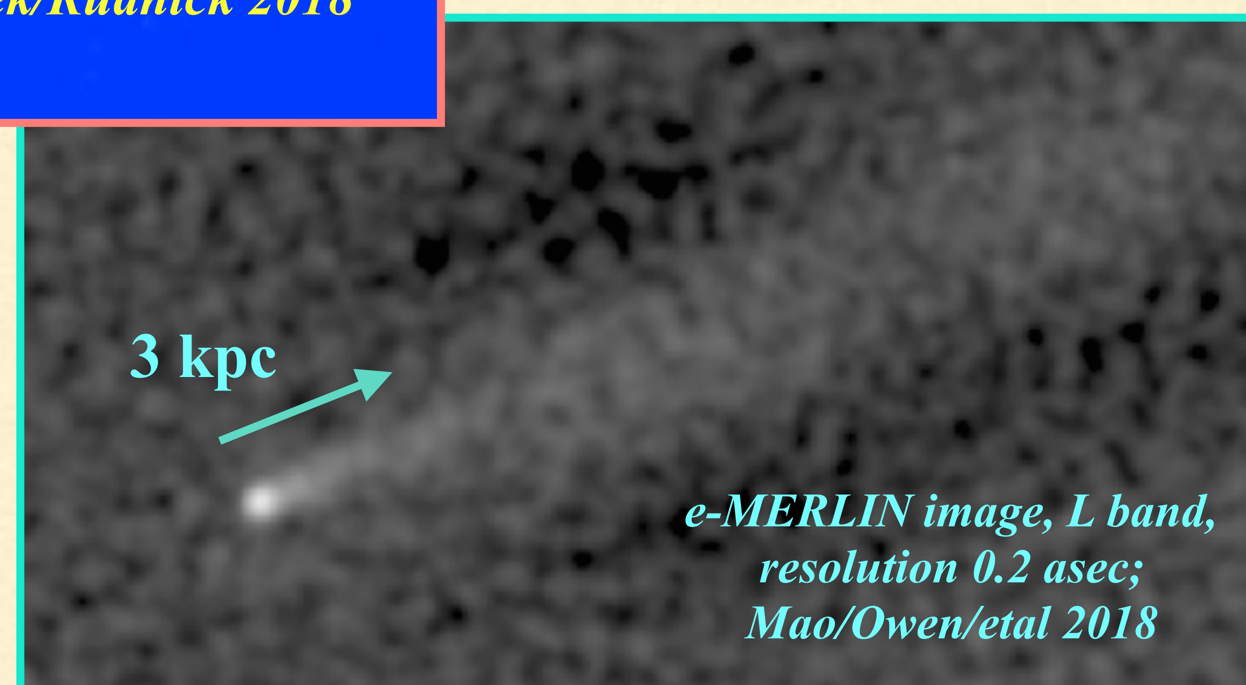
New Fact: Tail C is NOT a standard Narrow-Angle Tail

No sign of double bent jets, even within 1 kpc from the AGN



JVLA C-band image, resolution 0.6x0.3 asec; Owen/Eilek/Rudnick 2018

Inner part of tail < 1 kpc across; no sign of bifurcation except 20-40 kpc from core (structure within single flow?)



e-MERLIN image, L band, resolution 0.2 asec; Mao/Owen/etal 2018

Next question: is it a passive trail, or an active flow?

New Fact: Tail C is NOT a passive wake behind the galaxy

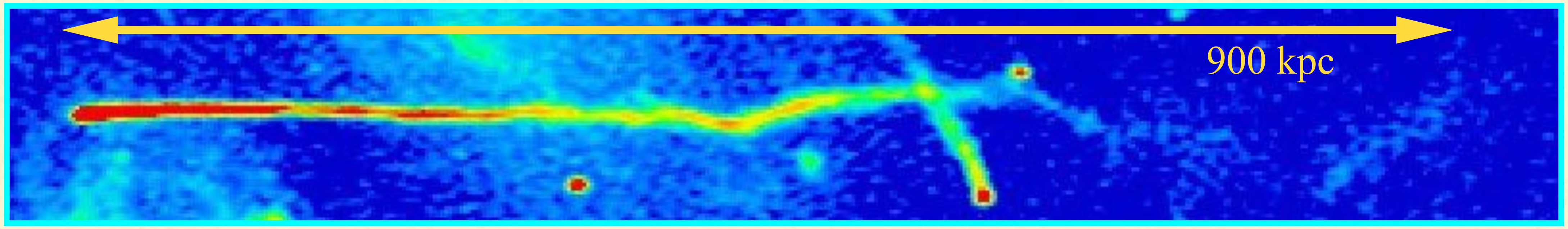
Evidence 1: Tail C is too long to stay bright without in situ reacceleration

Details: for slowest possible aging ("sewer rat model"), and 10 muG local B field, need galaxy speed > 3 times cluster velocity dispersion to avoid radiative losses for electrons seen at P band

Evidence 2: Radio spectrum of Tail C is not consistent with simple aging

Details: radiative aging predicts exponential decay of surface brightness and of electron/radio spectrum. Not seen in data: radio spectrum is pure power law, 150 - 1500 MHz, and surface brightness decay is too slow.

Infer: need energy transport to support local energization;
==> Tail C is ACTIVE



If Tail C is active, how is the energy transported?

Model 1: fluid/MHD flow ("hydro jet")

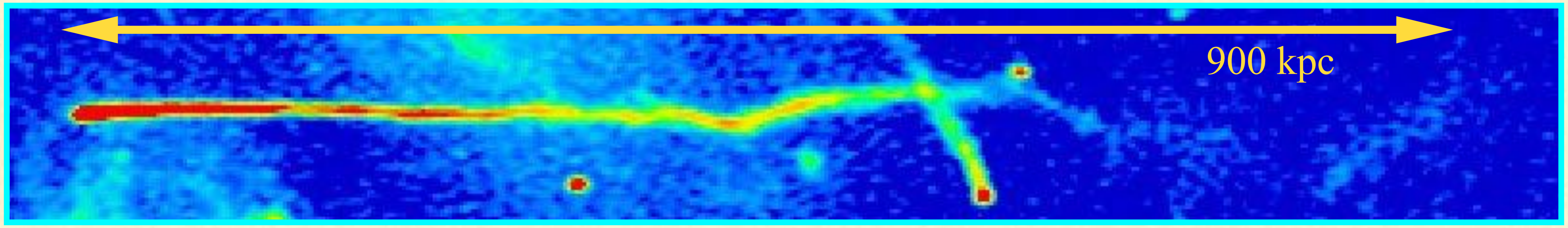
Details: energy, mass carried by fluid flow. Magnetic field dynamically weak, carried out with flow. Reaches pressure balance with ambient, may or may not have fast jet within slower cocoon.

Model 2: Poynting flux ("magnetic tower")

Details: magnetically dominated; dynamically weak plasma carried along with the current-carrying flow. High pressure core (quasi force free), outer layers which reach pressure balance with ambient.

Both models allow *in situ* particle acceleration

Details: particles can be re-accelerated by shocks, reconnection, turbulence, which can arise in either model (with details depending on specific situation).



If Tail C is an outflow, why don't we see a lobe?

Option 1: it's there but we can't see it

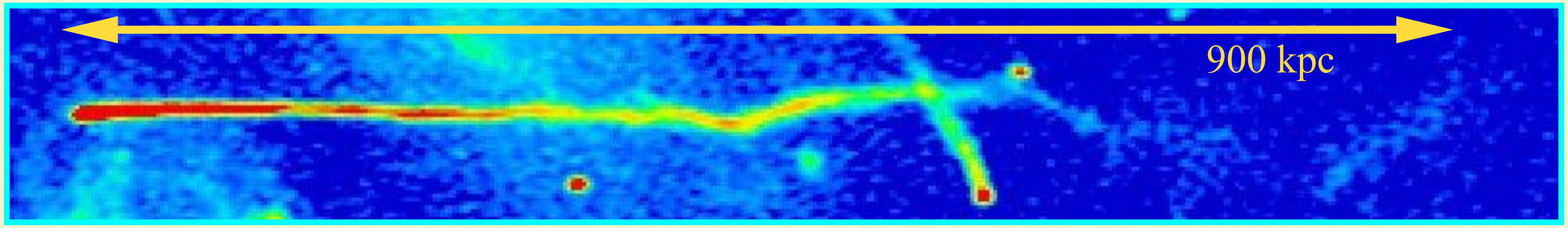
Details: It could be there, but radio-faint if B fields and/or relativistic electrons too weak. Or it could be distorted by cluster-merger shear flows. Unsatisfying, but can't rule this out.

Model 1: fluid/MHD flow ("hydro jet")

Details: hydro jets form lobes when fast, low-density jet runs into higher density background; jet slows down and jetted plasma has to go somewhere (sideways). But if jet is "ballistic" (higher density than background), do not expect a lobe to form.

Model 2: Poynting flux ("magnetic tower")

Details: magnetic towers advance more slowly, as B field near the head adjusts to ambient pressure. Only create a lobe if tower advances into lower density region.



If Tail C is an outflow, where is the other side?

Option 1: Doppler boosting?

Comment: would need relativistic flow over ~ Mpc scale; unlikely

Option 2: ram pressure from galaxy motion disrupts one jet

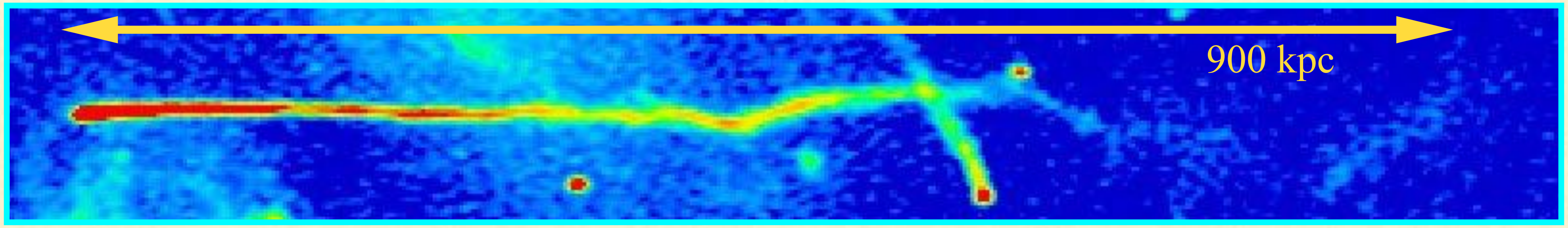
Comment: possible for known parameters if jet plasma is fast & tenuous.
BUT, where is the plasma from the disrupted jet? Why don't we see it?

Option 3: other side either very faint, or close to line of sight

Comment: both of these are possible, we know other examples of each; so can't rule this out.

Option 4: maybe the AGN only makes one jet?

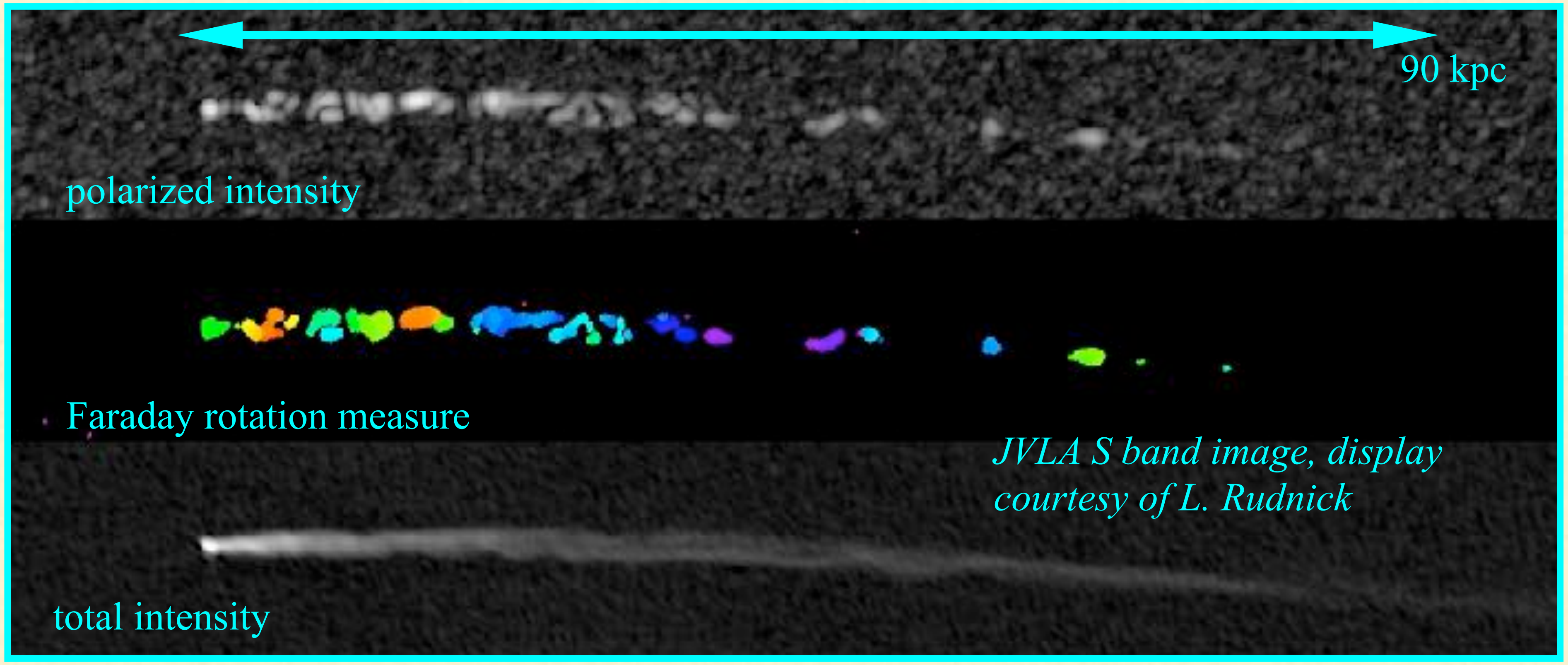
Comment: well, this would be thinking outside the box.



A different problem: unexpected Faraday rotation

Data: small patches of strong Rotation Measure (RM) along Tail C

Patch size: 1-2 kpc.   Magnitude: variable, 300 - 1100 rad/m2, both signs. Apparently disordered (no sign of pattern, along or across the source). RM Synthesis suggests more than one RM component possible.



Easy to find what *cannot* produce these Faraday rotating patches

Can't be thermal plasma inside the radio jet (would depolarize); can't be turbulence throughout the cluster (numbers don't work); can't be small patches of local Intracluster Medium (ICM; numbers really don't work).

What might produce the Faraday Rotation?

We need: cool, dense structures with ordered B field, local to radio source

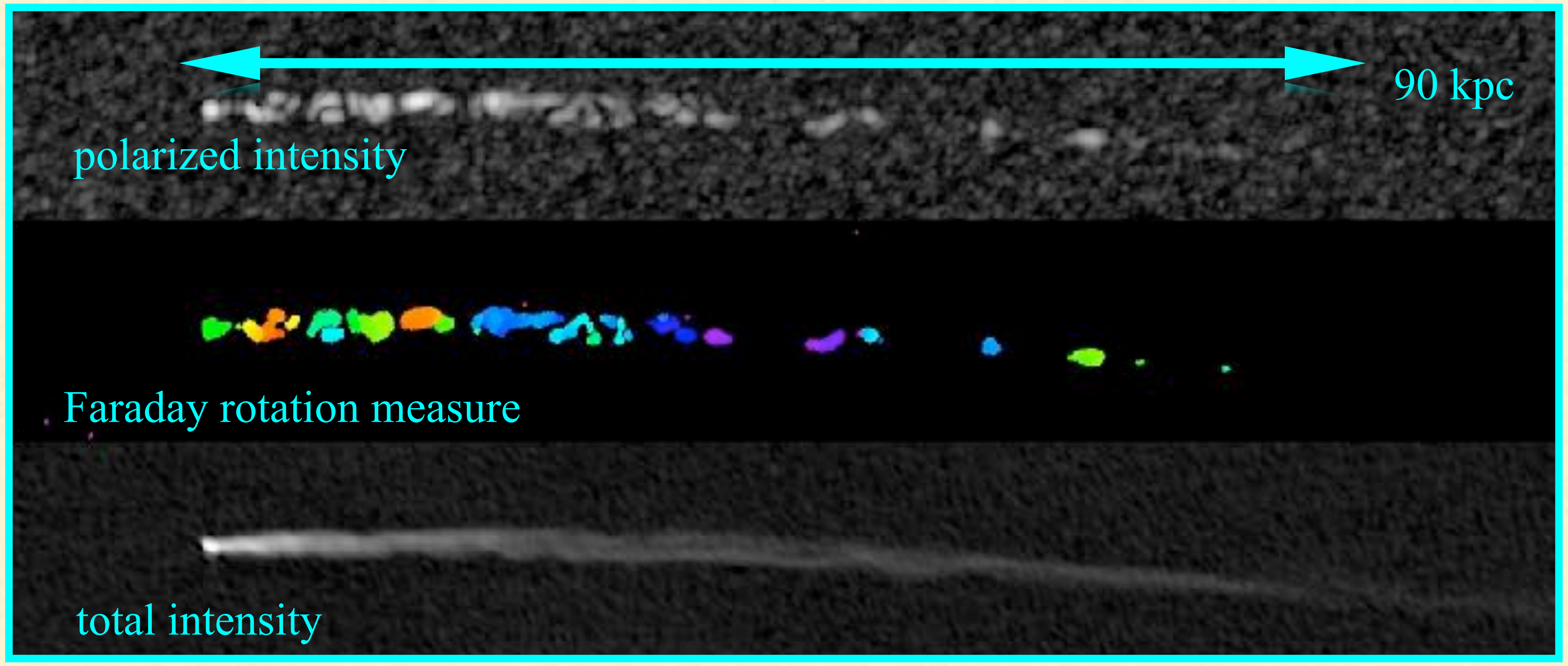
(to provide necessary RM without being at too high a pressure)

But: these can't originate in the hot (X-ray loud) ICM

Cooling is much too slow; so Kelvin Helmoltz, shocks, etc don't work

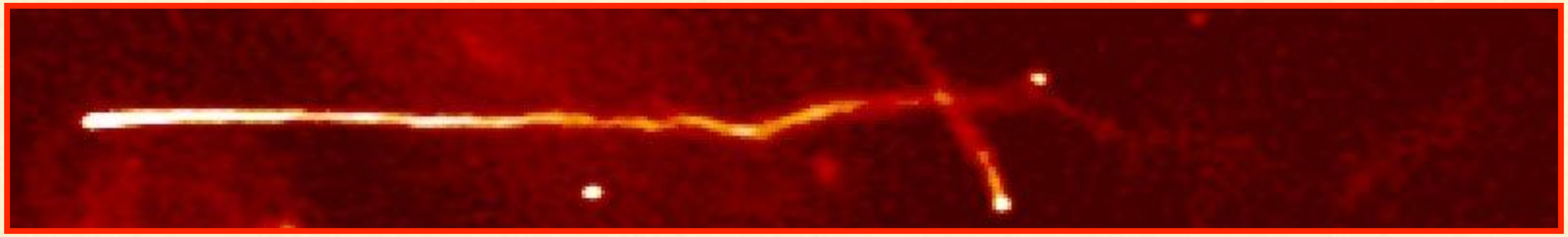
So, it's time to consider other options . . .

Is there a multiphase plasma in Tail C or in the local ICM?
If so, where does the cool, magnetized material come from?



Note: similar Faraday structures are being found in other radio galaxies (e.g., Fornax A, Anderson etal; Cygnus A, Sebokolodi/Perley); so can't be something unique to Tail C.

Quick summary:



I was wrong: Tail C is neither a passive wake, nor a trail created by double jets bent very close to the AGN.

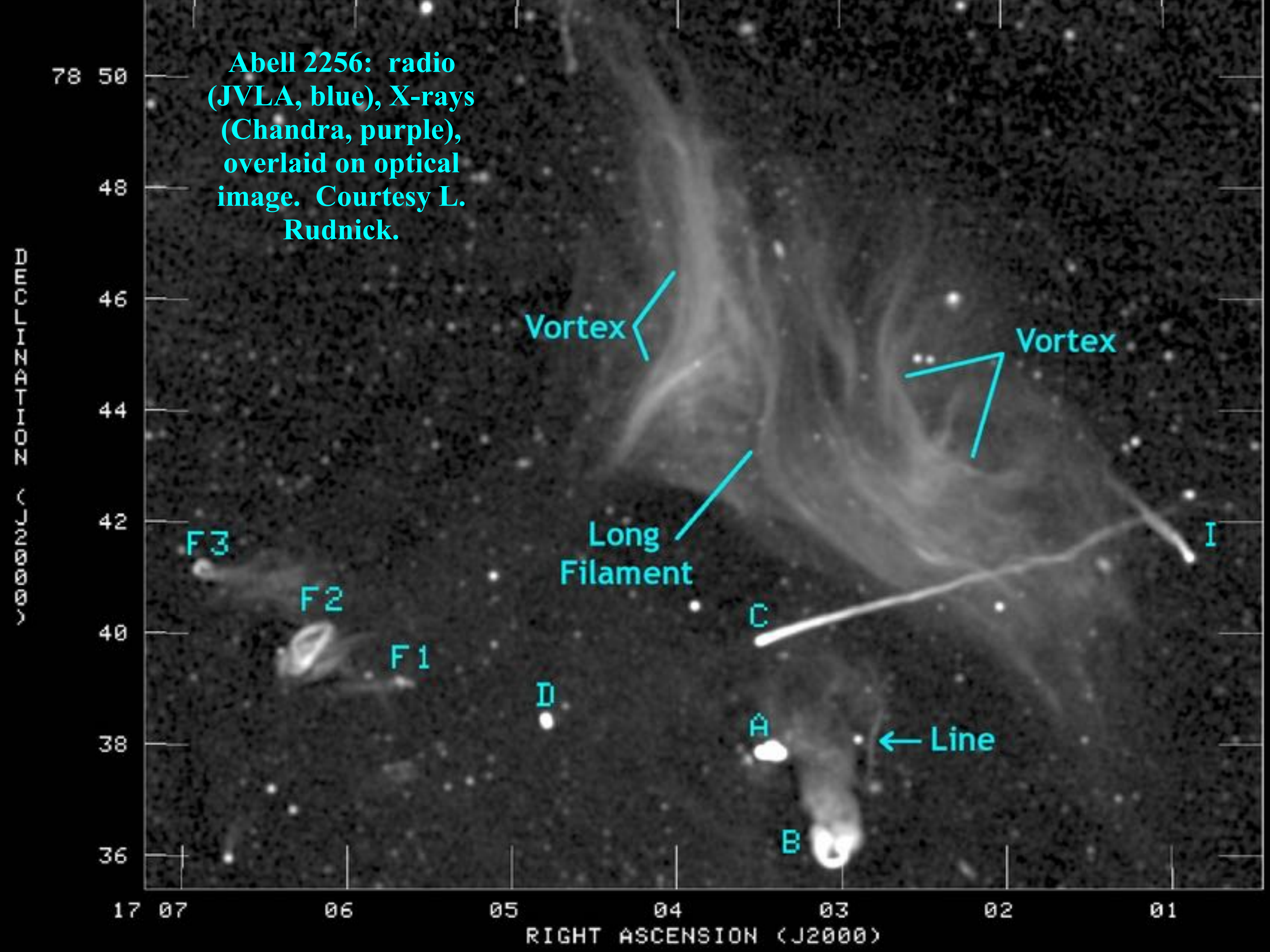
Instead: Tail C is a long, skinny, flow of mass and energy, reaching at least 900 kpc from its parent AGN.

We don't fully understand why Tail C looks one-sided, nor why it doesn't have an outer lobe, let alone what produces the high Faraday rotation patches

…. what are we missing?

… to finish, move on to the next page …

Abell 2256: radio (JVLA, blue), X-rays (Chandra, purple), overlaid on optical image. Courtesy L. Rudnick.



Abell 2256: radio (JVLA, blue), X-rays (Chandra, purple), overlaid on optical image. Courtesy L. Rudnick.