Insights on Jet Physics & High-Energy Emission Processes from Optical Polarimetry

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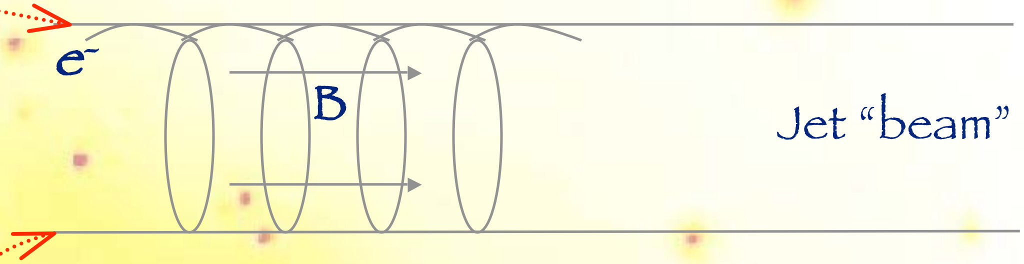
Radiation Processes in Jets



Synchrotron radiation emitted by relativistic particles in magnetic field

Inverse-Compton – scattering interaction between photon and a relativistic particle that results in a higher-energy photon.

Radiation from jets emitted by two processes: synchrotron and inverse-Compton.

For inverse-Compton, the 'scattered' photon can be either from within the jet (often called synchrotron self-Compton) or some external source (e.g, the cosmic microwave background or emission line regions).

Important questions:

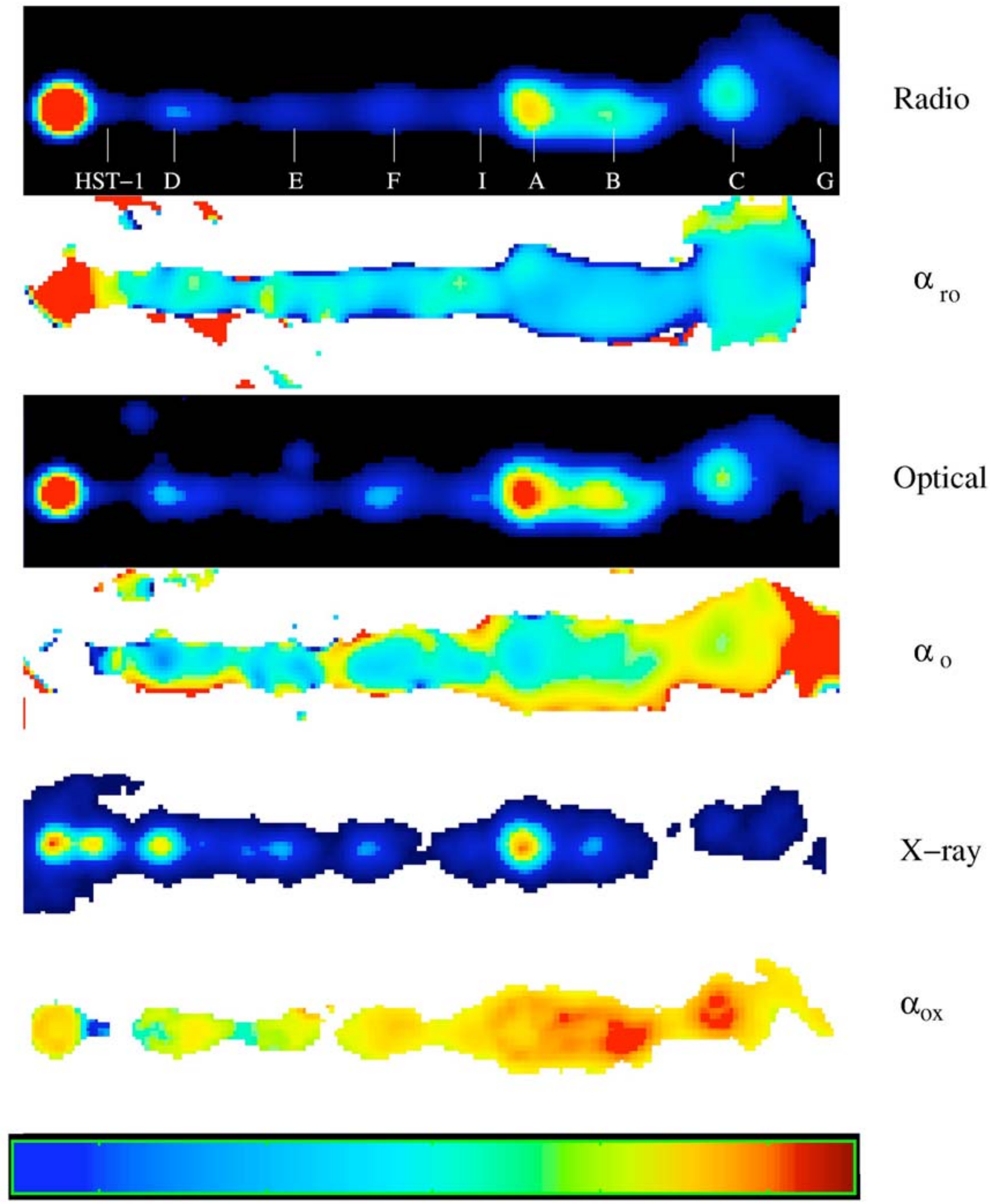
What does the magnetic field configuration look like?

Does it change as one goes up in energy?

What clues can the magnetic field configuration and ordering give us to radiation and physical mechanisms involved in producing high-energy emissions?

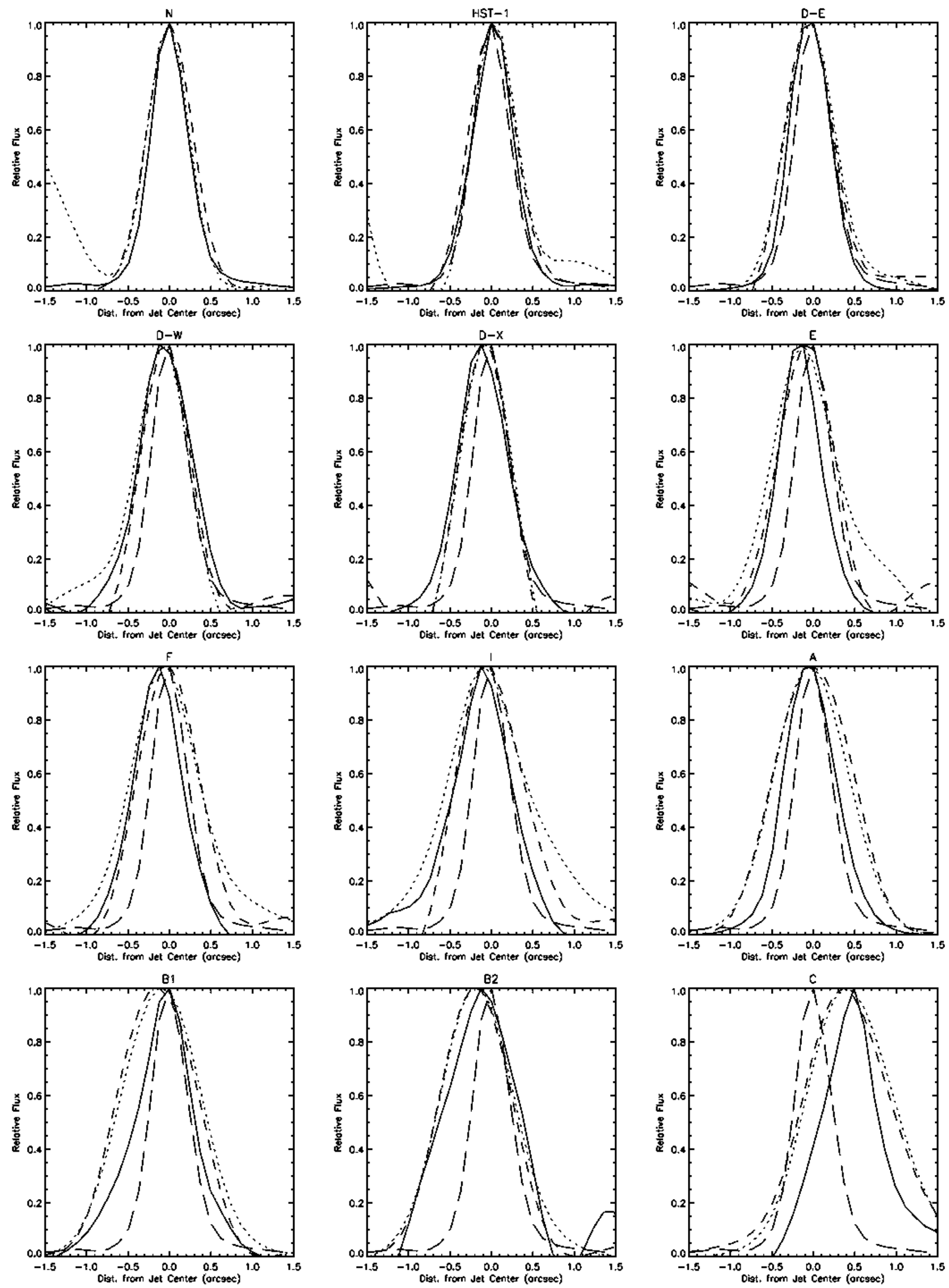
The M87 Jet:

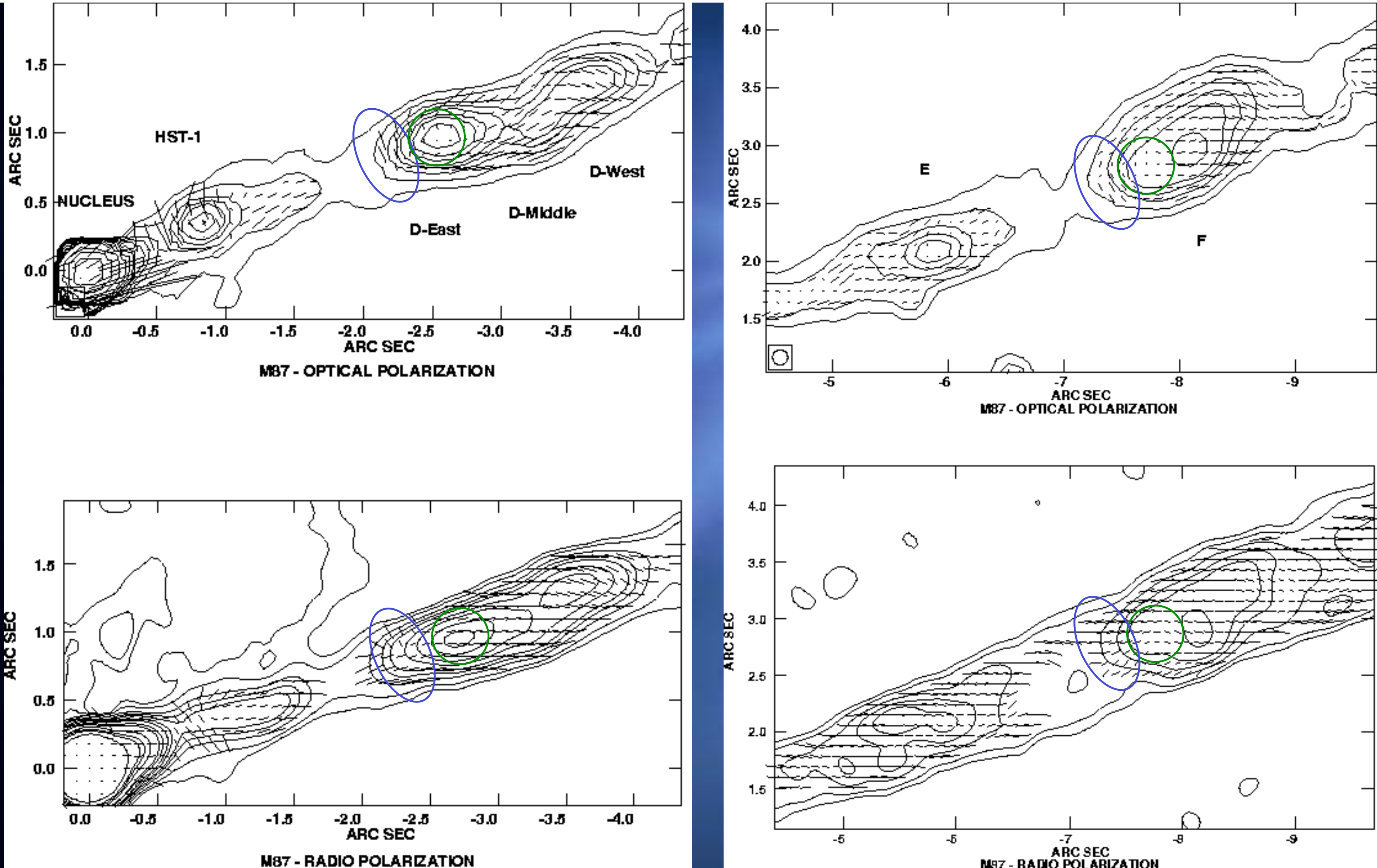
Perlman & Wilson 2005



Comparing jet width in Radio, optical, X-rays...

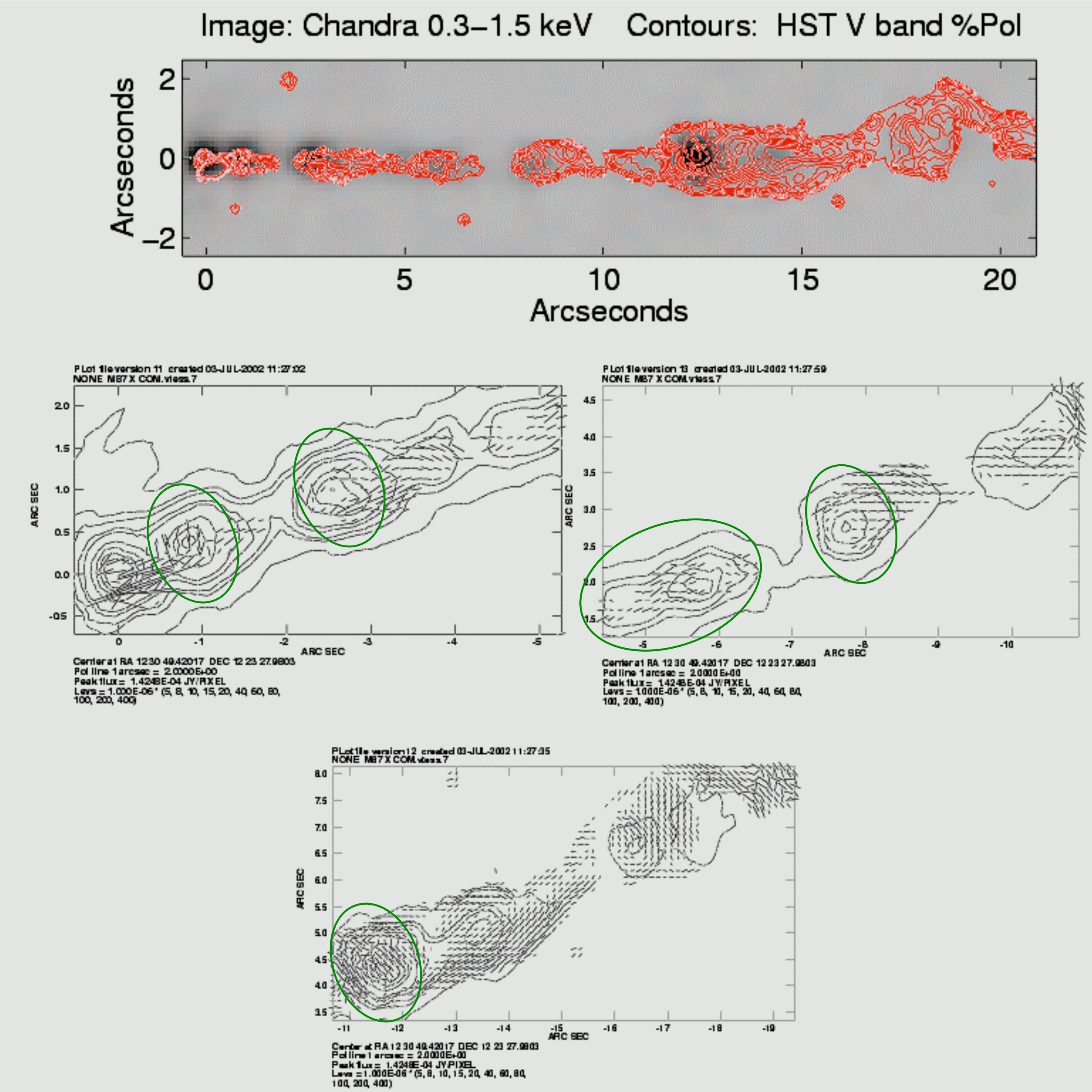
X-ray jet is narrowest
Optical jet is next
Radio jet is widest





Note the strong radio/optical polarimetry differences near knot maxima!
It is at these loci where we see X-ray flux maxima in M87 (next slide).

Perlman et al. 1999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Arcseconds
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Levs = 1.000E-06 * (5, 8, 10, 15, 20, 40, 60, 80, 100, 200, 400)
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Levs = 1.000E-06 * (5, 8, 10, 15, 20, 40, 60, 80, 100, 200, 400)
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Peak flux = 1.4248E-04 JY/PIXEL
Levs = 1.000E-06 * (5, 8, 10, 15, 20, 40, 60, 80, 100, 200, 400)

Stratified jet…

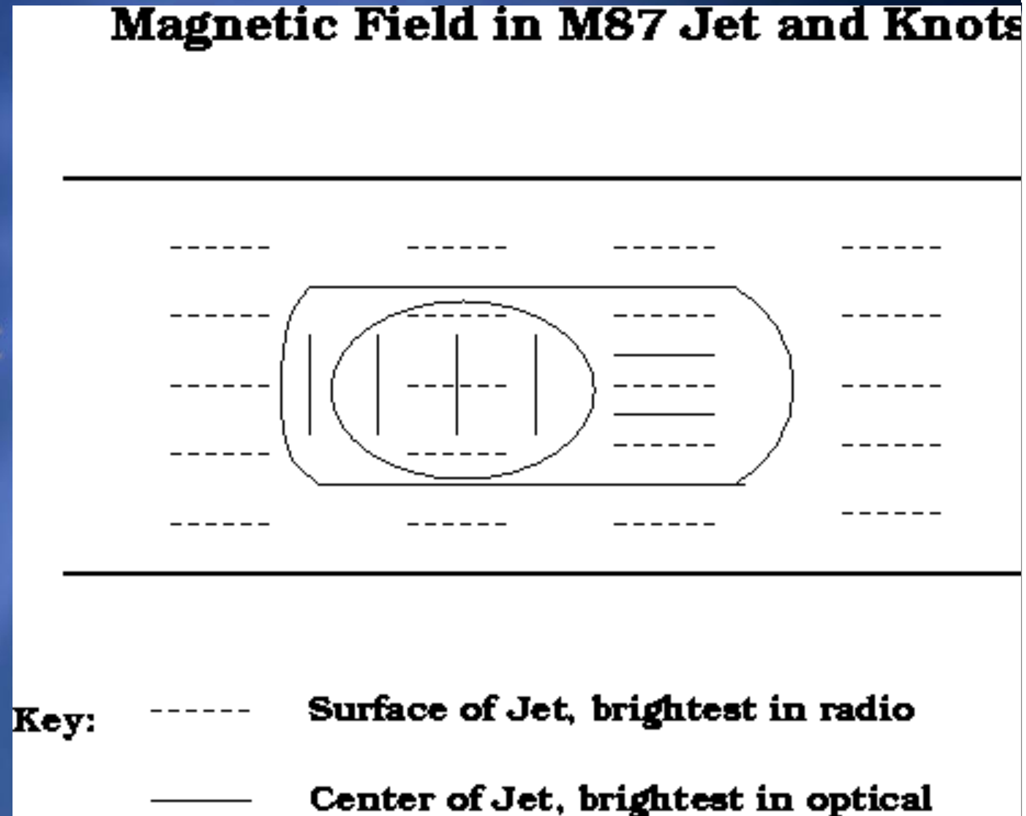
High energy particles -- and particle acceleration -- concentrated in knots and closer to jet axis.

B gets compressed, becomes ⊥ to jet in shocks inside jet

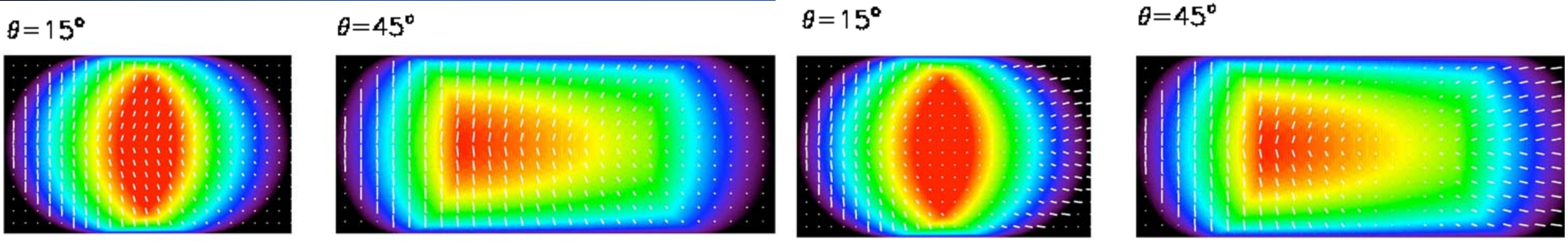
Further development of magnetic field depends on two scale lengths:

Magnetic field coherence length l_B

Synchrotron cooling length l_{cool}



Perlman et al. 1999



$l_B \approx l_{cool}$ Perlman, Georganopoulos & Kazanas, in progress $l_B \approx 2 l_{cool}$

Important questions raised by M87

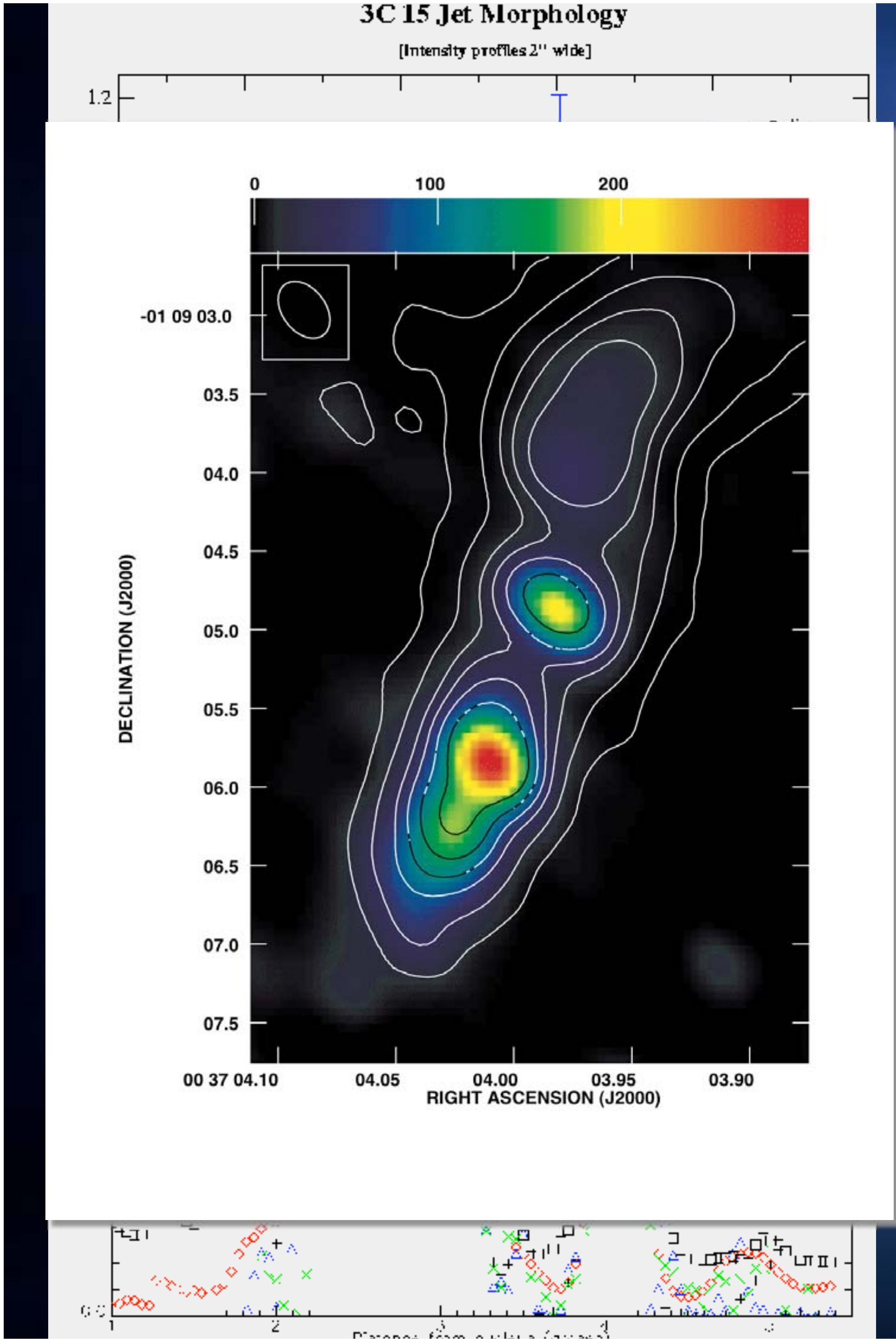
Can polarimetry act as a tracer for high-energy emission and/or particles?

- Would make sense for X-ray synchrotron emission
  - Requires in situ particle acceleration (traced by **B**)
- Less clear what the signal will be in objects with X-ray inverse-Compton emission (but see Uchiyama talk)
- Is the M87 pattern common in X-ray emitting jets?

If so, is the signal seen just in optical, or also in radio?

- Are there other radio-optical-X-ray differences?

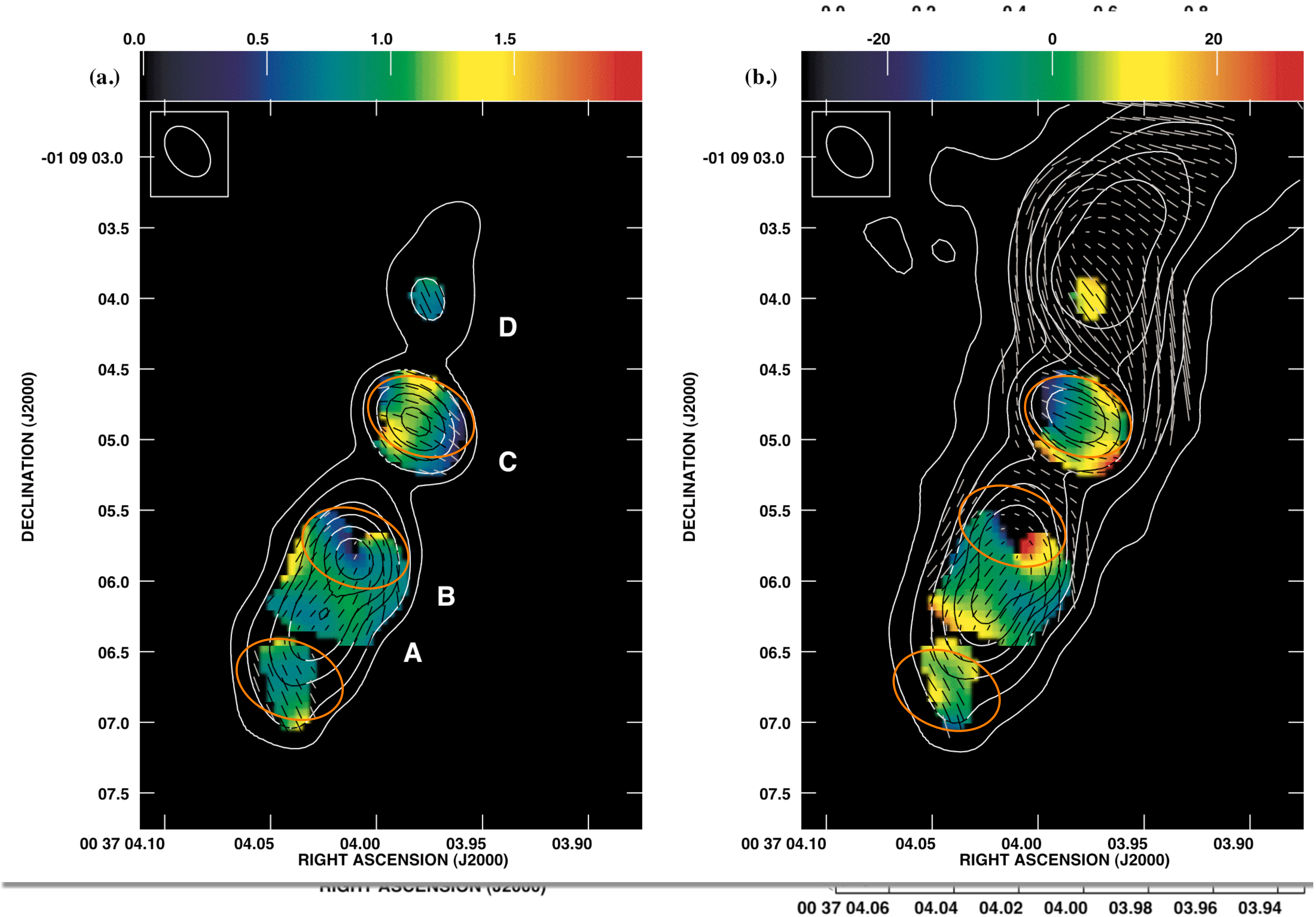
What physics does this reveal?



3C15

- Optical and radio jet roughly similar but optical jet narrower

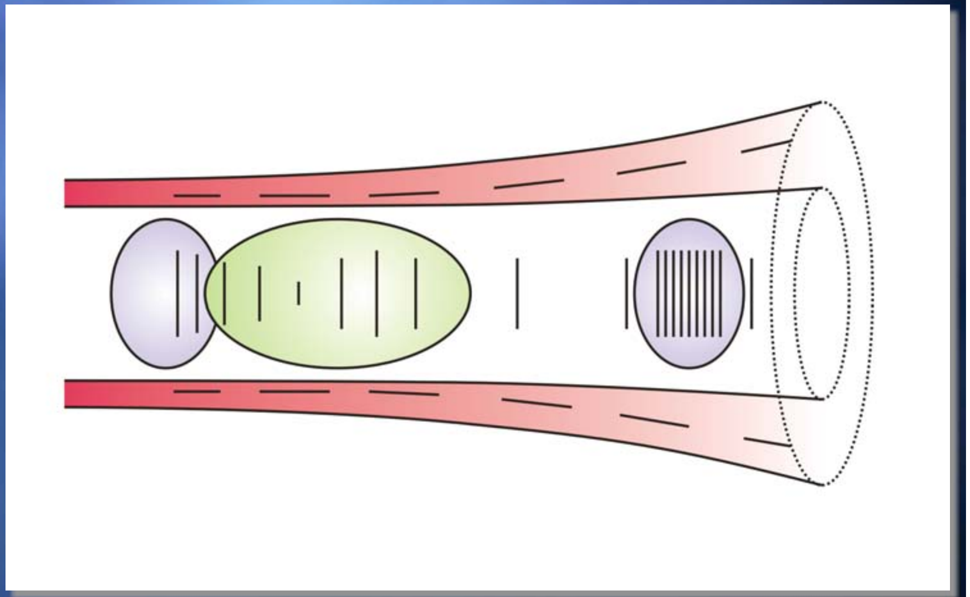
- 2 knots in X-ray:
  - One coincident with knot C
  - One (A′) not coincident with any radio/opt feature
    - Seen in UV


(a.)
0.0
0.5
1.0
1.5
-01 09 03.0
03.5
04.0
04.5
05.0
05.5
06.0
06.5
07.0
07.5
D
C
B
A
DECLINATION (J2000)
00 37 04.10
04.05
04.00
03.95
03.90
RIGHT ASCENSION (J2000)
(b.)
-20
0
20
-01 09 03.0
03.5
04.0
04.5
05.0
05.5
06.0
06.5
07.0
07.5
DECLINATION (J2000)
00 37 04.10
04.05
04.00
03.95
03.90
RIGHT ASCENSION (J2000)
00 37 04.06
04.04
04.02
04.00
03.98
03.96
03.94

3C 15

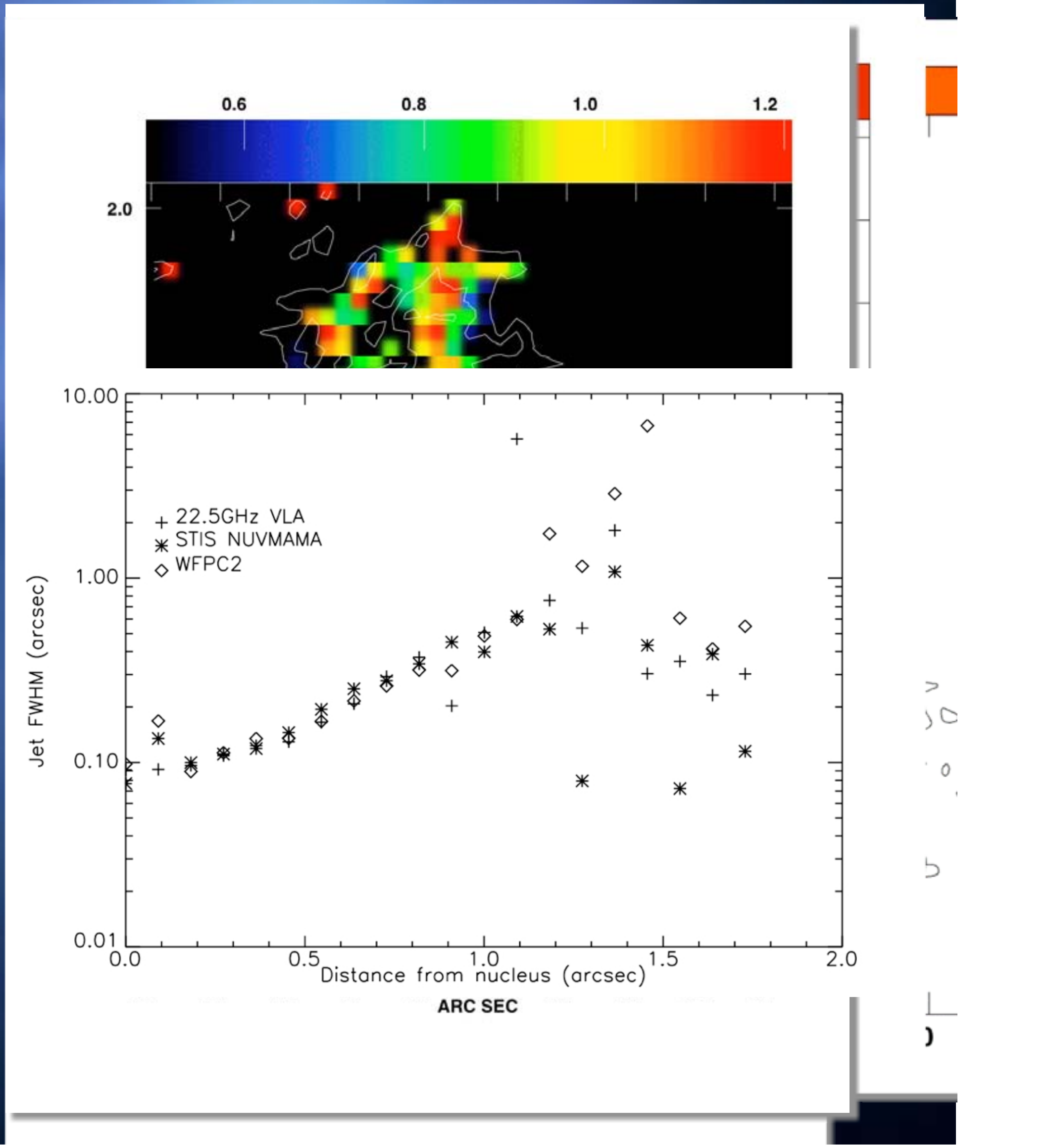
Stratification near knot C (Dulwich et al. 2007):

- 2-component plasma, relativistic spine, slower sheath
- Knot C is a torsional compression where X-ray emission is triggered



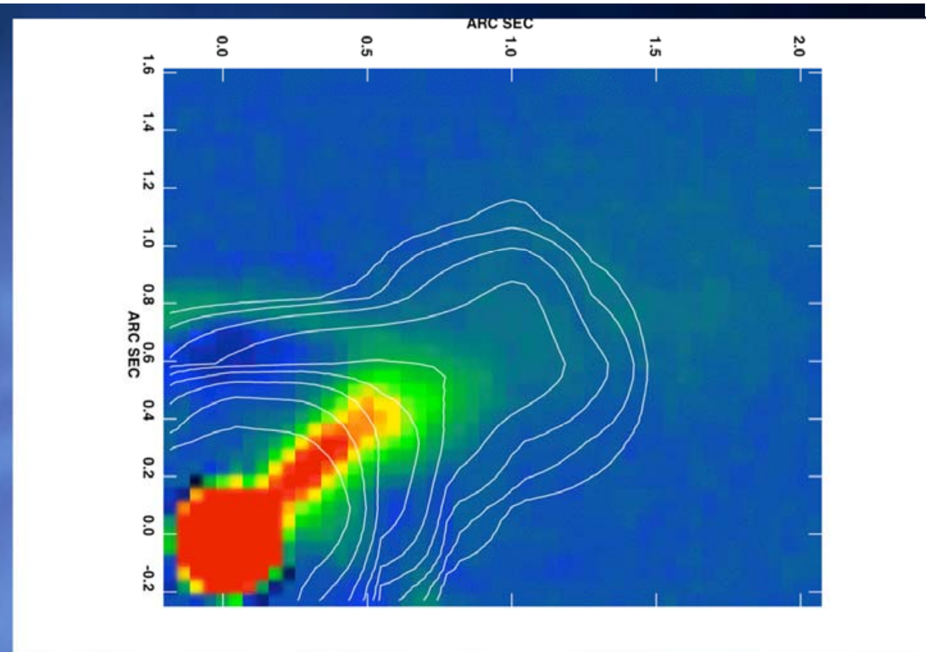
3C 264

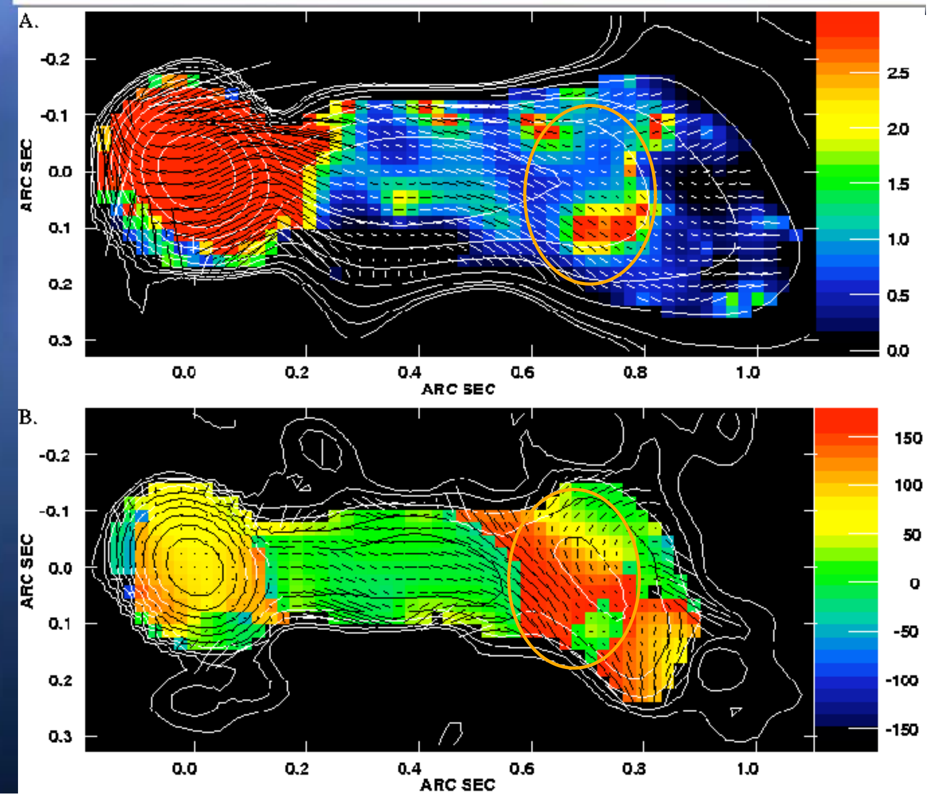
- Very short optical jet -- only 2” long
- X-ray emission both from inner jet as well as optically fainter outer jet
- Optical, UV jet NOT narrower than radio jet (contrary to 1997 Baum result)



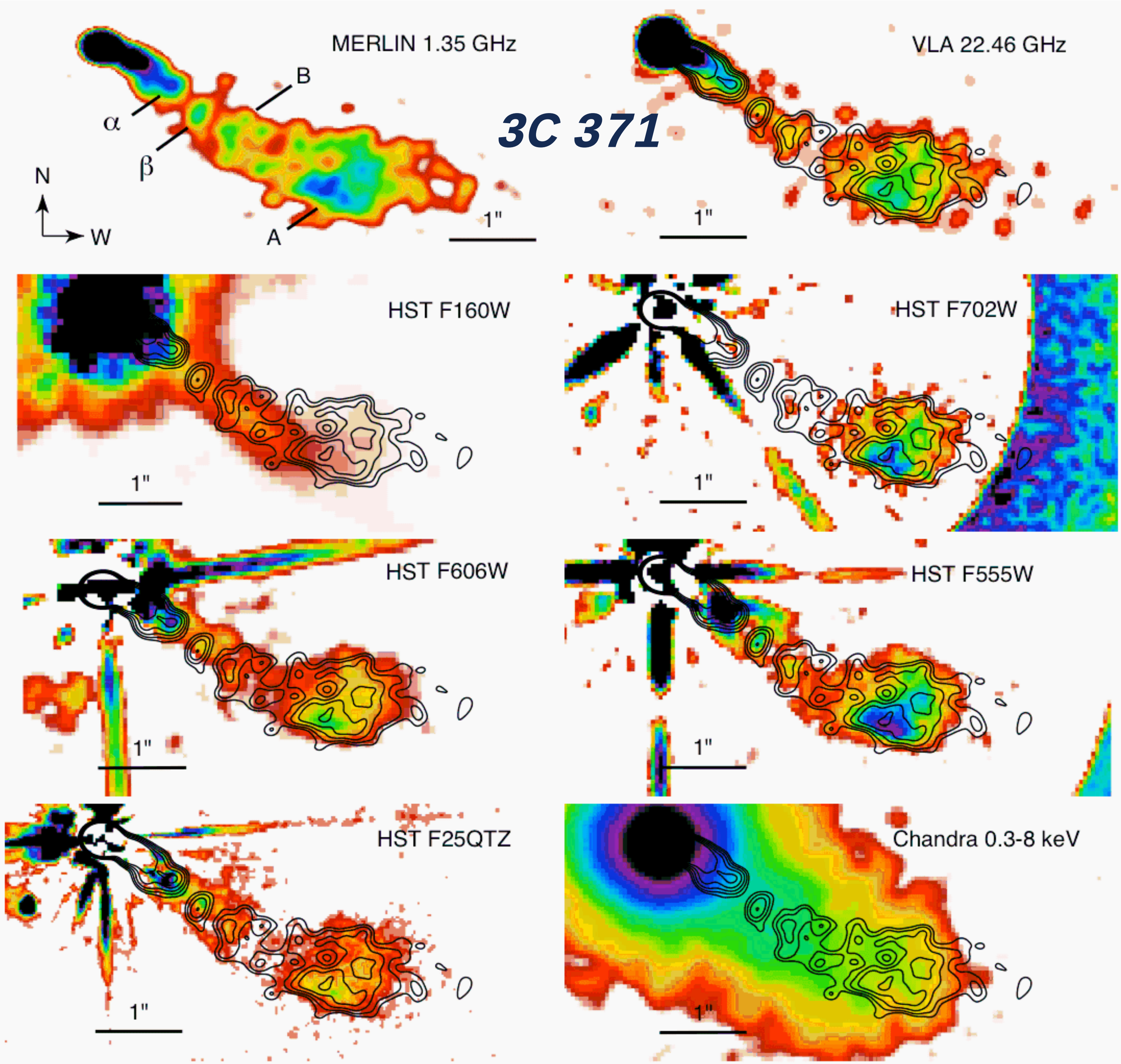
3C 264

- Resolution of Chandra data too low to firmly associate inner jet X-ray emission with optical feature
  - But polzn anomalies at 0.8" from nuclueus,just upstream of "ring" & near region of flatter optical spectrum
- Outer jet emission -- optically faint, hard to tell





3C 371

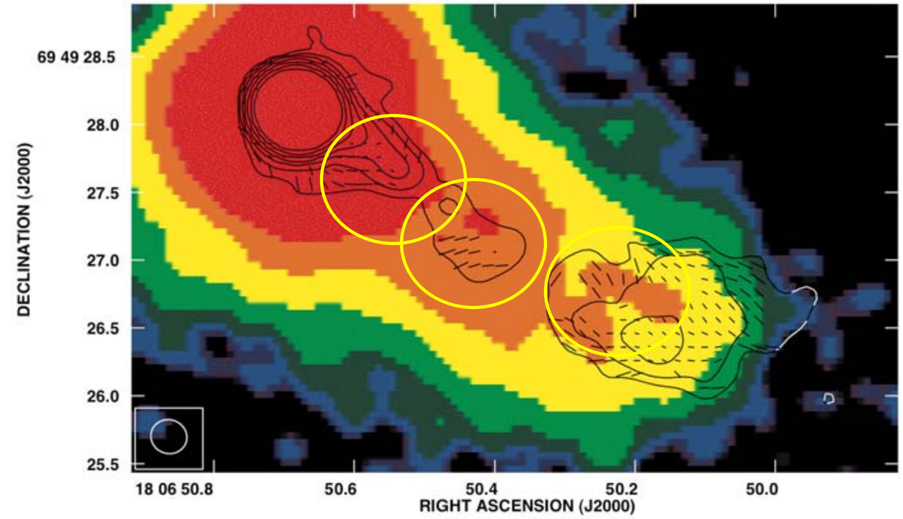

MERLIN 1.35 GHz
α
β
A
B
N
W
1"
VLA 22.46 GHz
1"
HST F160W
1"
HST F702W
1"
HST F606W
1"
HST F555W
1"
HST F25QTZ
1"
Chandra 0.3-8 keV
1"

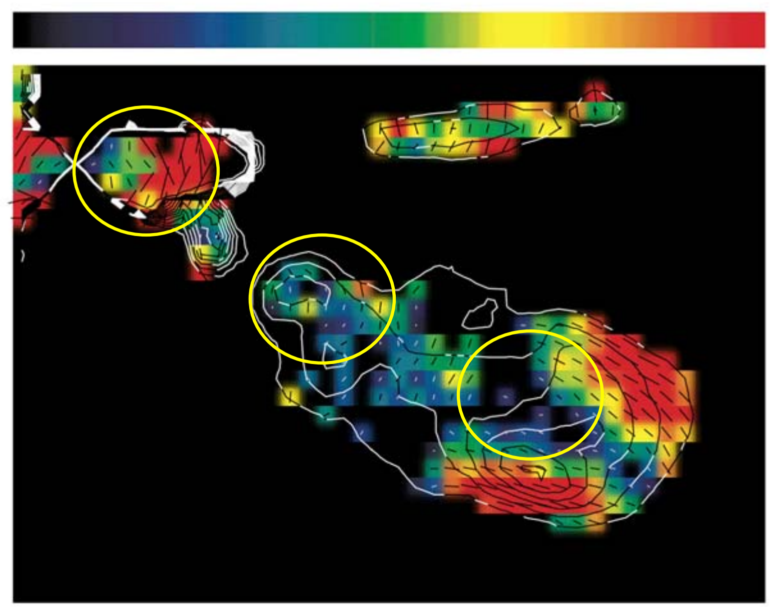
3C 371

Optical shows low polzn in 2 X-ray maxima, high polzn in one.

Significant rotations seen in optical

Neither is seen in radio





Summary

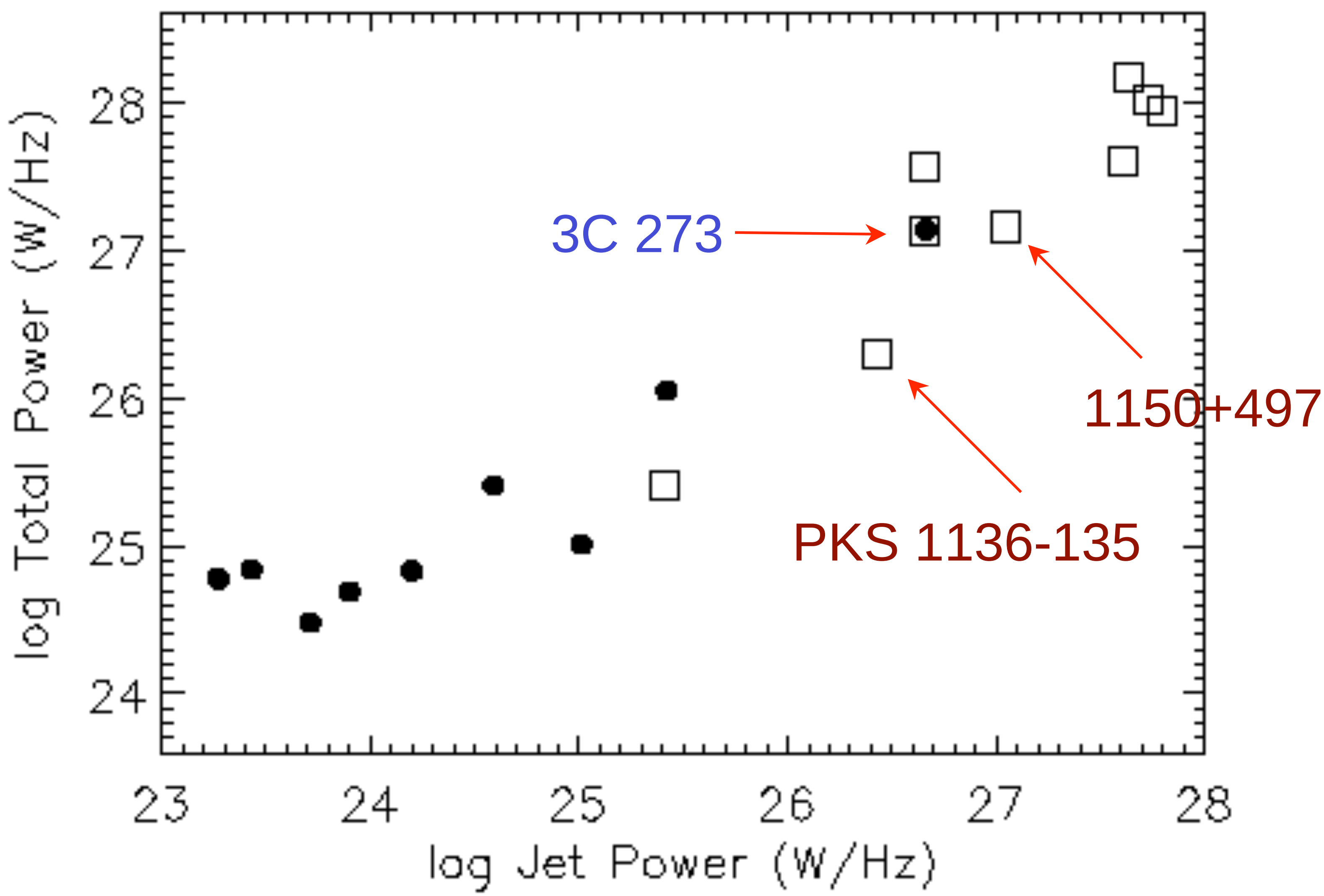
In all cases, *something* happens in opt polarization at X-ray maximum

- But: different in each jet and each component
- usually NOT seen in radio
- Synchrotron X-ray emission from only a small part of jet X-section

Optical Polarimetry can serve as a diagnostic for X-ray emission mechanism

- Important because X-ray polarimetry with Chandra resolution is at least a decade away.

This is crying out to be done for higher-power jets!



3C 273
1150+497
PKS 1136-135
28
27
26
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23
24
25
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27
28
log Total Power (W/Hz)
log Jet Power (W/Hz)

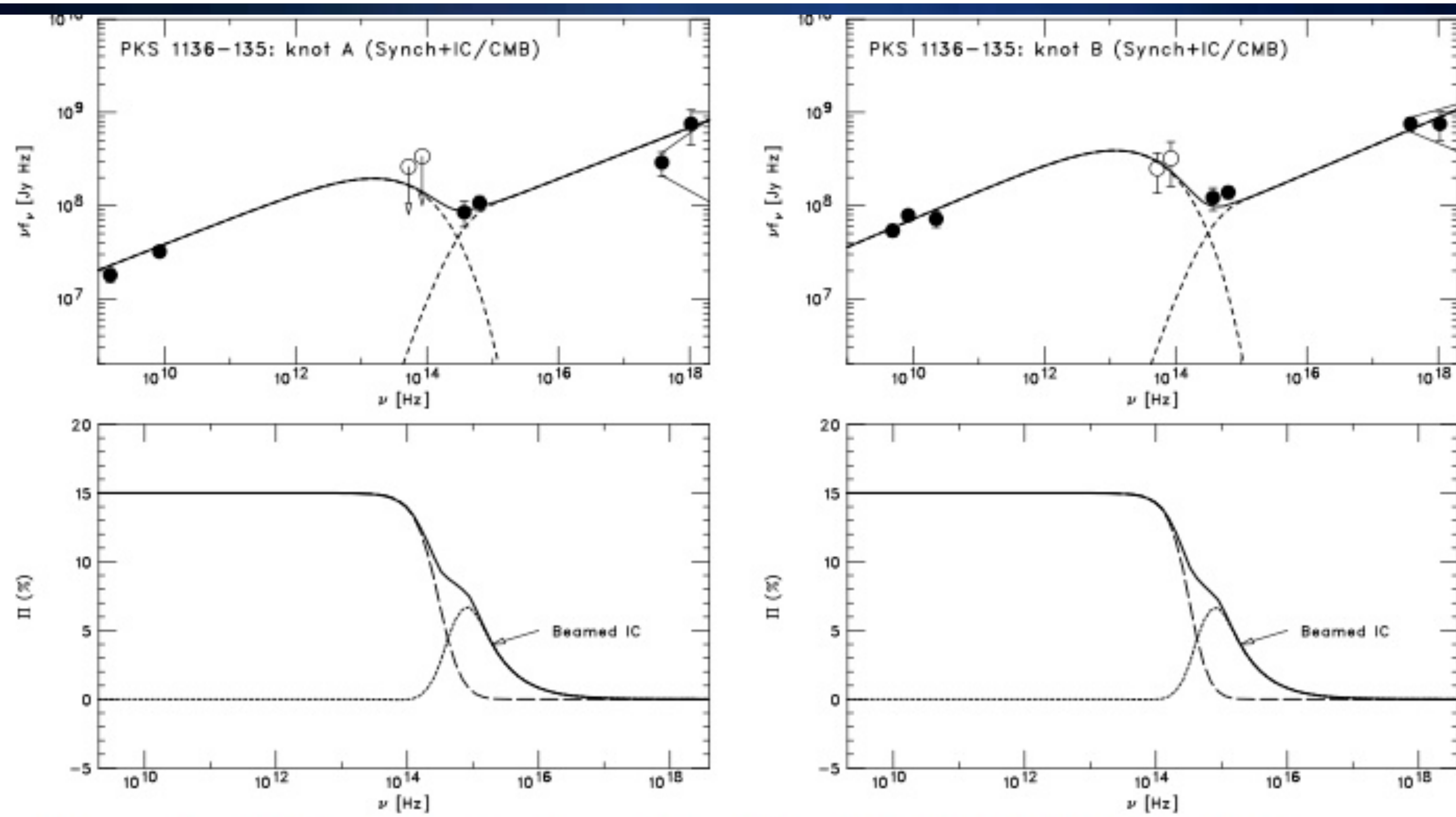
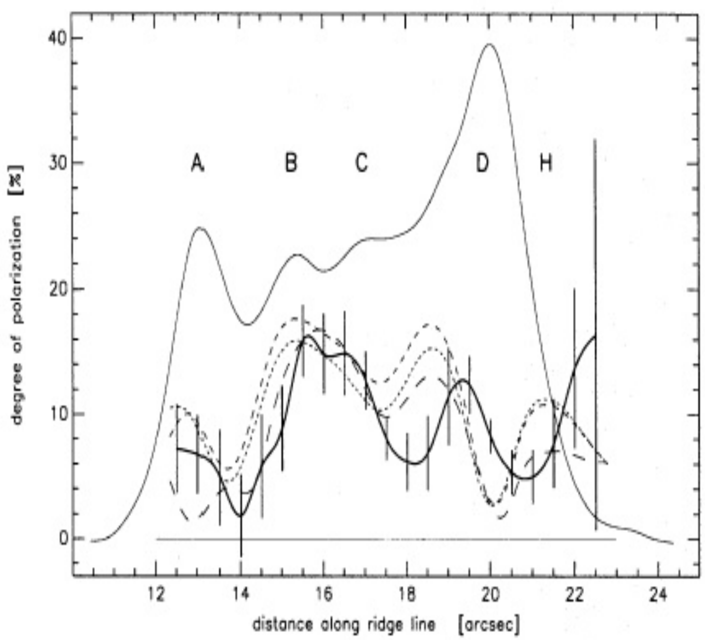
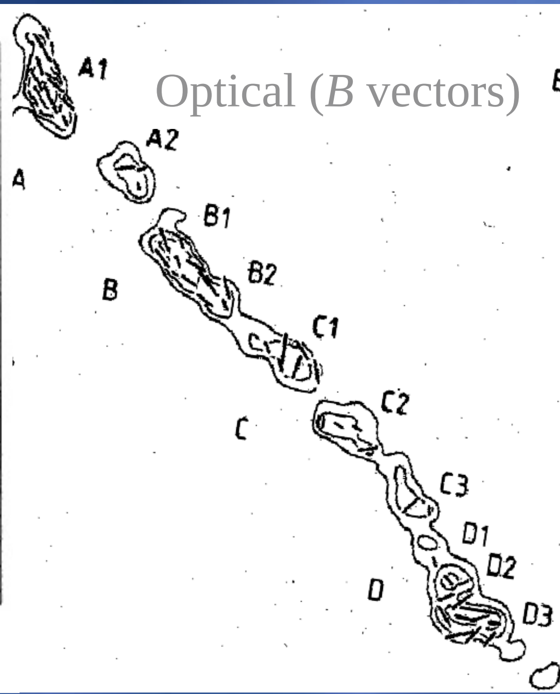
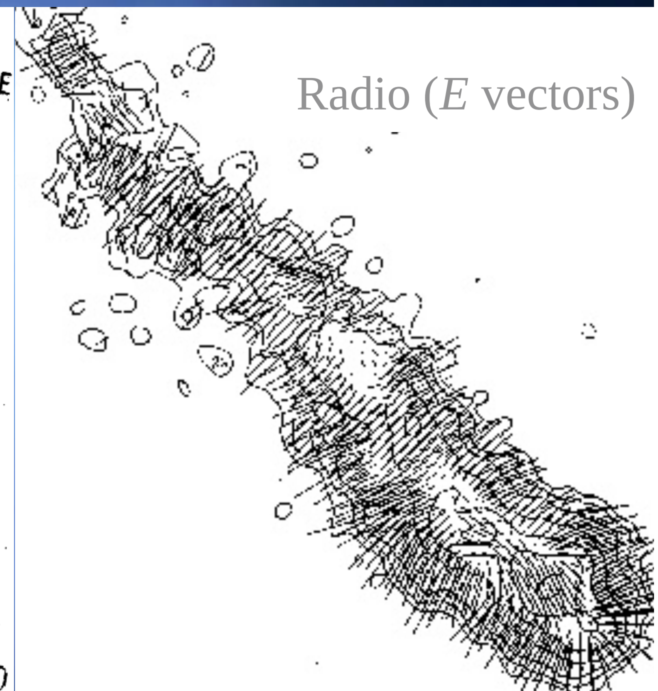


Figure 1. At top, the SEDs of knots A and B of the PKS 1136-135 jet (Uchiyama et al. 2007). The optical to X-ray emission is linked by a single component, the nature of which is unknown. At bottom, the expected degree of polarization for the case where IC-CMB is responsible for the optical-X-ray emission. The dashed line represents the synchrotron component, assumed to have 15% polarization, while the dotted line shows the beamed IC component. A power-law population of jet electrons, extending down to $\gamma = 2$ was assumed, plus a Doppler factor $\delta = \Gamma = 15$. Because the CMB seed photons are unpolarized, significant polarization is observed in the IC-CMB component only at the very lowest energies (Begelman & Sikora 1987, Poutanen 1994, Georganopoulos et al. 2005). *Optical polarimetry can uniquely determine the nature of the high-energy emission in FR II jets and its relationship to lower-energy particles and radiation.*

3C 273: Polarimetry







Thomson et al. 1993, Röser et al. 1996, Perley et al. 2001

P largely tracks flux in knots A, B, but is anticorrelated with flux in knots C, D

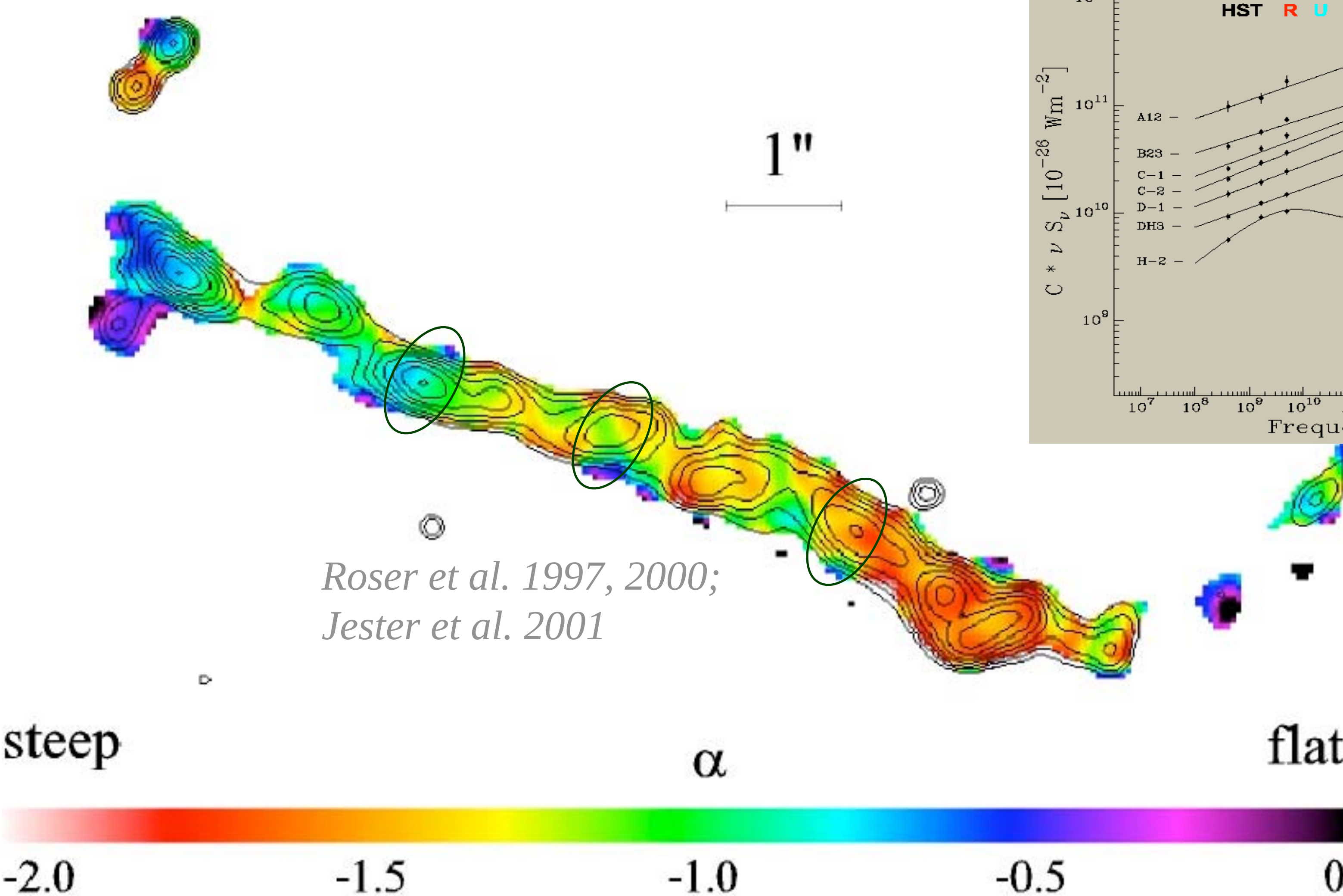
Strong, local, perpendicular magnetic field in knot H

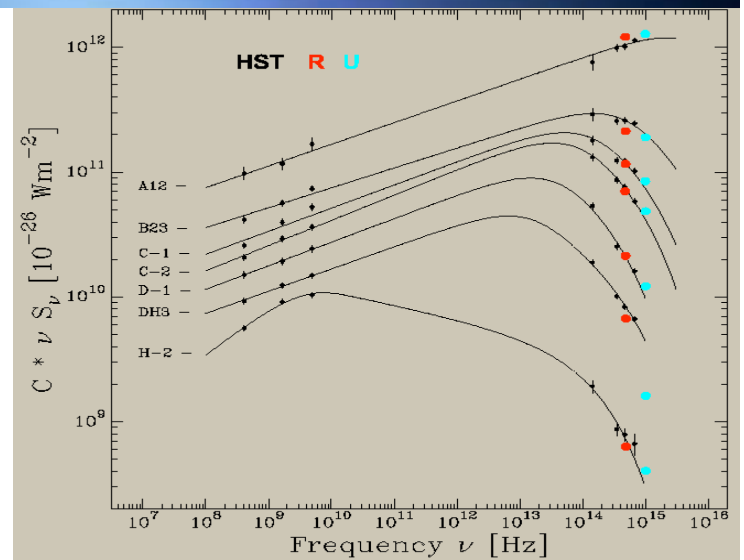
HST Polarimetry too low S/N in many faint, interesting regions - needs to be redone!

3C 273: Spectral Structure

Opt. spectrum steepens gradually & turnover frequency decreases gradually

Flatter spectra in knots BUT on 0.1” scale but poor correlation with flux





Roser et al. 1997, 2000;
Jester et al. 2001

3C 273: X-ray morphology

Knot B X-ray, optical max offset

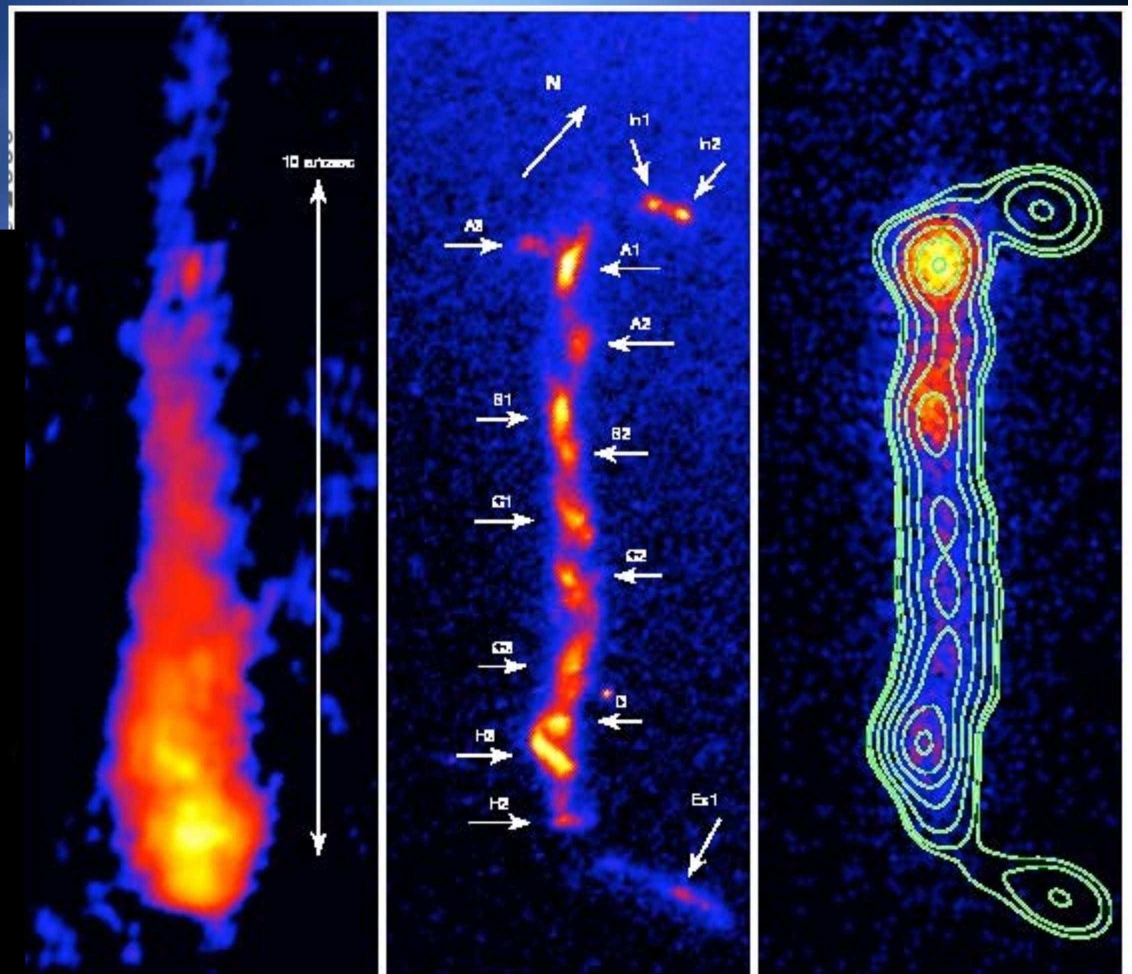
X-ray emission at downstream end stops before optical

Outer knots appear fainter in X-ray

Some X-ray knots are narrower than optical

Radio | HST | *Chandra (image) smoothed HST (cont*

Radio   *HST*   *Chandra (image) smoothed HST (cont*



Marshall et al. 2001, Sambruna et al. 2001; Perlman et al., in prep.