Particle distributions in large scale radio jets

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CANONICAL PARTICLE ACCELERATION IN FR I RADIO GALAXIES

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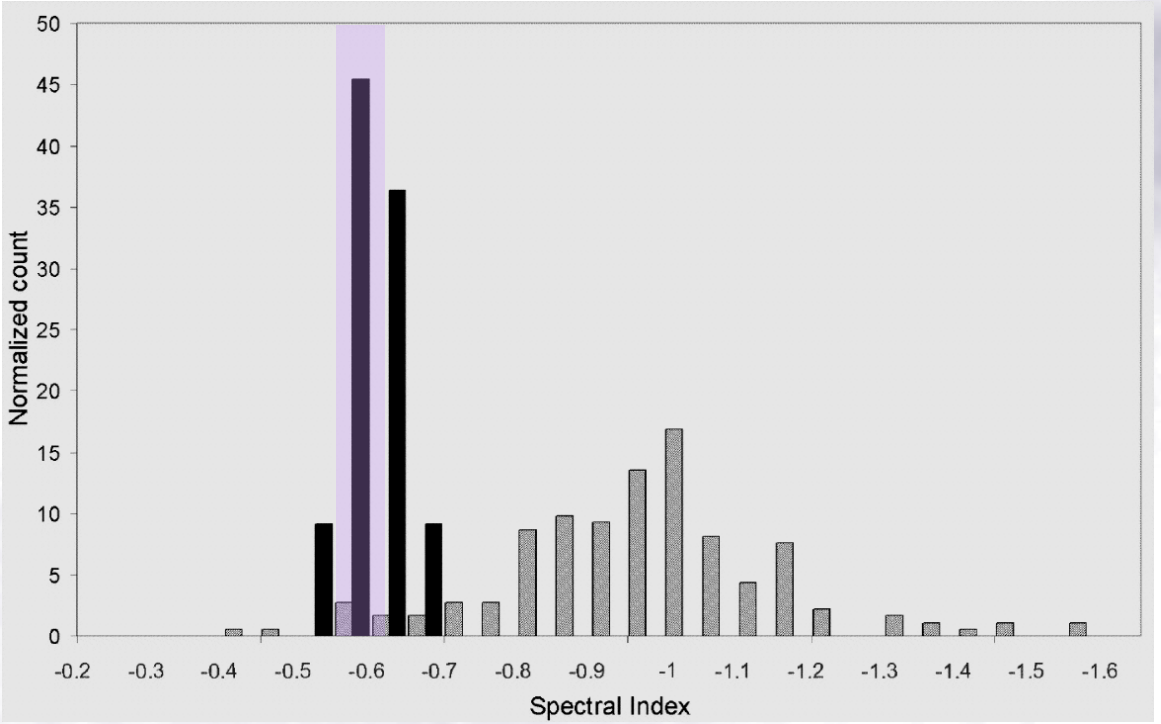
CONCLUSIONS



FRI (low luminosity, non-classical double source) jets have a narrow distribution of low frequency

spectral (energy) indices around -0.55 (-2.1),
not the test particle strong shock limit of ~~-0.50~~ (~~-2.0~~).

Particle acceleration in kpc jets

Why look in the radio?

How do you look in the radio?

What do we find about particle distributions?

WHY look in the radio?

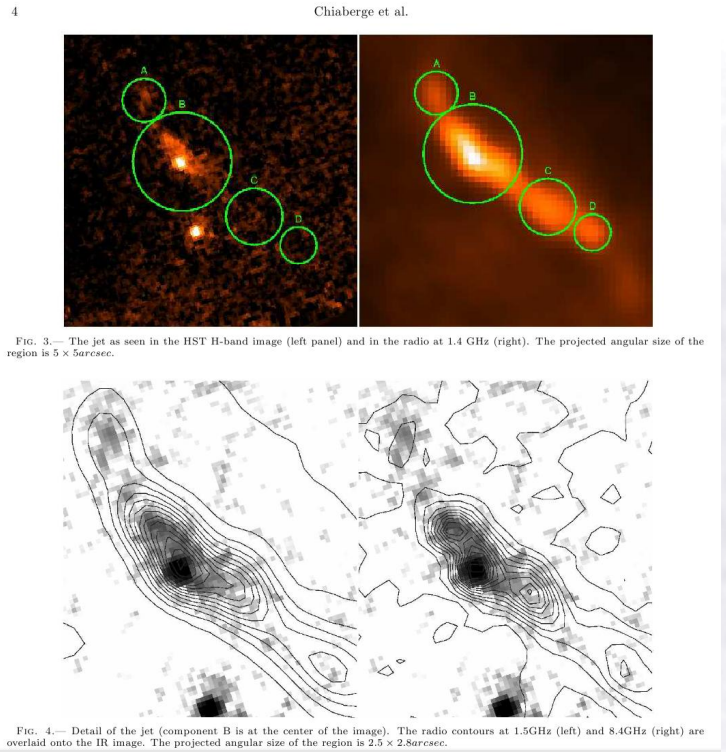
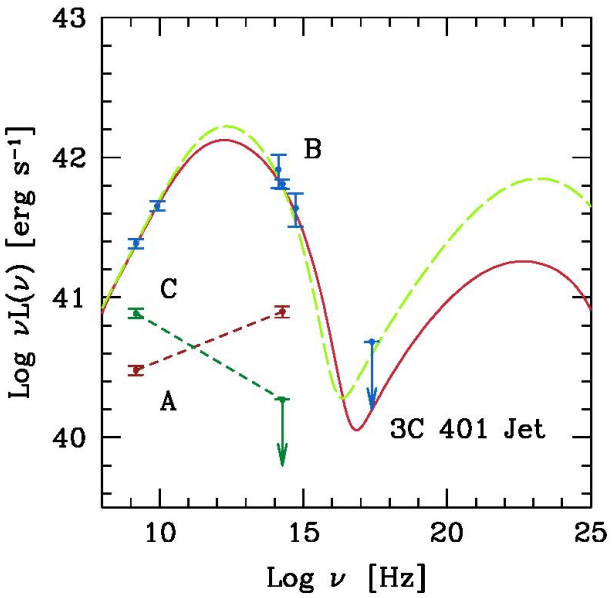


FIG. 3.— The jet as seen in the HST H-band image (left panel) and in the radio at 1.4 GHz (right). The projected angular size of the region is $5 \times 5 arcsec$.

FIG. 4.— Detail of the jet (component B is at the center of the image). The radio contours at 1.5GHz (left) and 8.4GHz (right) are overlaid onto the IR image. The projected angular size of the region is $2.5 \times 2.8 arcsec$.



Low frequencies – can see <u>injection power law</u>

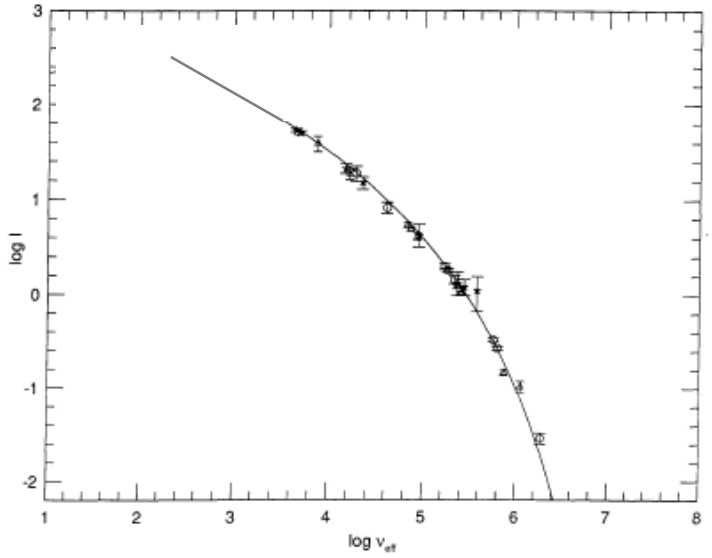
– averages over long timescales

HOW do you measure low frequency (injection) slope?

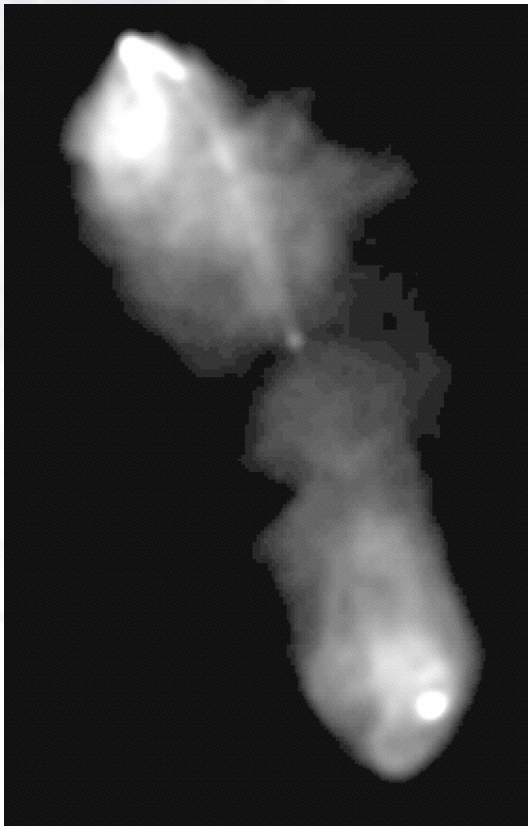
1. Need clear indication of low frequency power law

2. Must measure homogeneous population
   - resolve spatial variations in spectra
   - separate out background (lobe) confusion

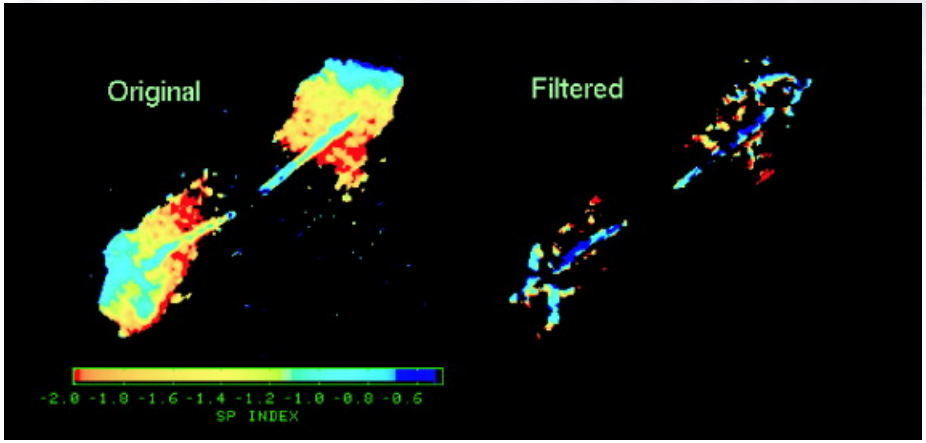
Has the low frequency power law been seen?



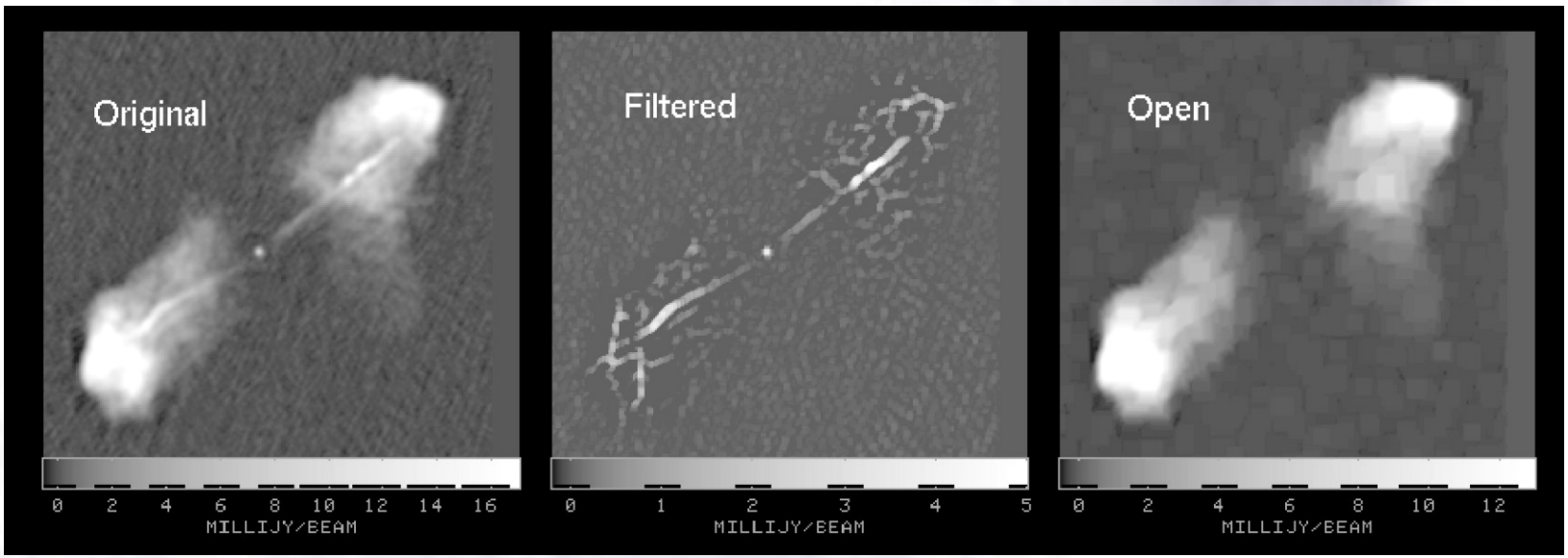
Has jet/lobe emission been separated?

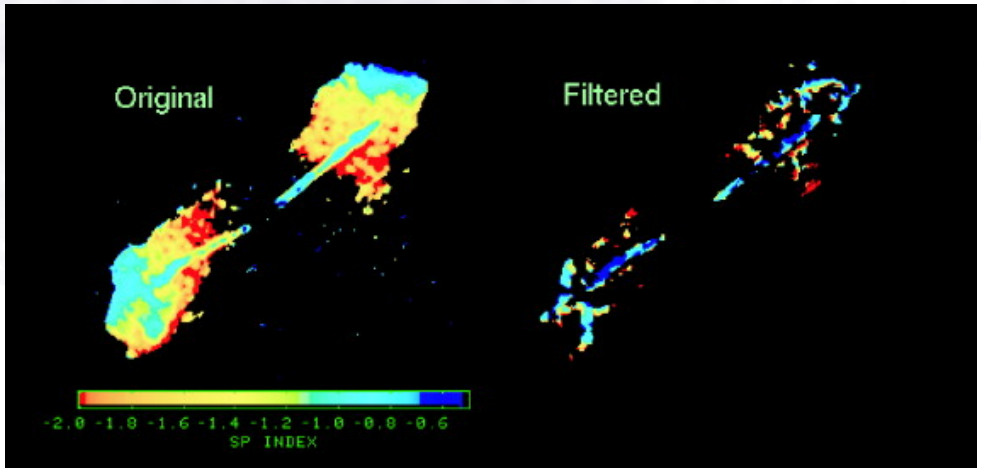


Are spectral variations adequately resolved?



Multi- resolution filtering





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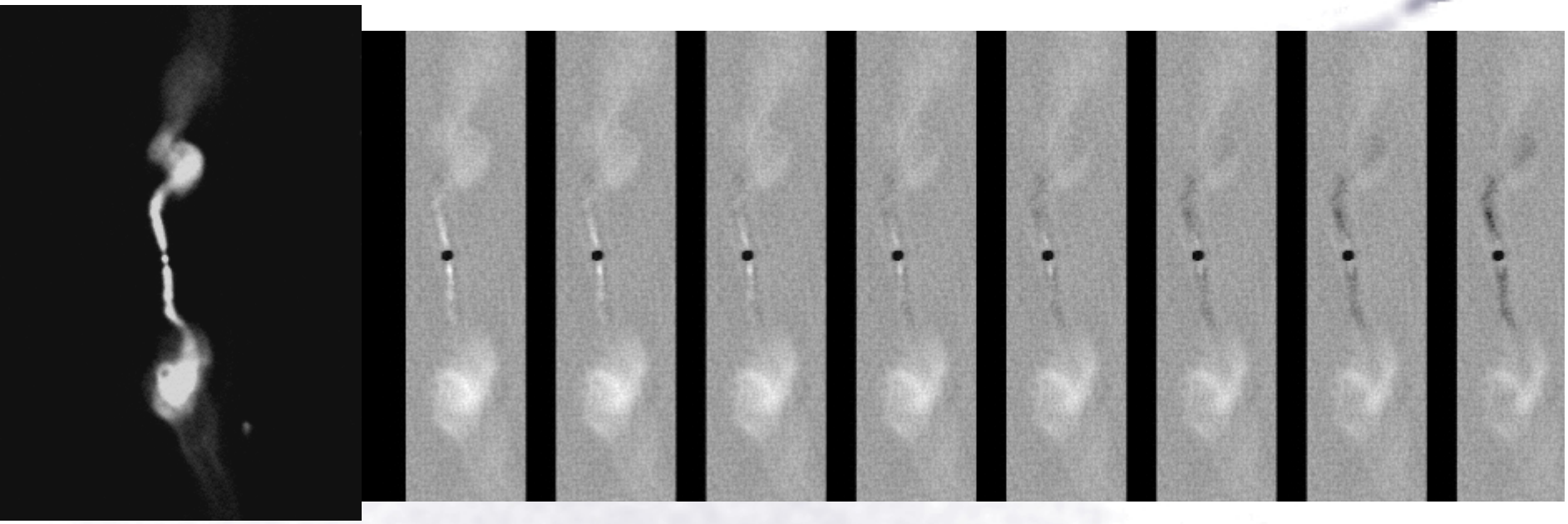
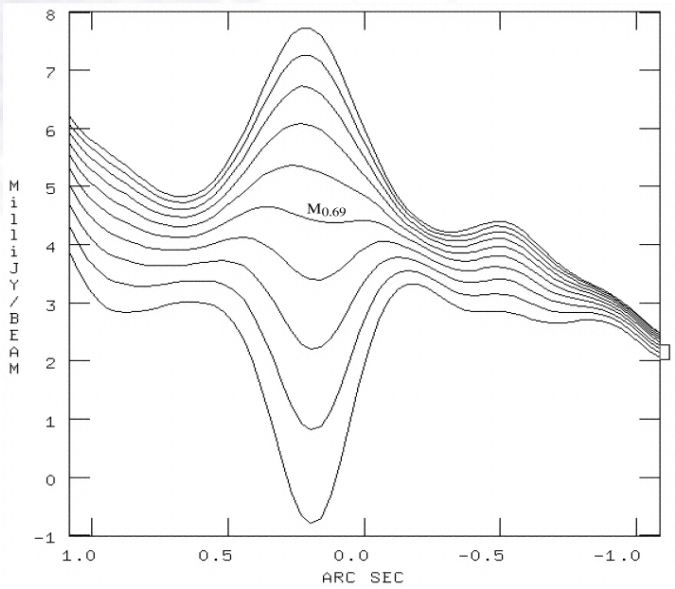
Spectral Tomography

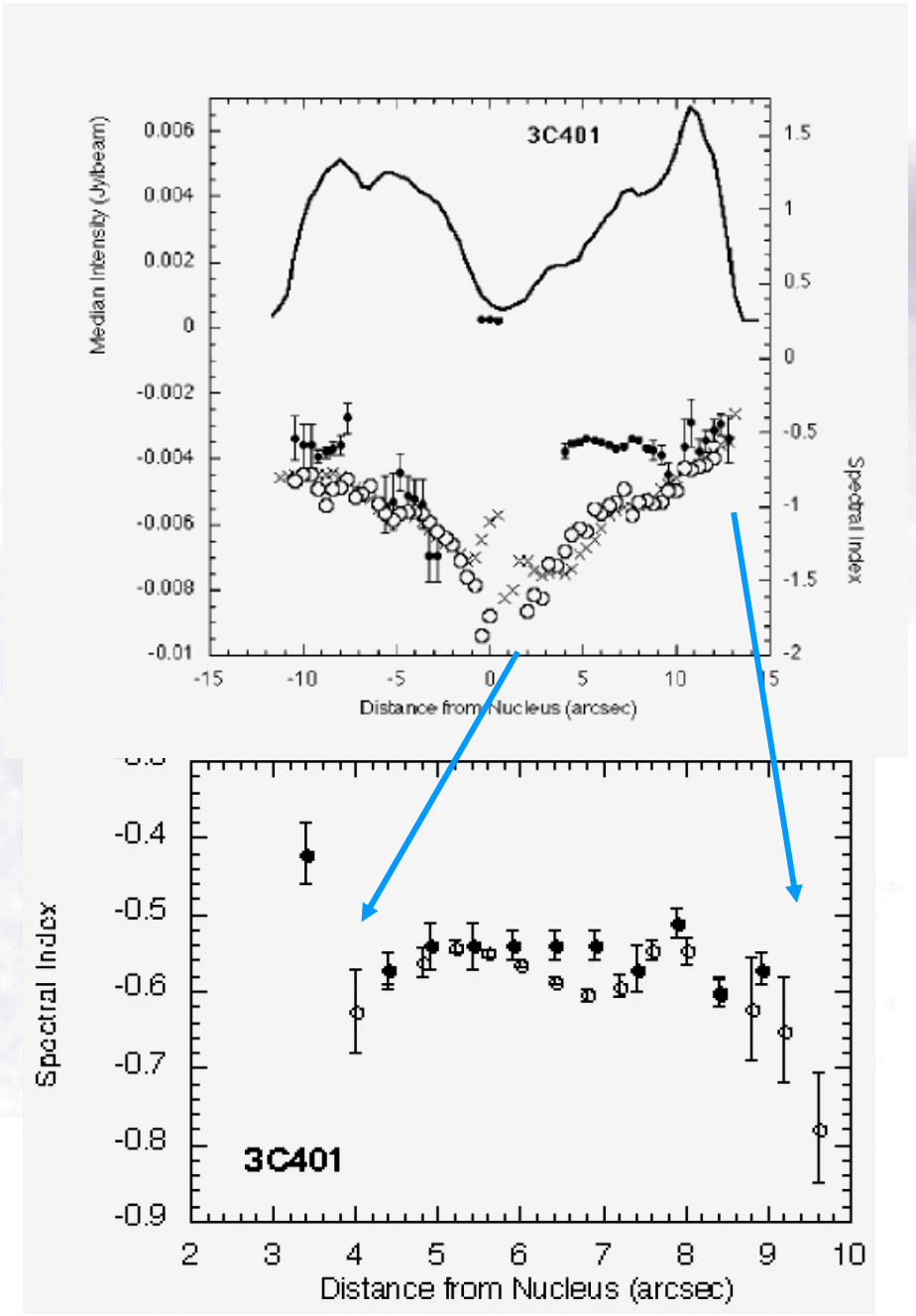
Make series of images, S_t by varying α_t

$$S_t = S(\nu_2) - (\nu_2/\nu_1)^{\alpha_t} * S(\nu_1)$$



Jet spectra from tomography





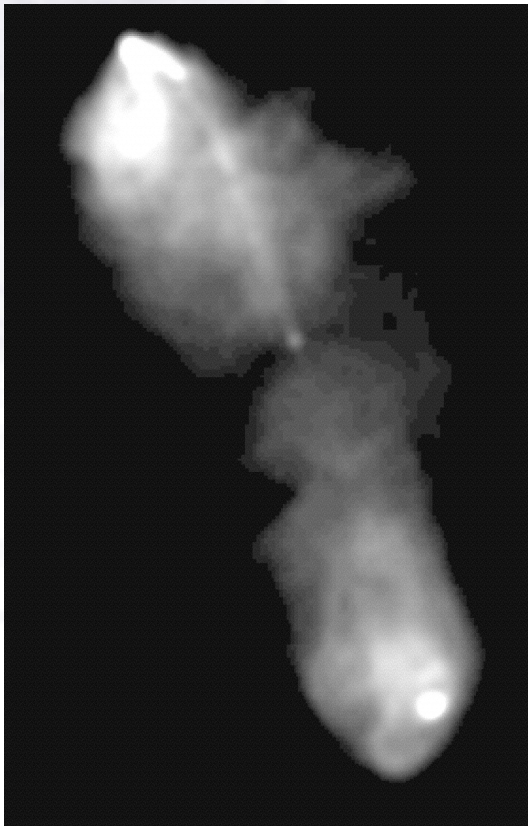
x = original map

● = filtered

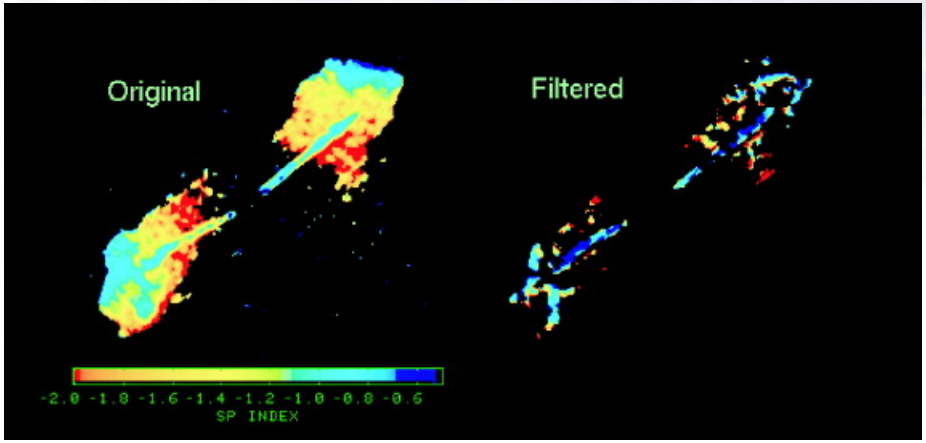
● = filtered

○ = tomography

Has jet/lobe emission been separated?



Are spectral variations adequately resolved?

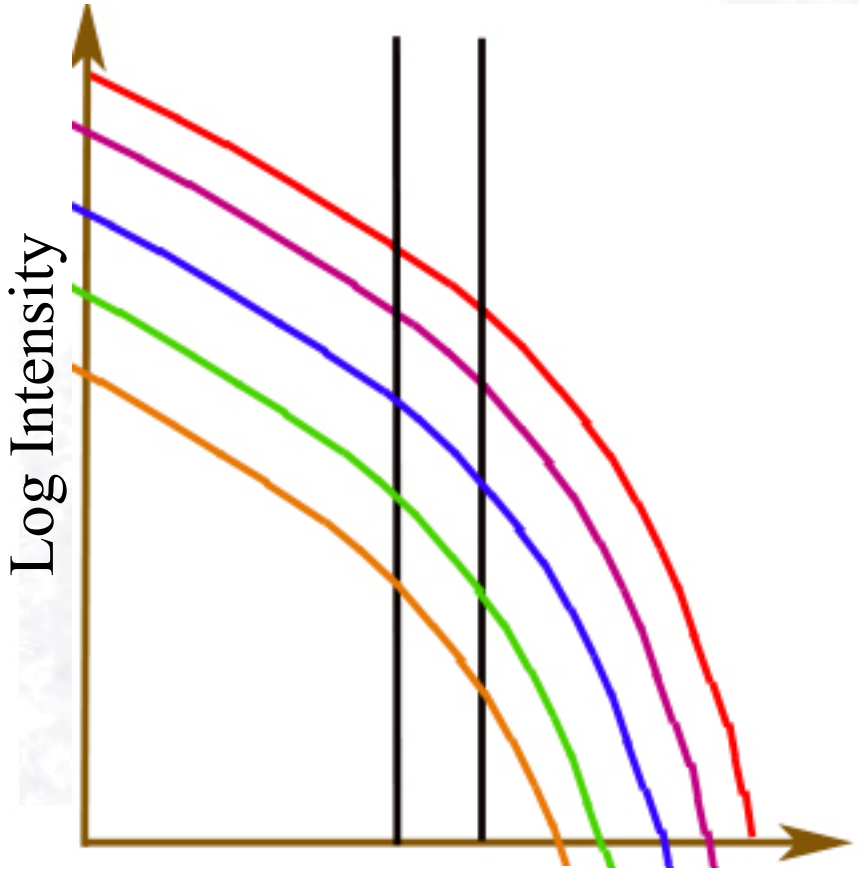


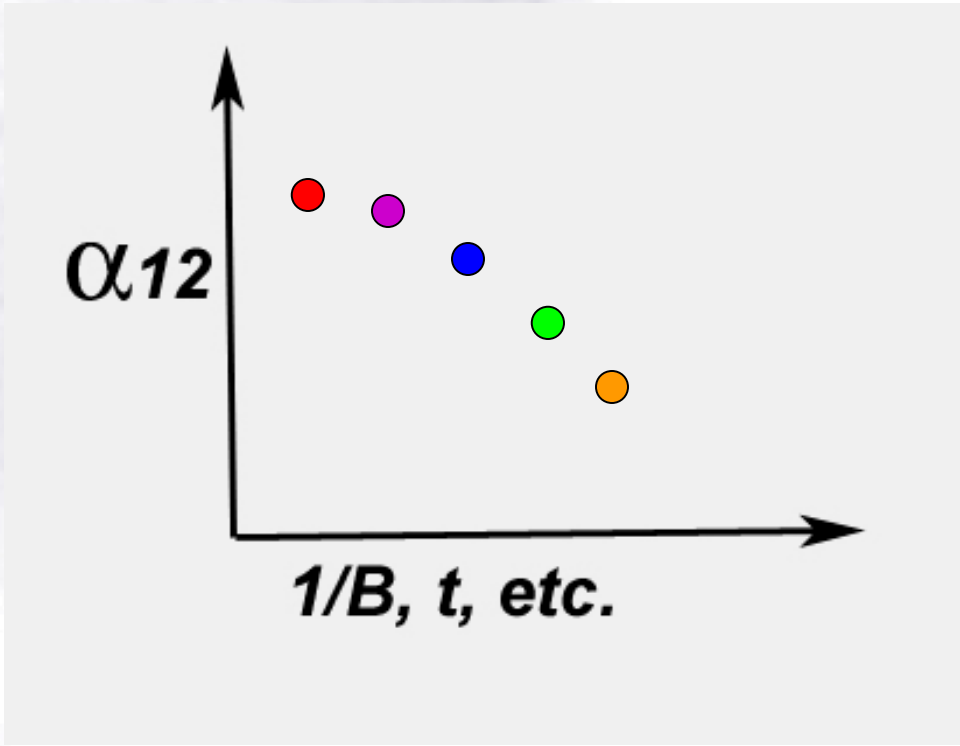
Determining the low frequency index

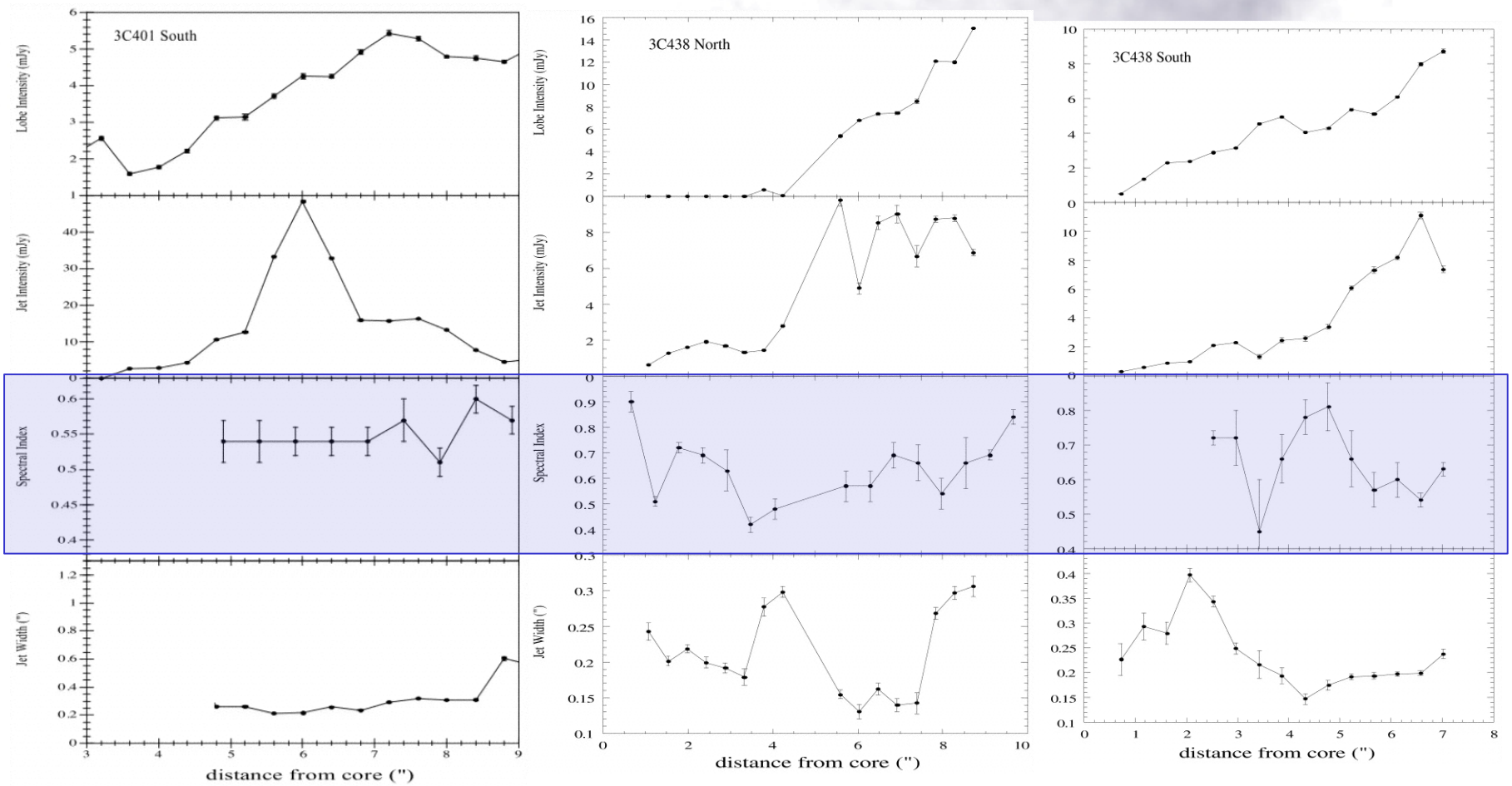
3. Asymptotic behavior → nucleus

4. Color-color diagrams

Evolving electron population – spectral changes







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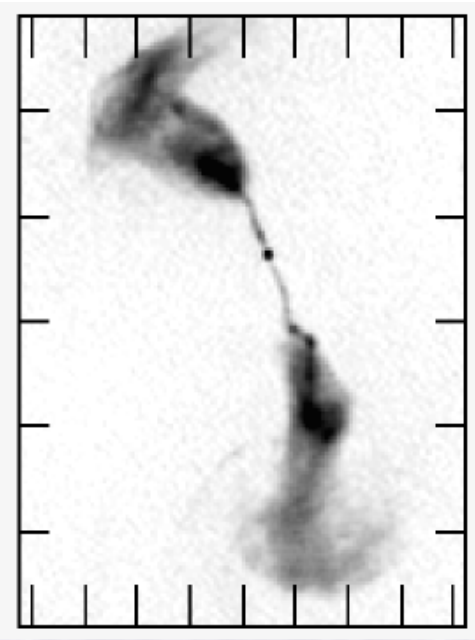
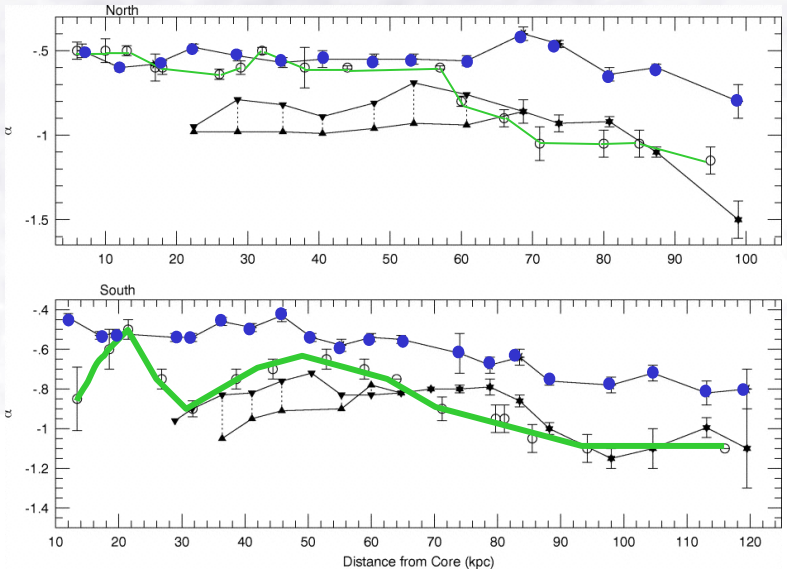
Tomography separation –

Original spectrum

Jet

(& sheath)

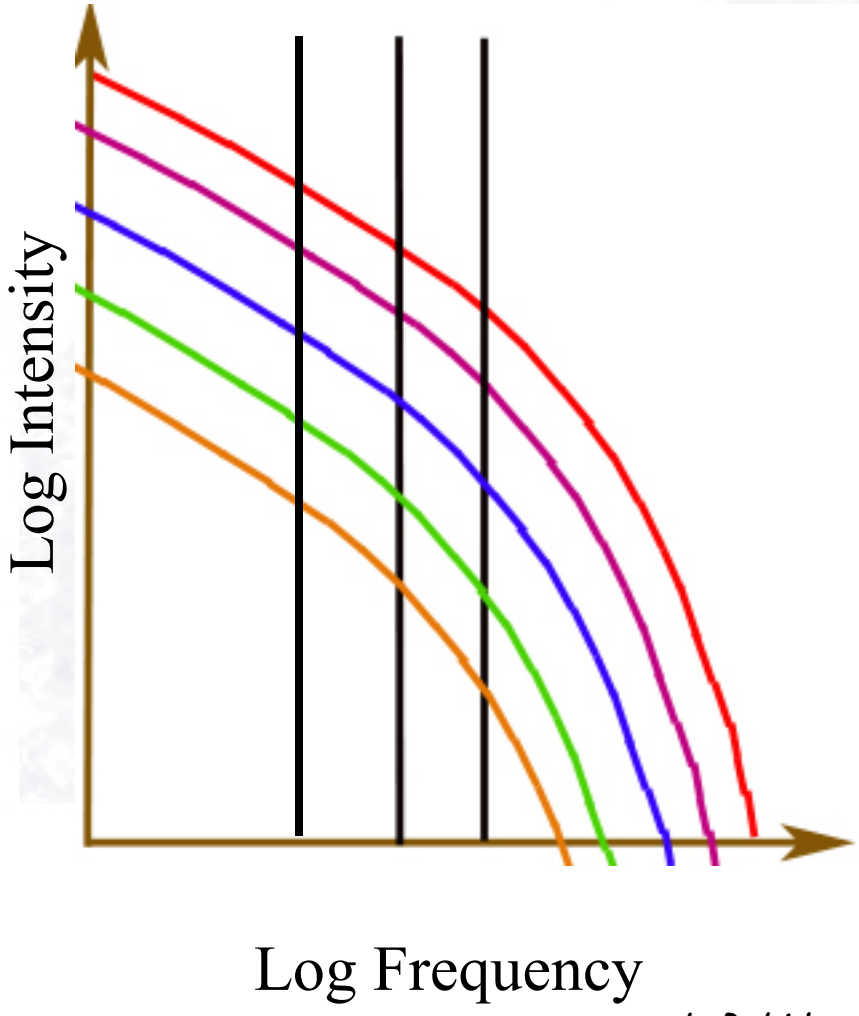


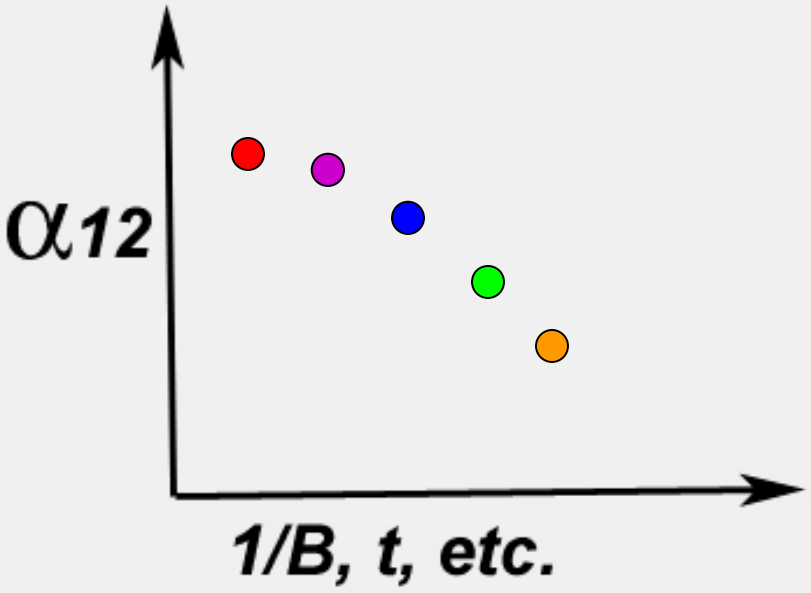


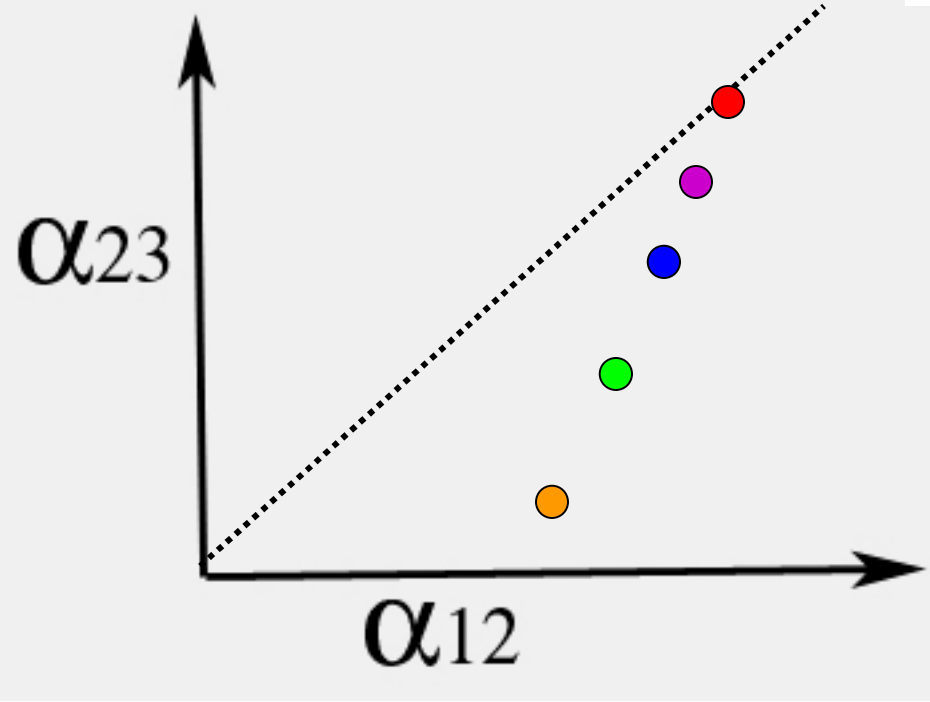
COLOR-COLOR Diagrams

reconstructing full spectral shapes from three frequency observations

Evolving electron population – mapping spectral shape







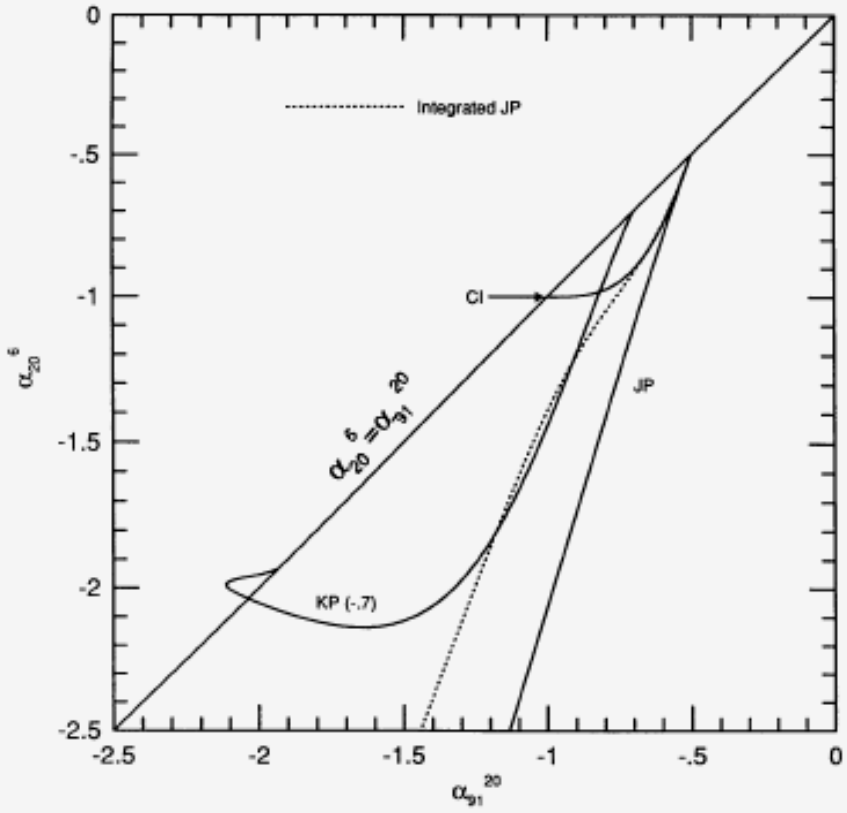
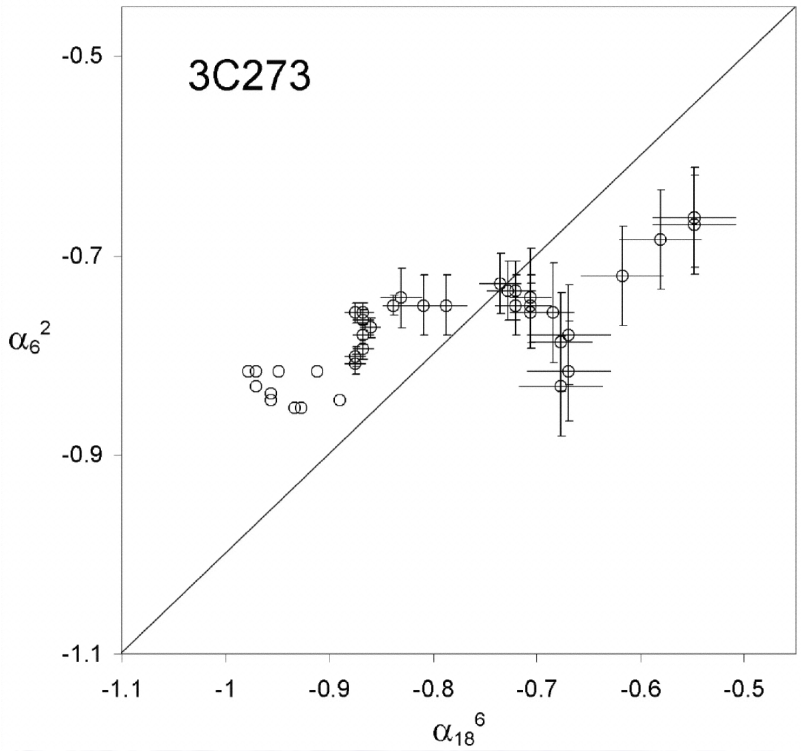


FIG. 2.—Color-color diagram displaying conventional aging models and an integration of JP spectra (*dotted line*). The $\alpha_{inj} = -0.5$ for all models except for KP, where $\alpha_{inj} = -0.7$. All the models intersect the $\alpha_{20}^{6} = \alpha_{91}^{20}$ line indicating a power law at the low-frequency end of the spectrum.

Color-color – problem diagnosis



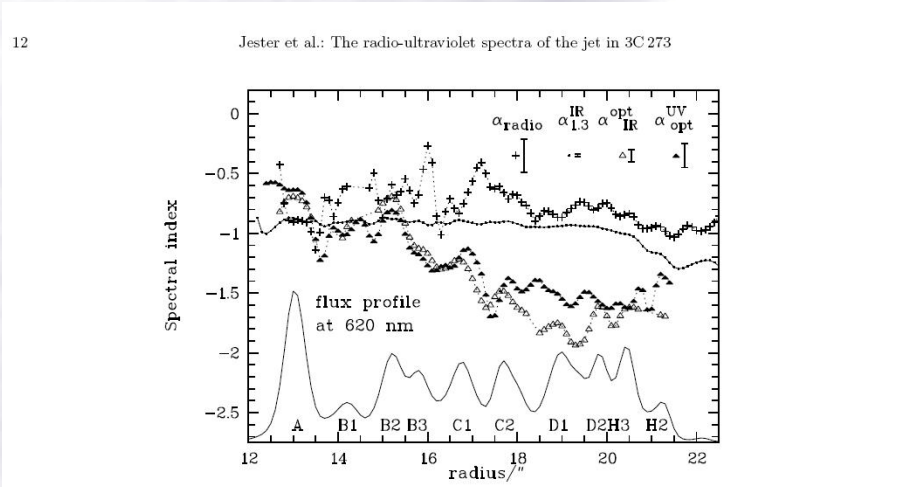


Fig. 8. Run of the spectral indices along the jet at 0.″3 resolution, sampled in 0.″1 intervals (cut along radius vector at position angle 222.°2). For sake of clarity, only typical 2σ error bars are shown for the random error. Systematic flux calibration uncertainties are of the same order and would shift an entire curve. The radio spectral index α_{radio} is obtained by a fit to the radio data at 3.6 cm, 2.0 cm, and 1.3 cm. The other spectral indices are derived from the jet photometry at the given wavelengths ($\alpha_{1.3}^{IR}$: 1.3 cm and 1.6 μm, α_{IR}^{opt}: 1.6 μm and 620 nm, α_{opt}^{UV}: 620 nm and 300 nm). The optical flux profile is shown for reference. Reprinted from Jester et al. (2002) for reference.

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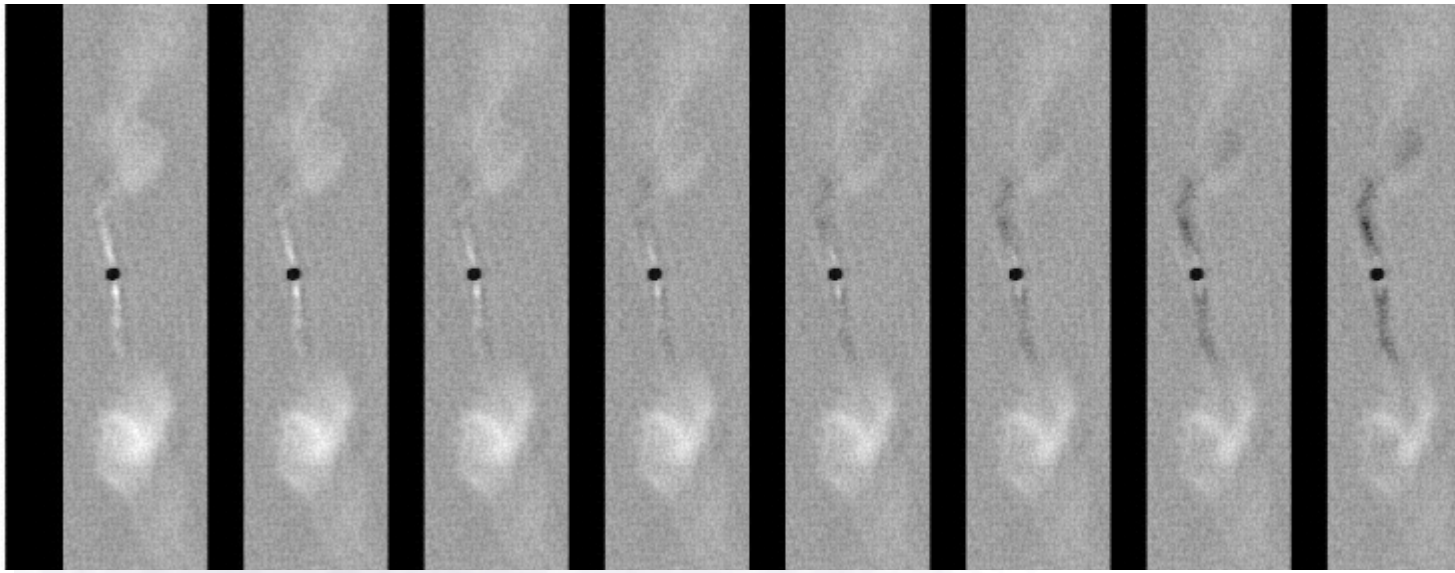

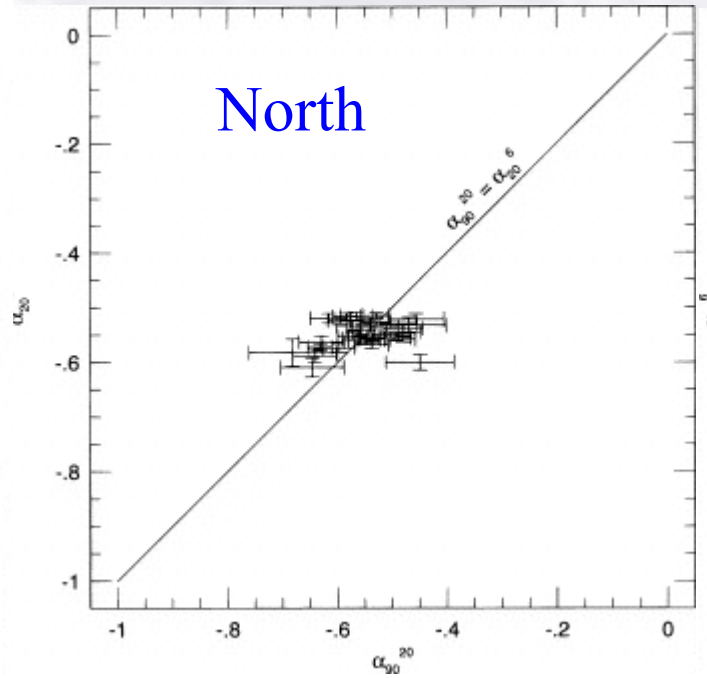

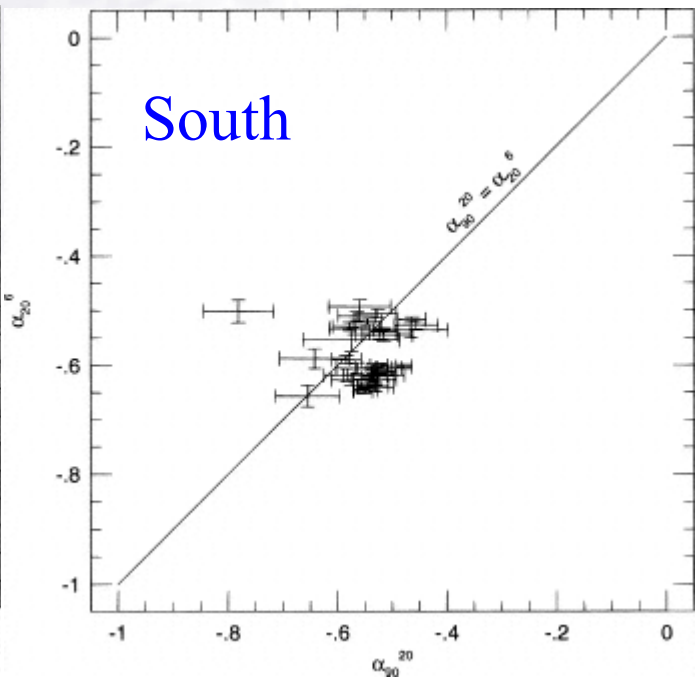

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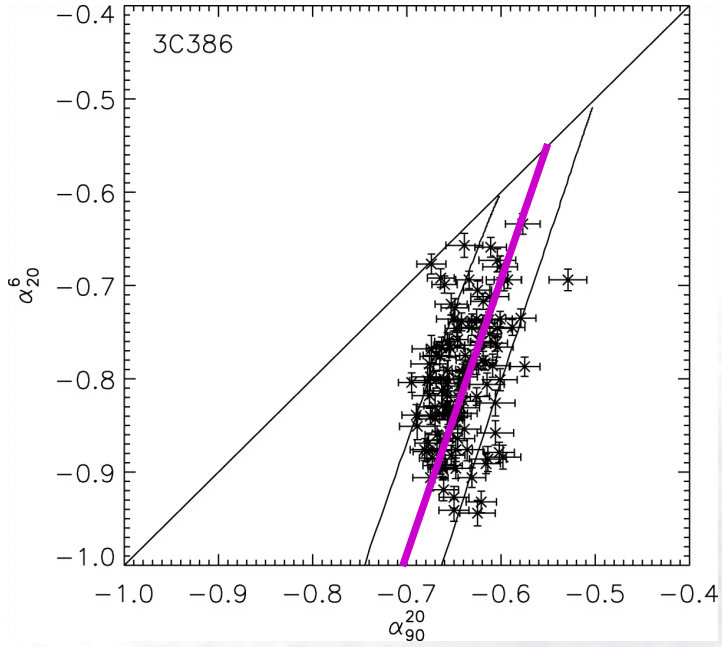
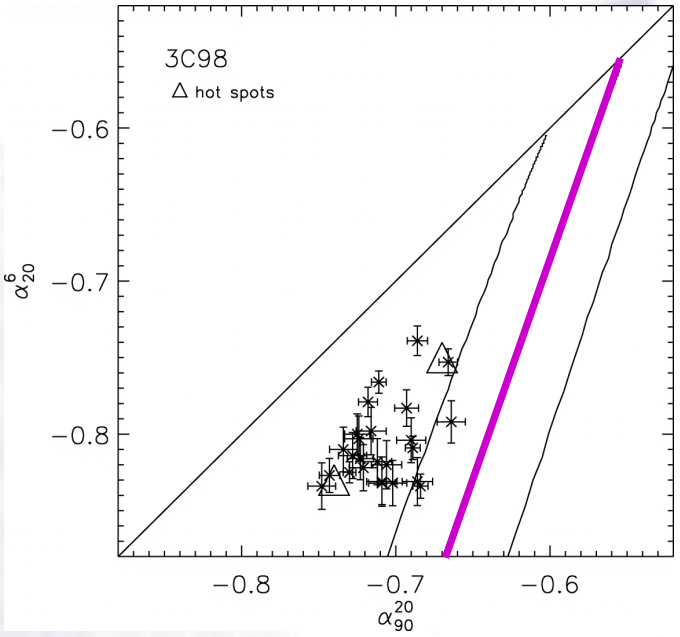
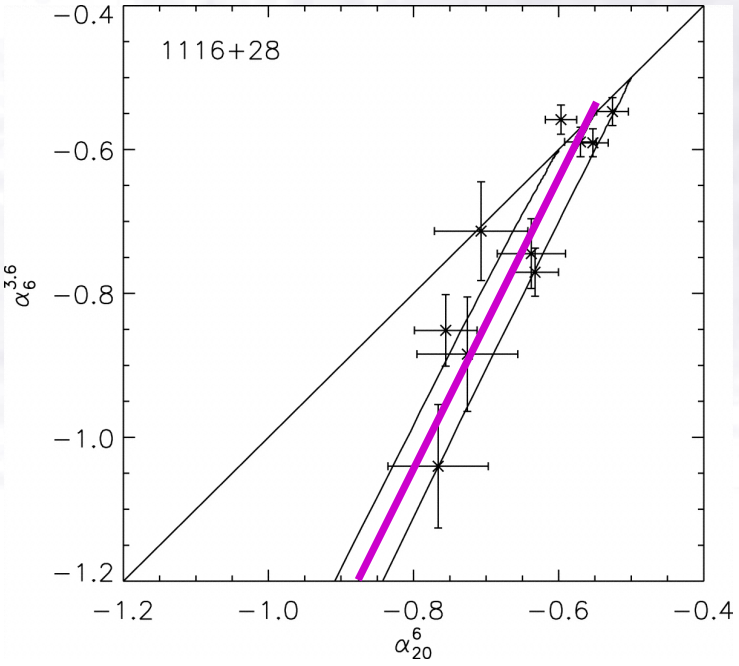
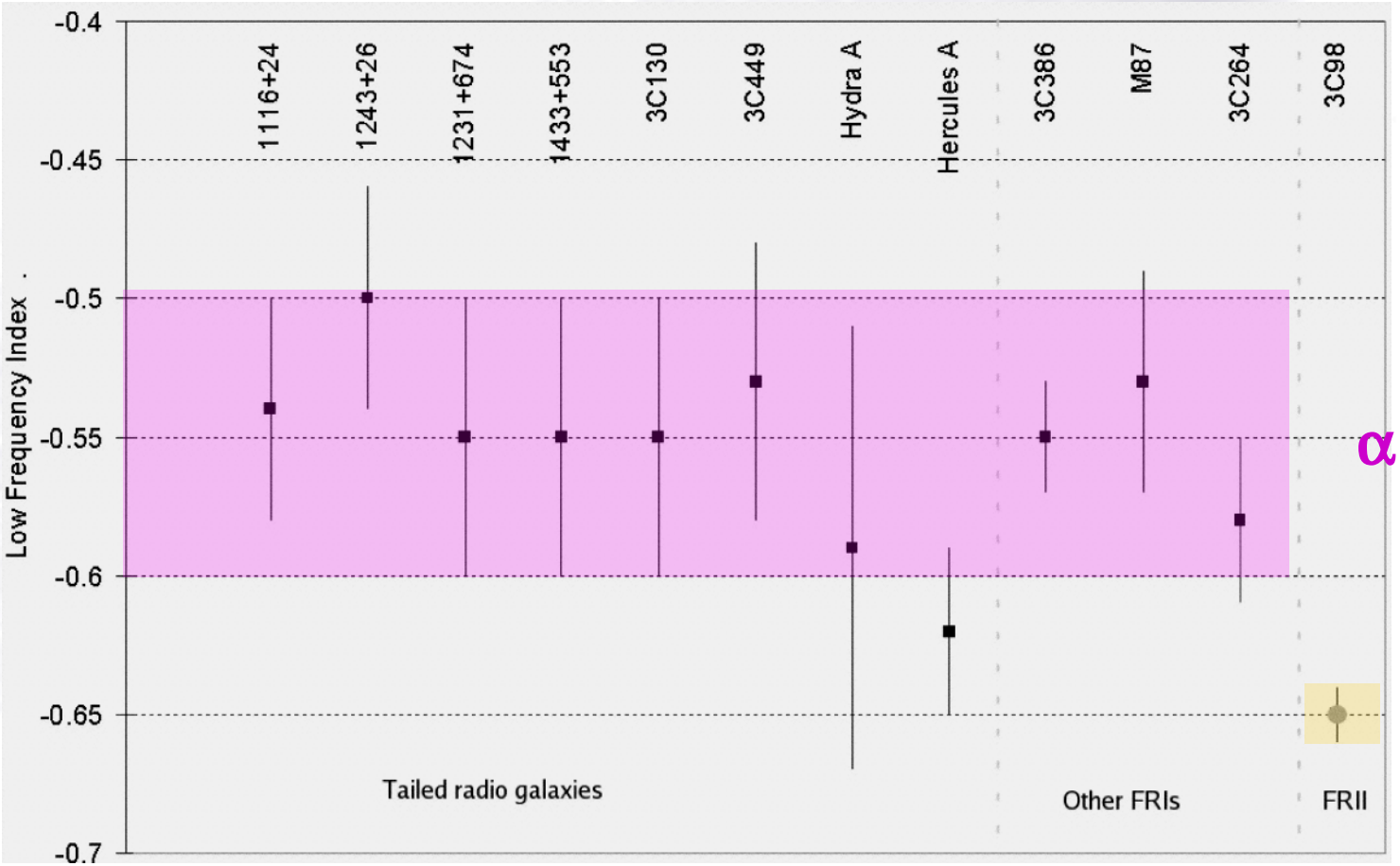

3C386
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
−1.0
α_{20}^{6}
−1.0 −0.9 −0.8 −0.7 −0.6 −0.5 −0.4
α_{90}^{20}


3C98
△ hot spots
−0.6
−0.7
−0.8
α_{20}^{6}
−0.8 −0.7 −0.6
α_{90}^{20}


1116+28
−0.4
−0.6
−0.8
−1.0
−1.2
$\alpha_{6}^{3.6}$
−1.2 −1.0 −0.8 −0.6 −0.4
α_{20}^{6}

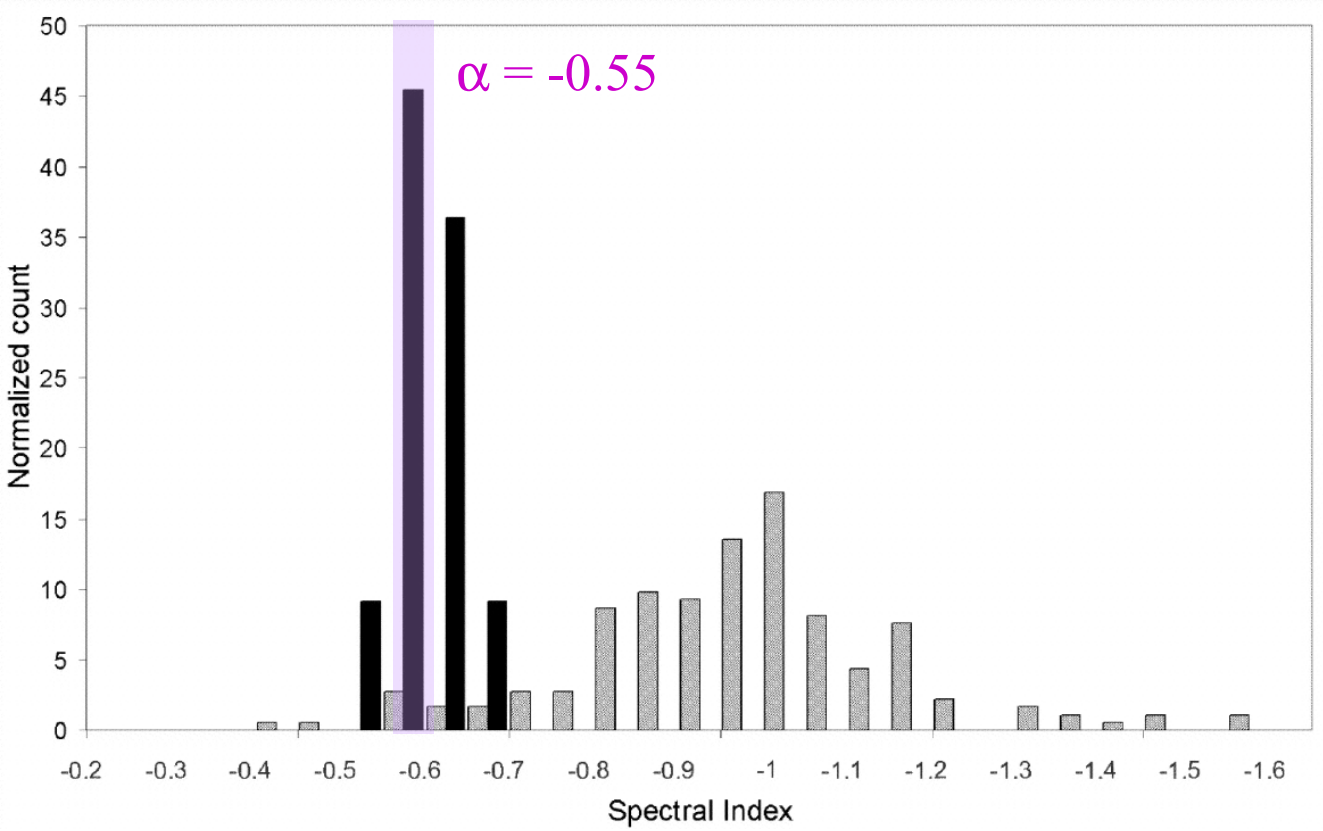
$\alpha = -0.55$

Summary of spectra



$\alpha = -0.55$

Summary of spectra



Regulating ~ -0.55 *-- where?*

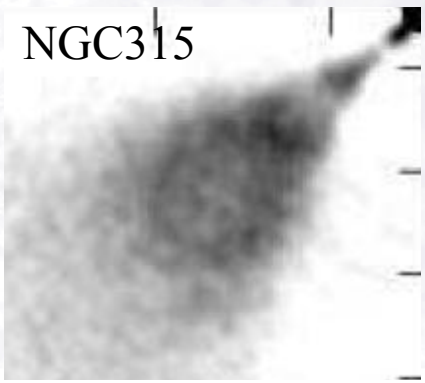
Initial acceleration at nucleus?

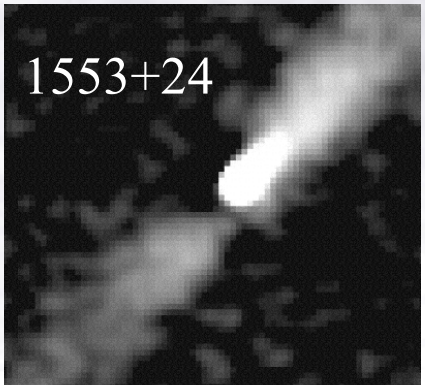
[– e.g.,Hydra A

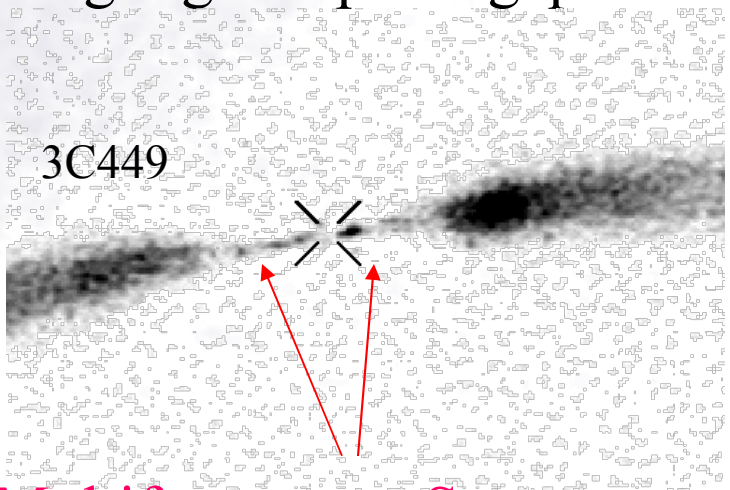
pc scale, optically thin regions -0.7,

kpc scale, ~ -0.59]

Flaring region? – jet flaring/ brightening regions post "gap"



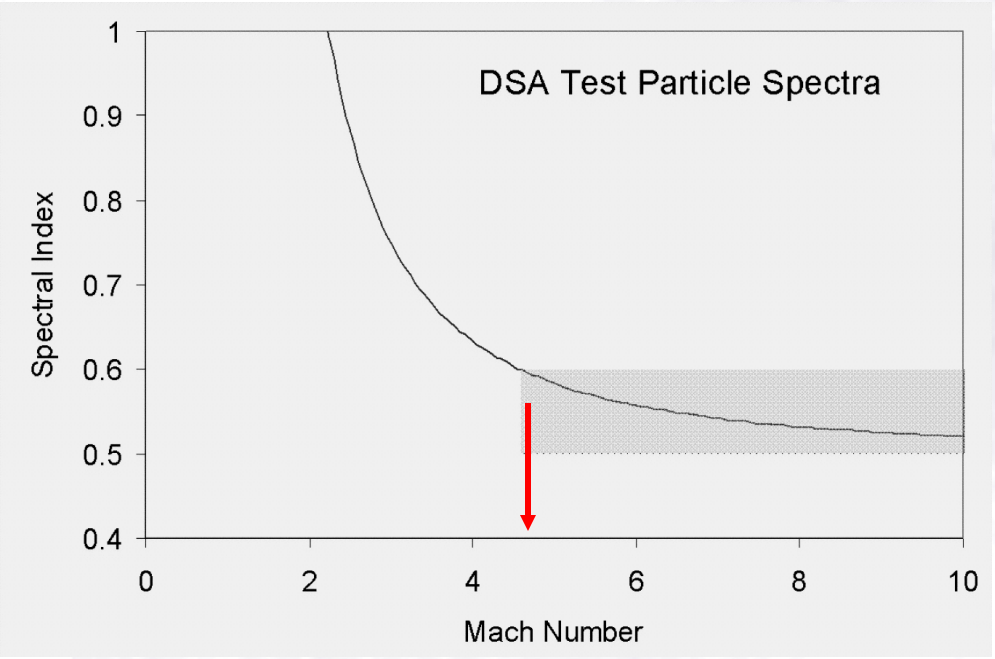




Multifrequency. Spectra needed

Regulating ~ -0.55 – how?

First-order regulation?



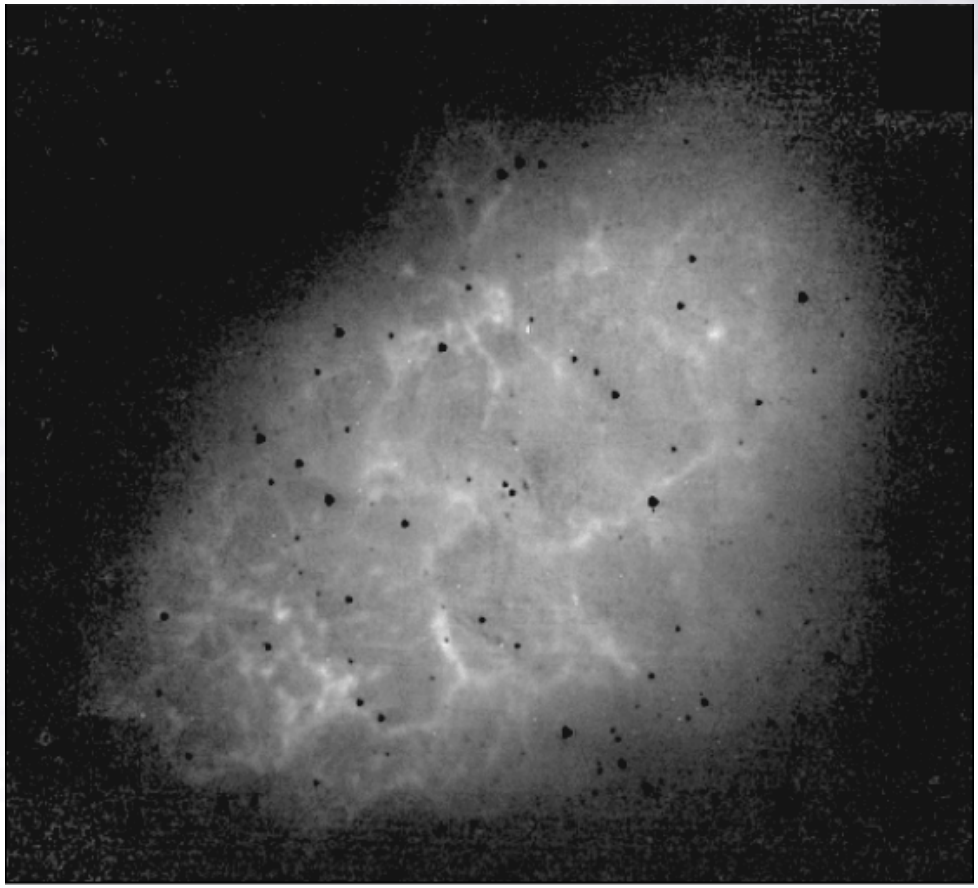
Other regulation?

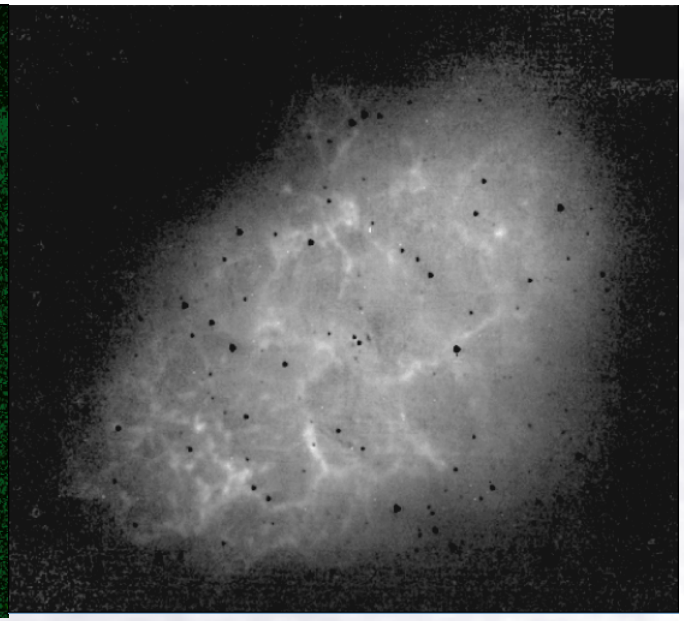
2nd order, shock-drift in turbulence/shear at flare?

Ultra-relavistic (but → -2.25?)

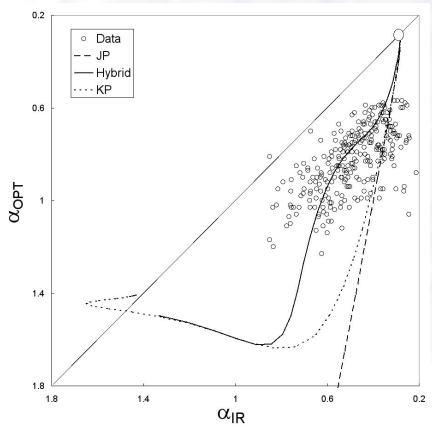
Shock modification – self-regulation?

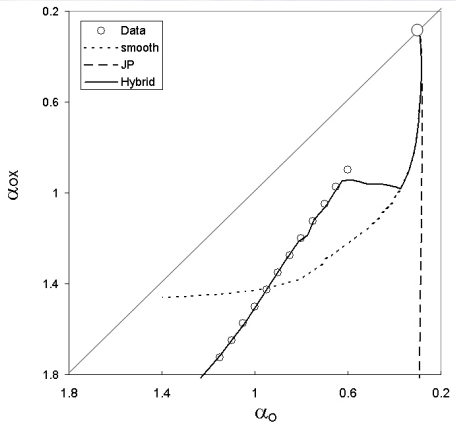
Short digression…





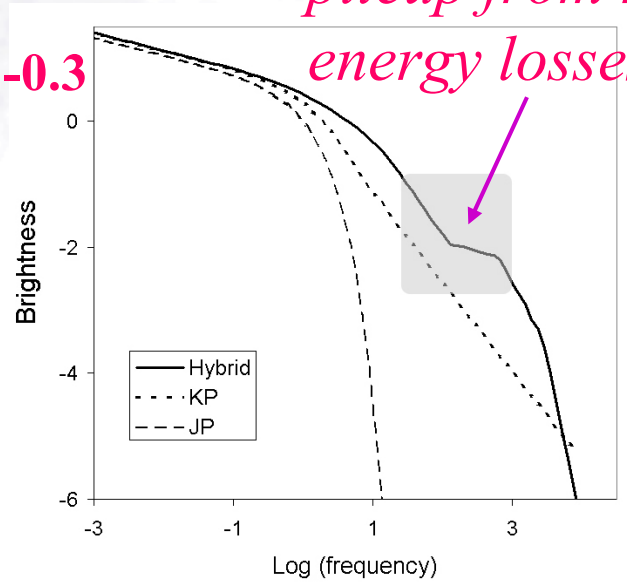
Crab Nebula





$\alpha = -0.3$

pileup from high energy losses



caveat - NGC315

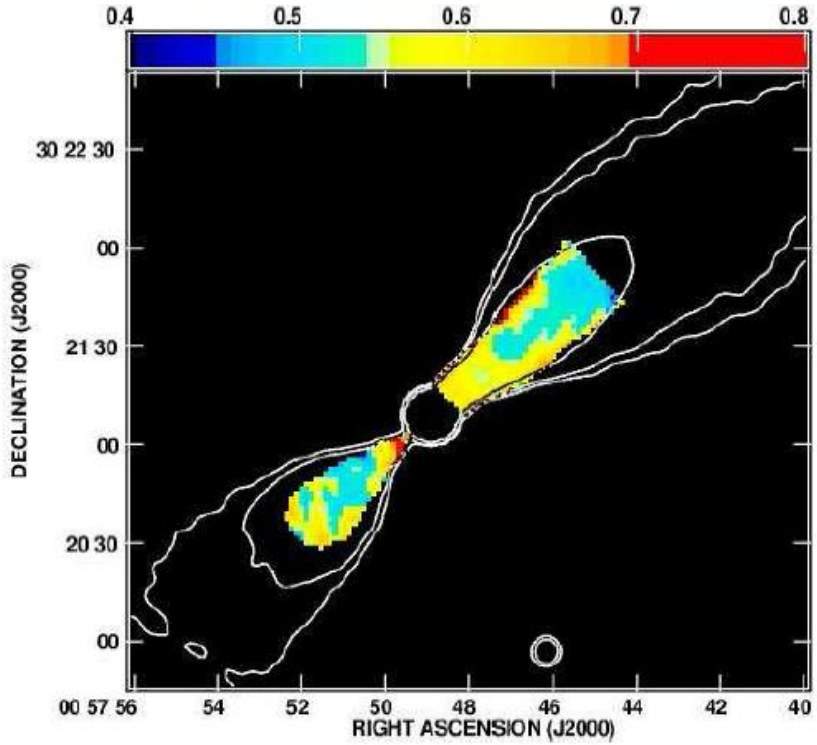


Figure 9. The false-colour plot shows an estimate of the spectral index for the on-axis emission component alone in the range $0.4 \leqslant \alpha \leqslant 0.8$. The spectral-index distribution is truncated at a distance of 66.5 arcsec along the axis and is shown only where the residual surface brightnesses exceed 0.5 and 1 mJy (beam area)$^{-1}$ at 5 and 1.365 GHz, respectively. A few contours of the 5 GHz I image are superposed to outline the jet structure. The area covered is the same as that in Fig. 8 and the resolution is 5.5 arcsec FWHM.

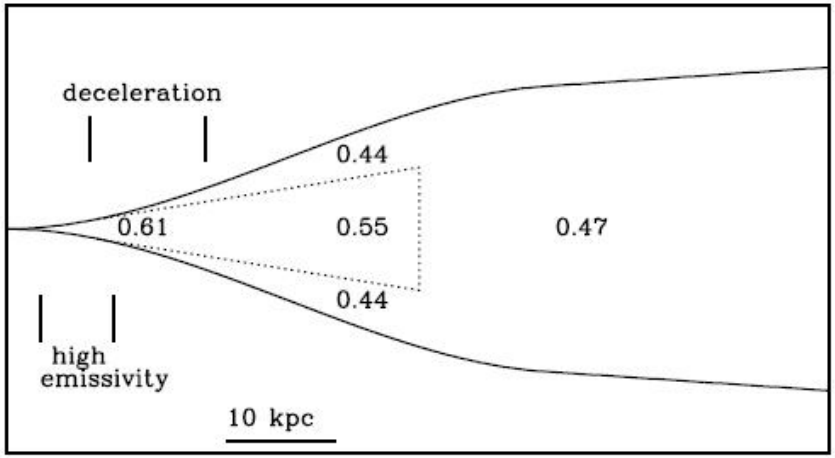
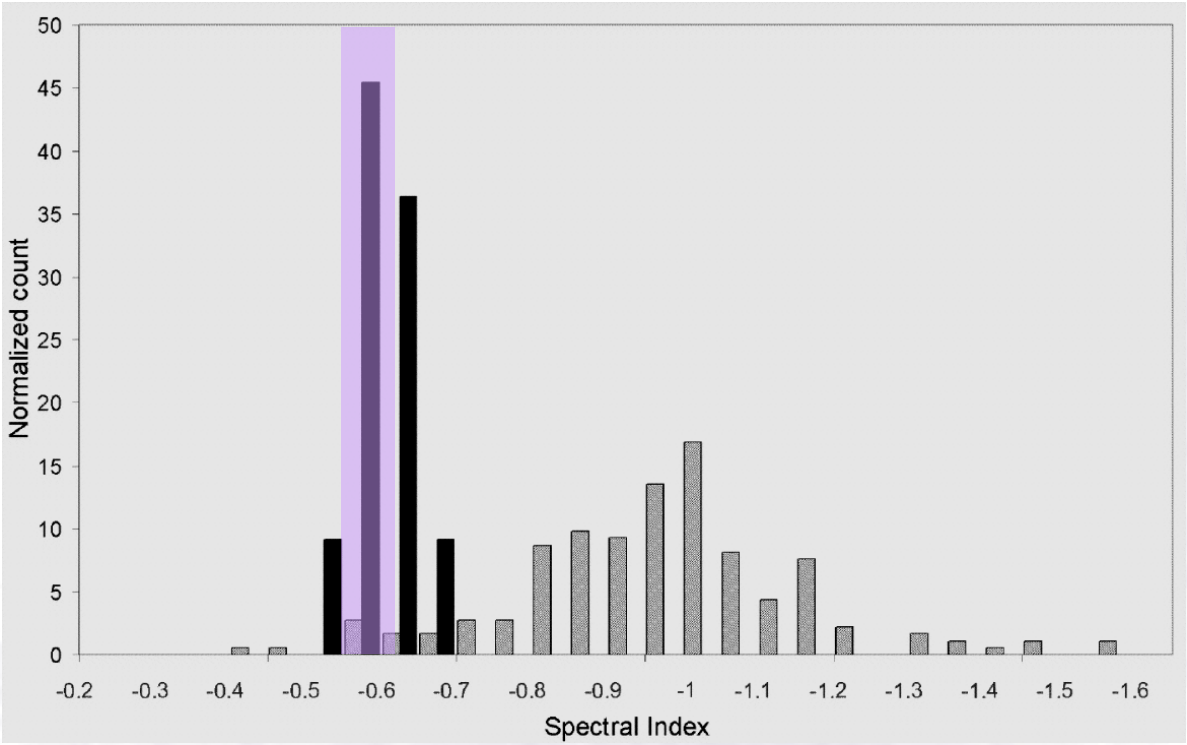


Figure 10. A sketch of our proposed three-dimensional distribution of spectral index in the jets of NGC 315. The sketch is in a plane containing the jet axis, assuming an angle to the line of sight of 37.9° (Canvin et al. 2005) and a linear scale is given. 10 kpc along the jet projects to 18 arcsec on the plane of the sky. The values of α at various points in the jet are marked, together with the approximate extent of the steep-spectrum component (dotted) and the regions of high emissivity and rapid deceleration (Canvin et al. 2005).

Multifrequency observations of the jets in the radio galaxy

NGC315, 2006MNRAS.368...48L

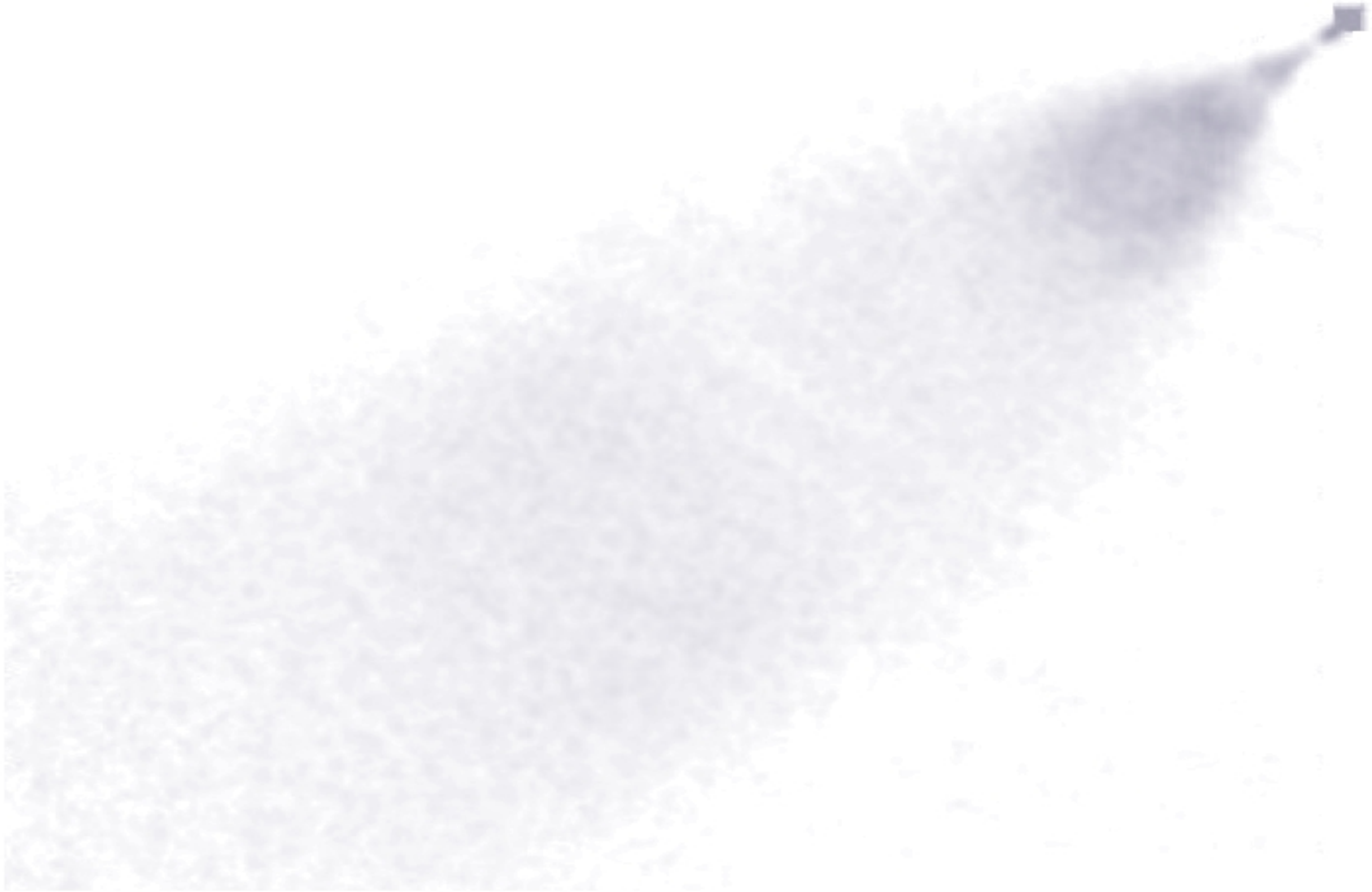
Laing, R. A.; Canvin, J. R.; Cotton, W. D.; Bridle, A. H.

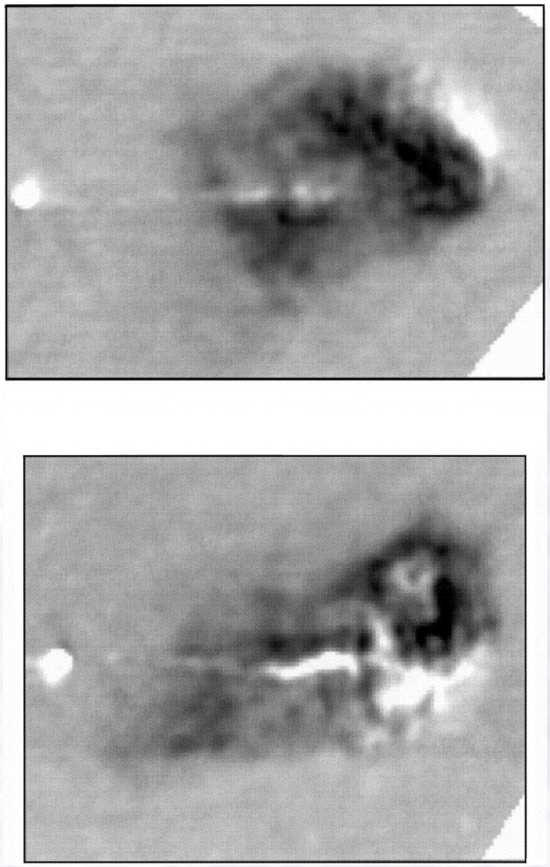


FRI (low luminosity, non-classical double source) jets have a narrow distribution of low frequency spectral (energy) indices around -0.55 (-2.1), **not** the test particle strong shock limit of ~~-0.50~~ (~~-2.0~~).

→ *We need a characteristic acceleration mechanism;*

→ *And, it's not the whole acceleration story.*





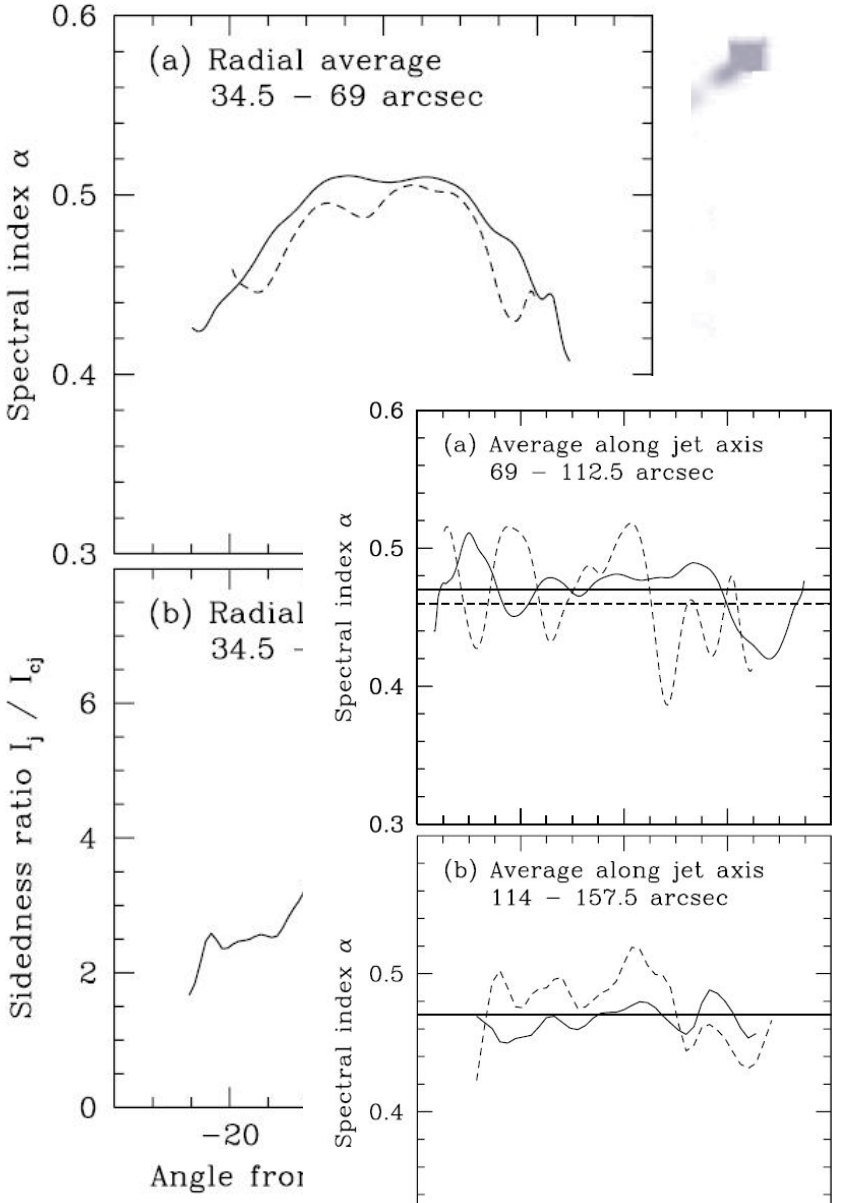
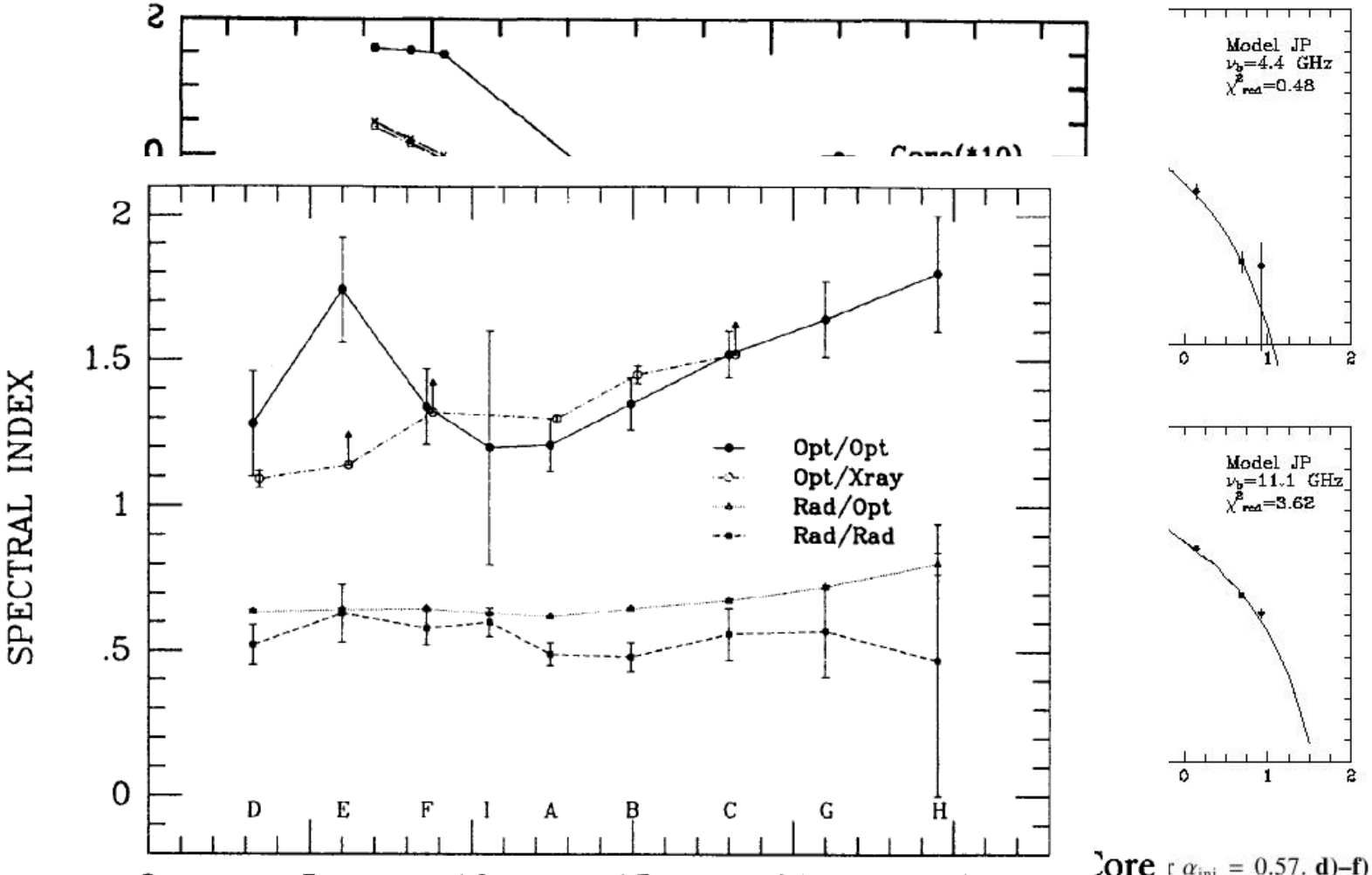


Figure 6. (a) Averaged tra
dex determined from a weig
five frequencies between 1.36
resolution is 5.5 arcsec FWH



Core r α_{inj} = 0.57. **d)–f)** The sar
ıd the distance of each strip from t

FIG. 6. Spectral index plot for the knots of M87 within the radio

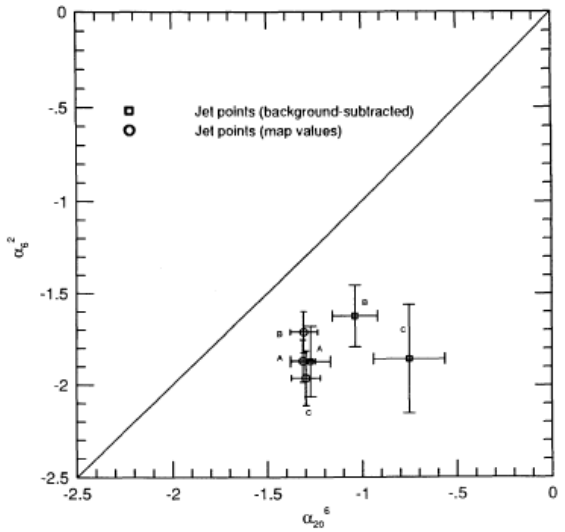
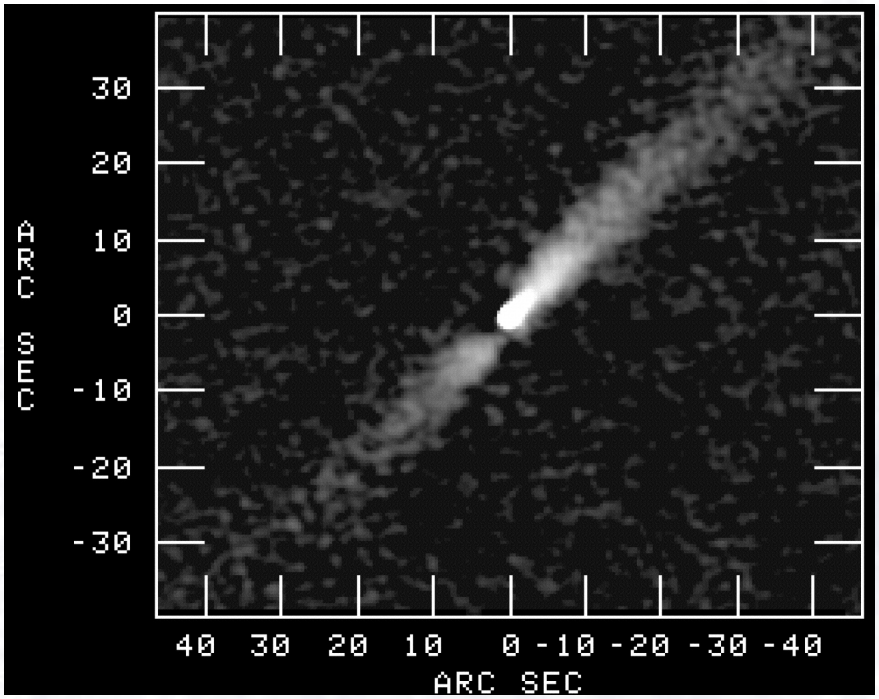
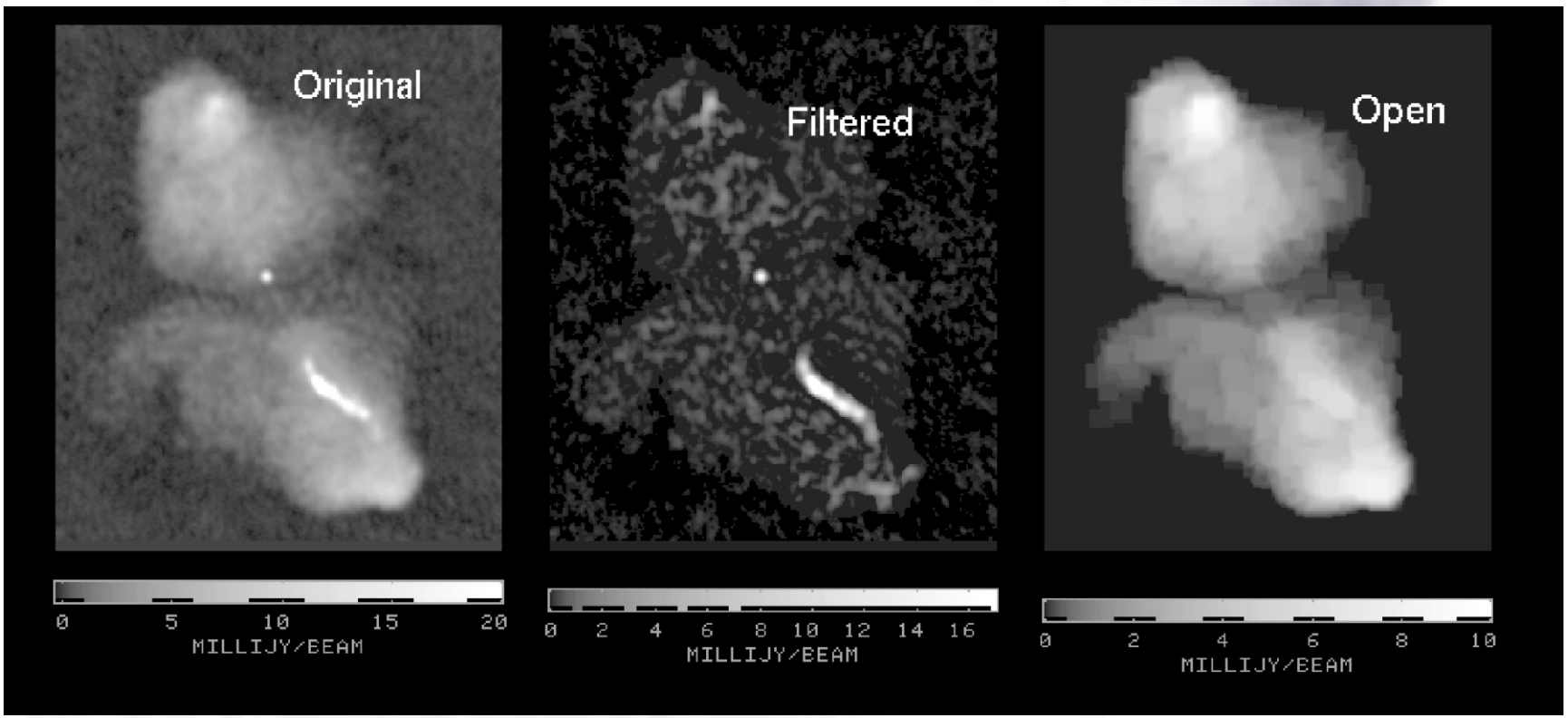
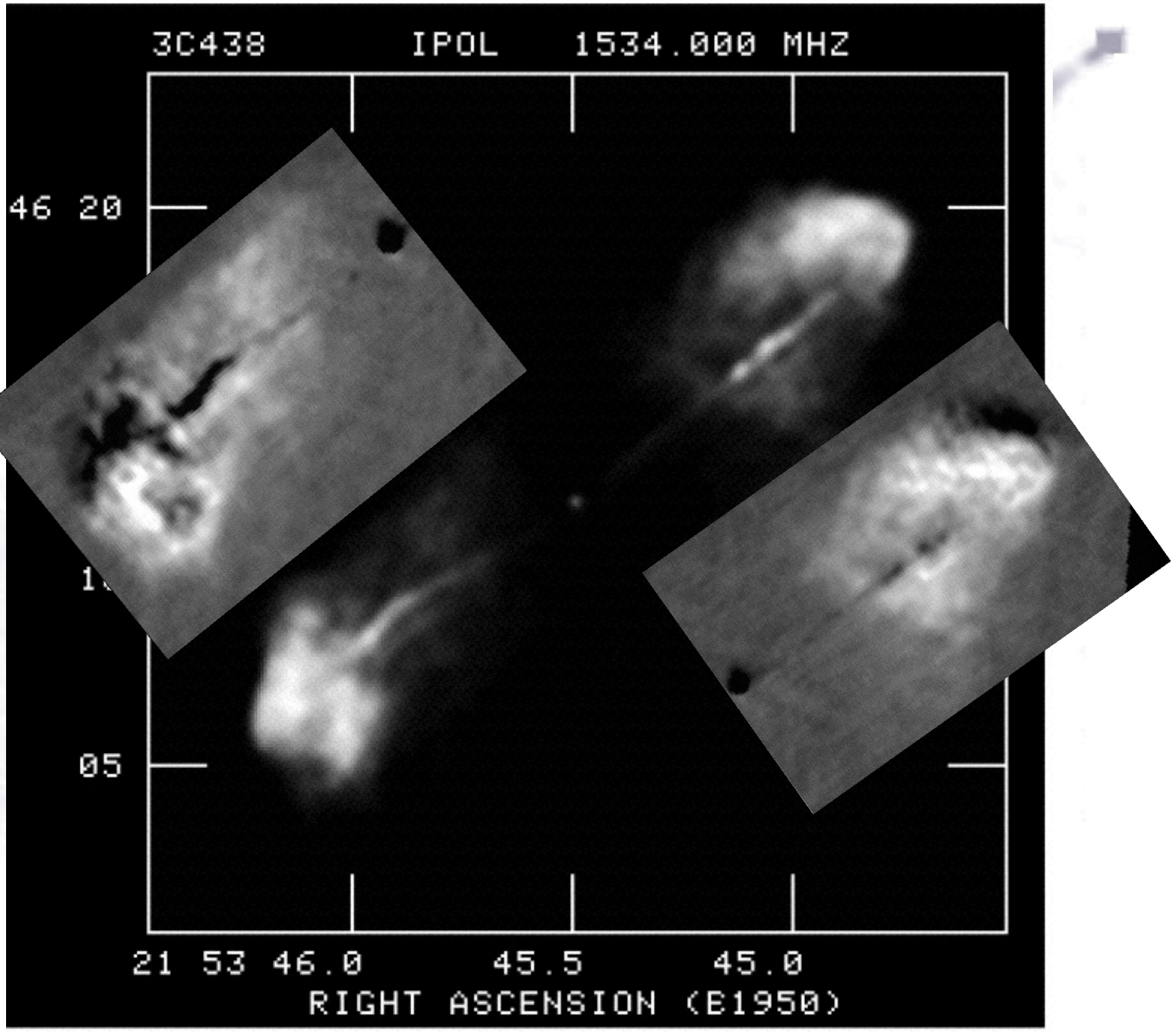
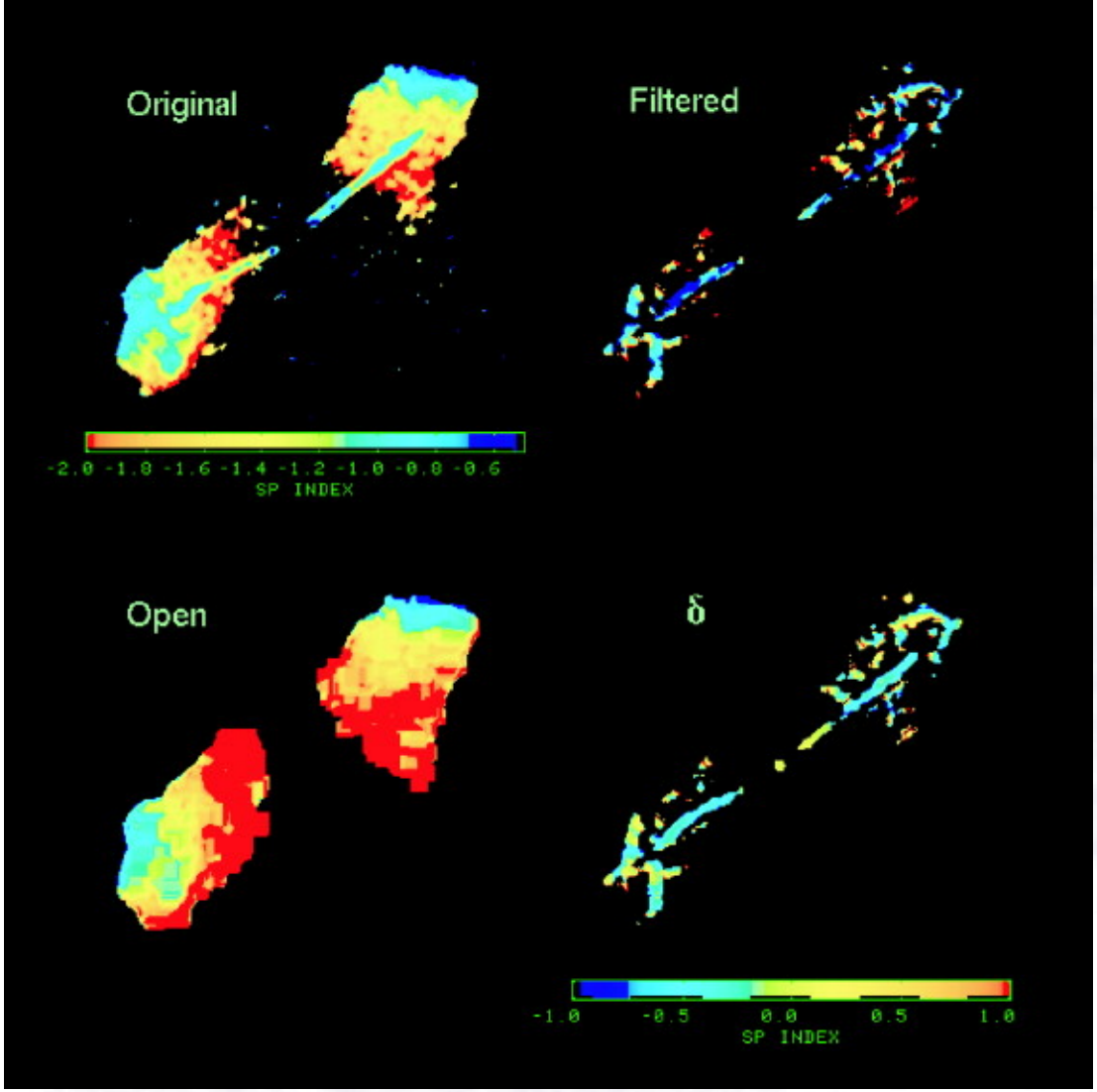


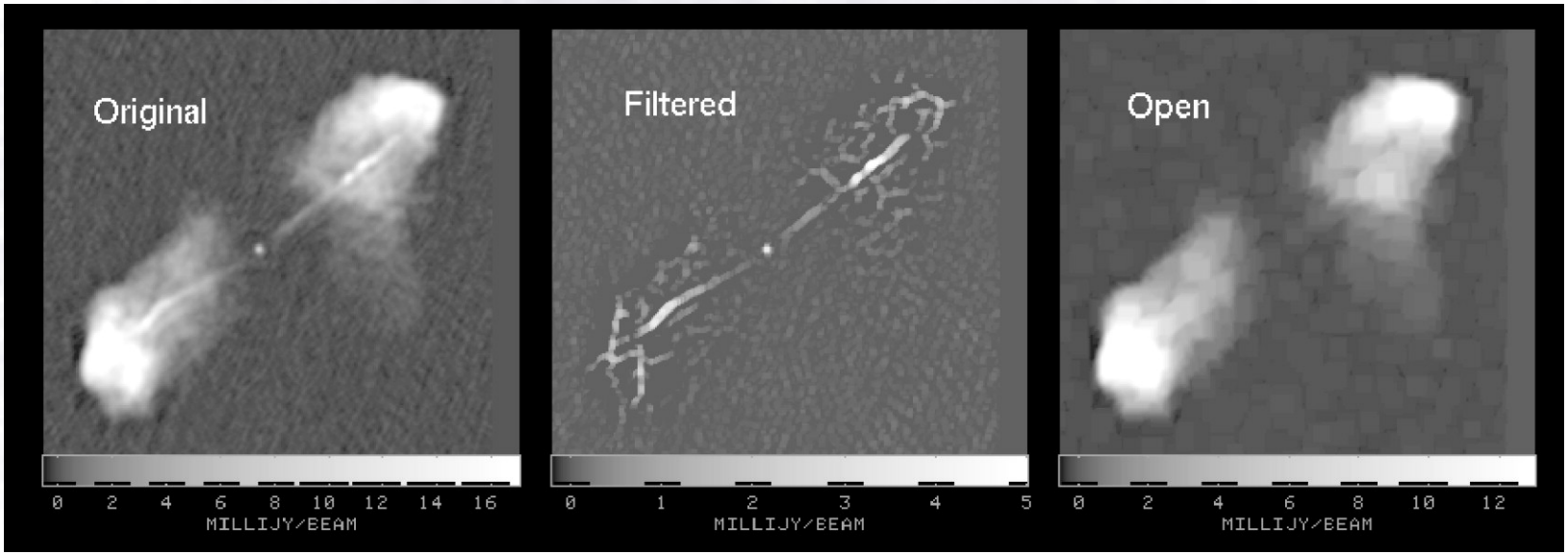
FIG. 8.—Color-color plot of three points in the jet that could be separated out from the background. The circles represent the peak values and the squares represent the background-subtracted values.


30
20
10
0
-10
-20
-30
ARC SEC
40 30 20 10 0 -10 -20 -30 -40
ARC SEC


Original
Filtered
Open
0 5 10 15 20
MILLIJY/BEAM
0 2 4 6 8 10 12 14 16
MILLIJY/BEAM
0 2 4 6 8 10
MILLIJY/BEAM


3C438 IPOL 1534.000 MHZ
46 20
05
21 53 46.0
45.5
45.0
RIGHT ASCENSION (B1950)


Original
Filtered
-2.0 -1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6
SP INDEX
Open
δ
-1.0 -0.5 0.0 0.5 1.0
SP INDEX


Original
0 2 4 6 8 10 12 14 16
MILLIJY/BEAM
Filtered
0 1 2 3 4 5
MILLIJY/BEAM
Open
0 2 4 6 8 10 12
MILLIJY/BEAM