M87 jet instability probed by multi-frequency observations

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on behalf of the RadioAstron KSP on Imaging nearby AGN

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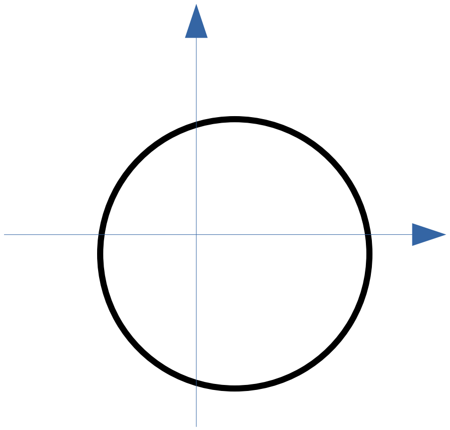
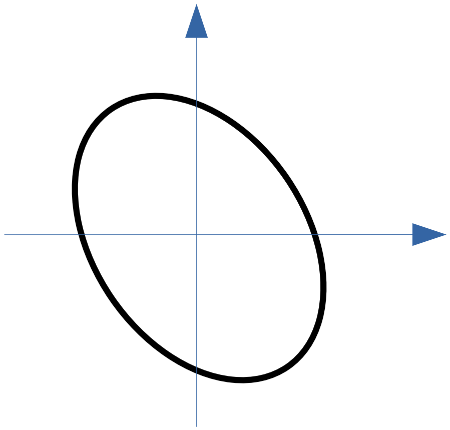
Kelvin-Helmholtz instability: Linear analysis

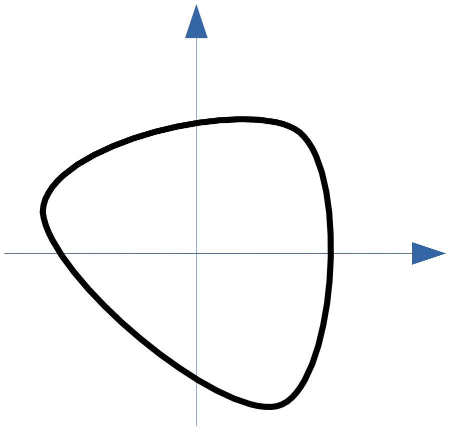
A random perturbation can be considered to consist of Fourier components:



Helical mode n = 1

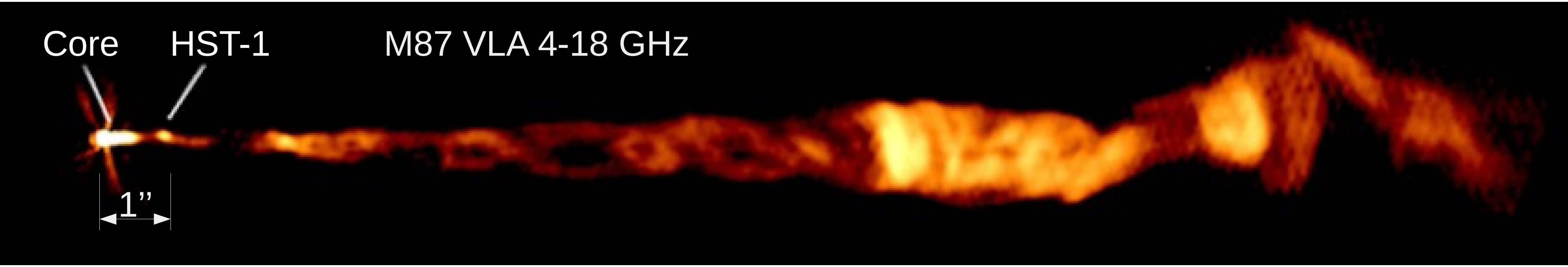


Elliptical mode n = 2

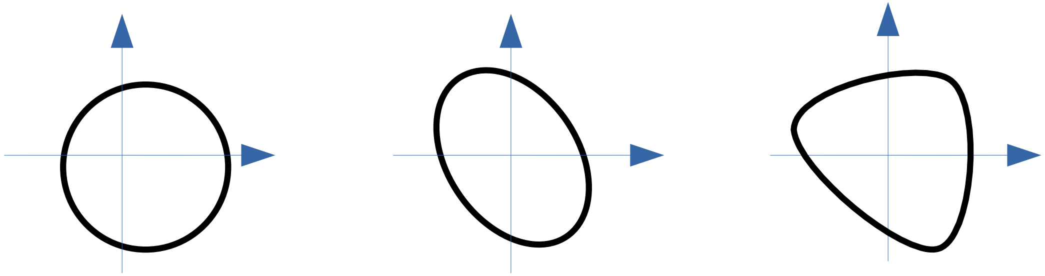


Triangular mode n = 3

Kelvin-Helmholtz instability: Linear analysis



A. Pasetto+ 2021

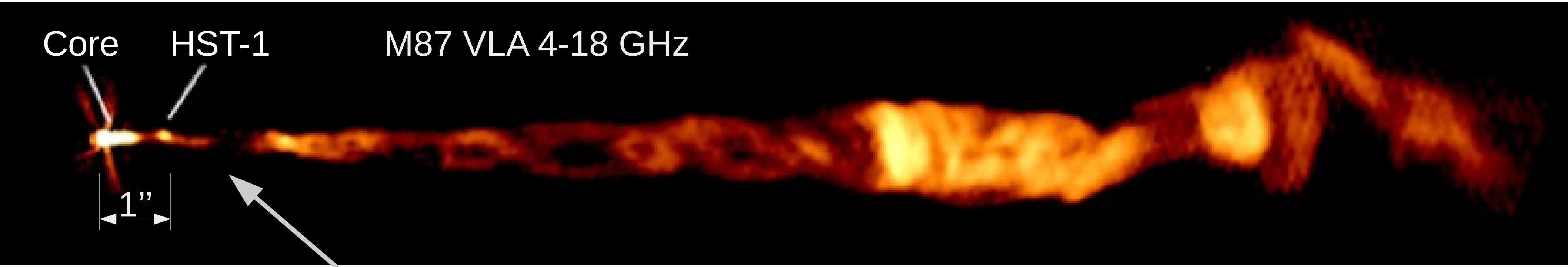


Helical mode n = 1

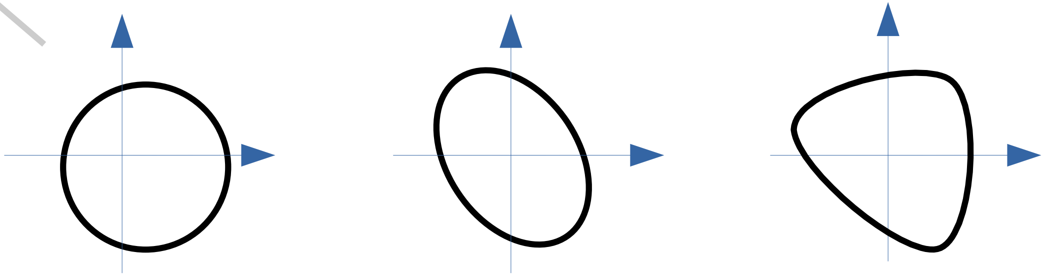
Elliptical mode n = 2

Triangular mode n = 3

Kelvin-Helmholtz instability: Linear analysis



A. Pasetto+ 2021

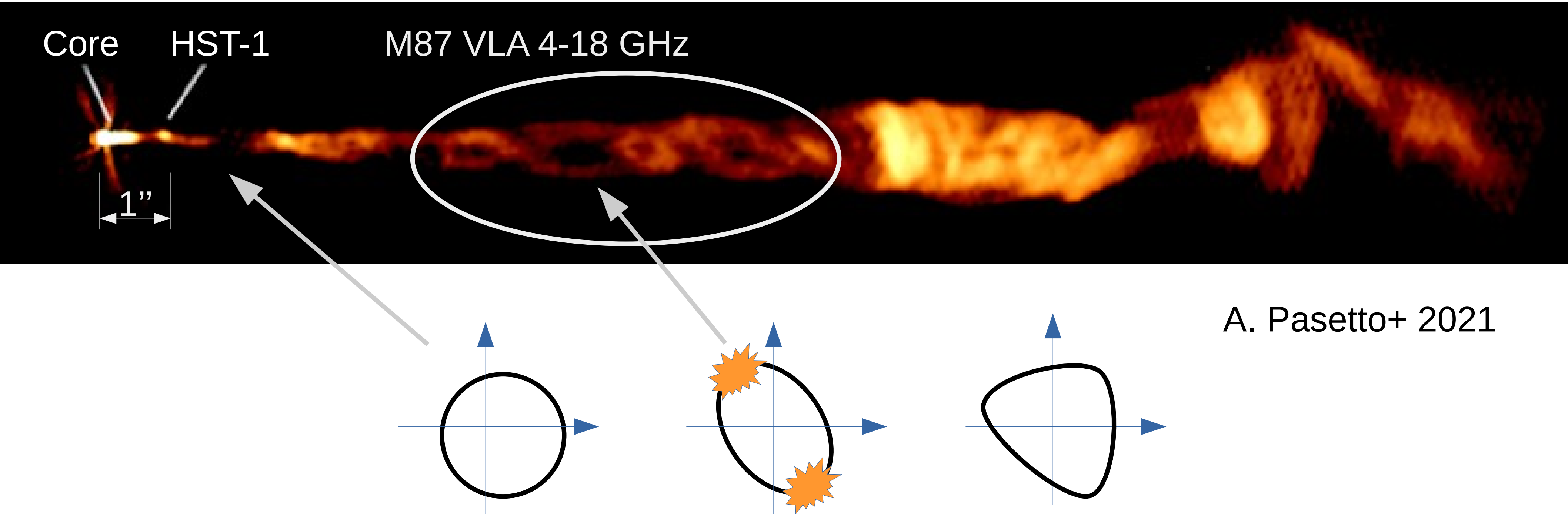


Helical
mode n = 1

Elliptical
mode n = 2

Triangular
mode n = 3

Kelvin-Helmholtz instability: Linear analysis



A. Pasetto+ 2021

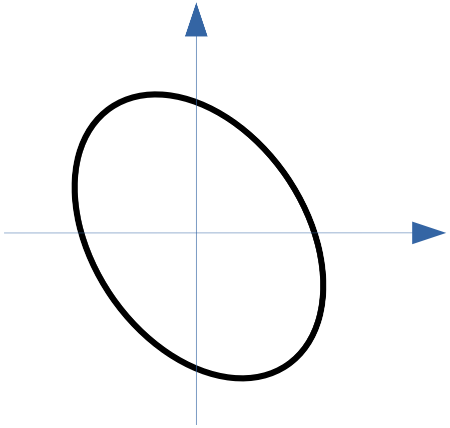
Helical
mode n = 1

Elliptical
mode n = 2

Triangular
mode n = 3

Kelvin-Helmholtz instability: Linear analysis

Normal mode n



Elliptical mode n = 2

Surface m = 0

Body modes m = 1,2,3...

$$\lambda nm = \frac{8\beta_w R}{a_x}\frac{1}{n+2m+0.5}$$

$$\frac{\lambda_{nm}}{R} = const$$

Example:

E_s – elliptical surface mode (n=2, m=0)

E_{b1} – elliptical first body mode (n=2, m=1)

Hardee 1998

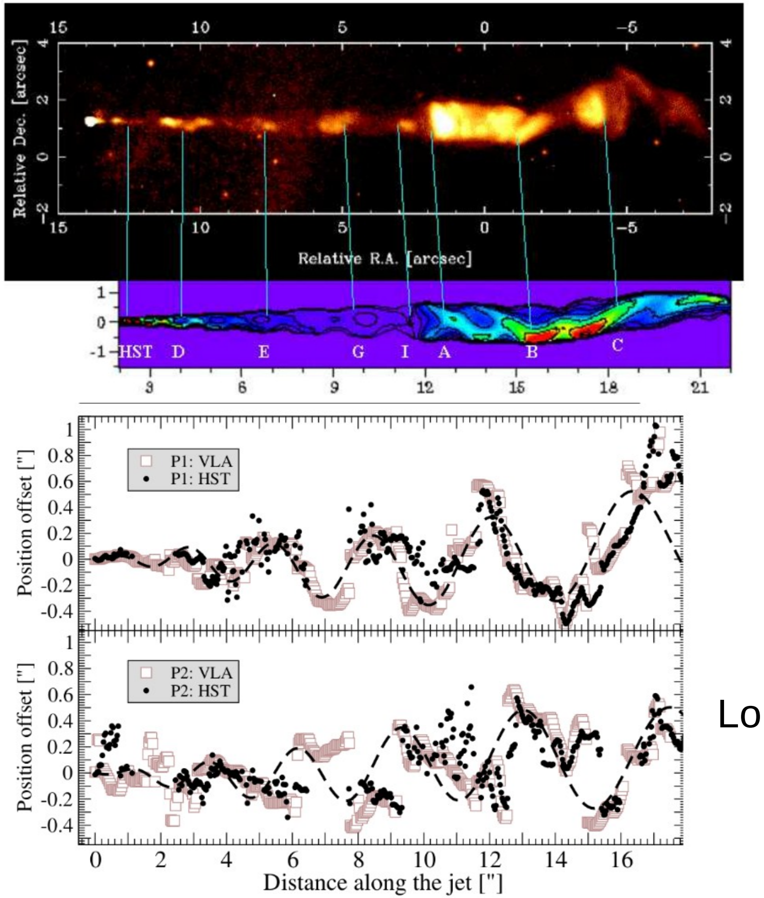
Kelvin-Helmholtz instability in kiloparsec-scale images of M87

Helical surface mode

$$\frac{\lambda_{H_s}}{R} = 170 \pm 73$$

Elliptical surface mode

$$\frac{\lambda_{E_s}}{R} = 26 \pm 4$$



Lobanov+ 2003

Kelvin-Helmholtz instability in kiloparsec-scale images of M87

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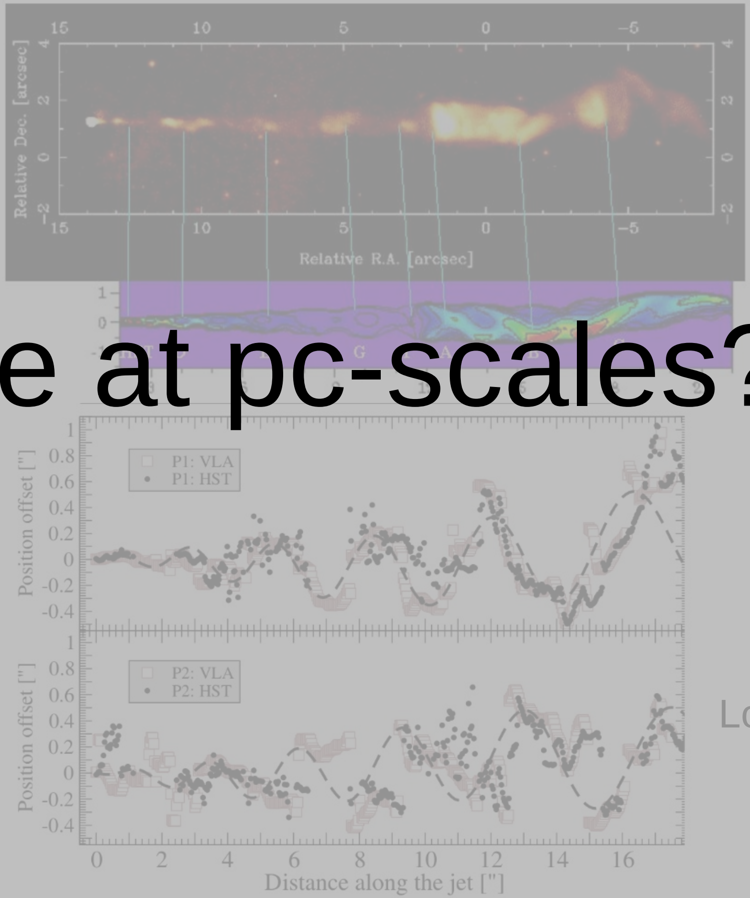


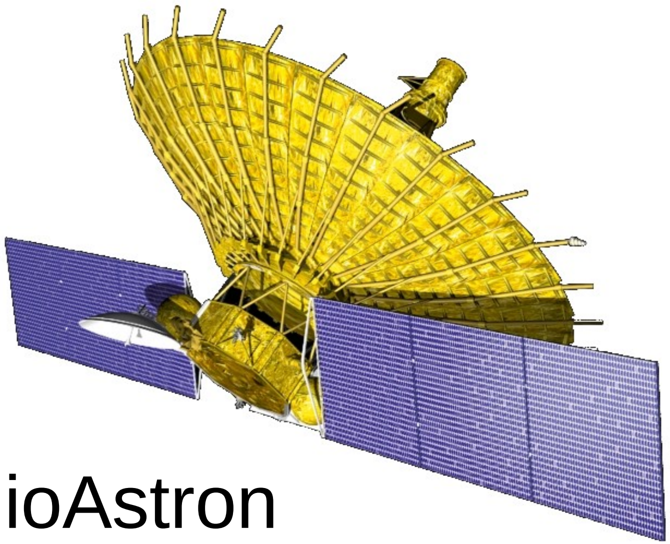
Lobanov+ 2003

What we will see at pc-scales?

M87 observations

VLBA

May 2009
8 & 15 GHz



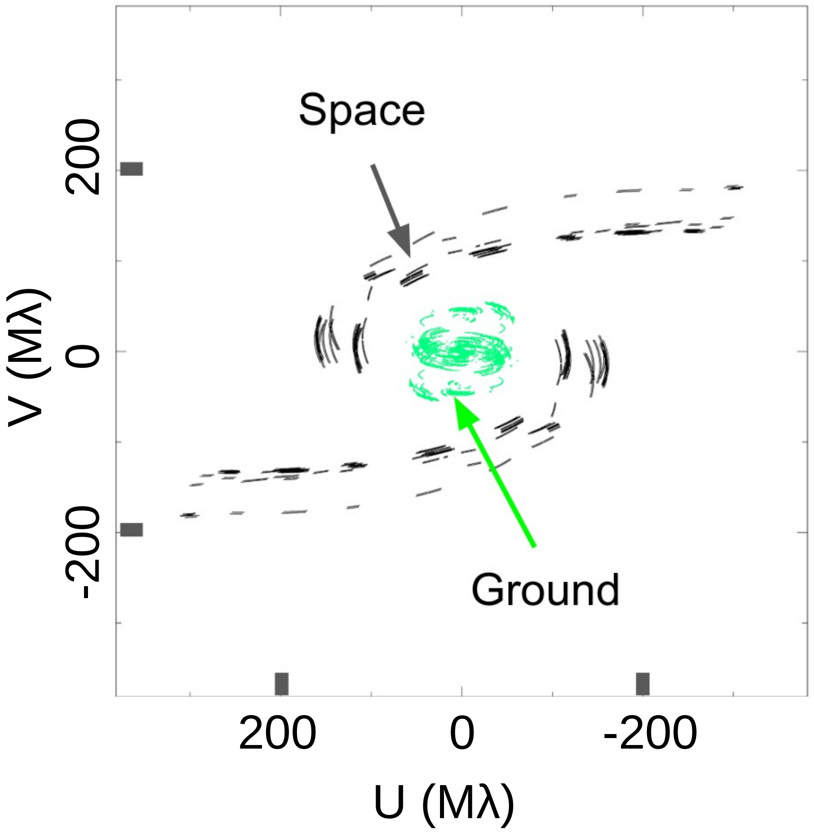
RadioAstron

February 2014
1.6 GHz

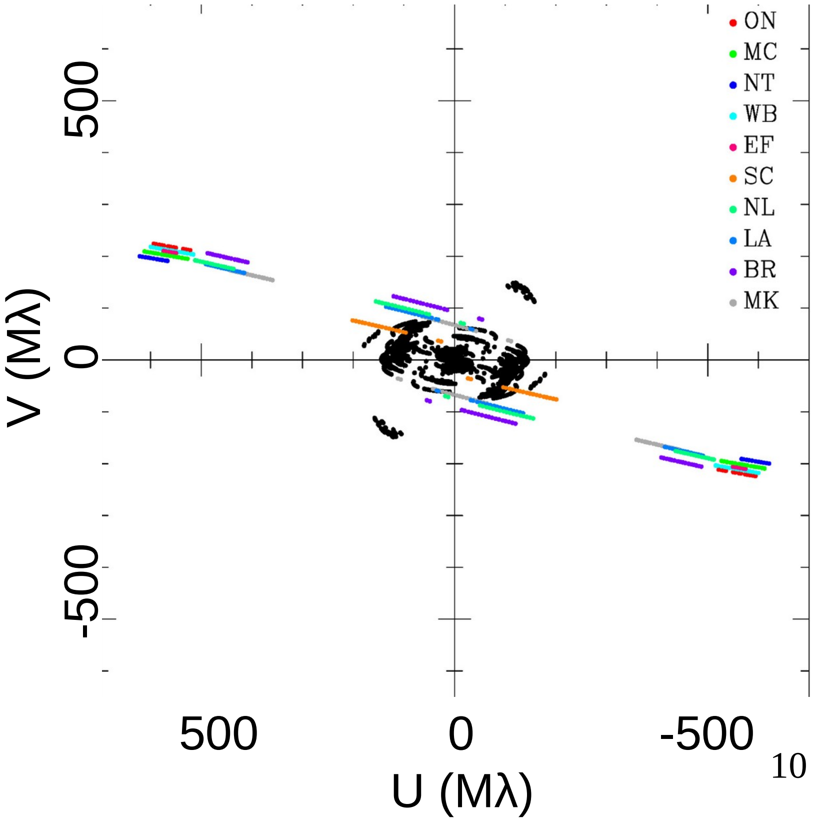
June 2014
5 GHz

RadioAstron 1.6 and 5 GHz

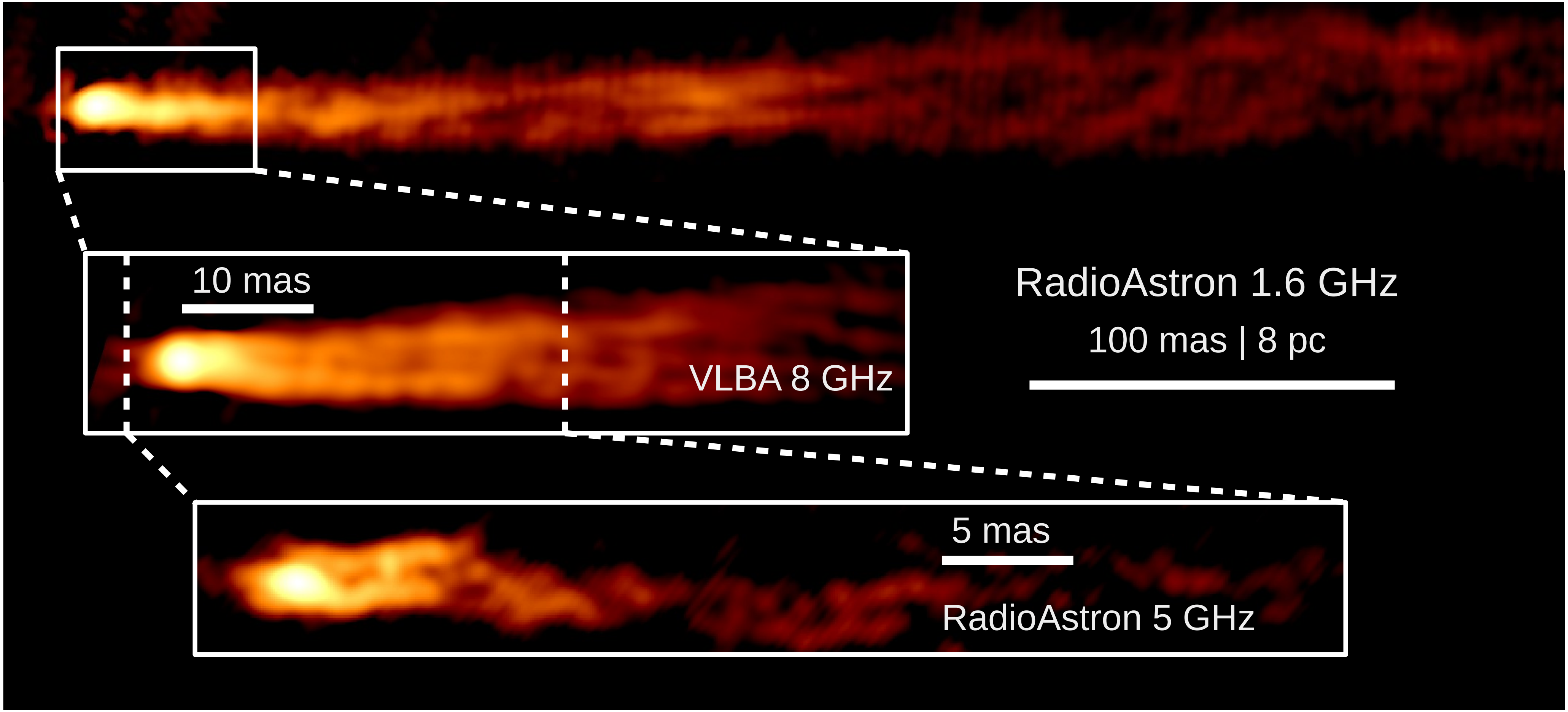
1.6 GHz 2014 June



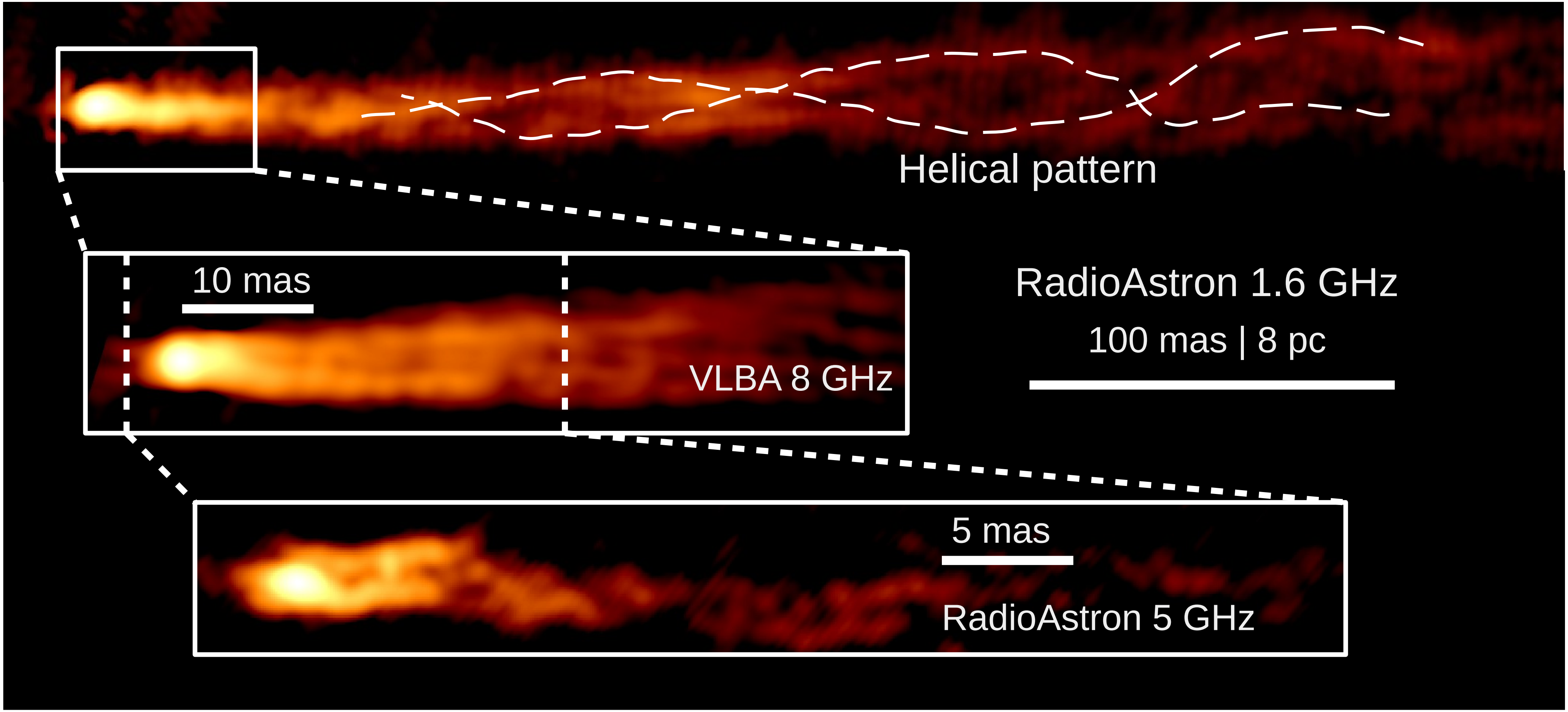
5 GHz 2014 Feb



The multi-frequency gallery of the M87



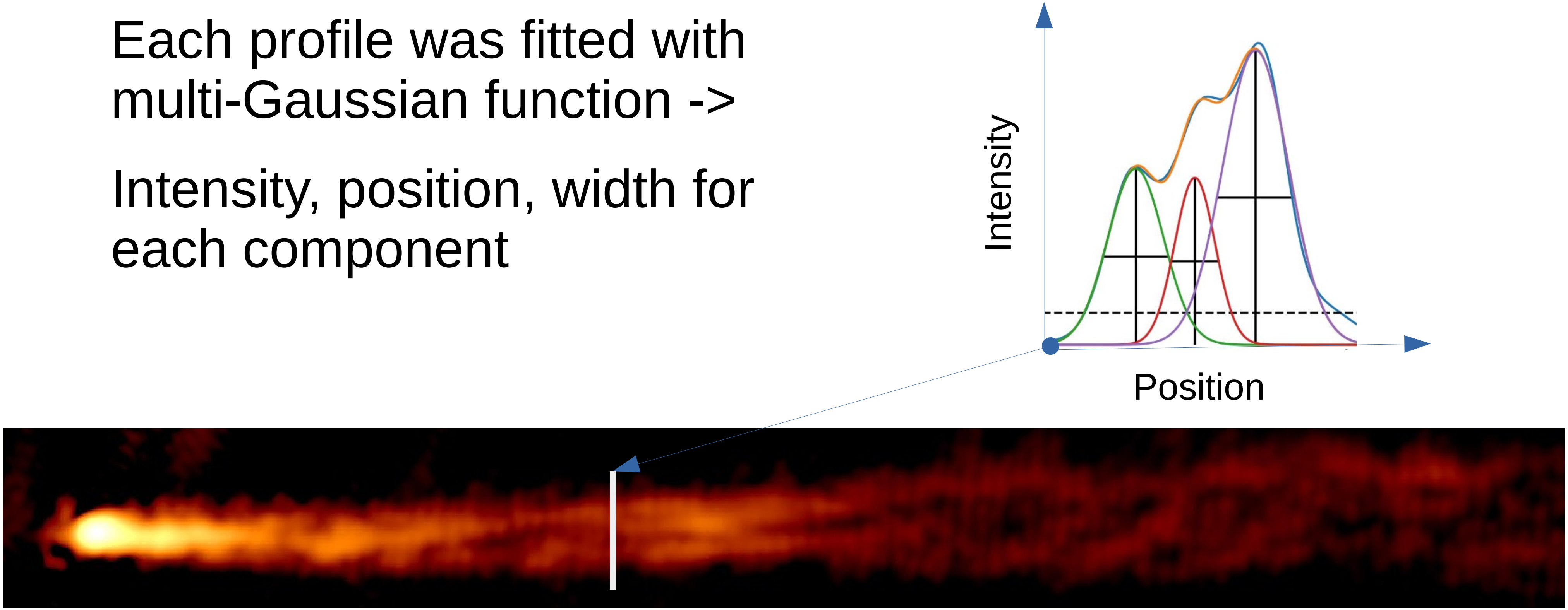
The multi-frequency gallery of the M87



Study of a helical pattern

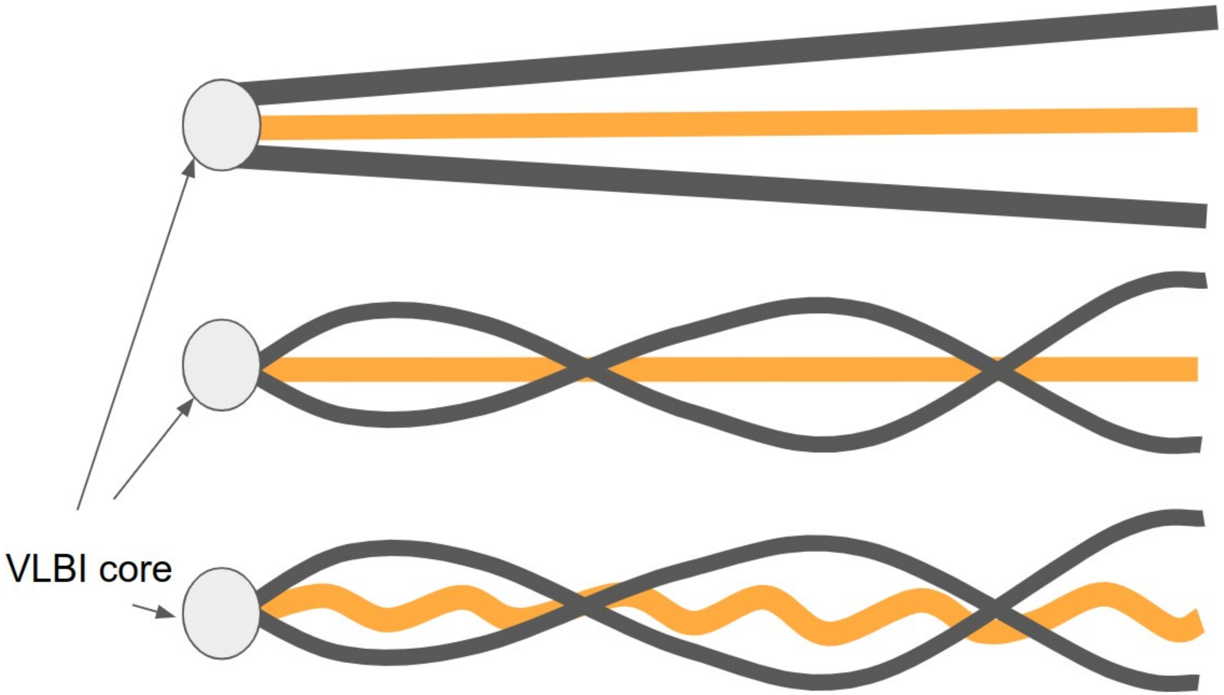
Each profile was fitted with multi-Gaussian function ->

Intensity, position, width for each component

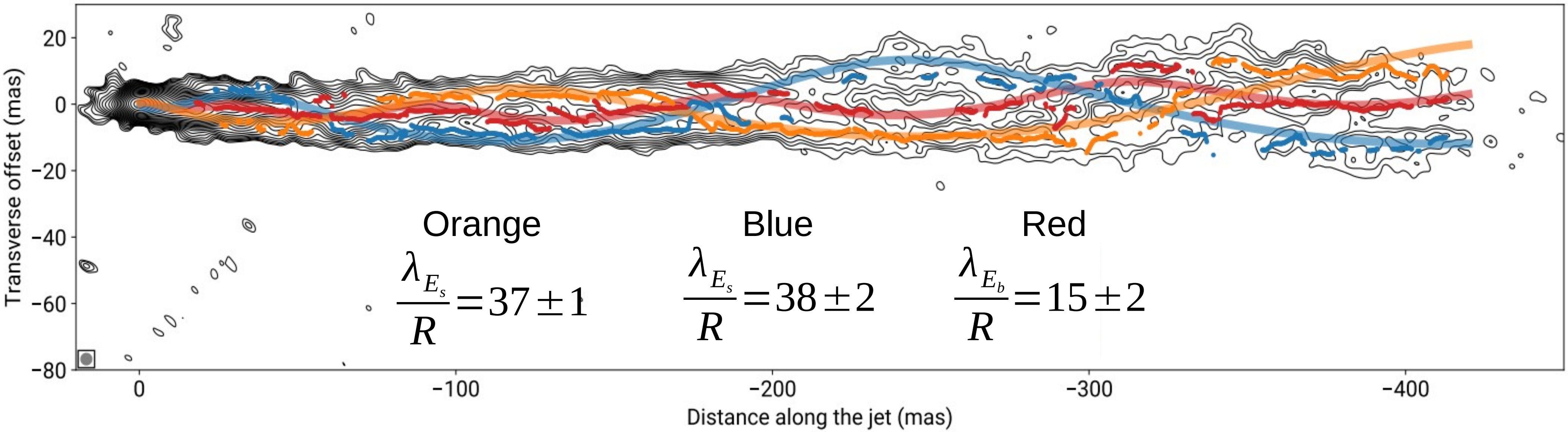


Choosing the scenario

1. No instability
2. Spine + two helical threads
3. Three helical threads



The 1.6 GHz RadioAstron results



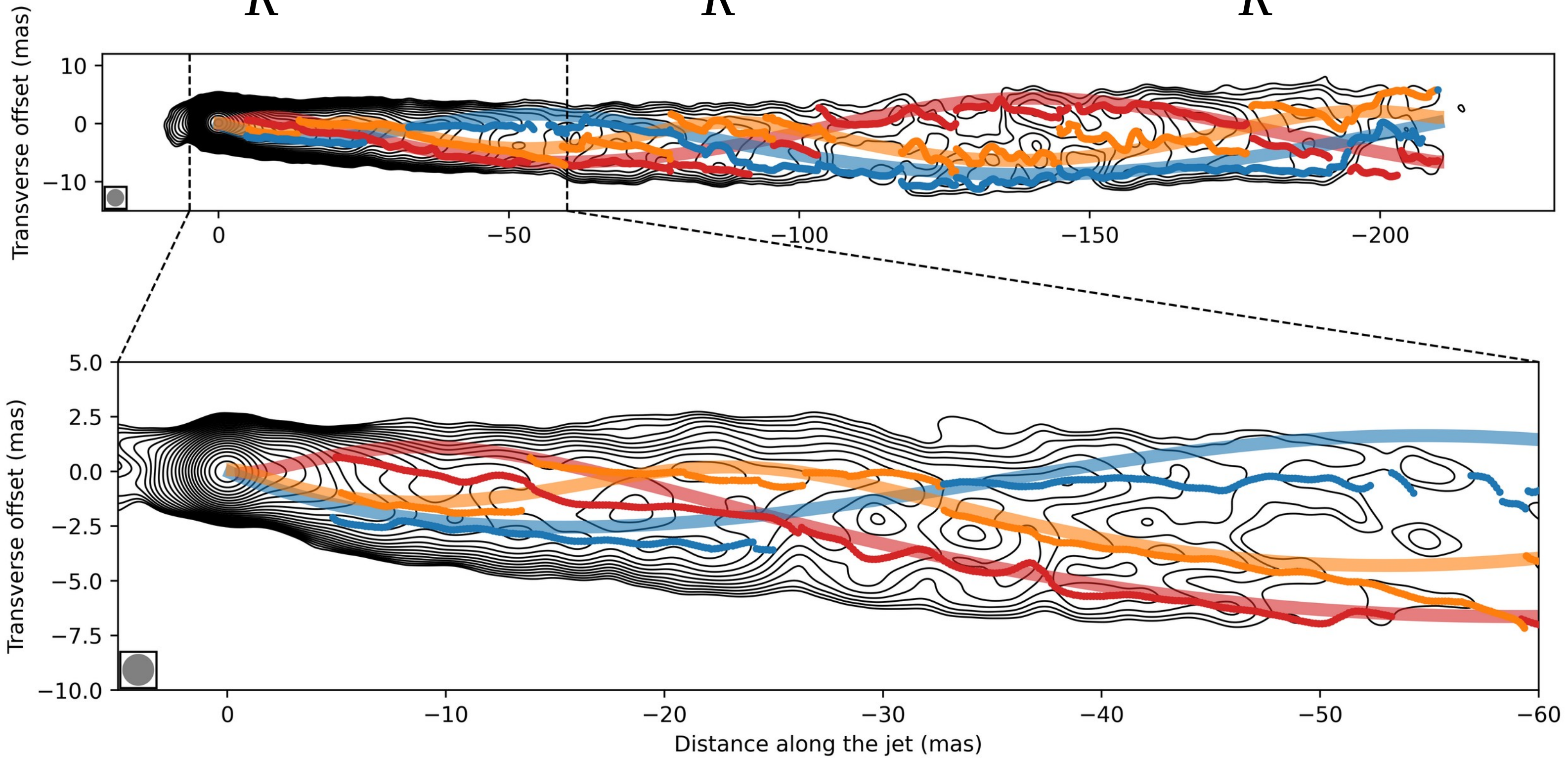
Orange: $\frac{\lambda_{E_s}}{R} = 37 \pm 1$

Blue: $\frac{\lambda_{E_s}}{R} = 38 \pm 2$

Red: $\frac{\lambda_{E_b}}{R} = 15 \pm 2$

The 8 GHz VLBA results

Red $\frac{\lambda_{E_s}}{R} = 33 \pm 1$ Blue $\frac{\lambda_{E_s}}{R} = 32 \pm 1$ Orange $\frac{\lambda_{E_b}}{R} = 17.0 \pm 0.3$

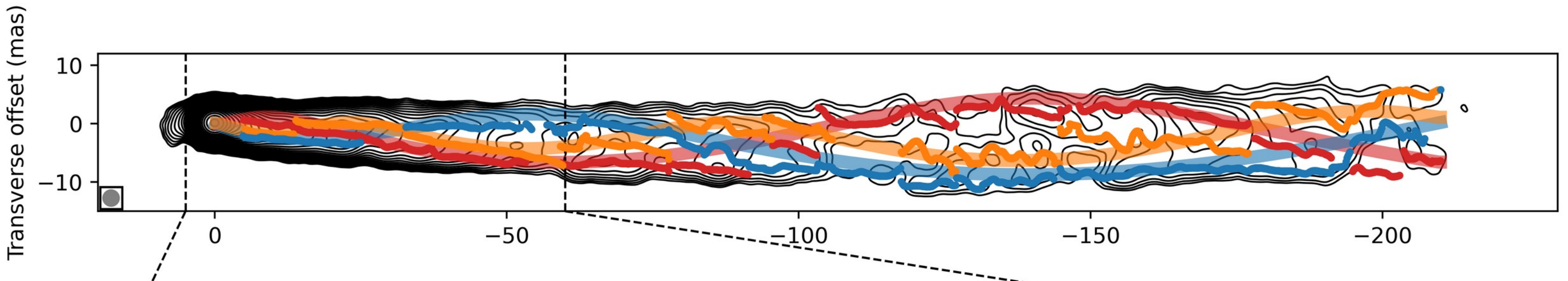


The 8 GHz VLBA results

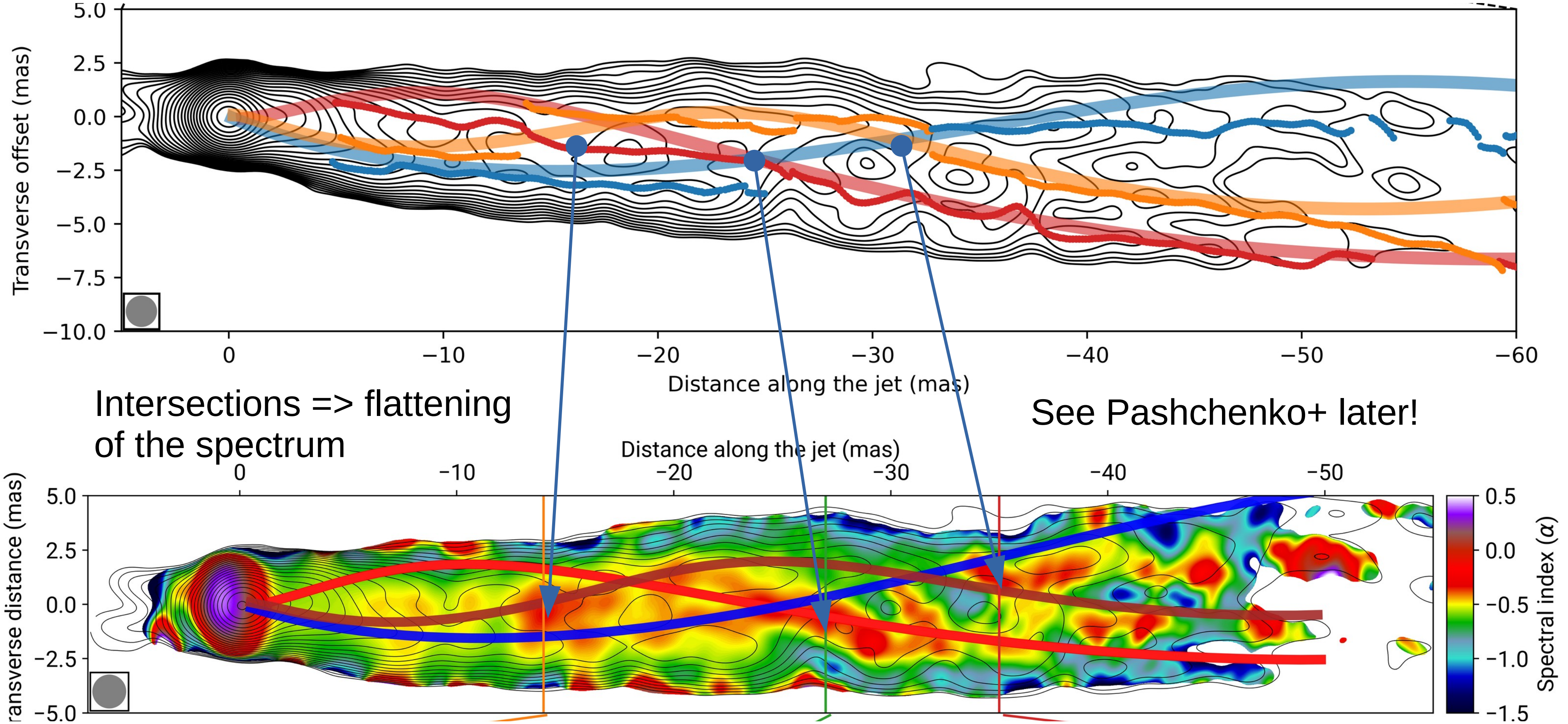
8 GHz	$\frac{\lambda_{E_s}}{R} = 33 \pm 1$	$\frac{\lambda_{E_s}}{R} = 32 \pm 1$	$\frac{\lambda_{E_b}}{R} = 17.0 \pm 0.3$
1.6 GHz	$\frac{\lambda_{E_s}}{R} = 38 \pm 2$	$\frac{\lambda_{E_s}}{R} = 37 \pm 1$	$\frac{\lambda_{E_b}}{R} = 15 \pm 2$

$$\frac{\lambda_{E_s}}{R} = 26 \pm 4$$

(Lobanov+ 2003)



The 8-15 GHz Spectral index



Intersections => flattening of the spectrum

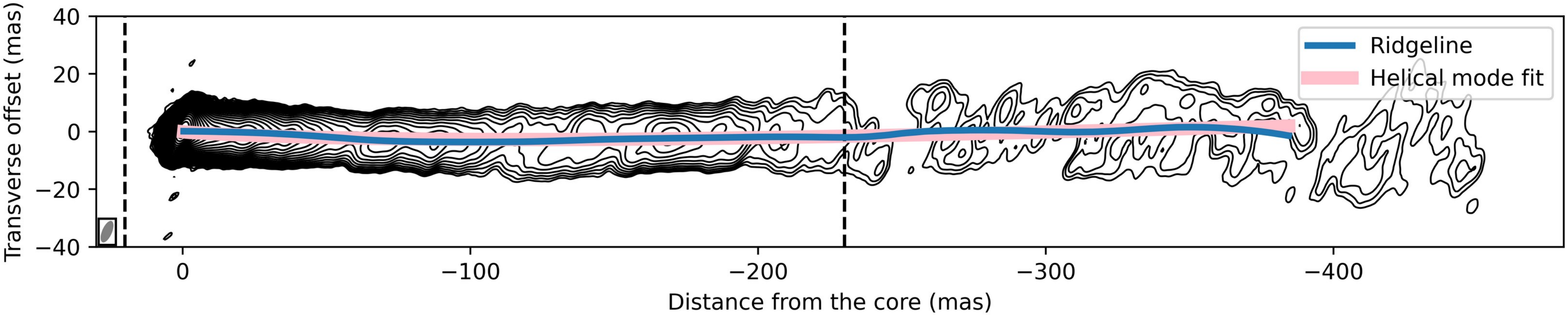
See Pashchenko+ later!

Helical surface mode

8GHz	1.6 GHz
$\frac{\lambda_{H_s}}{R} = 143 \pm 52$	$\frac{\lambda_{H_s}}{R} = 110 \pm 58$

$$\frac{\lambda_{H_s}}{R} = 170 \pm 73$$

(Lobanov+ 2003)



The 5 GHz RadioAstron image

$$\frac{\lambda_{E_b}}{R} = 16 \pm 3$$

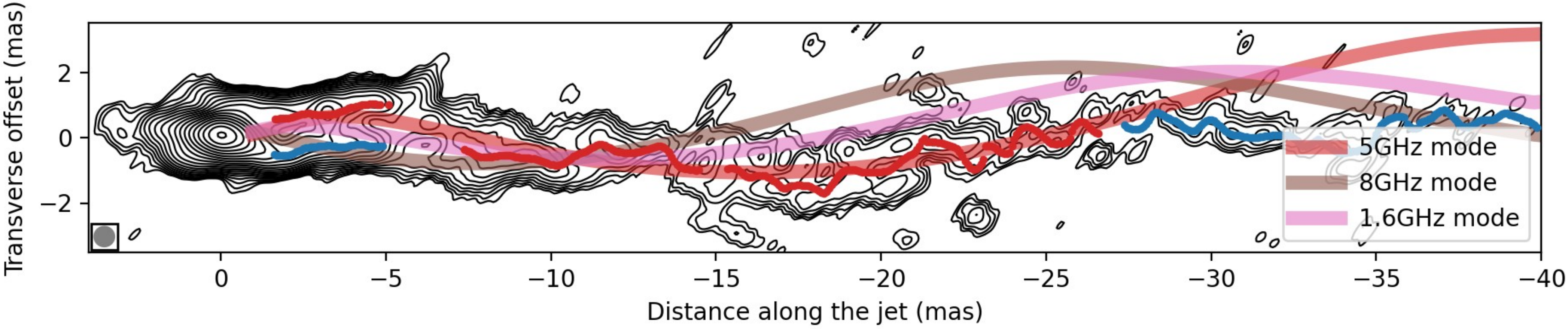
5 GHz

$$\frac{\lambda_{E_b}}{R} = 15 \pm 2$$

1.6 GHz

$$\frac{\lambda_{E_b}}{R} = 17.0 \pm 0.3$$

8 GHz



Summary

- Multi-frequency observations resolve the flow transversely and reveal regular oscillatory patterns inside
- Modelling these patterns provides strong evidence for Hs, Es modes of K-H instability to develop in the jet on pc to kpc scales
- Spectral index map support K-H analysis