# *Dynamics and emission model of the recollimation shock in BL Lacertae*


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# *Recollimation shock and moving features*

VLBA monitoring at 15 GHz (1995-2012)
in the frame of the MOJAVE program

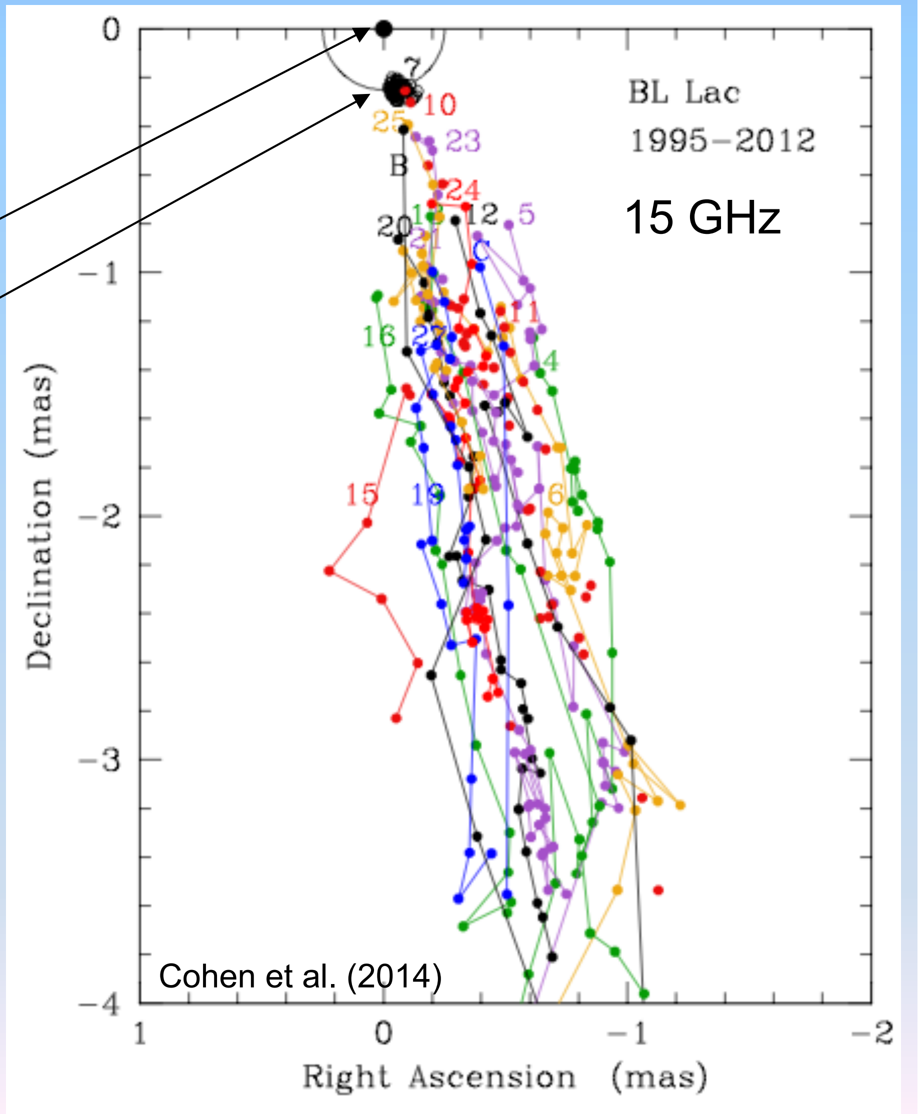
- Beam size: ~0.9 mas
- 1 mas = 1.29 pc; 114 epochs

Radio core:
- reference point; flat spectrum,
- compound str. at 43 GHz -> core shifts at 15 GHz

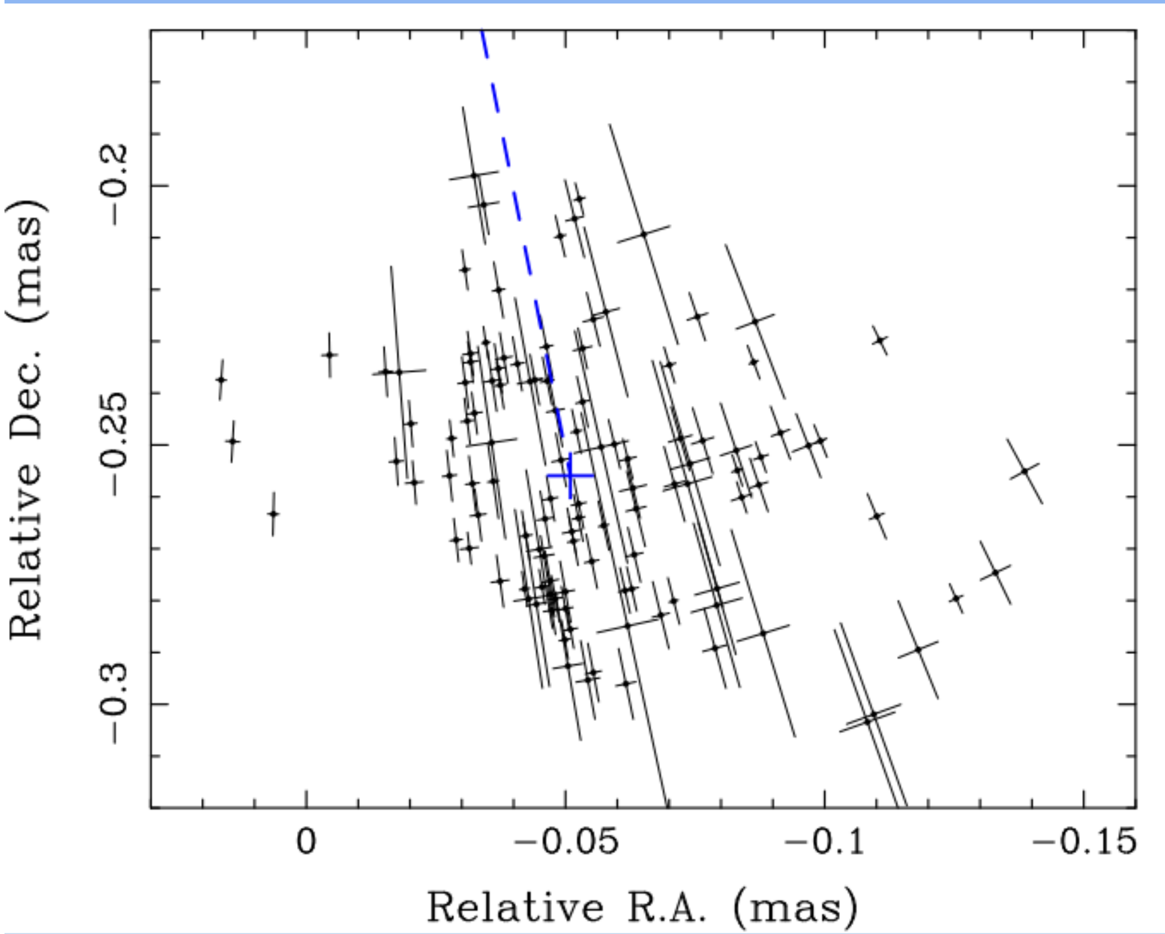
C7 component:
- Quasi-stationary component (recollimation shock)
- tightness of points

19 moving components emanate from C7; apparent speeds < 10c

"Whip" jet model: relativistic, rapidly shaken RCS generates transverse Alfven waves propagating downstream on helical magnetic field (Cohen et al. 2014, 2015).



# RCS scatter




Data: 116 epochs between 1999-2016 (Arshakian et al. 2020)

Data reduction as in Cohen et al. (2014)

Scatter:

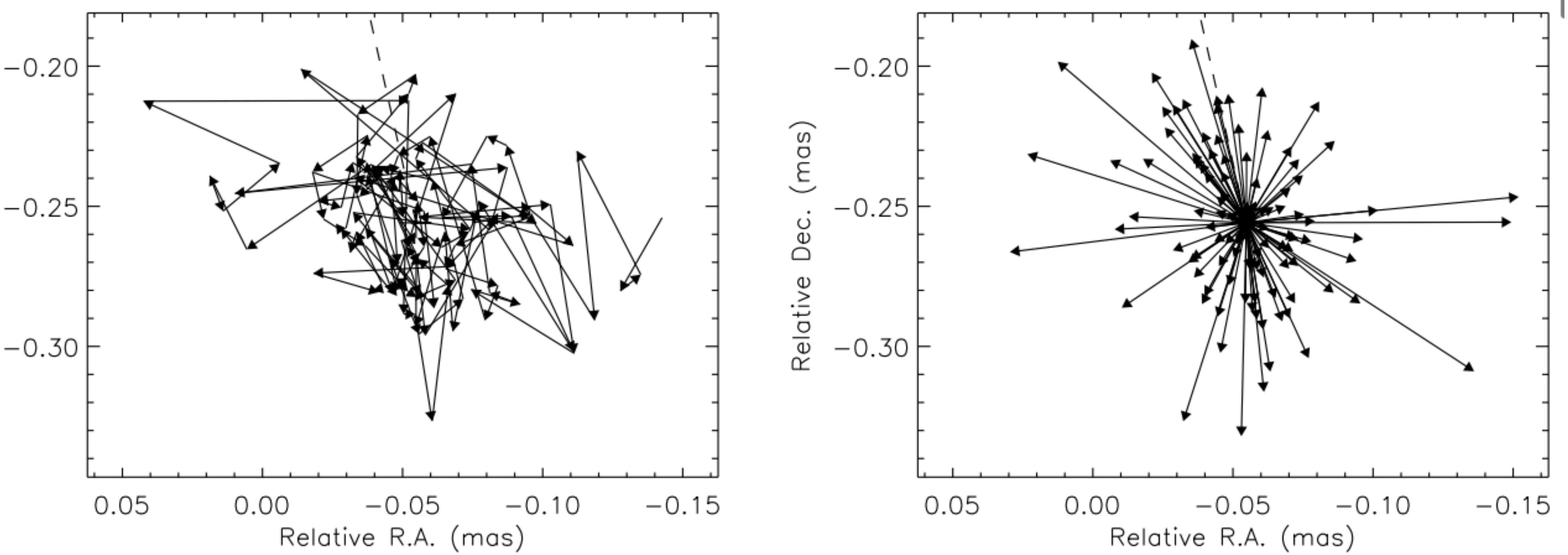
- Size ~0.1 mas
- Dynamical/geometry reasons.
- Moving of the core as a result of changes of a pressure/density.
- Intrinsic error of RCS.

Positional uncertainties:

Median: (4.9 x 1.6) μas

Flux leakage between core and RCS: Typically small (within 10%) but in rare cases can reach to 50%

# RCS trajectory



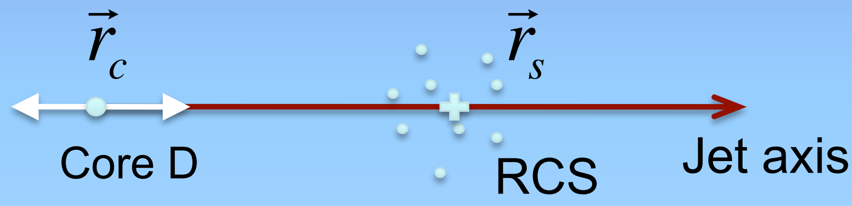

Motion vector – motion of RCS between two consequent epochs.

- Random orientation of six long motion vectors (>0.08 mas)
- Anisotropy: Motion vectors (<0.08 mas) have a statistically significant preferential orientation along the jet axis
- Asymmetry: Length of motion vectors are larger along the jet axis
- Anisotropy and asymmetry - preferential motion of the core along the jet axis

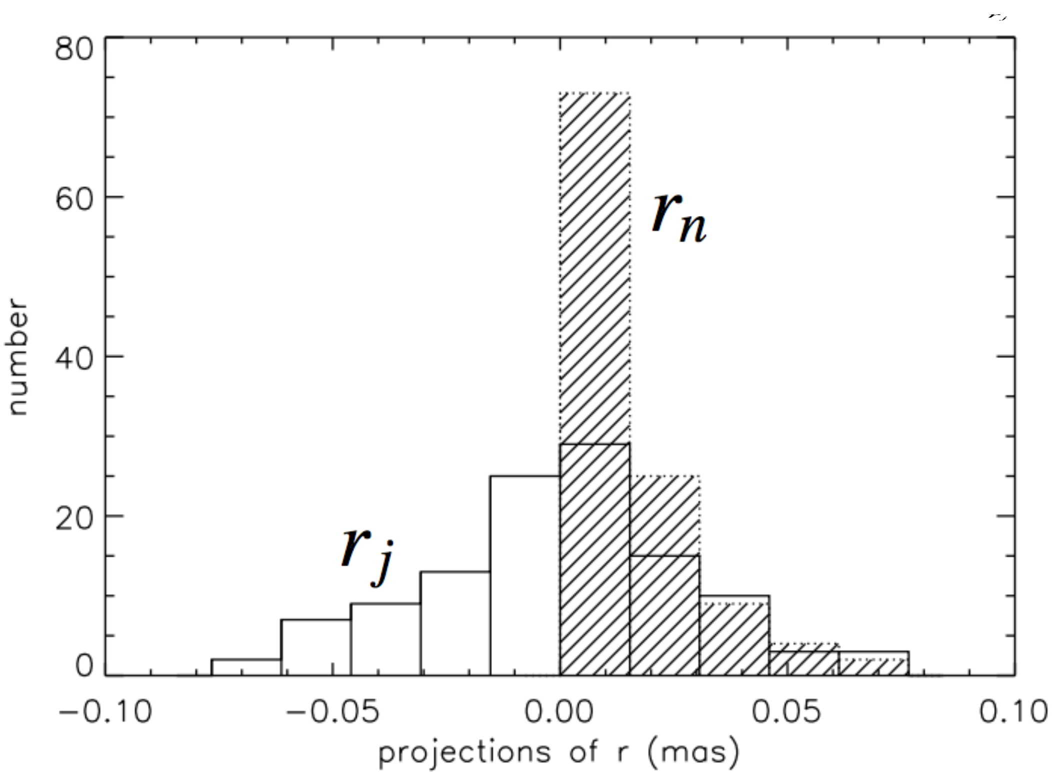
# Estimates of core shift and intrinsic motion of RCS

Apparent motion-vector of RCS:

$$\vec{r} = -\vec{r}_c + \vec{r}_s$$




- $r_c$ : The core position shifts in the direction of the jet
- $r_s$ : The RCS moves in random directions within a sphere




$$\mathrm{rms}_c = \sigma_c = \left(\sigma_{r_j}^2 - \sigma_{r_n}^2\right)^{\frac{1}{2}}$$

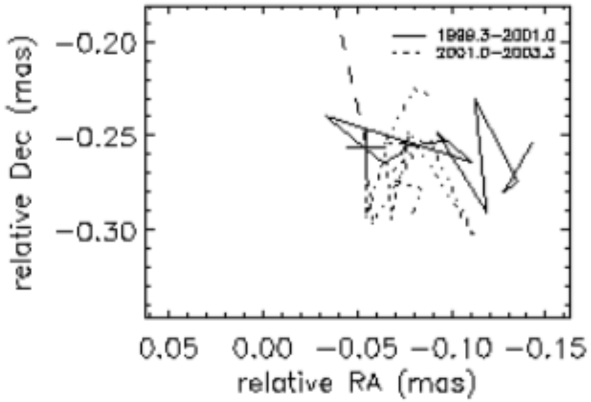
$$\mathrm{rms}_s = \left(\overline{s^2}\right)^{\frac{1}{2}} = \left(2\overline{r_n^2}\right)^{\frac{1}{2}}$$

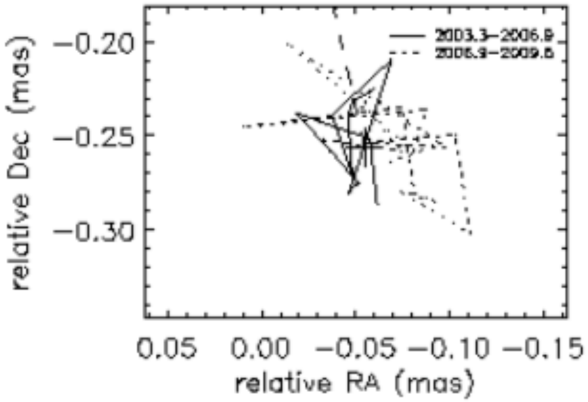
$$rms_c = 0.025 \pm 0.008\ mas$$

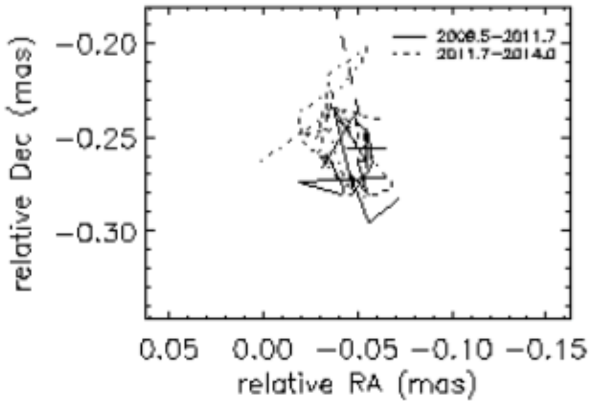
$$rms_s = 0.025 \pm 0.009\ mas$$

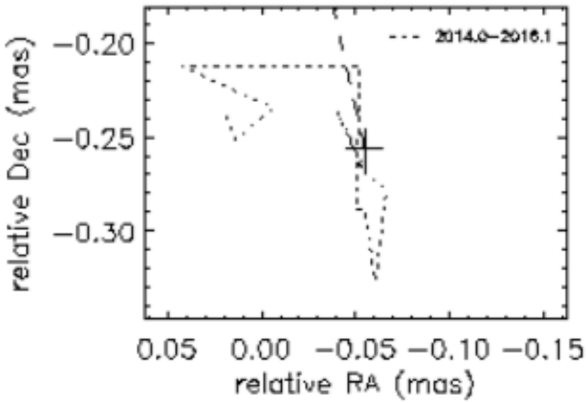
Contribution of core shift to the apparent motion of RCS is significant.

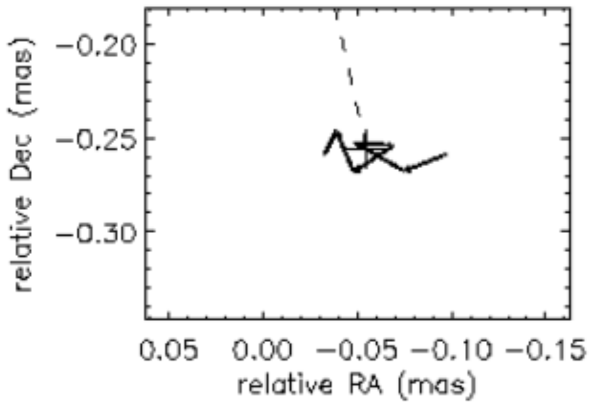
# RCS motion



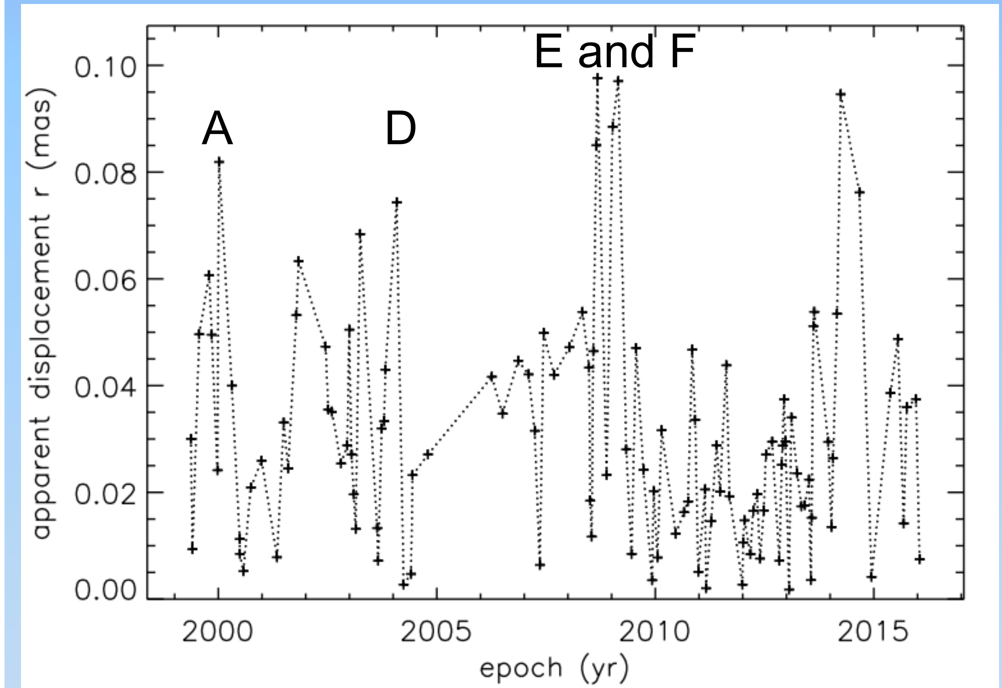



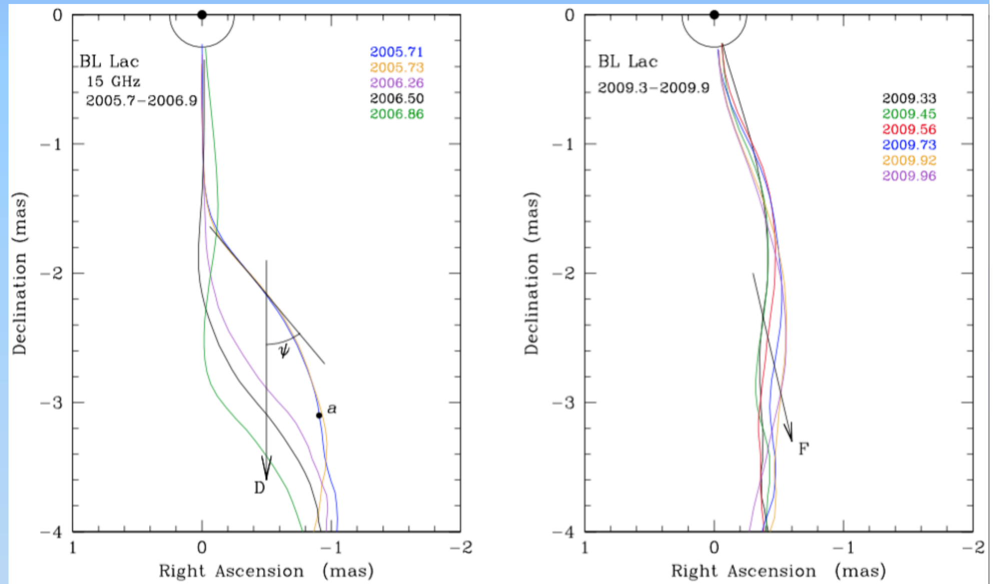




Time scales of weeks-months: erratic motion

Time scales of years: clock-wise motion (chance prob. 3%)?; mean speed - 0.1c

# Link between the motion of RCS and wave excitation

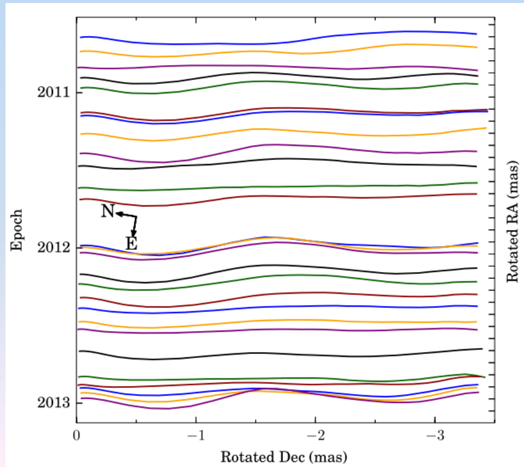


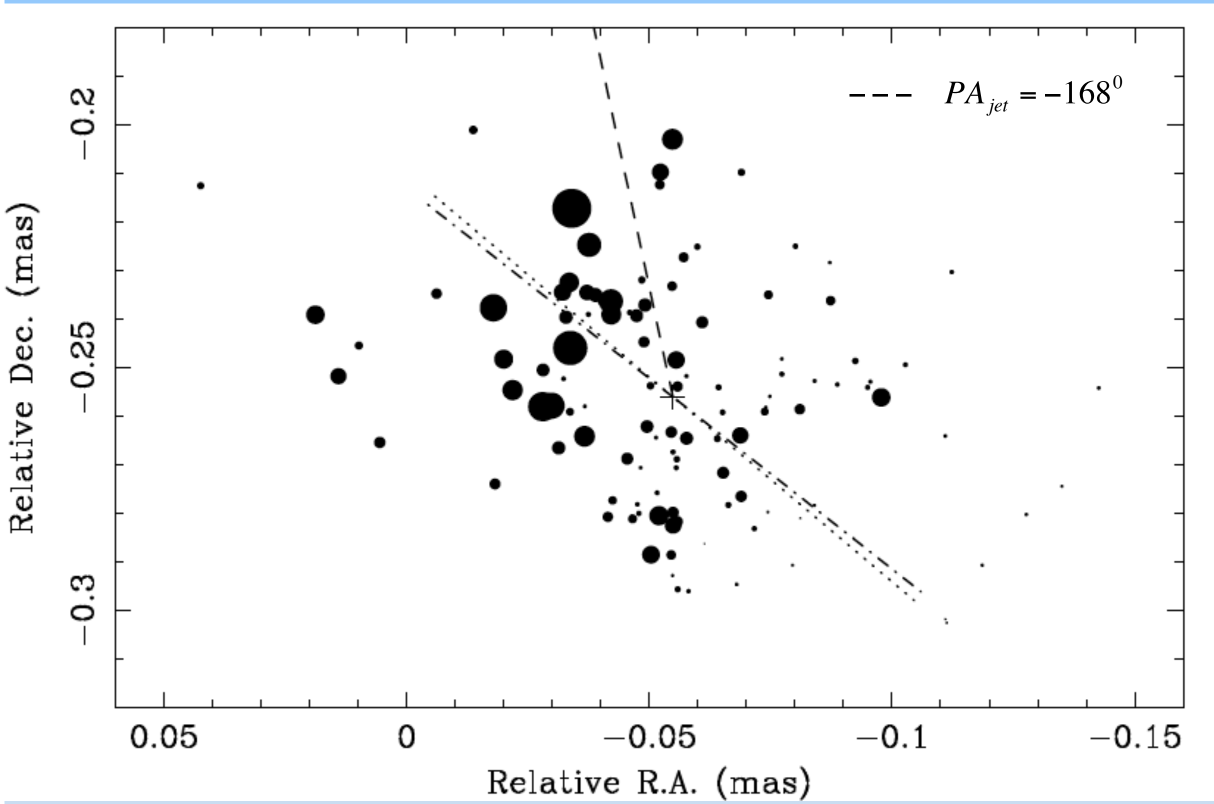

Waves D and F (Cohen et al. 2015)

• Relatively large shakings of RCS (≥ 0.07 mas) generates transverse waves A, D, E, and F in the jet.
• Jet stable state 2010-2013: The RCS acts as the nozzle of the jet and generates quasi-sinusoidal waves with amplitudes lower than ≈ 0.02 mas

Quasi-sinusoidal waves (Cohen et al. 2015)



# *Distribution of flux density of RCS on sky*




- Flux density range: 0.17-4.4 Jy
- Flux distribution is **asymmetric** along and transverse to the jet central axis ($PA_{jet}$=-168$^0$, dashed line).
- Statistically significant flux asymmetry with respect to the jet axis: $\alpha_{sym}$ = 46 deg.

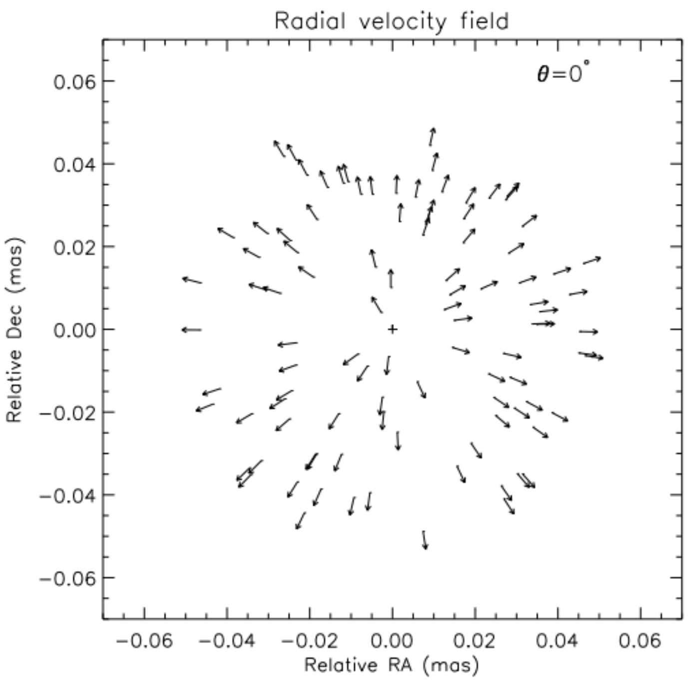
# Simulations of RCS emission

Toy model:

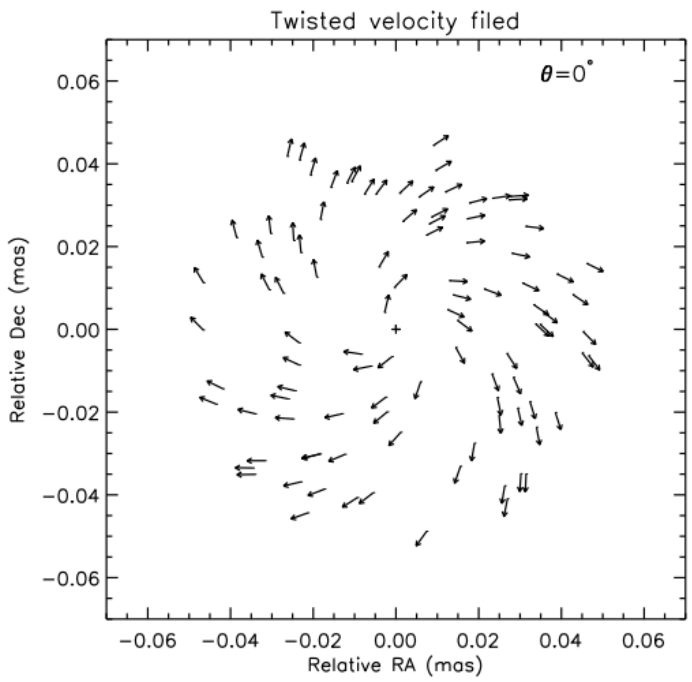
- RCS moves in a plane normal to the jet axis
- RCS drags the jet outflow in a swinging motion: $\theta_{RCS}(r,\varphi)$ is the viewing angle of the jet outflow at the position of RCS
- $S_0$, $\beta$ are constant
- Beaming is due to variation of $\theta_{RCS}$

Viewing angle of the jet central axis $\theta = 0^o$

Radial velocity field



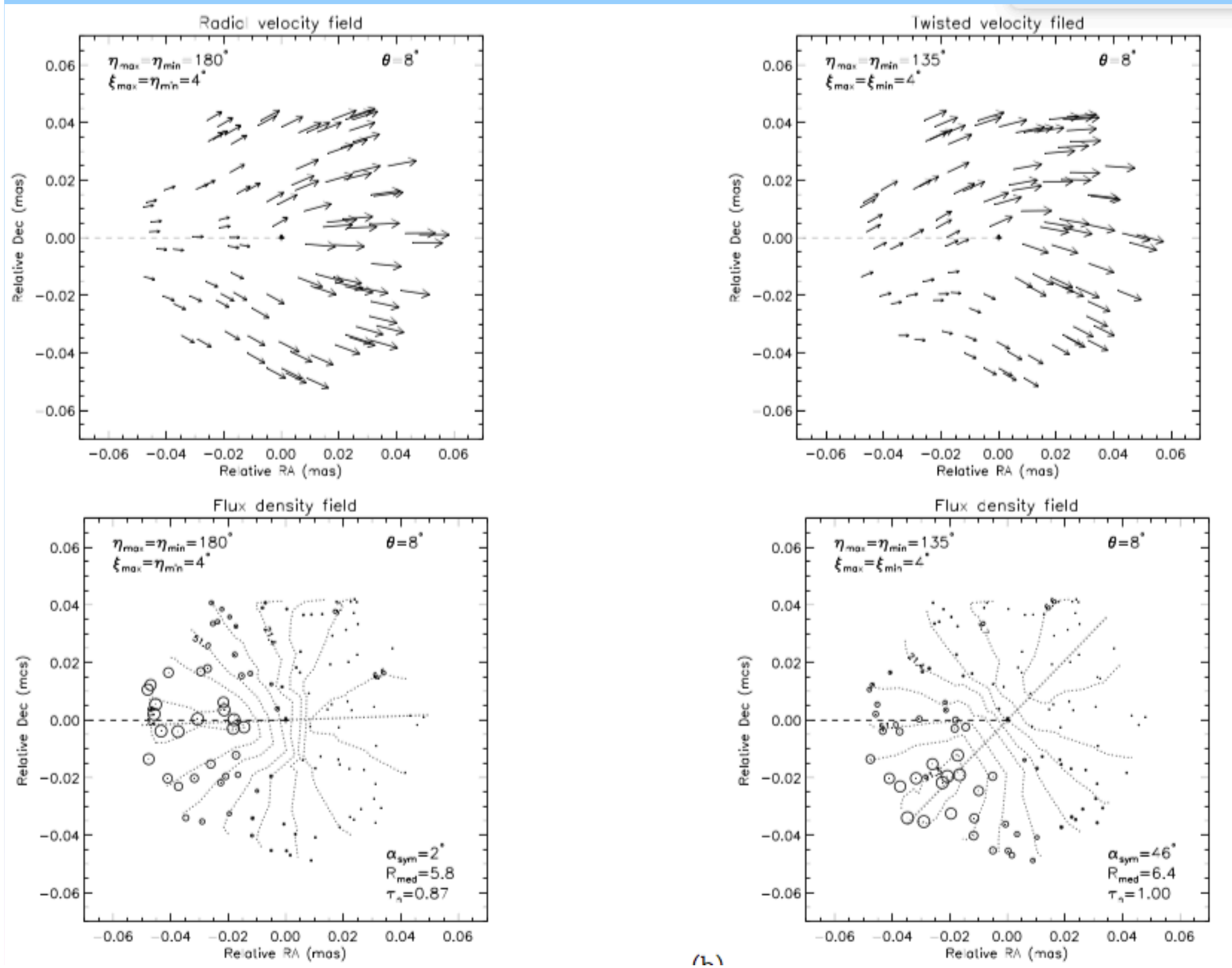

Twisted velocity field



# Simulations of RCS emission

Viewing angle of the jet central axis θ = 8°

Radial velocity field | Twisted velocity field




$$S(r,\varphi) = S_0 D\left(\beta, \theta_{RCS}(r,\varphi)\right)^{2-\alpha}$$

Flux density asymmetry is due to twisted velocity field of the jet at the position of RCS.

# Summary

• Vector motions of RCS are asymmetric along the jet axis – evidence of resolution-dependent core shift.

• We developed a statistical tool for estimating the core shift and intrinsic motion of RCS: Projected core motion is comparable to intrinsic motion of RCS

• RCS moves with sub-relativistic speed of about 0.1c on time scales of few years

• RCS acts as the nozzle of the jet and its motion generates transverse waves of various amplitudes traveling down the jet ("Whip" model)

• On-sky flux density distribution is asymmetric along and transverse to the jet axis

• Simple model of RCS having the twisted velocity field can account for the observed flux density asymmetry