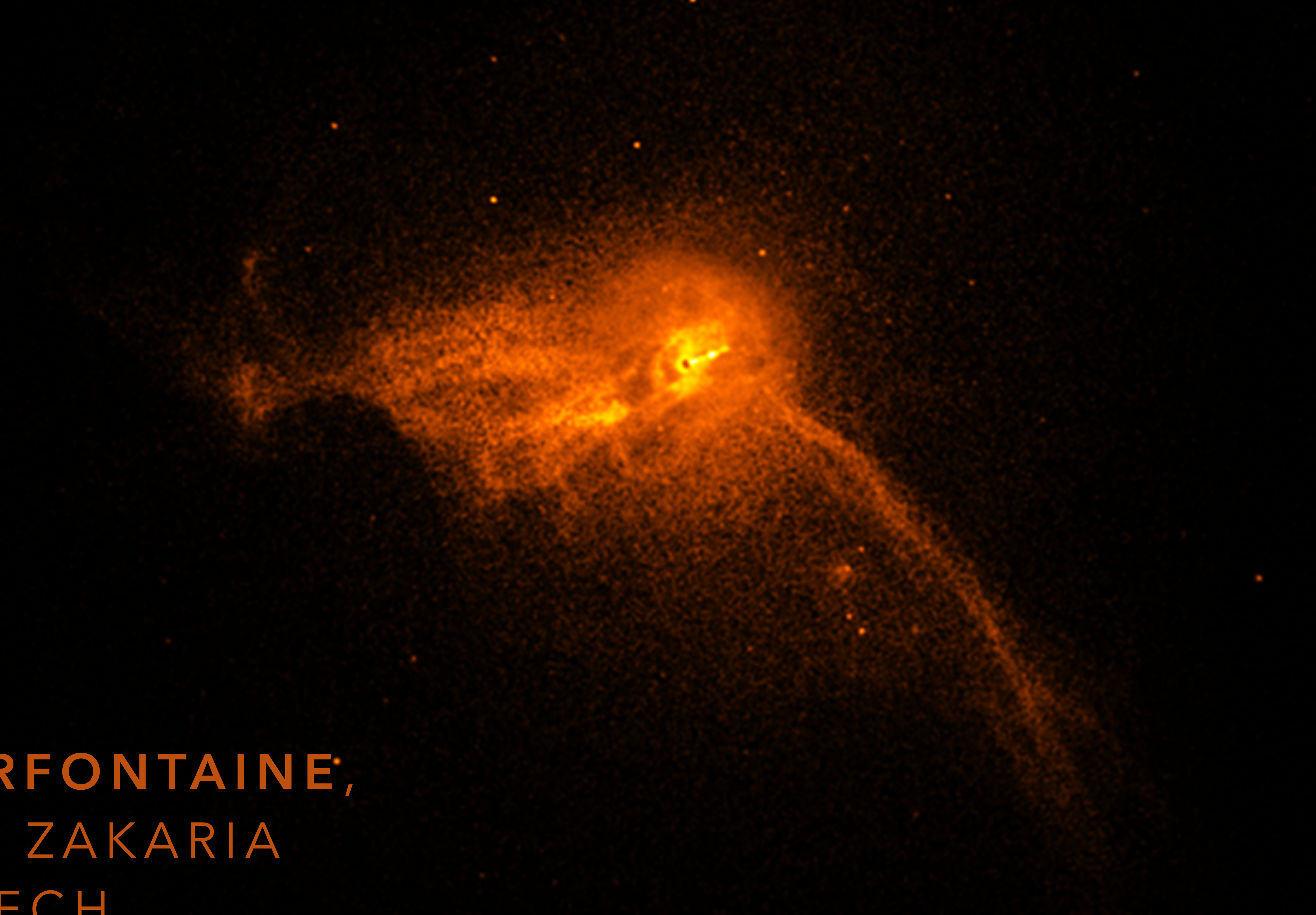
FLARE ECHOS FROM RELAXATION SHOCKS IN PERTURBED RELATIVISTIC JETS

GAËTAN FICHET DE CLAIRFONTAINE,
IN COLLABORATION WITH ZAKARIA MELIANI AND ANDREAS ZECH.

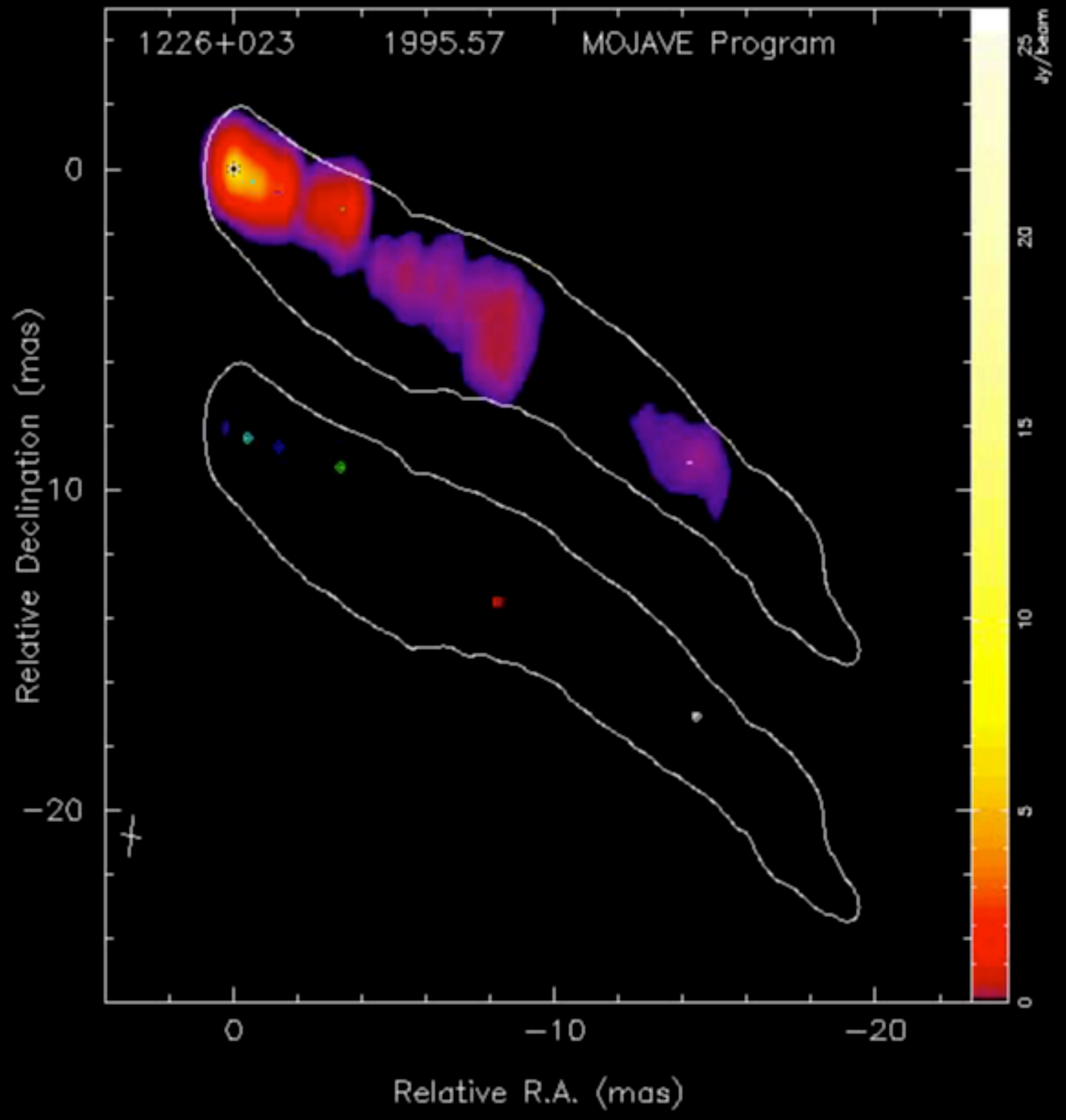


CHANDRA WIDE-FIELD VIEW OF M87 (NASA/CXC)

CONTEXT : TRAILING COMPONENTS

Object : 3C 273

- VLBI observations : standing and moving knots.
- Key features of radio observations with a great variety of velocities and trajectories [3].
- Some sources have showed trailing components (3C 111 [5]).



MOJAVE PROGRAM - OVRO 15 GHz [7]

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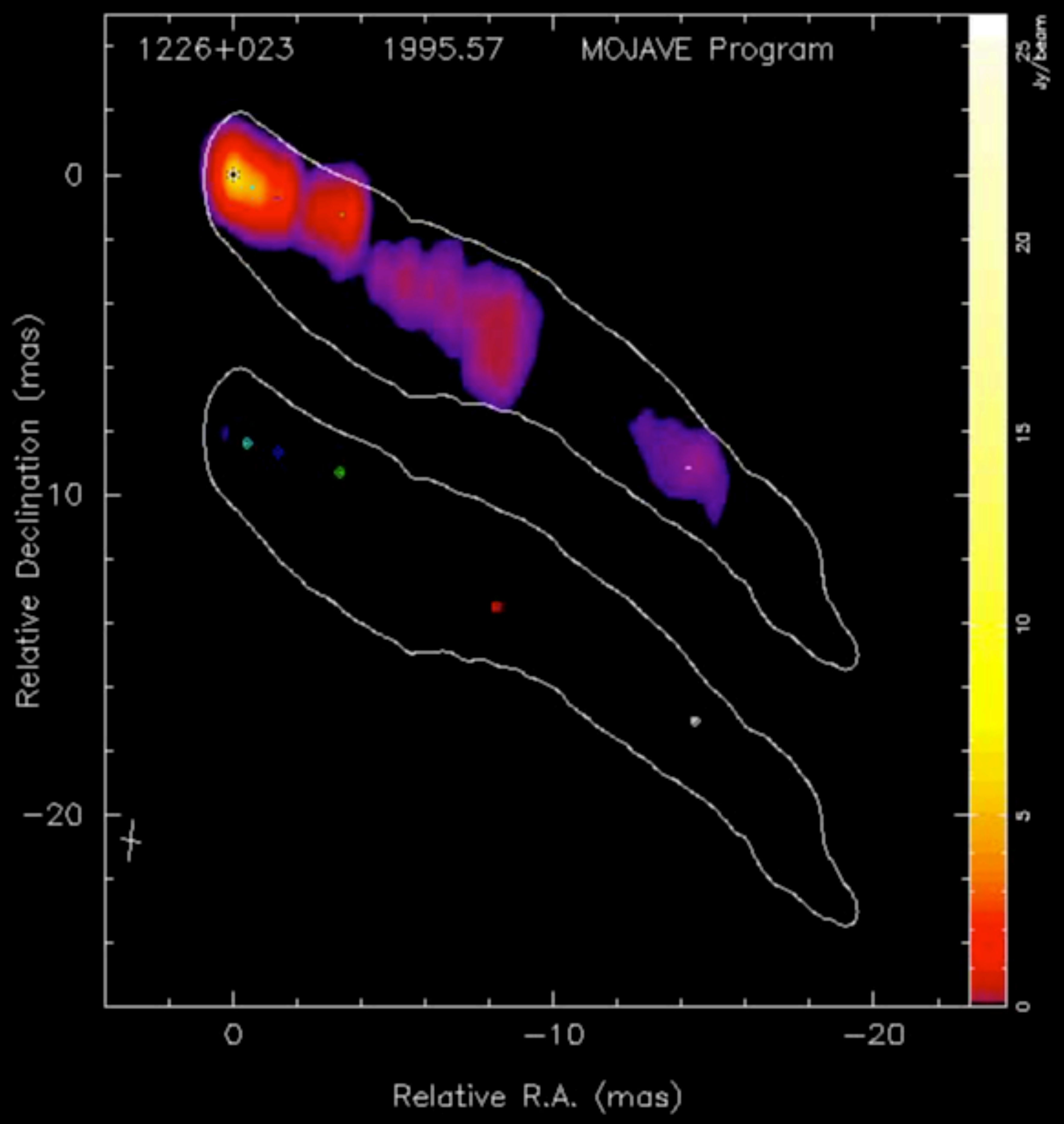

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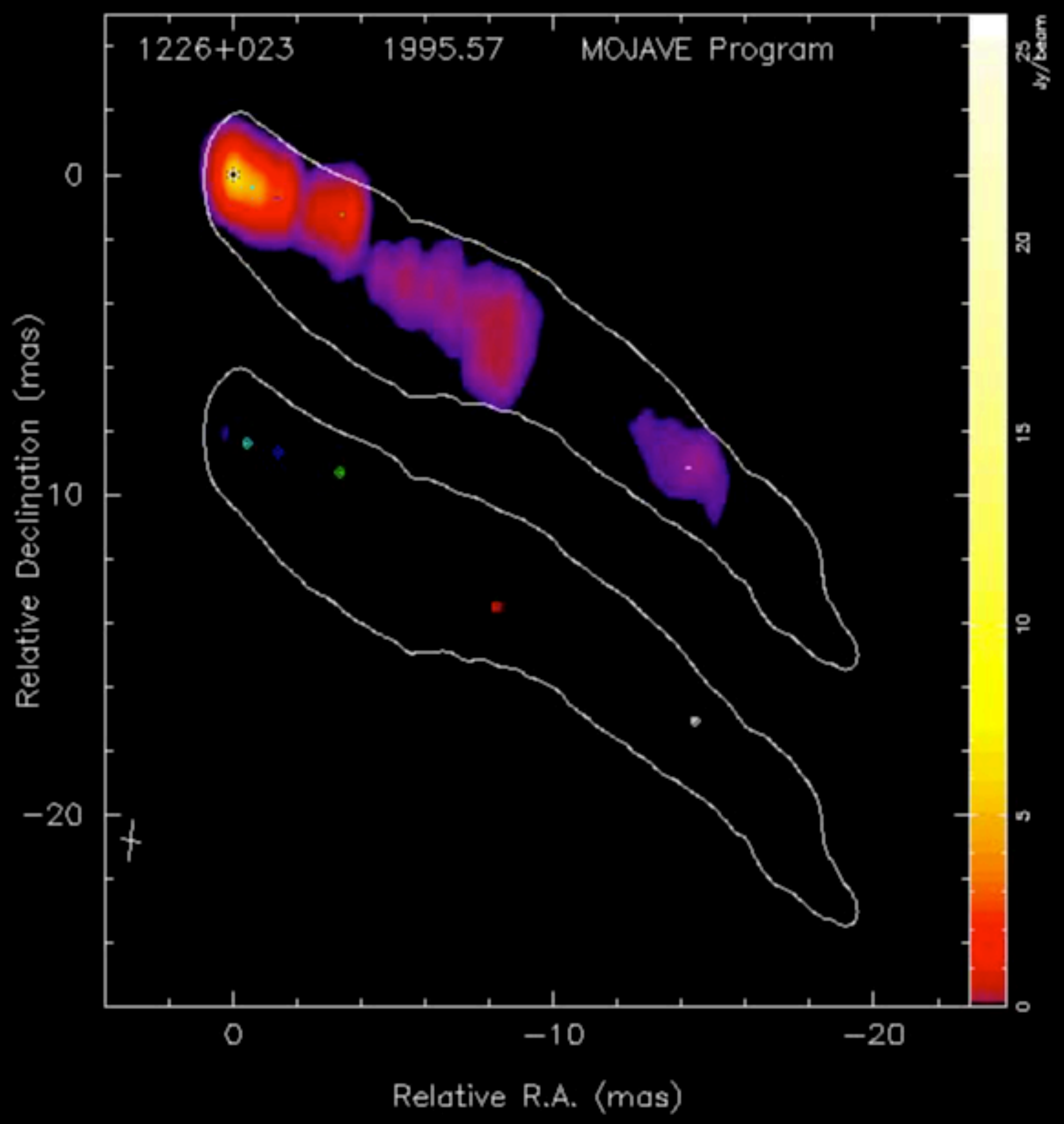

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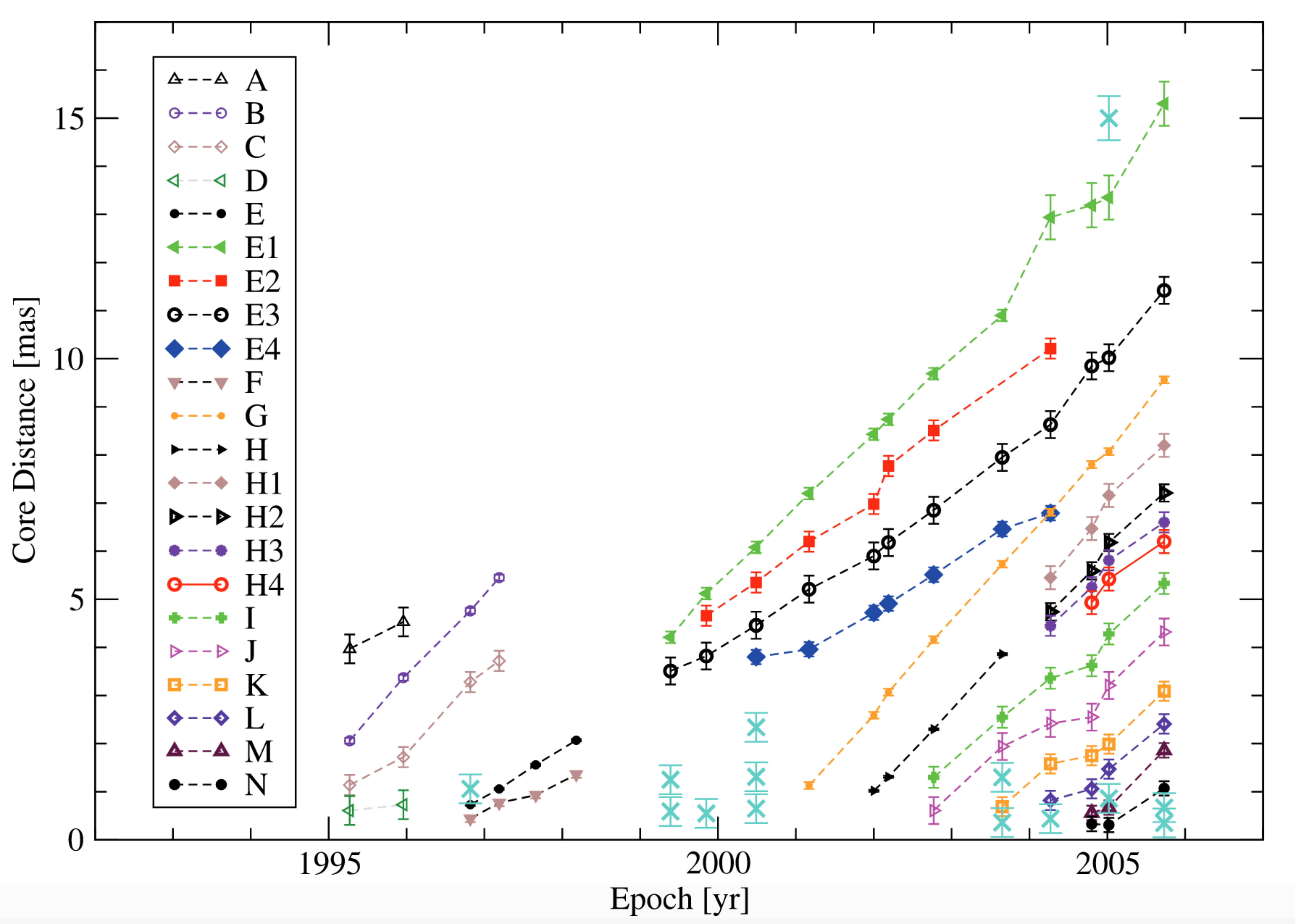

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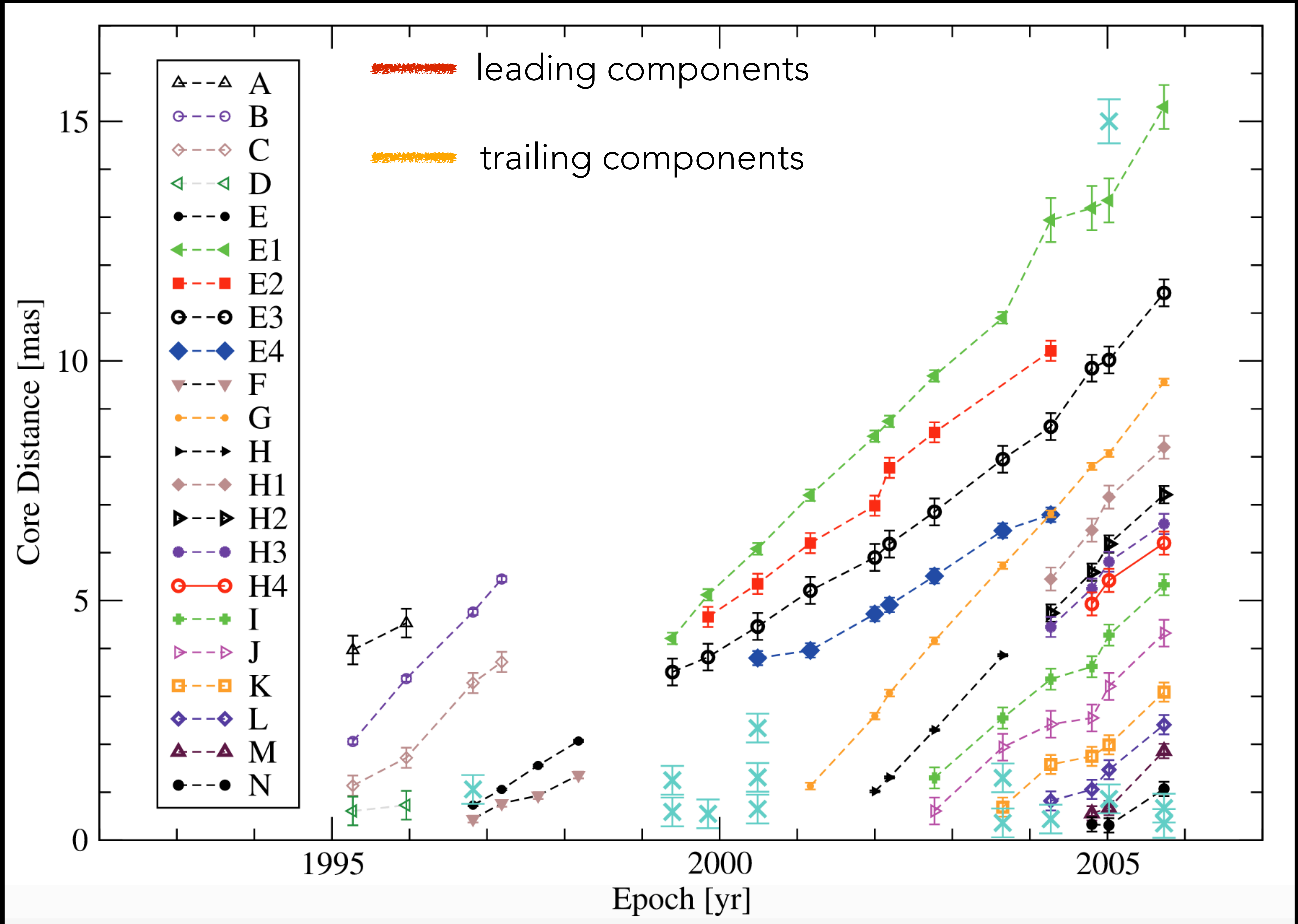

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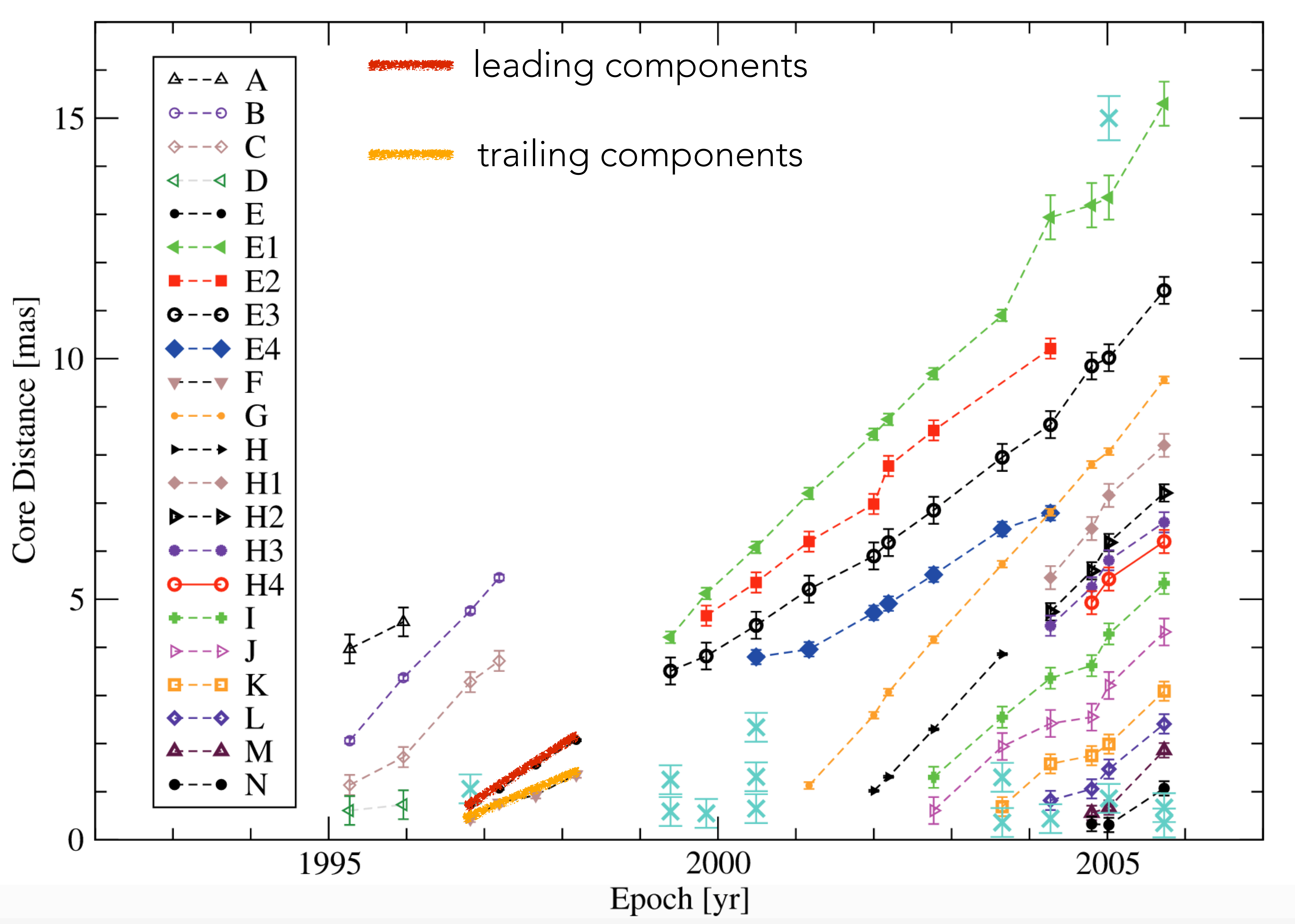

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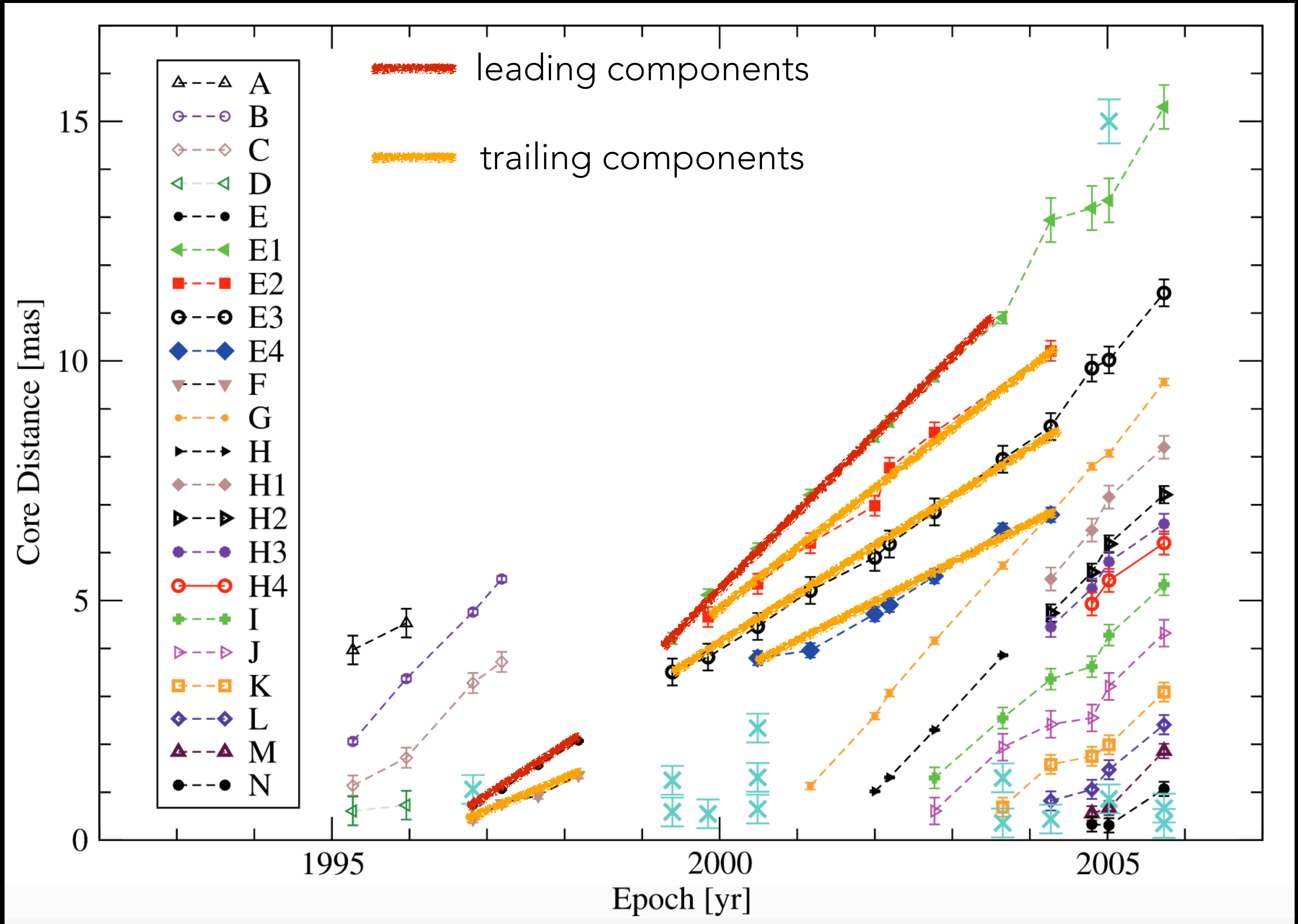

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OBJECTIVES

- Simulated standing and moving shocks and characterized shock - shock scenario in a MWL study.
- Is it possible to reproduce trailing components and determined MWL observational markers ? Can we compare them to observations ?

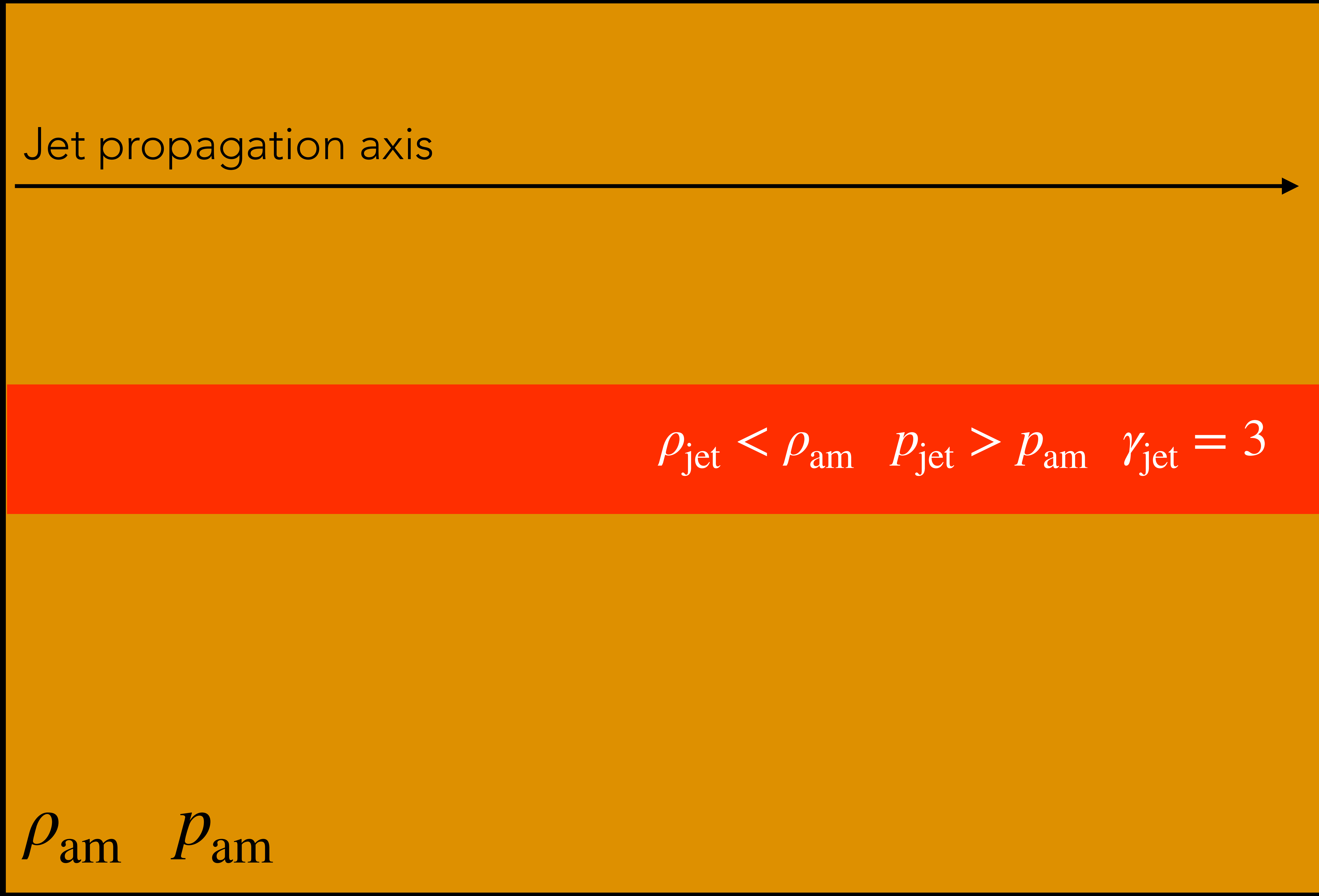
➡ Complete model: SR-HD + radiative processes !

MODEL (1) : RECIPE FOR A RELATIVISTIC JET

1. Use the AMRVAC code [6] which can resolve SR-HD equations inside an adaptive cell mesh.

2. Initial cylindrical jet set with initial conditions $(p, \rho, \overrightarrow{B}, \cdots)$.

3. To reproduce standing knots : use an over-pressured jet [2, 4] (compared to the ambient medium) : $p_{\text{jet}} > p_{\text{am}}$.



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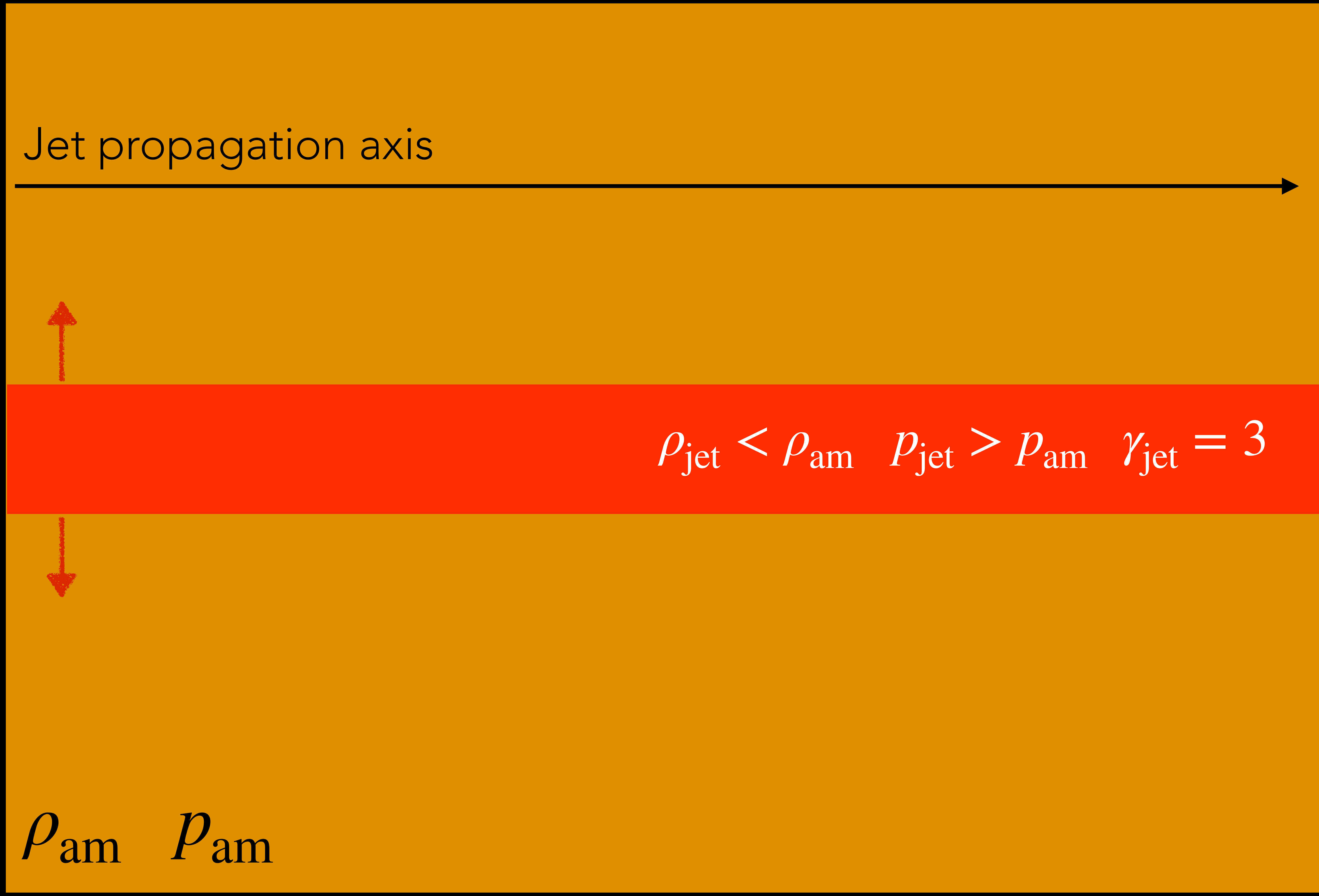

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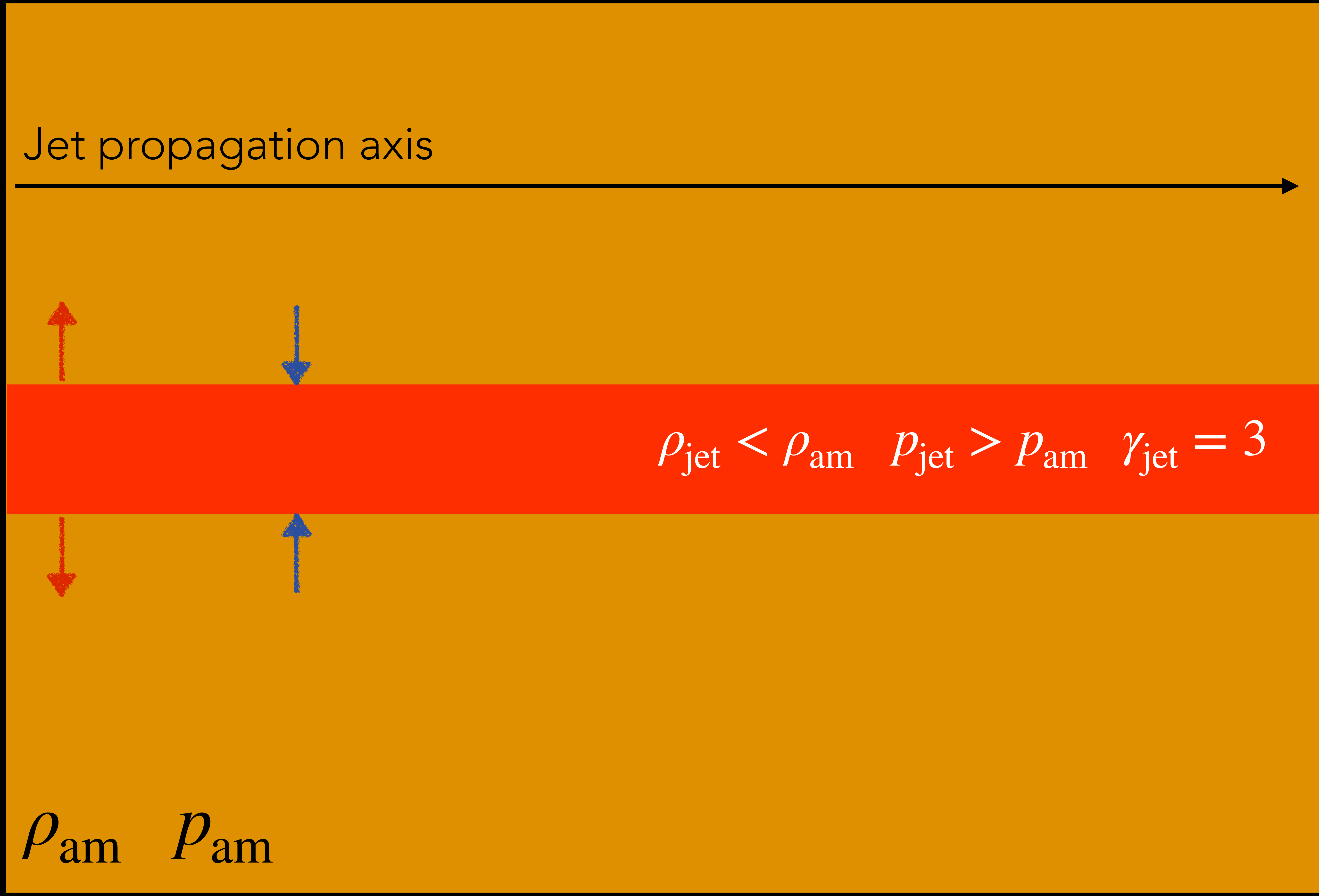

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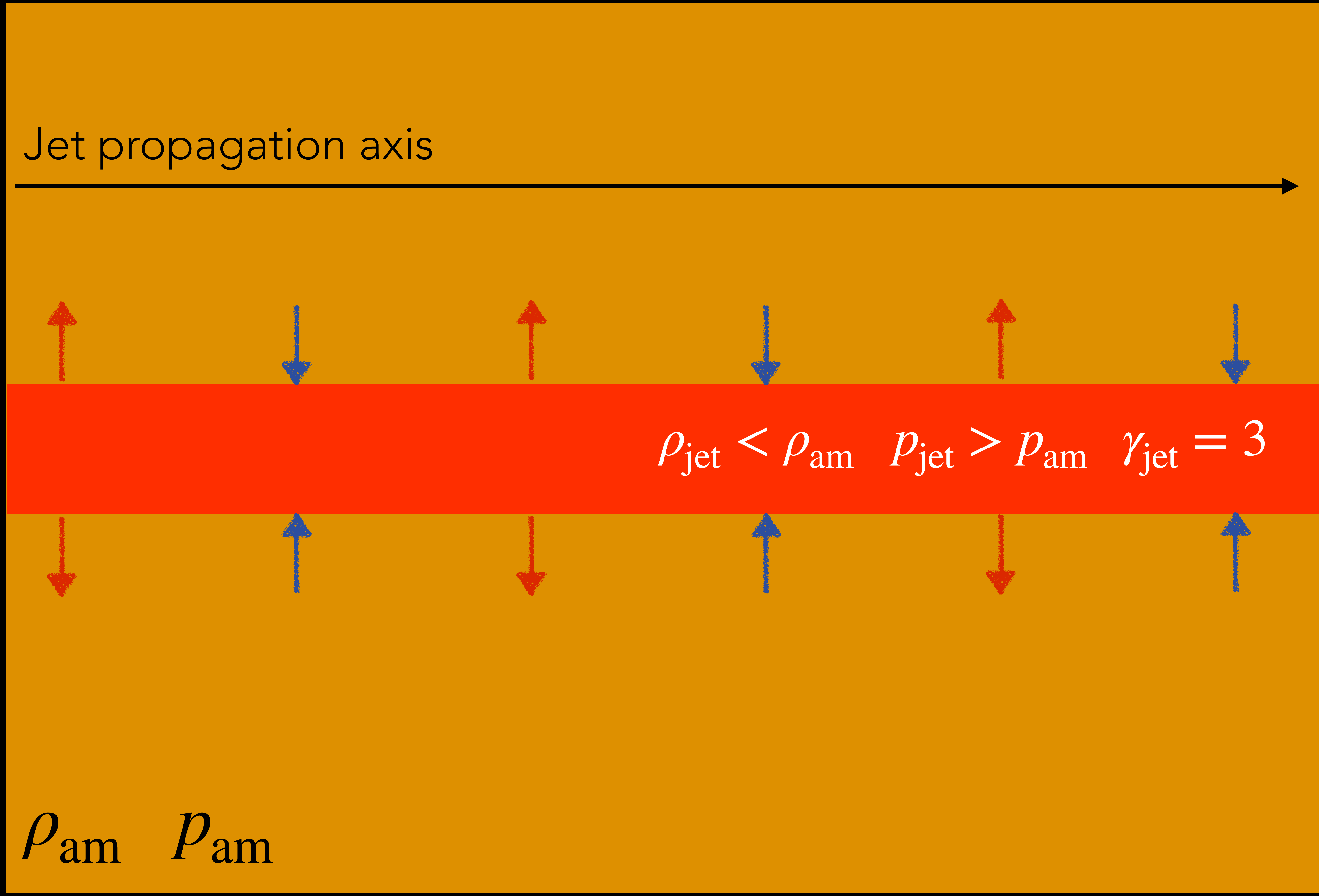


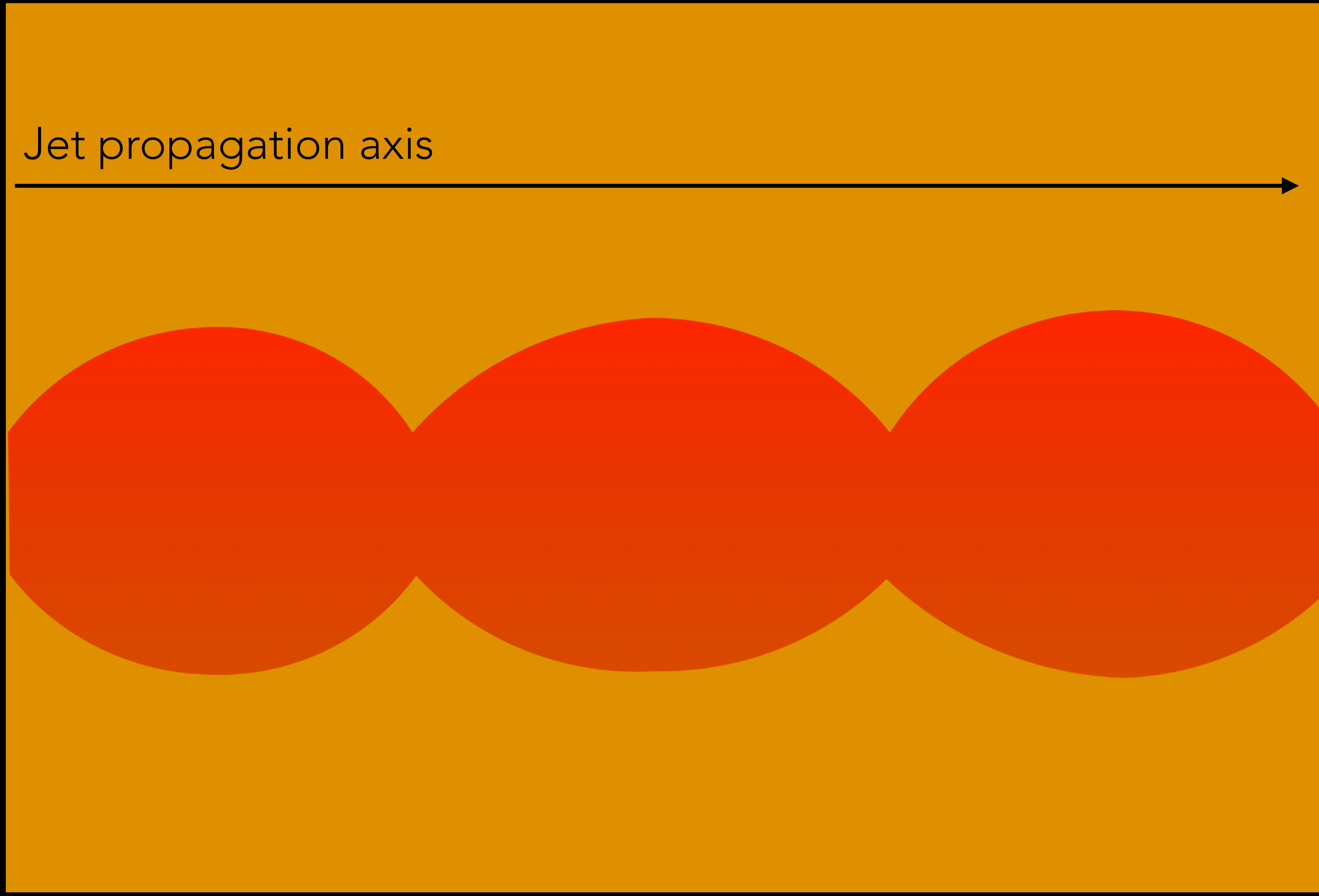
MODEL (1) : RECIPE FOR A RELATIVISTIC JET

4. Detect the shock regions in the jet by checking variations of $\mathscr{M}$.

5. Inject relativistic electrons in shocks. We define an energy γ_e and a density n_e.

6. Check for radiative cooling : extract a fraction of energy along time [8].

7. Perturbation : ejecta with the jet density and pressure but higher Lorentz factor.



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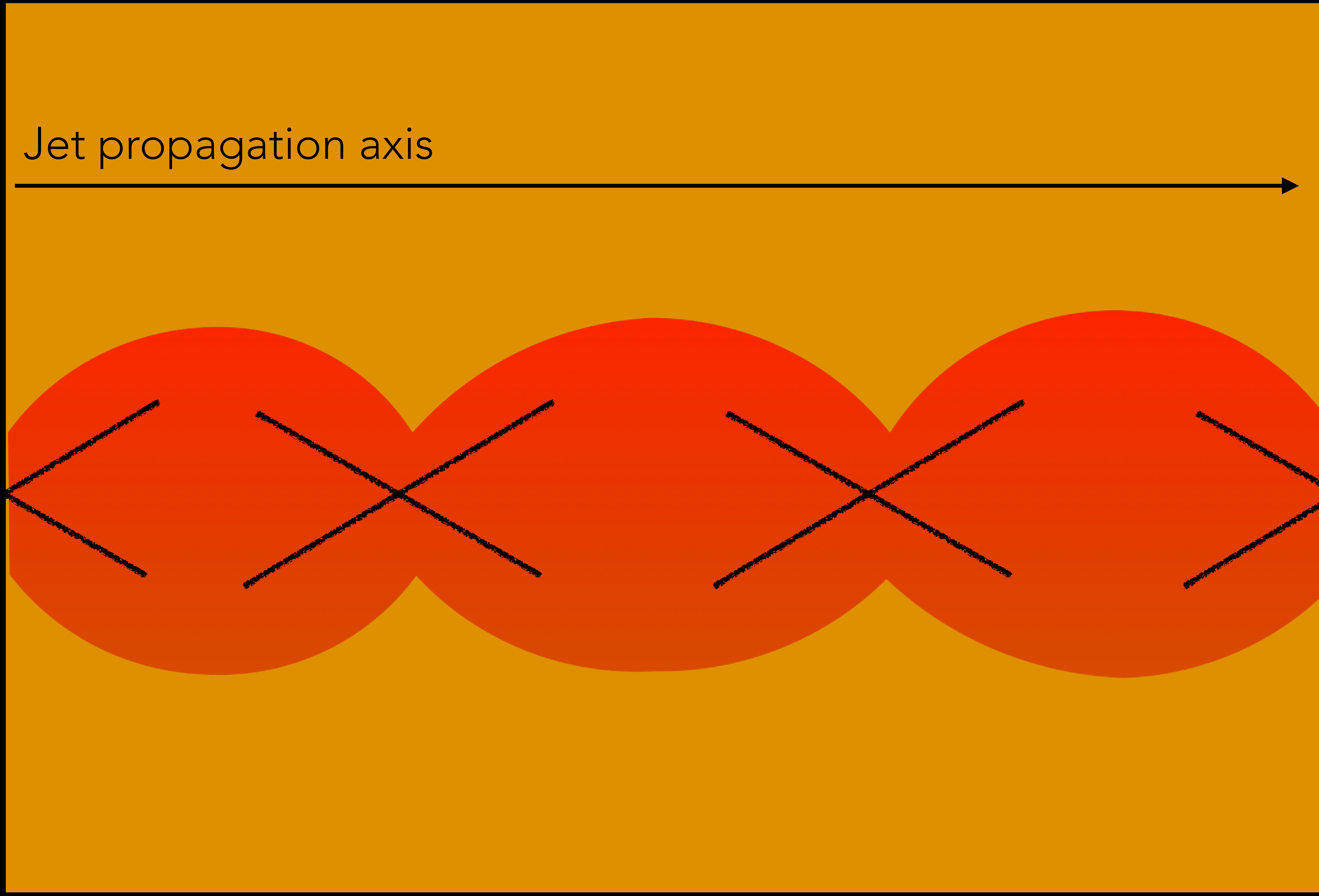

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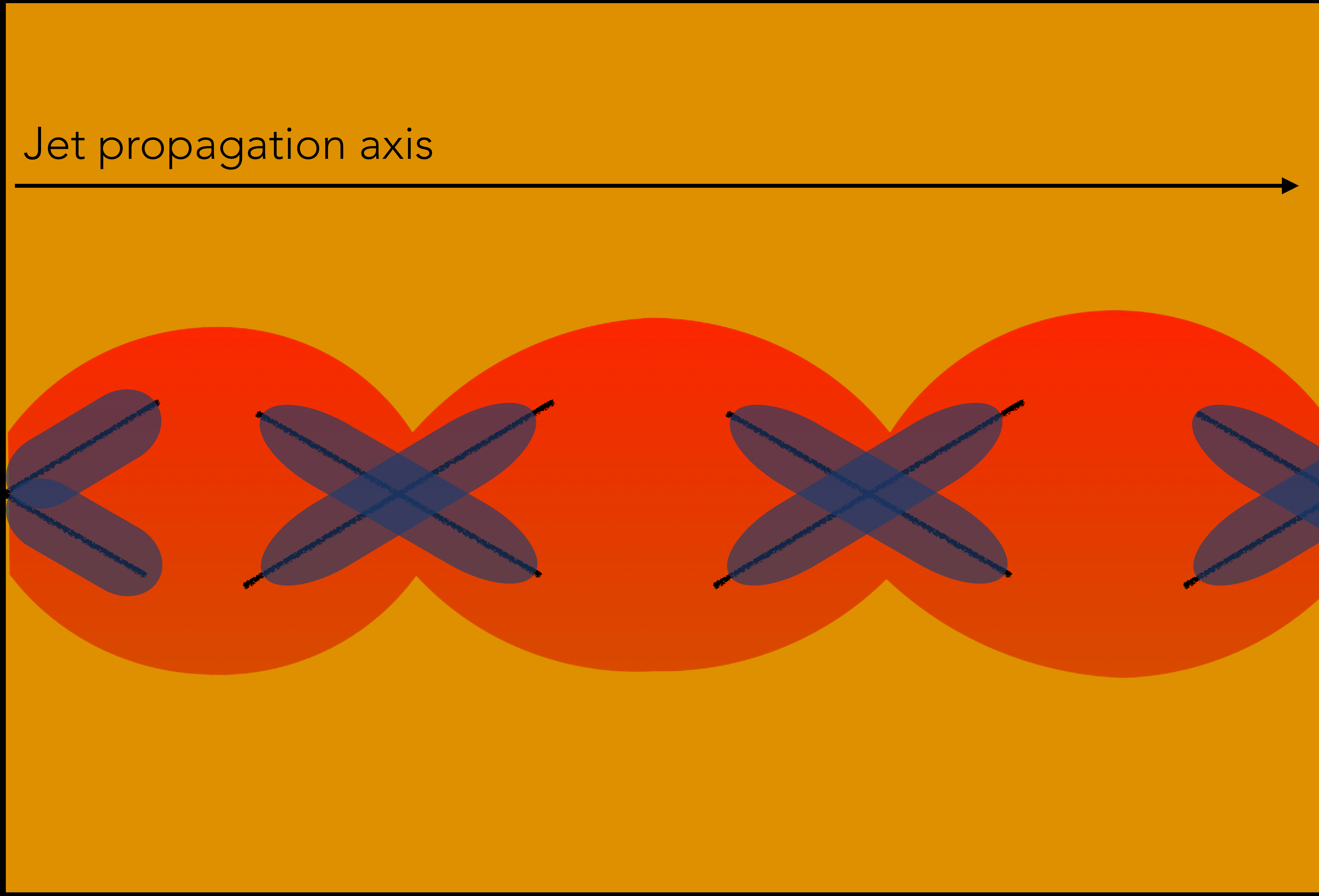

MODEL (2) : RIPTIDE CODE [4]

- *Radiation Integration Processes in Time-Dependent* code.
- Synchrotron parameters from relativistic electrons quantities (j_ν, α_ν, τ_ν).
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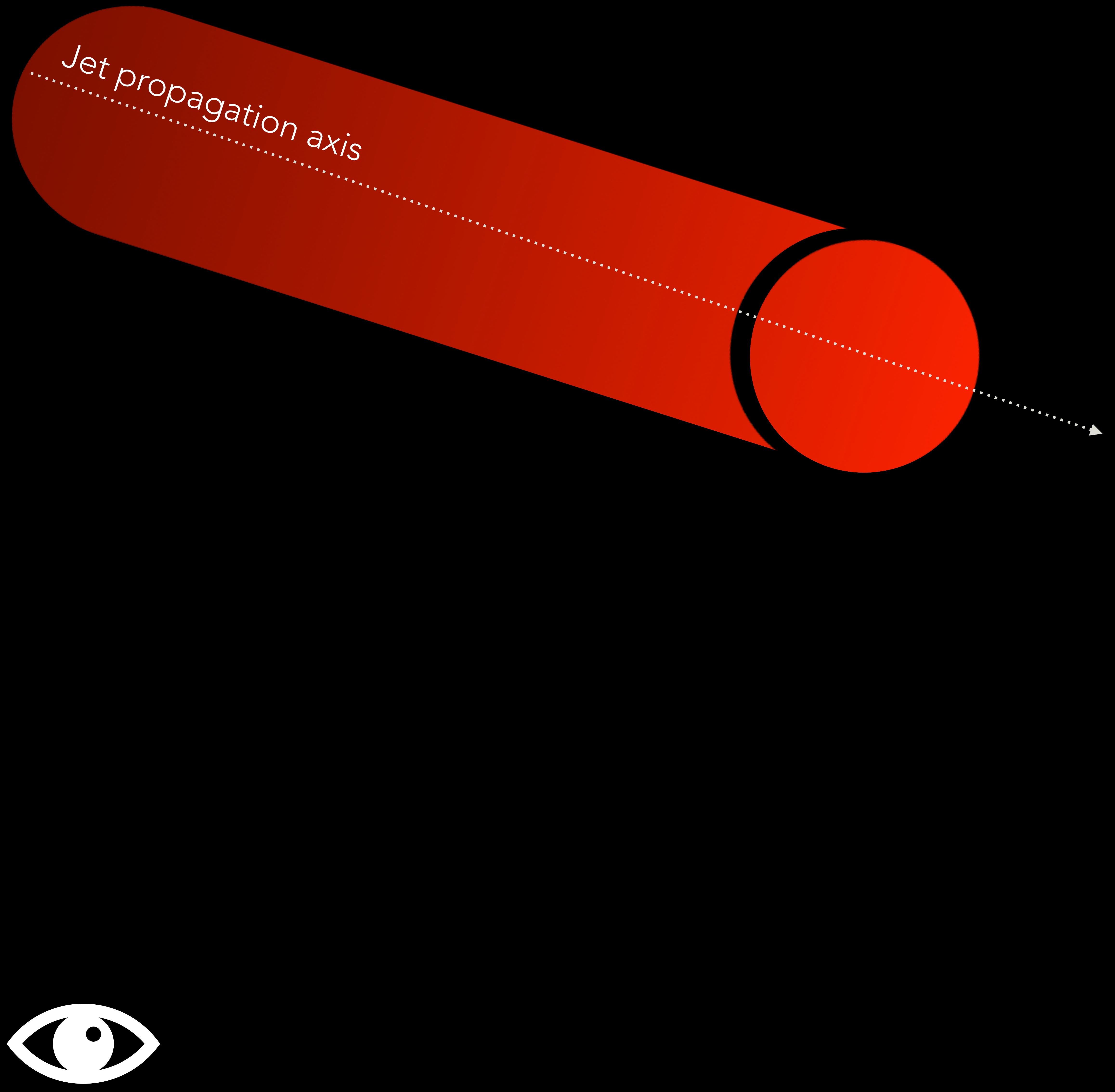
- Relativistic effects : Doppler beaming, light crossing time effect…



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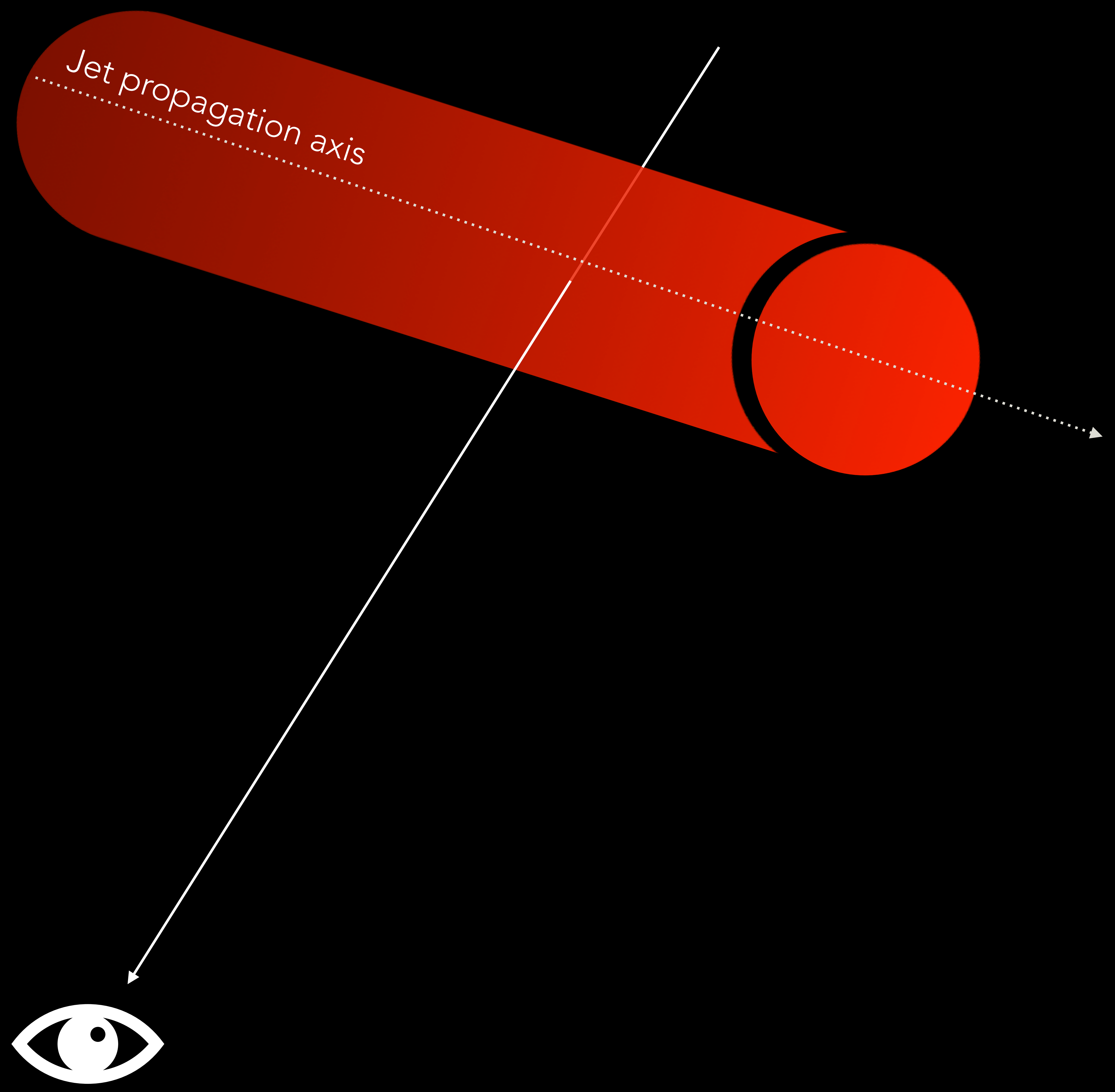

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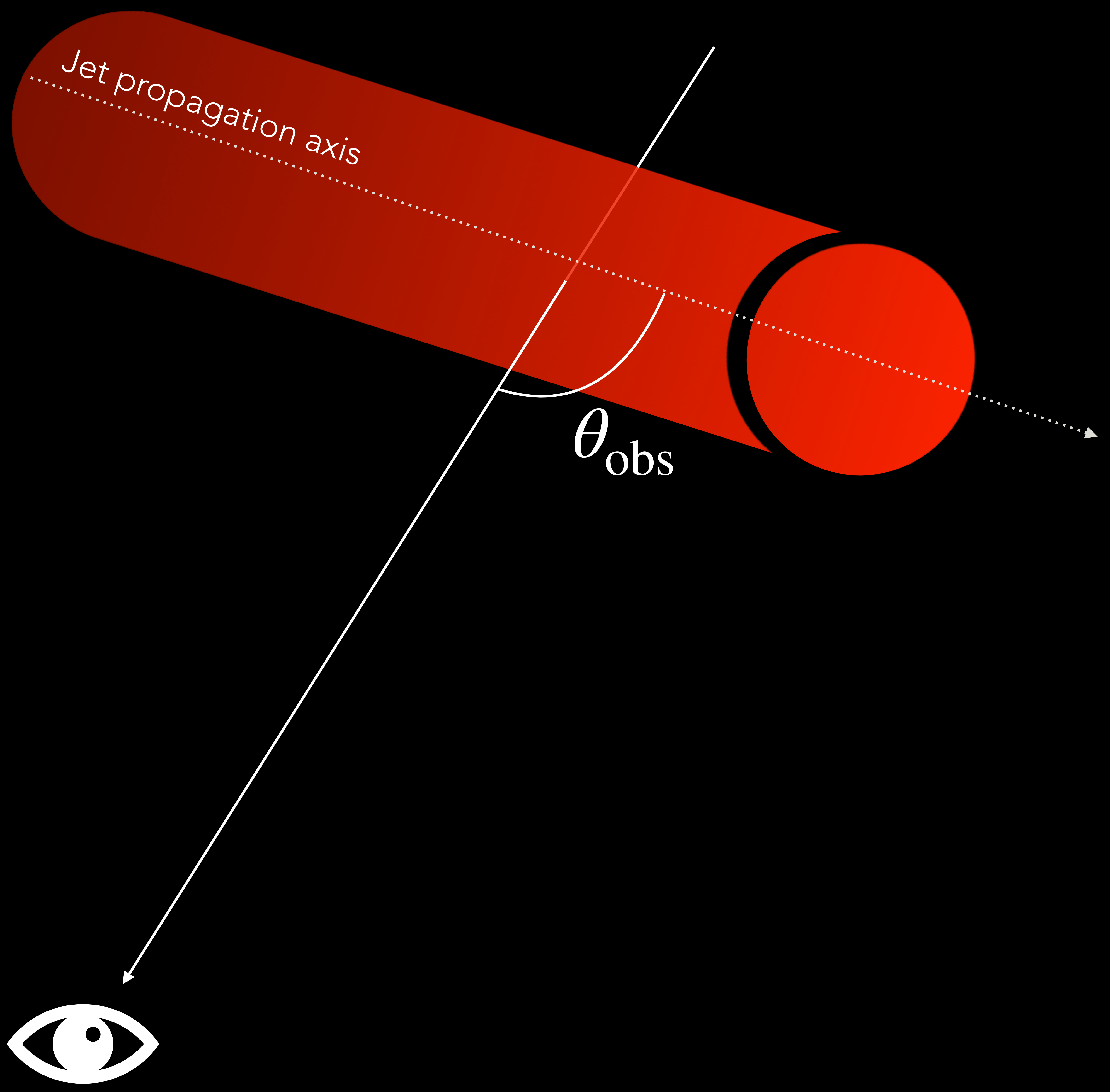

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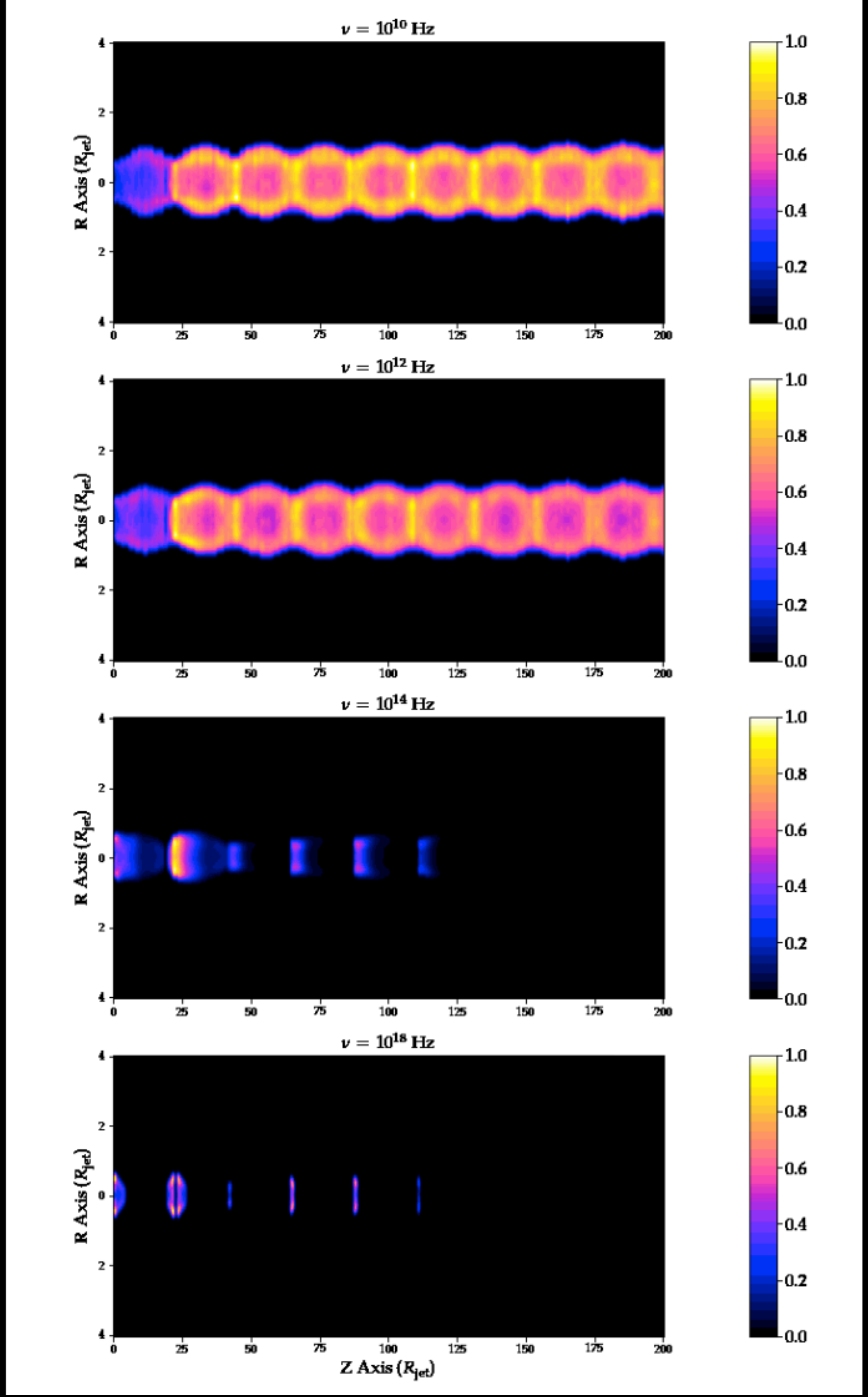
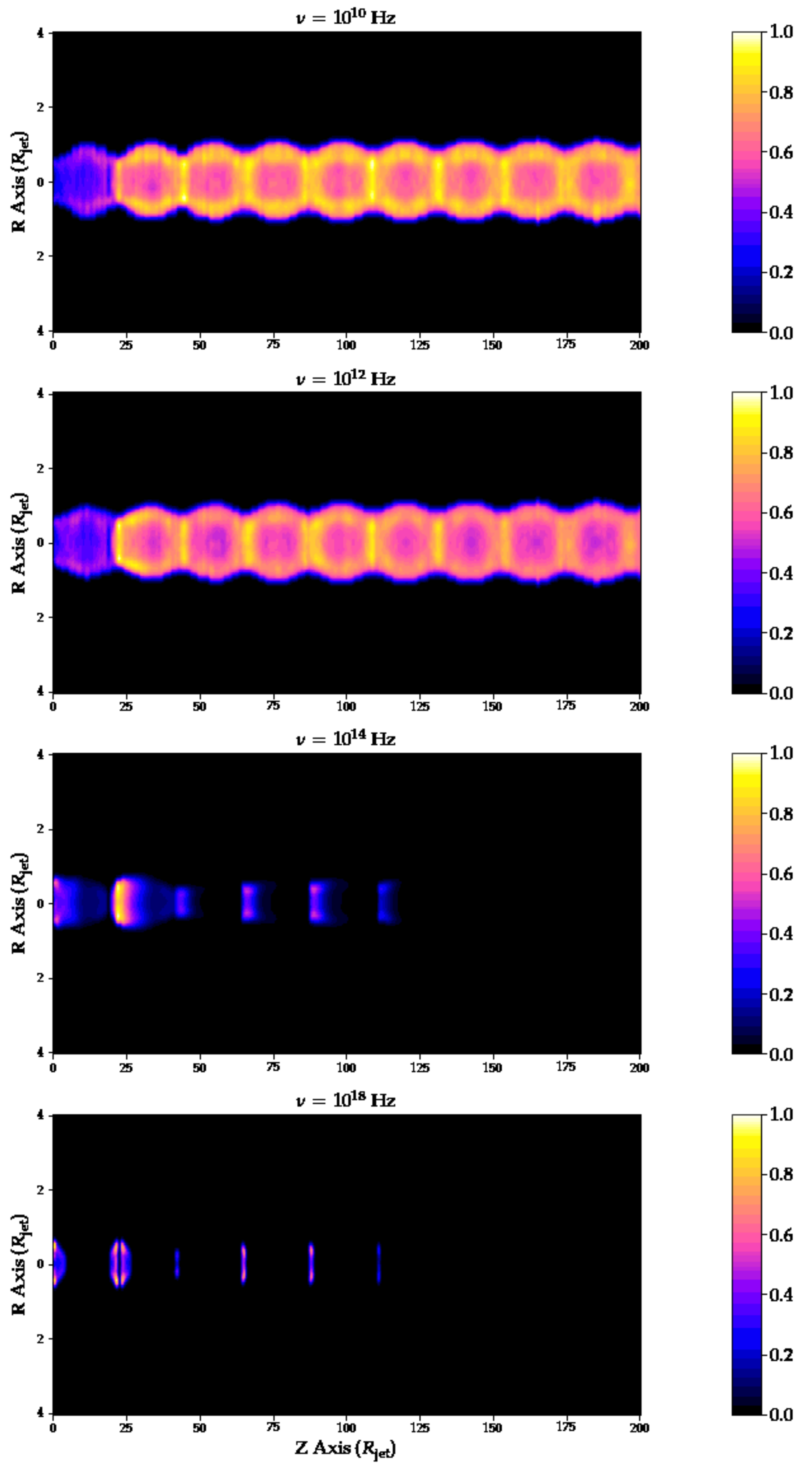


Synthetic synchrotron maps (normalized flux) for $\theta_{obs} = 90°$.

RELAXATION SHOCKS IN PERTURBED RELATIVISTIC JETS

- Shock - shock interaction disturbs the equilibrium position of a standing shock.
- Oscillation leads to a remnant emission.
- For strong enough interaction : the jet relax itself and allows the appearance of secondary moving shock in the wake of the ejecta.



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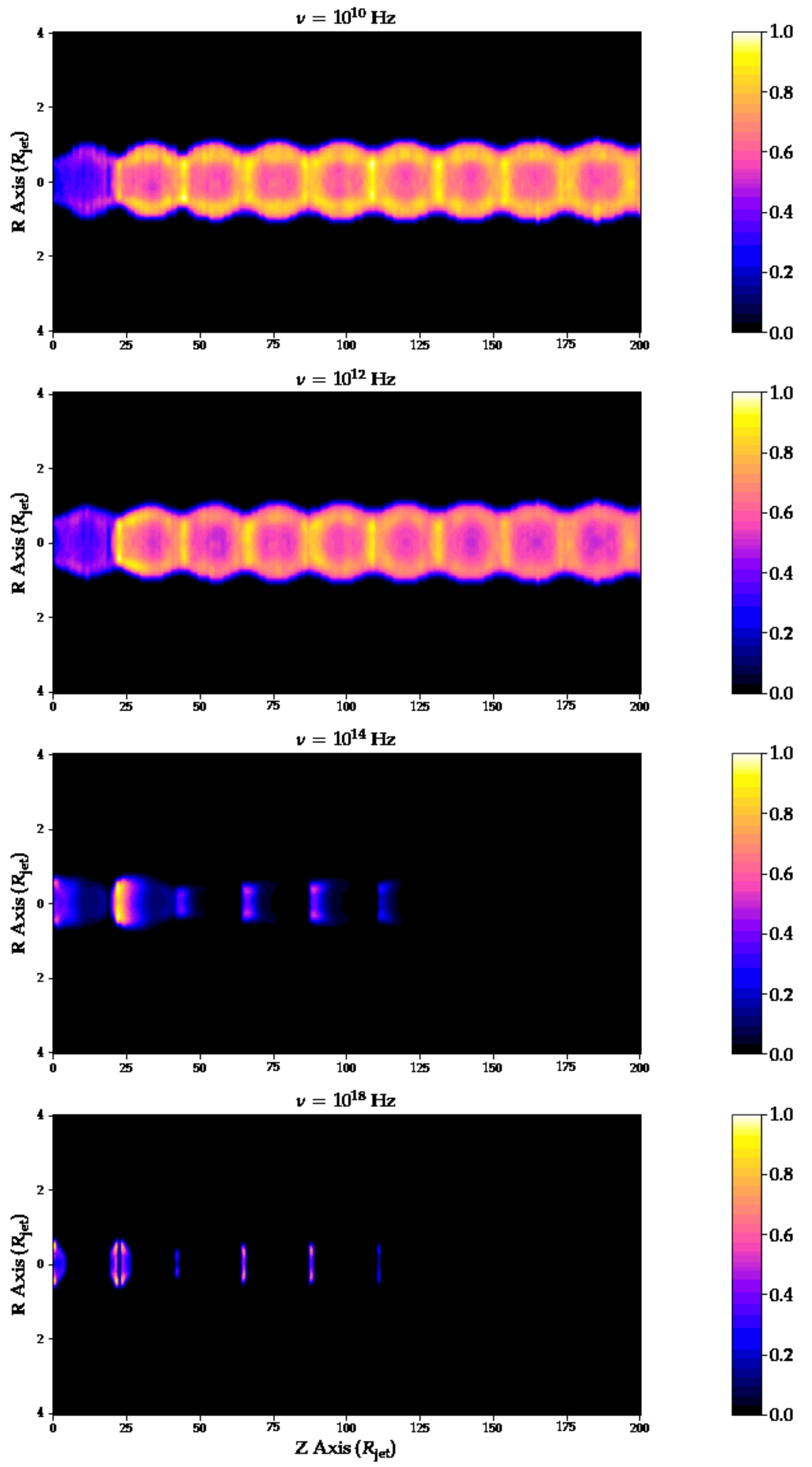
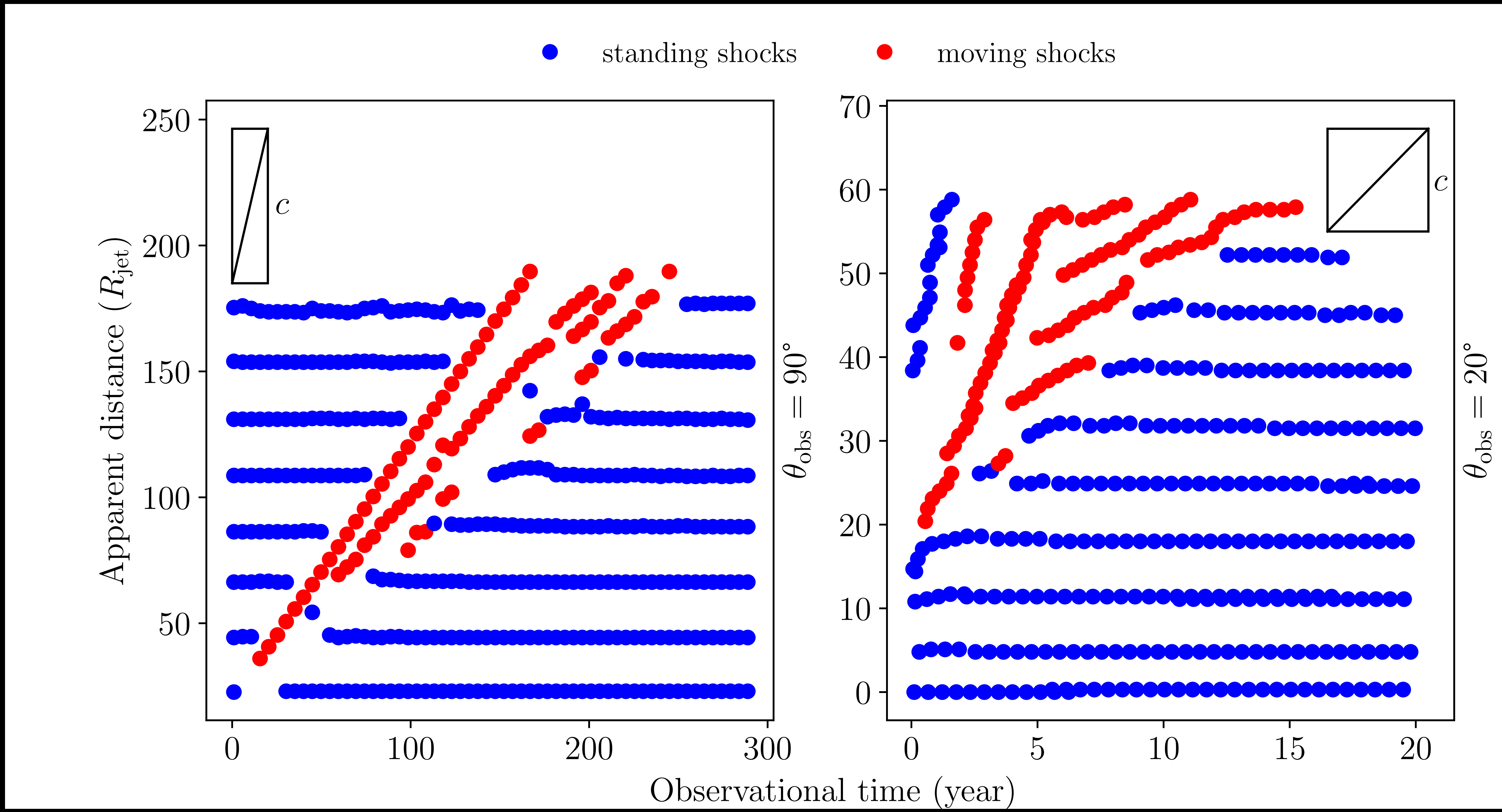


OBSERVATIONAL MARKER N°1 : THE FORK

- We report the distance traveled by moving & standing regions in time.
- Since the beginning, the leading moving shock is localized.
- A relaxation wave appears during the third shock - shock interaction and propagates at lower speed.

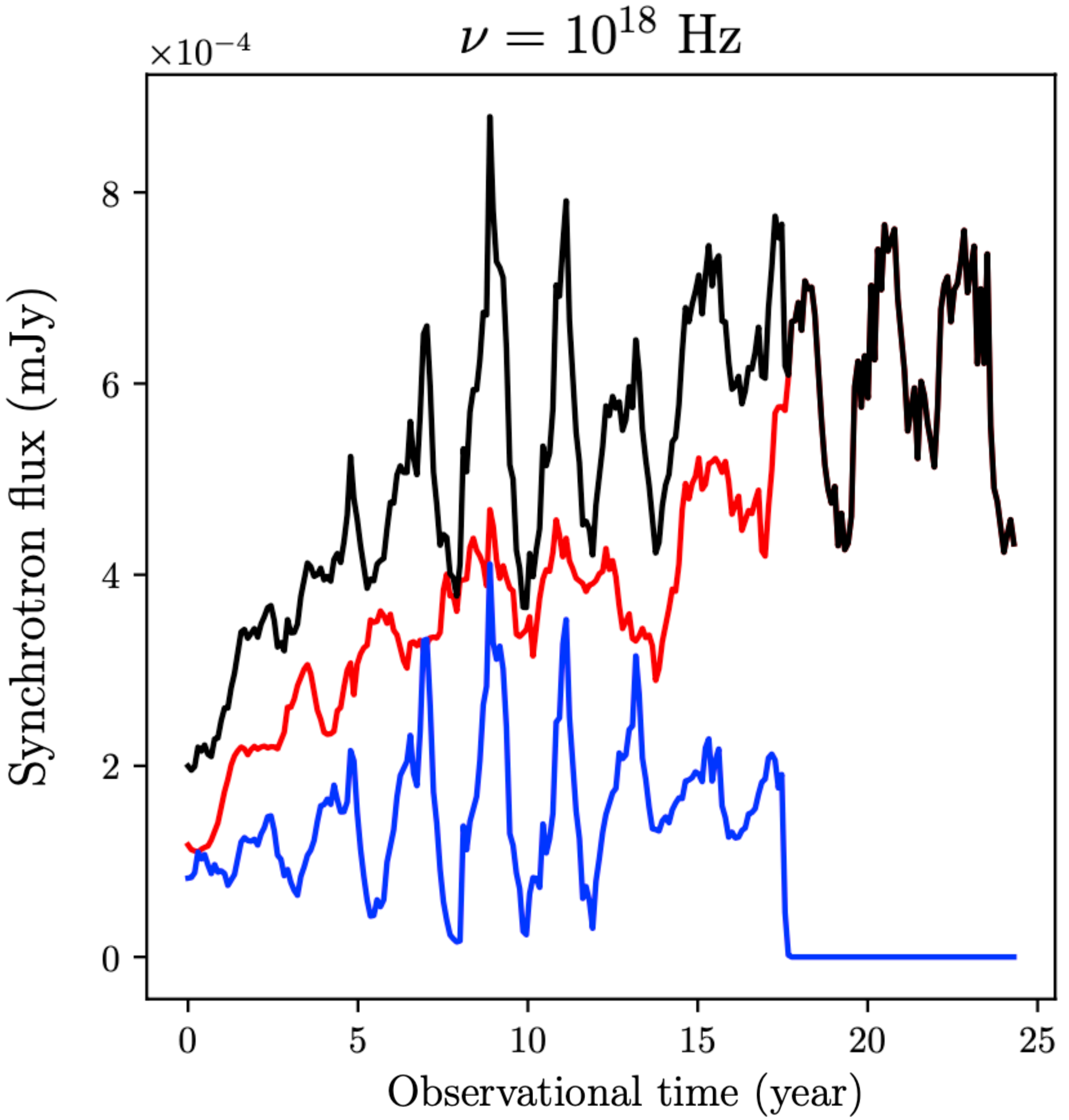


For low opacity and / or a high enough observation angle, we expect to see « fork » events in VLBI data.

OBSERVATIONAL MARKER N°2 : THE ECHO

- We distinguish emissions coming from the ejecta / the jet ($\theta_{obs} = 90°$).
- Clear echo after shock - shock interactions :
  - First ones : shocked standing shocks.
  - Others : shocked standing shock and relaxation shocks.

We expect to detect an echo for all frequencies, but especially in the X-ray band.



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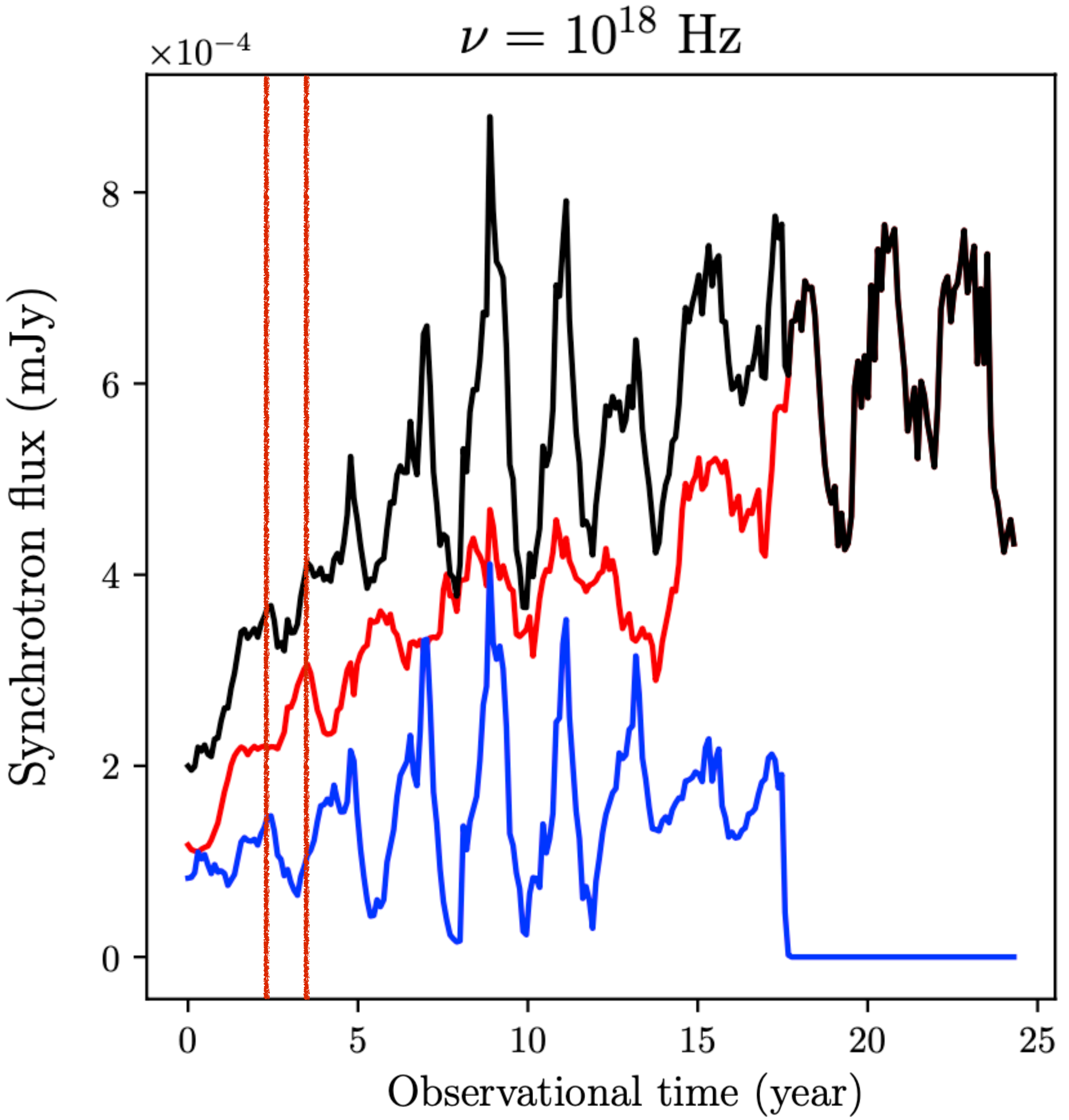
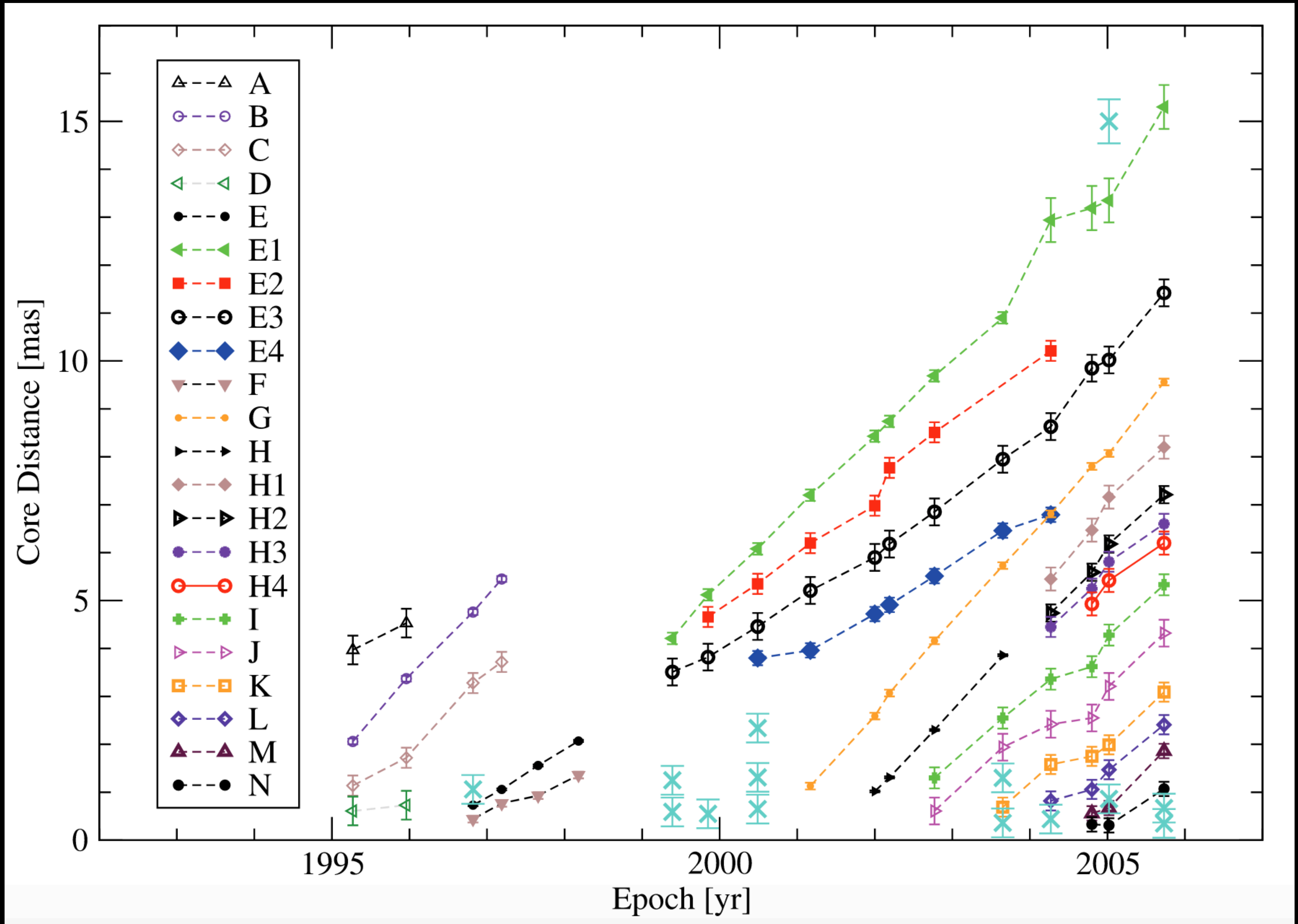


APPLICATION TO 3C 111 :

- Trailing components have been detected in 1997 [5].
- Associated radio flare events have been observed with asymmetry. **Emission coming from shocked standing shocks ?**
- Their origin are still matter of debate [1] but **our scenario can explain fork events and the outburst.**



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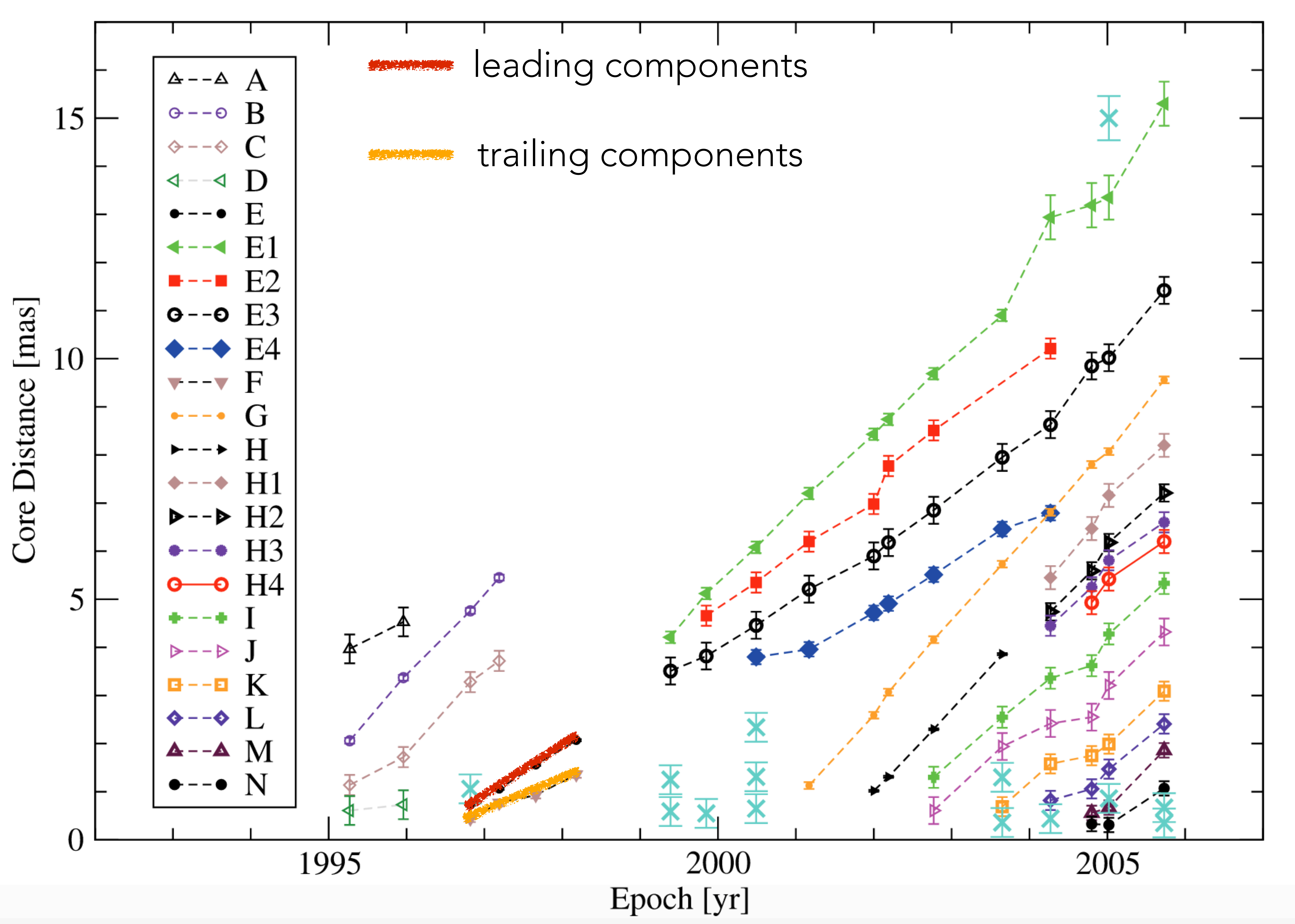

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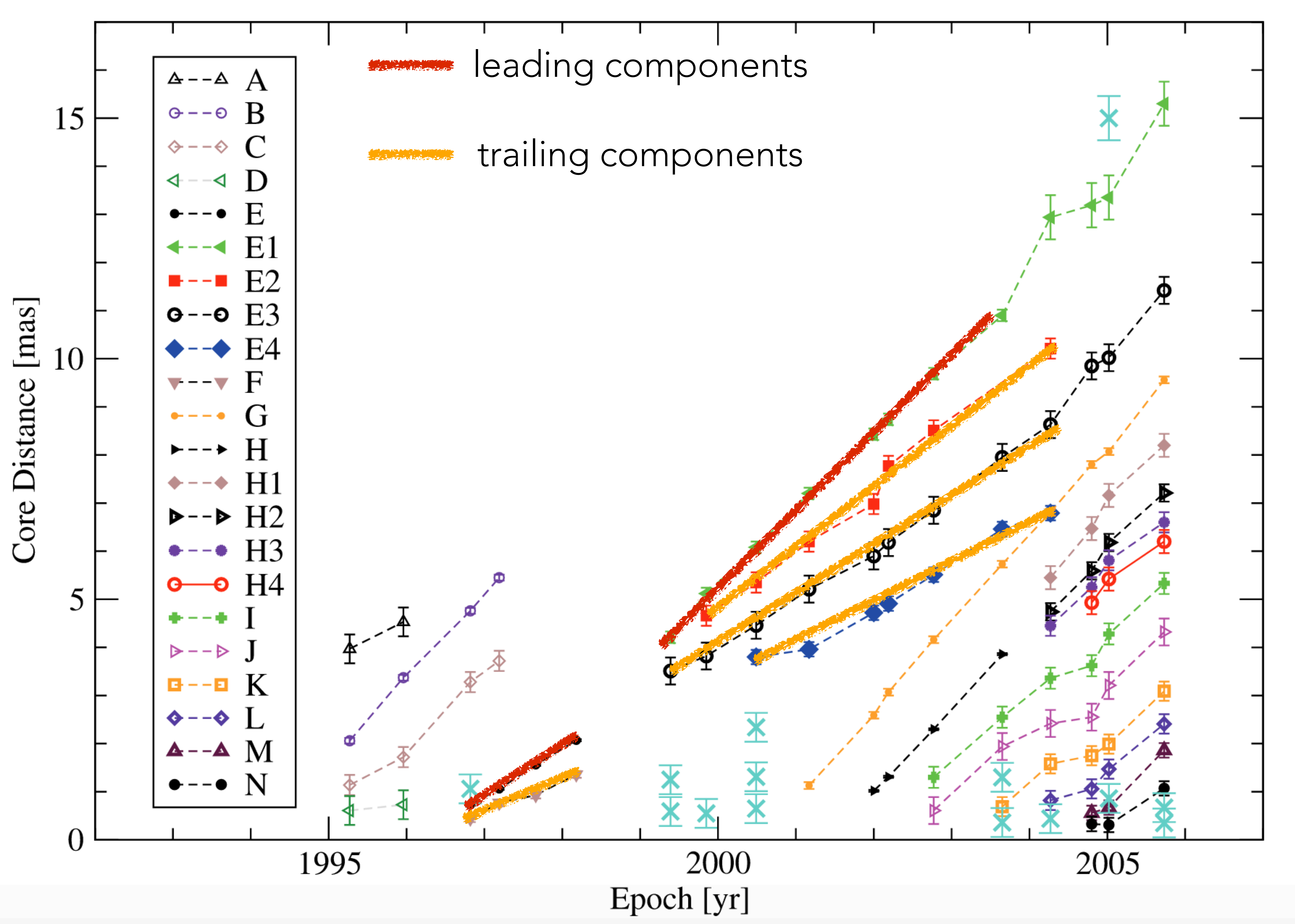

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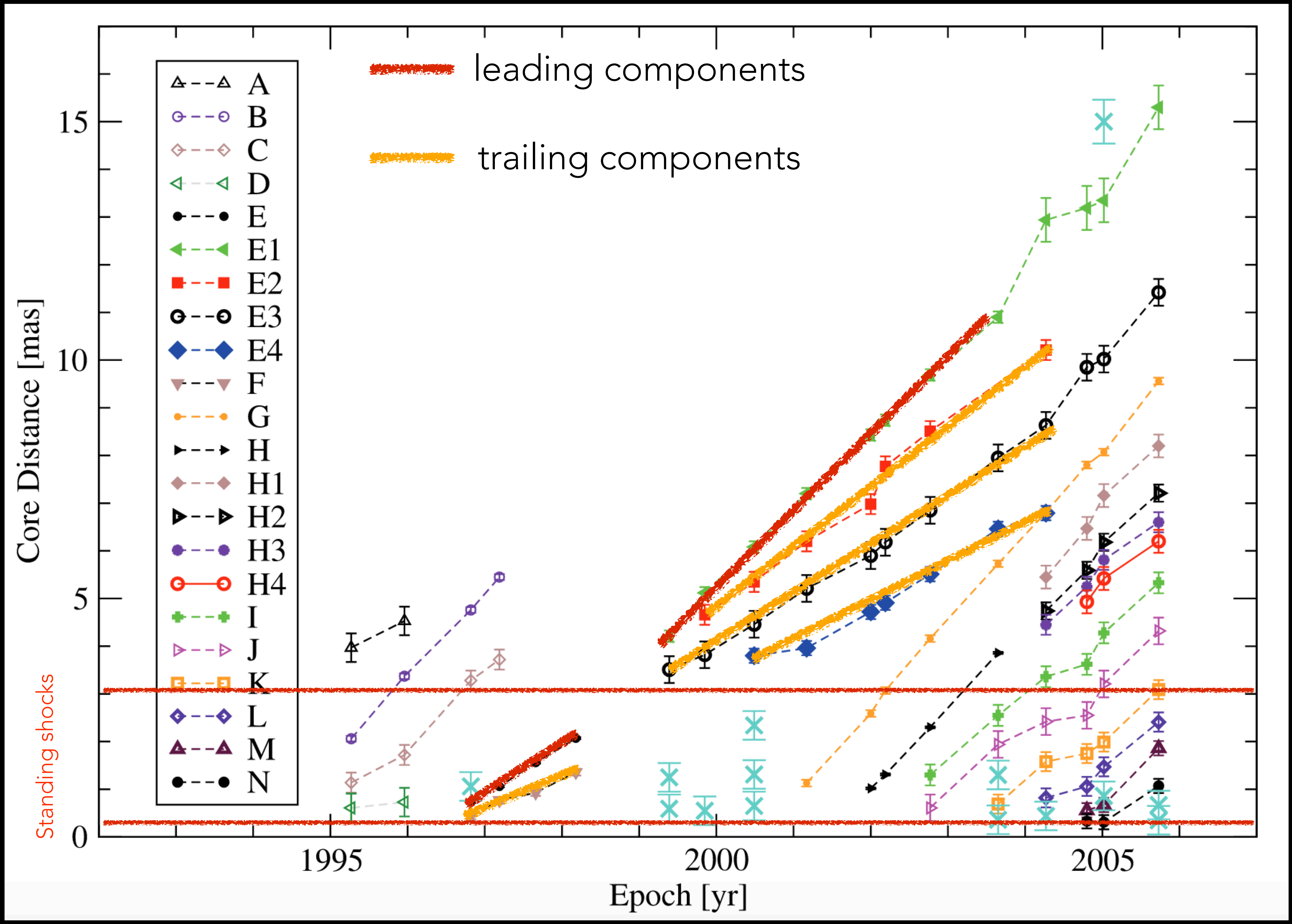

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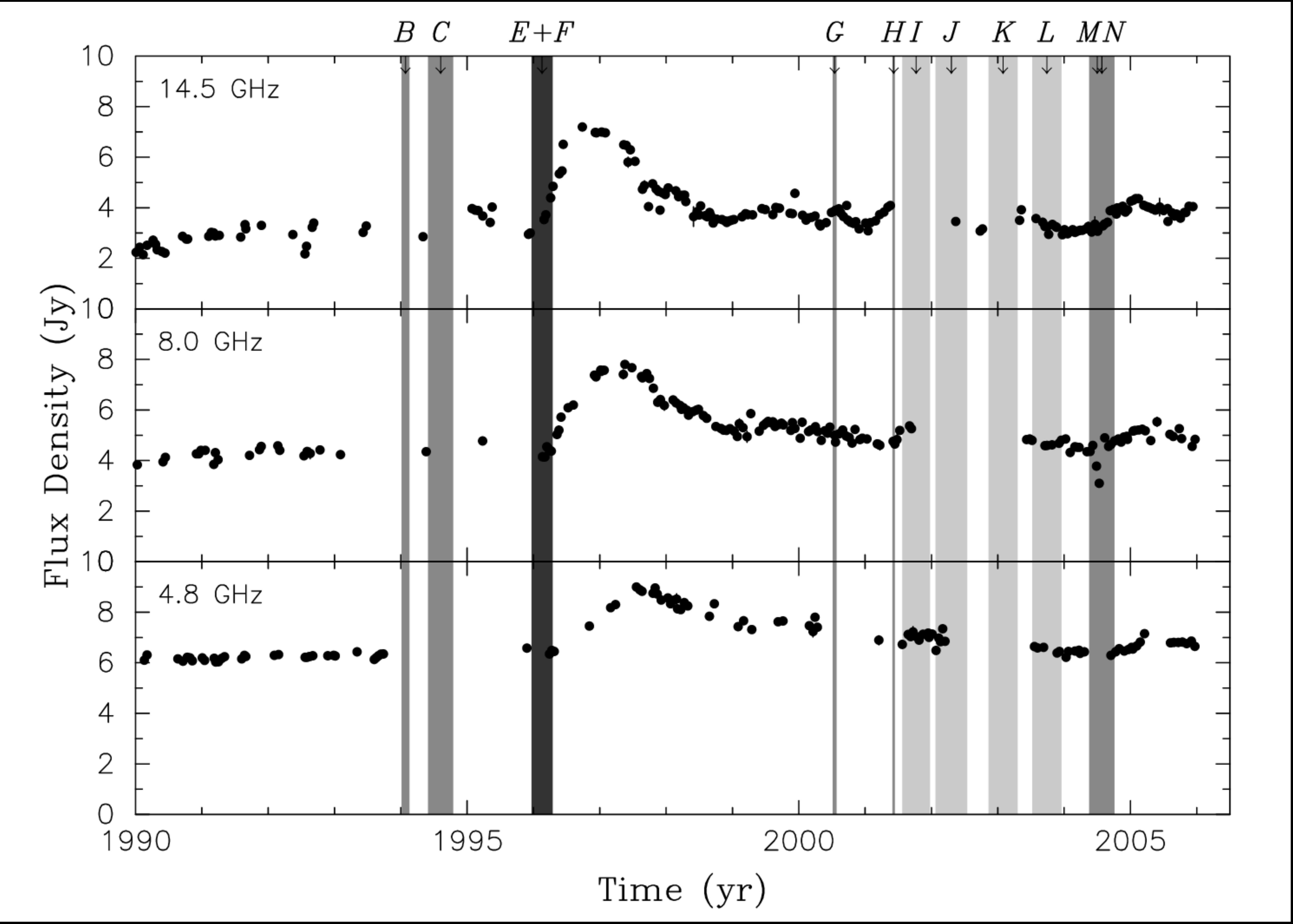

Light curves of 3C 111 at 4.8, 8 and 14.5 GHz [4].

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KEY TAKEAWAYS

Paper submitted to A&A !

- Thanks to a MWL study we aim to identify two relaxation shocks observational markers :

I. **At low frequency :** fork events could be detected and give us information on the jet physical parameters. Unlikely to be seen at low θ_{obs} due to opacity.

II. **At all frequencies (especially high)** : flare echo after shock - shock interactions coming from shock oscillations and / or relaxation shocks. Unlikely to be seen at very low θ_{obs} due to LCE.

Comparison with 3C 111 is promising and dedicated simulations need to be done. Relaxation shocks can help us to constraint the jet physics and build a coherent model of AGN.

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FLUX OBSERVATIONS OF TRAILING COMPONENTS

- First event may be explained with the propagation of leading ejecta (constant rise of flux) and a shocked standing shock (rise and steep fall).
- Second event may be explained with leading ejecta and relaxation shocks. The lower flux measured might be linked to lower jet density in this region as the moving shocks propagated in a expanding jet.

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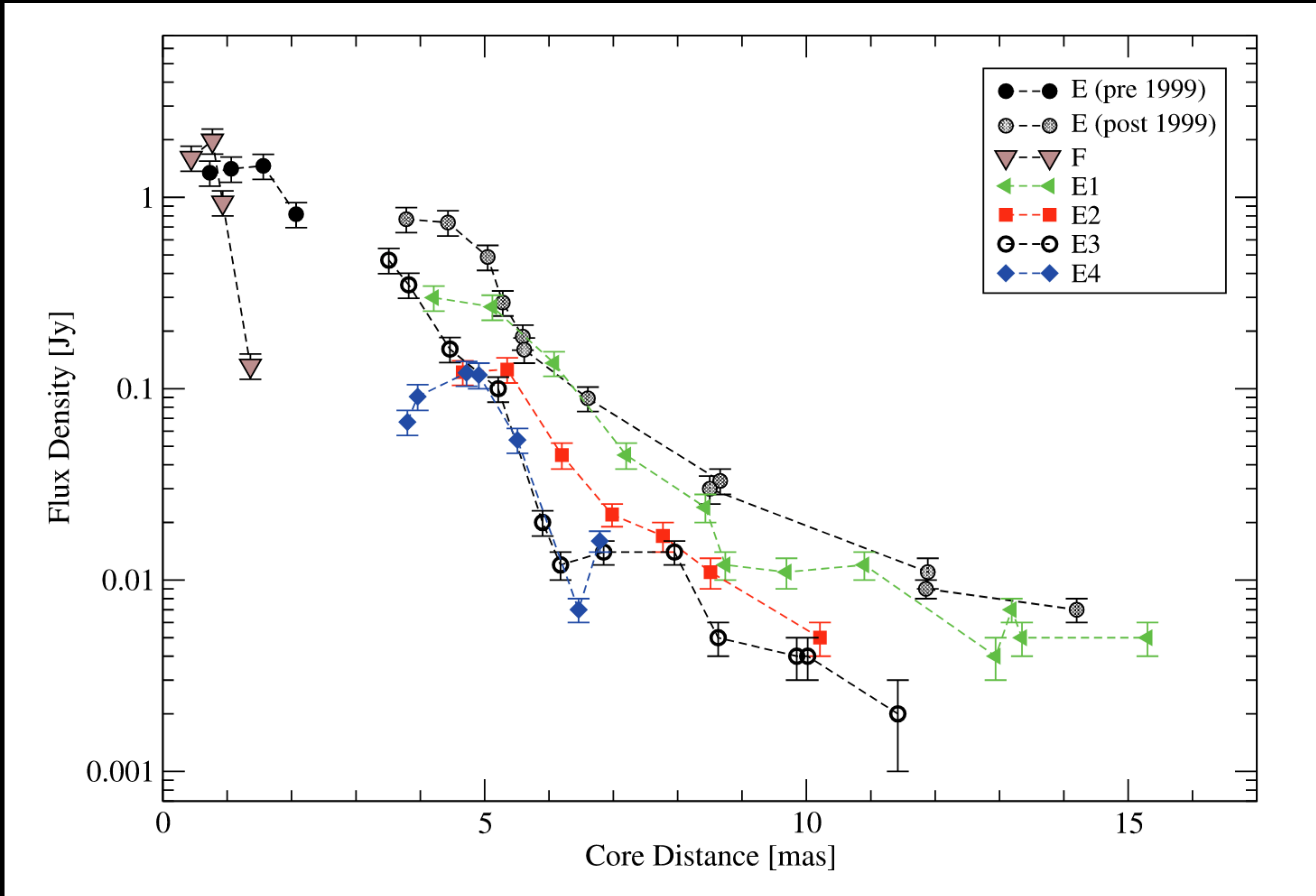

Flux (Jy) vs epoch (yr) for 3C 111 [5].