Variabilities in relativistic jets

ZAKARIA MELIANI

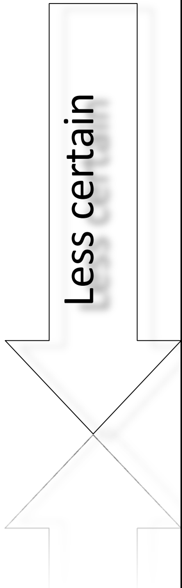
OBSERVATOIRE DE PARIS

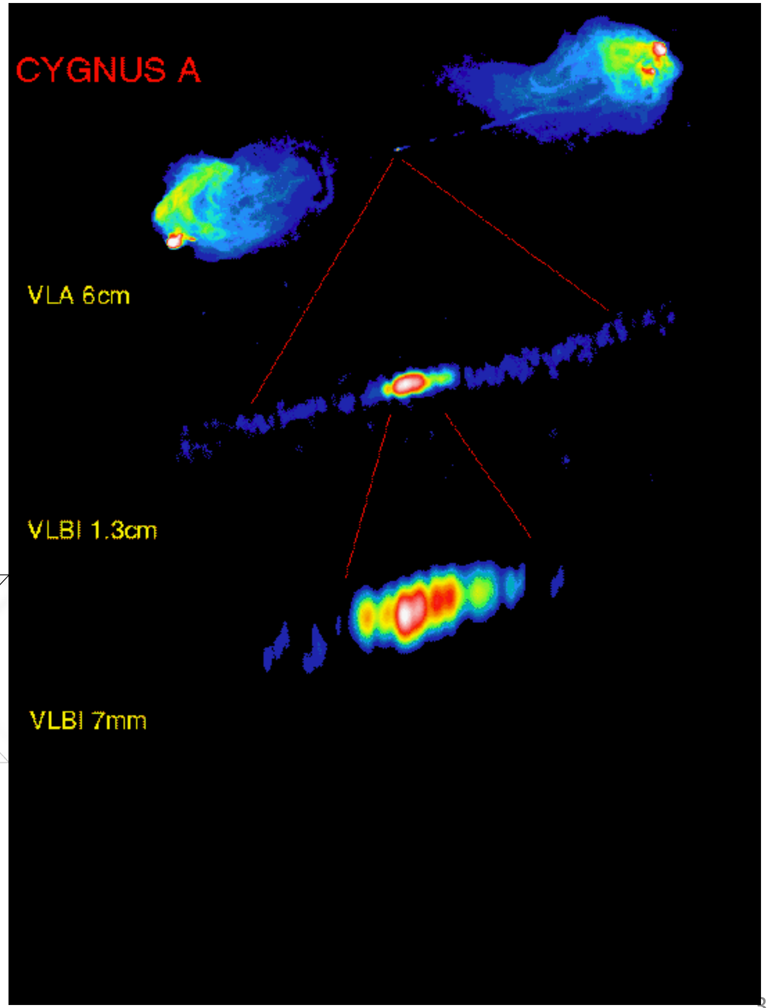
G. FICHET DE CLAIRFONTAINE, A. ZECH,

F. TORNATORE, J. MALZAC

Active galactic nuclei jet

- AGN jets are observed to Mega parsec
- It can be stable to large scale
- Reach a Lorentz factor 3-50
- Magnetic field
- Synchrotron radiation (polarisation)
- Current models focus on GR-SR-MHD





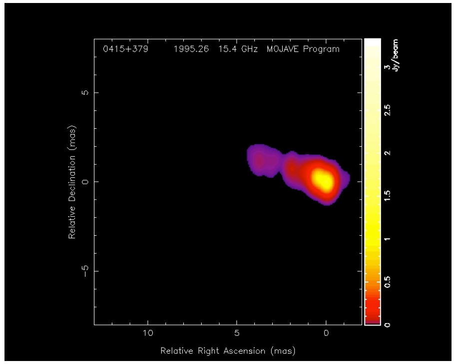
standing and moving radio knots

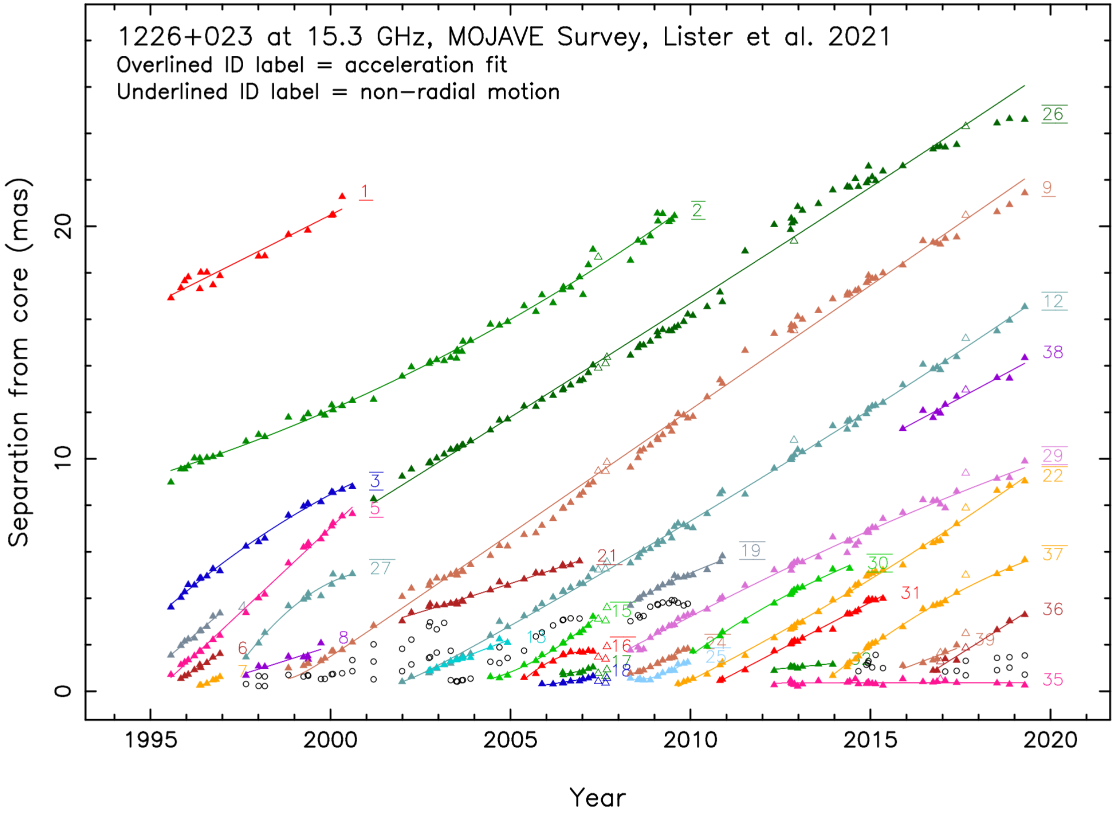
✓ Standing shocks

✓ Moving shock

✓ Trailing components

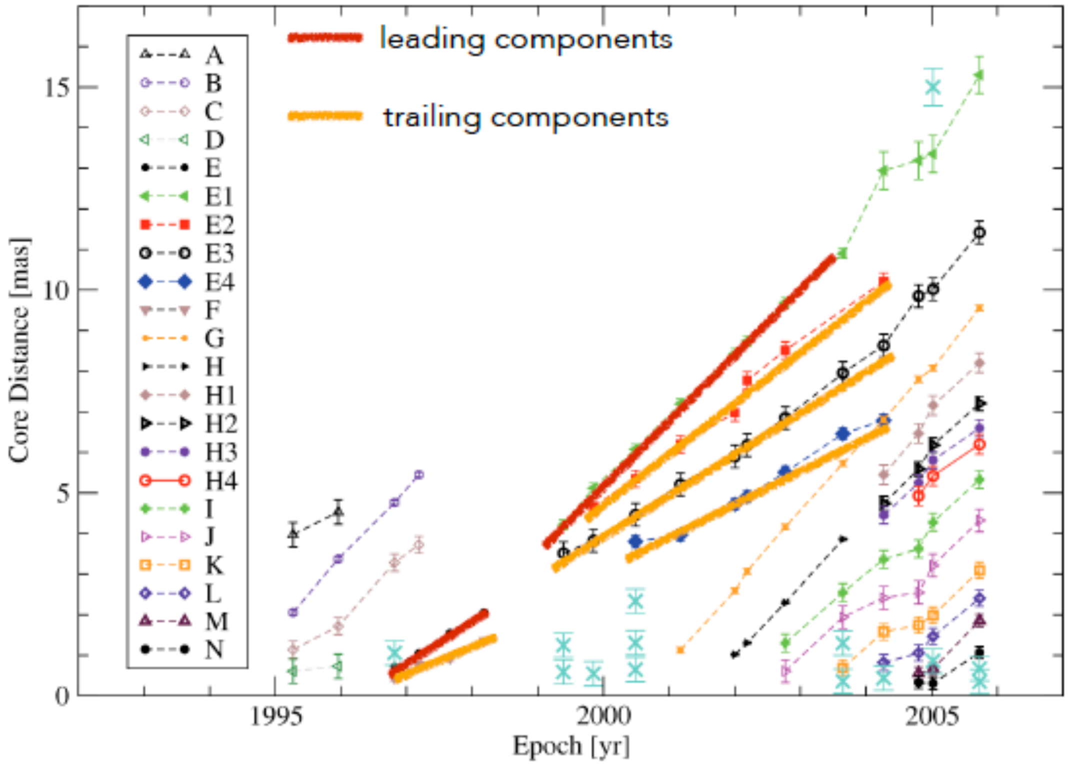
✓ Moving knots with a great varieties of trajectories (ballistic, accelerated, bended) (Jorstad et al. 2005) : can be understood as a **moving shock**.





standing and moving radio knots

Trailing components : moving knots appearing in the wake of leading ones.



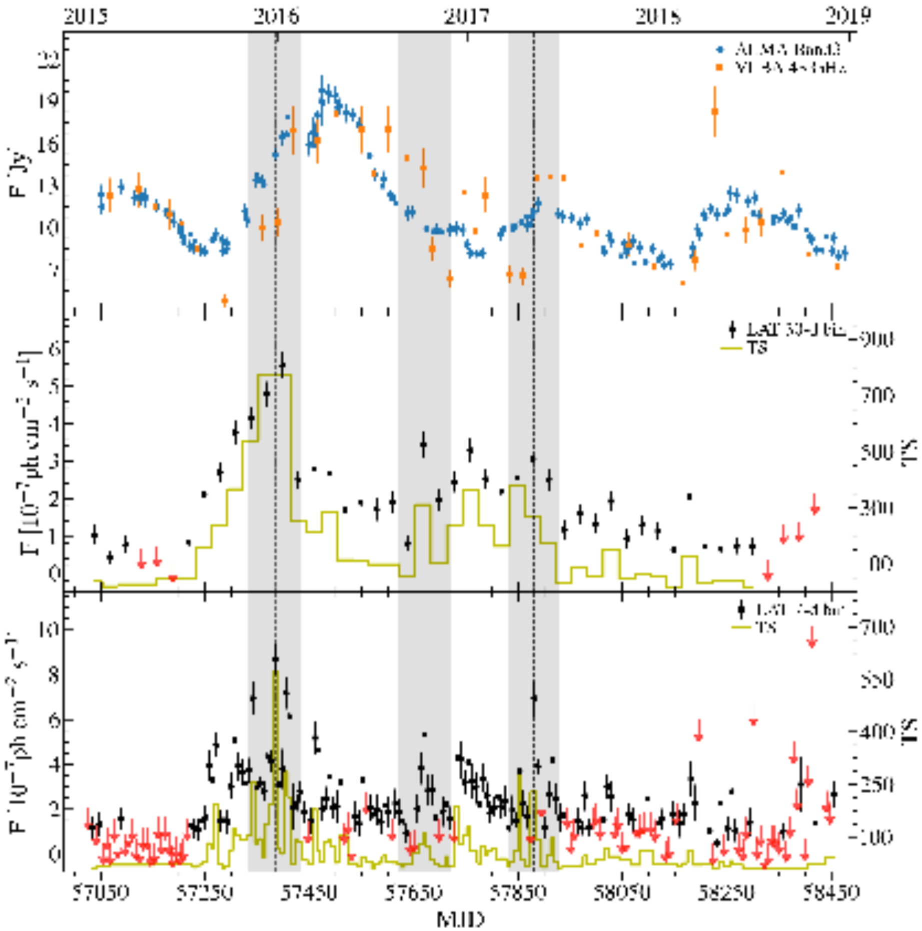
Link between flars and shocks

✓Evidence of MWL flare emission during interaction between standing and moving knots (Kim et al. 2020).

✓Apparent displacement of the standing shock + increase in brightnes

✓Rotation of EVPAs during such interactions.

- Several interpretations exist to explain such variabilities : **interaction between moving and standing knots.**



Over pressured jet

The relativistic jet covered a large distances covered in galactic medium

- Jet becomes over pressured

Result

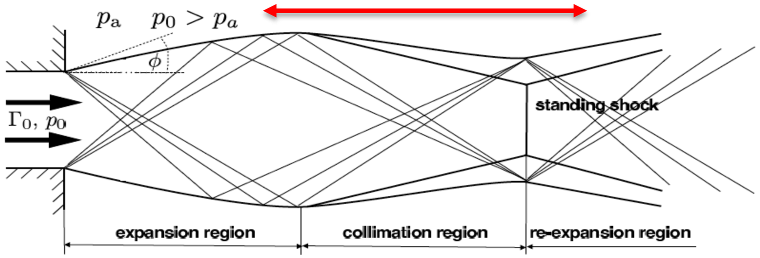
- re-collimation shocks
- Re-acceleration of the jet

Uniform jet

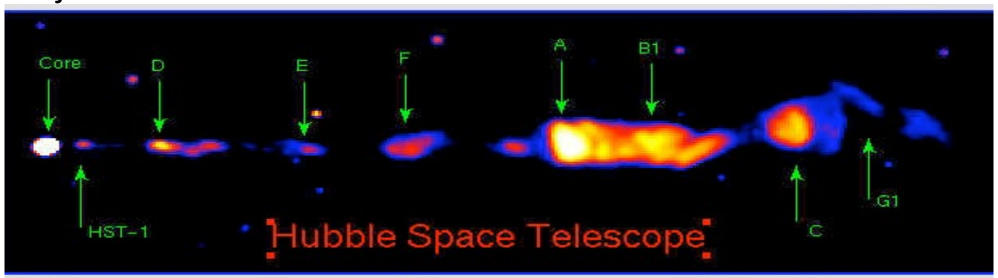
- Equidistance for cylindrical jet
- Increasing distance for the conical jet

Gómez et al 1996, Agudo et al. 2001, Mimica et al. 2009, Fromm et al. 2016, ...

$$dZ = 2MR$$



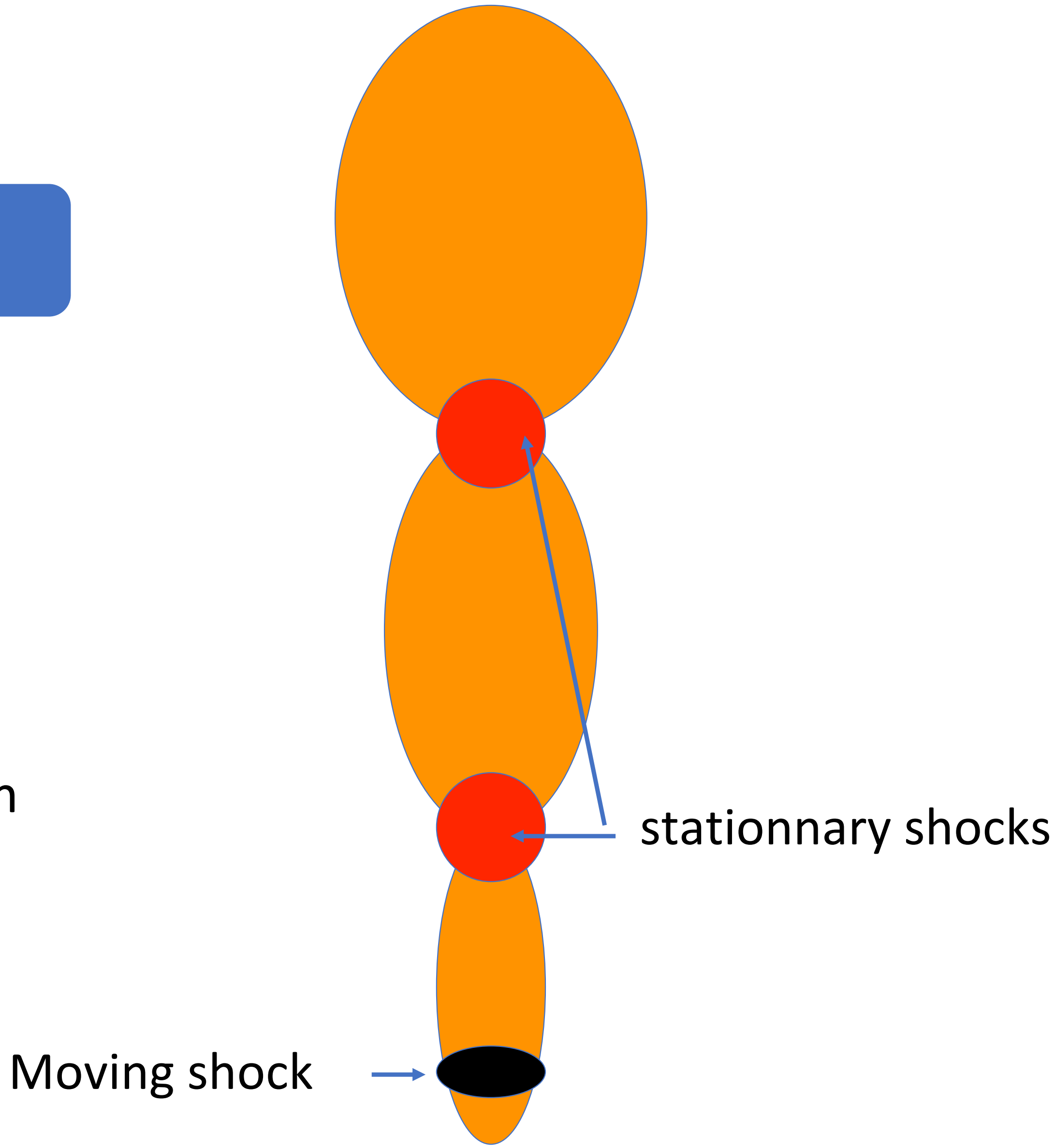
Daly & Marscher 1988



shocks

- Moving shock a perturbation is set at the jet base
- Detect the shock regions in the jet by checking variations of the Mach number

1. Inject relativistic electrons population at shocks.
2. Radiative cooling of electrons

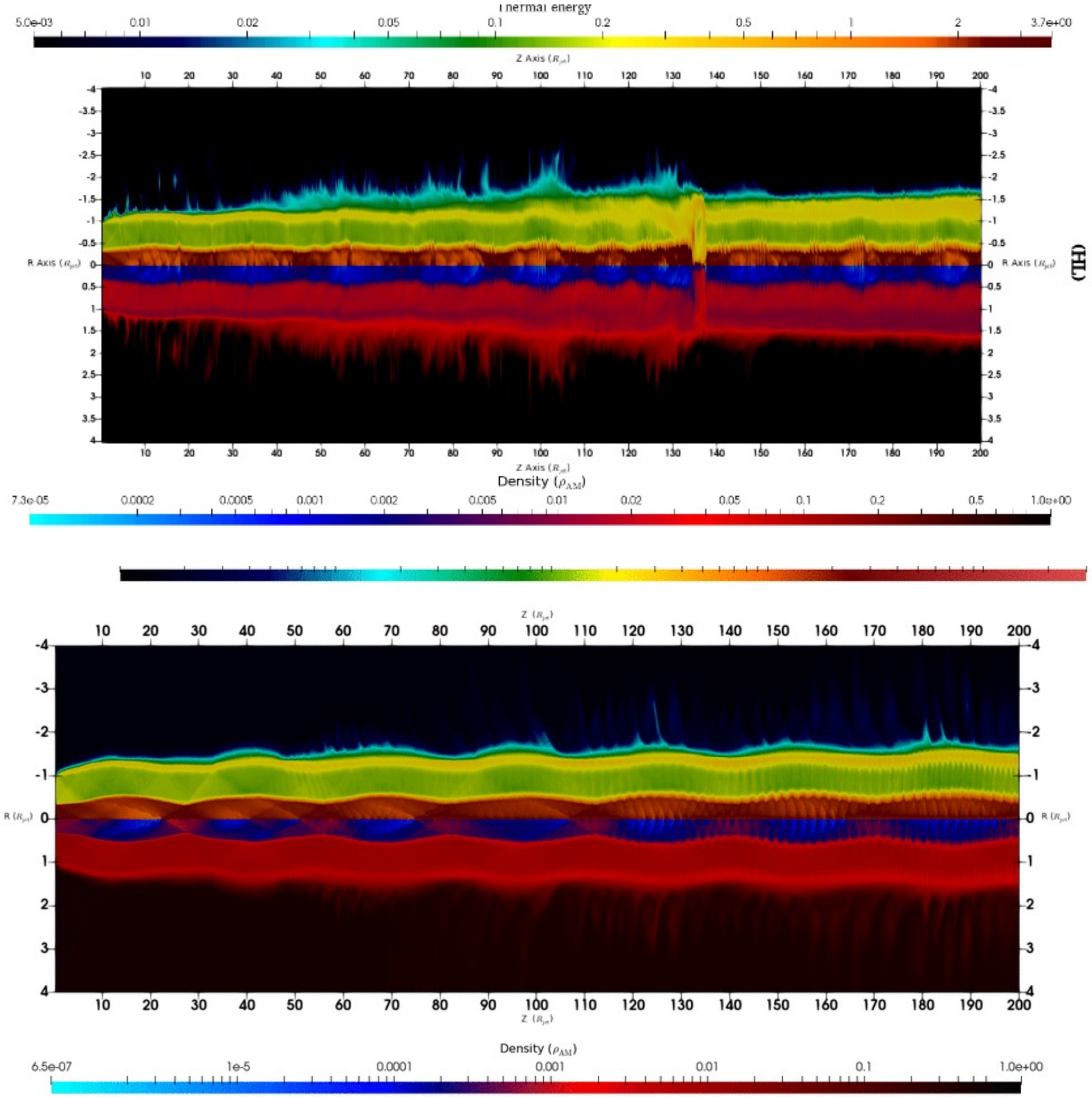


Moving shock

Phase 1
- Adiabatic acceleration

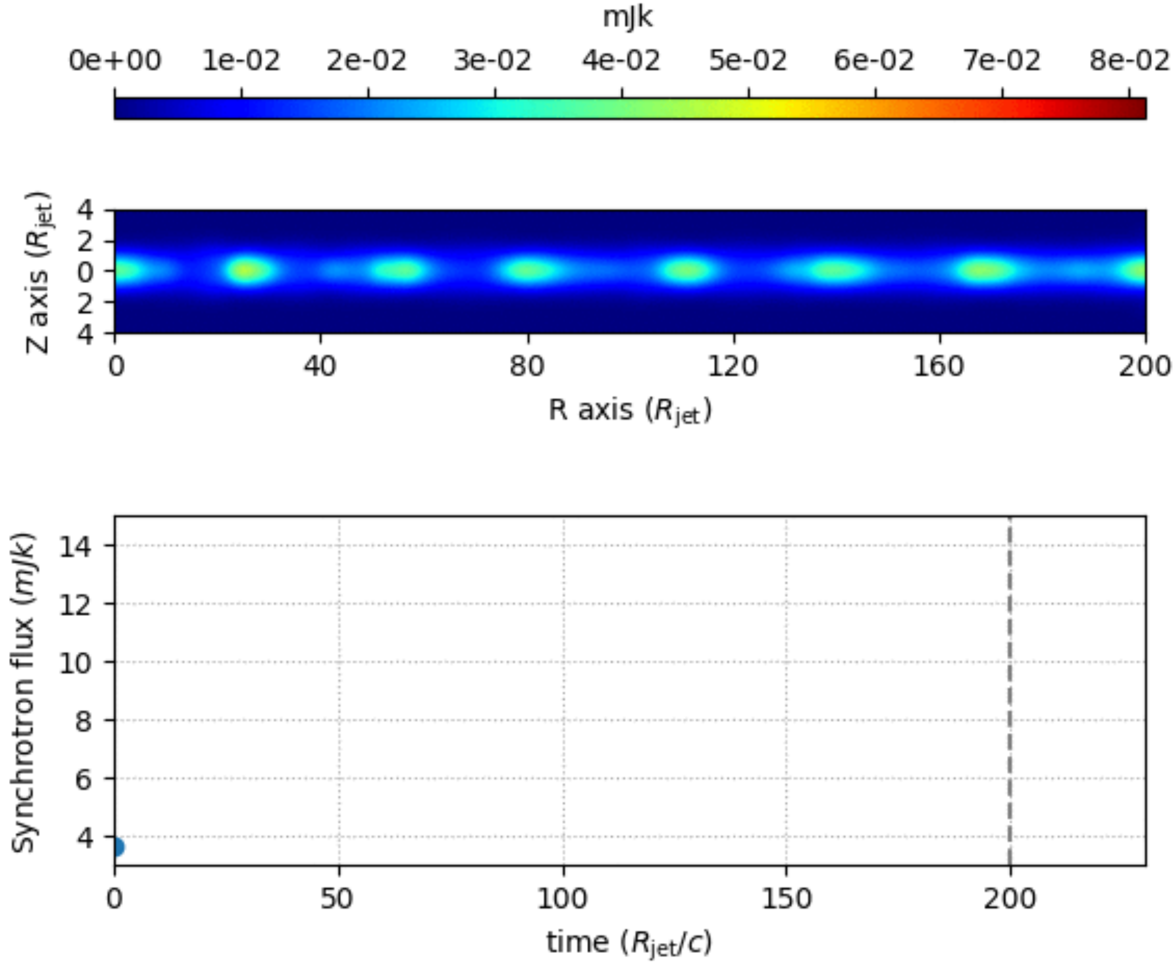
Phase 2
- Interaction with internal shocks

Phase 3
- Shock wave



Synthetic light curve

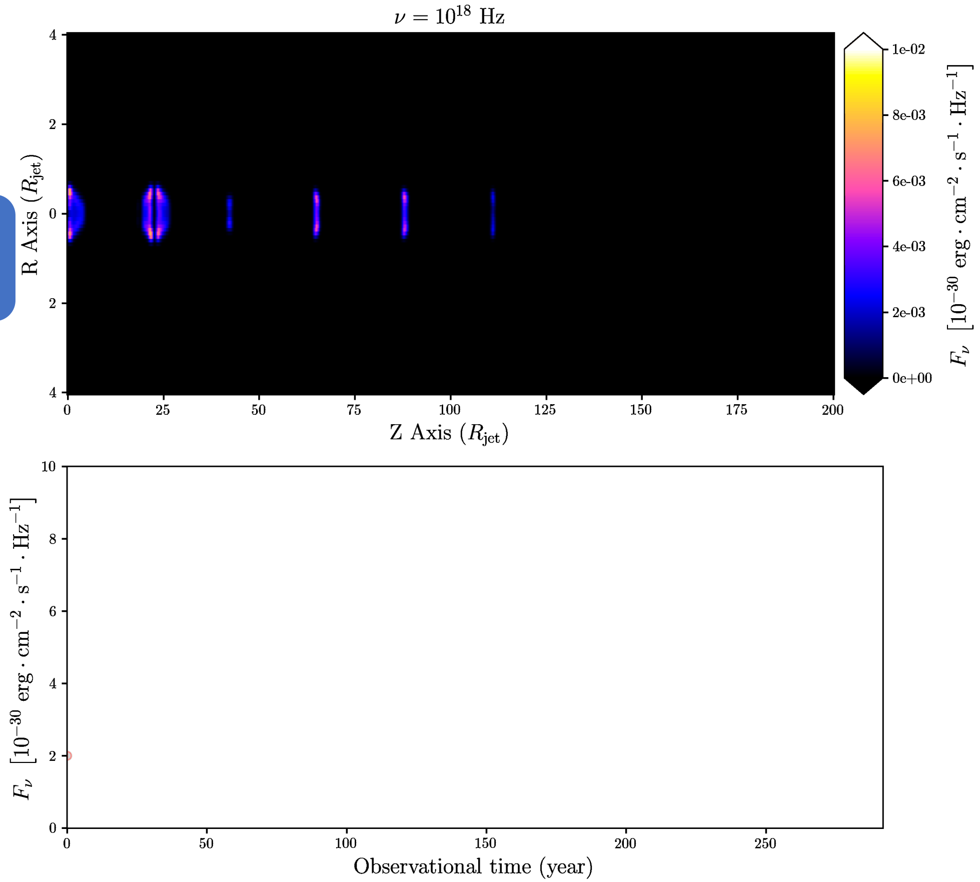
Moving shocks induces oscillation of knots
Oscillating knot responsible for the intense flare.



Light curves

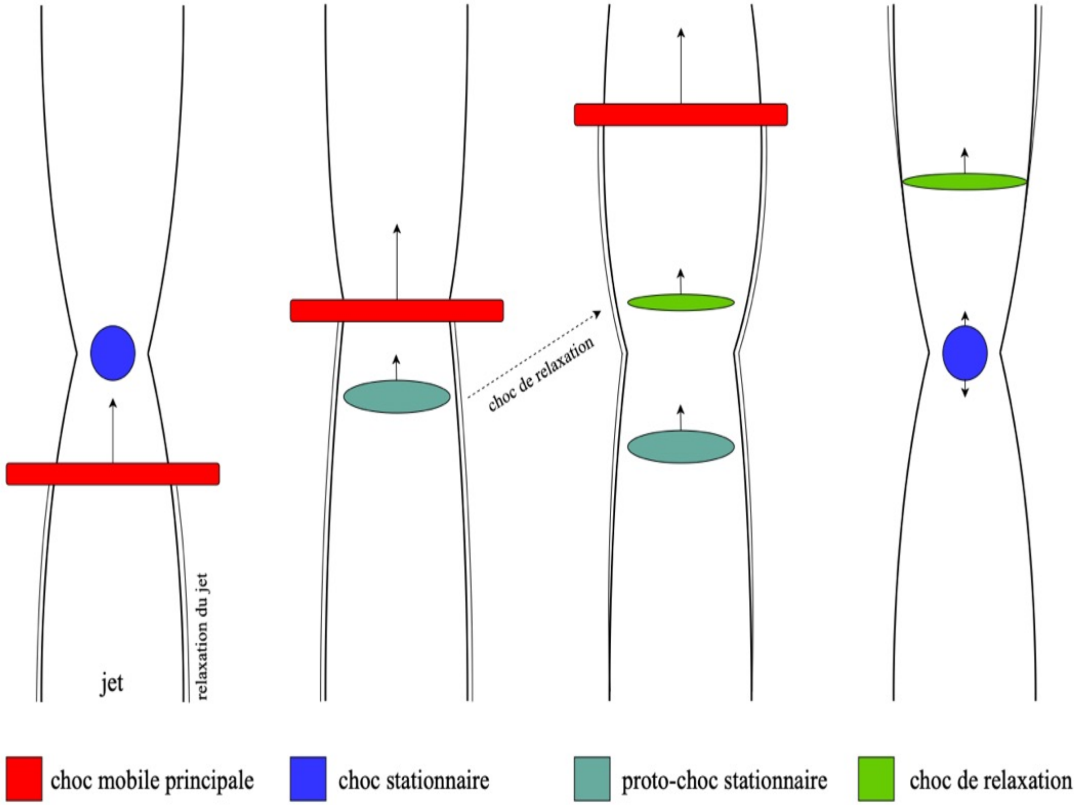
Four different sources of emission :

- Stationary jet, more or less extensive emission coming from electrons.
- Leading moving shock causing flare emission during shock - shock interactions.
- **Perturbed standing shocks : remnant emission.**
- **Relaxation shocks which may have their own emission signature.**



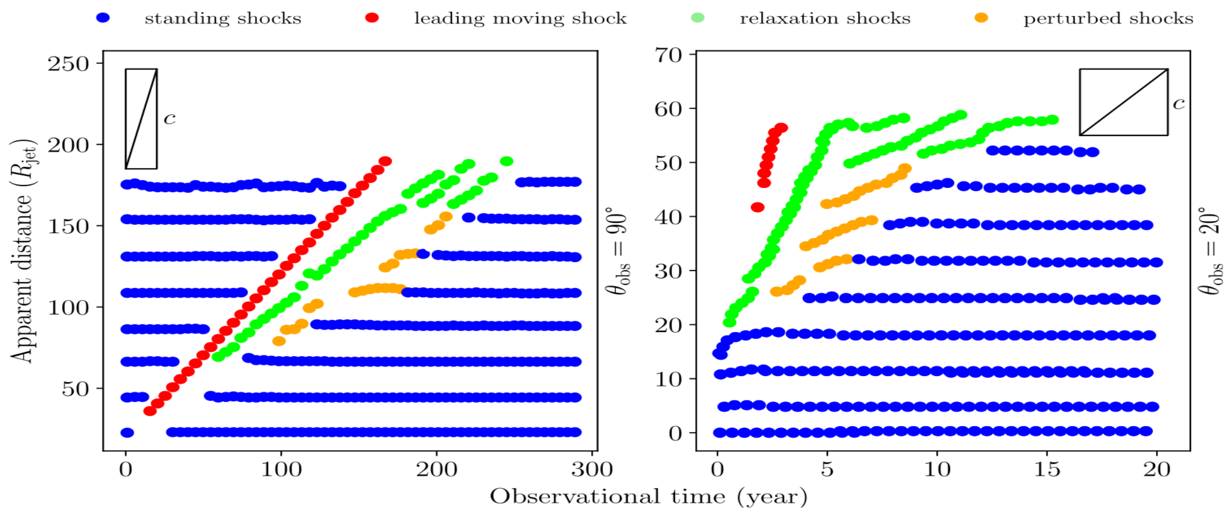
Relaxation shock formation :

- Moving shock disturbs a standing shock.
- Standing shock relaxes by releasing a new moving shock.



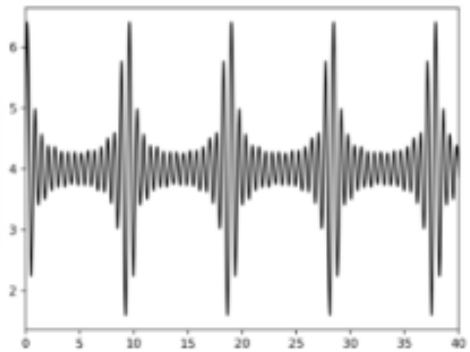
Relaxation shock

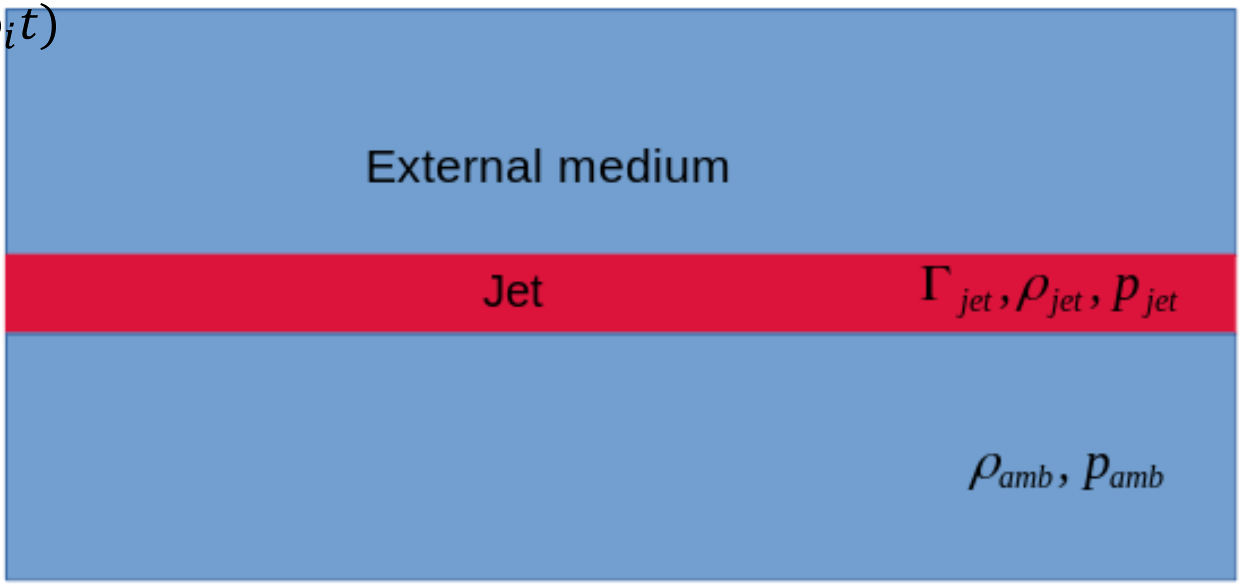
- Relaxation shock velocities always lower than the leading one.
- Apparent motion of perturbed standing shocks.



variable a Lorentz factor

$$F(t) = \Gamma_{\mathrm{jet}} + \sum_{i=1}^{N} (\Gamma_i - \Gamma_{\mathrm{min}}) \sin(\omega_i t)$$

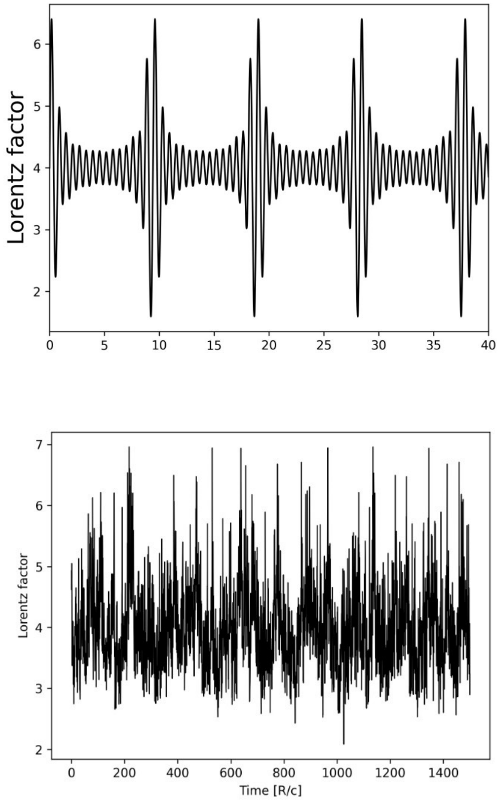


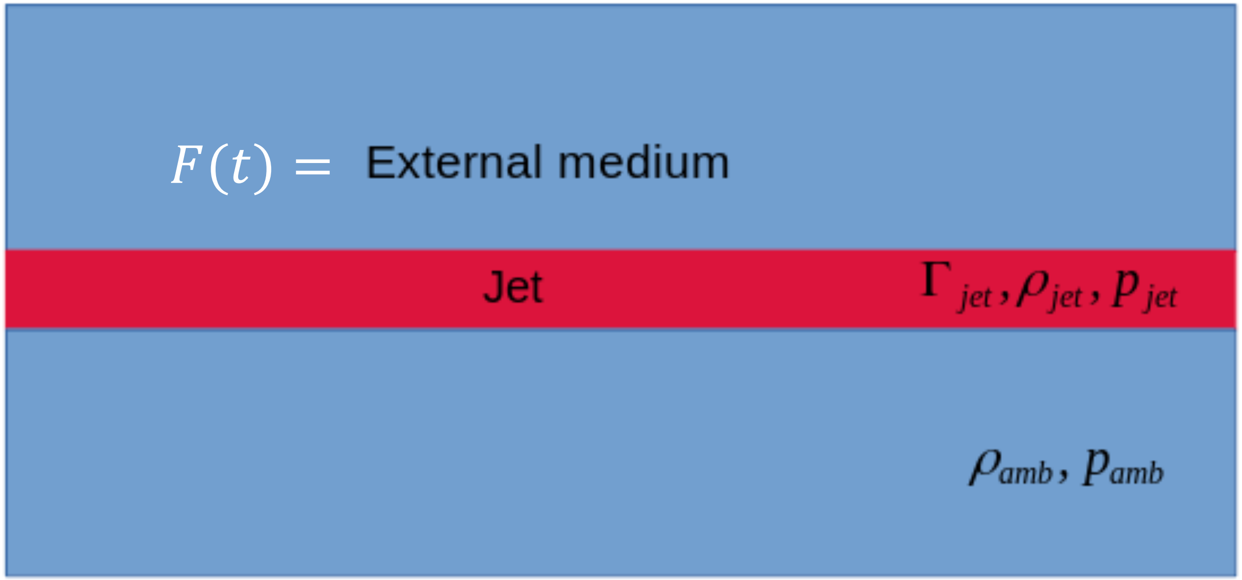


Variability induces internal shocks

variable a Lorentz factor

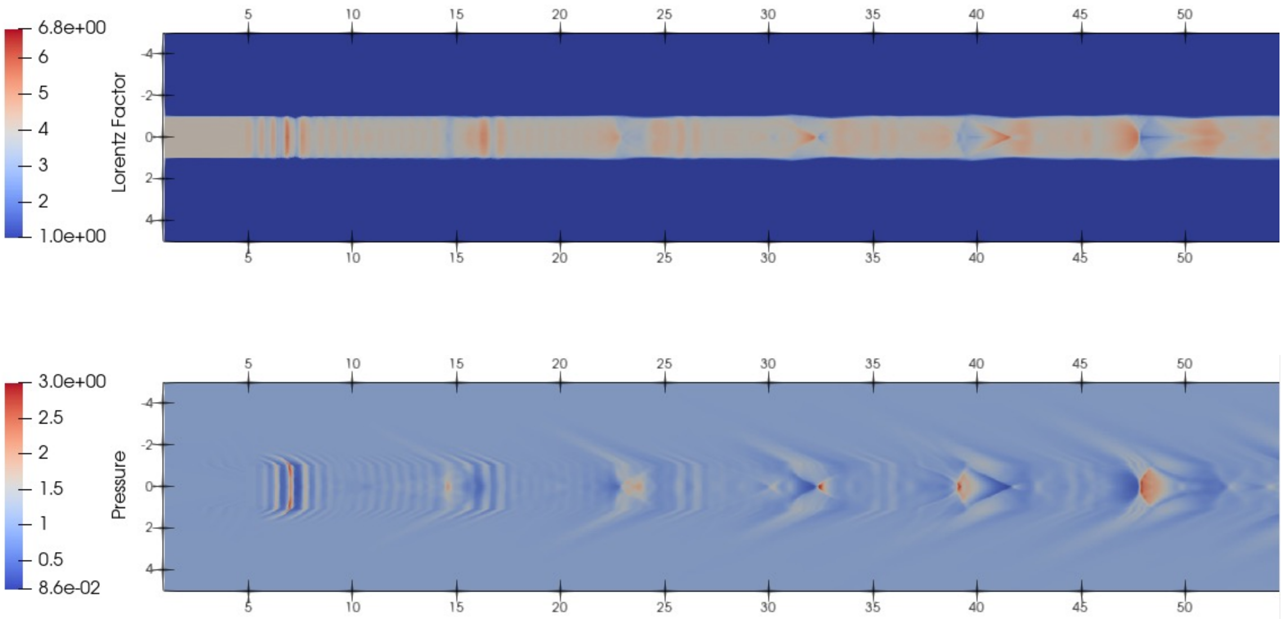
$$F(t) = \Gamma_{\text{jet}} + \sum_{i=1}^{N} (\Gamma_i - \Gamma_{\text{min}}) \sin(\omega_i t)$$





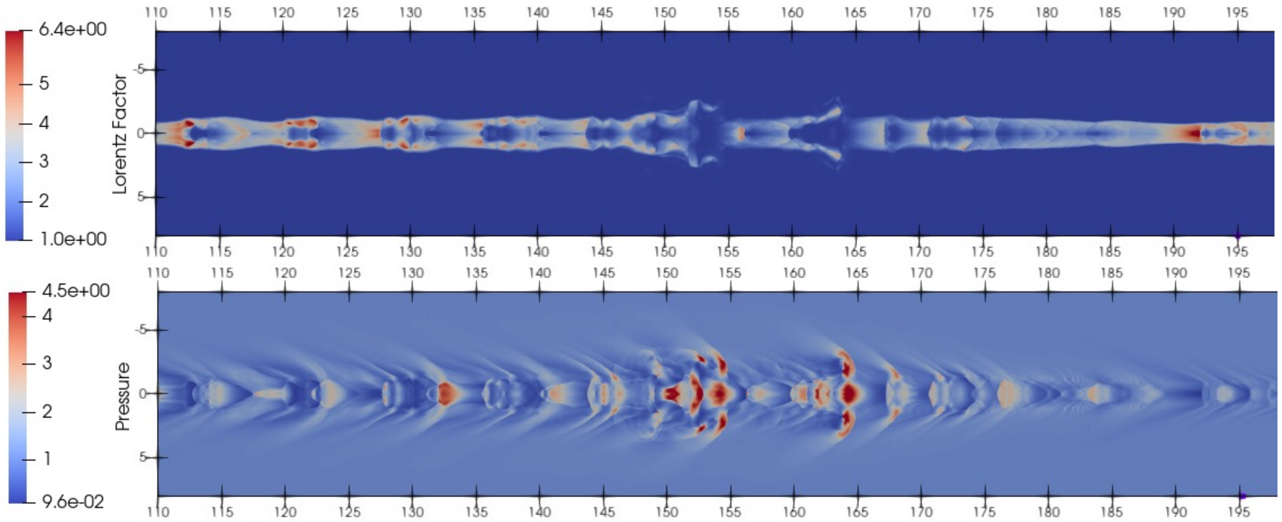
flicker noise power spectrum (Timmer & König 1995, Malzac, J. 2012)

Periodic Variability (near the jet inlet)



- *Evolving Shock Regions in the Wake of High-Velocity Shells*
- *Sustaining and Amplifying Mobile Shock Zones Through Injected Variability at t = 100 R/c*

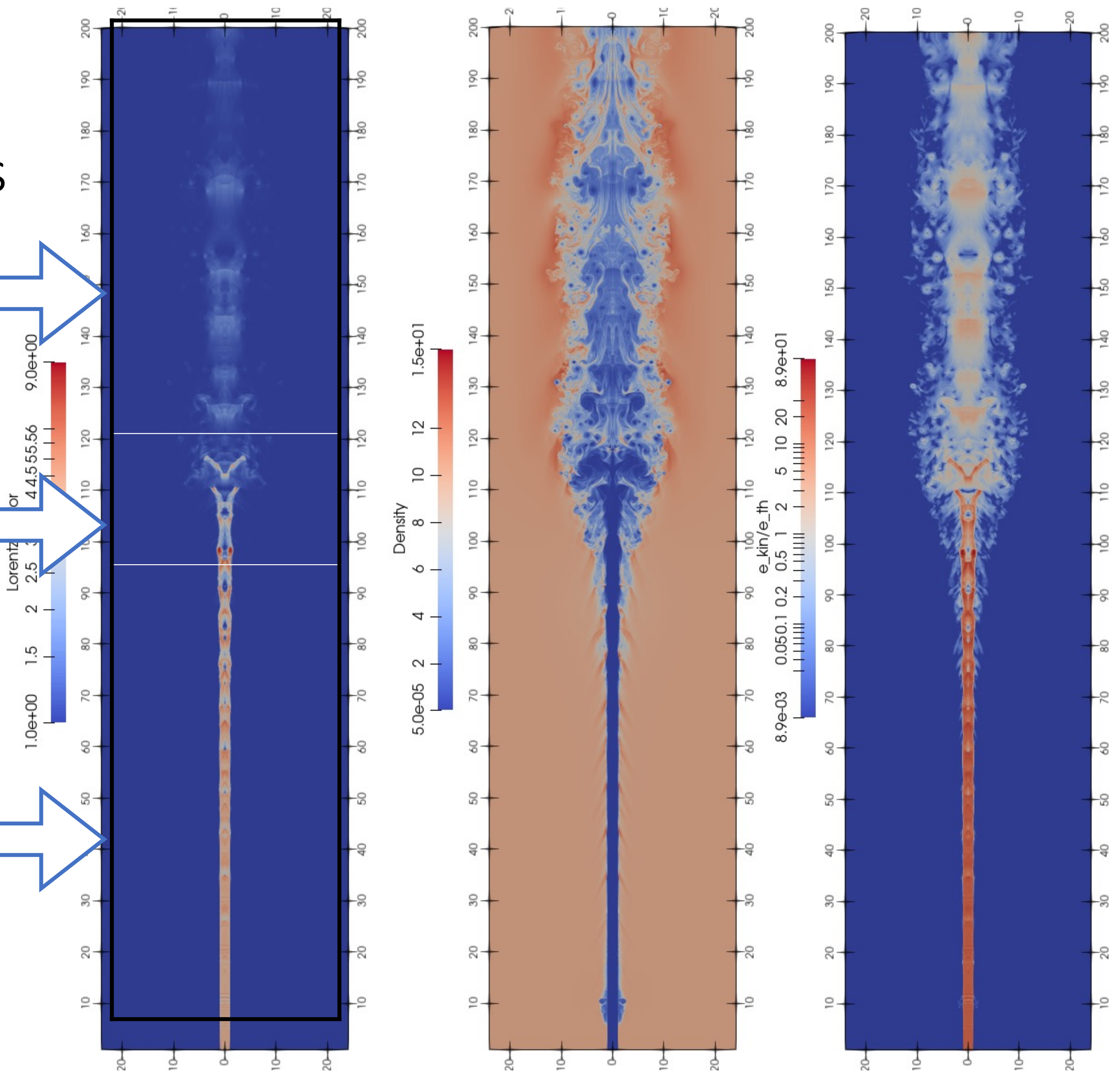
Rising of standing shocks



- Jet thermalisation at large scale
- Rising of Slow-Moving Shocks
- Development of slow flow regions

Dynamics of Jet Shockwaves

- Downstream
  - Steady shocks
  - Turbulent flow
- Terminal shock
  - Jet decollimation
  - Jet Deceleration and Thermalization
- Upstream
  - Compression waves
  - Moving Shocks

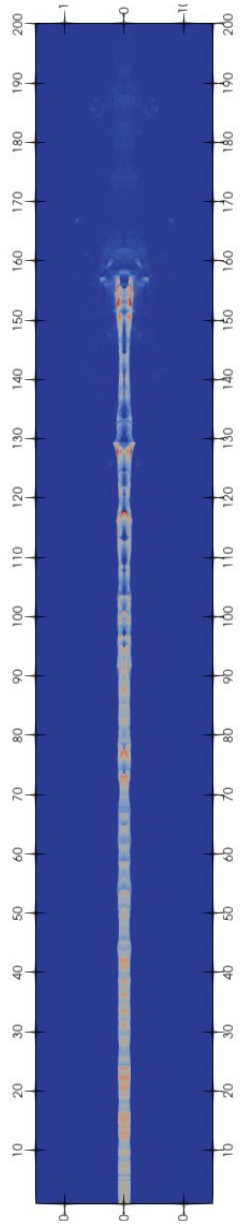


Perturbation: Flicker Noise

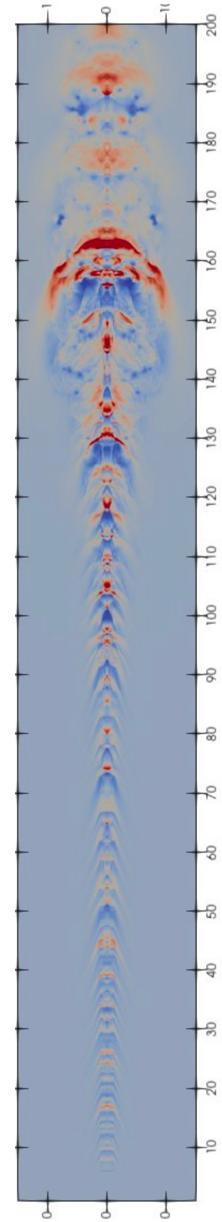
- Same Behavior as Cases with Periodic Variability

- Downstream Region
  - Reduced Turbulence
  - More Pronounced Quasi-Stationary Shocks

Lorentz Factor

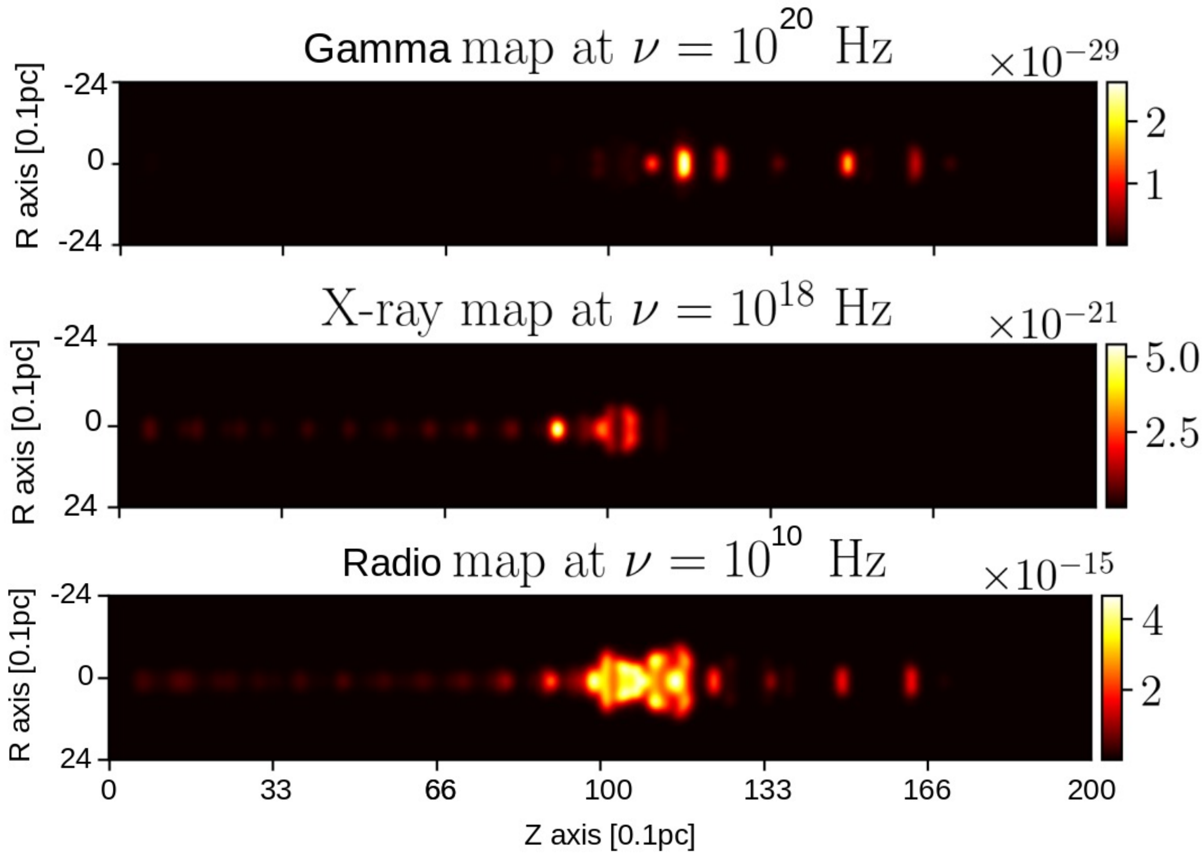


Density



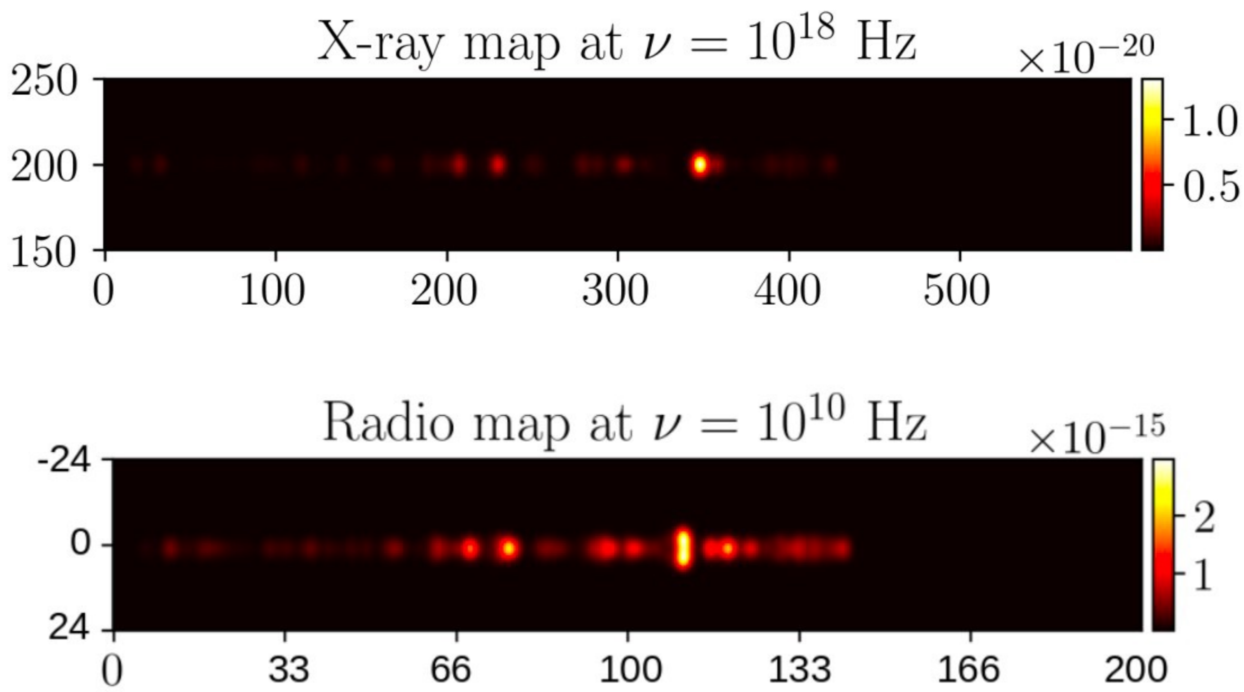
Synthetic Image (Periodic Variability)

- Moving Shock Region
  - Radio
  - X-ray
- Stationary Shock
  - Extended Radio
  - X-ray at the Shock Region
- Downstream
  - Steady Shocks with Radio and X-Ray



Synthetic Image (Flicker Noise)

Moving Shock Region Emits
    All Compression Region
Emits in Radio
    Shock Region Emits in X-ray
Stationary Shock
    Extended Radio
    X-ray at the Shock Region
Downstream
    Steady Shocks with Diffuse
Radio Emission



Unveiling the Jet through Shock-Shock Interactions

- Strong shock-shock interactions result in diverse emission regions.
- Fork events and flare echoes serve as observational indicators of relaxation shocks.
- Characterizing relaxation shocks contributes to constraining jet physics and verifying the plausibility of the "shock-shock" scenario.
- Strong variability at the jet inlet could induce terminal shock and a succession of quasi-stationary shocks.