Relativistic Stellar Jets: The Role of the Environment

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The Innermost Regions of Relativistic Jets and Their Magnetic Fields

Granada, June 11th, 2013

Outline

1. Introduction
2. Dynamics and non-thermal emission
3. Numerical calculations

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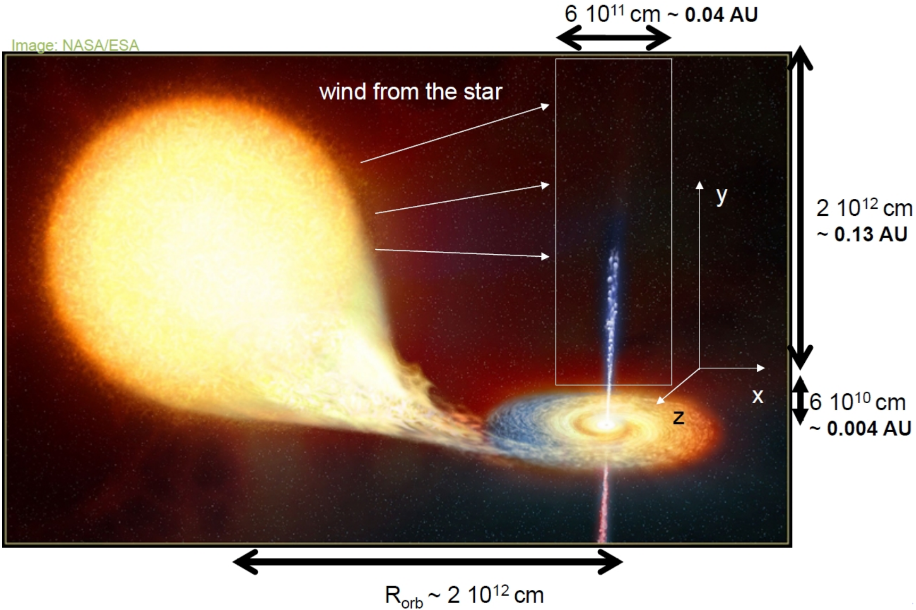
(Perucho, Barcelona 2013)



Introduction

As Galaxies, binary systems are not free ways for jets...

1. **Relativistic stellar jets are launched from a compact object neighboring a star that feeds accretion in the former.**
2. **Beyond their launching point, jets propagate through a dense, asymmetric and inhomogeneous medium characterized by the stellar wind.**
3. **In high-mass systems, the stellar wind serves as a heavy dynamical target for the jet.**
4. **Also in systems hosting a low-mass companion in its giant phase, the jet environment is not free of matter to interact with.**

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Relativistic stellar jets: formation and propagation

The jet faces an environment much heavier than itself.

1. **The jet is to face regions loaded with the mass of the wind.**
2. **For typical red giant parameters:** $M_{wj} \sim 10^{22}\dot{M}_{-7}R_{orb13}v_7^{-1}$ **g**
3. **and for a typical high-mass star:** $M_{wj} \sim 10^{21}\dot{M}_{-7}R_{orb13}v_8^{-1}$ **g**
4. **The jet mass is** $\lesssim 4\times10^{17}L_{j36}R_{orb13}\,\mathrm{g} \ll M_{wj}$**, so the jet will produce an interaction structure (FRI or FRII type).**

Internal jet dissipation will tend to be smoother than external jet-propagation effects but for very irregular jet injection on the suitable scales.

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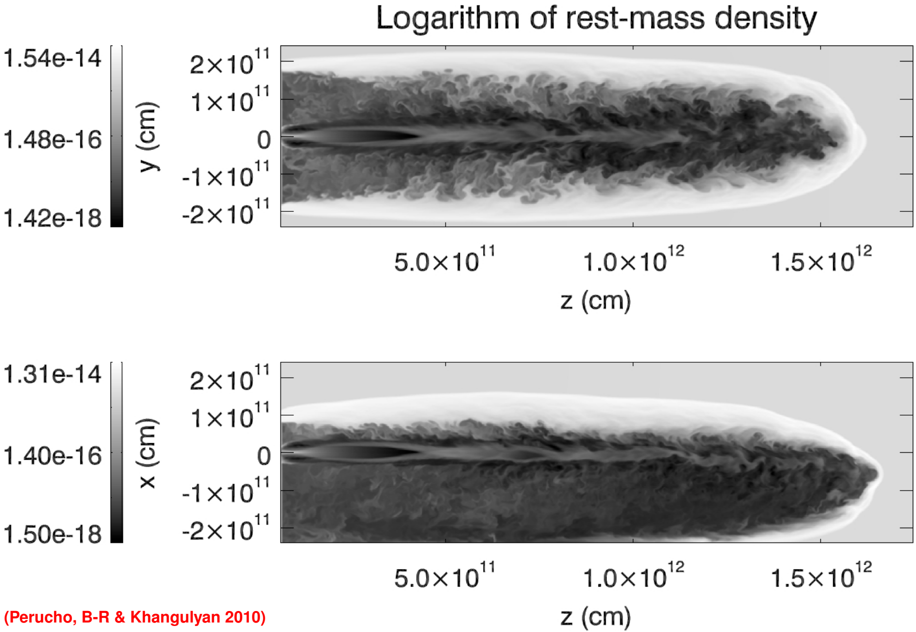

(Perucho, B-R & Khangulyan 2010)

Relativistic stellar jets: propagation and stability

Relativistic jets of large thrust can effectively propagate through the surrounding medium.

1. **Comparing energy fluxes, the *jet* will eventually leave the binary for $L_j > 3 \times 10^{34} \dot{M}_{-7} v_8$ erg/s**
2. **Comparing momentum fluxes, even for $L_j \sim 3 \times 10^{35} \dot{M}_{-7} v_8$ erg/s the jet is to bent significantly, acquiring a lateral momentum of the order of its own.**
3. **This suggests that even powerful jets, i.e. $L_j \gtrsim 10^{36} \dot{M}_{-7} v_8$ erg/s, may suffer important dynamical non-linear effects.**

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Preliminary conclusions and remarks:

1. **The jet will partially disrupt and mass-load.**
2. **However, even under disruption, the jet will inflate a strongly asymmetric bubble.**
3. **Kinetic energy is converted into internal and turbulent energy; this is suitable for non-thermal phenomena.**

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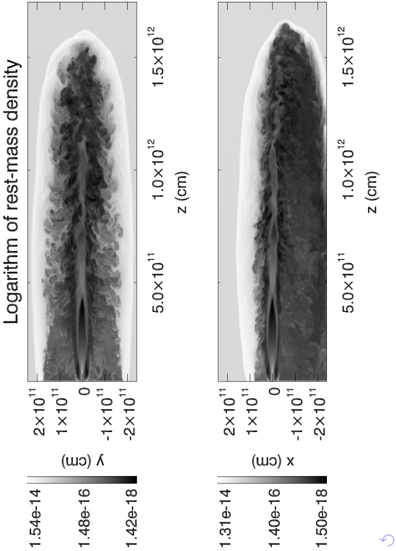
A summarizing remark...

At mas and arcsec scales, the jet cannot be laminar nor ballistic, and non-thermal radiation is expected.

...and a comment:

Orbital motion and the pressure gradient will lead to a bipolar outflow at spatial scales $v_j T_{orb} \lesssim 10^{16} T_6$ cm (arcsec).



Relativistic stellar jets: non-thermal emission

External dynamical factors should have an imprint on the jet emission.

1. **Jet termination shocks are strong and all the jet luminosity is reprocessed.**
2. **Lateral wind interaction implies asymmetric recollimation shocks and bending by $\theta \sim \dot{P}_w/\dot{P}_j \sim 0.3\,\dot{M}_{-7}\,V_{w8}\,L_{36}^{-1}$.**
3. **Bending and recollimation shocks can reprocess up to a fraction $\sim \theta$ of the jet luminosity.**
4. **The target fields and adiabatic cooling ($t \sim R/v$) determine the broadband non-thermal emission (synchrotron, IC, Bremss., *pp*...).**

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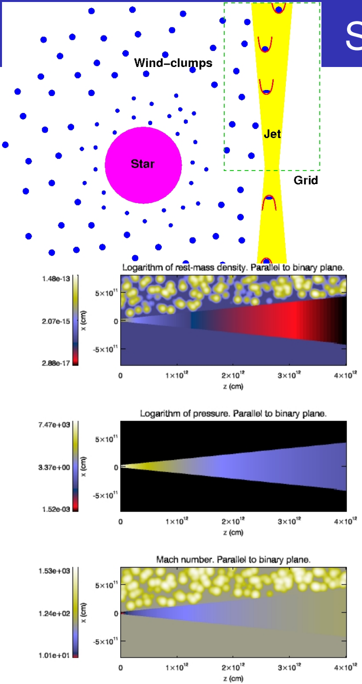
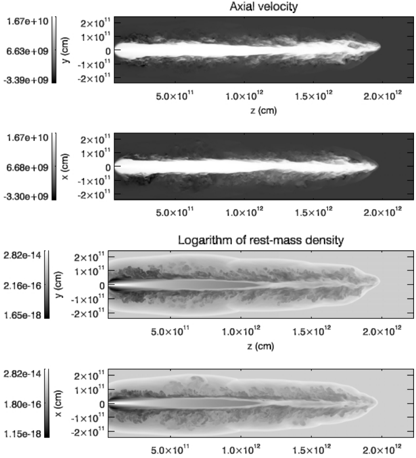
Smooth and clumpy wind MQs



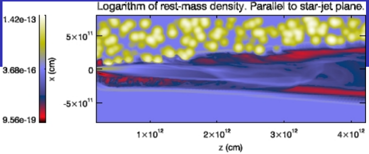


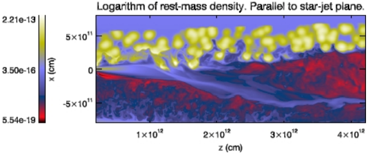
Setup for a clumpy wind simulation (left);

smooth wind-jet interaction (top)

(Perucho & B-R 2012; Perucho, B-R & Khangulyan 2010)

Clumpy wind MQ


Logarithm of rest-mass density. Parallel to star-jet plane.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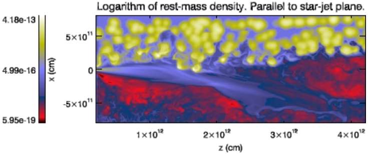
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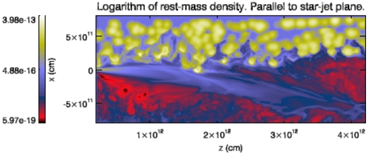
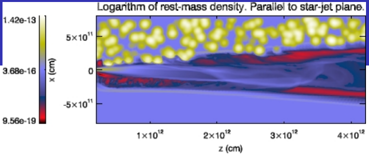
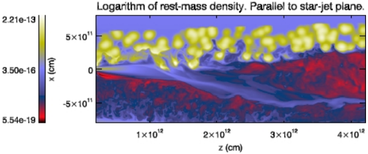

Logarithm of rest-mass density. Parallel to star-jet plane.

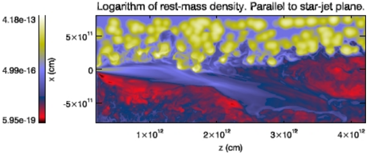
- **Moderately clumpy winds yield effective jet mass-entrainment.**
- **Clumps are shocked and eventually disrupt and mix with the jet.**
- **Clump entrainment enhances jet disruption.**
- **For $L_j \lesssim 10^{36}\,\dot{M}_{-7}$ erg/s jets will be likely disrupted at the binary scales.**

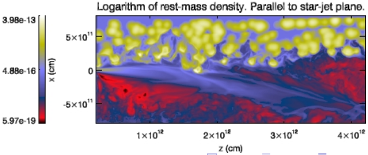
Clumpy wind MQ

- **A significant fraction of the jet kinetic energy is lost to heat and turbulence.**
- **The jet reprocessed energy can go to radiation or lead to jet reacceleration outside the binary.**
- **Mass-loading may be effective:** $\dot{M} \sim L_j/\Gamma_j c^2$







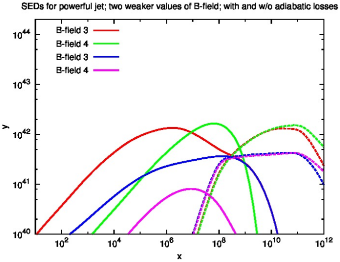


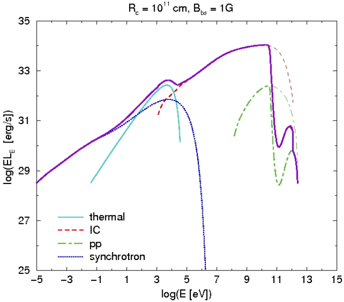
The broadband emission: smooth and clumpy wind

- **The jet wind interaction can trigger strong non-thermal activity.**
- **Adiabatic heating cannot be neglected.**

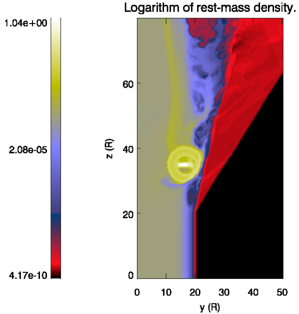
  (Khangulyan, B-R & Perucho, in prep. -top-)
- **Distinguishable jet-clump interactions may also occur for density contrasts $\gtrsim 10$.**

  (Araudo, B-R & Romero 2009 -bottom-)
- **Synchrotron and IC in the ambient fields are the dominant mechanisms.**


SEDs for powerful jet; two weaker values of B-field; with and w/o adiabatic losses

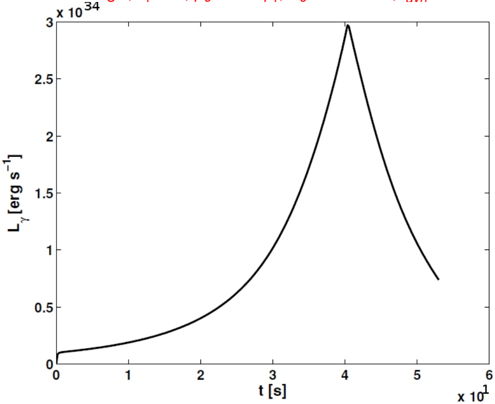

$R_c = 10^{11}$ cm, $B_{bs} = 1$G

Single clump-Jet interaction



(Perucho & B-R, in prep.)

$L_j = 8 \times 10^{36}$ erg/s, $\Gamma_j = 2$, $\rho_c = 10^4 \rho_j$, $R_c = 10^{10}$ cm, $t_{dyn} \sim 30$ s



The non-thermal lightcurve is determined by the clump dynamics under the jet impact.

(Barkov, Aharonian & B-R 2012 -adapted-)

In *blazar-type* sources, the emission can be strongly beamed ($\times\Gamma_c^2$) and rise fast ($< z/c\Gamma_c^2$).

(Barkov et al. 2012; Khangulyan et al. 2013)

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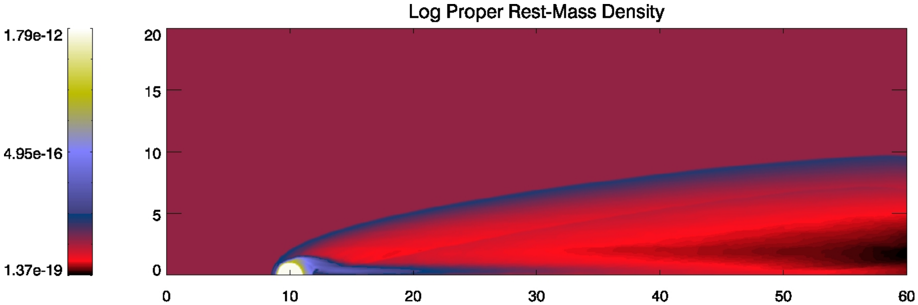

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(B-R, Perucho & Barkov 2012)

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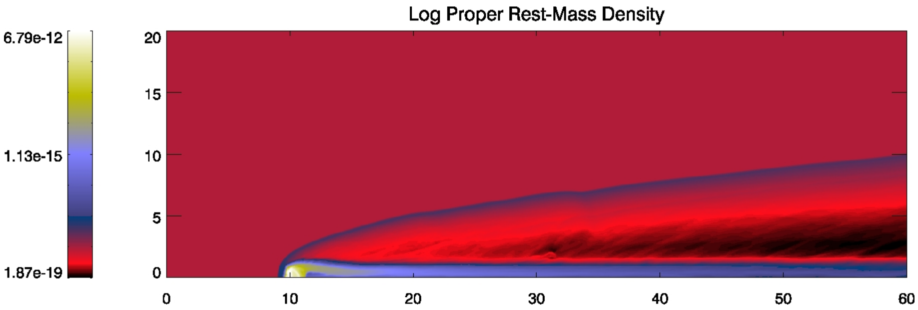

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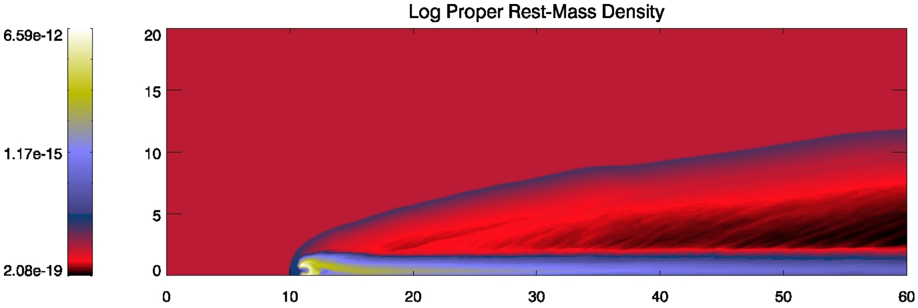

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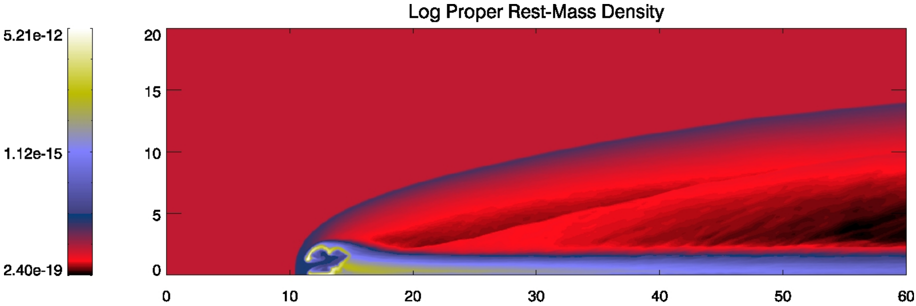

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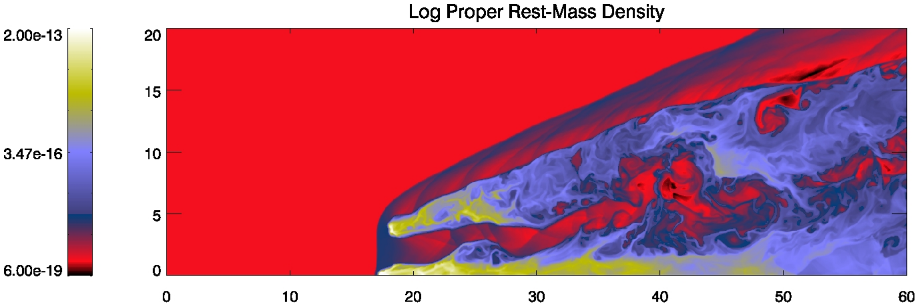

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