Radiative implications of obstacles embedded in microquasar and extragalactic jets

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The interaction of microquasar and extragalactic jets with relatively small obstacles, such us stellar wind inhomogeneities, clouds, or stars, can lead to important consequences from the radiative point of view. Particles can be accelerated in the interaction region up to very high energies either through Fermi mechanisms or magnetic reconnection, and produce Doppler boosted emission in different energy bands. In this talk, I will overview some important aspects of the non-thermal phenomena related to the entrainment of obstacles in galactic and extragalactic jets.

Subject :	:	oral
Topics	:	Astrophysics

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Valentí Bosch-Ramon

Universitat de Barcelona/ICC

Accretion and Outflows throughout the scales
Lyon, October 3, 2014

Outline

1. Introduction

2. Radiation

3. Radiation and dynamics coupling

4. Conclusions

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Introduction

General context: jet environment

1. **The ambient medium within massive binary systems and the nuclear regions of AGN is complex, rich in matter, magnetic and radiation fields.**
2. **The presence of stars, or clumps of material originated by different types of processes (instabilities, winds, tidal forces, irradiation, stellar collisions...), render the environment of relativistic jets strongly inhomogeneous.**

How much relevant can the medium inhomogeneities be for the jet dynamics and radiation?

(e.g. Burbiddge 1970; Krolik 1981; Shull 1983; Rees 1987; Penston 1988; Runacres & Owocki 2002)

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Introduction

Moving, dense obstacles can interact with jets

1. Stellar wind inhomogeneities of different origin (MQ)
2. Molecular clouds, clouds from the BLR, etc. (AGN)
3. Massive stars and red giants within galaxies (AGN)

Clouds can penetrate in the jet as long as

$$L_{\rm j}/S_{\rm j}c < \rho_{\rm o}\, v_{\rm o}^2$$

(e.g. Blandford & Koenigl 1979; Coleman & Bicknell 1985; Steffen et al. 1997; Hubbard & Blackman 2006; Owocki et al. 2009)

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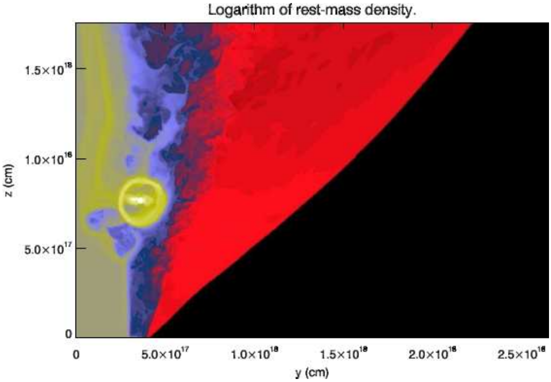

A red giant entering in an AGN jet (density map).

(Perucho, B-R, Barkov, in prep.)

Introduction

These obstacles trigger instabilities affecting jet propagation

1. **Jets suffer kinetic energy dissipation: slow-down and heating**
2. **Jets entrain matter: mass-load**
3. **Jets suffer strong instabilities: disruption**

Stellar mass-load may be important decelerating/disrupting for FR I jets, but the stellar populations may not be well known.

The role of clouds may be also important.

Stellar wind clumps are likely dynamically relevant in high-mass microquasar jets.

(e.g. Komissarov et al. 1994, Bowman et al. 1996,Perucho & B-R 2012, B-R, Perucho & Barkov 2012, Laing & Briddle 2014, Perucho et al. 2014)

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Jet-obstacle interaction can generate

1. **Strong shocks and velocity gradients**
2. **Magnetic activity**
3. **Different emitting sites**

(e.g. Dar & Laor 1997; Bednarek & Protheroe 1997; Araudo, B-R, Romero, 2009, 2010; B-R 2012; Barkov, Aharonian, B-R 2010; Barkov, B-R, Aharonian 2012; Barkov et al. 2012; Khangulyan, Barkov, B-R et al. 2013, Araudo, B-R, Romero 2013)

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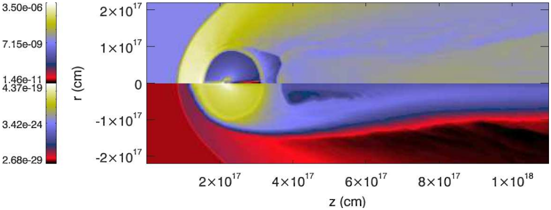

RG bubble dragged by the jet (density map).

(Perucho, B-R, Barkov, in prep.)

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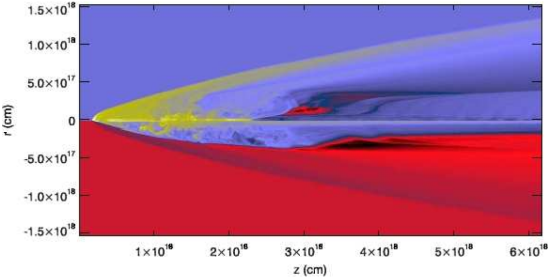

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Radiation

Strong shocks and velocity gradients

1. **Magnetic pressure is much smaller than the momentum flux.**
2. **The obstacle inertia stops the flow, which is supermagnetosonic.**
3. **A bow-shaped shock surrounds the obstacle.**

Diffusive shock acceleration can accelerate particles if enough chaotic field is present. Shear acceleration may also accelerate particles far downstream.

(e.g. Derishev et al. 2003; Rieger & Duffy 2007; Sironi et al. 2013; Lemoine et al. 2014)

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Magnetic activity (I)

1. **If B_ϕ is not negligible, magnetic energy can accumulate in front of the obstacle.**
2. **The accumulated magnetic lines dragged by the jet may reconnect behind the obstacle.**
3. **Strong non-linear dynamical processes are expected also to take place behind the obstacle.**

All this can trigger magnetic field reconnection, turbulence, and particle acceleration.

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Magnetic activity (II)

1. **If *B* presents polarity reversals, it can reconnect in the accumulation region.**
2. **Magnetic energy turns into heat (and kinetic energy far downstream) and potentially non-thermal particles.**

Electric field acceleration can occur in the current sheet, and Fermi I acceleration can occur between the sheet and/or the in-coming flows.

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Radiation and dynamics coupling

Simulation: basic scenario

1. **Clumps in a stellar wind that can penetrate a microquasar jet on binary scales.**
2. **Clouds can interact with an AGN jet on different scales.**
3. **RG and massive star winds can interact with an AGN jet on different scales.**

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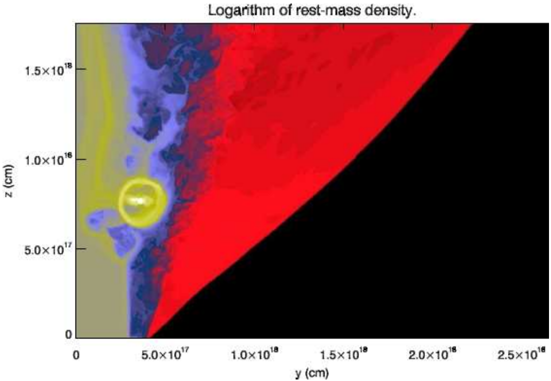

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Clumps entering into a MQ jet (density map):

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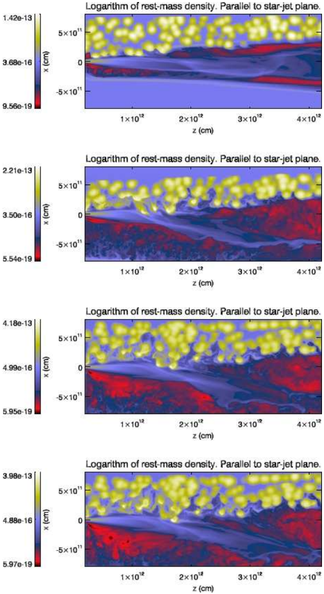

Simulation: assumptions

1. **Relativistic hydrodynamical flow.**
2. **Axisymmetric relativistic simulation.**
   (2nd spatial order, Marquina solver, 300×600 cells; $R_{\rm o} = 30$ cells)
3. **Adiabatic interaction; relativistic ideal gas.**
4. **A jet meets an obstacle of very large inertia.**
   ($\Gamma = 10$, $L_{\rm j} = 10^{44}$ erg/s and $R_{\rm j} = 10^{15}$ cm vs $R_{\rm o} = 10^{14}$ cm)

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Radiation and dynamics coupling

Simulation: steady state

1. **Fluid lines accelerate as they circumvent the obstacle and stream away.**
2. **The post-shock flow velocity gets quickly relativistic.**
3. **The effective size of the obstacle is larger than its radius.**

$$(\dot{U}/L_{\mathrm{j}\to\mathrm{o}})^{1/2} \sim (R_{\mathrm{o,eff}}/R_{\mathrm{o}}) \sim 6$$

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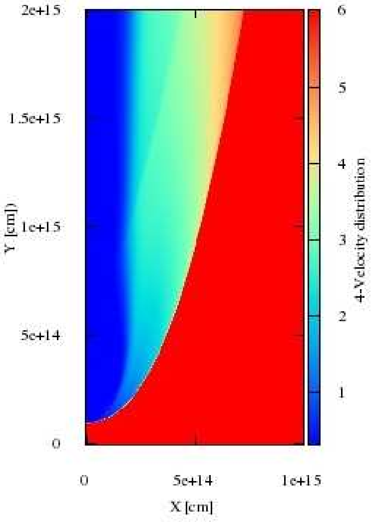

Steady state map of $\gamma|\beta|$.

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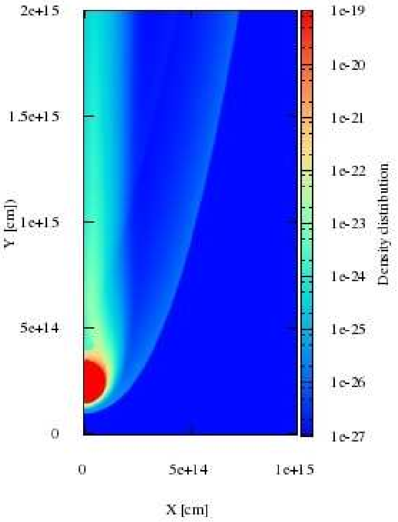

Steady state density map.

Radiation and dynamics coupling

Radiation: relevant ingredients

1. The power of non-thermal particles comes from the internal energy produced at the interaction.
2. The internal and the non-thermal energy should distribute similarly under adiabatic cooling.
3. Downstream Doppler boosting is considered in the shocked flow.

A rough estimate of the expected radiation luminosity can be derived.

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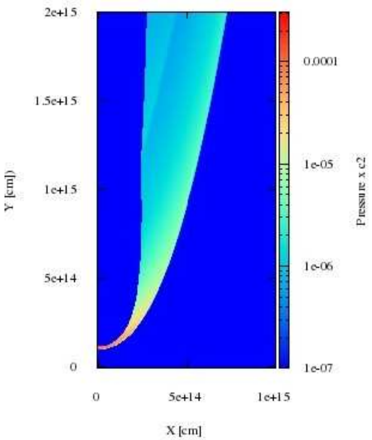
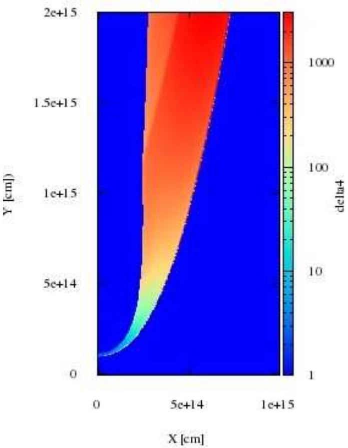
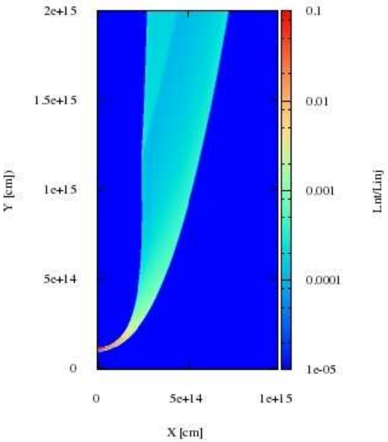


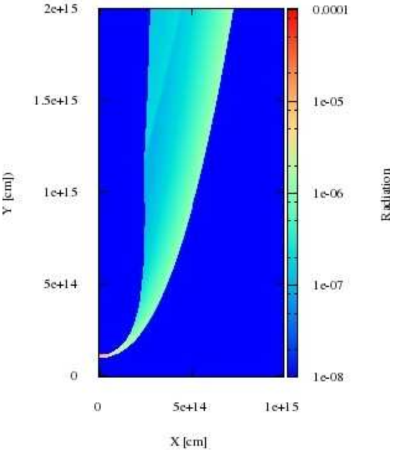
Pressure distribution in the interaction region.



Distribution of δ^4 (on axis).

Radiation and dynamics coupling





Radiation efficiency distribution in the interaction region.

Distribution of radiation (on axis).

Outline

Conclusions

1. **Clouds have a fixed radius before disruption. In the lab frame:**

$$L_{\rm NT} \lesssim <(R_{\rm o,eff}/R_{\rm j})^2> L_{\rm j} \sim 10^{37}\,(R_{\rm o13}/R_{\rm j,pc})^2\,L_{\rm j45}$$

2. **Ram pressure balance leads to a constant luminosity for stellar winds:**

$$L_{\rm NT} \lesssim (R_{\rm o,eff}/R_{\rm o})^2 < \dot{M}_{\rm w}\,v_{\rm w} > c \sim 10^{37}\,\dot{M} v_{\rm w25}\,{\rm erg/s}$$

3. **The non-thermal efficiency ($\eta_{\rm NT}$), the radiation to adiabatic cooling ratio ($t_{\rm ad/rad}$), and Doppler boosting ($\delta^4\Gamma^{-2}$), and the distribution of obstacles ($N_{\rm o}$; clumps, stars or clouds), will determine the global outcome.**

A persistent (sometimes variable) component of the non-thermal emission could come from jet-obstacle interactions; in the observer frame:

$$L_{\rm NT,obs} \sim < L_{\rm NT}\delta^4\Gamma^{-2}\eta_{\rm NT}\,t_{\rm ad/rad}N_{\rm o} > \sim 10^{45}L_{\rm NT37}\delta_{20}^4\Gamma_{10}^{-2}\eta_{\rm NT-1}\,t_{\rm ad/rad,0}N_{\rm o6}^{100\ \rm pc}\ {\rm erg/s}$$

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$$L_{\rm NT} \lesssim (R_{\rm o,eff}/R_{\rm o})^2 < \dot{M}_{\rm w}\, v_{\rm w} > c \sim 10^{37}\, \dot{M} v_{\rm w25}\, {\rm erg/s}$$

3. **The non-thermal efficiency ($\eta_{\rm NT}$), the radiation to adiabatic cooling ratio ($t_{\rm ad/rad}$), and Doppler boosting ($\delta^4\Gamma^{-2}$), and the distribution of obstacles ($N_{\rm o}$; clumps, stars or clouds), will determine the global outcome.**

A persistent (sometimes variable) component of the non-thermal emission could come from jet-obstacle interactions; in the observer frame:

$$L_{\rm NT,obs} \sim < L_{\rm NT}\delta^4\Gamma^{-2}\eta_{\rm NT}\, t_{\rm ad/rad} N_{\rm o} > \sim 10^{45} L_{\rm NT37}\delta_{20}^4\Gamma_{10}^{-2}\eta_{\rm NT-1}\, t_{\rm ad/rad,0} N_{\rm o6}^{100~\rm pc}\, {\rm erg/s}$$

Conclusions

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