Astrophysical perspectives and experimental challenges for plasma jets experiments

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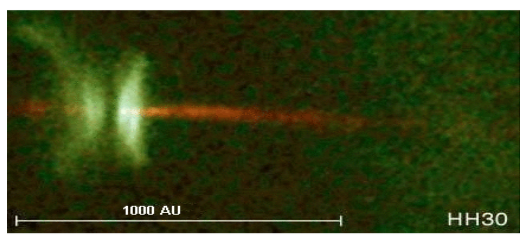
Astrophysical jets perspectives

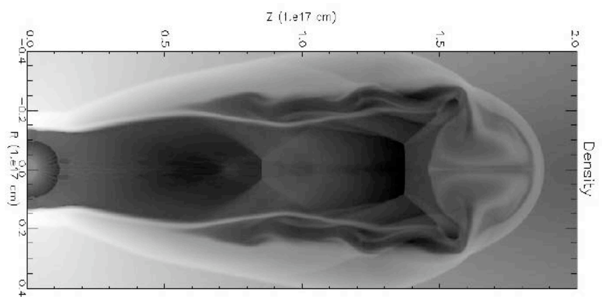
What is the problematic ?

Several problematics concerning plasma jet propagation can be study experimentally in order to provide useful data for astrophysical models. Broadly speaking, the difficulties for modeling these phenomena are the number of physical processes involving during the jet propagation like its collimation, interaction with the interstellar medium and knots formation.

Collimation



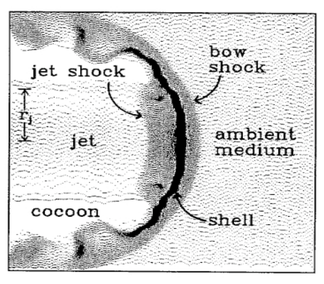
What are the efficiency of each phenomena supposed to maintain or to produce the plasma collimation?



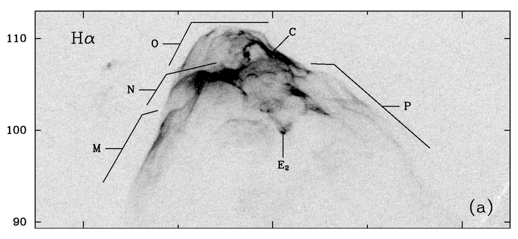
➢ Hydrodynamic collimation and ambient medium effect
We can study the effect of a particular ambient medium density profile to the jet evolution and the effect of the oblique shocks formation.
A. Frank and G. Mellema.. Astrophys. J., 472 :684, 1996.

➢ Radiation losses efficiency
J. M. Blondin, B. A. Fryxell, and A. Konigl. Astrophys. J., 360 :370, 1990.

➢ Magnetics fields effect close and far from the source
P. Hartigan, A. Frank, P. Varniere, and E. G. Blackman.. Astrophys. J., 661 :910, 2007.



Bow shock



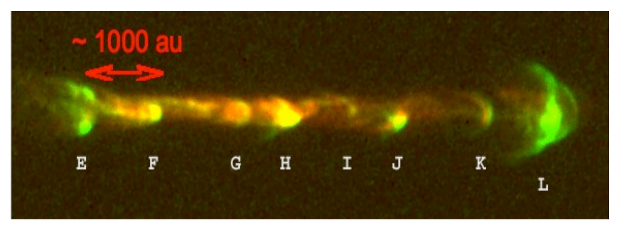
Why the bow shock is so perturbed ?

➢ Effect of a clumpy interstellar medium and shocks collision

The presence of dense clouds or a modulated density for the interstellar medium can explain the fragmentation of the bow shock during its evolution as well as shocks collision.
P. Hartigan. Astrophys. Spac. Sci., 298 :99, 2005.

➢ Instabilities **(Radiative Kelvin-Helmholtz, Vishniac, Cooling)**
J. M. Blondin, A. Konigl, and B. A. Fryxell. Astrophys. J., Lett., 337 :L37, 1989.
E. T. Vishniac. Astrophys. J., 274: 152, 1983.

Knots



What are the knots?

➢ Star pulsation
The knots formation can be linked with a pulsation of the star. The knots velocities are related with the period of pulsation.
A. C. Raga et al. Astrophys. J., 364 :601(1990).
E. M. de Gouveia Dal Pino. Astrophys. J., 551 :347, 2001.

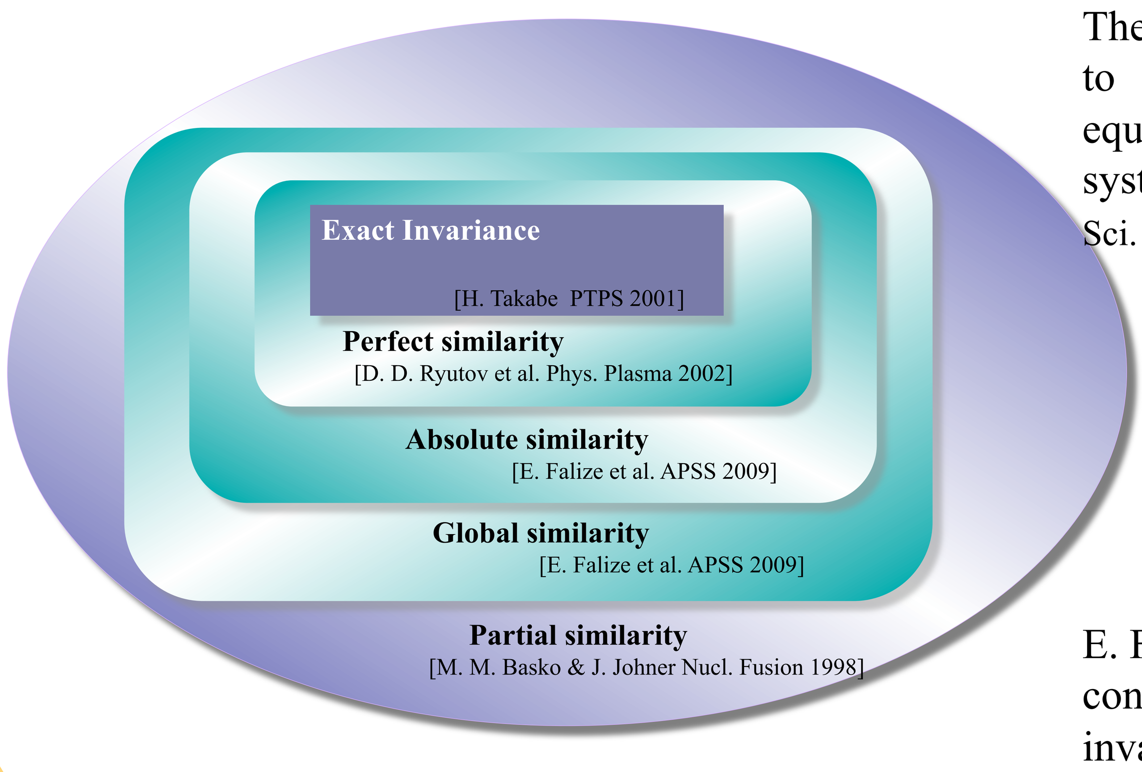
➢ Instabilities (hydrodynamics and magneto hydrodynamics)
E. M. de Gouveia dal Pino, M. Birkinshaw, and W. Benz.. Astrophys. J., Lett., 460 :L111, 1996.

Similarity criteria

How do we want to answer ? What is the needed accuracy for each problematic ?

In order to assure the equivalence between the experimental system and the astrophysical system we must elaborate scaling laws which will allow to characterize the astrophysical character of experimental plasma.

Consequently scaling laws play a pillar role in laboratory astrophysics. Laboratory astrophysics experiments can be divided into **several fundamental classes** which are connected to the type of similarity used as we see on the following diagram:



Resemblance
[E. Falize et al. (in preparation)]

The existence of scaling laws results to fundamental symmetry of the equations which give the evolution of system [E. Falize et al. Astrophys. Spac. Sci. (2009)].

E. Falize et al. introduce recently the concept of absolute invariance & global invariance, which is less constraining and let more degree of freedom.

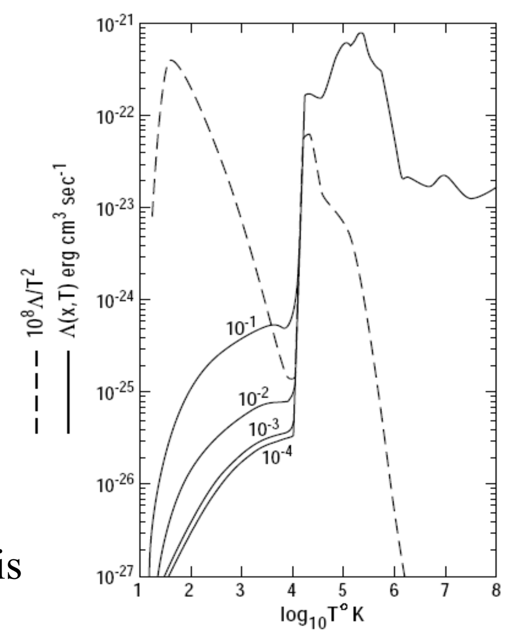
Several studies are realized: hydrodynamics system [D. D. Ryutov et al. Astrophys. J. 518 :821 (1999)], [E. Falize et al. Astrophys. Spac. Sci. (2009)], MHD [D. D. Ryutov et al. Astrophys. J. Suppl. S., 127 :465 (2000)], radiation hydrodynamics [D. D. Ryutov et al. Phys. Plasma 8: 1804 (2001)], [J. Castor Astrophys. Spac. Sci. 307 : 207(2007)], [E. Falize et al. J. Phys.Conf. Series 112 :042016(2008)], [E. Falize et al. Astrophys. Spac. Sci. (2009)]

The number of freedom parameters and the way we use scaling laws are linked to the degree of accuracy we want to access for the astrophysical phenomenon

➢ The more the physical phenomena depends of the microscopic processes the more it is difficult to assure the invariance of phenomena.

➢ Moreover, the more phenomena we add, the harder it is to rescale an experiment.

One of problem of jets is that their hydrodynamics evolution is dependant two the microscopic physics of system.

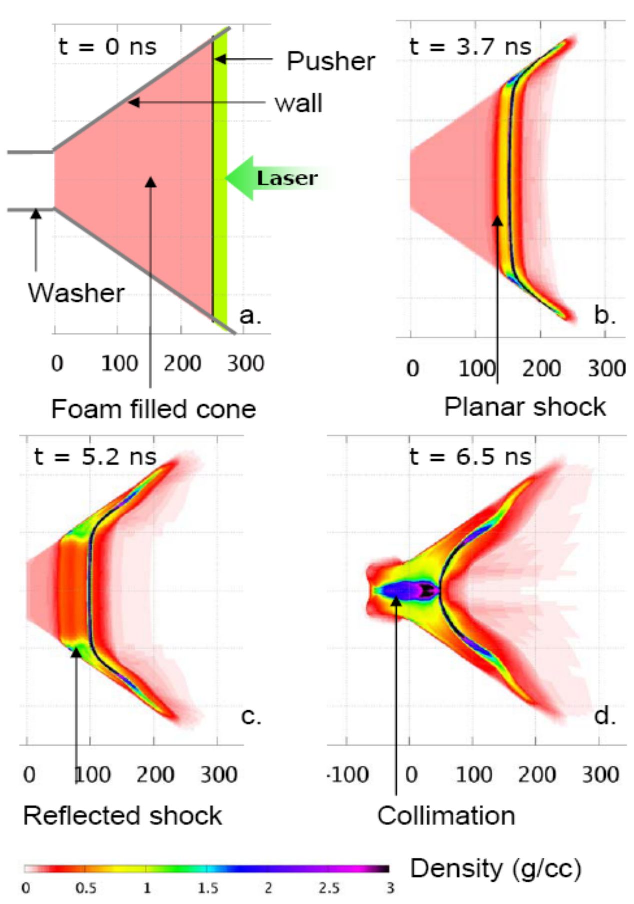


Experimental plasma jets challenges

How can we generate plasma jets? What are the limited conditions? What do we need to measure?

The experimental challenges concern the **target** design and the **measurements**. The target design need to satisfy the dimensionless parameters and limited conditions in order to verify the scaling laws at least during few moments.

Target example: foam cone



Simulation DUED: 2D radative hydrodynamic code (Lagrangien, multigroupe)

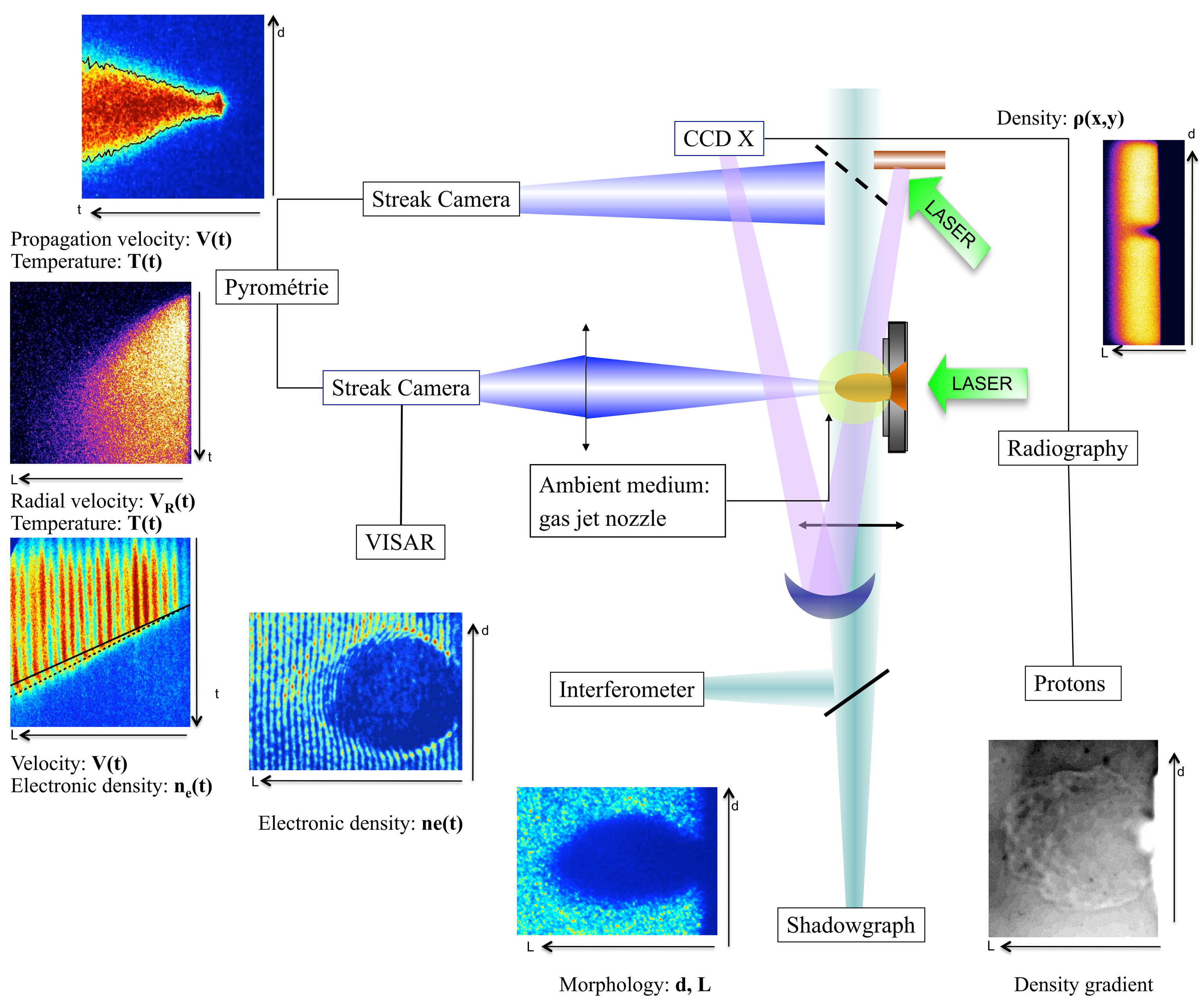
T. Vinci et al., J. Phys. Conf. Series, 112: 042012 (2008)

Advantage:
- High amount of matter
- High velocity

Disadvantage:
- Too cold
- Plasma in expansion

➢ The key point for the astrophysical experiment is to match the scaling law criteria and the limited conditions at the first moment of the plasma jet generation.

➢ If we want to study with accuracy the efficiency of the radiative losses for the astrophysical jet collimation it is needed to use material close to the astrophysical case (H, He) to verify similarity.



➢ The plasma jet parameters we need to measure are:
- **Velocity** (it appears in all the dimensionless parameters)
- **Temperature** (key parameters to satisfy the radiative losses)
- **Density**
- **Morphology** (to check the plasma collimation)

➢ All these parameters need to be measure with time resolution in order to obtain quantitative results for astrophysical problematics and to estimate the time of range for the similarity.

➢ Experimental challenges concern our ability to measure temperature and density when the plasma jet interact with an ambient medium. The cocoon formation hides the plasma jet. This problem highlights the need to measure the jet parameters at different wavelength to access to the plasma jet.