Magnetic collimation of relativistic jets

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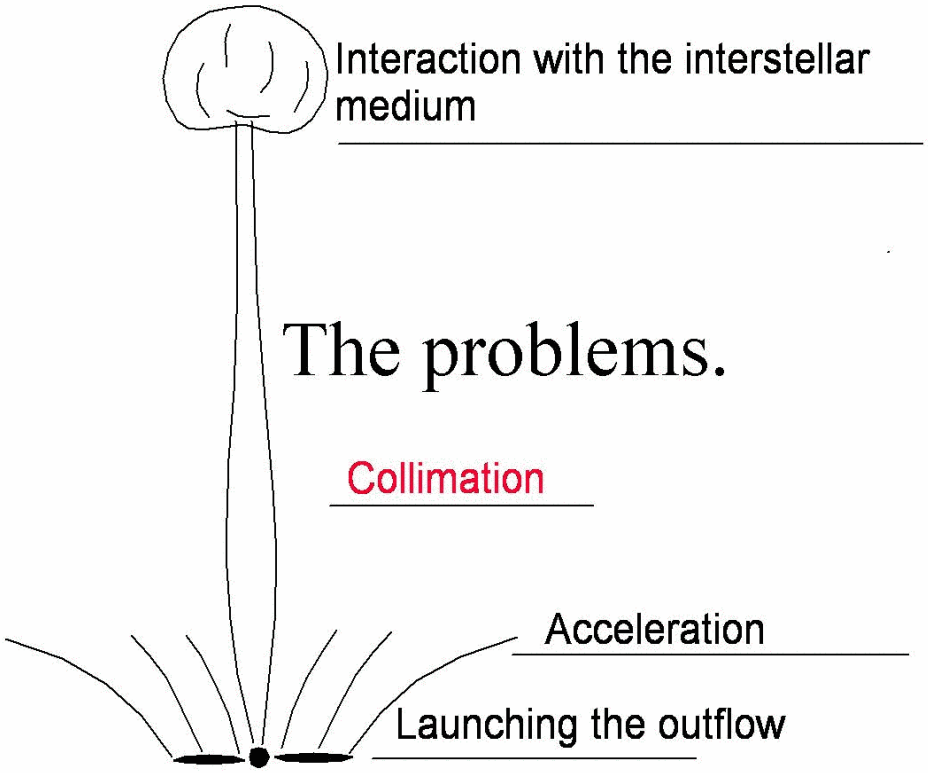
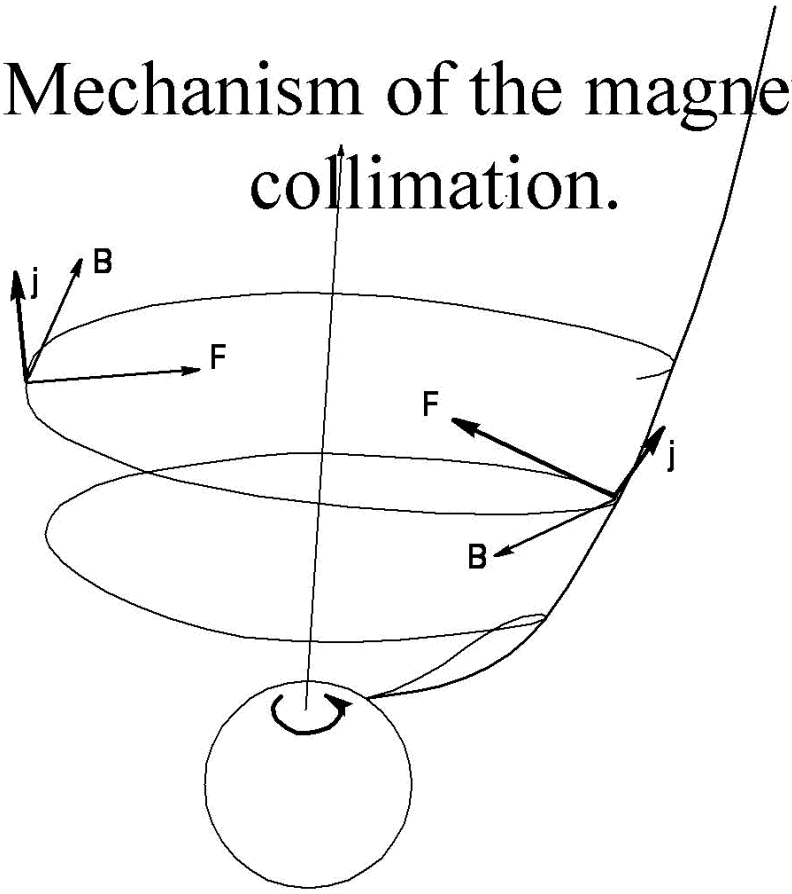


Mechanism of the magnetic collimation.



Heyvaerts & Norman THEOREM

(Heyvaerts J.& Norman C.A.1989, Chiueh T., Li Z.-Y., & Begelman M. 1991, Bogovalov S. 1995)

If some object:

1. Rotates ($\Omega \neq 0$ at least on some flux tubes);
2. Magnetized;
3. Ejects a wind,

Then at the distances R >> D (characteristic size of the central object)

Some part of the wind will be inevitably cylindrically collimated and the other part will flow radially,

Provided that the ideal MHD is not violated and the wind is not terminated by the interstellar medium.

Why the self collimation of the magnetized winds is inevitable?

Let us assume that there is no collimation.

Then

$$B_\varphi \sim \frac{1}{r};\ n \sim \frac{1}{r^2};\ J \sim \frac{1}{r^2}.$$

$$\frac{mnv^2}{R_c} = |\vec{J} \times \vec{B}|;\Rightarrow \frac{1}{R_c} \sim \frac{1}{r};$$

$$\frac{1}{R_c} = \frac{\partial \theta}{\partial r} \sim \frac{1}{r};$$

$$\theta \sim \ln r$$

To understand:

1. At what distances from the central source the jets are produced
2. What are the characteristics of the jets:

Their size, mass and energy flux in the jets

We need numerical simulation

Basic demands to the model

The magnetic self collimation is the general property of the magnetized winds. It must take place in a wind from any source provided that the conditions of the THEOREM are fulfilled.

Therefore we can choose the model which is "simple" and convenient for the analysis.

This is "split monopole" model with cold wind without gravitation.

Split monopole axisymmetric model

Advantage of the simplicity

The plasma flow in the split monopole model is controlled only by two parameters

$$\sigma = \left(\frac{R_f}{R_l} \right)^2 ; \qquad \frac{R_f}{R_l} = \sqrt{\sigma} ;$$

- σ - is the expected magnetization of the wind

One more parameter

$$\alpha = \frac{R_f}{R_l U_0} = \frac{\sqrt{\sigma}}{U_0}; \quad U_0 = \gamma \frac{\mathrm{v}}{c}.$$

In the non relativistic limit

$$\sigma \Rightarrow 0; \quad \alpha \Rightarrow \frac{R_f \Omega}{\mathrm{v}}.$$

And all the flow depends only on one parameter

$\varsigma < 1$ – slow rotator

$\varsigma > 1$ – fast rotator

Method of the solution

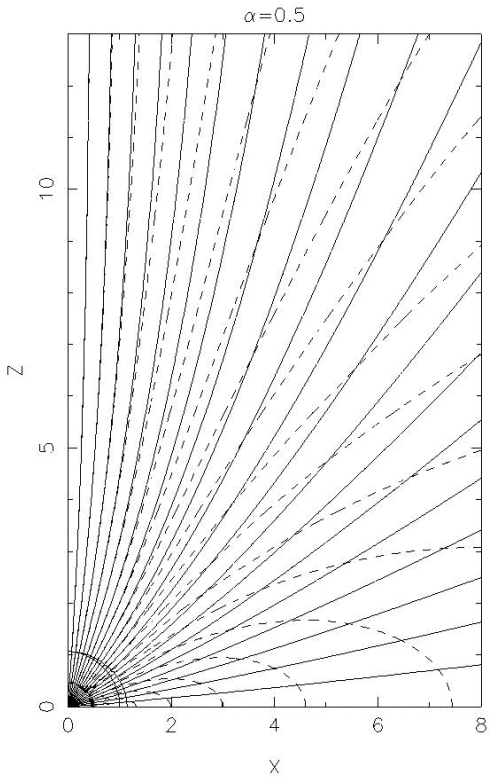
1. Solution of the problem in the nearest zone

(Time dependent solution in the region including all the critical surface)

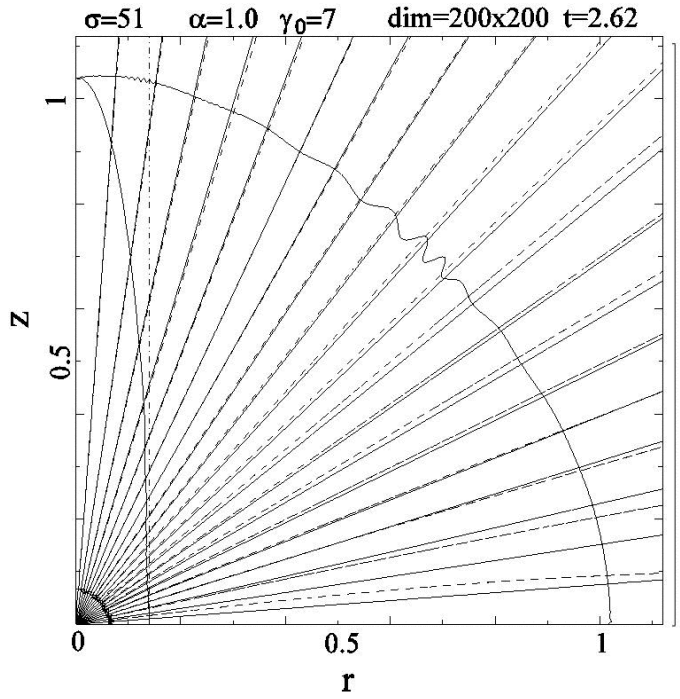
2. Steady state solution of the problem in the far zone

(the problem is solved as the initial value problem)

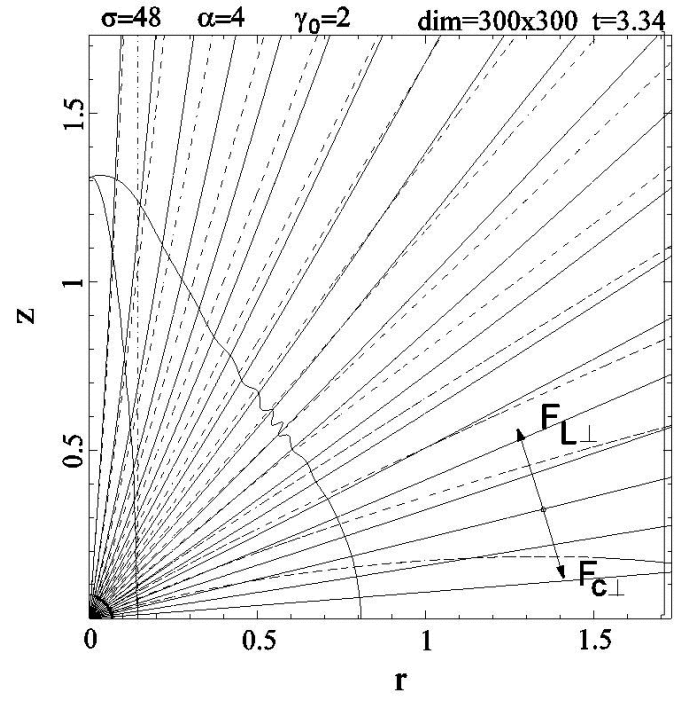
Non relativistic solution



Relativistic solution (♋=1)



Relativistic solution (♋=4)

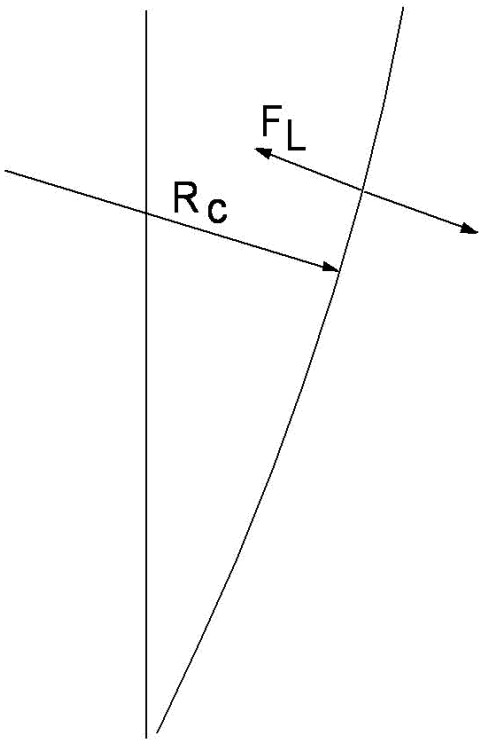


Why collimation is so small in the relativistic case?

May be Heyvaerts & Norman theorem is not correct?

NO. Heyvaerts & Norman theorem is correct!

The problem is only in distance.



$$\frac{(mn\mathrm{v}^2\gamma + \frac{1}{4\pi}|\vec{E}\times\vec{B}|)}{R_c} = |\vec{J}\times\vec{B}| - qE;$$

$$\frac{(1+\sigma\sin^2\theta)}{R_c} = \frac{\sigma}{U_0{}^2 r}\sin 2\theta = \frac{\alpha\sin 2\theta}{r};$$

$$D_{coll} \approx R_f \exp(U_0{}^2 \frac{\theta(1+\sigma\sin^2\theta)}{\sigma\sin 2\theta}).$$

For Crab this means

$$D_{coll} \approx R_f \exp(5000);$$

For AGNs with $\gamma = 5$

$$D_{coll} \approx R_f 10^{5.4}$$

But there is another problem

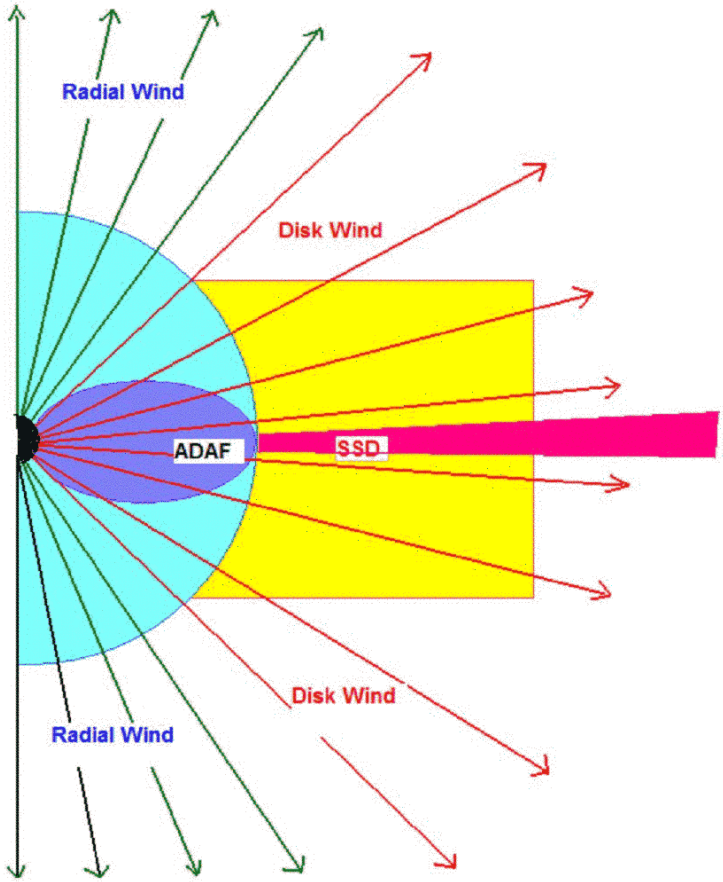
The mass and energy flux in the jet is only 0.001 of the total mass and energy flux in the wind.

Too small!

(For relativistic and non relativistic winds: Bogovalov & Tsinganos 1999, Bogovalov 2001, Krasnopolsky R., Li Z.-Y, Blandford R. 2003)

What to do?

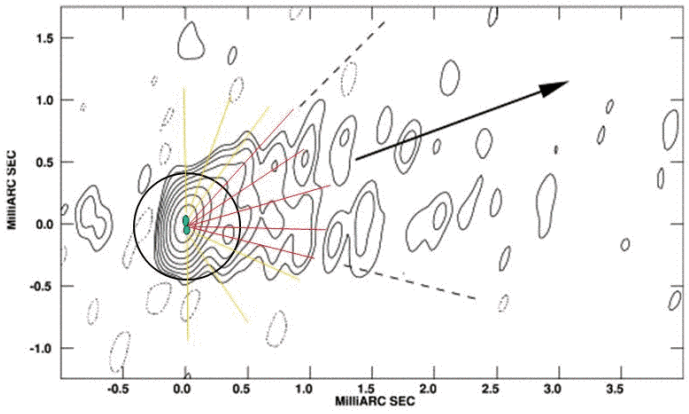
We need two component model.



Can the magnetic self-collimation provide collimation of jets from M87 at reasonable parameters of the outflow at the base?

M87 Jet sub parsec structure

BirettaJ.A,Junor W., Livio M. (New Astr. Rev. 2002)



The basic parameters (M87)

Mass of the central object $M=3\cdot10^9 M_\odot$

$Rg=10^{15}$ cm

Mass flux in the jet $M_{jet}= 10^{24}$ gr/sec

$T_{jet}=3\ mc^2$; $\gamma_0= 1.8$:

$B_{(at\ 100\ Rg)}=1$ G

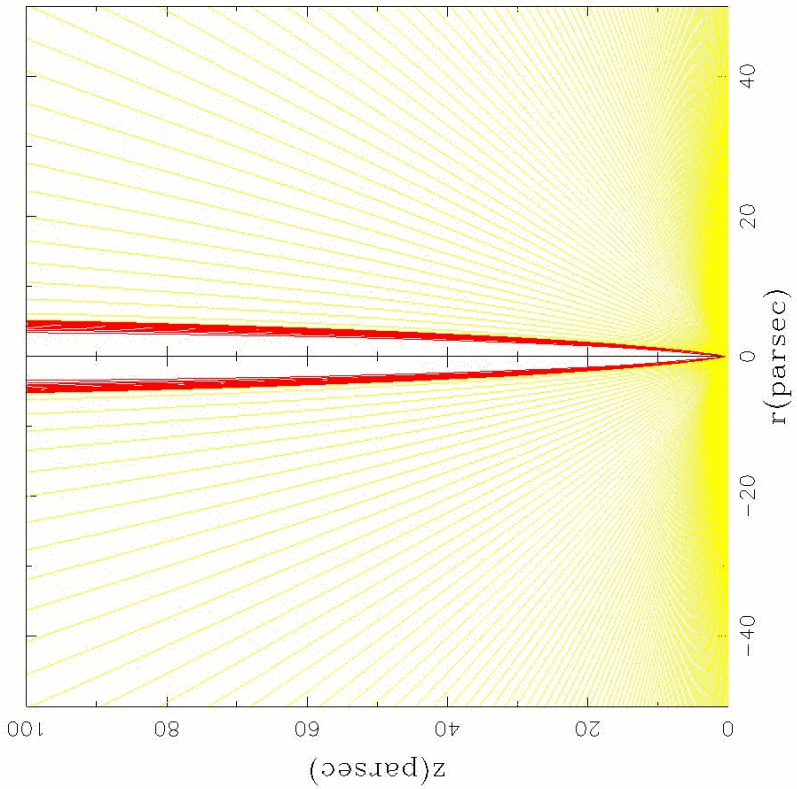
$R_f=30$ Rg

Mass flux in the wind 10 M_{jet}

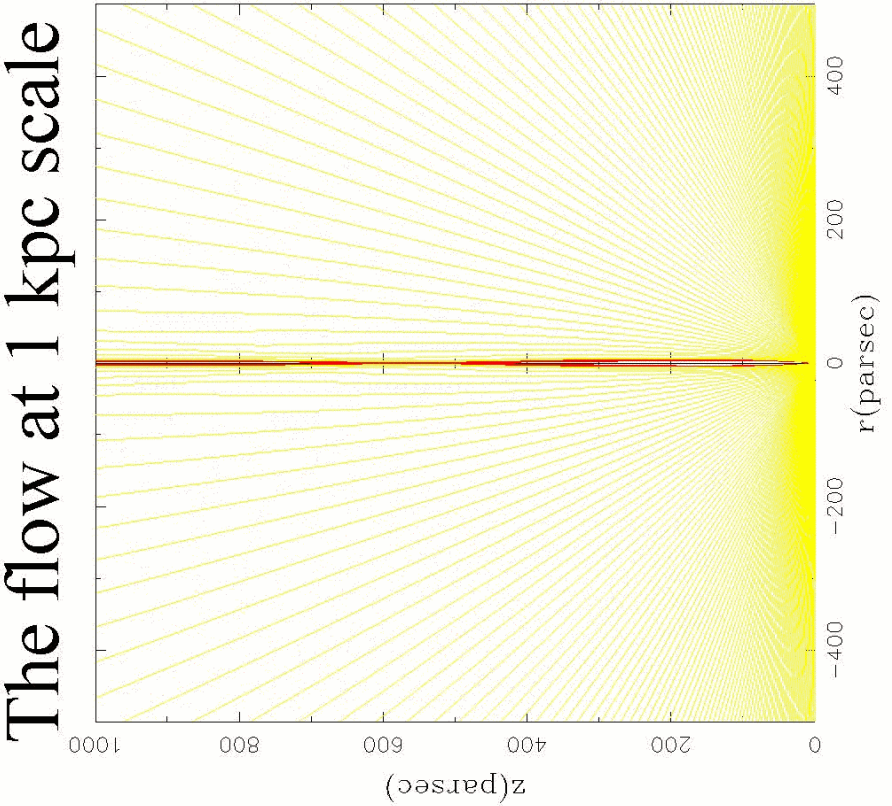
$V_0=0.288$ c

The flow at the base

The Flow at 100 pc scale



The flow at 1 kpc scale



Comparison with observations

Basic conclusions

1. In the one component model we are not able to provide essential energy flux in the jet.
2. To produce relativistic jets with an acceptable mass and energy flux we need disk and non relativistic wind from it.
3. Two component model allows us to reproduce jet characteristics in M87

Another view on the jet - disk connection

Conventional point of view:

Jet – disk connection means that jets originate directly from the disks

May be it is not totally correct.

To produce jets we really need disks.

But jets could not originate directly from the disks?