Non Thermal Emission from Astrophysical Jets

Luca Pezzini
luca.pezzini@edu.unito.it
Supervisor: A. Mignone, S. Massaglia

University of Torino
Physics Department

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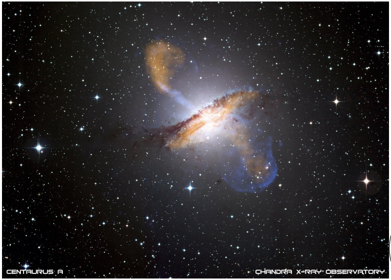
Galaxy: two types

Normal galaxies:

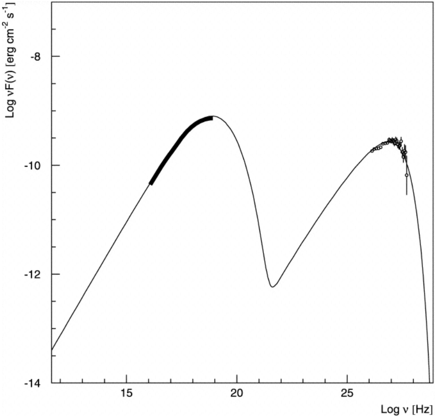
- Emission by stars, gas and dust.
- Optical bandwidth.

Active galaxies:

- Significant fraction of emission is produced by non-thermal mechanisms.
- Spectrum from radio to gamma wavebands.



The dominant emission is originated by non-thermal processes from high energy particles:



- Radio ray: $\nu \leq 0.1$ GHz
- X ray: 1 KeV $\leq E \leq 100$ KeV
- Gamma ray: E > 100 KeV

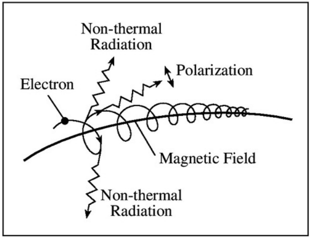
SED (brightness vs frequency): we can see two humps respectively for radio and gamma commonly attributed to synchrotron (radio to soft X) and inverse compton processes.

Non thermal emission process

Synchrotron: Emission by charged particles moving in magnetic fields.

$$\dot{E}_s = \frac{4}{3}\sigma_T c\beta^2 \left(\frac{E}{m_e c^2}\right)^2 U_B(t)$$

$$U_B = \frac{B^2}{8\pi}$$

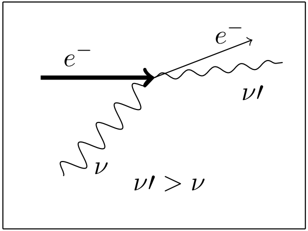


Inverse Compton: Lower energy photons scattered to higher energies by relativistic electrons.

$$\dot{E}_c = \frac{4}{3}\sigma_T c\beta^2 \left(\frac{E}{m_e c^2}\right)^2 U_{rad}(E_{ph}, t)$$

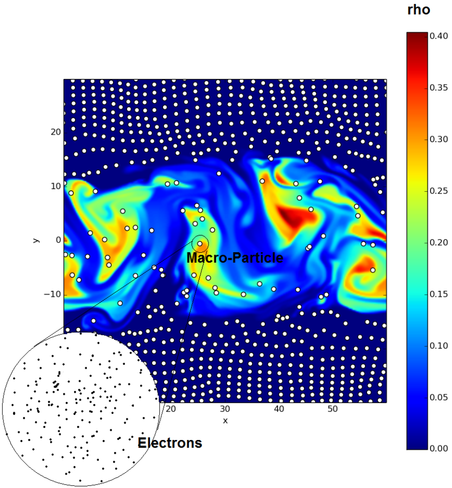
$$U_{rad} = a_{rad}T^4 = a_{rad}T_0^4(1+z)^4,$$

$z = 0$ (local source)



Thesis objectiv

- Acces the validity of numerical models to reproduce in a consistent way NTE from AGN.
- **Challenge**: Huge separation between dyamical and radiative scale.



Solution approach:
hybrid computational model where distributions of NTe are sampled by points-like entities (LP) passively transported at the local fluid speed.
Bulk (ion) motion described by MHD fluid.

Hybrid Model: coupling Eulerian with Lagrangian

Fluid: MHD equations are solved on an Eulerian grid to describe fluid (ions) dynamics:

- Continuity eq.: $\partial_t \rho + \nabla \cdot (\rho \vec{u}) = 0$
- Motion eq.: $\rho(\partial_t \vec{u} + \vec{u} \cdot \nabla)\vec{u} = -\nabla p + \frac{\vec{J}}{c} \wedge \vec{B}$
- Faraday law: $\partial_t \vec{B} = \nabla \wedge (\vec{u} \wedge \vec{B})$
- First law of thermodynamics: $\partial_t p + \vec{u} \cdot \nabla p + \Gamma p \nabla \cdot \vec{u} = 0$

Particles: ensemble of relativistic particles, following the fluid streamlines:

$$\frac{d\vec{x_k}}{dt} = \vec{u}$$

Cosmic ray transport equation

To each macro-particle k we associate a time-dependent energy distribution function $N_k(E, \tau)$. Evolution of the energy is described by the equation below:

$$\frac{dN}{d\tau} + \frac{\partial}{\partial E}[(-\frac{E}{3}\nabla_\mu u^\mu + \dot{E}_l)N] = -N\nabla_\mu u^\mu$$

- Adiabatic gain/loss term
- Radiative loss term (sync and IC)
- Fluid compression term
- Additional gain term is given by diffursive shock acceleration (DSA)

We initialize each macro-particle as a power law in a log scale:

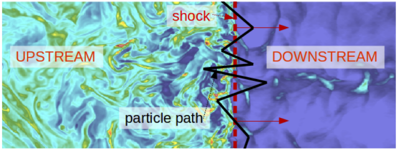
$$N_k(E, 0) \propto E^{-p}$$

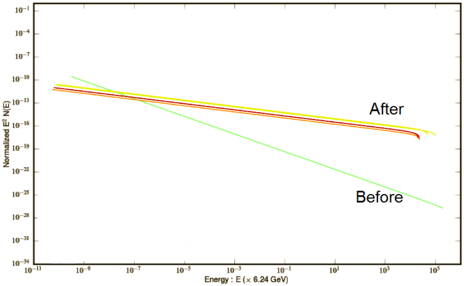
Diffusive shock acceleration (DSA)

Also known as Fermi I order mechanism, non-thermal particles can be accelerated by being repeatedly scattered across a shock wave.
The outcoming energy spectrum turns in a power-low, depending on:

- Strength of magnetized shock: compression ratio $r = \dfrac{\rho_d}{\rho_u}$.
- Topology of the $\vec{B}$ field.

The particles distribution index p is related to the compression ratio: $p = \dfrac{3r}{r-1}$.





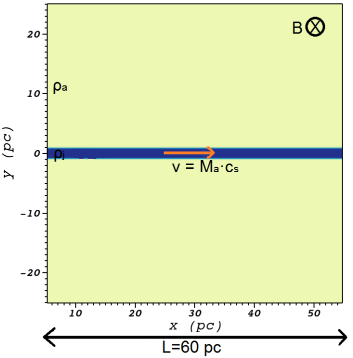
Introduction to PLUTO Code

- Developed at Torino University by A. Mignone and Co.: `http://plutocode.ph.unito.it/index.html`
- Finite-volume code designed to integrate systems of partial differential equations (conservation laws).
- Can solve different systems of conservation laws. The four basic physics modules are: HD, MHD, RHD, RMHD.
- PLUTO adopts a structured mesh approach: flow quantities are discretized on a logically rectangular computational grid enclosed by a boundary.

We consider 2D (Cartesian) periodic slab jet. We do various simulations by changing jet parameters:

- Jet/ambient density ratio: $\eta = \dfrac{\rho_j}{\rho_a}$
- Gas/magnetic pres. ratio: $\beta = \dfrac{p_t}{p_m}$
- Mach number: $M_a = \dfrac{v}{c_s}$

Resolution: [384, 226]

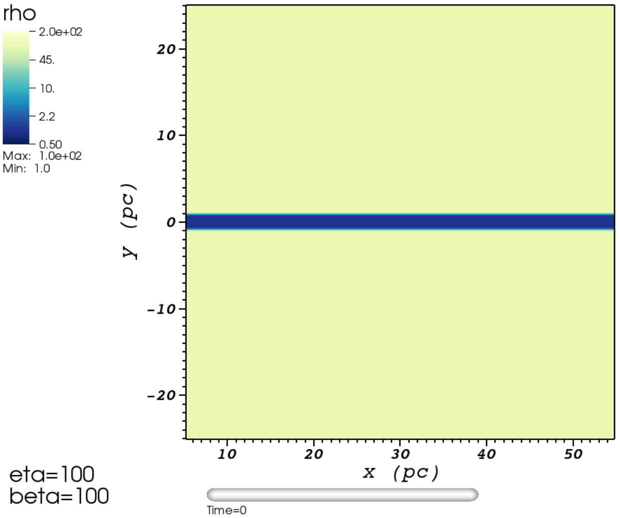


Introduce units:

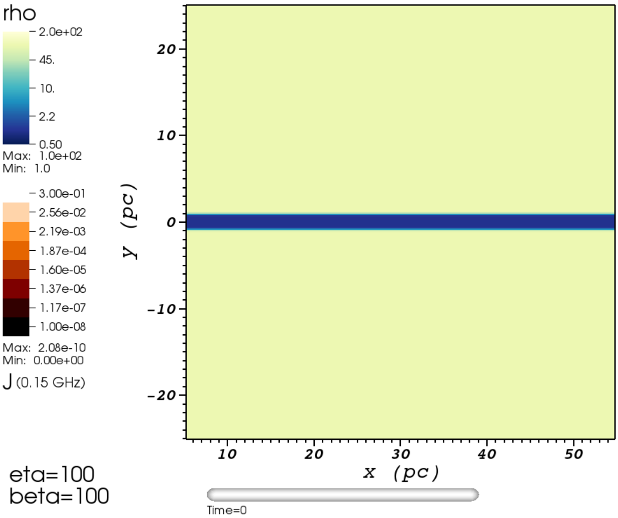
- Density: $\rho_0 = 1.66 \cdot 10^{-28}\ g\ cm^{-3}$
- Length: $L_0 = 3.08 \cdot 10^{18}\ cm$
- Velocity: $v_0 = 4.0 \cdot 10^{8}\ cm\ s^{-1}$

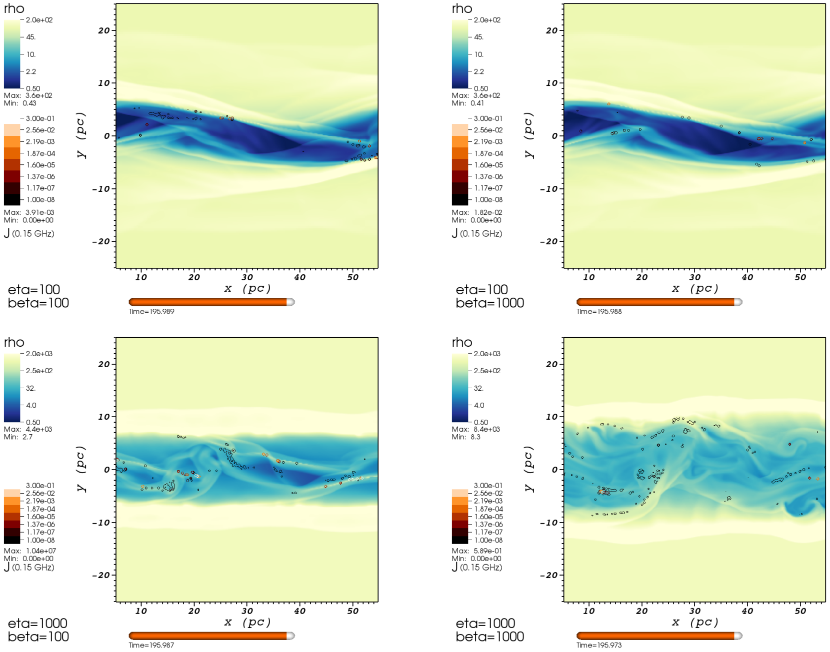
η	β
100	100
100	1000
1000	100
1000	100

Slab jet dynamics: KH instability



Slab jet emission




rho
2.0e+02
45.
10.
2.2
0.50
Max: 3.6e+02
Min: 0.43
3.00e-01
2.56e-02
2.19e-03
1.87e-04
1.60e-05
1.37e-06
1.17e-07
1.00e-08
Max: 3.91e-03
Min: 0.00e+00
J (0.15 GHz)
eta=100
beta=100
Time=195.989
rho
2.0e+02
45.
10.
2.2
0.50
Max: 3.6e+02
Min: 0.41
3.00e-01
2.56e-02
2.19e-03
1.87e-04
1.60e-05
1.37e-06
1.17e-07
1.00e-08
Max: 1.82e-02
Min: 0.00e+00
J (0.15 GHz)
eta=100
beta=1000
Time=195.988
rho
2.0e+03
2.5e+02
32.
4.0
0.50
Max: 4.4e+03
Min: 2.7
3.00e-01
2.56e-02
2.19e-03
1.87e-04
1.60e-05
1.37e-06
1.17e-07
1.00e-08
Max: 1.04e+07
Min: 0.00e+00
J (0.15 GHz)
eta=1000
beta=100
Time=195.987
rho
2.0e+03
2.5e+02
32.
4.0
0.50
Max: 8.4e+03
Min: 8.3
3.00e-01
2.56e-02
2.19e-03
1.87e-04
1.60e-05
1.37e-06
1.17e-07
1.00e-08
Max: 5.89e-01
Min: 0.00e+00
J (0.15 GHz)
eta=1000
beta=1000
Time=195.973
y (pc)
x (pc)
20
10
0
-10
-20
10
20
30
40
50

Conclusions

Sim. value	$J\ [Jansky\ cm^{-1}]$
$\eta = 100, \beta = 100$	3.25
$\eta = 100, \beta = 1000$	0.87
$\eta = 1000, \beta = 100$	$1.6 \cdot 10^5$
$\eta = 1000, \beta = 1000$	$0.96 \cdot 10^2$

The results obtained are in accordance with the theory. From the simulations we see:

- Emissivity increases with the decrease of β (for larger $\vec{B}$).
- Emissivity is strongly enhanced as η increases.

Future perspectives:

- Real emission maps for direct comparison with emission in reality.
- Extend the study to relativistic case.
- Develope a 3D Jets.

References

[1] B. Vaidya, A. Mignone, G. Bodo, P. Rossi, and S. Massaglia
Hybrid Framework for Modelling Non-Thermal Emission from Relativistic Magnetised Flows 2017,

[2] B. Vaidya, A. Mignone, G. Bodo, and S. Massaglia
Journal of Physics: Conference series 719 (2016) 012023,

[3] A. Mignone, G. Bodo, S. Massaglia, T. Matsakos, O. tesileanu, C.Zanni, and A. Ferrari,
The Astrophysical Journal Supplements Series, 170:228-242, 2007 May

[4] J. H. Croston, M. J. Hardcastle, D. E. Harris, E. Belsole, M. Birkinshaw, and D. M. Worral
The Astrophysical Journal, 626:733-747, 2005 June 20,

[5] Rybicki, G. B., & Lightman, A. P. 1979, New York, Wiley-Interscience, 1979. 393 p.,

[6] Kembhavi, A. K., & Narlikar, J. V. 1999, Quasars and active galactic nuclei : an introduction /Ajit K. Kembhavi, Jayant V. Narlikar. Cambridge, U.K. : Cambridge University Press, c1999. ISBN 0521474779.,