3D simulations of Pulsar Bow Shock Nebulae

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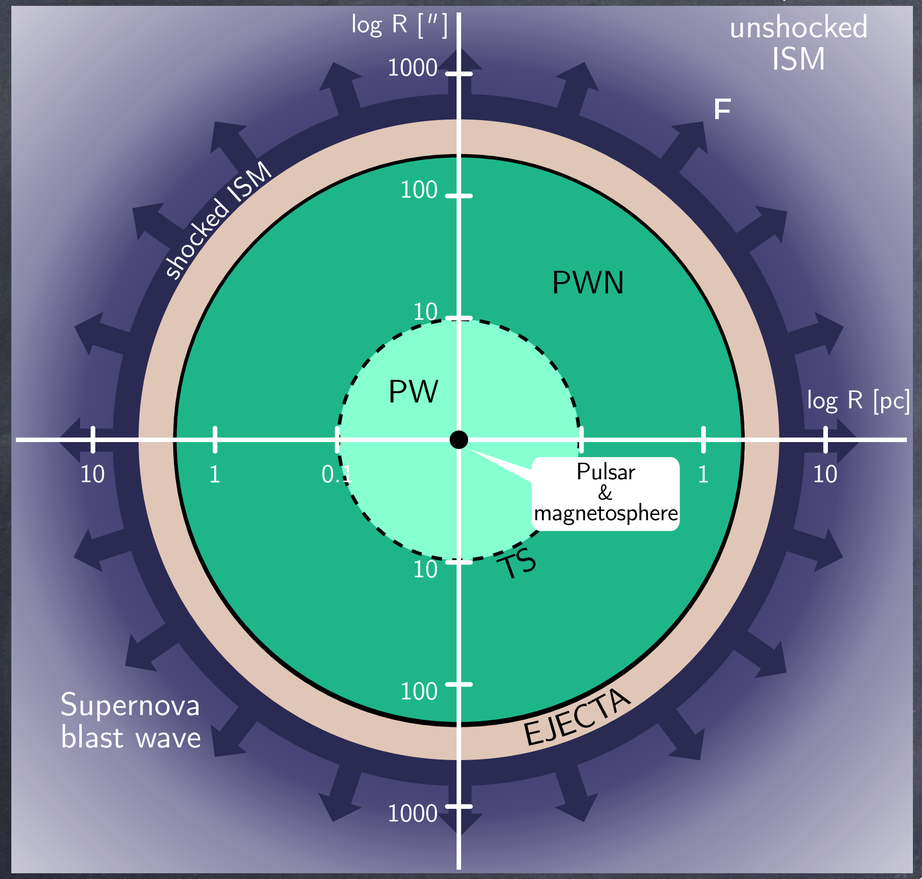
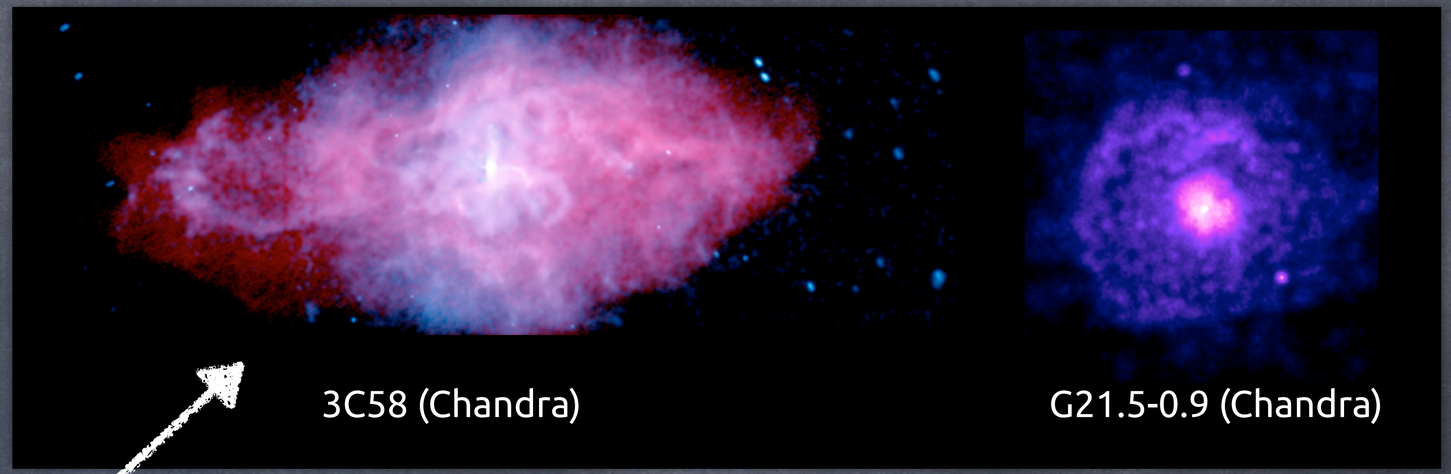
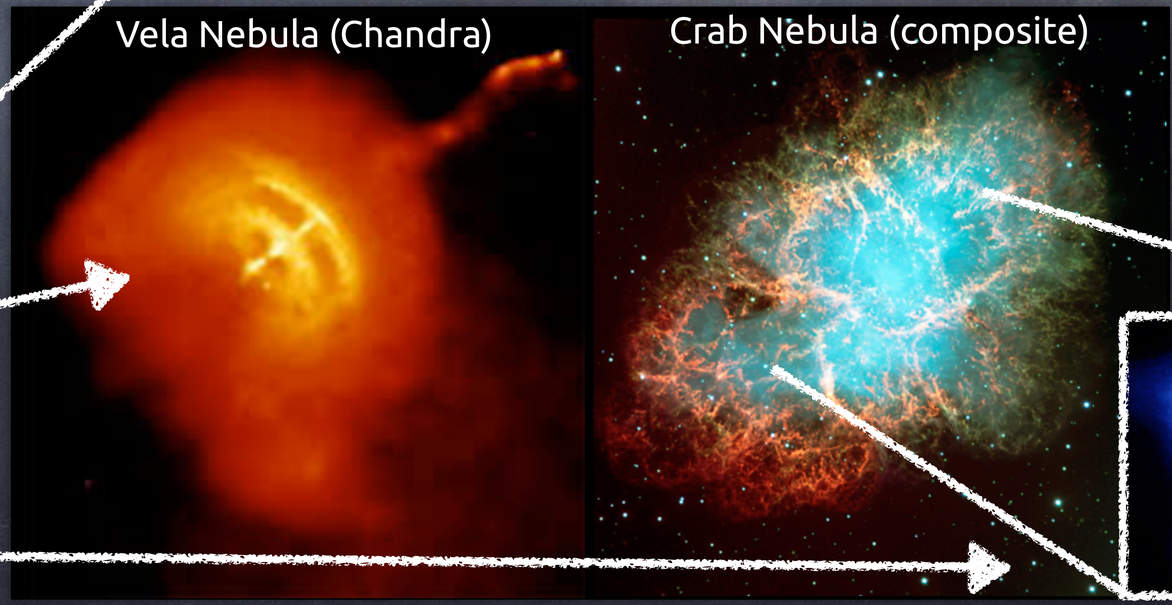
1st Science Symposium

Standard picture of Pulsar Wind Nebulae



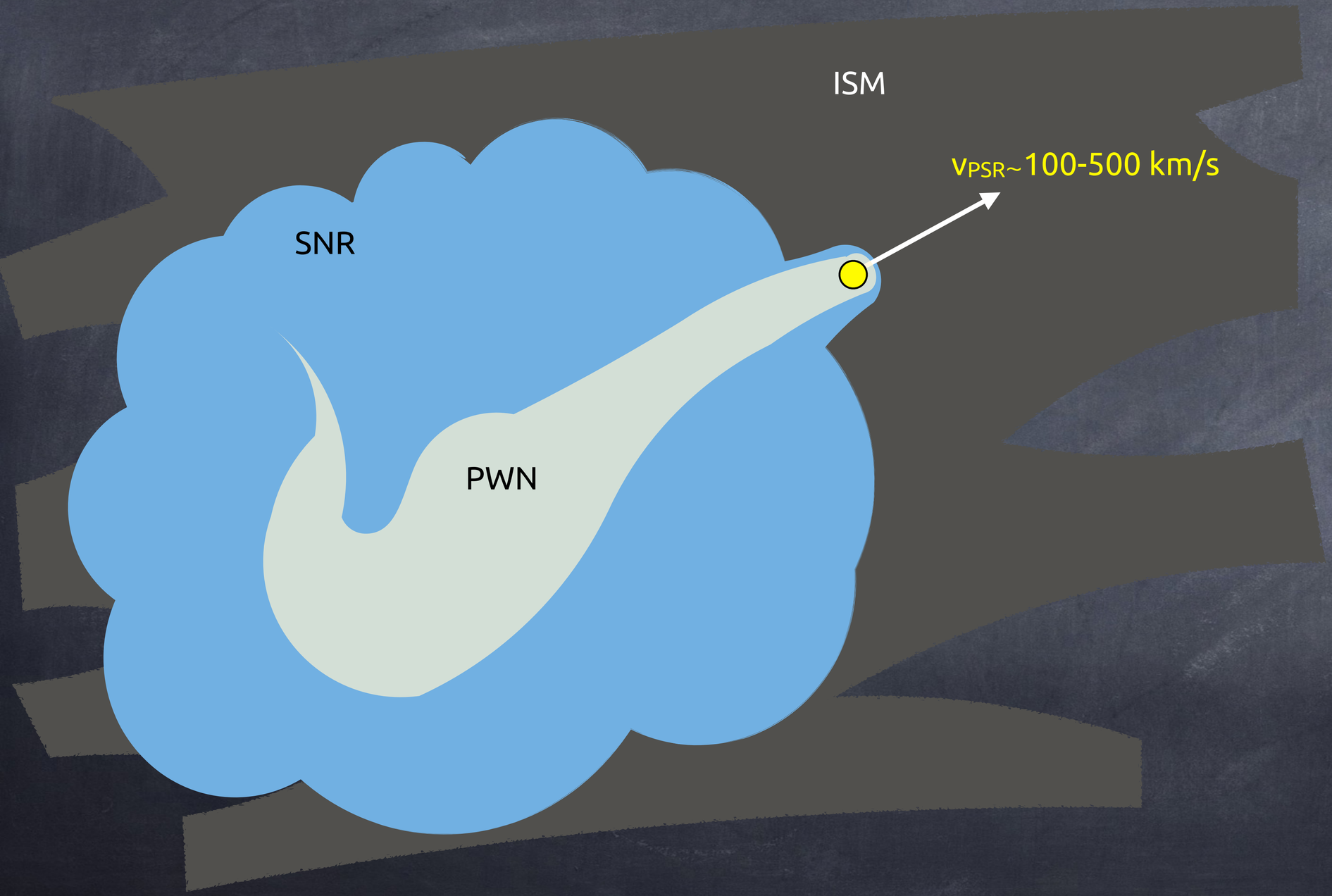
[Del Zanna & Olmi 2017]





- Emission dominated by non-thermal processes with fill centered morphology
- Broad band spectra
- Jet-torus morphology at high energy

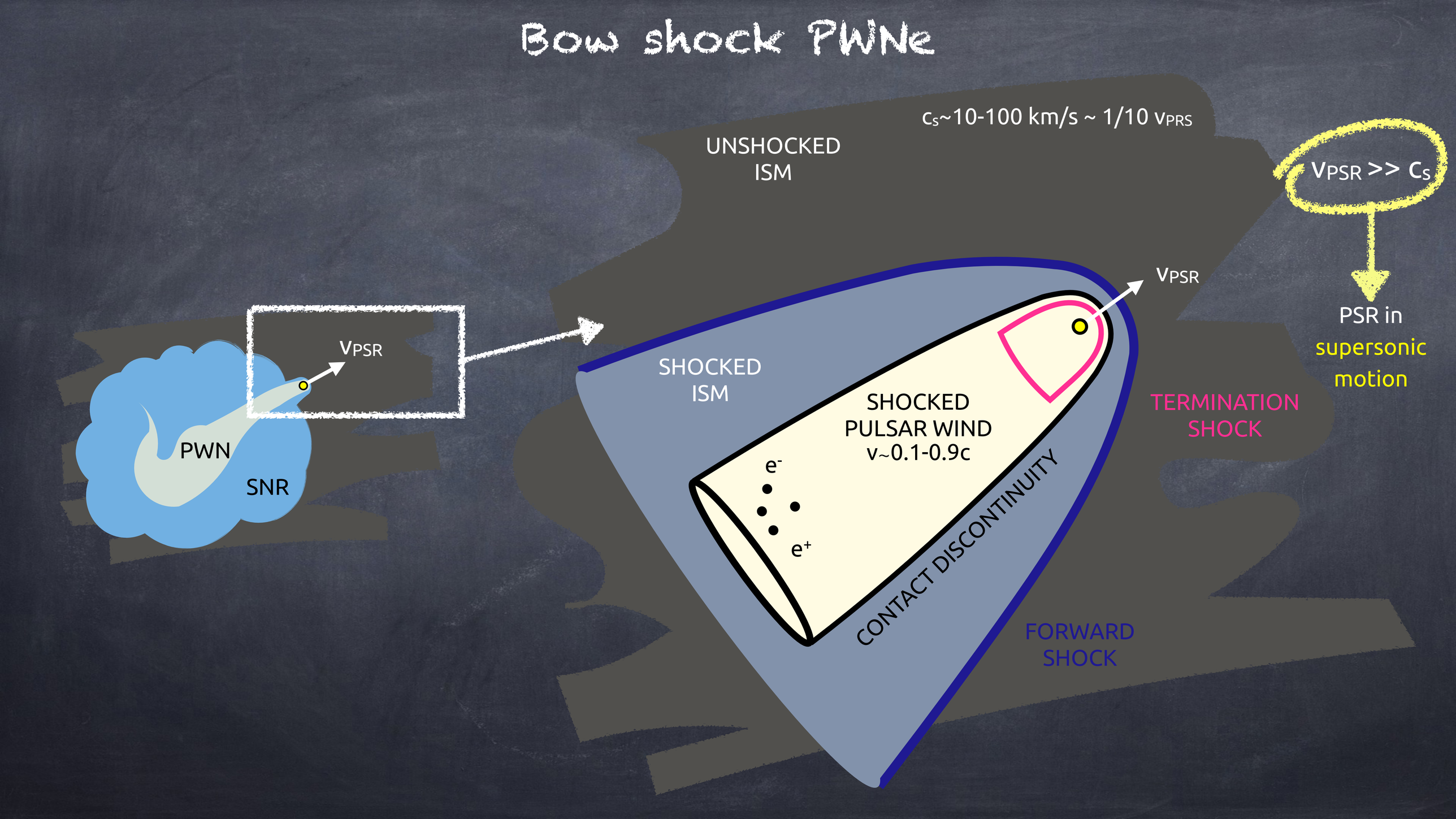
Bow shock PWNe



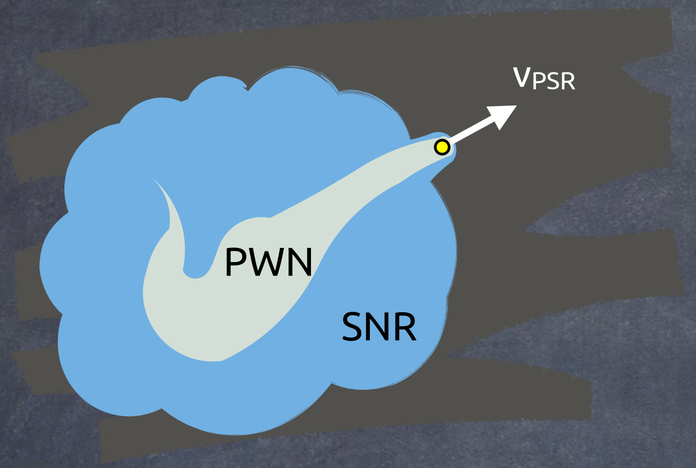
Large fraction of all the pulsars born with high kick velocity (10%-50%)

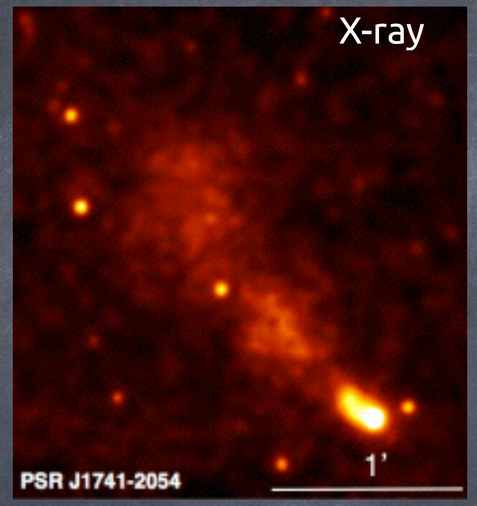
fated to escape the SNR on timescales << than typical pulsar ages (~10^6 yr)

Bow shock PWNe

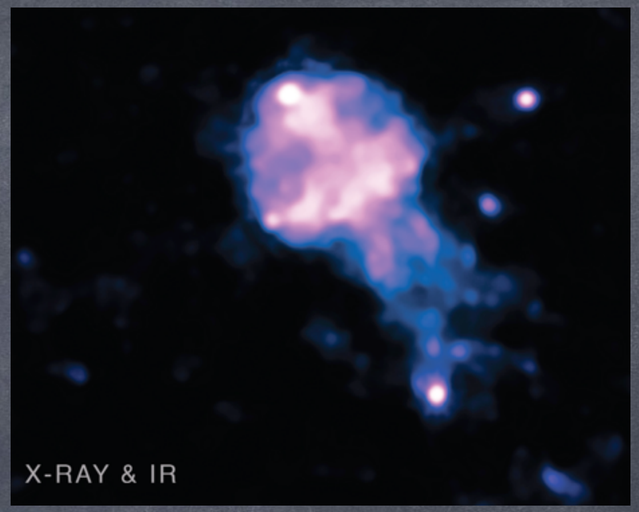


Bow shock PWNe: cometary shape

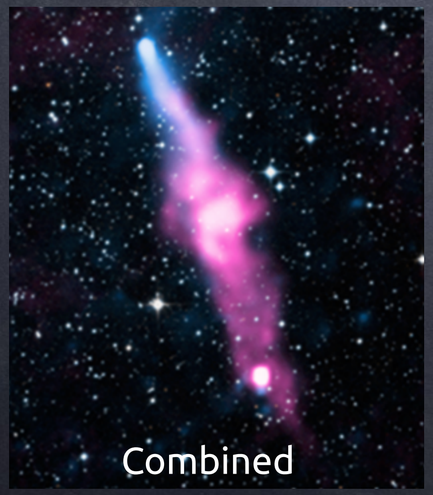


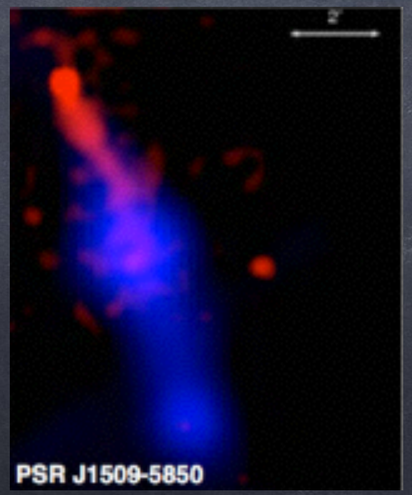


PSR J1741-2054
[Kargaltsev et al. 2016]

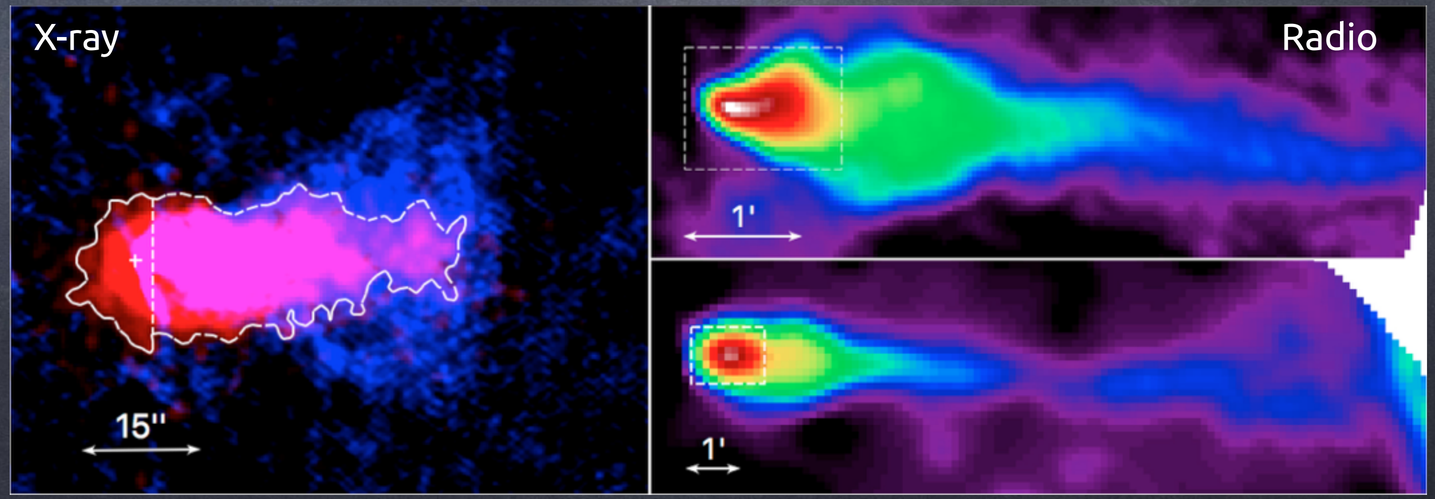


B0355+54
[Emre et al. 2005]



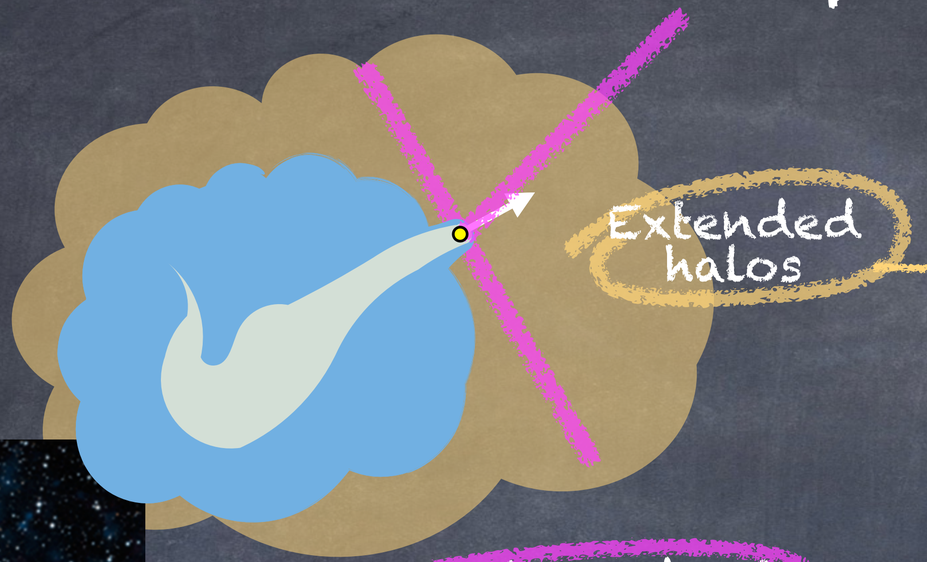


PSR J1509-5850
[Hui & Becker 2007, Klinger et al. 2016]

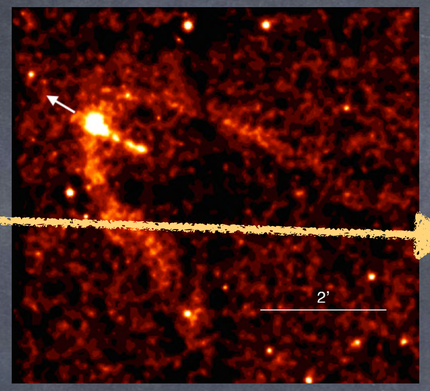


Mouse PWN
[Yusef-Zadeh & Bally 1987, Yusef-Zadeh & Ganesler 2005, Klinger et al. 2018]

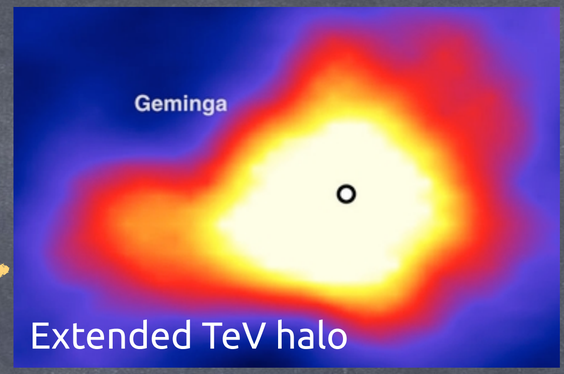
Bow shock PWNe: puzzling outflows and halos



X-ray

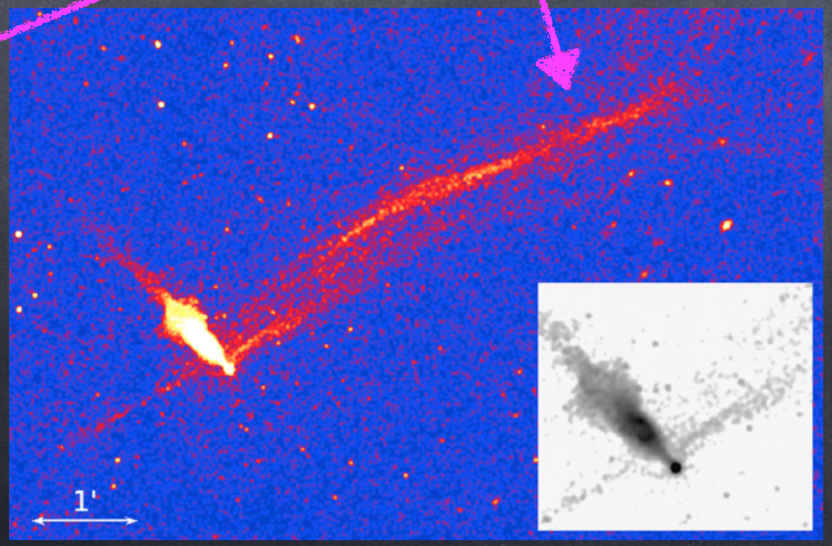


Geminga
[Posselt et al. 2017]

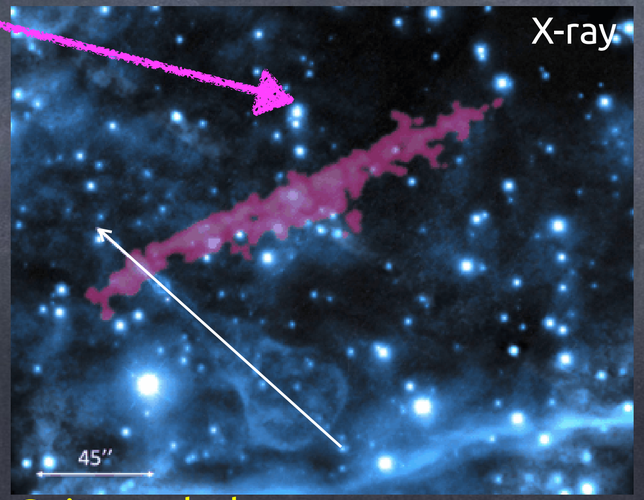


[Abeysekara et al. 2017]

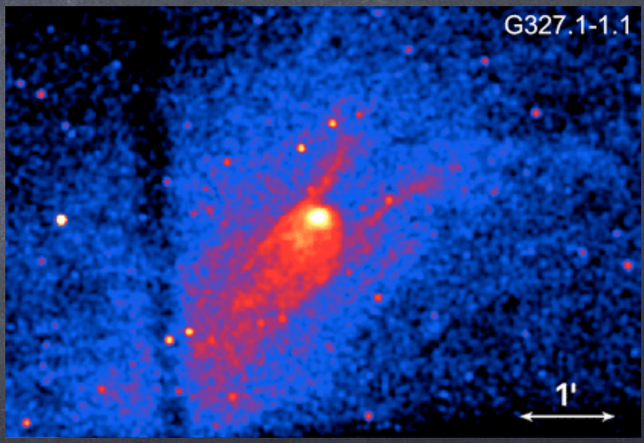
PSR J1509-5850
[Klinger et al. 2016]



Lighthouse nebula
[Pavan et al. 2016]



Guitar nebula
[Cordes et al. 1993, Wong et al. 2003]

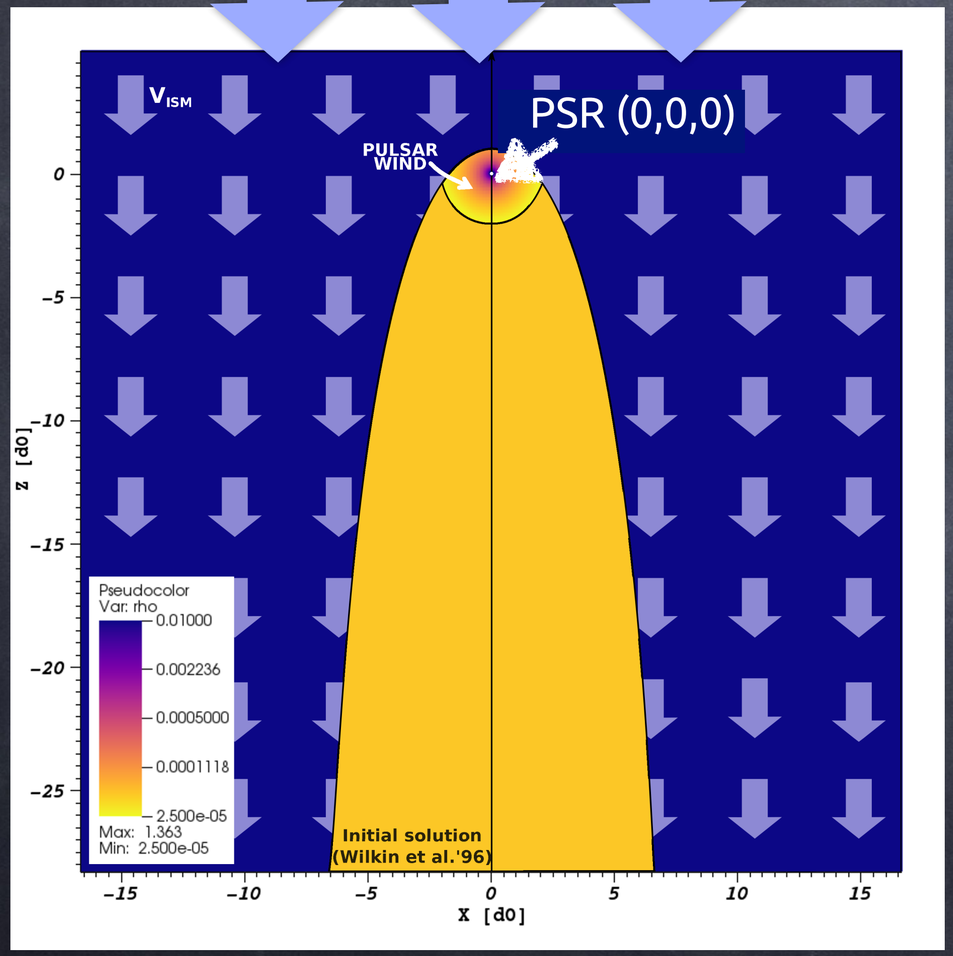


G327
[Temim et al. 2009]

Simulations overview

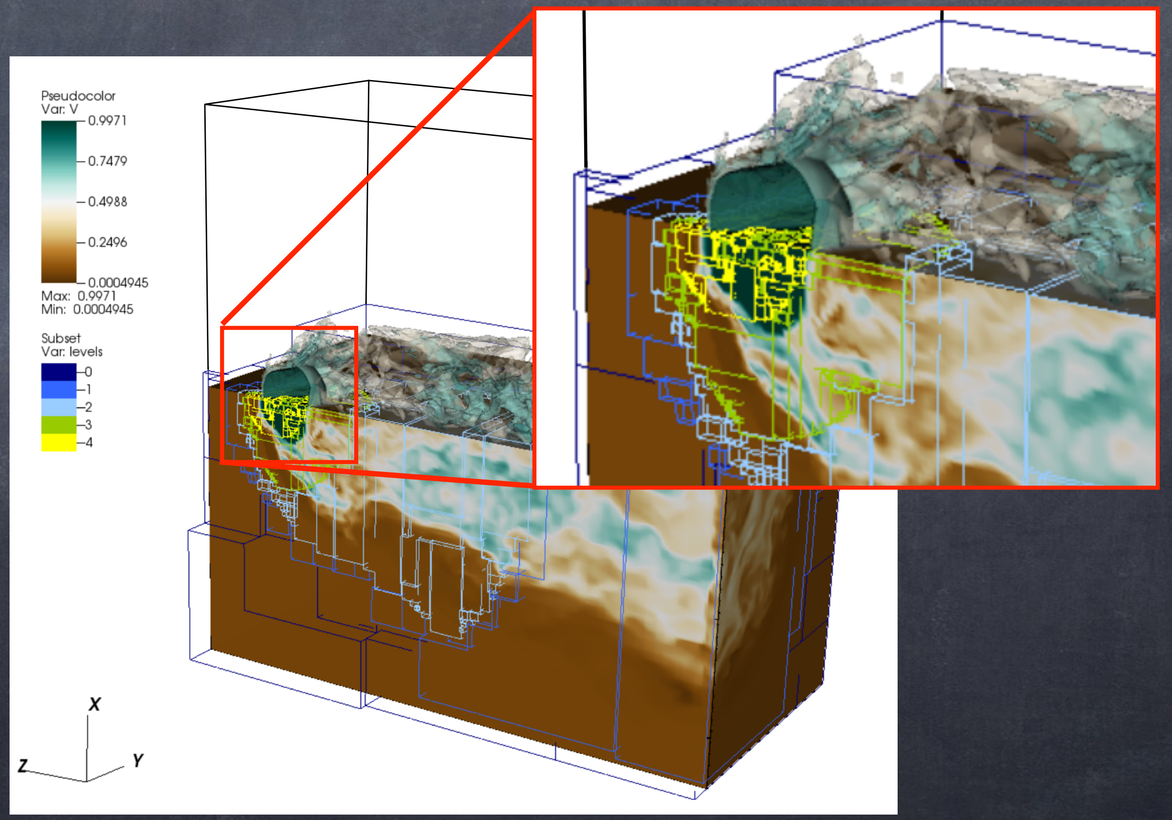
from Olmi & Bucciantini 2019

Uniform unmagnetized ISM V=-V_{PSR}



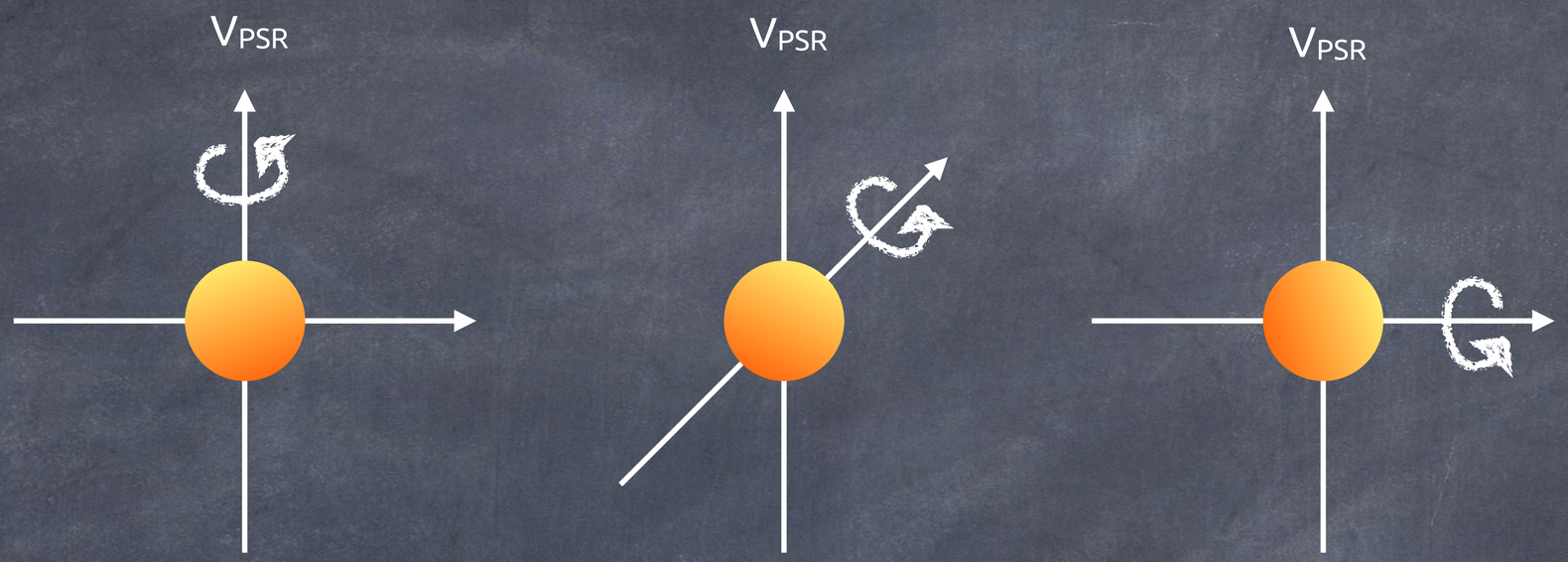
PLUTO code [Mignone et al. 2007]

High resolution to resolve the PW injection region and allow the TS to correctly detach from the inner boundary (AMR with 4 levels)



Model overview

Geometry →



Spin-axis aligned with pulsar motion
Φ_M=0°

Φ_M=45°

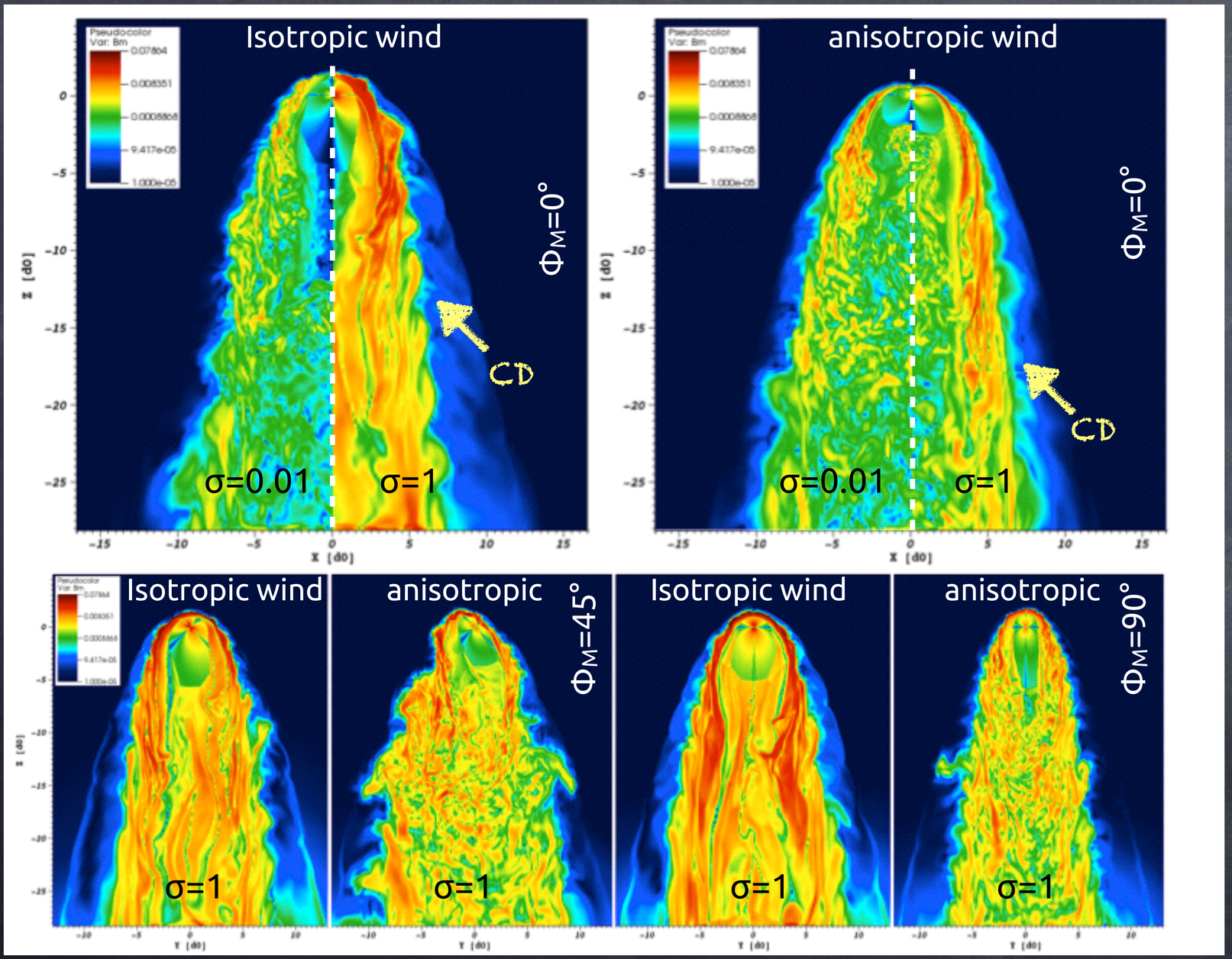
Φ_M=90°

Energy flux in the wind → ISOTROPIC (α=0) or ANISOTROPIC (α=10): $F(\psi) \propto 1 + \alpha \sin^2 \psi$

ψ colatitude from the spin-axis

Magnetization of the wind → σ=[0.01, 0.1, 1]

Main findings



Maps of the magnetic field for different geometries and magnetizations

PW model strongly affects the internal structure:

GEOMETRY (different inclinations)

↓

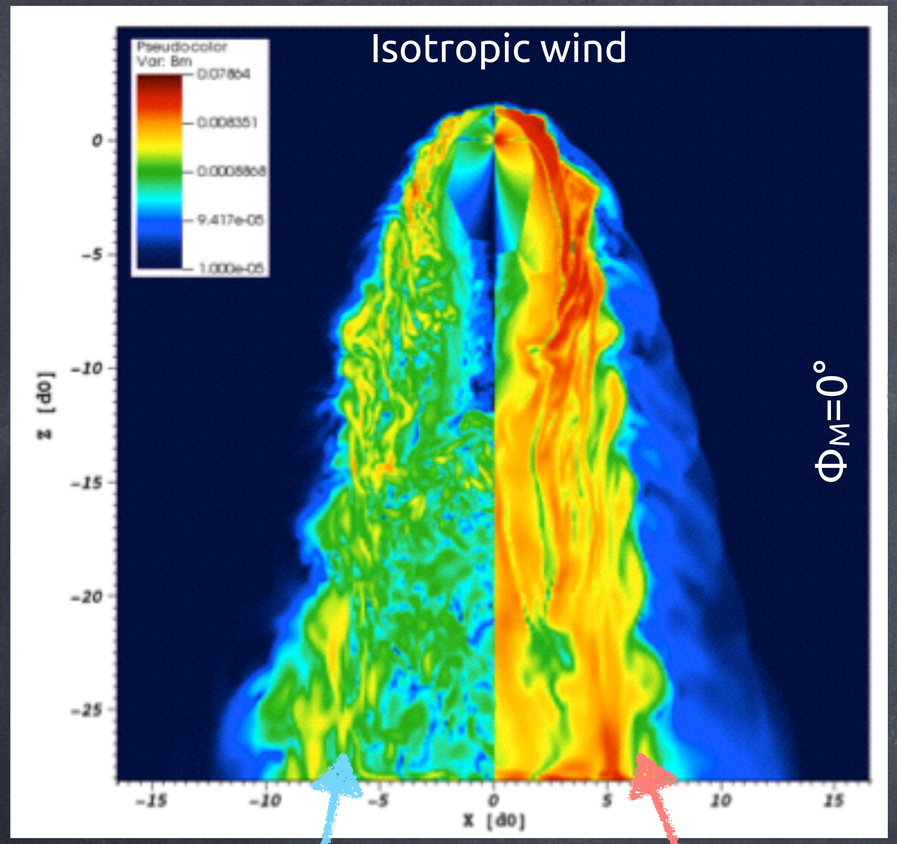
CD shape and extension

MAGNETIZATION + DISTRIBUTION OF THE ENERGY in the wind

↓

tail flow dynamics

Turbulence



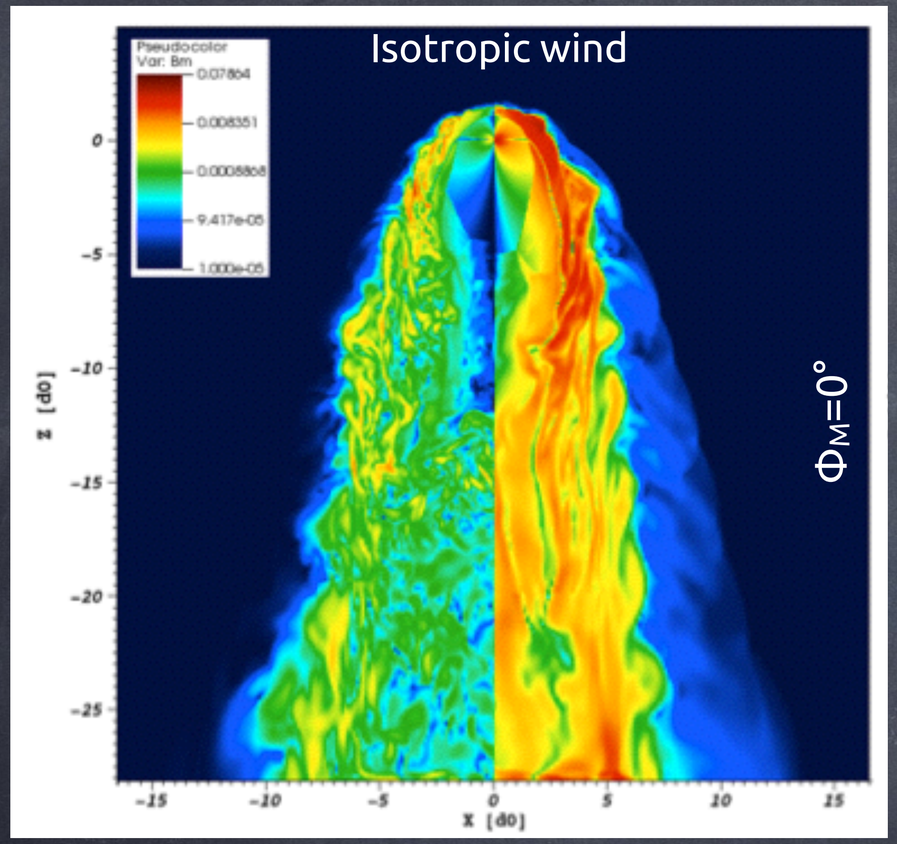
Low magnetization

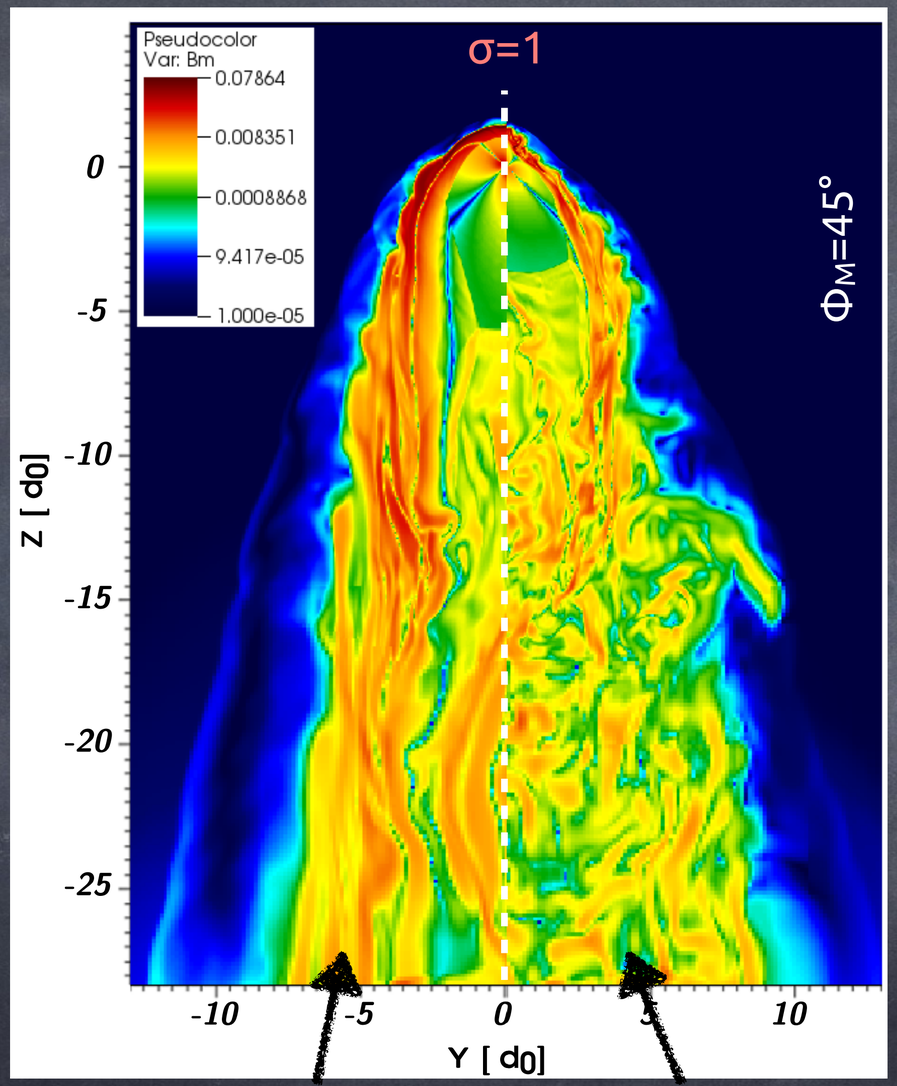
high level of turbulence,
chaotic flow

High magnetization

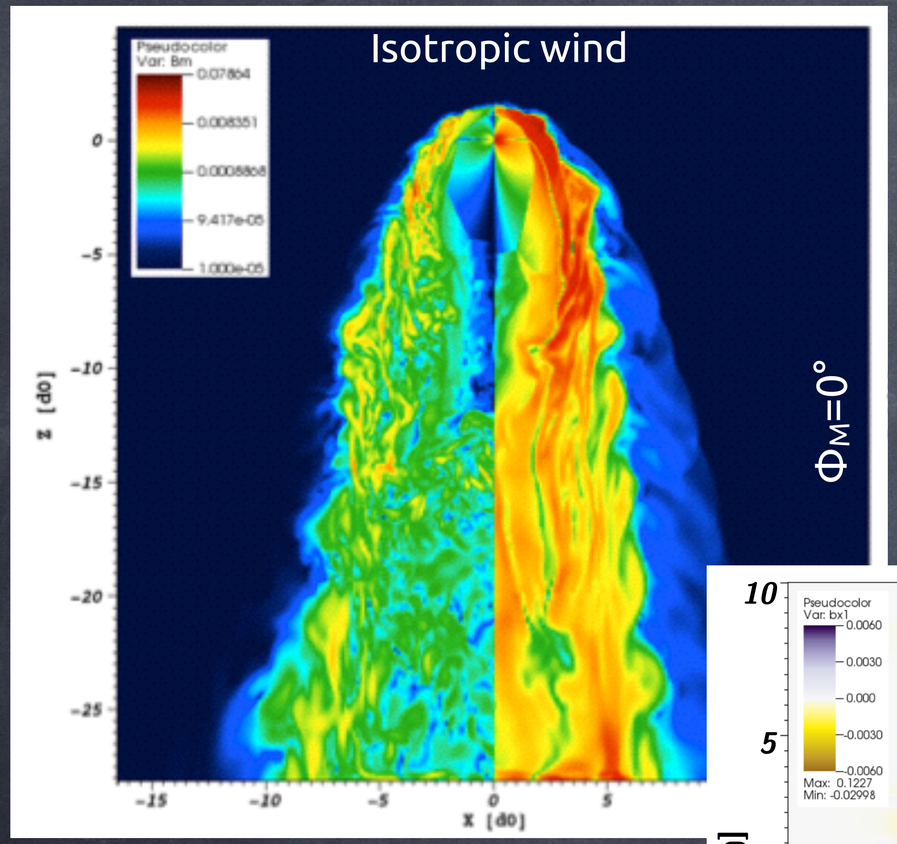
low level of turbulence,
flow almost laminar

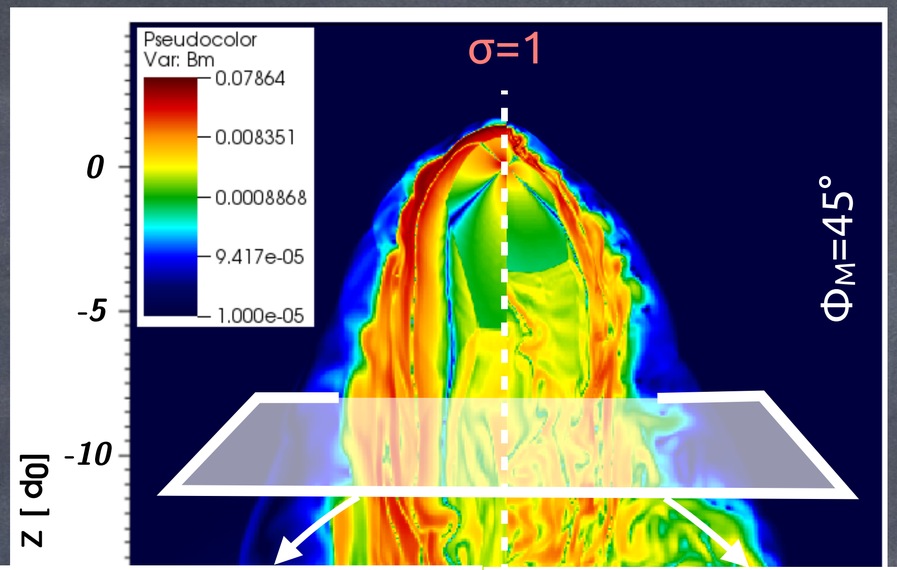
Turbulence

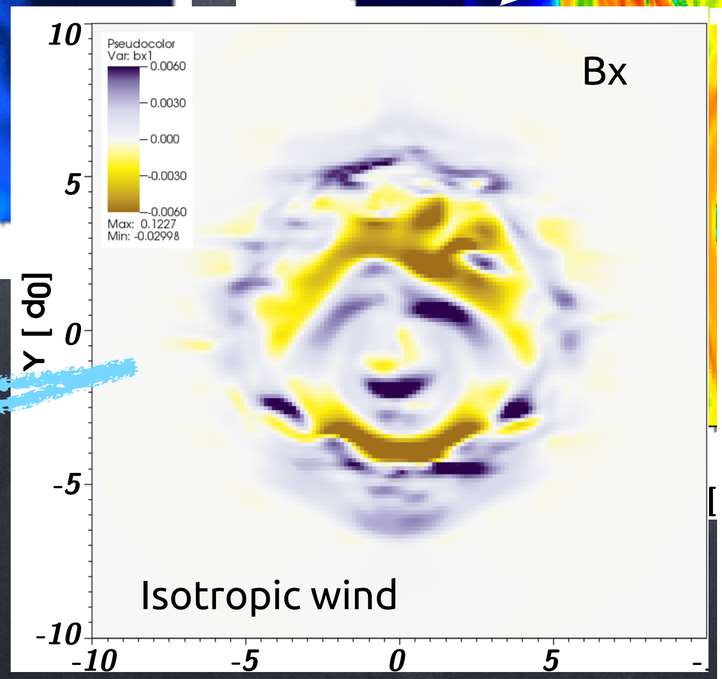

Isotropic wind
Pseudocolor
Var: Bm
0.07864
0.008351
0.0008868
9.417e-05
1.000e-05
ΦM=0°
z [d0]
X [d0]

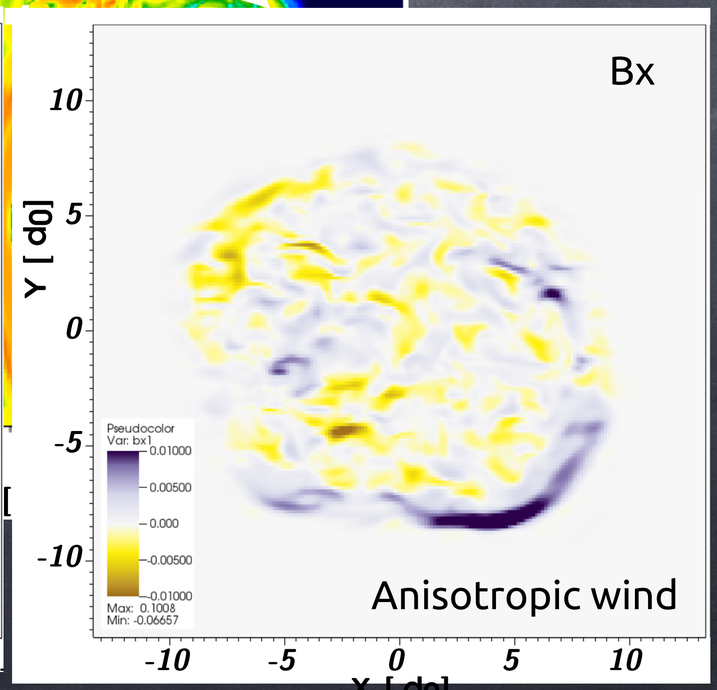

σ=1
Pseudocolor
Var: Bm
0.07864
0.008351
0.0008868
9.417e-05
1.000e-05
ΦM=45°
Z [d0]
Y [d0]
Isotropic wind
Anisotropic wind

Turbulence



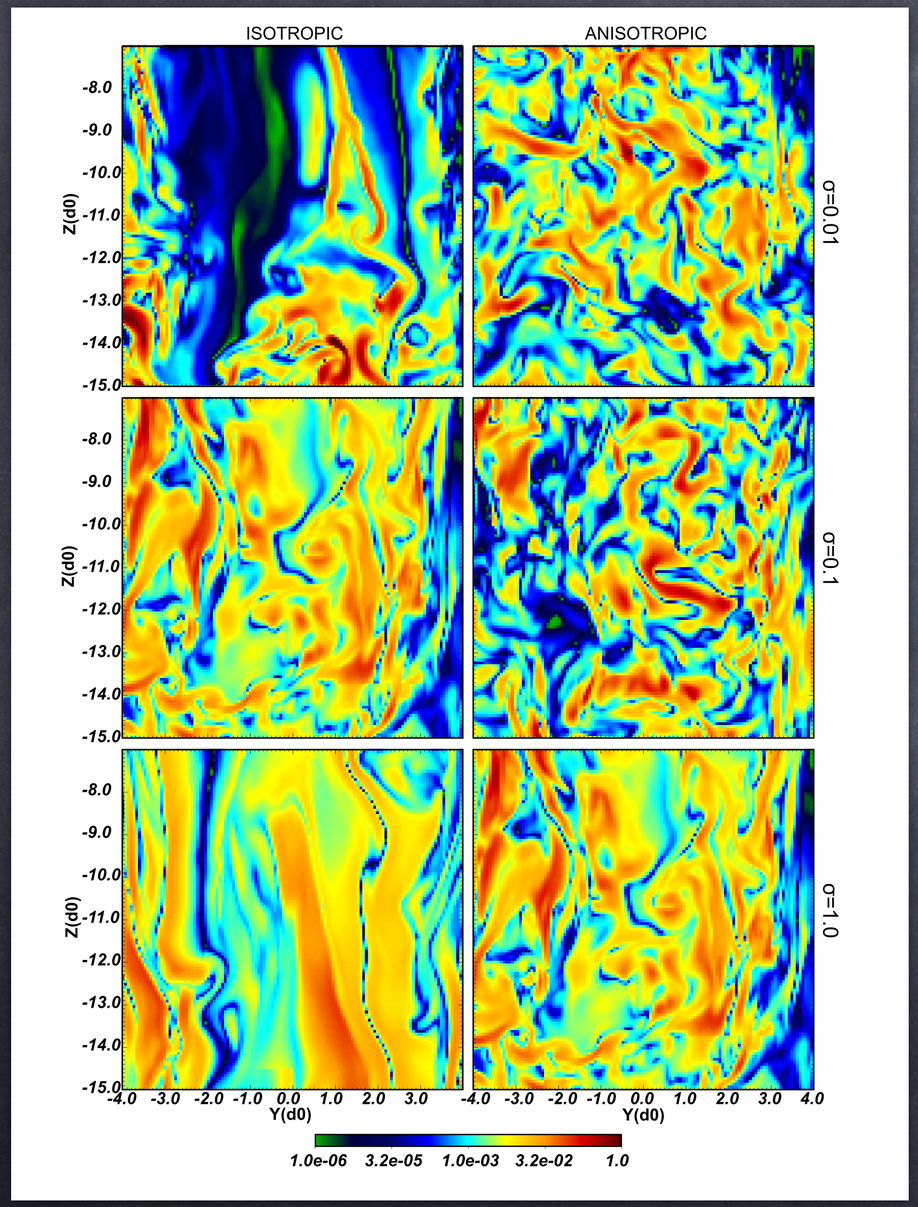






injection properties only maintained for isotropic models

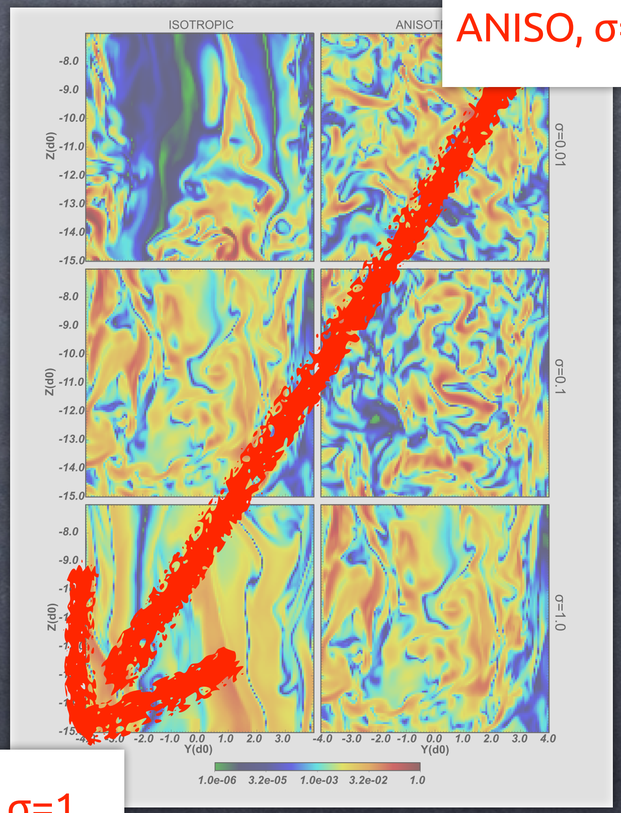
Level of Turbulence in the tail



Maps of the magnetization

HIGH TURBULENCE with complete loss of injection information

ANISO, σ=0.01



ISO, σ=1

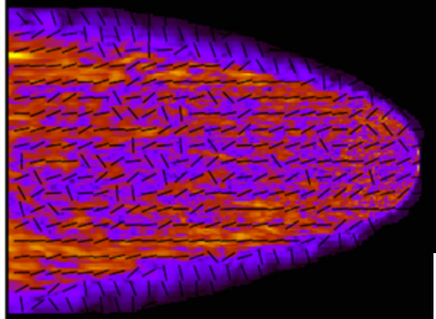
LOW TURBULENCE with injection information maintained and laminar flow

Consequences for emission

Olmi & Bucciantini 1 in prep

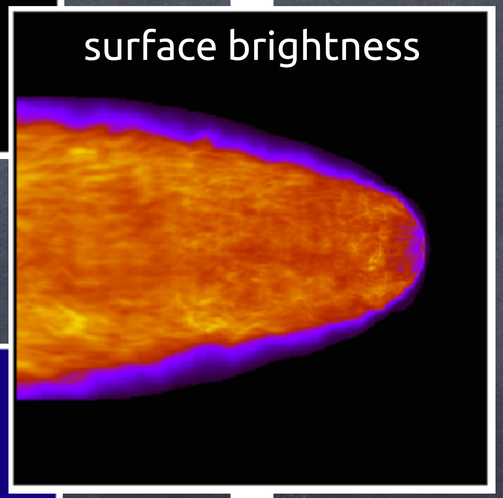
ANISOTROPIC σ=0.01

polarization vector

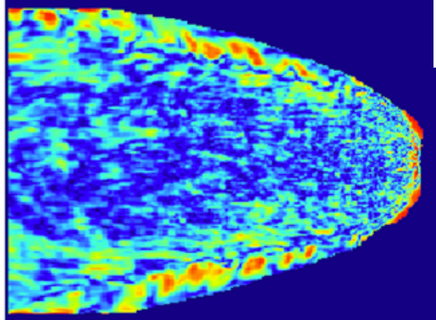


High level of turbulence

surface brightness



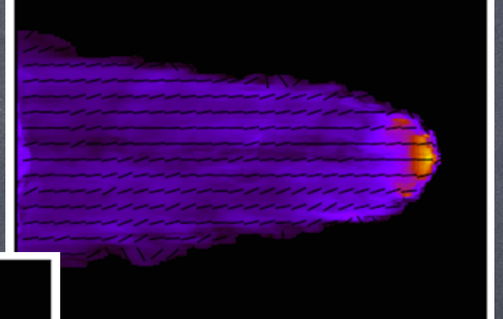
polarization level



Uniform emissivity.
Unpolarized

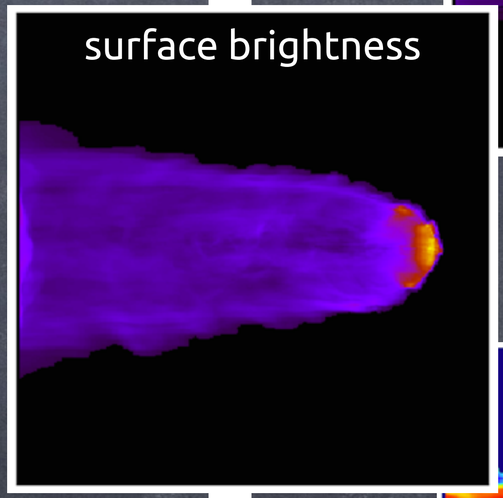
ISOTROPIC σ=1

polarization vector



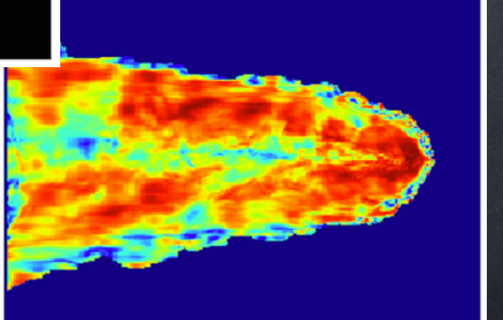
Low level of turbulence

surface brightness



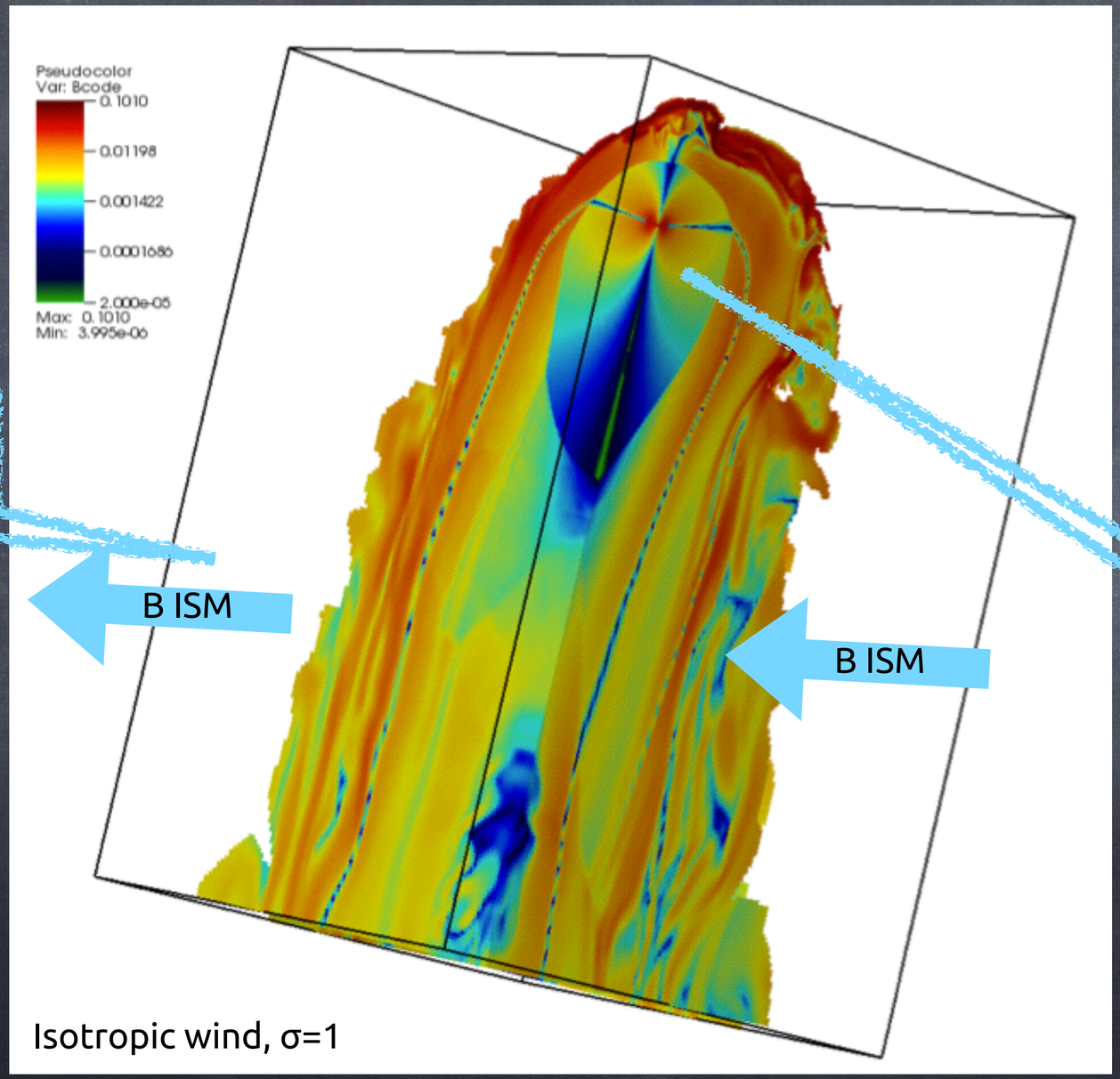
Emission dominated by the head.
Strong polarization.

polarization level



Escape of particles

Olmi & Bucciantini 2 in prep



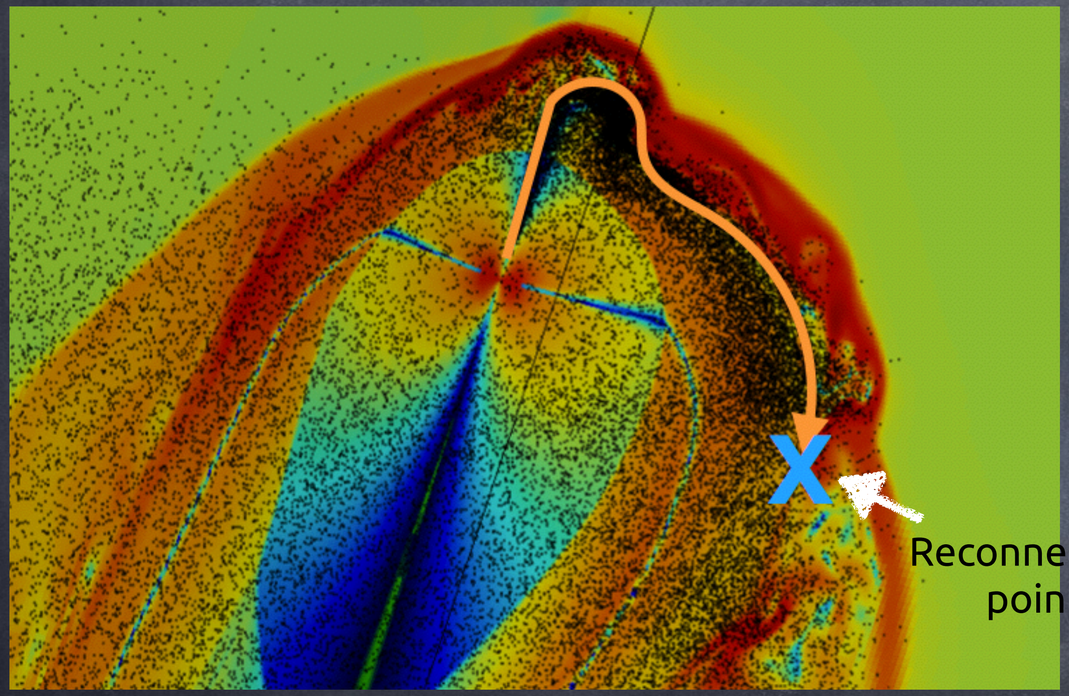
ISM magnetic field switched on

leptons with $\gamma=3\times10^7$ injected into the wind

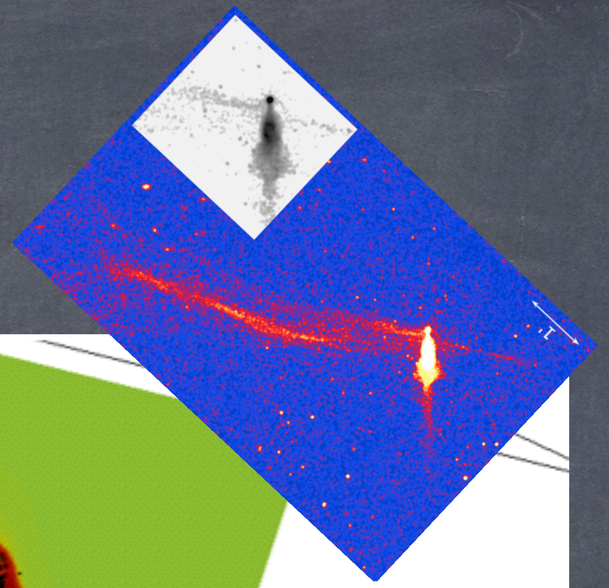
Escape of particles

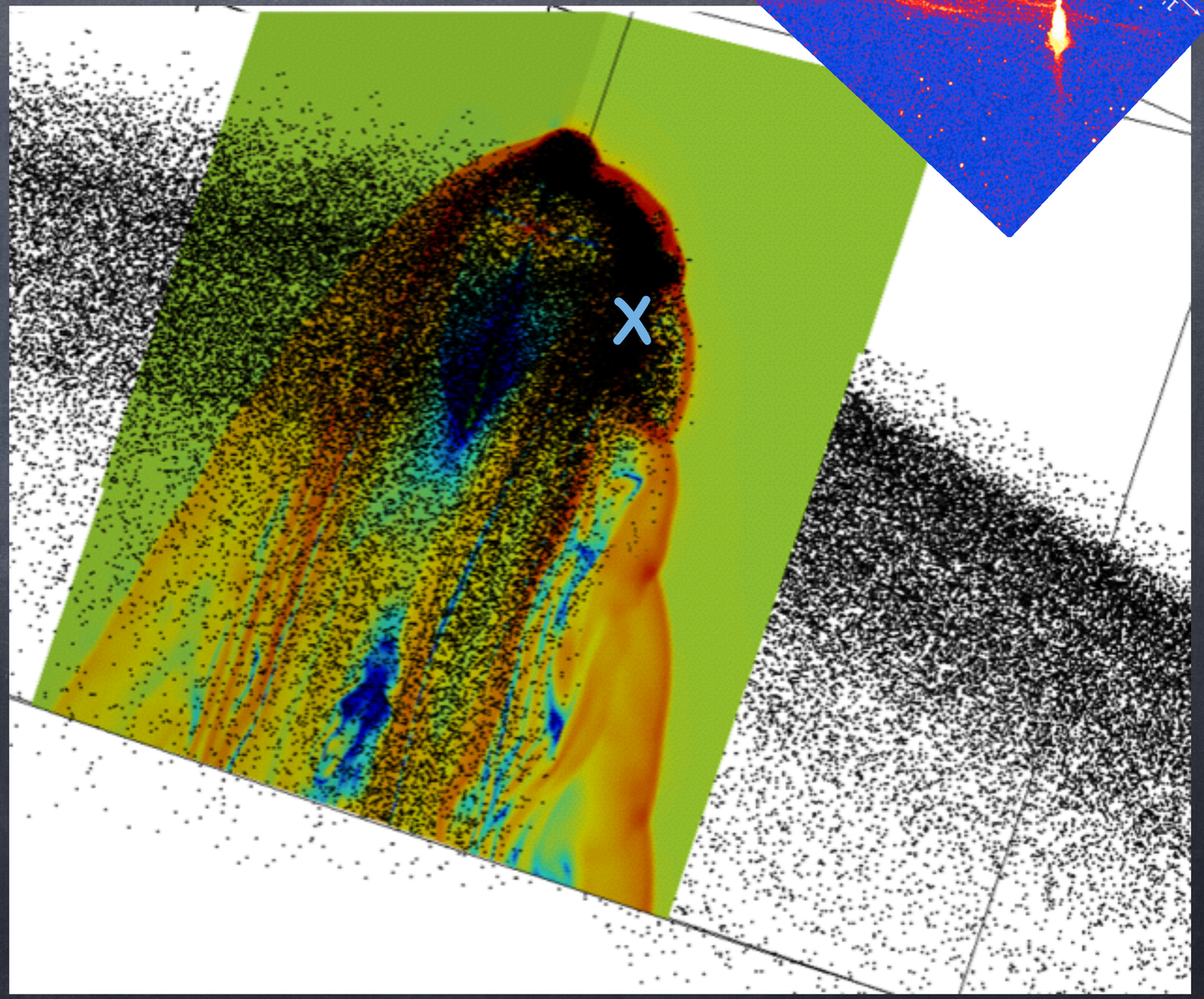
Olmi & Bucciantini 2 in prep

Particles in the polar flow are confined by the currents in the magnetopause layer.



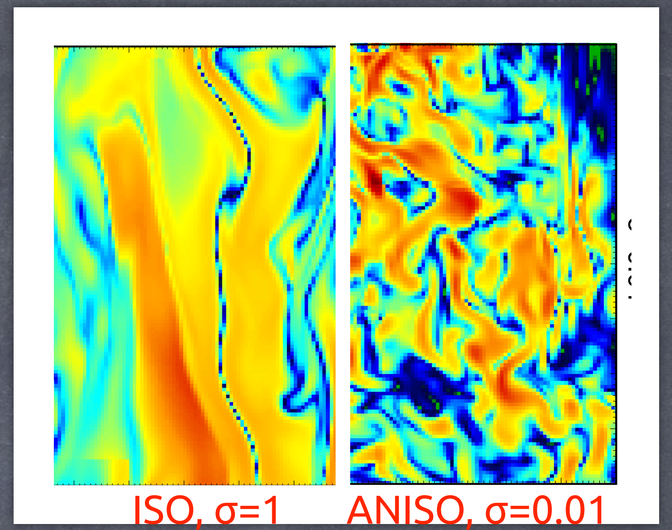
From the reconnection point particles stream out along the ISM magnetic field, forming jets (here symmetric since the wind is symmetric).



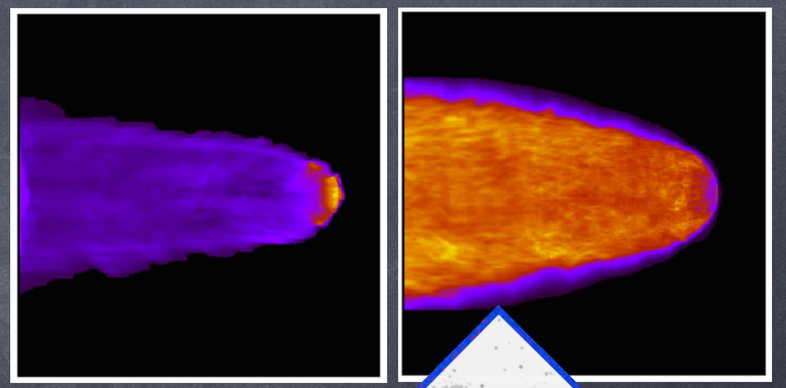


Conclusions:

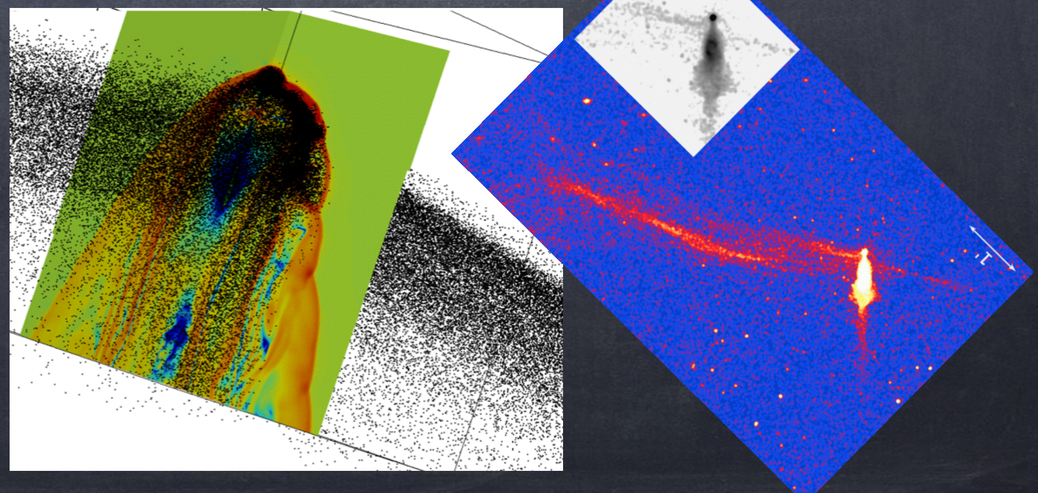
Turbulence strongly dependent on wind magnetization and energy isotropy



Affects the emission properties: synchrotron emissivity only depends on magnetic configuration for low turbulence



Escape of particles affected by the presence of current sheets.
Anisotropic jets can result from dynamics in the magnetopause.



Simulations supported by MoU INAF-CINECA class A projects