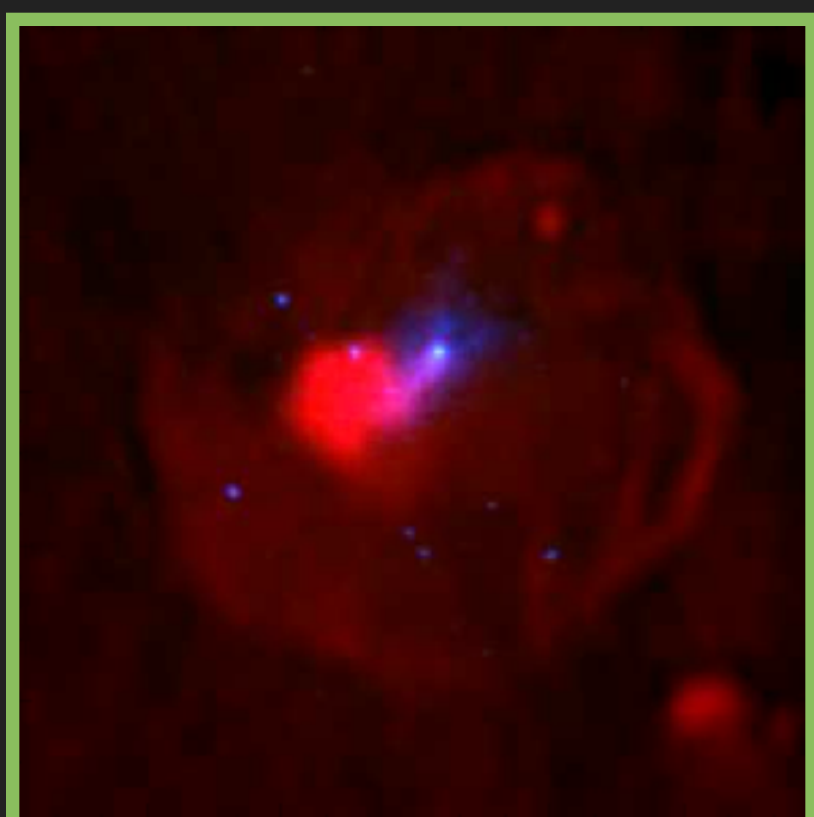
BOW SHOCK PULSARS WIND NEBULAE:
A TAIL OF TRAILS.

NICCOLO' BUCCIANTINI & BARBARA OLMI

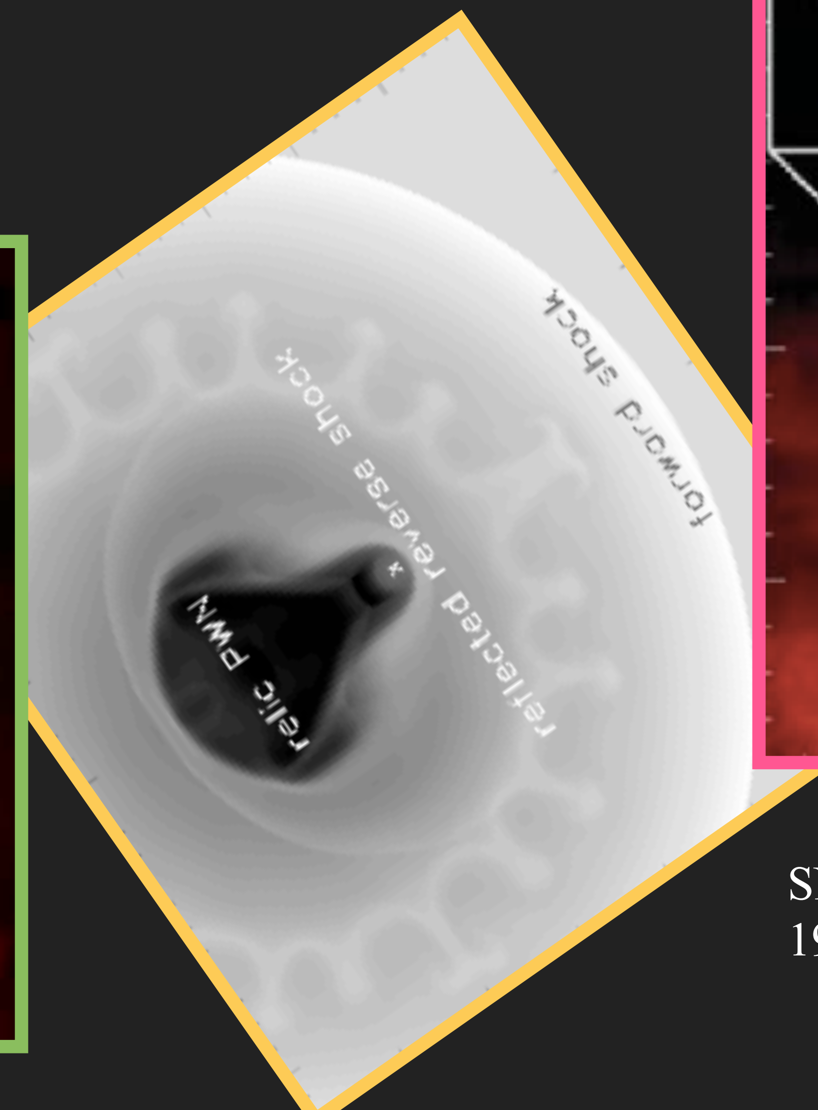
INAF ARCETRI - UNIV. FIRENZE - INFN

FATED TO ESCAPE

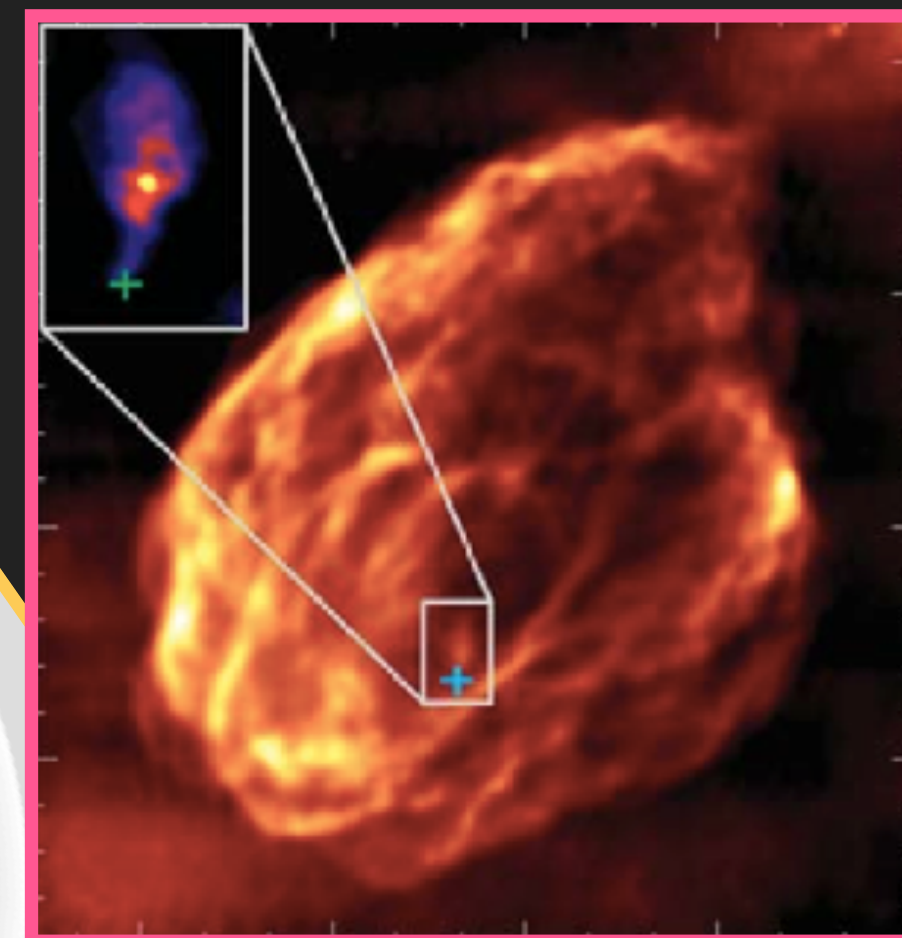
PWN EXPANDS INTO SHOCKED EJECTA
“RELIC” RADIO PWN LEFT BEHIND
NEW PWN AROUND PULSAR (X-RAY)



SNR G327.1-1.1, Gaensler & Slane 2006



van der Swaluw (2004)

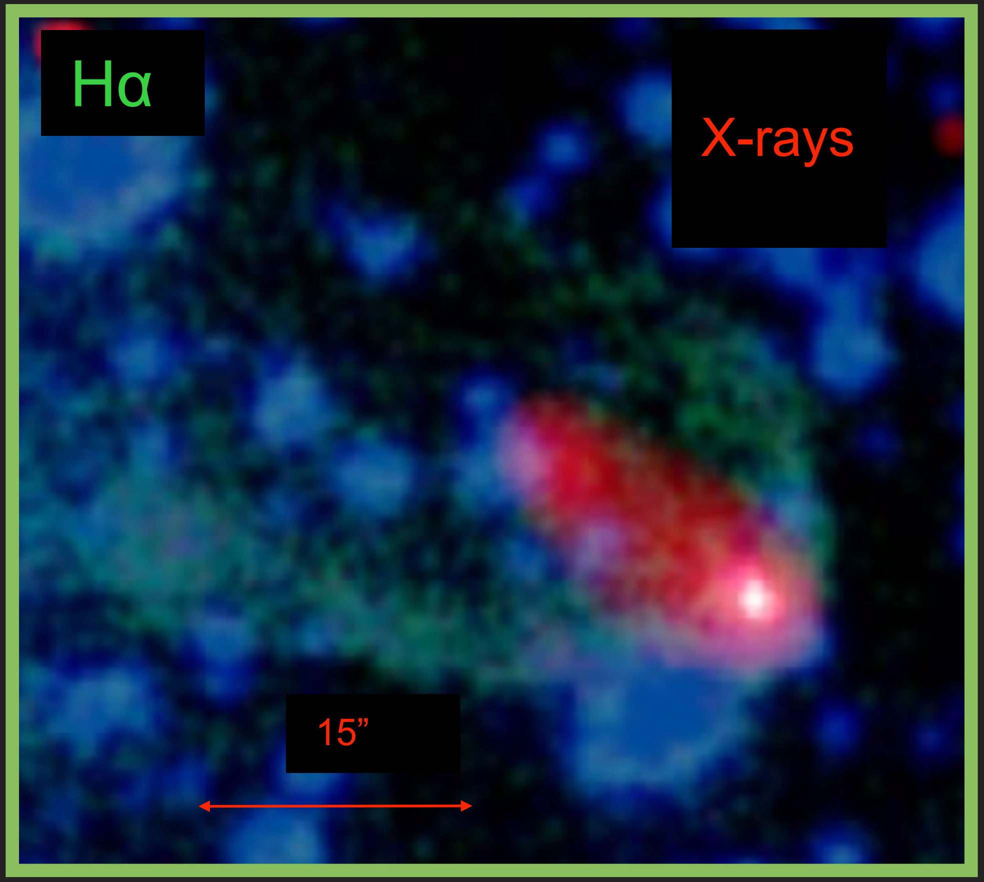


SNR W44 (Frail et al. 1996, Giacani et al. 1997)

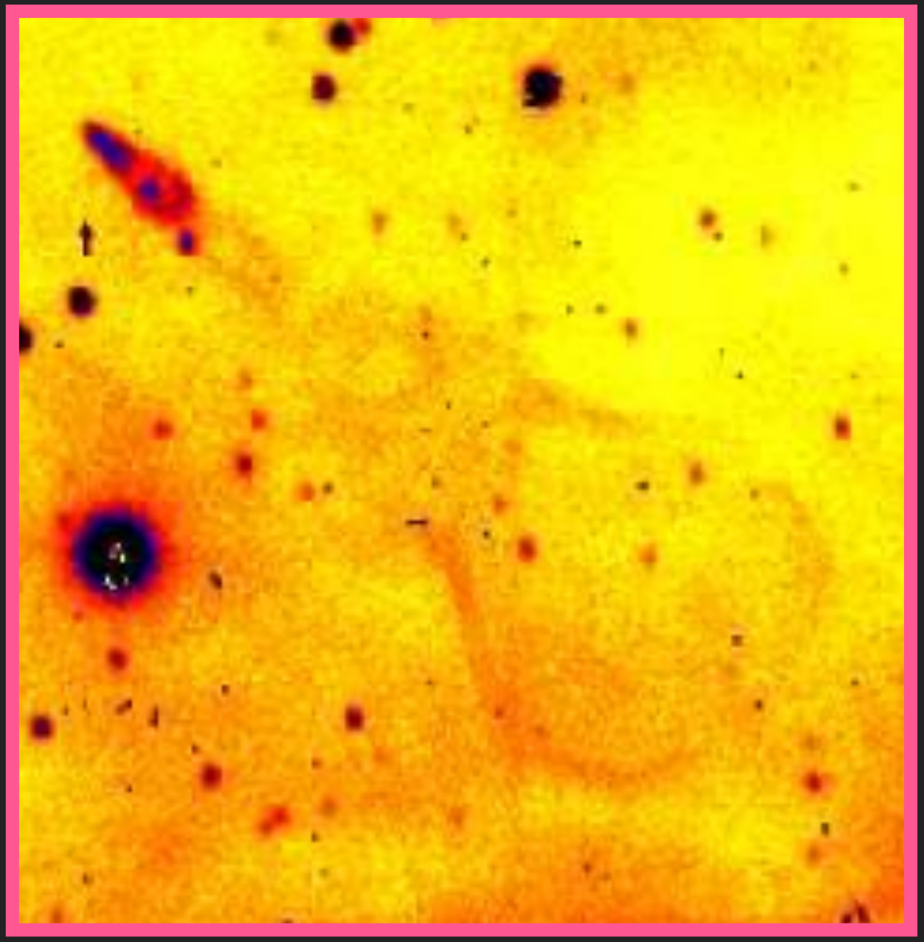
BOW SHOCK PWNE

$$t_{esc}V_{psr} = R_{snr} = \left(\frac{E_{sn}}{\rho_{ism}}\right)^{1/5} t_{esc}^{2/5}$$

$$\Rightarrow t_{esc} \approx \left(\frac{E_{sn}}{\rho_{ism}}\right)^{1/3} \left(\frac{1}{V_{psr}}\right)^{5/3} \approx 2\times 10^5\mathrm{yr}\left(\frac{E_{sn}}{10^{51}\mathrm{erg}}\right)^{1/3}\left(\frac{V_{psr}}{200\mathrm{km\ s^{-1}}}\right)^{5/3}\left(\frac{n_{ism}}{1\mathrm{cm^{-3}}}\right)^{-1/3}$$



PSR B1957+20 (Stappers et al. 2003)

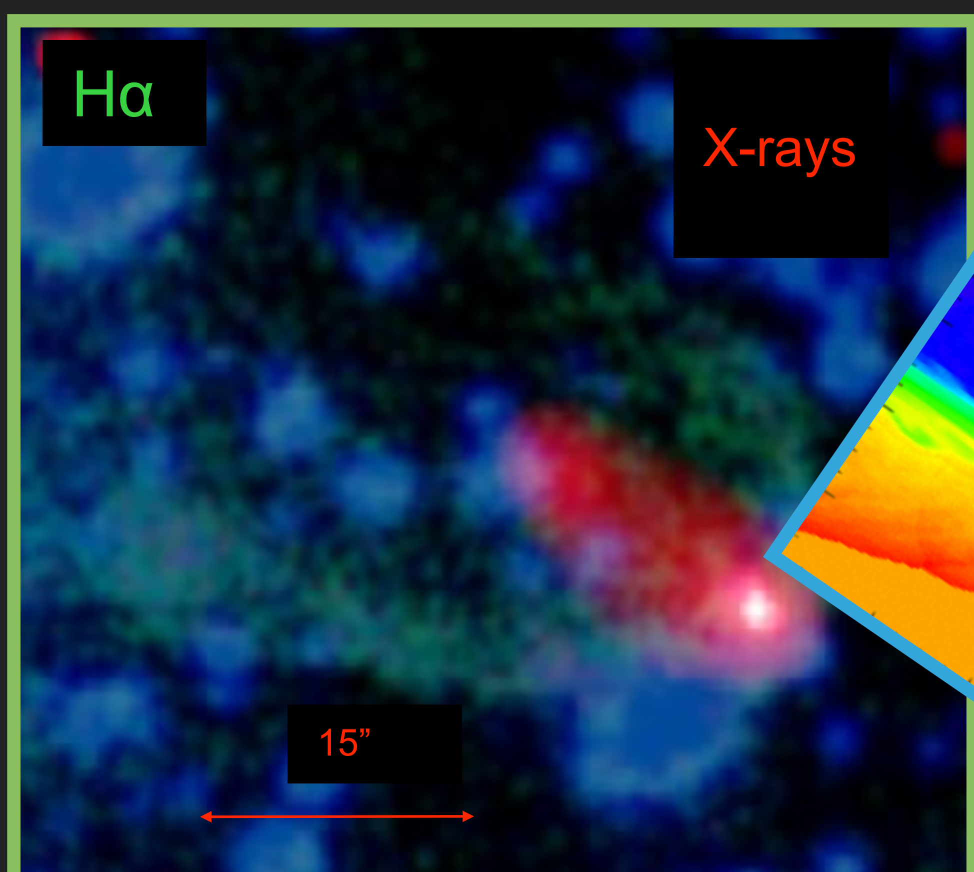


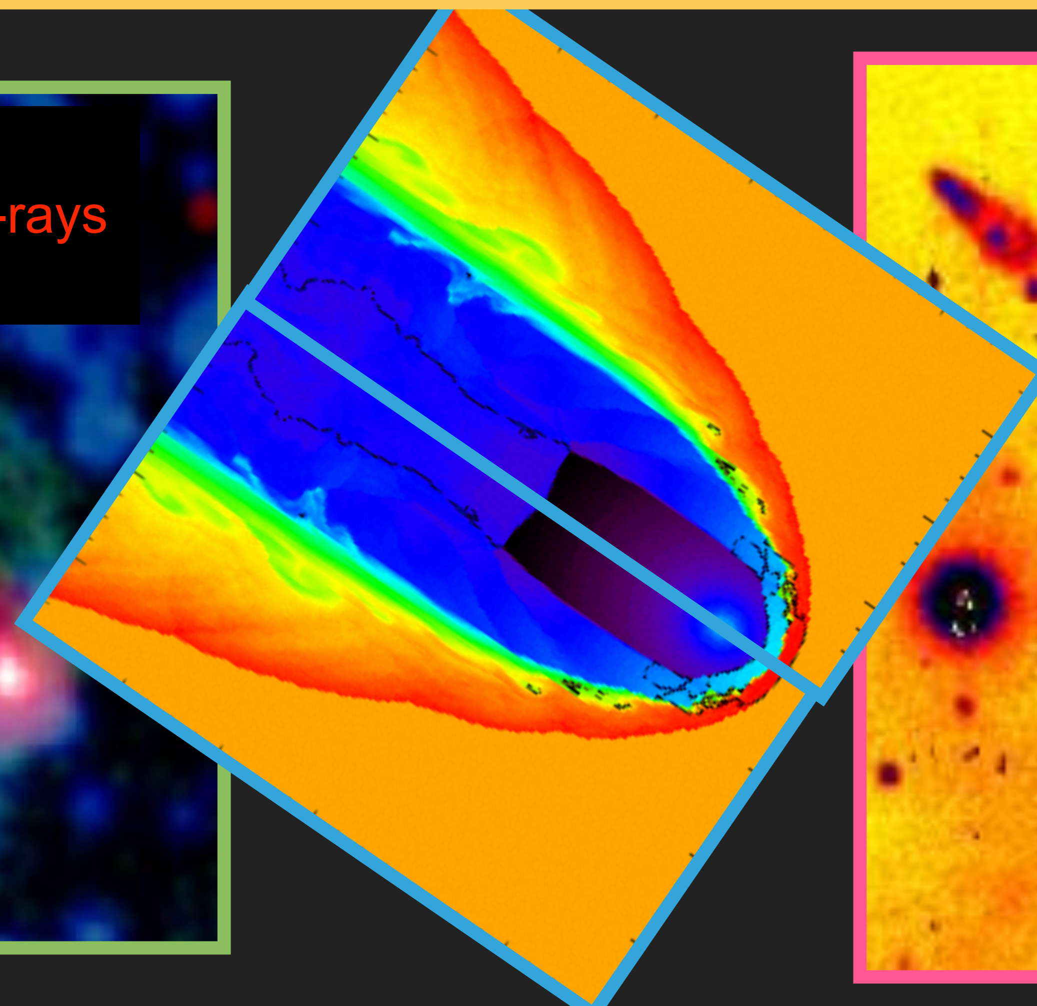
PSR B2224+65 (Chatterjee & Cordes 2002)

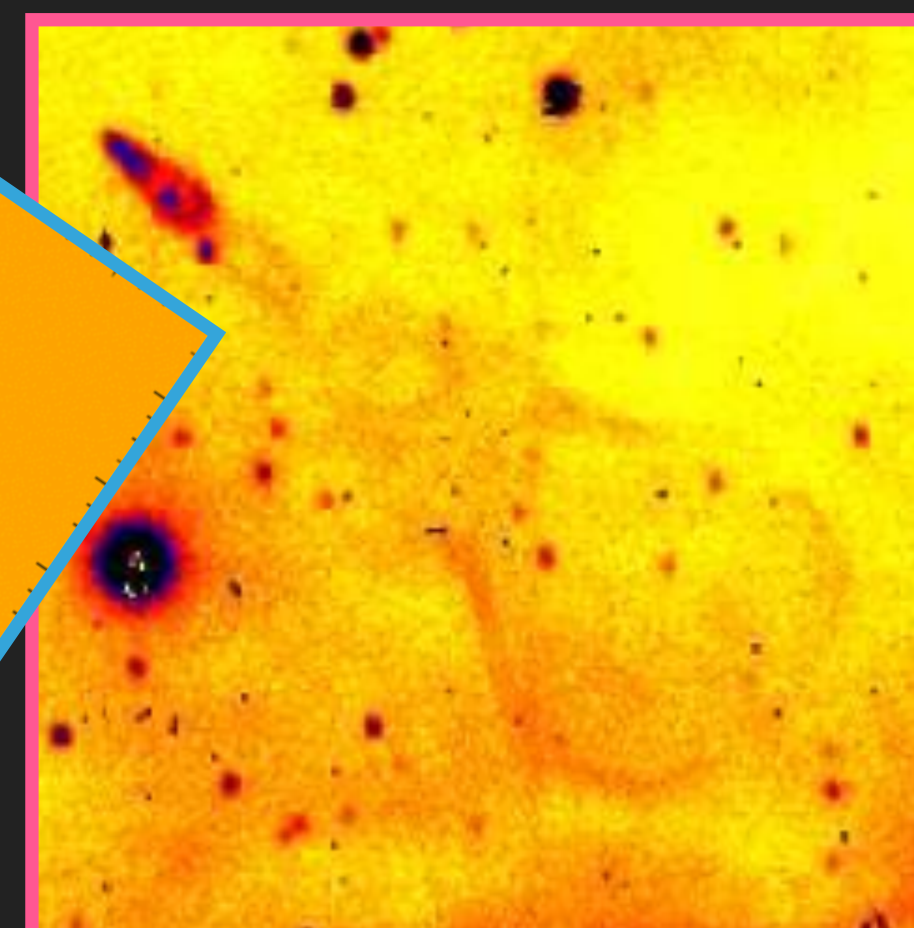
BOW SHOCK PWNE

$$t_{esc}V_{psr} = R_{snr} = \left(\frac{E_{sn}}{\rho_{ism}}\right)^{1/5} t_{esc}^{2/5}$$

$$\Rightarrow t_{esc} \approx \left(\frac{E_{sn}}{\rho_{ism}}\right)^{1/3}\left(\frac{1}{V_{psr}}\right)^{5/3} \approx 2\times 10^5\mathrm{yr}\left(\frac{E_{sn}}{10^{51}\mathrm{erg}}\right)^{1/3}\left(\frac{V_{psr}}{200\mathrm{km\ s}^{-1}}\right)^{5/3}\left(\frac{n_{ism}}{1\mathrm{cm}^{-3}}\right)^{-1/3}$$







PSR B1957+20 (Stappers et al. 2003)

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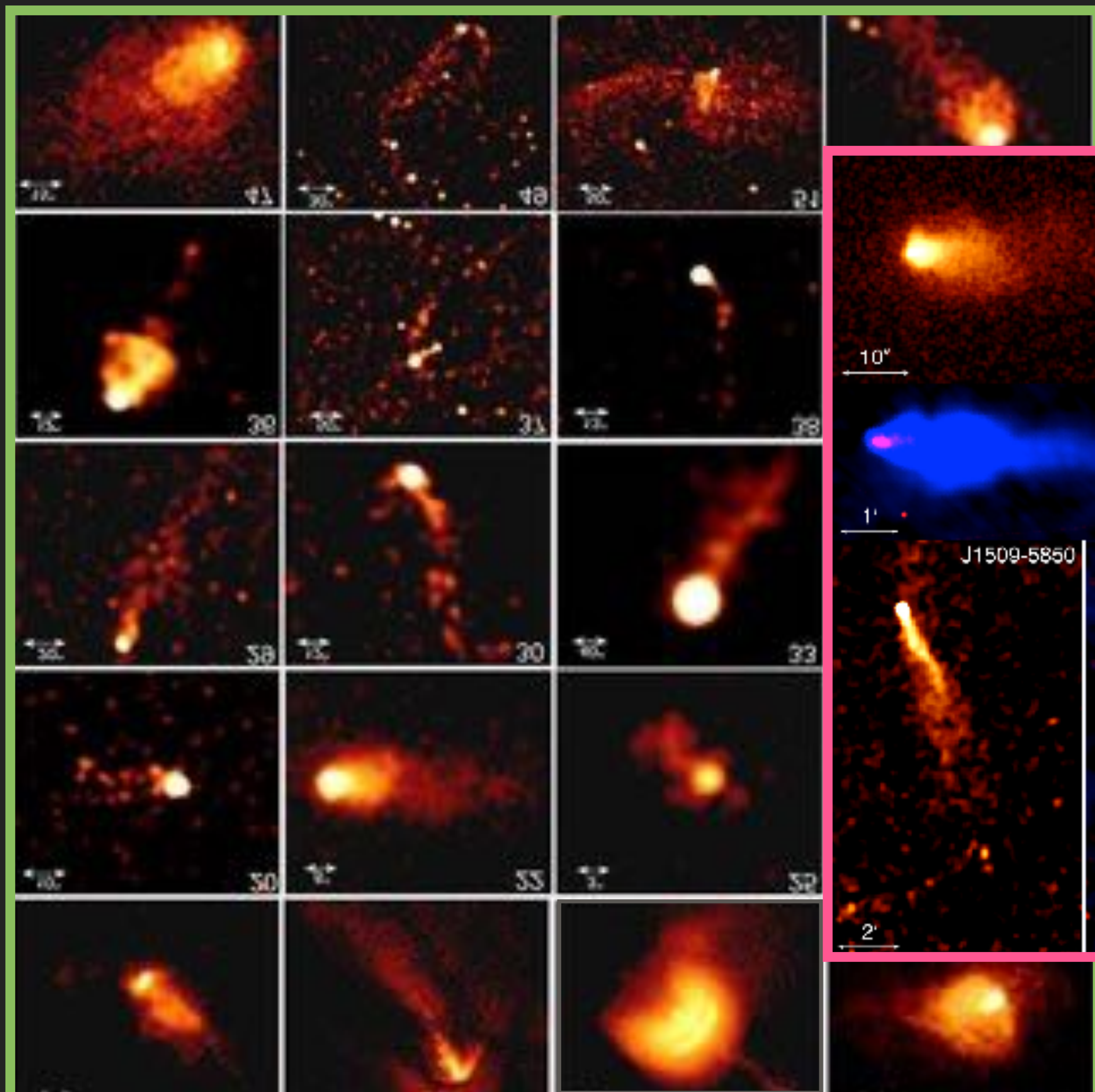
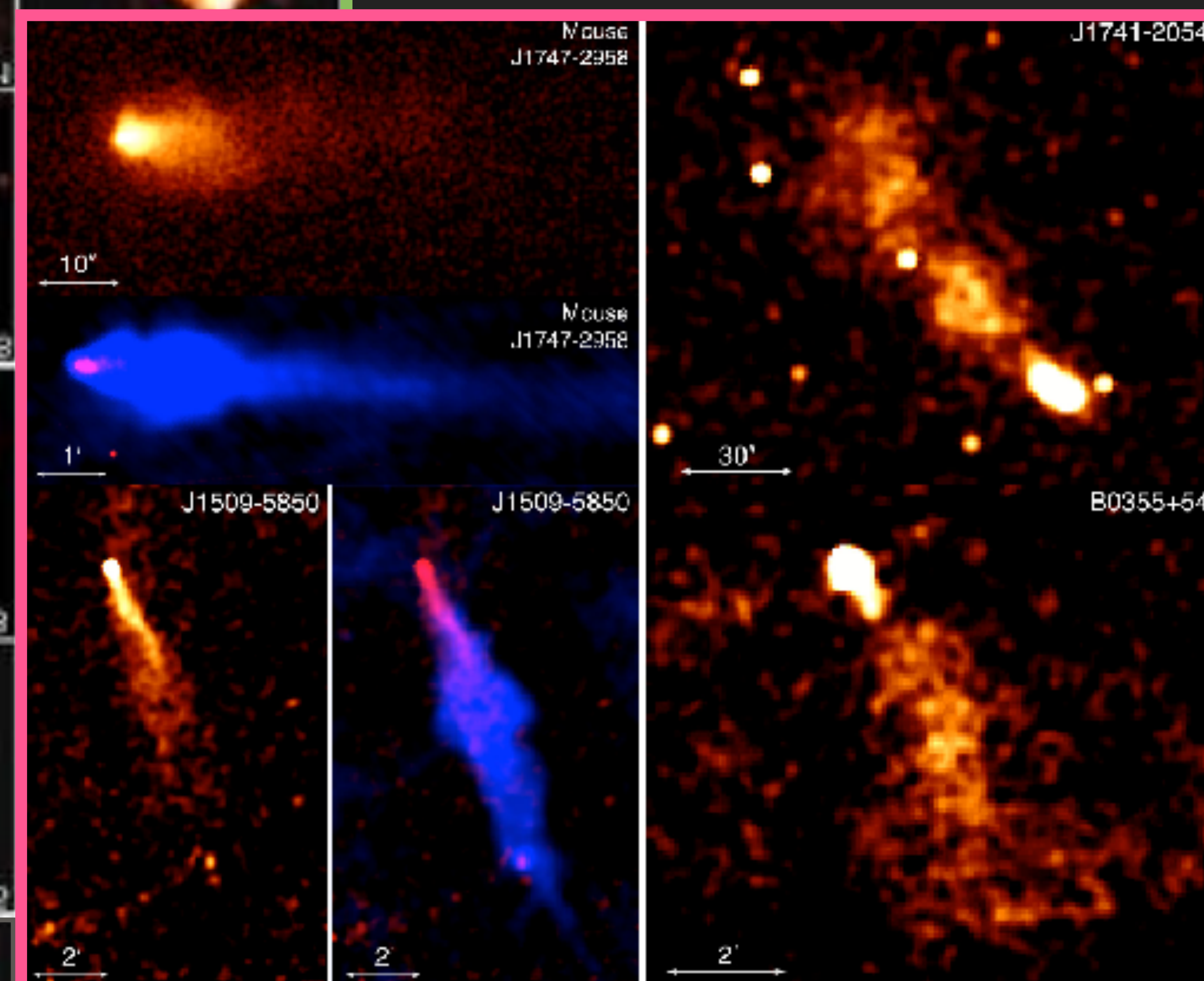
BOW SHOCK PWNE



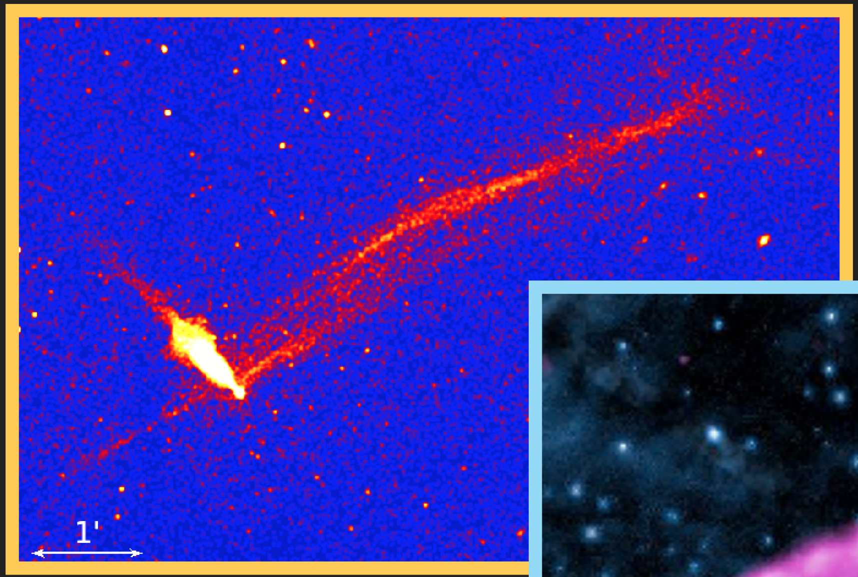


PARTICLE ESCAPE

THE ARE BS PWNE WHERE THE X-RAY “TAIL” IS WHERE IT SHOULD NOT BE!

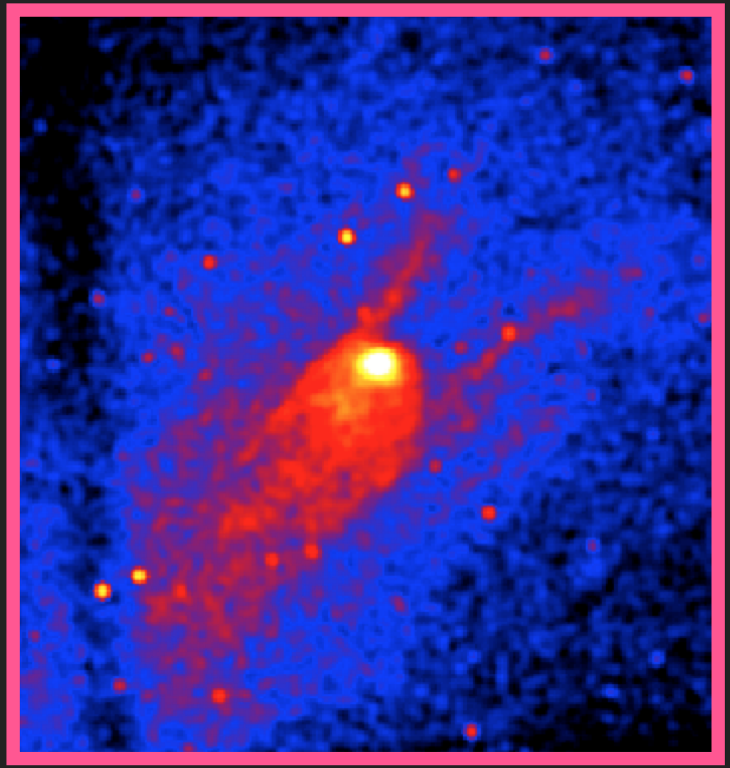
THE PARTICLES IN THESE FEATURES ARE ~ PSR VOLTAGE

PSR J1101 (Pavan et al 2016)

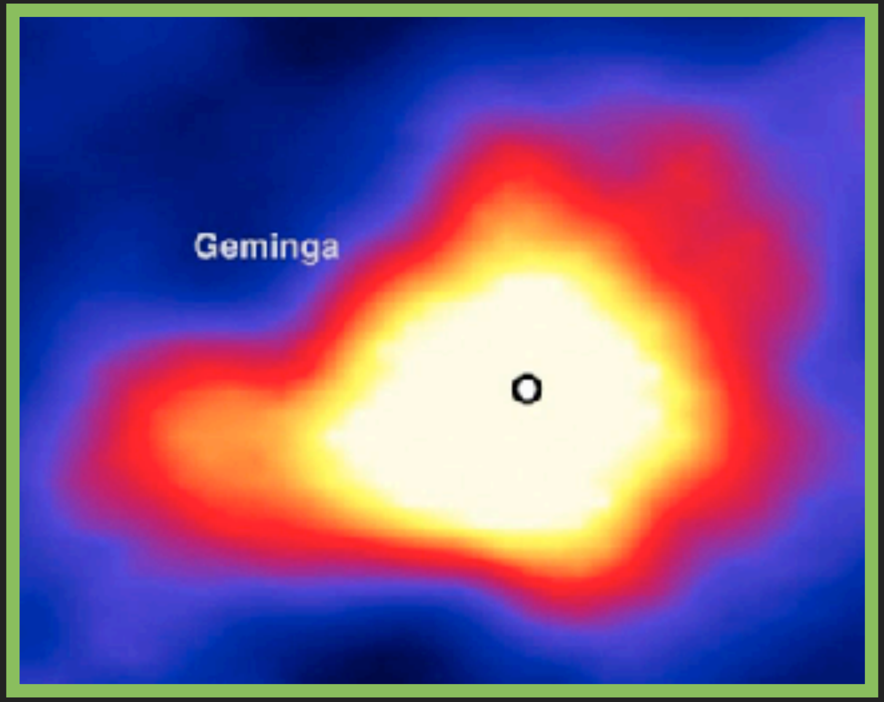


Guitar (Wong et al 2003)

TEV HALO SUGGEST STRONG DIFFUSION



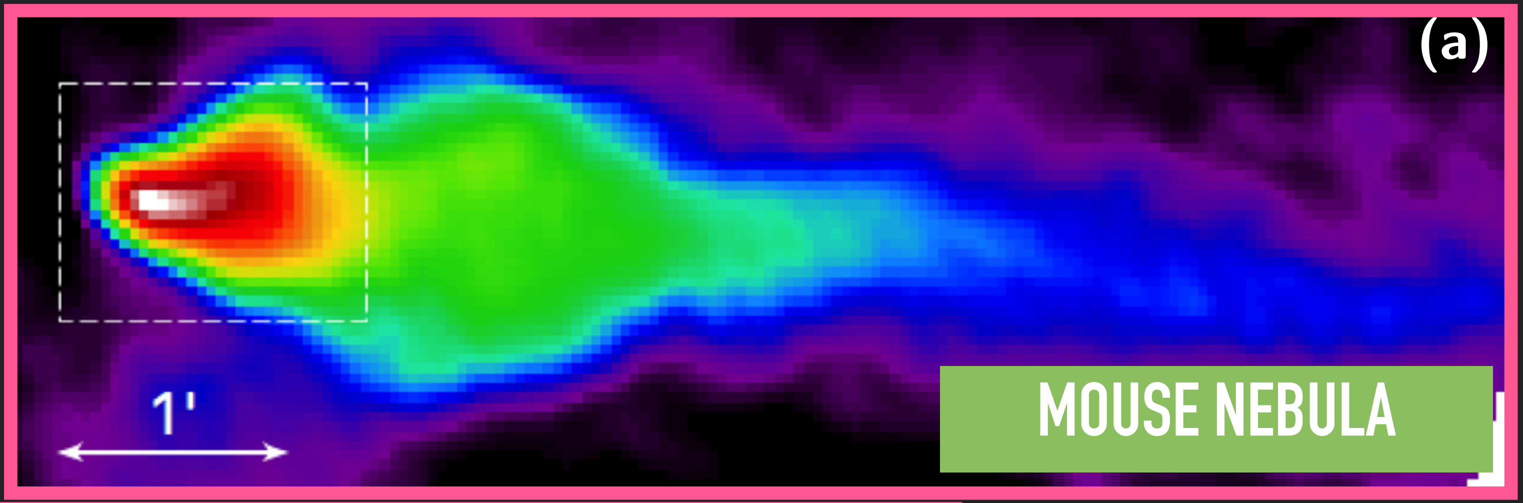
G327 (Temin et al 2009)

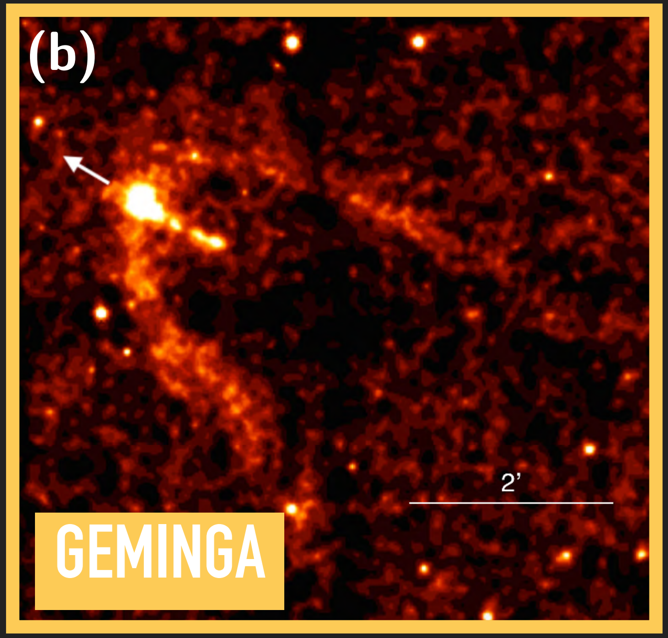


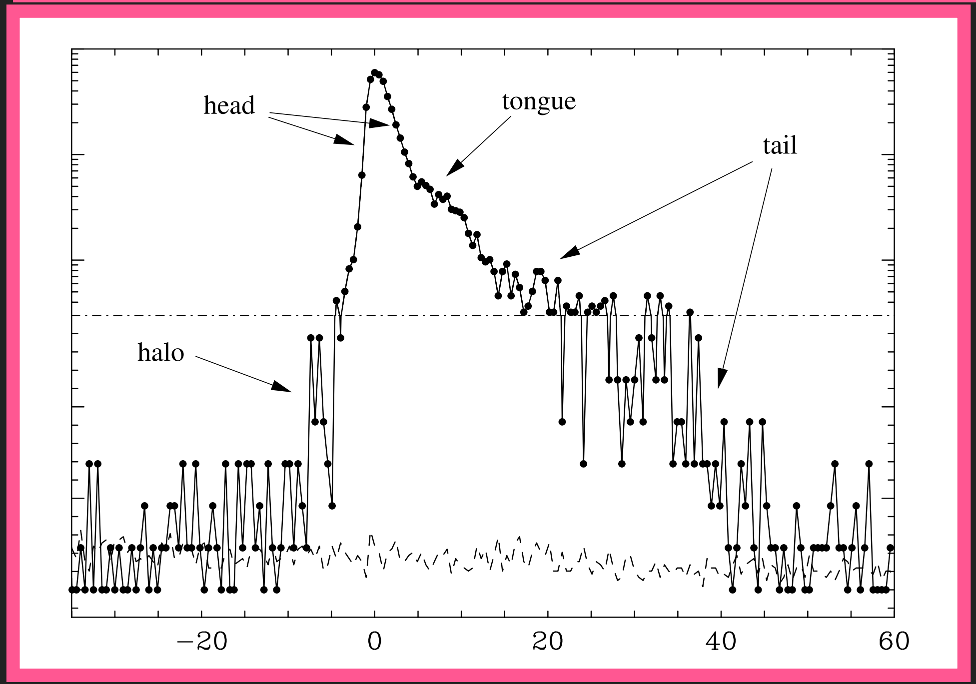
Geminga (HAWC Abeysekara et al 2017)

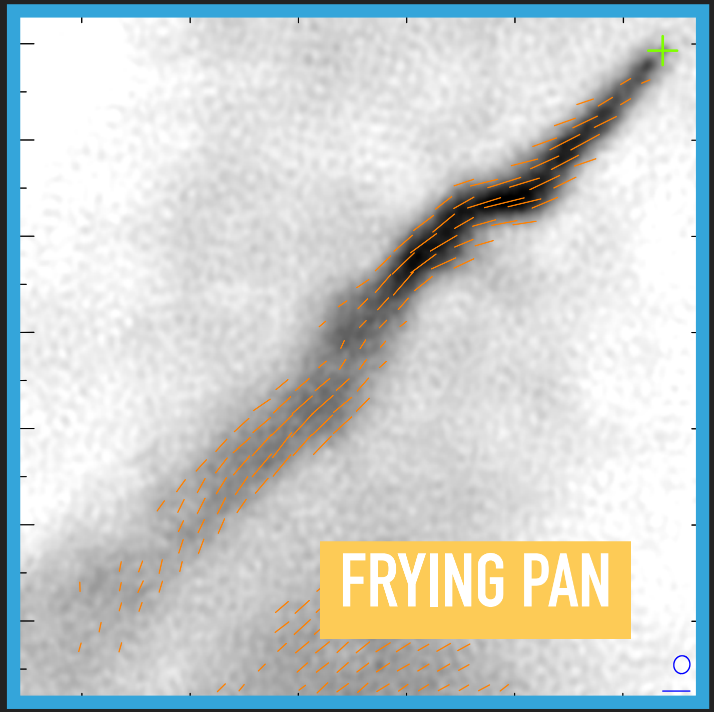
PARTICLE ESCAPE - GC

DIVERSITY


(a)
1'
MOUSE NEBULA

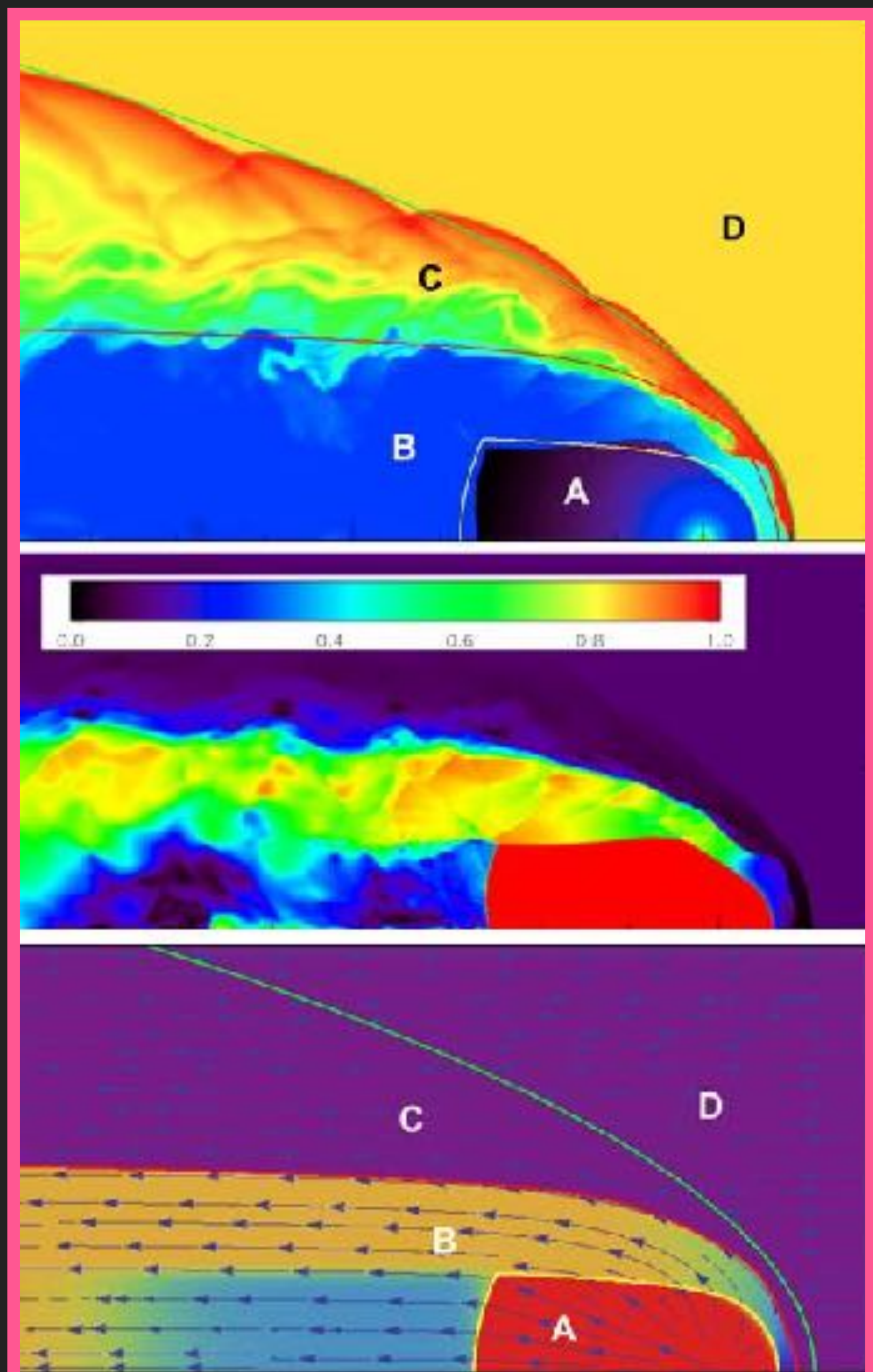

(b)
2'
GEMINGA


head
tongue
tail
halo
−20
0
20
40
60

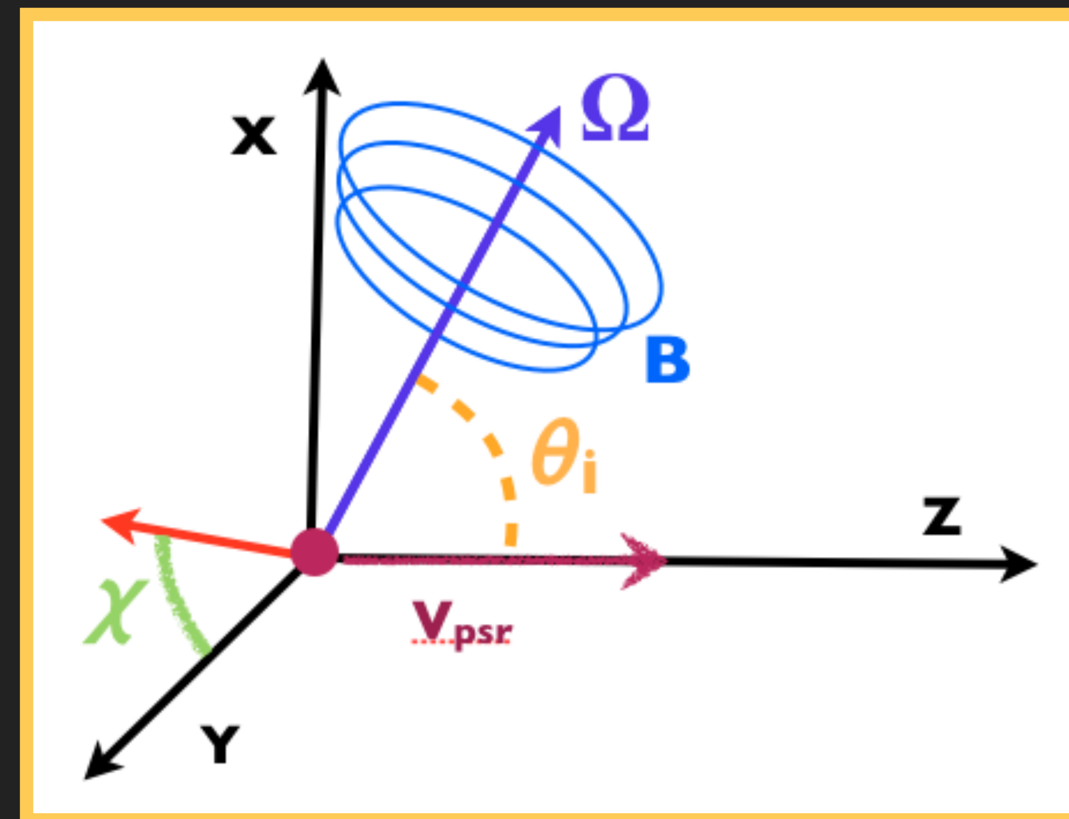

FRYING PAN


BLACK WIDOW

GEOMETRY



Bucciantini 2018



THIS IS A FUNDAMENTALLY 3D SYSTEM
SPIN VEL INCLINATION
BISM SPIN INCLINATION
PSR WIND ANISOTROPY
PSR WIND MAGNETIZATION

OBSERVER INCLINATION

COMPUTATIONAL REQ.

- RELATIVISTIC MHD - CORRECT JUMP AND POST SHOCK DYNAMICS
- AMR - NECESSARY TO HANDLE DIFFERENT STRUCTURAL FEATURES OF VARIOUS SCALES
- NEED TO SAMPLE A VAST PARAMETER SPACE IN TERMS OF CONFIGURATIONS
- NEED TO EVOLVE FOR A LONG TIME IN ORDER TO REMOVE BIASES DUE TO INITIAL CONDITIONS

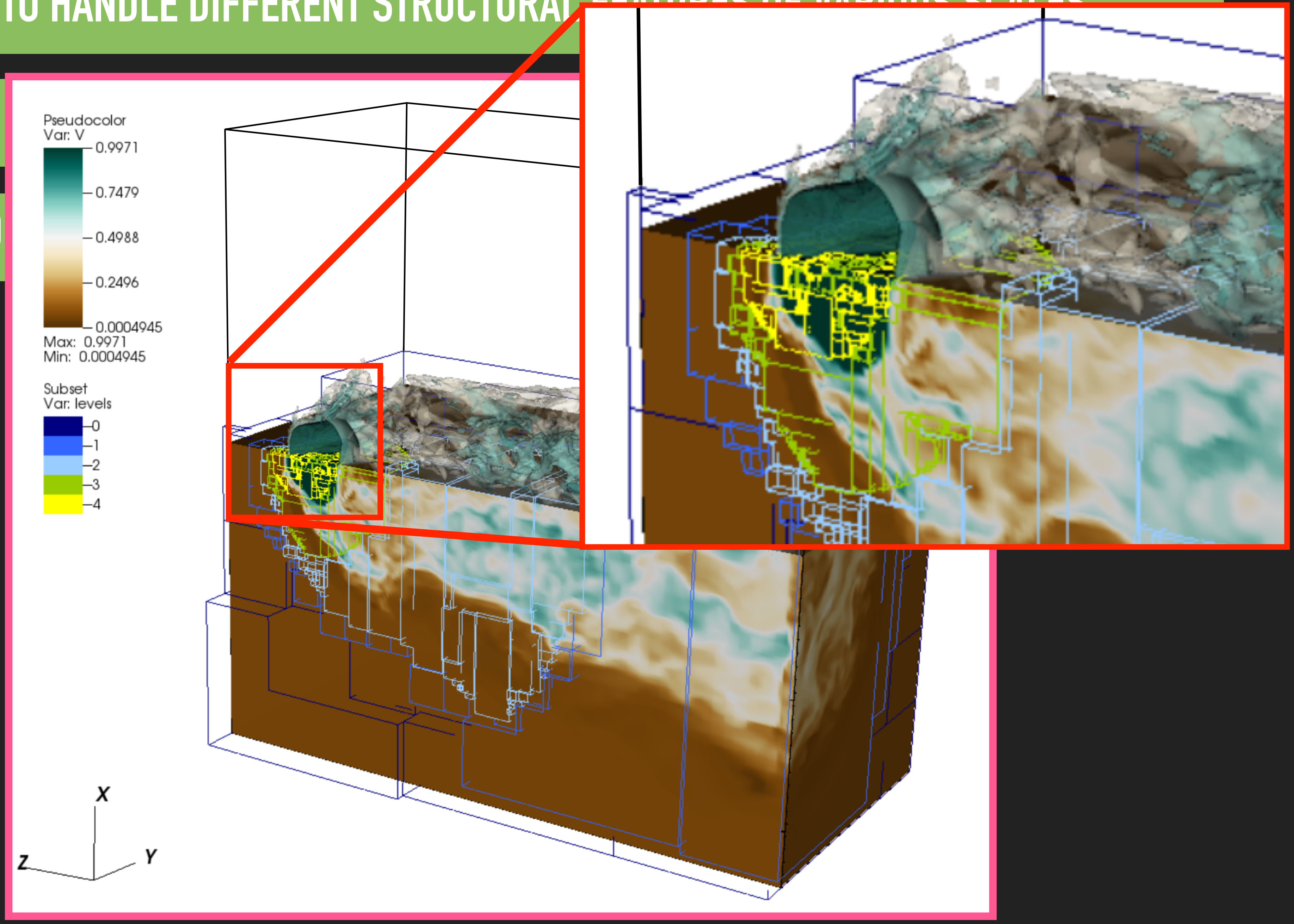
COMPUTATIONAL REQ.

RELATIVISTIC MHD - CORRECT JUMP AND POST SHOCK DYNAMICS

AMR - NECESSARY TO HANDLE DIFFERENT STRUCTURAL FEATURES OF VARIOUS SCALES

NEED TO SAMPLE A

NEED TO EVOLVE FO



COMPUTATIONAL REQ.

PLUTO + CHOMBO AMR

CINECA - BRD & KNL - MARCONI

ABOUT 50 DIFFERENT CONFIGURATIONS

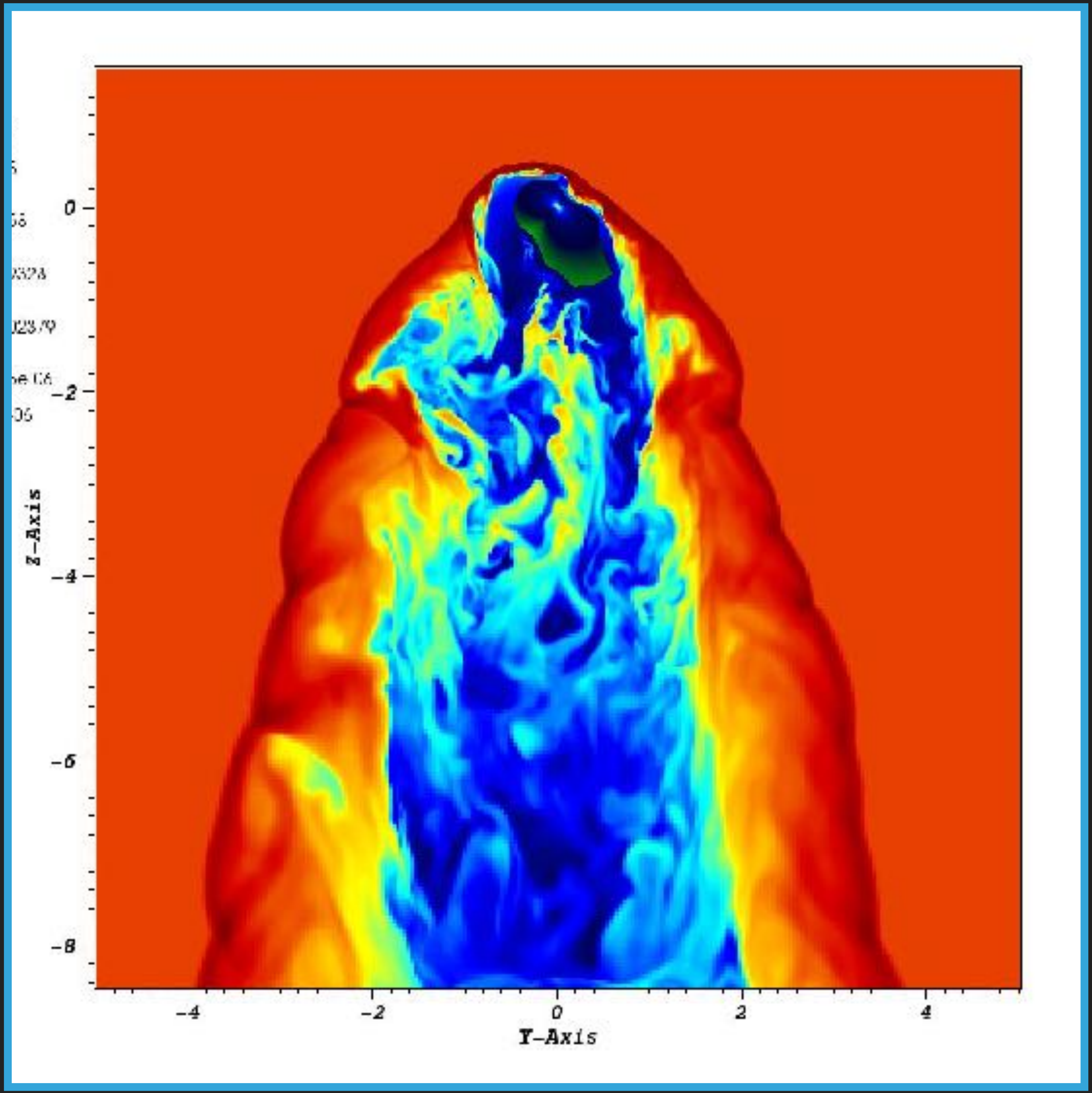
TEMPO VIA 2 REQUESTS WITH INAF - CINECA CALSS A

TOTAL TIME 2018 - 2019 ABOUT 10MHR

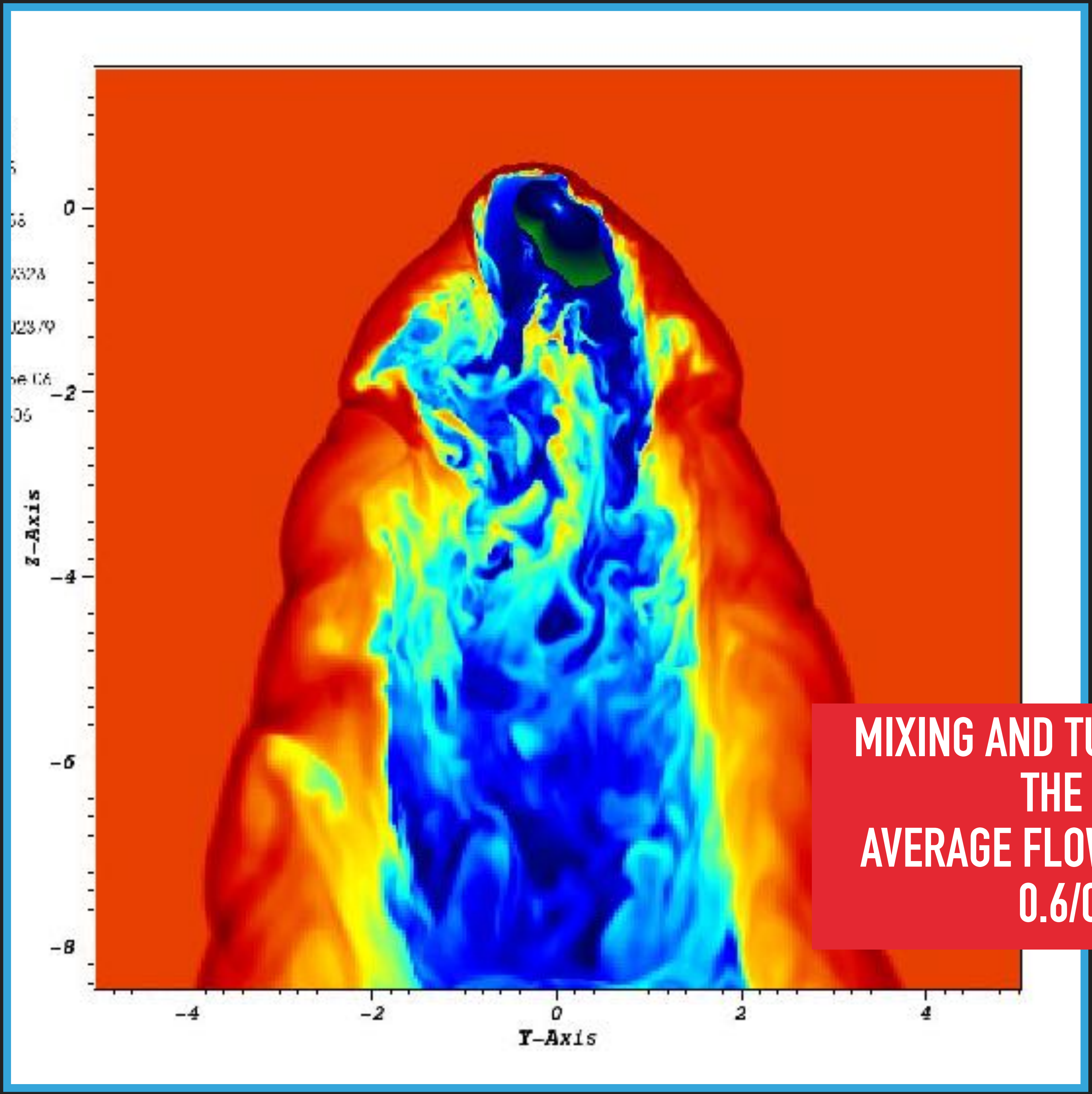
ABOUT 10GB OF DATA FOR EACH RUN

POST PROCESSING - IN HOUSE CLUSTER

BOW-SHOCK

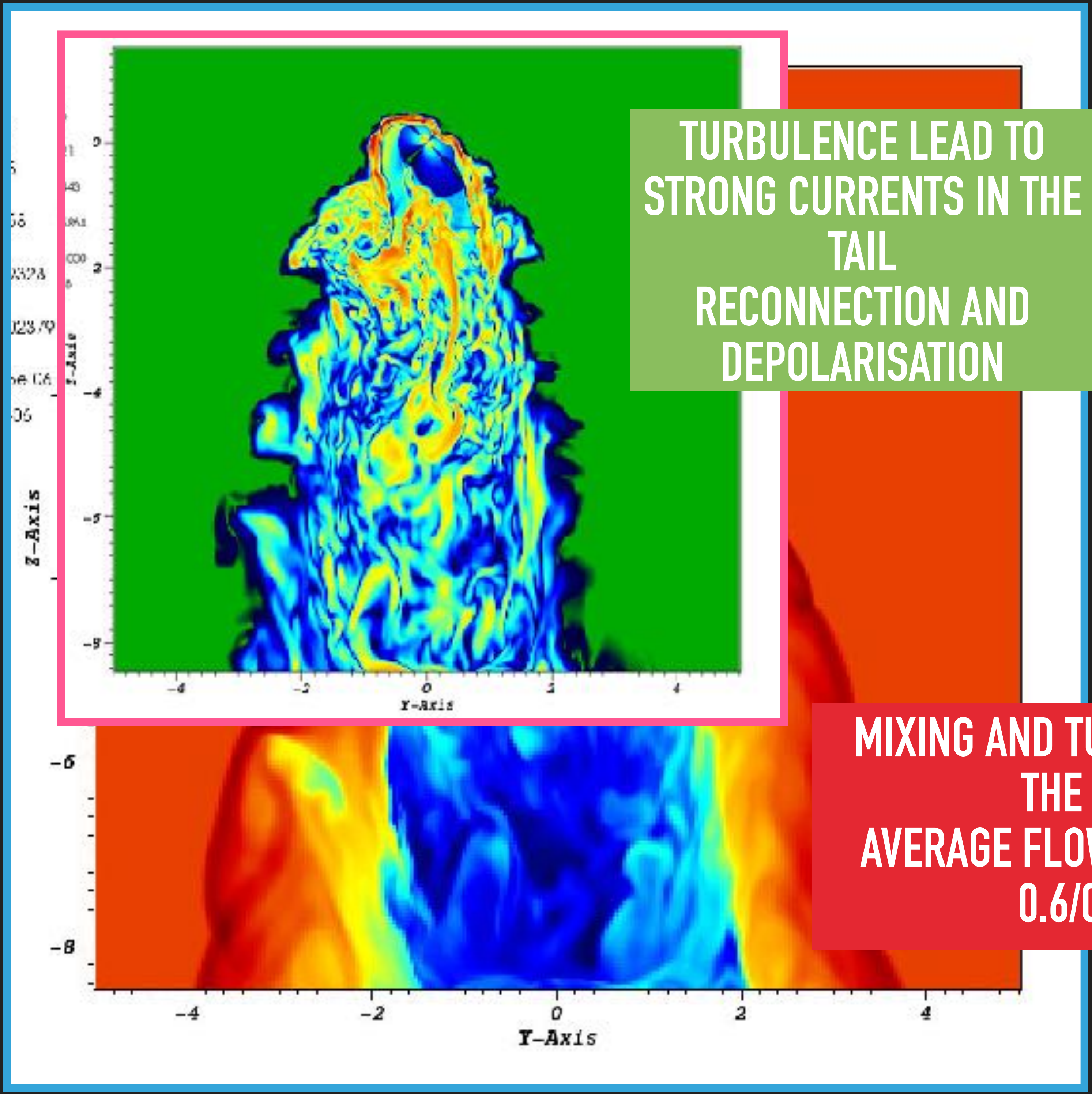


BOW-SHOCK

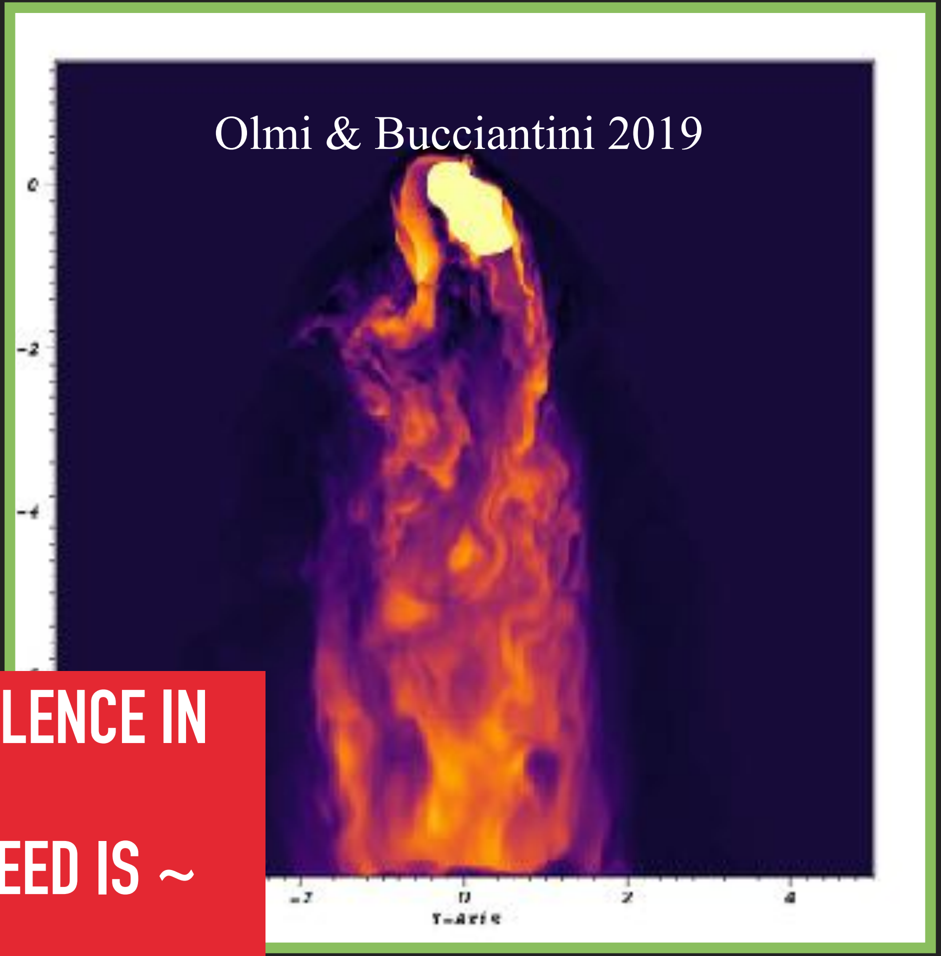


MIXING AND TURBULENCE IN THE TAIL
AVERAGE FLOW SPEED IS ~ 0.6/0.8 C

BOW-SHOCK

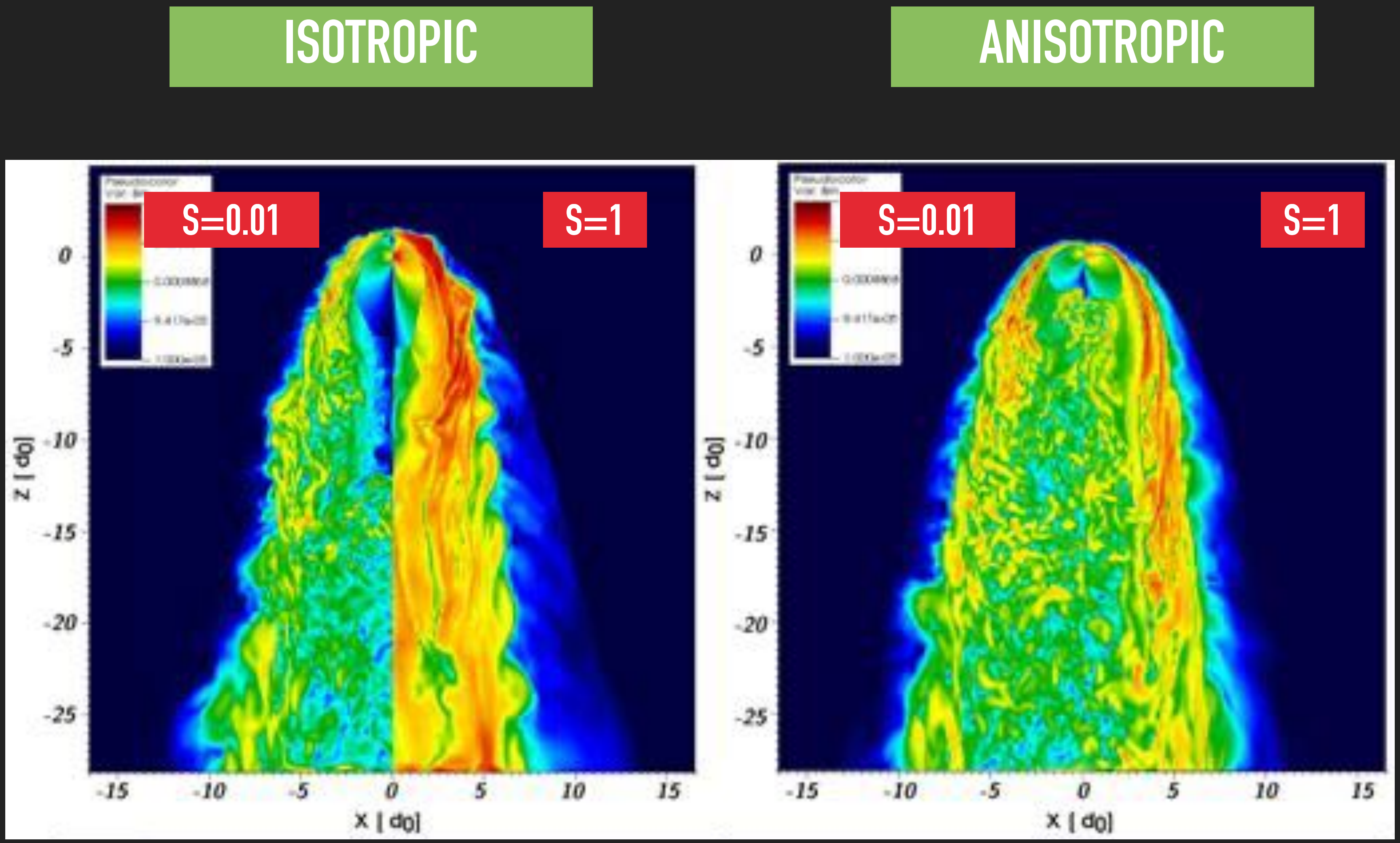


TURBULENCE LEAD TO STRONG CURRENTS IN THE TAIL
RECONNECTION AND DEPOLARISATION



MIXING AND TURBULENCE IN THE TAIL
AVERAGE FLOW SPEED IS ~ 0.6/0.8 C

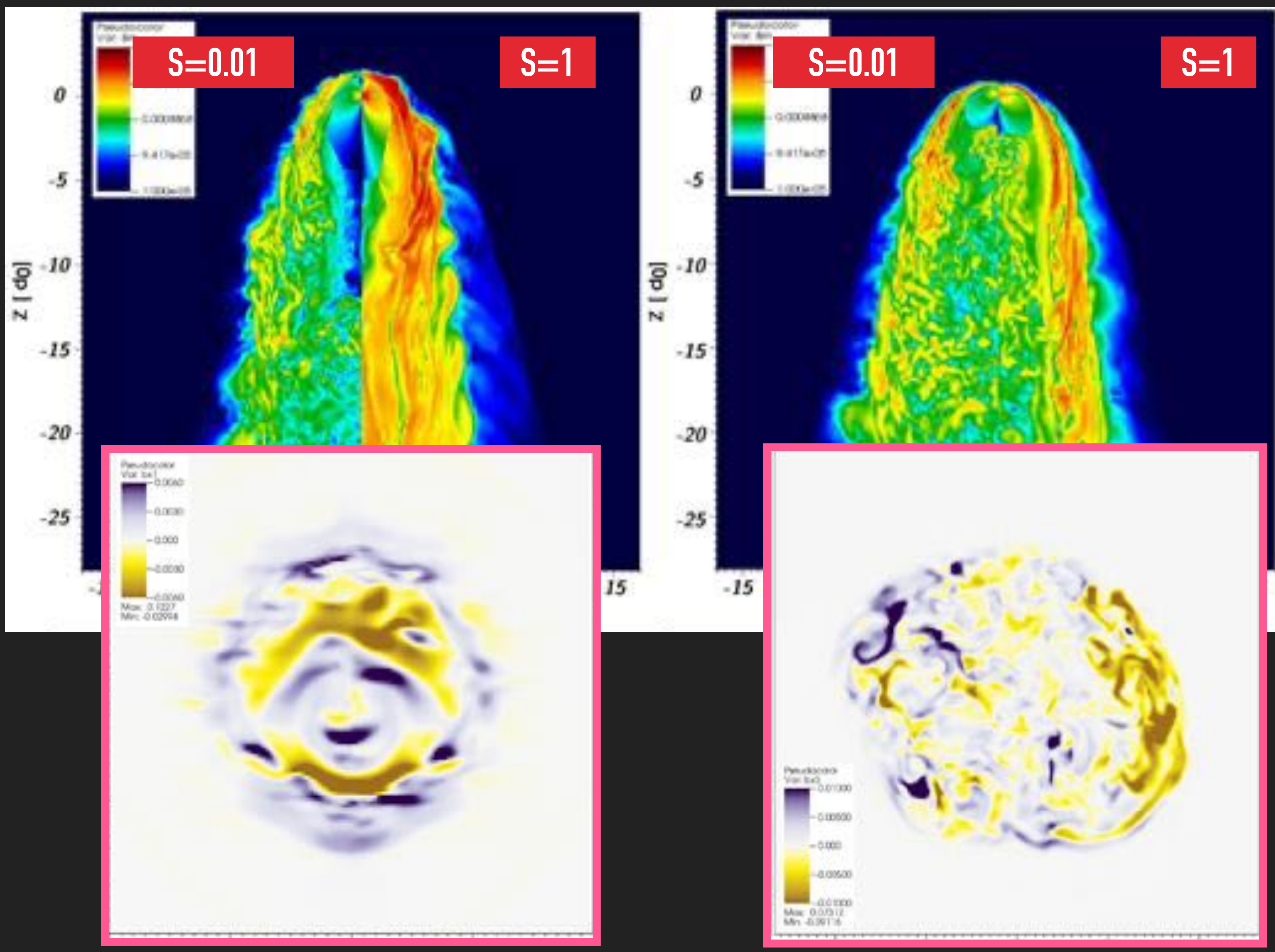
TURBULENCE



TURBULENCE

ISOTROPIC

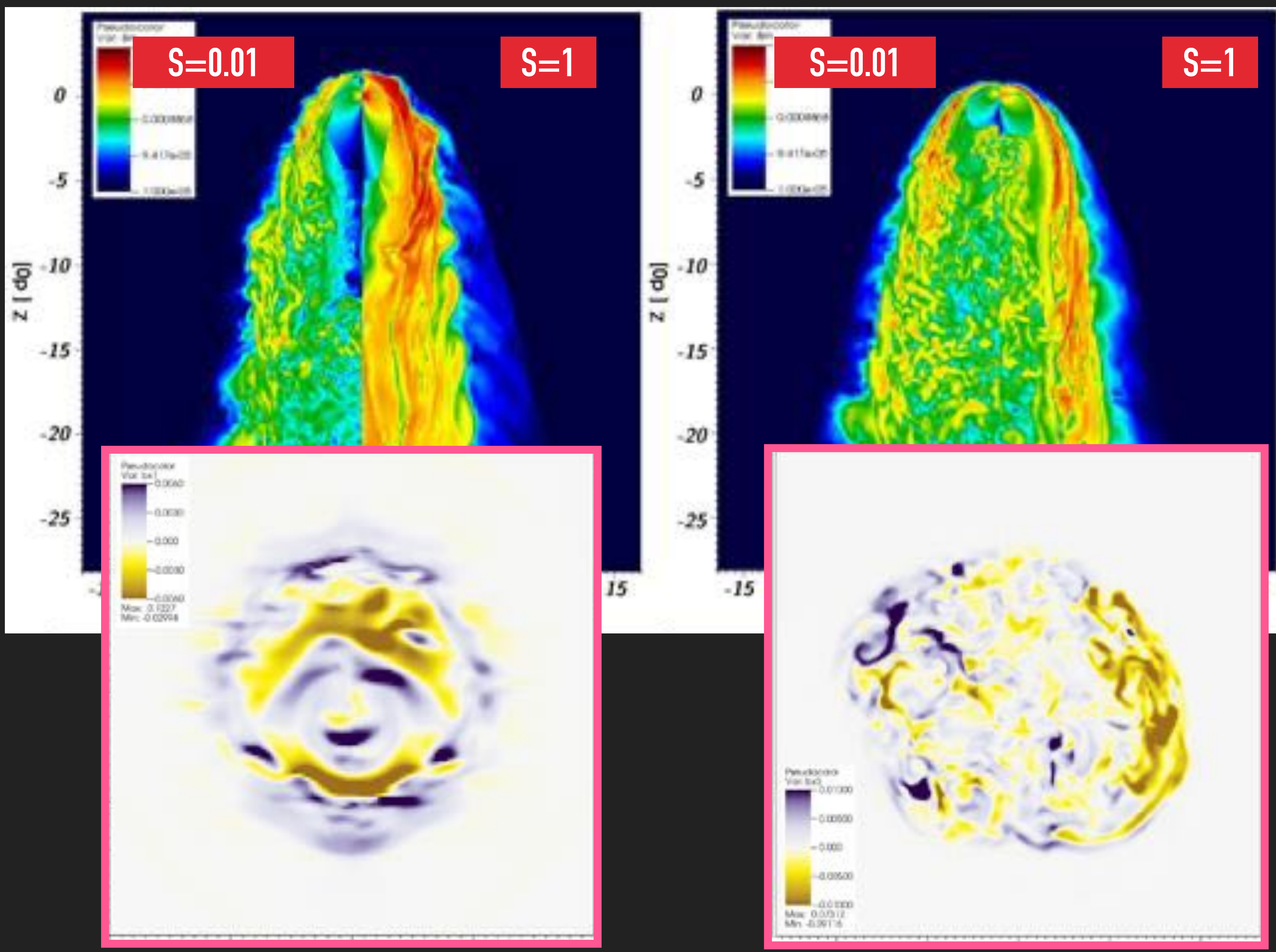
ANISOTROPIC

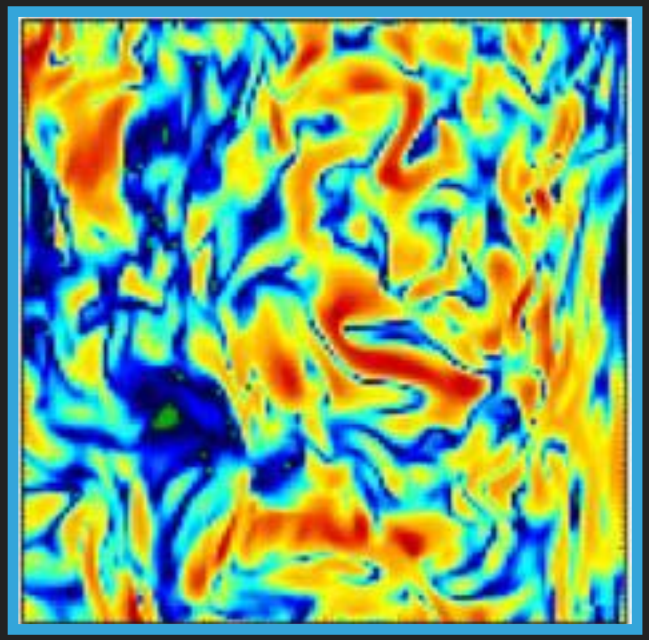


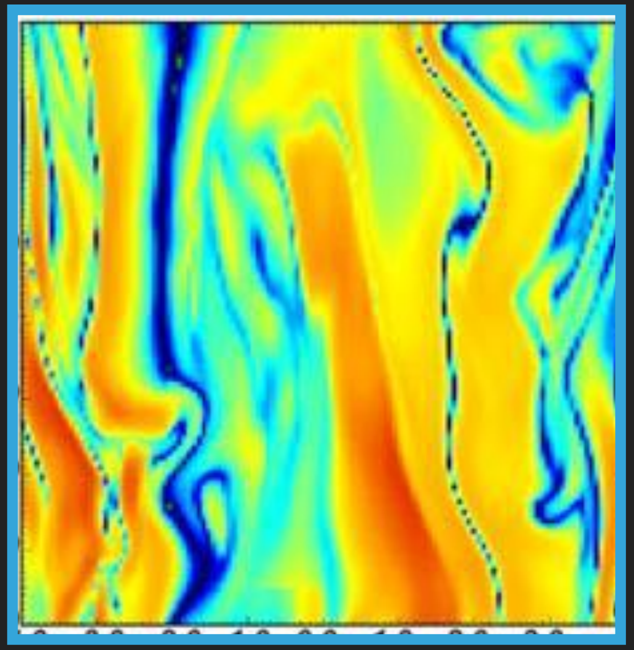
TURBULENCE

ISOTROPIC

ANISOTROPIC



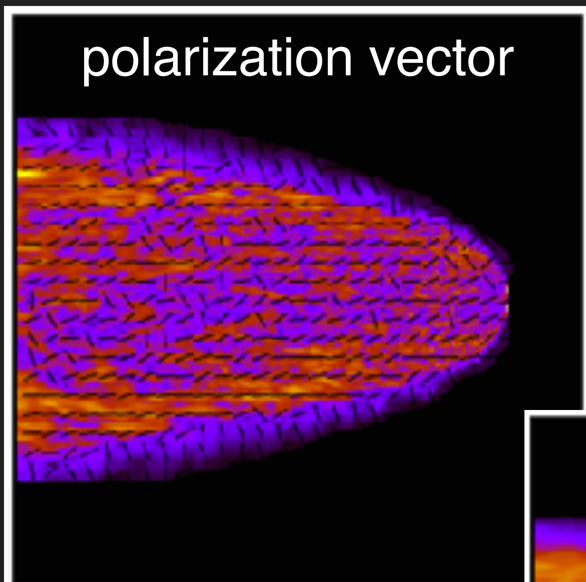




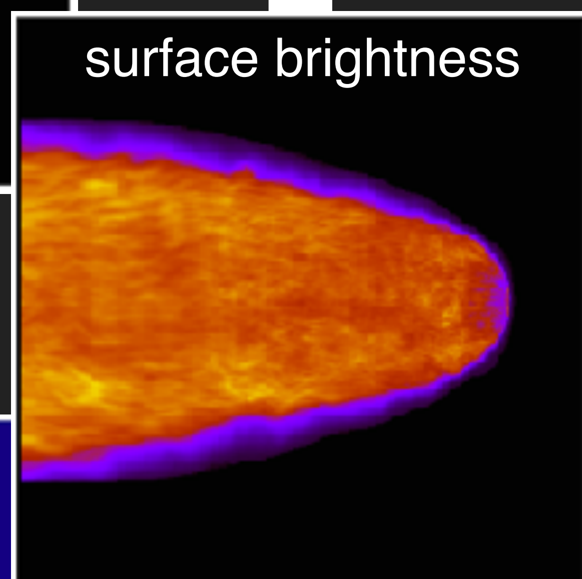
Olmi & Bucciantini 2019

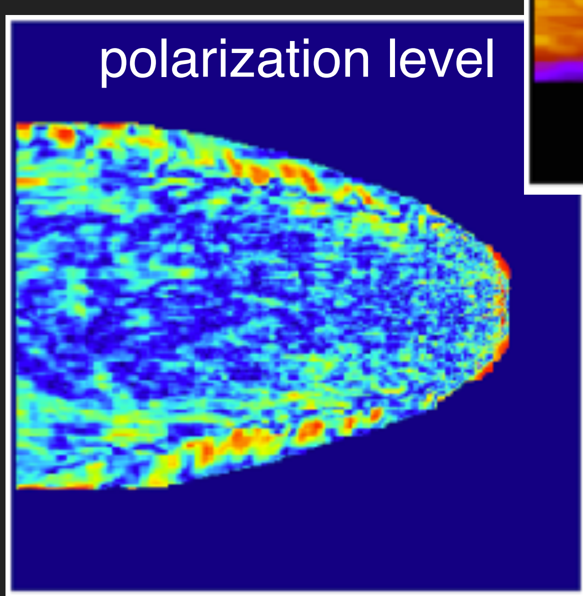
EMISSION

ANISOTROPIC σ=0.01



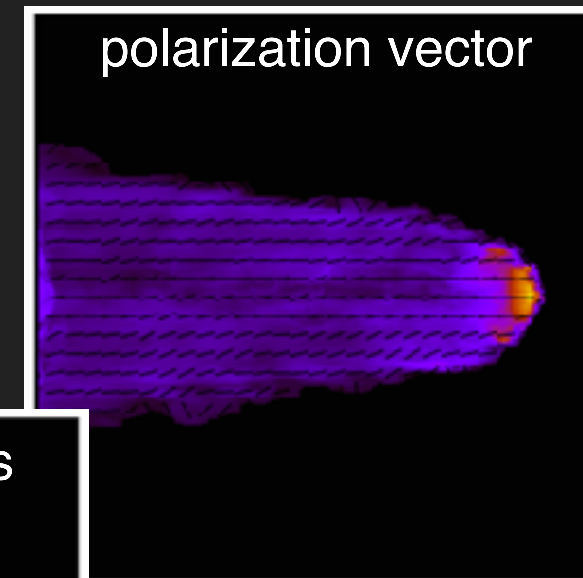
High level of turbulence



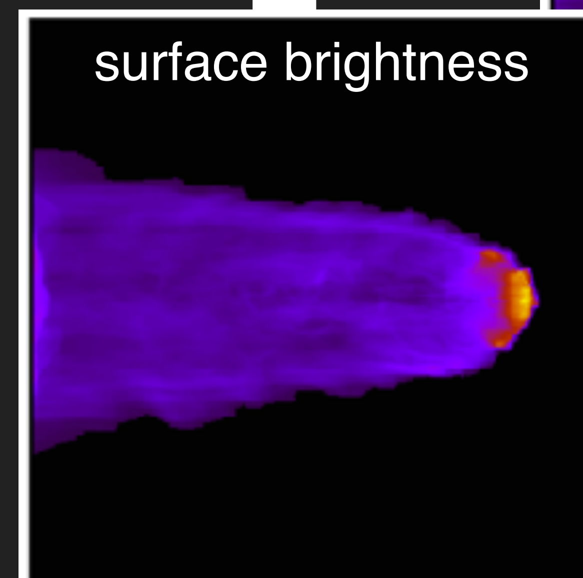


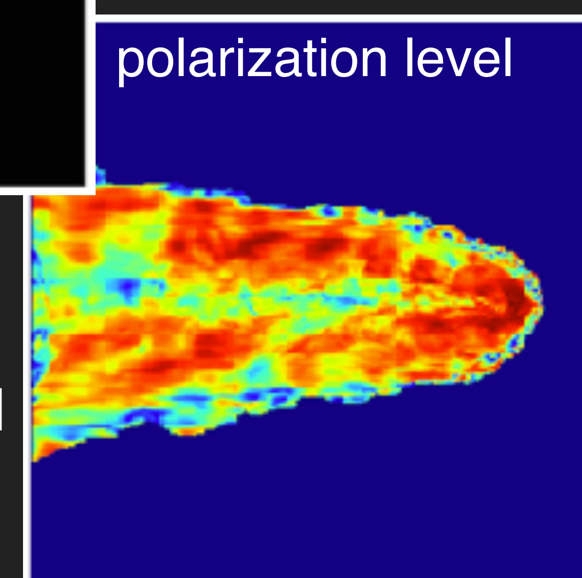
Uniform emissivity.
Unpolarized

ISOTROPIC σ=1



Low level of turbulence





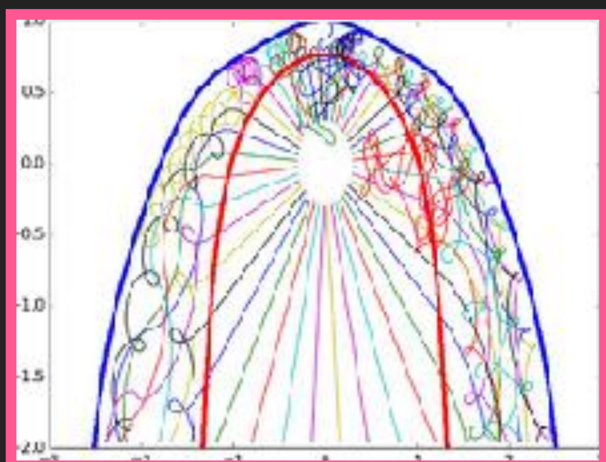
Emission dominated by the head.
Strong polarization.

Olmi & Bucciantini 2019b

PARTICLE ESCAPE

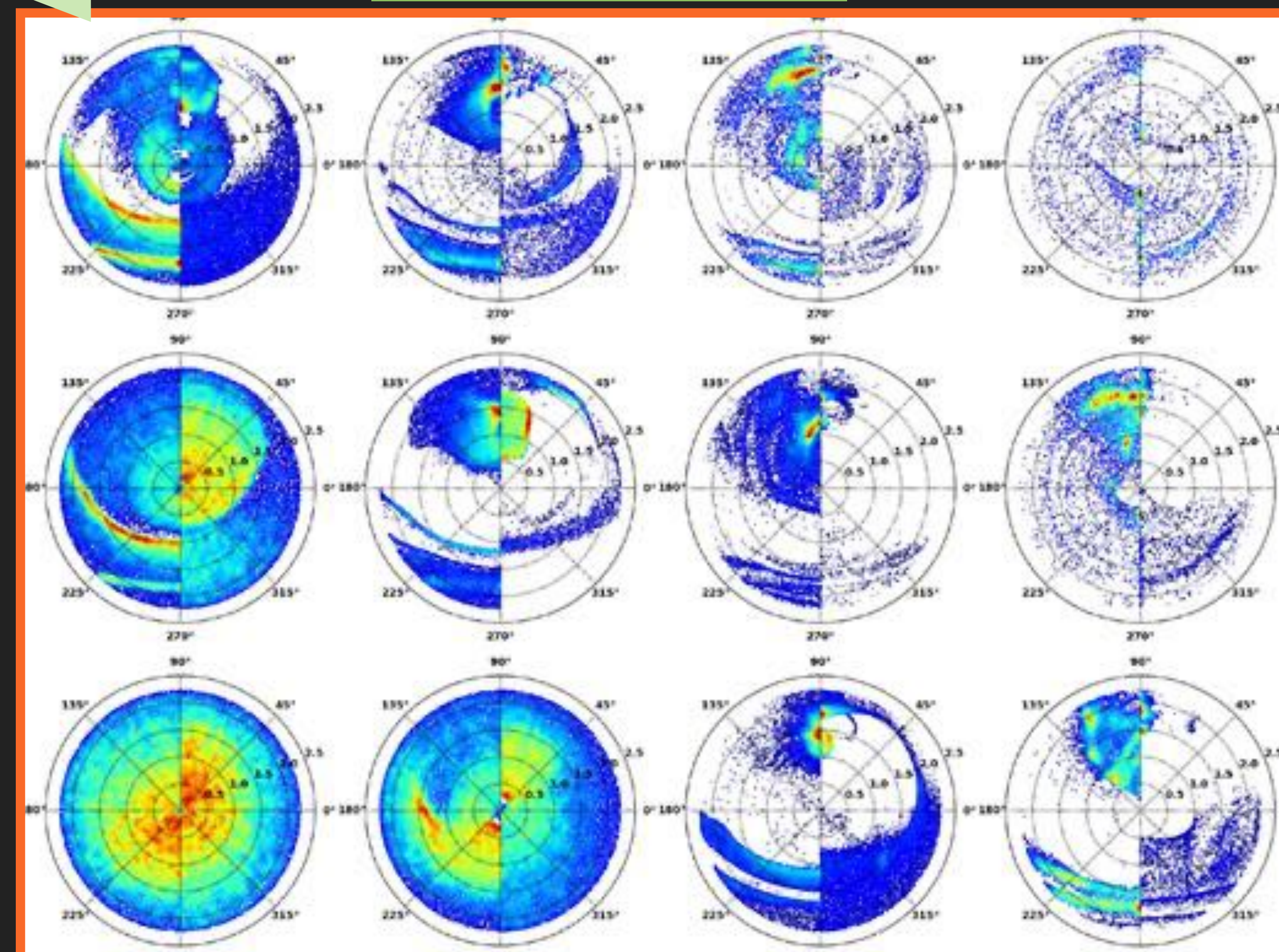
$$d_o = \sqrt{\frac{L}{4\pi c \rho_o V^2}}, ,$$

PARTICLE AT VOLTAGE HAVE LARMOUR RADIUS ~ DO

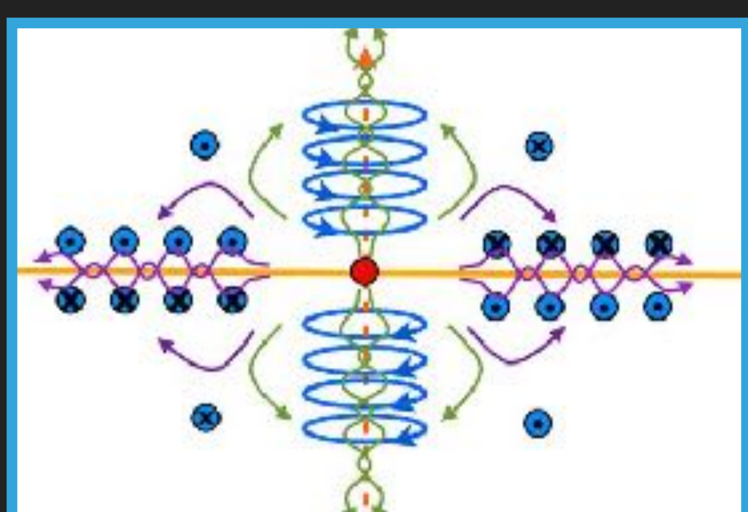


ENERGY

MAG STRUCTURE



CURRENT SHEETS PRODUCE CONFINEMENT



PARTICLE ESCAPE

PARTICLE AT VOLTAGE HAVE LARMOUR RADIUS ~ DO

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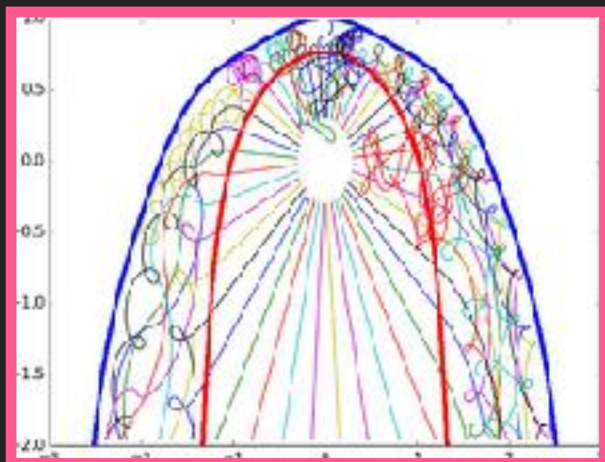
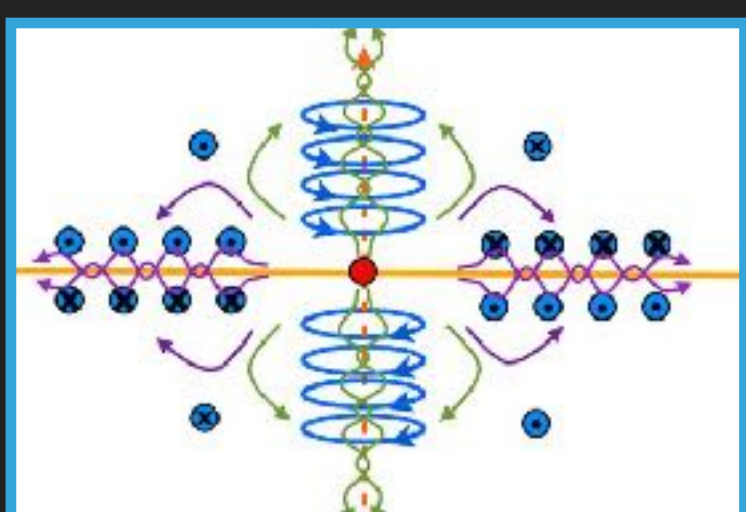
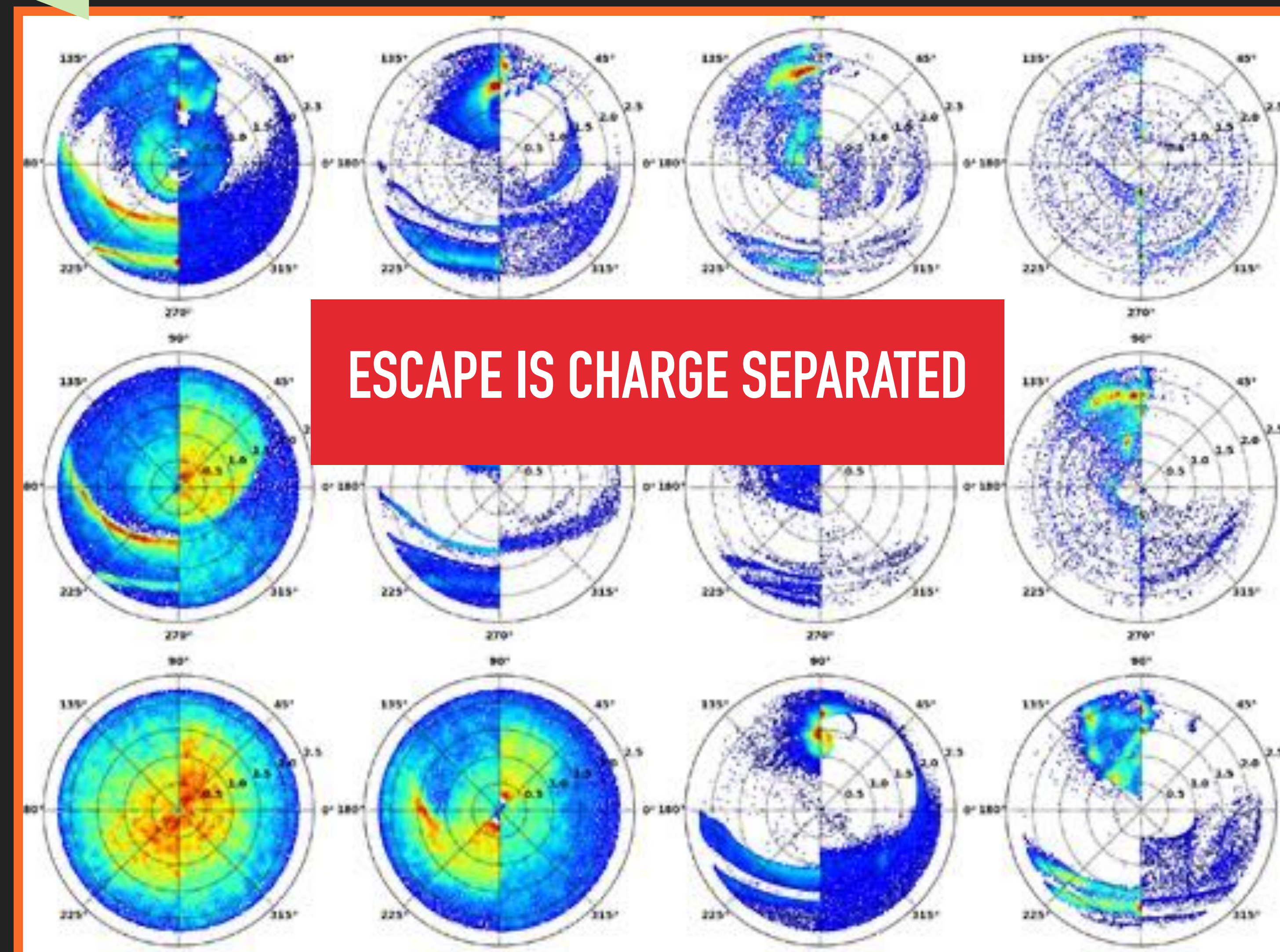


CURRENT SHEETS PRODUCE CONFINEMENT



ENERGY

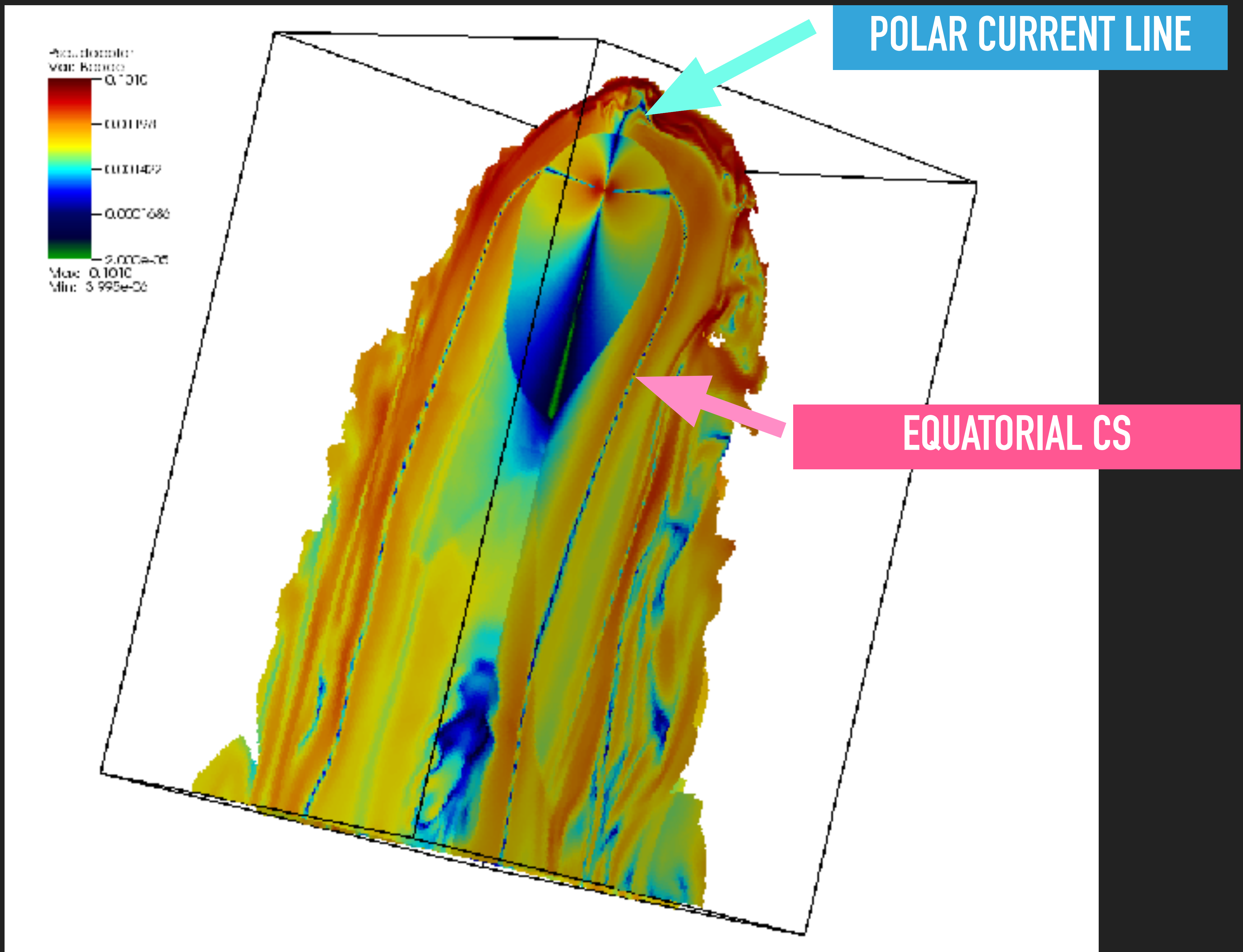
MAG STRUCTURE



ESCAPE IS CHARGE SEPARATED

Bucciantini 2018

ROLE OF CURRENTS



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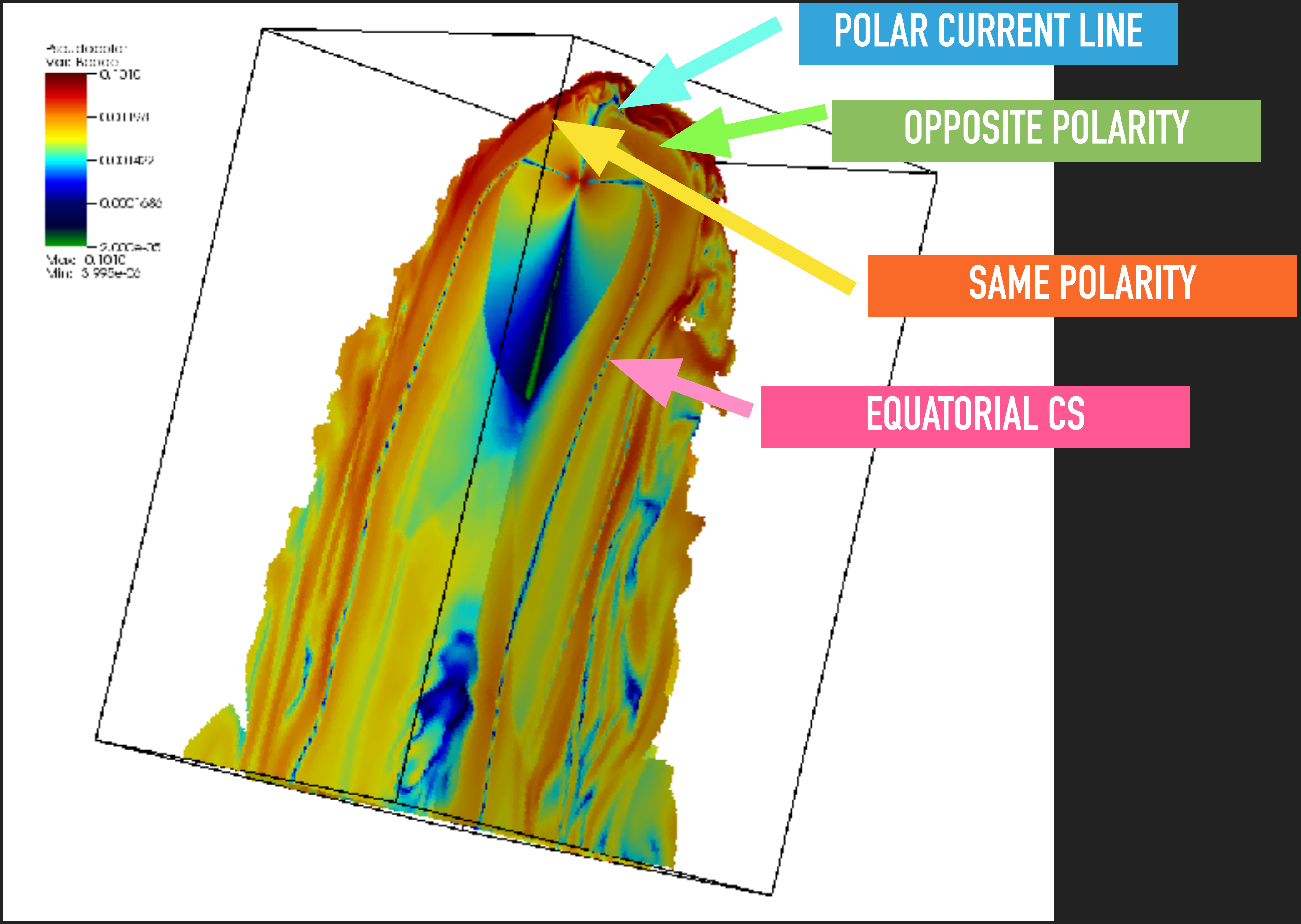
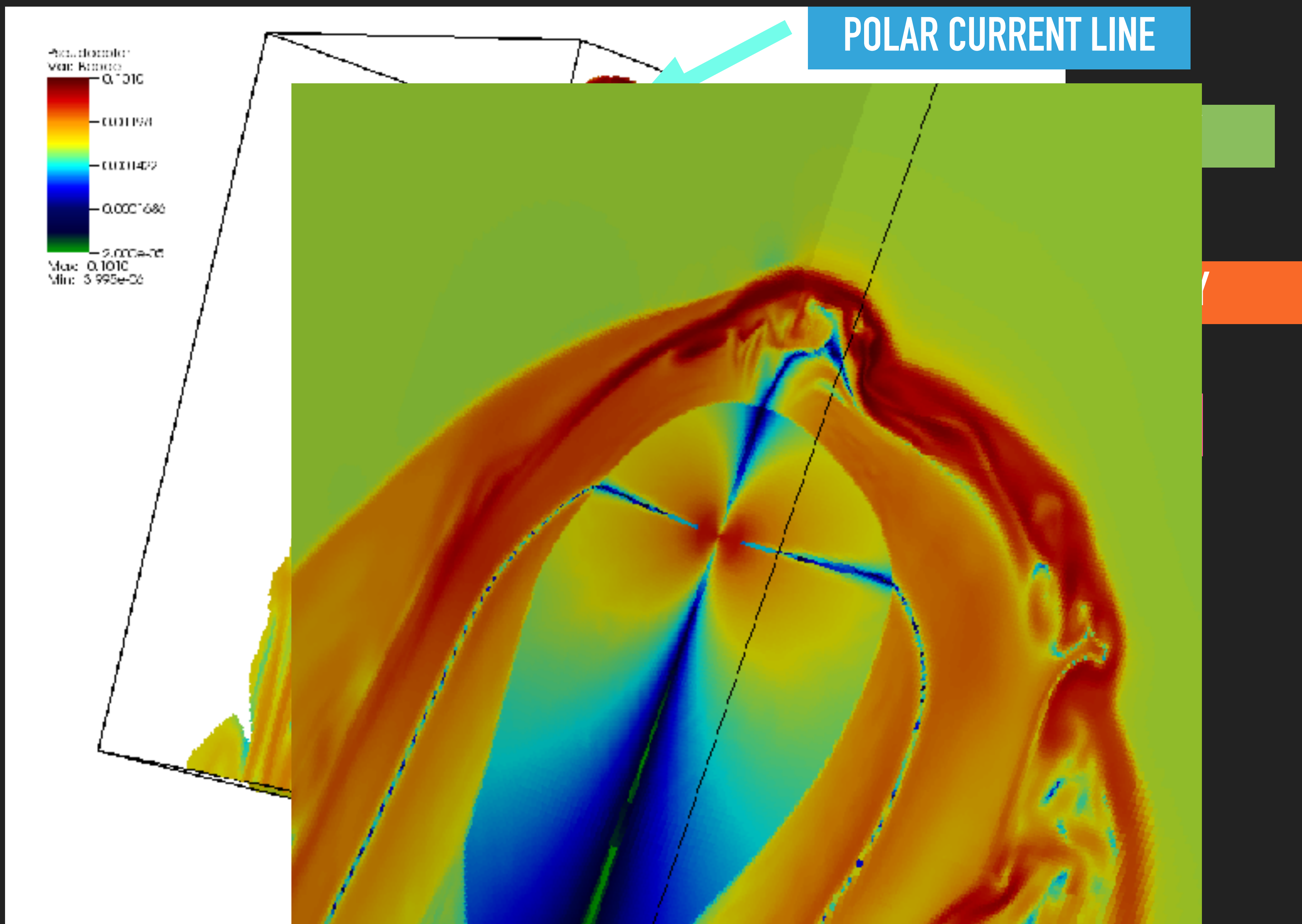
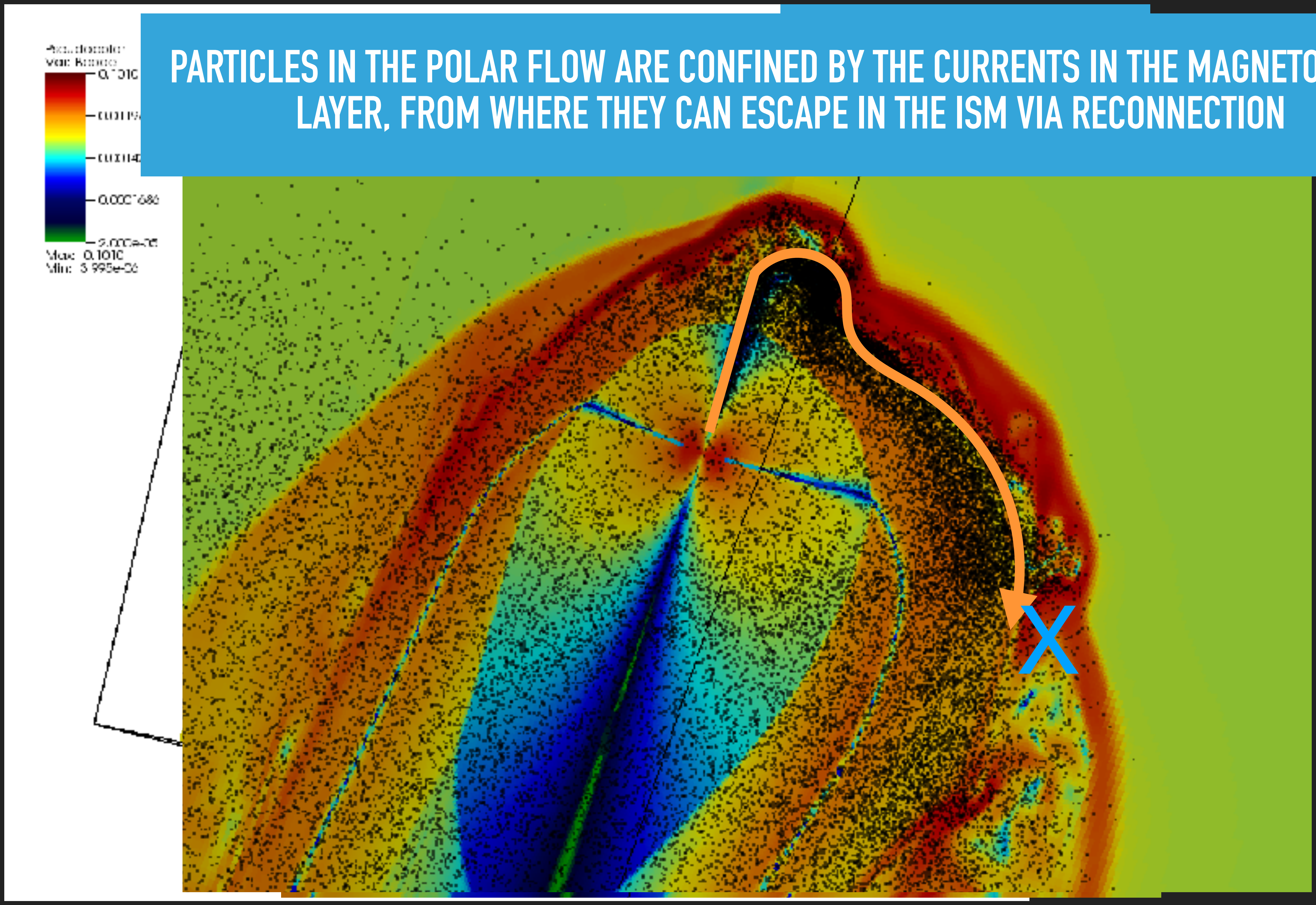


ROLE OF CURRENTS

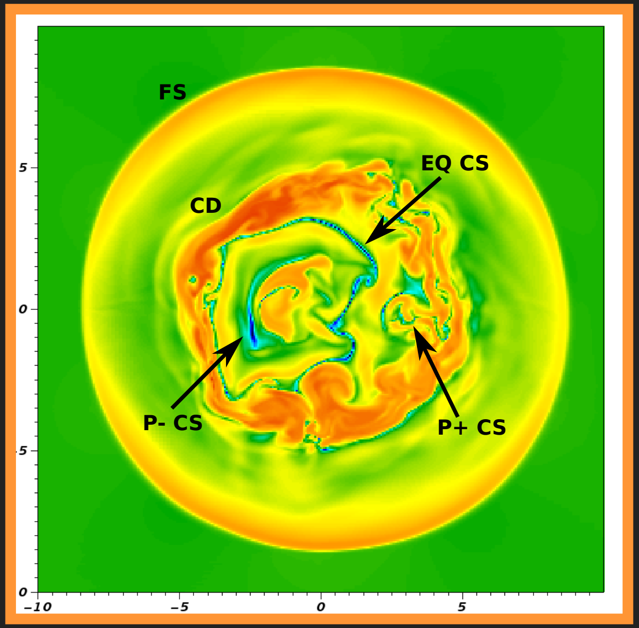


ROLE OF CURRENTS

PARTICLES IN THE POLAR FLOW ARE CONFINED BY THE CURRENTS IN THE MAGNETOPAUSE LAYER, FROM WHERE THEY CAN ESCAPE IN THE ISM VIA RECONNECTION

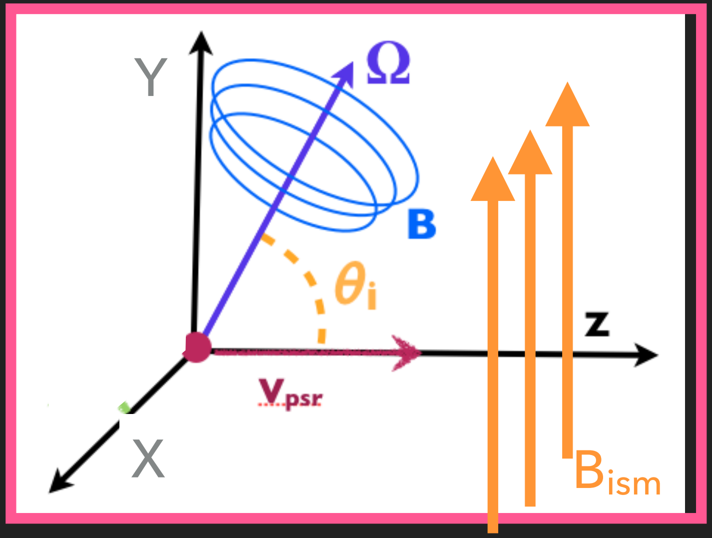


CONFINEMENT

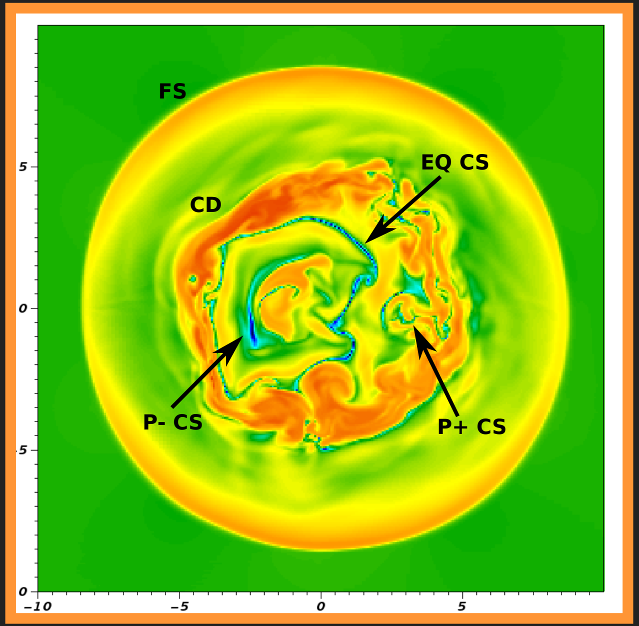


MAGNETIC FIELD AND CURRENT STRUCTURE IN THE TAIL

ISM MAGNETIC FIELD IS IN THE Y (HORIZONTAL) DIRECTION



CONFINEMENT



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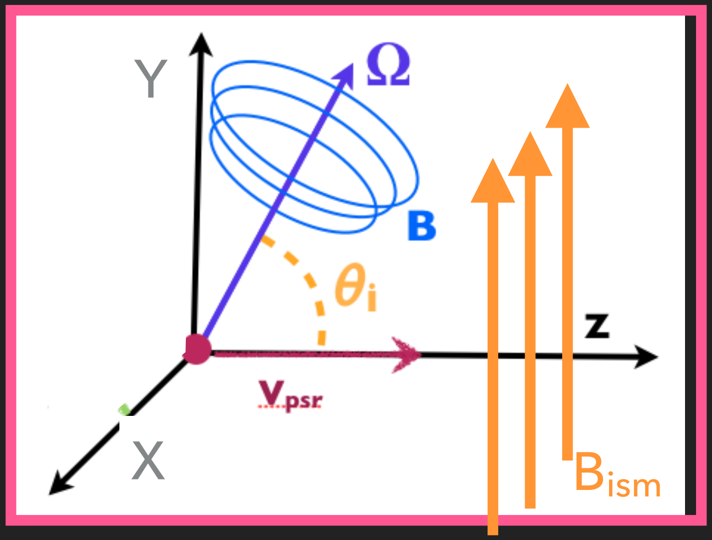
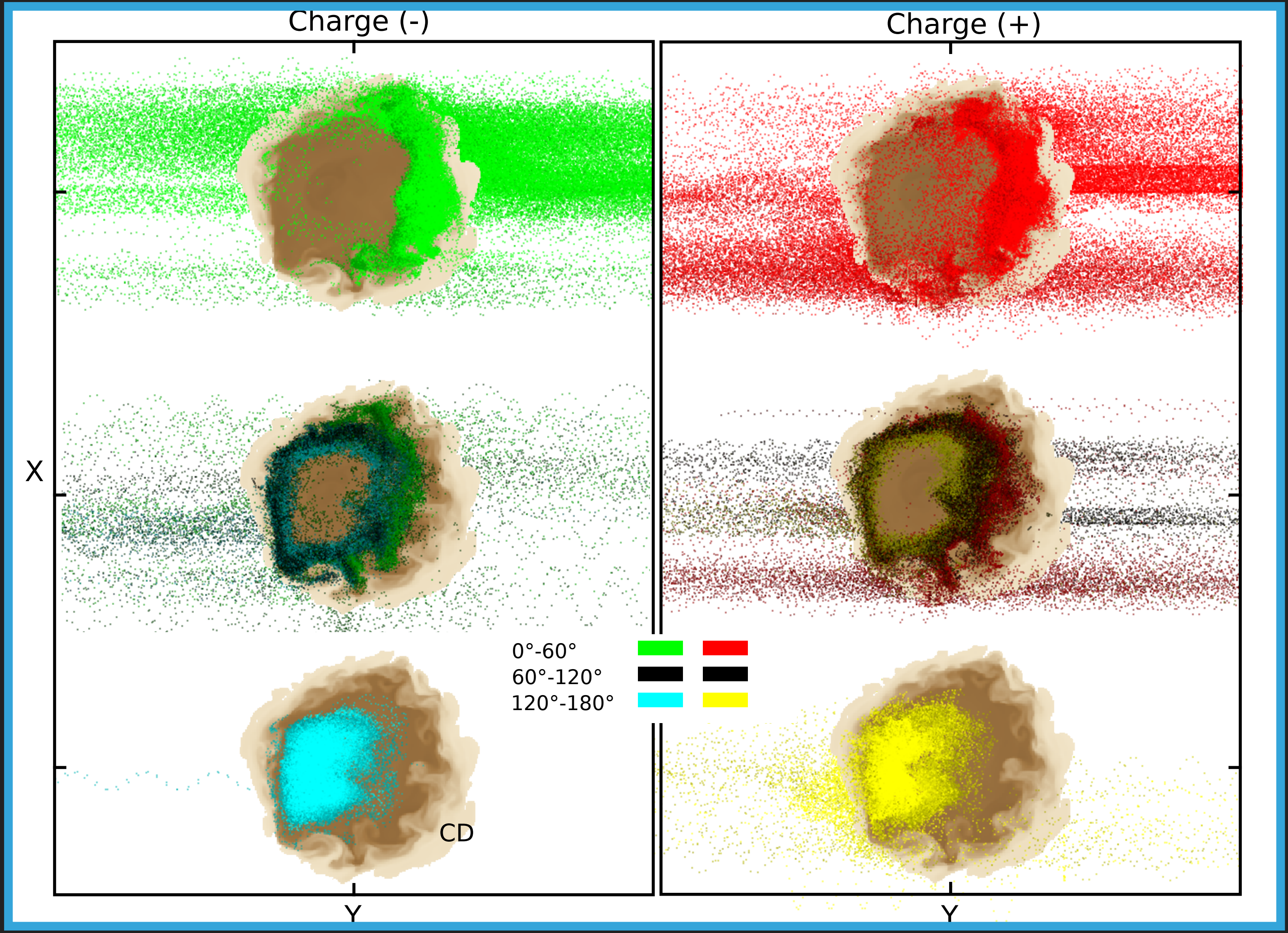
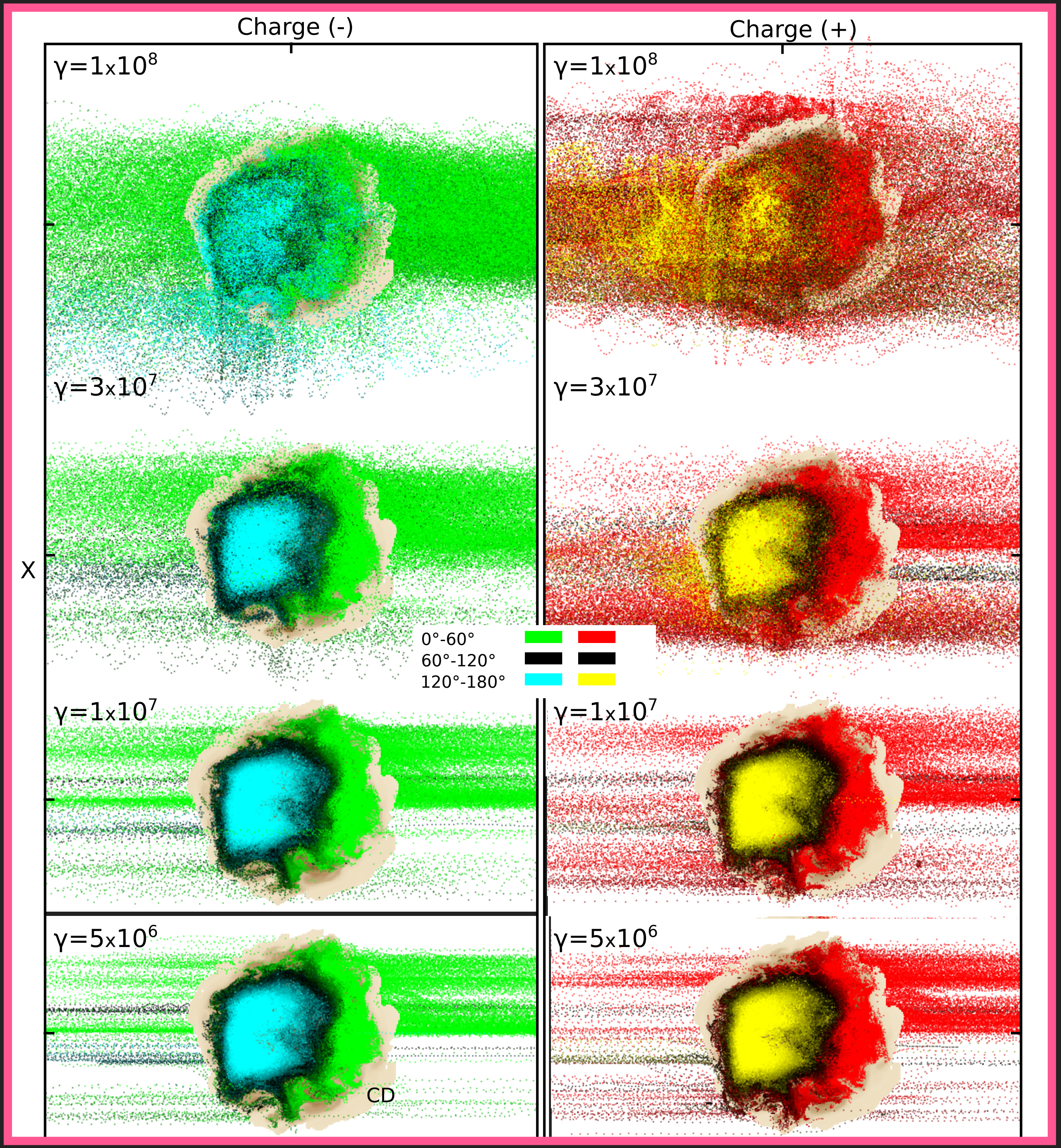


Olmi & Bucciantini 2019



JETS



VERY HIGH ENERGY

DIFFUSION

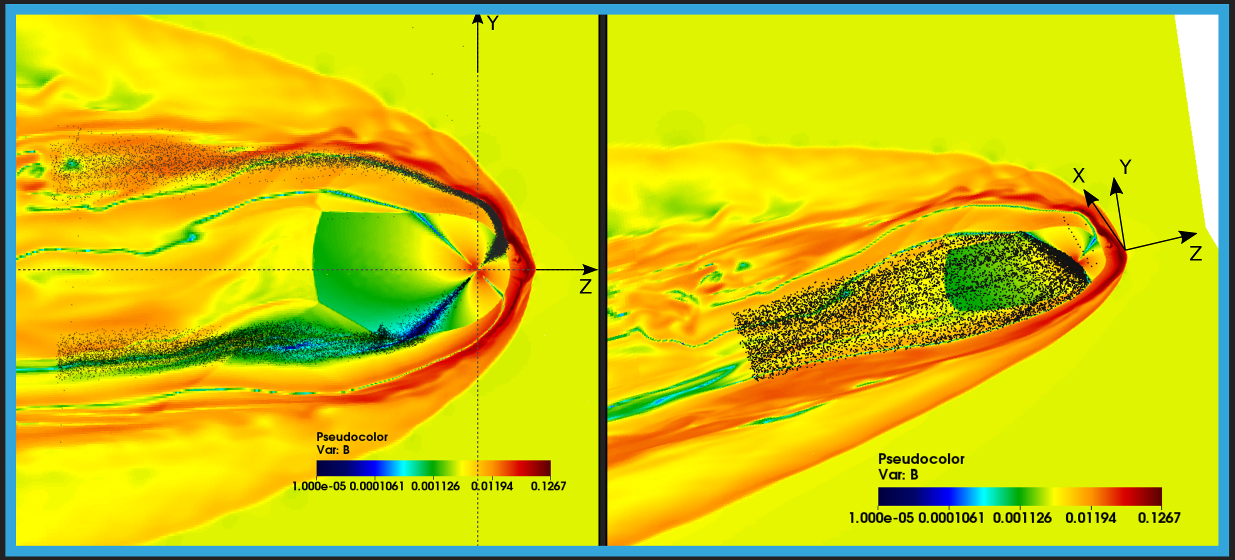
HIGH ENERGY

CURRENT CONFINEMENT

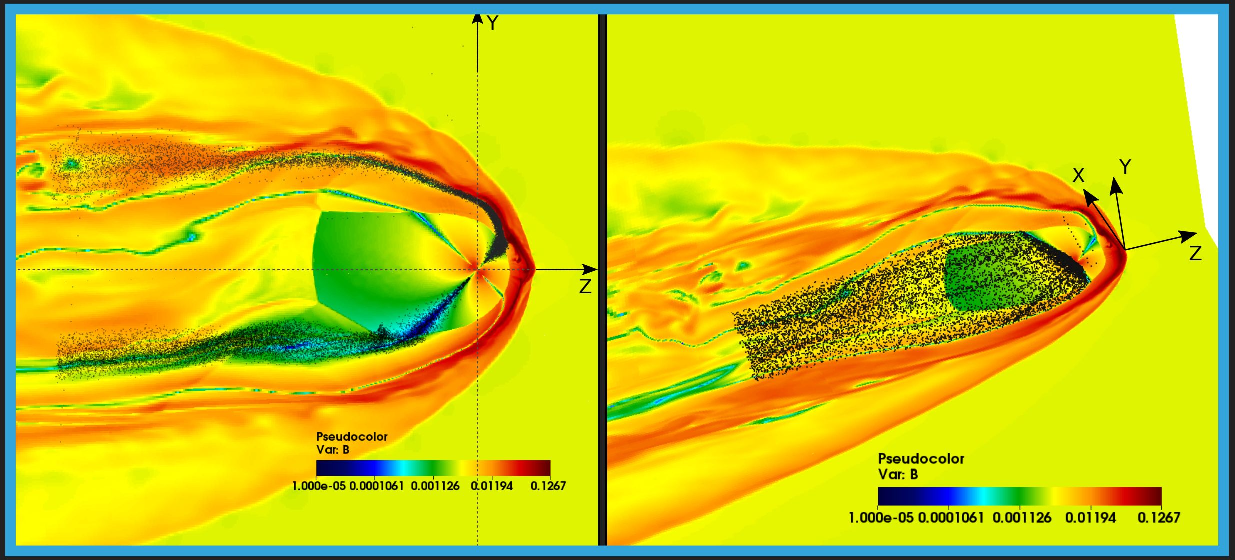
LOW ENERGY

RECONNECTION

JETS

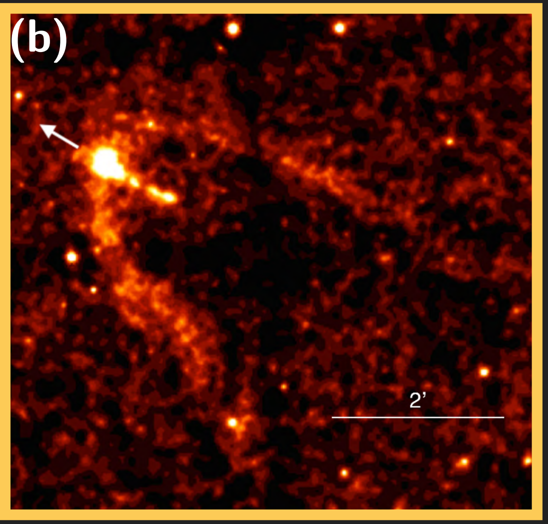

Y
Z
Pseudocolor
Var: B
1.000e-05 0.0001061 0.001126 0.01194 0.1267
X
Y
Z
Pseudocolor
Var: B
1.000e-05 0.0001061 0.001126 0.01194 0.1267

JETS

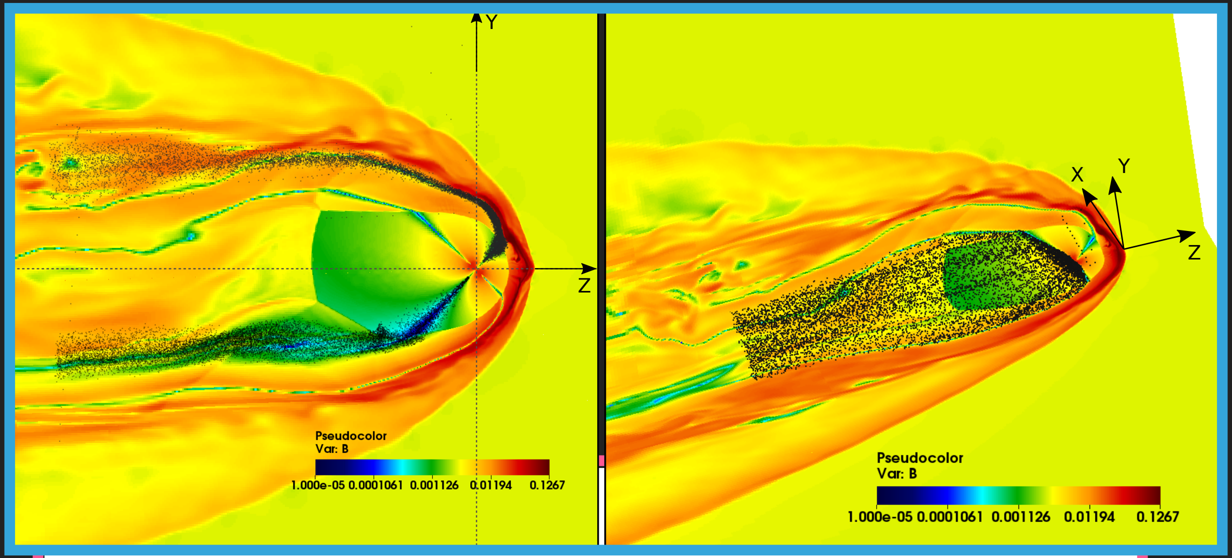


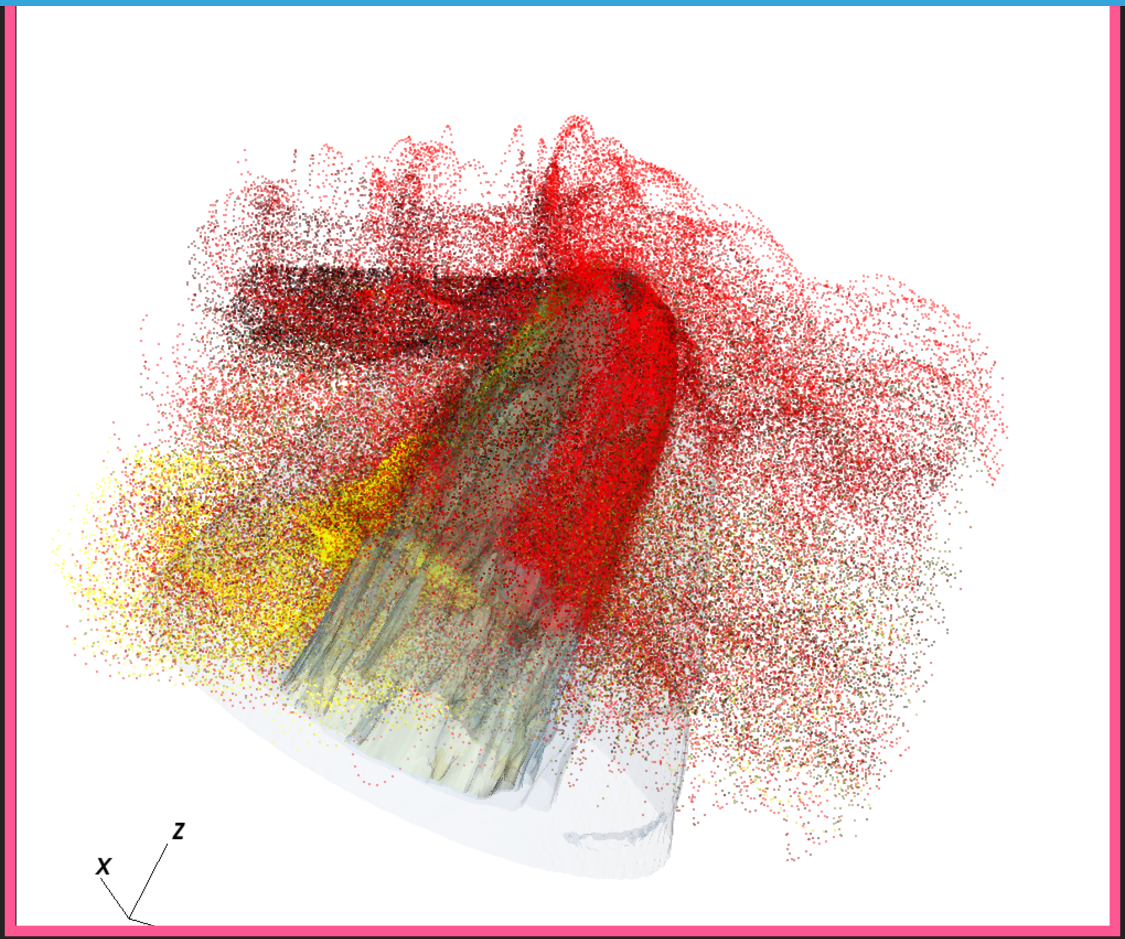
LOW ENERGY PARTICLES REMAIN CONFINED IN CURRENTS

GEMINGA HARD TAILS



JETS





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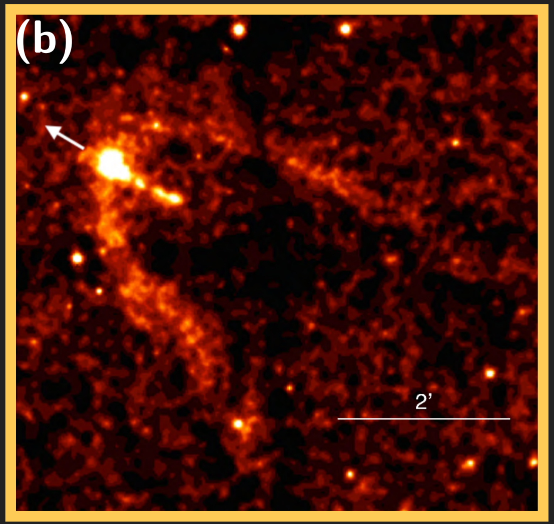
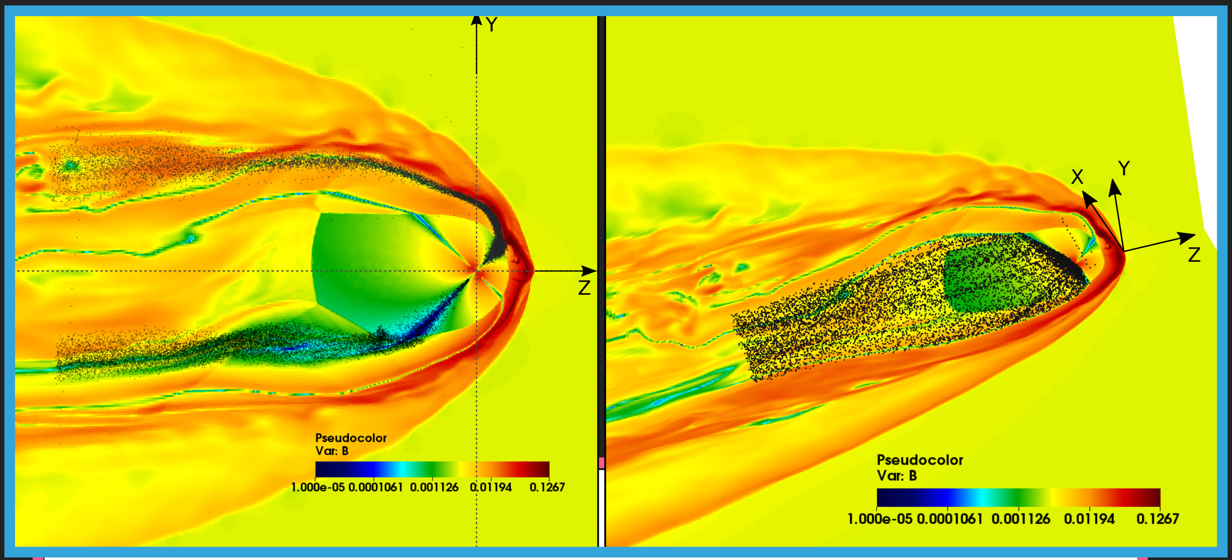
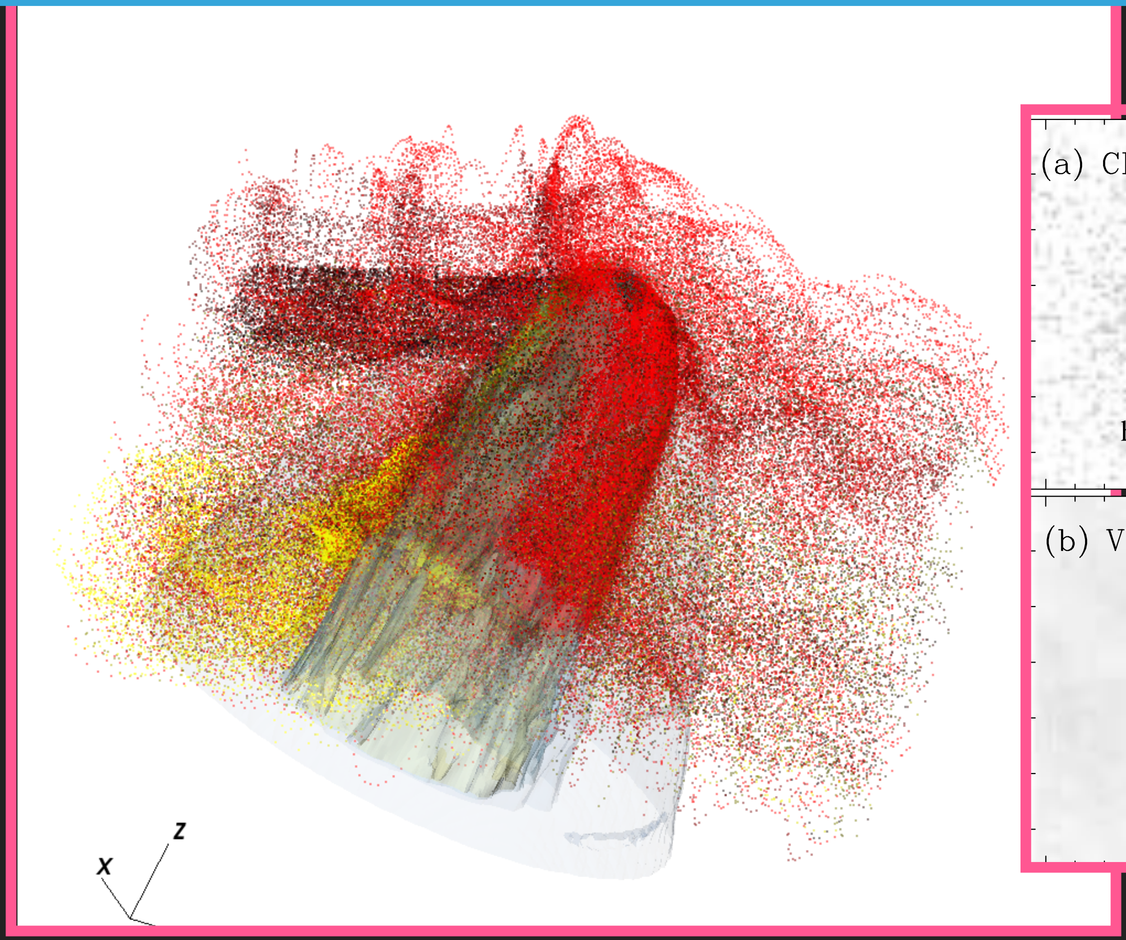


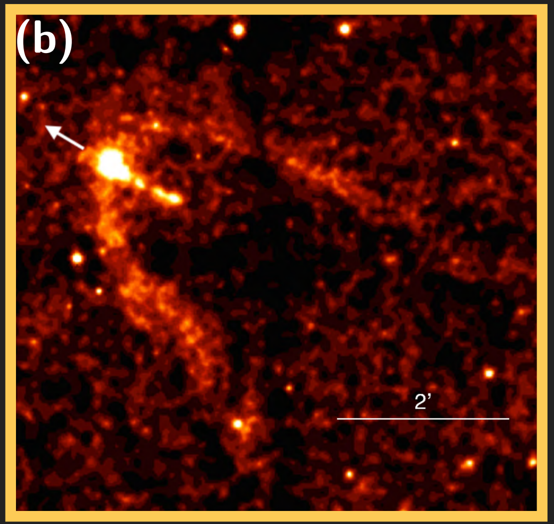
JETS

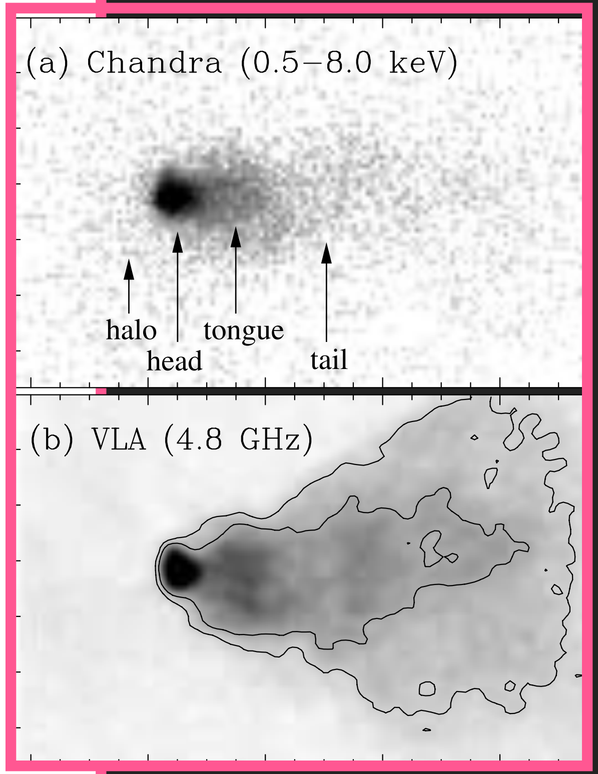




LOW ENERGY PARTICLES REMAIN CONFINED IN CURRENTS

GEMINGA HARD TAILS

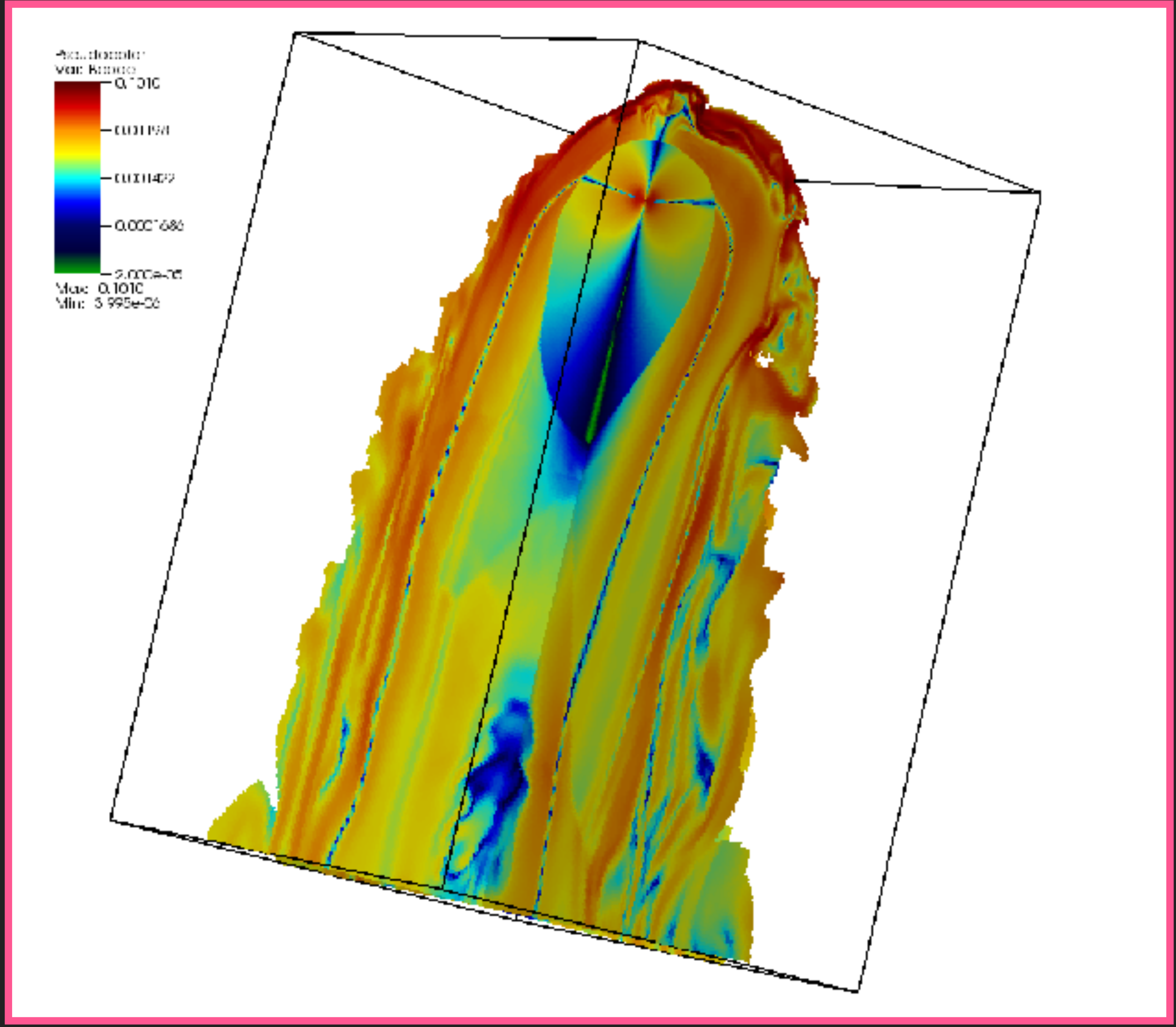




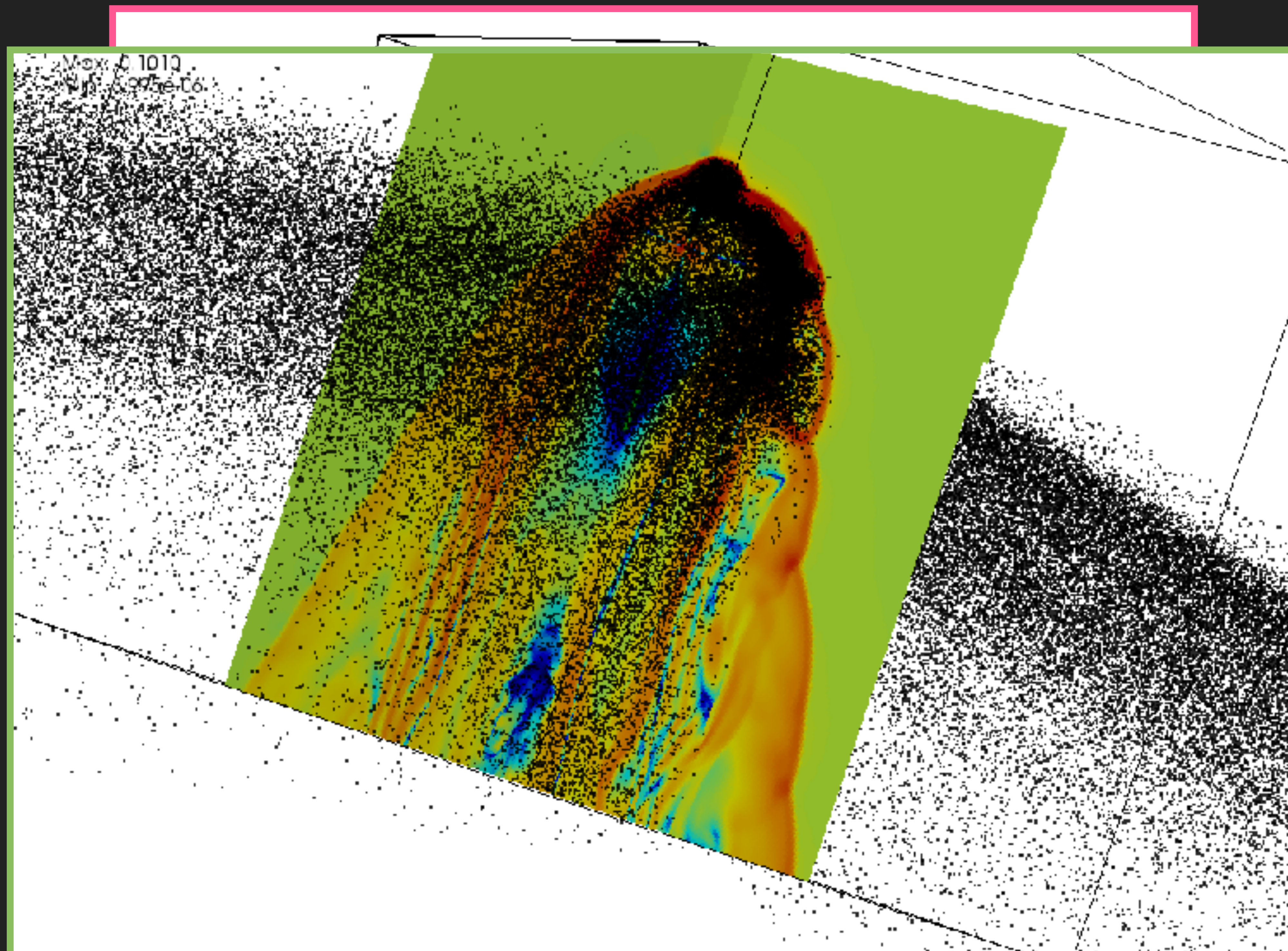
VERY HIGH ENERGY PARTICLES CAN ALSO DIFFUSE AHEAD

MAUSE X-RAY HALO

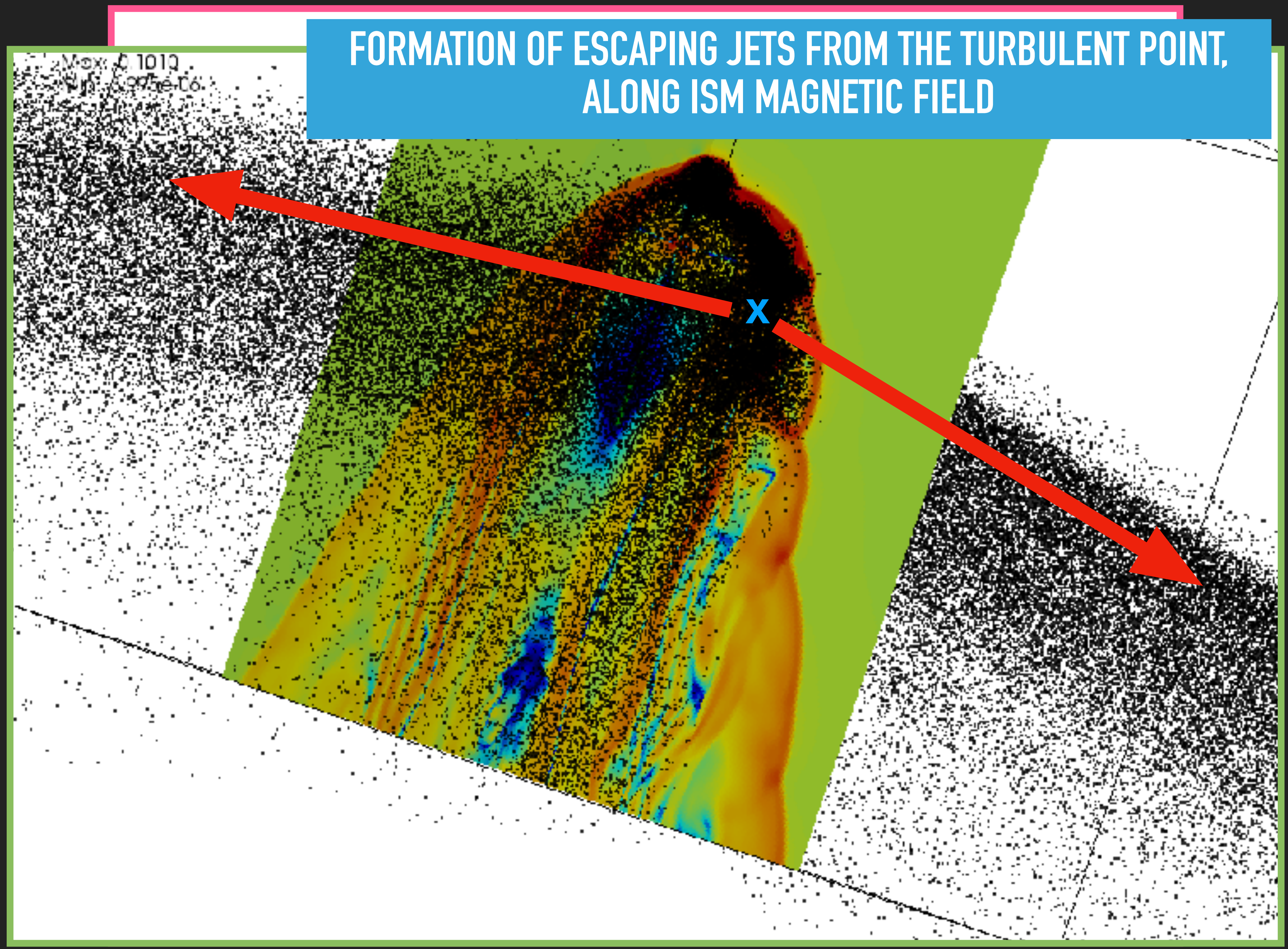
JETS



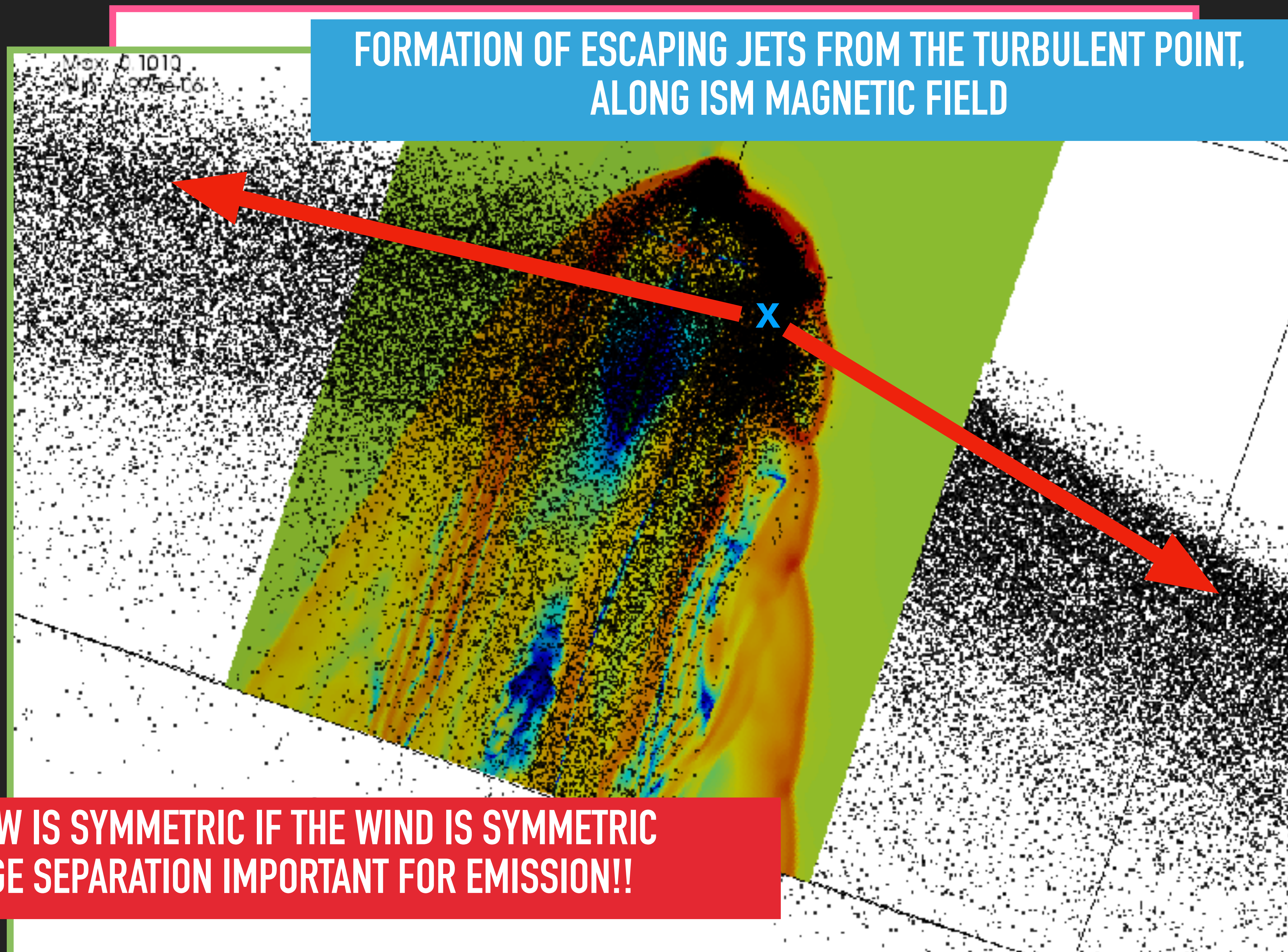
JETS



JETS


FORMATION OF ESCAPING JETS FROM THE TURBULENT POINT, ALONG ISM MAGNETIC FIELD
X

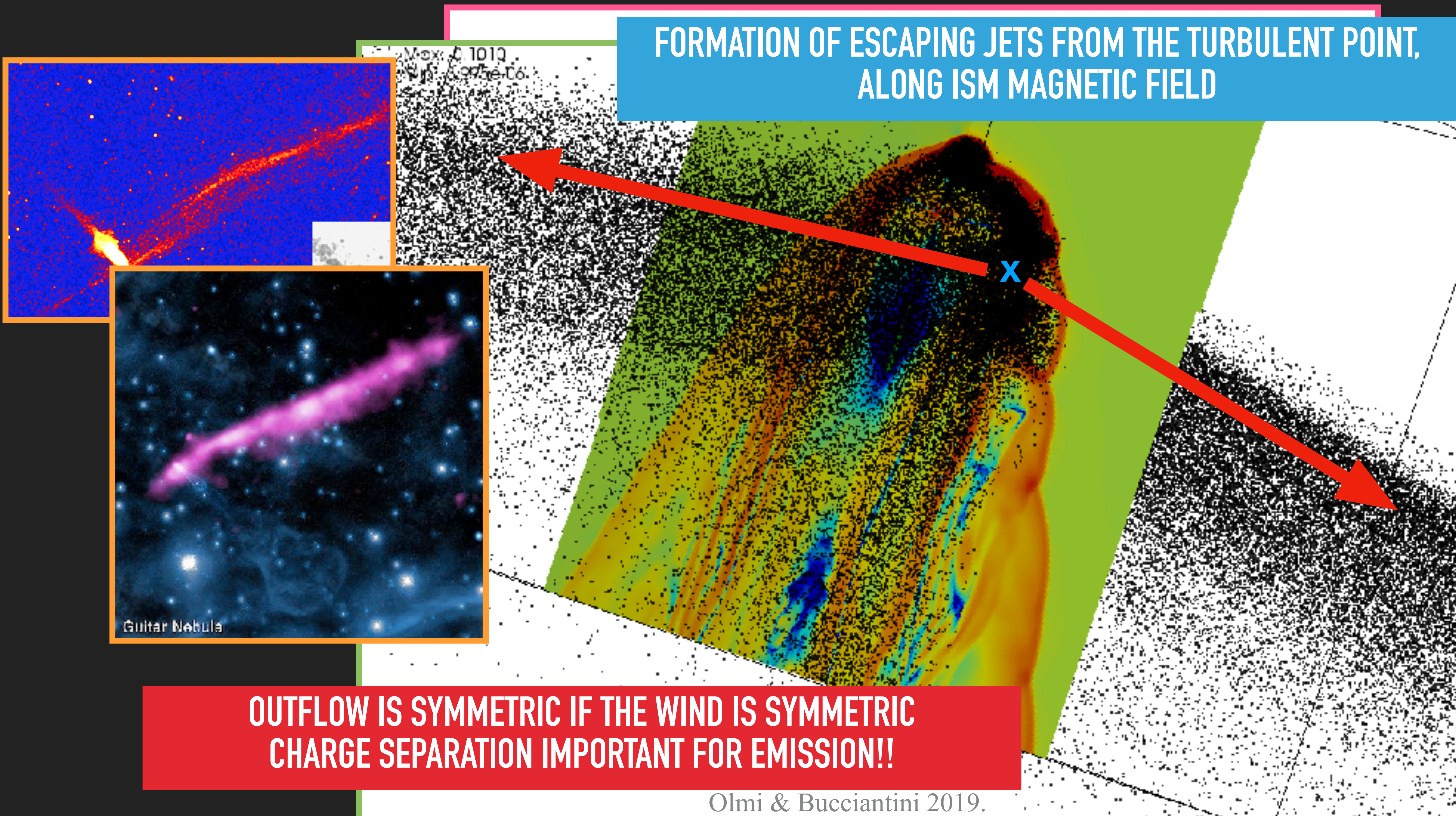
JETS



FORMATION OF ESCAPING JETS FROM THE TURBULENT POINT, ALONG ISM MAGNETIC FIELD

OUTFLOW IS SYMMETRIC IF THE WIND IS SYMMETRIC
CHARGE SEPARATION IMPORTANT FOR EMISSION!!

JETS


FORMATION OF ESCAPING JETS FROM THE TURBULENT POINT, ALONG ISM MAGNETIC FIELD
X
Guitar Nebula
OUTFLOW IS SYMMETRIC IF THE WIND IS SYMMETRIC
CHARGE SEPARATION IMPORTANT FOR EMISSION!!
Olmi & Bucciantini 2019.

CONCLUSIONS

3D SIMULATIONS NECESSARY TO COMPARE THE CORRECT DYNAMICS IN THE HEAD AND TAIL.

MAGNETIC TURBULENCE STRONGLY DEPENDENT ON WIND MAGNETISATION AND ENERGY ANISOTROPY

SYNCHROTRON EMISSIVITY SENSITIVE TO MAGNETIC CONFIGURATIONS ONLY FOR HIGH MAGNETISATIONS, AND QUASI-LAMINAR FLOW

HIGH ENERGY PARTICLES ESCAPE STRONGLY AFFECTED BY THE PRESENCE OF CURRENT SHEETS

DYNAMICS AT THE MAGNETOPAUSE CAN LEAD TO STRONG ANISOTROPY IN THE EMERGENT PARTICLE ENERGY FLUX

THANK YOU