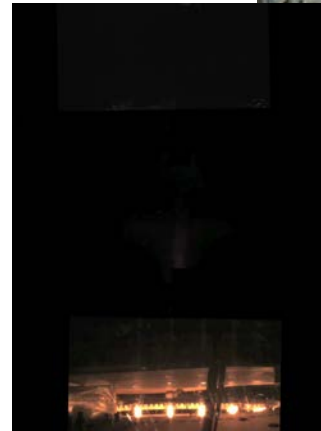


Morphology: PROTO-SPHERA experiment vs. the inner wind region of the Crab Nebula supernova remnant

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ISTW 2022

21th International Spherical Torus Workshop (ISTW 2022), Tsinghua University, Beijing, China, Oct. 31-Nov. 4 2022

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Giuseppe Galatola Teka

OUTLINE

A plasma torus and two kinked and broad plasma jets characterize both systems

Very different plasmas are implied (relativistic e^+/e^- couple plasma for the astrophysical one)

The magnetic field geometry seems however quite similar

Both plasma configurations are oblique rotators

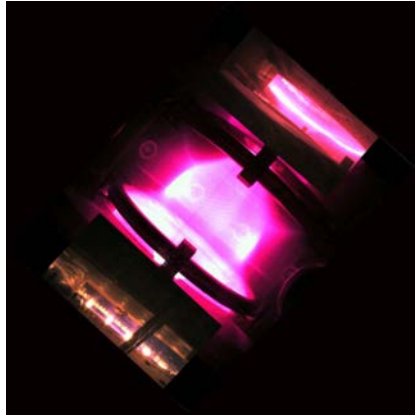
Magnetic reconnections are observed in both systems

Symmetry breakings are observed in both systems (breaking axisymmetry and up/down symmetry)

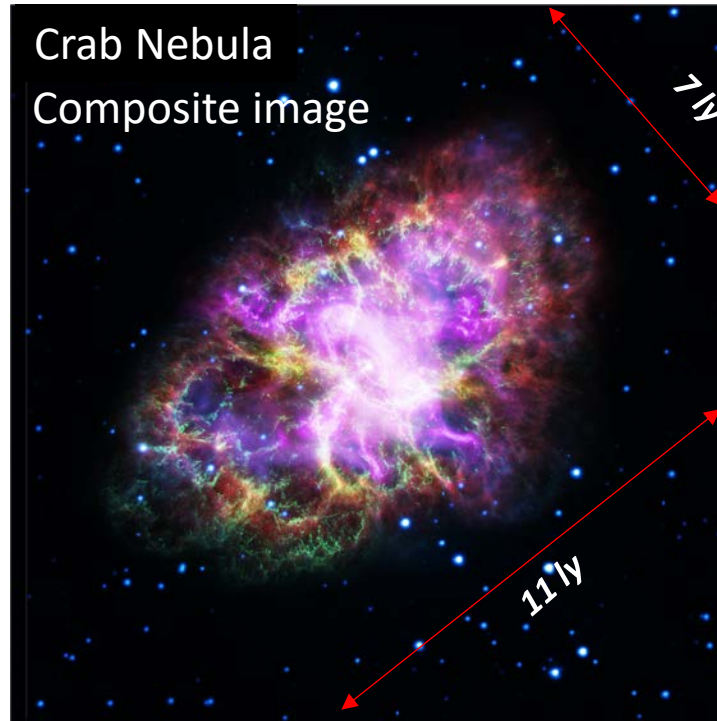
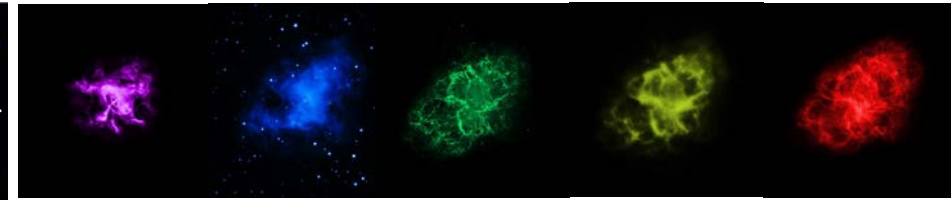
The current model of the Pulsar Wind Nebulae and of the Acceleration due to reconnections is outlined

A relevant difference in the jet electric current return between PROTO-SPHERA and the Wind models

A plasma torus and two kinked and broad plasma jets characterize both systems



PROTO-SPHERA



X-ray

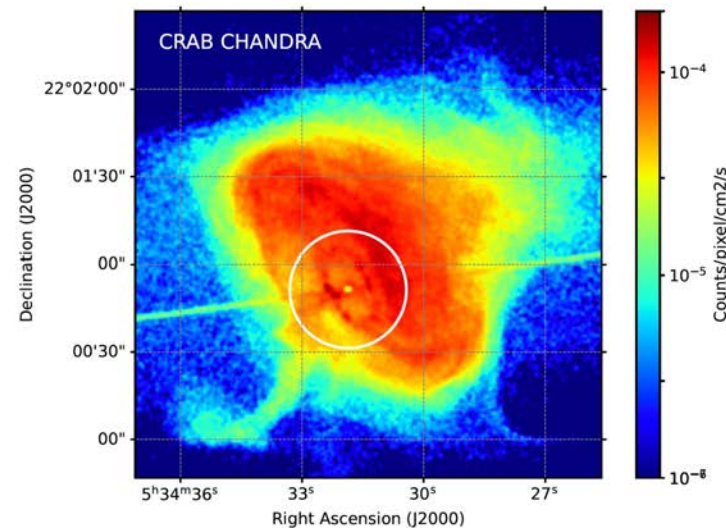
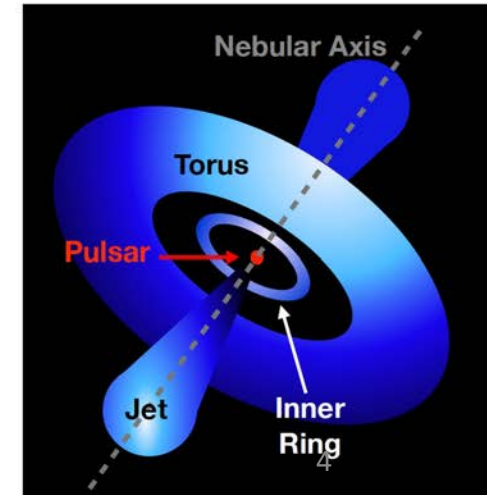
UV

Visible

IR

Radio

...but the Pulsar Wind Nebula torus is visible only in the high-energy part of the em. spectrum



Structure of the Crab Nebula

1 Unusually bright pulsar near the center powers everything

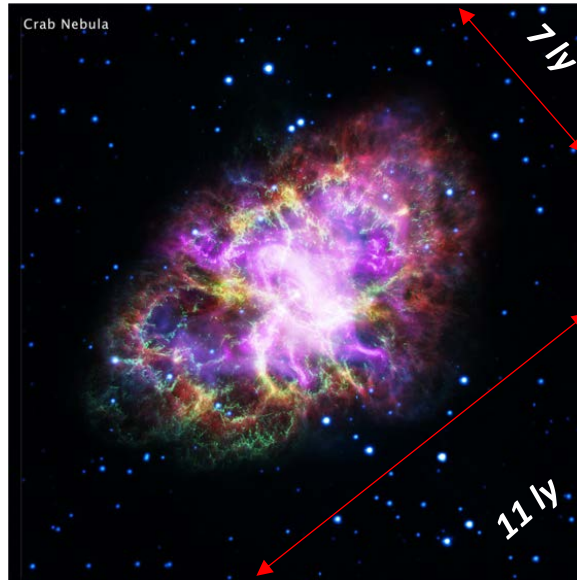
2 Pulsar's strong magnetic field accelerates and energizes nearby electrons

3 Lit-up electrons, called a "synchrotron nebula," fill much of the inside

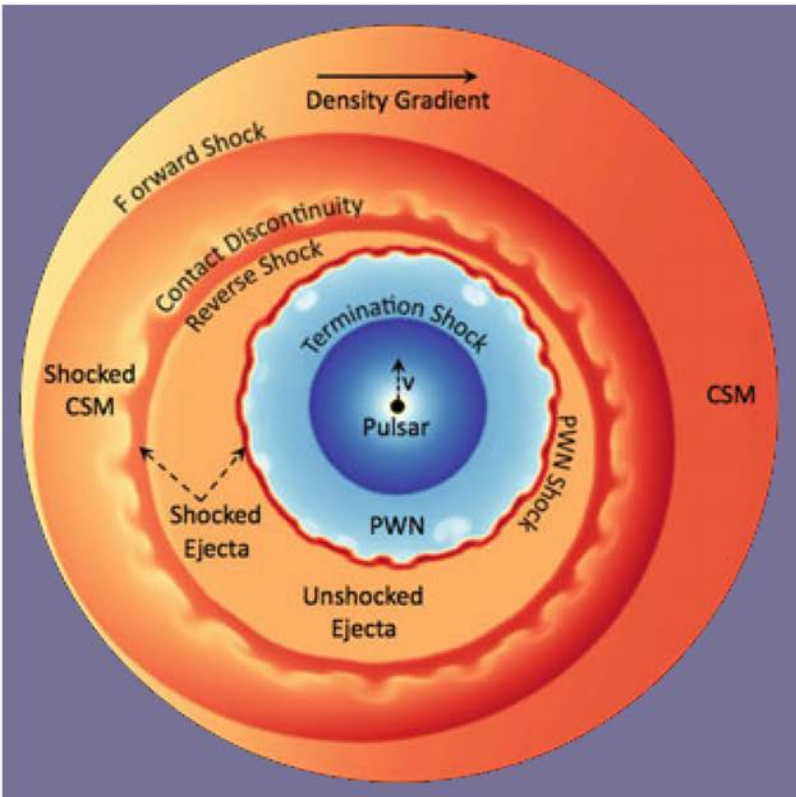
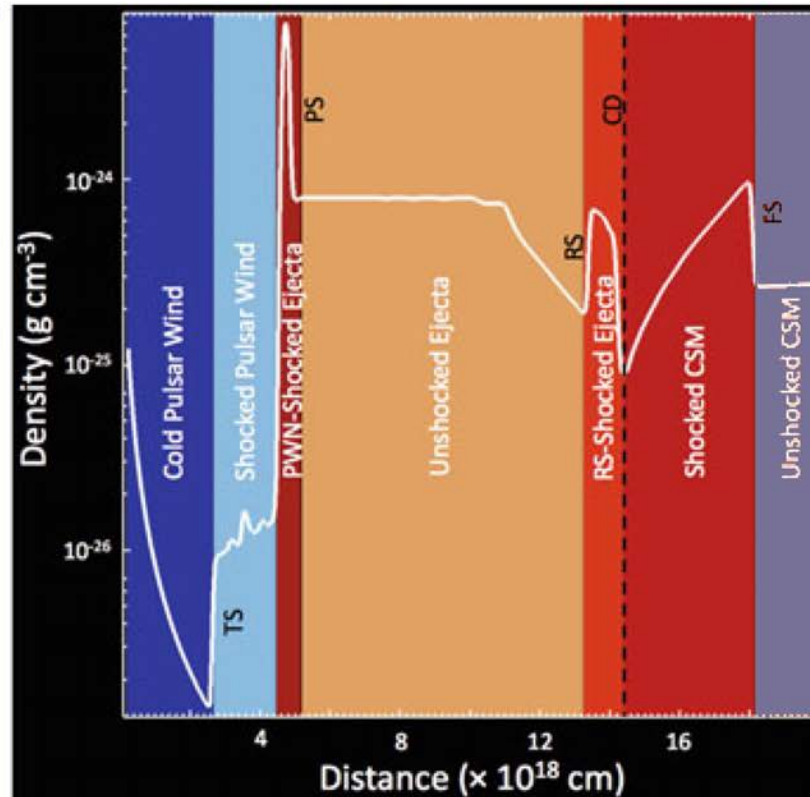
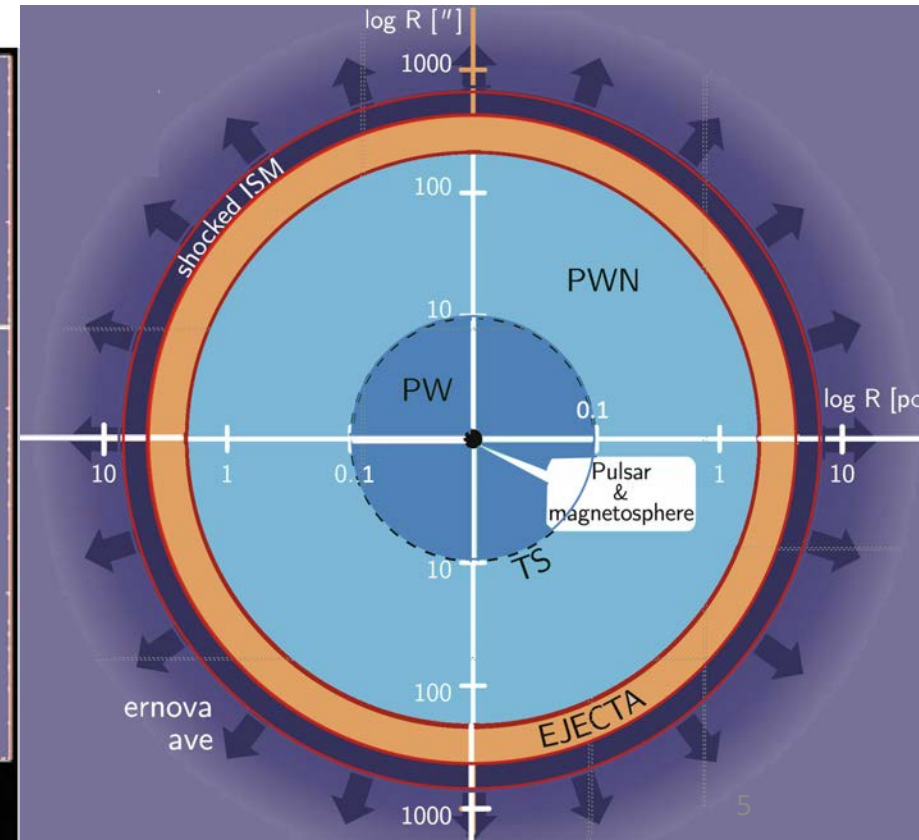
4 Synchrotron nebula pushes against the remains of progenitor star, creating shock waves

5 Shock waves transform stellar leftovers into subtle, visible filaments that encase the system

Astronomy: Roen Kally



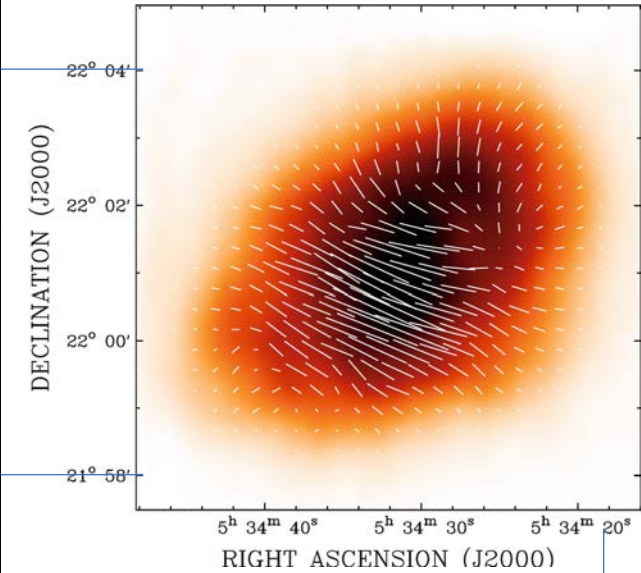
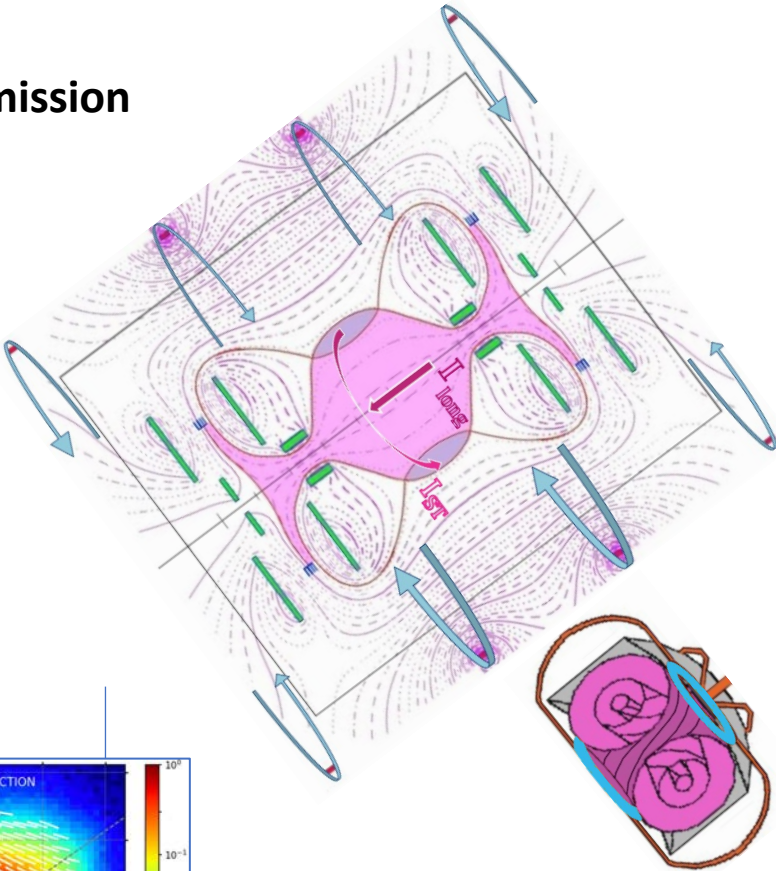
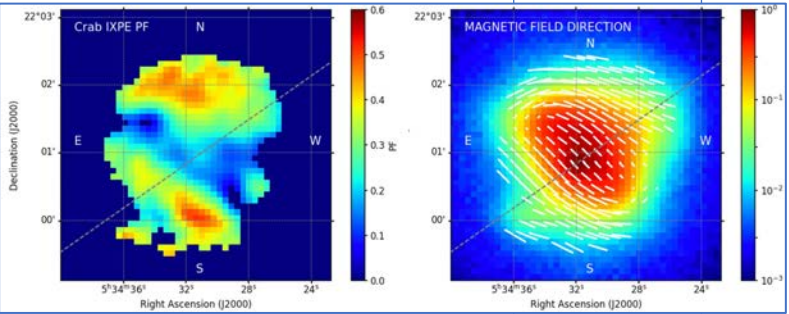
Such a wind downstream impinges on the Pulsar Ejecta and develops shock waves and is enriched by ions



in the Crab nebula the direction of the magnetic field (diagnosed from radio to X-ray emission) matches the expectations



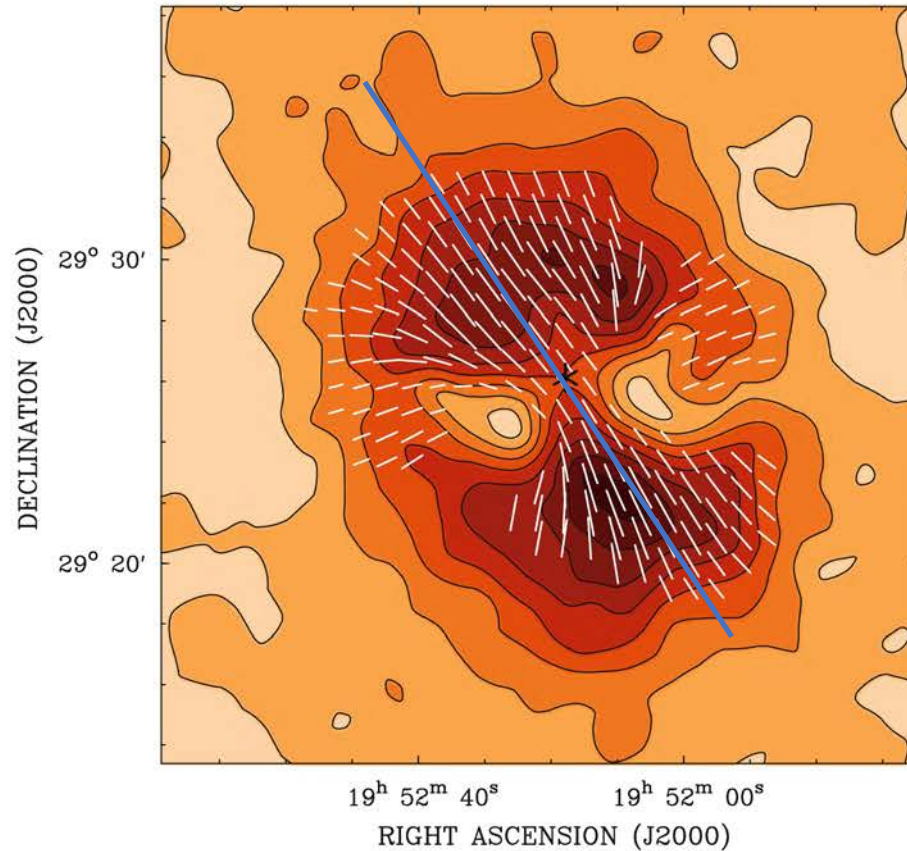
B-field direction from radio emission



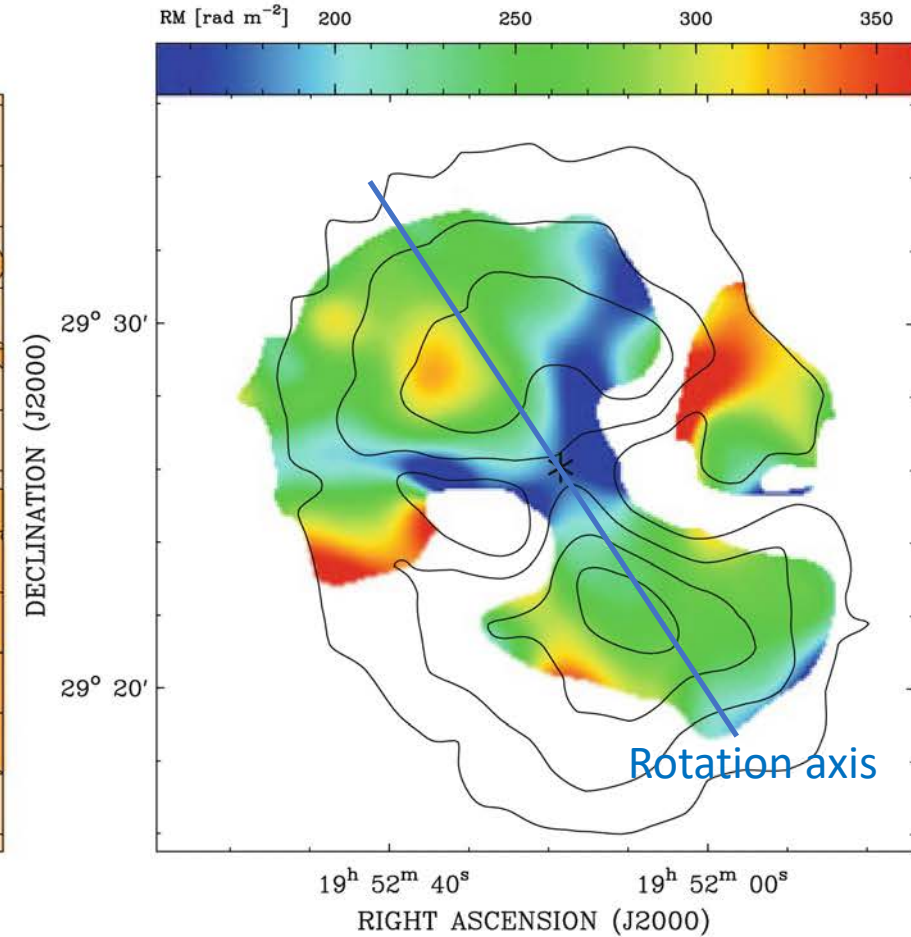
B-field direction from X-ray polarization

Other Pulsars Wind Nebulae confirm the Magnetic field geometry

Pulsar DA 495



B-field direction from radio emission

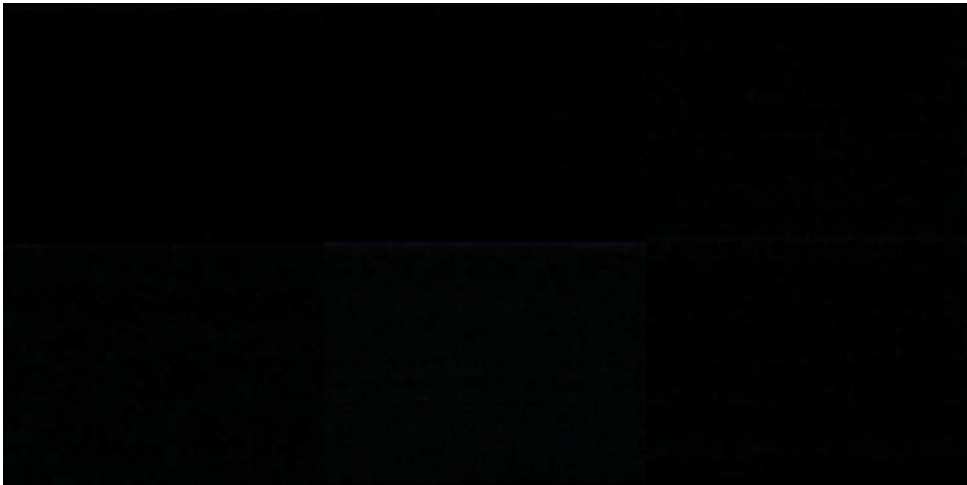
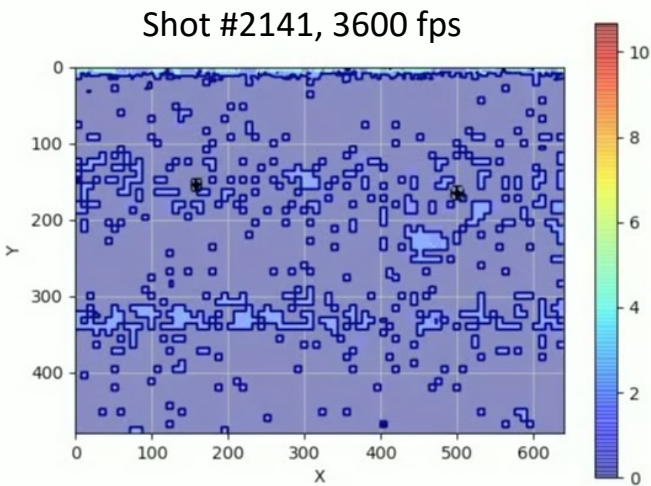


Color: rotation map; contours Polarization intensity

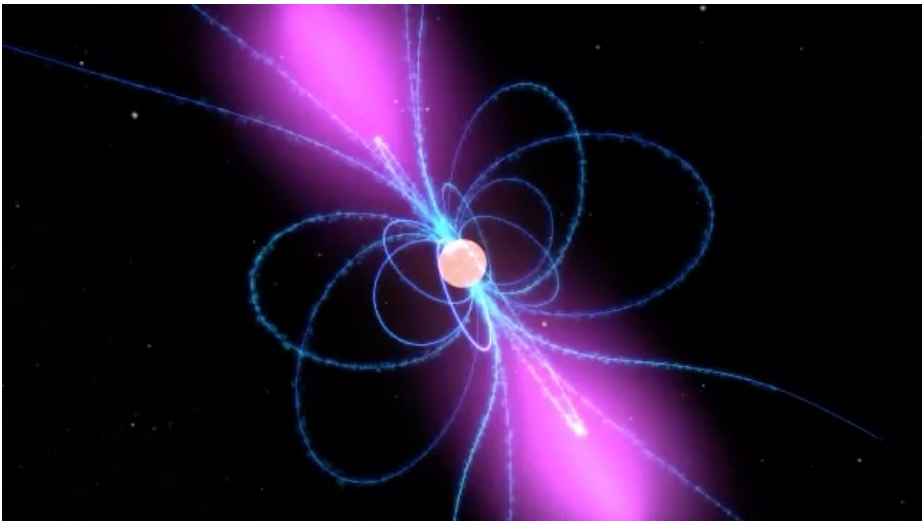
PROTO-SPHERA acts as an oblique rotator: tilted azimuthal rotation of the plasma



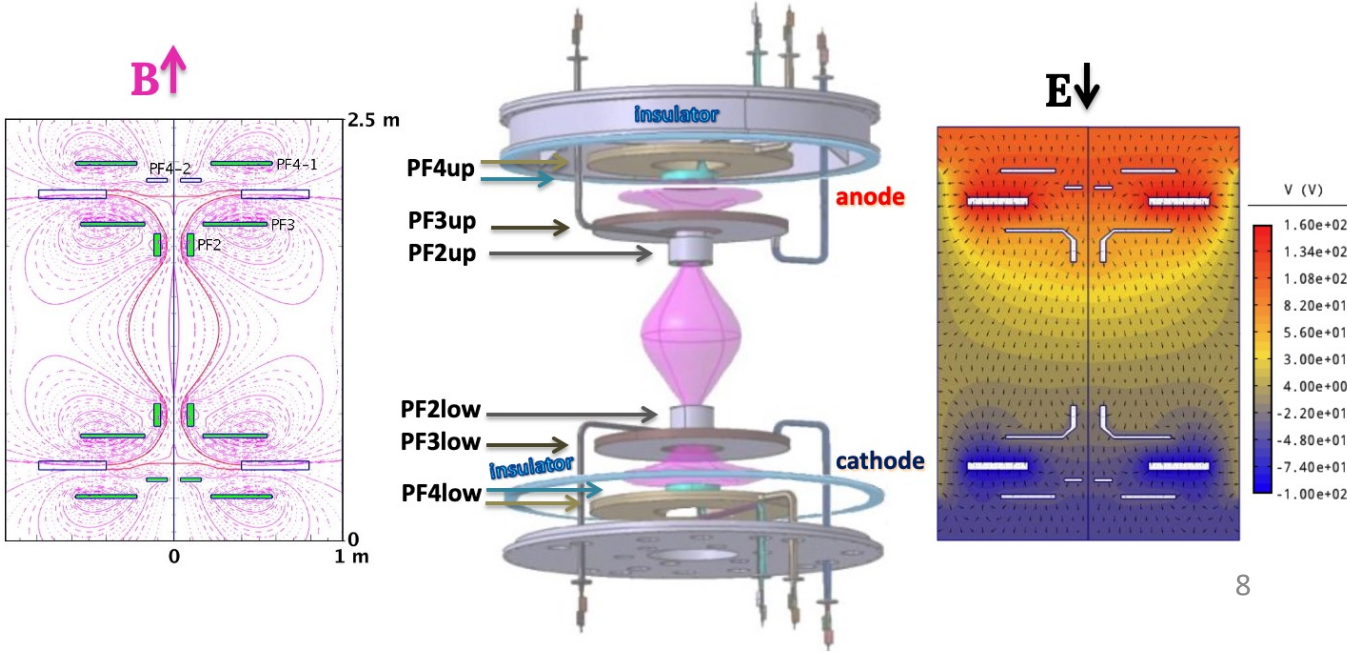
Shot #2141, 600 fps



Central engine of Pulsar Nebulae : Pulsar, born spinning, provides energy as a braked oblique rotator



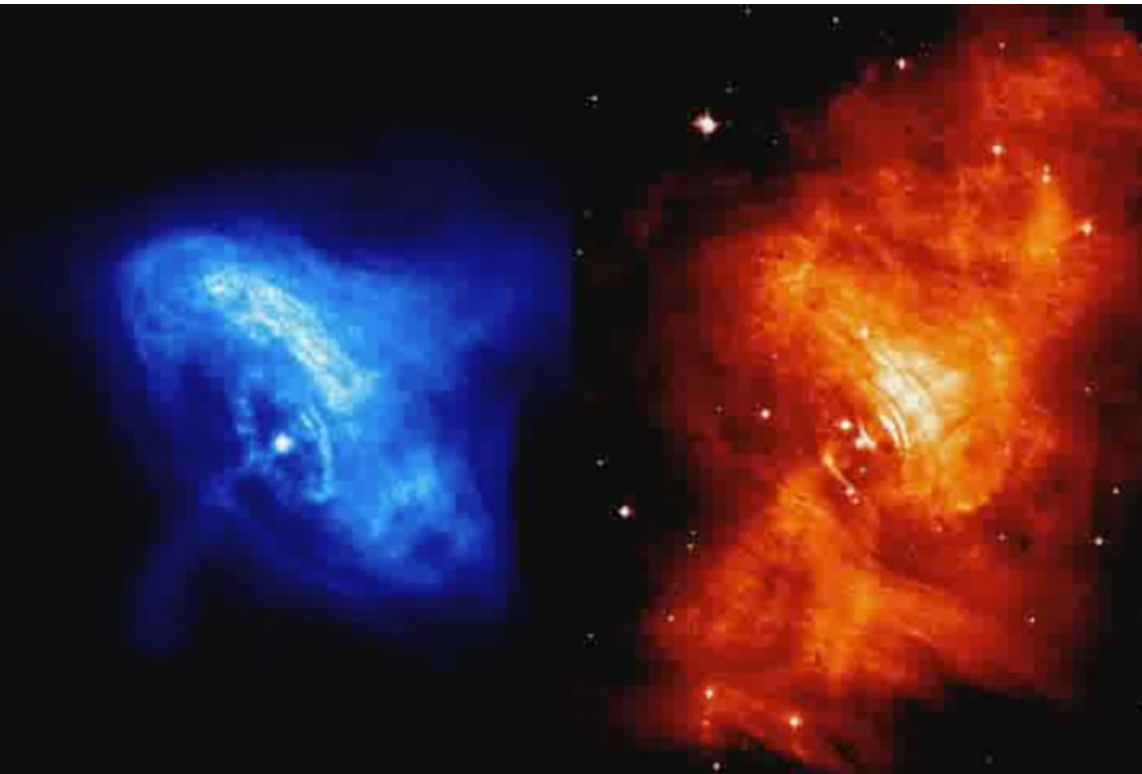
Rotation of PROTO-SPHERA is due to up/down symmetry breaking of electrostatic field E , albeit magnetic field B is up/down symmetric



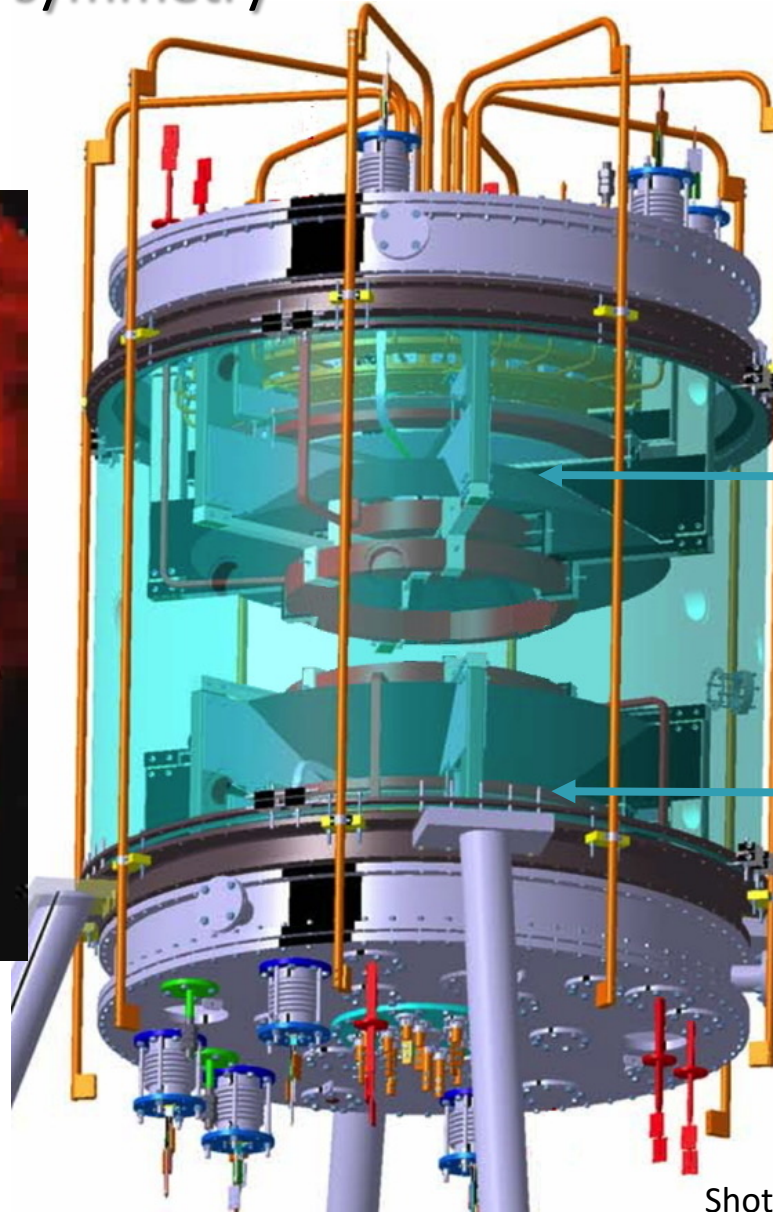
Magnetic reconnections appear as continuous pulsations in both case, they break: axisymmetry and “up/down” symmetry

Crab Nebula:

1) Non-axisymmetric Inner Ring activity



2) Dissimmetry of Jets



PROTO-SPHERA:

- 1) 3D magnetic reconnection
- 2) Up/down dissymmetry

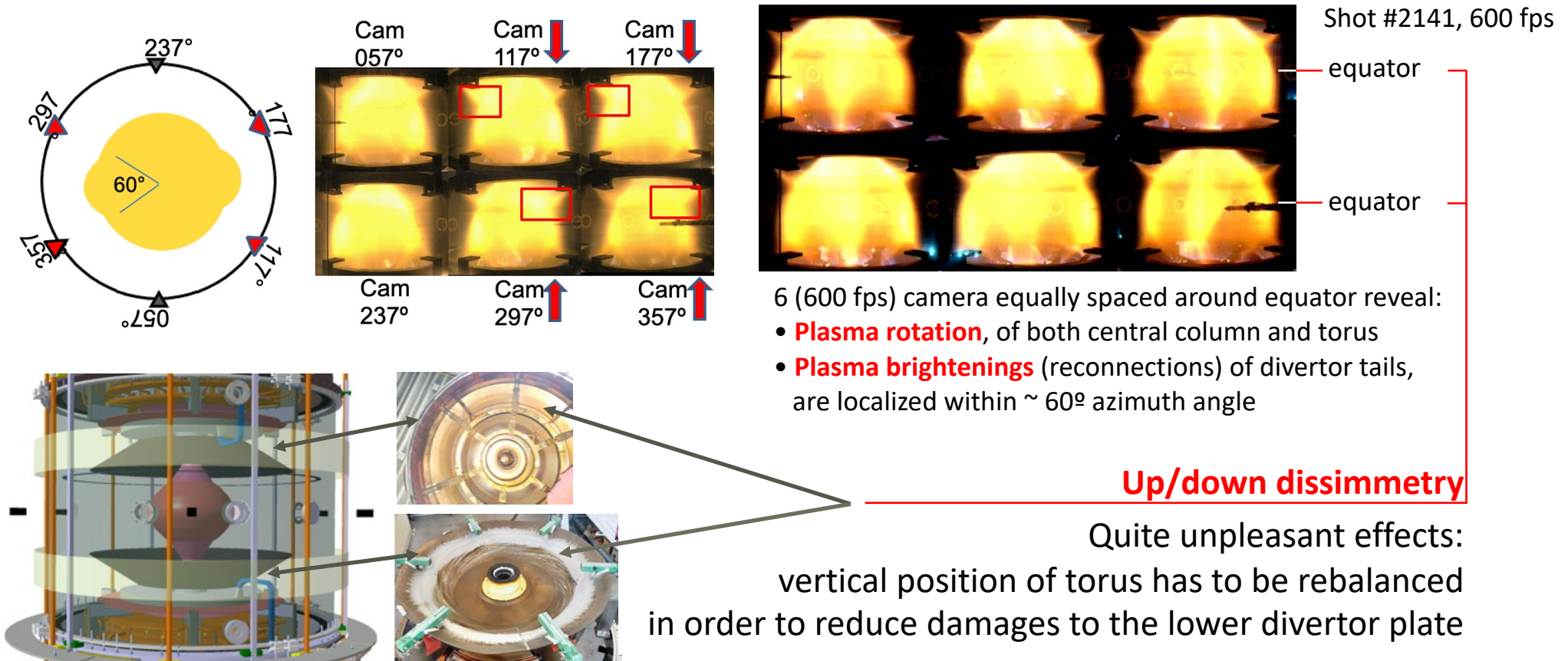
on 2 circles **ordinary X-points** ($B_{\text{tor}} \neq 0$)
& “divertor tails” top & bottom



Shot #2126
3600 fps

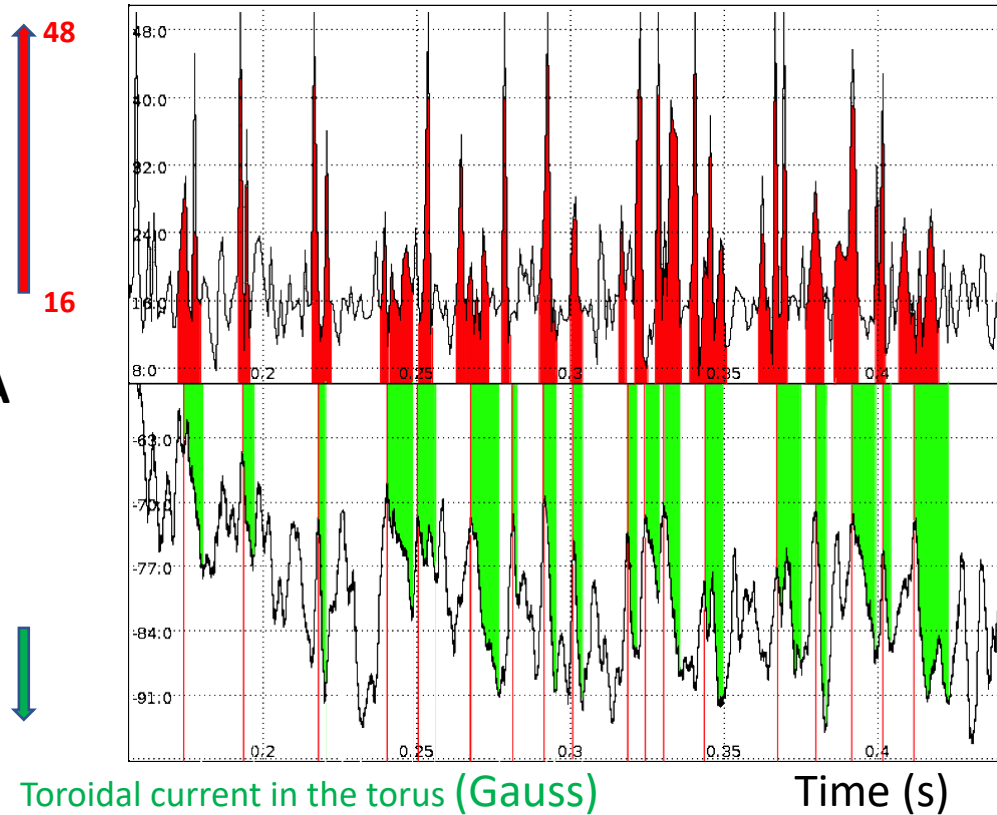
Symmetry breaking: Actions on PROTO-SPHERA

Axisymmetry breaking: is required in order to inject current in the torus (Cowling anti-dynamo theorem)

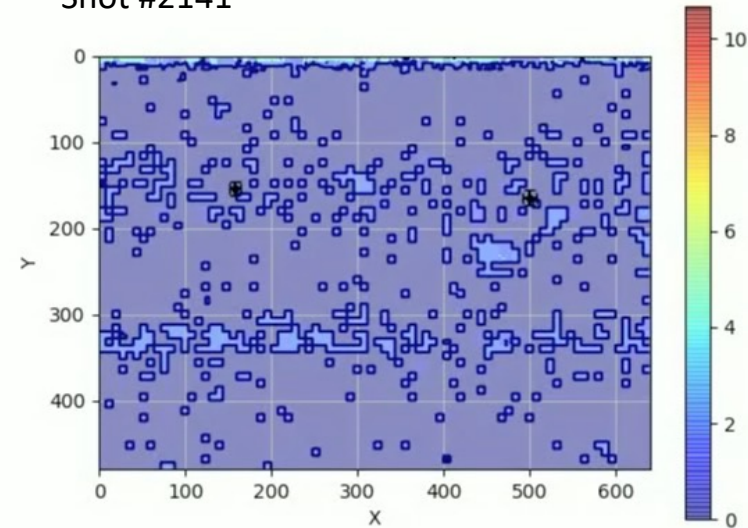


Effects of magnetic reconnection on plasma temperature and/or particle acceleration

Electron temperature at outer equatorial torus edge T_{e-edge} (eV)



Shot #2141



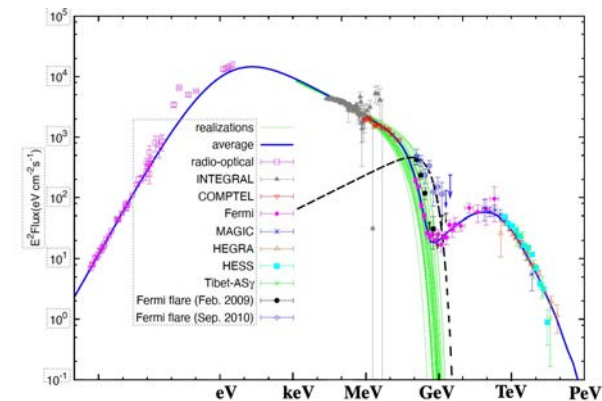
Magnetic reconnections, T_{e-edge} spikes
20 eV $\rightarrow$ 50 eV (heating? Acceleration?),
Followed by toroidal current injected into Torus

Crab Nebula



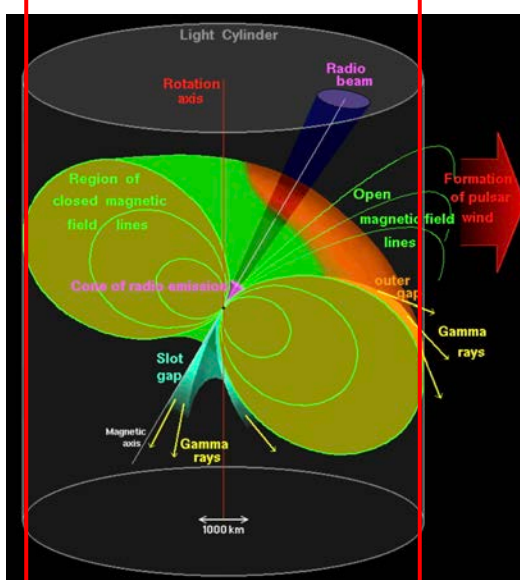
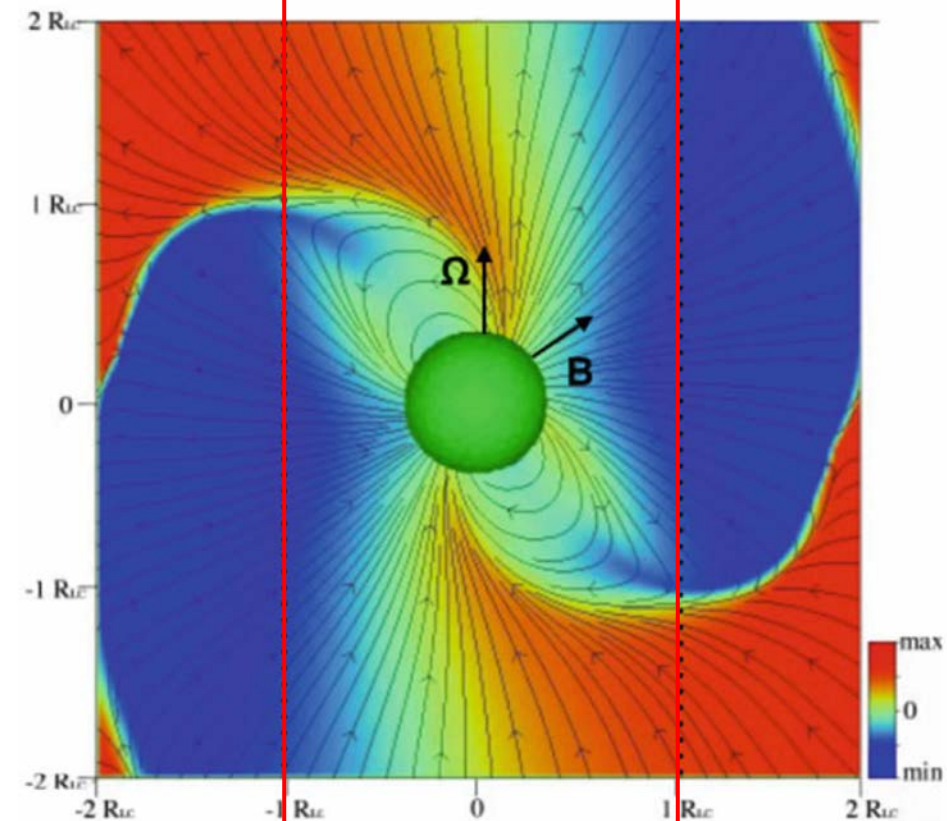
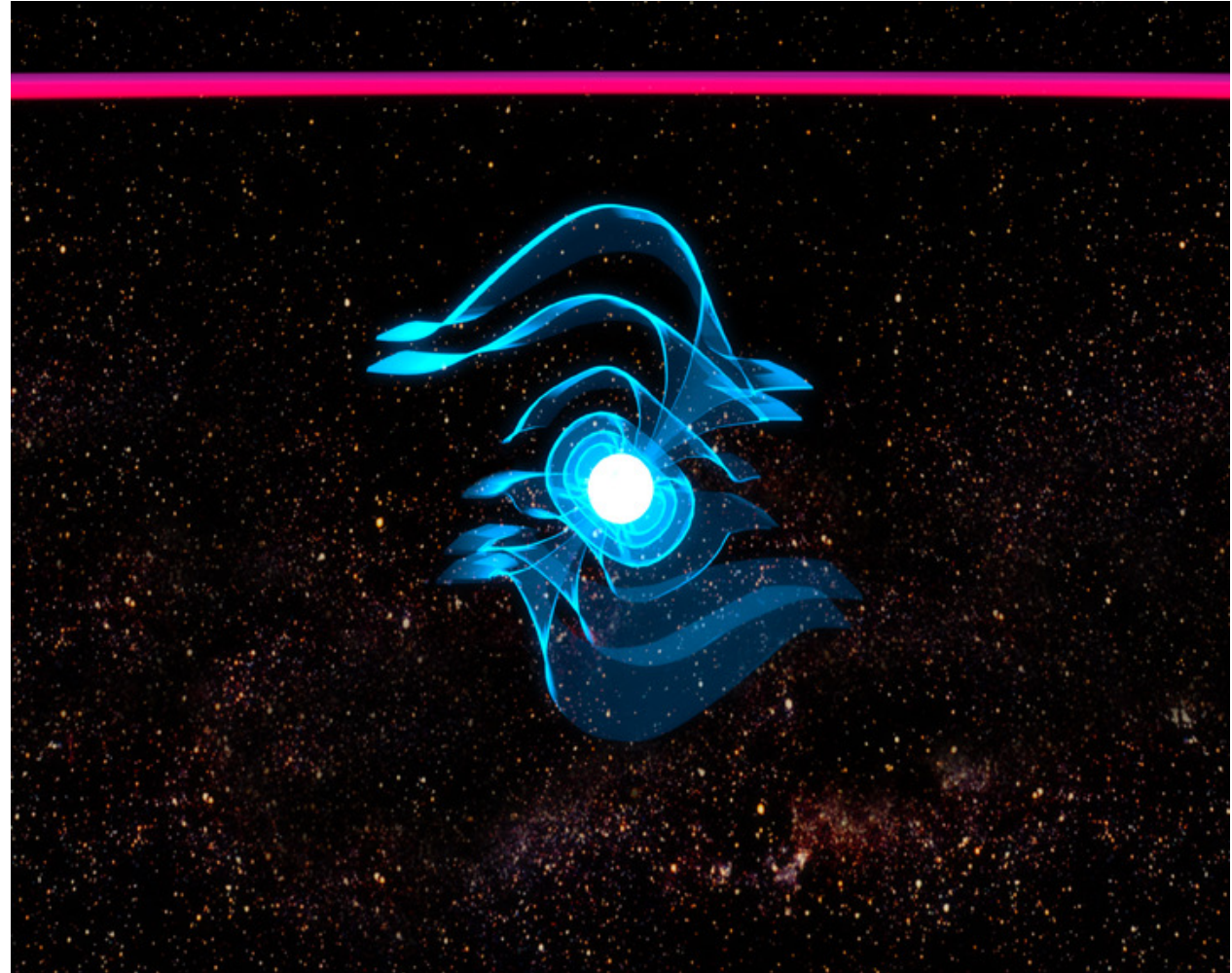
The best accelerator in the Galaxy!
 $\text{PeV} = 10^{15} \text{ eV}$

efficient acceleration due to
magnetic reconnections?

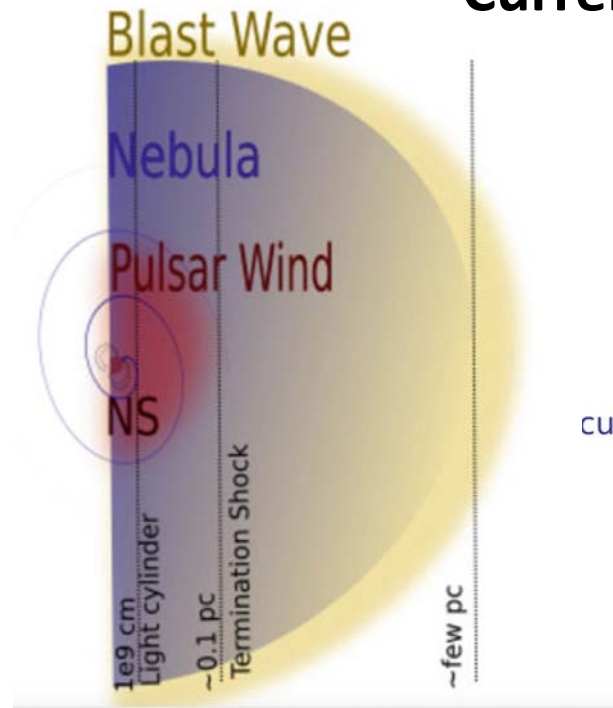
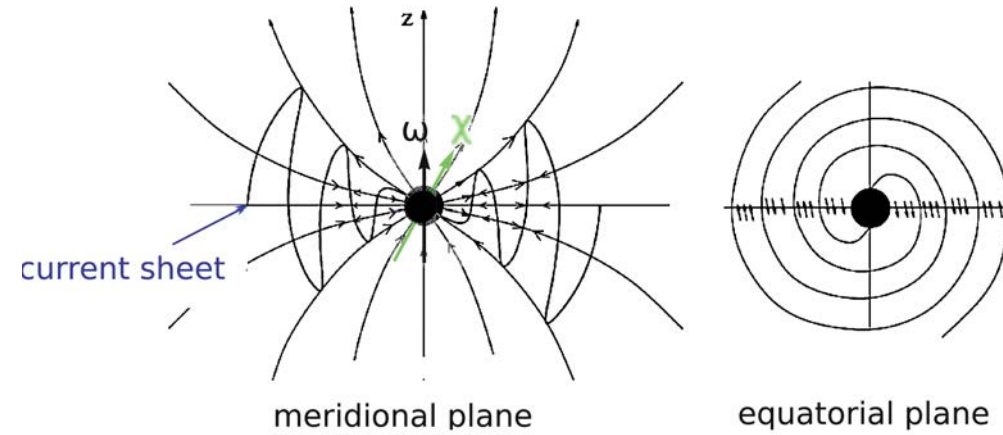


Current model of the Pulsar Wind Nebulae

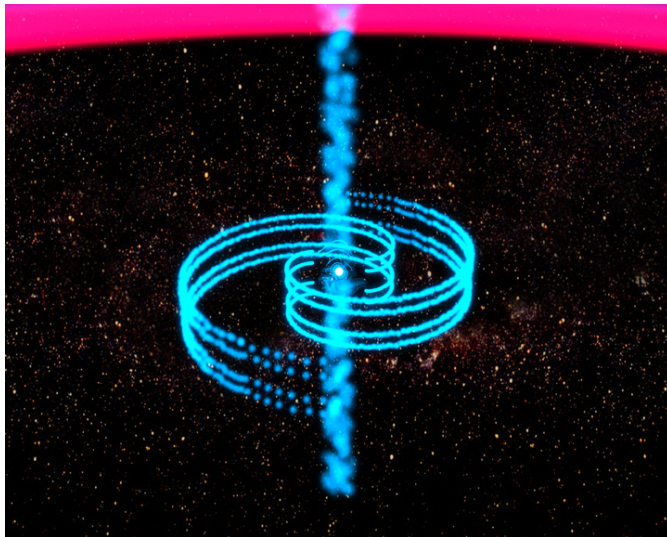
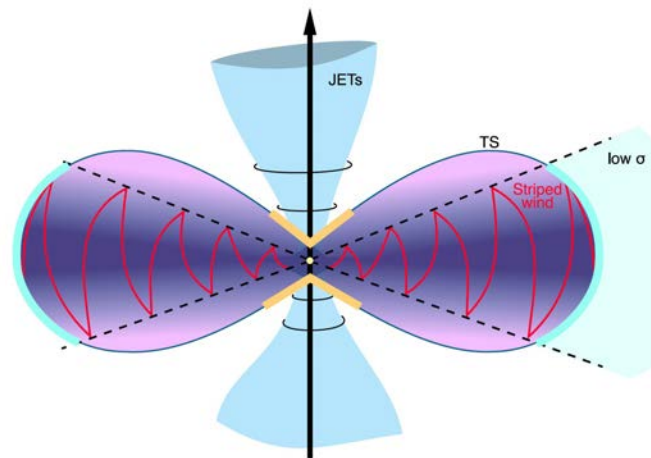
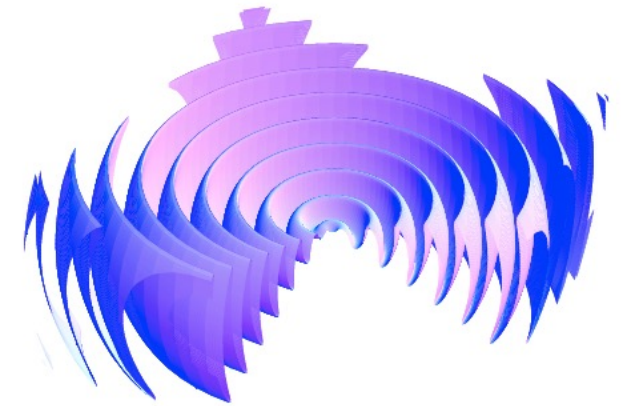
Magnetic reconnection occur at the **light cylinder**, where the Wind emitted by the Pulsar reaches by corotation the speed of light



Current model of the Pulsar Wind Nebulae

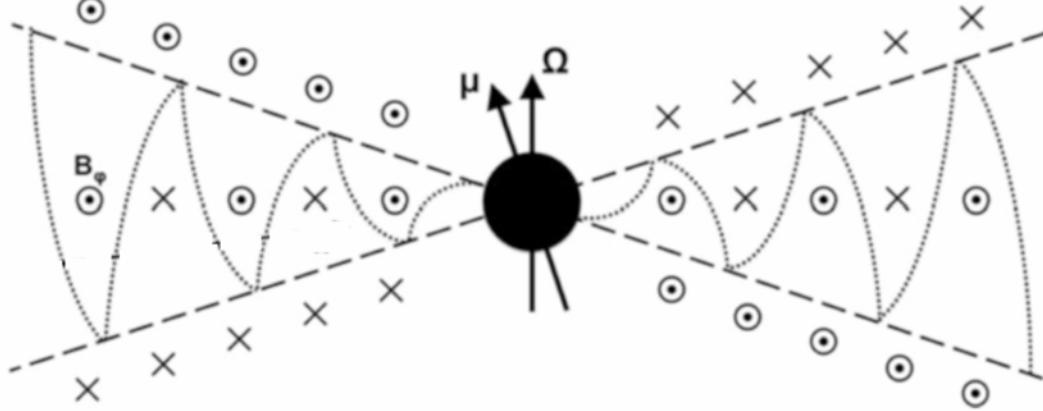


Outside the light cylinder the Wind emitted by the Pulsar gives rise to the Pulsar striped Wind



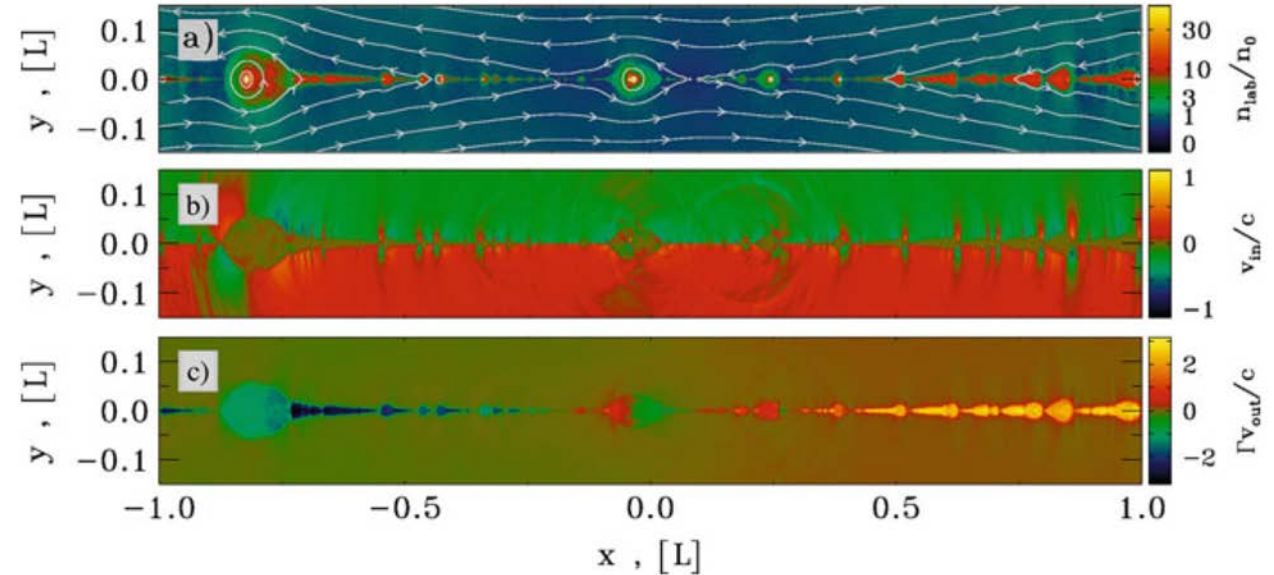
Current model of the Acceleration In Pulsar Wind Nebulae *

The sign of the toroidal B field is opposite on the two emispheres



But current sheets develop on the equator
Relativistic Magnetic Reconnections
develops on the equatorial plane

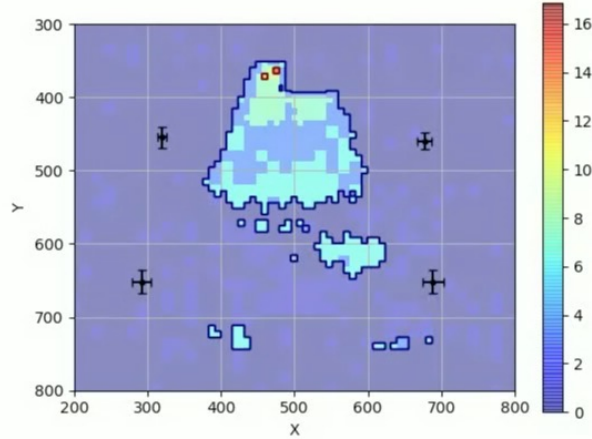
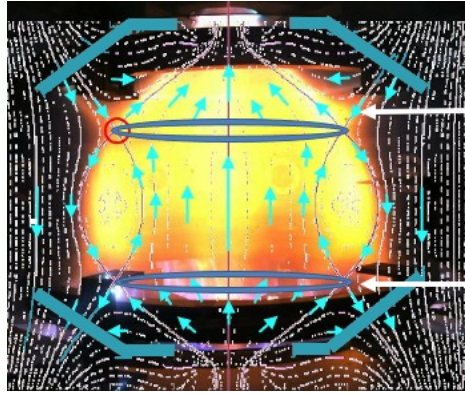
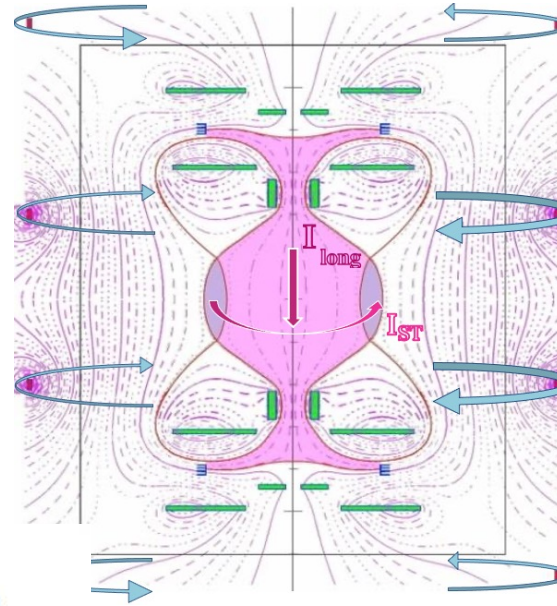
Giving rise to plasmoids moving
at large fractions of the speed of light



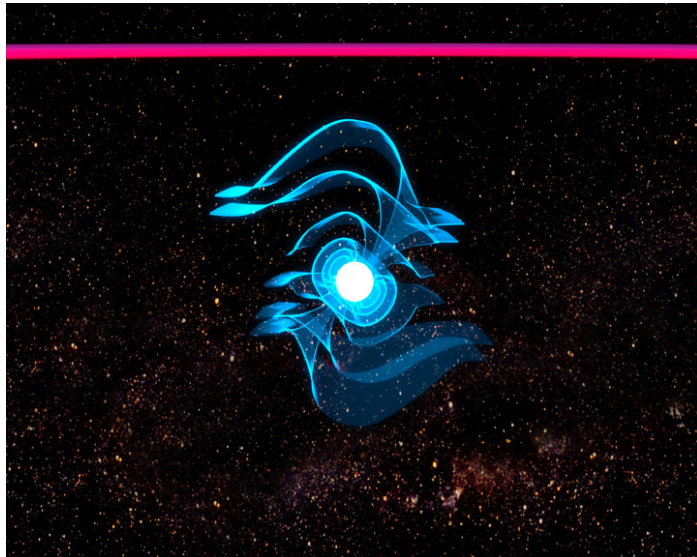
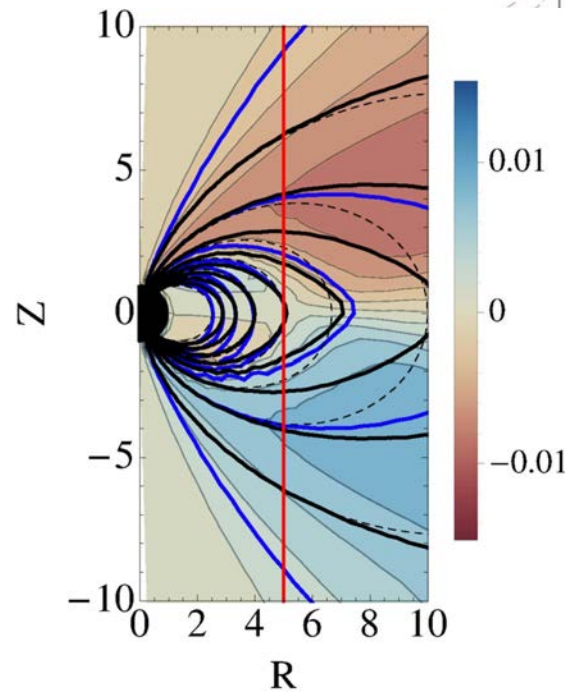
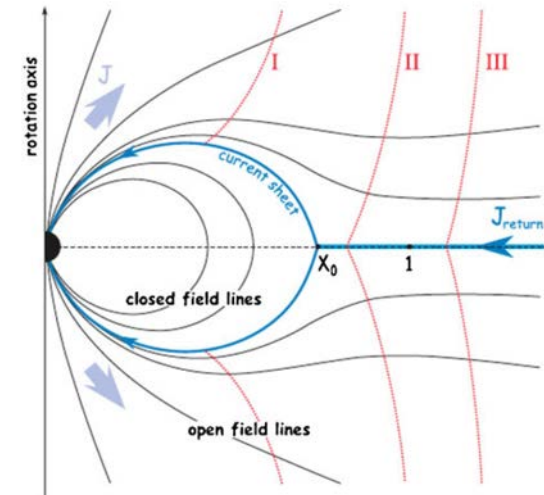
* ...if the Acceleration is due to Magnetic Reconnections

A remarkable difference appears between PROTO-SPHERA and the current model of Pulsar Wind Nebulae:

Shot #2092, 3600 fps



In **PROTO-SPHERA** the plasma current density goes through the center of the configuration without changing direction



In the **Pulsar Wind Nebulae** models the plasma current reverses direction in the 2 emispheres

CONCLUSIONS:

Morphology and most of the magnetic structure are quite similar

...but plasma regimes are totally different

...a major difference is revealed in the direction of the current densities of the two Jets