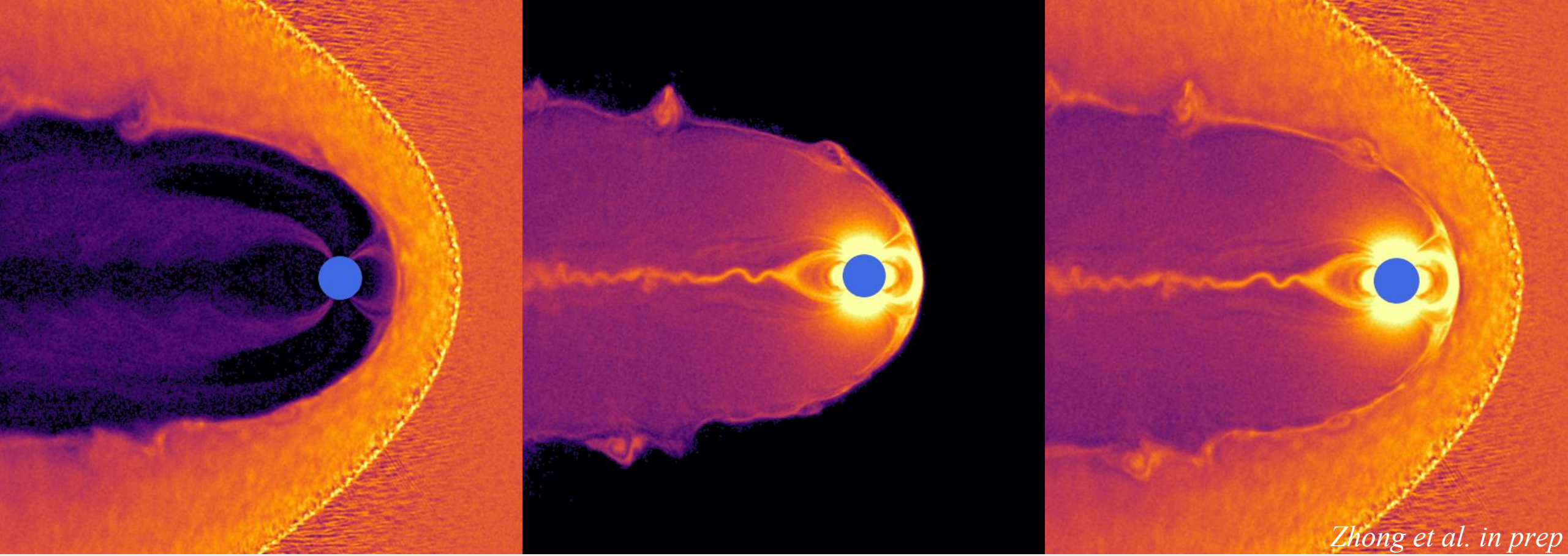
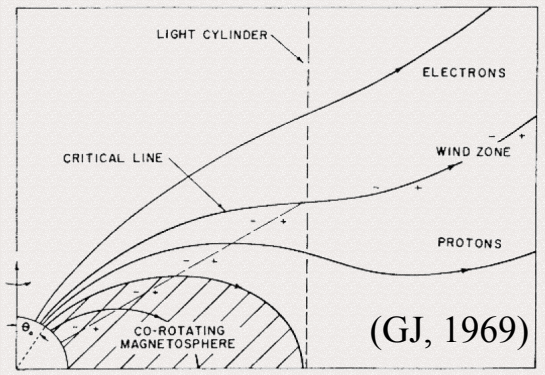
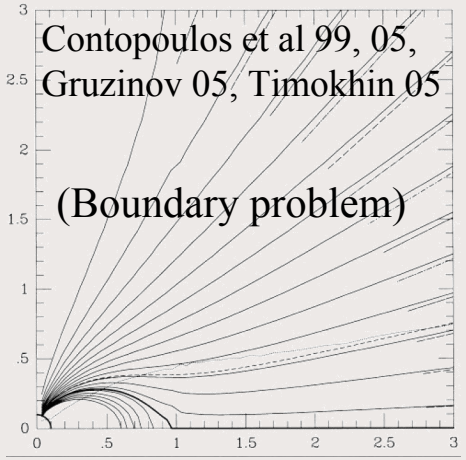


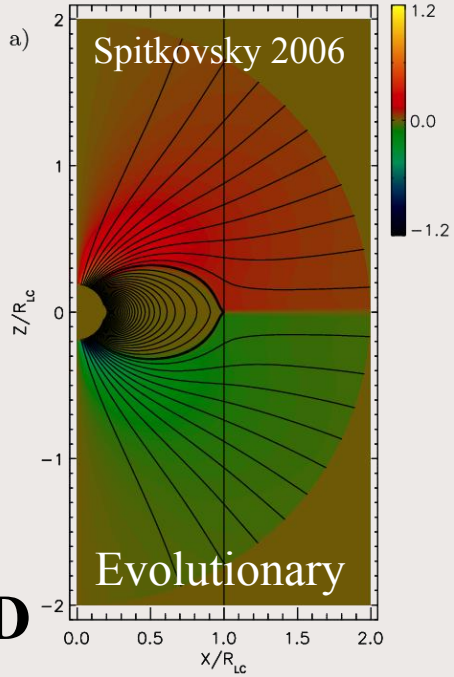
SPINDOWN OF PULSARS INTERACTING WITH COMPANION WINDS

Yici Zhong (The U. of Tokyo), Anatoly Spitkovsky (Princeton U.), Jens Mahlmann (Columbia U.) and Hayk Hakobyan (Columbia U.)

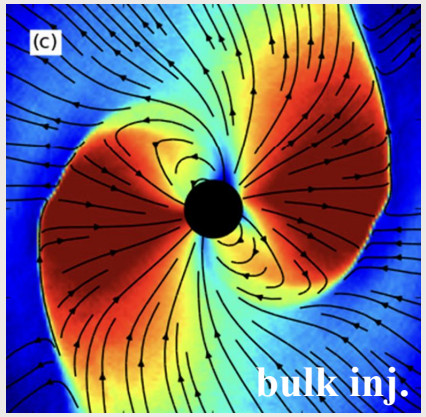
(ISOLATED) PULSAR MAGNETOSPHERE FOR 50 YEARS



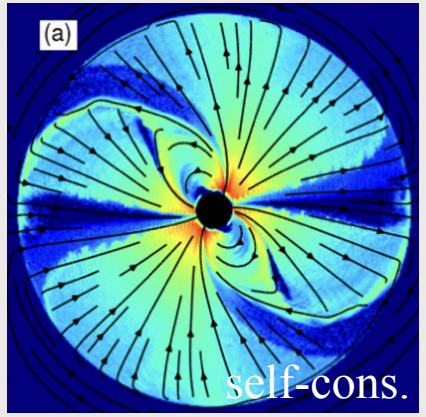




Philippov et al. 2015



Philippov et al. 2018

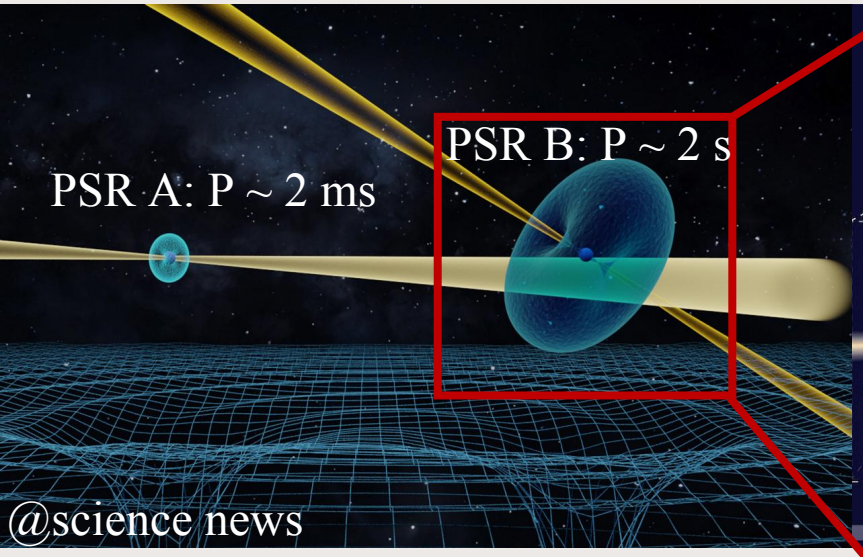


- **Charge-separated model** • **Force-free MHD**
- **Full kinetic + Pair production, GR effects etc**

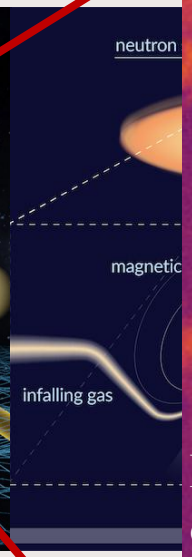
Known knowns:

- Open-closed field structure (Y point -> LC)
- Current flowing along open field lines => spindown $L_{\rm iso} \sim \frac{\mu^2 \Omega^4}{c^3}(1+\sin^2\chi)$
- Current sheet beyond LC produces high energy emission
- Pair production at polar cap/Y-point is important for pulsar wind to launch
- …

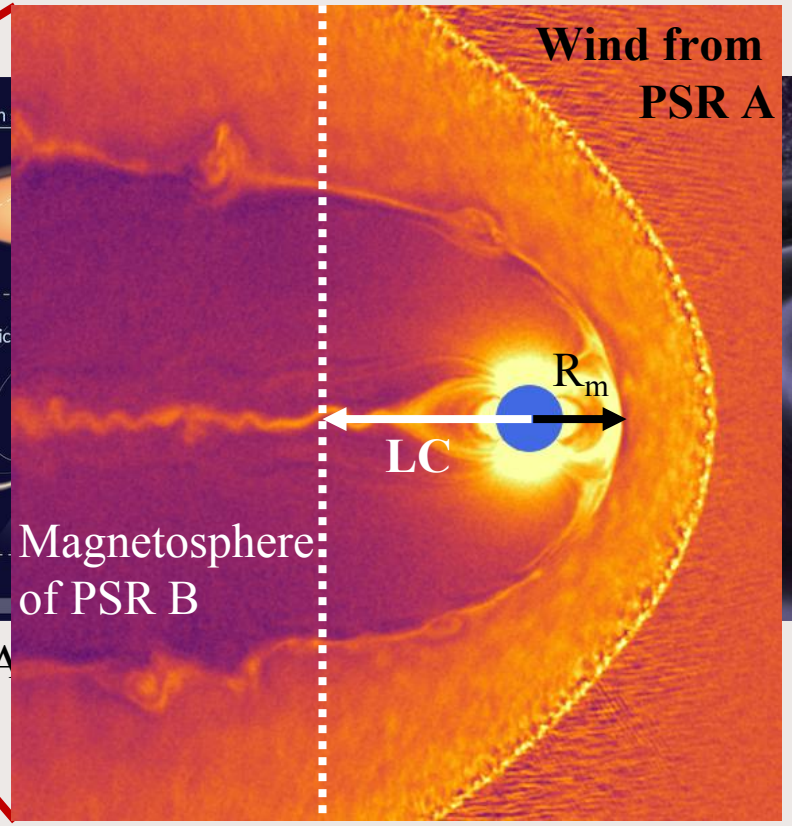
NOT ALL PULSARS LIVE ALONE



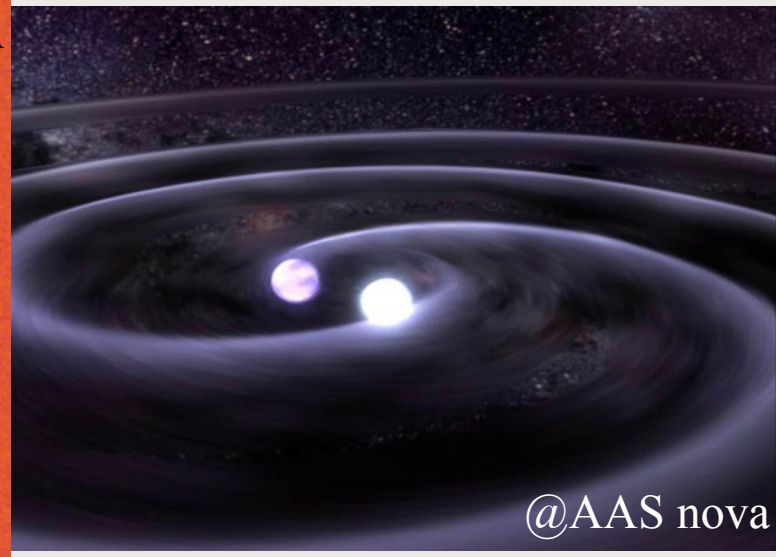
a) Double pulsar system PSR J0737-3039



b) A



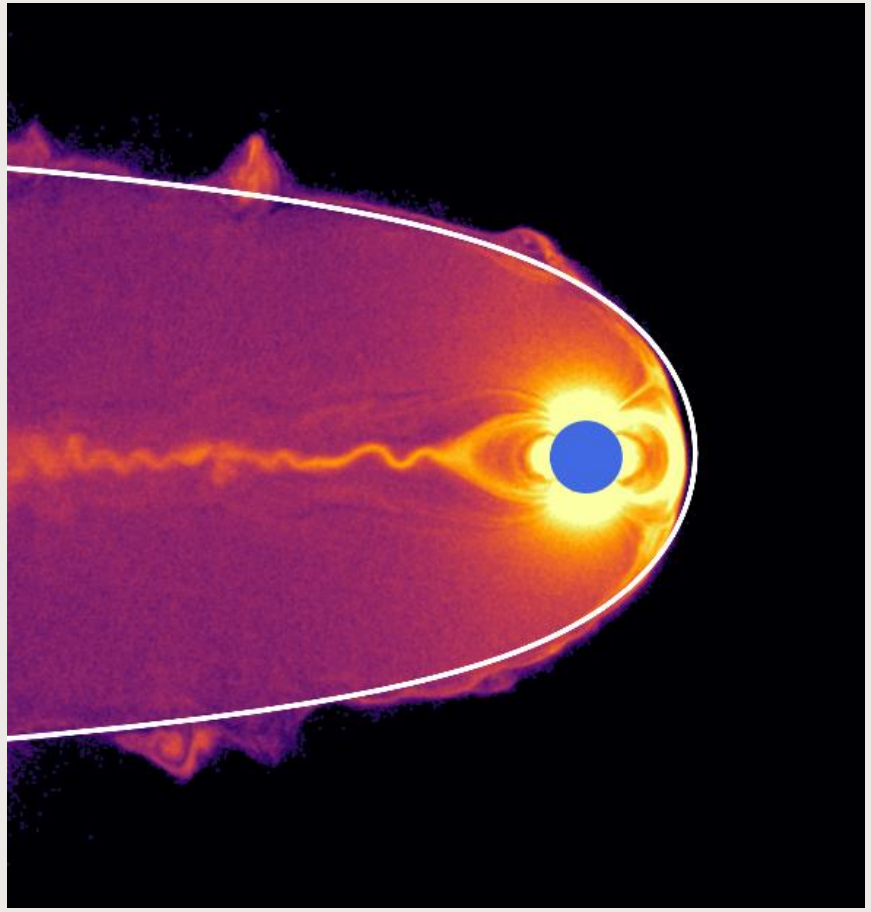
$R_m/R_{LC} \sim 1/3$ (*Lyne et al. 2004*)



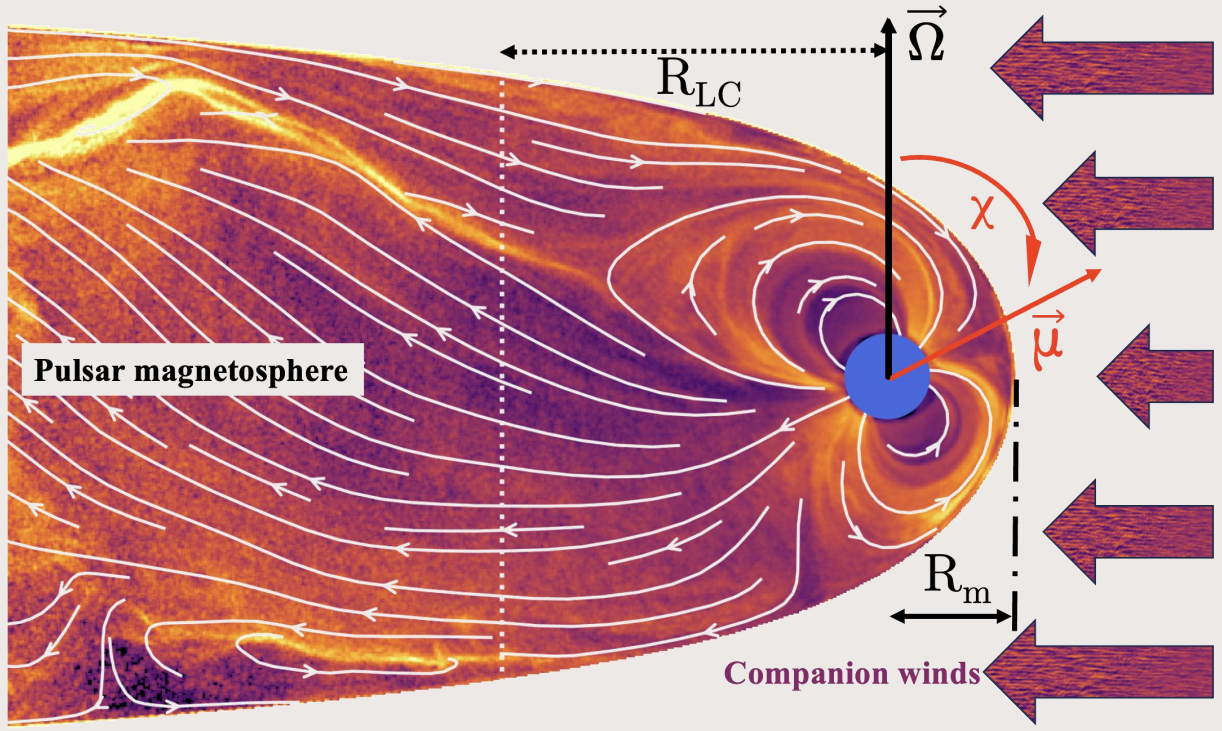
c) Neutron star merger

and etc…

MAGNETOSPHERE-WIND INTERACTION



simplify



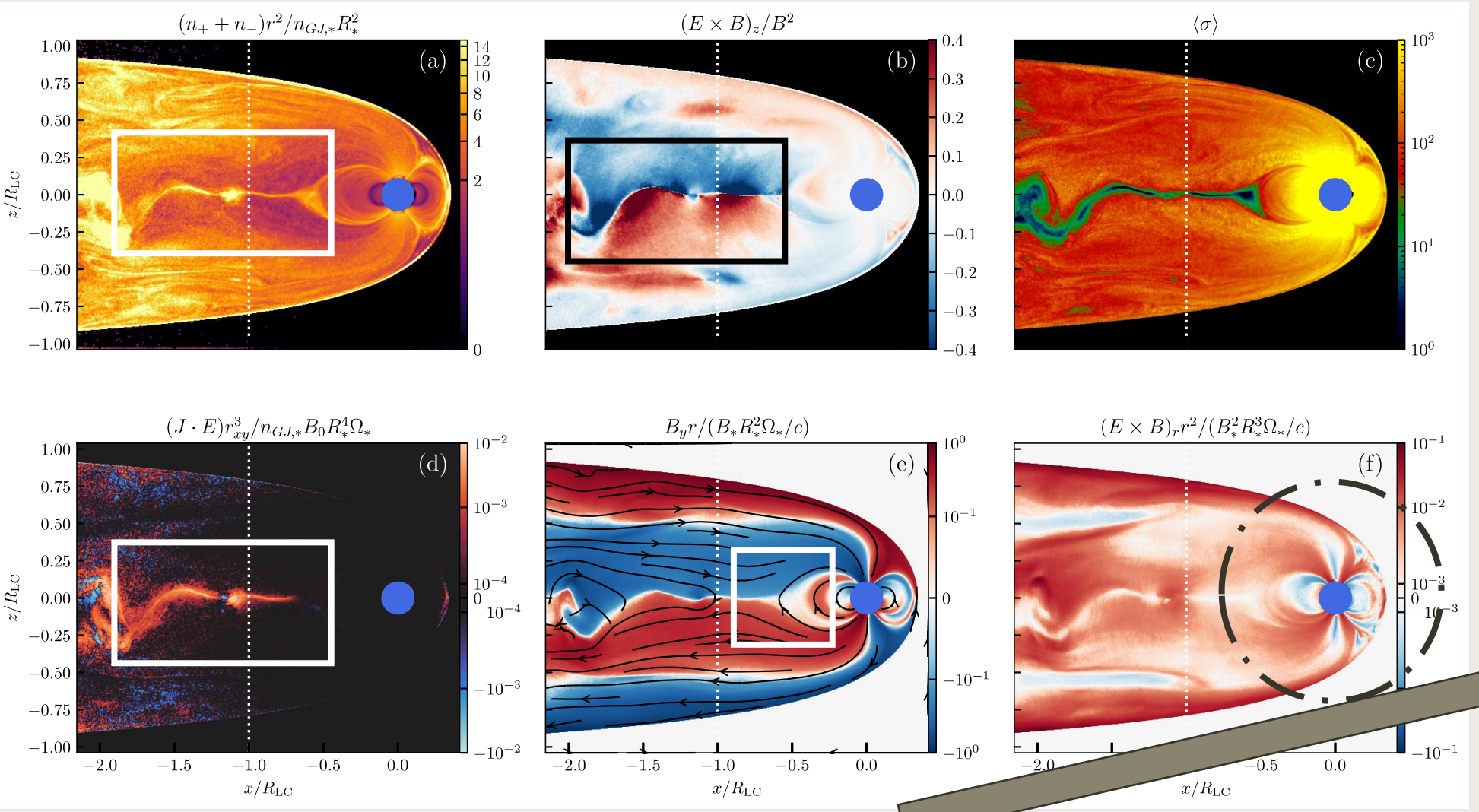
- Wind enclosure: perfect conductor (R_m/R_{LC})
- Pulsar with bulk plasma injection around the surface

A simple question: how is pulsar spindown changed by this kind of interactions?

$$\dot{E} = \frac{\mu^2 \Omega^4}{c^3}(1 + \sin^2\theta)$$

?

ALIGNED ROTATOR: MAGNETOSPHERE STRUCTURES ($R_{\rm m}/R_{\rm LC} = 1/3$)



- Only one current sheet
- Order of magnitude stronger dissipation
- $\langle\gamma\rangle_{LC} \sim \sigma_{LC}$
- Overall higher reconnection rate (0.3-0.4)

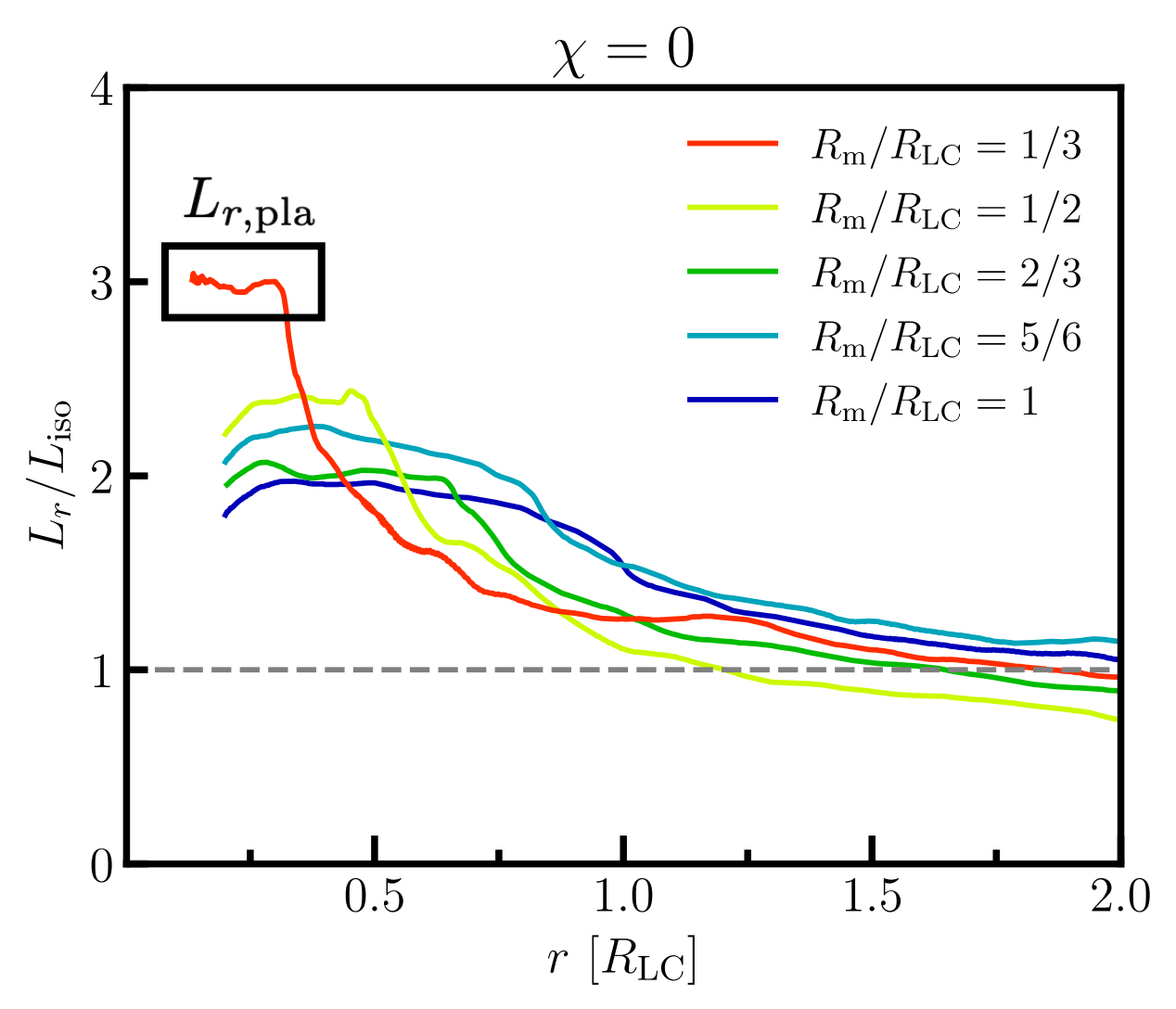
$$L_r \equiv \frac{c}{4\pi} \oiint_r (\mathbf{E} \times \mathbf{B})_r \mathbf{dS}$$

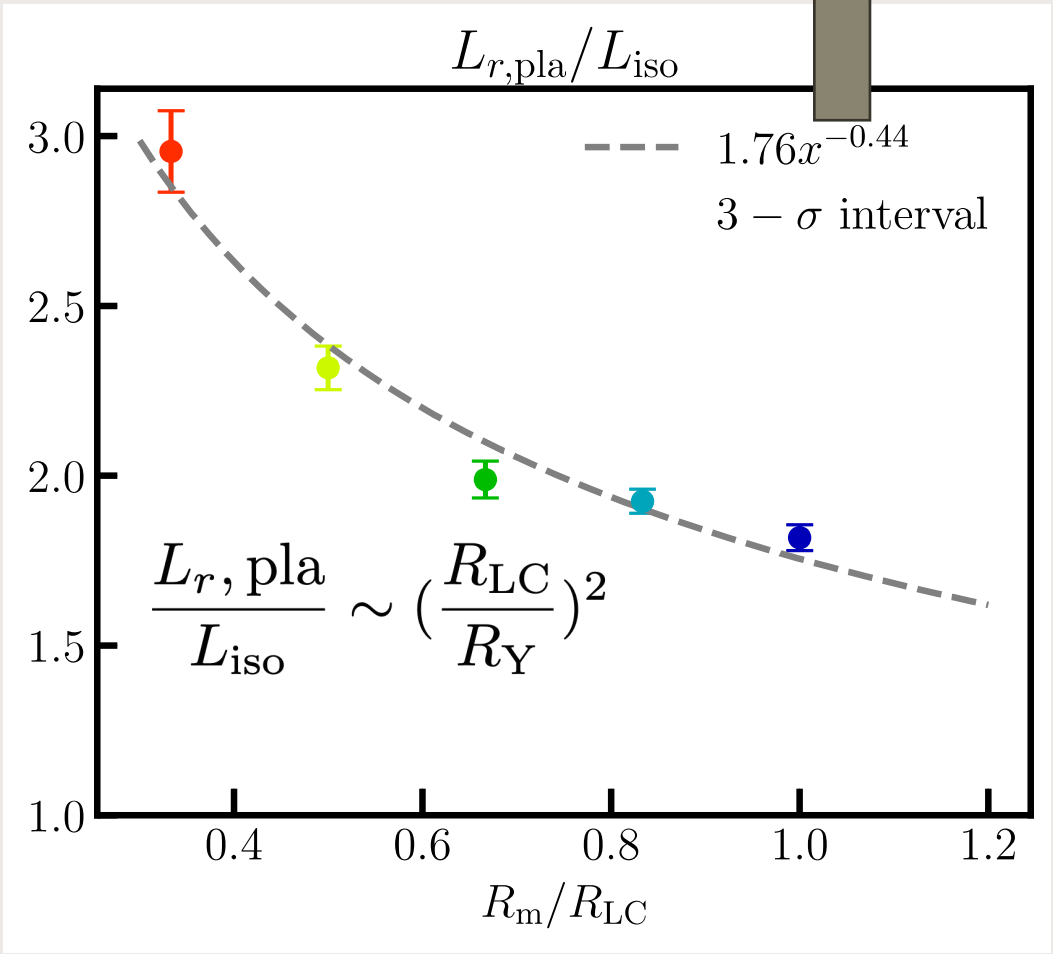
Enhanced spindown

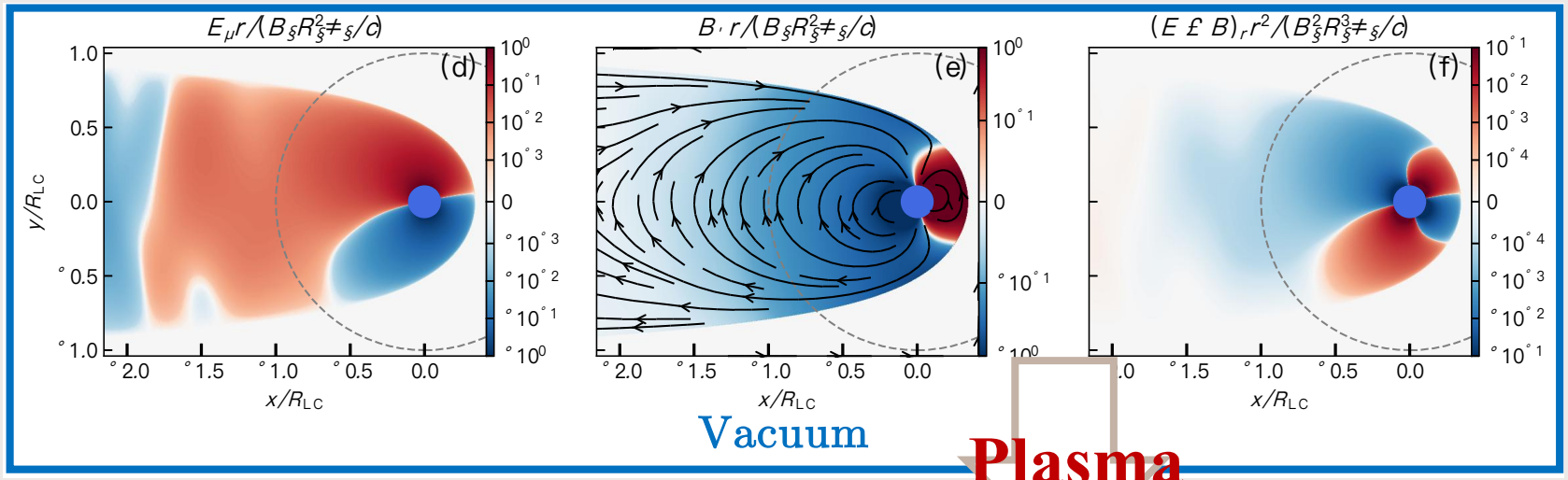
$$\mathbf{r_Y < R_{LC}}$$

r-L_r curve for different R_m/R_{LC}

$$n \equiv -\Omega\ddot{\Omega}/\dot{\Omega}^2 \sim 2.56$$

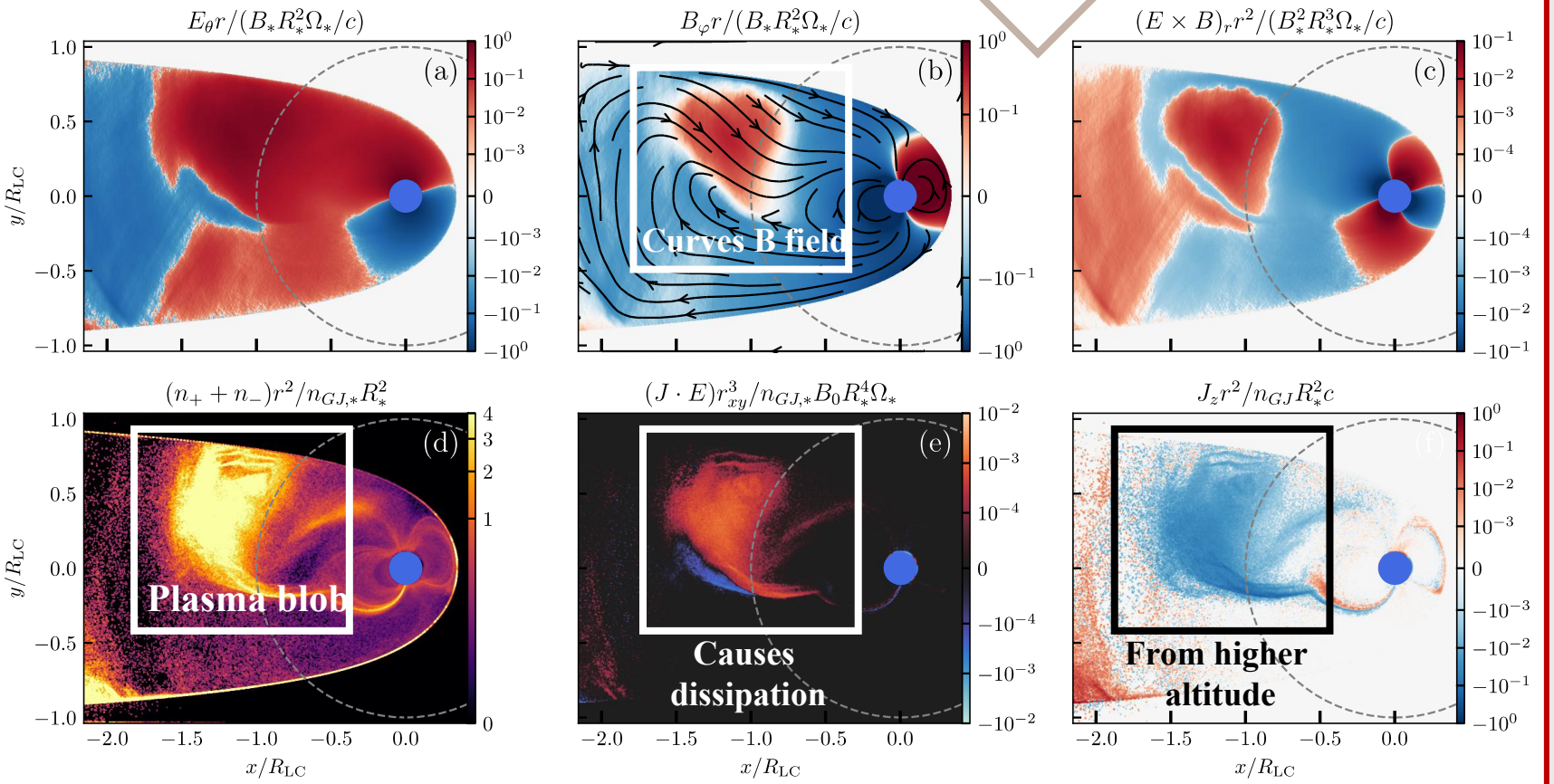


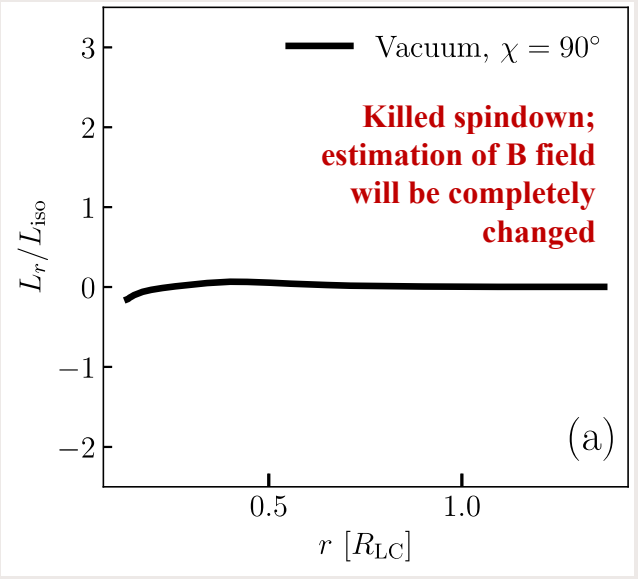


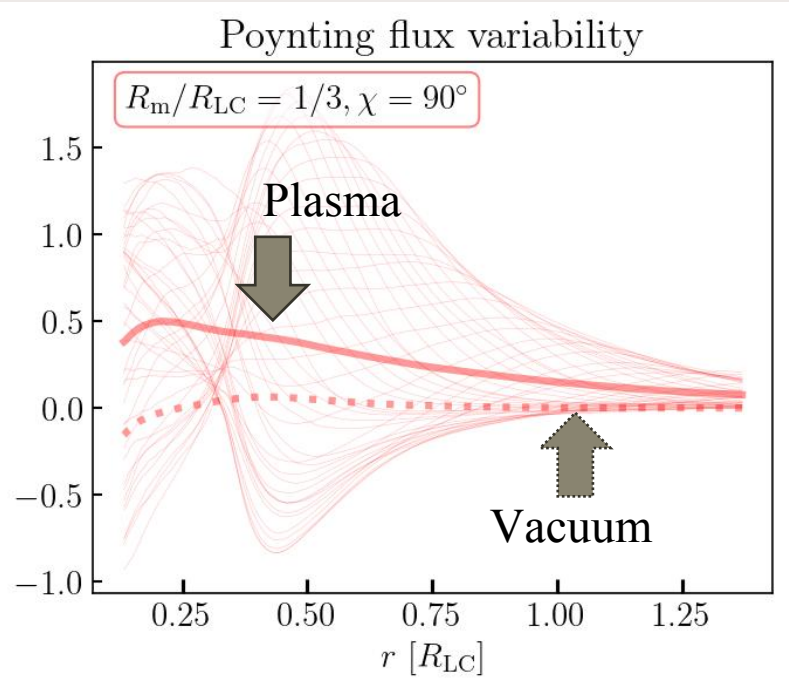


Vacuum

Plasma

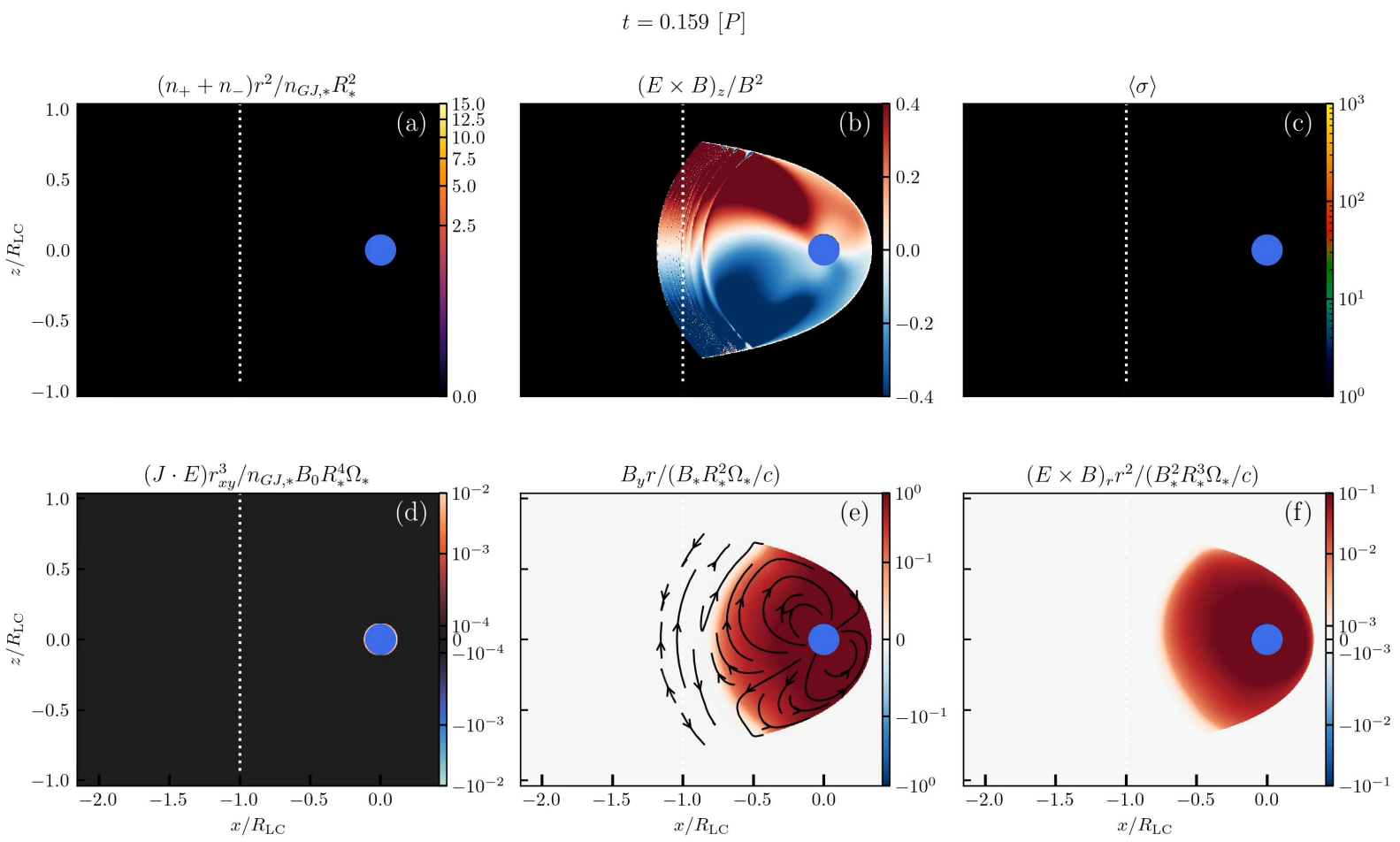




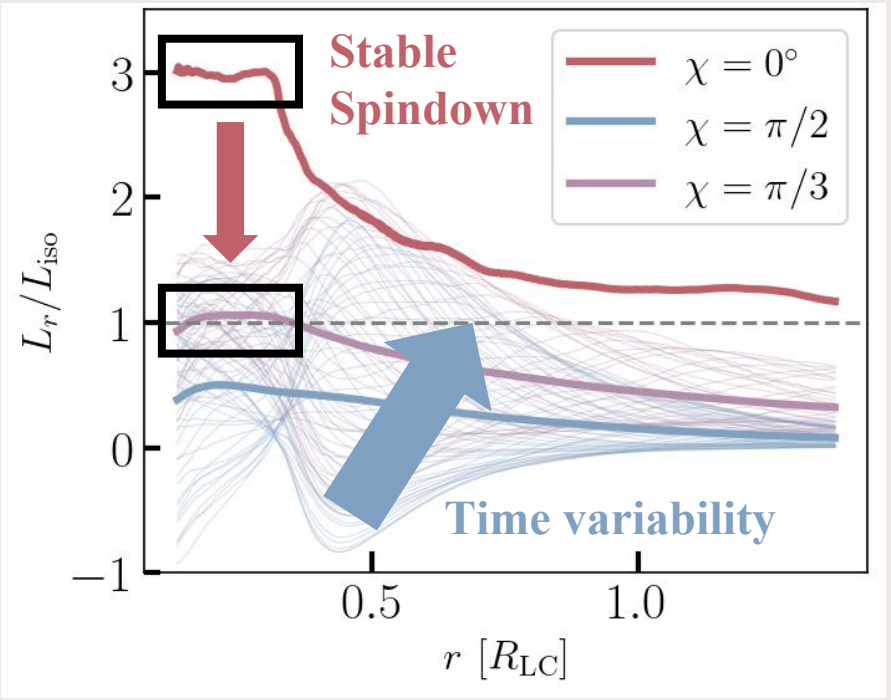


Suppressed Spindown

Oblique rotator ($\chi = 60°$, $R_{\rm m}/R_{\rm LC} = 1/3$)



Superposition of both!



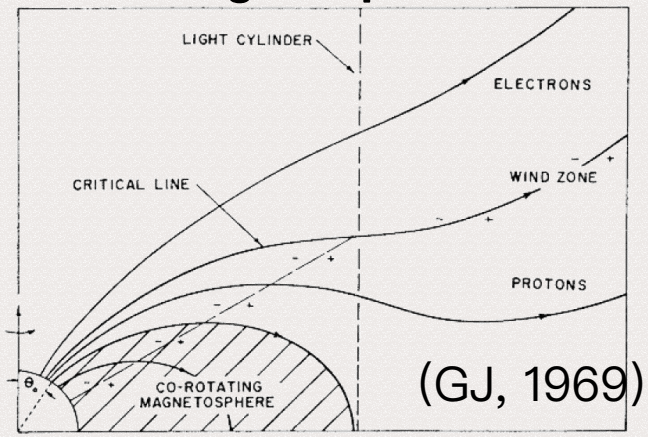
CONCLUSIONS

- We simulate pulsar magnetospheres confined by companion winds **inside** their light cylinder
- In this kind of unusual magnetosphere:
  - *For aligned rotators: spindown is **enhanced** due to inwardly moving Y-point*
  - *For perpendicular rotators: spindown is **suppressed** due to wave-guide effects, but not completely killed due to the outflowing plasma that carries the current*
  - *Dissipation **is order of magnitude stronger than isolated ones** due to both stronger toroidal B field and faster reconnection: more efficient particle energization => GRB/FRB?*
- For normal pulsar PSR J0737-3039B in double pulsar system PSR J0737-3039 ($\chi \sim 70^\circ$, $R_m/R_{LC}=1/3$): spindown energy ~ L_{iso} => $B^* \sim 6 \times 10^{11}$ G instead of 10^{12} G estimated from the vacuum 90 formula

Backup slides

Pulsar Magnetosphere for 50 years

- **Charge–separated model**



(GJ, 1969)

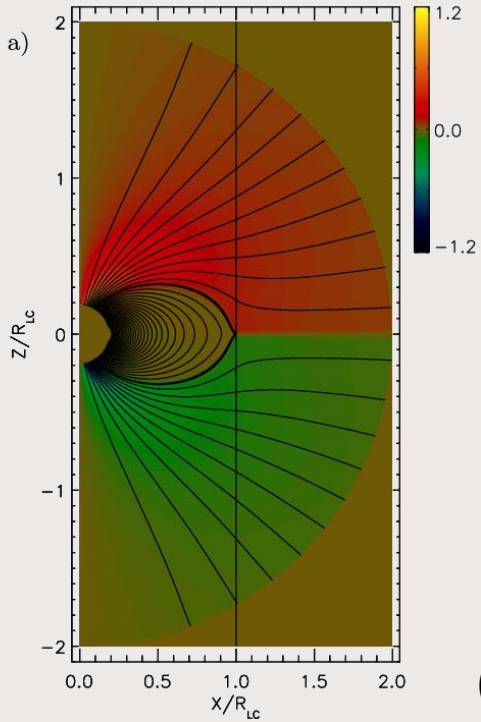
- **Force–free MHD**

Steady state; axisymmetric; **analytics** (monopole/dipole without current)

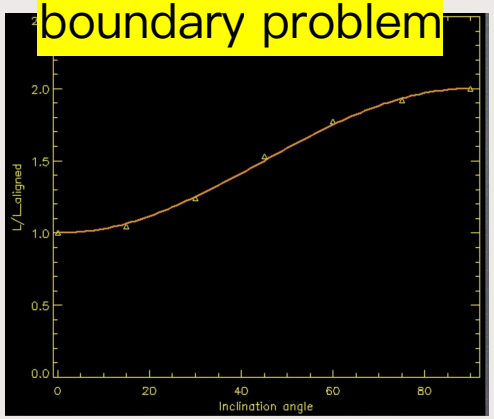
"Pulsar equation" (Michel '73; Scharleman &Wagoner '73):

$$\frac{\partial^2\Psi}{\partial x^2}+\frac{\partial^2\Psi}{\partial z^2}-\frac{1+x^2}{x(1-x^2)}\frac{\partial\Psi}{\partial x}=-\frac{I(\Psi)I'(\Psi)}{R_L^2(1-x^2)}$$

Philippov et al. 2014



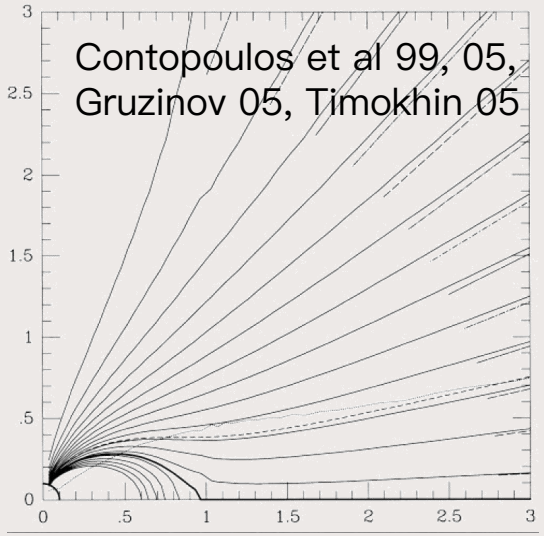
Evolutionary, instead of a boundary problem



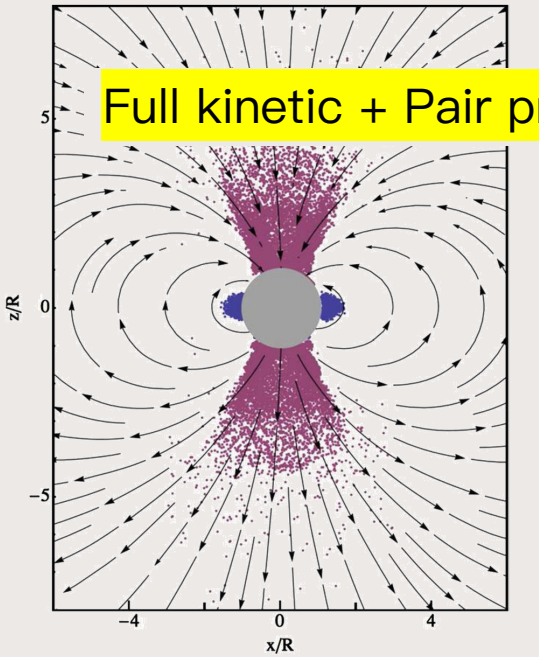
Spitkovsky 2006

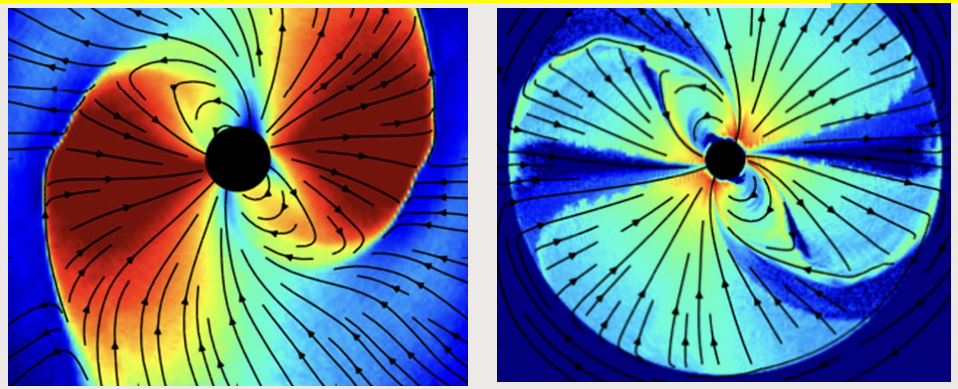
(3D) Time–dependent FFE

Numerics (aligned dipole + I)



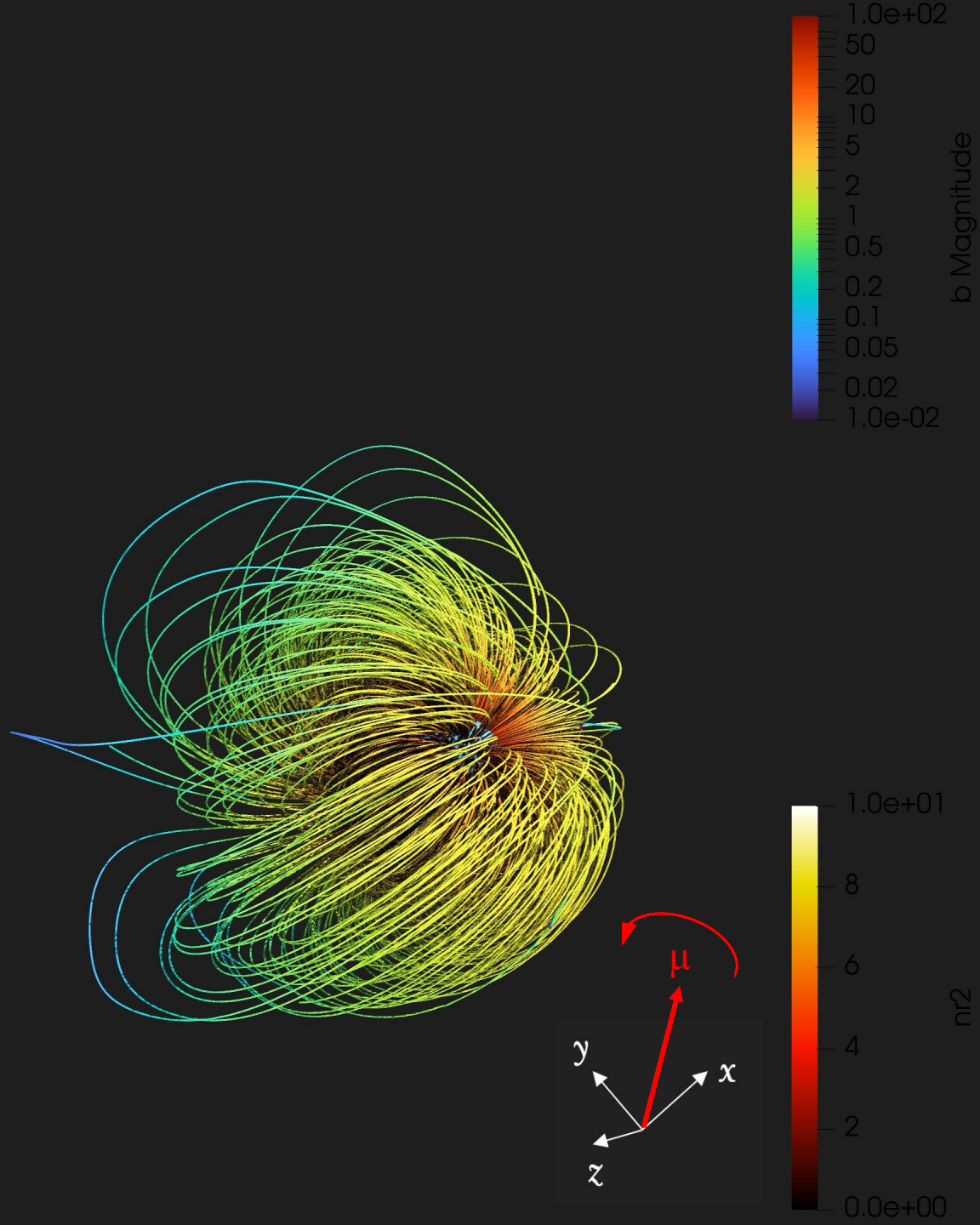
Full kinetic + Pair production (bulk inj./self–cons.), GR effects et





Philippov et al. 2015 Philippov et al. 2018

- **Where do plasma live**



90 rotator — 3D rendering