Galactic transients and fast radio bursts : Radio emissions from pulsar companions

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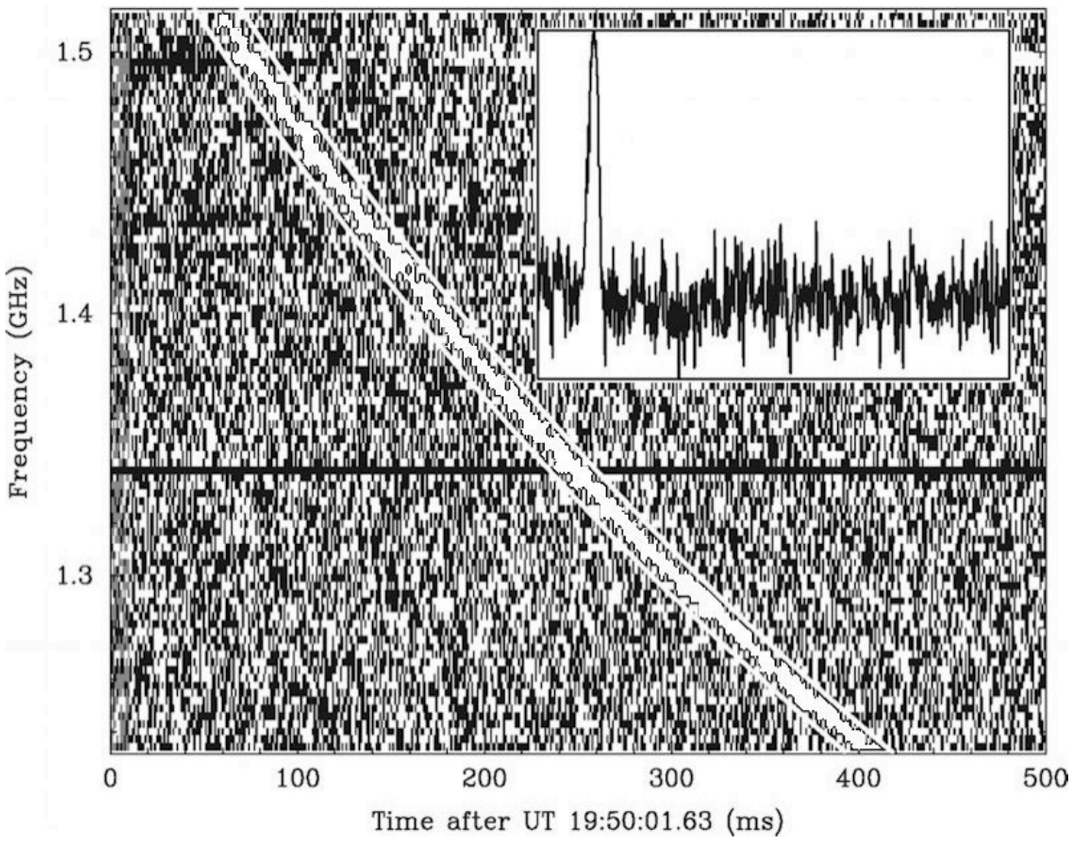
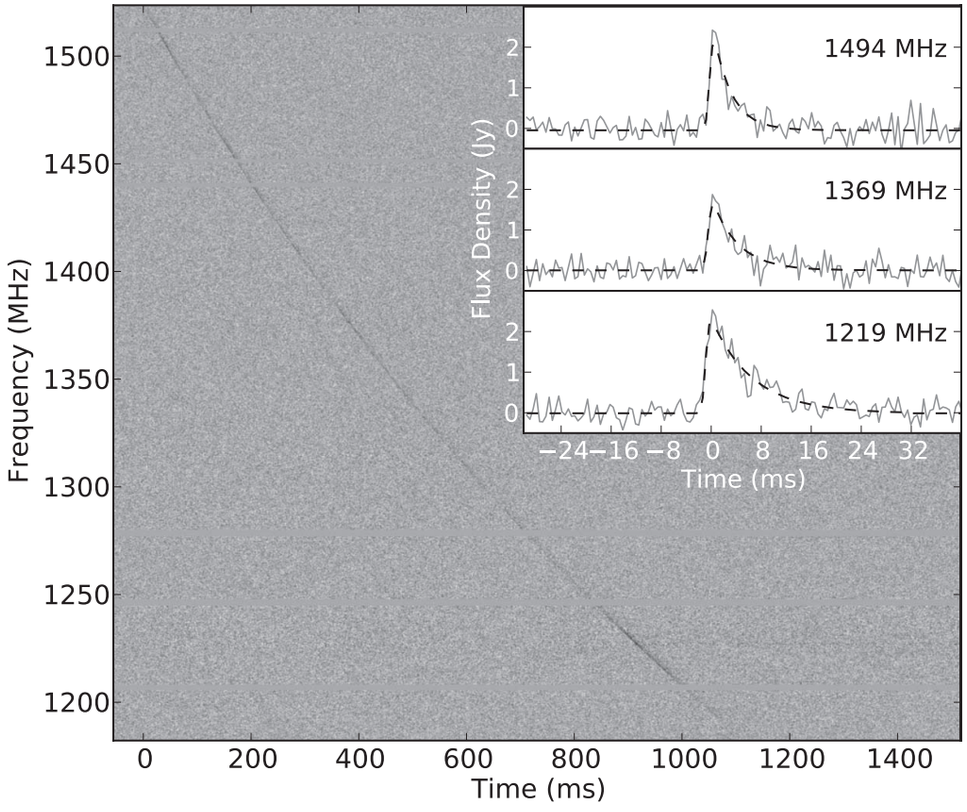
- A dozen FRBs known (Parkes & Arecibo)
- DM = 100's → 1000, mostly extragalactic → distance 0.5 - 3 Gpc
- 1-5 msec duration, 1 scattering tail
- ~1 Jy level → very high intensity, $E_{iso} \sim 10^{33}$ J



[Lorimer et al., 2007]

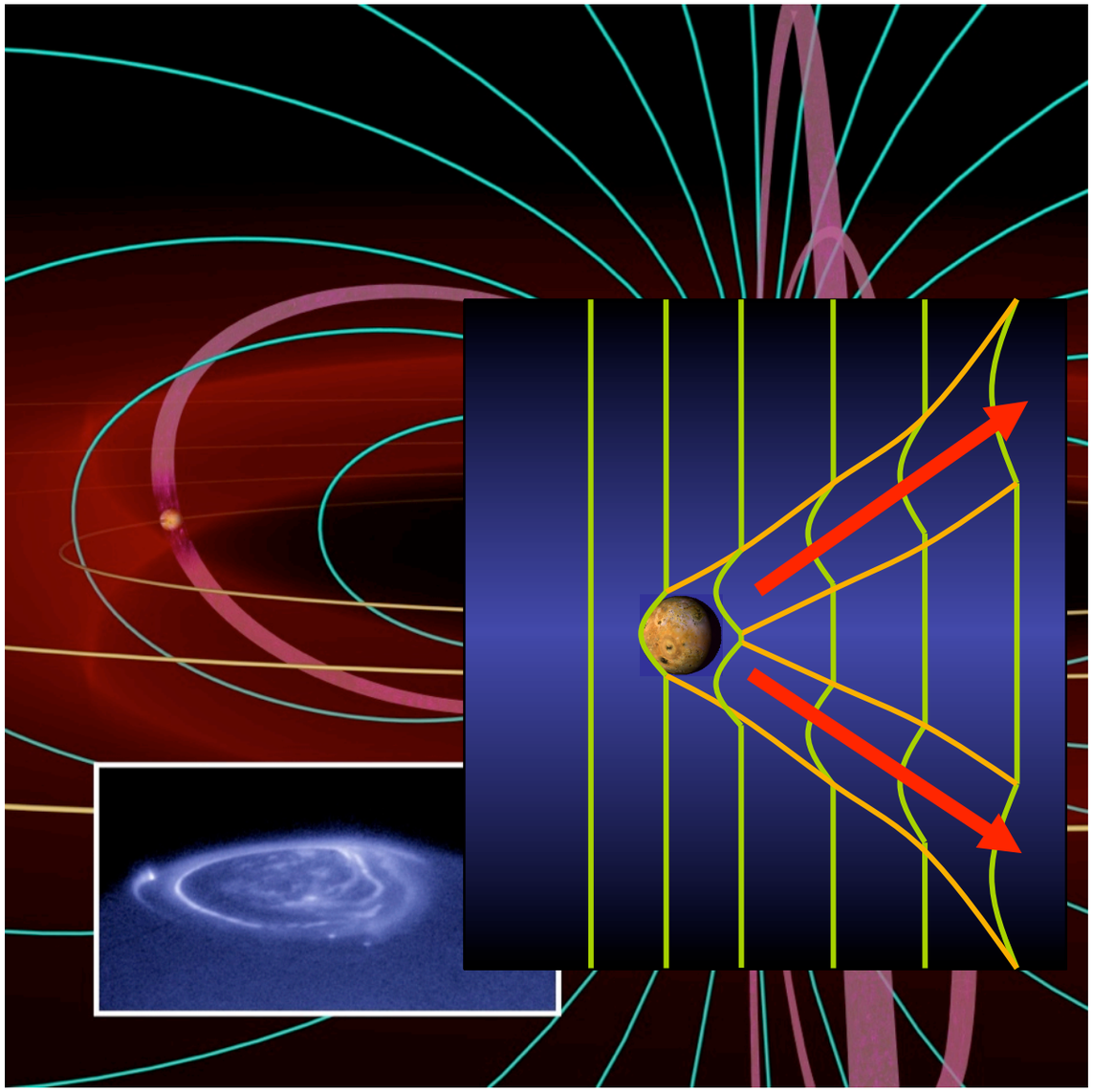


[Thornton et al., 2013]

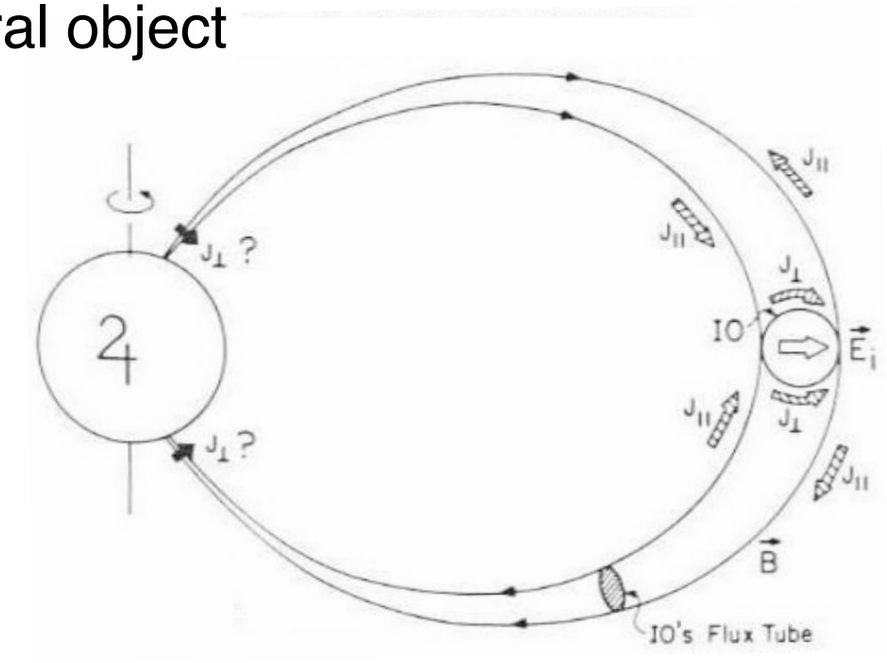
- super-energetic scenarii (mini BH annihilation, WD or NS mergers, implosion of supra-massive NS…) → isolated events
- giant pulses of young pulsars, close-by flaring stars ? → irregularly repeatabe but inconsistent with DM

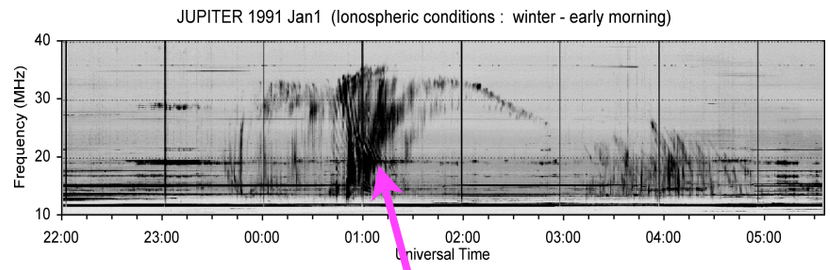
- We propose an explanation requiring modest energy, consistent with observations :
- Interaction Pulsar wind – Companion (WD, planet, asteroid) → intense radio waves ?

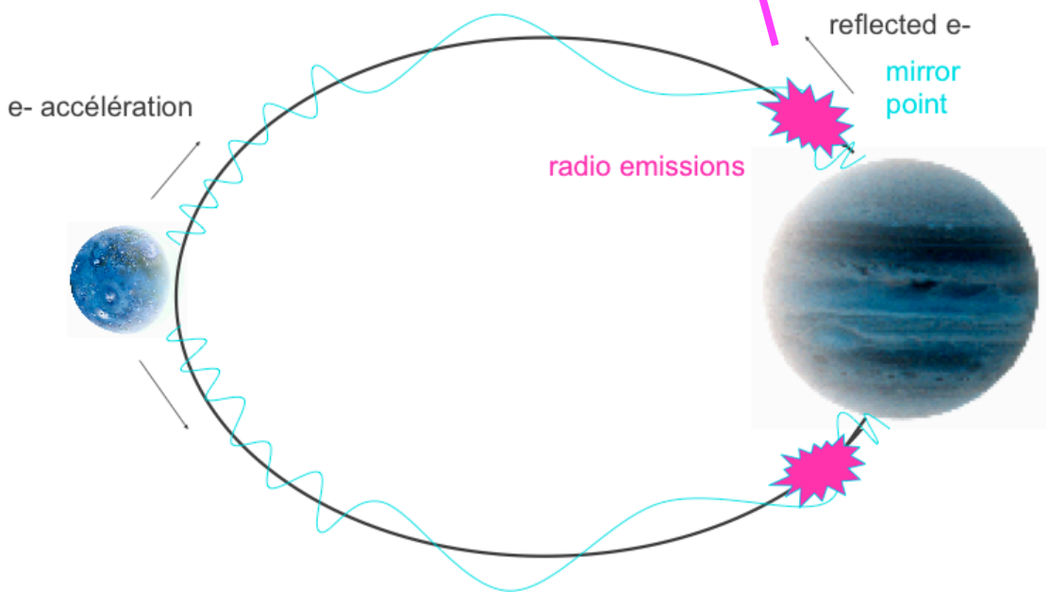
- Io-Jupiter interaction → Alfvén Waves → J → energetic e^-
  → 10^{12} W dissipation including radio waves near central object



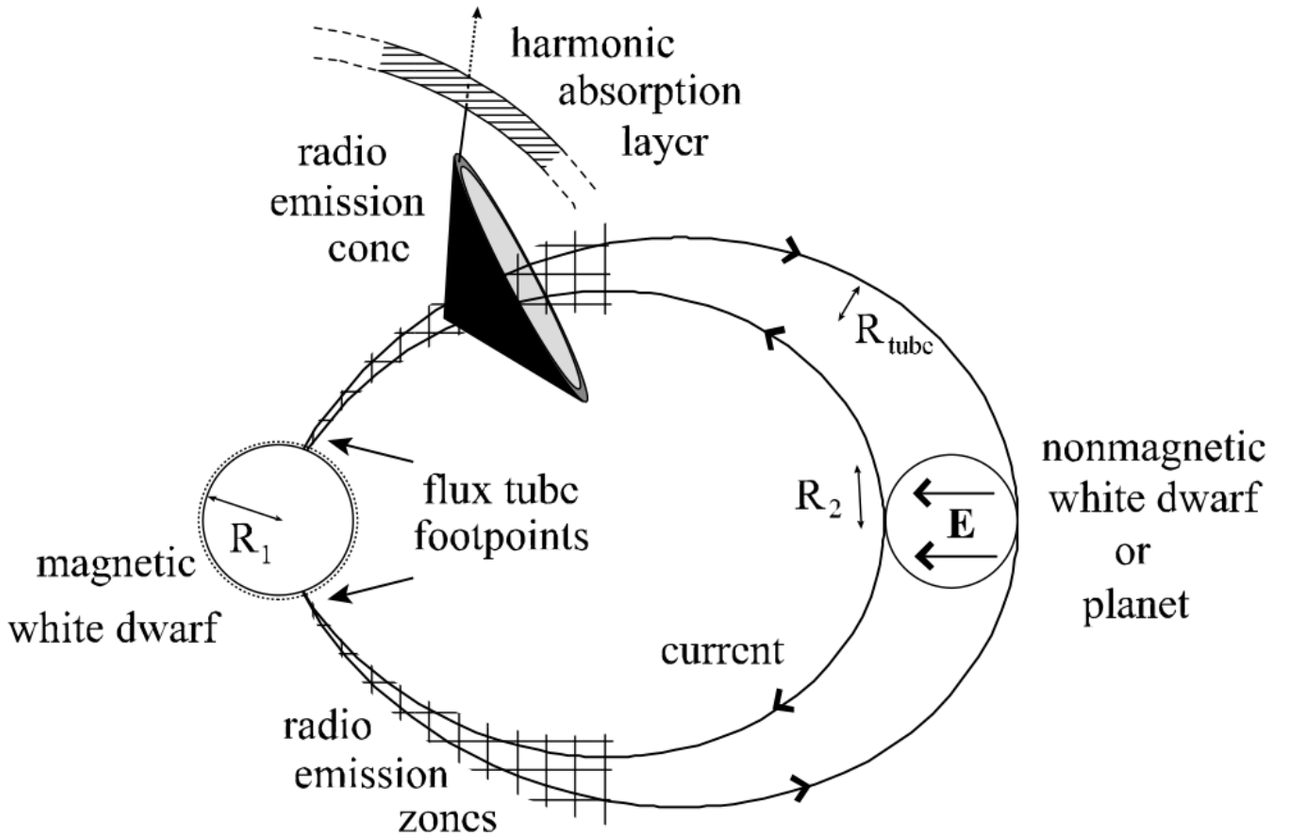
[Saur et al., 2004 ; Hess et al., 2007]







- Same physics for WD-planet interaction



[Willes & Wu, 2004]

- Interaction Pulsar Wind (relativistic) - companion
  - → relativistic Io-Jupiter or WD-planet interaction
  - → radio waves in Alfvén wings ?

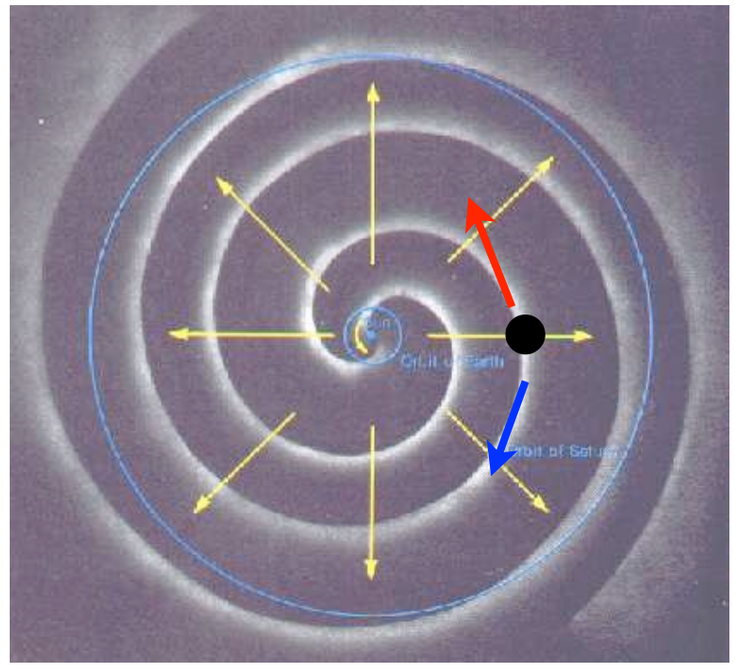
- Io-Jupiter → both Alfvén wings to the planet

- Star - exoplanet

  → 1 Alfvén wing propagates counterflow of the stellar wind,

  & 1 goes to infinity

  [Preusse et al., 2006]

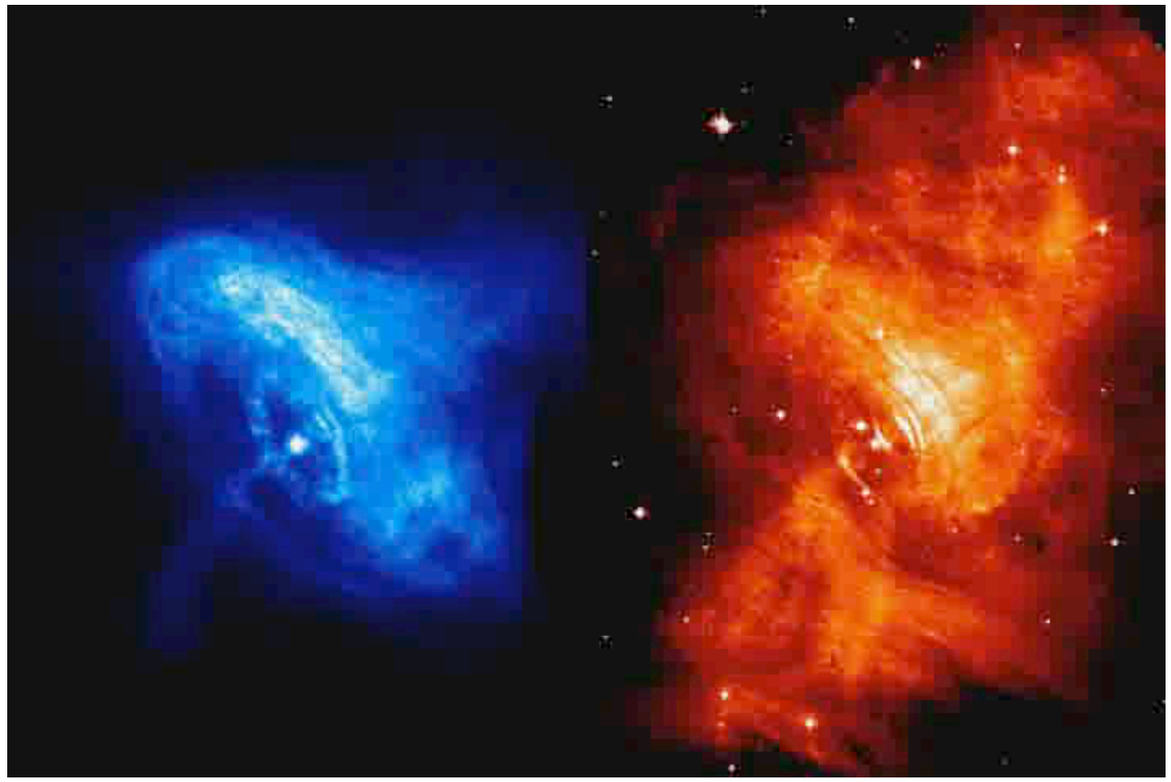


- Pulsar : radial relativistic wind

  ($\gamma \sim 10^1 - 10^7$),

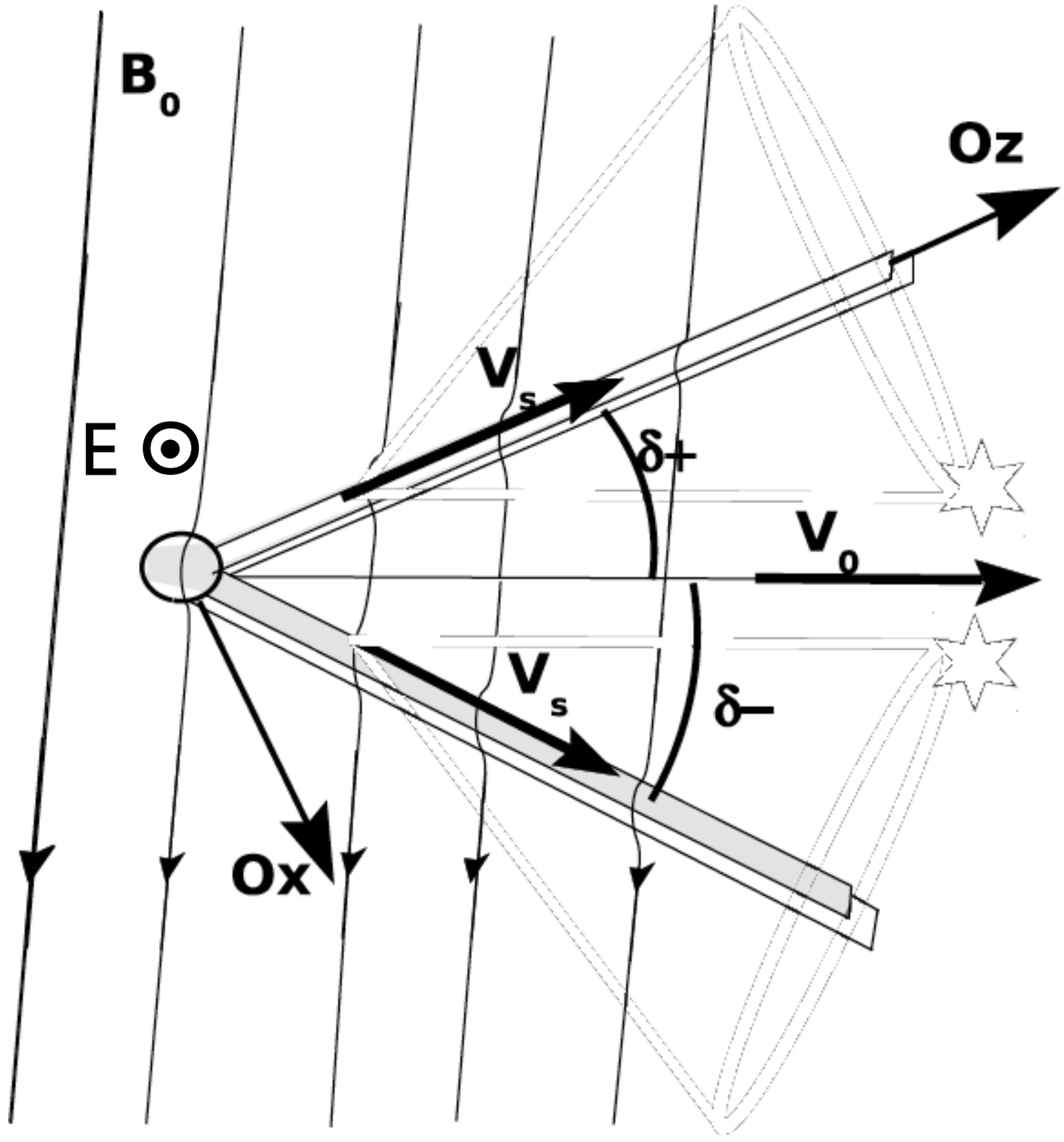
  Poynting flux dominated, $B=B_\Phi$

  [Mottez & Heyvaerts, 2011]

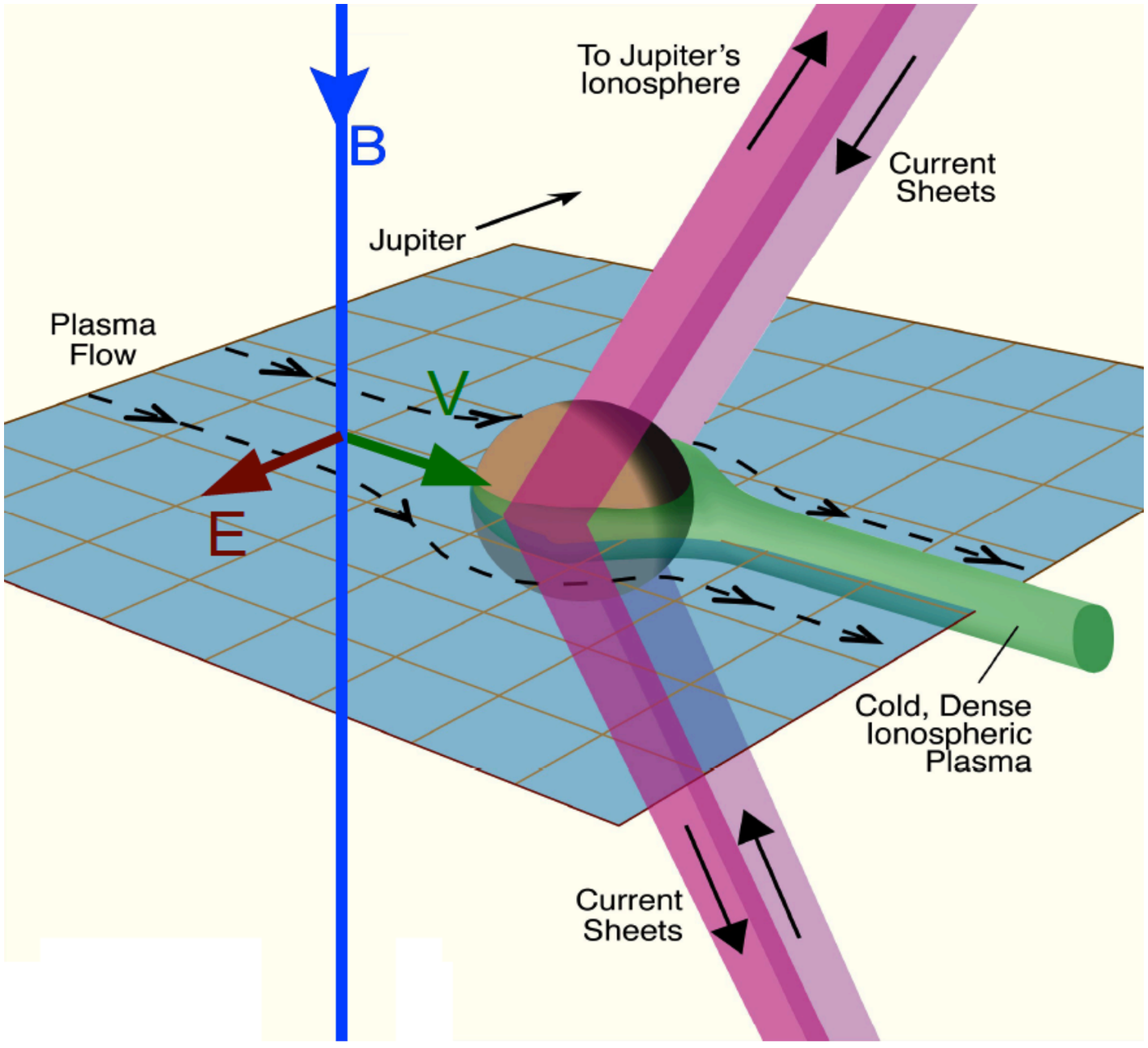


Chandra Hubble

- Pulsar companion at 100's r_{LC}
- $V_{wind} < V_A$, V_{fast}, all ~ c → no shock → AW connected to companion



- Io-Jupiter : E = V x B ~ 0.1 V/m → U ~ 400 kV , I ~ 3×10^6 A → P ~ 10^{12} W

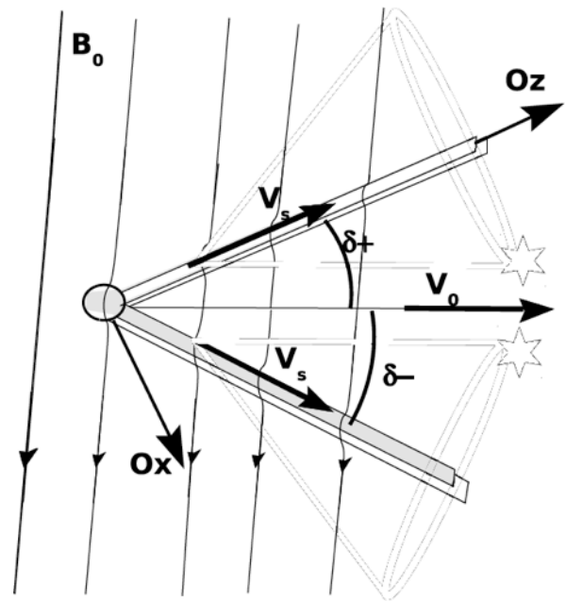


[Bagenal, 2007]

- Pulsar : E = $10^{4\text{-}6}$ V/m → U ~ 2RE ~ $10^{11\text{-}13}$ V, I ~ $10^{9\text{-}11}$ A, P ~ $10^{20\text{-}24}$ W
  (depending on B_{pulsar}, P_{pulsar}, $R_{companion}$ - here $10^{5\text{-}8}$ T, R_{Earth}, 1 sec)

- Hypothesis of aligned Pulsar B → angle AW / radial direction = δ+/δ- small, symmetrical or not depending on $x = \frac{r}{\gamma_0 r_{LC}}$

r (AU)	γ_0	x	δ_+ (°)	δ_- (°)	τ_+/s	τ_- (s)
0.1	10	78.	5.7	-5.6	$3.\,10^{-3}$	$3.\,10^{-3}$
0.01	10^3	$7.8\,10^{-2}$	1.4	$-2.\,10^{-3}$	$1.\,10^{-4}$	$8.\,10^{-2}$
0.1	10^3	0.78	0.16	$-2.\,10^{-2}$	$1.\,10^{-3}$	$1.\,10^{-2}$
1.0	10^3	7.83	$6.5\,10^{-2}$	$-5.\,10^{-2}$	$3.\,10^{-3}$	$4.\,10^{-3}$
40.	10^5	3.13	$7.8\,10^{-4}$	$-42\,10^{-4}$	$2.\,10^{-3}$	$5.\,10^{-3}$
10.	10^5	0.78	$1.7\,10^{-3}$	$-2.\,10^{-4}$	$1.\,10^{-3}$	$1.\,10^{-2}$
0.1	10^5	$7.8\,10^{-3}$	0.14	$-2.\,10^{-6}$	$(1.\,10^{-5})$	0.85
0.01	10^6	$7.8\,10^{-5}$	1.4	$-2.\,10^{-9}$	$(1.\,10^{-7})$	85

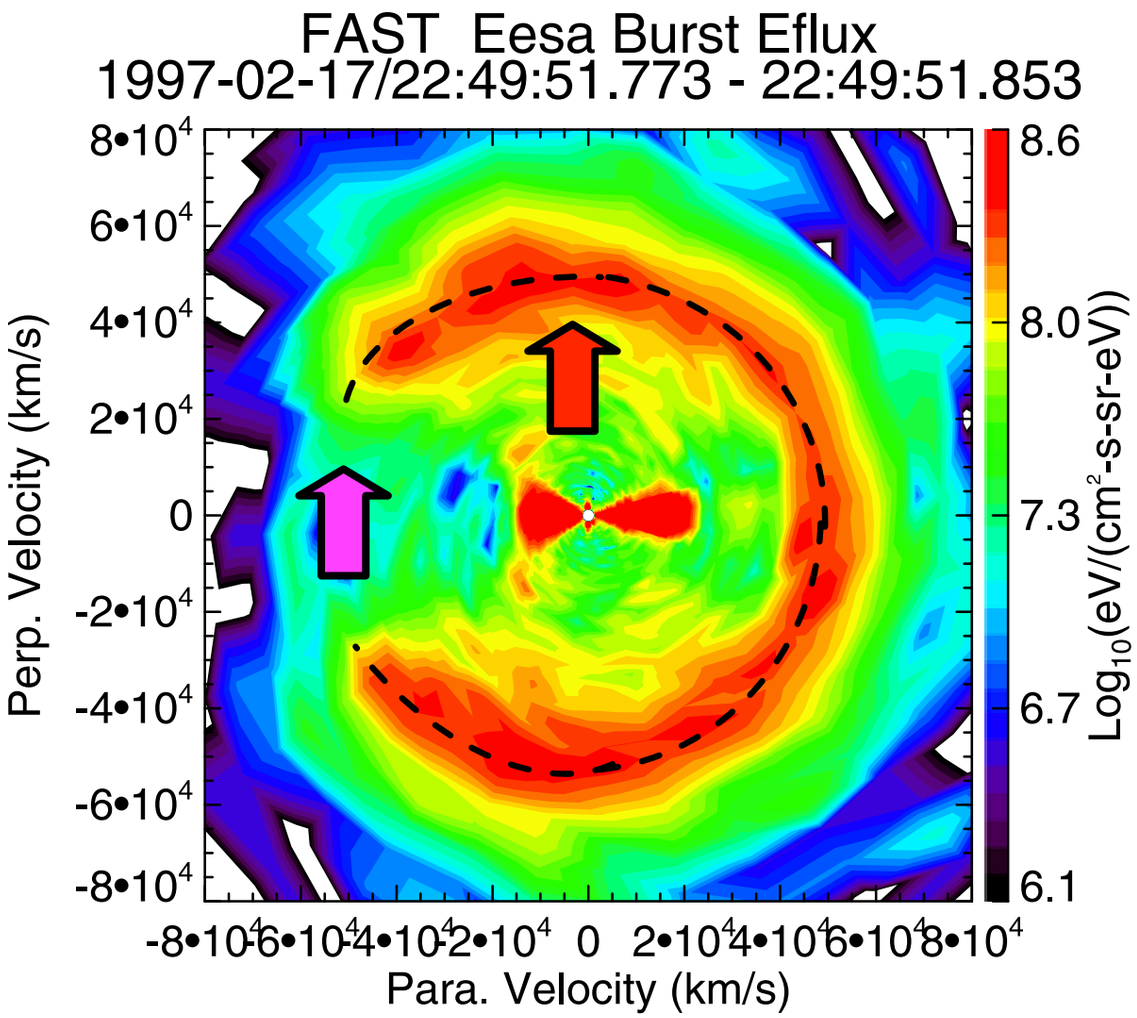


- Jupiter : radio source ~fixed / Jupiter & Io because unstable e- distribution
  (at f ~ f_{ce}) near the planet

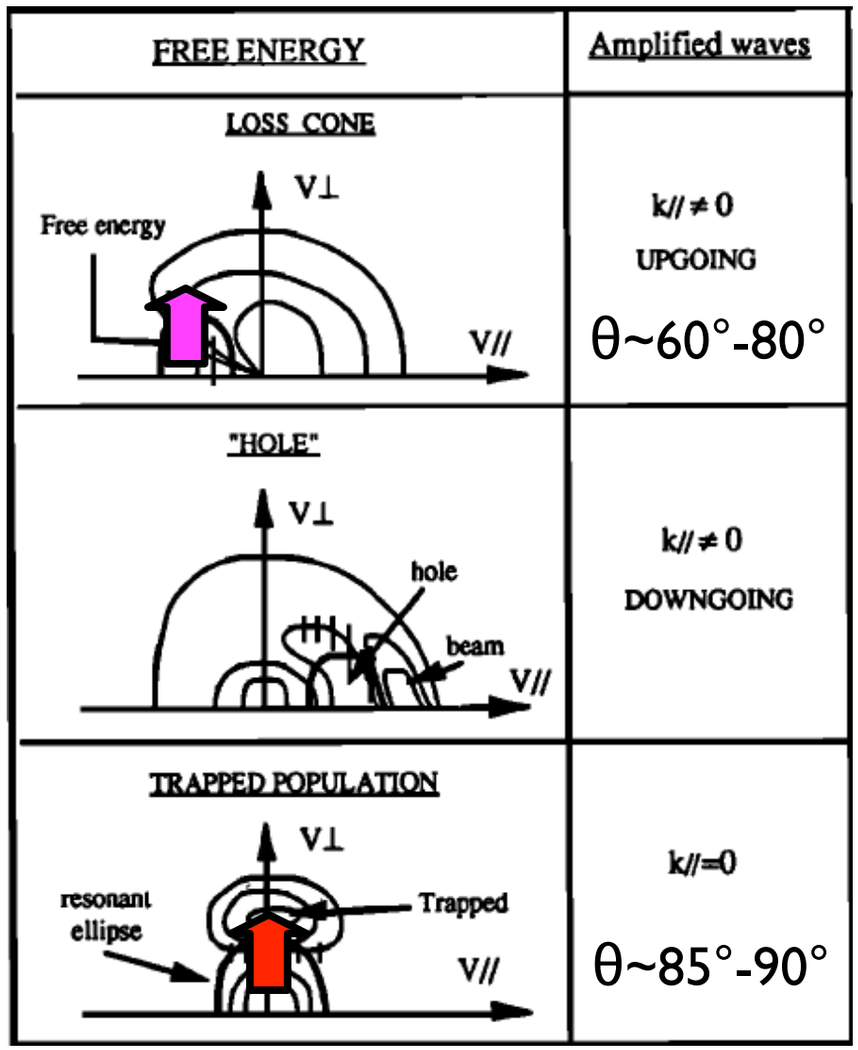
- Cyclotron Maser Instability : Resonance condition $\omega = \omega_c/\Gamma - k_\parallel v_\parallel$

[Treumann, 2006]

Growth rate $\gamma = \frac{\omega_p^2 c^2}{8\omega_c} \int_0^{2\pi} v_\perp^2(\theta) \nabla_{v_\perp} f(\mathbf{v_0}, \mathbf{R}(\theta)) d\theta$



[Su et al., 2008]



[Roux et al., 1993]

- Radio emission fixed in pulsar frame → not detectable at Gpc distances

- AW to infinity → ∃? radio source convected in the wind along AW at $V_{wind}/\cos\delta$?

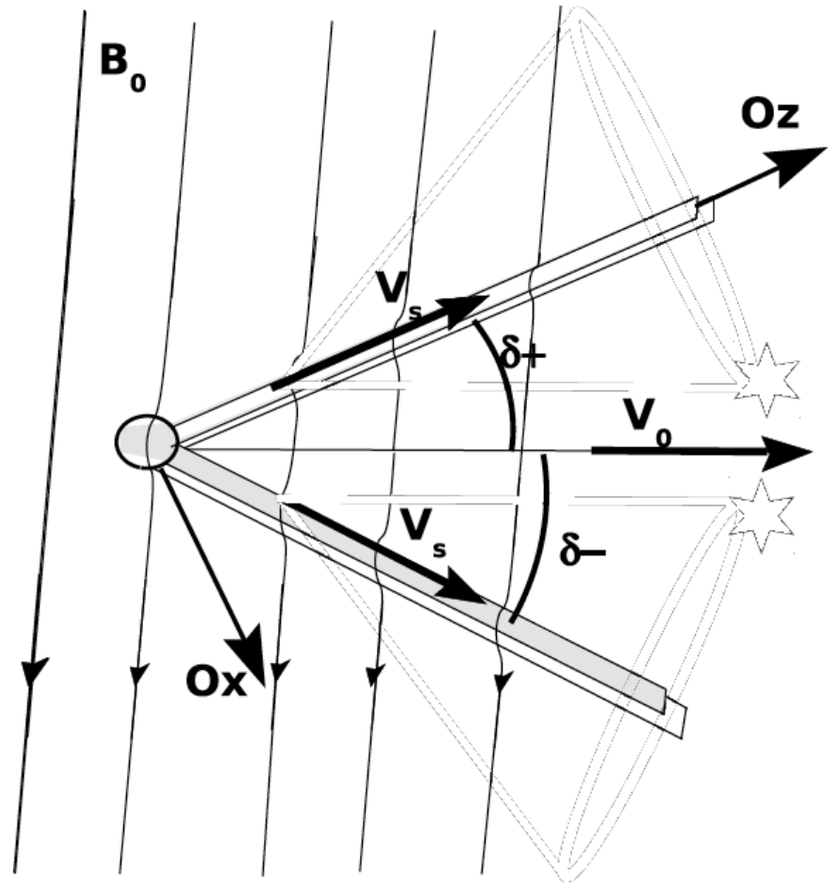
  → possible only for δ- wing if x<<1, both δ- & δ+ if x>>1

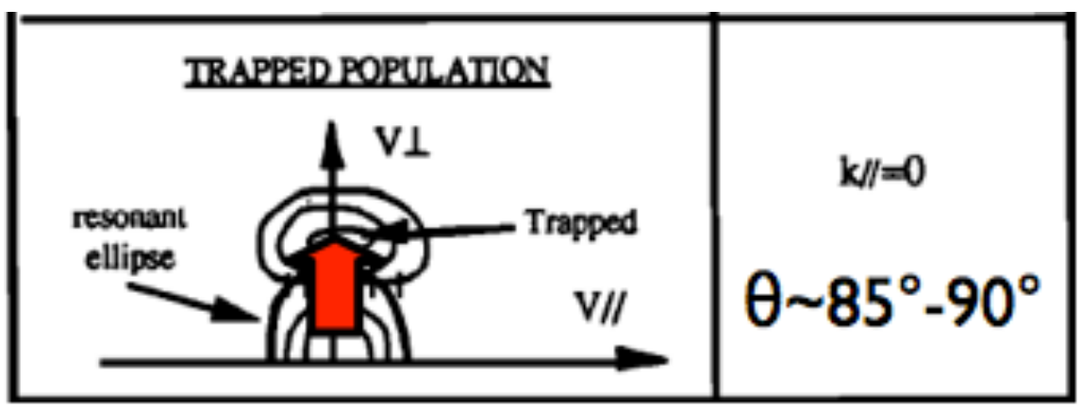
  $\delta \rightarrow 1/\gamma$ for large γ

- In source frame (V_{Source}, Oxyz)

  → significant V_x & $B_{//}$ ($B_\Phi = B_{\Phi o}/\gamma$)

  → large $V_\perp$ = large free energy source for CMI

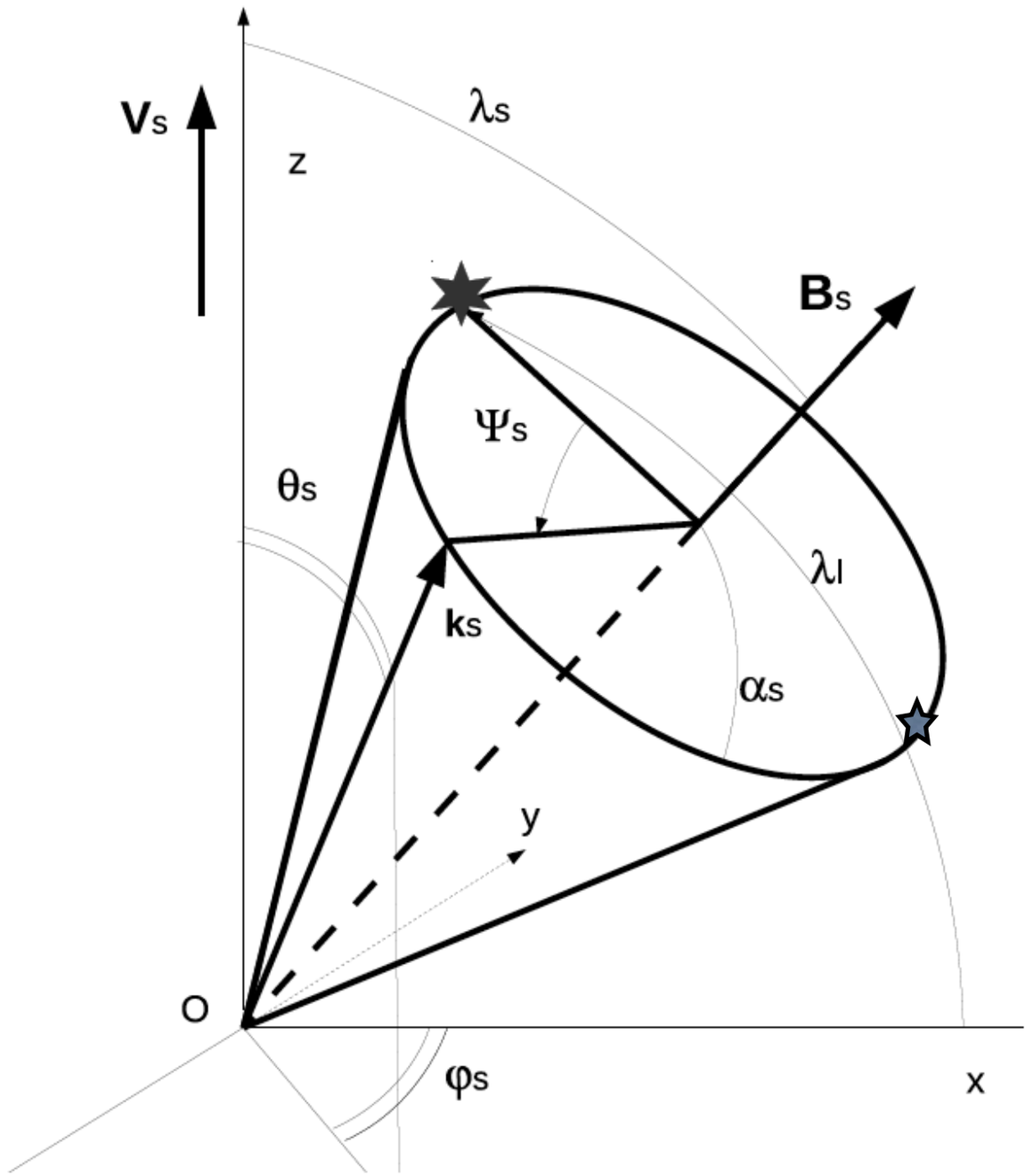




[Roux et al., 1993]

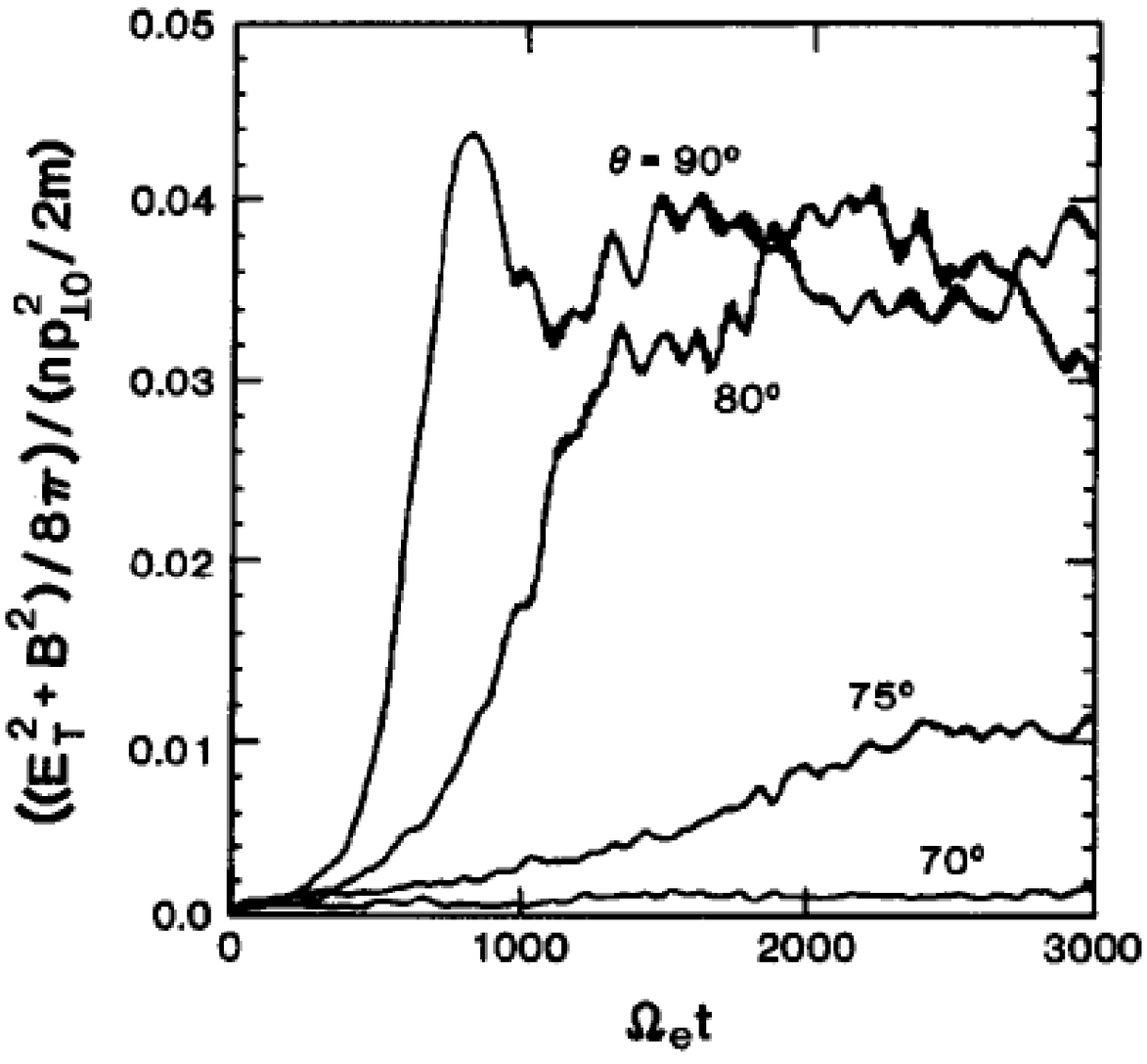
- Most unstable waves : $f \sim f_{ce\_source}$, cone θ ~85°-90°
- Plasma distribution non gyrotropic (at given azimuth)

  → growth rate maximum at same azimuth (+ opposite ?)



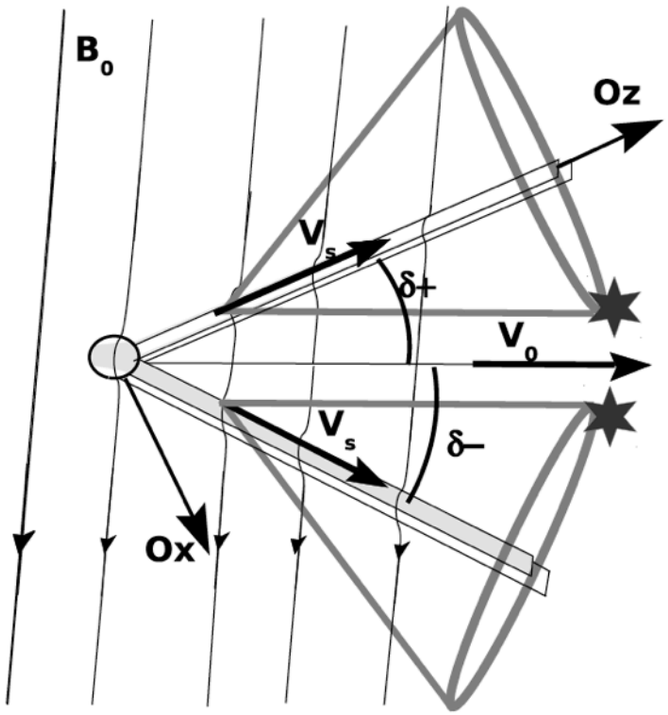
- Plasma crosses the AW in $\tau_s \sim \eta R_b / \delta \gamma_0 v_0$

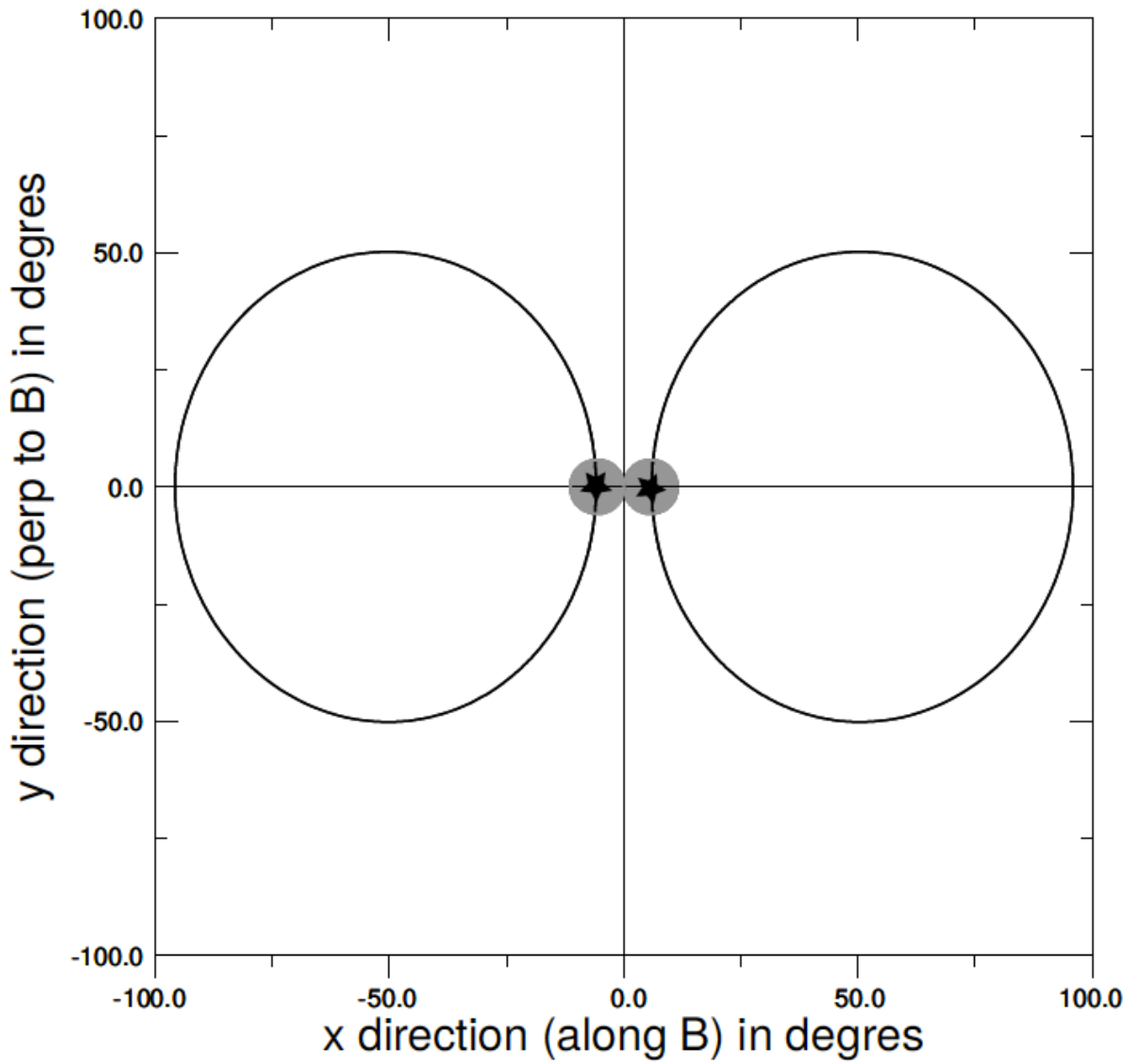
  ~ msec - sec >> saturation time (10's of μsec)



[Pritchett, 1986]

- Relativistic "aberration"
  - → radiation from a moving source : half-space "folded" in cone of half-angle ~ $1/\gamma$
  - → luminosity in the cone $\times \gamma^2$
- CMI non isotropic: hollow cone (+ hot spots when plasma distribution non gyrotropic)
  - → diagrams in source & observer's frame (z along wind - radial - direction)
  - → sweeps observer in angle/360*$P_{orbital}$





- $\gamma = 10$, a = 0.1 AU, $\theta = 85°$ → 2 hot spots separated by several °
- If B tilted, oscillation → several bursts separated by pulsar period, of ≠ intensities

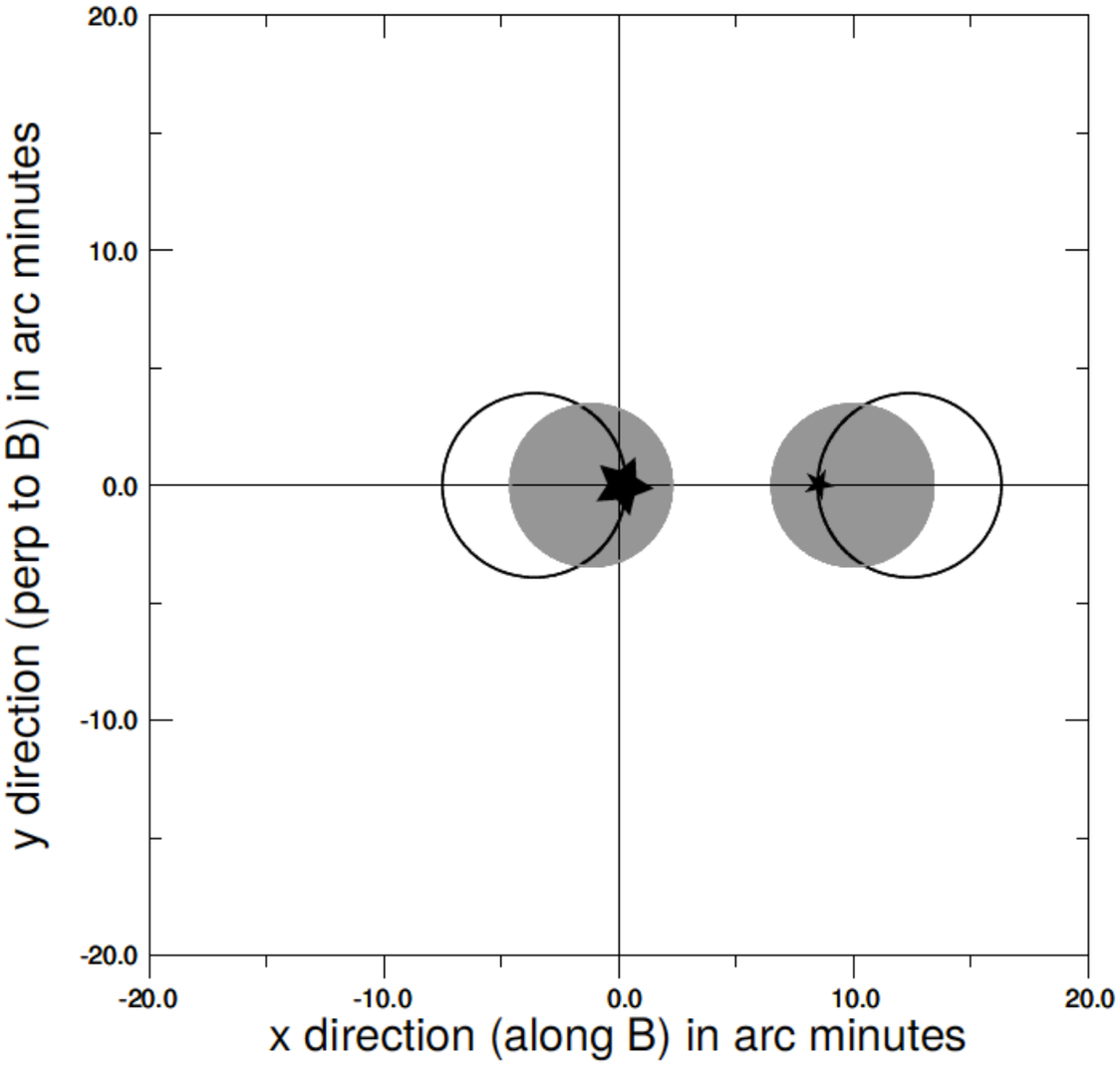
- $\gamma = 10^3$, a = 0.1 AU, $\theta = 85°$

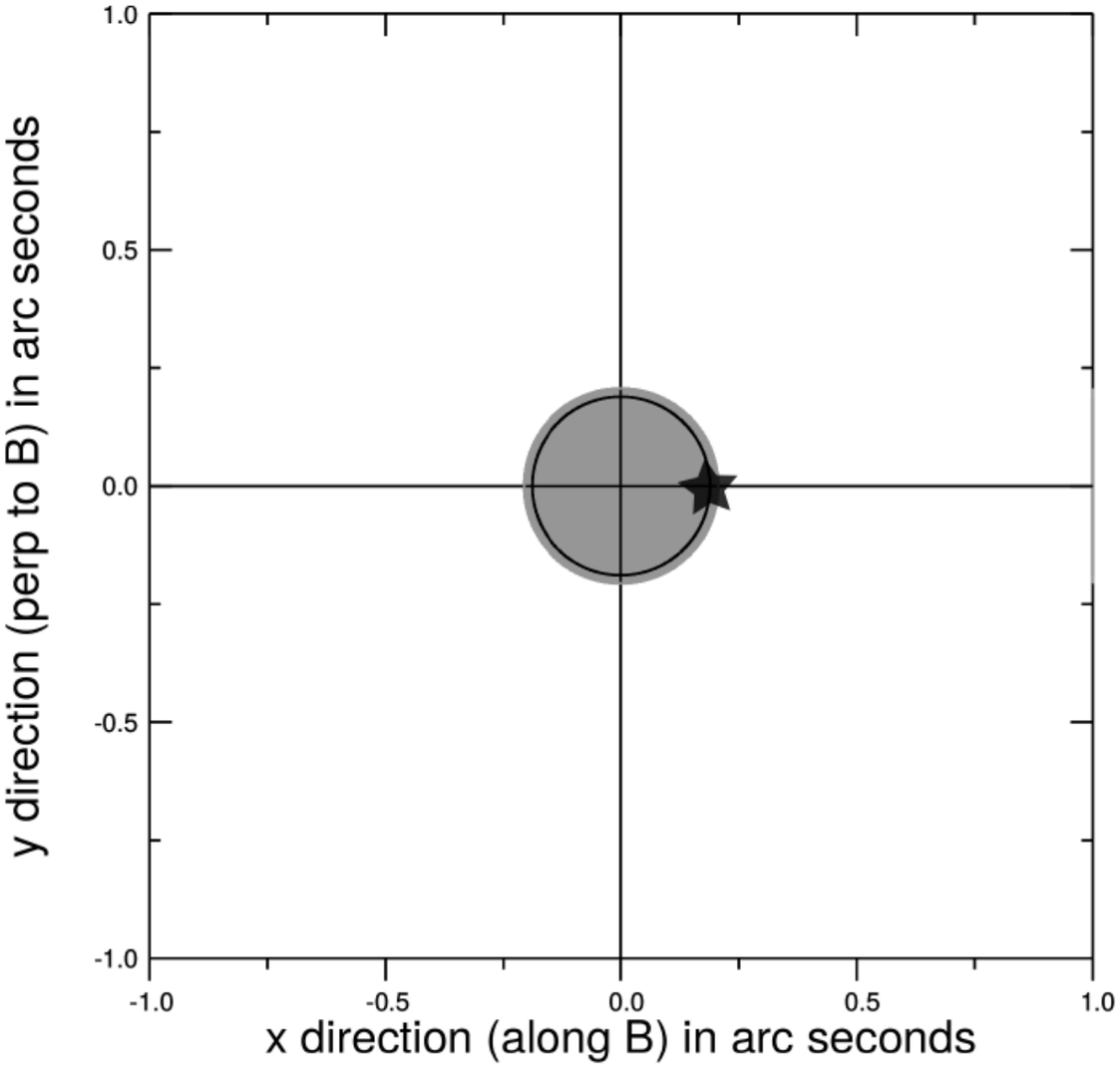
→ small angle → rare events, up to 4 pulses (2 intense) separated by 10's of sec to min

- $\gamma = 10^6$, a = 0.1 AU, $\theta = 85°$

→ 1 emitting wing

→ grey disk crossed in msec (in sec for $\gamma = 10^5$)



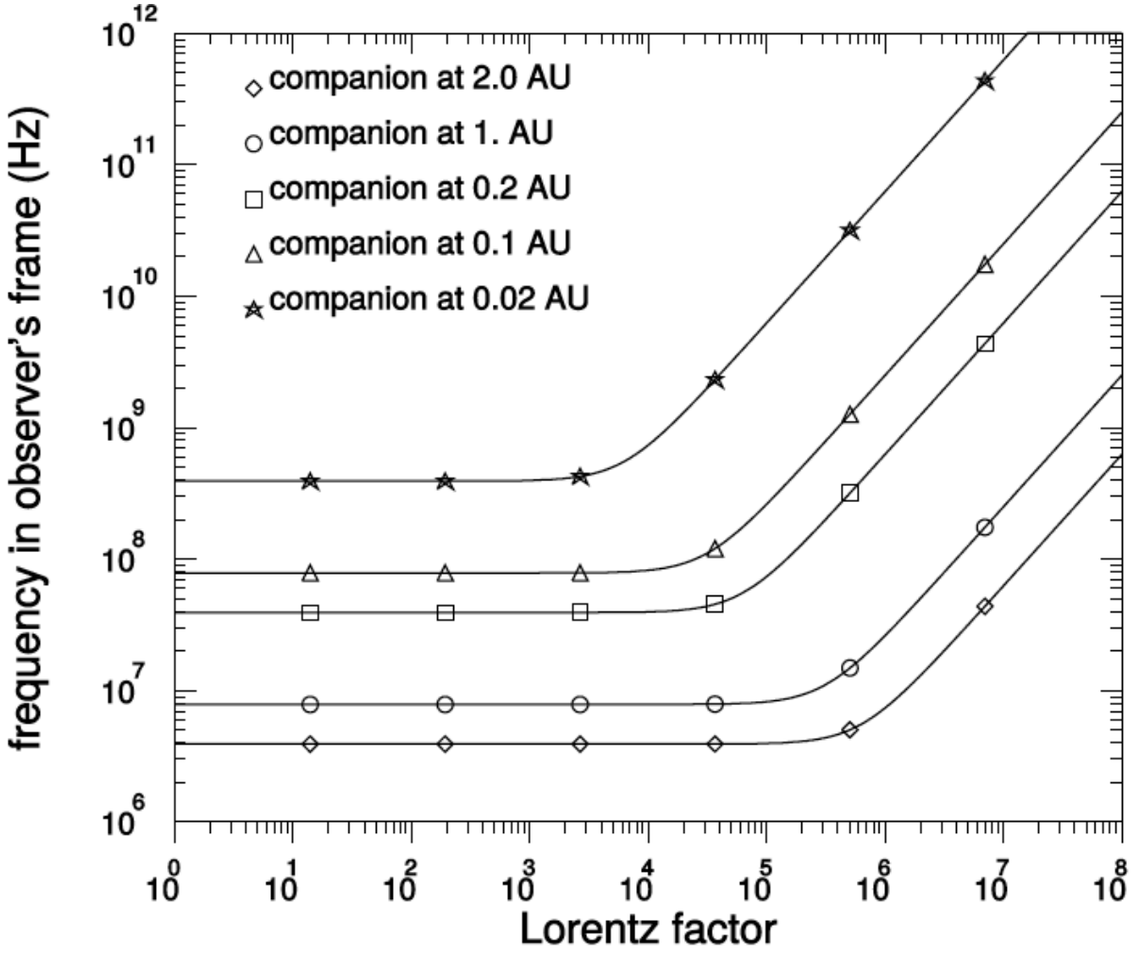


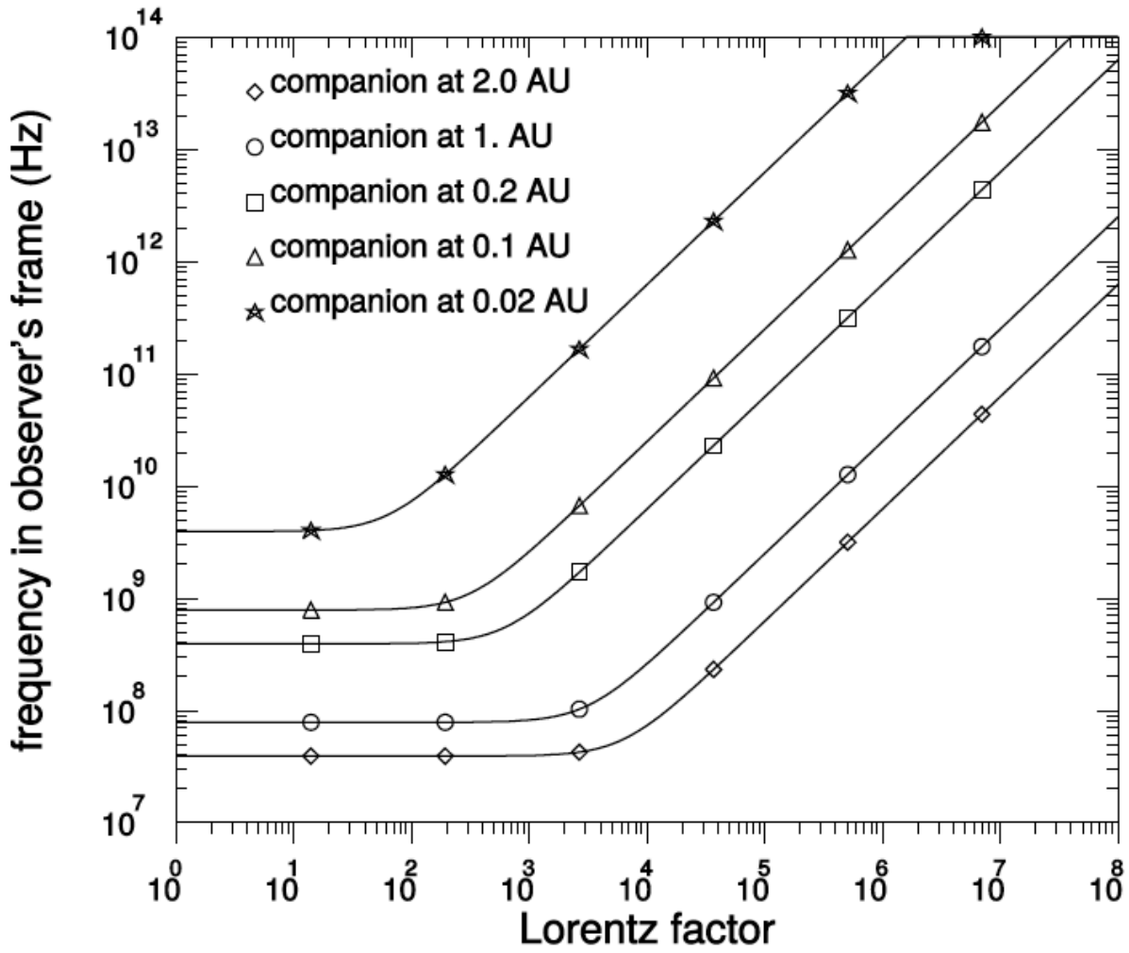
- Frequency $f_{ce\_source} \rightarrow f_{ce\_observer}$:

$$f_{c,o} = 25\ \gamma \left(\frac{B_*}{10^5\mathrm{T}}\right)\left(\frac{1\mathrm{AU}}{r}\right)^2\left(\frac{R_*}{10^4\mathrm{m}}\right)^2\left\{1+\left[\frac{\pi\ 10^5}{\gamma}\left(\frac{10\mathrm{ms}}{T_*}\right)\left(\frac{r}{1\mathrm{AU}}\right)\right]^2\right\}^{1/2}$$

10's MHz to GHz → sub-mm for large γ (10^7)
for msec pulsar (B~10^5 T)

up to IR for pulsars with B~10^8 T

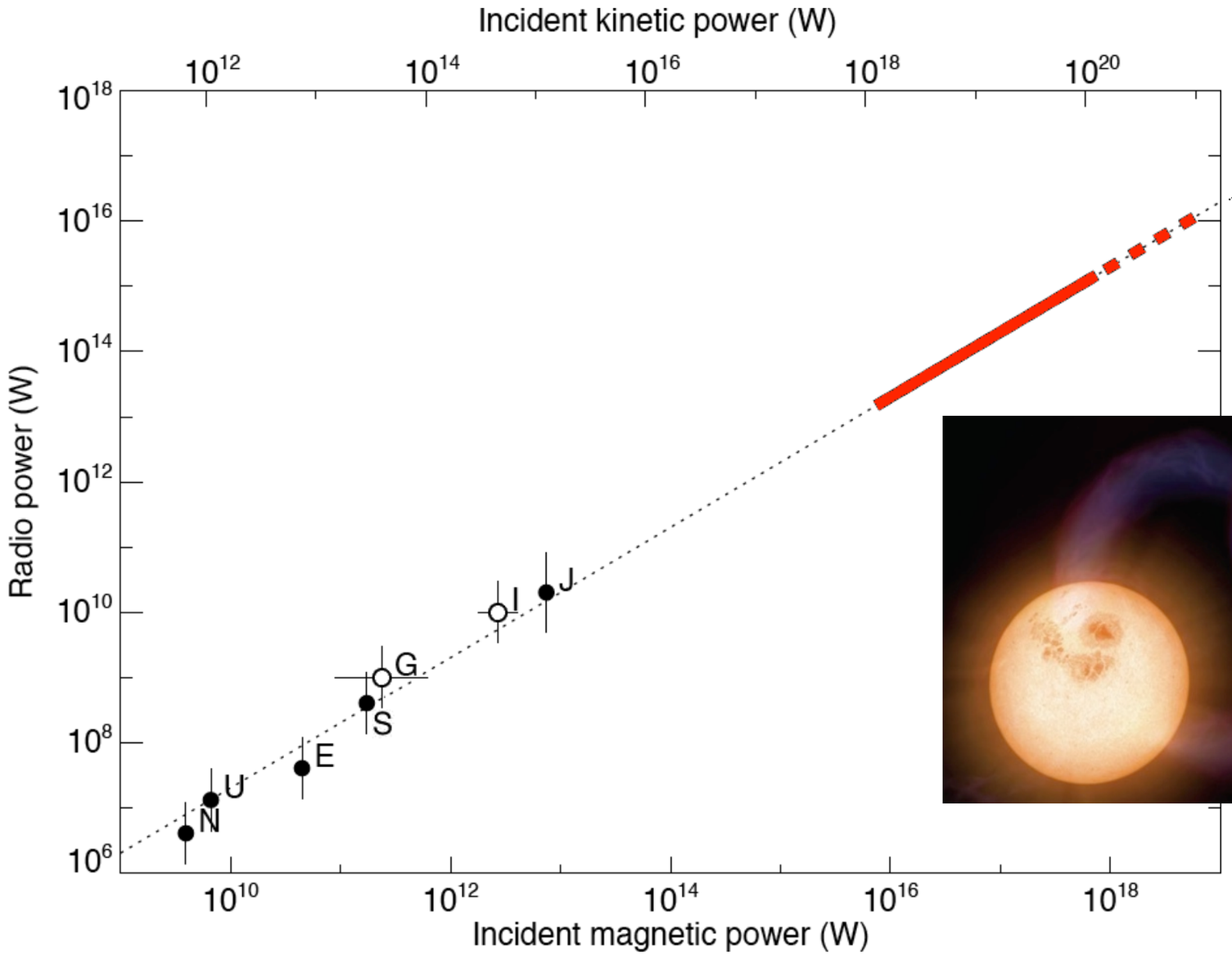


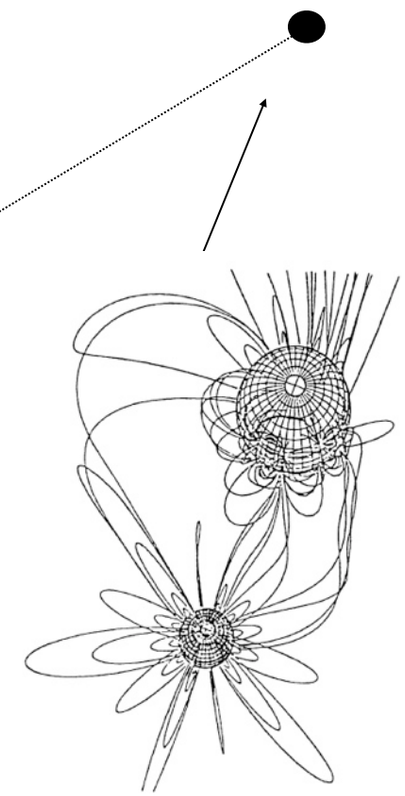


- Power dissipated in AW → fraction ε ~ 10^{-2} to 10^{-4} in Radio power

$$\dot{E}_J = \frac{\pi}{\mu_0 c} R_b{}^2 r^{-2} R_*^4 B_*^2 \Omega_*^2 \qquad P_{radio} = \epsilon \dot{E}_J$$

[Mottez & Heyvaerts, 2011 ; Zarka et al., 2001]

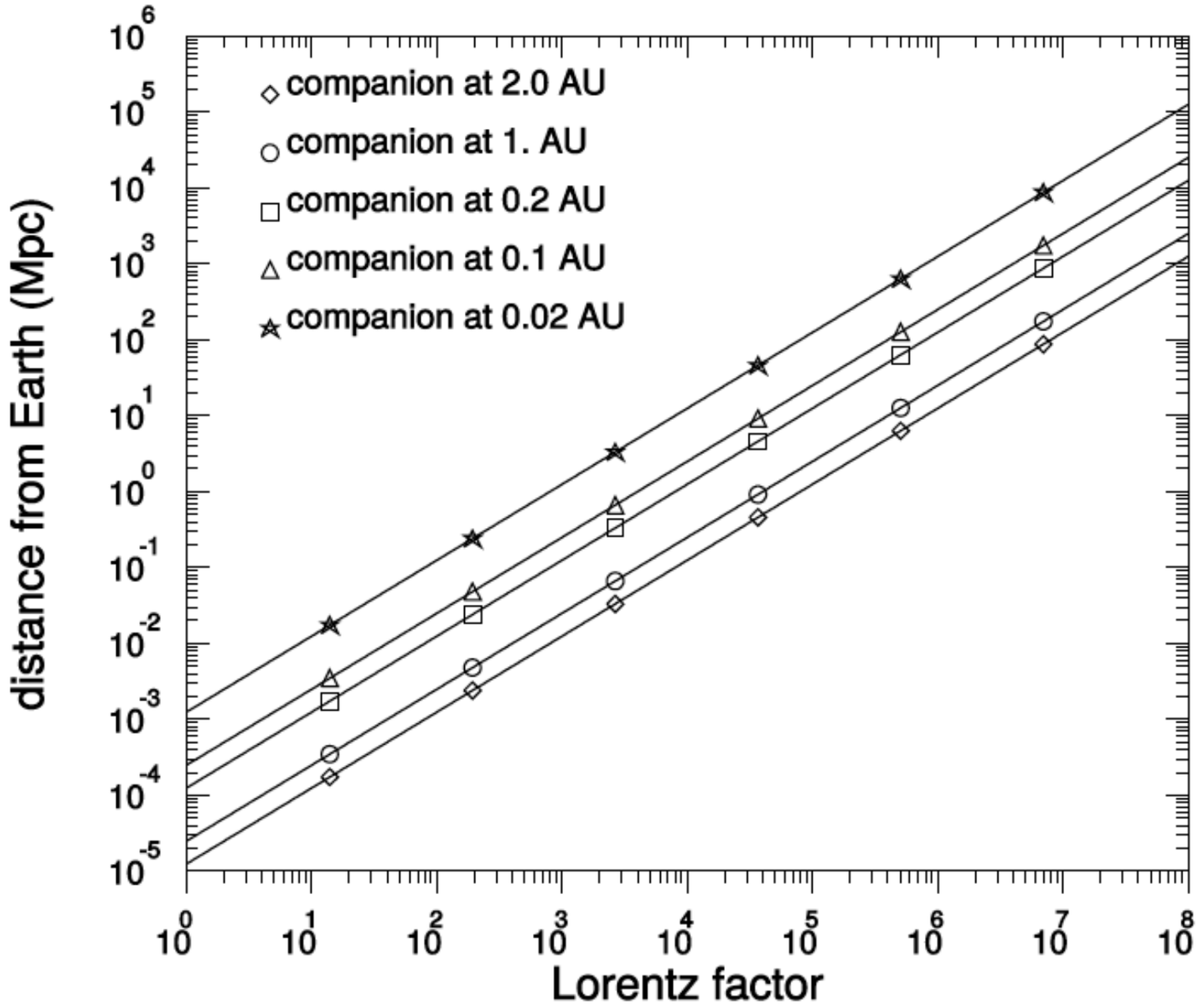




[Zarka et al., 2001 ; Zarka, 2007, 2010]

- Flux density (isotropic) : $\left(\frac{< S >}{\mathrm{Jy}}\right) = 6.5\left(\frac{\gamma}{10^5}\right)^2\left(\frac{\epsilon}{10^{-3}}\right)\left(\frac{R_b}{10^7\mathrm{m}}\right)^2\left(\frac{1\mathrm{AU}}{r}\right)^2\left(\frac{R_*}{10^4\mathrm{m}}\right)\left(\frac{B_*}{10^5\mathrm{T}}\right)^2\left(\frac{10\mathrm{ms}}{T_*}\right)^2\left(\frac{Mpc}{D}\right)^2\left(\frac{1\ \mathrm{GHz}}{\Delta f}\right)$

→ max distance (for S ~ Jy) ≥ 1 Gpc for $\gamma \geq 10^{5\text{-}6}$



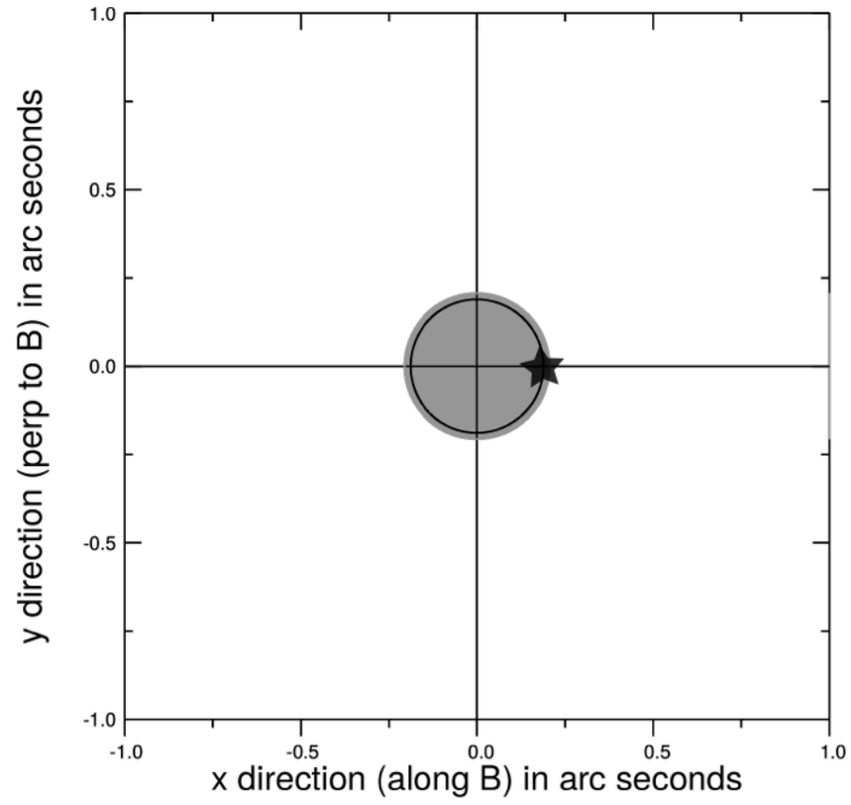
× >10 for CMI (anisotropic)

[+ constructive scintillations ?]

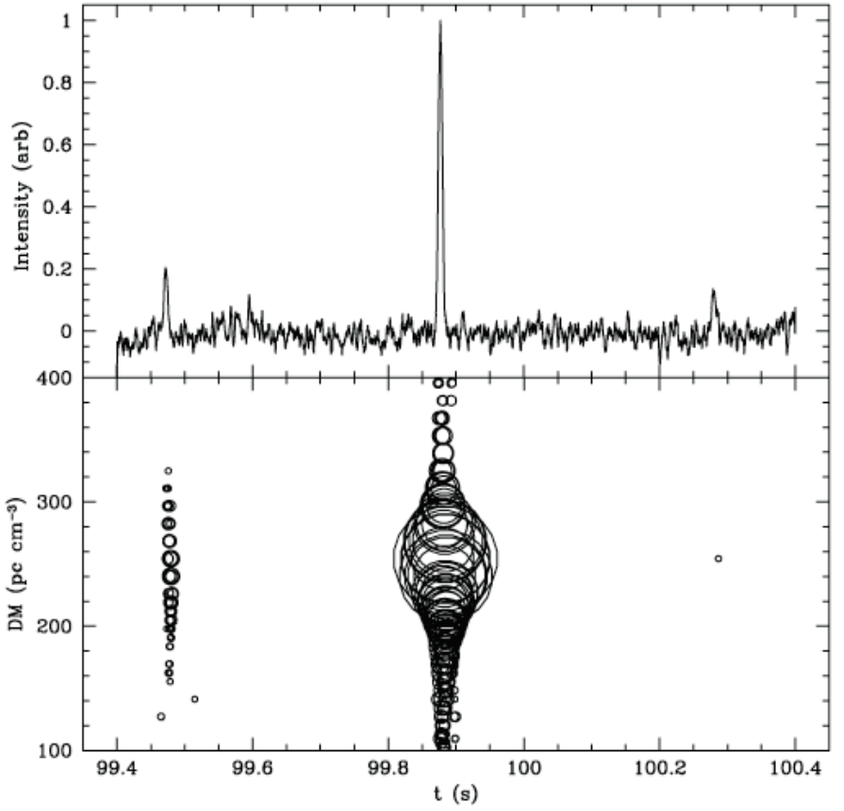
- $P_{Radio} \sim 10^{20\pm2}$ W ≤ isolated pulsars, but γ^2 amplification

  (~BL Lac collimated jets, but synchrotron 10^5 × weaker than CMI)

- FRB rare bursts (statistics TBD - cf [Hassal et al., 2013])
- For $\gamma \geq 10^{5\text{-}6}$, duration 1-5 msec → $P_{orbital} \sim 0.1\text{-}1$ day
  (>70 pulsar companions known with $P_{orbital} \leq 1$ day
  + possible low mass planets & asteroids)
- Consistent with no re-detection within 1.5 hours of FRBs

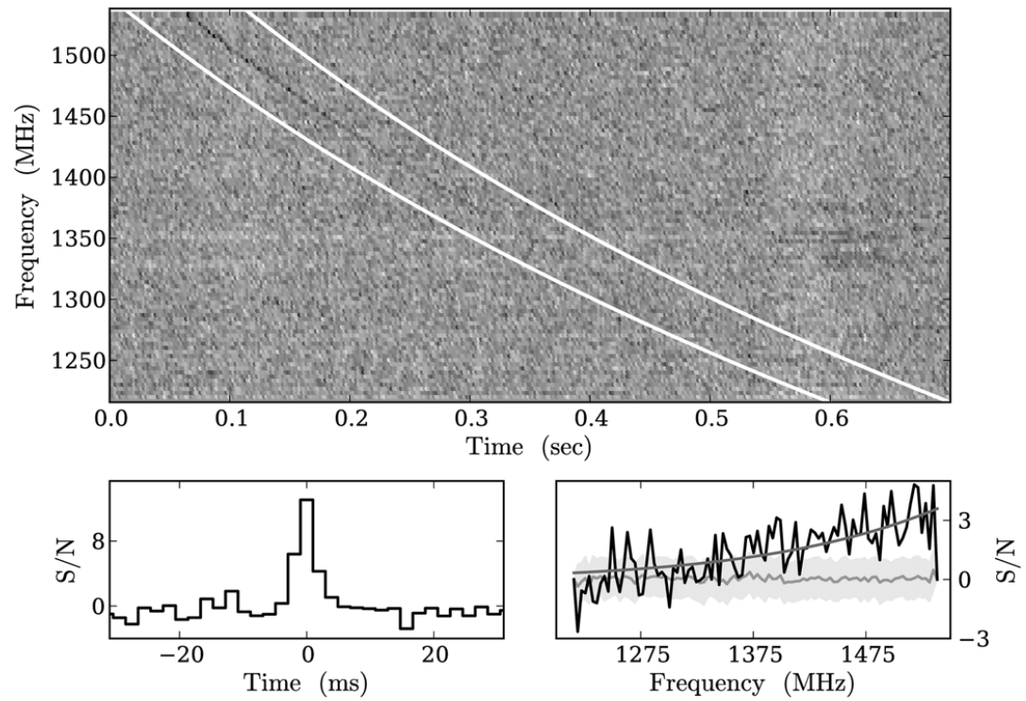


- PSR J1928+15 : three 30 msec peaks
  separated by 403 msec, DM = 242 (galactic)
  → Dormant pulsar accretion from asteroid belt ?
- $\gamma \sim 10^3$, 1000 km body @ 0.01 AU
  around a 0.403 sec pulsar
  → δ- AW traversed in 1.5 sec = 3 pulsar rotations,
  1 intense = *
- 180 mJy @ 10 kpc → small asteroid (km size)
  → limited growth ?



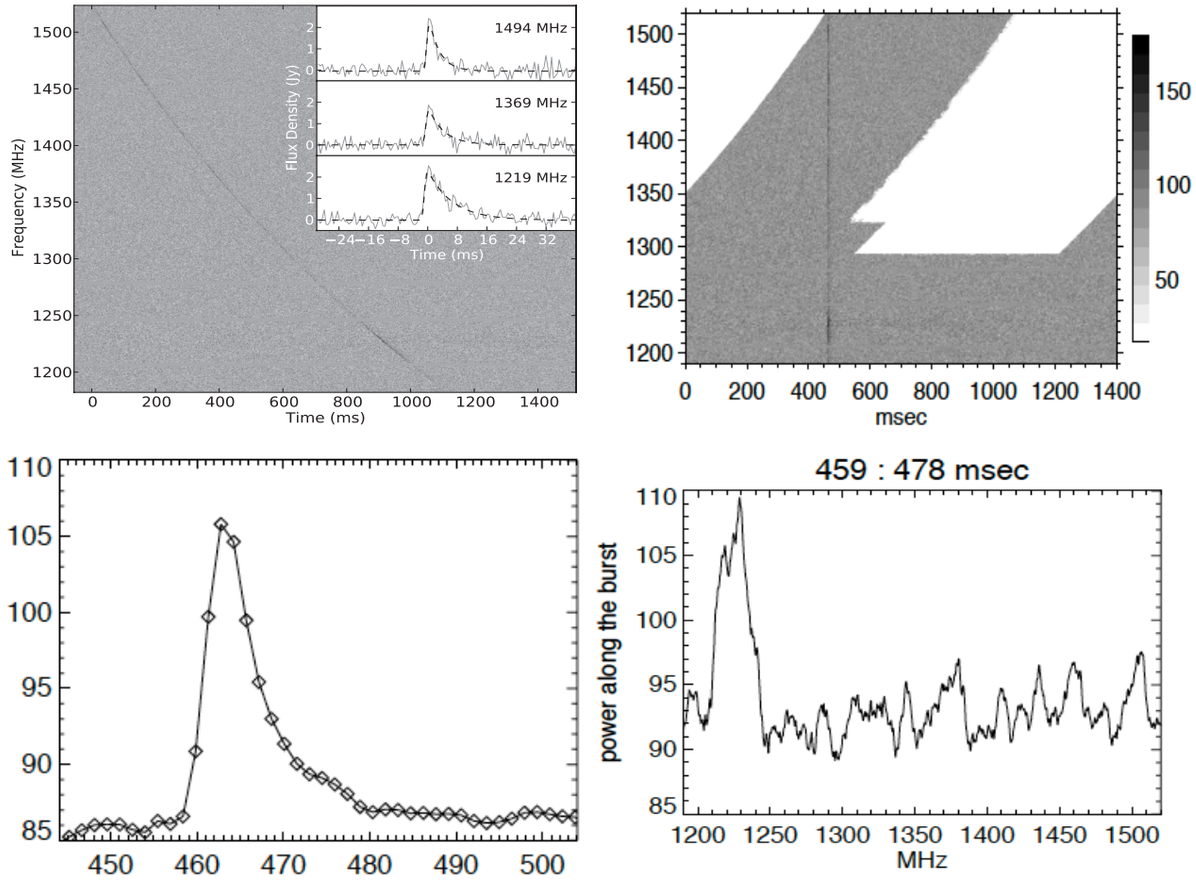
[Deneva et al., 2009]

- Spectral range ($\Delta f/f \geq 25\%$)
  → large radial range (B & γ variation)
  or very saturated CMI
  → harmonics → broad spectrum above f_{ce}
  (= LF cutoff) from a localized source



[Spitler et al., 2014]

- FRB 110220 has 100-MHz-wide bright bands
  → B ?



[based on Thornton et al., 2013]

Refutability tests :

- Regular repeatability : 1-5 msec every $P_{orbital}$ (days or more …)

- Predicted burst for edge on system (e.g. PSR J2222-0137 : sin i = 0.9985±0.0005)

[Deller et al., 2013]

- LF cutoff, harmonic bands, circular polarization

→ if confirmed, explanation of FRBs

& unique probes of Pulsar winds, surrounding bodies, γ