Title: Transient Radio Emission of Quiescent Magnetars

Speakers: Alexander Philippov

Collection/Series: Magnetic Fields Around Compact Objects Workshop

Subject: Strong Gravity

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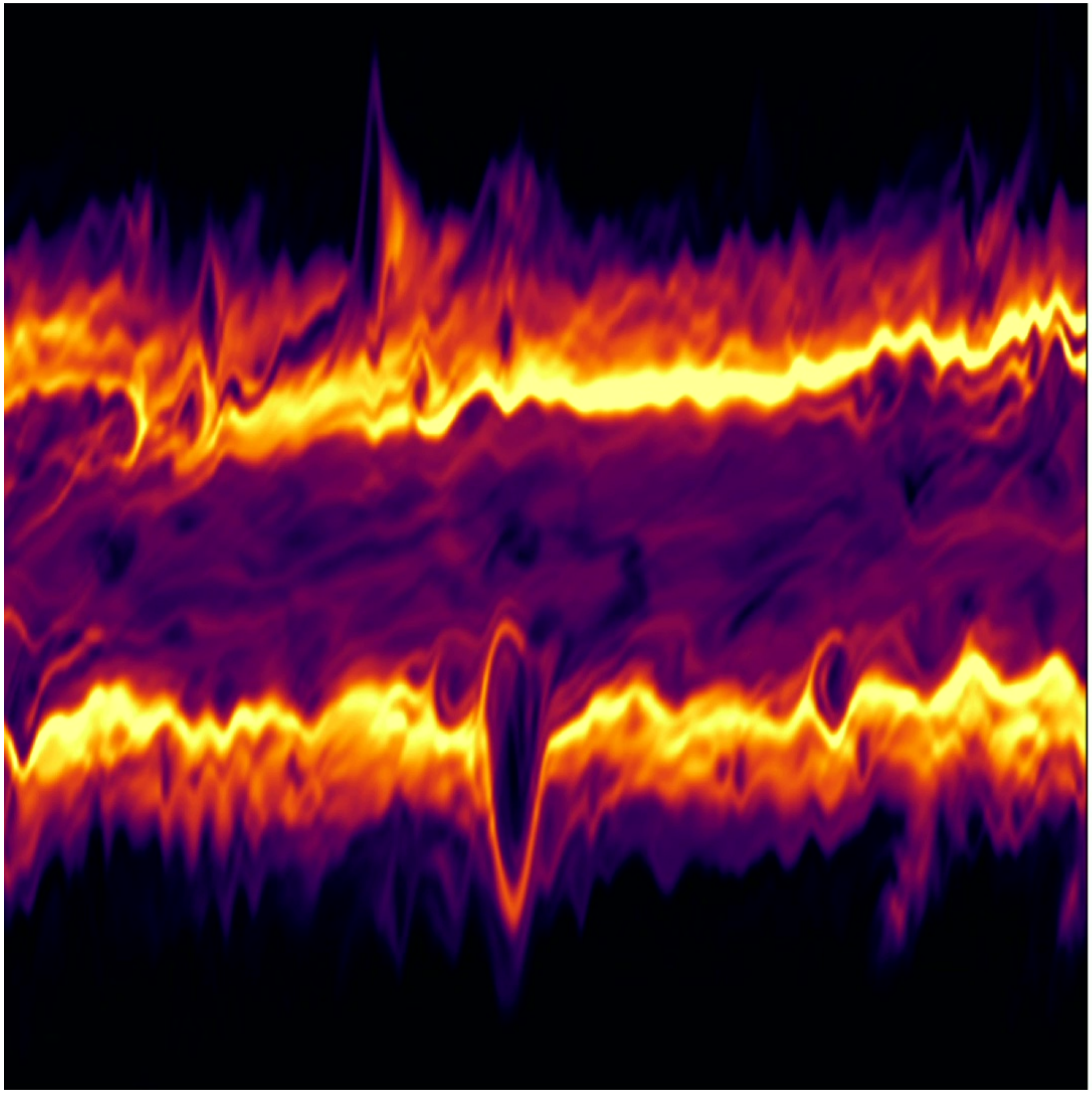

RADIO EMISSION OF QUIESCENT MAGNETARS: ELECTROMAGNETIC TURBULENCE POWERED BY RADIATIVE COOLING

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with:

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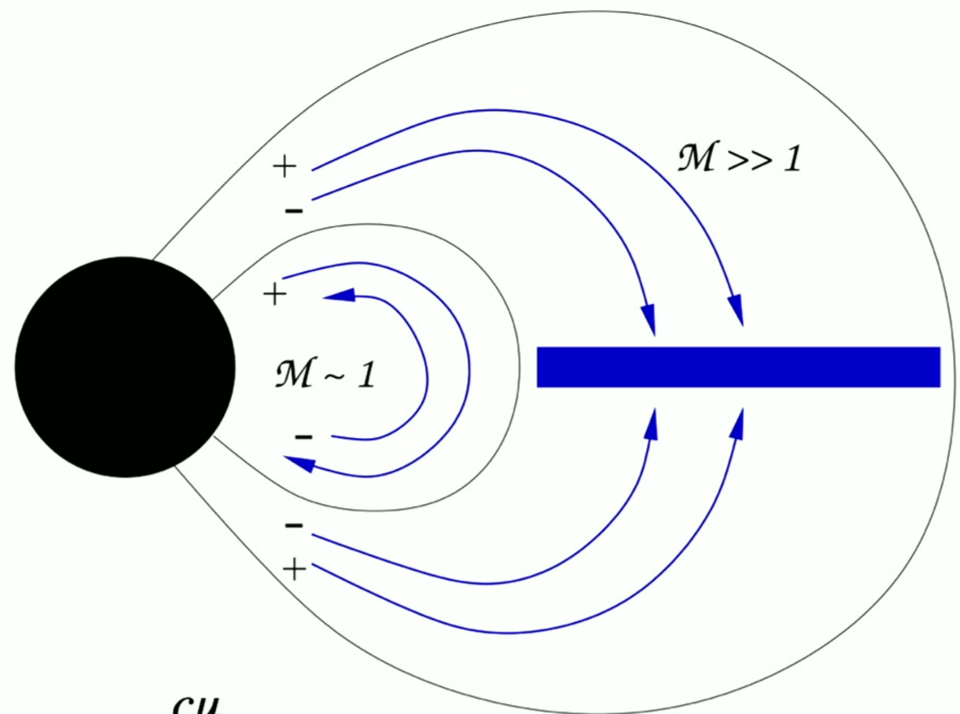
SIMONS FOUNDATION

SCEECS

Magnetospheres of Quiescent Magnetars

- Magnetars are neutron stars powered by magnetic energy (Duncan, Thompson 1992).
- Bright post-outburst X-ray emission $\sim 10^{35}$ erg/s $\gg$ spin-down power.
- Activity is powered by residual twist in the magnetosphere.
- Resonant inverse Compton scattering (RICS) produces energetic photons. $e^{\pm}$-creation sustains the current.
- Voltage of ~1GeV multiplied by current required to provide the twist with angle ~1radian explains the luminosity.



$$\hbar\gamma_{\pm}(\omega - \mathbf{k}\cdot\mathbf{v}_{\pm}) = \hbar\omega_B$$

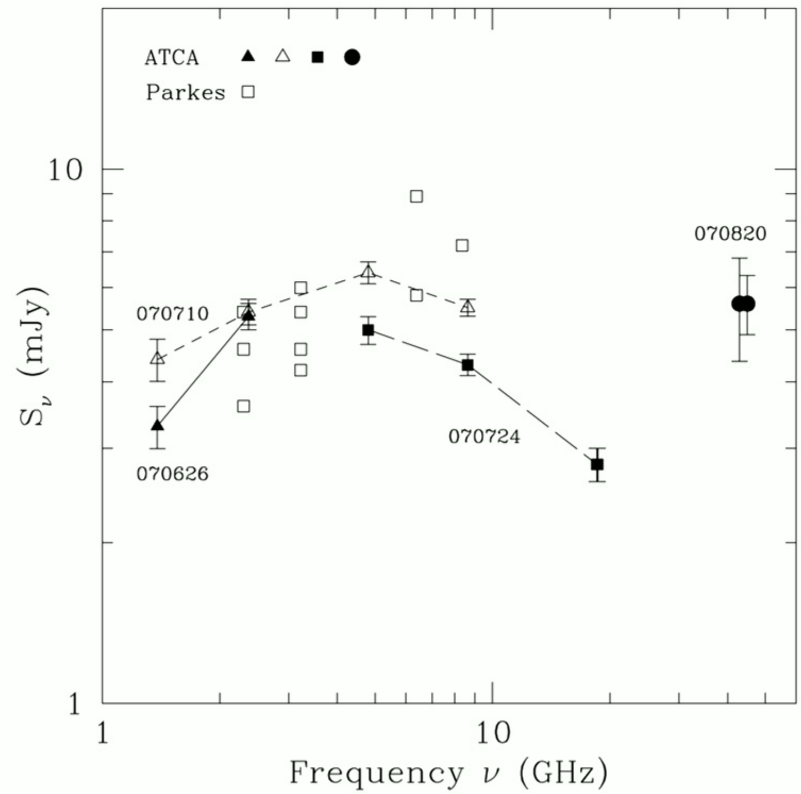
$$\gamma \sim \omega_B/\omega_X \sim 10^3(B/B_Q)(1\ \mathrm{keV}/\hbar\omega_X)$$

$$L_X \sim I\Phi \sim \psi\frac{c\mu}{4R^2}\Phi$$

Beloborodov, Thompson, 2008
Beloborodov, 2013

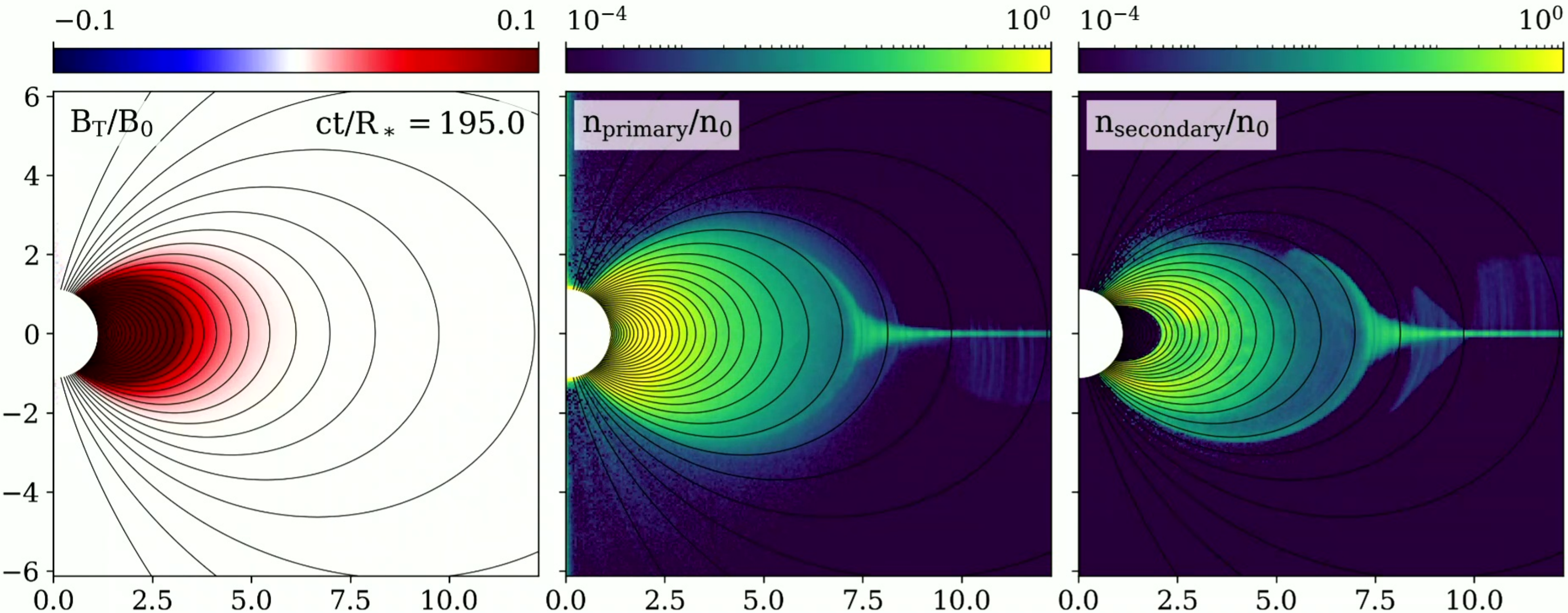
Radio Emission of Quiescent Magnetars

- Radio activated post-outburst
- Very hard spectrum extends to high frequencies (very different from pulsars)
- Broad radiation beams (radio lightcurve; significantly wider than for normal pulsars)
- Luminosity $\sim 10^{30}$ erg/s
- Activity in the open field line region (like in pulsars) can not explain the luminosity.



Camilo et al., 2008

Magnetospheres of Quiescent Magnetars



Mahlmann, Philippov et al., *in prep*

$$\gamma \sim \omega_B/\omega_X \sim 10^3 (B/B_Q)(1\ \mathrm{keV}/\hbar\omega_X)$$

Electric Current and Plasma Flow

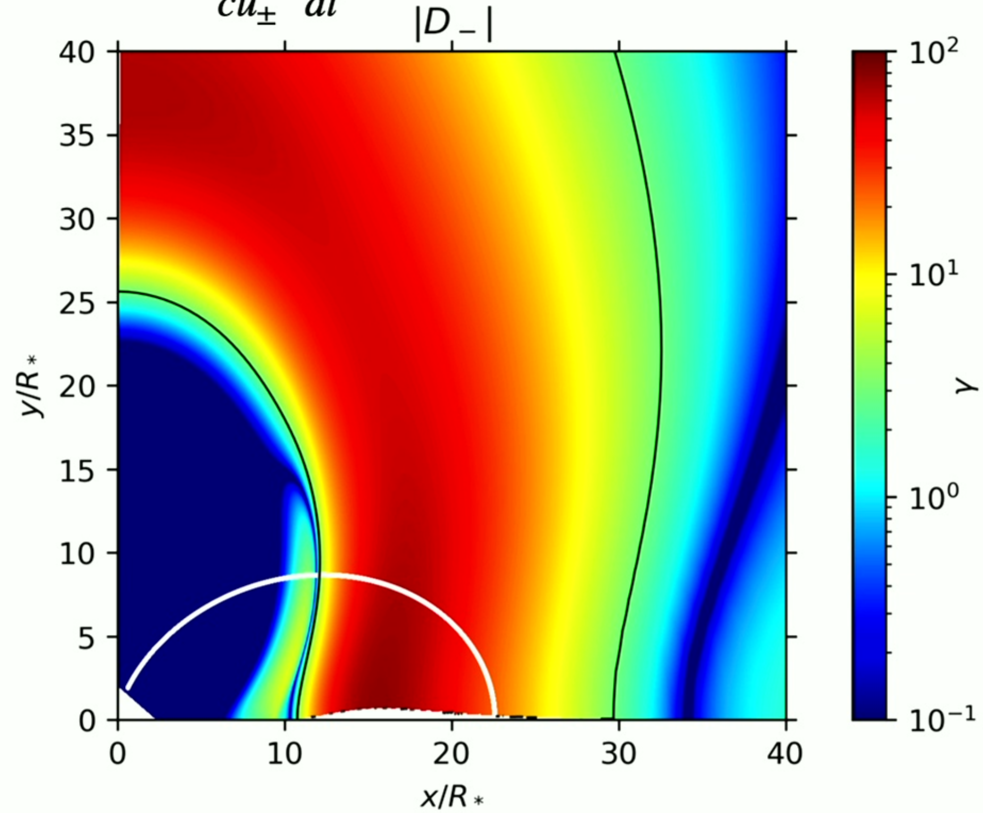
- e^- & e^+ resonate with the bulk of the stellar photons somewhere at 10-30 $R_\star$.

- The current has to flow despite the drag.

$$m_e c \frac{du_\pm}{dt} = \pm eE_\parallel + F_{\rm rad}(u_\pm)$$
$$j_0 = n_\pm |e| (\beta_+ - \beta_-)$$

- The plasma flow consists of two radiatively cooled e^- & e^+ beams.

$$D_\pm = \frac{r}{cu_\pm}\frac{du_\pm}{dt}$$



1D: Radiatively-Driven Two-Stream Instability

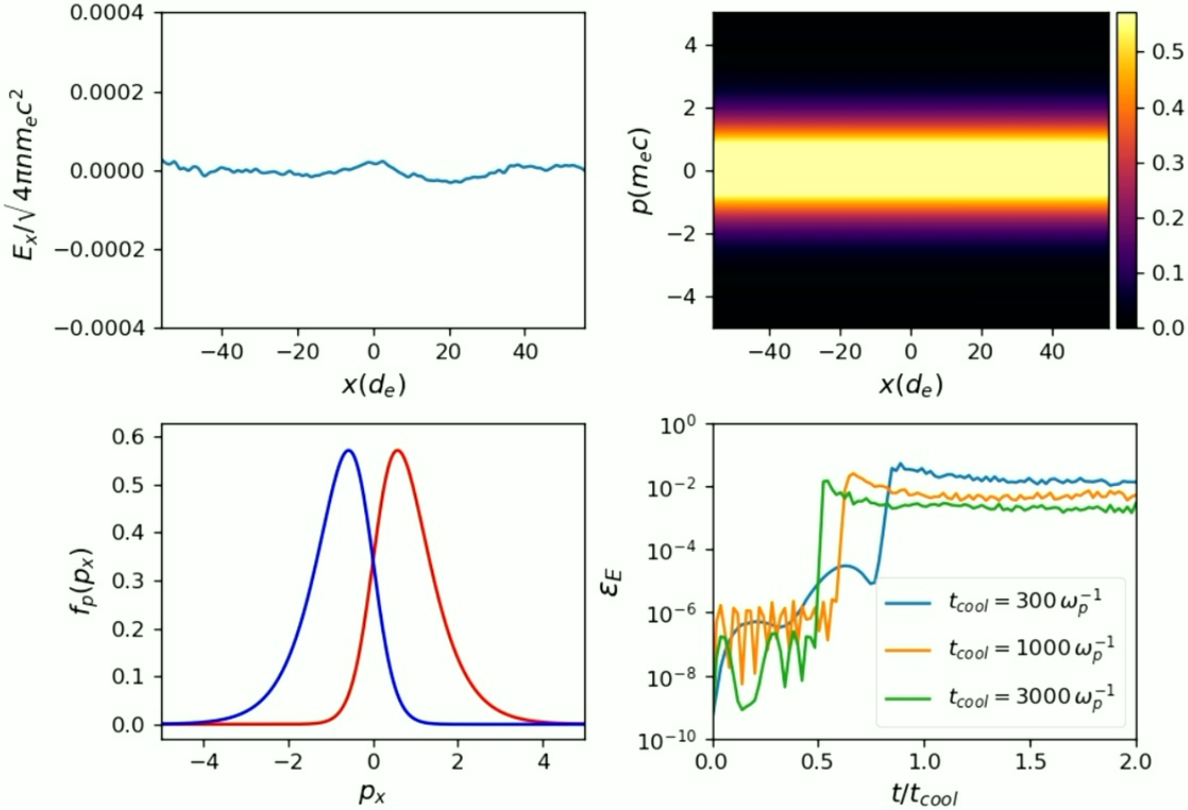
- As the hot flow gets cooled, instability is excited.
- Squeezing of beams by RICS cooling is balanced by diffusion due to electrostatic turbulence.
- Power decreases as cooling time increases:

$$\epsilon_E = \frac{E^2}{8\pi W_{\rm th}} \sim (\omega_p \tau)^{-1} \ll 1$$

- Turbulence stays strong! This is because the pump shifts to long wavelengths.

$$\chi = \frac{eE}{kmv_{\rm th}} \sim 1$$

Gkeyll



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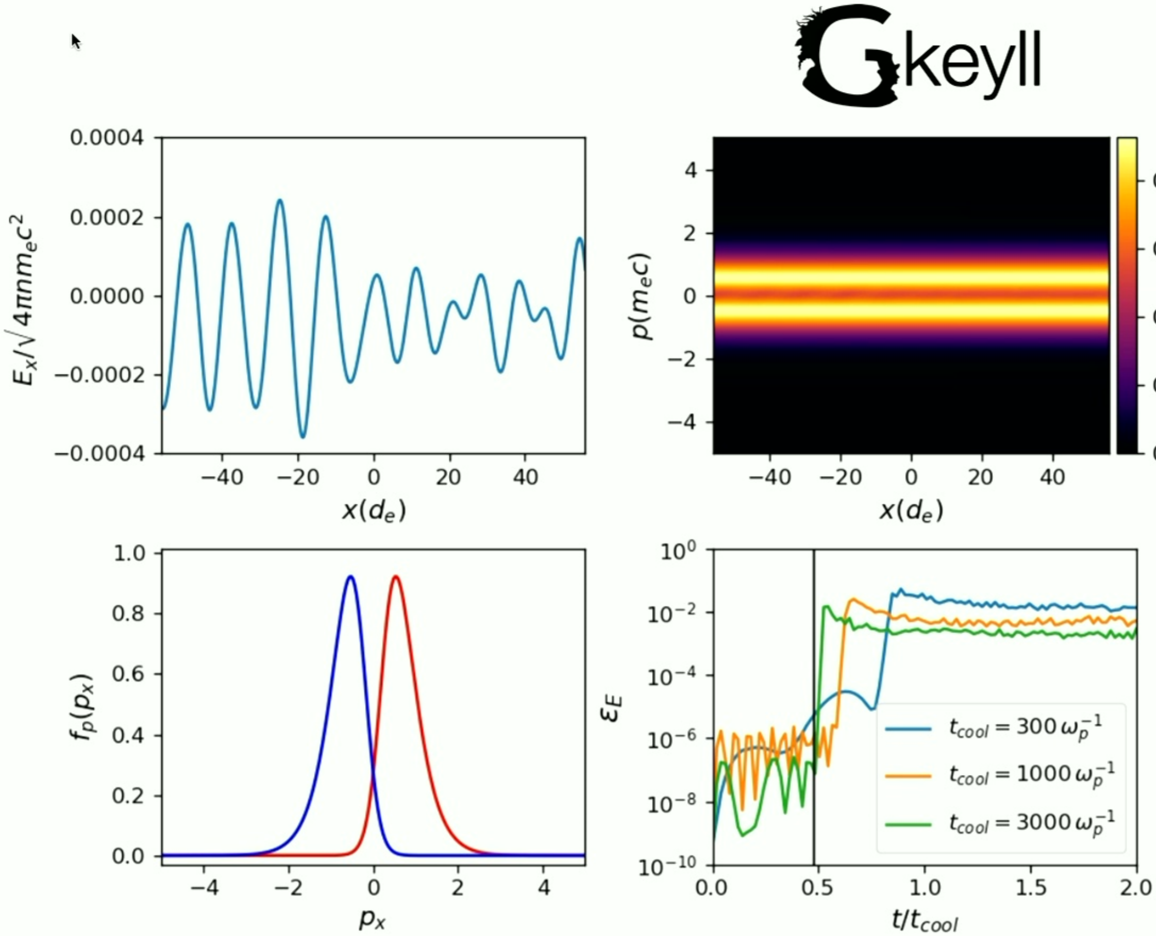
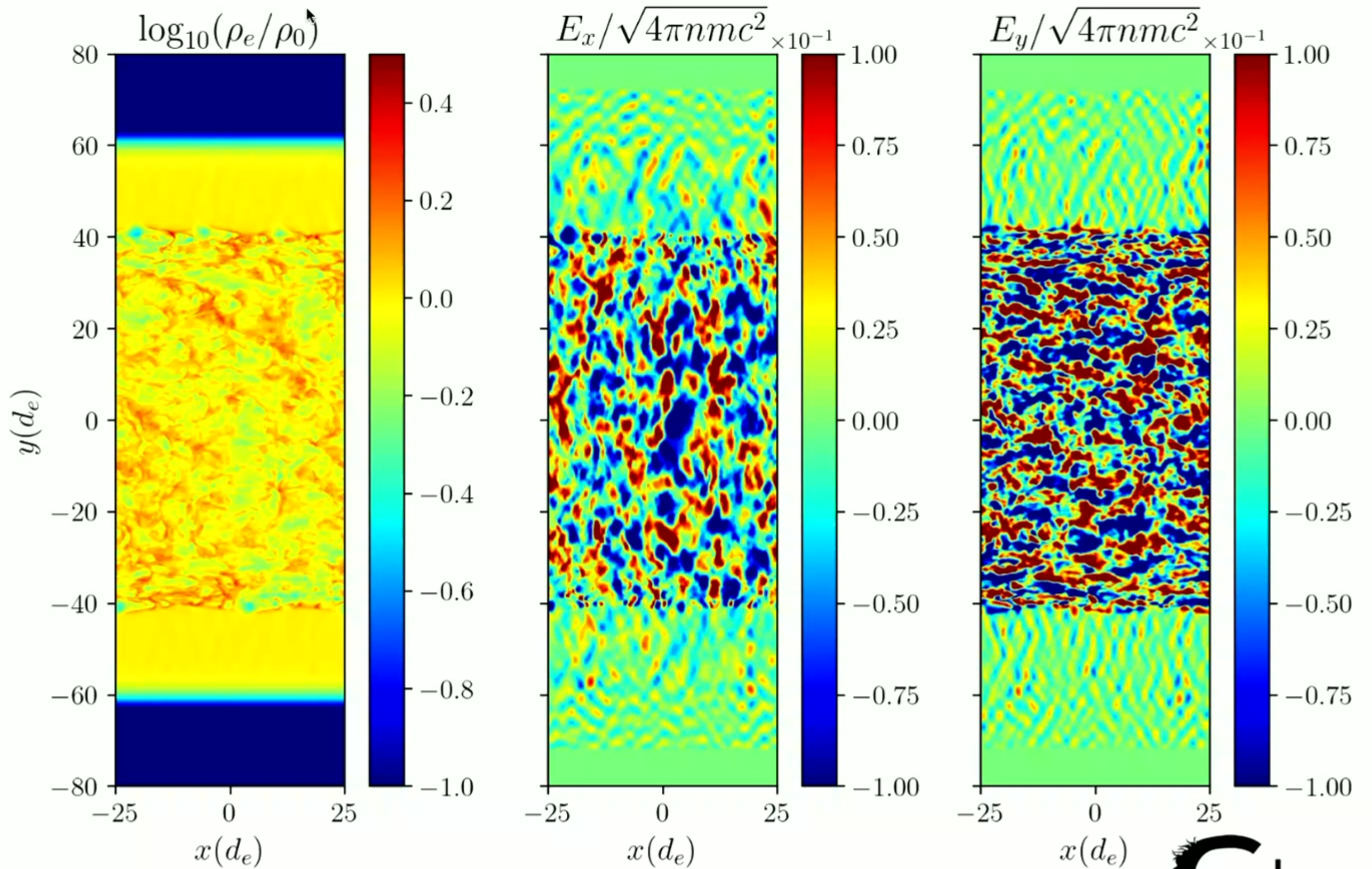


2D: Radiatively-Driven Two-Stream Instability

- In 2D, electromagnetic modes are excited!
- Our simulation setup achieves steady state.



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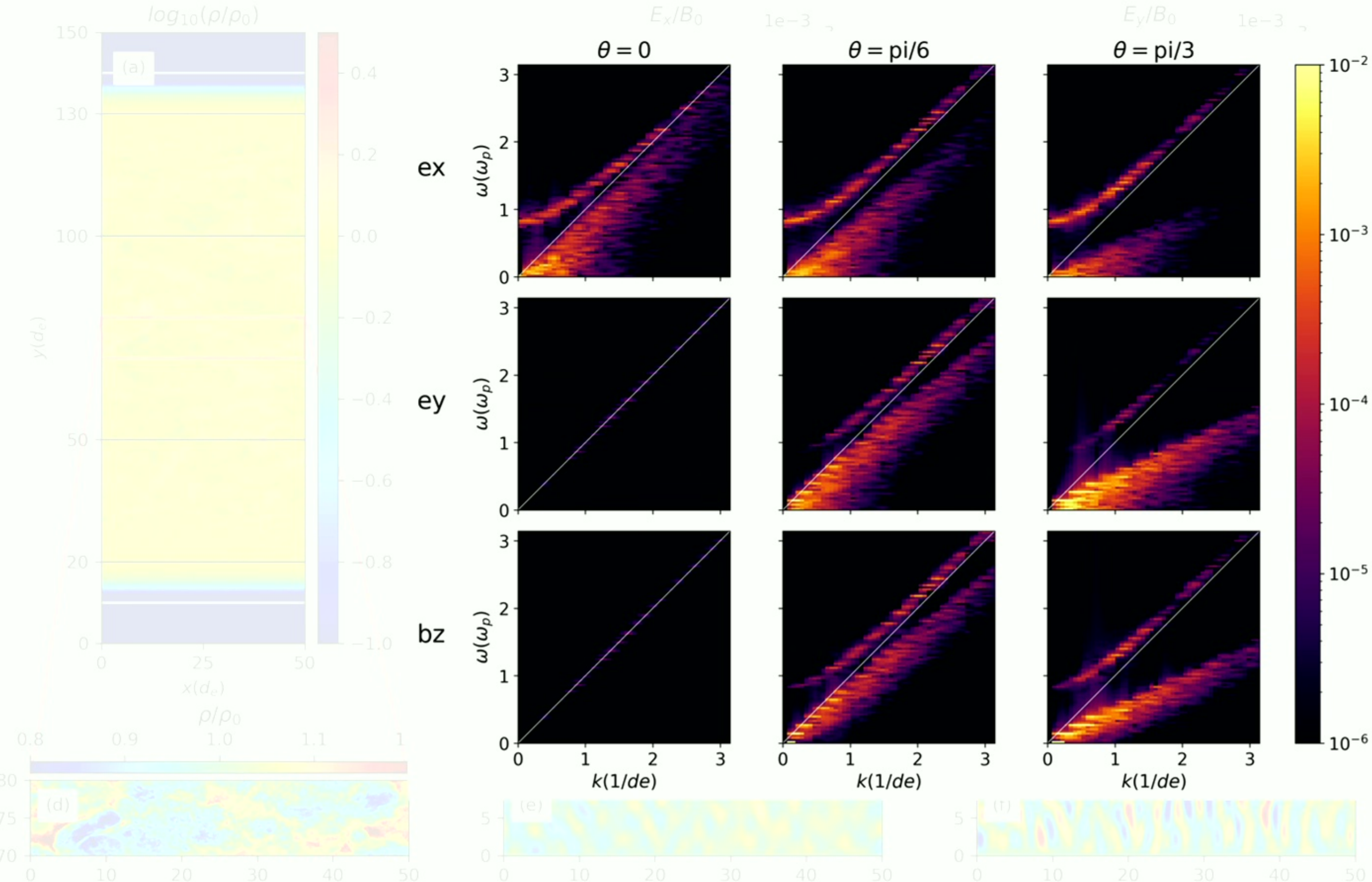
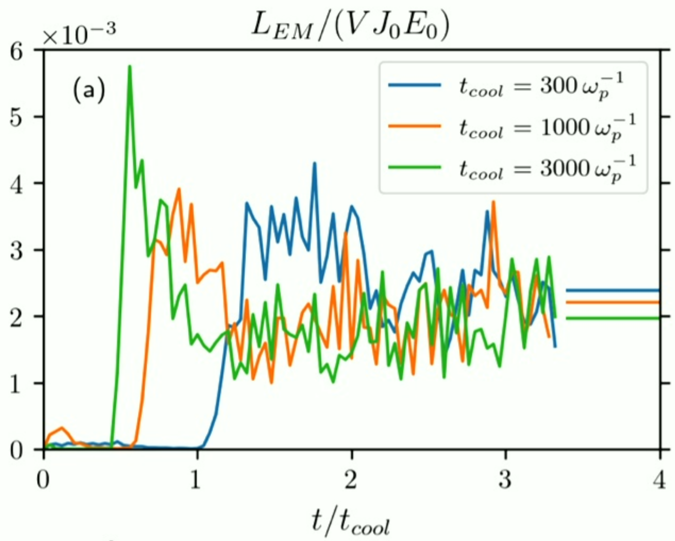
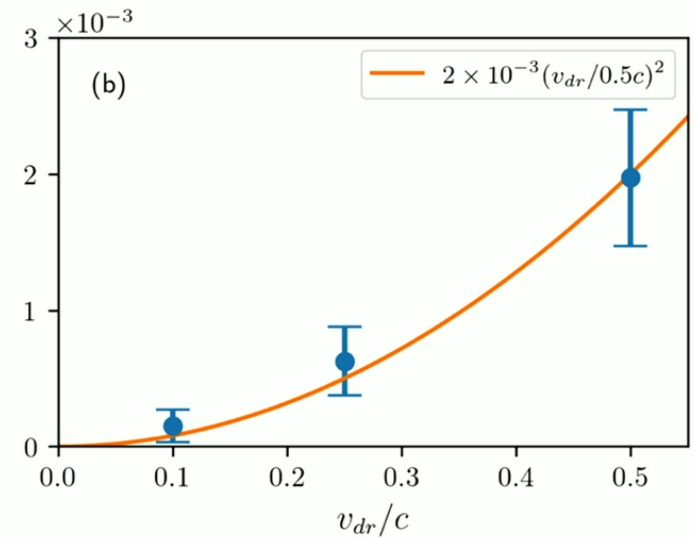


"Sub-Grid" Model

Can extract the luminosity from simulations

$I_{\rm rad} \sim 2 \times 10^{-3} \gamma^2 (j_0 F_{\rm rad}/e)(v_{\rm dr}/0.5c)^2$





Large-Scale model: Lamppost

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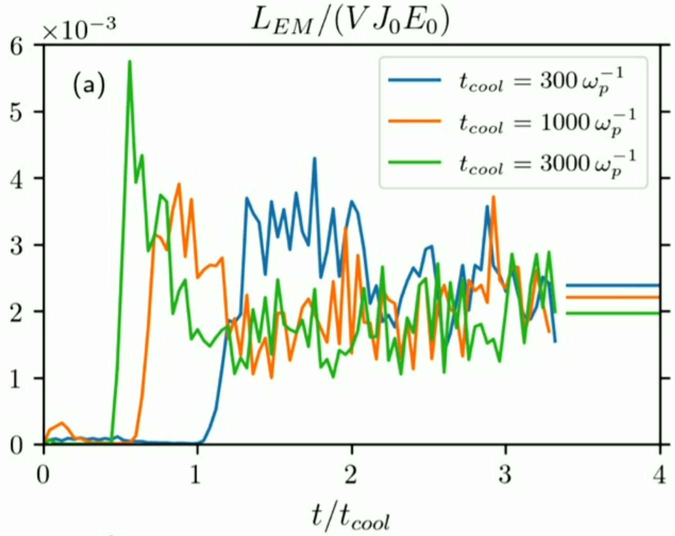
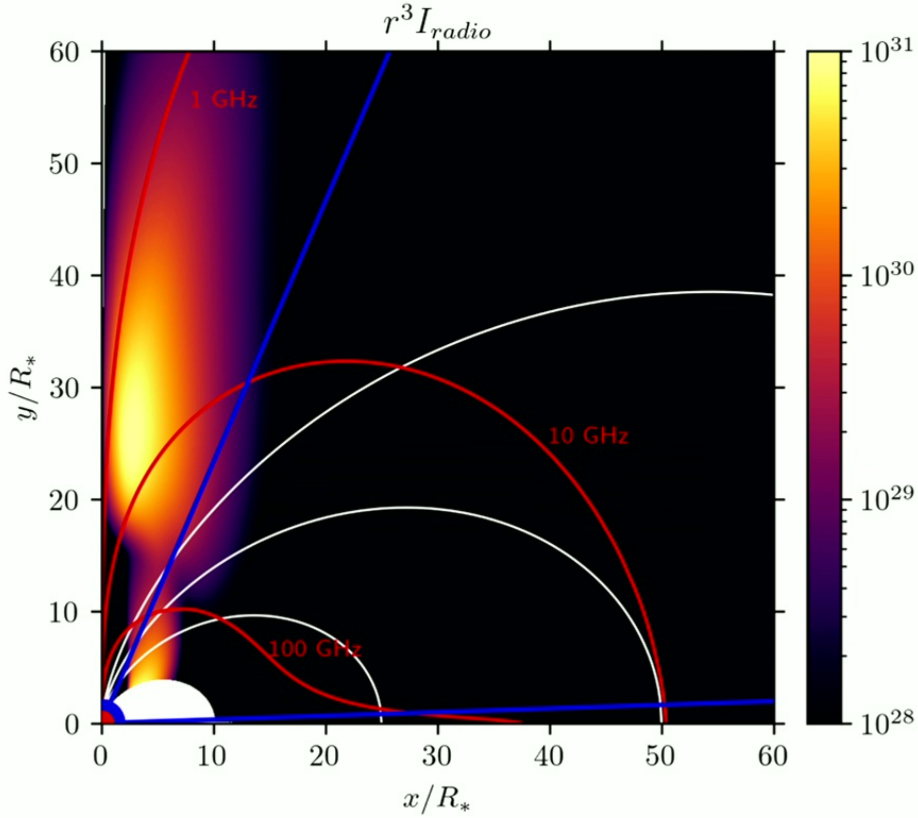
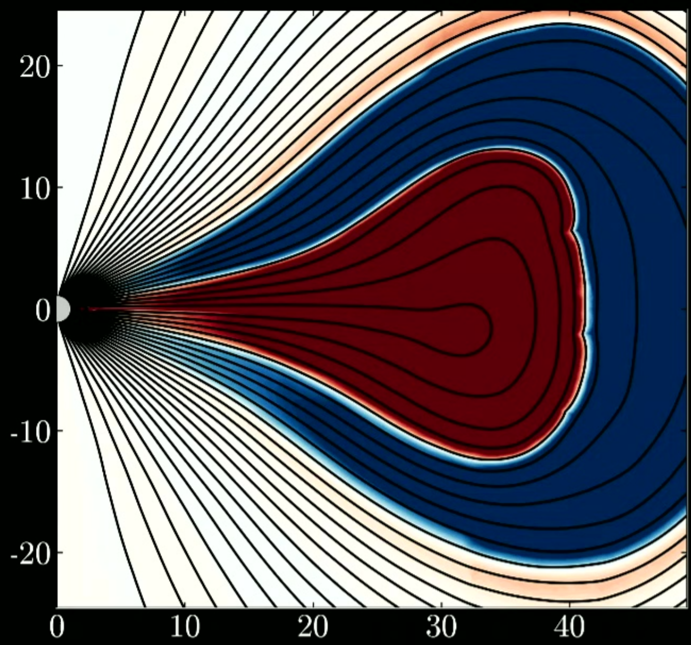
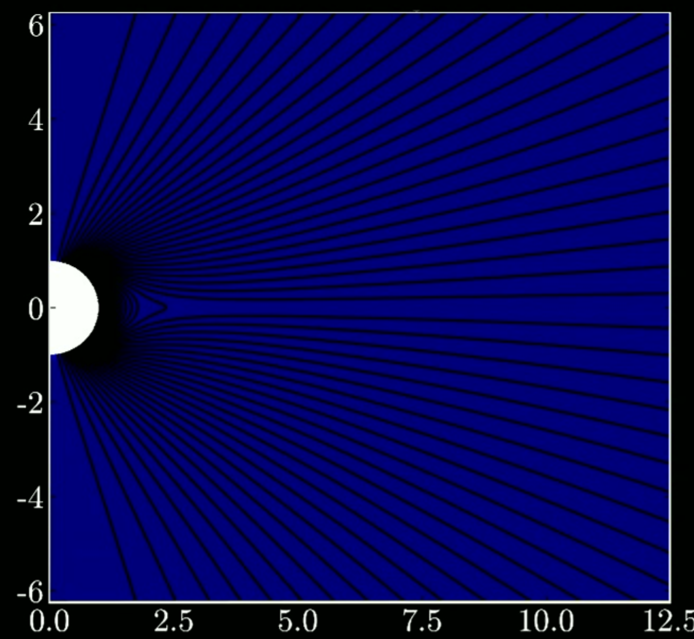


Matches with observed $\sim 10^{30}$ erg/s



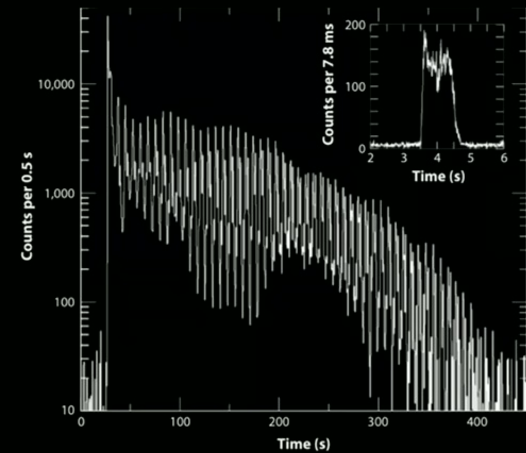
Magnetar Giant Flares





First MHD simulations of outbursts / giant flares

(Chatterjee, Philippov, Beloborodov et. al., in prep)



Israel et. al., 2005

- Our simulations explain rapid onset, duration and energetics of the main peak of giant flares; qualitatively, the post-peak fireball emission and enhanced spin-down.
- Eruptions produce relativistic electromagnetic pulses.

Conclusions

- We developed a first-principles model of transient radio emission from magnetars.

- Next steps: include time-evolving magnetospheric X-ray radiation field during the untwisting. Can we predict the time of onset and spectrum of radio emission?

- Observational test(s): cutoff at high frequencies?