RADIATIVELY DRIVEN EVAPORATION FROM MAGNETAR'S SURFACE DURING GIANT FLARES

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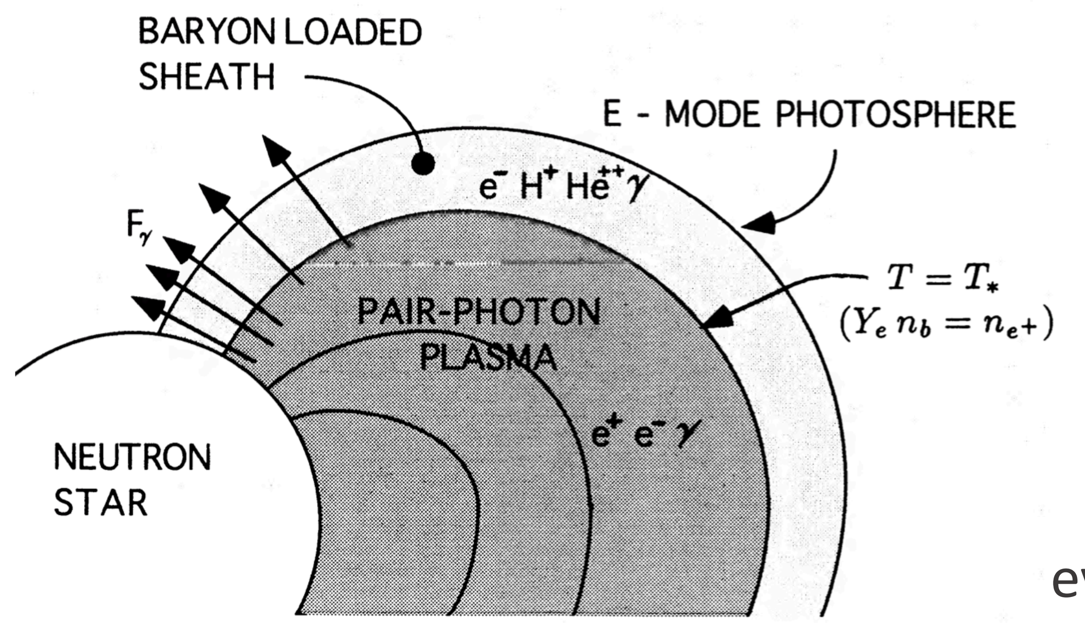
Previous work and challenge

According to the Thompson & Duncan model (1995), the rest of the released energy of giant flares remains confined within the magnetosphere in the form of a radiatively cooling fireball. The radiation from the fireball ablates the material from the surface of the magnetar until the radiation flux drops below the modified Eddington flux. As a result, a baryon-loaded sheath is formed.



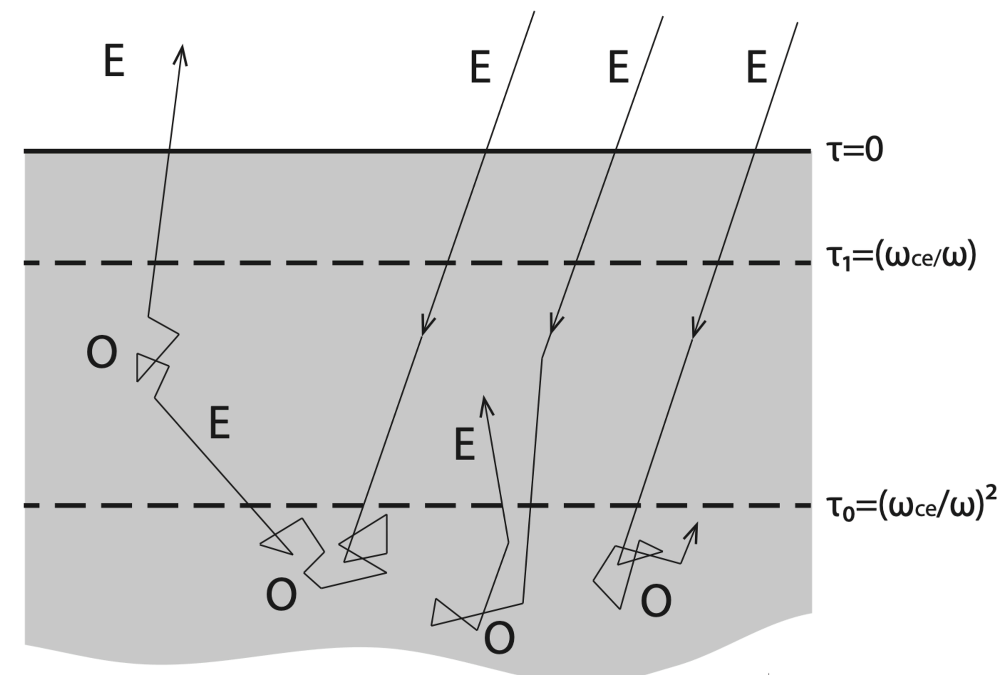
Paradox: how material can be ablated if radiation falls on the surface from above?

What happens if evaporation occurs along open magnetic field lines?

MNRAS 1995, 275, 2, 255-300

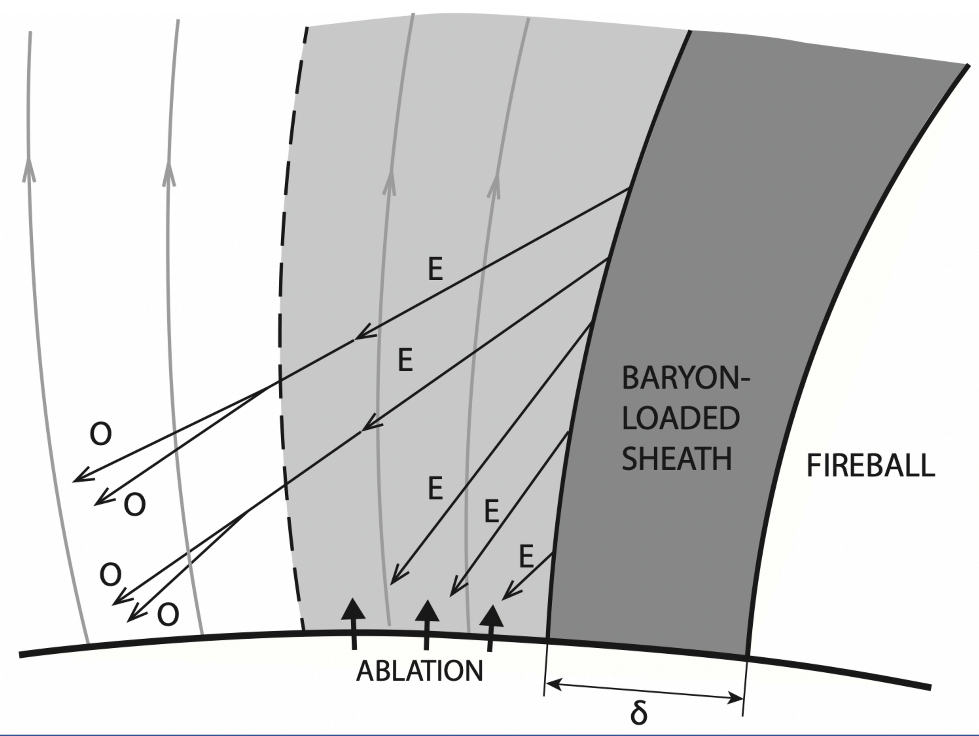
Simple explanation of the evaporation mechanism

1) The star's surface is illuminated by E-photons emitted by the fireball
2) Within the upper layers of the surface, these photons are Compton scattered into O-photons
3) O-photons create radiation pressure inside the surface layer and expel plasma upwards



Due to photon splitting, evaporation is possible only within the region of the size ~1 km near the bottom of the fireball

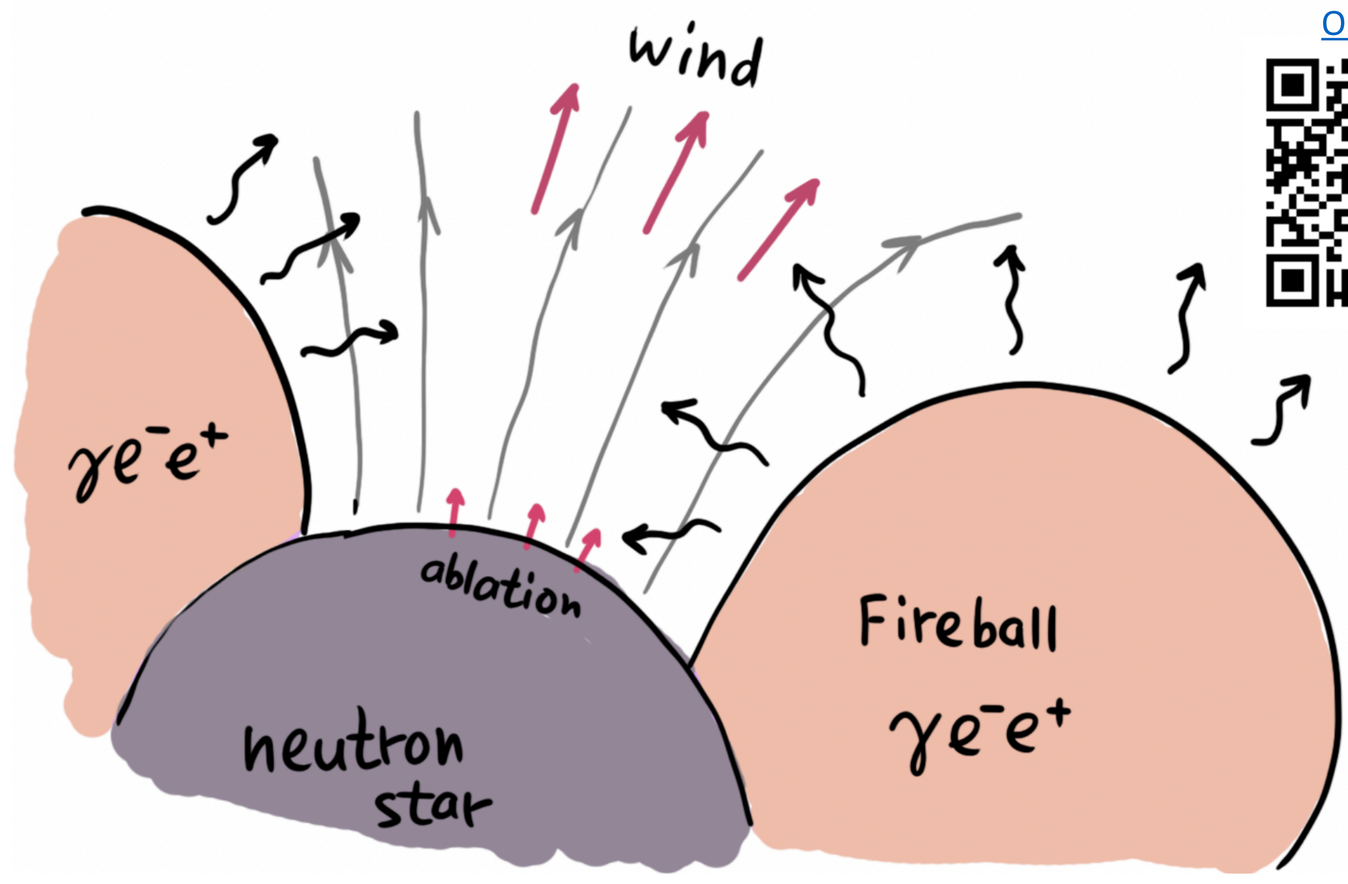
As a result, the baryon-loaded sheath is formed **layer-by-layer**



We proposed a **physical mechanism** for plasma evaporation from the surface of a magnetar during giant flares. If evaporation occurs near polar caps, we found that:

1) The mass flux of the wind ~10^{16}-10^{18} g/s
2) The wind is mildly-relativistic Γ~1
3) The wind is weakly magnetized σ~10^{-2}

Our article



Such an outflow from the surface of the magnetar is **unable** to provide the observed spin-down rates during giant flares!

Evaporation along open magnetic field lines

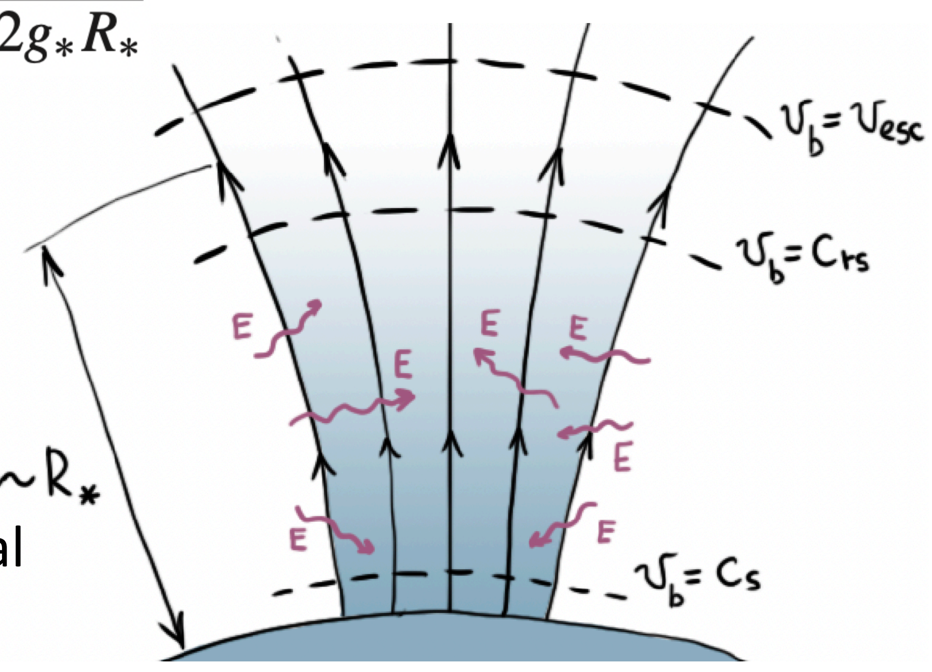
To escape, evaporated plasma must reach the escape velocity

$$v_{\rm esc} = \sqrt{2 g_* R_*}$$

Before this plasma has to pass through the sound barrier

$$c_{\rm rs}^2 = (1/3)\,{\rm d}\mathcal{E}_{\rm O}/{\rm d}\rho_b$$

which corresponds to the radiative speed of sound (thermal plasma pressure is negligible)



We solved equations of the radiative hydrodynamics for the dipolar magnetic field. The plasma mass flow rate is obtained from the condition that the plasma flow smoothly passes through the sound barrier

Our analysis shows that the radiative speed of sound is reached at altitudes comparable with the stellar radius and the outflow is mildly-relativistic

Results

The Alfven radius is an order of magnitude smaller than the radius of the light cylinder for a typical magnetar

The total mass flow rate $$\dot{M} \approx 7\times10^{15}\left(\frac{B(R_*)}{10B_{\rm QED}}\right)^2\left(\frac{kT}{20\,{\rm keV}}\right)^{-8/3} q^{16/9}\ \ {\rm g/s}$$

where the parameter q shows how many times the flux of E-photons incident on the surface of the star exceeds the modified Eddington flux

The magnetization parameter at the Alfven radius

$$\sigma = \frac{E B_\varphi}{4\pi\Gamma\rho_b c^2} \sim \left(\frac{R_A}{R_L}\right)^2 \sim 10^{-2}$$

For the duration of a giant flare, the magnetar period is increased by:

$$\frac{\Delta P}{P} \sim 6\times10^{-8}\left(\frac{\tau}{100\,{\rm s}}\right)\left(\frac{B(R_*)}{10B_{\rm QED}}\right)^2\left(\frac{kT}{20\,{\rm keV}}\right)^{-4/3} q^{8/9}$$

Observations:

SGR 1806-20	$\Delta P/P < 5\times10^{-6}$
SGR 1900+14	$\Delta P/P \sim 10^{-4}$

Woods et al (1999), Woods et al (2007)

Therefore, because of the small duration of flares, the resulting increase in the magnetar period is small. Such outflow is unable to provide the observed spin-down rates