Models of hydrostatic atmospheres of magnetars at high luminosities

Thijs van Putten[1]

Anna Watts[1], **Caroline D'Angelo**[1], **Matthew Baring**[2], **Chryssa Kouveliotou**[3]

[1]University of Amsterdam, [2]Rice University, [3]NASA/Marshall Space Flight Center

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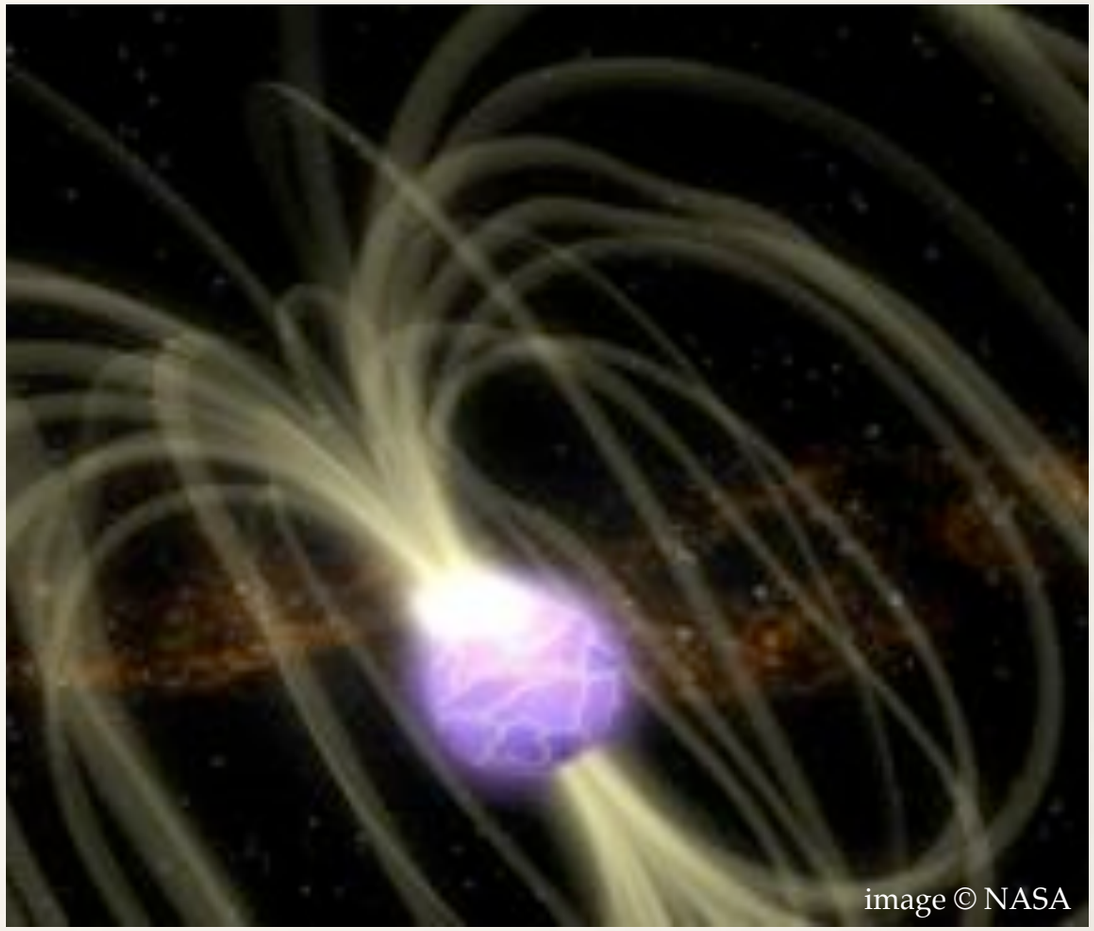
Magnetars

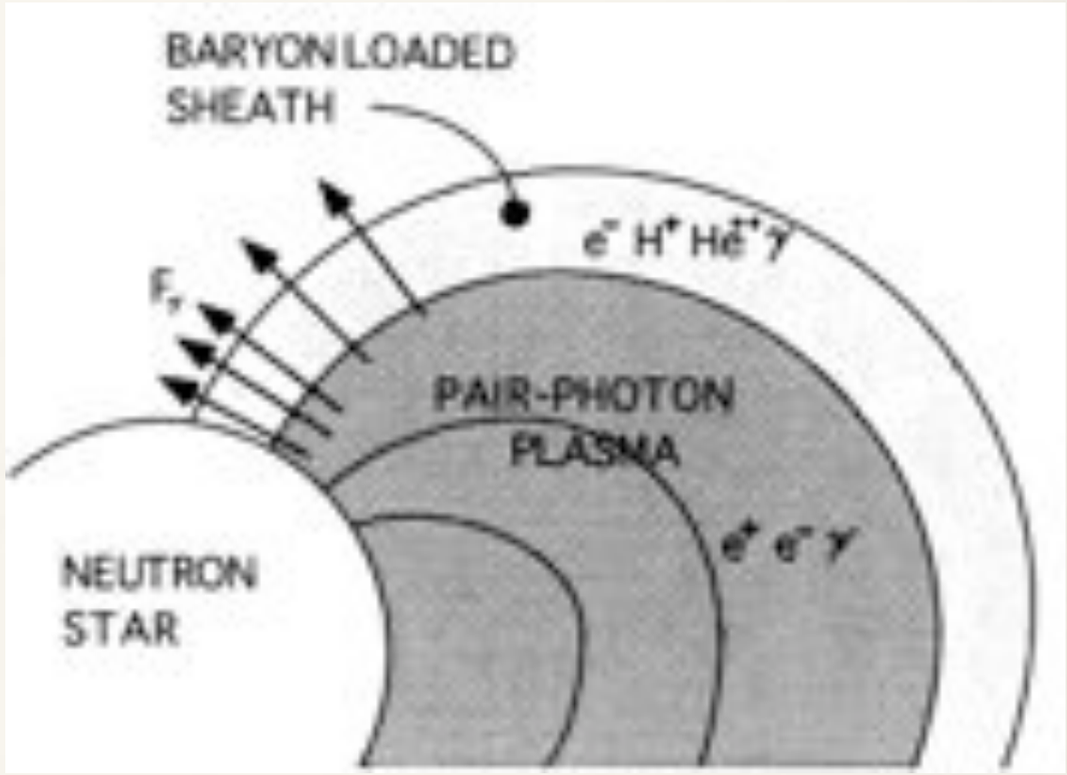
- Neutron stars with inferred dipole magnetic field $B \sim 10^{13}$-10^{16} G.

- Exhibit pulses (X-ray & radio), soft gamma ray bursts (~10^{40} erg s^{-1}) and giant flares (~10^{44} erg s^{-1}).



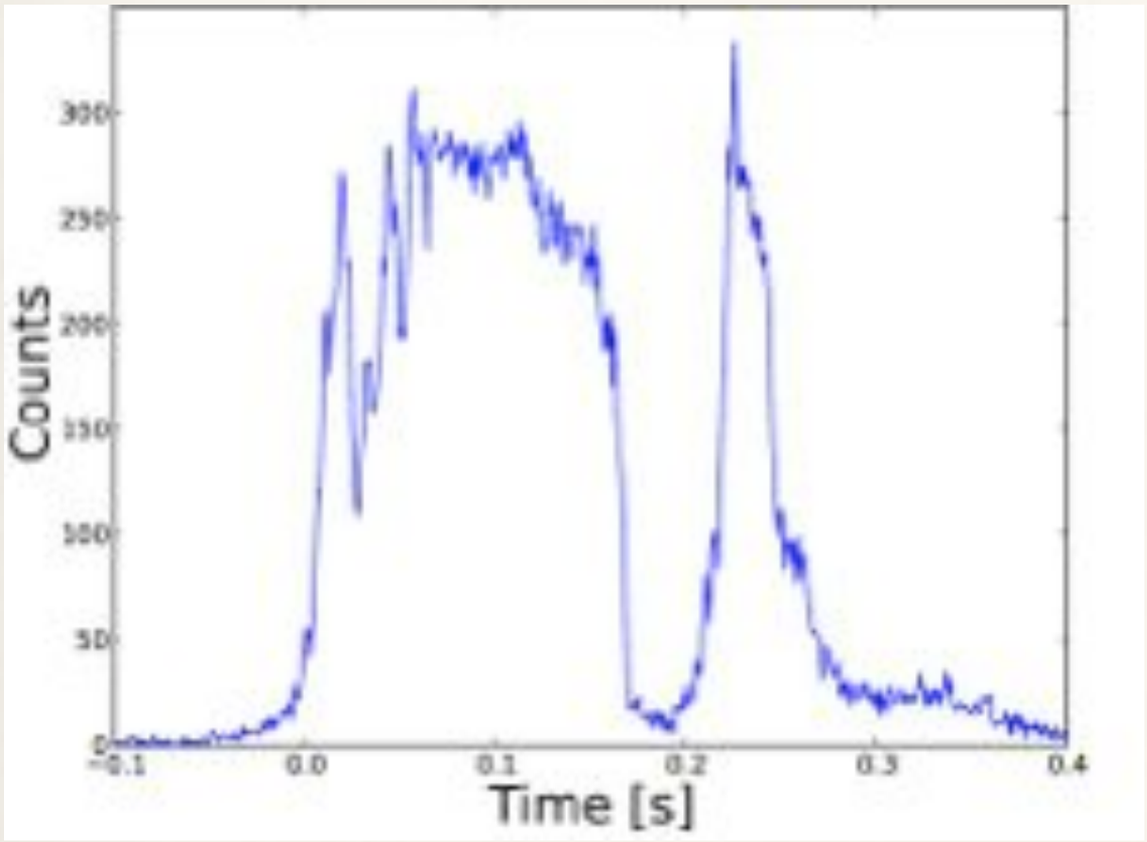
Magnetar model

- What is the equation of state?
- How and where is the emission created?
- What is the magnetic field configuration?

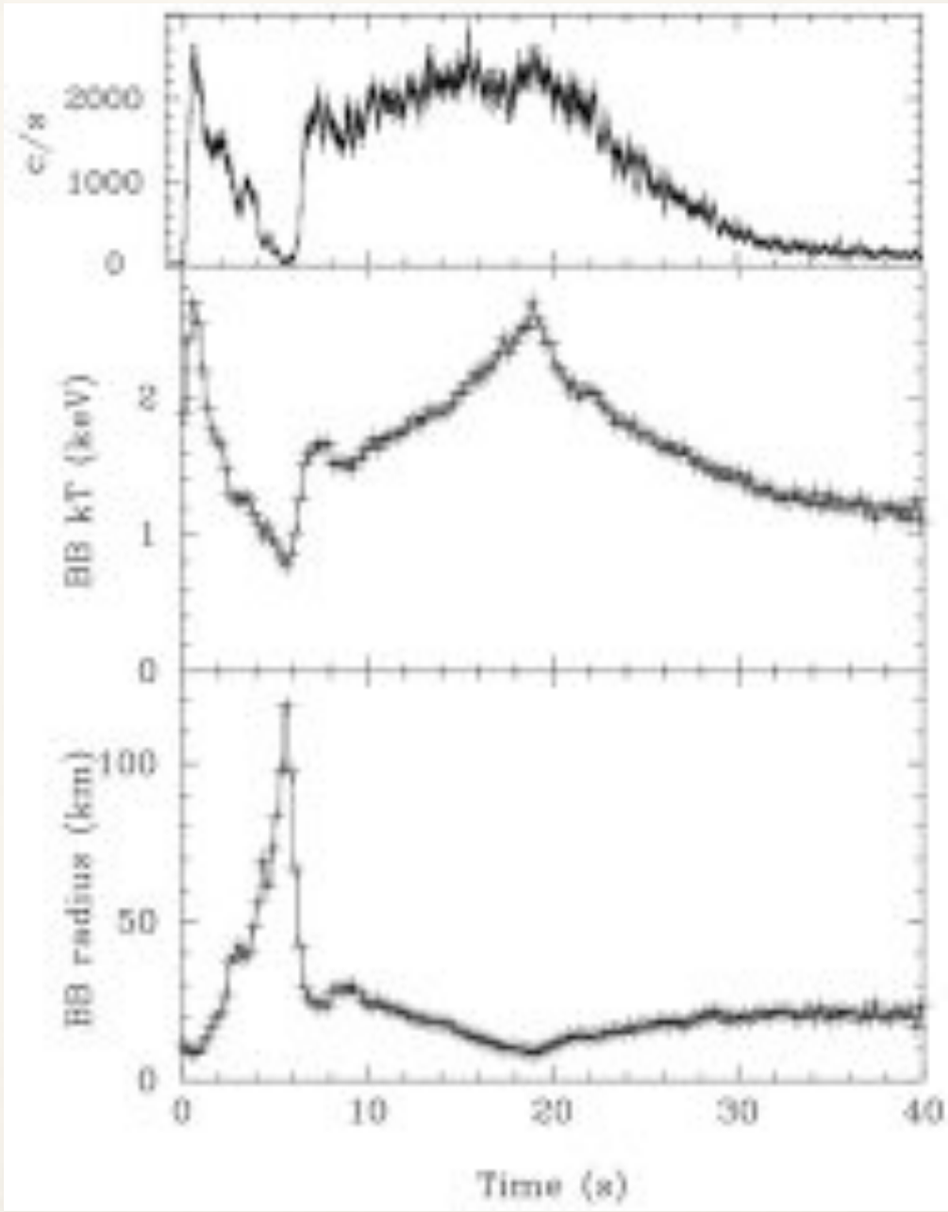


Thompson & Duncan (1995)

A peculiar magnetar burst

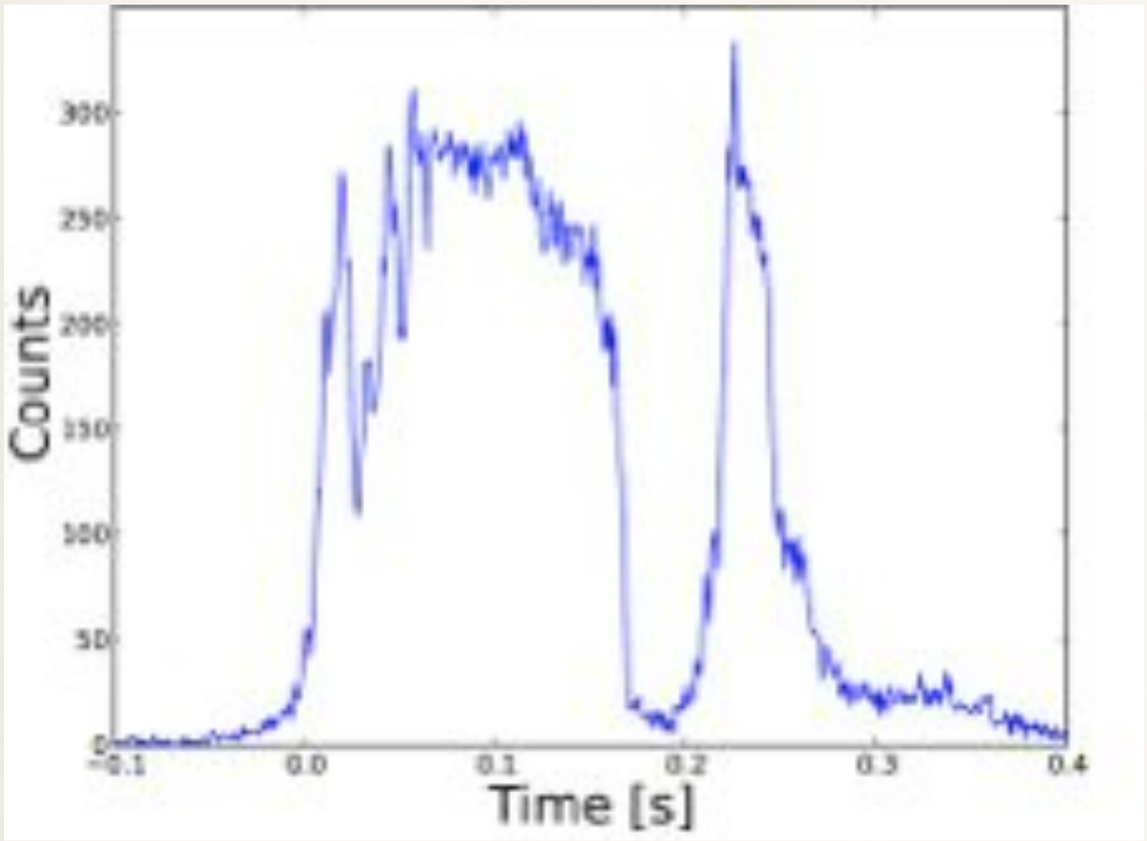


Fermi GBM light curve of August 2008 burst from SGR 0501+4516.



Light curve and black body fits of X2127 (Smale 2001)

Photospheric Radius Expansion in magnetars?



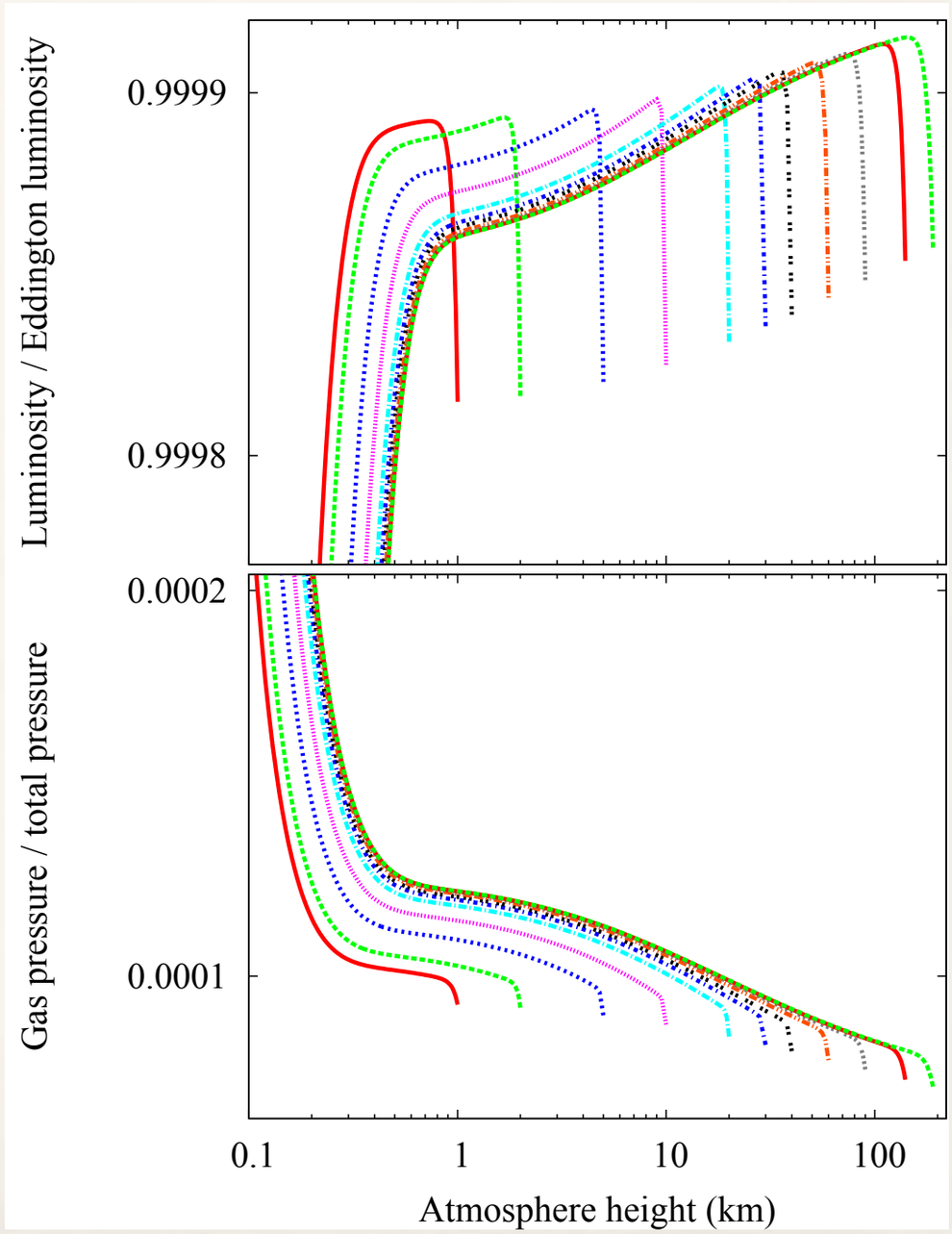
Fermi GBM light curve of August 2008 burst from SGR 0501+4516.

- PRE in magnetars seems qualitatively possible (Watts et al. 2010) if magnetars have:
  - Emission from optically thick region
  - A critical luminosity
  - Photosphere cooling with expansion
  - Opacity increasing with radius
- Observing it would constrain EoS, *B* and the emission location.

Nonmagnetic models

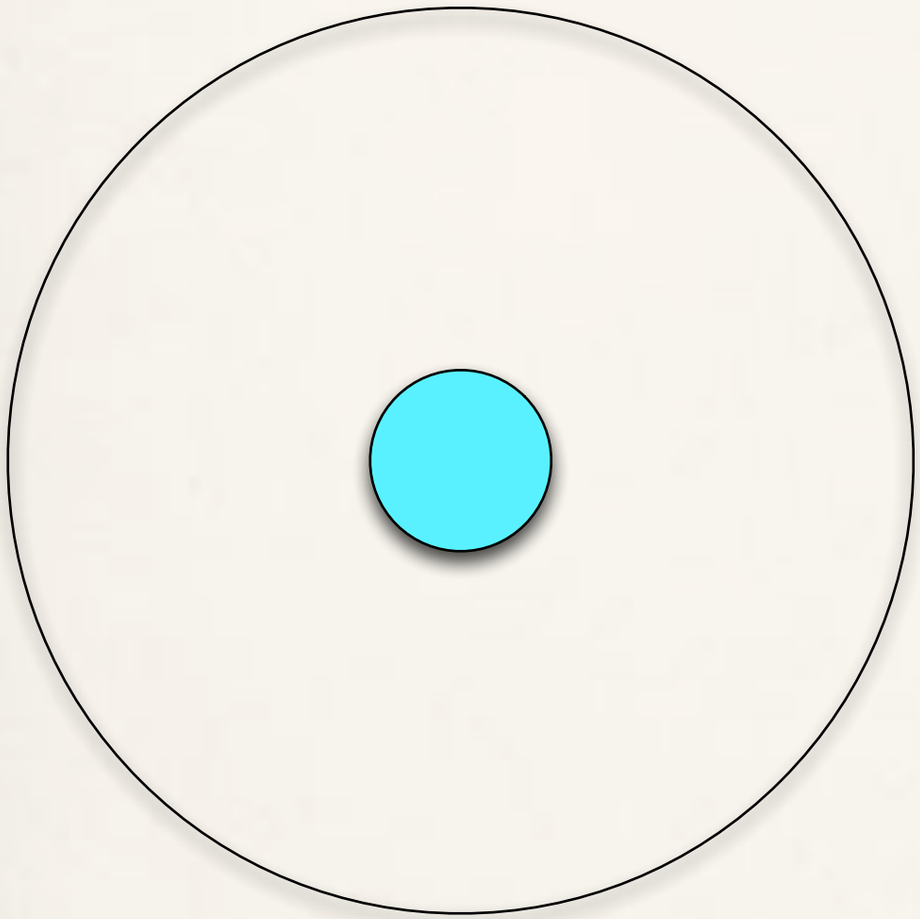
- PRE requires sequence of extended stable atmospheres.
- Nonmagnetic models made by Paczynski & Anderson (1986).
- Stable nonmagnetic atmospheres exist up to r = 200 km.

$$\frac{\mathrm{d}P_\mathrm{r}}{\mathrm{d}r} \simeq -\rho\frac{GM}{r^2} \rightarrow \frac{L}{L_\mathrm{cr}} \simeq 1$$

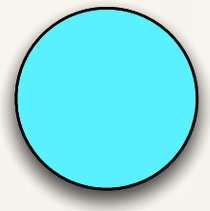


We find:

No hydrostatic magnetar atmospheres with photospheric height > 10 m.



Nonmagnetic case



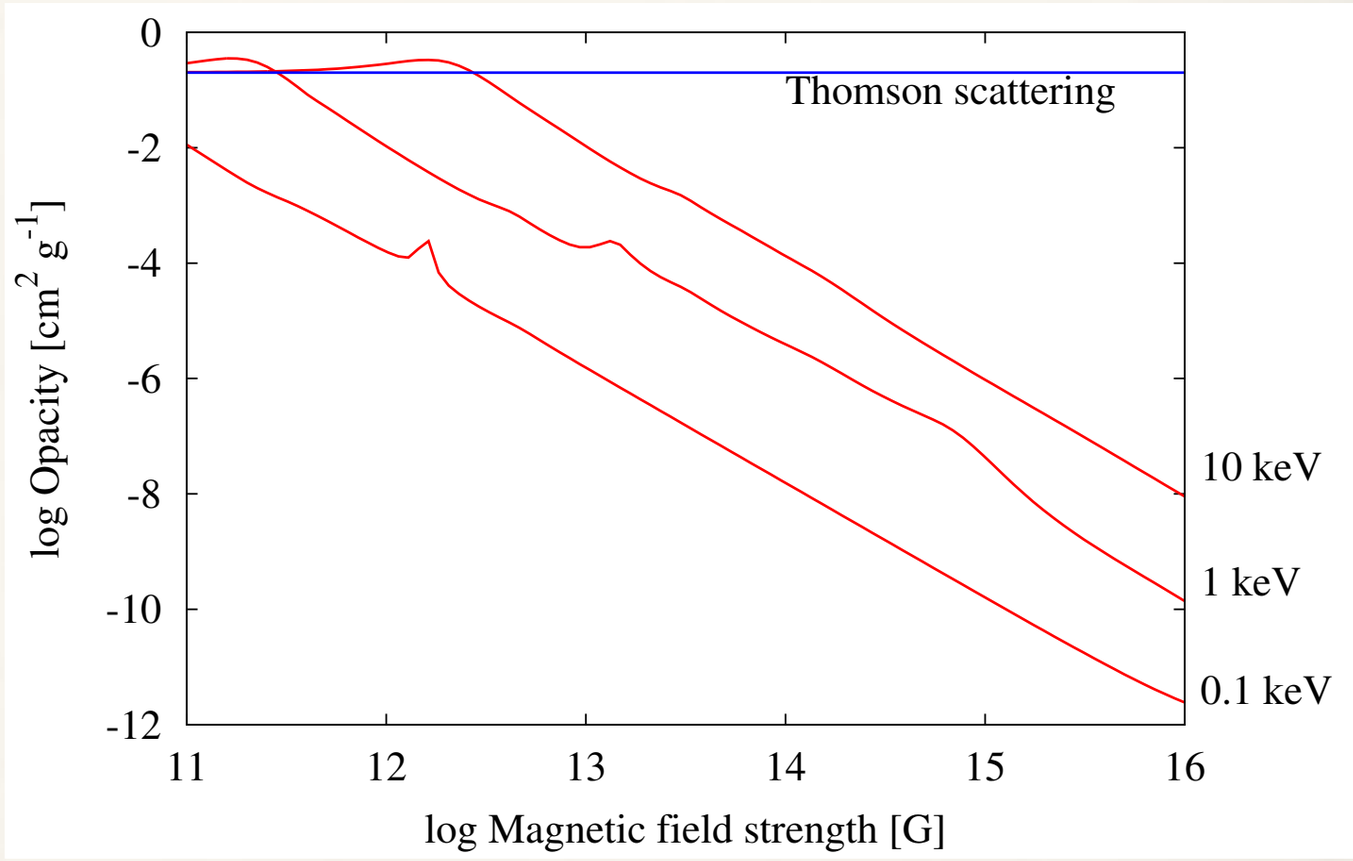
Our result

Opacity in a super strong magnetic field

- Two photon polarizations: O-mode (**E**∥**B**) and E-mode (**E**⊥**B**)

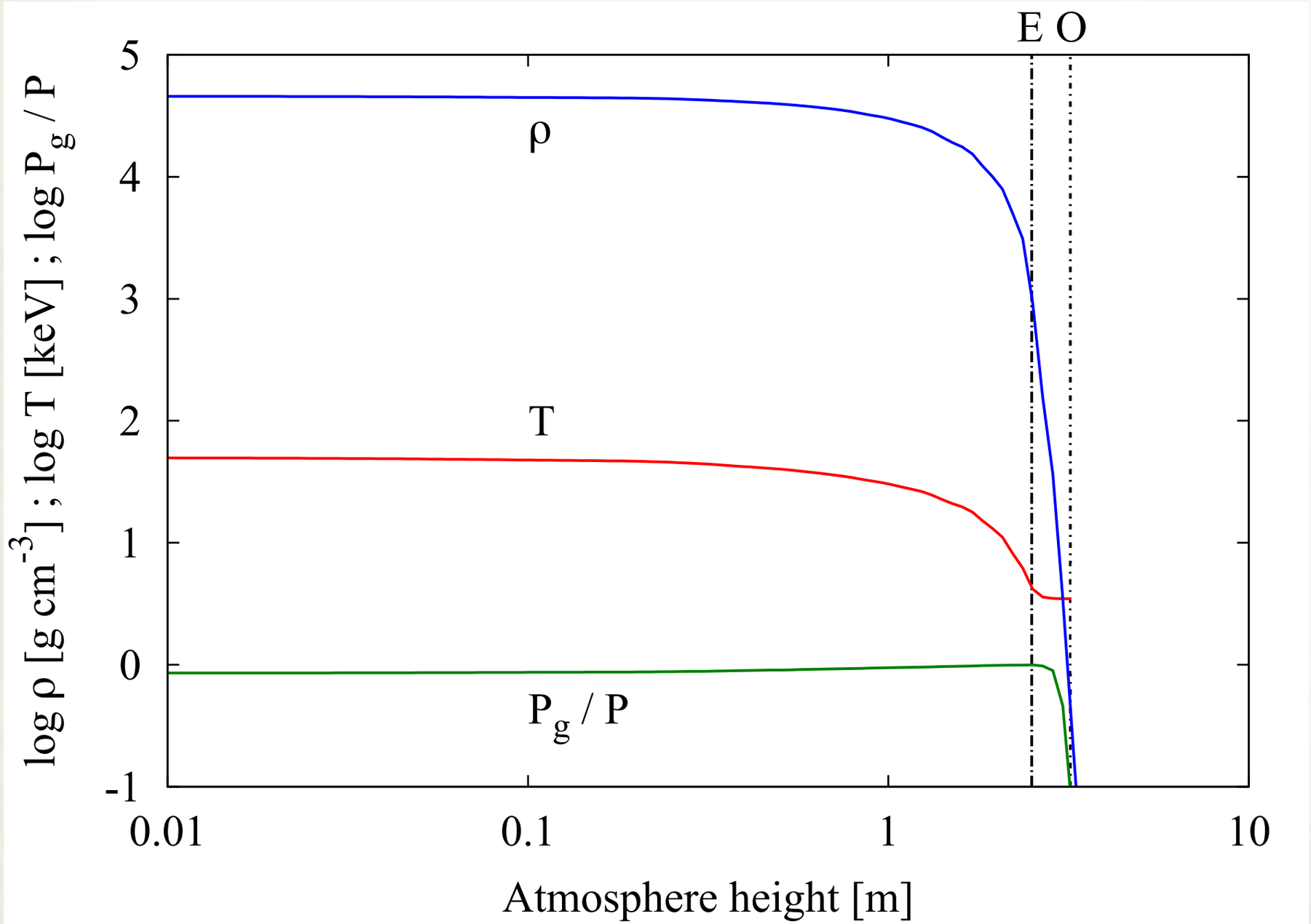
$$\sigma_{\mathrm{O}} \simeq \sigma_{\mathrm{Th}}$$

$$\sigma_{\mathrm{E}} \simeq \sigma_{\mathrm{Th}} \frac{\omega^2}{\omega_{\mathrm{C}}^2} \propto \frac{T^2}{B^2}$$



E-mode Rosseland mean electron scattering opacity

Atmosphere models



$$\kappa \propto \frac{T^2}{B^2}$$

$$L_{\rm cr} \propto \kappa^{-1}$$

$$L/L_{\rm cr} \neq 1$$

Conclusions

- Hydrostatic extended magnetar atmospheres do not exist in open field line regions.

- Photospheric Radius Expansion cannot occur in magnetars.

- Spectral models of magnetar bursts considering two distinct components attributed to the E- and O-mode photospheres may have to be reconsidered.

- Future work: what *does* happen when L reaches L_{cr} in a magnetar atmosphere?