Magnetars and Fundamental QED Physics in the MeV Band

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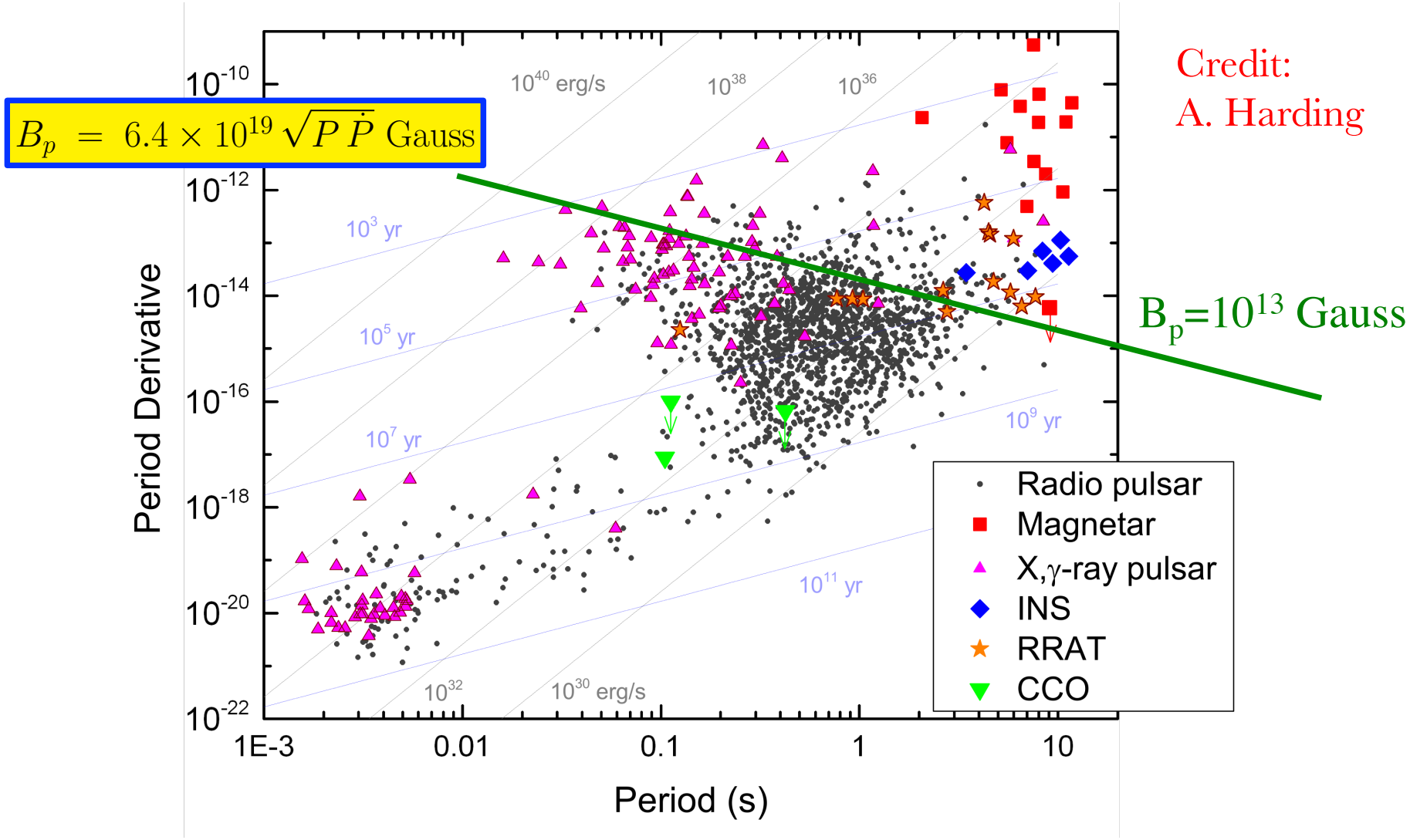
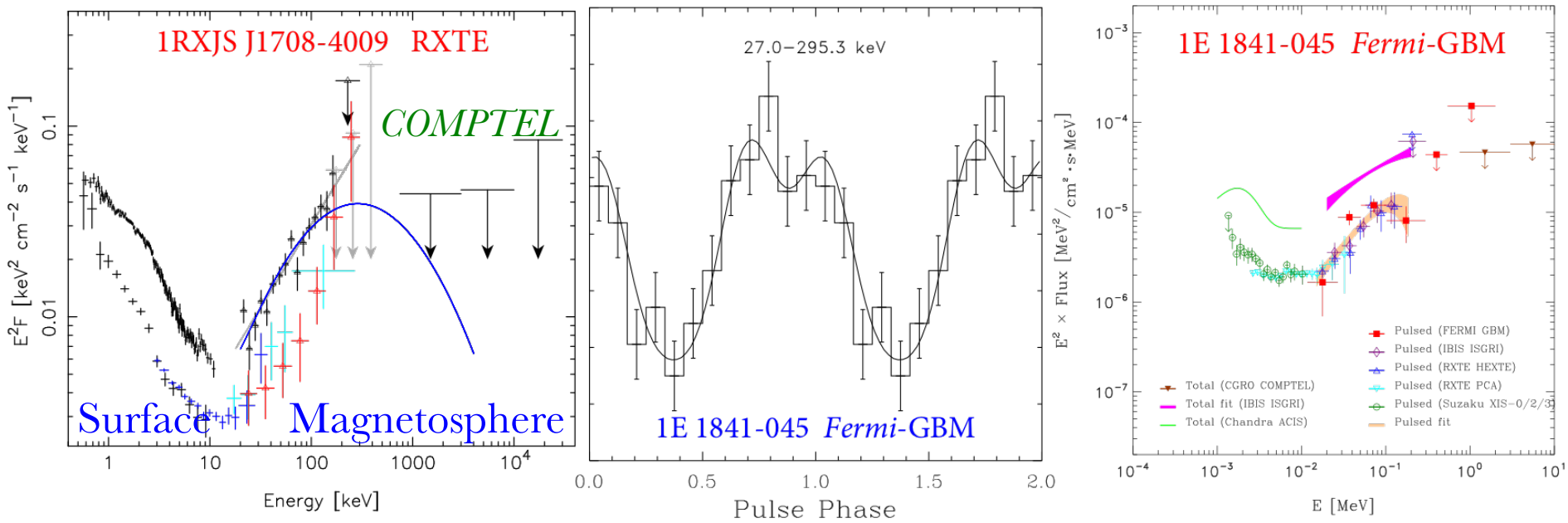
Isolated Pulsar P-Pdot Diagram: *Fermi* era



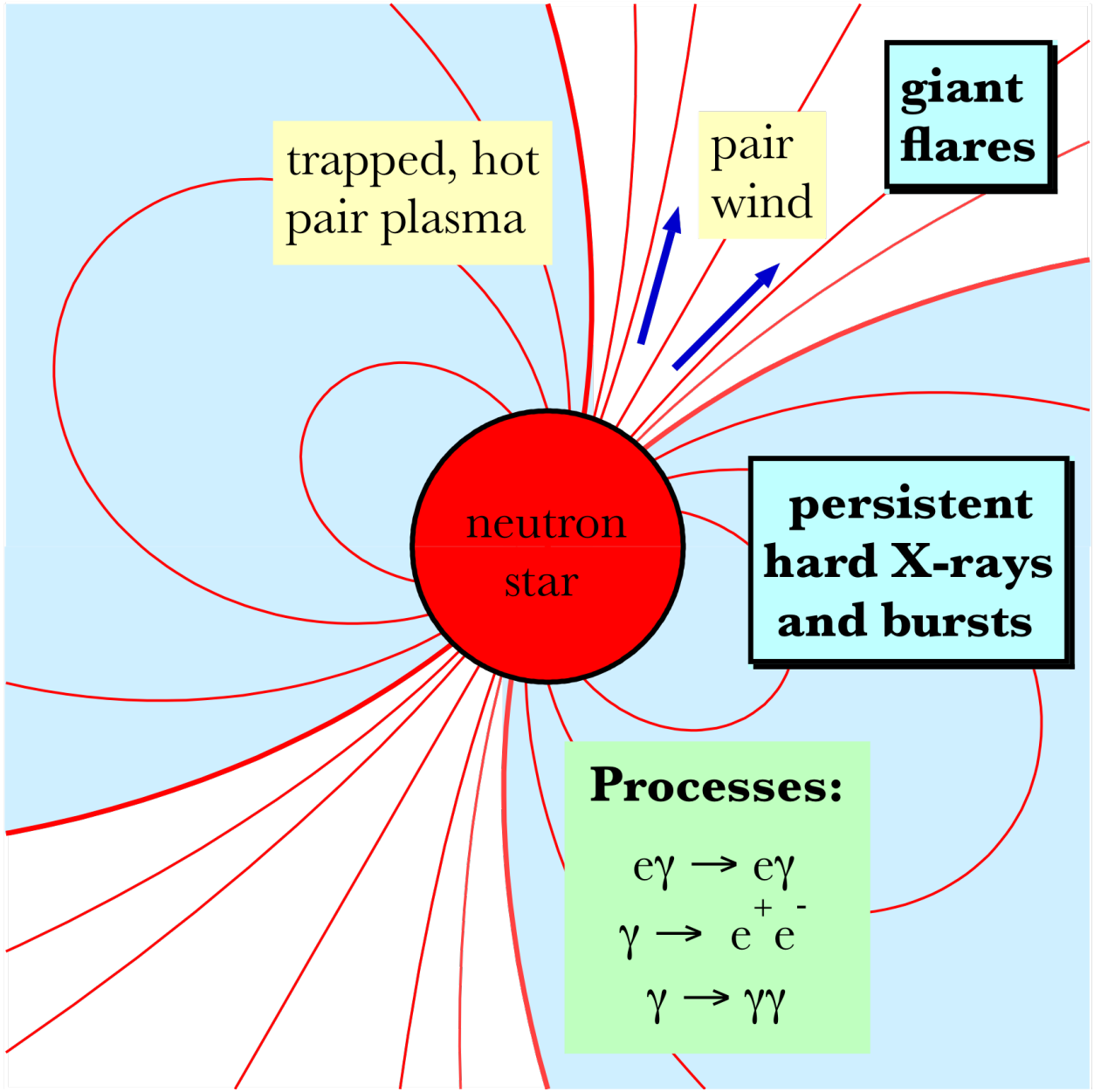
- The phase-space plot for the pulsar population. Dipole field strength B_p inferences scale as the observable (P Pdot)$^{1/2}$. Nearly 30 magnetars.

Magnetar Hard X-ray Tails



- *Left panel*: X-ray spectrum of the AXP 1RXJS J1708-4009, with XMM data below 10 keV, and the RXTE-PCA/HEXTE data above 10 keV (red=pulsed) – see den Hartog et al. (2008). The non-contemporaneous COMPTEL upper limits above 1 MeV are also shown => turnover.
- *Middle panel*: Pulse profile of AXP 1E 1841-045 from *Fermi*-GBM (ter Beek 2012). Smooth line shows the profile observed by INTEGRAL IBIS-ISGRI, 10-Mar-2003 to 30-Sep-2009, at 50-150 keV.
- *Right panel*: The spectrum of quasi-thermal (<10 keV) and tail (> 10 keV; magnetosphere) quiescent emission from 1E 1841-045, with pulsed emission represented by points: red is *Fermi*-GBM (maybe with a break at ~150 keV). COMPTEL upper limits above 1 MeV are also shown. (ter Beek 2012)

Magnetar Geometry



Focal point: QED Physics

- The Schwinger domain is when the electron cyclotron and rest mass energies are comparable: i.e. when $B \sim B_{cr} = m_e^2 c^3/e\hbar = 4.4 \times 10^{13}$ Gauss (or electric field equivalent).
- Principal manifestations:
  - Compton scattering is resonant at the cyclotron frequency $\omega = eB/m_e c$ [classical but modified by QM]
  - Exotic conversion processes of pair creation $\gamma \rightarrow e^+e^-$ and photon splitting $\gamma \rightarrow \gamma\gamma$ can proceed and can be prolific.
  - Vacuum birefringence imprints strong polarization signatures in X rays.

Magnetic QED: Feynman Diagrams

Conversion of photons into $e^{\pm}$ pairs

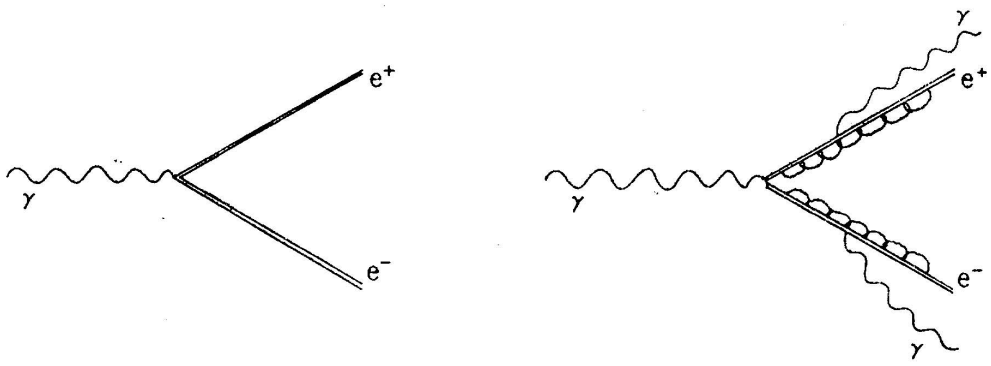


FIG. 1. (a) Pair production in a moderately strong field. The double lines denote the binding effects. (b) Pair production in a strong field. The bound propagators are modified by virtual photon (radiation reaction) loops.

Splitting of photons in two

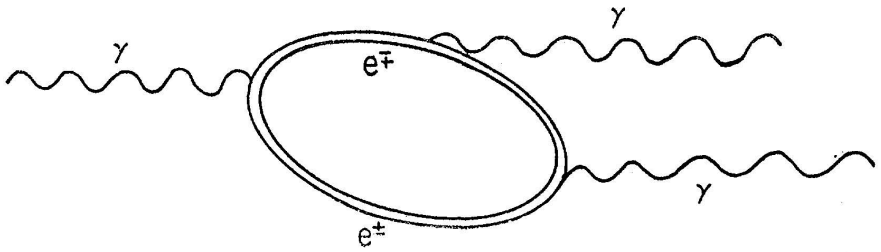
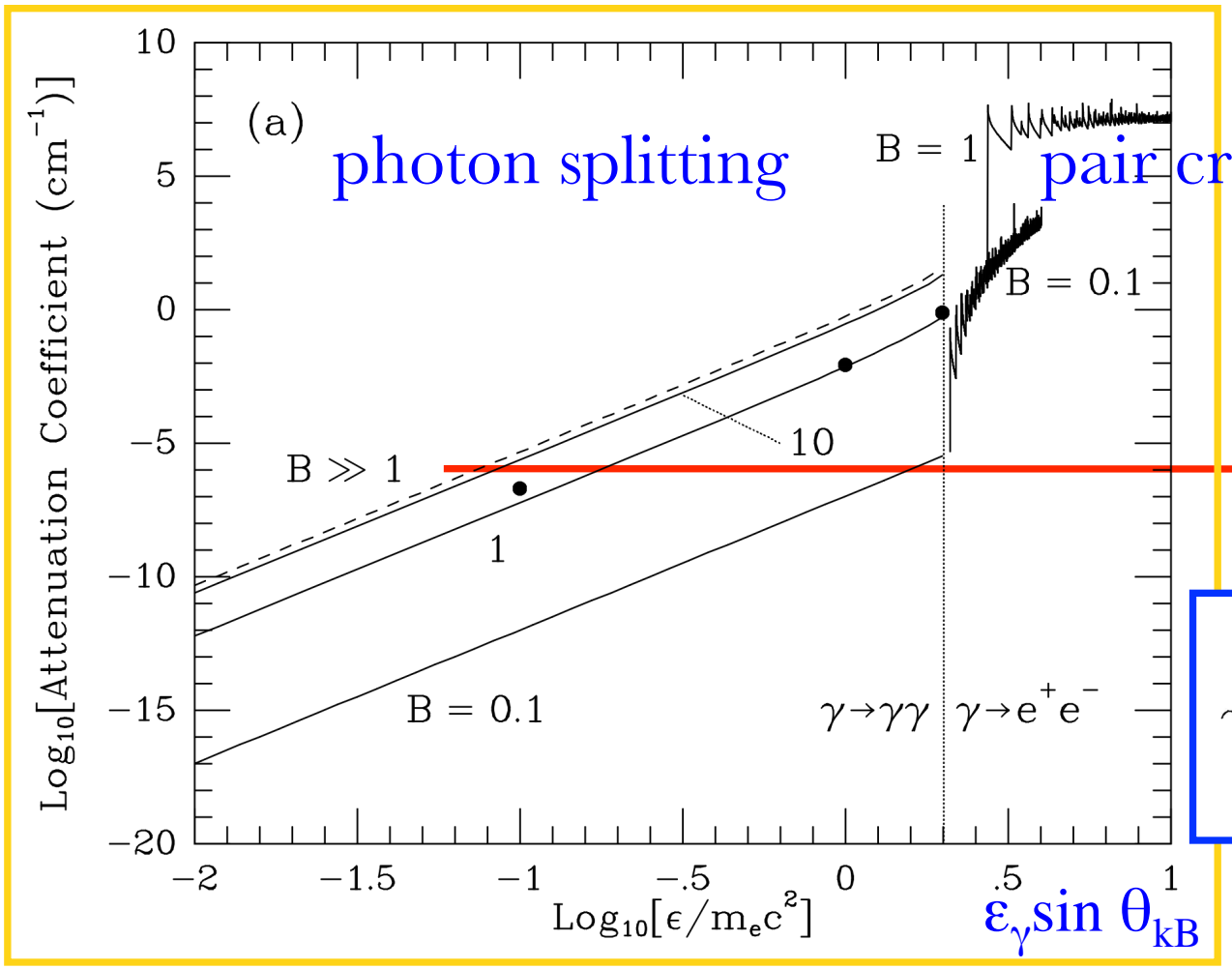


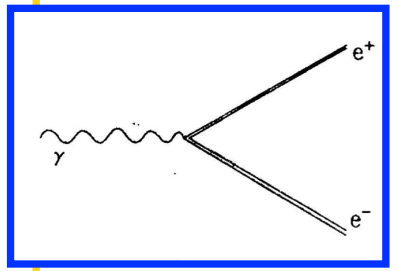
FIG. 2. Photon splitting in a strong field. One of the intermediate particles in a vacuum polarization loop emits a photon.

- (From Erber 1966)

Photon Splitting and Pair Creation Rates

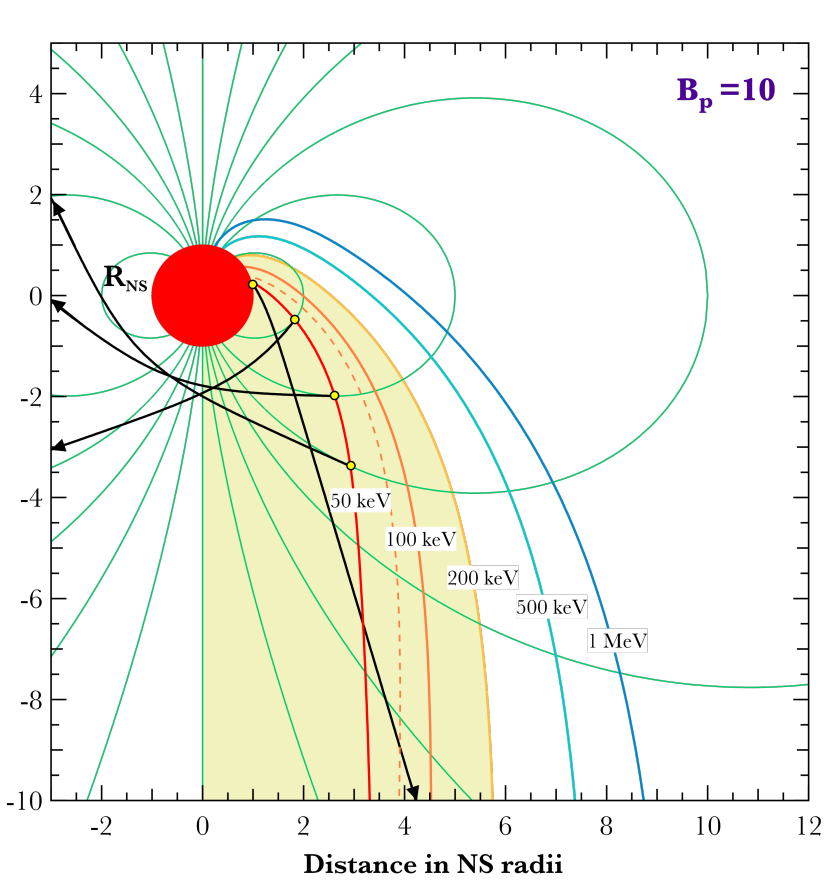


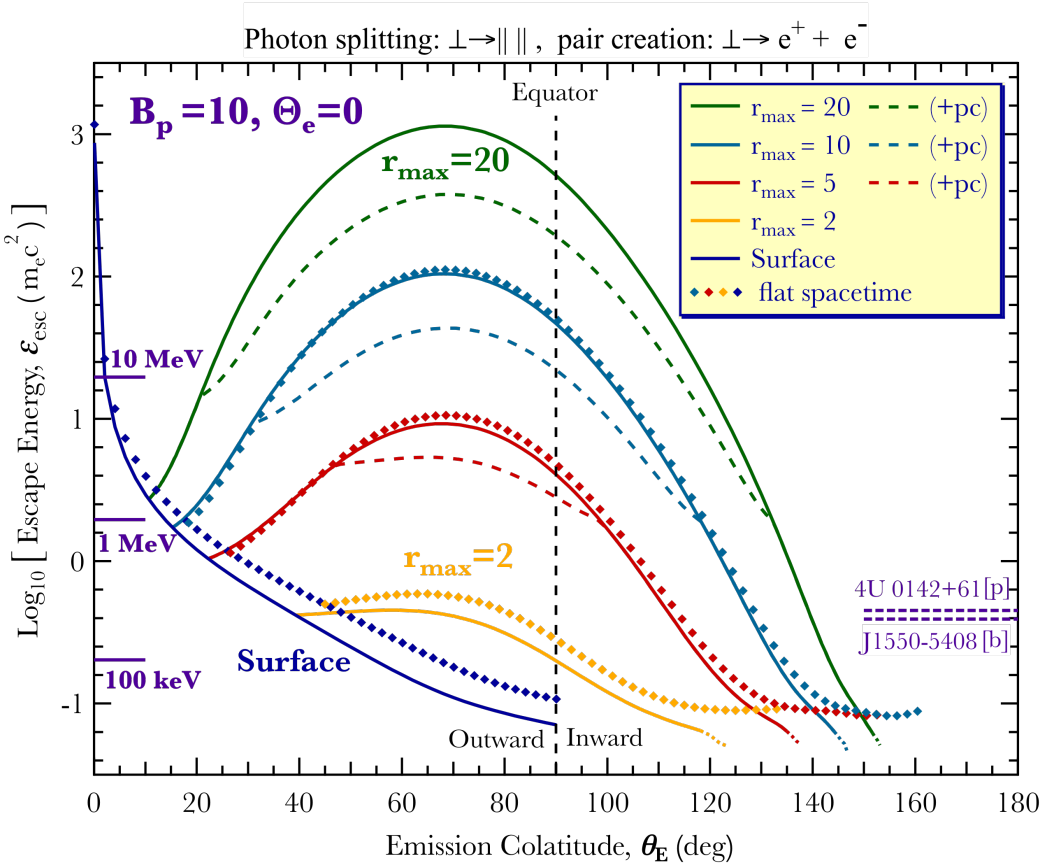
Baring & Harding (1997)



- **Splitting rate calculated originally by Adler (1971); see also Papanyan & Ritus (1972); Stoneham (1979), Baier et al. (1986); Weise et al. (1998); Baring (2000).**

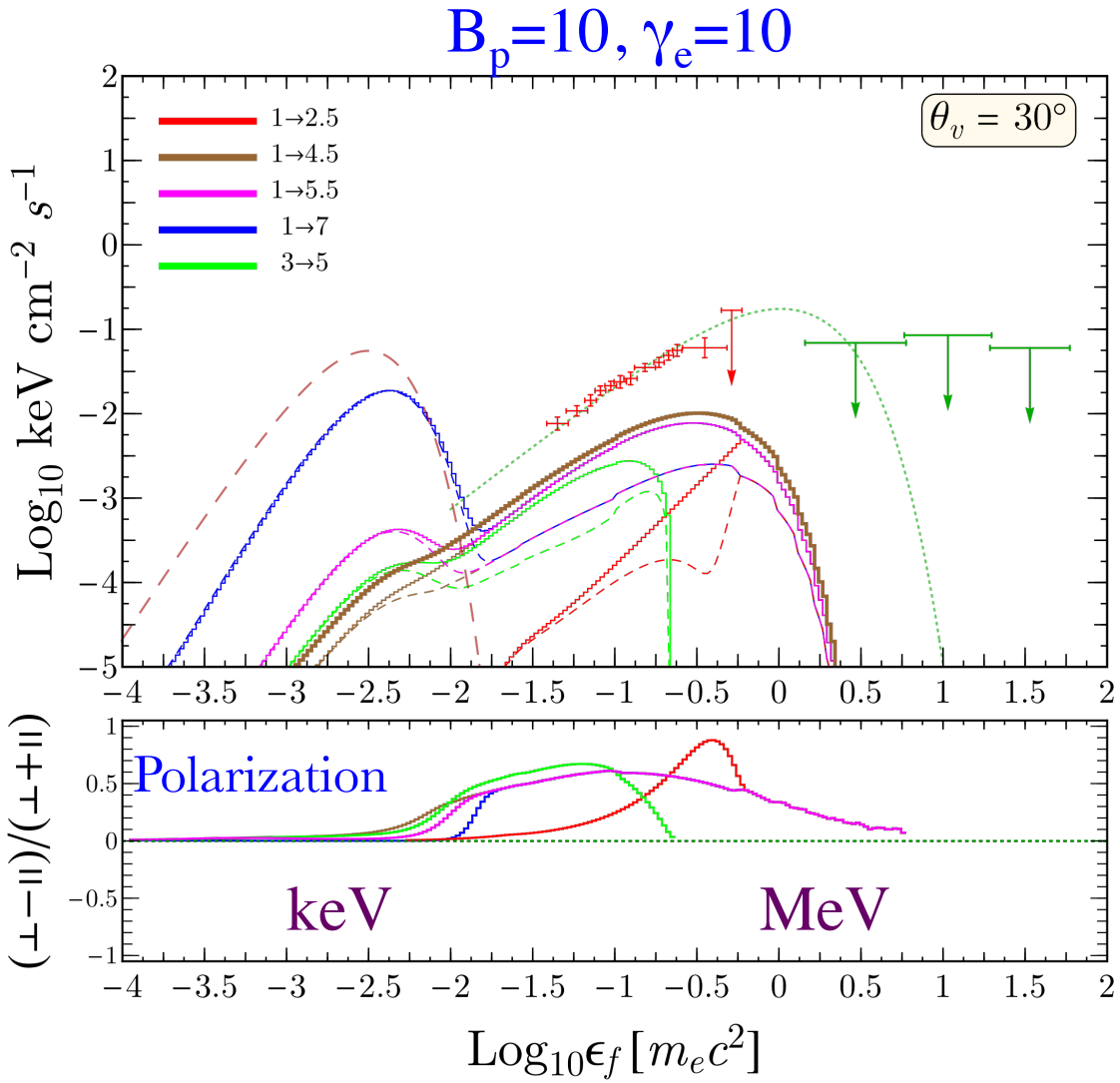
Photon opacity in magnetar magnetospheres

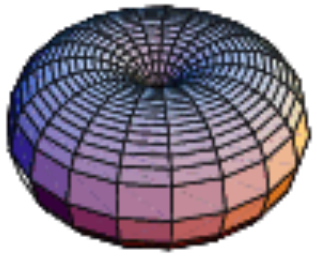




- *Left panel*: GR zones of opacity near the magnetic axis to photon splitting.
- *Right panel*: escape energies in GR for combined splitting and pair creation at different magnetic colatitudes. From Hu et al. MNRAS 486, 3327 (2019).

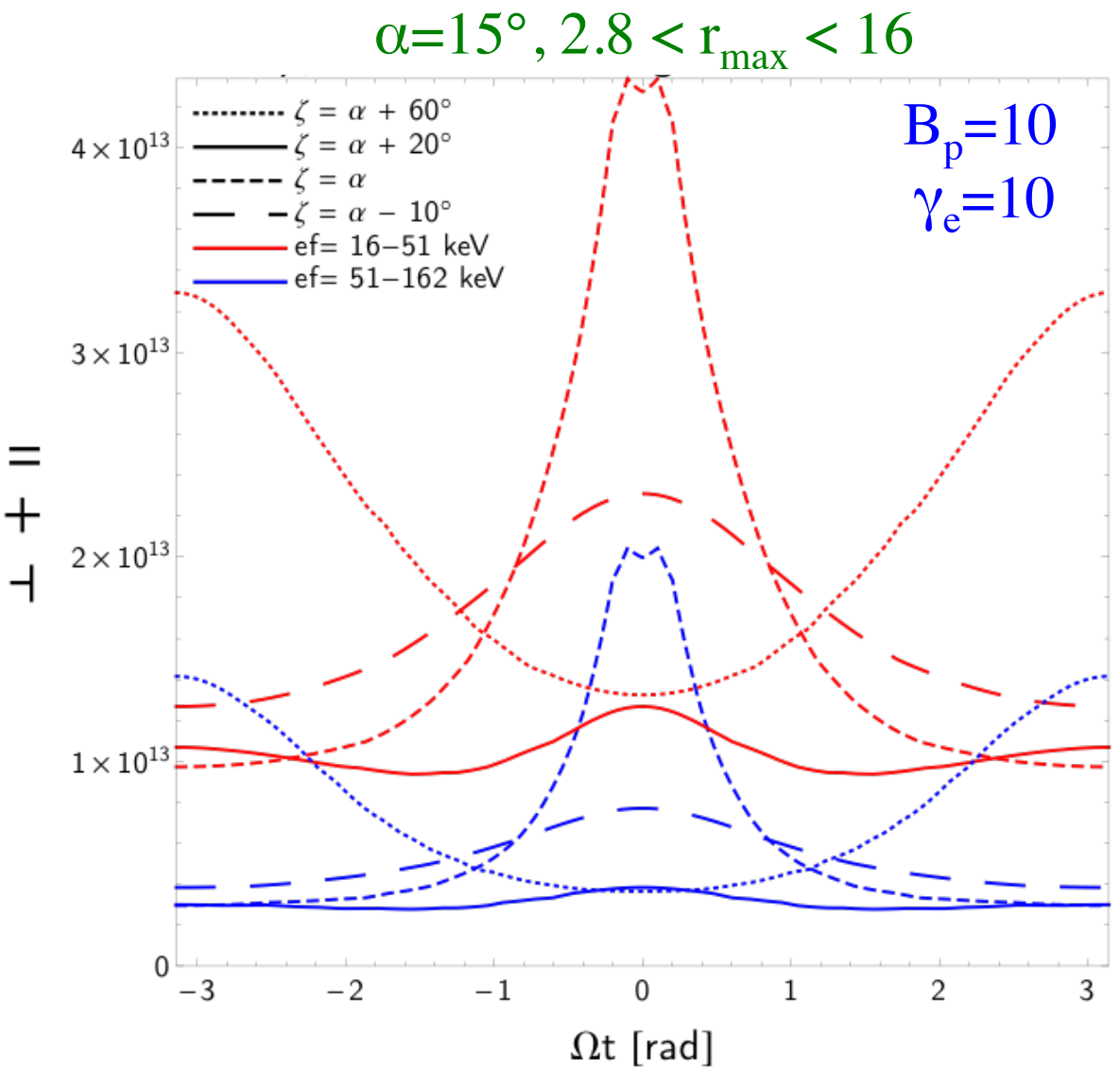
Resonant Compton Emission Spectral Diagnostics

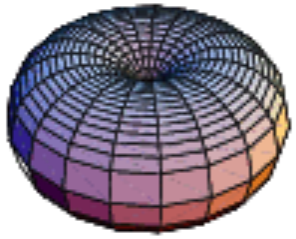




- Spectra for volume integrations of resonant Compton signals. Approximate fits to data restrict toroidal volume and magnetic inclination α and viewing direction ζ.
- Perpendicular (X-mode) exceeds parallel (O-mode) polarization at the highest energies.
- Wadiasingh et al. (ApJ in prep.)

Pulse Profile Diagnostics



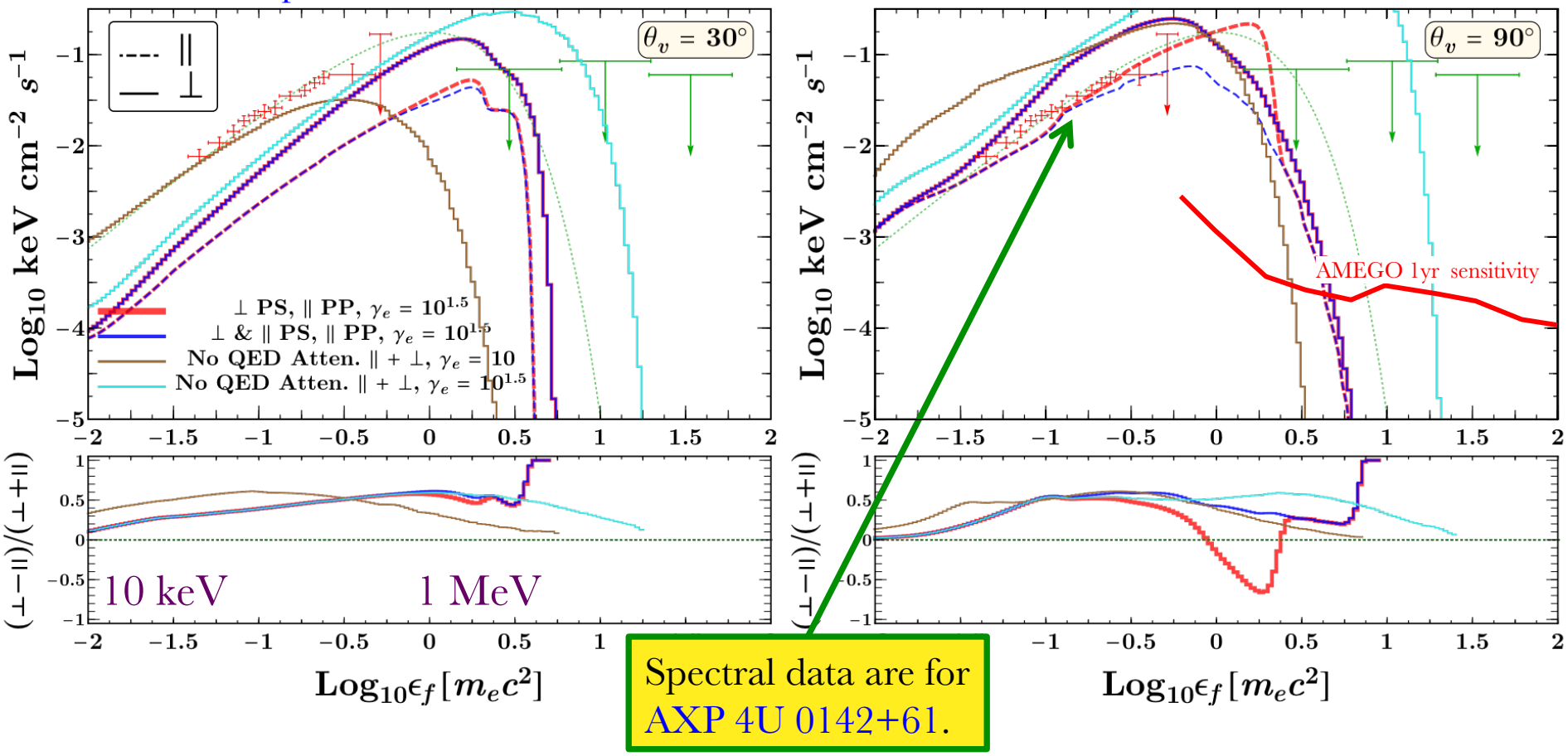


- Pulse profiles for volume integrations of resonant Compton signals. Approximate fits to data restrict toroidal volume and magnetic inclination α and also the viewing direction ζ.
- Wadiasingh et al. (ApJ in prep.)

Spectro-Polarimetry Diagnostics

B_p=10, γ_e=31,10

Wadiasingh et al. ApJ, in prep.



Spectral data are for AXP 4U 0142+61.

- Phase-resolved model RICS spectra of a generic magnetar overlaid on phase-averaged data for 4U 0412+61. Emission is highly polarized and phase dependent.

Conclusions

- Measuring magnetar persistent emission in 100 keV – 10 MeV window will probe action of fundamental QED physics processes of photon splitting and magnetic pair creation.
- Polarimetric capability will enable strong diagnostics on emission locale and attenuation processes for magnetars.
  - Includes refined measures of α and B in population.
- AMEGO will have the continuum sensitivity above 200 keV to realize these goals for several magnetars in 1-2 years of operations in sky survey mode, shorter for pointed observations.