What caused the GeV flare of PSR B1259-63 ?

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PSR B1259-63 is a binary system composed of a pulsar and a massive star. Weak gamma-ray emission was detected by the Fermi/LAT at the last periastron passage, unexpectedly followed 30 days later by a flare during which the flux was higher by a factor >10. This flare is a major puzzle for models of gamma-ray binaries. We propose that the flare is due to Compton scattering of X-ray radiation from the pulsar wind nebula. We predict an MeV flare prior to periastron.

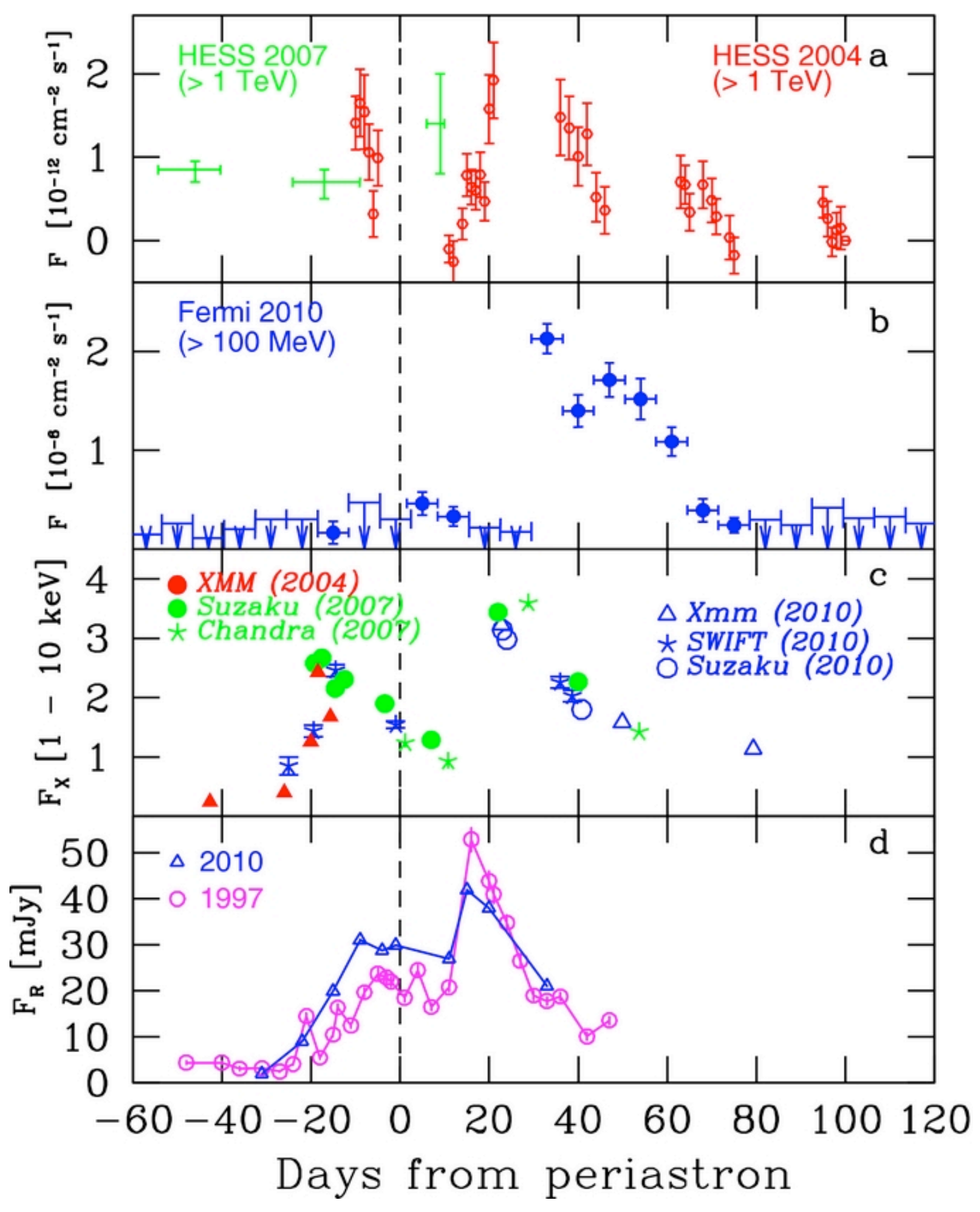
The GeV flare of PSR B1259-63

PSR B1259-63 is a 47.7 ms radio pulsar in a 3.5 year orbit around a Be star. The pulsar has a high spindown power of 8×10^{35} erg s^{-1}.

An outburst of VHE, X-ray, and radio emission occurs at periastron passage, when the pulsar wind interacts with the stellar wind and the equatorial outflow (disk) of its Be companion. Non-thermal emission from gamma-ray binaries is thought to be due to particles in the pulsar wind or in the shocked wind (pulsar wind nebula).

HE emission was detected for the first time by *Fermi*/LAT during the last passage in 2010 (Tam et al. 2011, Abdo et al. 2011). The system brightened dramatically starting about 1 month after periastron passage τ. The flare lasted nearly 2 months (Fig. 1)

The average spectrum during the flare was a power law of photon index Γ=1.4 with an exponential cutoff at 0.3 GeV (Fig. 1). The spectrum hardened with decreasing flux.



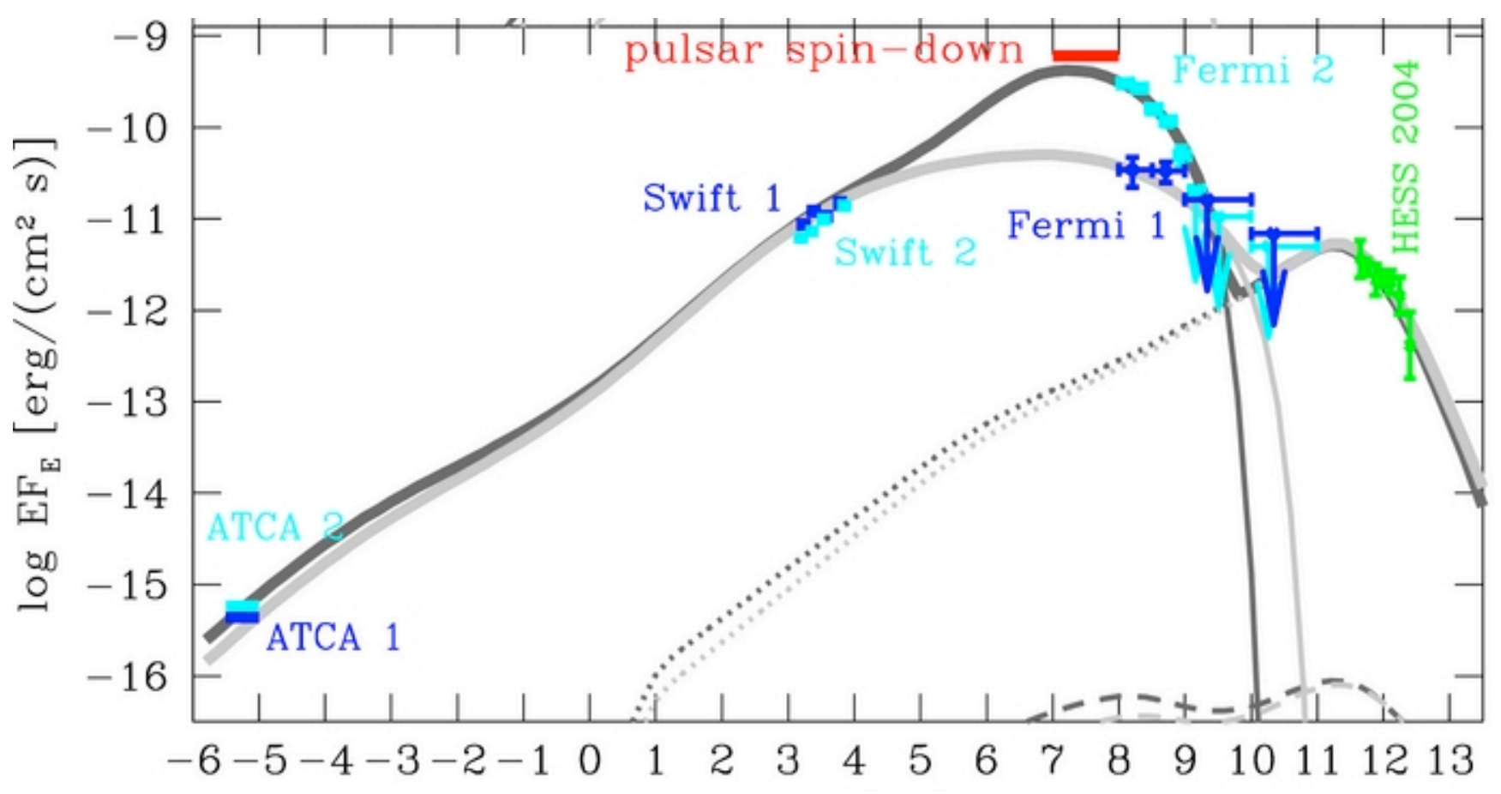


Fig. 1: Lightcurves and spectral energy distribution during the GeV flare.

Figures from Abdo et al. (Fermi/LAT collaboration) 2010

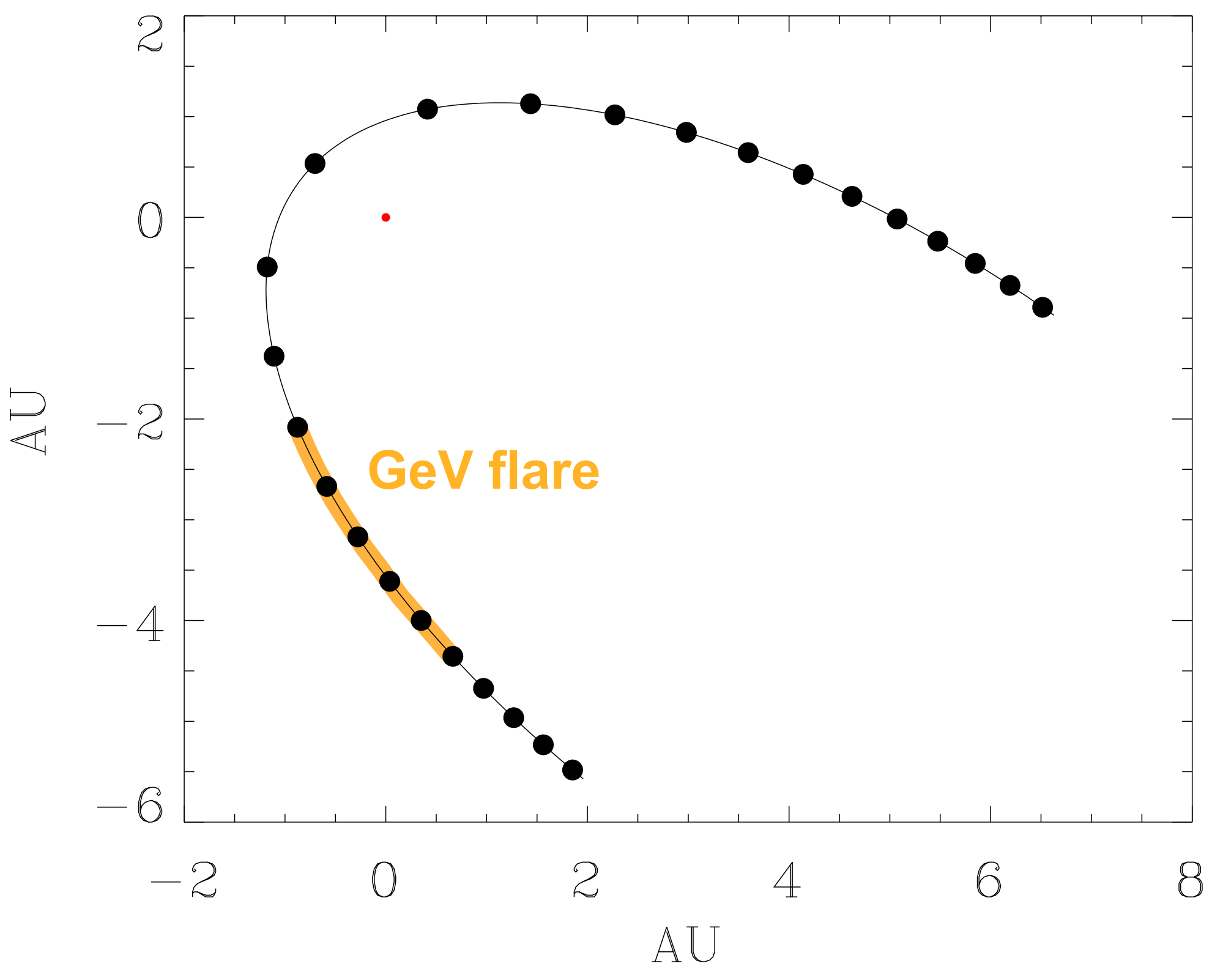


Fig. 2 Orbit of PSR B1259-63 around Be star

As seen by the observer (i=30º). Red dot is the star. Black dots mark the pulsar position in 10 day intervals from τ-120d to τ+120d.

The puzzle

The GeV flare reached a luminosity close to the pulsar spindown power (Fig. 1).

The spindown power is carried away by the pulsar wind. One possibility for conversion to γ rays is efficient inverse Compton scattering by high-energy pairs in the wind or at the shock.

The particles follow the pulsar along the orbit. Compton scattering on the anisotropic stellar photons leads to a lightcurve with a peak slightly before periastron (Fig. 3a): up-scattering of star photons, the most obvious source of seed photons, is excluded.

How is the spindown power efficiently converted to γ-rays ?
Why did this occur one month after periastron passage ?

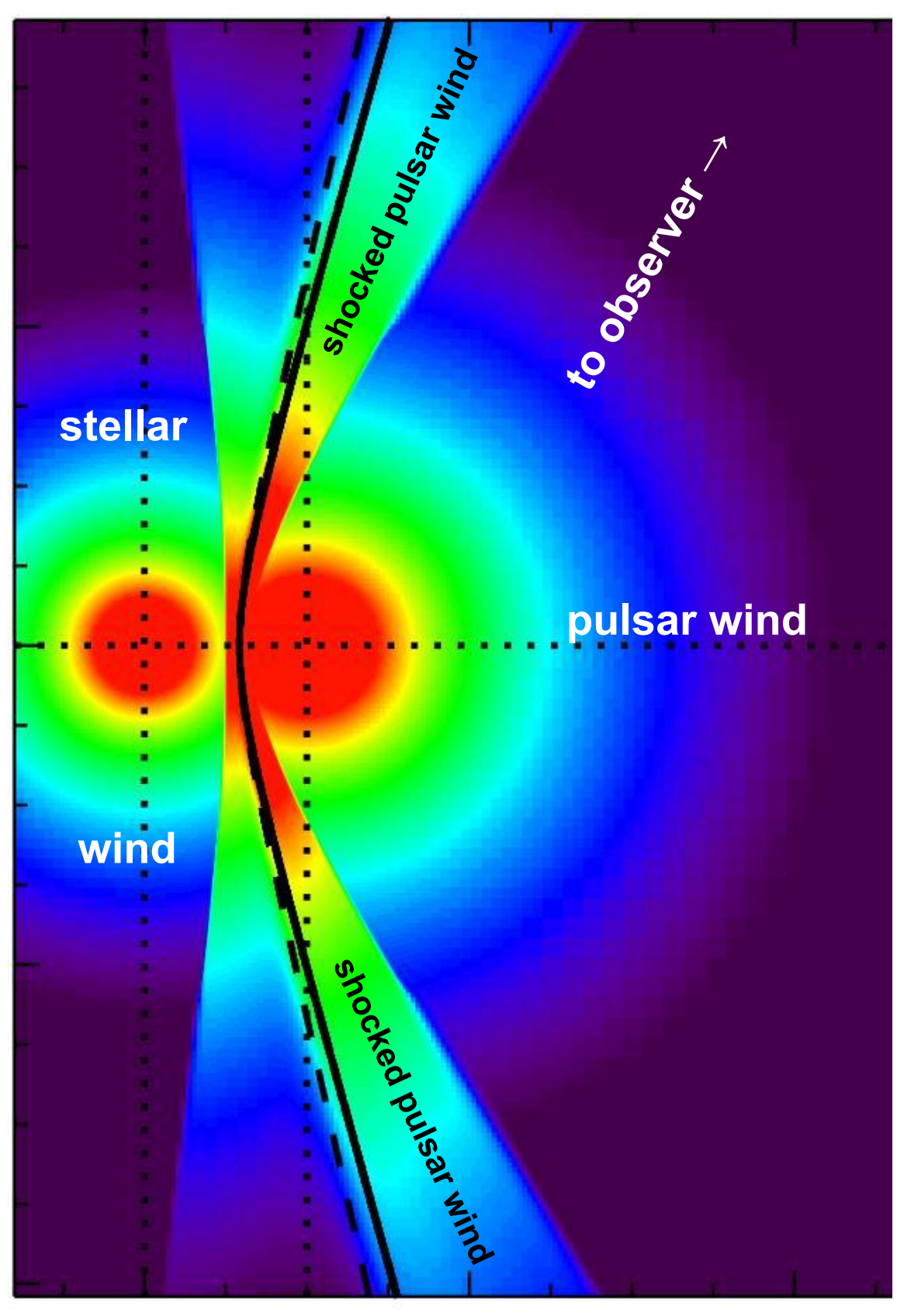
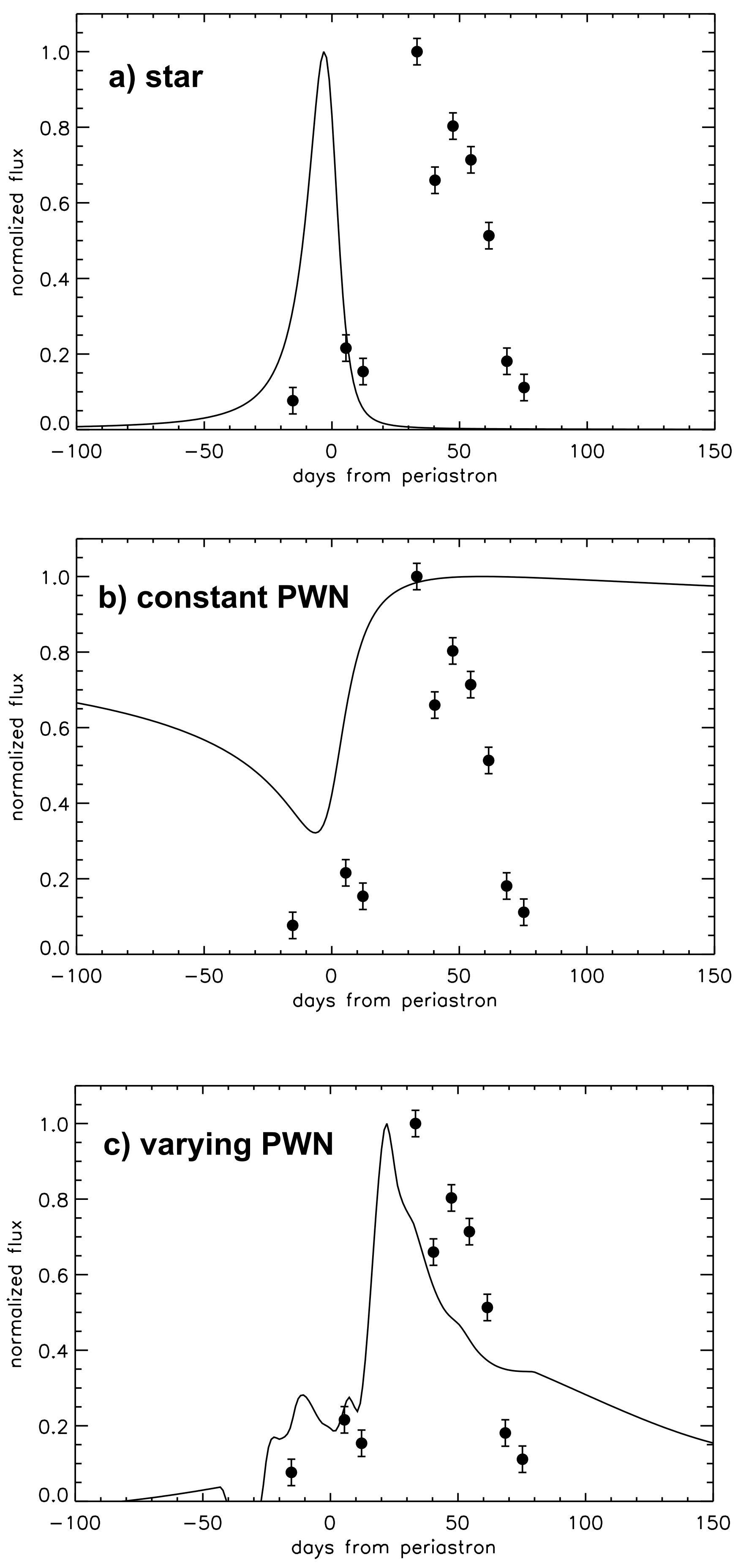


Fig. 4 stellar - pulsar wind interaction

3D hydrodynamical simulation of colliding winds with η=2 (Lamberts et al. 2011).

Fig. 3 Inverse Compton lightcurve for different sources of seed photons.



Solutions proposed by others

Be disk photons: up-scattering Be disk photons has been proposed as a possible solution (Khangulyan et al. 2012). However, the photons come predominantly from the innermost disk so the effect on the inverse Compton lightcurve is identical to the star photons (van Soelen et al. 2012, Yamaguchi priv. comm.).

Be disk material: the passage of the pulsar close to the Be disk can lead to a complex interaction. However, the flare started when the pulsar is >60 R* away from the star, beyond the reach of the Be disk (extending to 15-20 R*, Grundstrom & Gies 2006): it is unlikely to play a major role in the flare.

Doppler boosting: the interaction with the stellar wind generates a bow shock (Fig. 4). The geometry depends on the ratio of momentum η

$$\eta=\frac{\dot{M}_w v_w}{\dot{E}/c}\approx 2\left(\frac{v_w}{1000\,\mathrm{km\,s^{-1}}}\right)\left(\frac{\dot{M}_w}{10^{-8}\,\mathrm{M_\odot\,yr^{-1}}}\right)\left(\frac{\dot{E}}{10^{36}\,\mathrm{erg\,s^{-1}}}\right)$$

For this value, the shocked pulsar wind is a hollow cone with opening angles 60º to 75º (Fig. 4). During the flare, the pulsar is at inferior conjunction and the line-of-sight (*i*=30º) crosses the shocked wind. Post-shock material has a speed c/3 so Doppler boosting (Dubus et al. 2010) has been proposed for the flare (Tam et al. 2011, Kong et al. 2012). All co-located emission is impacted so the lack of simultaneous flaring at other frequencies (X-rays, VHE) is a difficulty for this model.

Scattering of shocked pulsar wind

At inferior conjunction, electrons will efficiently upscatter radiation from the shocked pulsar wind in the direction of the observer.

The radiation energy density is primarily in X-rays (Fig. 1). Electrons of energy 0.1-1 GeV upscatter these photons to the *Fermi*/LAT range. The spectrum will be narrow if the distribution of electrons is narrow, for instance if they are thermal pairs in the striped wind (see poster by Arka & Dubus).

These pairs also upscatter stellar photons to 1-10 MeV energies, with a lightcurve like that in Fig. 3a. **We predict an MeV flare slightly before periastron.**

We calculated the expected inverse Compton emission, assuming the shocked pulsar wind is a hollow cone of uniform, constant emissivity, oriented directly away from the star, with the electrons at apex. The lightcurve is in Fig. 3b. Emission peaks close to inferior conjunction (τ+60d), but the decay is too slow. If the cone emissivity is allowed to vary with orbital phase like the observed X-rays, the resulting lightcurve is closer to the observed one (Fig. 3c).

RMHD simulations are required to compute the synchrotron emission in the shocked wind and obtain a more precise lightcurve.

References

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