ORIGIN OF GAMMA-RAYS IN DIFFERENT EMISSION STATES OF REDBACK MSP BINARY SYSTEMS

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Transition states in MSP binary systems

- Three (four) redback MSP binaries has been caught in the transition

PSR J1023+0038 (Archibald et al. 2009)
PSR J1824-2452 (Papitto et al. 2013)
PSR J1227-4853 (de Martino et al. 2014; Roy et al. 2014)
(1RXS 3154439.4-112820, Bogdanov & Halpern 2015) (?)

- Rotation powered state: radio and γ-ray pulsar

- Accretion powered state: no radio, enhanced X-rays and γ-rays

- X-ray pulsations with pulsar period in the accretion state

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Evidence for accretion of matter onto NS surface !

Theoretical interpretation

- **Propeller model (Papitto et al. 2014):**

Electrons accelerated in the turbulent transition region of the inner disk

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comptonize synchrotron radiation

- **Truncated disk model (Takata et al. 2014):**

Leptons in the pulsar wind

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comptonize optical radiation from the disk truncated at $\sim 10^{10}$ cm

Redback MSP binary: PSR J1227-4853

- Existing accretion disk disappeared in 2012
  (in optical $\longrightarrow$ de Martino et al. (2014)
- Discovery of radio pulsar (1.69 ms, PSR J1227-4853)
  (Roy et al. 2014)
- Discovery of γ-ray flux (Fermi) increased by a factor of ~ 2
  kom(Xing & Wang 2014, Johnson et al. 2015)
- Redback binary MSP with companion ($0.06 - 0.12$ $M_\odot$), period 6.9 hrs
  (de Martino et al. 2014)
- X-ray (0.3-10 keV) luminosity during accretion state: 5×10^{33} erg s^{-1},
  modulated X-ray emission with the pulsar period
  (Papitto et al. 2014)

Emission stages of PSR J1227-4853

disk state

rotation powered state

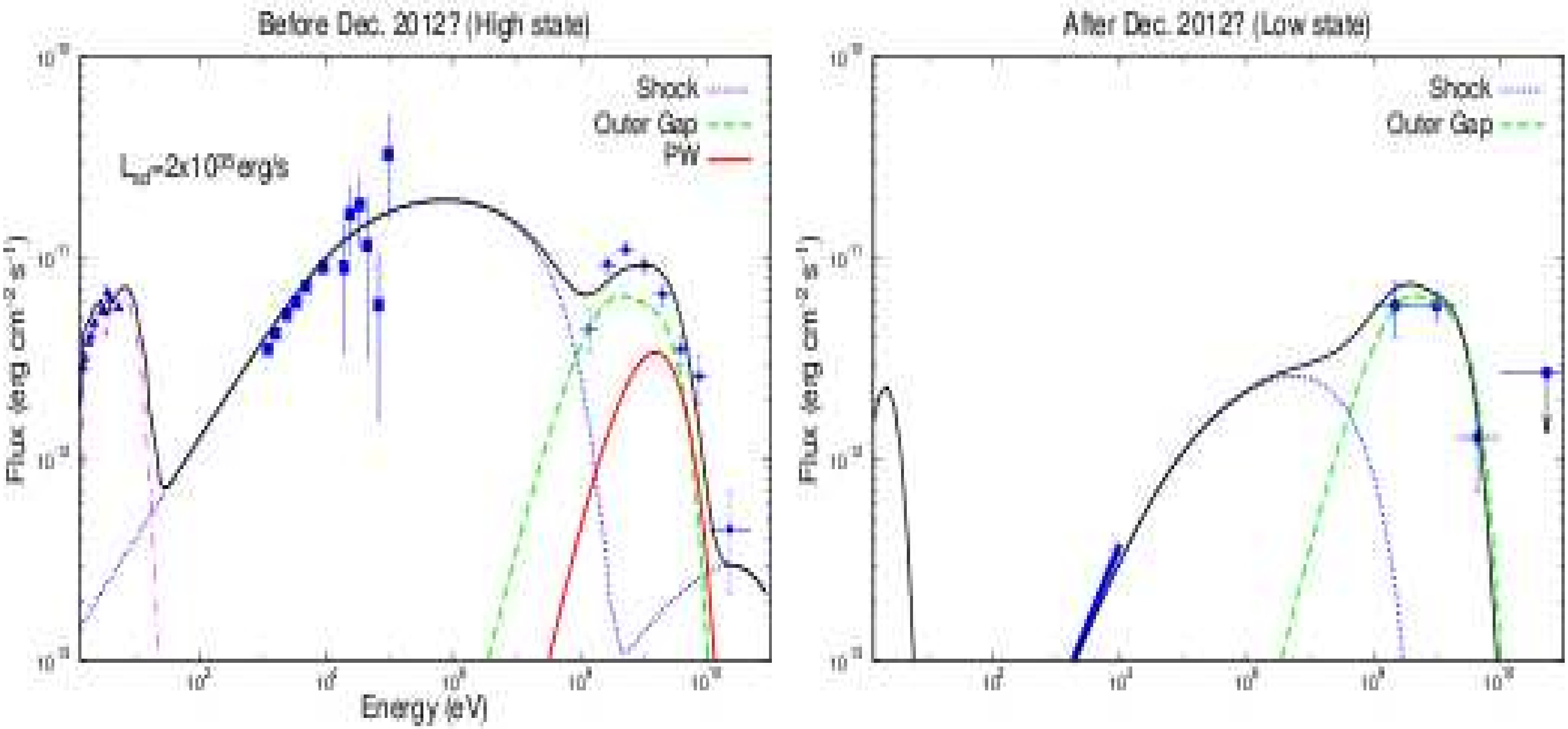


Figure 1: Spectrum of PSR J1227-4853 in rotation and accretion-powered states (from Tam et al. 2014).

Gamma-ray emission stages of PSR J1227-4853

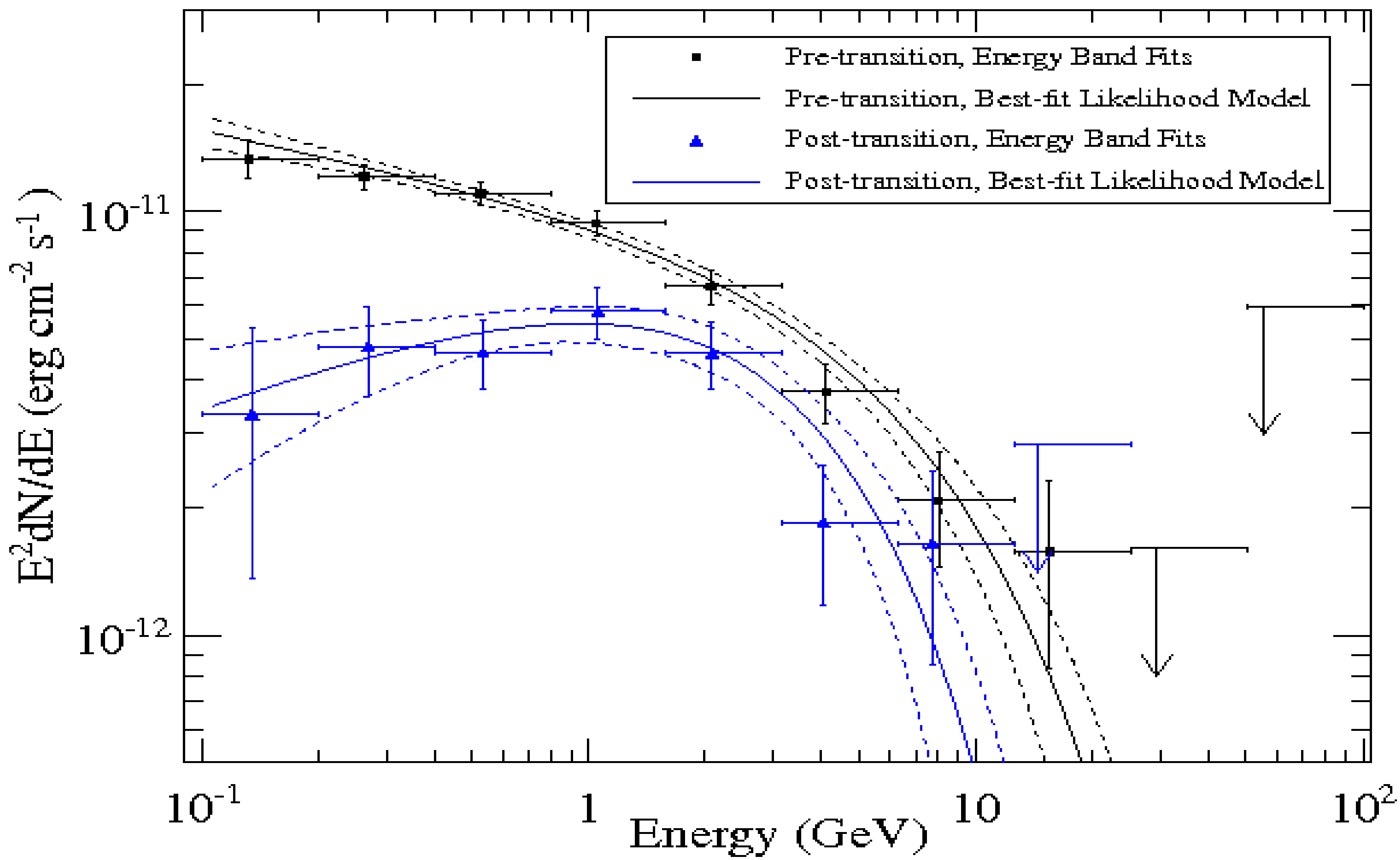
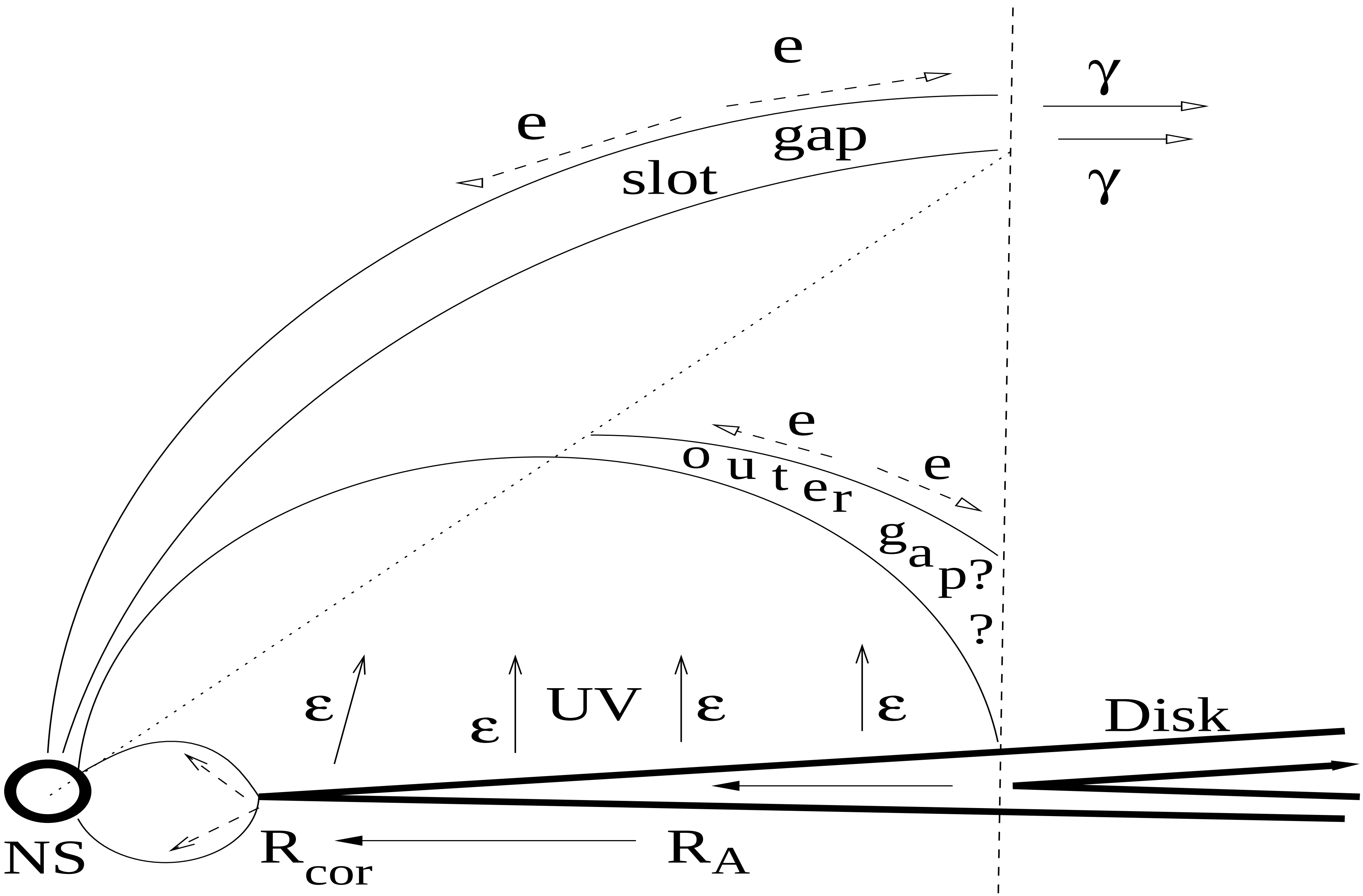


Figure 2: Gamma-ray spectra of PSR J1227-4853 in different states (from Johnson et al. 2015).

Considered model: basic assumptions

- Accretion disk penetrates NS magnetosphere below the light cylinder radius
- The accretion disk builds up accumulating matter
- Magneto-spheric radius for the plasma in the inner disk reaches corotation radius of the pulsar
- Matter falls onto the NS surface
- Leptons accelerated in the slot gap of the pulsar magnetosphere
- Disk radiation creates additional target for secondary leptons in this gap

Accretion disk within the MSP pulsar magnetosphere



Accretion disk within the pulsar inner magnetosphere

- The kinetic energy of the disk matter balanced by the magnetic energy at the Alfven radius,

$$R_{\rm A} = 8.4 \times 10^4 (B_8^2/\rho)^{1/5} \quad {\rm cm}, \tag{1}$$

where $B = 10^8 B_8$ G is the surface magnetic field of MSP, ρ is density of disk matter in grams

- The disk inner radius expected to be at the magneto-spheric radius

$$R_{\rm m} = \chi R_{\rm A}, \tag{2}$$

where χ is argued to be in the range χ ~0.1-1 (Lamb, Pethick & Pines 1973)

- Matter flows onto NS when, $R_{\rm m} \approx R_{\rm cor}$, where

$$R_{\rm cor} = (GM_{\rm NS})^{1/3} (P_{\rm NS}/2\pi)^{2/3} \approx 1.7 \times 10^6 P_{\rm ms}^{2/3} \quad {\rm cm}. \tag{3}$$

- The light cylinder radius at $R_{\rm LC} = cP/2\pi \approx 4.8 \times 10^6 P_{\rm ms}$ cm

- Inner disk temperature ($L_{\rm D} = GM_{\rm NS}\dot{M}/2R_{\rm in} = 4\pi R_{\rm in}^2 T_{\rm in}^4$):

$$T_{\rm in} \approx 1.5 \times 10^6 L_{34}^{1/4}/P_{\rm ms}^{1/3} \quad {\rm K}, \tag{4}$$

where disk luminosity $L_{\rm D} = 10^{34} L_{34}$ erg s^{-1}.

- Disk temperature profile (Shakura & Sunyaev 1973):

$$T(R) \approx T_{\rm in}(R_{\rm in}/R)^{3/4}. \tag{5}$$

Gamma-ray emission in the accretion state

- Secondary leptons produced in the slot gap
  from absorption of primary gamma-rays

- Leptons comptonize disk radiation

- Leptons have power law spectrum between 100 MeV and 100 GeV

- We simulate propagation of leptons in the disk radiation

(synchrotron losses included, γ-ray absorption included)

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Gamma-ray spectra in the accretion state

Example γ-ray spectra in the accretion stage

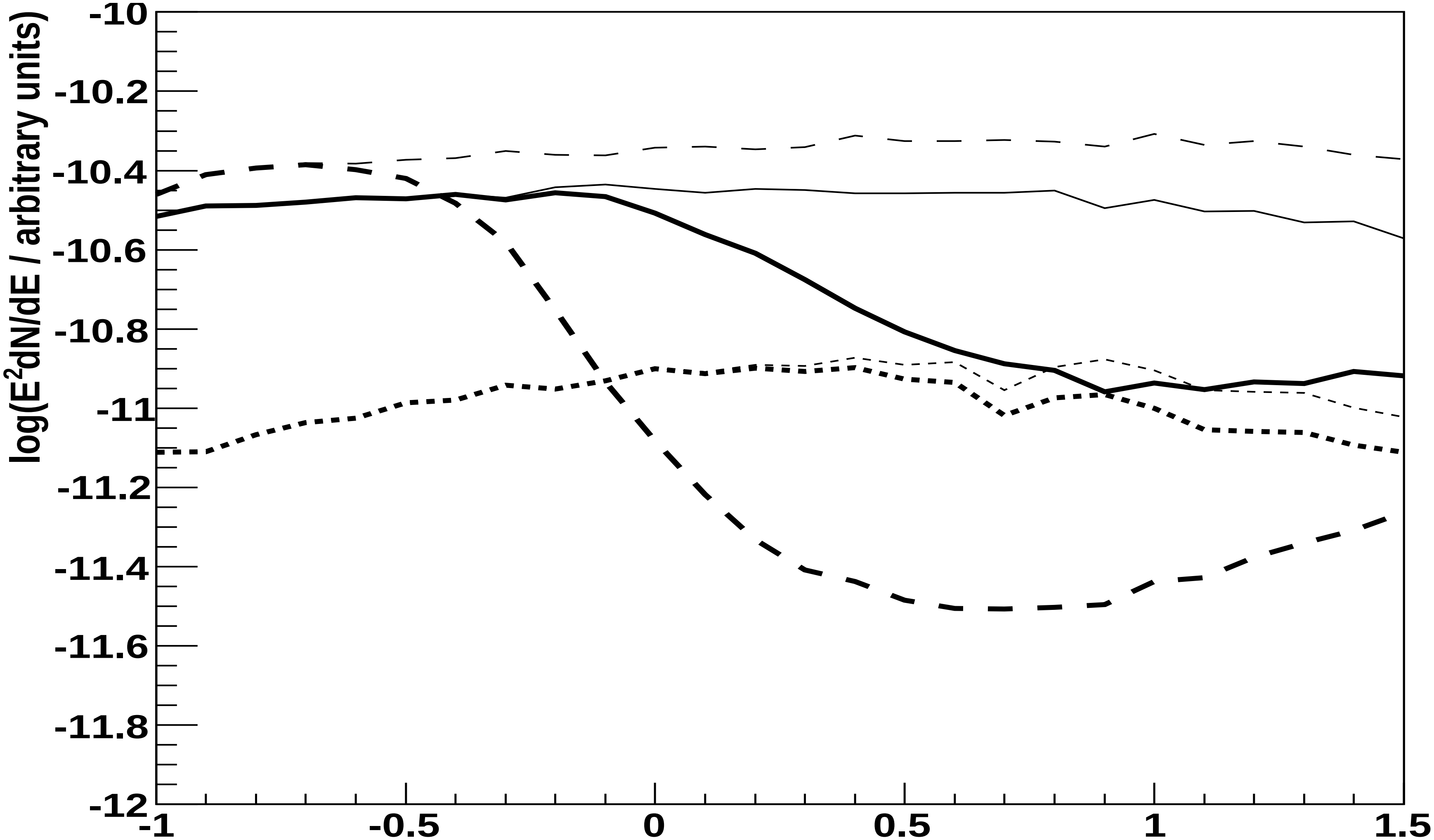

Figure 3: SED of γ-rays produced in the IC scattering of the accretion disk radiation by secondary leptons with the power law spectrum and spectral index equal to -2 between 100 MeV and 100 GeV (thin curves) and the spectra after absorption of γ-rays in the disk radiation (thick curves). Specific spectra are calculated for luminosities of the accretion disk $L_D = 10^{33}$ erg s^{-1} (dotted), 10^{34} erg s^{-1} (solid), and 10^{35} erg s^{-1} (dashed). The disk extends up to the co-rotation radius and the period of the pulsar is equal to 1.7 ms (Bednarek 2015).

SED of the accretion state in MSP J1227-4853

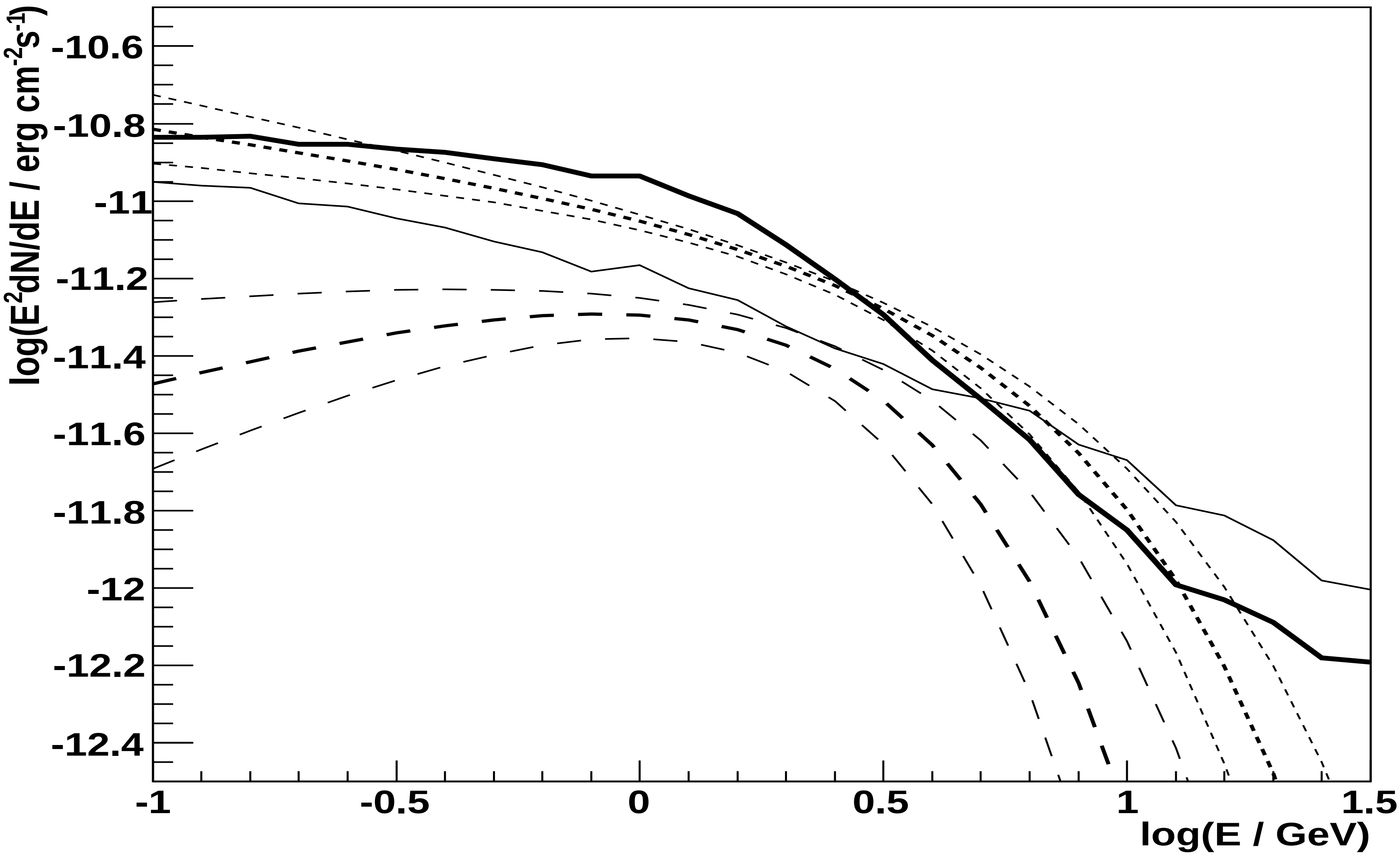

Figure 4: SED of the Redback type binary system containing MSP PSR J1227-4853. The approximation of the pre-transition and post-transition spectra from PSR J1227-4853 (dotted and dashed curves, see Johnson et al. 2015). The IC spectrum produced by secondary $e^{\pm}$ pairs which comptonize thermal radiation from the accretion disk, before (thin solid curve) and after absorption in the disk radiation (thick solid). It is assumed that the secondary $e^{\pm}$ spectrum is of a simple power law type with the spectral index -2.6 between 0.1-100 GeV. The accretion disk luminosity is assumed to be equal to $L_{\rm D} = 3 \times 10^{33}$ erg s^{-1} (Bednarek 2015).

Summary

- We propose that accretion disk penetrates deep into the NS magnetosphere,
- The matter flows onto the NS surface in the accretion state of transiting MSPs,
- Pulsar mechanism is still active: acceleration of leptons in slot gap,
- Secondary leptons comptonize disk radiation producing enhanced γ-rays

Conclusions

- γ-rays in accretion state might be modulated with the NS period (?)
- Accretion disk emission should be observable at ~ 0.1 keV (UV)
- The accretion disk might influence emission geometry of the slot gap

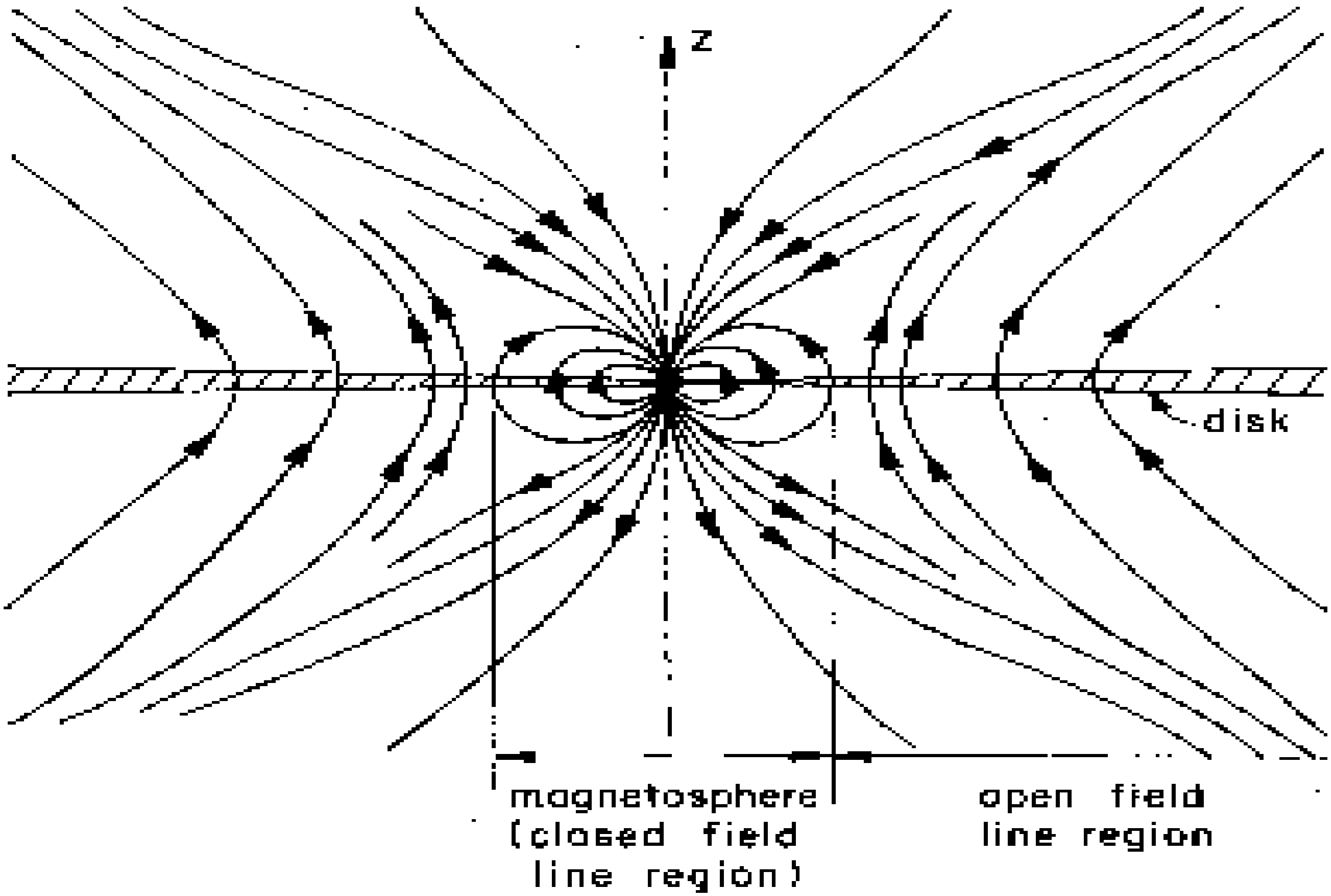

Figure 5: (from Lavelace et al. 1995)