High-energy gamma-ray emission from Cyg X-1 measured by *Fermi* and its theoretical implications

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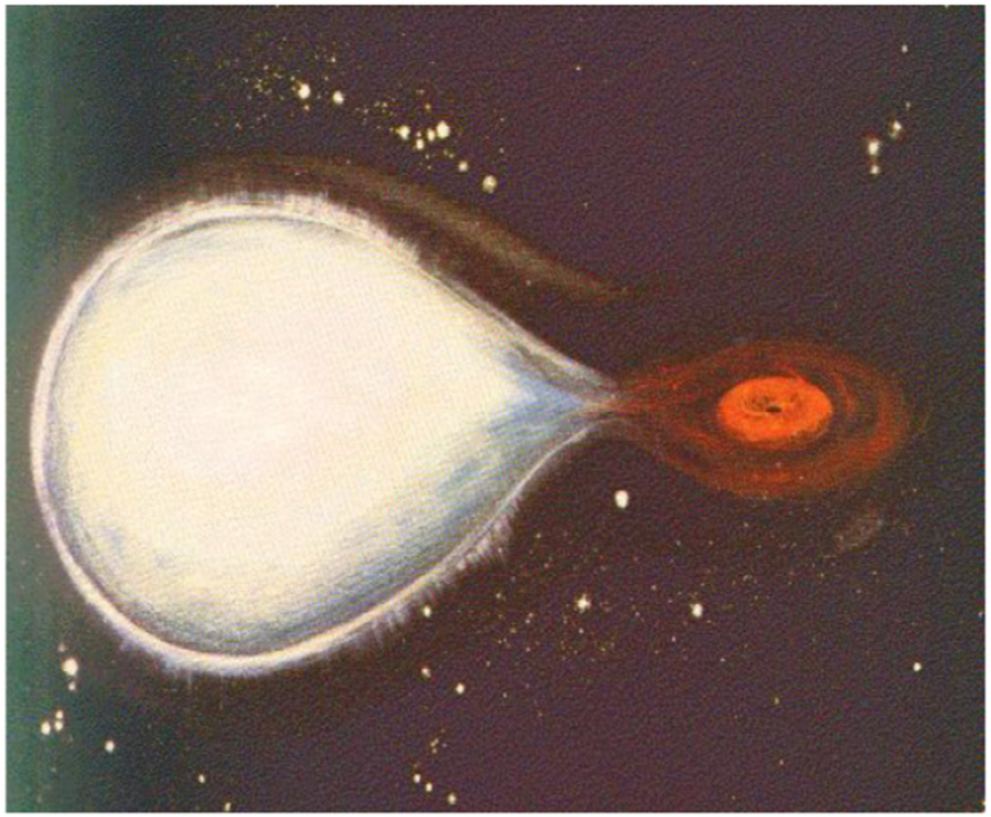
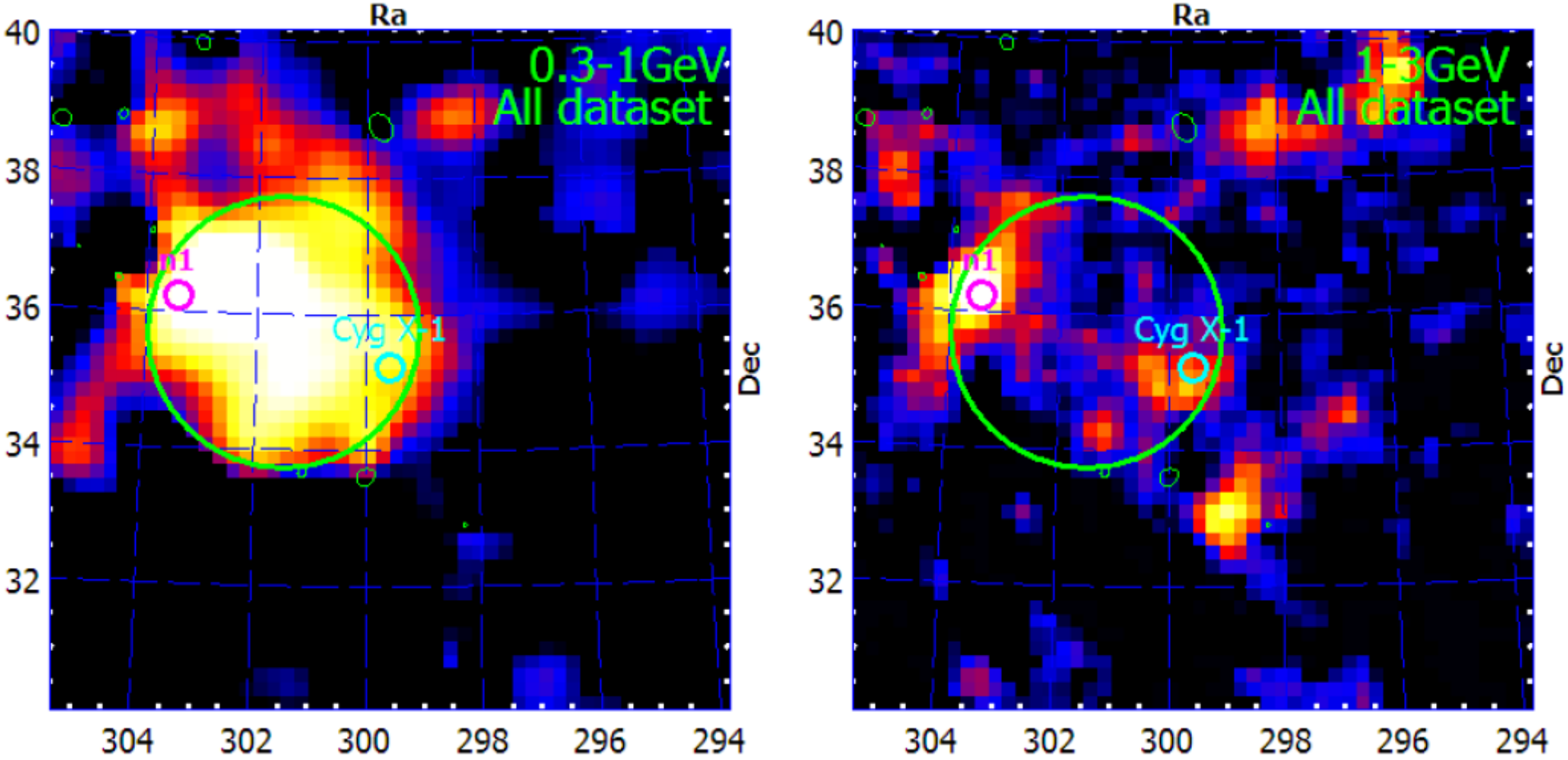
I. Cyg X-1



- An accreting black-hole binary. Donor: OB supergiant. $P = 5.6$ d, $d \approx 1.9$ kpc, $M_{\rm BH} \approx 15\ {\rm M}_\odot$.
- Wind accretion, the donor nearly fills its Roche lobe.

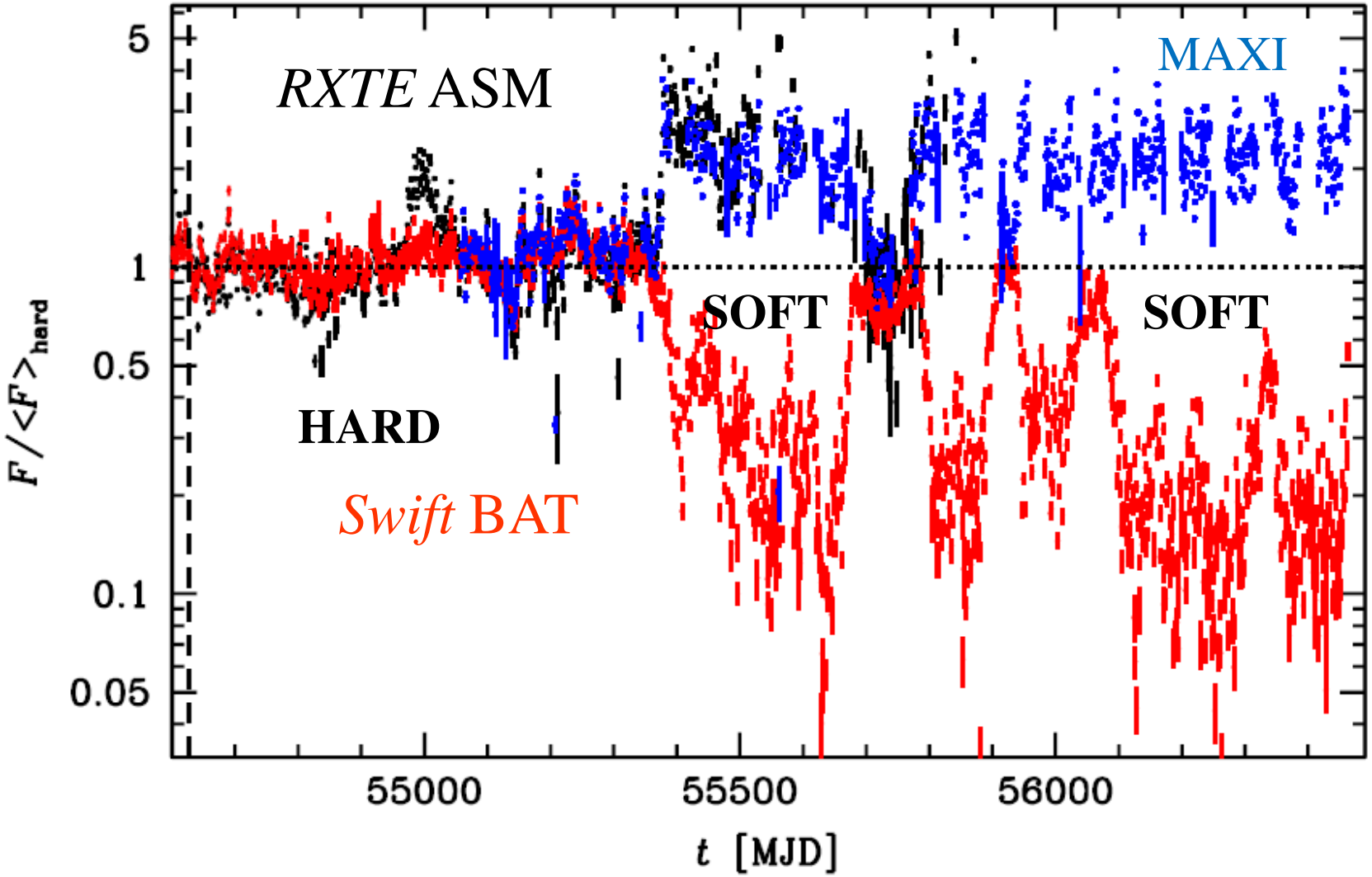
The Cyg X-1 region



In addition to known *Fermi* catalogue sources, we have found an extended source, probably the Cyg OB3 association, and a point source, probably a SNR. We included those in the analysis.

Malyshev, Z., Chernyakova 2013

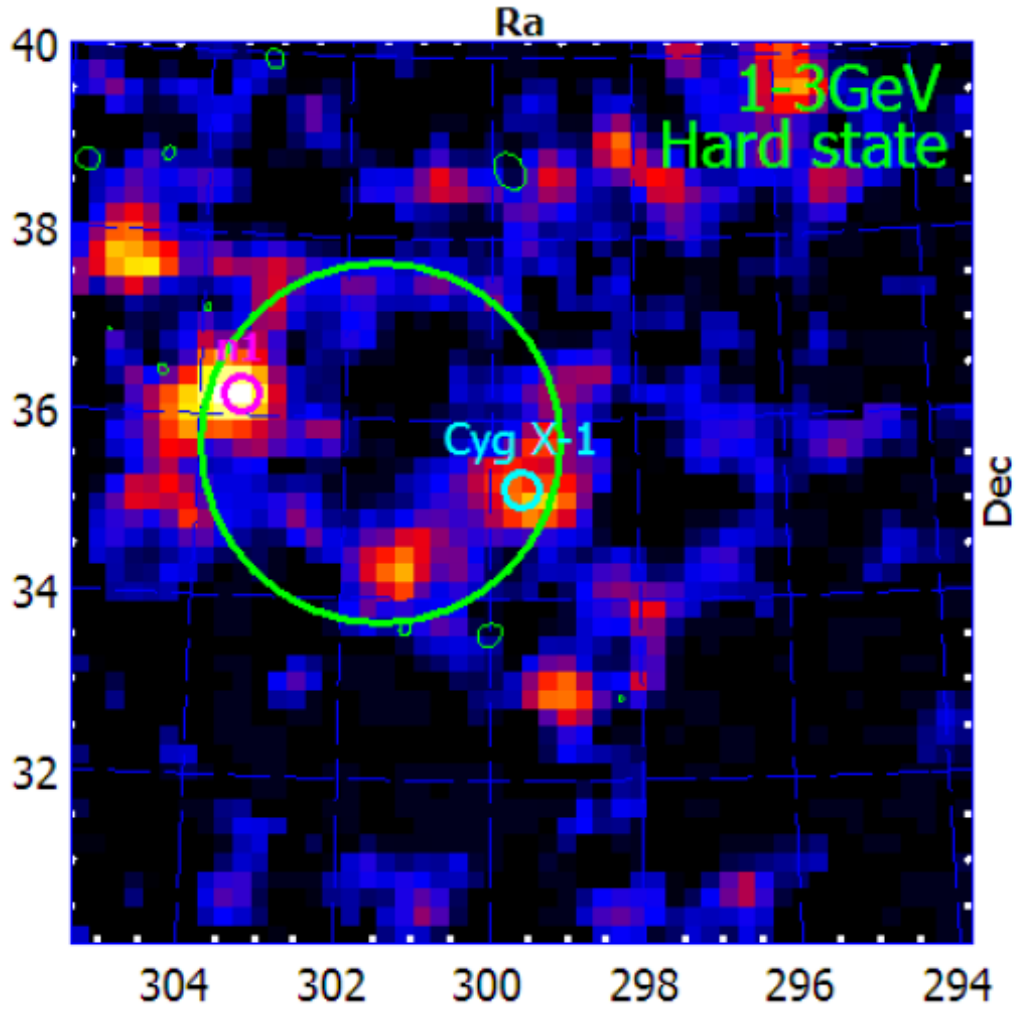
The spectral states of Cyg X-1during *Fermi* observations

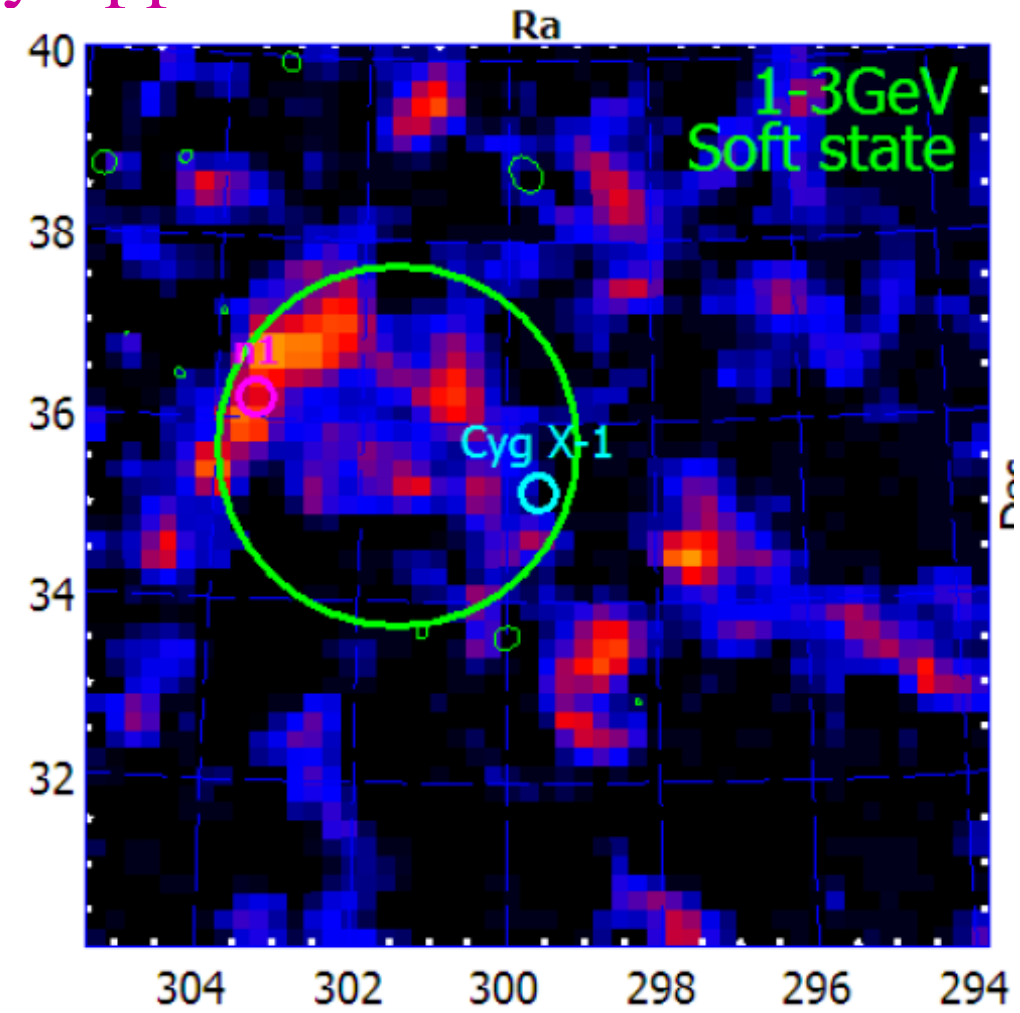


Similar exposure times in the hard (822 d) and soft (575 d) states.

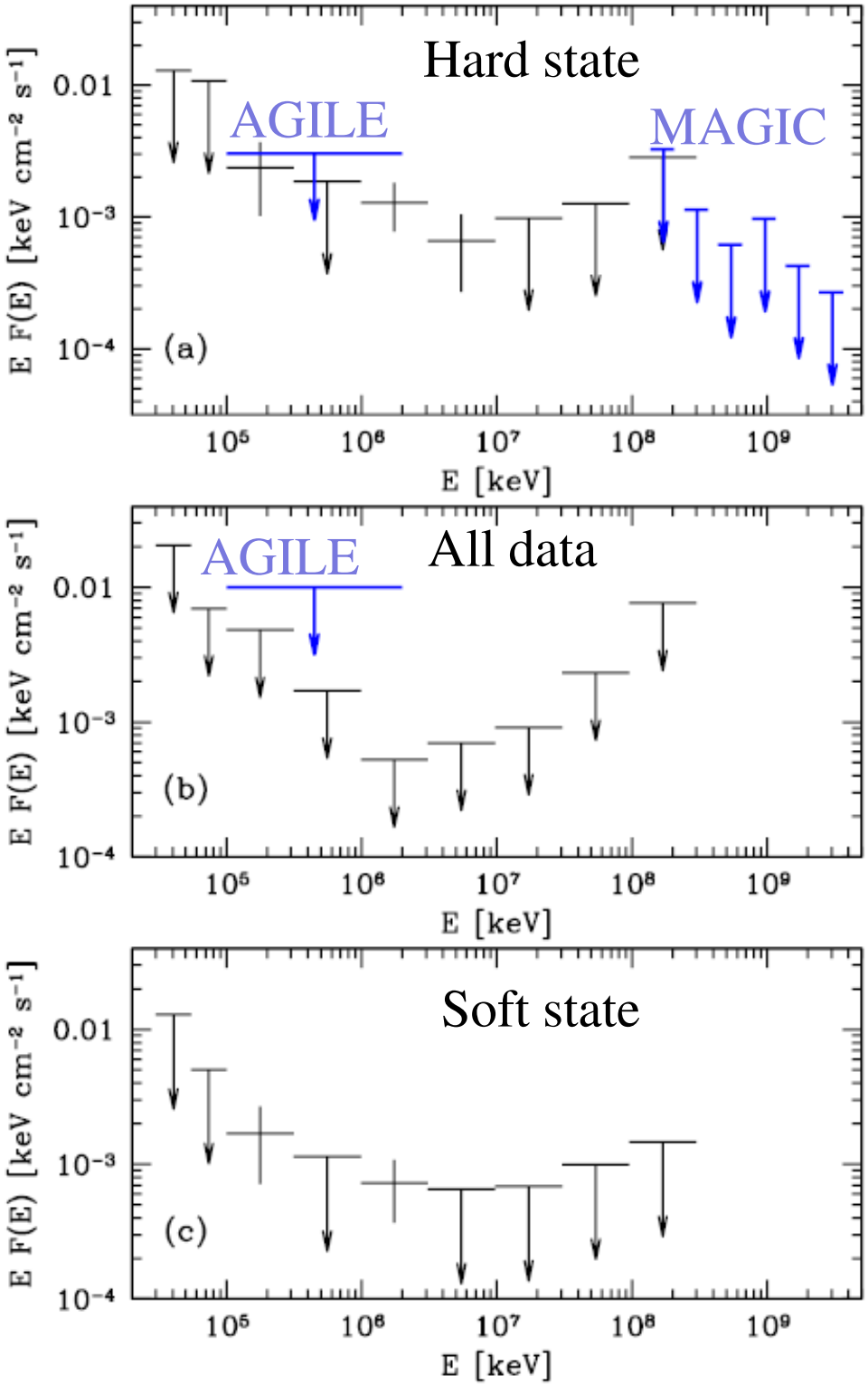
A tentative (4σ) detection of Cyg X-1 in the hard state

Only upper limits in the soft state





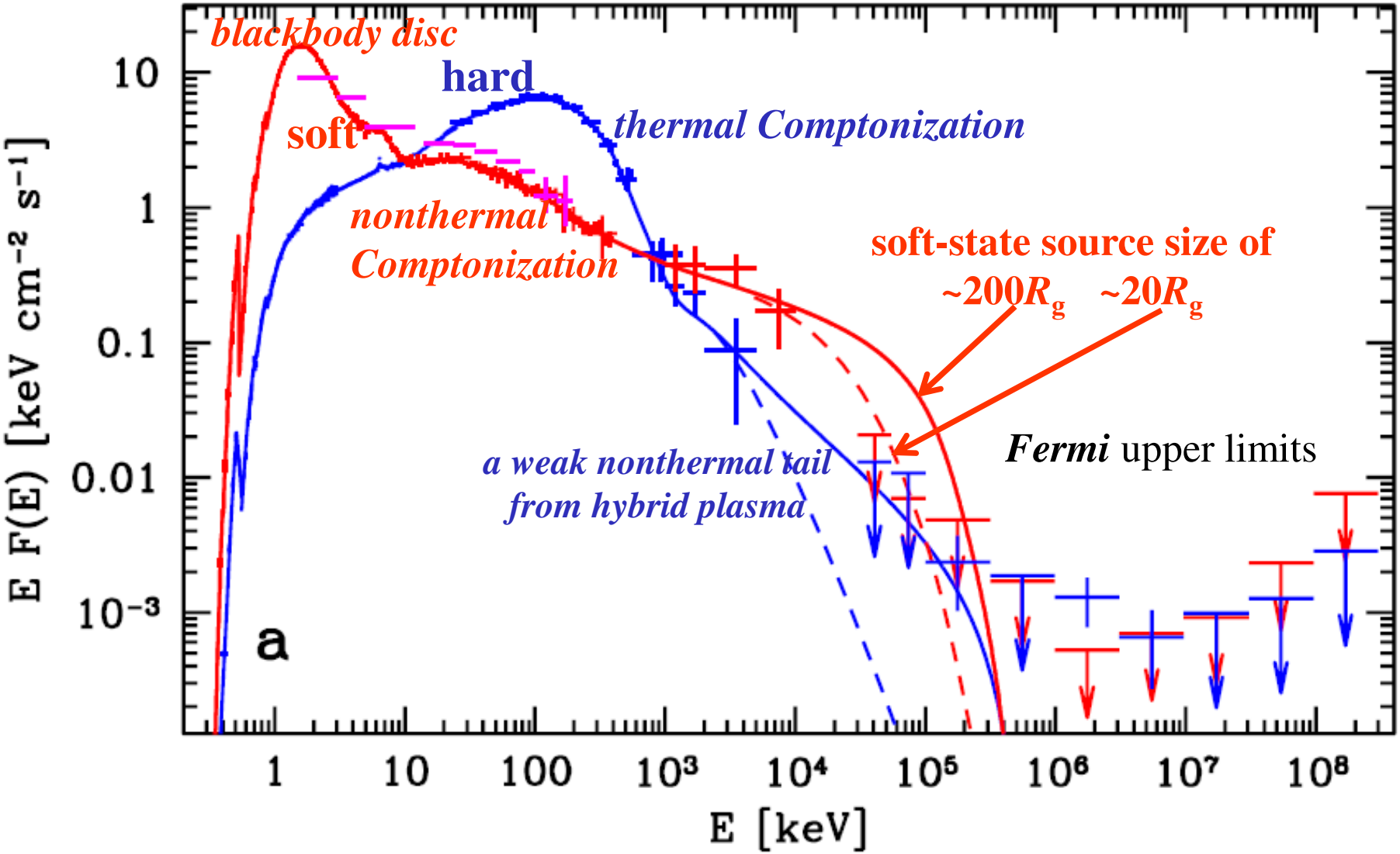
Fermi spectra/ upper limits



A recent confirmation of these results: Bodaghee et al., ApJ, submitted, found 21 days with detectable γ-ray emission from Cyg X-1, with 20 of them in the hard/intermediate state, and only one in the soft state.

Accretion models of X-rays/γ-rays of Cyg X-1

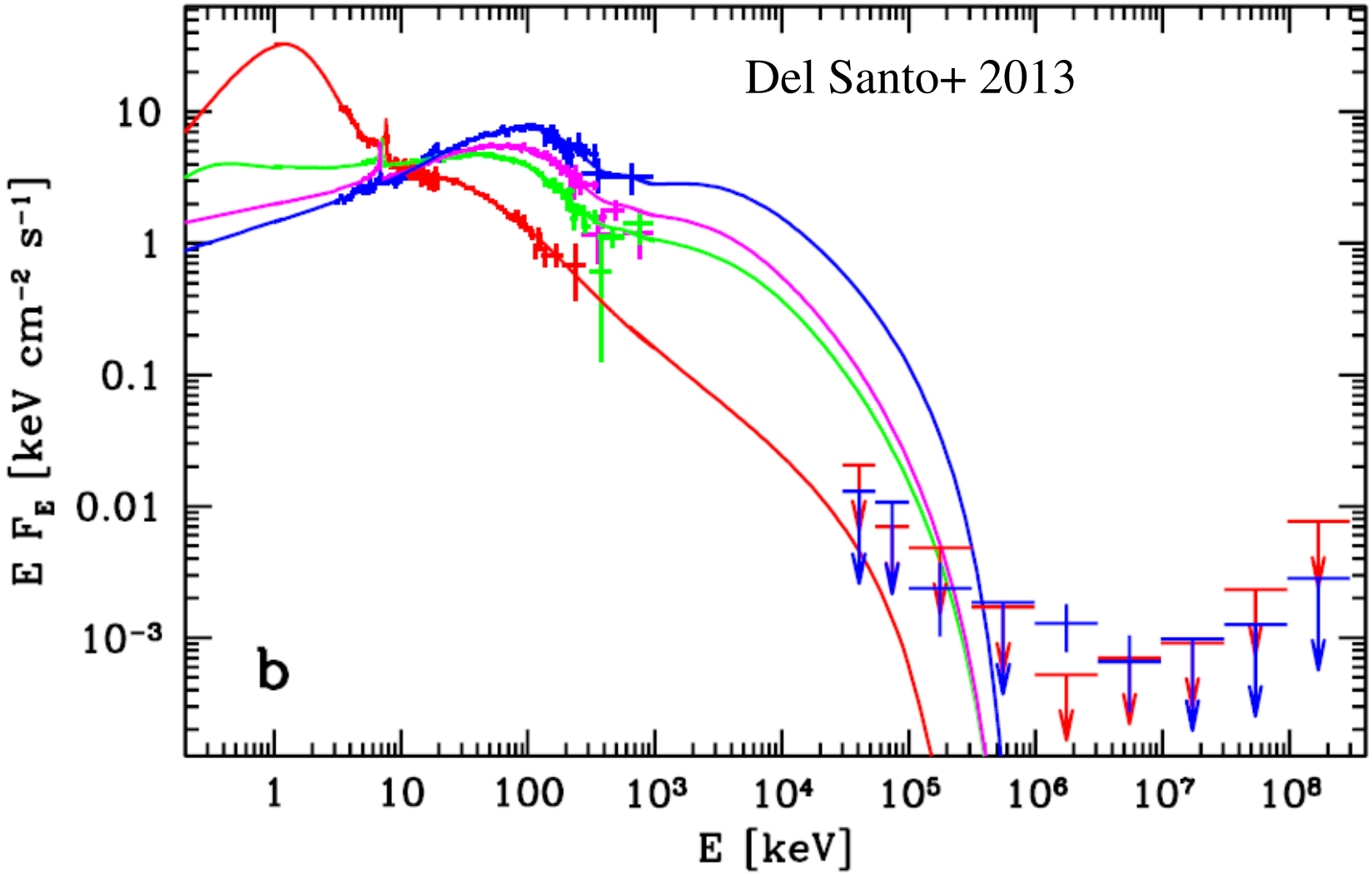
A hot Compton-scattering plasma with thermal electrons and a nonthermal tail



The current Fermi data do not impose constraints on the hard-state models. In the **soft state**, **pair absorption in γγ collisions** constrains the source size.

Leptonic accretion models

A hot Compton-scattering plasma with thermal electrons and a nonthermal tail

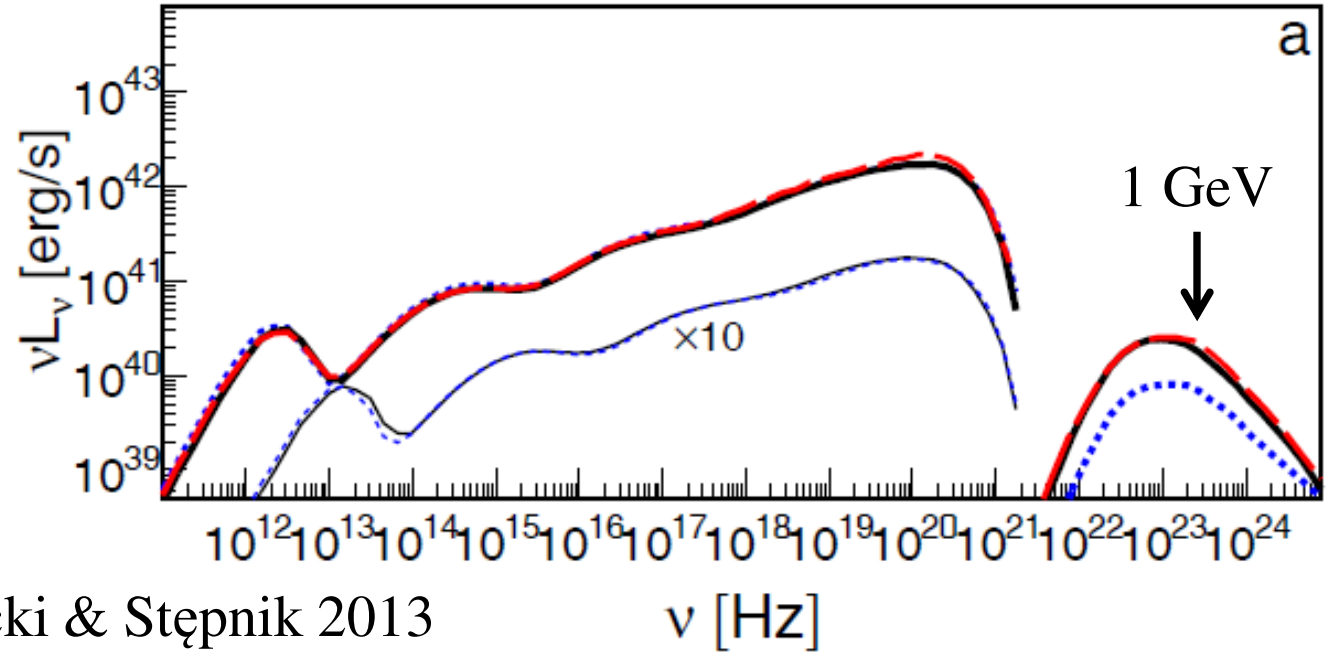


INTEGRAL data sorted by the hardness and fitted by the model of Malzac & Belmont (2009). The fitted model is purely non-thermal, with acceleration but no heating. The model ruled out by the *Fermi* data for the 3 **hard-state** spectra.

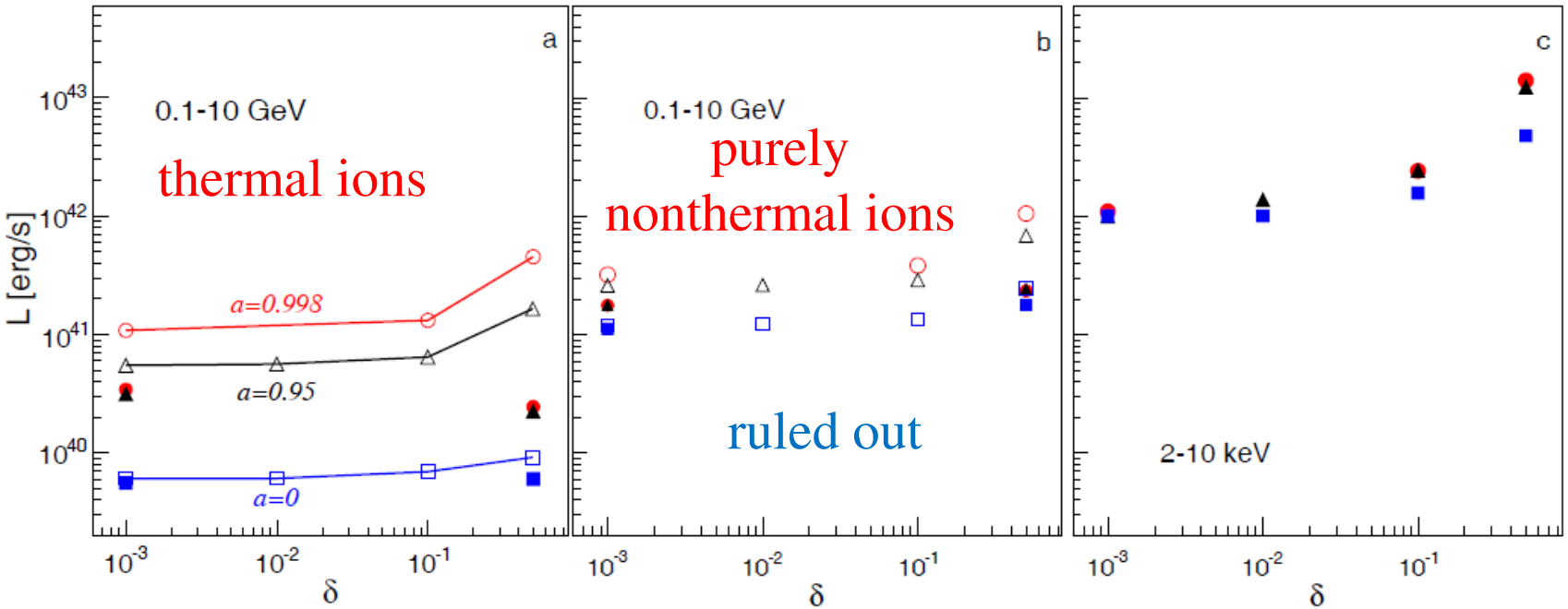
Constraints on hadronic accretion models

- Pion production in ion collisions in inner parts of hot accretion flows during hard state possible in principle.
- Decay of π^0 would give rise to GeV emission.
- In Cyg X-1, $L(0.1\text{–}10\ \text{GeV}) \leq 10^{-3} L(2\text{–}10\ \text{keV})$.
- This is $\ll$ than that ratio for most published hadronic accretion models, e.g., Mahadevan+ 97, 99.
- Thus, pion production in actual accretion flows in the hard state is at most weak.

Some predictions of hadronic models



Niedźwiecki & Stępnik 2013

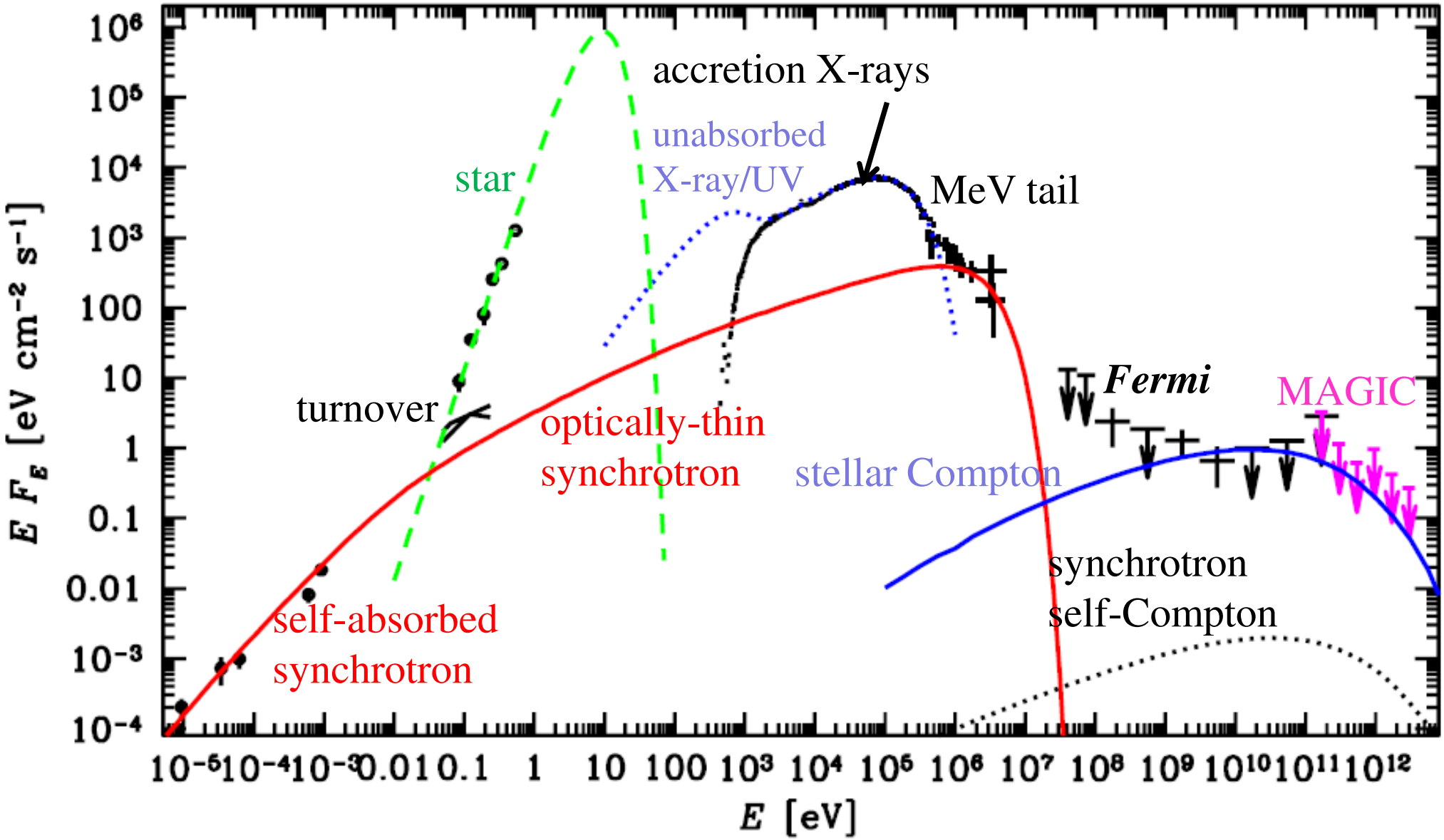


A jet model for the hard state

- A continuous jet needed to account for the radio spectrum with the spectral index of $\alpha \approx 0$ (unlike blazar one-zone models).
- Dissipation distributed along the jet accounting for $\alpha \approx 0$.
- The electron distribution solved from the continuity equation including all energy losses and the Klein-Nishina cross section.
- The radiative transfer equation solved at each height.
- Relativistic electrons in the jet Compton upscatter the stellar and synchrotron radiation, the former dominates.

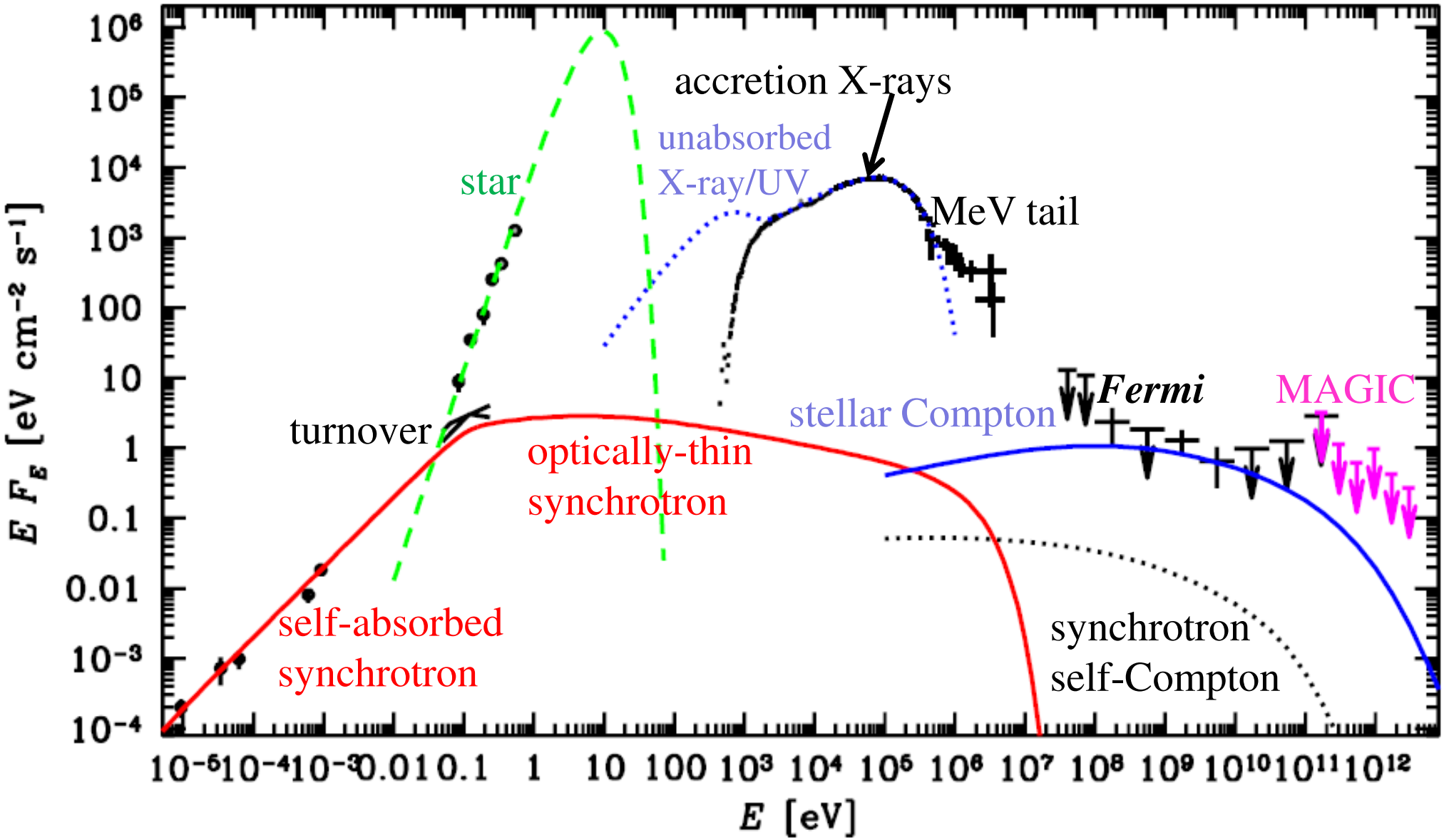
Z., Pjanka & Sikora 2013

A model reproducing the MeV tail (claimed to be polarized).



The acceleration index $p = 1.5$ (very hard), $B_0 = 5\times10^5$ G at the jet base of $z_0 = 240R_g$, extreme $(B^2/8\pi)/u_{gas} \sim 10^5$. The magnetic power $\approx 10^{36}$ erg/s.

A jet model, in which the MeV tail is from accretion.



The MeV tail in the hard state from hybrid Comptonization in the accretion flow. The acceleration index $p = 2.5$ (typical), $B_0 \approx 10^4$ G at the jet base of $z_0 \approx 800R_g$, equipartition of $(B^2/8\pi)/u_{gas} \sim 1$. The *Fermi* spectrum fitted.

Conclusions

- **Hard state**:
- A 4σ detection of Cyg X-1 in the hard state by *Fermi*.
- They rule out some purely non-thermal hot-flow models.
- Strong constraints on accretion models with pion production.
- The *Fermi* data can be fitted by jet models, the dominant emission from Compton upscattering of stellar blackbody.
- **Soft state**:
- Low upper limits at 30 MeV–300 GeV from *Fermi*.
- The upper limits constrain the size of a hot coronal region in accretion models to ~$20R_g$.