Interacting pulsar winds in high-mass binaries

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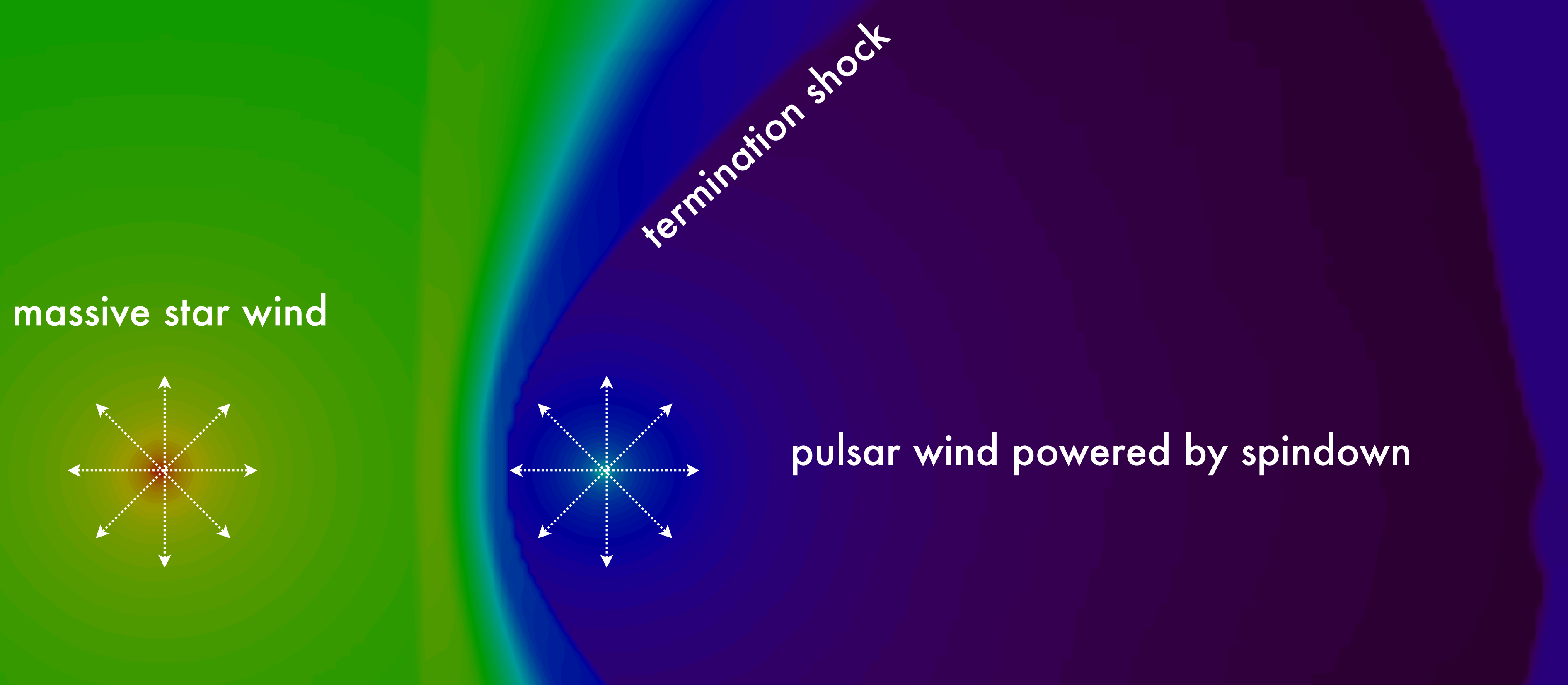
Emission powered by spindown of a pulsar

Ram pressure equilibrium between pulsar wind and stellar wind gives rise to small-scale pulsar wind nebula with a bow shock structure, set by

$$\eta = \frac{\dot{E}/c}{\dot{M} v_{\rm w}}$$



Termination shock is close to pulsar, about 10^4 R_{LC}

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High-mass gamma-ray binaries

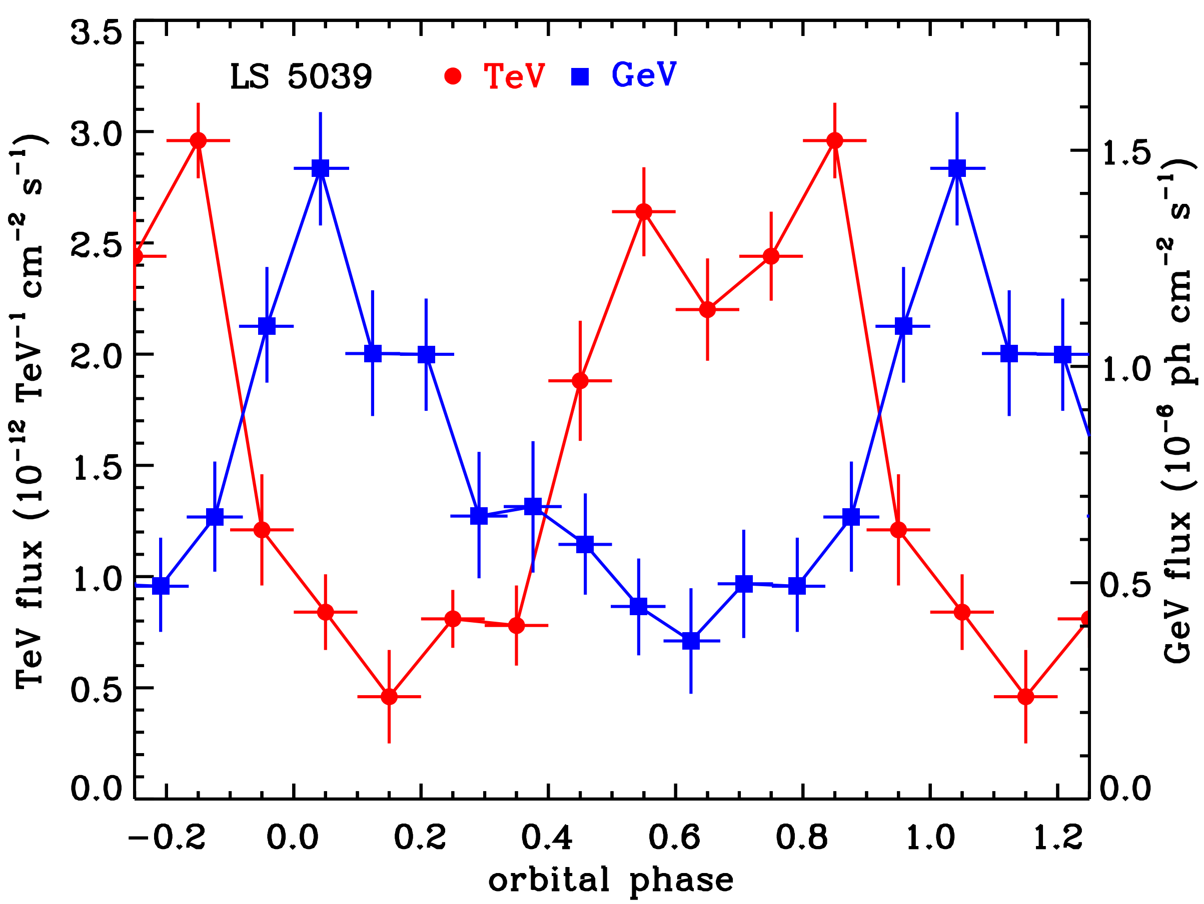
Sources of non-thermal emission up to GeV and TeV gamma-rays

system	star	radio pulsar	P_{orb} (days)	HE or VHE gamma-rays ?
PSR B1259-63	Be	yes	1237	yes
LS 5039	O	?	3.9	yes
LS I +61 303	Be	(?)	26.5	yes
HESS J0632+057	Be	?	320	yes
1FGL J1018.6-5856	O	?	16.6	yes

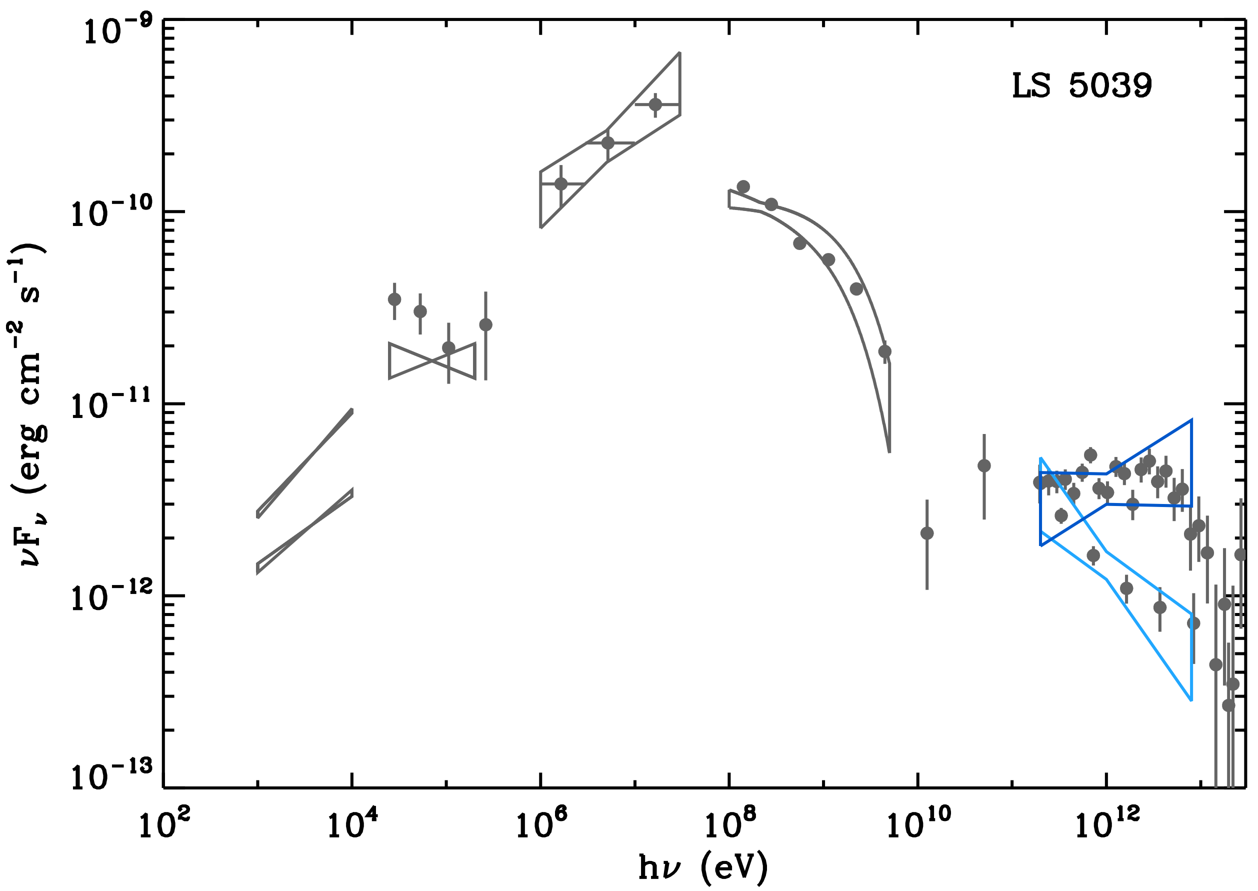
(*) there are also **low-mass** gamma-ray binaries (tomorrow)

Well-established phenomenology in LS 5039

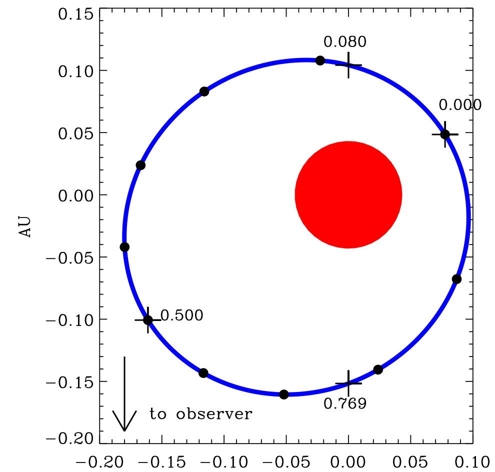
orbital modulation



spectrum



Good constrains on 3.9 day orbit



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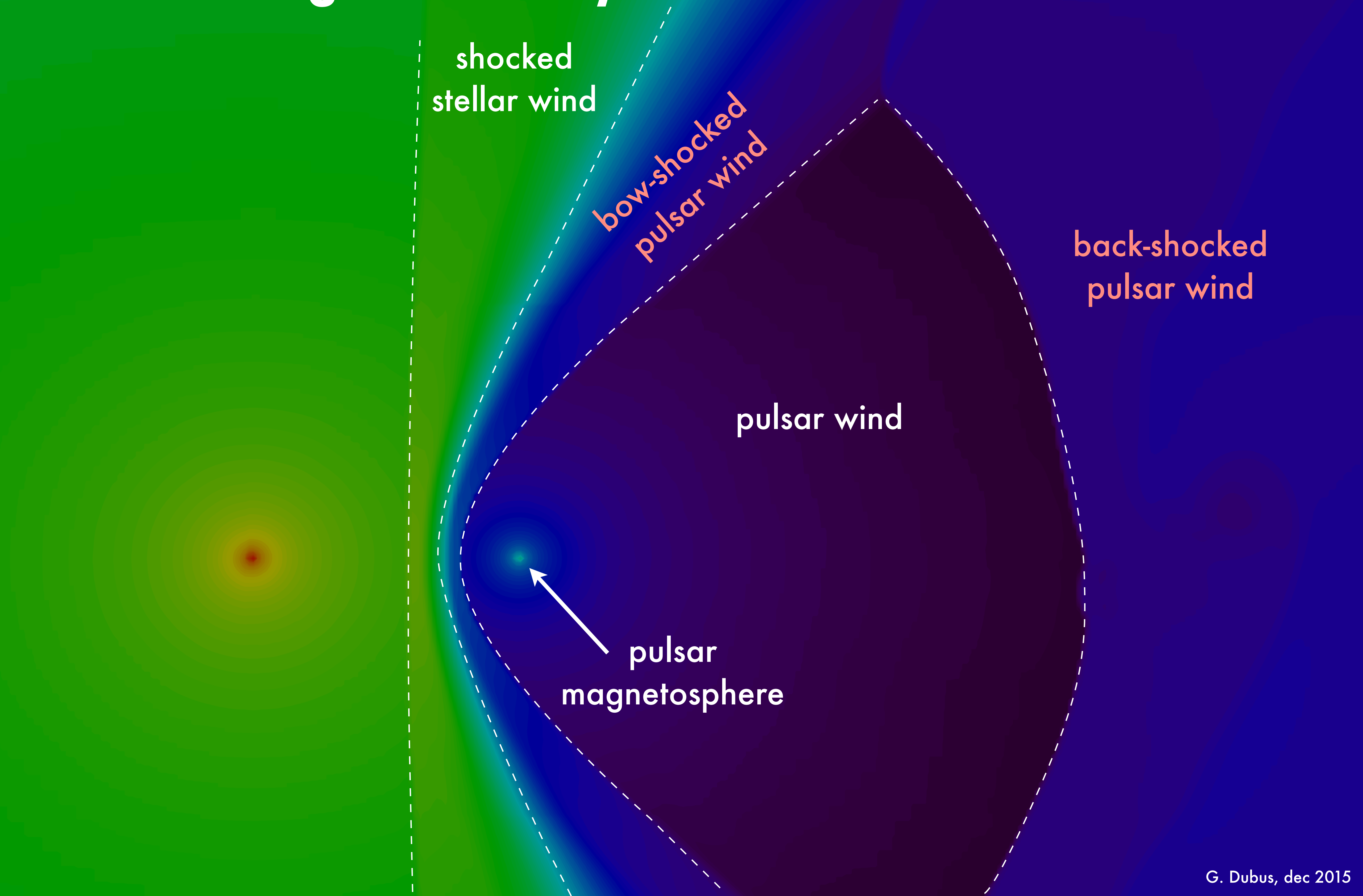
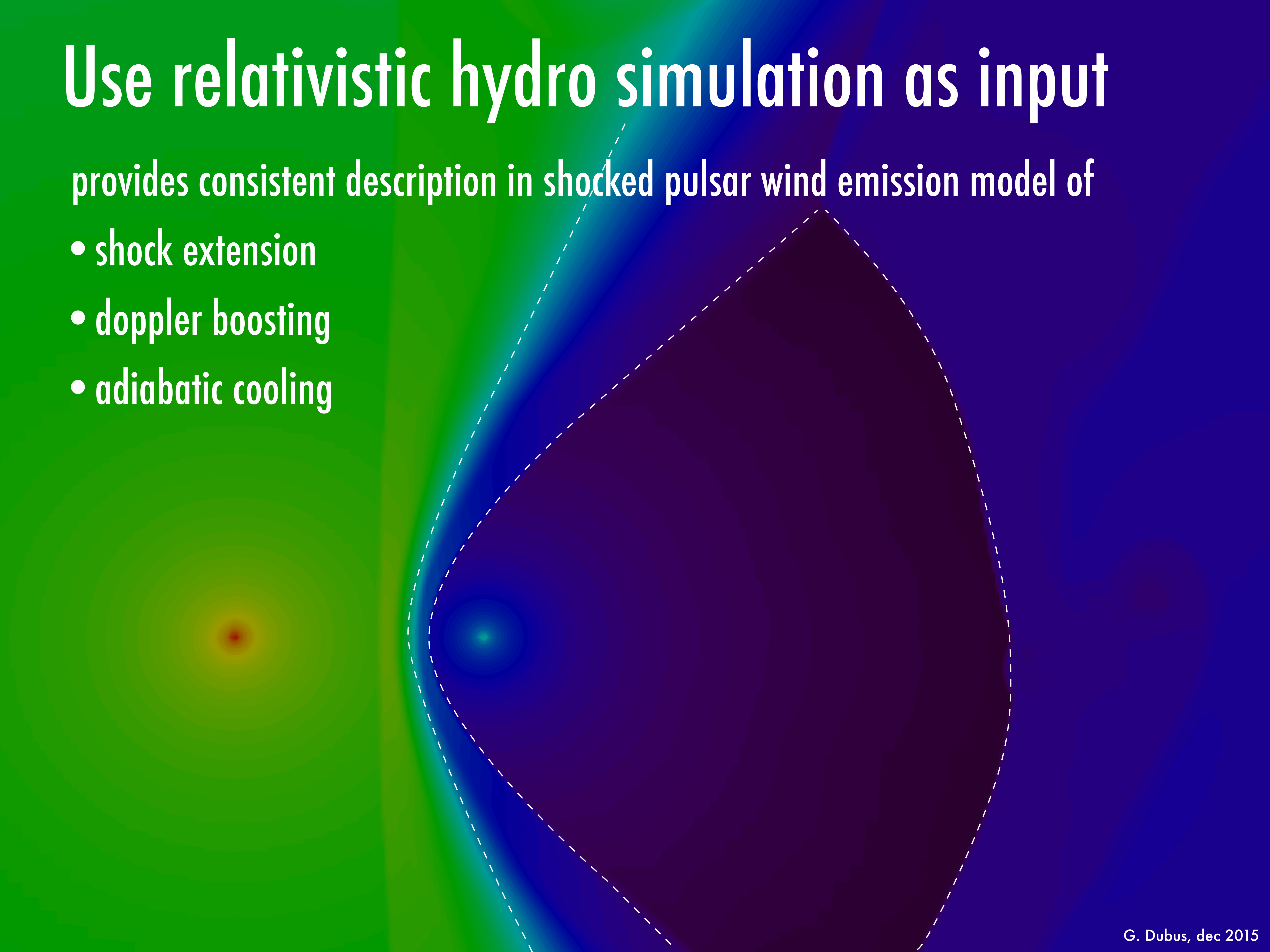
Possible gamma-ray emission sites



Use relativistic hydro simulation as input

provides consistent description in shocked pulsar wind emission model of

- shock extension
- doppler boosting
- adiabatic cooling



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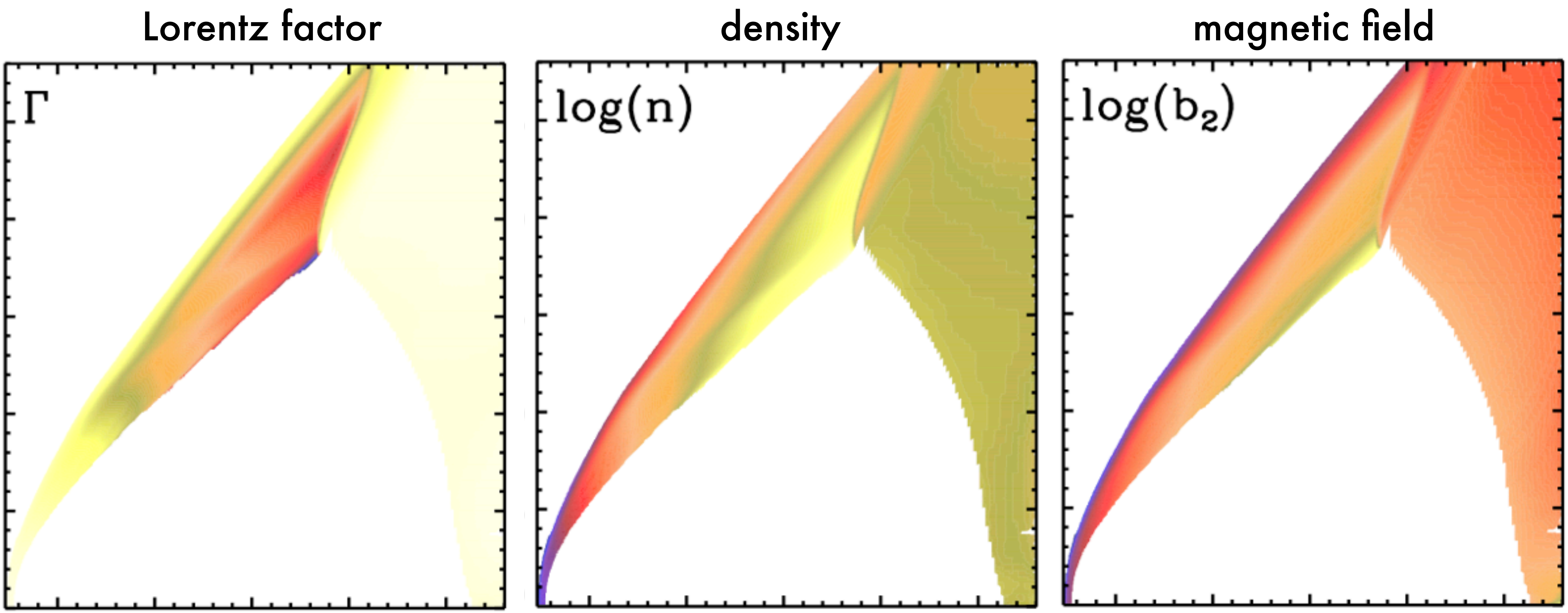
Conditions in the shocked pulsar wind

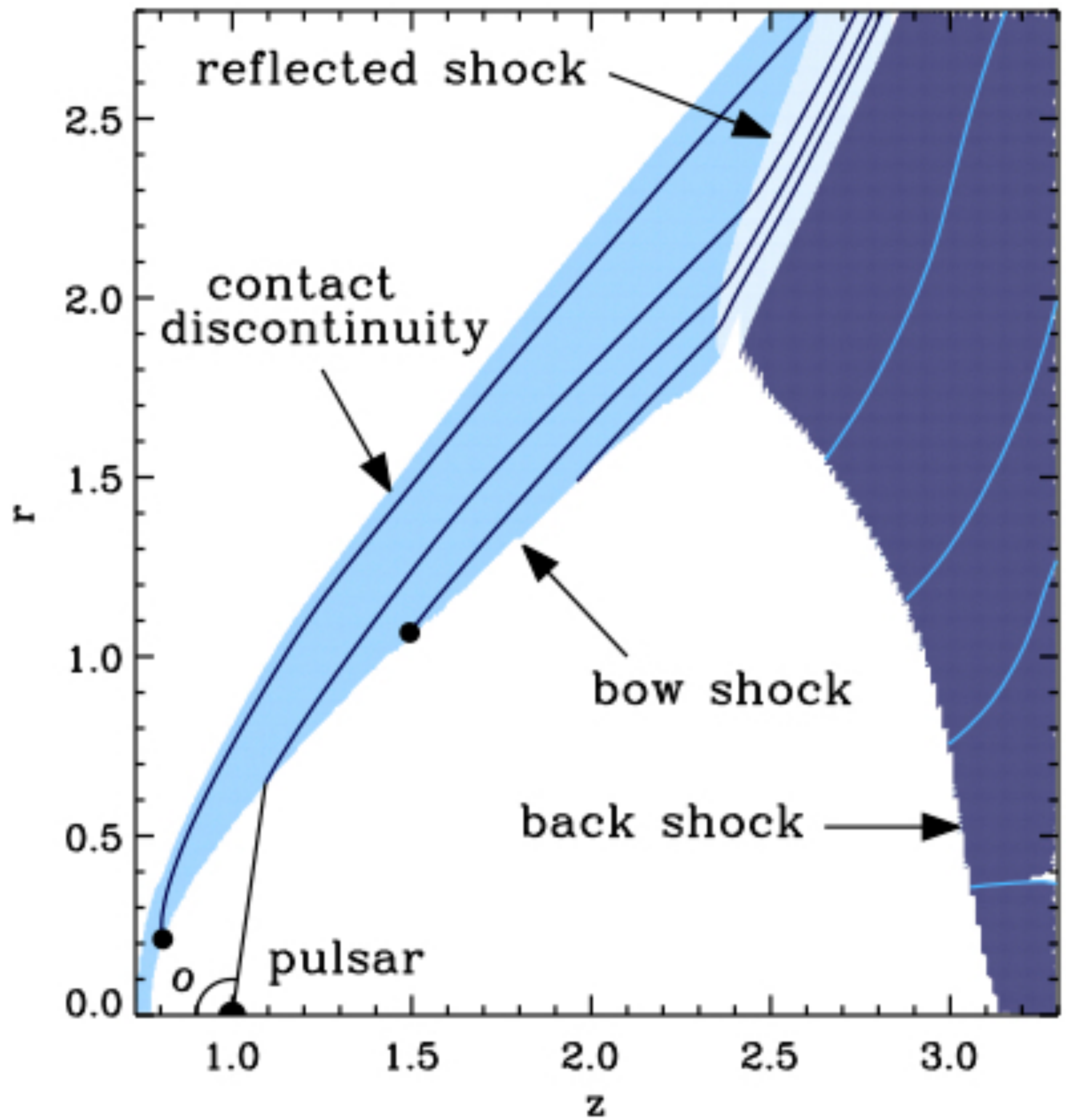


$B \sim 1/d_p$ at shock (assumed perpendicular)

Field is passive so induction equation $\Rightarrow B \sim \Gamma n r$

see Lamberts et al. 2013 and Dubus et al. 2015 for code & setup

Particle evolution in a post-processing step



in units of orbital separation

1- inject particles at shock

four global parameters:

- power-law slope
- acceleration timescale (E_{max})
- pulsar power (E_{min})
- magnetisation (B)

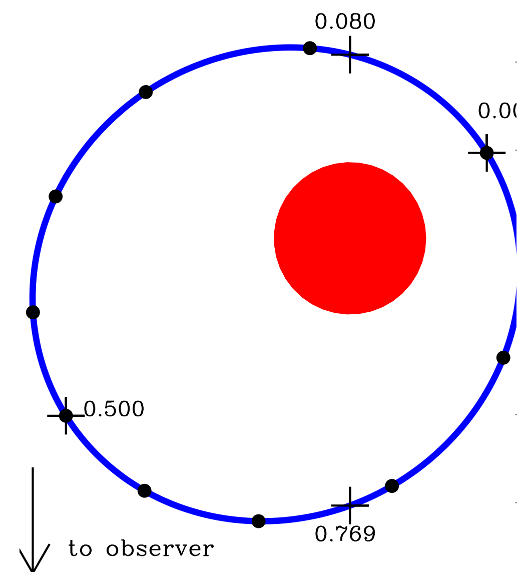
2- evolve along streamlines with radiative & adiabatic cooling.

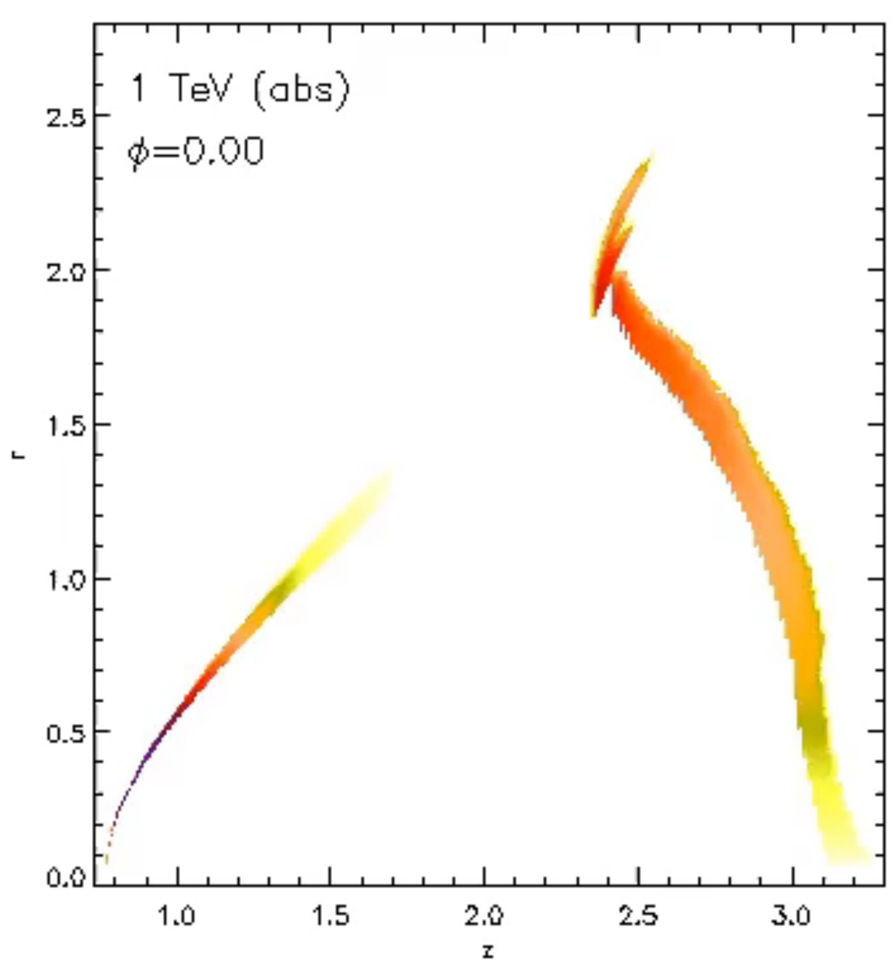
3D calculation for particle emission

- Synchrotron and inverse Compton emission

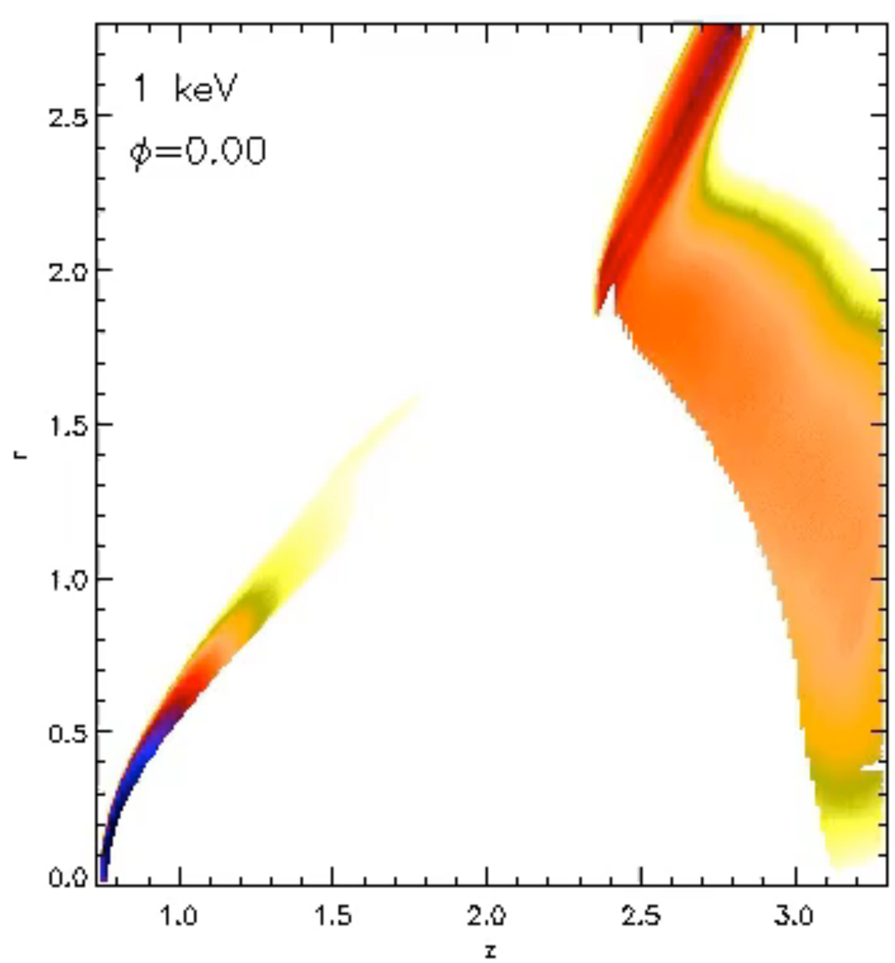
  eccentric orbit, relativistic effects, anisotropic scattering & pair production on stellar photons

- phase-dependent spectra & orbital modulation





in units of orbital separation



in units of orbital separation

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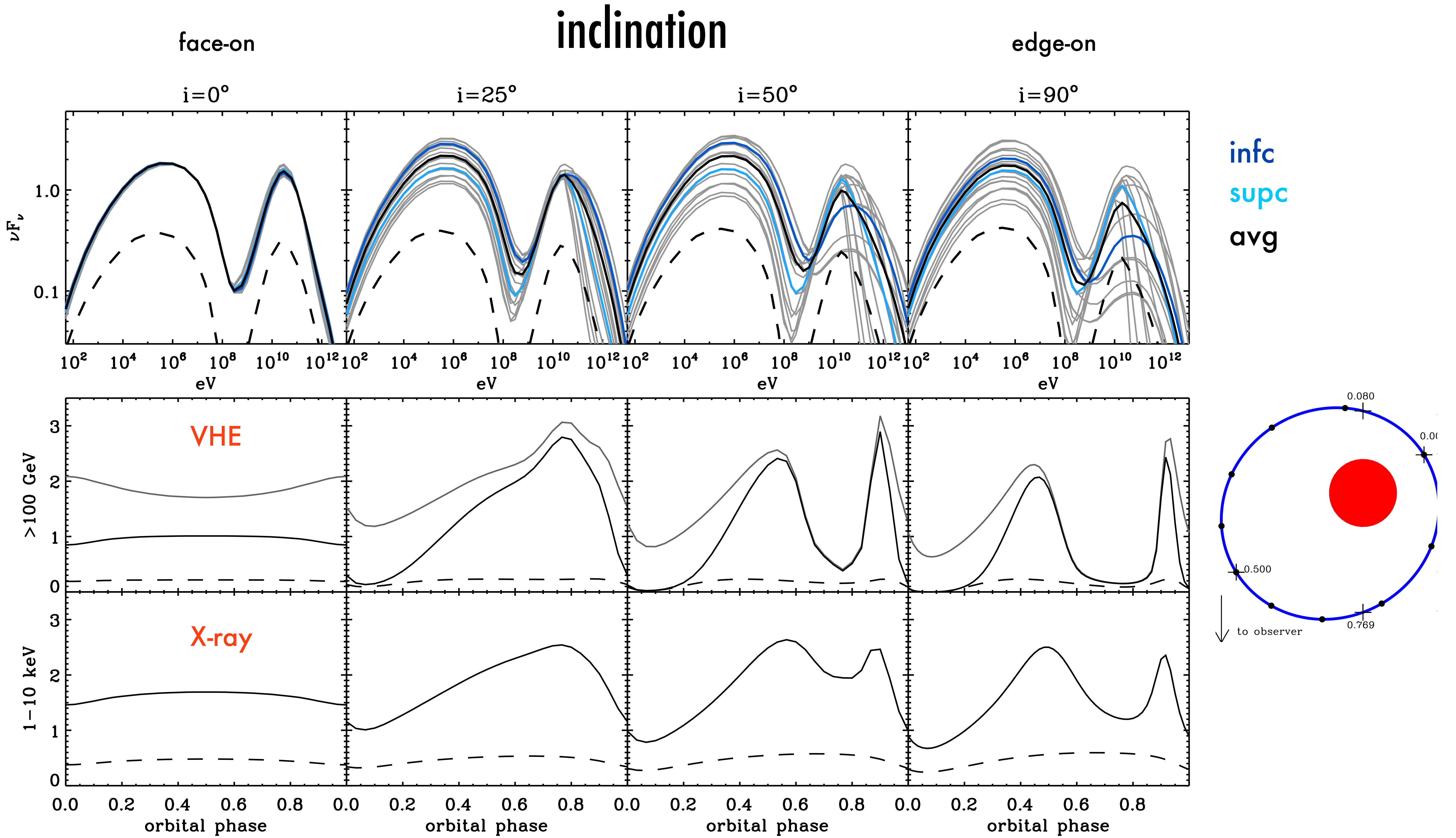
Doppler boosting shapes the modulation



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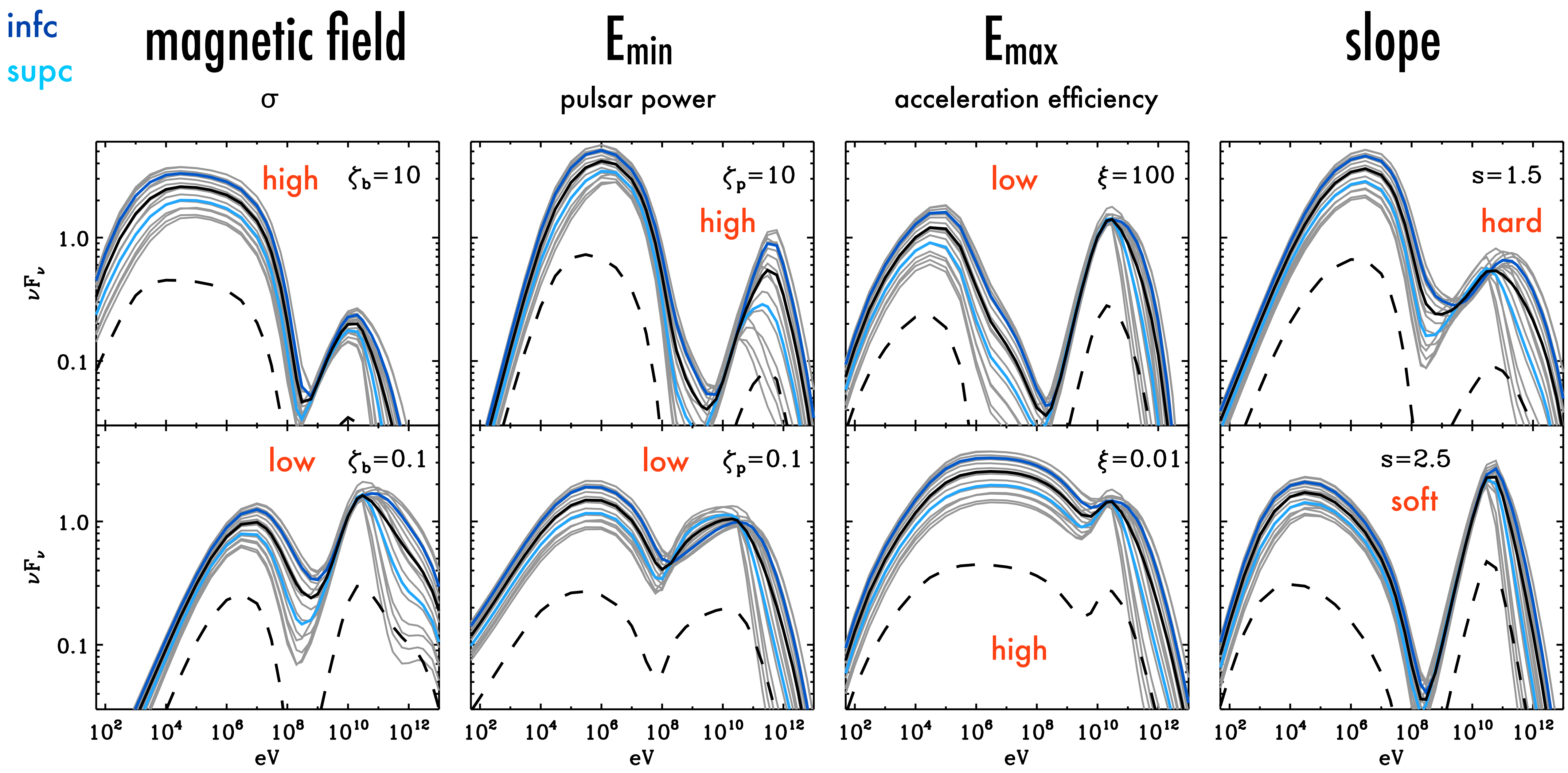
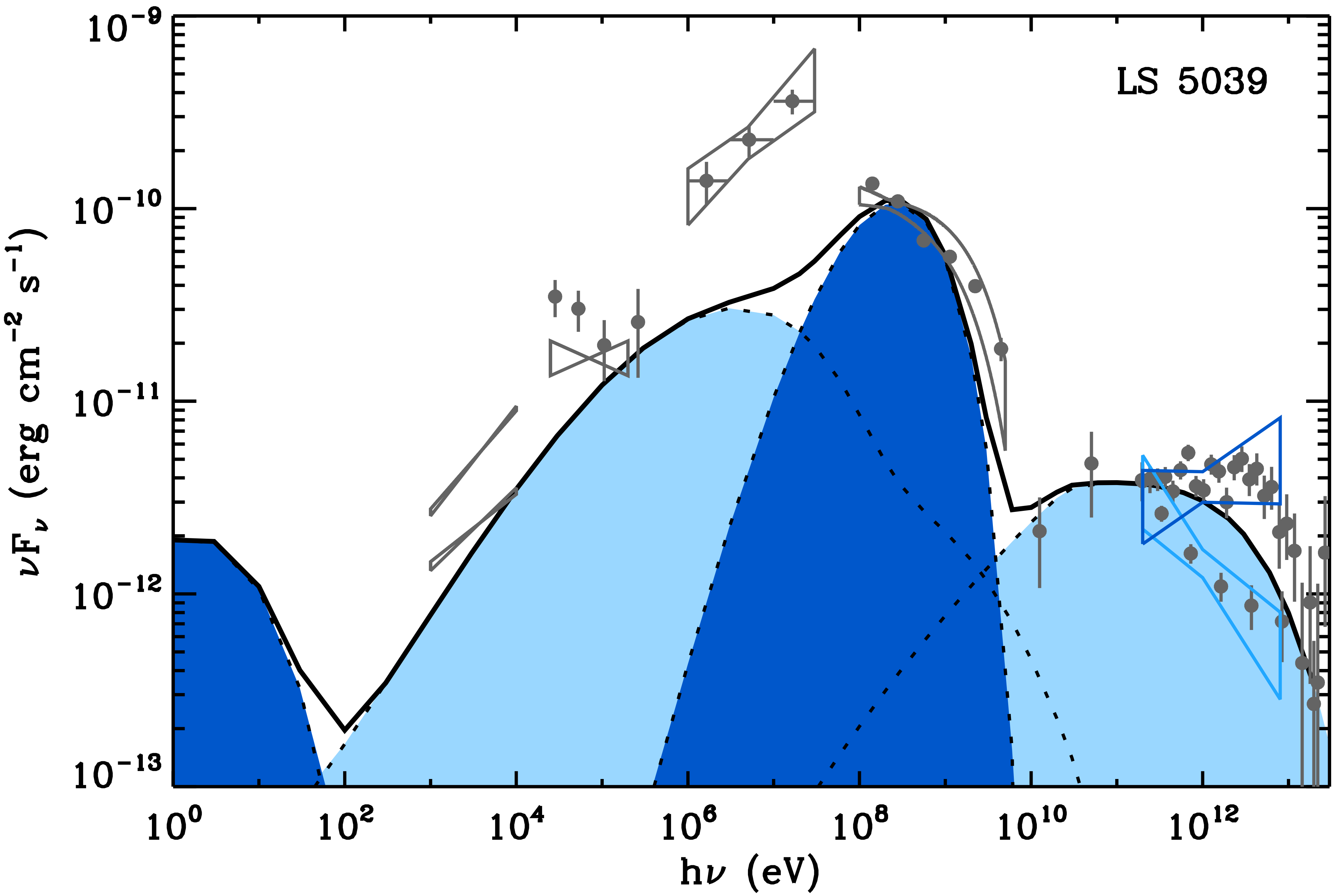
Influence of particle injection parameters



Tough to reproduce hard VHE spectrum + level of X-ray emission in LS 5039

LS 5039 requires two particle populations

Power-law with hard slope $E^{-1.5}$ + Maxwellian with $\Gamma \approx 5000$



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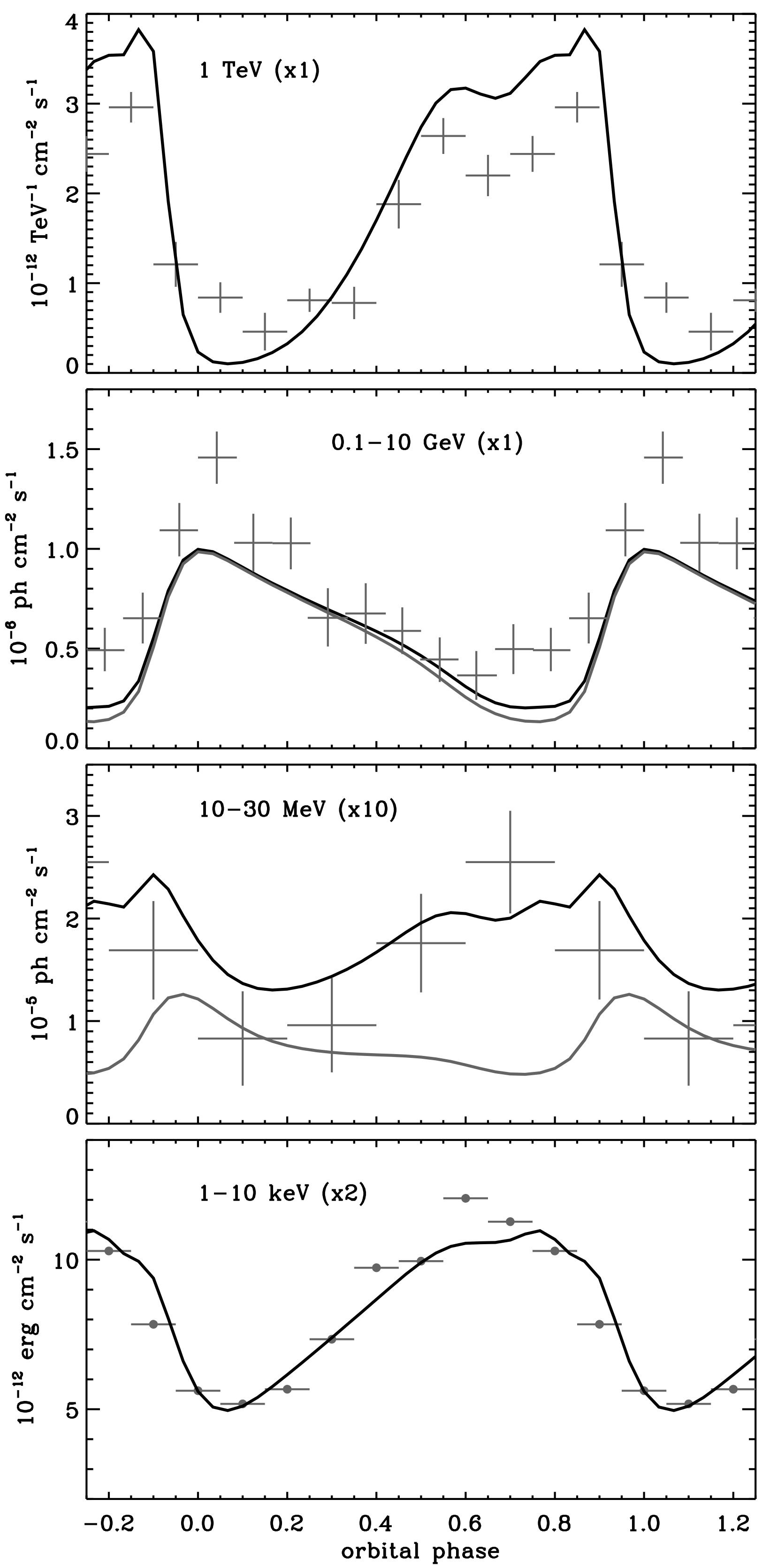
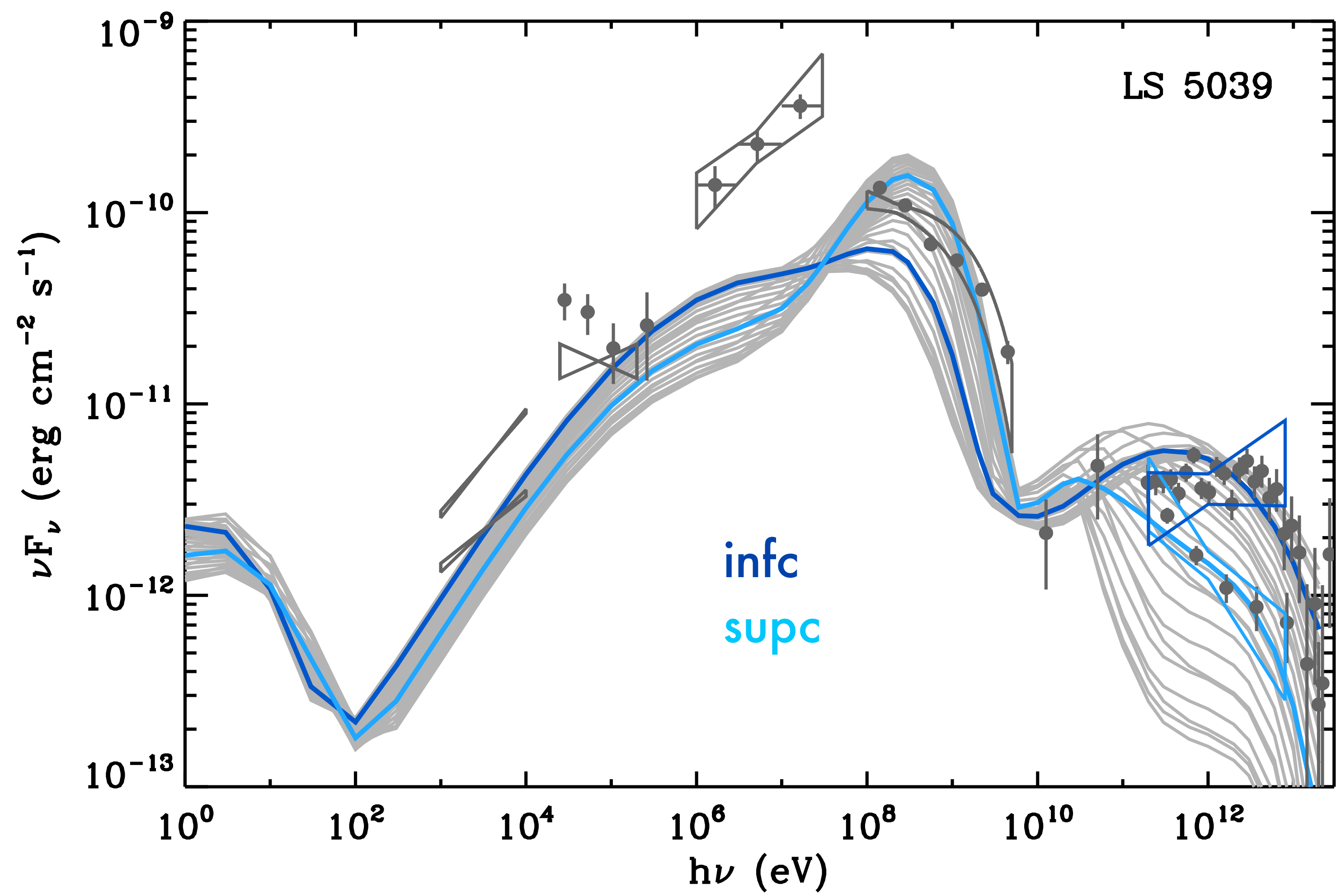
Orbital variability in reasonable agreement





modulation set by Doppler boost ⇒ $i \approx 35^o$

(for assumed η=0.1)

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First RHD-based model of LS 5039's emission

- emission concentrated at head of bow shock
- modulation mostly due to Doppler boosting
- power-law is radiatively-efficient, adiabatic cooling negligible
- maxwellian carries most of the energy but radiatively-inefficient

- particle acceleration extremely fast (Bohm)
- hard power-law, pulsar wind magnetisation $<\sigma>\approx 1$
- shock-driven reconnection in gamma-ray binaries ?

requires (Sironi & Spitkovsky 2011)

$$\kappa\frac{R_{\rm lc}}{R_{\rm ts}}\geq 1$$ easier in binaries !

Dubus, Lamberts, Fromang 2015, A&A, 581, A27