

Variability of non-thermal emission
from SNRs induced by reflected
shocks

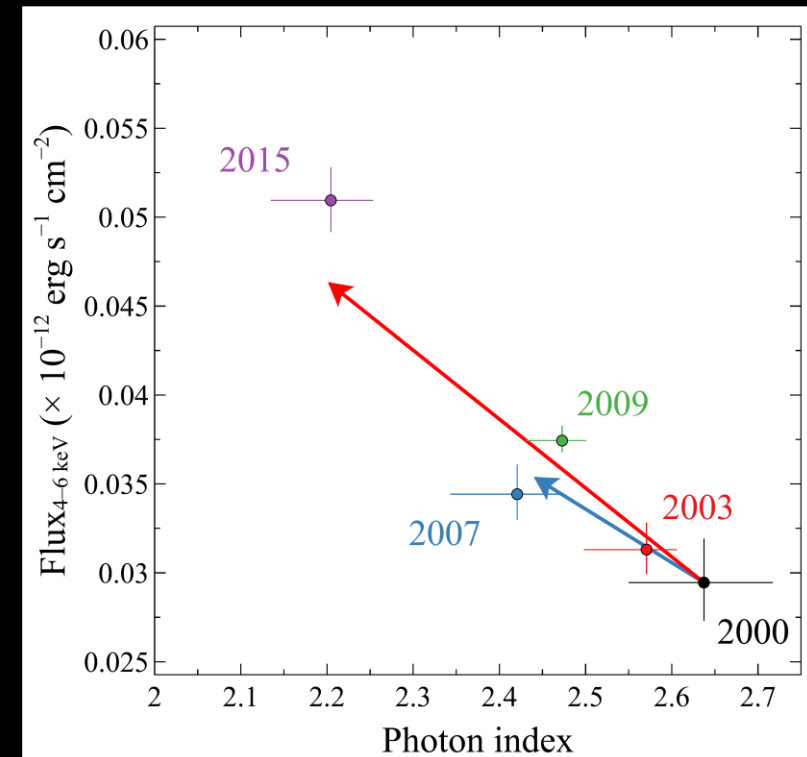
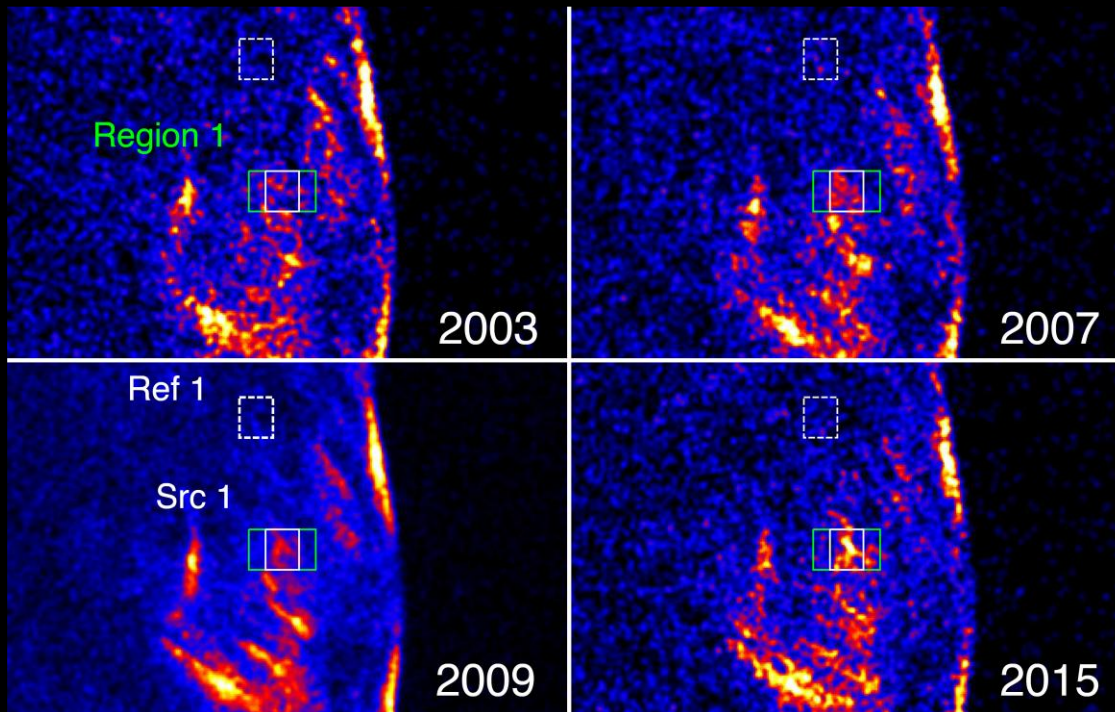
Iurii Sushch

Robert Brose

Variability in SNRs

Localized X-ray variability in the Tycho SNR

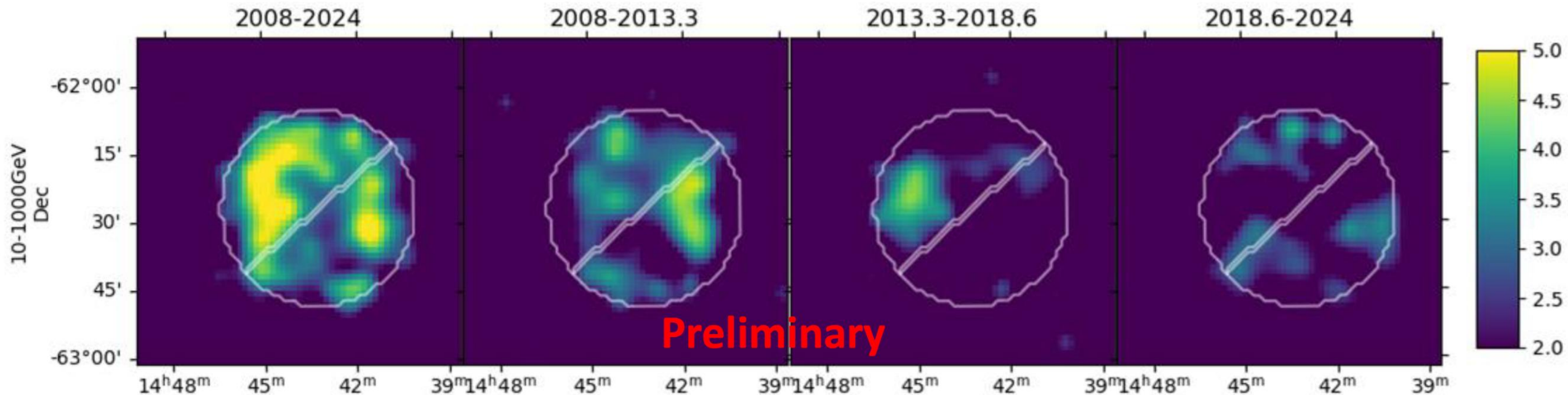
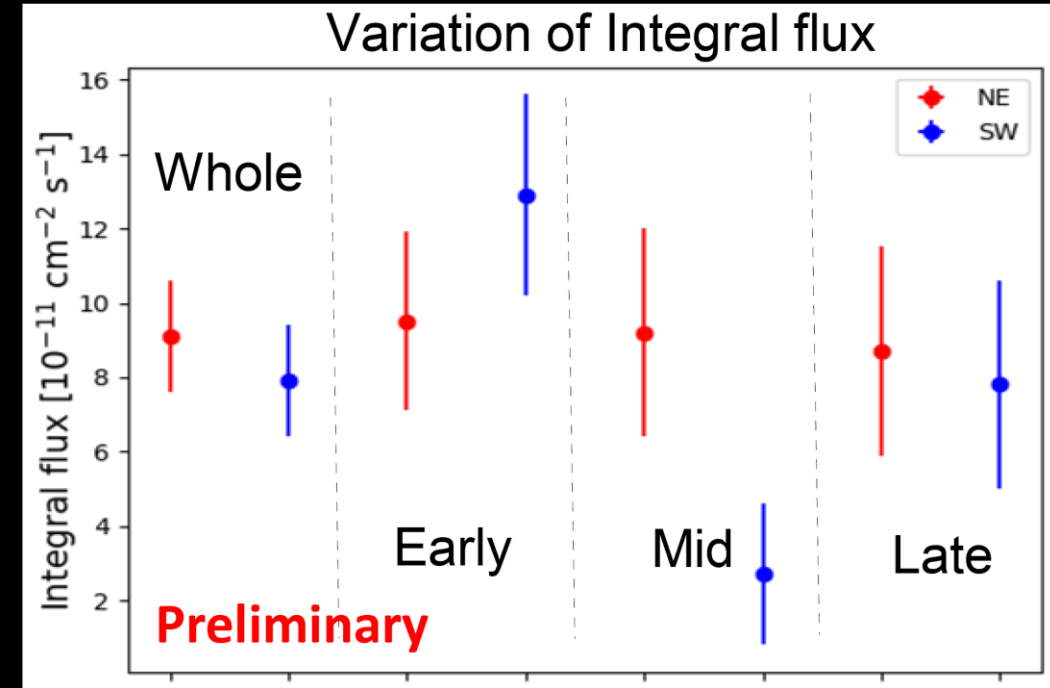
70% brightening over 12 years accompanied by the significant hardening of the spectrum.
(Okuno et al. 2020)



Variability in SNRs

See the poster by
Robert Brose

Hints of gamma-ray variability of RCW 86
as observed by Fermi-LAT



Reflected shock

Forward shock

Contact discontinuity

Reverse shock

Dense stuff

Reflected shock

Dense stuff



Reflected shock



The diagram illustrates a reflected shock wave. A solid yellow arc represents the incident shock wave moving from left to right. A dashed yellow arc represents the reflected shock wave moving from left to right, reflecting off a horizontal surface at the bottom. A blue cloud-like shape labeled 'Dense stuff' is positioned to the right of the shock waves. A vertical blue line is located to the left of the 'Reflected shock' text.

Dense stuff

Reflected shock

Dense stuff

Reflected shock

Reflected shock

Dense stuff



The diagram illustrates a shock wave phenomenon. A large, irregular blue cloud is labeled "Dense stuff". A dashed yellow line, representing a shock wave, originates from the top left, passes through the cloud, and reflects off its surface. A solid yellow arc is positioned below the dashed line. A pink squiggly line is drawn within the cloud. The text "Reflected shock" is located near the top left dashed line, and "Dense stuff" is centered within the blue cloud.

Reflected shock

Dense stuff

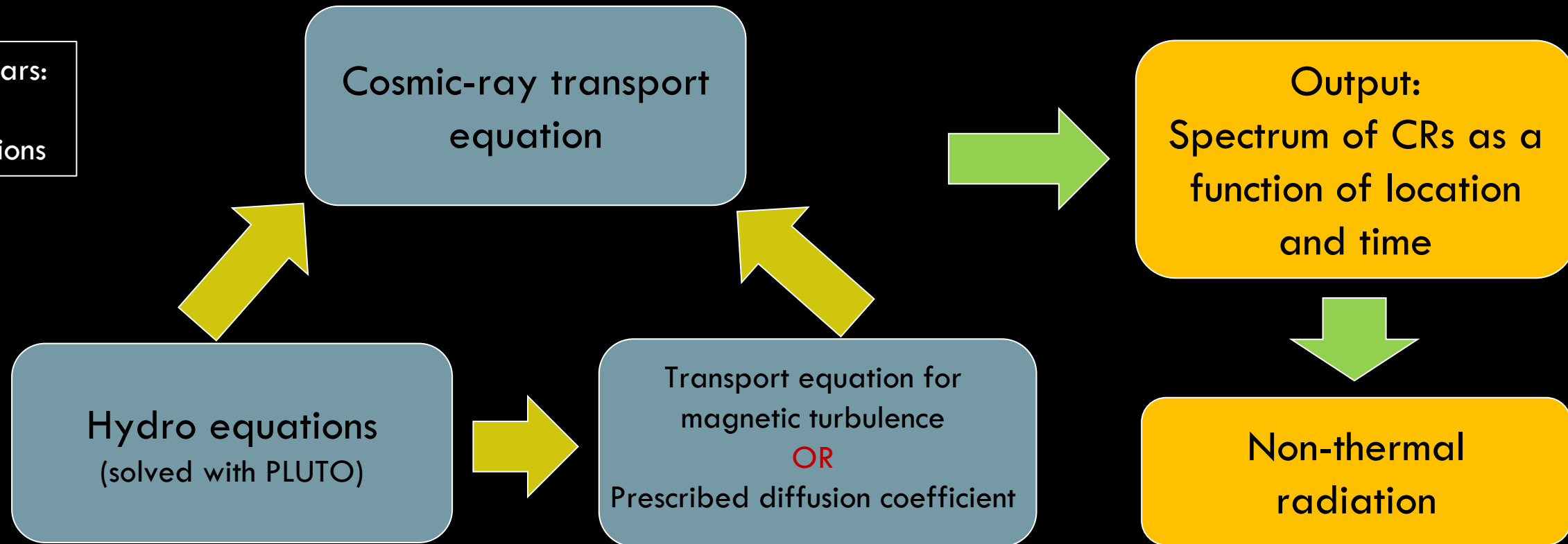
RATPaC

Radiation Acceleration Transport Parallel Code

See also talks:
Robert Brose on 03.11
Qiqi Jiang on 04.11



In last 5 years:
13 papers
>170 citations



Wind bubble

Setup motivated by
previous work:
Sushch et al. 2022

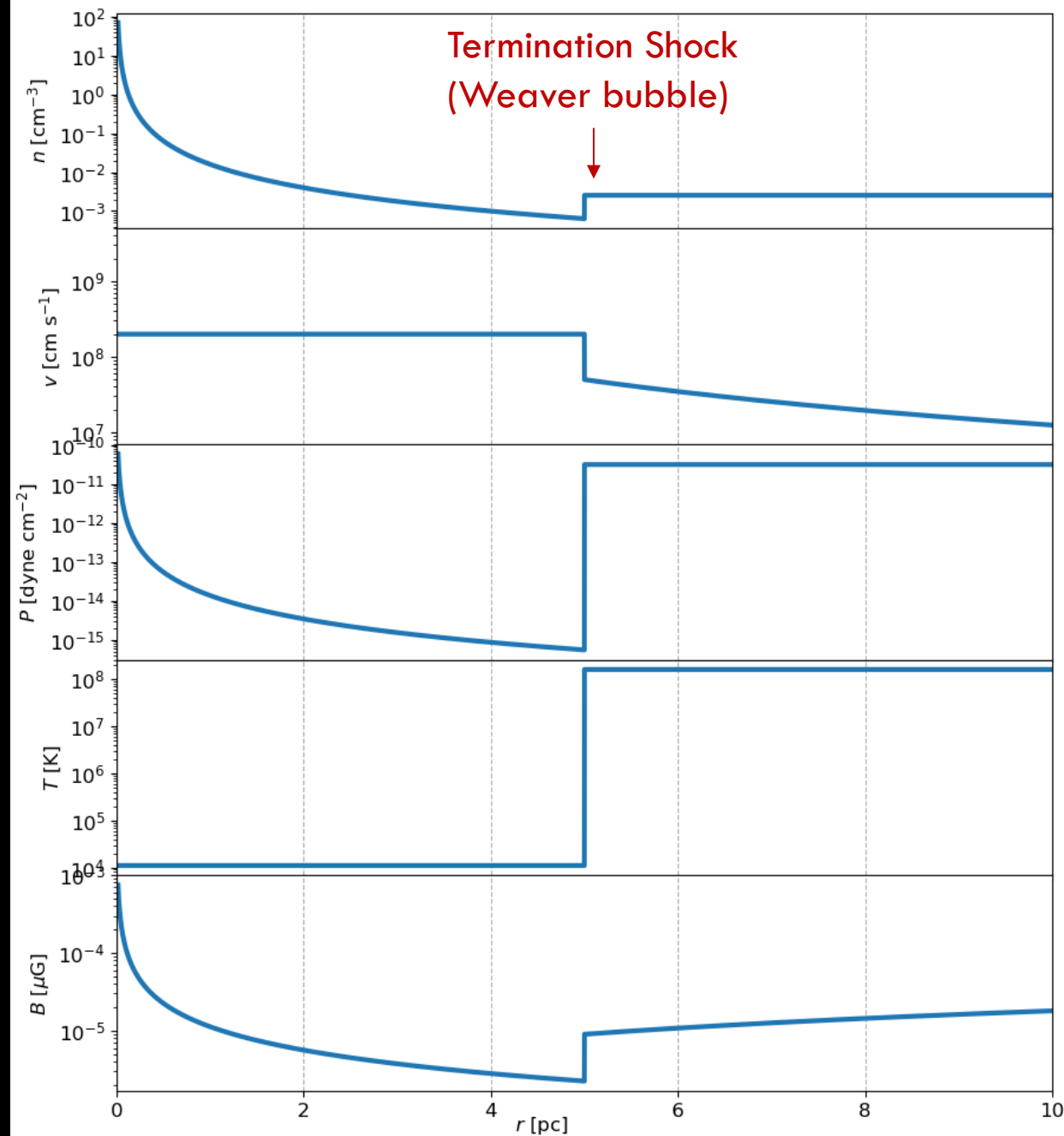
Wolf-Rayet wind:

- $\dot{M} = 10^{-5} M_{\odot}/\text{year}$
- $v_w = 2 \times 10^8 \text{ cm/s}$

Magnetic field:

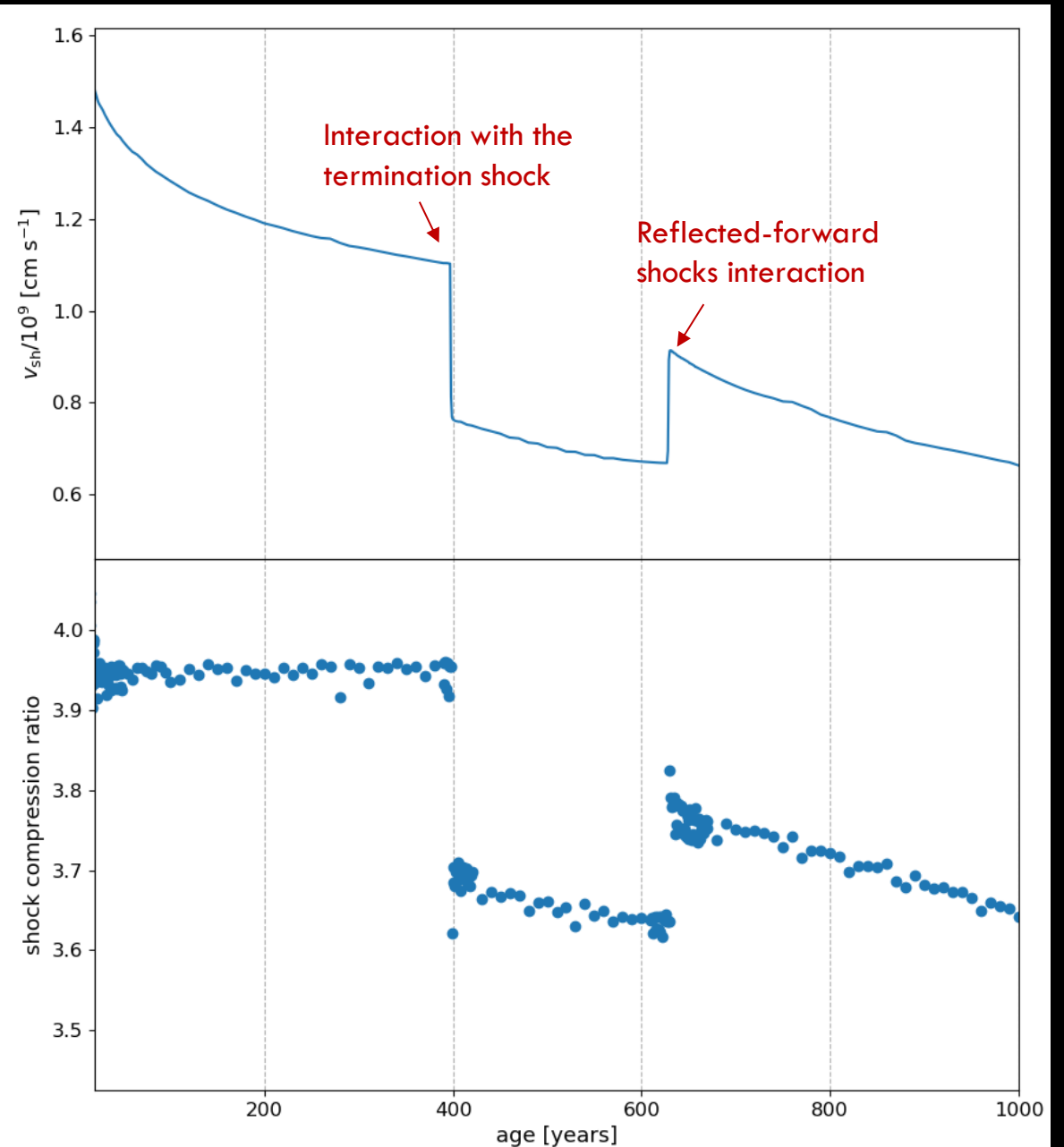
$$\begin{cases} B_0 \frac{R_*}{r}, r \leq R_{TS} \\ 4B_0 \frac{R_*}{R_{TS}} \frac{r}{R_{TS}}, R_{TS} < r < R_b \end{cases}$$

$B_0 = 50 \text{ G}; B_{TS} = 9 \mu\text{G}$



Shock evolution

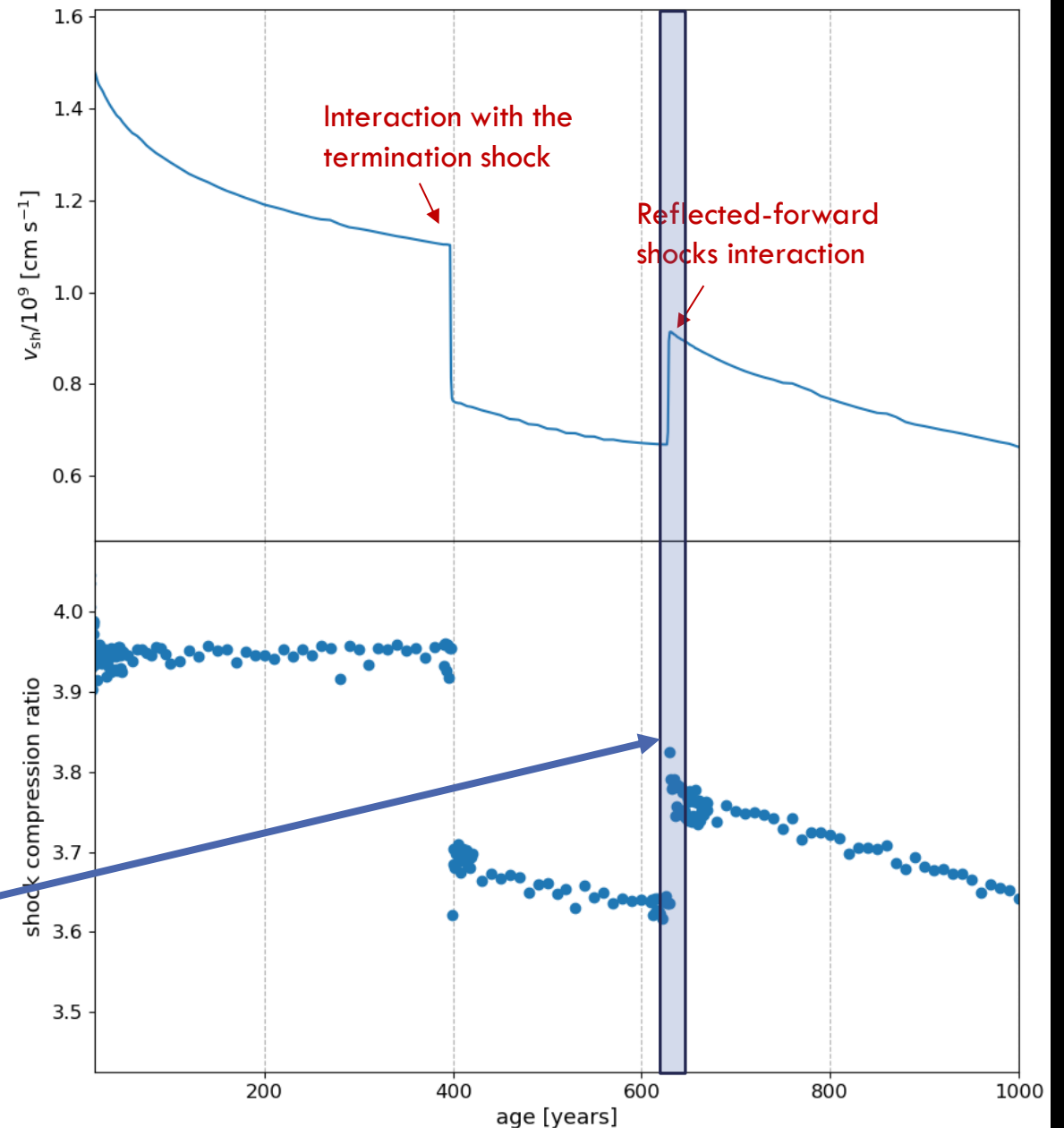
- Significant weakening of the shock in the hot medium downstream of the termination shock
- Interaction of the reflected shock with forward shock accelerates the latter



Shock evolution

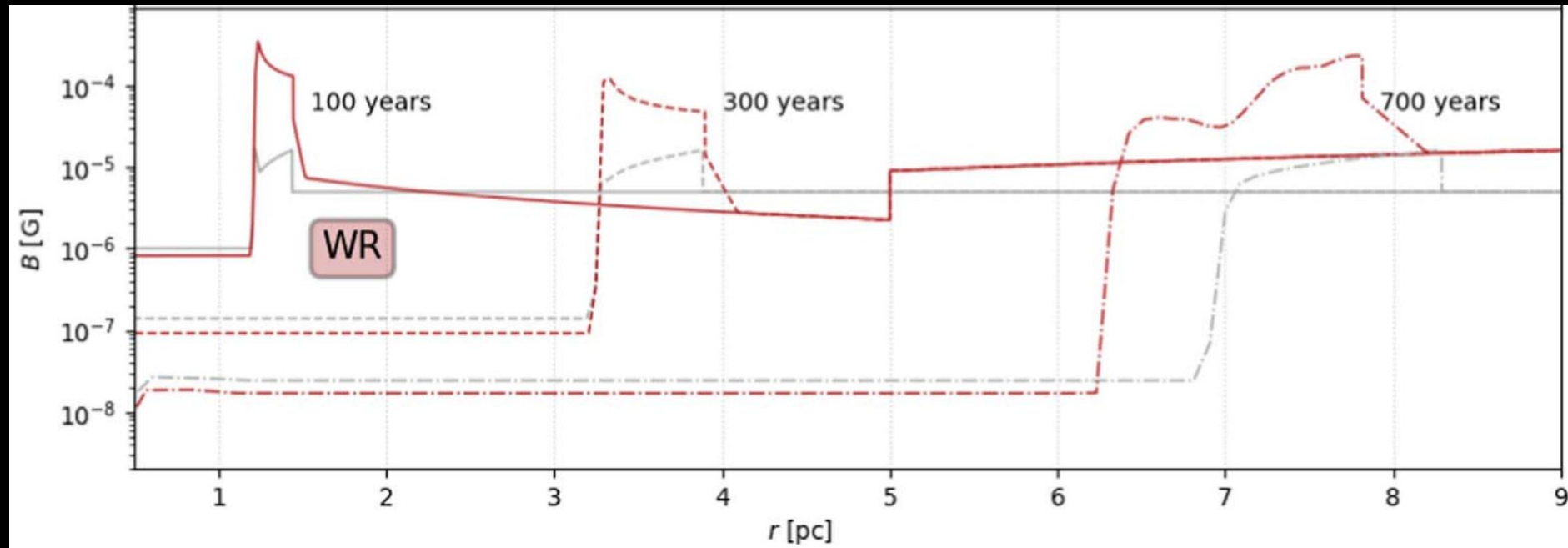
- Significant weakening of the shock in the hot medium downstream of the termination shock
- Interaction of the reflected shock with forward shock accelerates the latter

We focus on a short time window around shock-shock interaction event



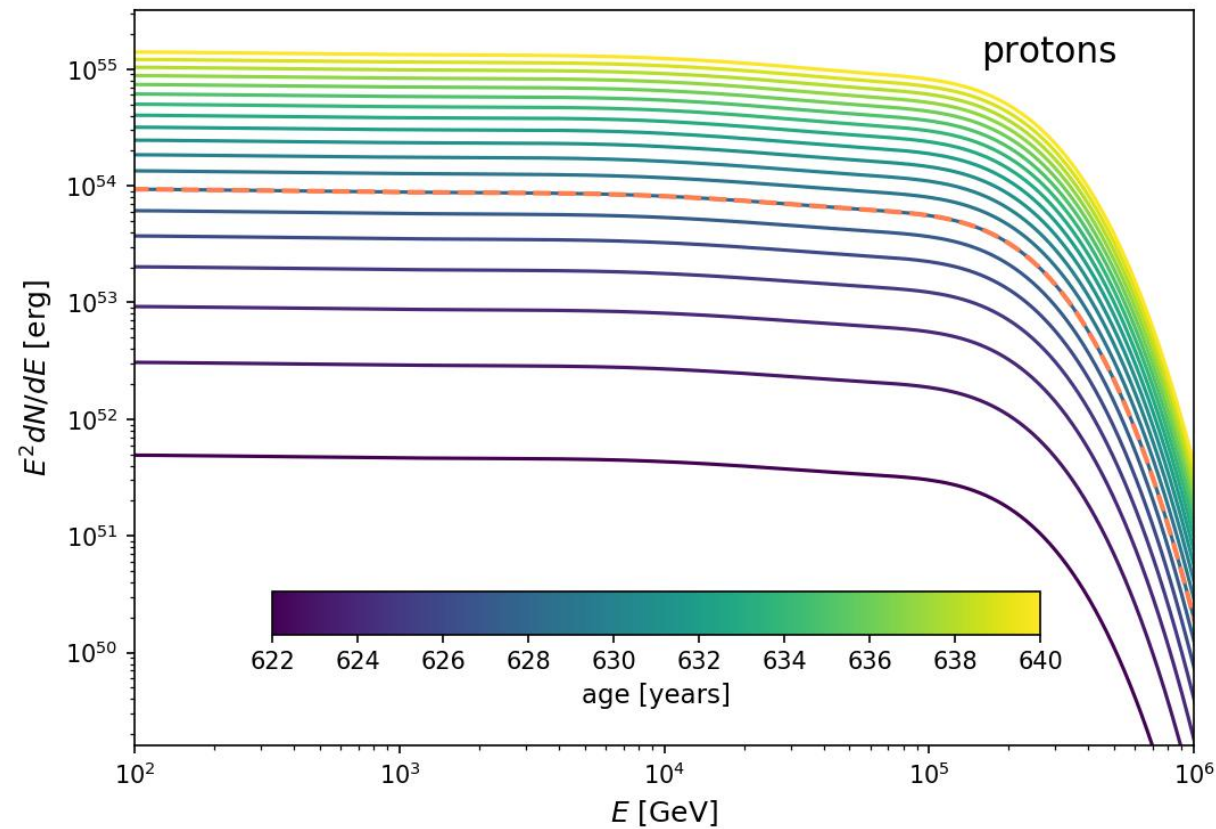
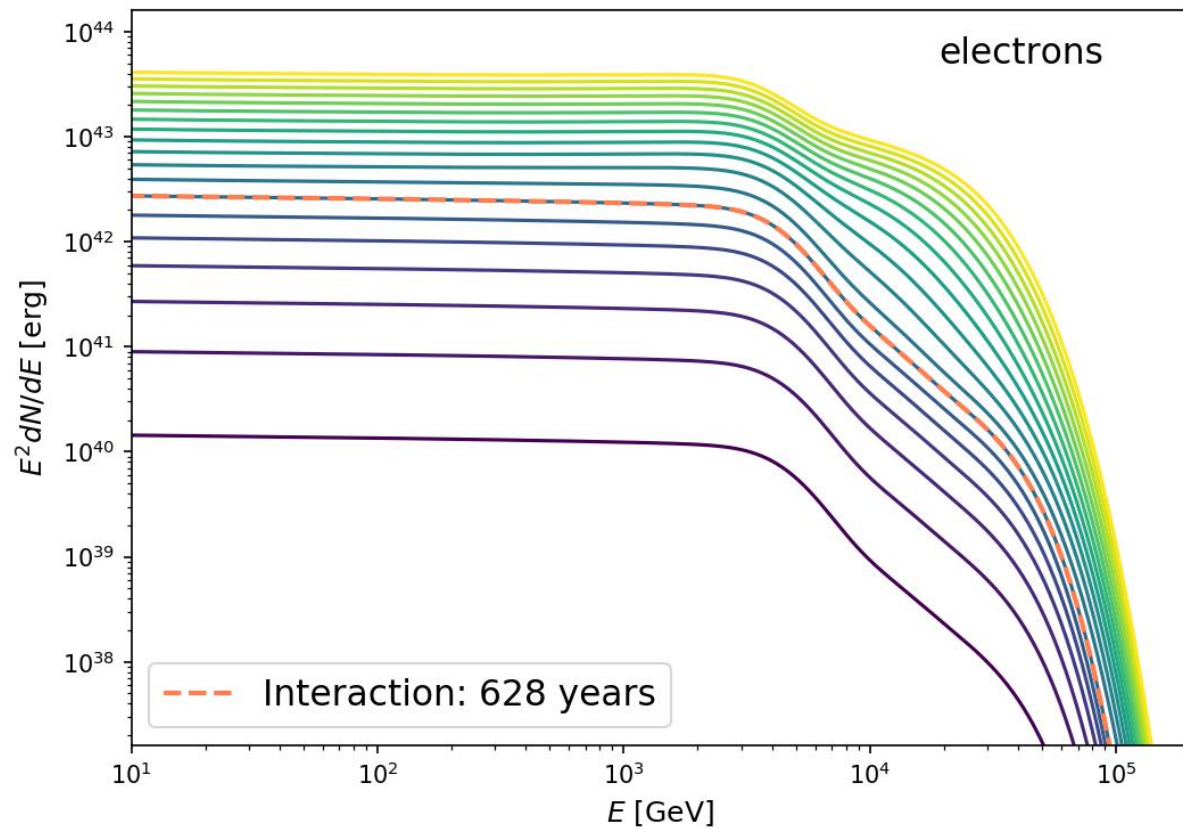
Magnetic field amplification and diffusion

- Magnetic field amplified by a factor of 5 at the shock
- Bohm diffusion $D = \eta_B \frac{pc^2}{3eB}$

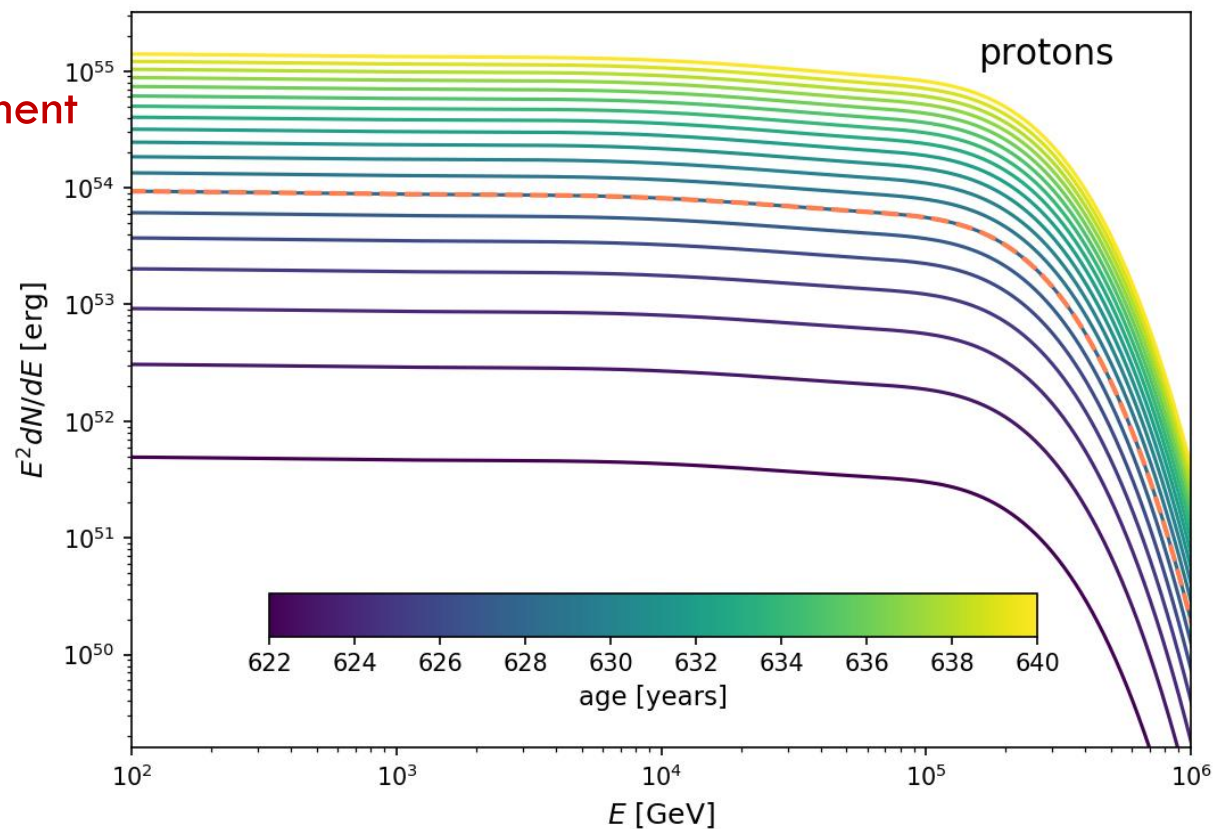
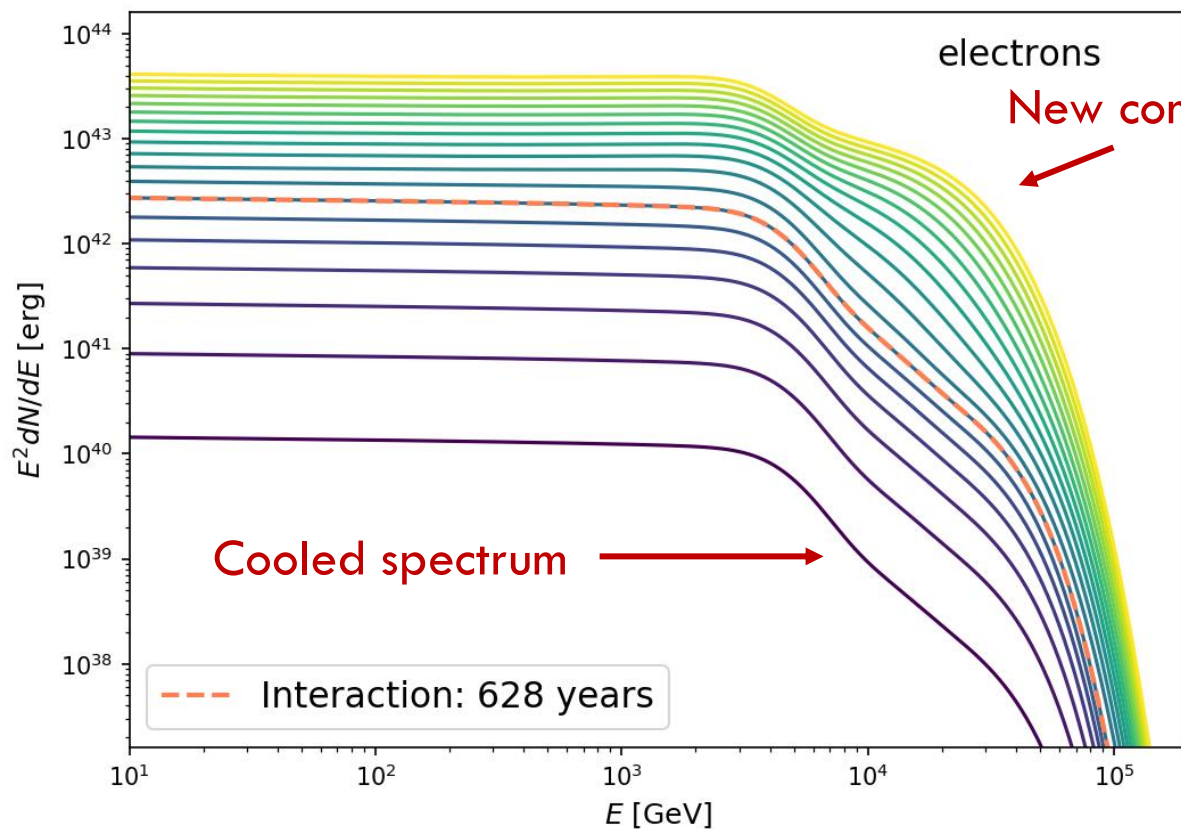


Sushch et al. 2022

Electron and proton spectra

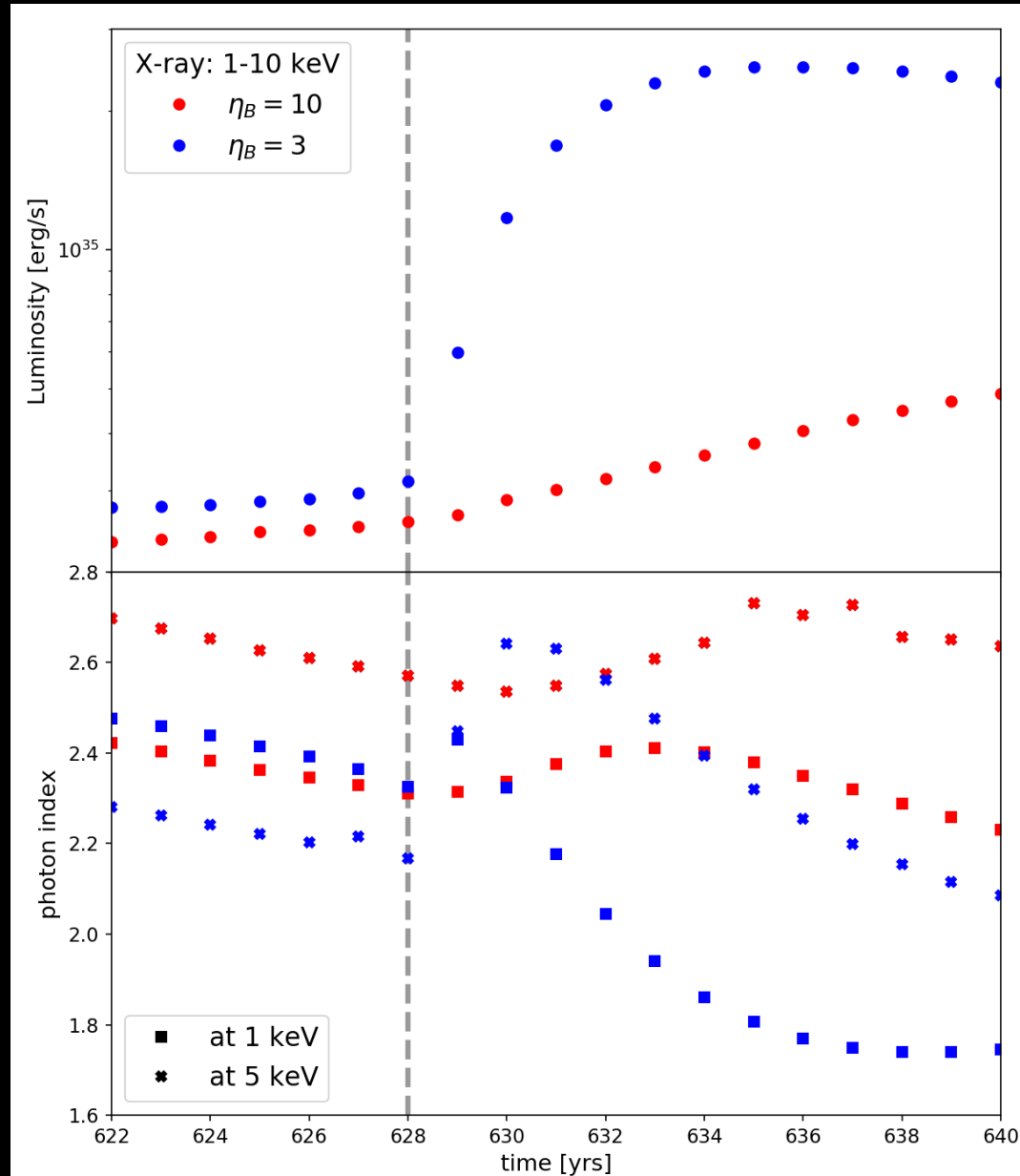


Electron and proton spectra



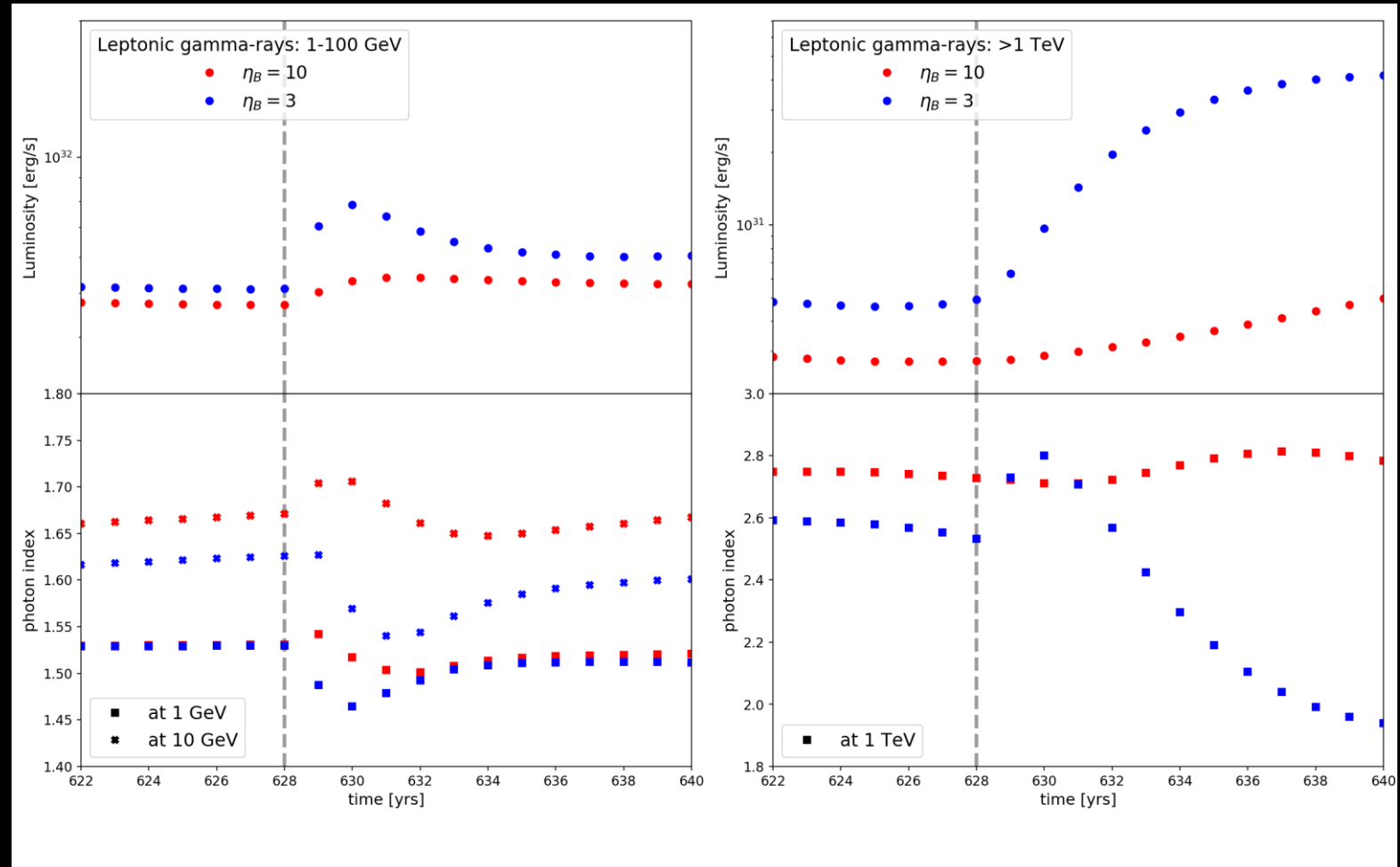
X-ray radiation

- very significant increase of the X-ray emission if the acceleration is efficient
- after interaction spectrum first softens and then starts hardening. This time delay is essentially a measure of acceleration time to the right energies



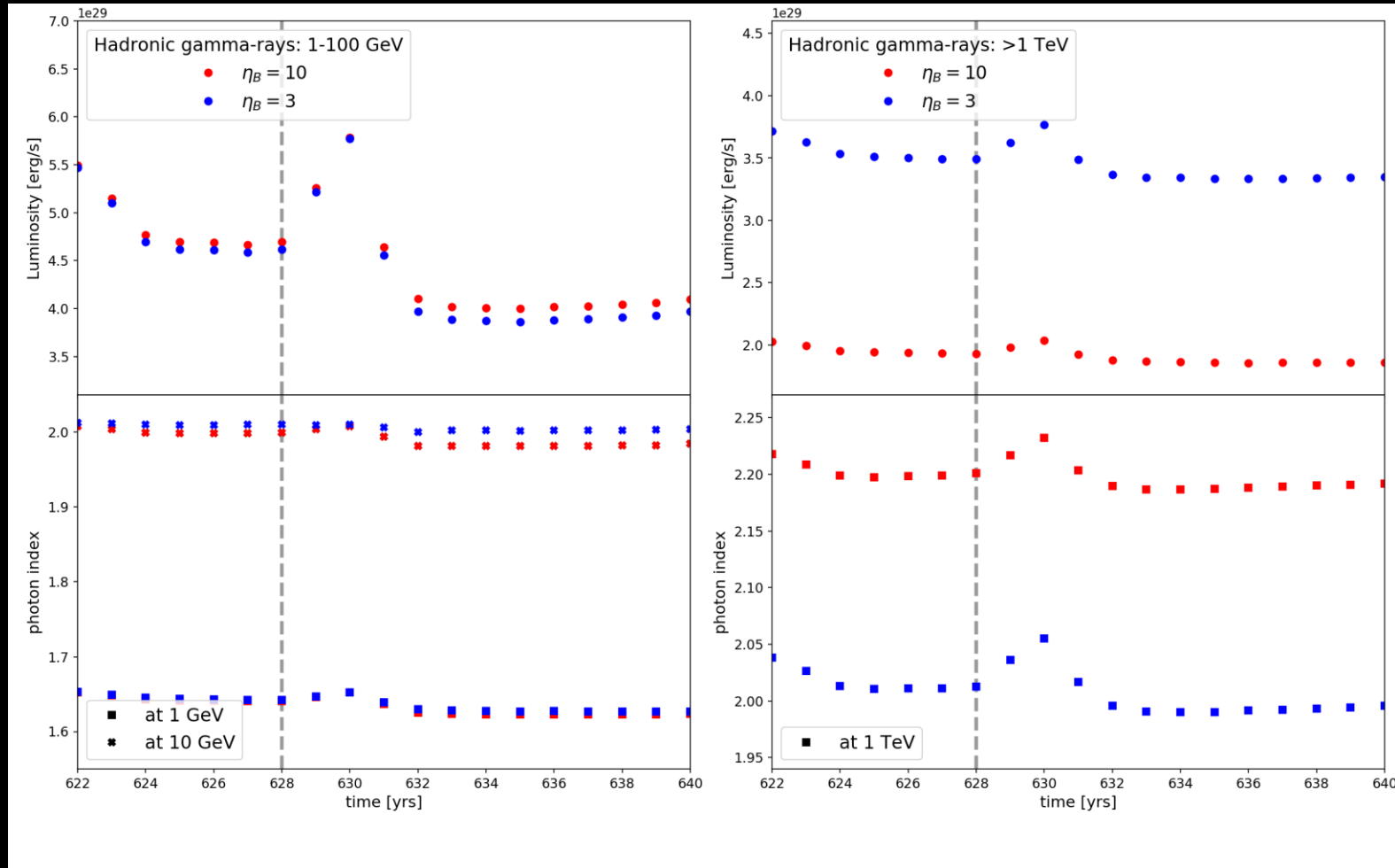
Gamma-ray radiation (leptonic)

- Similar behavior to X-rays
- Changes are naturally less pronounced at lower energies



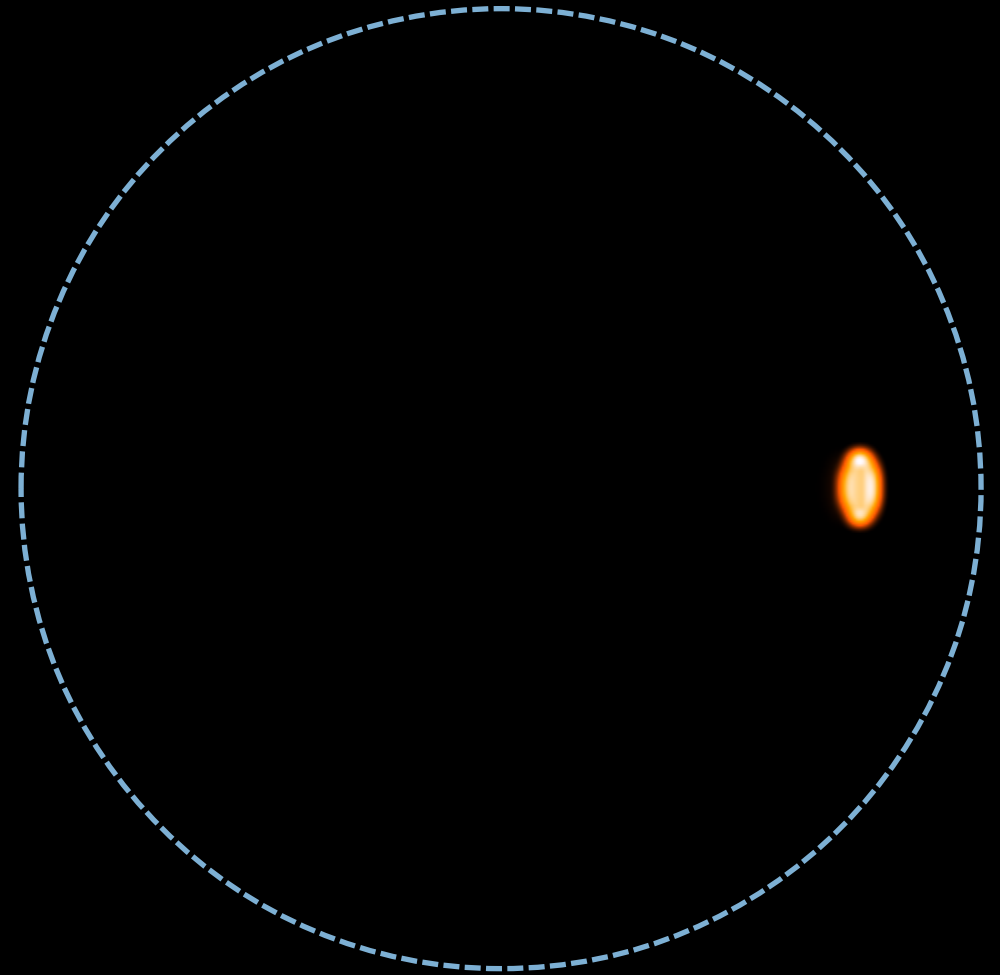
Gamma-ray radiation (hadronic)

- No significant variability
(note the scale is linear here)



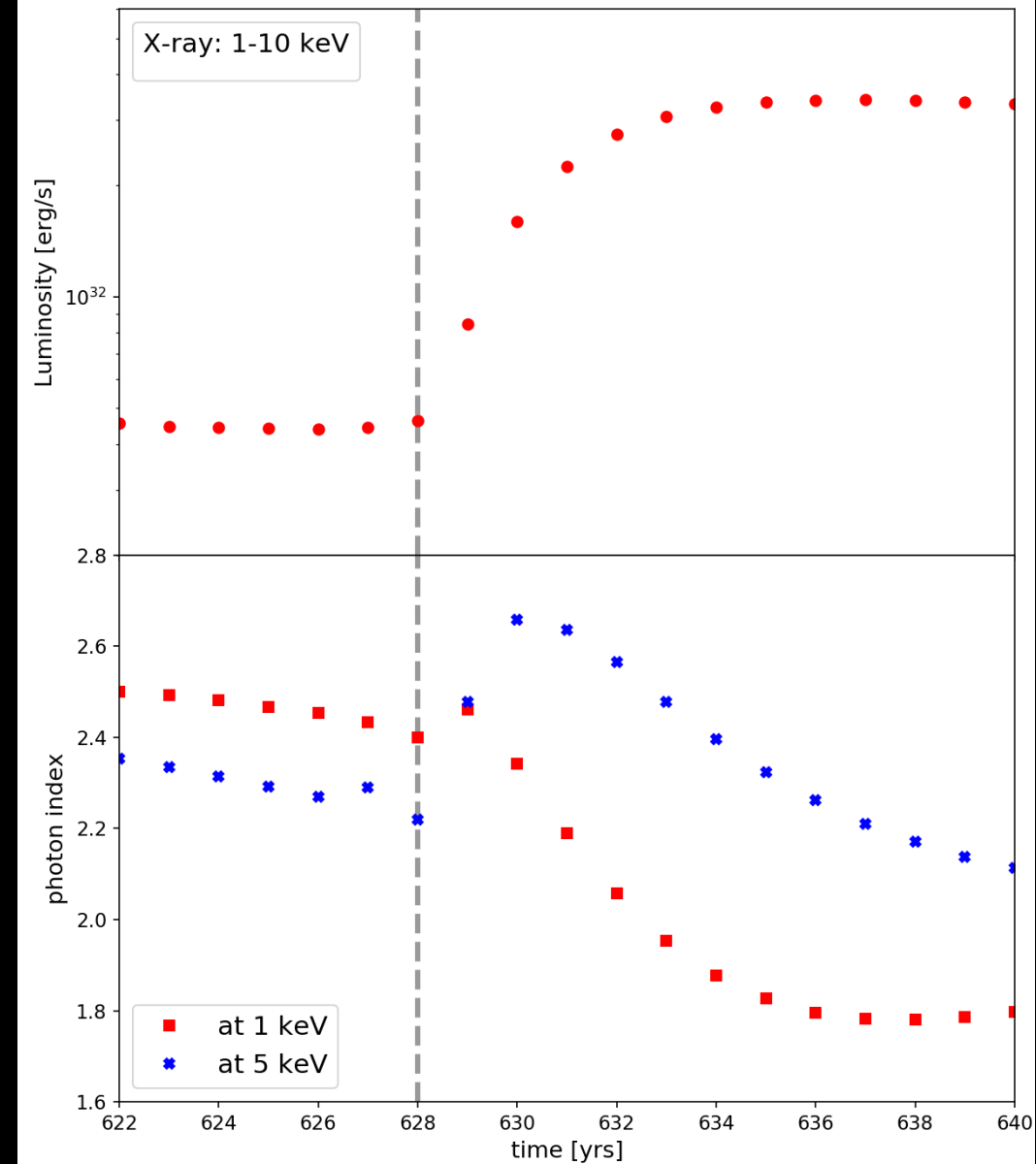
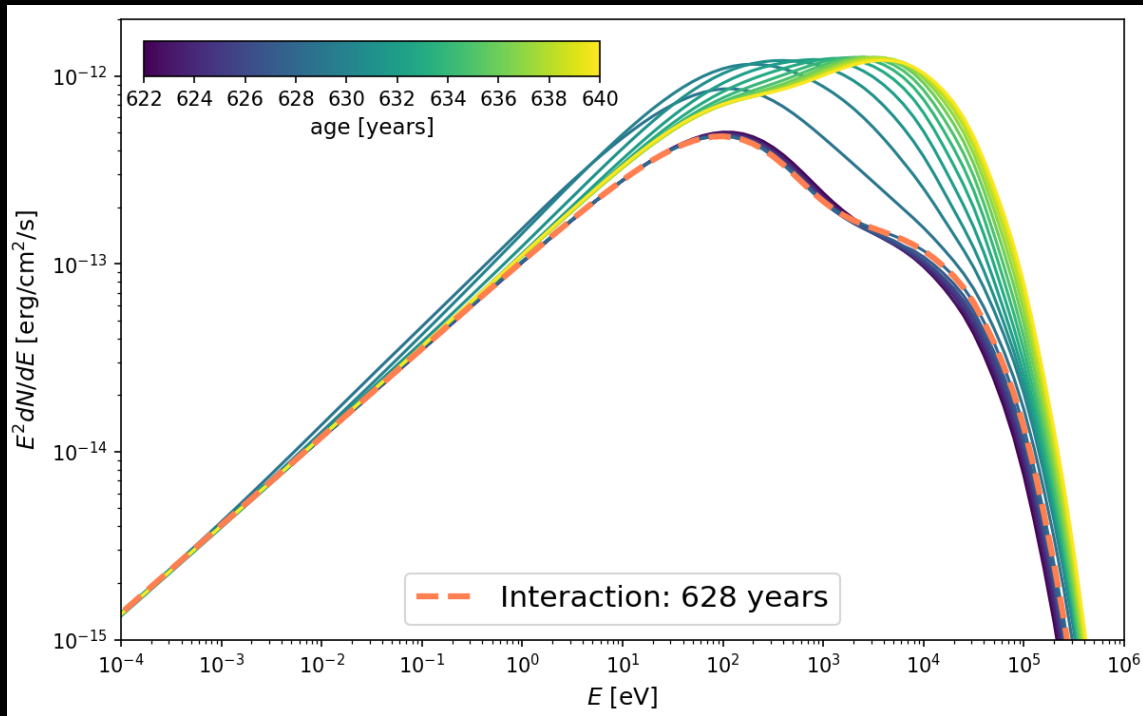
Filament

- Emission is considered only within a cone with an opening angle of 5 degrees (instead of the whole sphere)
- The cone is rotated by 30 degrees and the calculated X-ray emission projected on the 2d plane



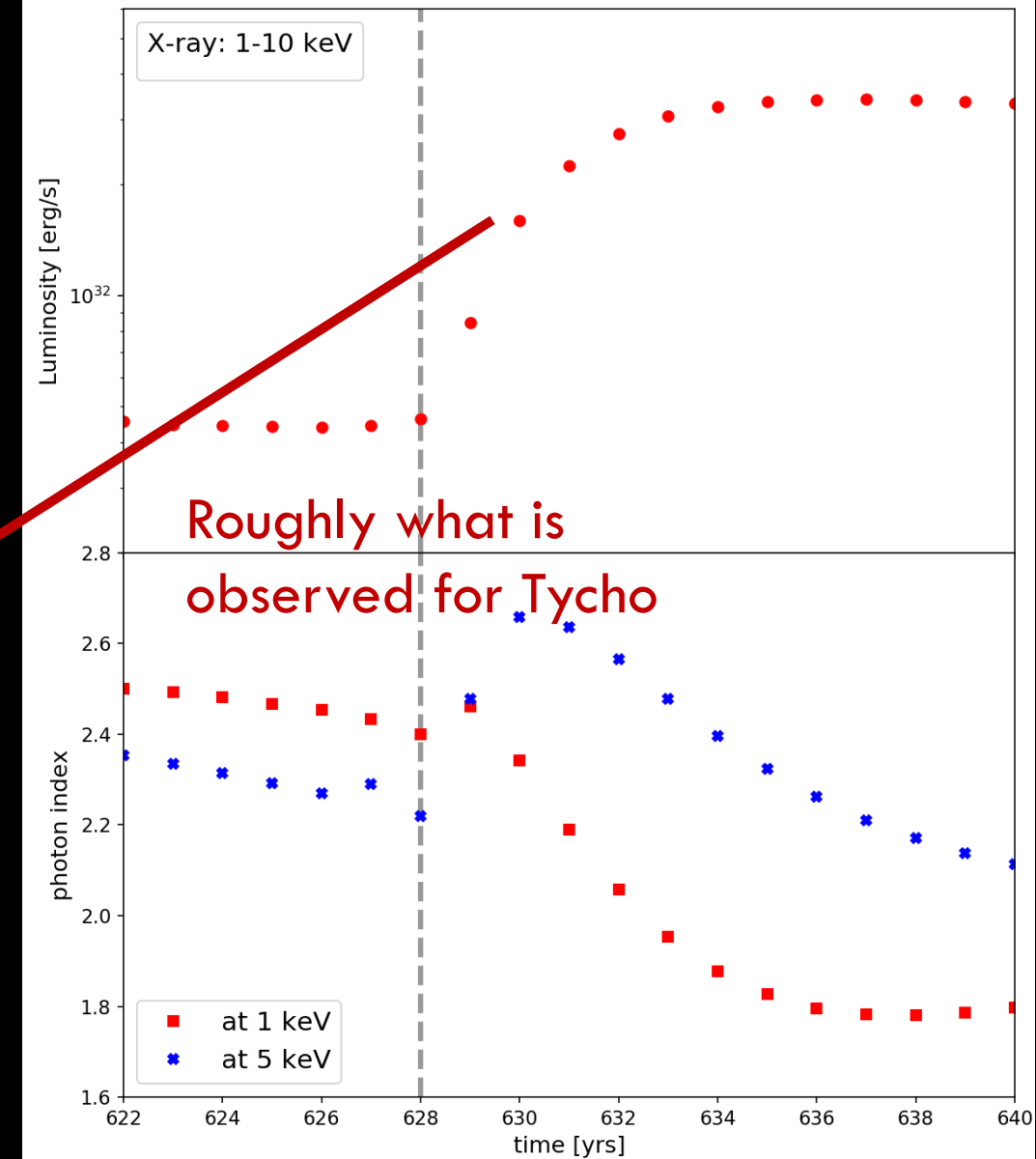
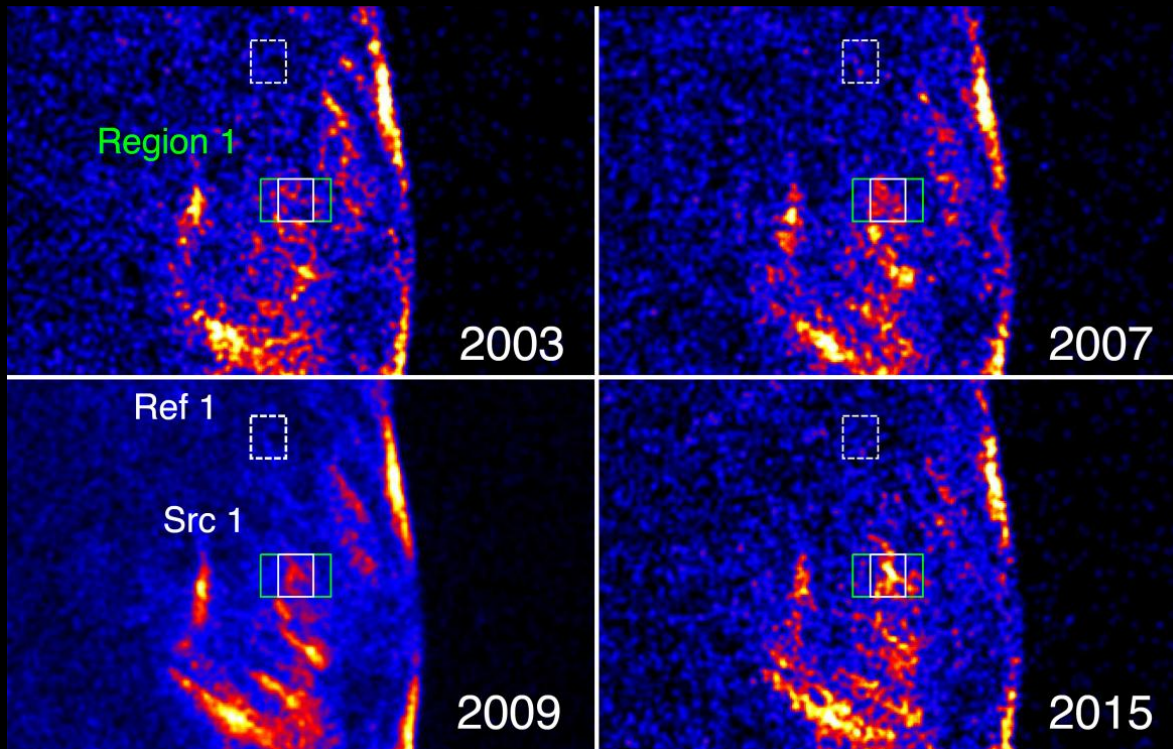
Filament

- X-ray fluxes and spectra are extracted from the stripe-like emitting region for the times around the reflected shock-forward shock interaction
- $\eta_B = 3$ and the distance to the source of 1 kpc are assumed



Filament

- X-ray fluxes and spectra are extracted from the stripe-like emitting region for the times around the reflected shock-forward shock interaction
- $\eta_B = 3$ and the distance to the source of 1 kpc are assumed



Take-home message

Reflected shocks that are formed when an SNR shock encounters abrupt density changes may cause X-ray and gamma-ray variability through the interaction with the forward shock.

Support **UKRAINE!**
Charity foundation

