GAMMA-RAY NEBULAE AROUND RECURRENT NOVAE

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Novae at γ-rays

- **GeV gamma-rays observed from several novae**
- **Prompt γ-ray emission up to days to a few tens of days**
- **A few γ-ray novae observed per year**
- **In nova RS Oph emission observed up to $\sim$TeV energies (MAGIC and HESS Collab. 2021)**
- **Total energy in γ-rays: $\sim$ a few 10^{42} ergs**
- **Lepto-hadronic/hadronic models for prompt emission:**

  Tatischef & Hernanz (2007) + several other
- **What determines the time scale of γ-ray flare:**

  radiation process or acceleration limited in time ?
- **Can electrons be accelerated during a year time scale ?**

Symbiotic Nova (White Dwarf + Red Giant)

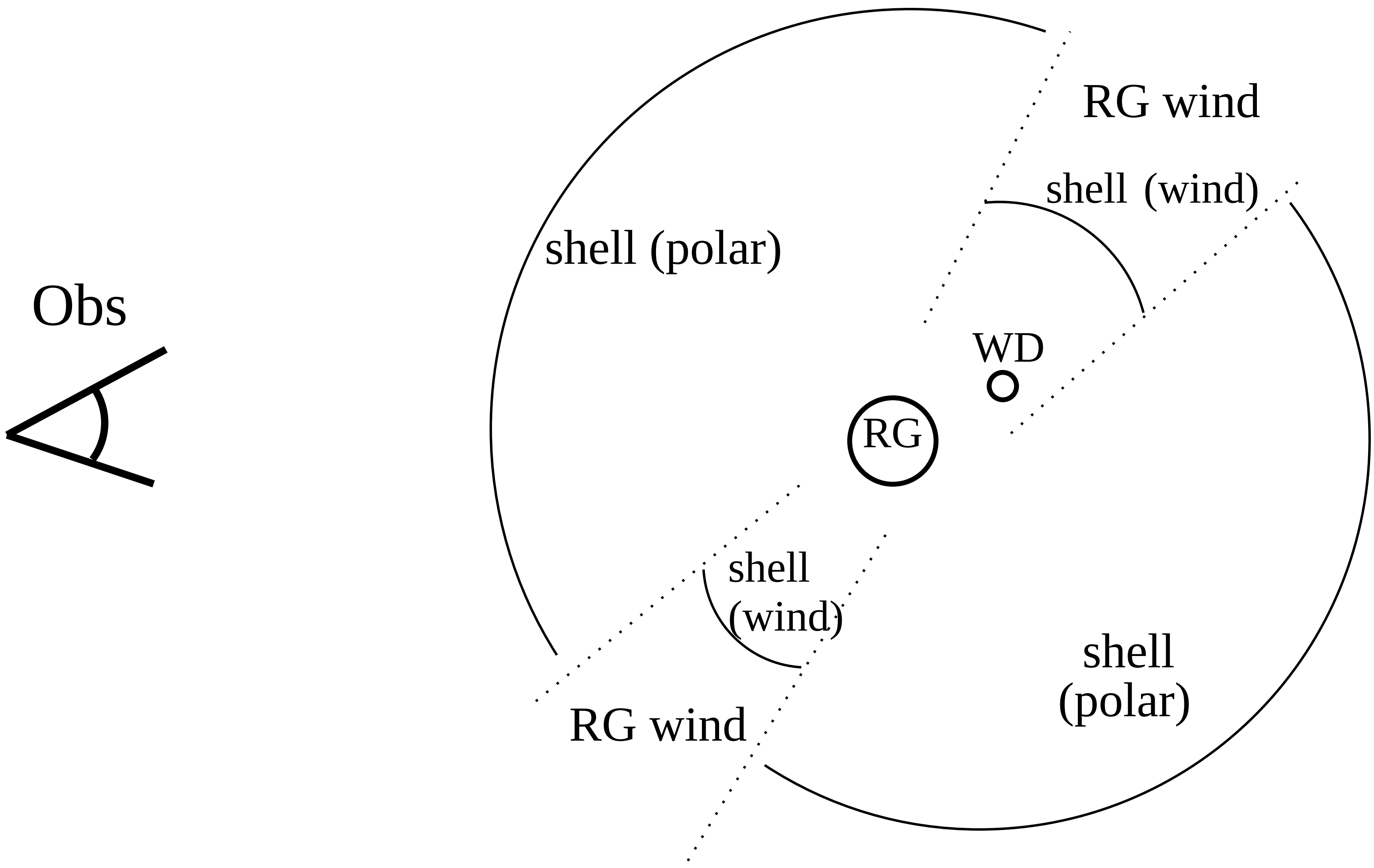

Figure 1: **Schematic picture of the Symbiotic Nova explosion: polar shell → fast, equatorial shell → slow.**

Acceleration, propagation of electrons in the shell

(details in Bednarek 2022 MNRAS 515, 1644)

- Electrons accelerated in the shell continuously
- 10% of the shell energy converted to relativistic electrons
- Their maximum energies determined by losses or escape
- They are injected with the power law spectrum (index -2)
- Their spectrum evolves in time (during shell expansion)
- Electrons interact with the soft radiation
- Produced gamma-ray spectra evolve in time

Gamma-rays from the nova shell late (years) after explosion

(details in Bednarek 2022 MNRAS 515, 1644 (parameters of RS Oph))

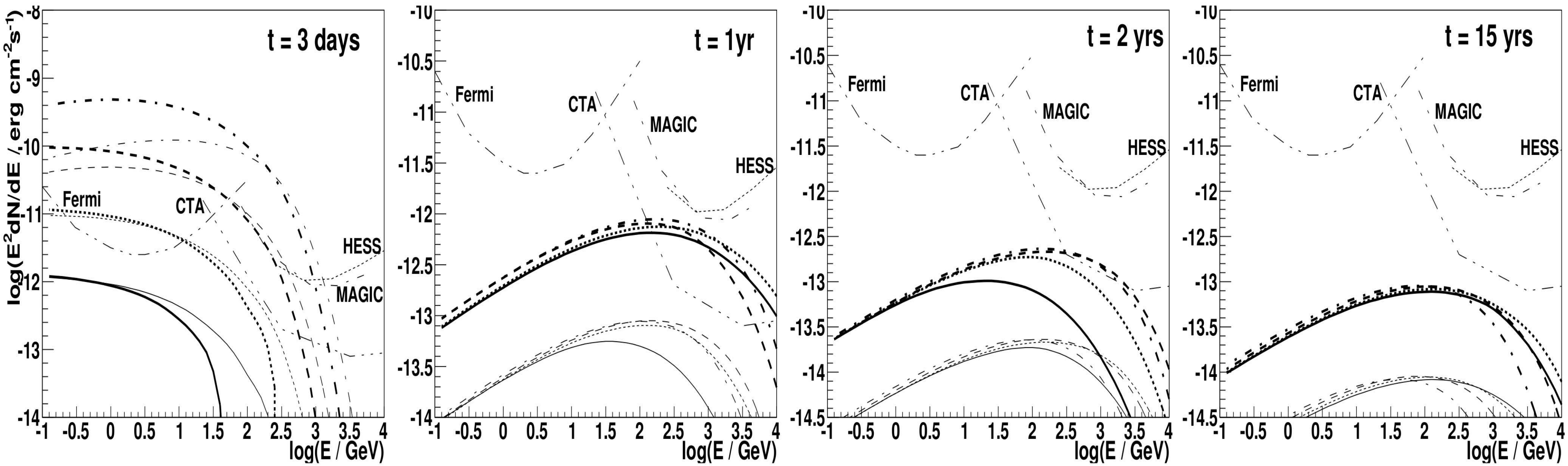

Figure 2: **Electrons accelerated in the shell also long after nova explosion, long scale evolution of electron spectrum, gamma-rays from the IC of electrons within the shell, predictions for the observation of late γ-ray emission (Fermi, CTA).**
(different mass of the shell 10^{-6} M$_\odot$ (thick curves) and 10^{-7} M$_\odot$ (thin);
different magnetic field in the shell: $\alpha = 0.1$ (solid curves), 10^{-2} (dotted), 10^{-3} (dashed), 10^{-4} (dot-dashed).

What is the fate of electrons escaping from the shell ?

A model for nebulae around recurrent nova

- **Symbiotic Nova shells accelerate electrons**
- **Acceleration process active during the re-currency period of the nova**
- **Nova injects shells with similar rate for** $\sim 10^4 - 10^5$ **yrs**
- **Electrons accumulate within the nebula around the nova**
- **Electrons comptonize radiation from the red giant and MBR**
- **Nova Super-remnant: Persistent source of gamma-rays**

Nebulae around recurrent novae

(details in Bednarek & Sitarek 2023 JHEA 38, 22)

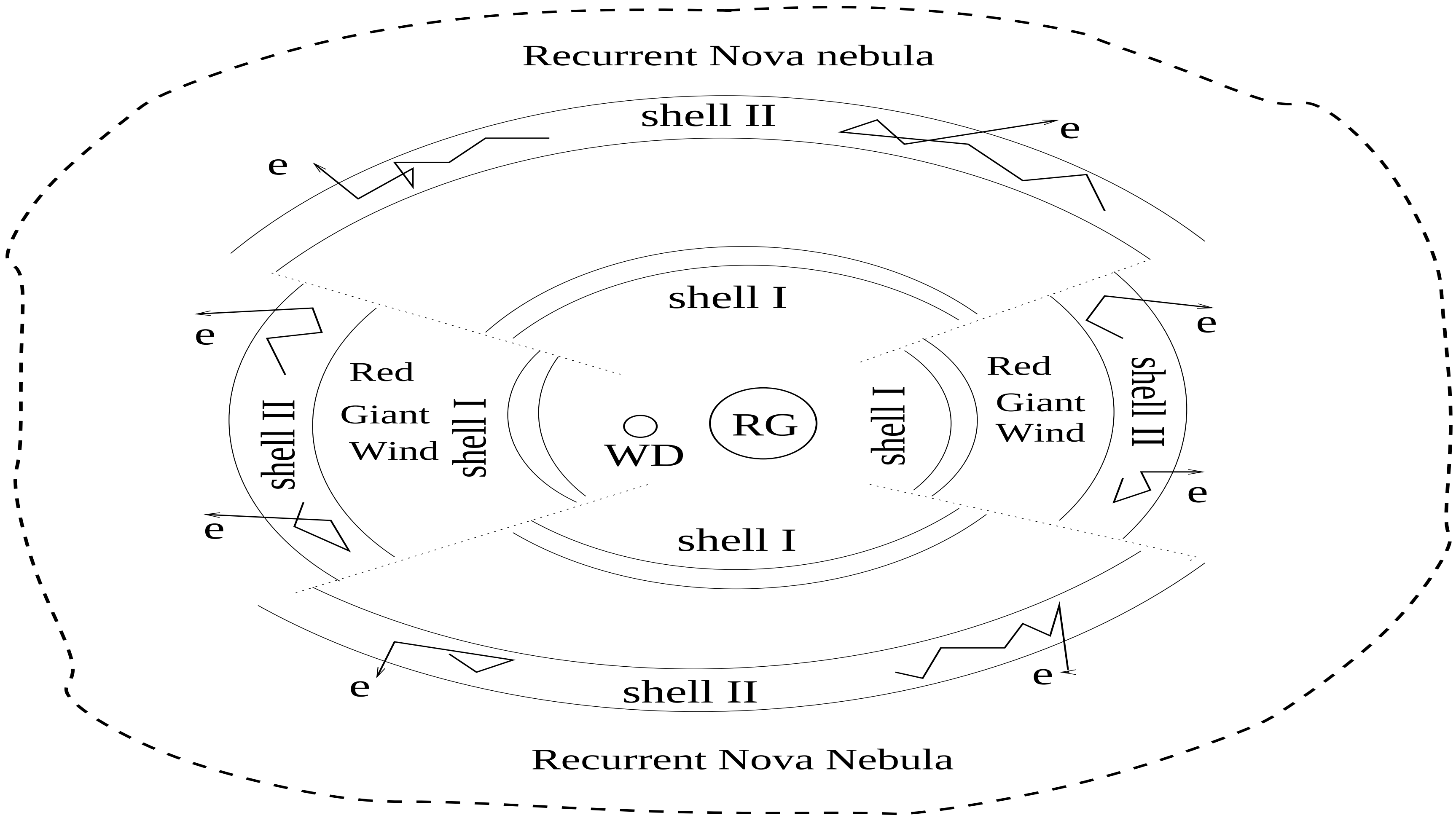

Figure 3: **Electrons accelerated continuously,**
a part of electrons escape from the nova shell,
electrons accumulate in the nebula around nova,
contribution from many recurrent explosions to the nebula (e.g. RS Oph),
γ-rays produced by electrons scattering RG radiation and MBR.

Maximum energies of electrons in the shell

(as a function of time after explosion)

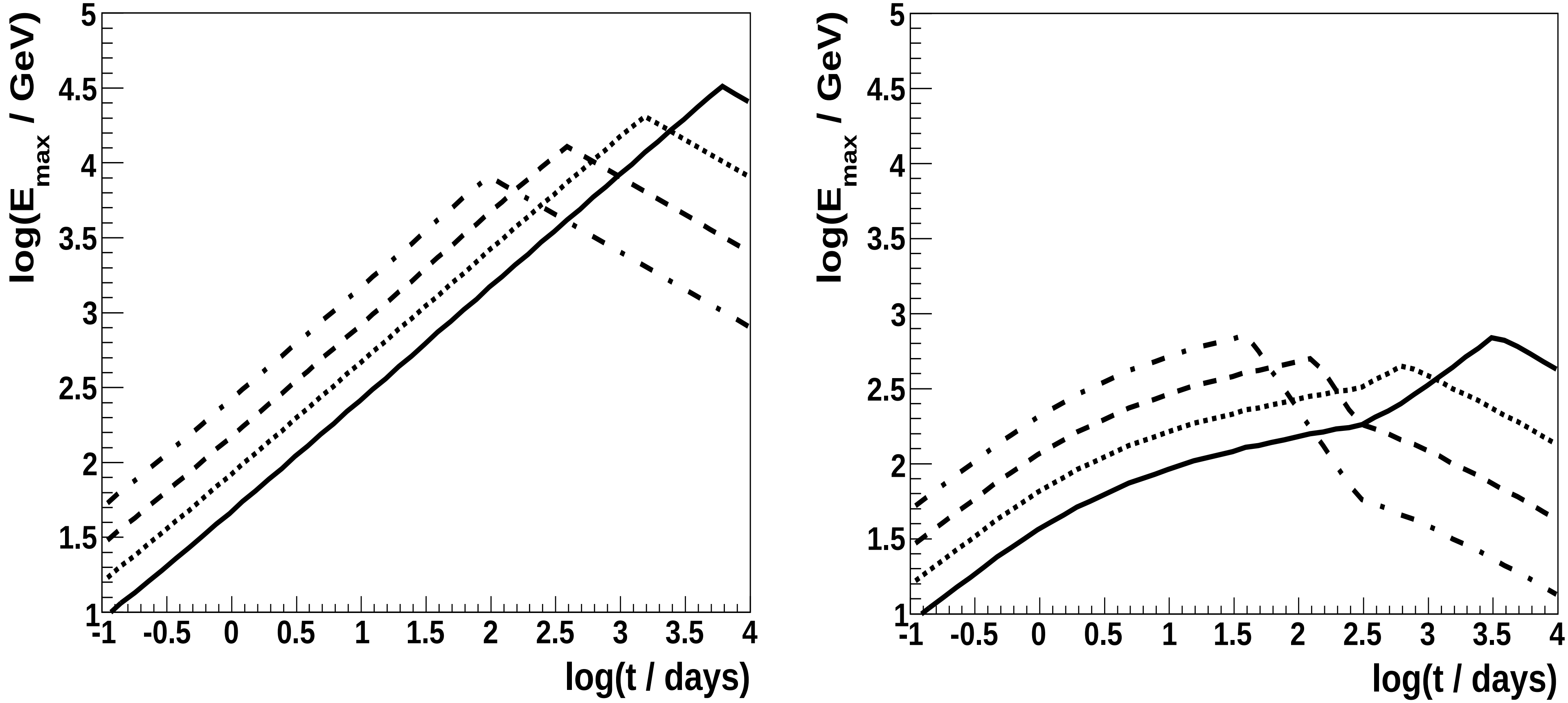

Figure 4: **Electrons accelerated within the polar region of the shell (the so-called "no deceleration" case, see panel on the left) and in the equatorial wind of the RG (deceleration case, $\Omega = 0.1$) The magnetization of the nova shell is defined by $\alpha = 10^{-4}$ (dot-dashed curve), 10^{-3} (dashed), 0.01 (dotted), and 0.1 (solid). The initial mass of the nova shell is $M^0_{\rm sh} = 10^{-6}\ M_\odot$ and its initial velocity is $v^{\rm sh}_0 = 6000$ km s^{-1}. The mass loss rate of the RG wind is $M_{\rm RG} = 10^{-7}$ M$_\odot$ yr^{-1} and its velocity $v_{\rm RG} = 40$ km s^{-1}.**

Spectra of electrons escaping from the nova shell

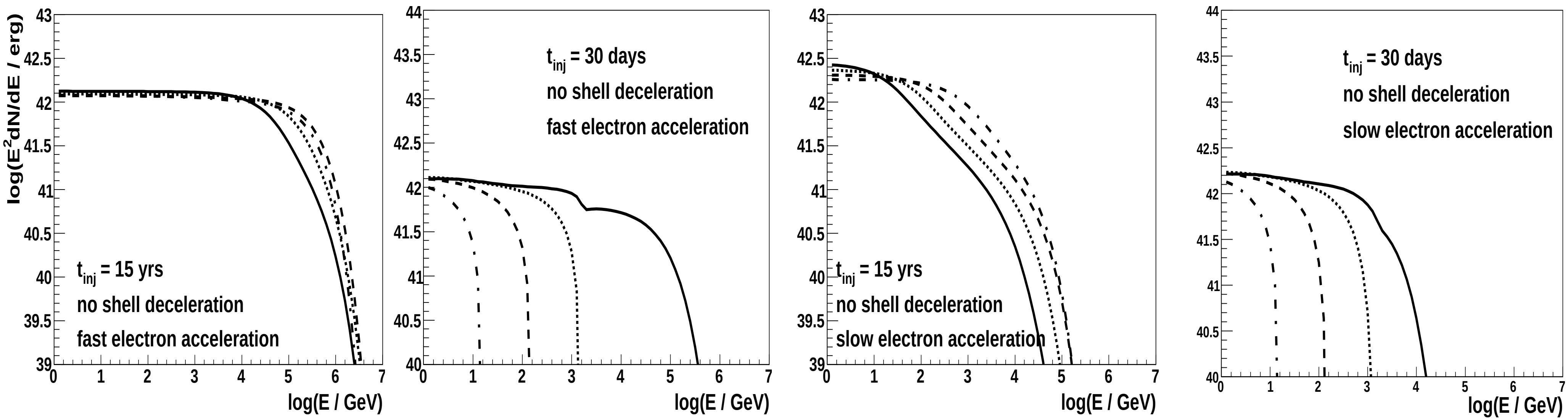

Figure 5: **The differential spectral energy distribution of the electrons escaping from the nova shell into the Nova Super-remnant assuming that their acceleration process operates only during the short period after the nova explosion (assumed to be 30 days) or during the whole recurrence period of the nova (i.e. 15 yrs). The electrons are accelerated within the shell to a power-law spectrum with a spectral index** -2 **and the exponential cut-off at** $E_{\rm max}$**. The cut-off energy of** $E_{\rm max}$ **is defined by two acceleration prescriptions, slow and fast. The magnetization of the nova shell is defined by** $\alpha = 10^{-5}$ **(solid curve),** 10^{-4} **(dotted),** 10^{-3} **(dashed), and** 10^{-2} **(dot-dashed). The shell propagates in the polar region of the nova binary system (no deceleration case). The initial mass of the nova shell is** $M_{\rm sh}^0 = 10^{-6}\ M_\odot$ **and its initial velocity is** $v_0^{\rm sh} = 6000$ **km s**$^{-1}$**.**

Gamma-rays from nebulae around recurrent novae

(details in Bednarek & Sitarek 2023 JHEA 38, 22 (parameters of RS Oph))

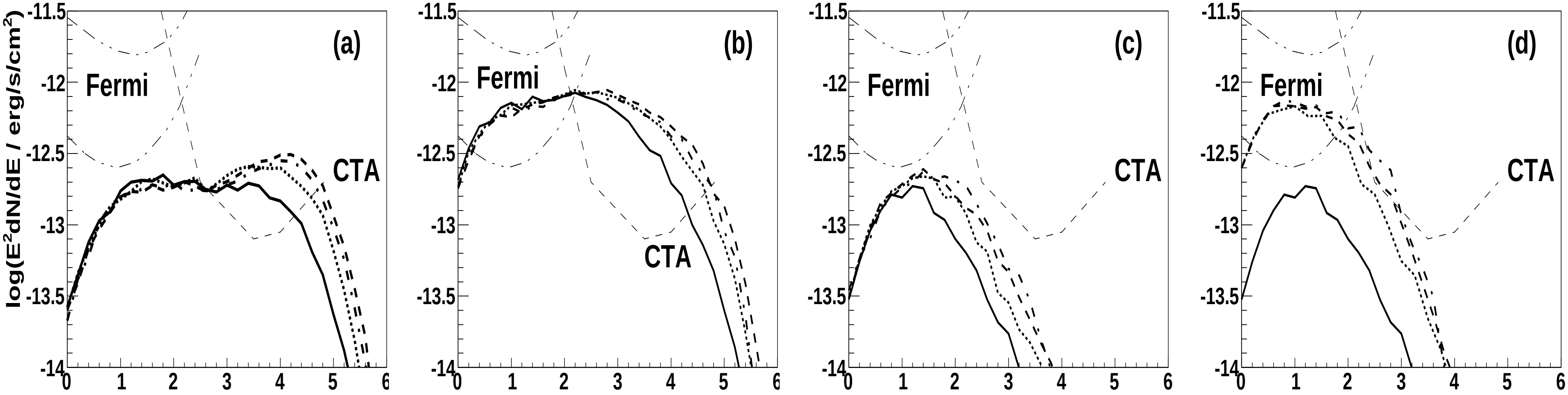

Figure 6: γ-ray emission from nova nebula expected in terms of different acceleration models of electrons within the nova shell, electrons accelerated in the polar regions of the shell, during the recurrence period of RS Oph ($t_{\rm max} = 15$ years);
Different magnetic field in the shell: $\alpha = 10^{-5}$ (solid), 10^{-4} (dotted), 10^{-3} (dashed), 120^{-2} (dot-dashed);
Fast acceleration (figures (a) and (b) and slow acceleration (c) and (d);
Activity period of recurrent nova $T_{\rm active} = 10^4$ yrs ((a) and (c)) and 10^5 yrs ((b) and (d));

Gamma-ray spectra from Nebulae around recurrent novae

(dependence on the magnetic field within nebula and active time)

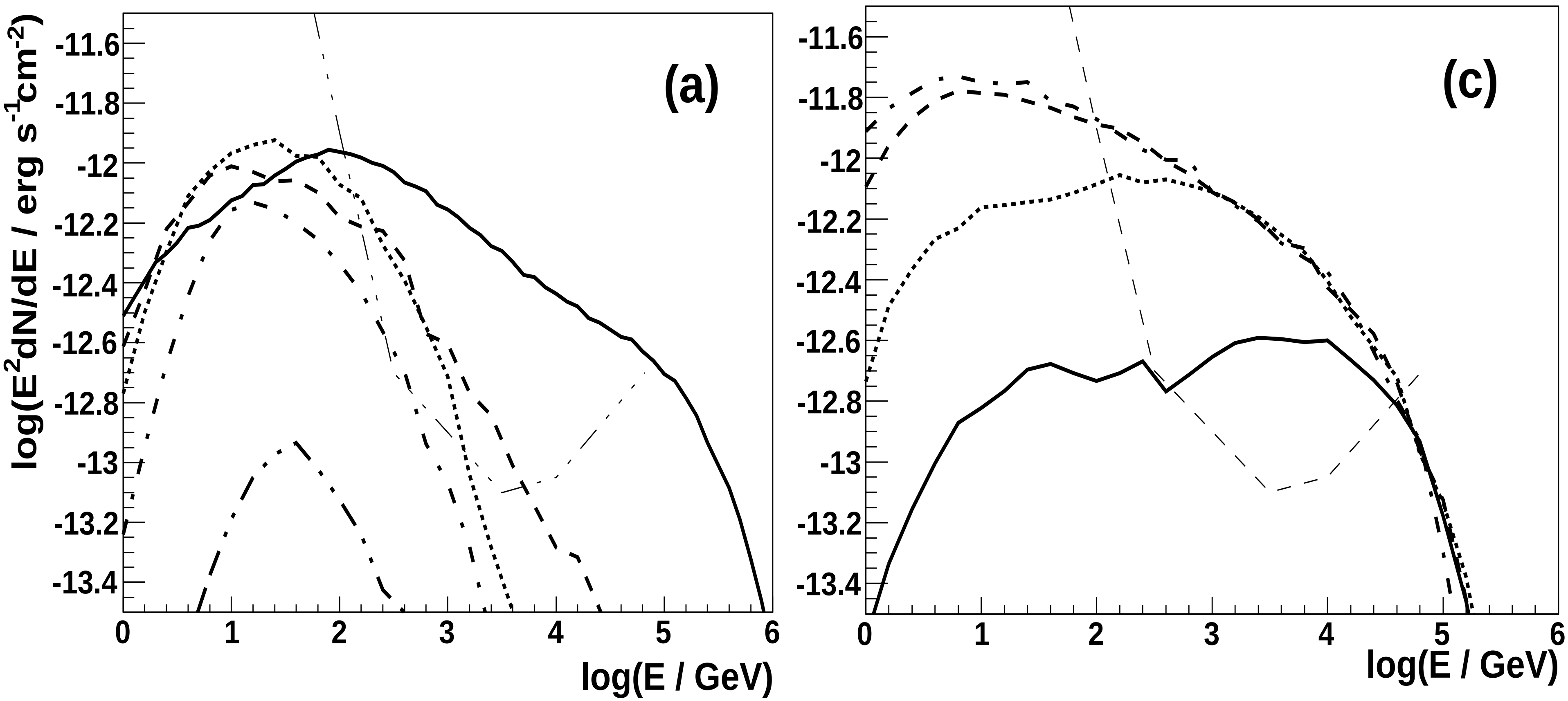

Figure 7: **The γ-ray spectral energy distribution as a function of: (a) the strength of the magnetic field within the Nova Super-remnant $B_{\rm NSR} = 3$ μG (solid), 10 μG (dashed), 30 μG (dotted), 100 μG (dot-dashed), and 300 μG (dot-dot-dashed) (a). The other parameters are $\alpha = 10^{-4}$, $R_{\rm inj} = 2 \times 10^{17}$ cm, $T_{\rm rec} = 15$ yrs, $T_{\rm active} = 10^5$ yrs; The other parameters are as above and $B_{\rm NSR} = 3$ μG; and (c) as a function of the activity stage of the nova $T_{\rm active} = 10^4$ yrs (solid), 10^5 yrs (dotted), 10^6 yrs (dashed), and 10^7 yrs (dot-dashed).**

Summary

- Particles accelerated to $\sim$GeV energies in several novae
- γ-ray emission observed up to $\sim$month after explosion
- Nova RS Oph accelerates particles to $\sim$TeV energies

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- Acceleration sites (?): WD wind, internal shock, external shock

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- Considered hypothesis: acceleration of electrons at nova shells long after explosion
- Escape of electrons into the nebula surrounding recurrent nova

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- GAMMA-RAY NEBULAE AROUND RECURRENT NOVAE

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- Future obs. (CTA + other) should constrain this hypothesis