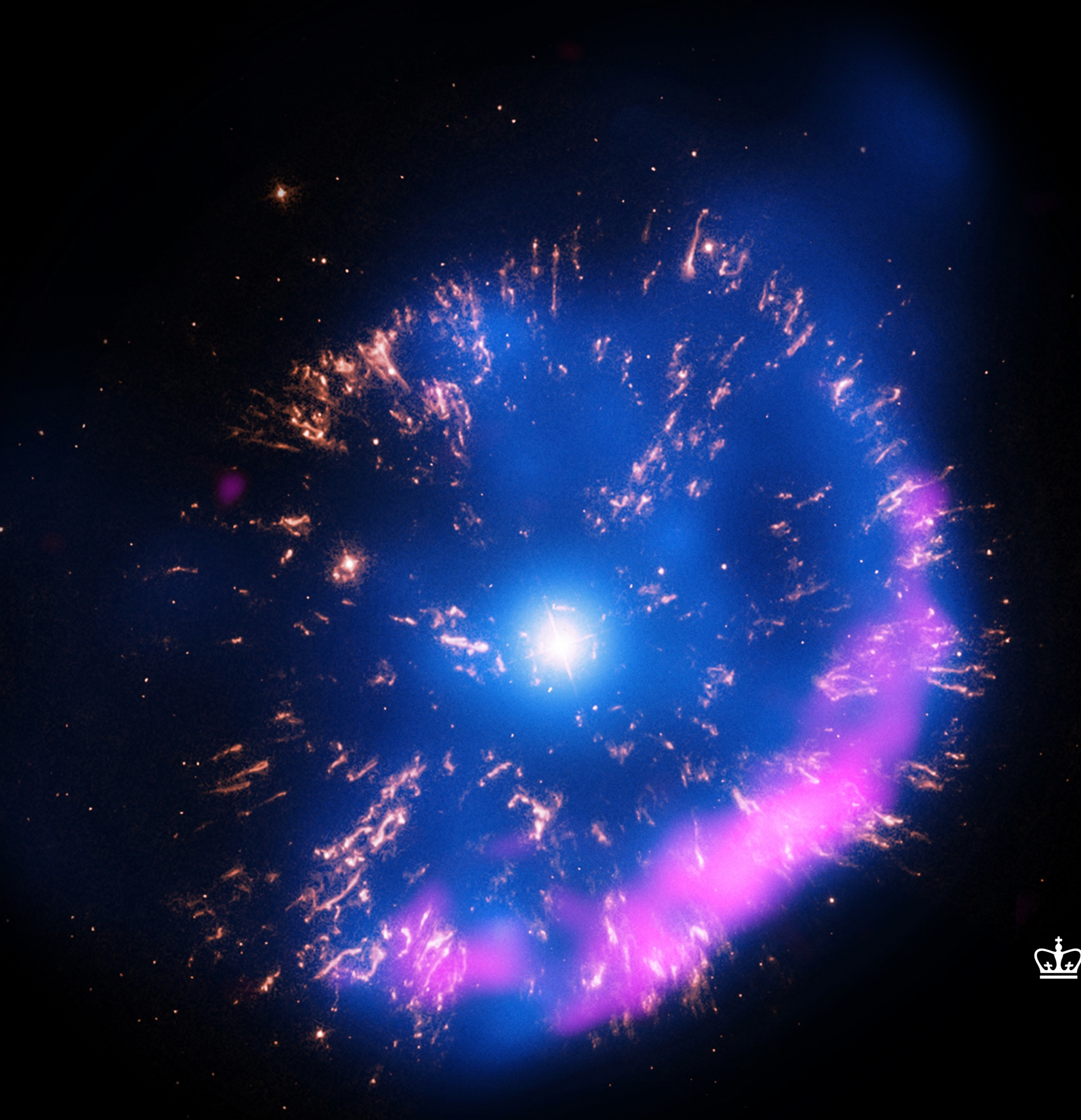


Image: GK Persei; Credit: Chandra, Hubble, VLA

Delayed TeV Emission from Classical Novae

REBECCA DIESING & BRIAN METZGER

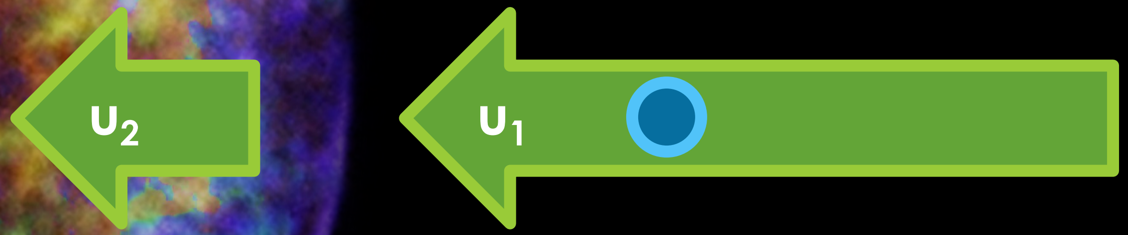
TEVPA | SEPTEMBER 2, 2026

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

IAS
INSTITUTE FOR
ADVANCED STUDY

Shock physics: the standard paradigm

Strong shocks accelerate protons and electrons via diffusive shock acceleration (DSA). This is the primary mechanism by which supernova remnants accelerate Galactic cosmic rays.*



Downstream (ρ_2) **Upstream (ρ_1)**

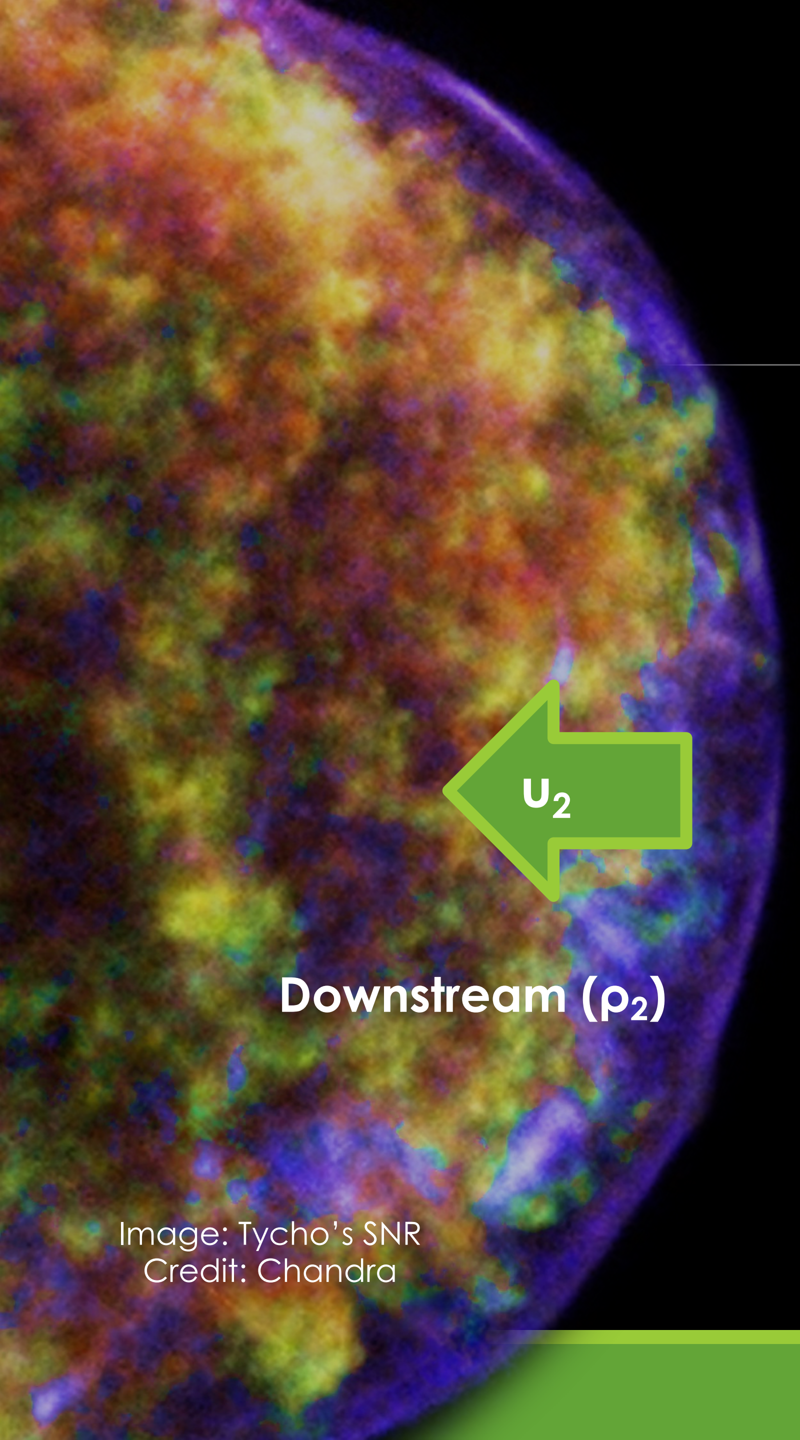
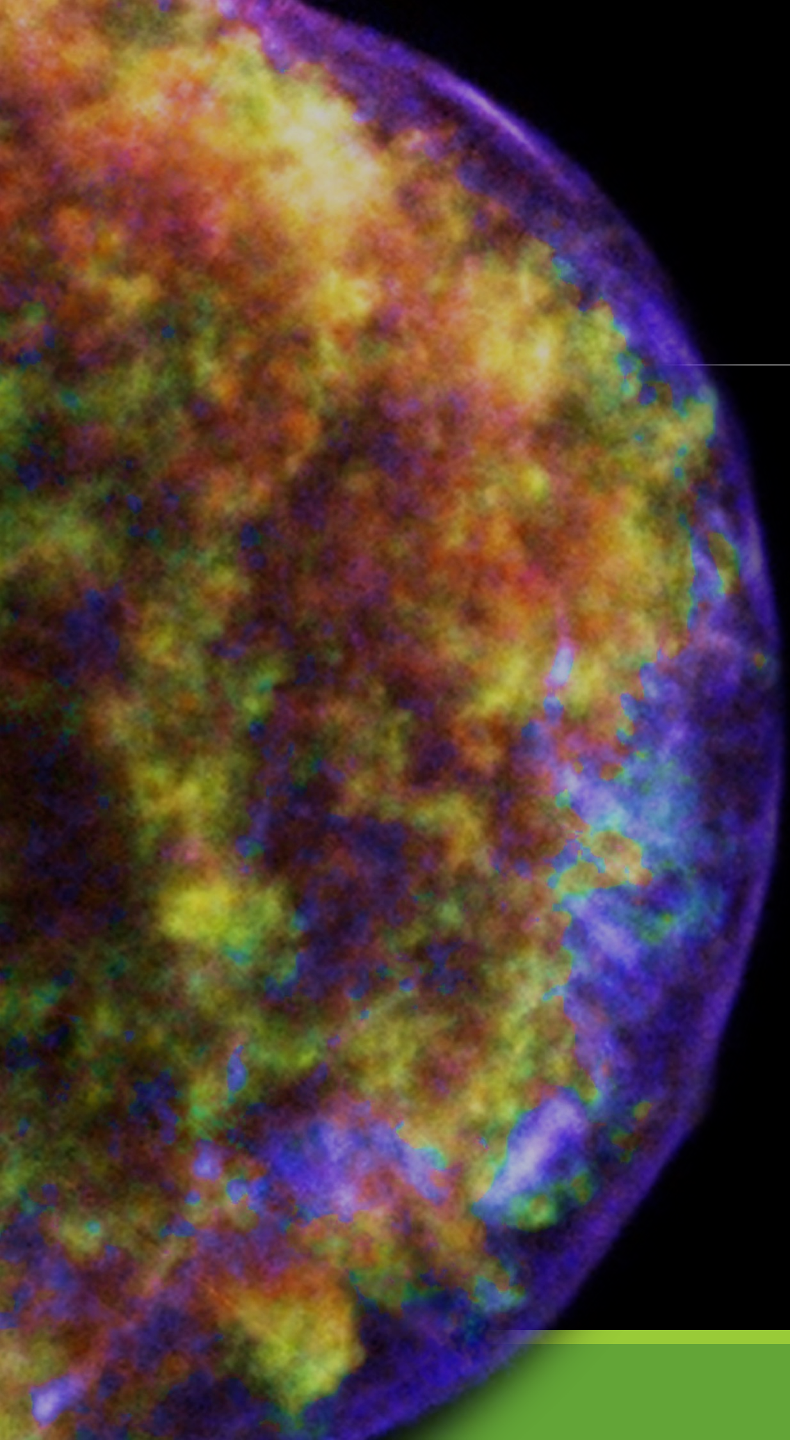


Image: Tycho's SNR
Credit: Chandra

*Fermi54, Krymskii77, Axford+77, Bell78, Blandford+78



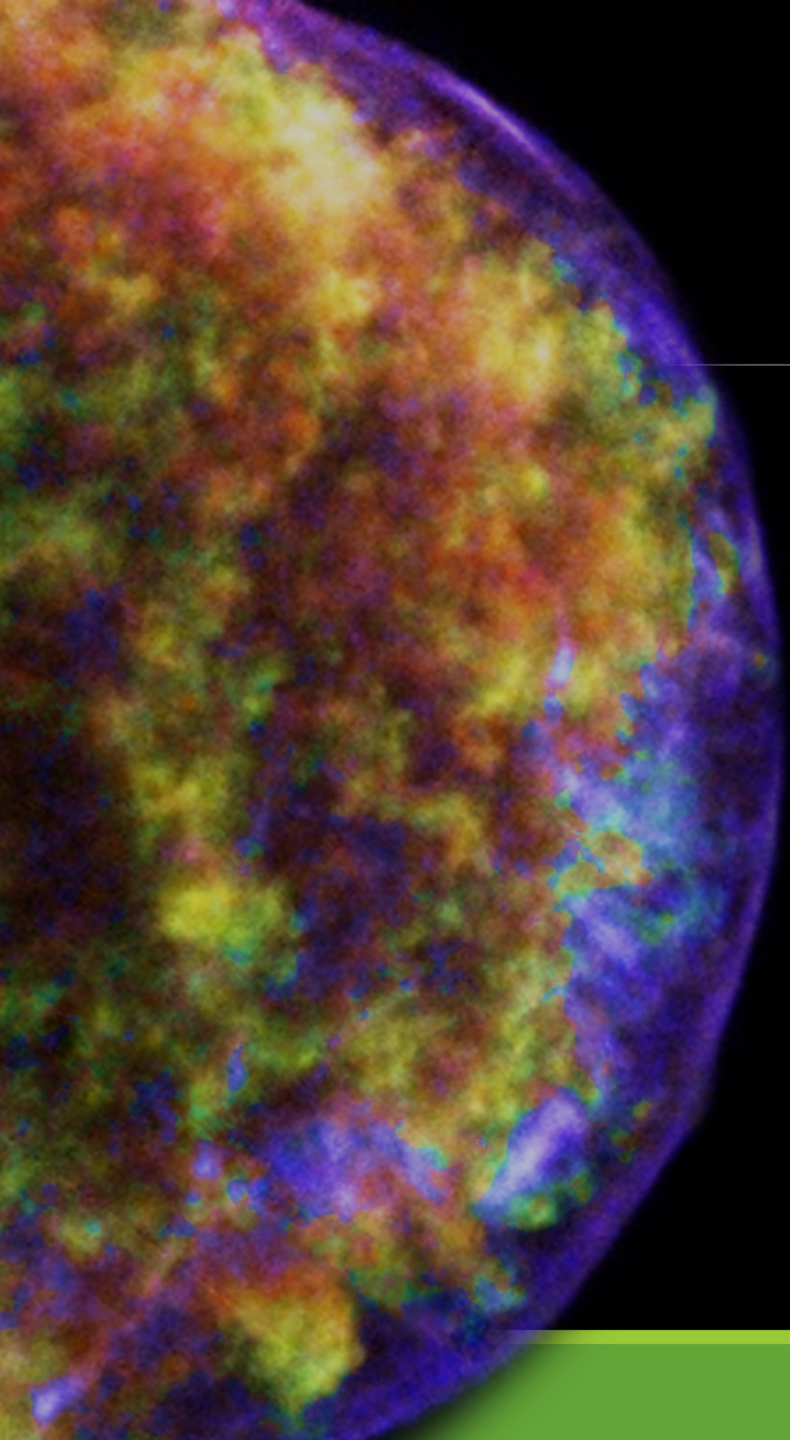
The maximum energy

LIMIT #1: AGE

The acceleration time must be shorter than the age of the system.

$$\tau_{\mathrm{acc}} \sim \frac{D(E,B)}{v_{\mathrm{sh}}^2} \leq \tau_{\mathrm{age}}$$

Drury83



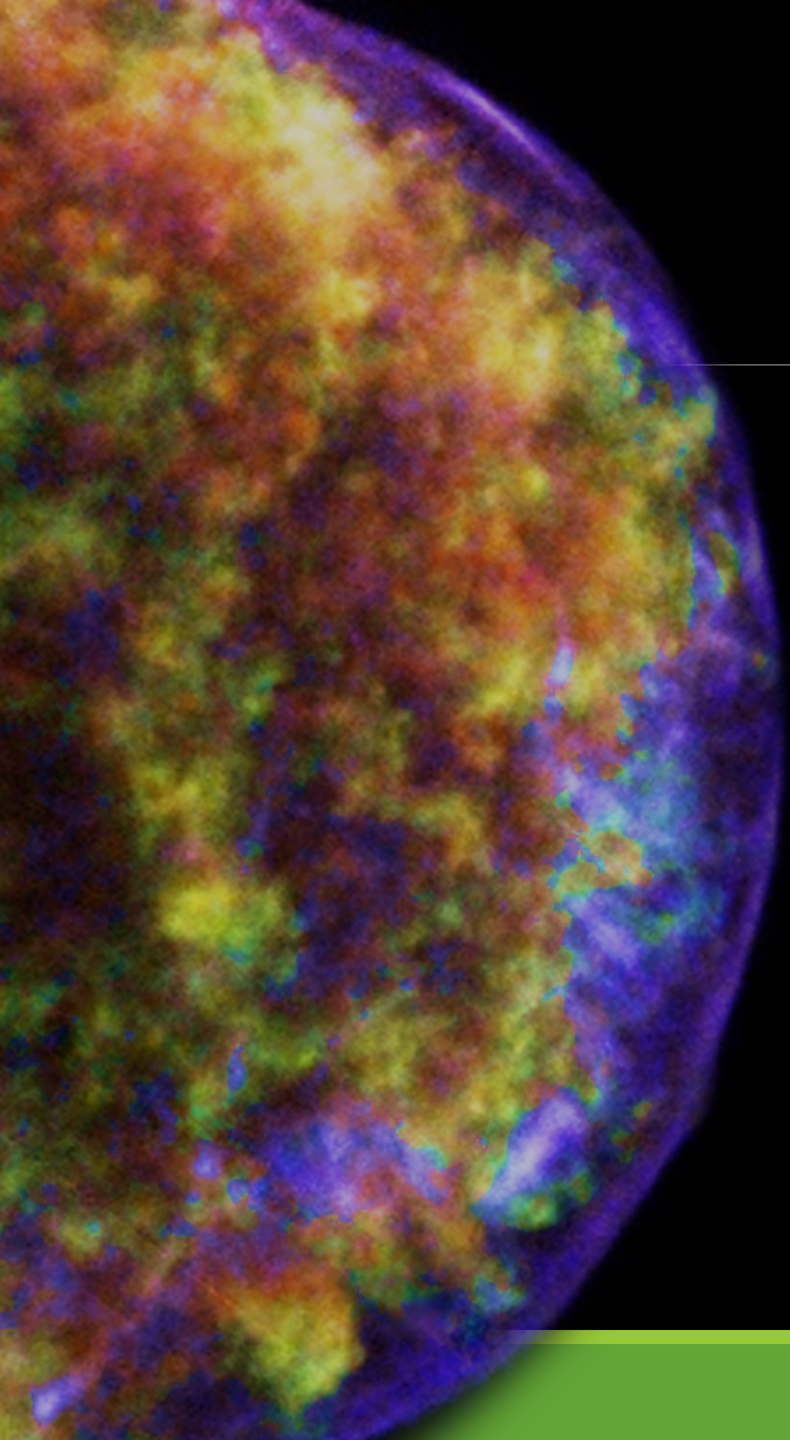
The maximum energy

LIMIT #2: CONFINEMENT

The diffusion length must be smaller than the size of the system.

$$\ell_{\mathrm{diff}} \sim \frac{D(E,B)}{v_{\mathrm{sh}}} \ll R_{\mathrm{sh}}$$

Hillas84



The problem with the supernova remnant paradigm

LIMIT #2: CONFINEMENT

Assuming Bohm diffusion (optimistic),

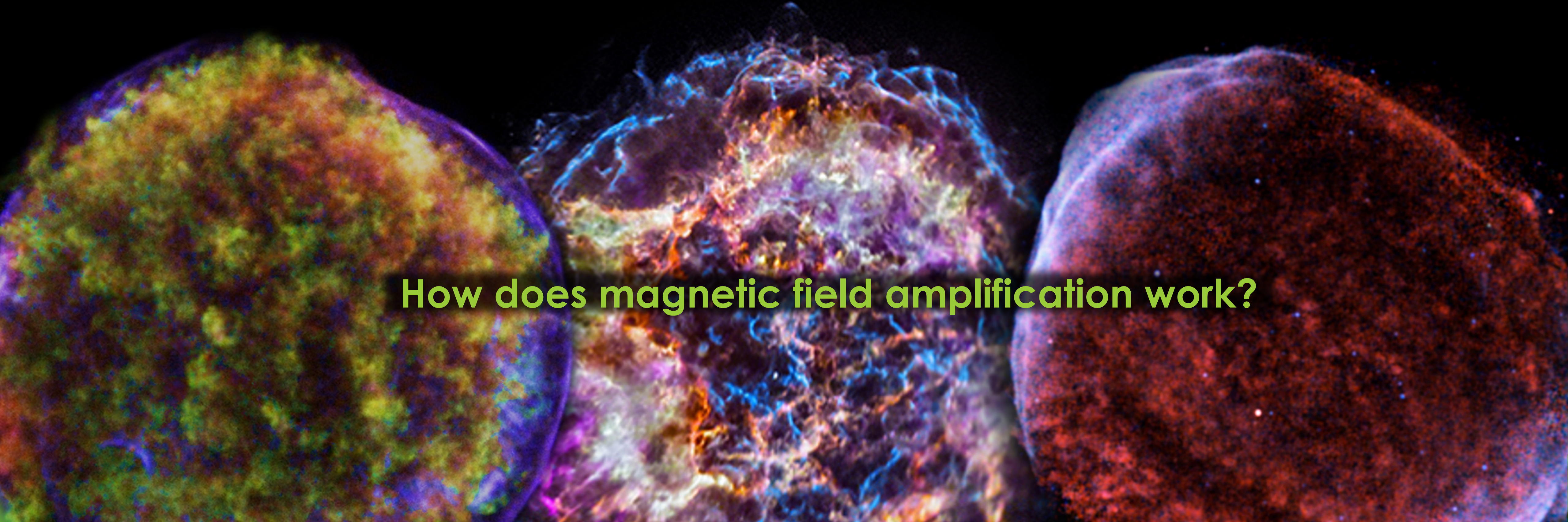
$$E_{\rm max} \approx 5 \ {\rm TeV} \left(\frac{v_{\rm sh}}{5000 \ {\rm km \ s^{-1}}} \right) R_{\rm pc} B_{\mu {\rm G}}$$

This is inconsistent with TeV observations of SNRs!

A note about magnetic fields

Thin synchrotron-emitting rims indicate that supernova remnants have enhanced magnetic fields (~ 100 μG compared to ~ 30 μG in the interstellar medium).*

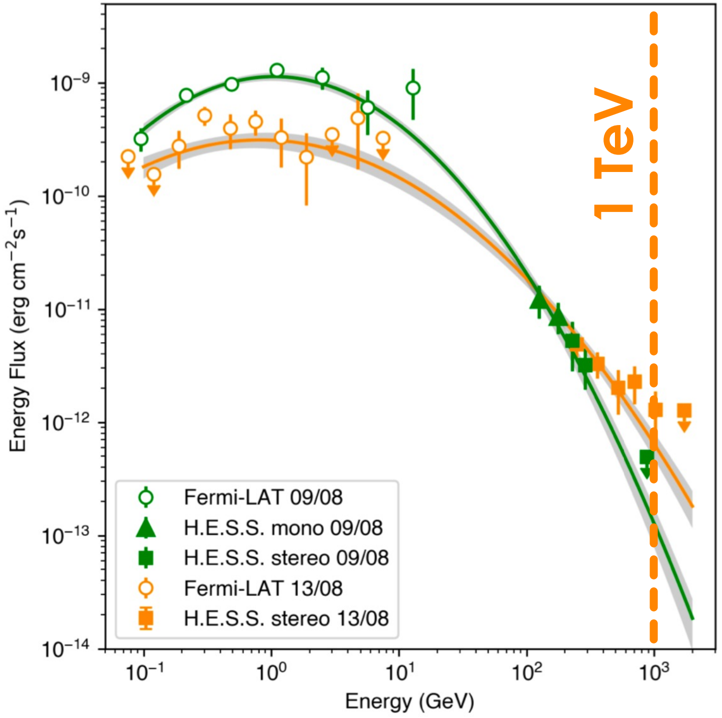
*e.g., Bamba+05, Parizot+06, Morlino+10, Ressler+14



Magnetic field amplification in RS Ophiuchi

RS Oph's 2021 outburst produced TeV ɣ-rays, corresponding to ~10 TeV protons.

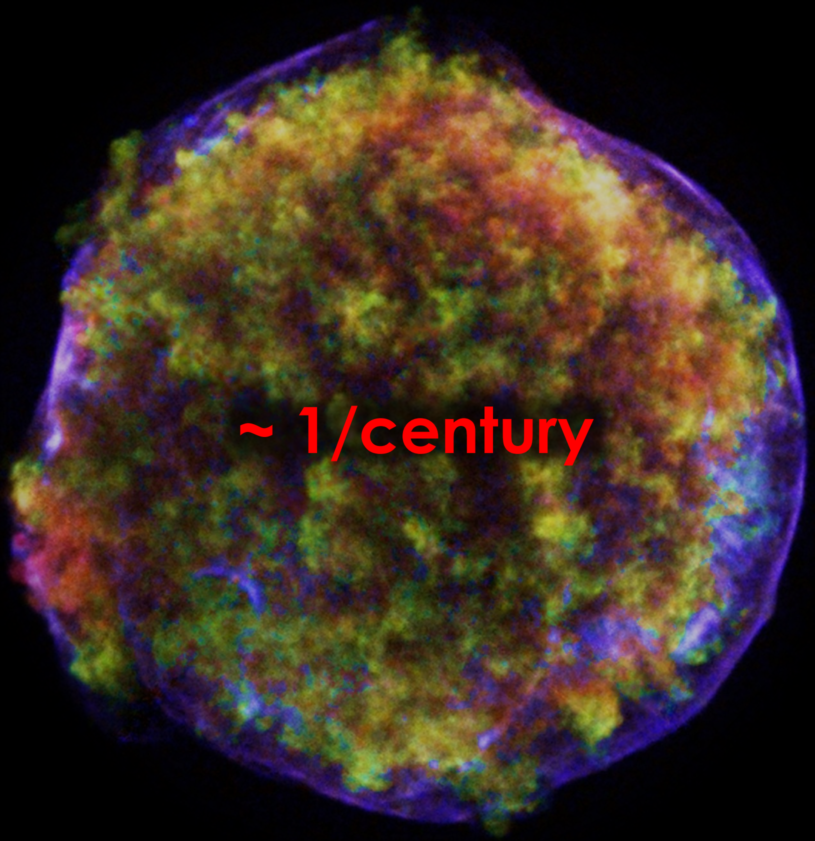
HESS22

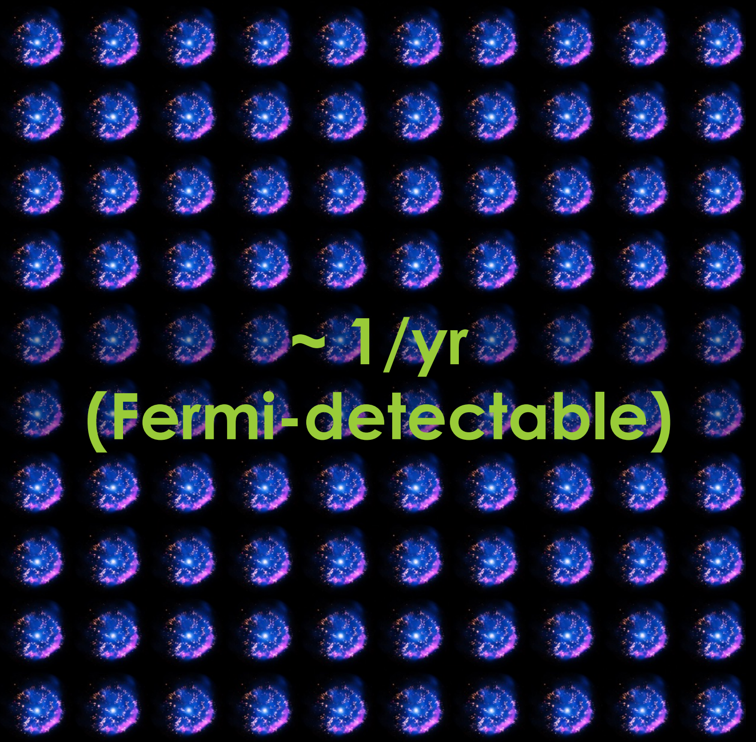


$$B \approx 0.5\ \mathrm{G} \left(\frac{E_{\mathrm{max}}}{10\ \mathrm{TeV}}\right)\left(\frac{v_{\mathrm{sh}}}{4000\ \mathrm{km\ s^{-1}}}\right)^{-1} R_{\mathrm{AU}}^{-1}$$

Why novae?

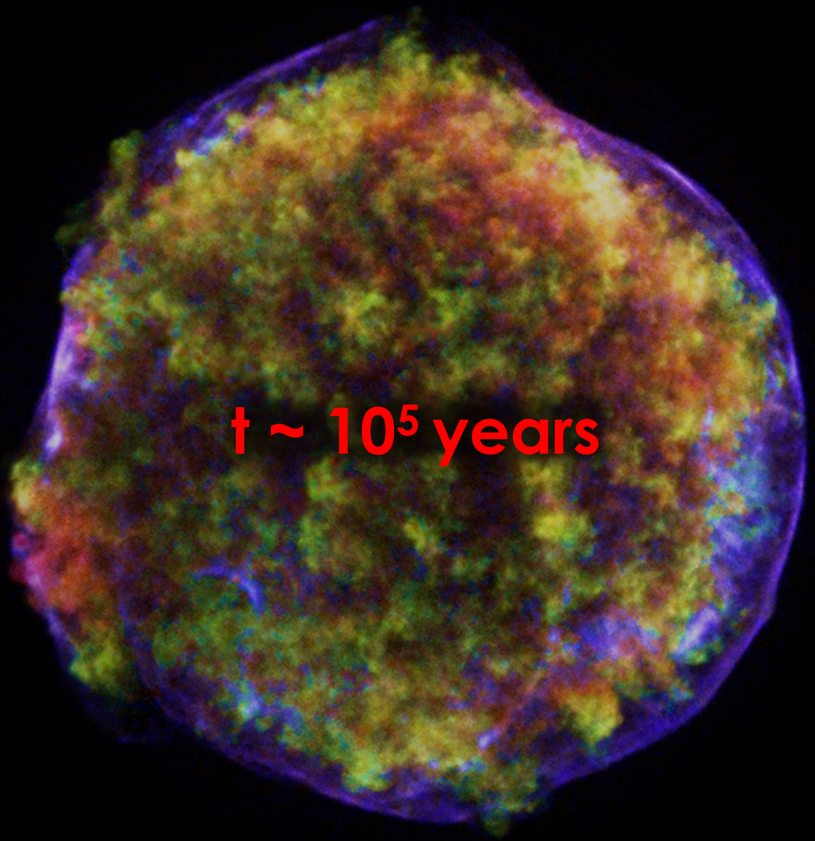
1. Novae are common.



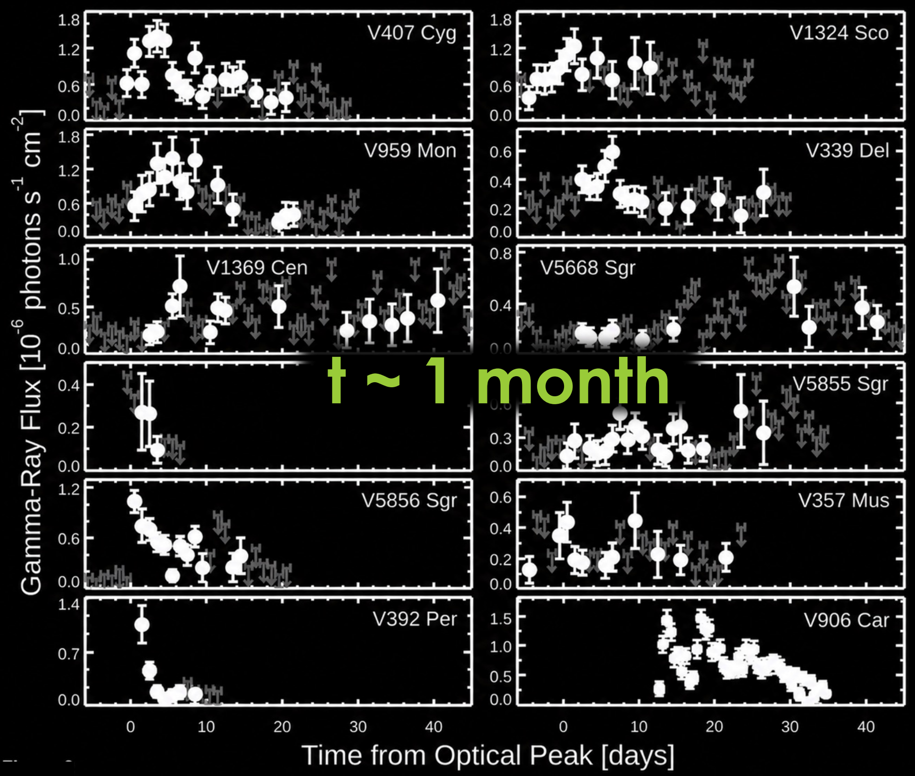


Why novae?

2. Novae are fast.



Chomiuk+21

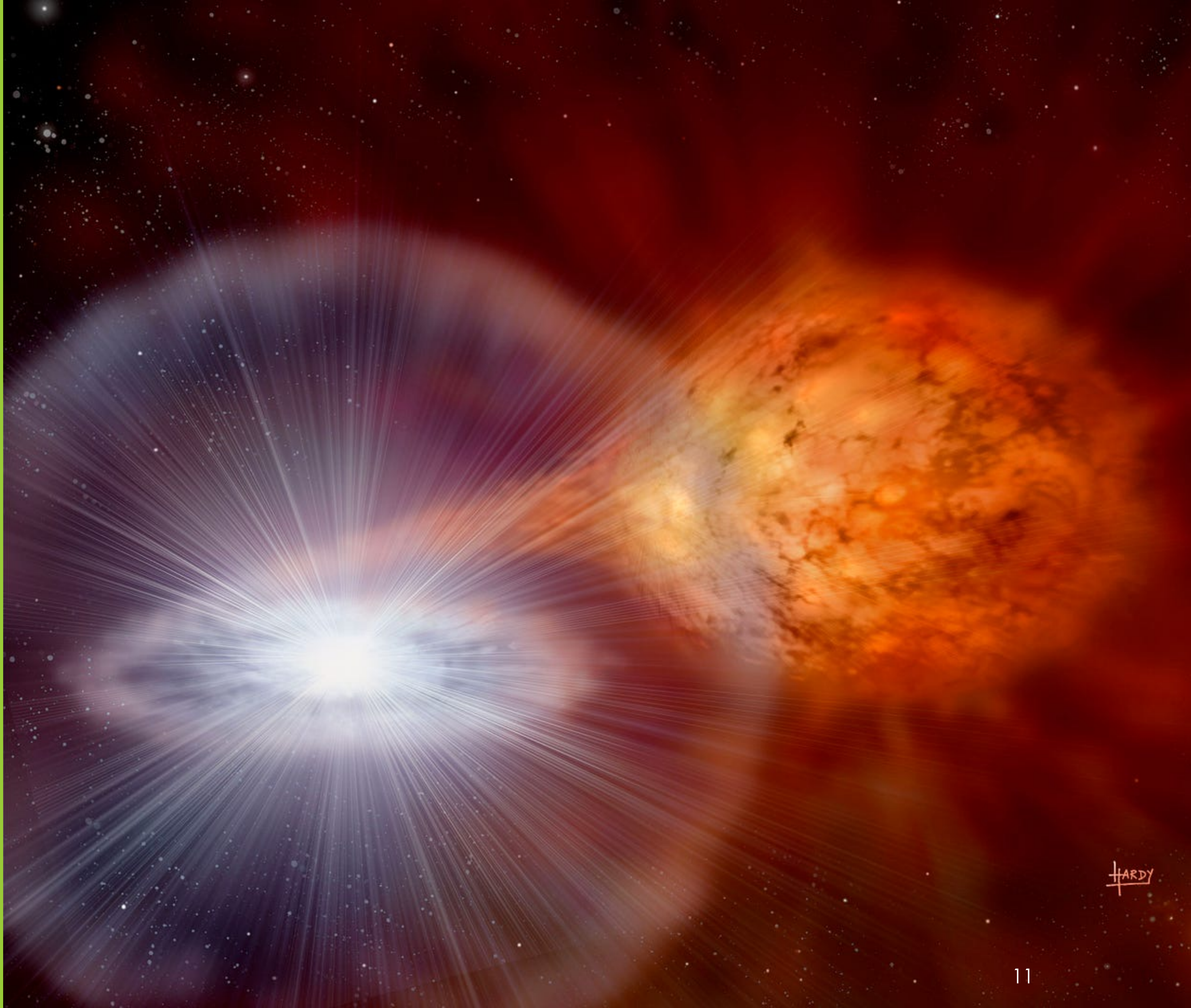


Why novae?

3. The size of the acceleration region can be constrained observationally.

Novae

Accretion from a stellar companion triggers runaway nuclear fusion on the surface of a white dwarf, leading to an outburst.



ɣ-ray production in symbiotic novae

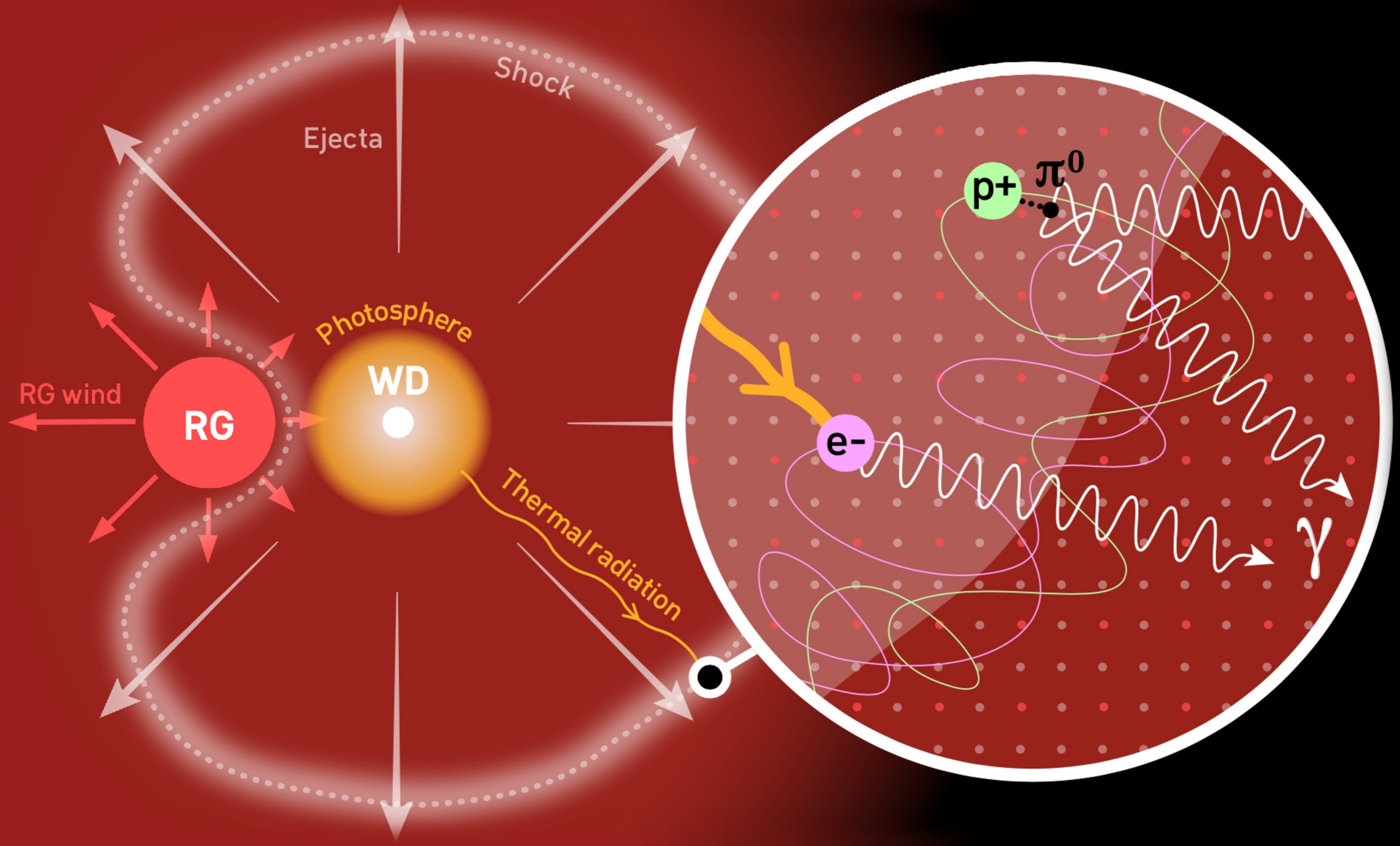


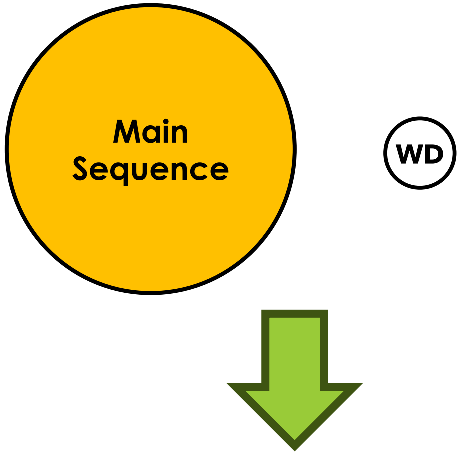
Image Credit: MAGIC22

γ-ray production in classical novae

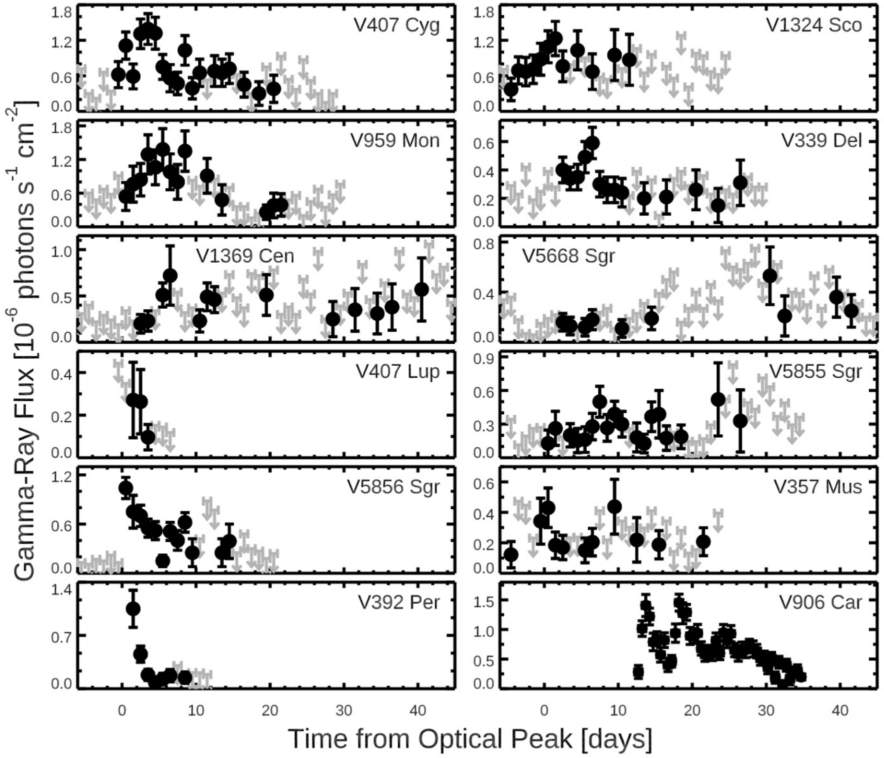
Classical novae have main sequence companions, with little to no stellar wind.

But, **they still produce GeV γ-rays!**

The shocks responsible are "internal" (fast material colliding with previously-ejected slow material).*



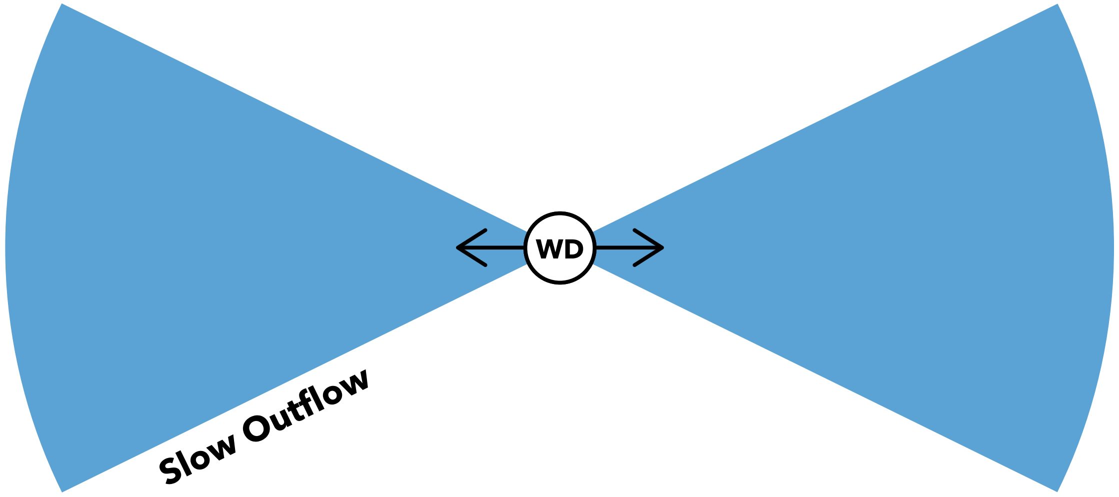
Chomiuk+21



*Friedjung+87, Metzger+14, Martin+18, Hachisu+22

The hydrodynamic picture

This scenario is consistent with optical/infrared/radio imaging*, as well as the evolution of optical spectral lines**.



*Schaefer+14, Aydi+25, Chomiuk+14

**Ribeiro+13, Shore+13, Aydi+20

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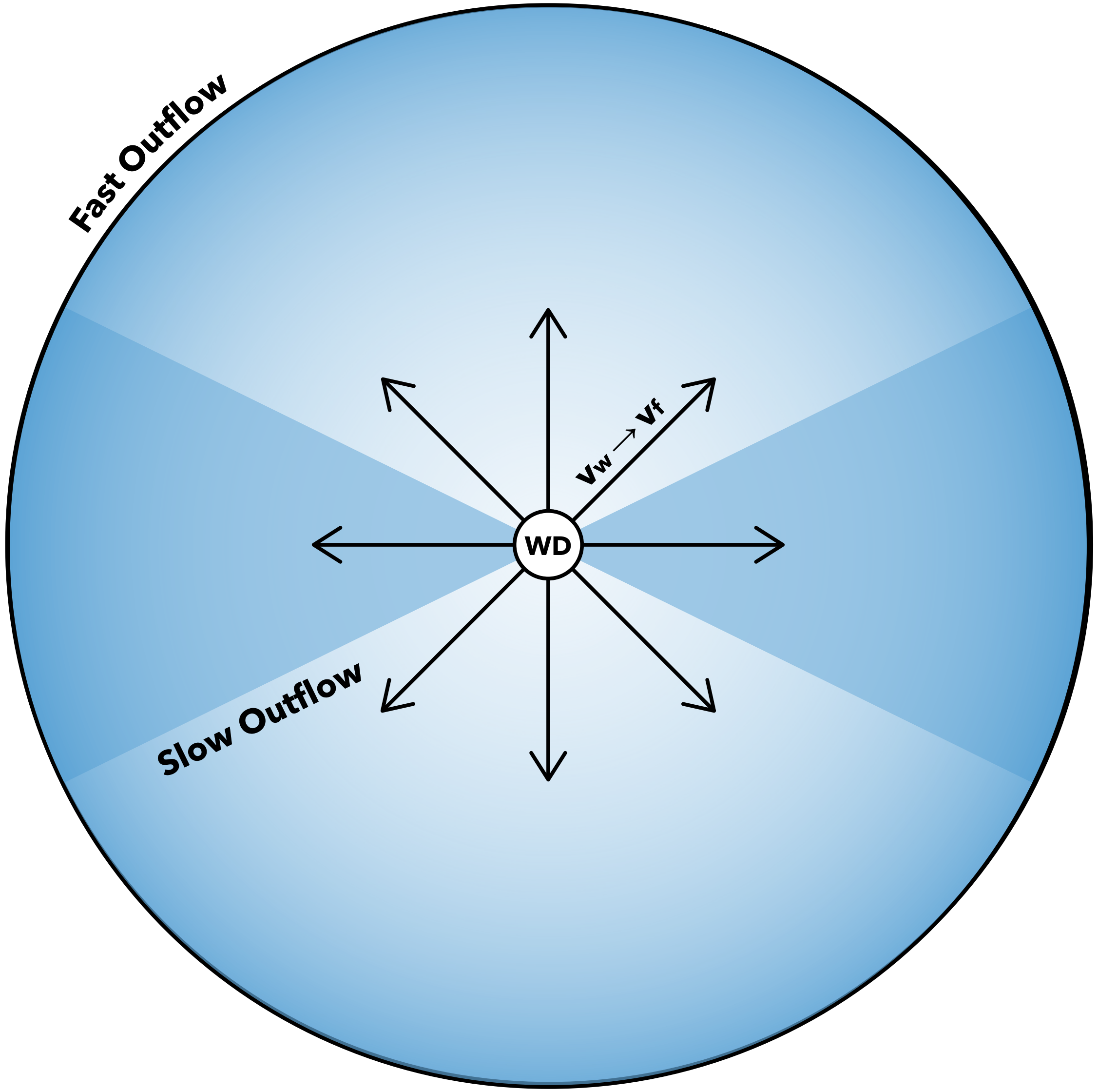

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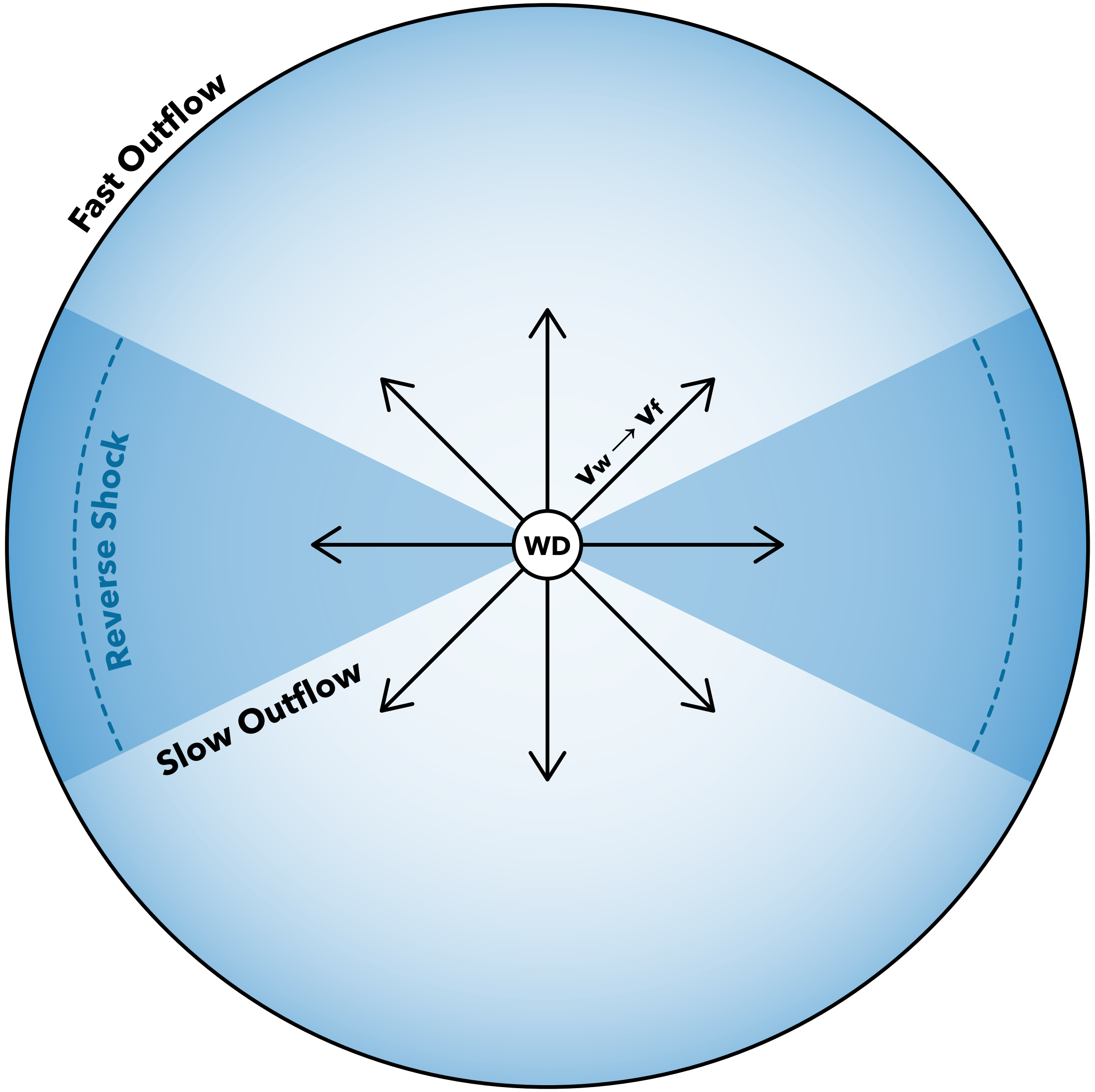

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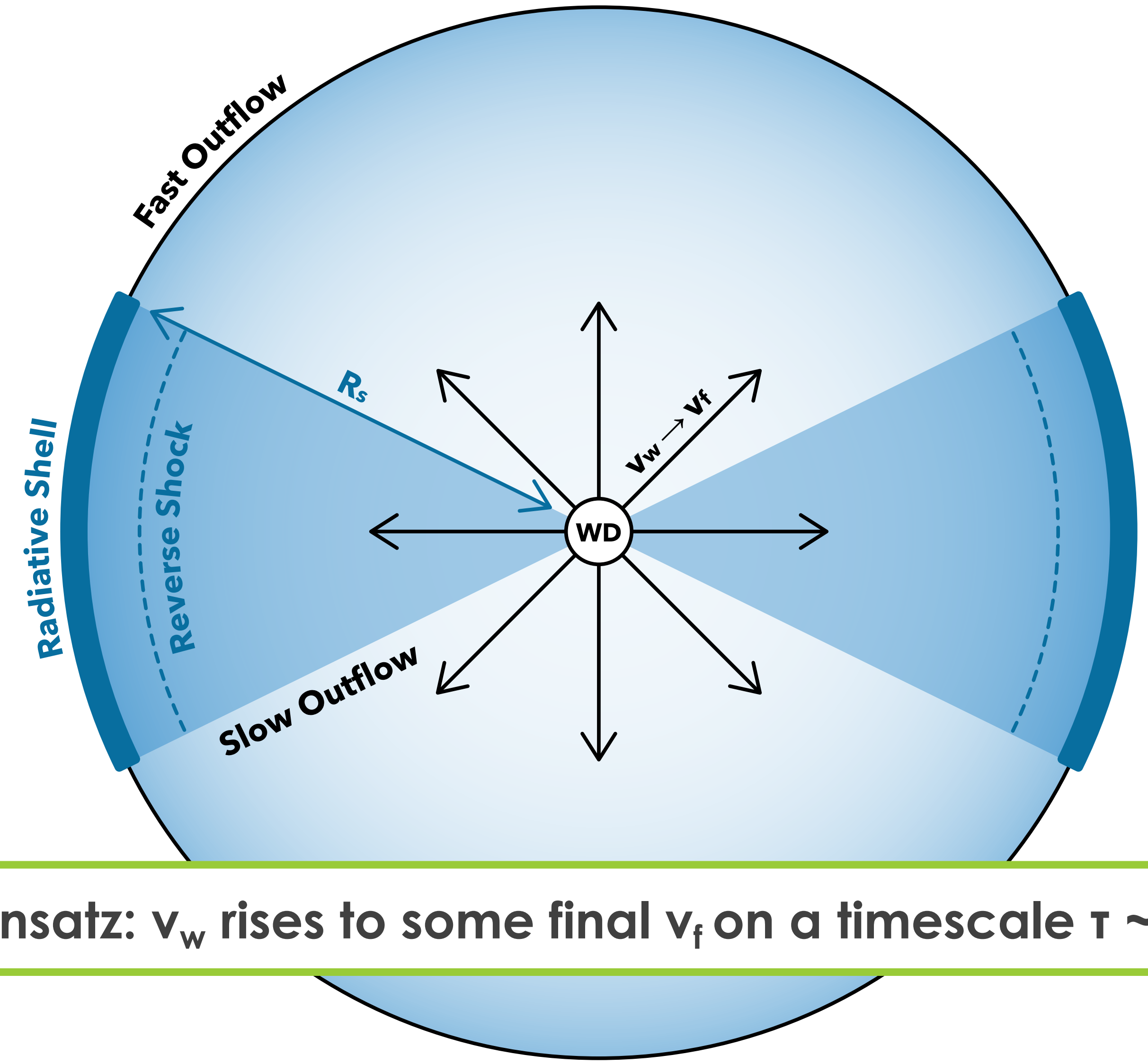


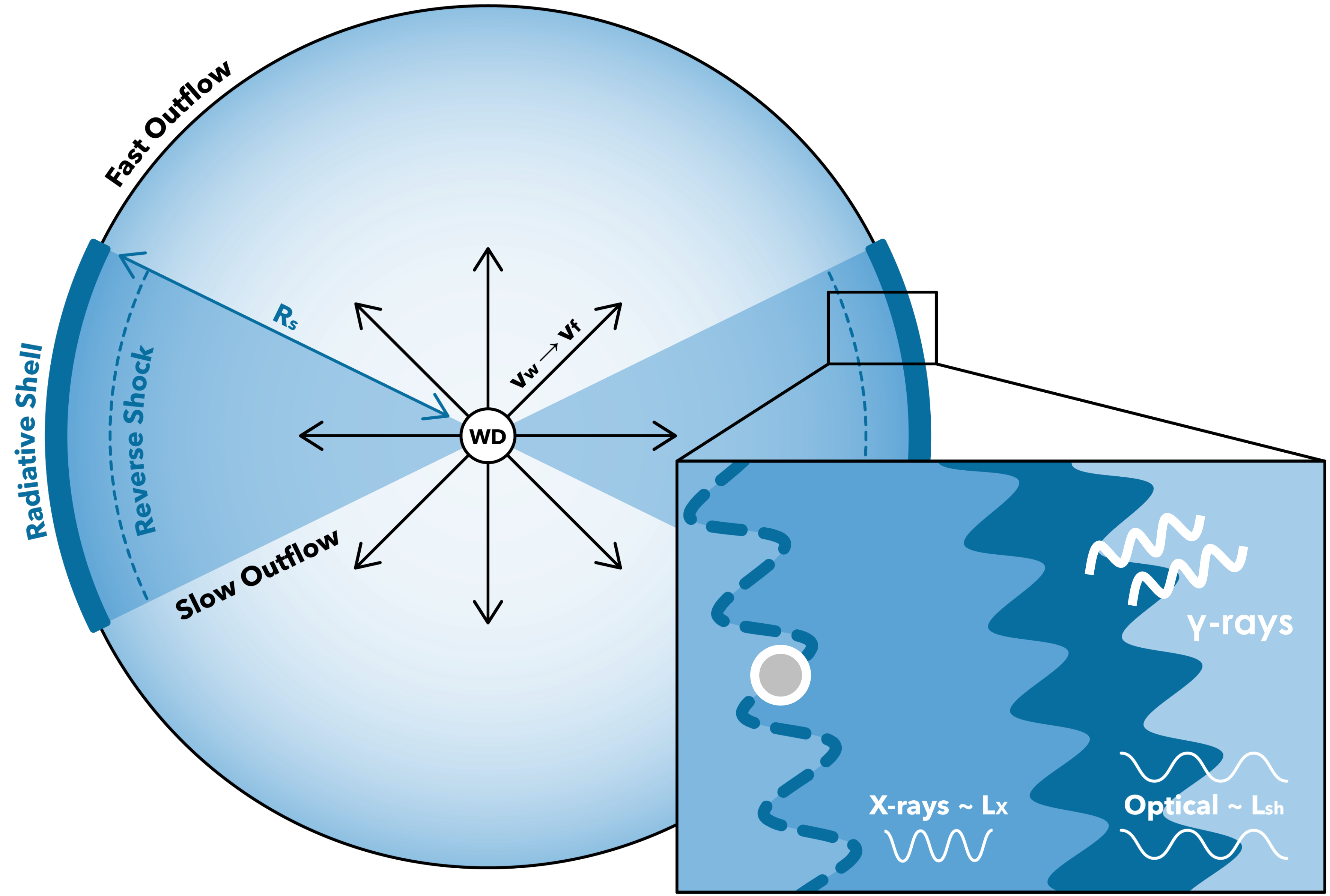
Ansatz: v_w rises to some final v_f on a timescale $\tau \sim t_2$

*Schaefer+14, Aydi+25, Chomiuk+14

**Ribeiro+13, Shore+13, Aydi+20

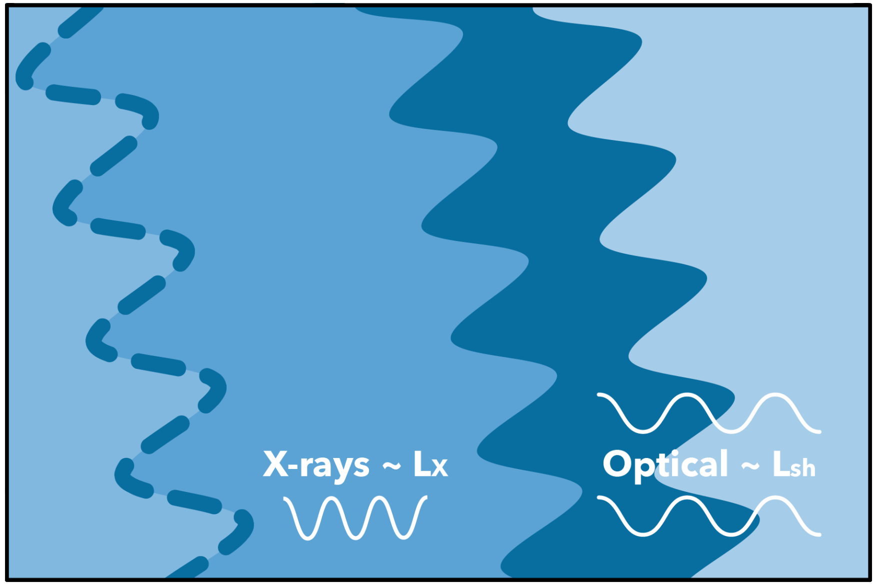
Particle acceleration

Internal shocks provide a very narrow (but observationally constrained) region in which to accelerate particles.



Particle acceleration

The acceleration region grows with time; so too does the maximum energy.



Putting it all together

Symbol	Description	Fiducial Value (Range)
$M_{\rm env}$	Envelope mass	10^{-4} $(10^{-6} - 10^{-4}) M_\odot$
$\tau \approx 0.5 t_2$	Envelope removal time	20 $(10 - 75)$ d
$v_{\rm f} \approx 2 v_2$	Final wind speed	6000 $(2000 - 10^4)$ km $\rm s^{-1}$
$f_{\rm X} \equiv L_{\rm X}/L_{\rm sh}$	X-ray efficiency	5×10^{-5} $(10^{-4} - 10^{-5})$
$\Delta_{\rm s}/R_{\rm s}$	Cool shell thickness	10^{-2} $(10^{-3} - 10^{-2})$
$f_\Omega \equiv \Delta\Omega/4\pi$	Slow outflow covering fraction	0.3 $(0.1 - 1)$
$\xi_{\rm CR}$	Cosmic ray acceleration efficiency	0.03 $(0.01 - 0.1)$
$\xi_{\rm B}$	B-field amplification efficiency	0.01 $(10^{-3} - 0.1)$

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Constrained with radio observations

Constrained with optical observations

Constrained with X-ray observations

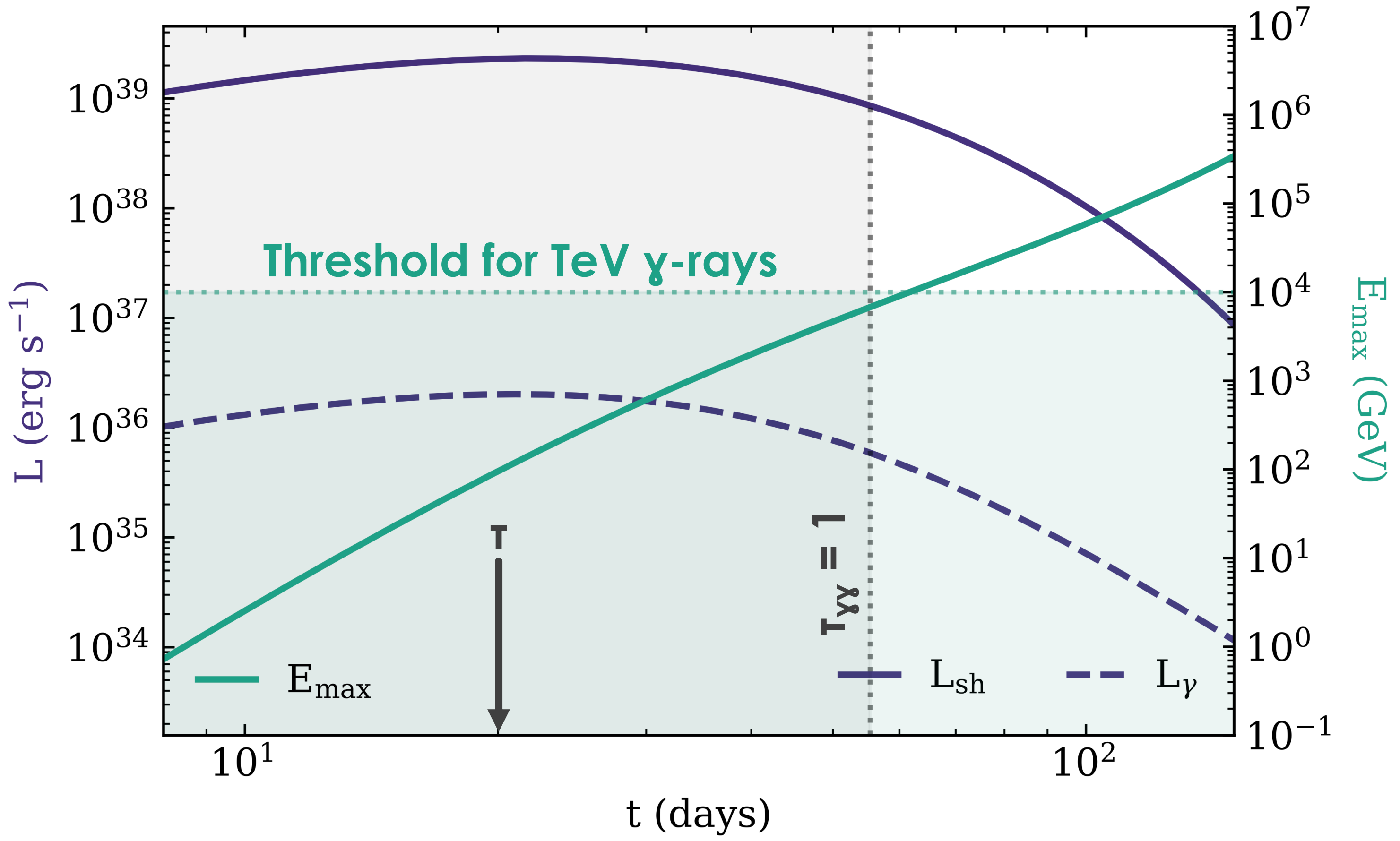
Constrained with γ-ray observations

Typical γ-ray light curve

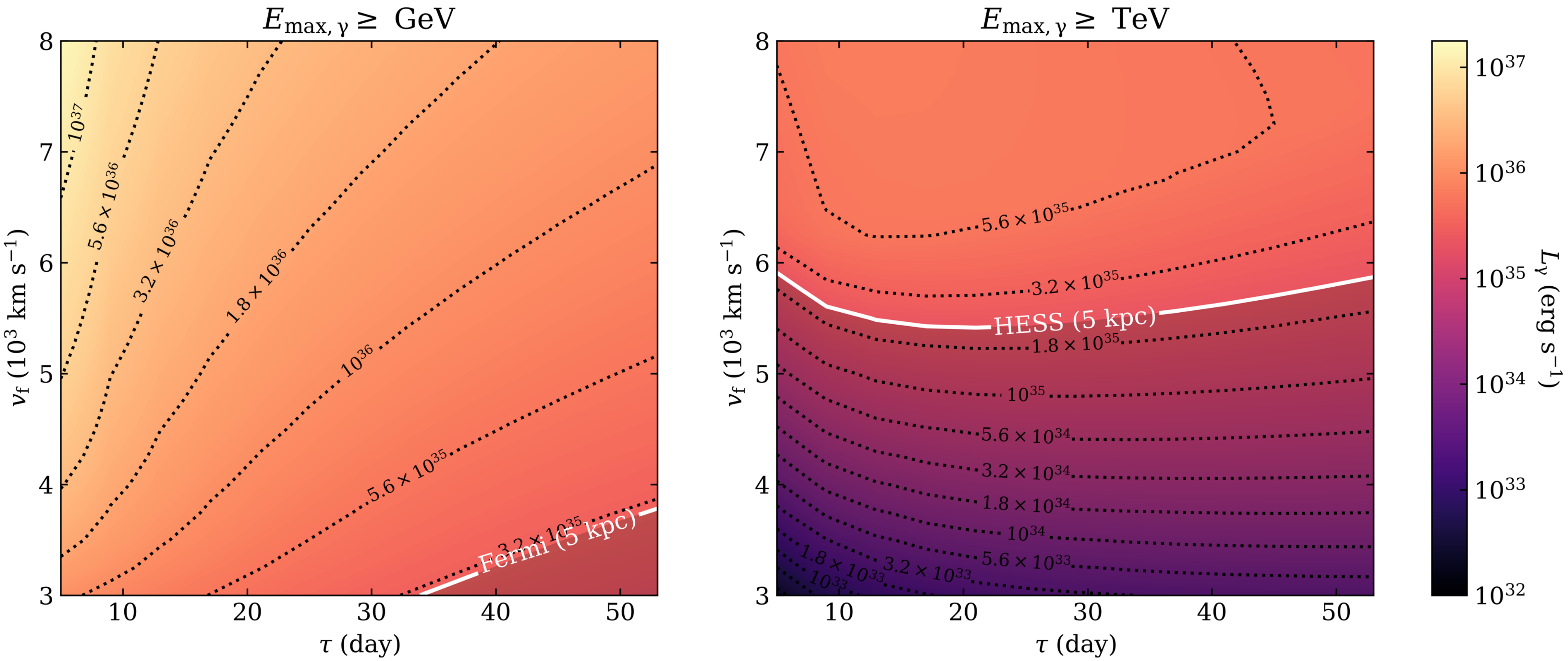
At early times ($t \lesssim \tau$), $t_\pi < t$; classical novae are cosmic ray calorimeters.

At late times, classical novae can produce TeV γ-rays!

$$\frac{dE_{CR}}{dt} = L_{CR} - \frac{E_{CR}}{t_\pi} - \frac{E_{CR}}{t}$$

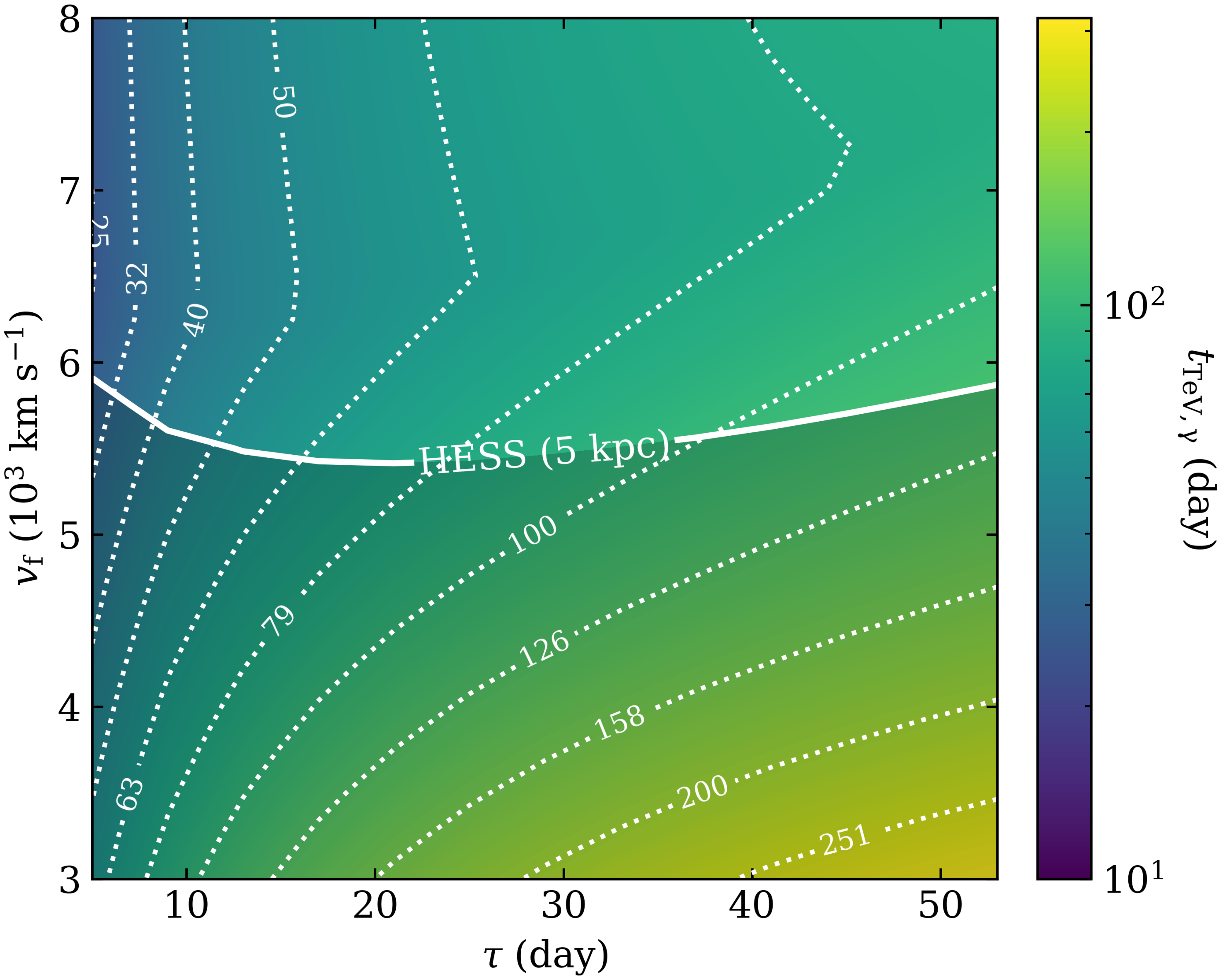


For some parameters, TeV emission may be detectable…



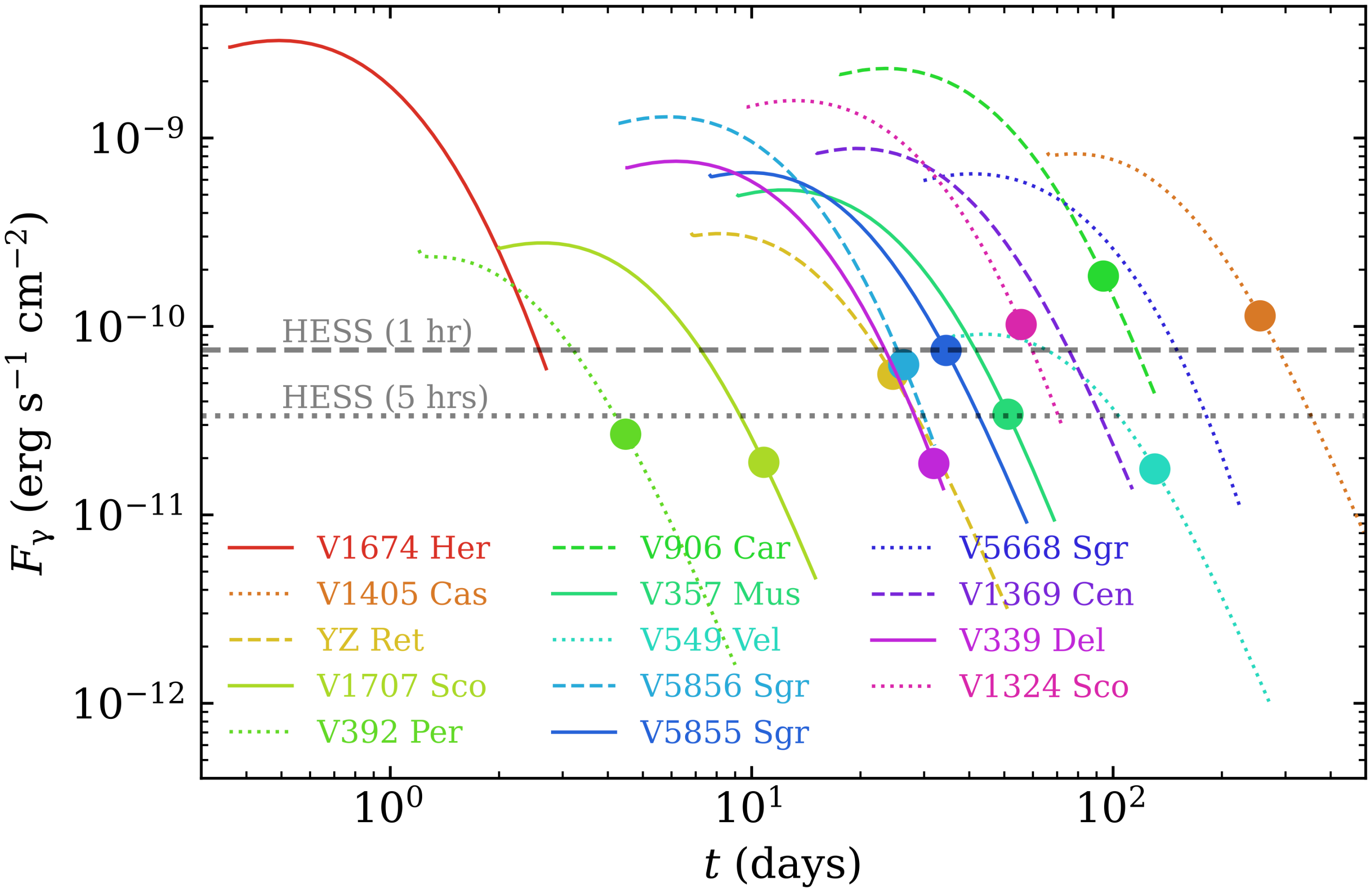
…but only at late times

The best candidates have large characteristic timescales and outflow velocities.



Applying this model to real novae

A handful of Fermi-detected classical novae may have been (briefly) detectable at TeV energies.



Summary

Novae are excellent laboratories for shock physics and particle acceleration.

To leverage this capability, we developed a parameterized (“toy”) model for classical nova evolution.

The parameters in this model can be constrained observationally, but require multi-wavelength coordination.

Classical novae may produce detectable TeV emission at late times.

For more information, see Diesing+26