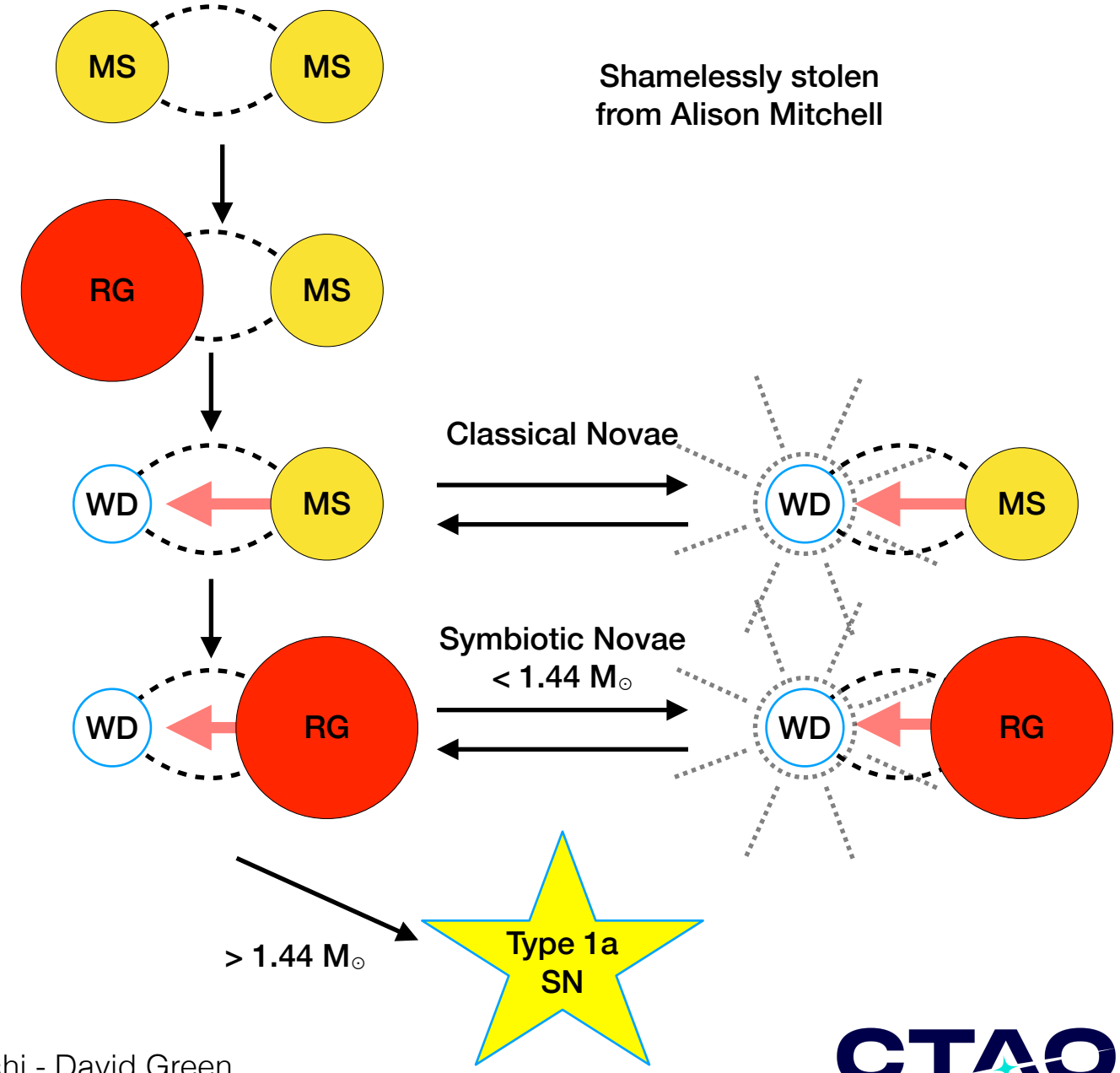
A Short Introduction to Novae

- Thermonuclear explosions caused by matter from a donor star collecting on a white dwarf surface in a binary system
- Matter on surface is in thermal equilibrium and eventually reaches fusion flashpoint
- Nova have a rate ~ 50 per year (Shafer, A. ApJ 2017)
- Various Classifications are adopted, in particular:
  - Classical -> MS donor star
  - Symbiotic -> Evolved donor star/RG
  - Recurrent -> Multiple observed outbursts
  - Dwarf -> mini-outbursts (thought to be AD instabilities)

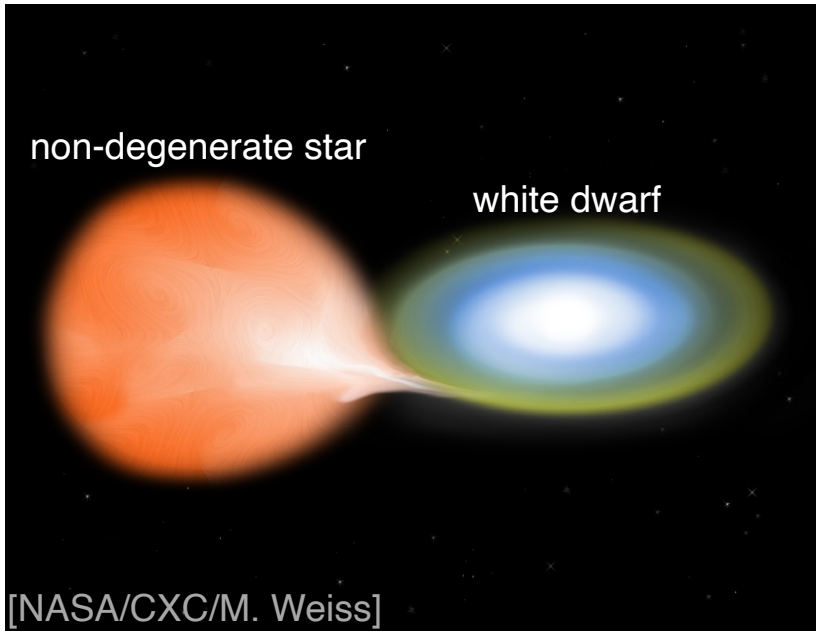


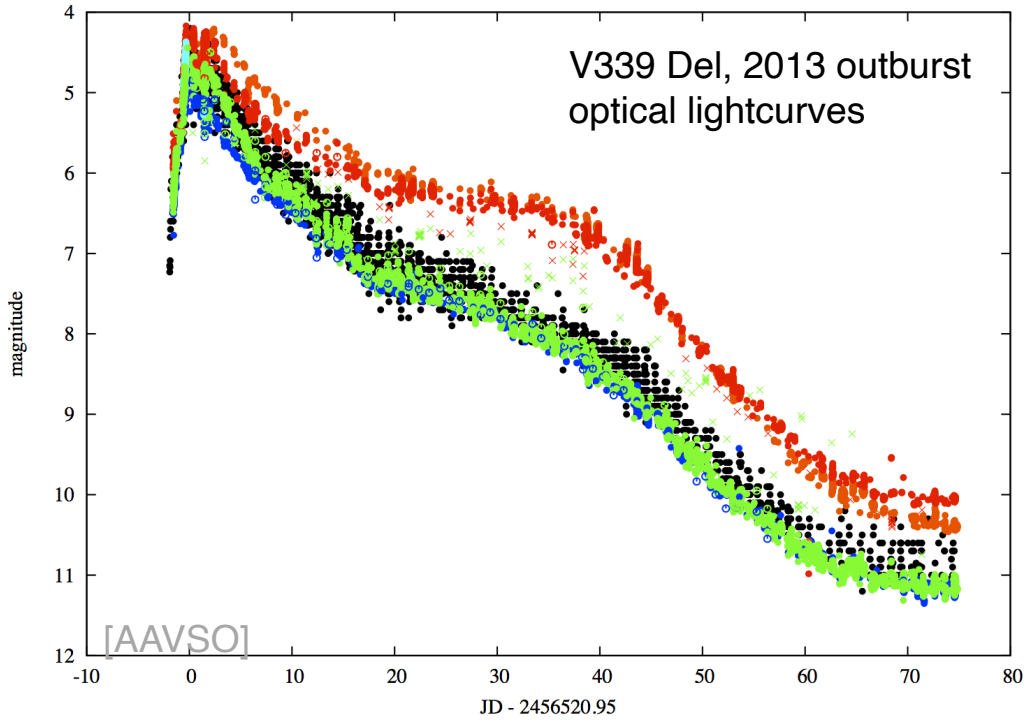
Shamelessly stolen from Alison Mitchell

Novae

Have long been observed in optical light, known to emit up to X-rays

main sequence companion: “classical nova”
red giant companion: “symbiotic nova”



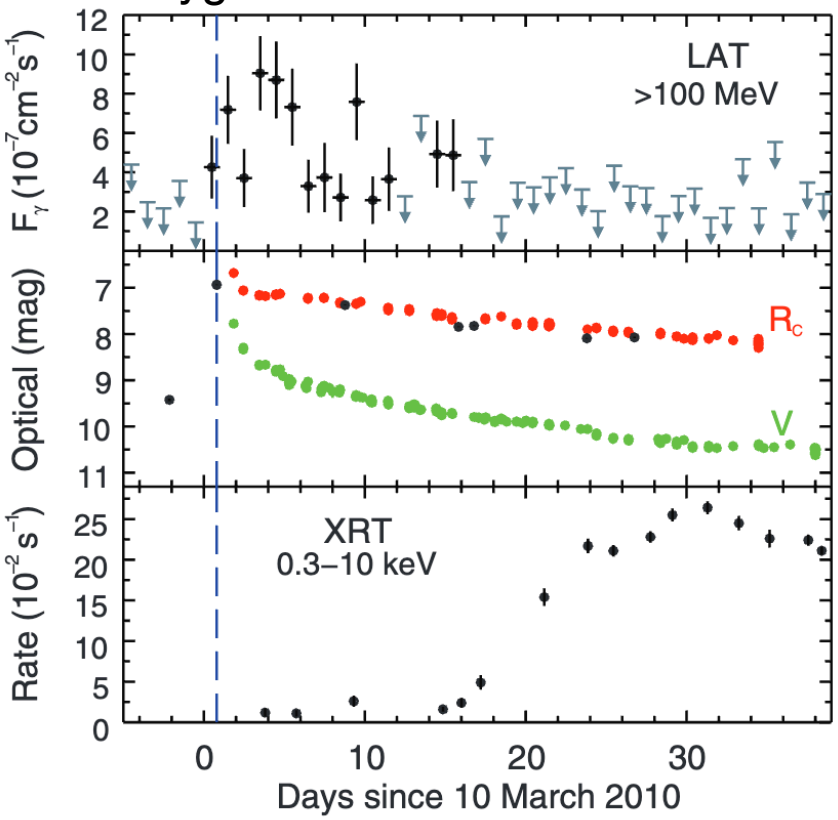


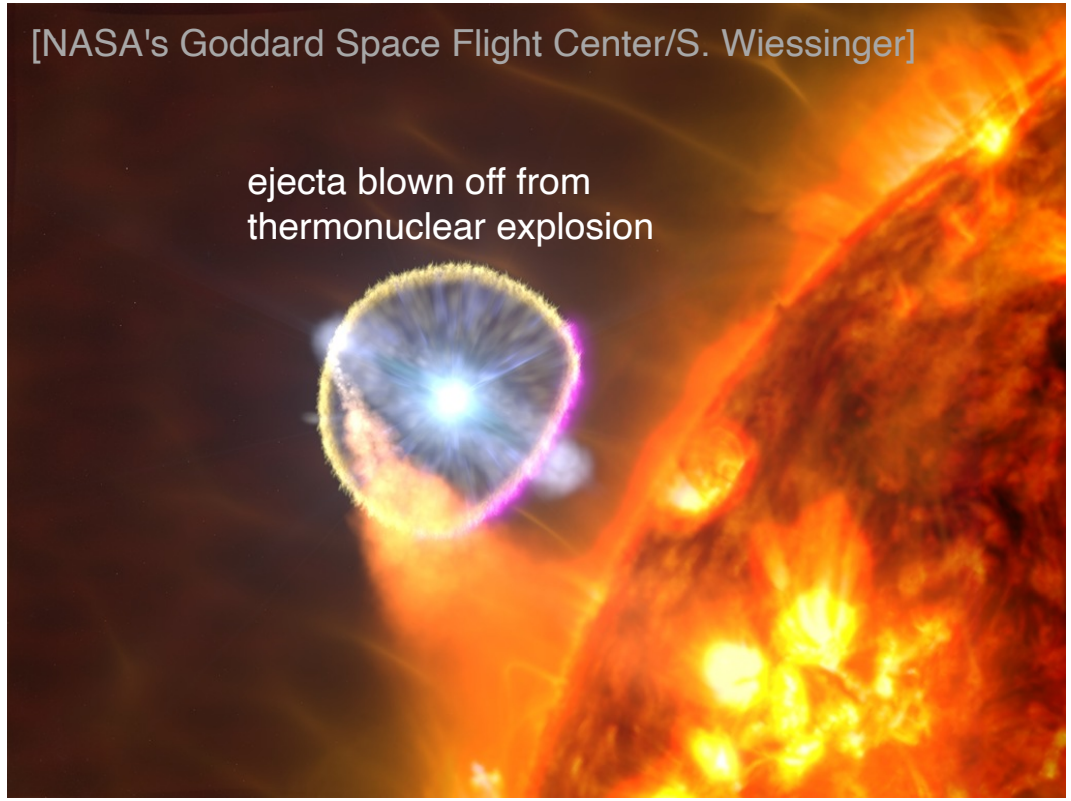
(David is the expert here, not me … ask him if you have any questions!)

Novae

Have long been observed in optical light, known to emit up to X-rays
In 2010, we learned they can also emit high-energy gamma rays (>100 MeV; Fermi-LAT)

V407 Cyg [A. A. Abdo et al., Science 329 (2010)]





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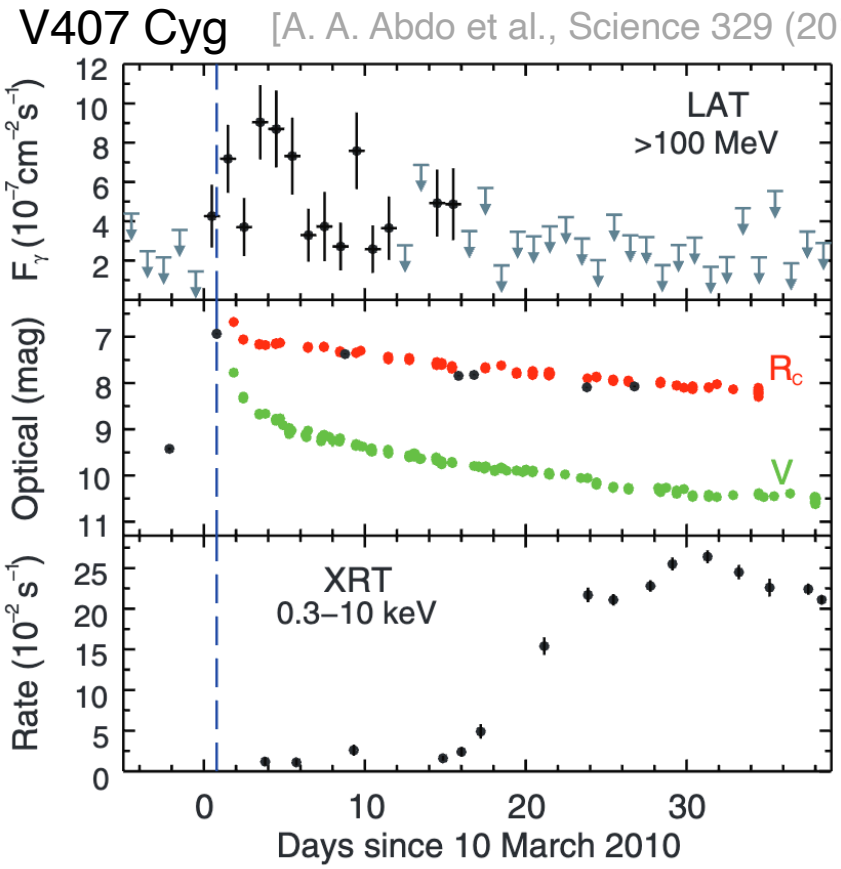

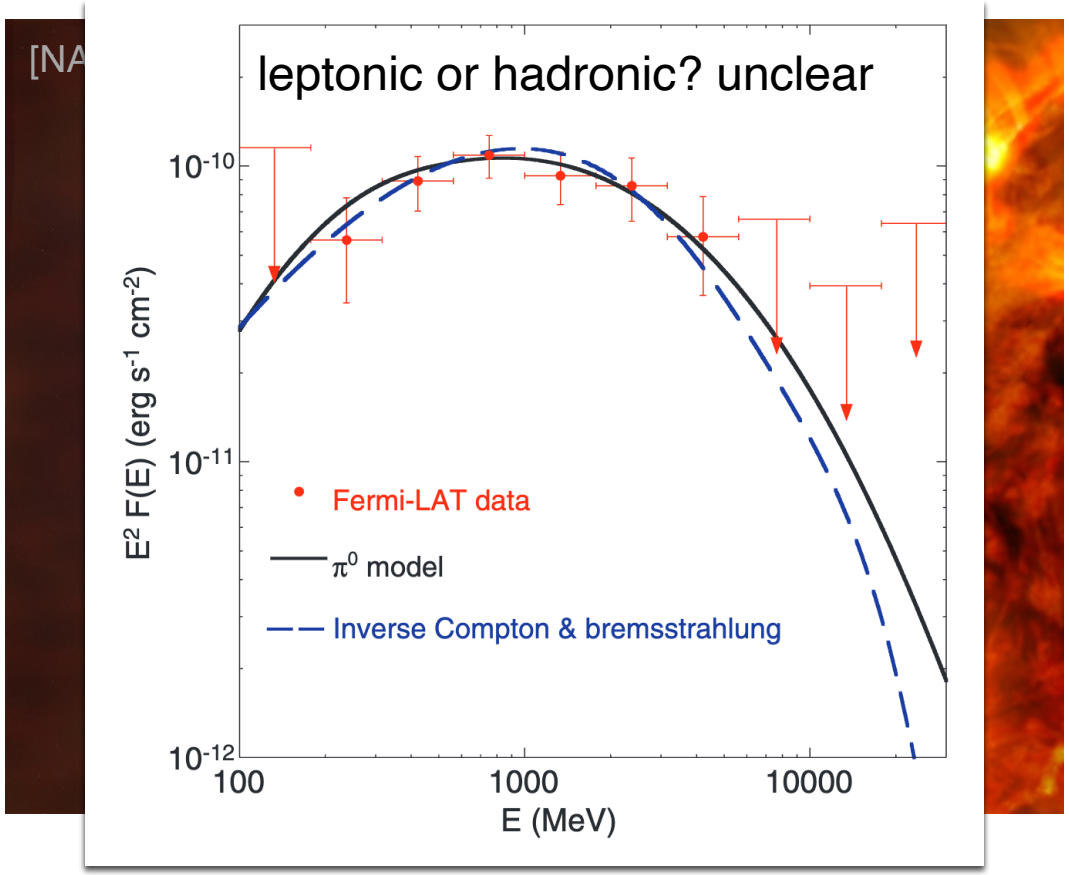

Novae

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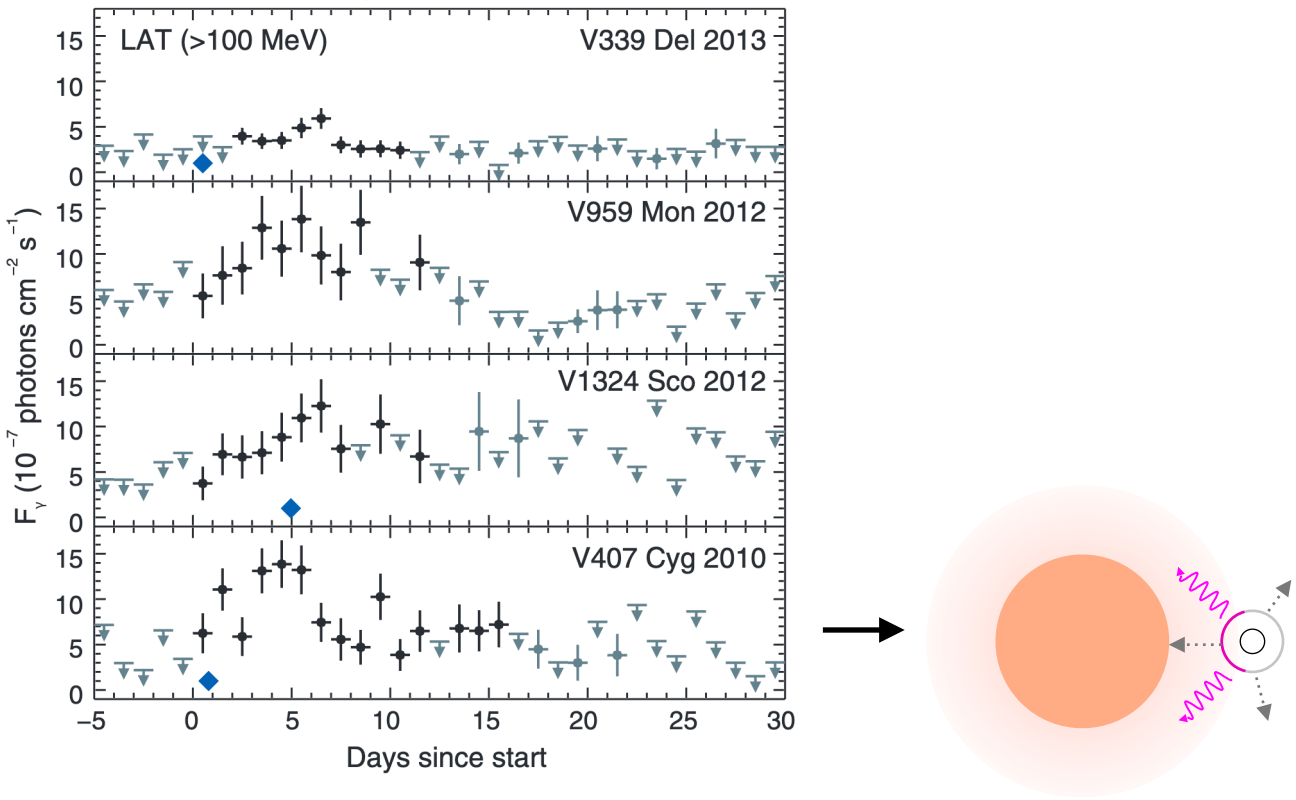
More Fermi-LAT novae have been discovered since then, w the gamma rays likely coming from different regions

[M. Ackermann et al., Science 345 (2014)]



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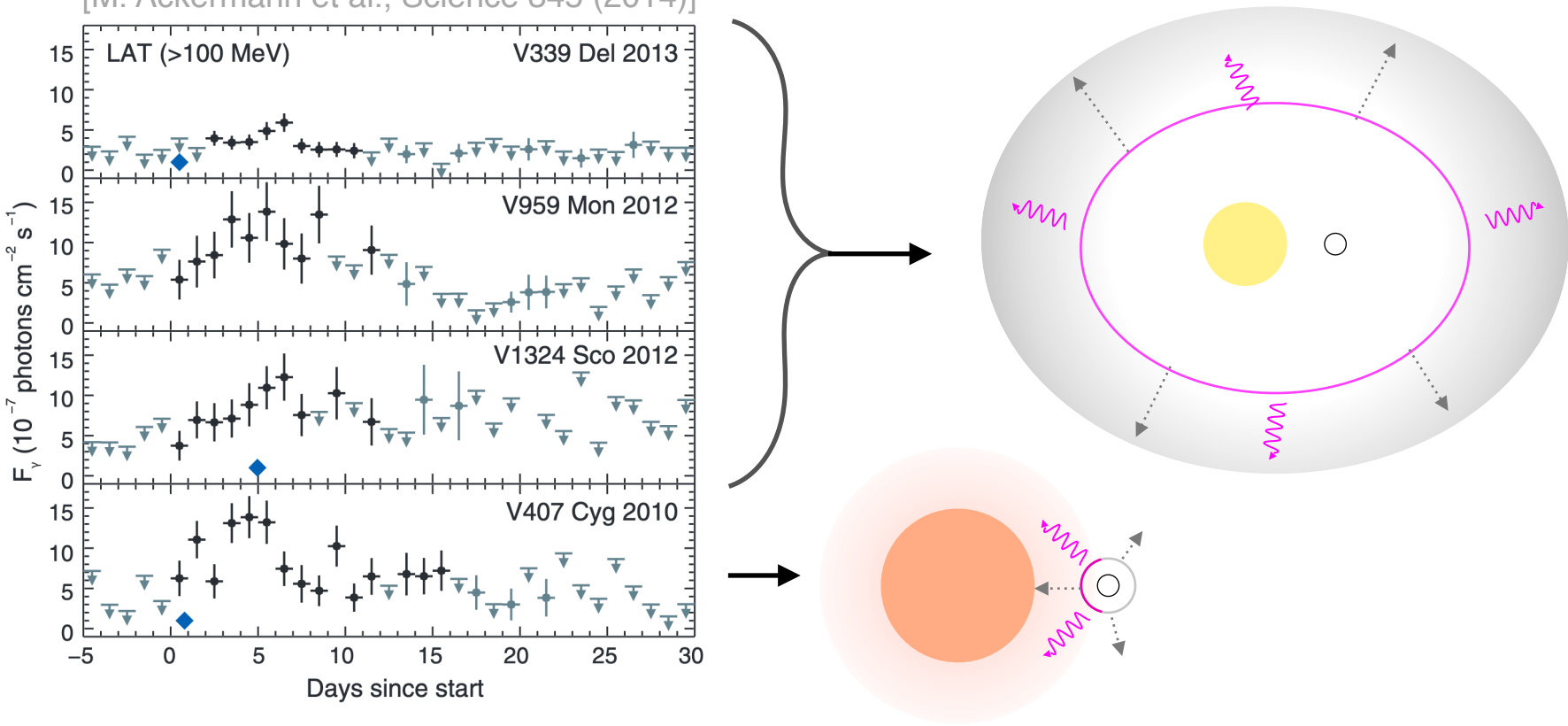

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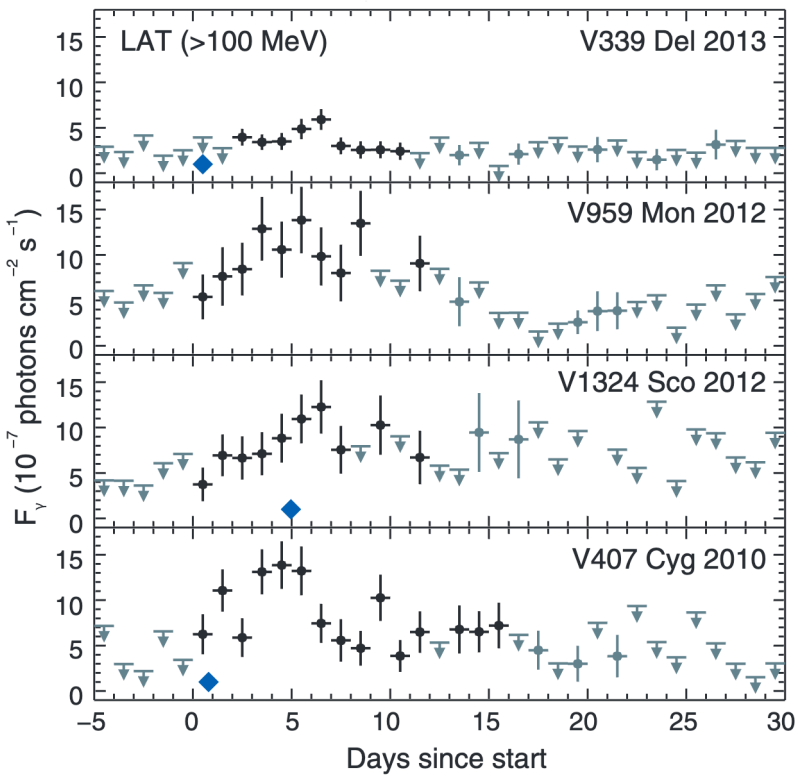
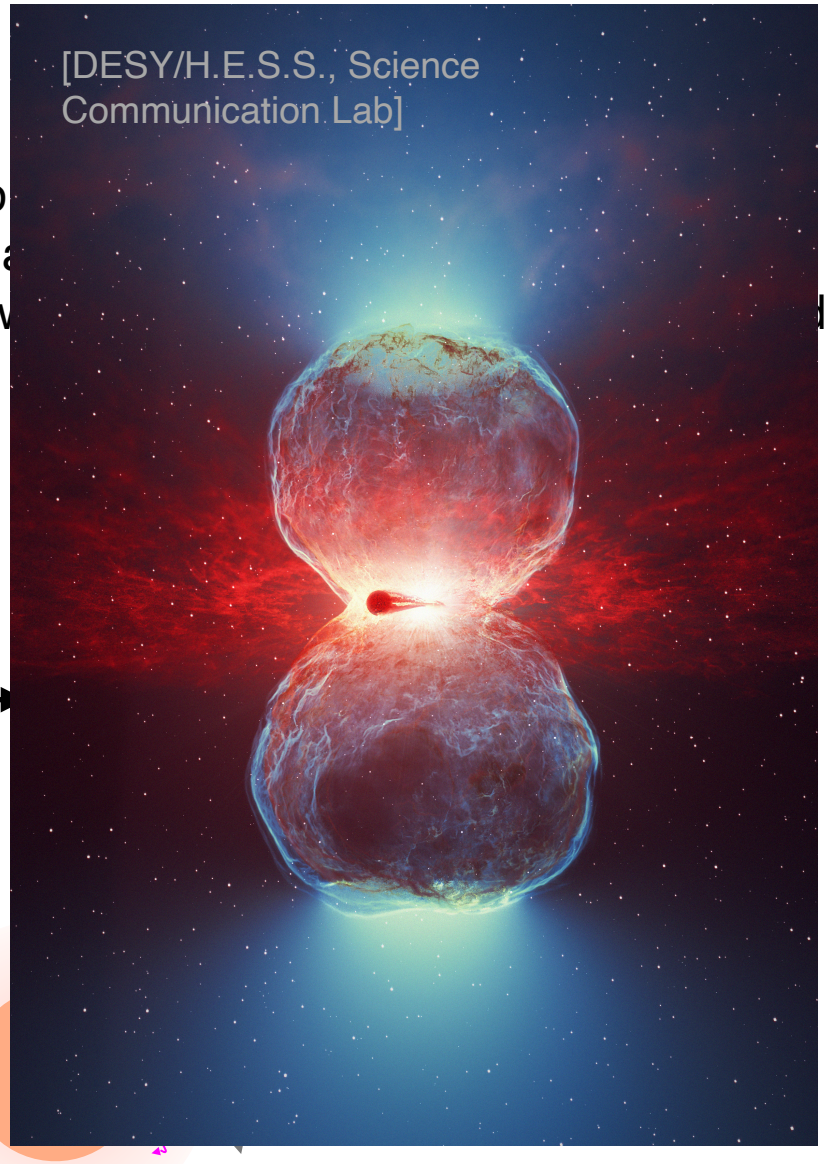
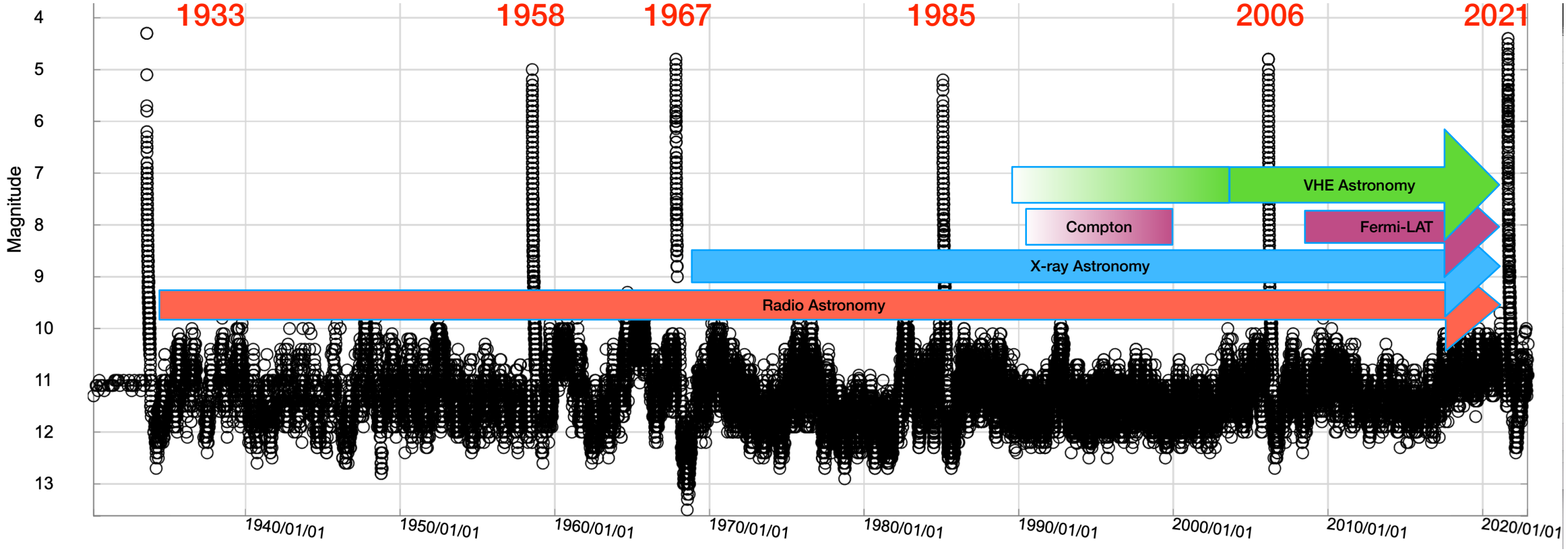




RS Ophiuchi



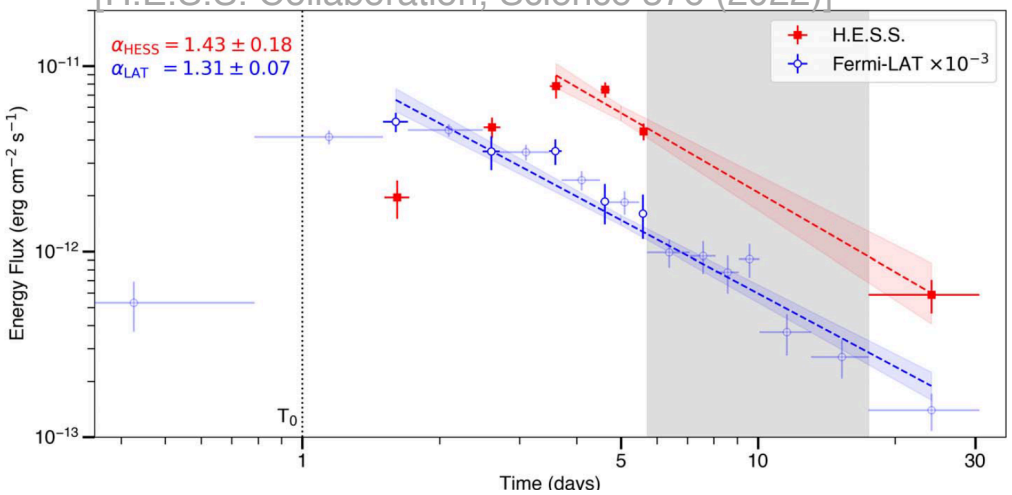
- Has major outburst every ~ 15 - 20 years
- 2021 outburst very well studied in almost all wavelengths

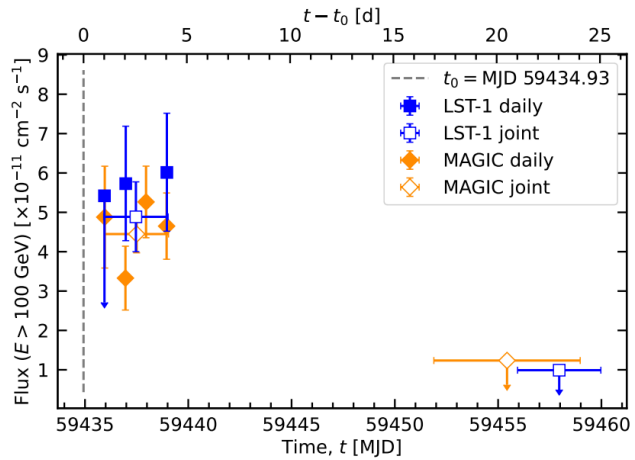
RS Ophiuchi

Very-high-energy gamma-ray emission

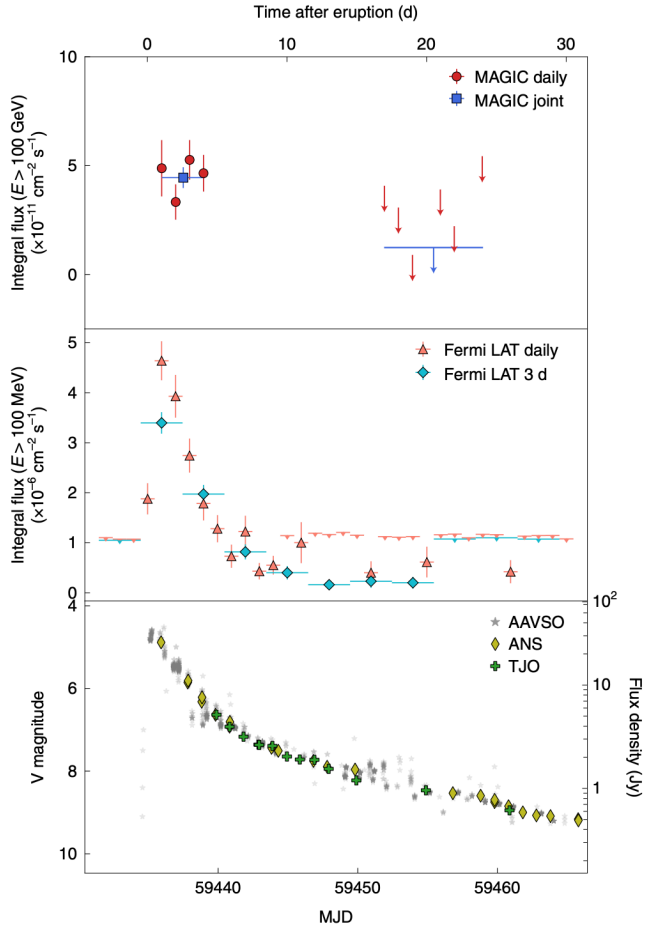
In 2021, VHE gamma rays were detected from the recurrent nova RS Ophiuchi by H.E.S.S, MAGIC, LST-1

[H.E.S.S. Collaboration, Science 376 (2022)]





[K. Abe et al., A&A 695 (2025)]



[V. A. Acciari et al., Nature Astronomy 6 (2022)]

RS Ophiuchi 2021

- Many telescopes had been anticipating RS Oph's eruption
- Optical Discovery by Brazilian Astronomer Alexandre Amorim (https://www.aavso.org/rs-ophiuchi) and confirmed by Keith Geary (vsnet-alert 26131) and Fermi-LAT ATel #14834
- VHE (HESS, MAGIC, LST-1) observations began on 9 Aug 21:30 UTC

RS Ophiuchi

AAX
Affiliation: Nucleo de Estudo e Observacao Astronomica - Jose Brazilicio de Souza (Florianopolis, Brazil) (NEOA-JBS)
Sun, 08/08/2021 - 22:22

Dear friends,

RS Ophiuchi seems to be in outburst.

In August 8, 2021, at 21:55 UT I estimated it in magnitude 5.0.

An image was taken and it is at website:

http://www.geocities.ws/costeira1/img/20210808_2159ut.jpg

with regards,

AAX

[Previous | Next | ADS]

Detection of VHE gamma-ray emission from the recurrent nova RS Ophiuchi with H.E.S.S.

ATel #14844; ***Stefan J. Wagner, for the H. E.S. S. collaboration***
on 10 Aug 2021; 18:34 UT
Credential Certification: Stefan J. Wagner (swagner@lsw.uni-heidelberg.de)

ubjects: Gamma Ray, >GeV, TeV, VHE, Binary, Nova

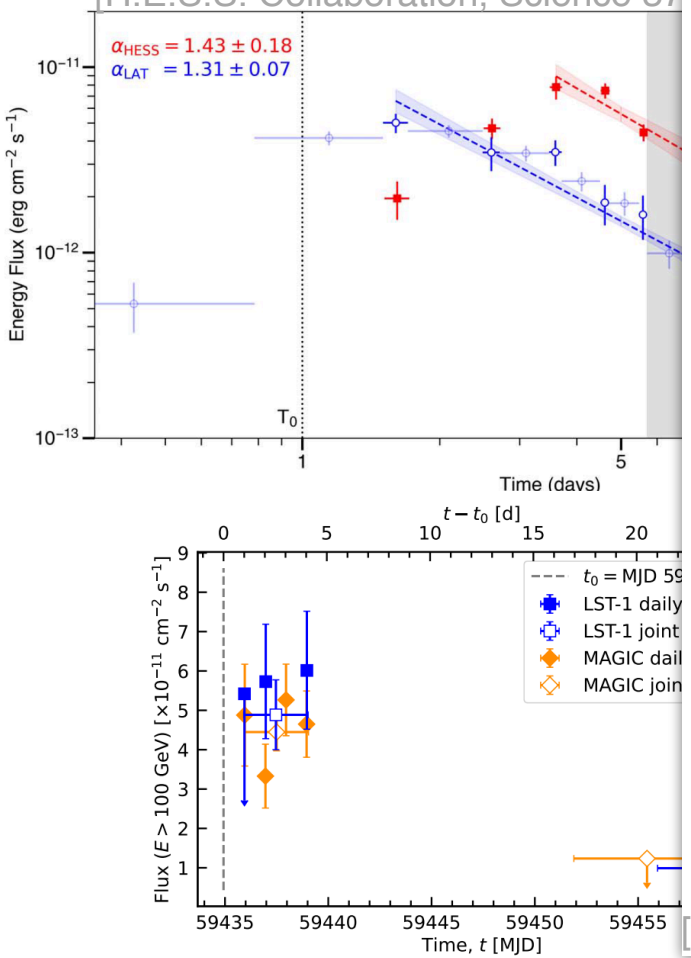
eferred to by ATel #: 14845, 14846, 14848, 14849, 14851, 14855, 14857, 14858, 14860, 4882, 14885, 14886, 14894, 15169

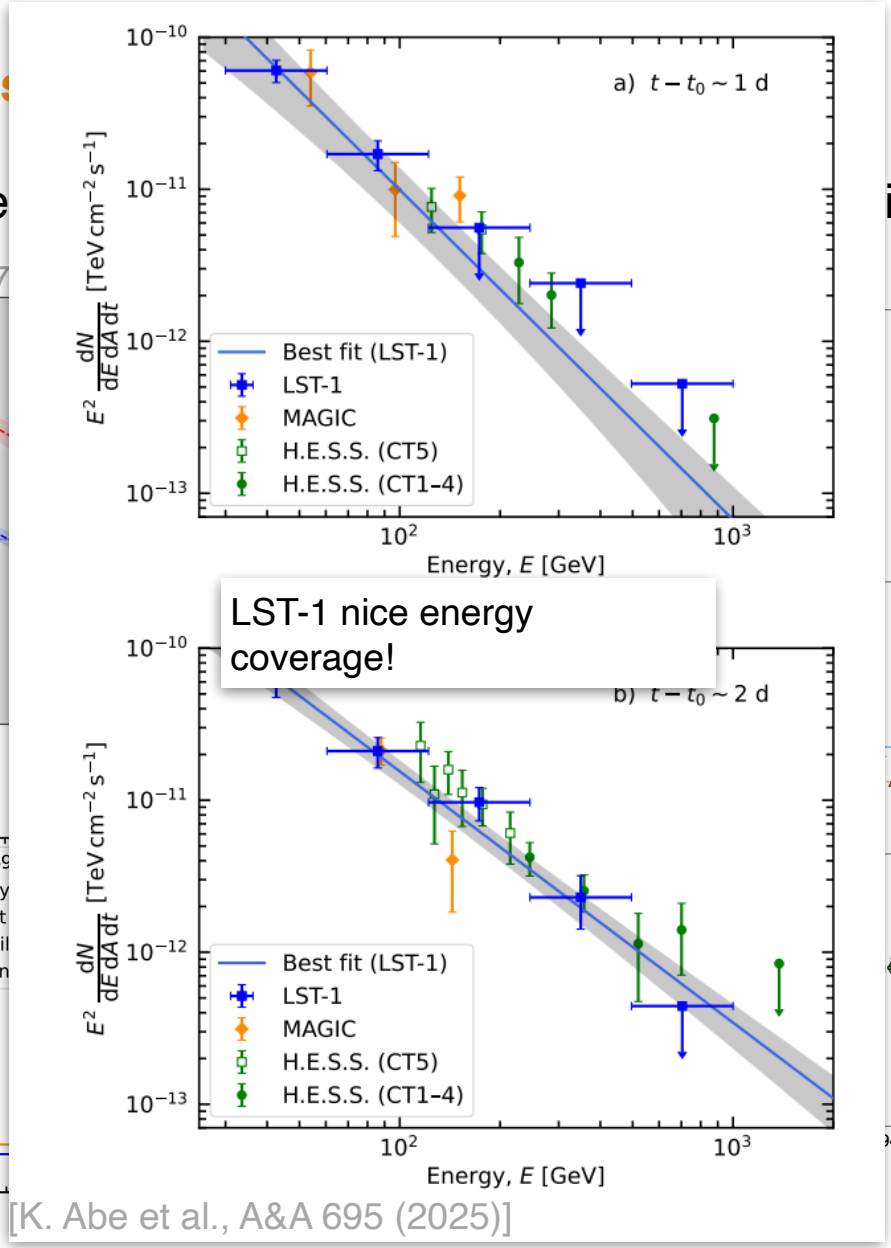
RS Ophiuchi

Very-high-energy gamma-ray emiss

In 2021, VHE gamma rays were dete i by H.E.S.S, MAGIC, LST-1

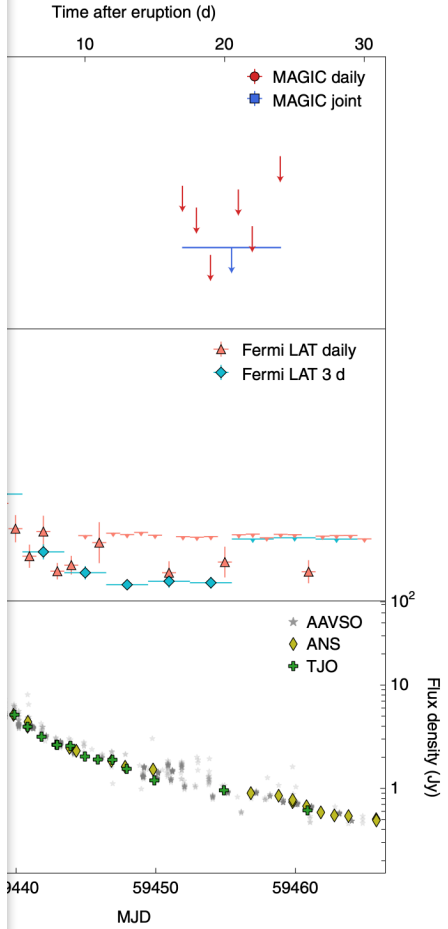
[H.E.S.S. Collaboration, Science 37





LST-1 nice energy coverage!

[K. Abe et al., A&A 695 (2025)]



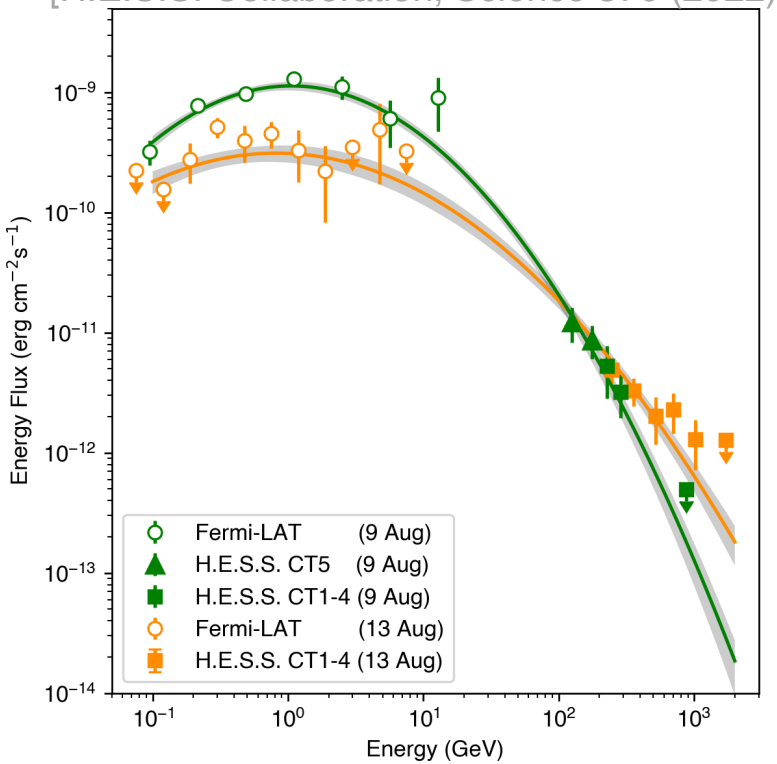
al., Nature Astronomy 6 (2022)]

RS Ophiuchi

Very-high-energy gamma-ray emission

Everyone agrees: more naturally explained by **hadronic** than leptonic processes

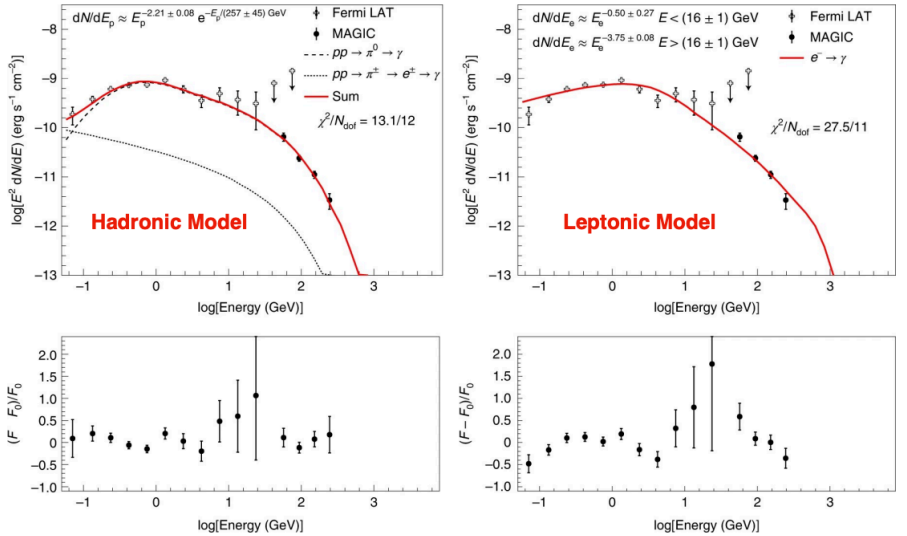
[H.E.S.S. Collaboration, Science 376 (2022)]



Gamma-ray Modeling

- Time dependent modeling based from MAGIC Coll., A&A, 582 (2015)
- Hadronic model favored over leptonic model
- Hadronic model has natural CR index ~2
- Leptonic requires ad hoc break and fits poorly

Acciari, V.A. Nat Astro 2022



RS Ophiuchi - David Green

[D. Green, 19th Recontres du Vietnam (2023)]

RS Ophiuchi

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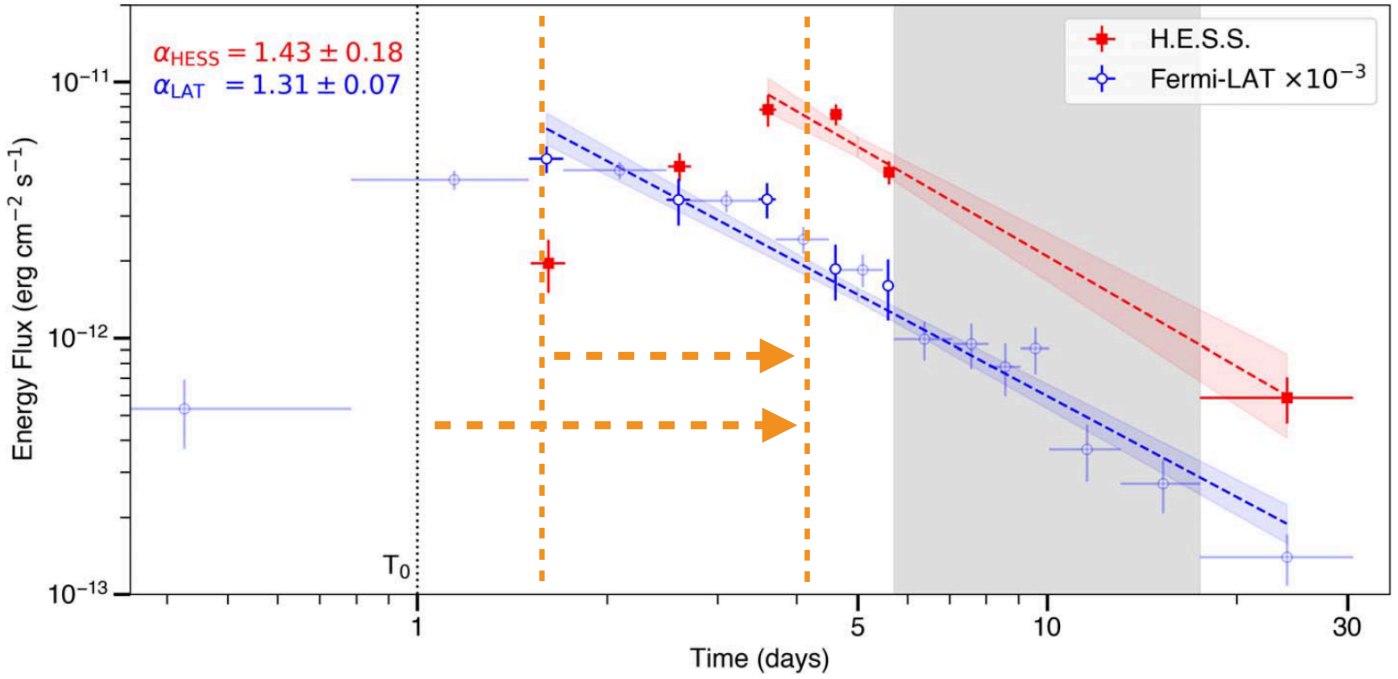
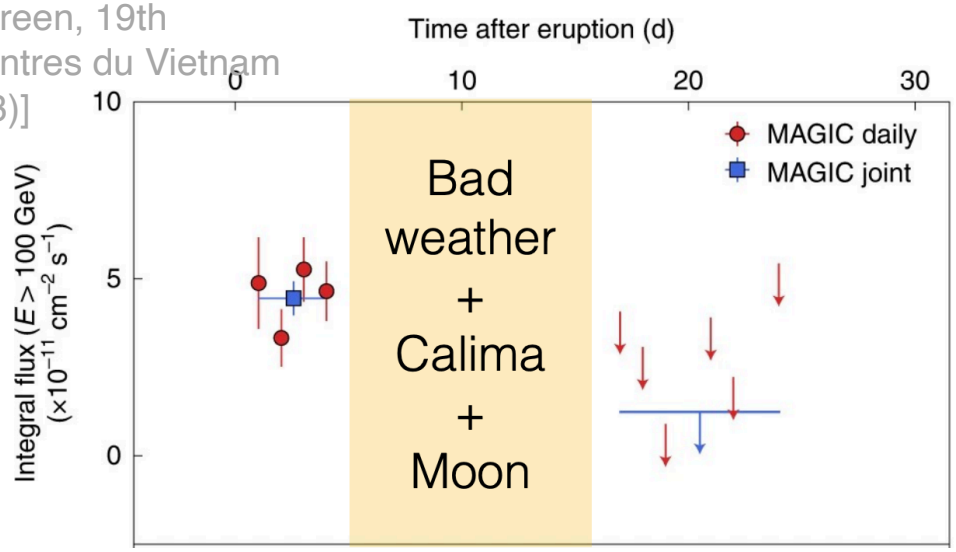


need more time for higher energy particles to be accelerated

RS Ophiuchi

pause to talk about atmospheric issues

[D. Green, 19th Recontres du Vietnam (2023)]



[Derek Strom, Giovanni Ceribella, MAGIC Collaboration]

[SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE]

RS Ophiuchi

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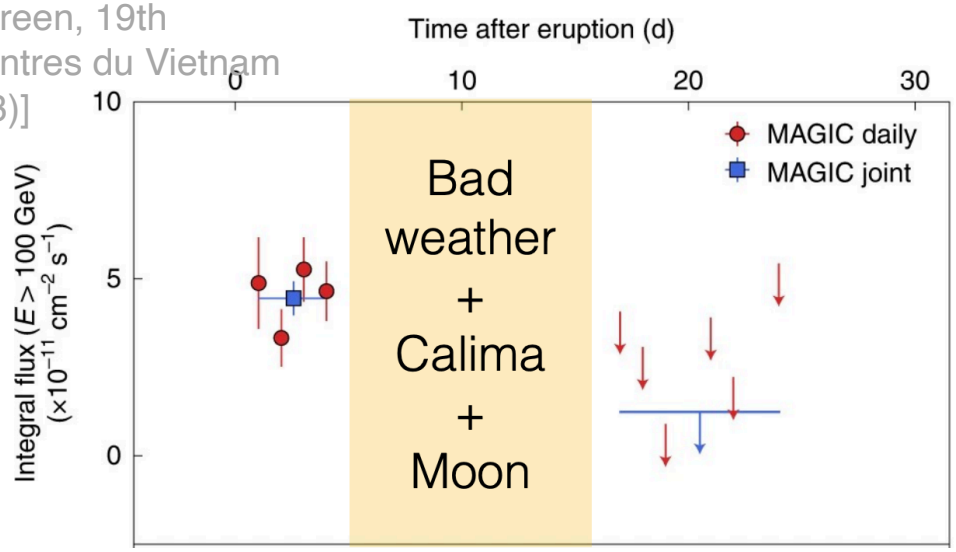
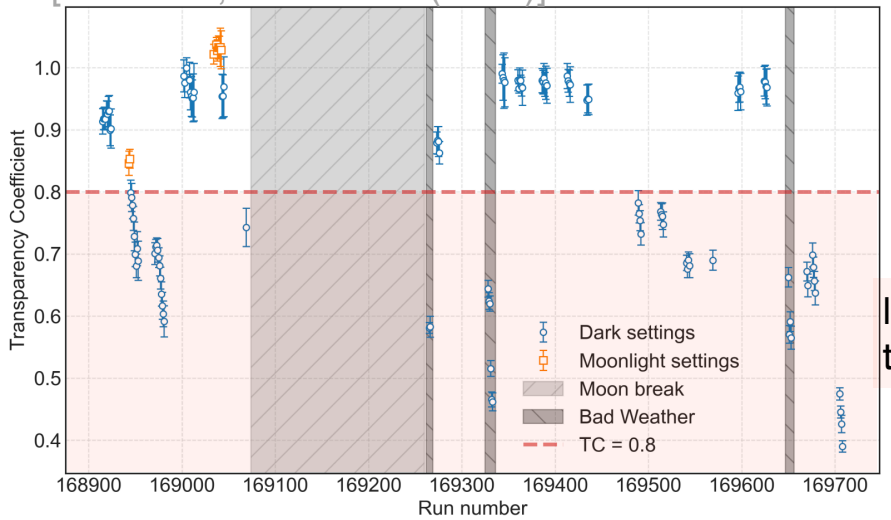
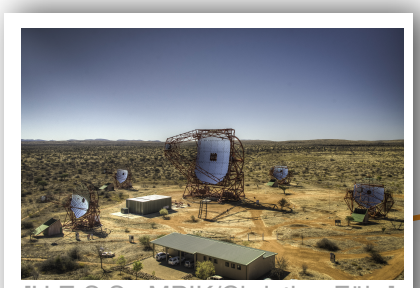
[D. Green, 19th Recontres du Vietnam (2023)]



[R. Konno, PhD thesis (2024)]

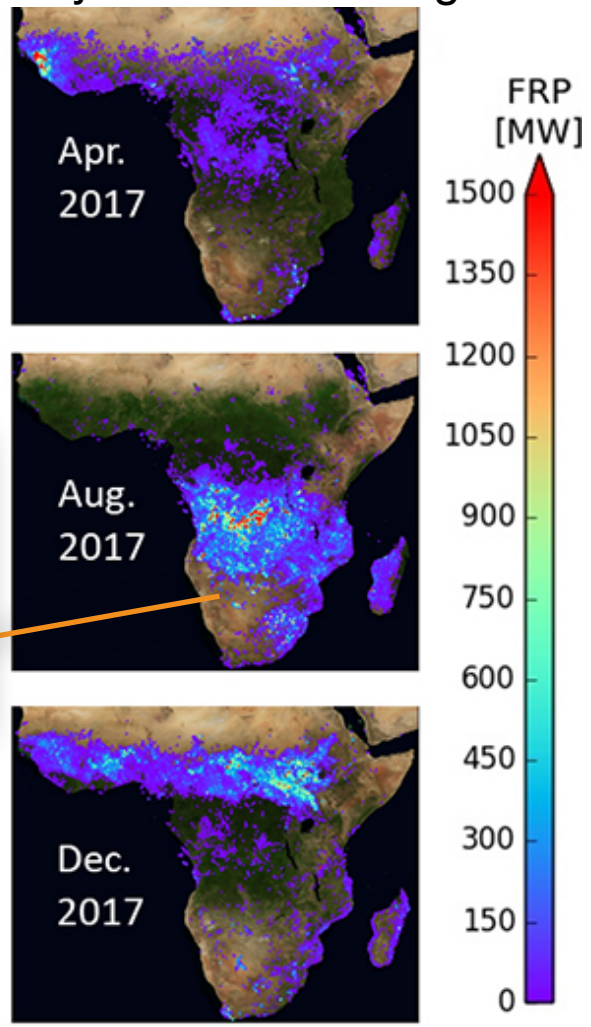


low atmospheric transparency



[H.E.S.S., MPIK/Christian Föhr]

yearly biomass burning



[C. Ichoku, ORE Climate Science (2020)]

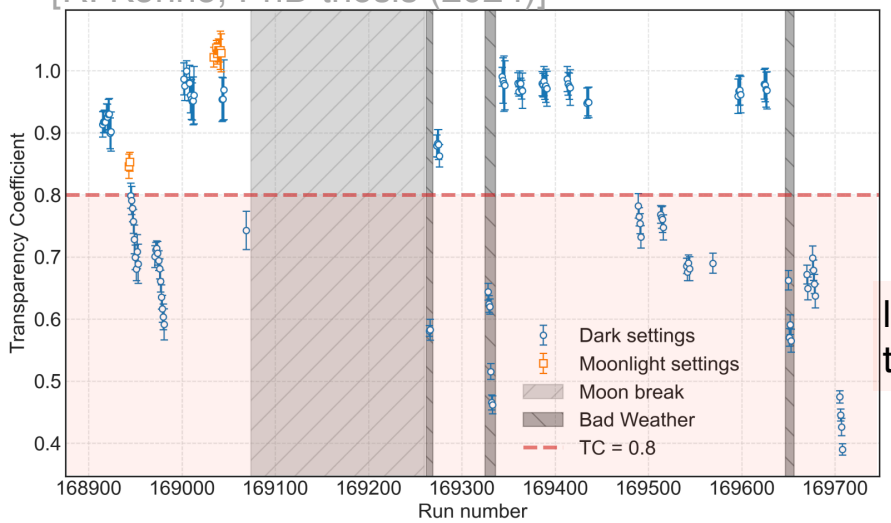
RS Ophiuchi

pause to talk about atmospheric issues

If the atmospheric issue is too bad, then we can't do anything :(

If the atmospheric issue is *not too* bad, we can try to correct for it

[R. Konno, PhD thesis (2024)]



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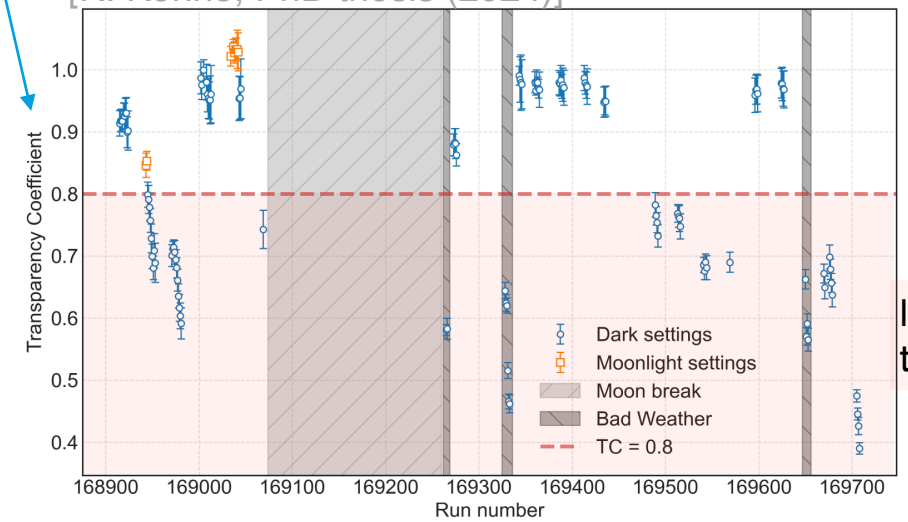
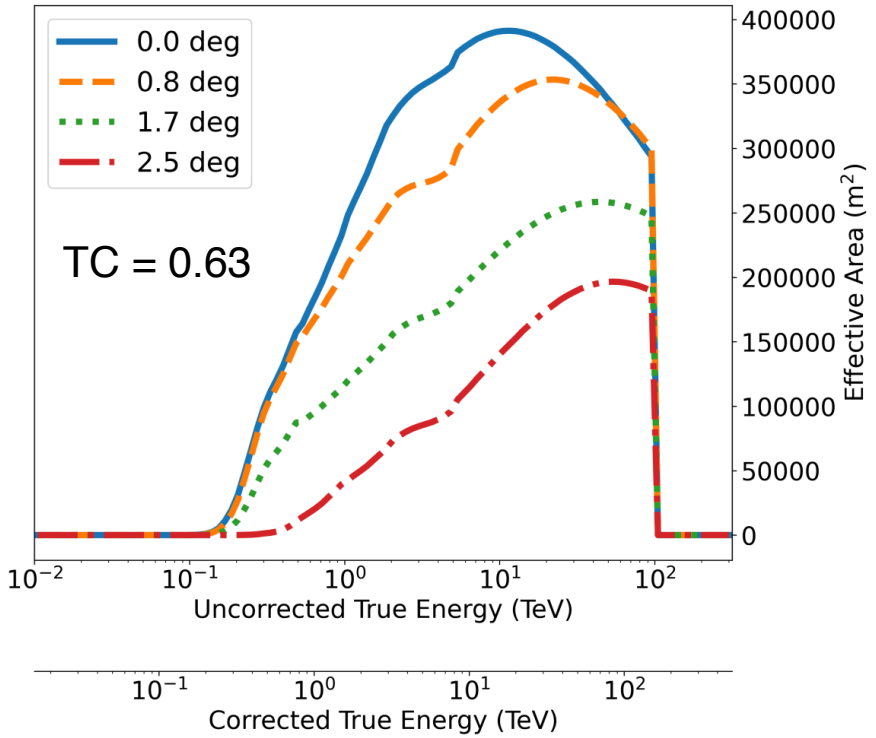
fraction of Cherenkov photons that reach the ground compared to simulations

[R. Konno, PhD thesis (2024)]



low atmospheric transparency

e.g., scale the instrument response functions (IRFs) to take the lower transparency into account



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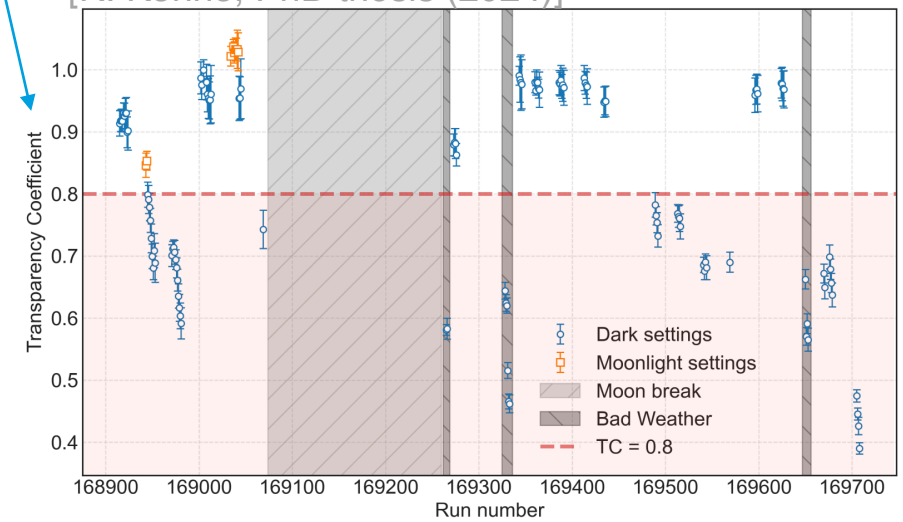

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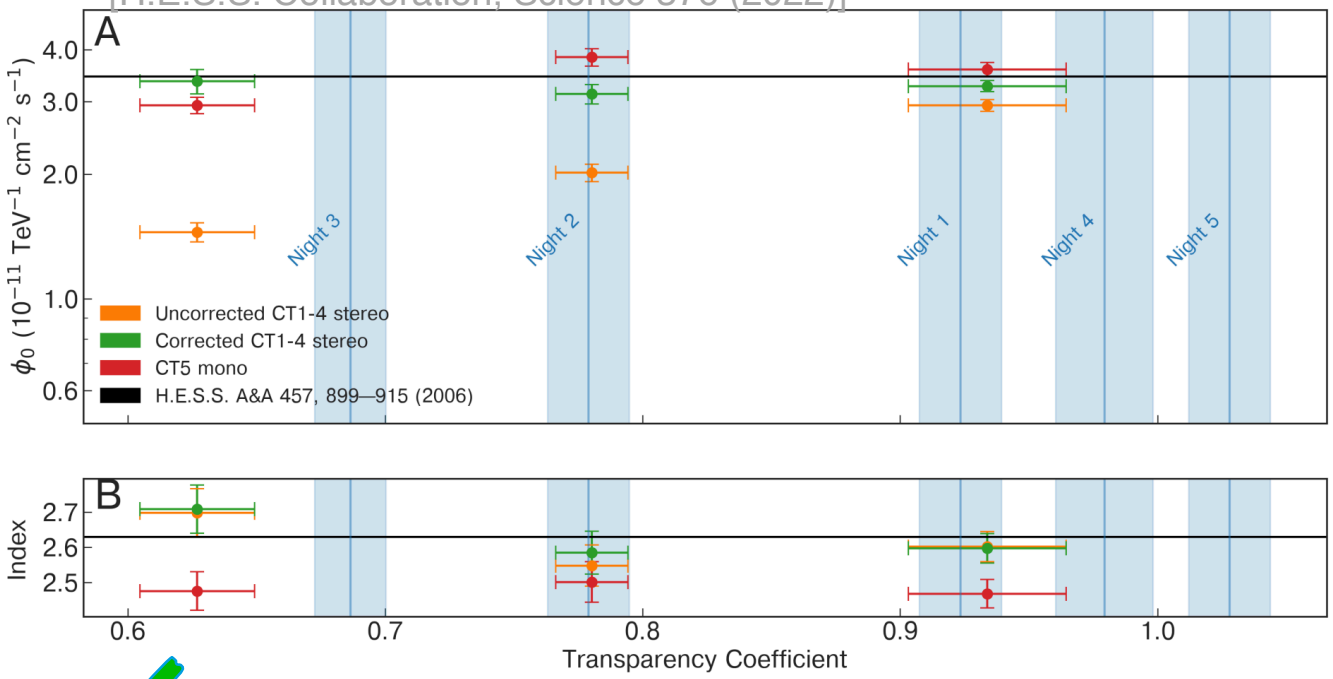


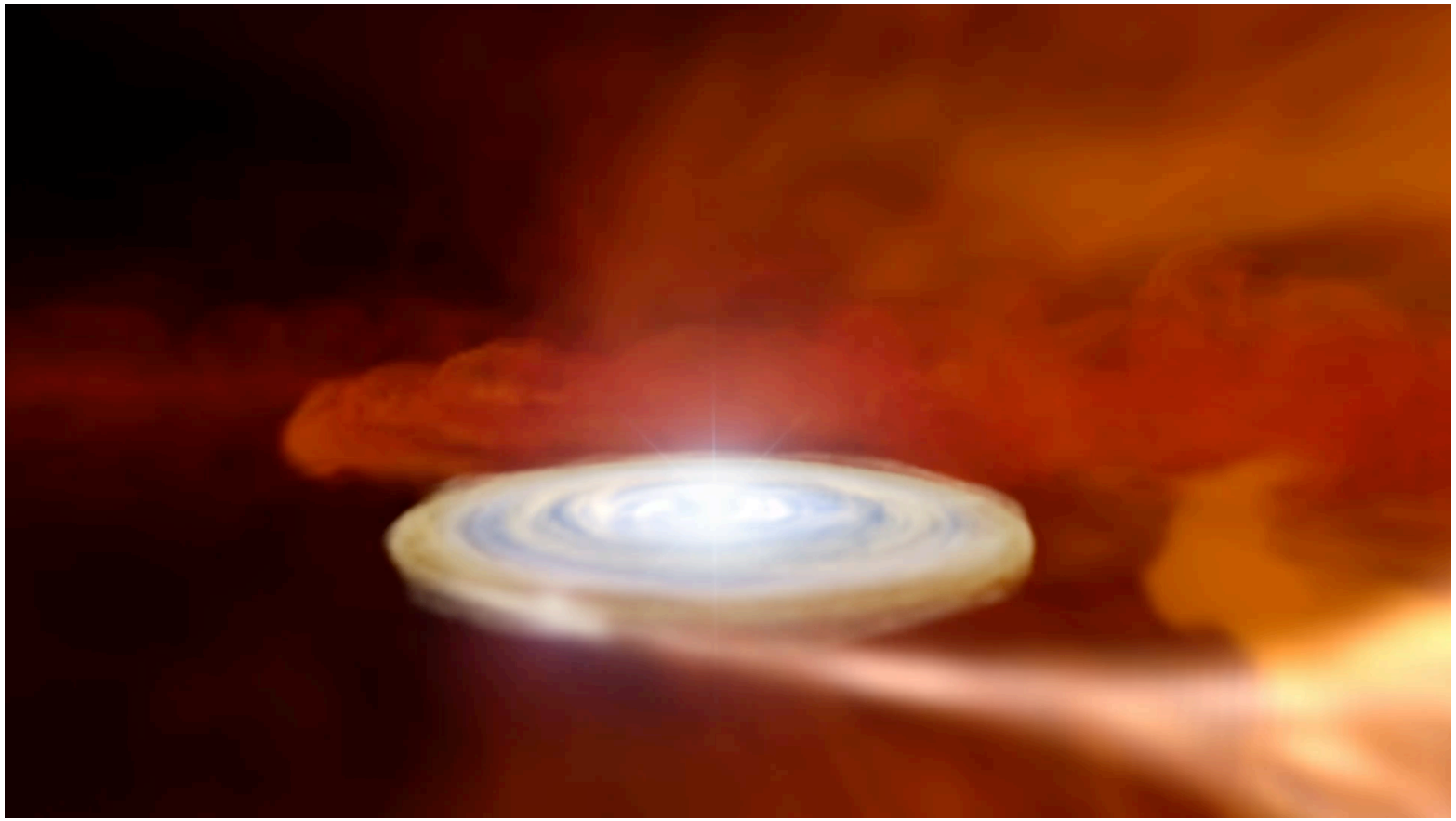
✓ use a "standard candle" source (Crab) to verify method

or more sophisticated methods: T. L. Holch et al. 2022, T. L. Holch 2025

T Coronae Borealis

What's next?

Explodes every ~80 years; should have happened last year 😬 but should happen soooooon



[NASA's Goddard Space Flight Center Conceptual Image Lab]

Supernovae

Since we know novae produce gamma rays, what about supernovae?

Supernova taxonomy[62][63]

<table>
<tr><td rowspan="5">Type I
No hydrogen</td><td colspan="3">Type Ia
Presents a singly ionised silicon (Si II) line at 615.0 nm (nanometers), near peak light</td><td>Thermal runaway</td></tr>
<tr><td rowspan="2">Type Ib/c
Weak or no silicon absorption feature</td><td colspan="2">Type Ib
Shows a non-ionised helium (He I) line at 587.6 nm</td><td rowspan="6">Core collapse</td></tr>
<tr><td colspan="2">Type Ic
Weak or no helium</td></tr>
<tr><td rowspan="3">Type II
Shows hydrogen</td><td rowspan="2">Type II-P/-L/n
Type II spectrum throughout</td><td rowspan="2">Type II-P/L
No narrow lines</td><td>Type II-P
Reaches a "plateau" in its light curve</td></tr>
<tr><td>Type II-L
Displays a "linear" decrease in its light curve (linear in magnitude versus time)[64]</td></tr>
<tr><td colspan="2">Type IIn
Some narrow lines</td></tr>
<tr><td colspan="3">Type IIb
Spectrum changes to become like Type Ib</td></tr>
</table>

Supernovae

Super nova should produce gamma-rays, but it is all about the winds

OB Stars produce have HUGE winds, produce massive bubbles

Density is close to star is high, then falls off drastically, usually as $1/r^2$

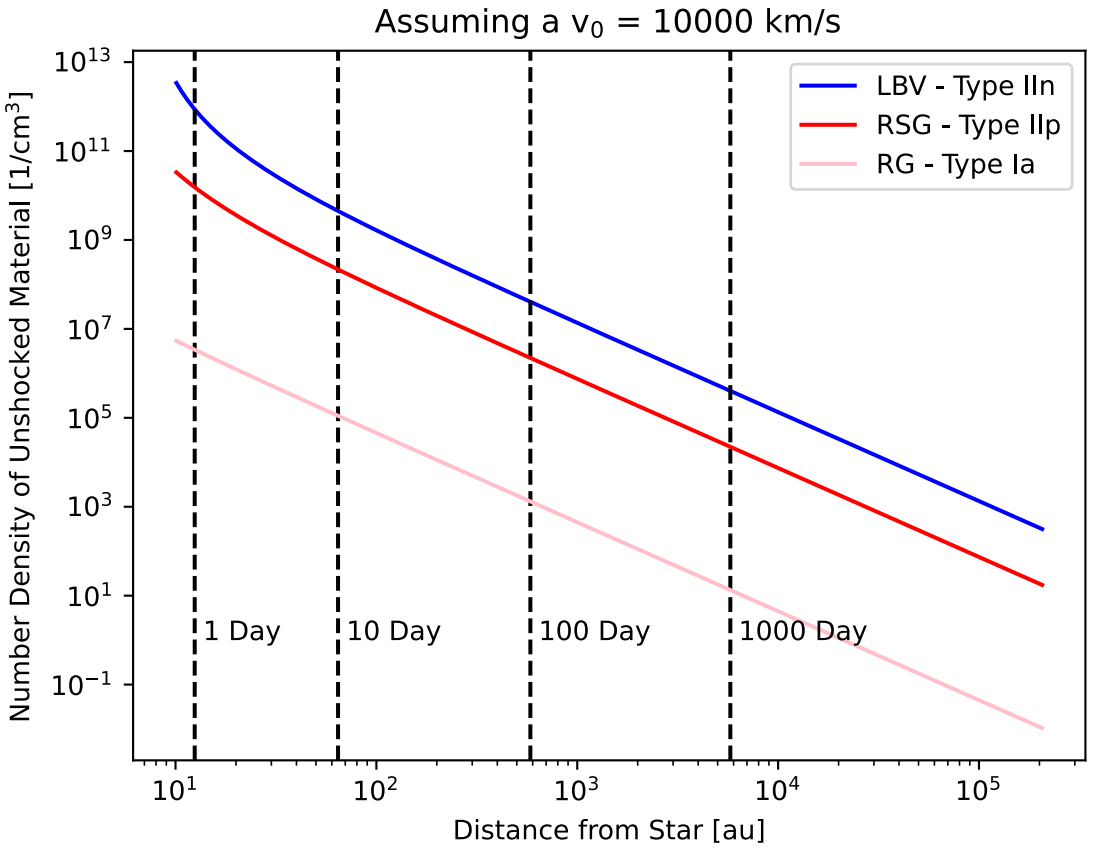
Density of wind determined by star mass loss rate and wind velocity

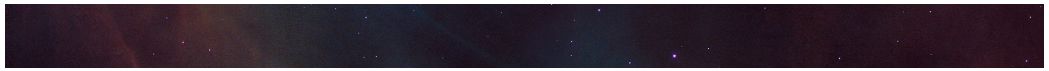
$$\beta(r) = v_W(1 - R^*/r)^3 \qquad \rho(r) = \frac{\dot{M}}{4\pi r^2 \beta(r)}$$

LBV: Mass losses ~ 1e-2 Msun/year, Vw ~ 100 km/s

RSG: Mass losses ~ 1e-5 Msun/year, Vw ~ 30 km/s

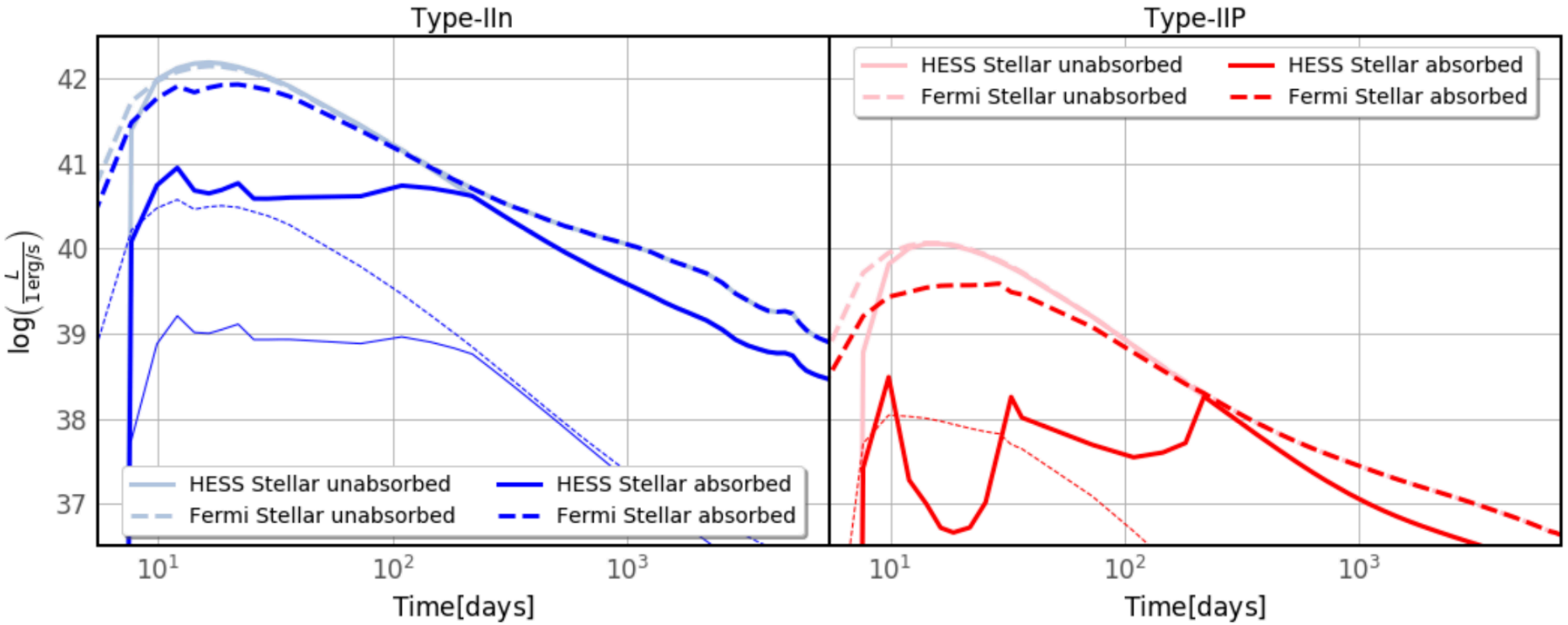
RG: Mass losses ~ 1e-7 Msun/year, Vw ~ 30 km/s





Supernovae

Super nova should produce gamma-rays, but it is all about the ~~winds~~ absorption



Gamma-gamma absorption plays a role in detecting SNe

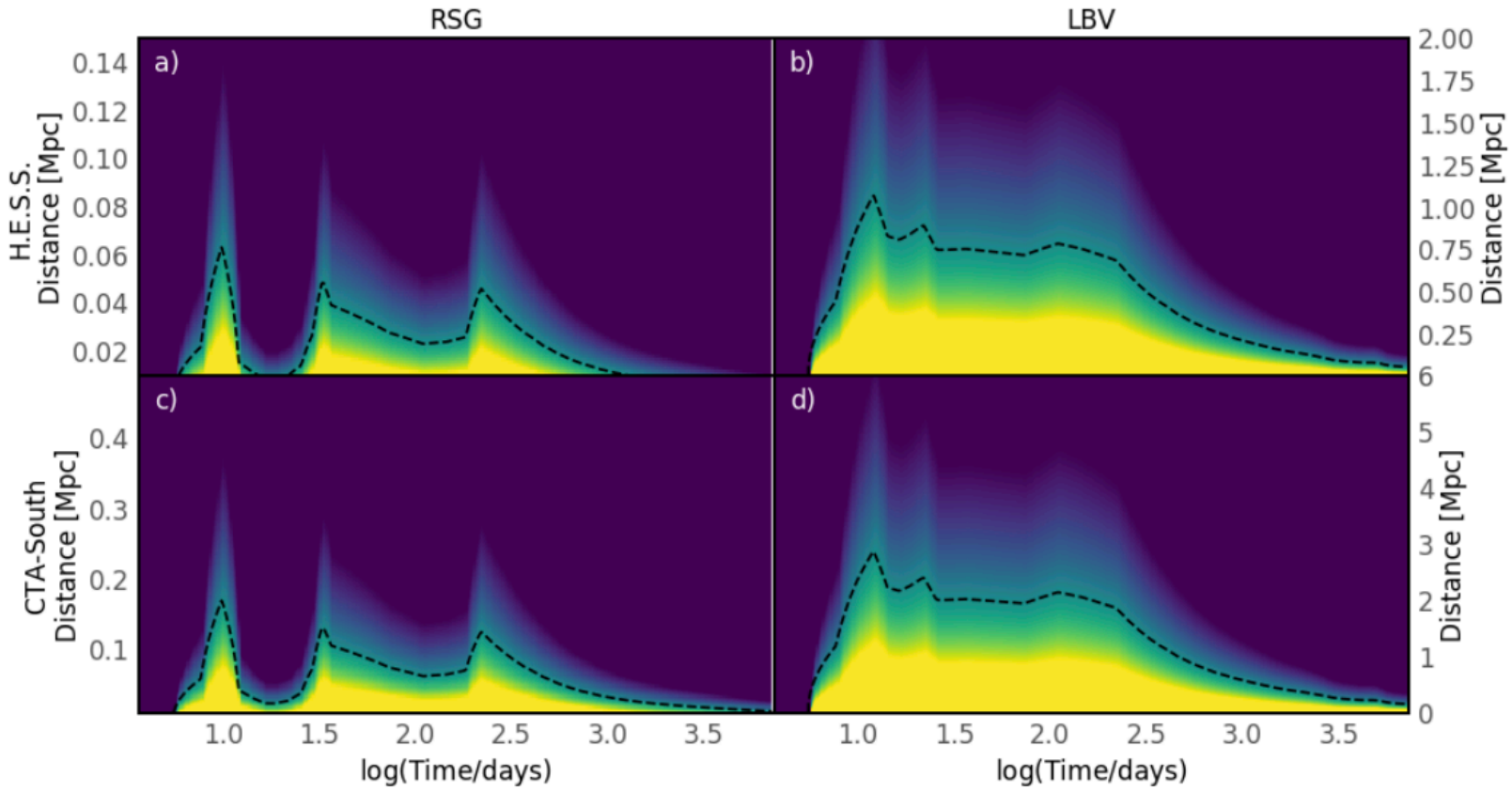
Supernovae

There is pretty much no hope for detecting an RSG SNe within unless it within our Galaxy or LMC/SMC

LBV SNe are better choices

CTAO South could detect LBV up to 6 Mpc

Detectable emission is significantly delayed from eruption, due to gamma-gamma absorption

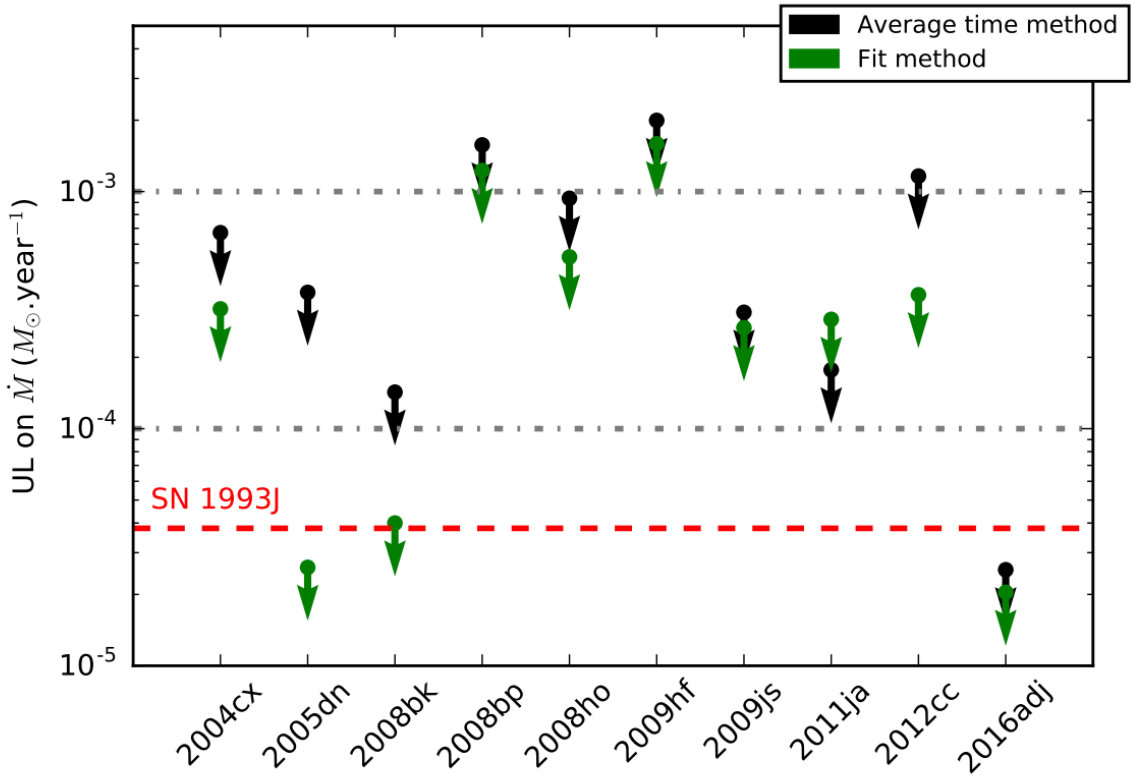


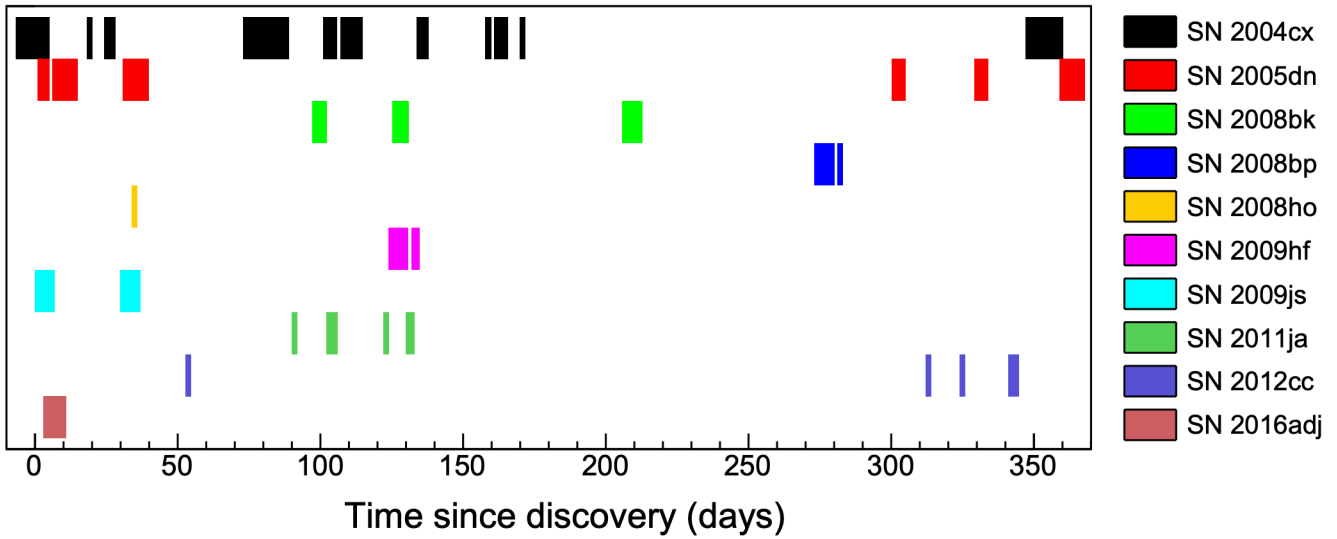
Supernovae

HESS has published lots of ULs on SNe observations

All just too far away

Maybe CTAO will change the picture and detect VHE emission from an SNe



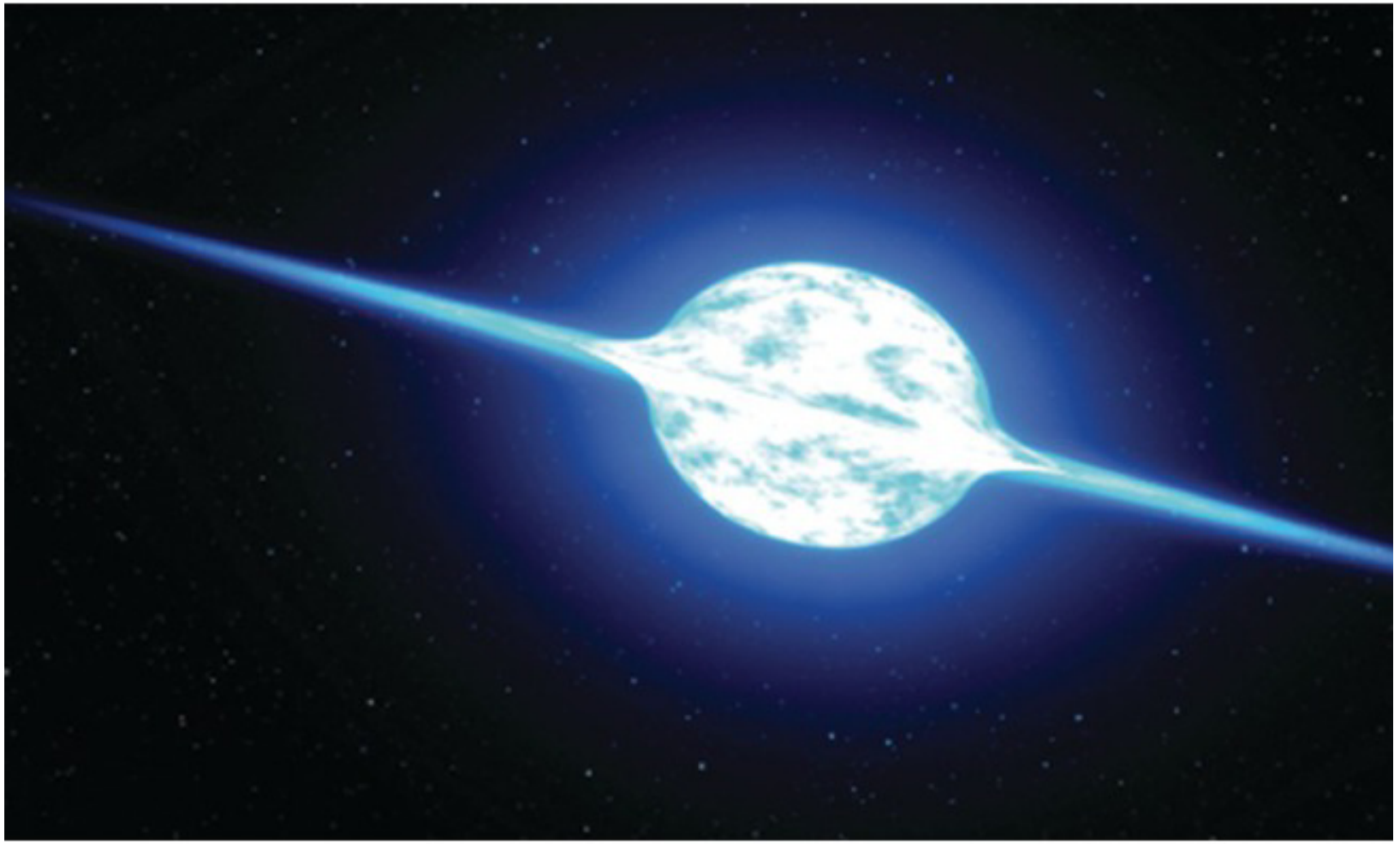


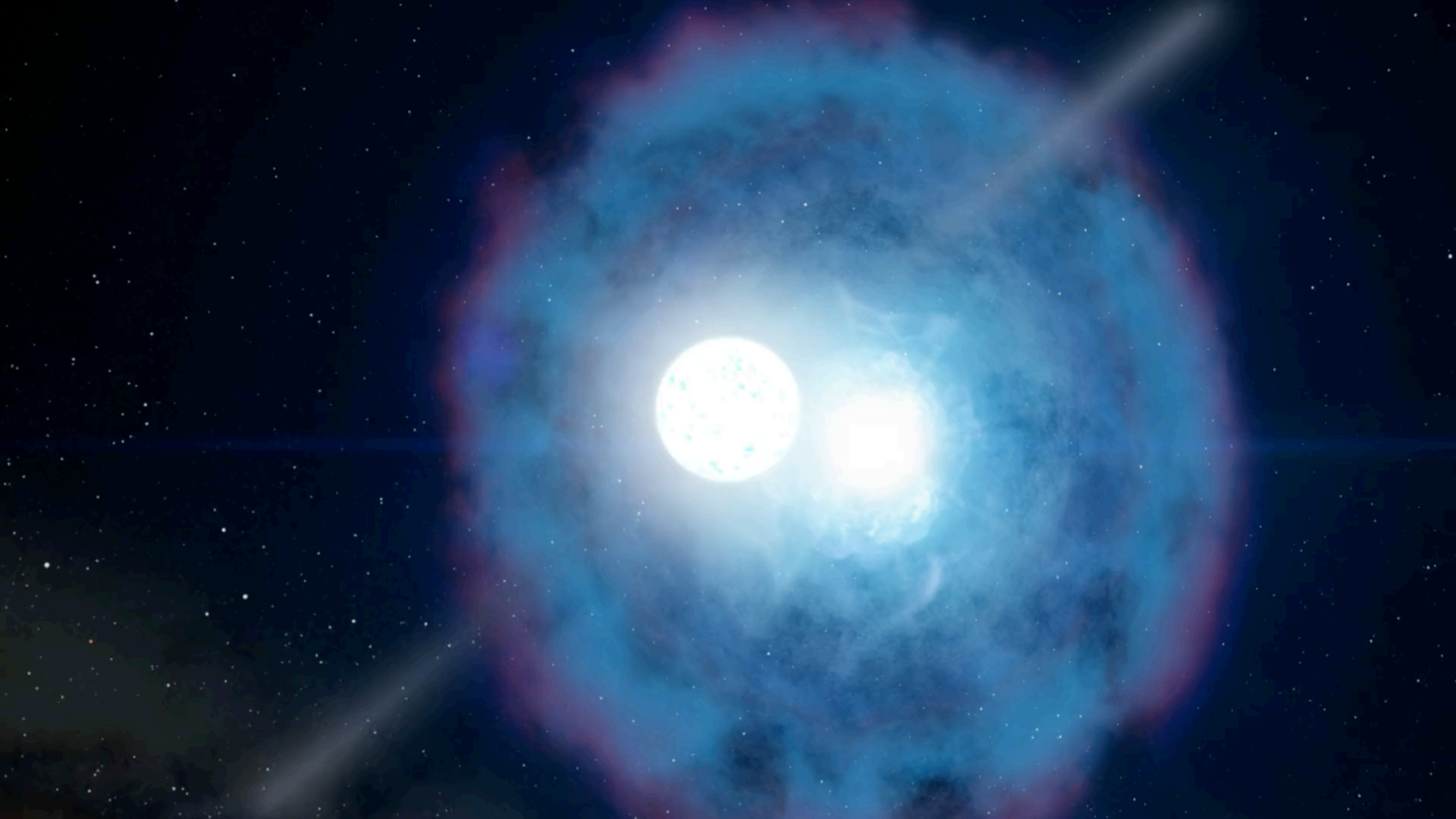
Gamma-ray binaries (not micro quasars)

A different class of gamma-ray binaries exist than micro quasars

Be Stars are stars rotating so rapidity that they create decretion disks

If a pulsar is orbiting the Be star, then as the pulsar passes through the decretion disk, x-rays + gamma-rays can be produced





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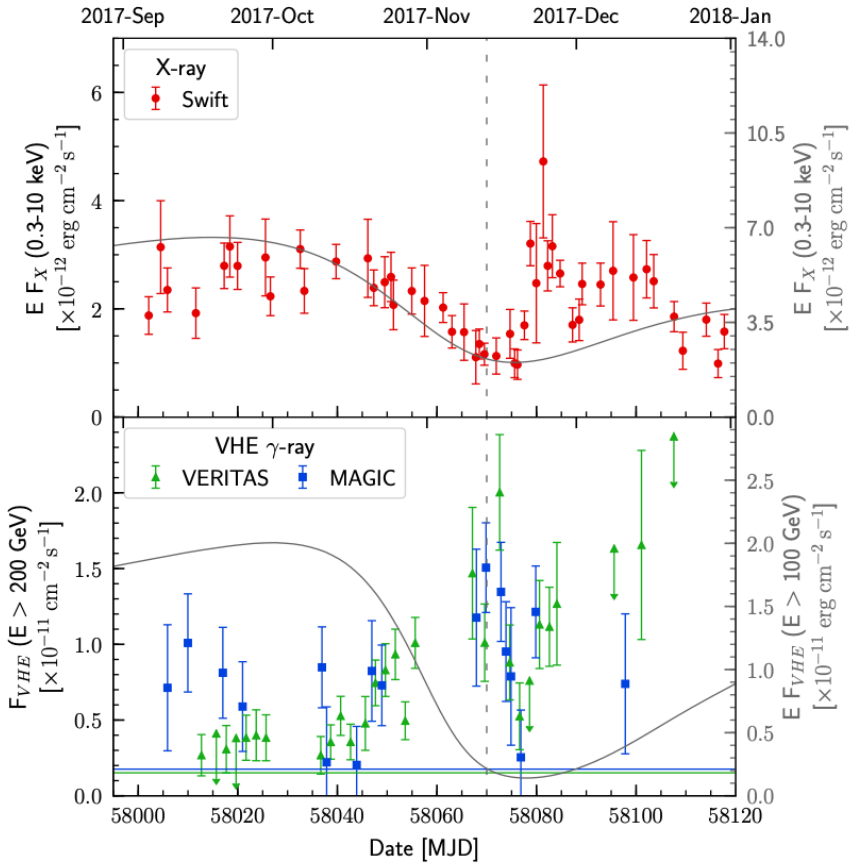
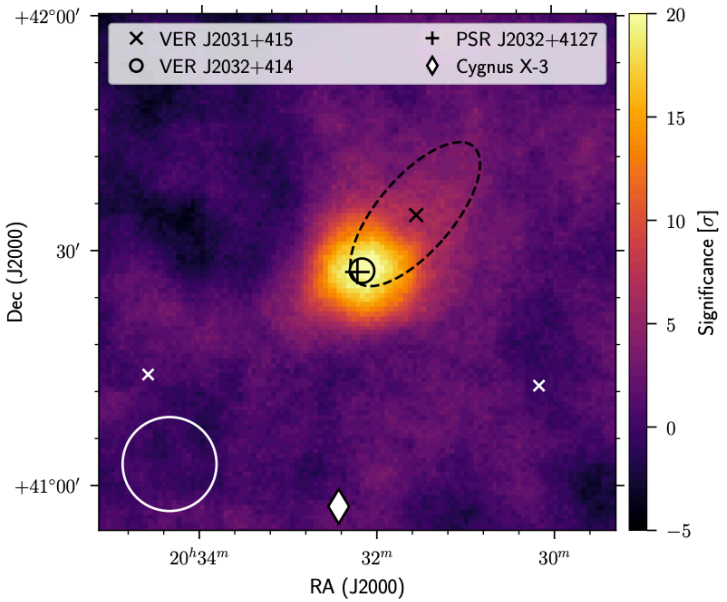
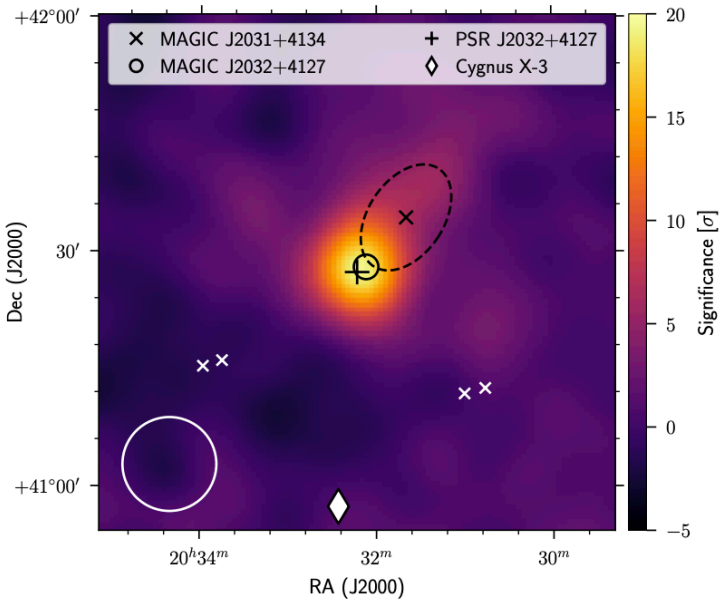


(b) Periastron



(a) VERITAS 2017 fall sky map

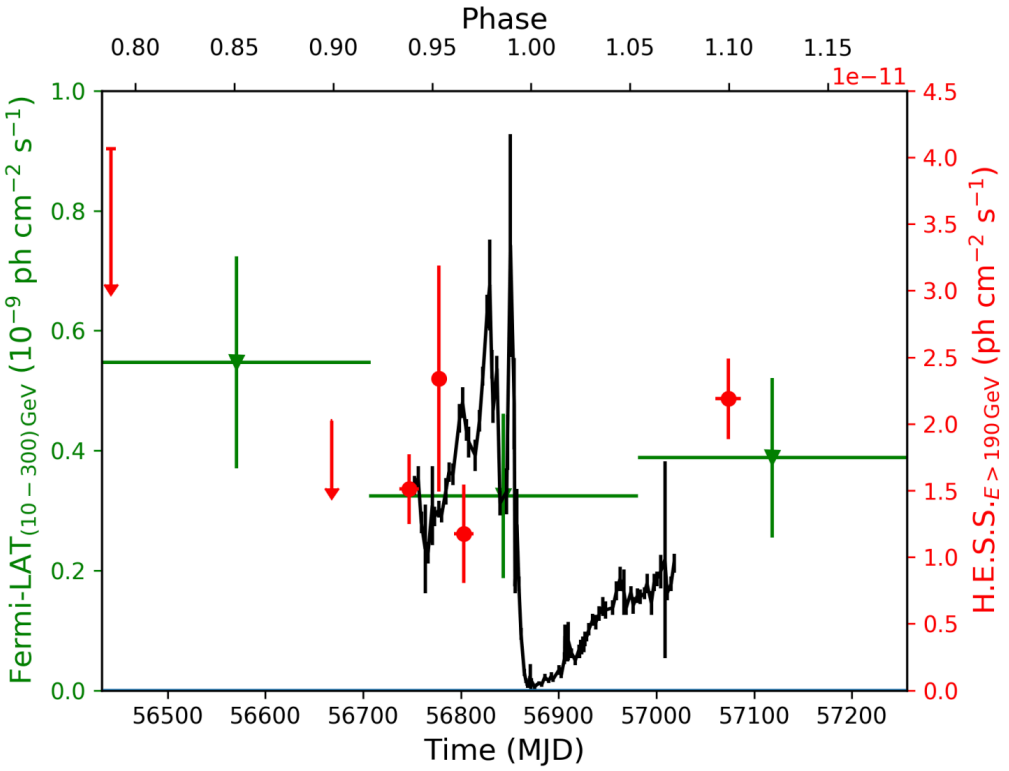


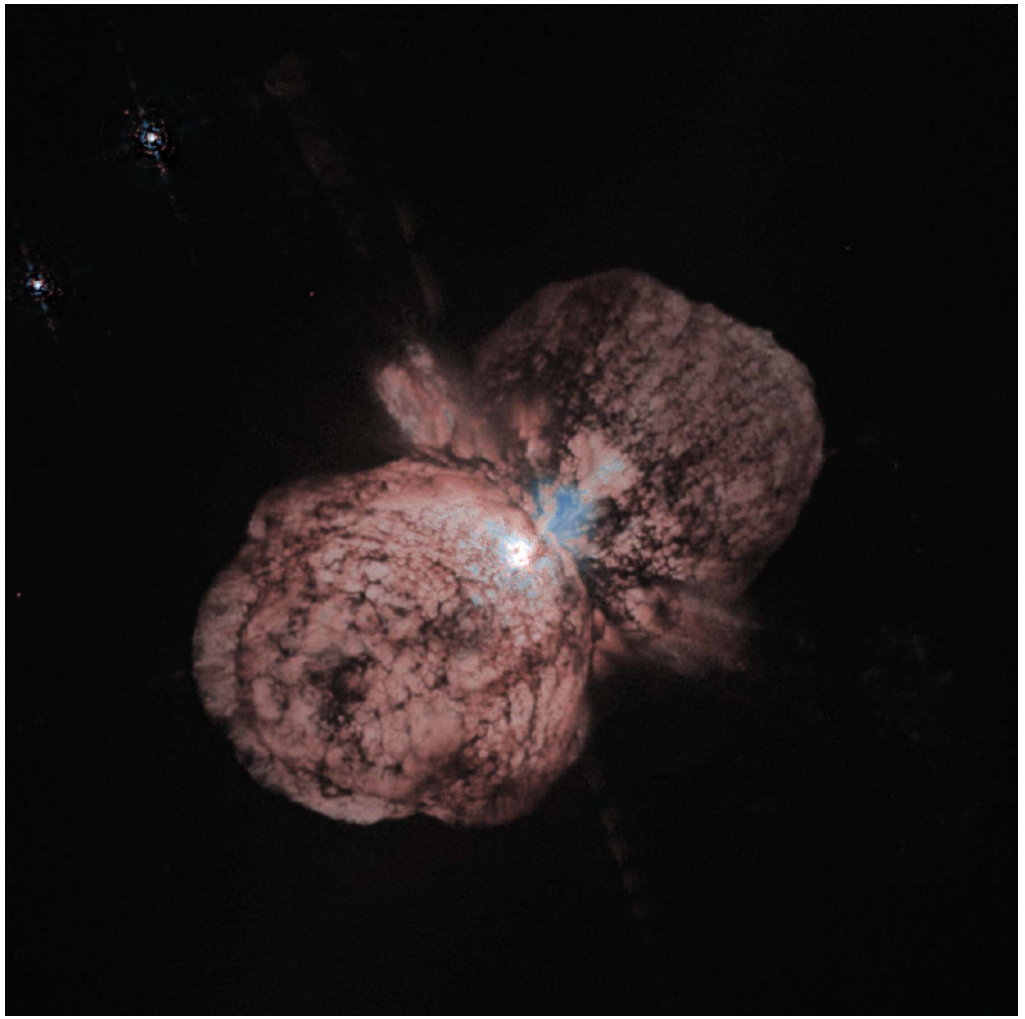
(b) MAGIC 2017 fall sky map

Emission is high correlated with phase of binary, but not 100% correlated

These can be planned far in the future but sometime surprises occur

Gamma-ray binaries (not micro quasars)

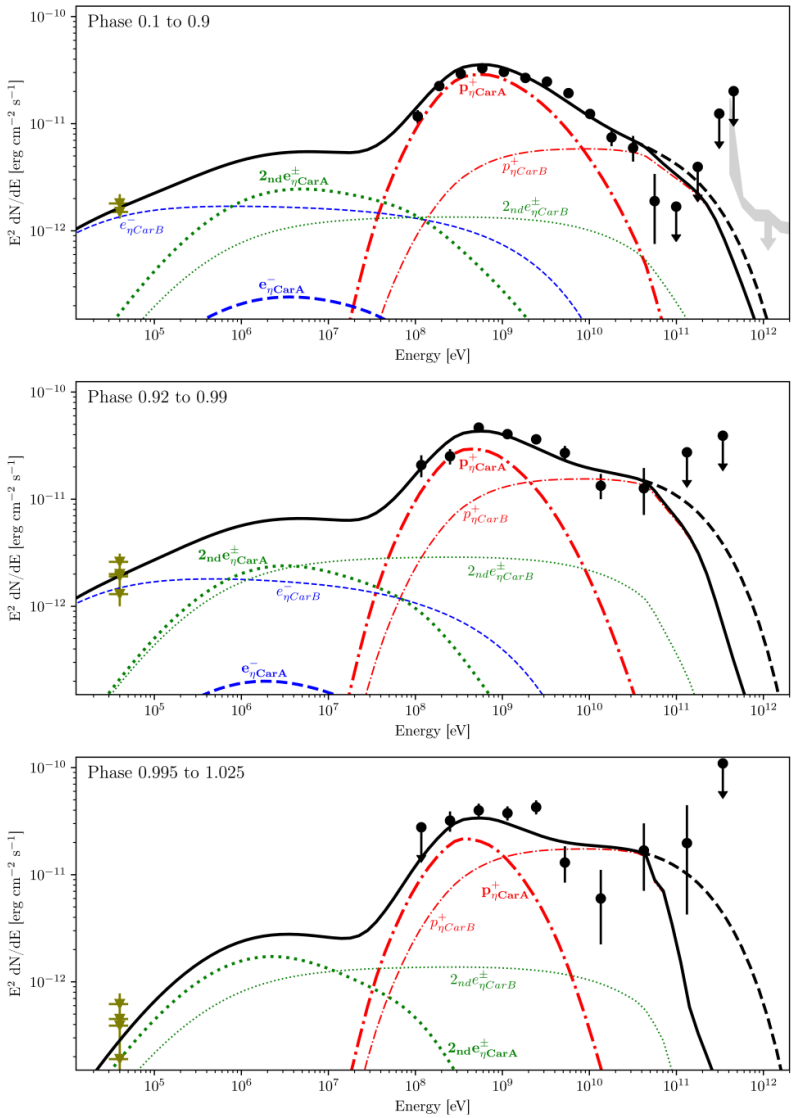




Eta Carinae is a colliding wind binary of two massive stars (30 and 100 M⊙ and a period of ~2000 days

HE and VHE gamma-rays can be seen in different parts of the phase near periastron

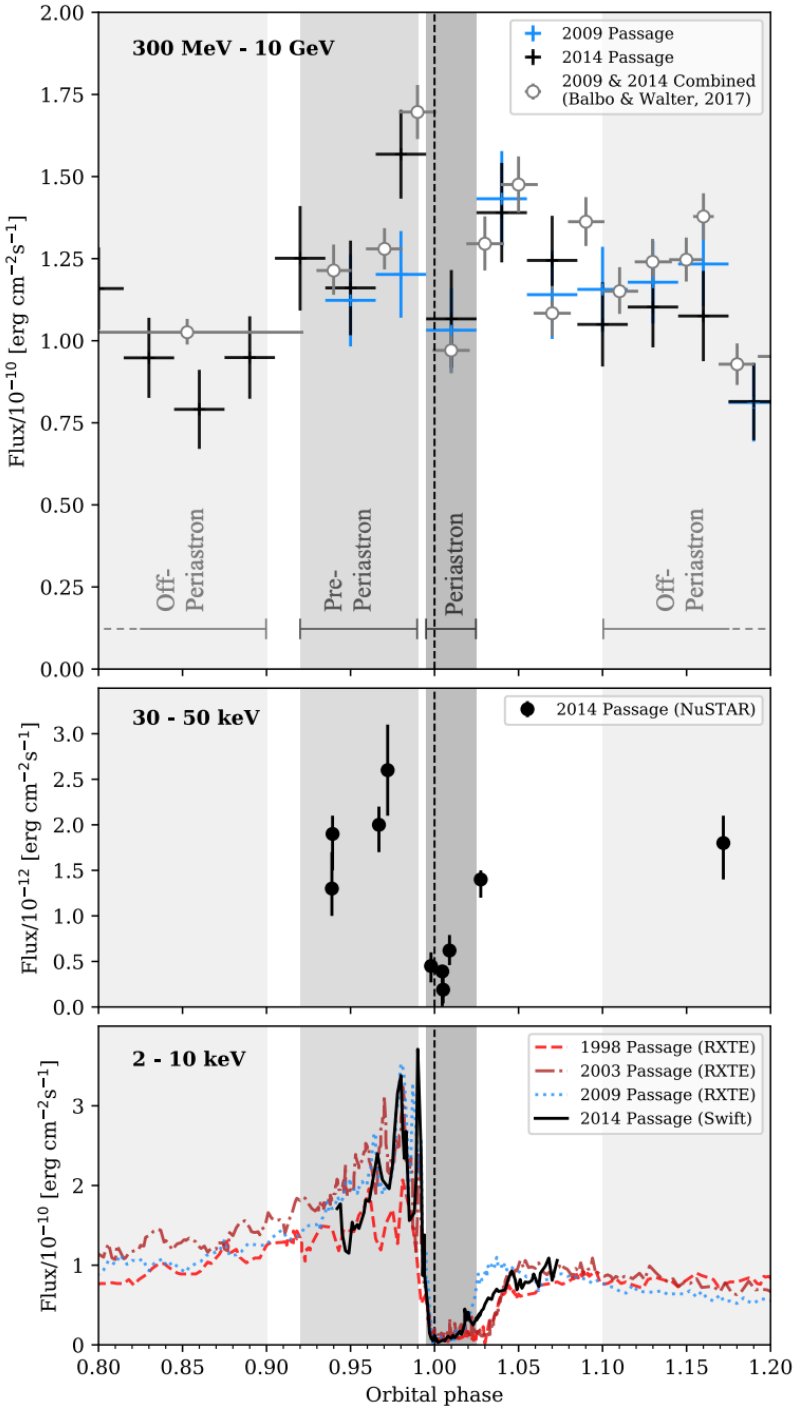
Gamma-ray binaries (not micro quasars)

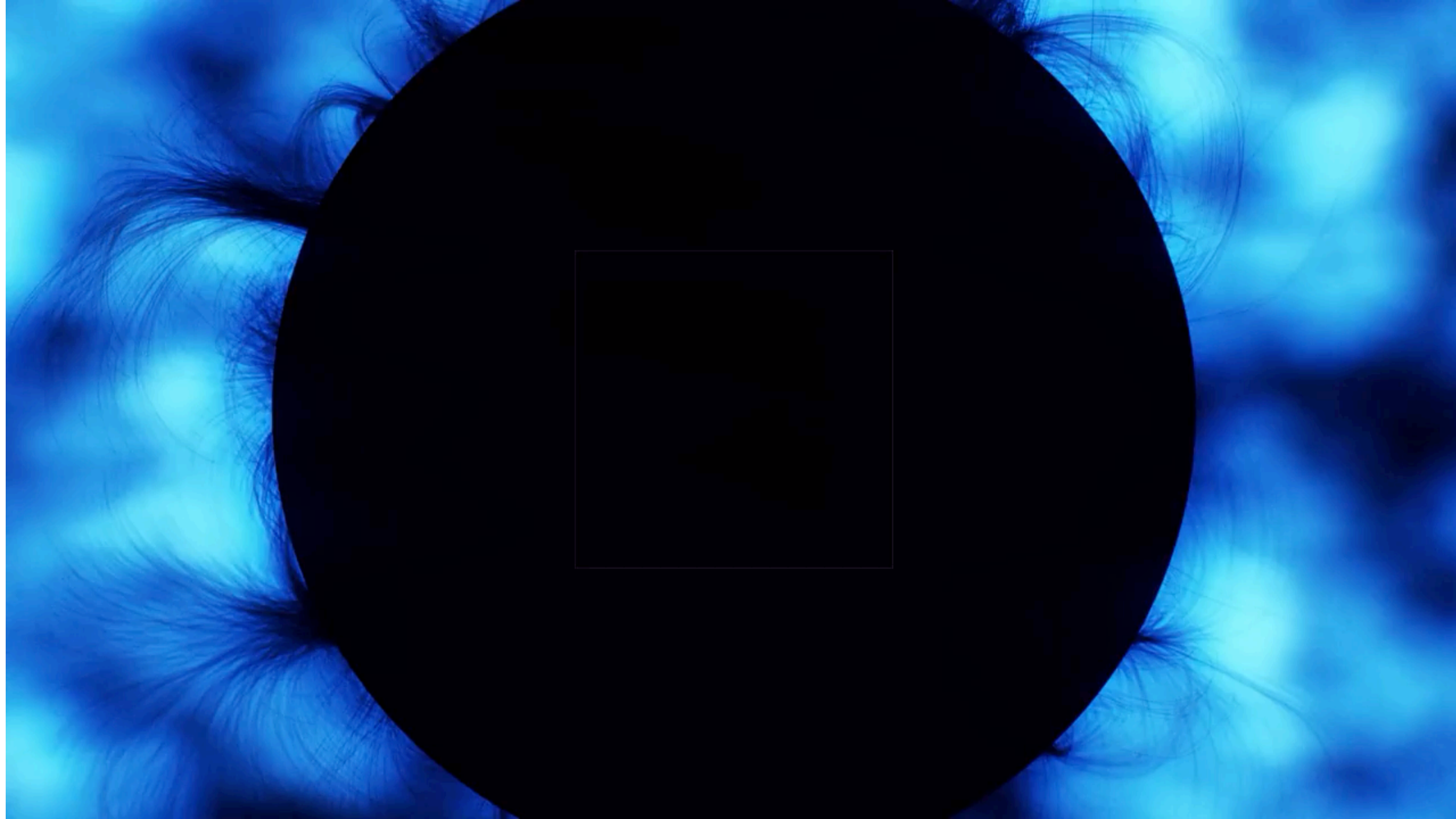


Majority of emission is generated from shocks of the colliding wind between the two massive stars

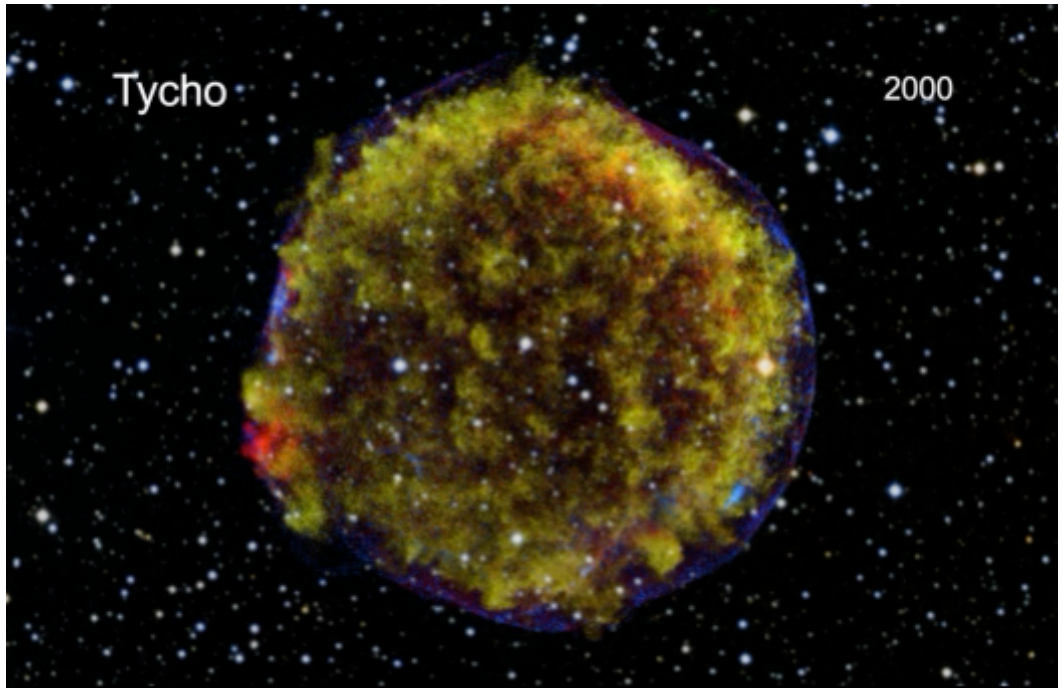
Dominated by hadronic emission

Binaries really represent the evolution of systems on years time scales

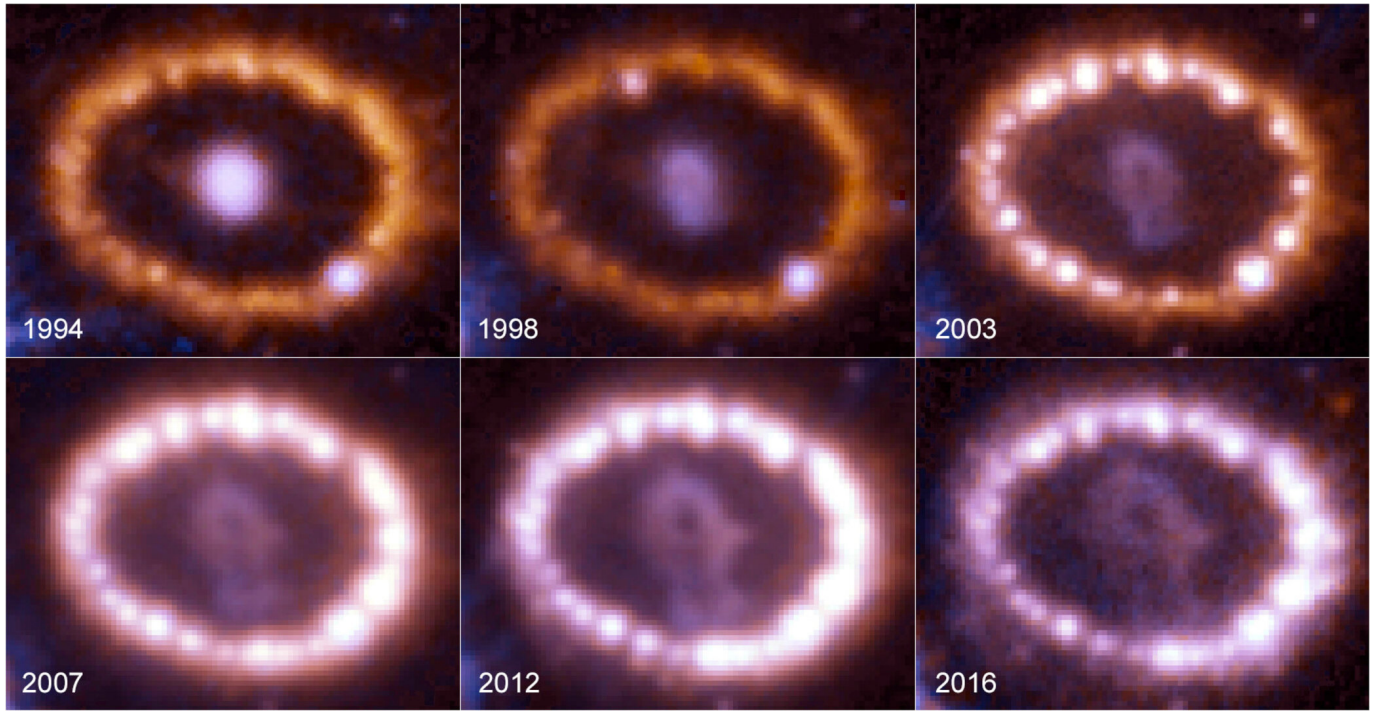




Supernova remnants



SN 1987a



Supernova remnants also show evolutions

Shocks expand, interact with material, change in flux and in general evolve

Seen mostly in young SNRs over long long time scales in x-rays and optical

30 years of CTAO could see this for certain sources as well

What does Time-Domain Astronomy mean?

I wanted to highly a few sources but there are many many more Galactic transients

We can see from theses sources that time-domain is more than just bursts and short events

Time-domain can be

- days - Novae
- Months - Binaries
- Years - Supernovae/Binaries
- Decades - SNRs