Time-domain astronomy

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Rough outline

Day 1: Intro

How are gamma rays produced? What do we learn from them?

Day 2: Observations

How do we detect gamma rays? How do we decide what/when to observe?

Day 3 + 4: Sources

What astronomical objects do we observe in the time domain?

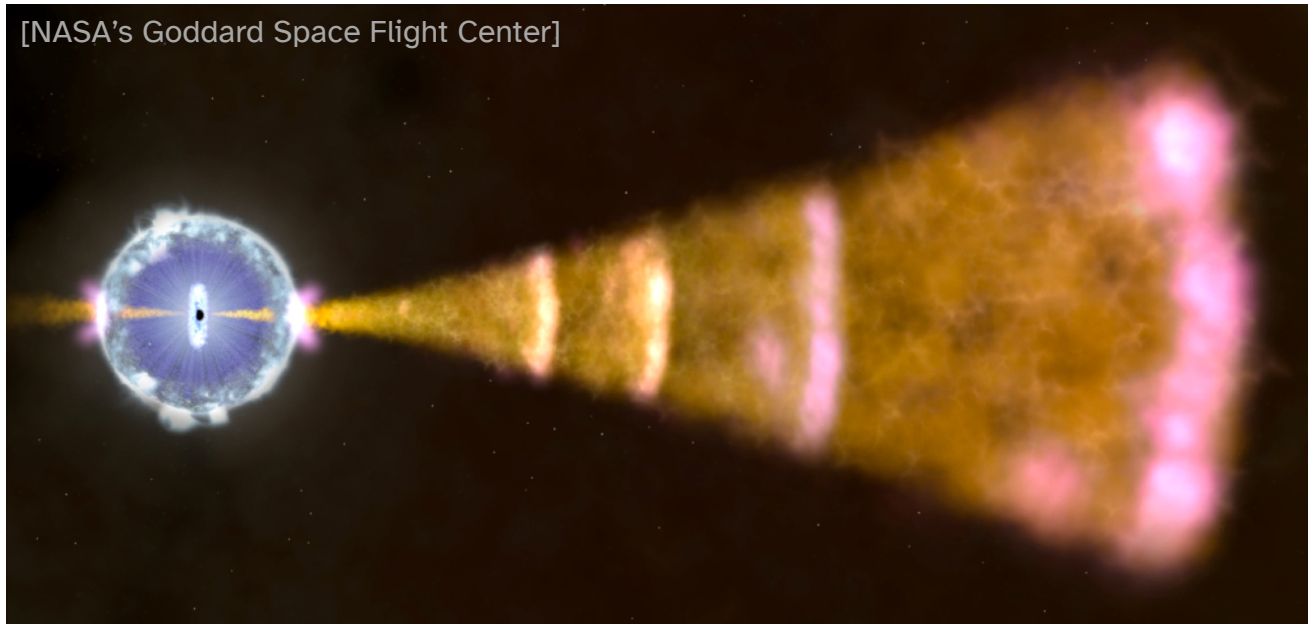
today: I'll talk about more extragalactic transient sources
and then David will talk about Galactic stuff

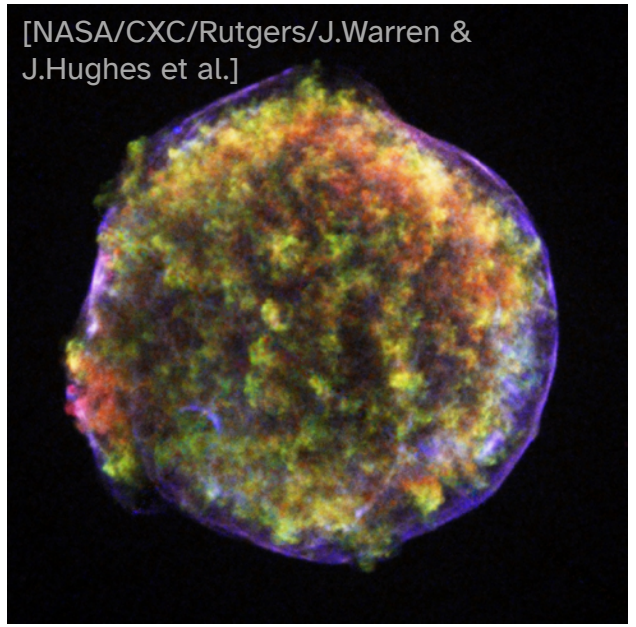
Part 3b-1. Sources: Non-jetted extragalactic phenomena

that's very specific

Non-jetted phenomena

So far my focus has been on jetted phenomena, but gamma rays don't have to come from jets
-> *Shocks* are what produce the gamma rays (jets just provide relativistic shocks)



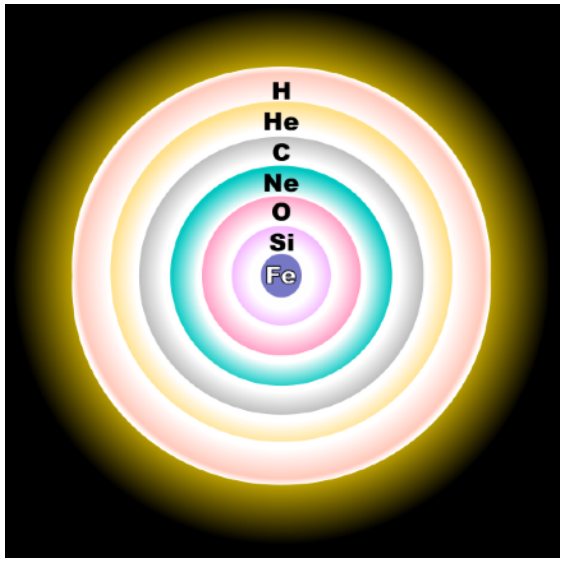


To get shocks, we just need matter running into some medium

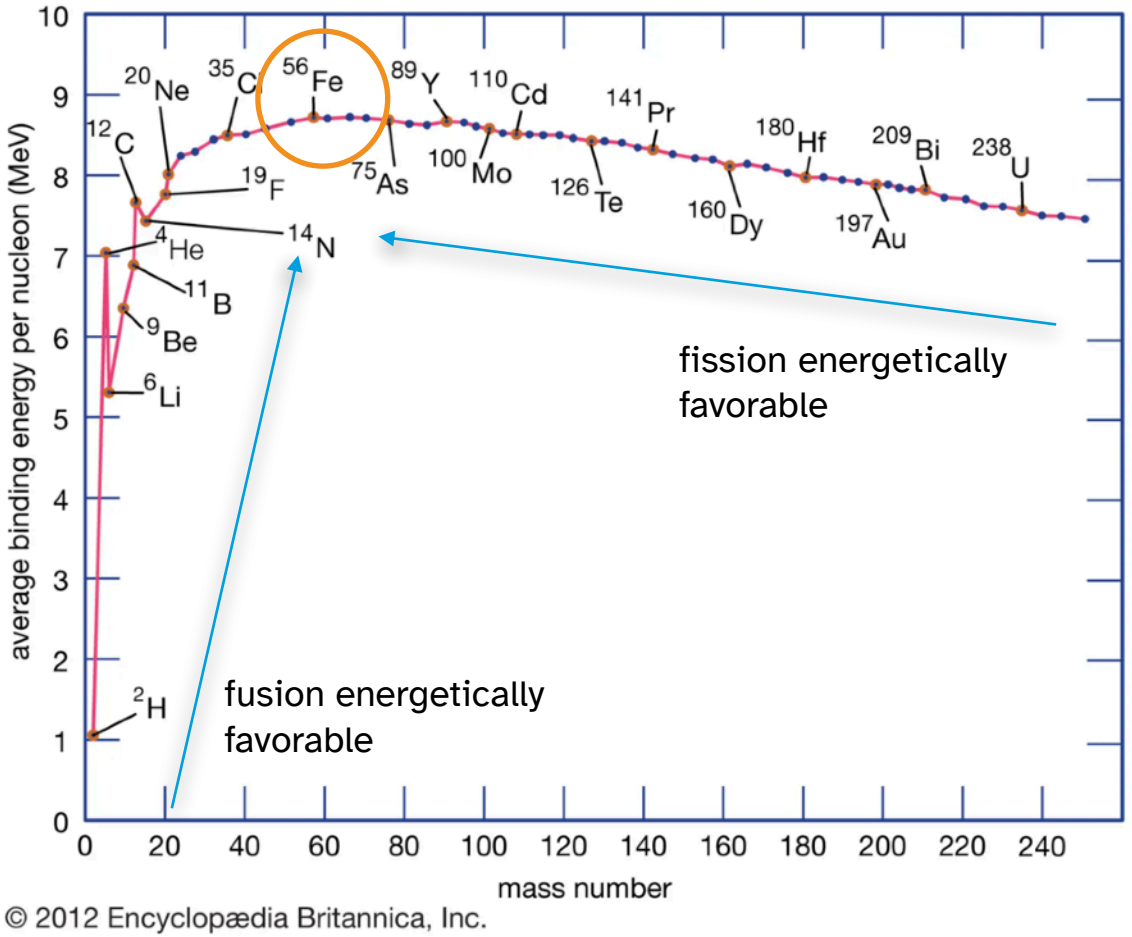
(also: we don't always need shocks but we won't talk about that)

Core-collapse supernovae from astronomy 101

Massive stars fuses successively heavier elements until iron



R. J. Hall



Core-collapse supernovae from astronomy 101

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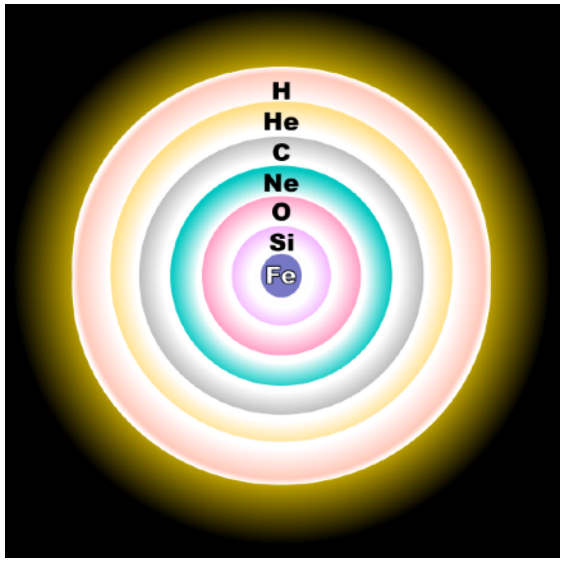

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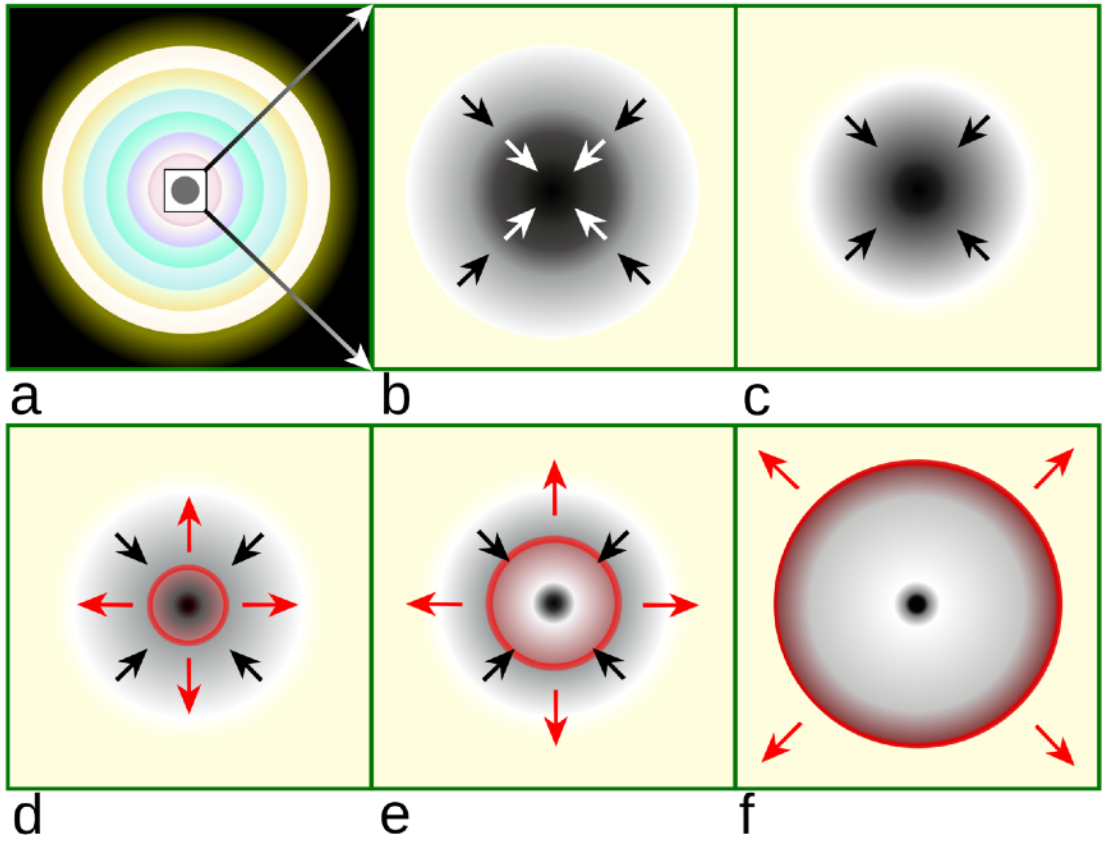
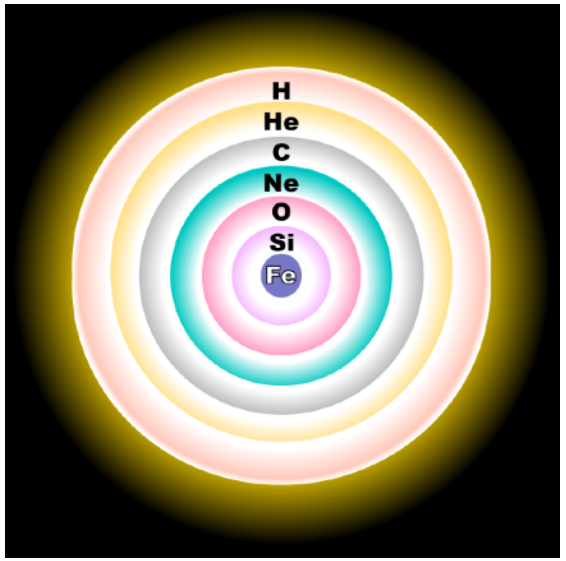


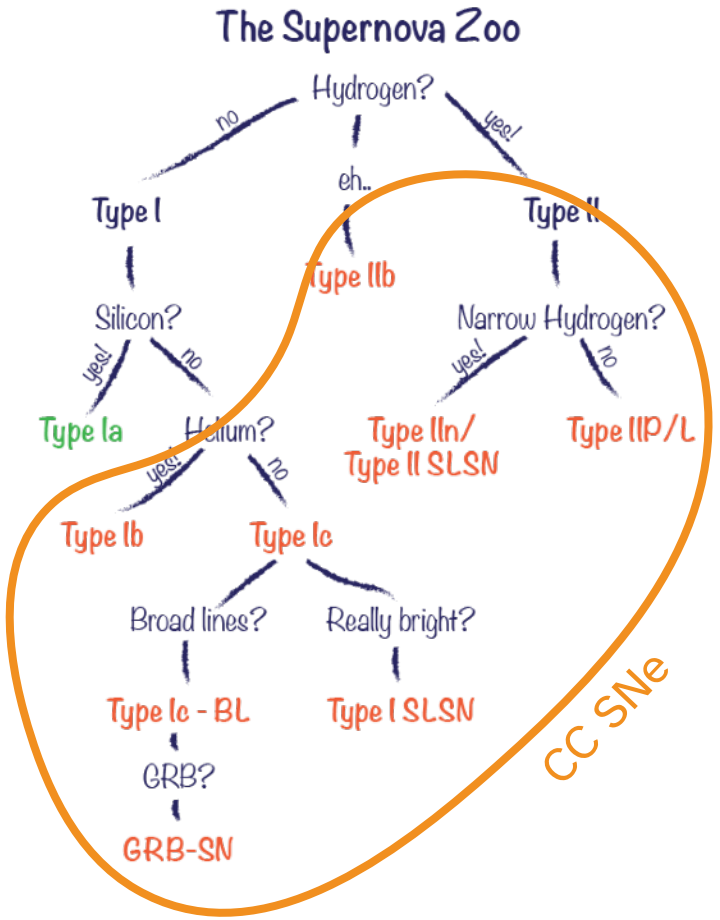
R. J. Hall

Core-collapse supernovae from astronomy ~~101~~ 102

Any non-Ia supernova is a core collapse supernova



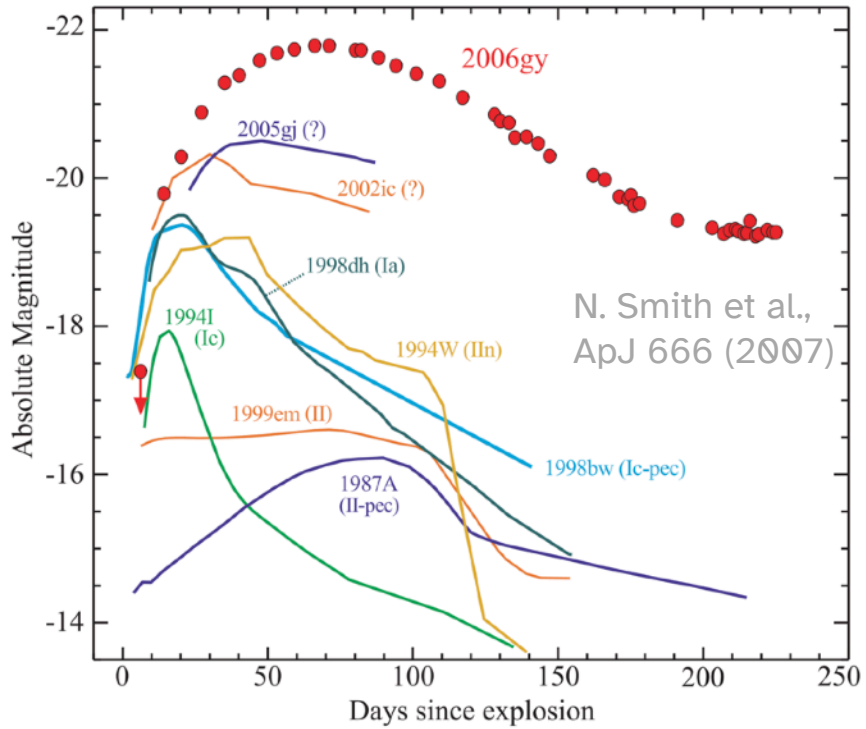
R. J. Hall



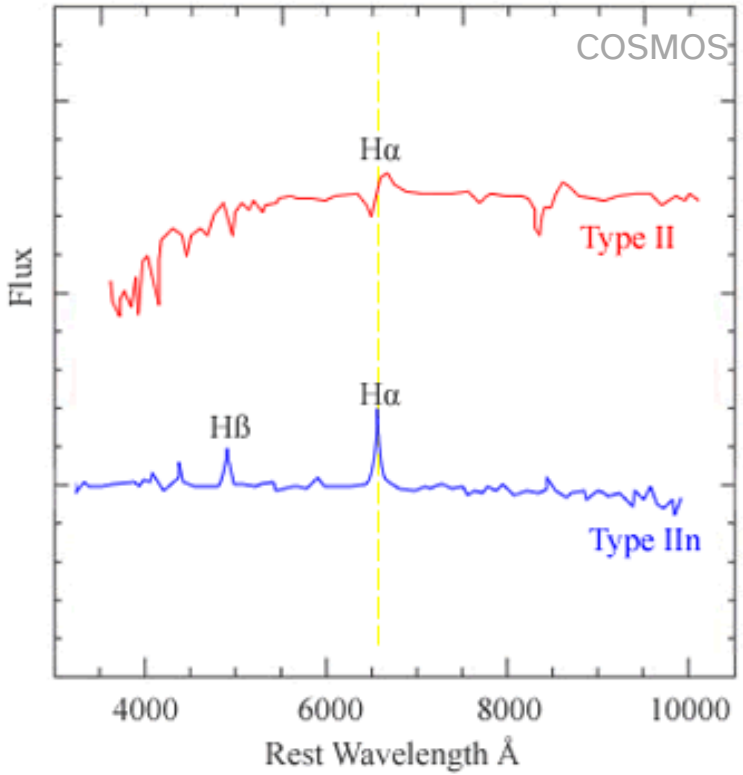
A. Villar

Core-collapse supernovae from astronomy ~~101~~ 102

Any non-Ia supernova is a core collapse supernova
Some SNe seem to be *interaction powered*



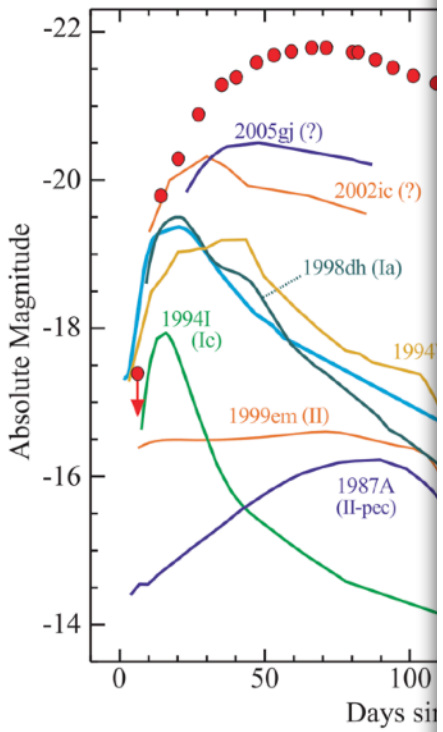
Some SN lightcurves rise very fast and/ or fade very slowly



Some SN spectra show (narrow) emission lines

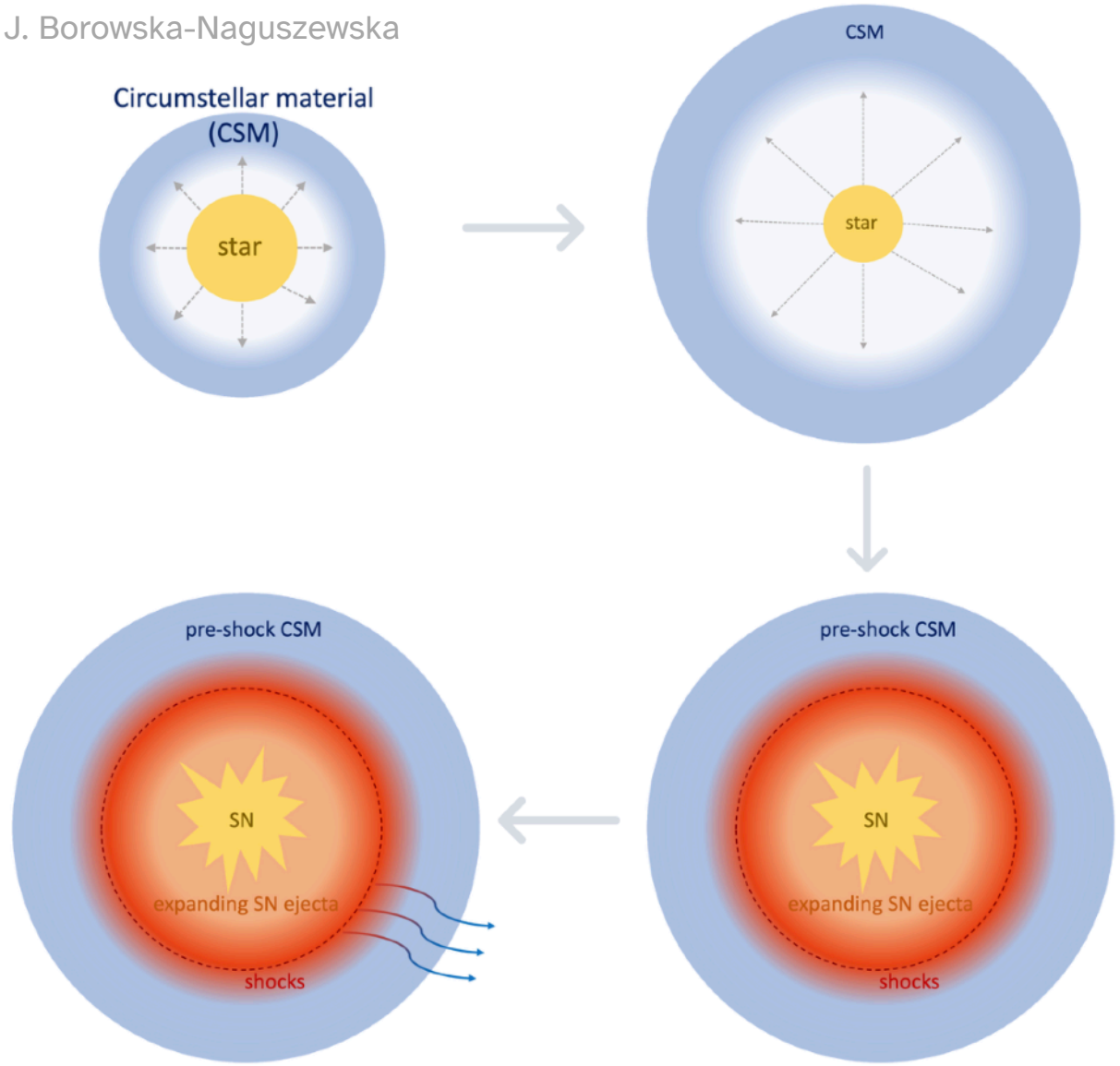
Core-collapse supernovae from astronomy ~~101~~ 02

Any non-Ia supernova is a
Some SNe seem to be *int*

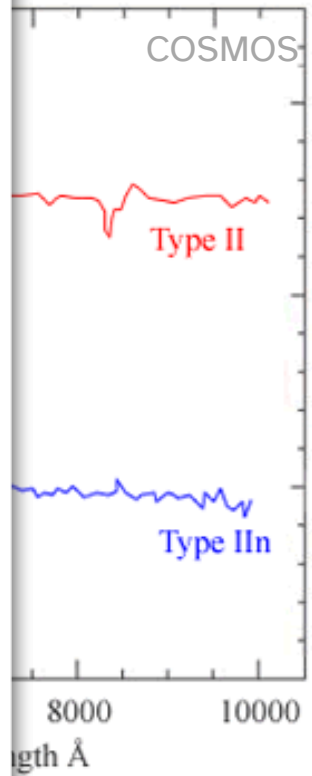


Some SN lightcurv
or fade very slowly

J. Borowska-Naguszewska



shocks => gamma rays???

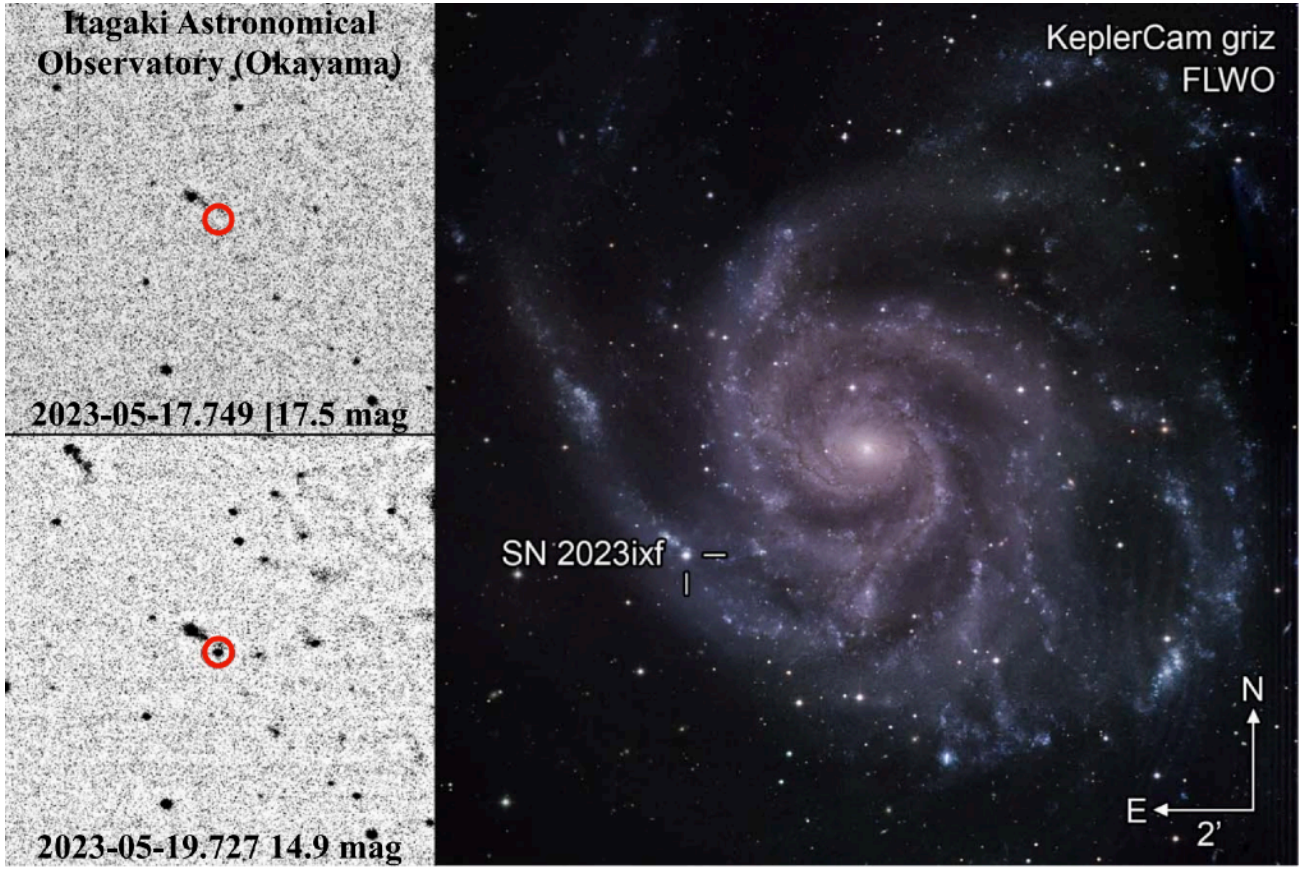


tra show
ion lines

Searches for gamma-ray emission from CC SNe

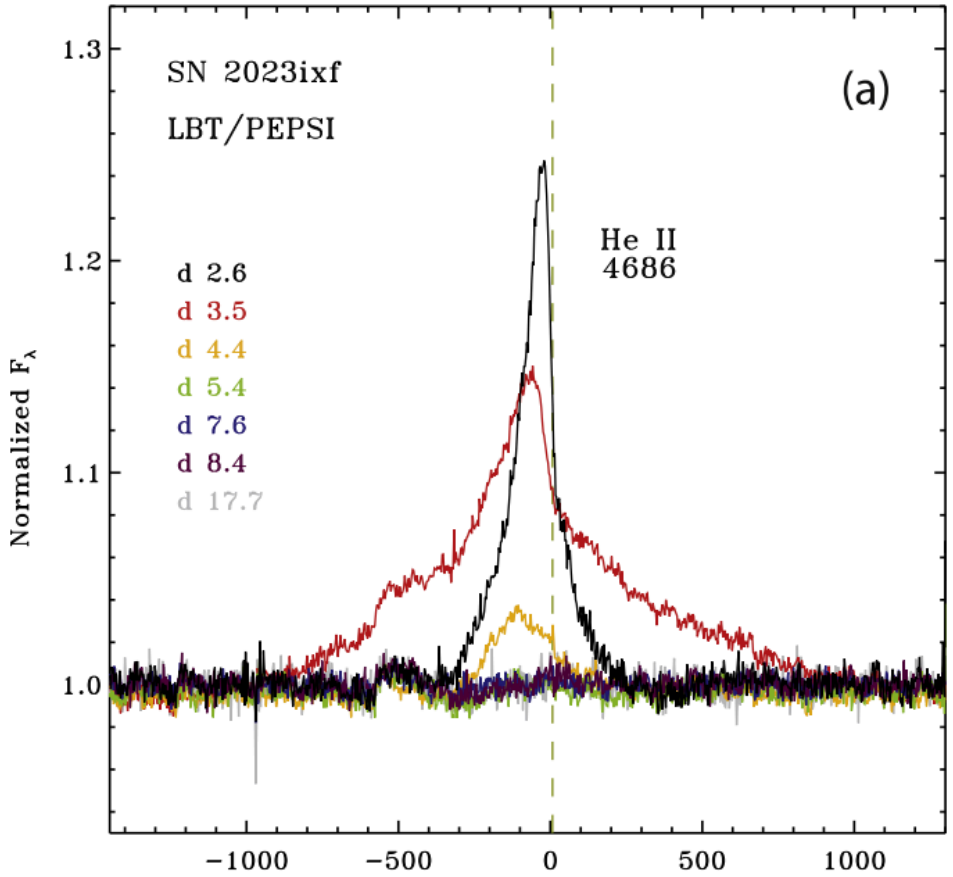
Fermi-LAT observations of SN 2023ixf

A SN II-n just 7 Mpc away (z = 0.0008)



[K. Murase et al., MNRAS 440 (2014)]

strong emission lines that faded over time



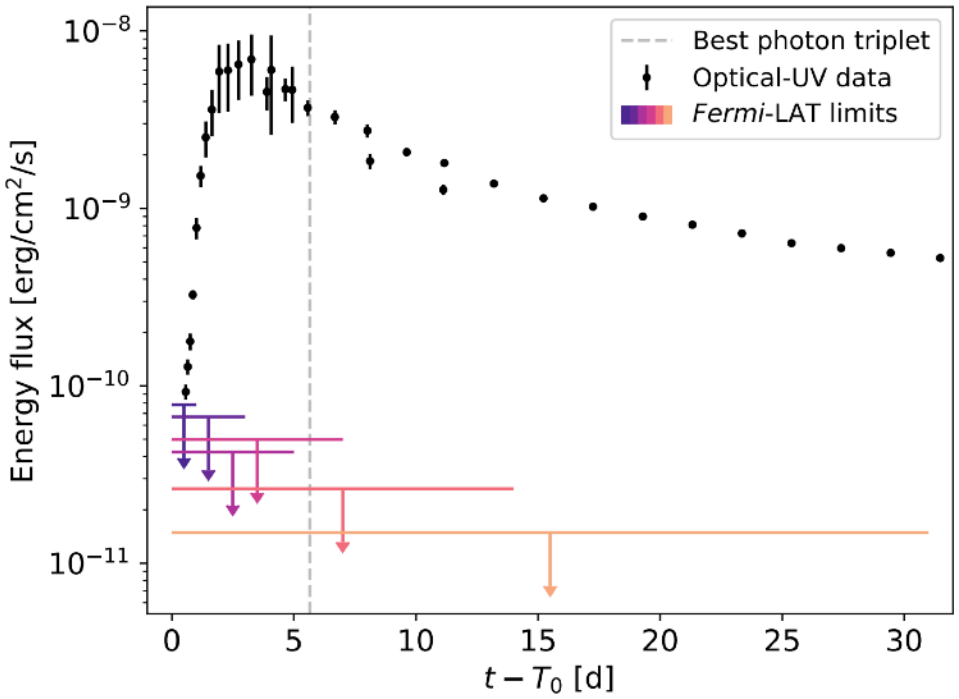
[N. Smith et al., ApJ 956 (2023)]

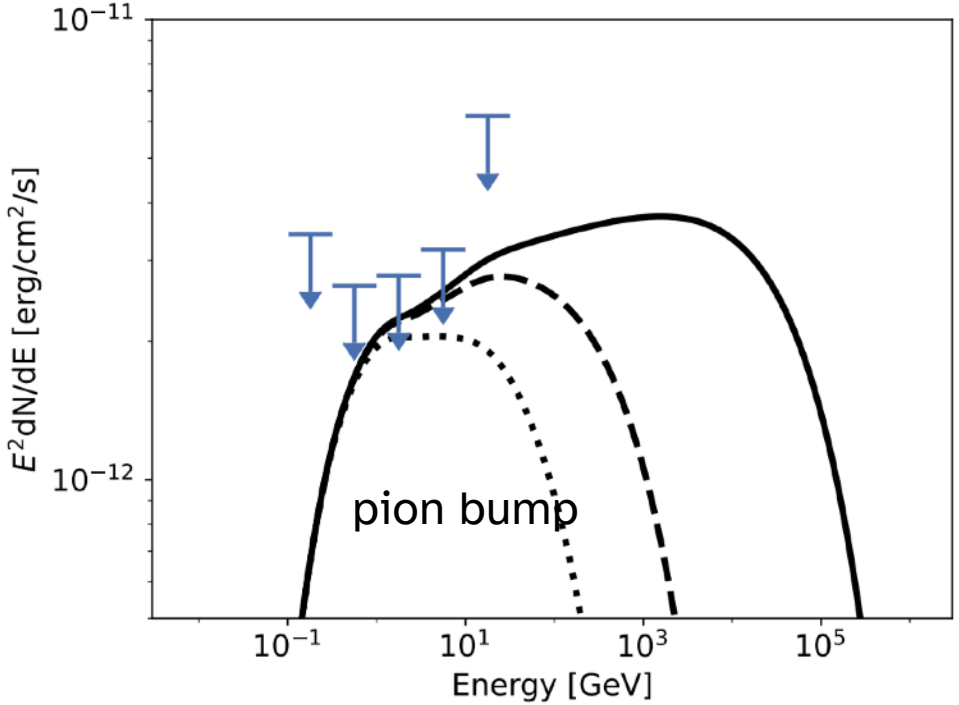
Searches for gamma-ray emission from CC SNe

Fermi-LAT observations of SN 2023ixf

LAT upper limits on >100 MeV flux -> upper limits on efficiency of cosmic ray acceleration

[G. Martí-Devesa, A&A 686 (2024)]



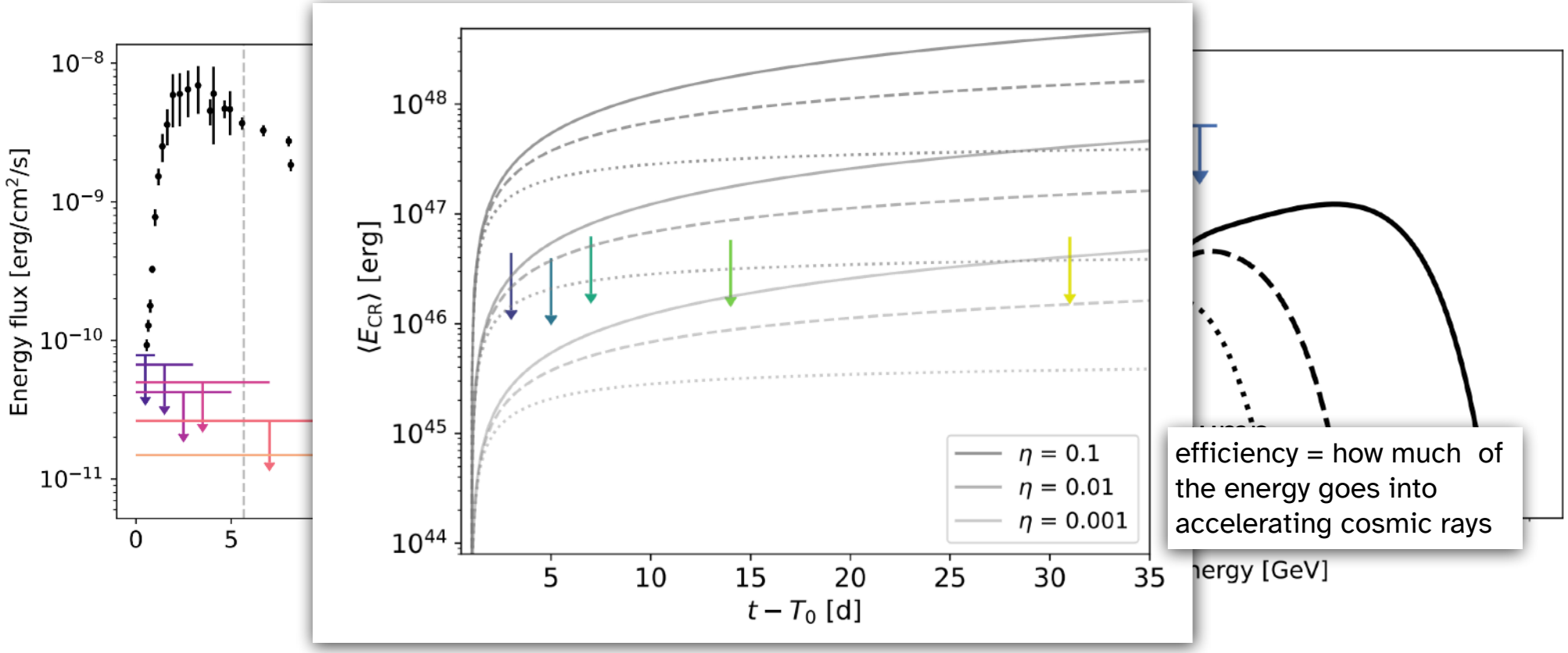


Searches for gamma-ray emission from CC SNe

Fermi-LAT observations of SN 2023ixf

LAT upper limits on >100 MeV flux -> upper limits on efficiency of cosmic ray acceleration of ≲1%

[G. Martí-Devesa, A&A 686 (2024)]



efficiency = how much of the energy goes into accelerating cosmic rays

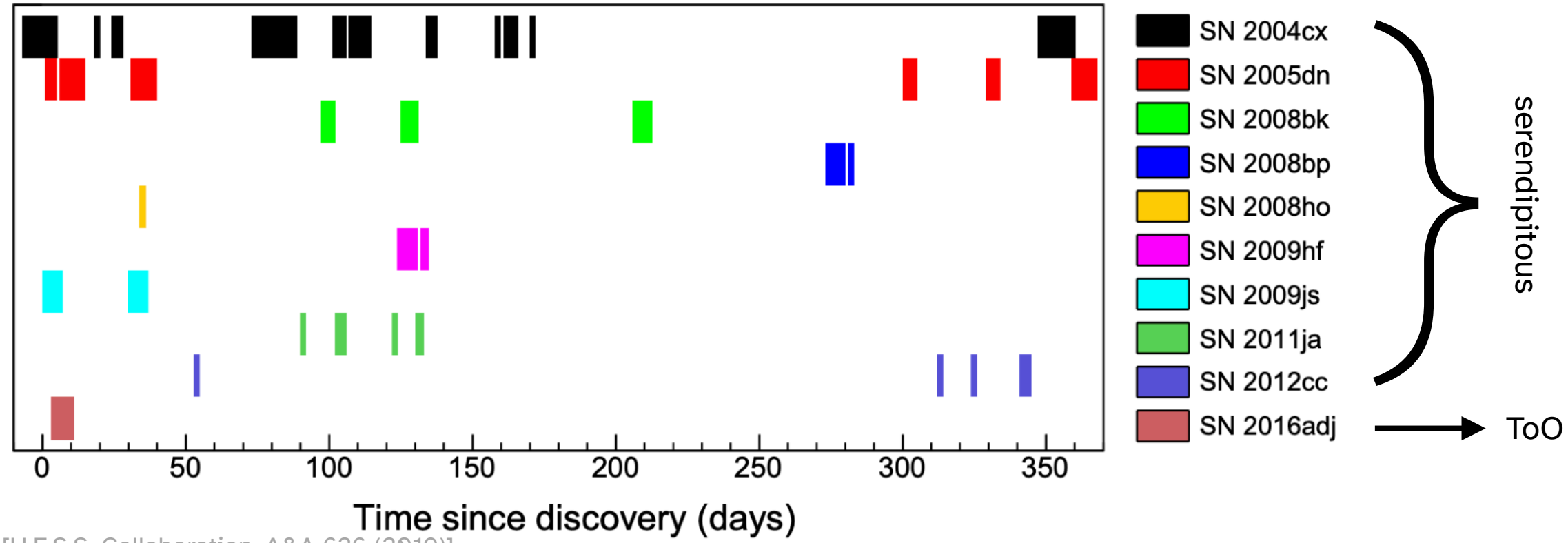
Searches for gamma-ray emission from CC SNe

H.E.S.S. observations of CC SNe

VHE photons from CC SNe need to wait until the opacity decreases sufficiently (estimate of ~1 week)

[A. Marcowith et al., Nuc Phys B 256 (2014)]

H.E.S.S. observations:



[H.E.S.S. Collaboration, A&A 626 (2019)]

Searches for gamma-ray emission from CC SNe

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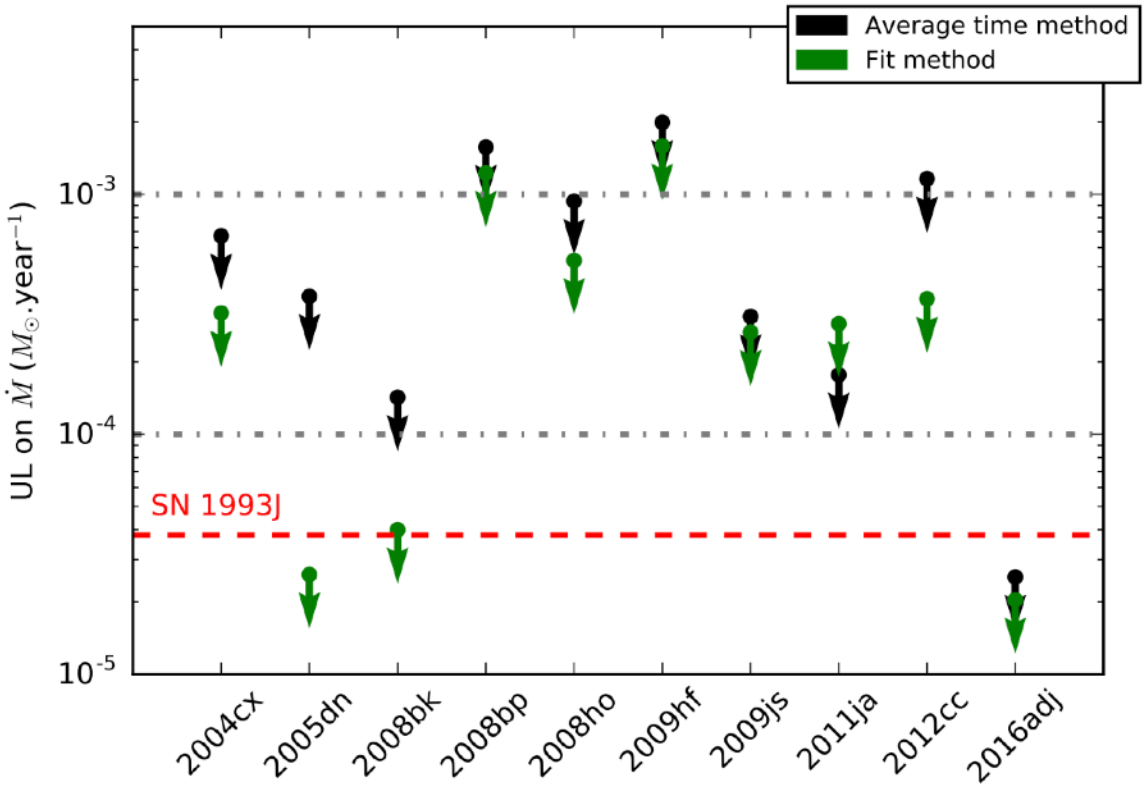
[A. Marcowith et al., Nuc Phys B 256 (2014)]

H.E.S.S. upper limits on mass loss rate for an efficiency of 10% (+ other assumptions)



[H.E.S.S. Collaboration, A&A 626 (2019)]

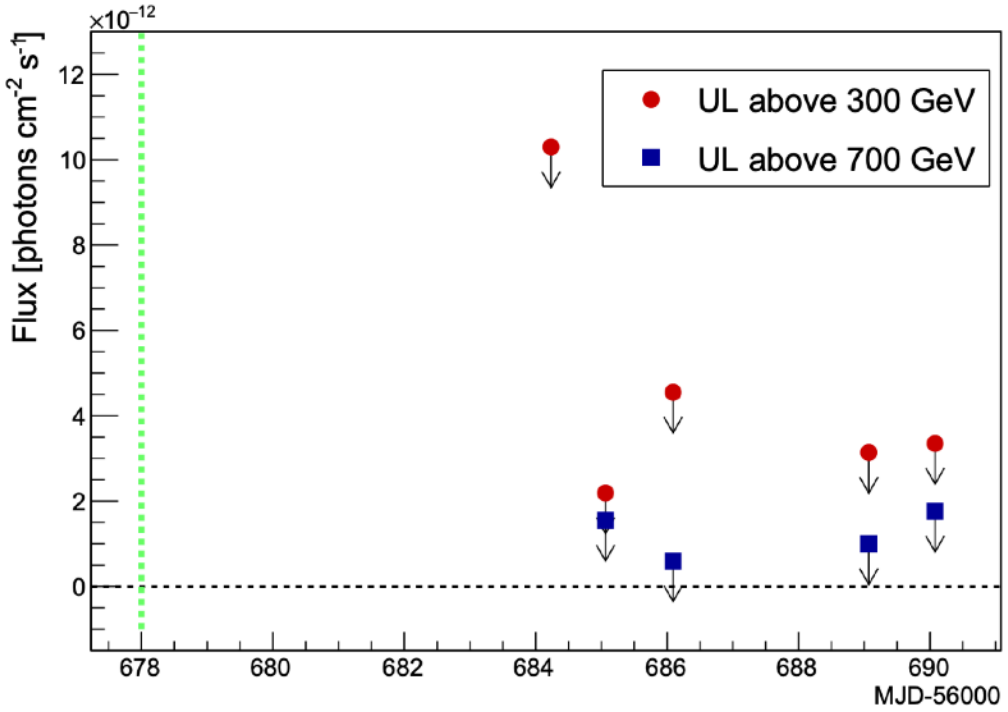
Searches for gamma-ray emission from CC SNe

MAGIC observations of SN 2014J

VHE photons from CC SNe need to wait until the opacity decreases sufficiently (estimate of ~1 week)

[A. Marcowith et al., Nuc Phys B 256 (2014)]

MAGIC observed a very nearby SN Ia (3.6 Mpc):



ally (Dwarkadas & Chevalier 1998). Although the flux keeps increasing with time according to Eq. (1), with this low expansion parameter it will still be about 10^{-21} photons $cm^{-2}\,s^{-1}$ 100 yr after the SN occurred, which is well below the sensitivity of the current and planned VHE observatories – several orders of magnitude below the sensitivity that the future Cherenkov Telescope Array (CTA[1]) will reach.

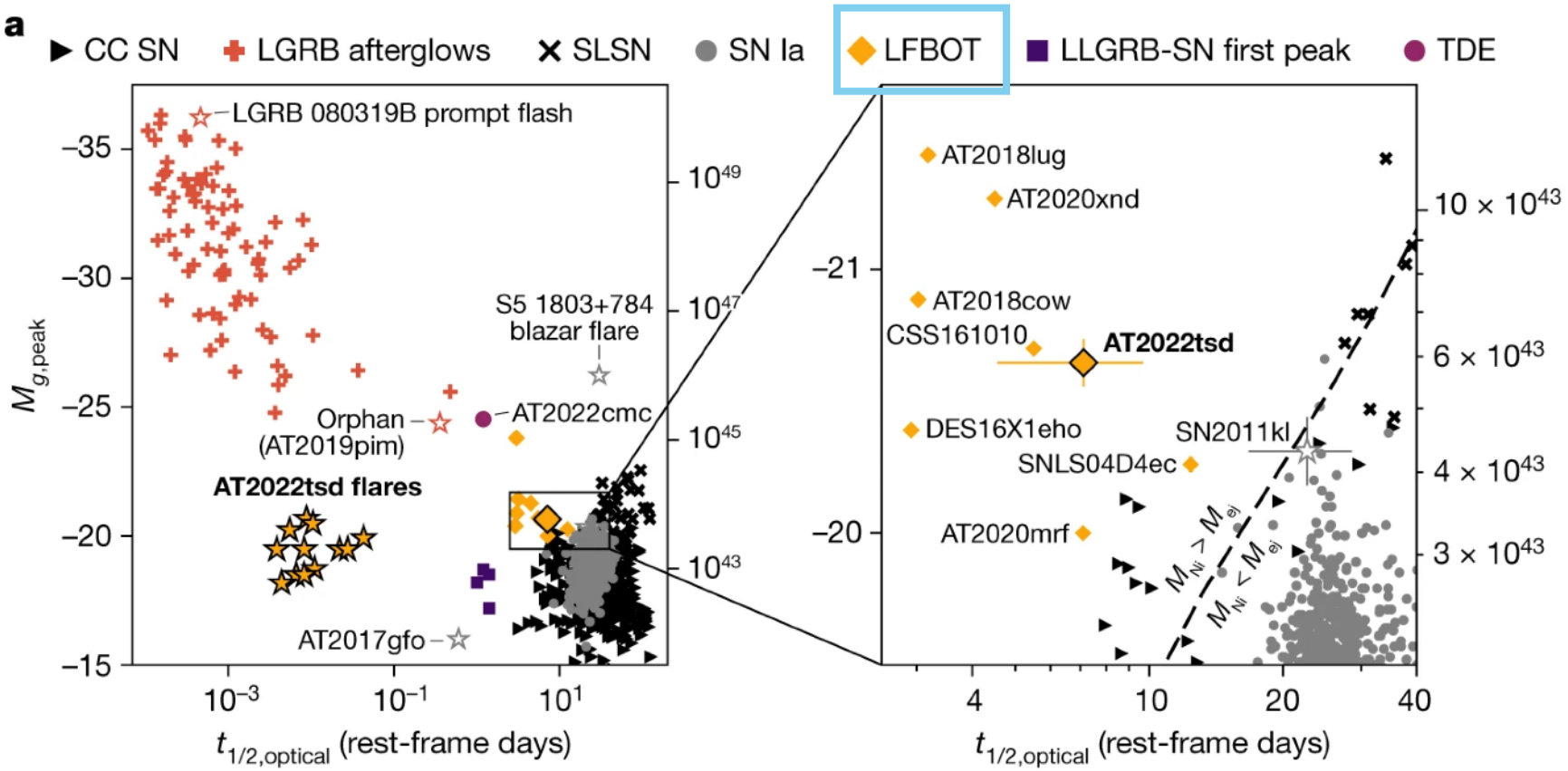
No detection -> no VHE detection possible for any SN Ia-CSM?

[M. L. Ahnen et al., A&A 602 (2017)]

Optical transients are getting weird

Time-domain astronomy in the era of optical surveys

FBOTs are a new class of optical transients

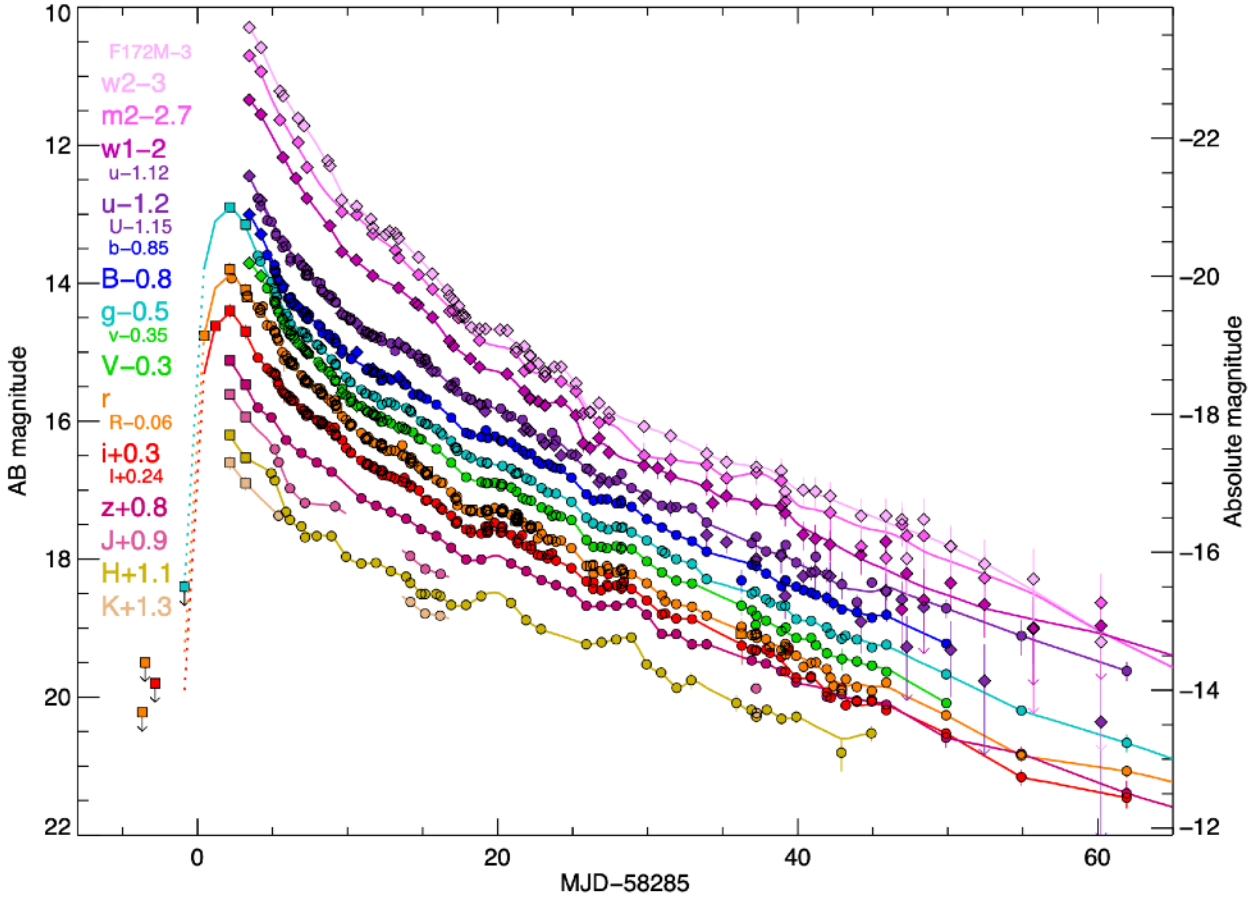


A. Y. Q. Ho et al., Nature 623 (2023)

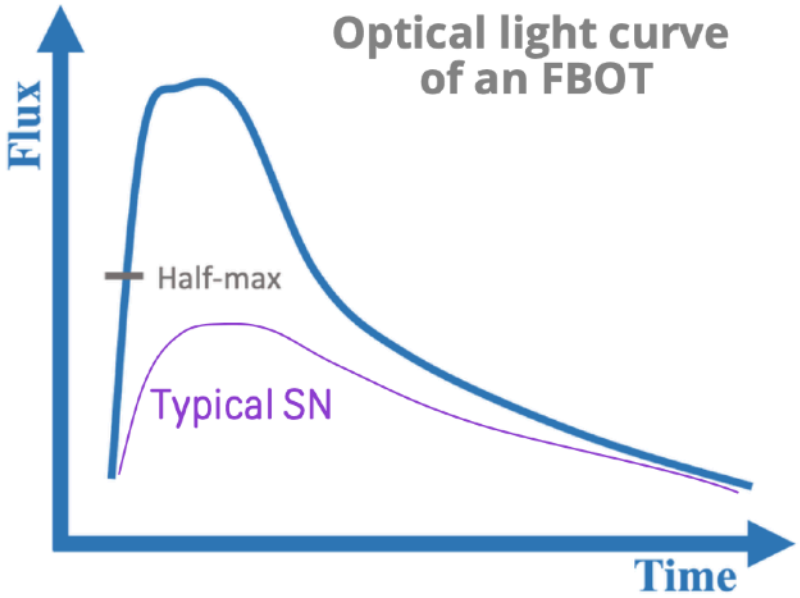
Fast blue optical transients (FBOTs)

AT2018cow

very short rise time (< a few days)



D. Perley et al., MNRAS 484 (2019)

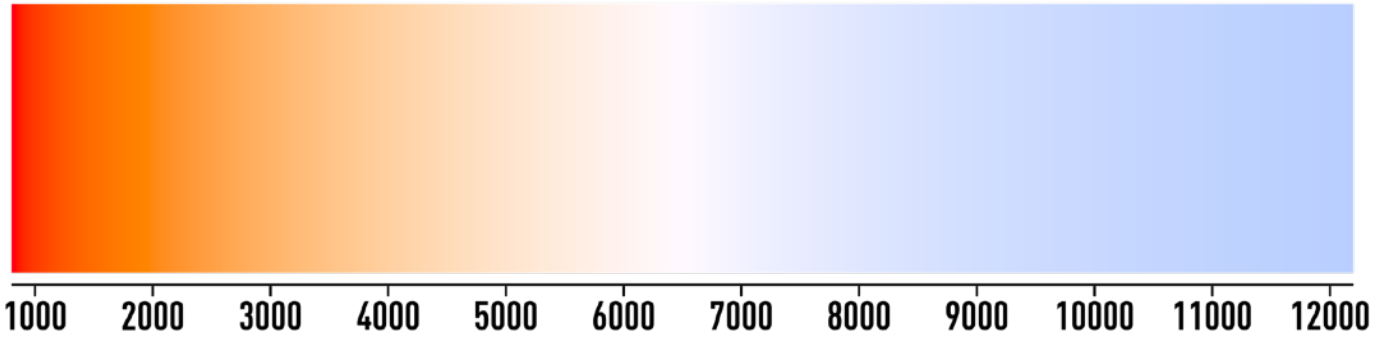


J. Borowska-Naguszewska

Fast blue optical transients (FBOTs)

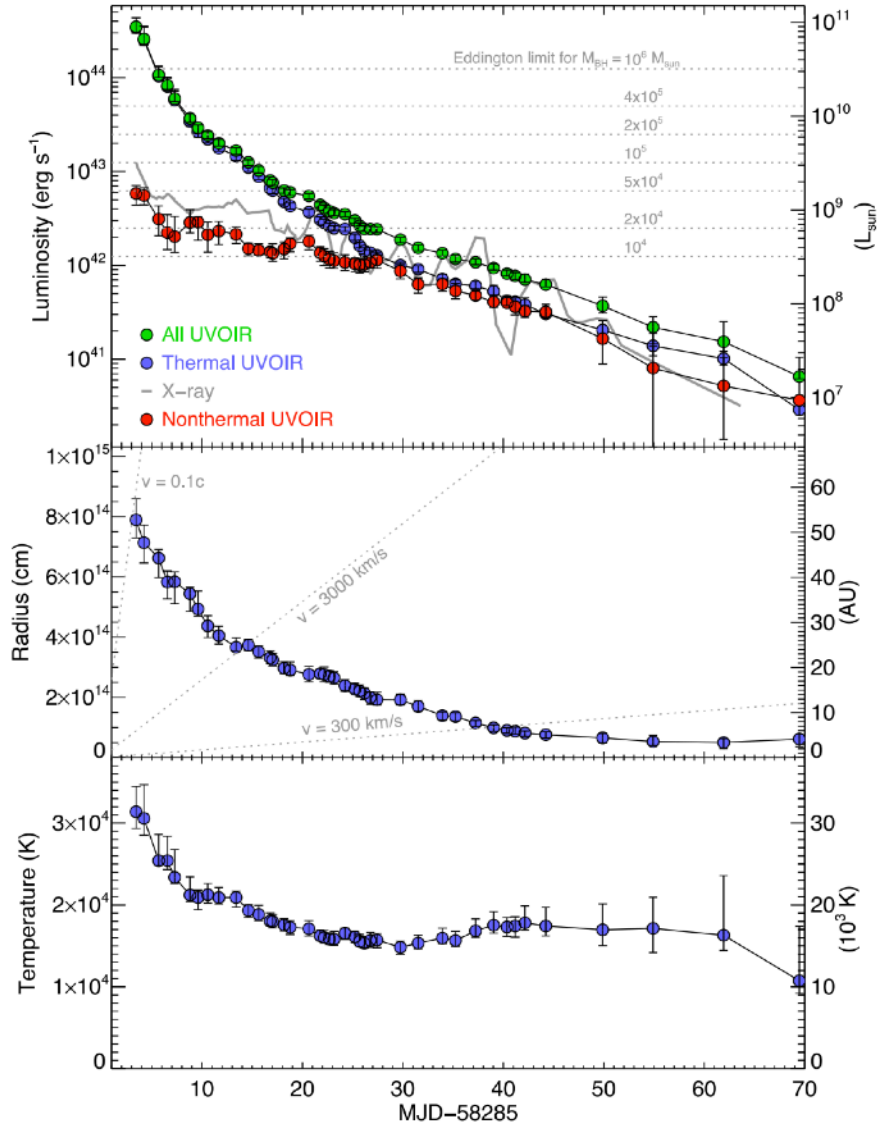
AT2018cow

T ~ 10^4 K => blue



Some FBOTs have been established as various kinds of CC SNe

early times: blackbody with T ~ 10^4 K



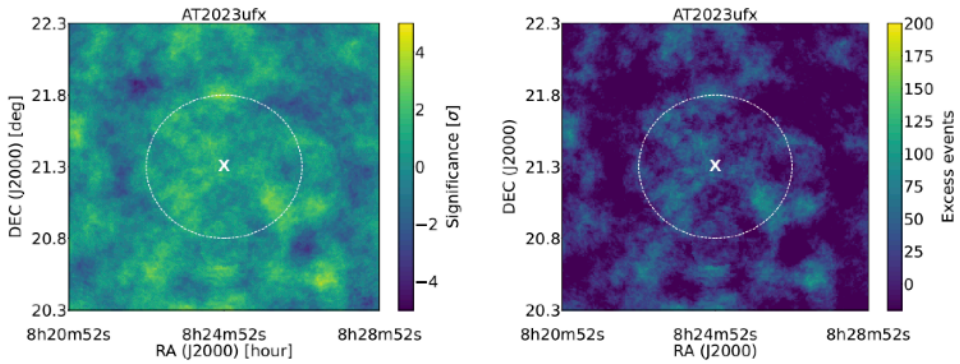
Fast blue optical transients (FBOTs)

Searches for gamma-ray emission?

I couldn't find much in the public literature … but, H.E.S.S. and VERITAS (and MAGIC?) have ToO programs

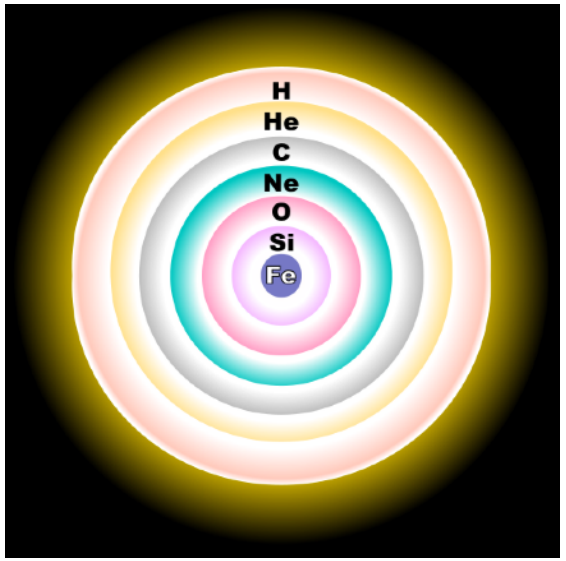
e.g., VERITAS observations of AT2023ufx:

M. Kherlakian, PhD thesis (2025)

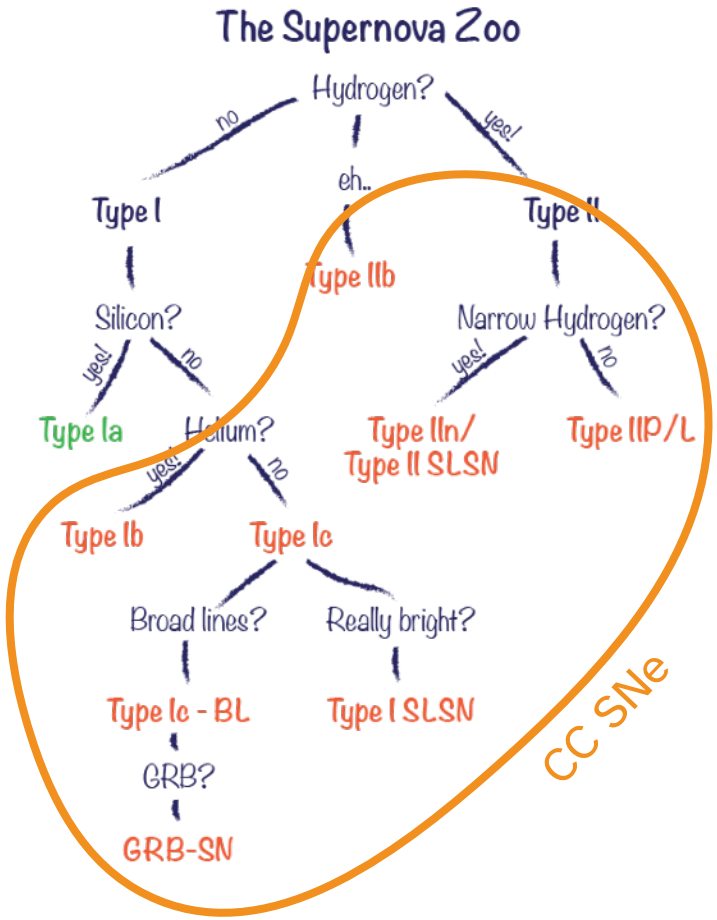


Core-collapse supernovae from astronomy ~~101~~ 102

Any non-Ia supernova is a core collapse supernova



R. J. Hall



A. Villar

Core-collapse supernovae from astronomy ~~101~~ ~~102~~ 999

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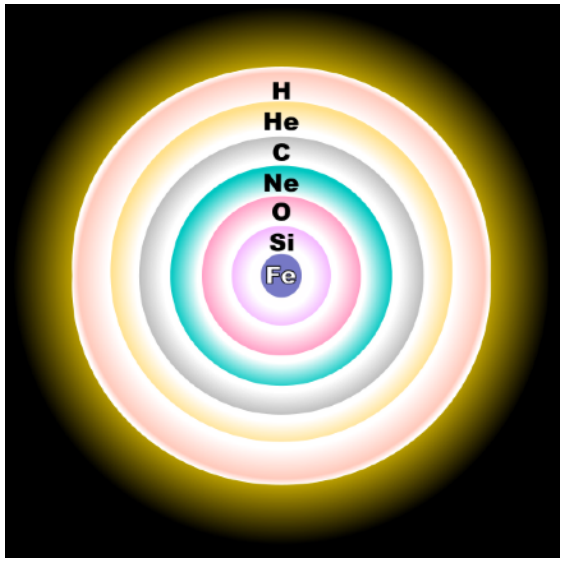
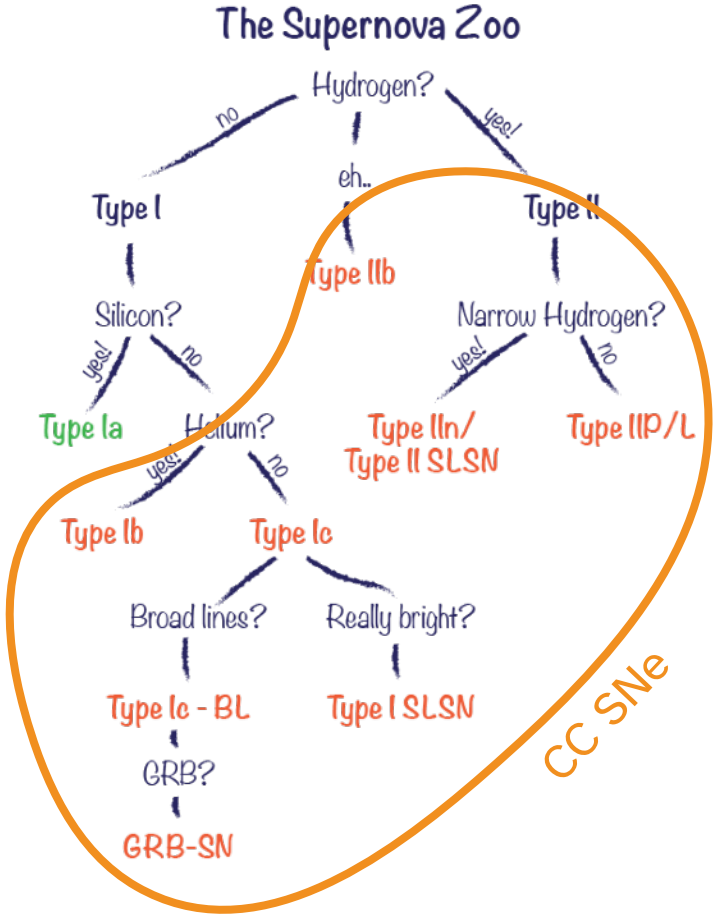
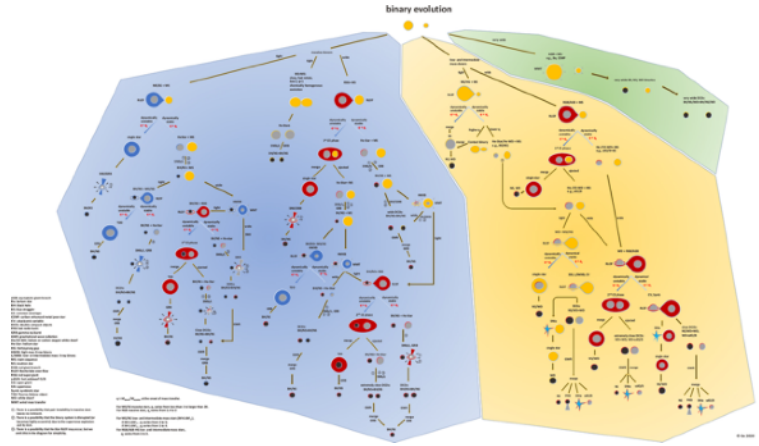


R. J. Hall



A. Villar

a large fraction of stars
are in binaries



Z.-W. Han et al., Res Astron Astrophys 20 (2020)

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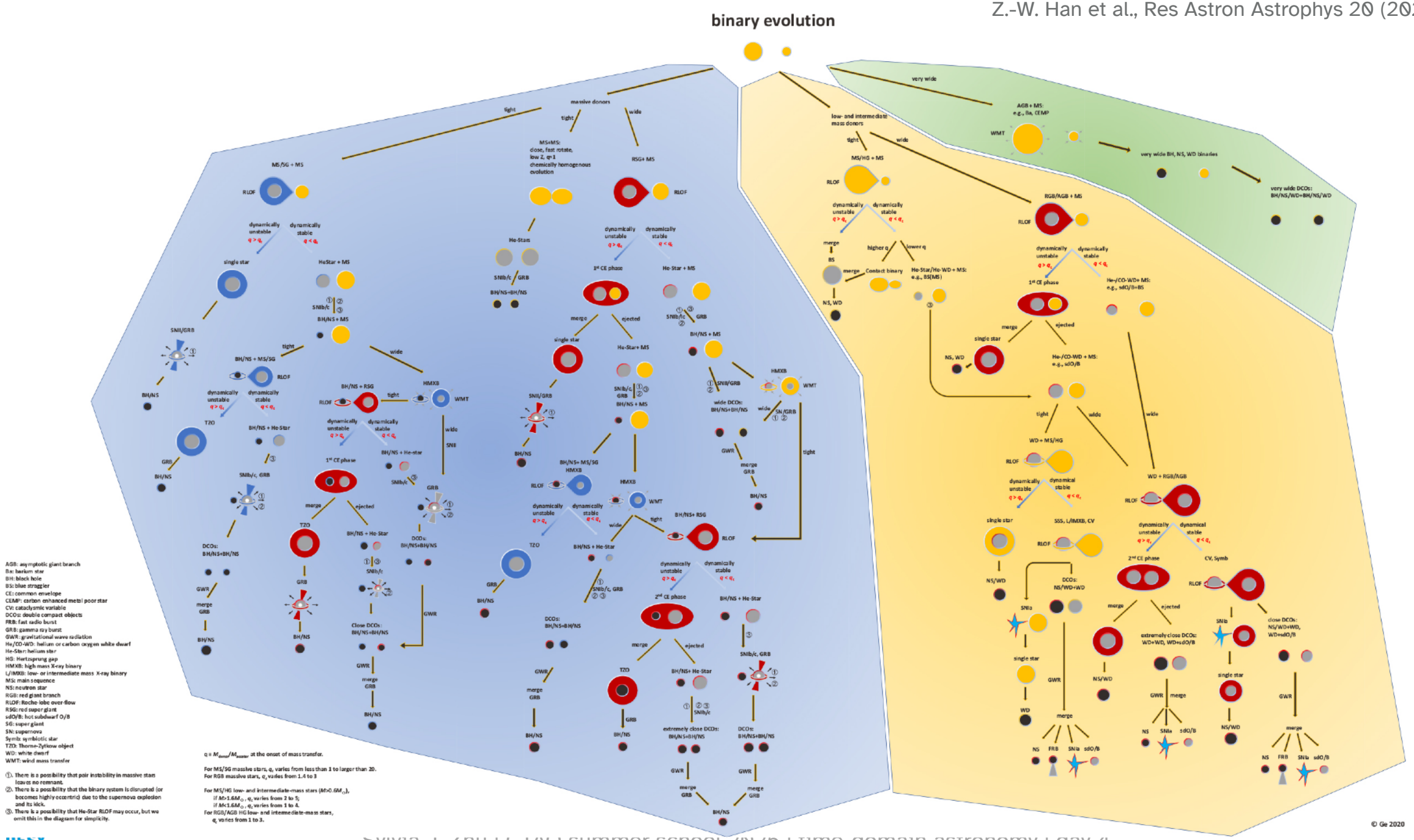
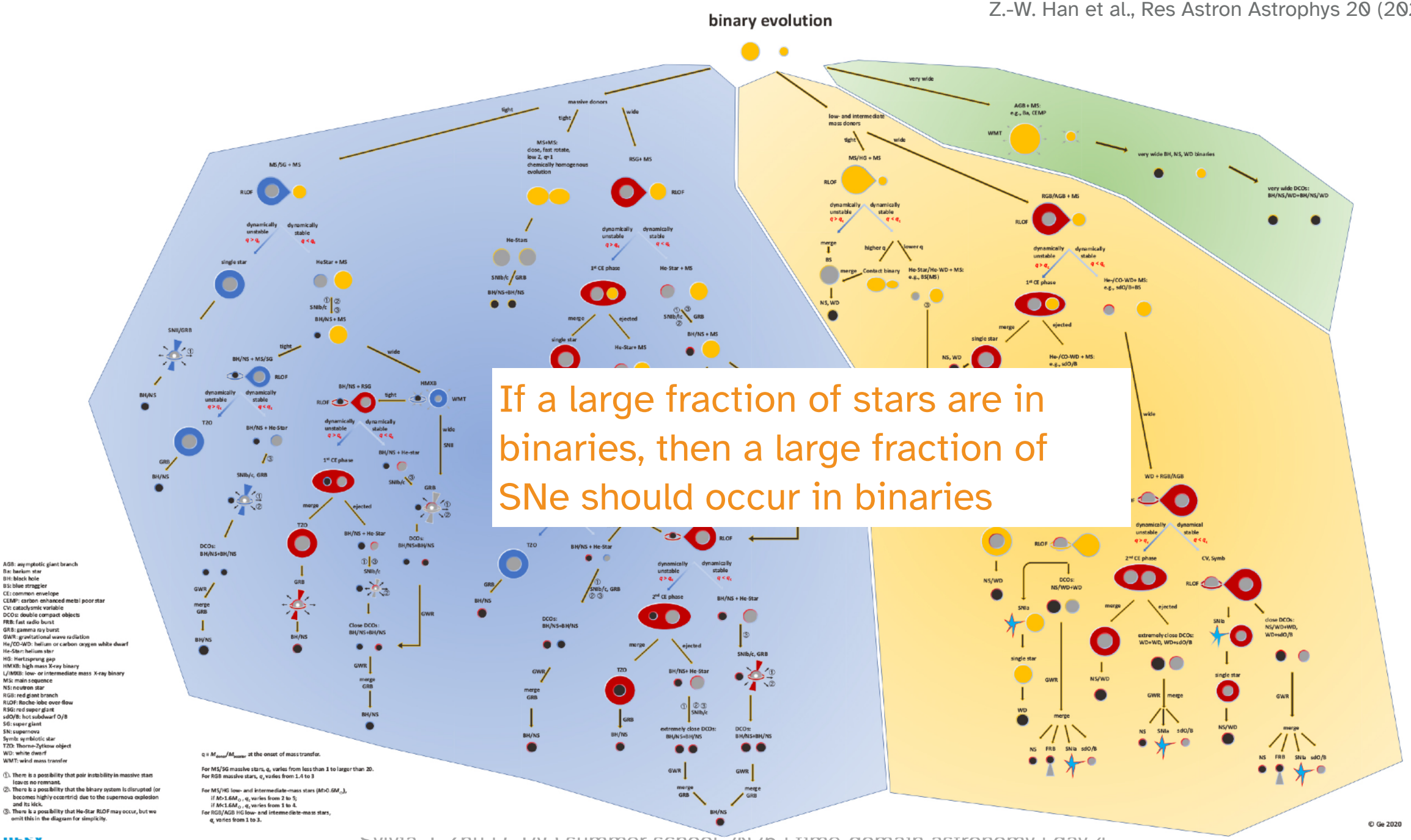


Z.-W. Han et al., Res Astron Astrophys 20 (2020)

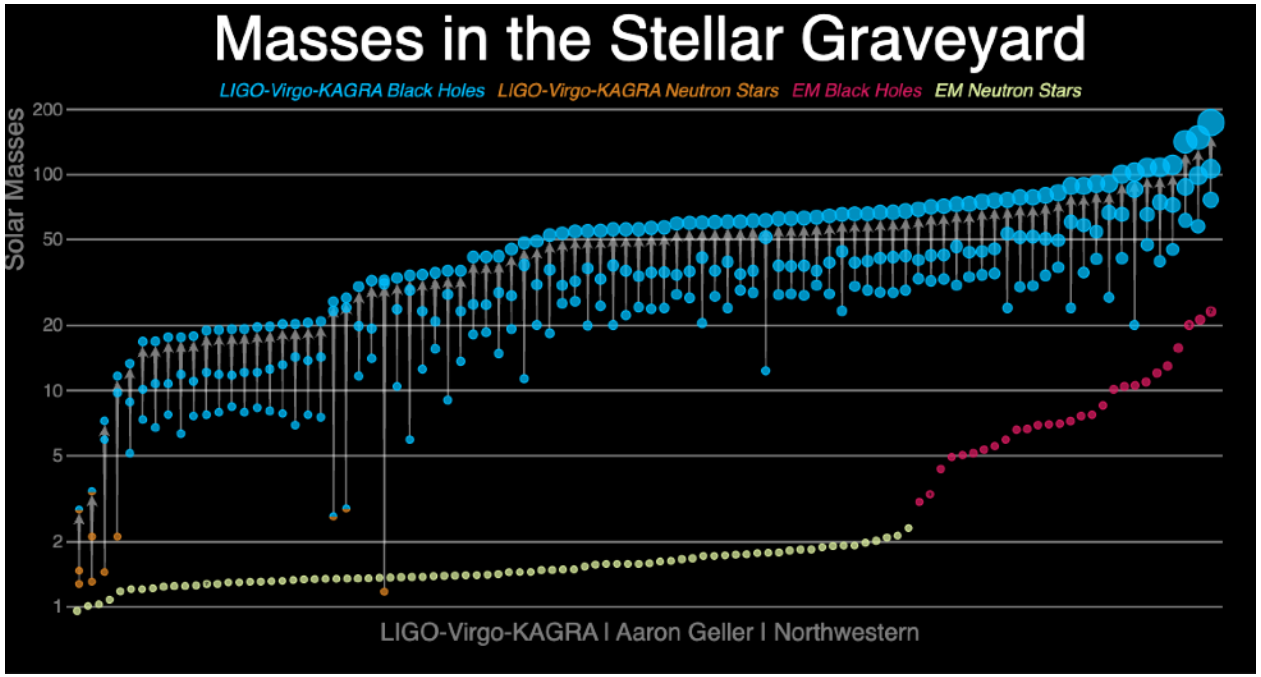


If a large fraction of stars are in binaries, then a large fraction of SNe should occur in binaries

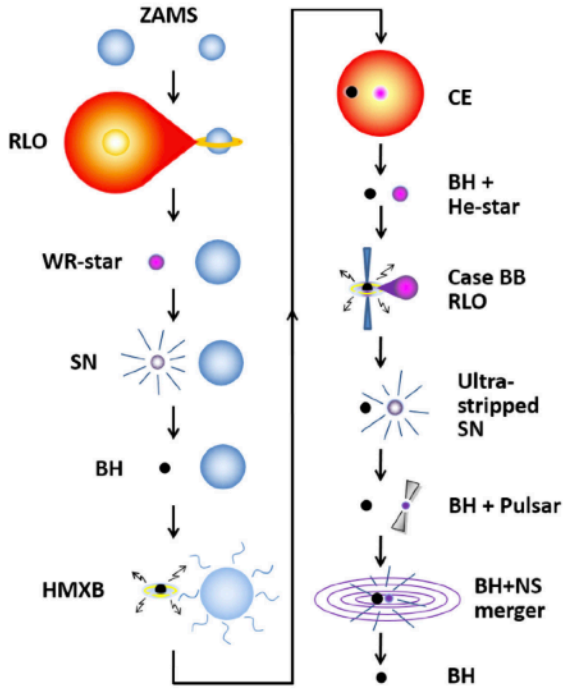
Supernovae in binaries are important

Time-domain astronomy in the era of GW detections

How do the gravitational-wave binaries form and evolve?



LIGO-Virgo-KAGRA / Aaron Geller / Northwestern

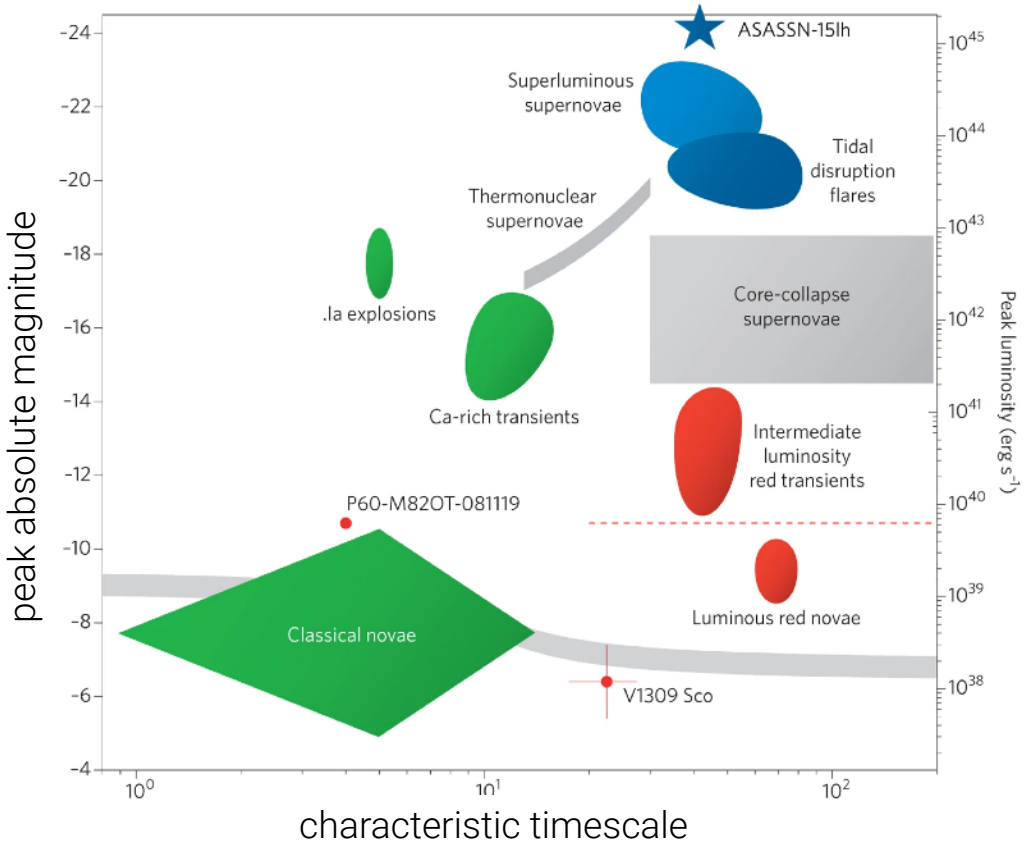


M. U. Kruckow et al., MNRAS 481 (2018)

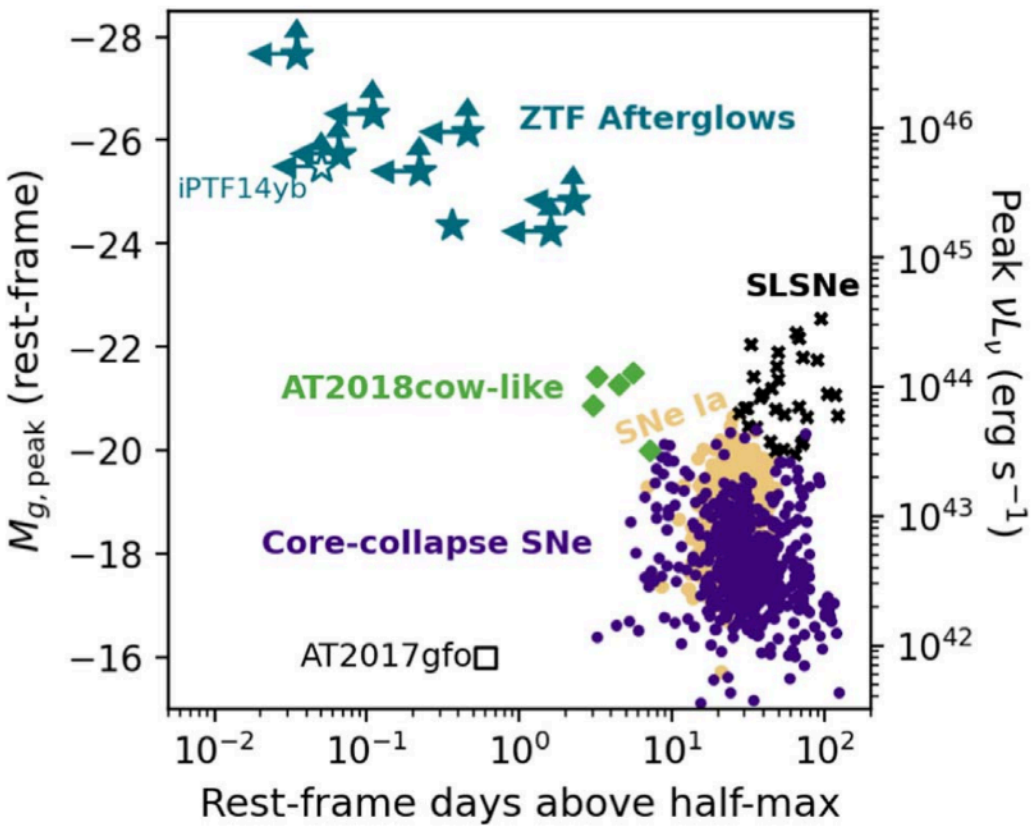
Optical transients are getting weird

Time-domain astronomy in the era of optical surveys

We're uncovering new kinds of transients, and often we don't know what produced them



S. B. Cenko, Nature Astro 1 (2017)



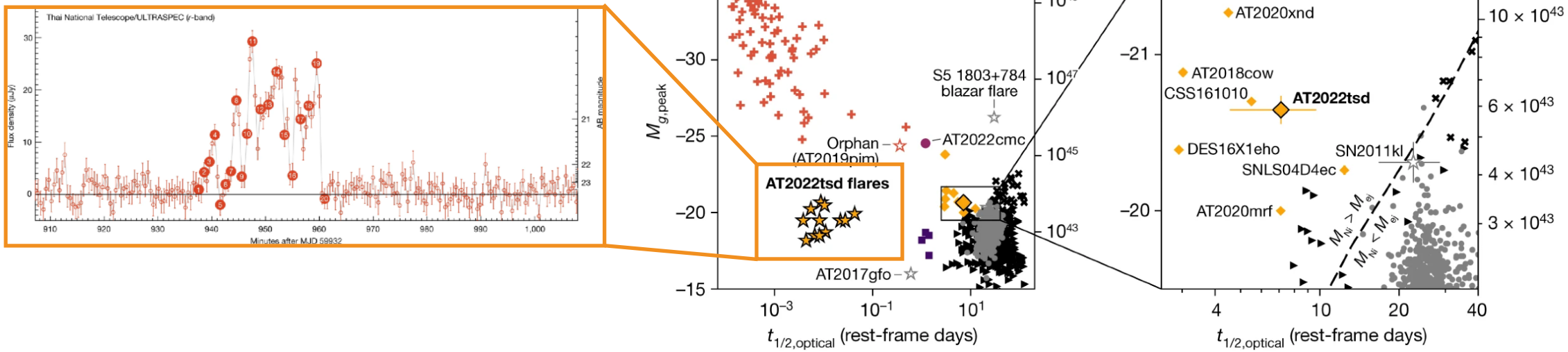
A. Y. Q. Ho et al., ApJ 938 (2022)

Optical transients are getting weird

Time-domain astronomy in the era of optical surveys

We're uncovering new kinds of transients, and often we don't know what produced them

Some seem to produce nonthermal emission over short timescales



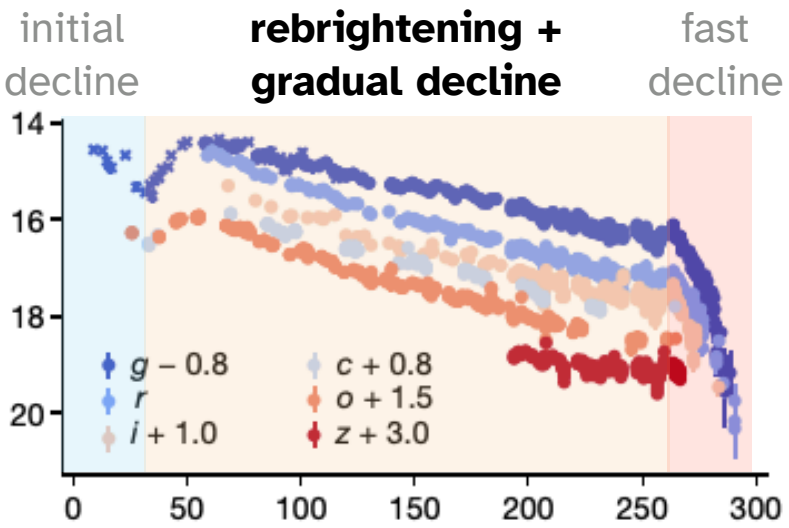
A. Y. Q. Ho et al., Nature 623 (2023)

Is there a class of **engine-driven supernovae**?

The curious case of SN2022jli

CC SNe in a binary system

P. Chen et al., Nature 625 (2024)



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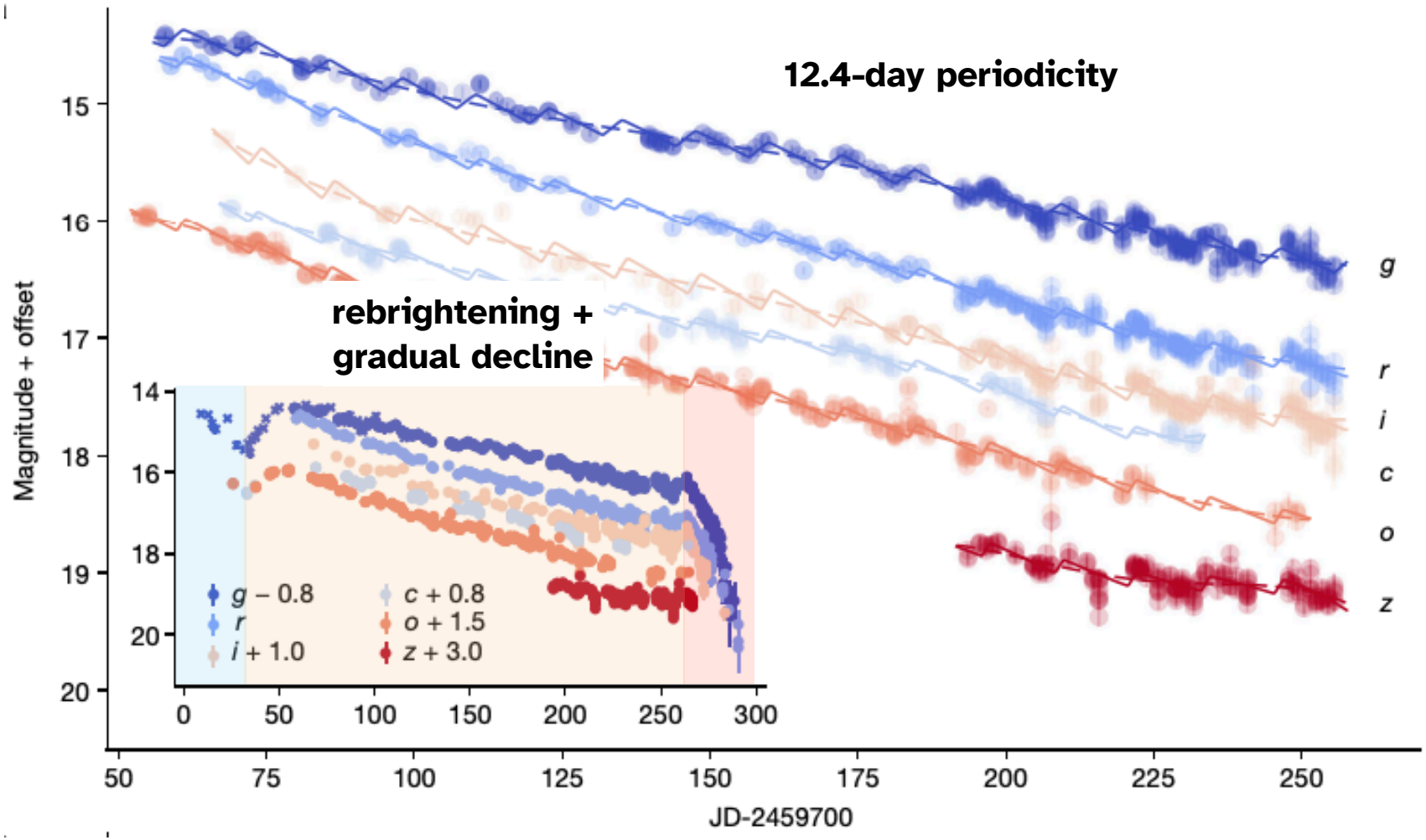
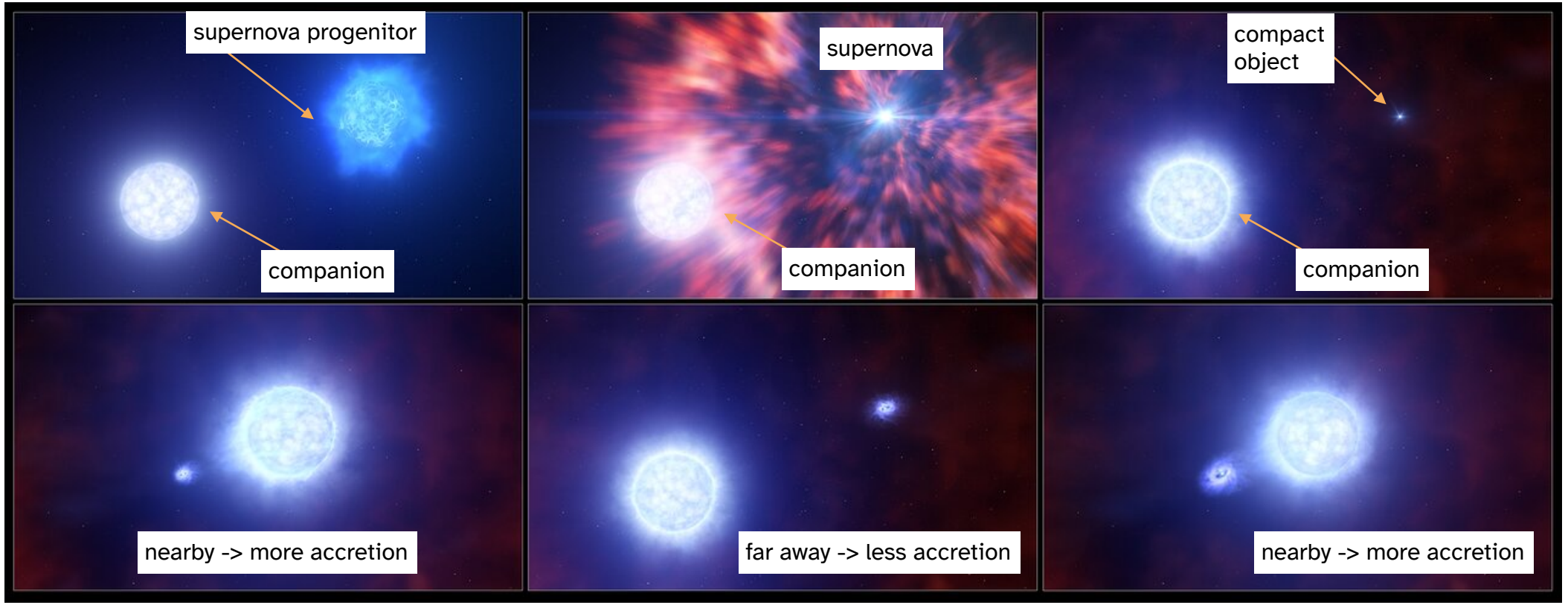


The curious case of SN2022jli

CC SNe in a binary system

P. Chen et al., Nature 625 (2024)

Interpretation: Compact object remnant is accreting from companion in a binary w/ a 12.4-day orbit



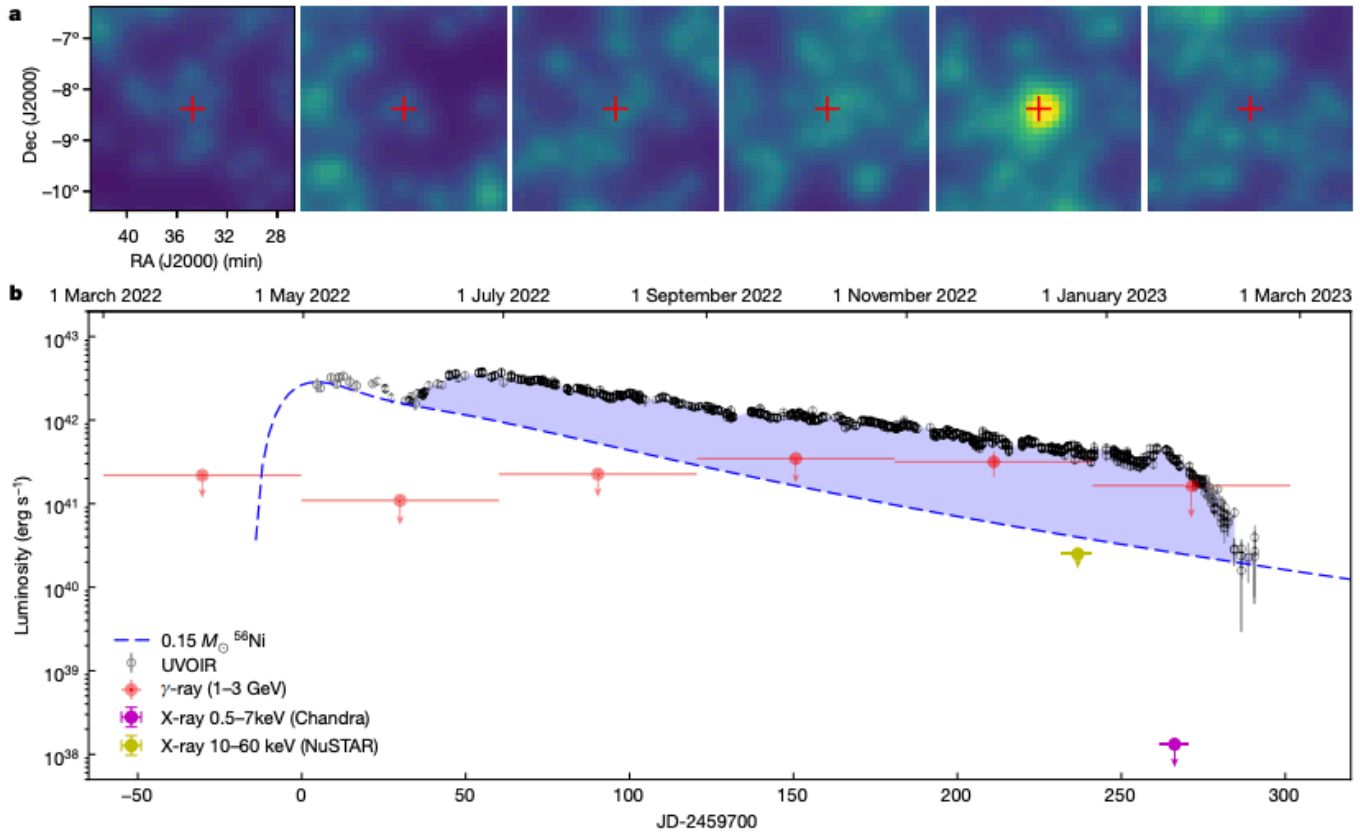
ESO / L. Calçada

The curious case of SN2022jli

CC SNe in a binary system

P. Chen et al., Nature 625 (2024)

Gamma rays six months after explosion?



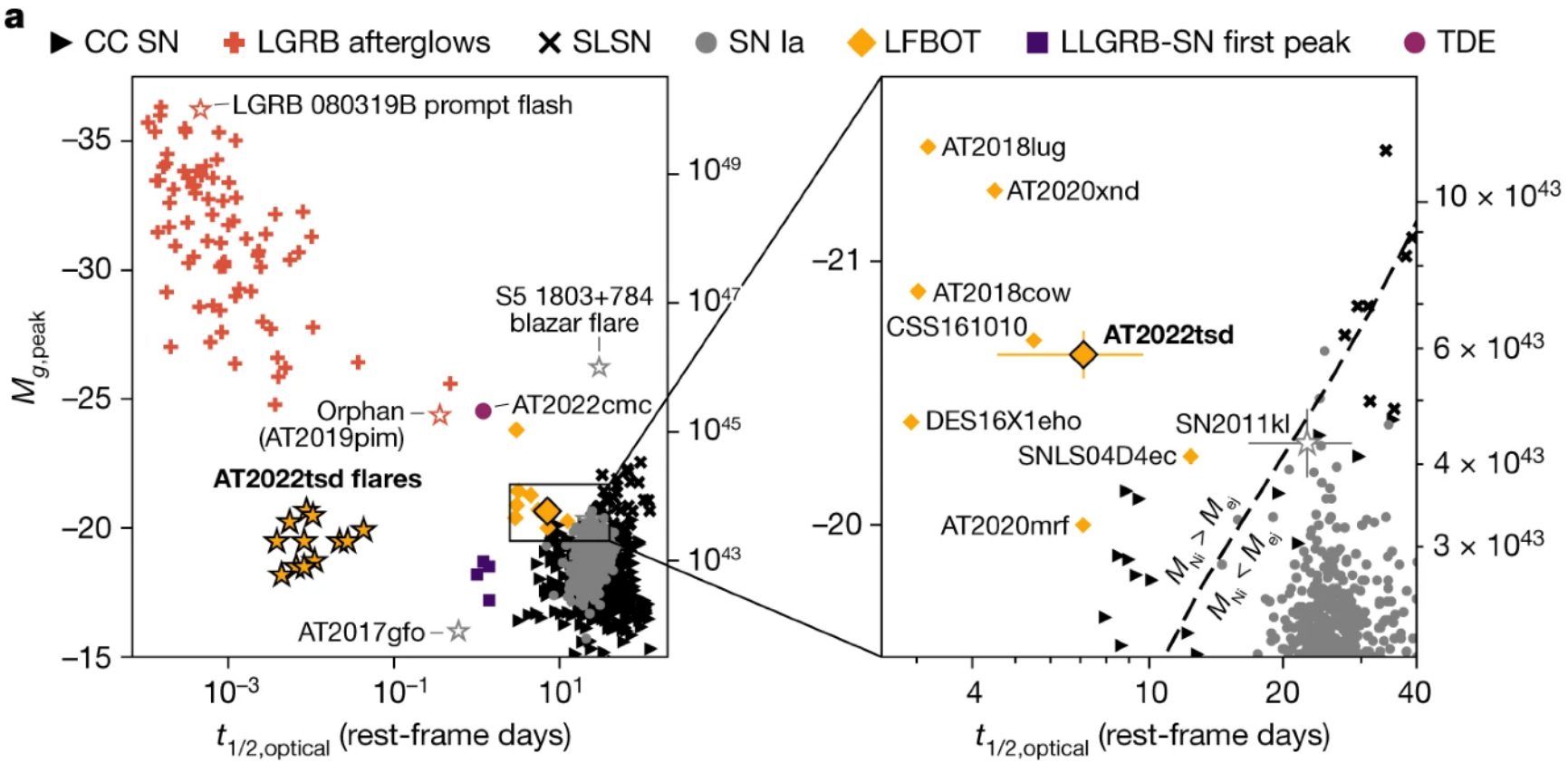
Interpretation:
accretion results in a jet
-> particle acceleration
-> gamma rays (once region is no longer opaque)

Is there a class of **engine-driven supernovae**?

Optical transients are getting weird

Time-domain astronomy in the era of optical surveys

A lot of discovery space for new transients, some maybe with gamma-ray emission



A. Y. Q. Ho et al., Nature 623 (2023)

ok I’m done

david will now tell you stuff