VHE Supernovae: state of the art and latest observations with the CTAO LST-1

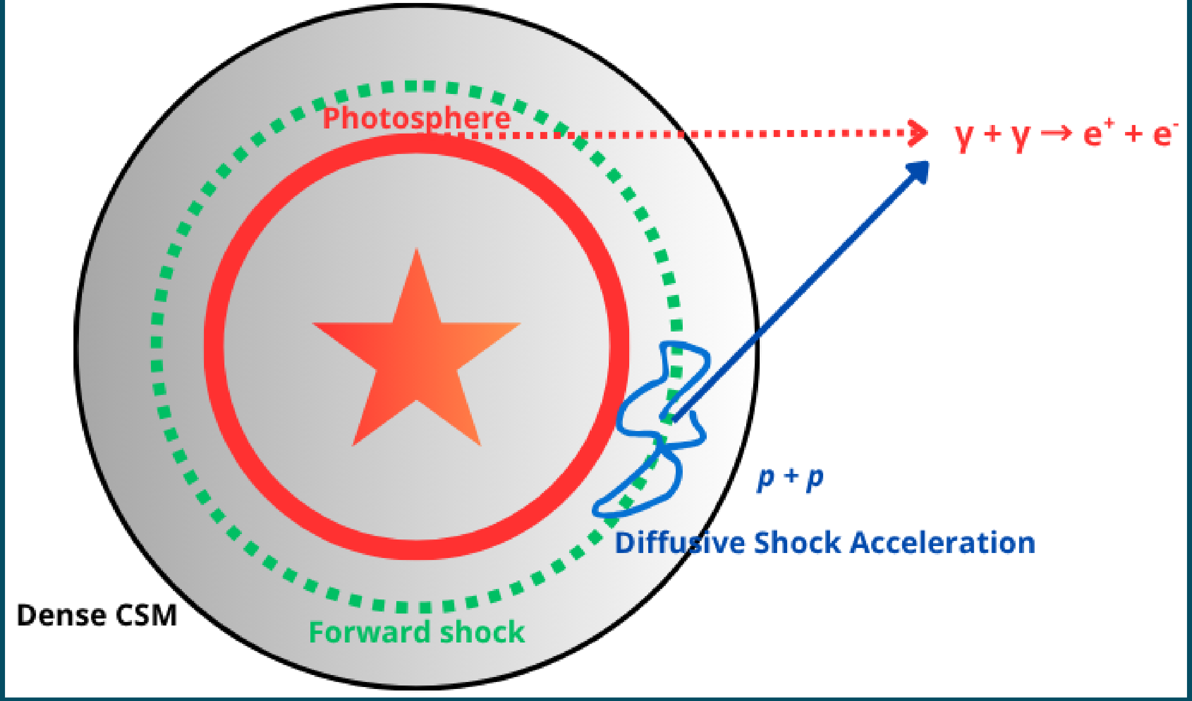
Andrea Simongini
andrea.simongini@inaf.it

Core collapse SNe

- Massive star $M > 8\ \mathbf{M}_{\odot}$.
- Gravitational instability.
- Collapse and core bounce.
- Neutron star or black hole remnant.
- Emission of γ, ν, GWs.
- Multimessenger and multiwavelength source.

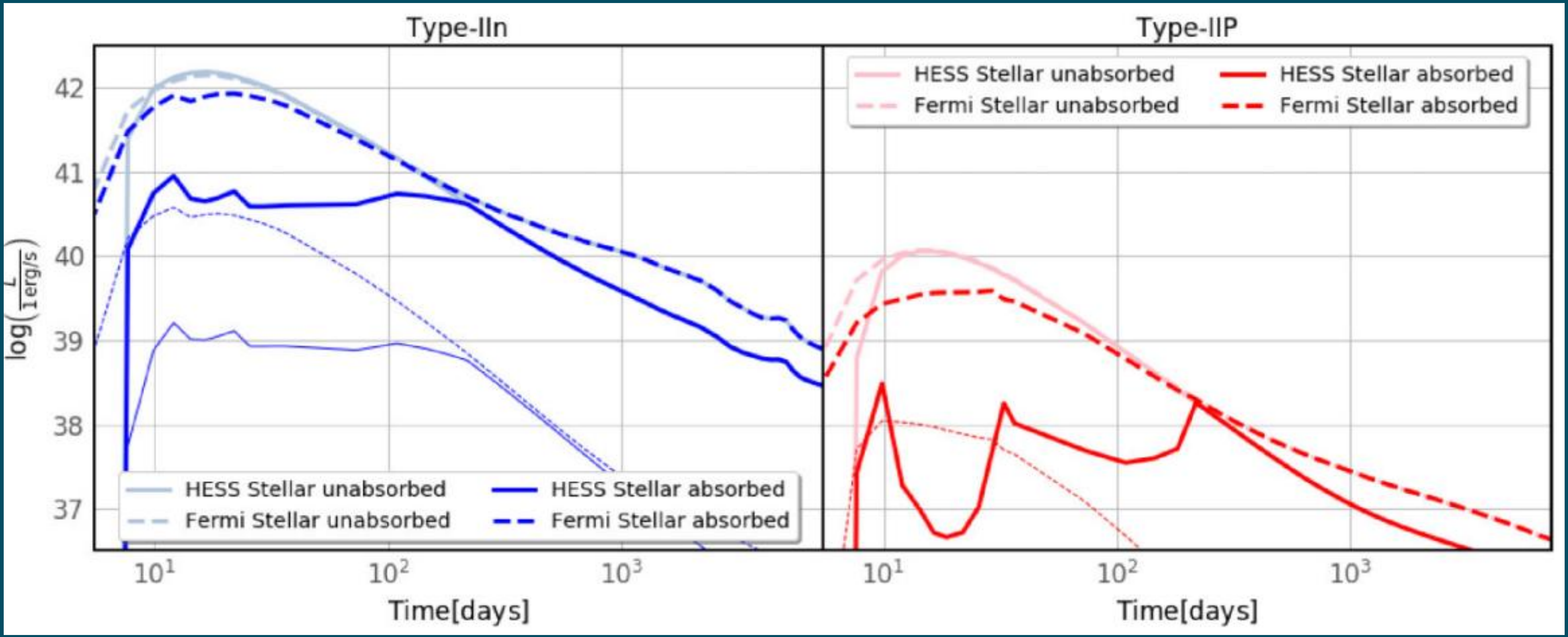
Why gamma-rays?

- The shock-wave propagating in a dense Circumstellar Medium (CSM) accelerates particles up to VHE regime.
- The low-energy photons of the photosphere critically attenuate the flux by pair-production.
- Difficult treatment: a lot of free parameters, a lot of models, very few data.



Credits: Fabio Acero

The gamma-gamma problem



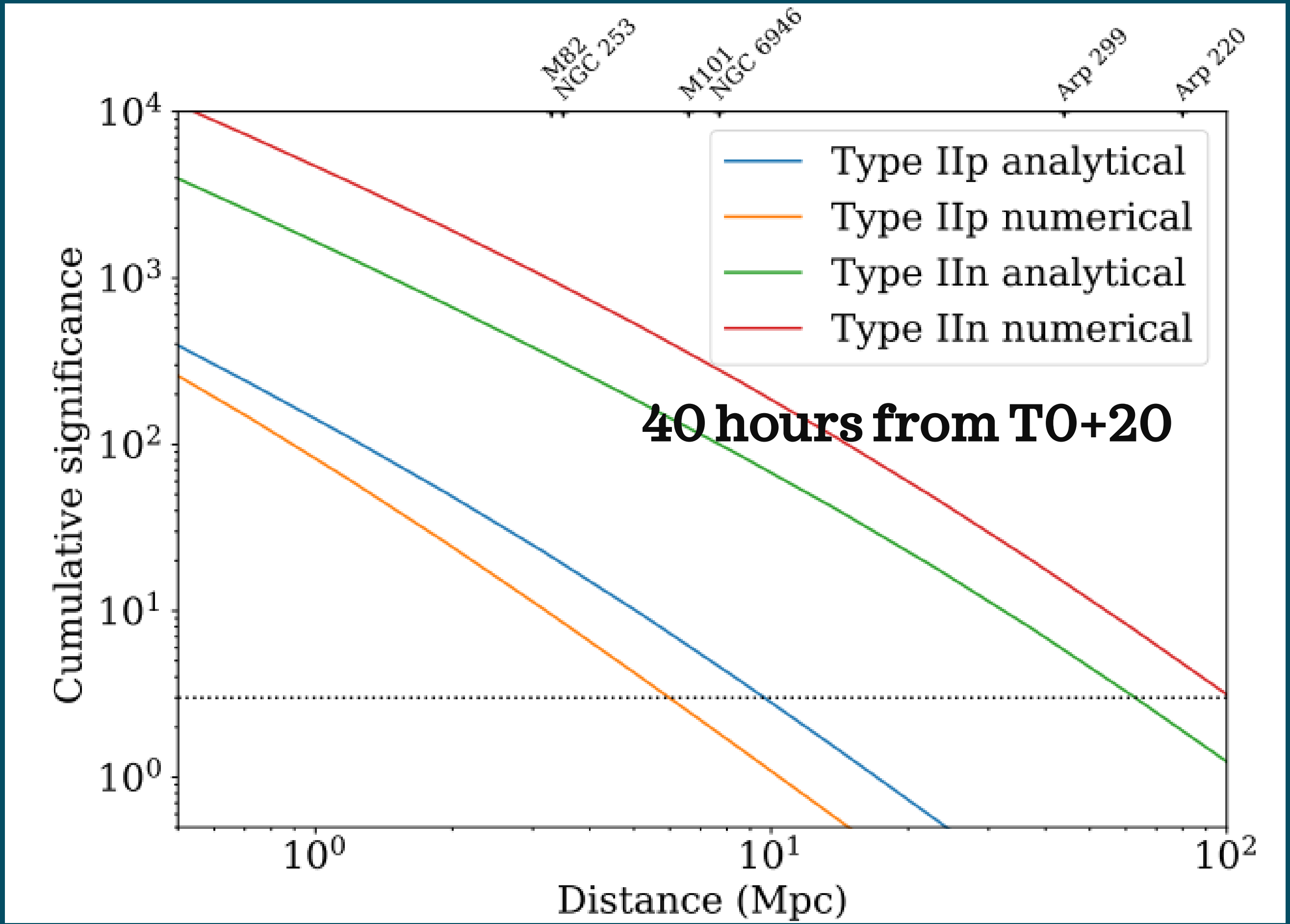
Credits: Brose+2022

What defines a good candidate?

1. Distance: as $F \propto d^{-2}$ the Supernova must be as close as possible!
2. CSM: a denser CSM increases the chances of having a more intense flux (IIn, IIP, …)
3. MWL: other wavelengths can provide useful insights into the particle acceleration mechanism.
4. Luck: main ingredient for new discoveries

Is there hope?

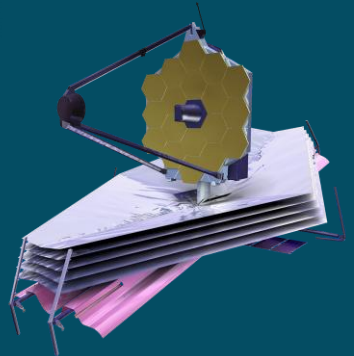
- The expected horizon of detectability of CTAO is around 7-10 Mpc for type II-P and 70 Mpc for type IIn.
- Current IACTs can still make the difference: the improved sensitivity and lower energy threshold of the MAGIC+LST-1 configuration may catch a big explosion!

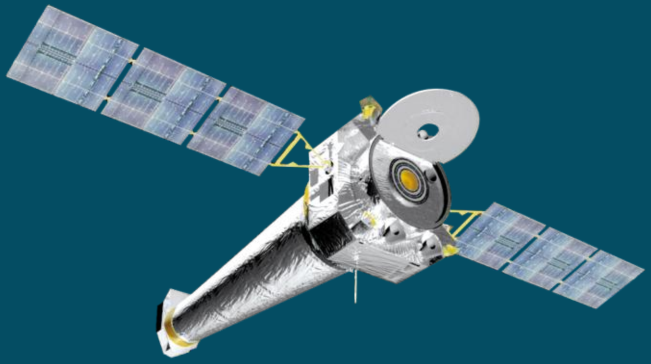


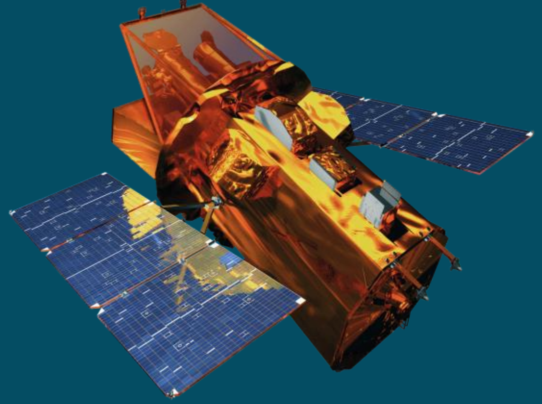
Credits: Fabio Acero

MWL SNe: current state

Radio	more than 70 SNe detected
UV-O-IR	routine detections.
X-rays	more than 100 SNe detected.
γ-rays	some Fermi candidates (no clear)
VHE γ-rays	???







VHE Supernovae: current state

MAGIC	observed the Type Ia SN 2014J.
H.E.S.S.	observed 10 CCSNe of type II, IIP and IIb.
VERITAS	observed the SLSNe SN 2015bn and SN 2017egm
LST-1	observed the type IIn-L SN 2024bch (Abe et al. for the CTAO-LST collaboration, in prep.)

VHE Supernovae: current state

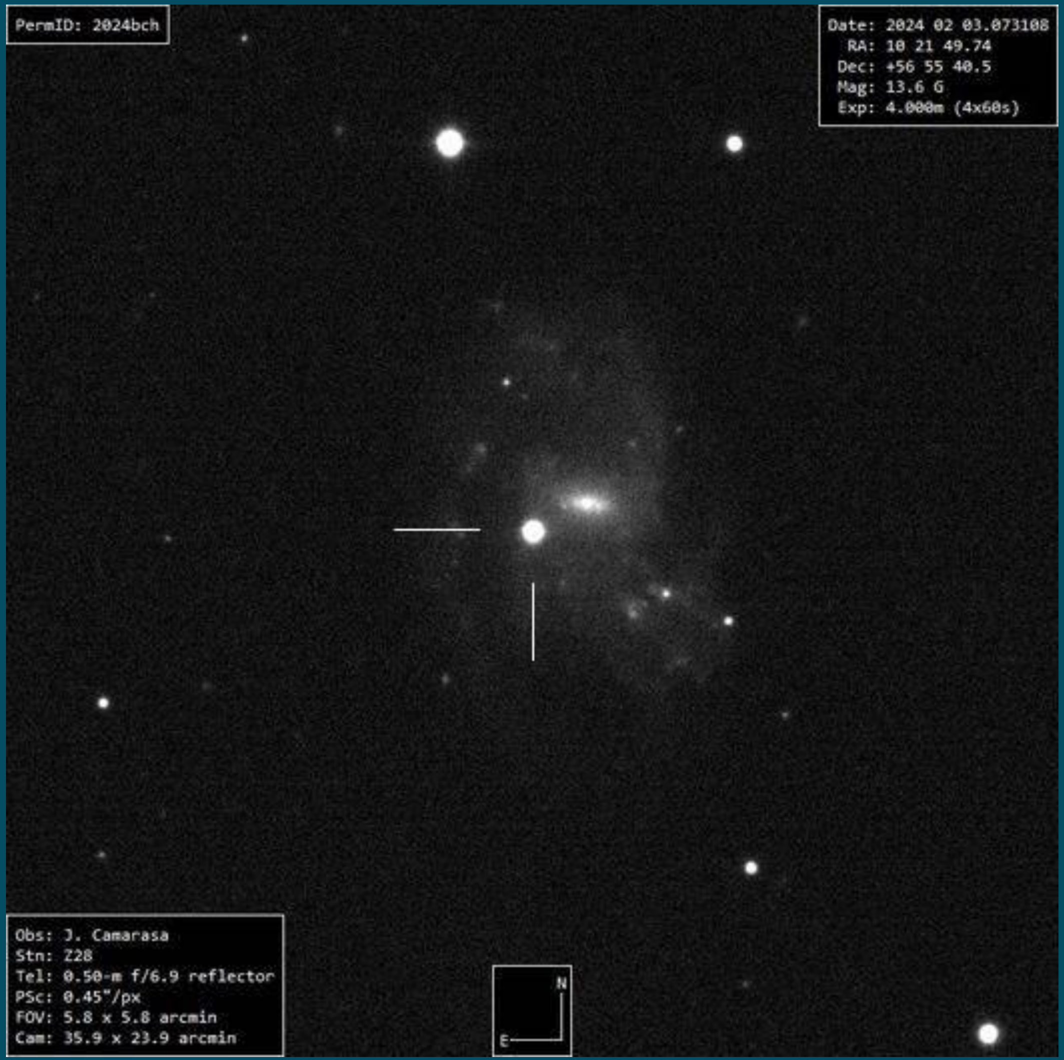
MAGIC	observed the Type Ia SN 2014J.
H.E.S.S.	observed 10 CCSNe of type II, IIP and IIb.
VERITAS	observed the SLSNe SN 2015bn and SN 2017egm
LST-1	observed the type IIn-L SN 2024bch (Abe et al. for the CTAO-LST collaboration, in prep.)

NO DETECTION!

SN 2024bch

SN 2024bch

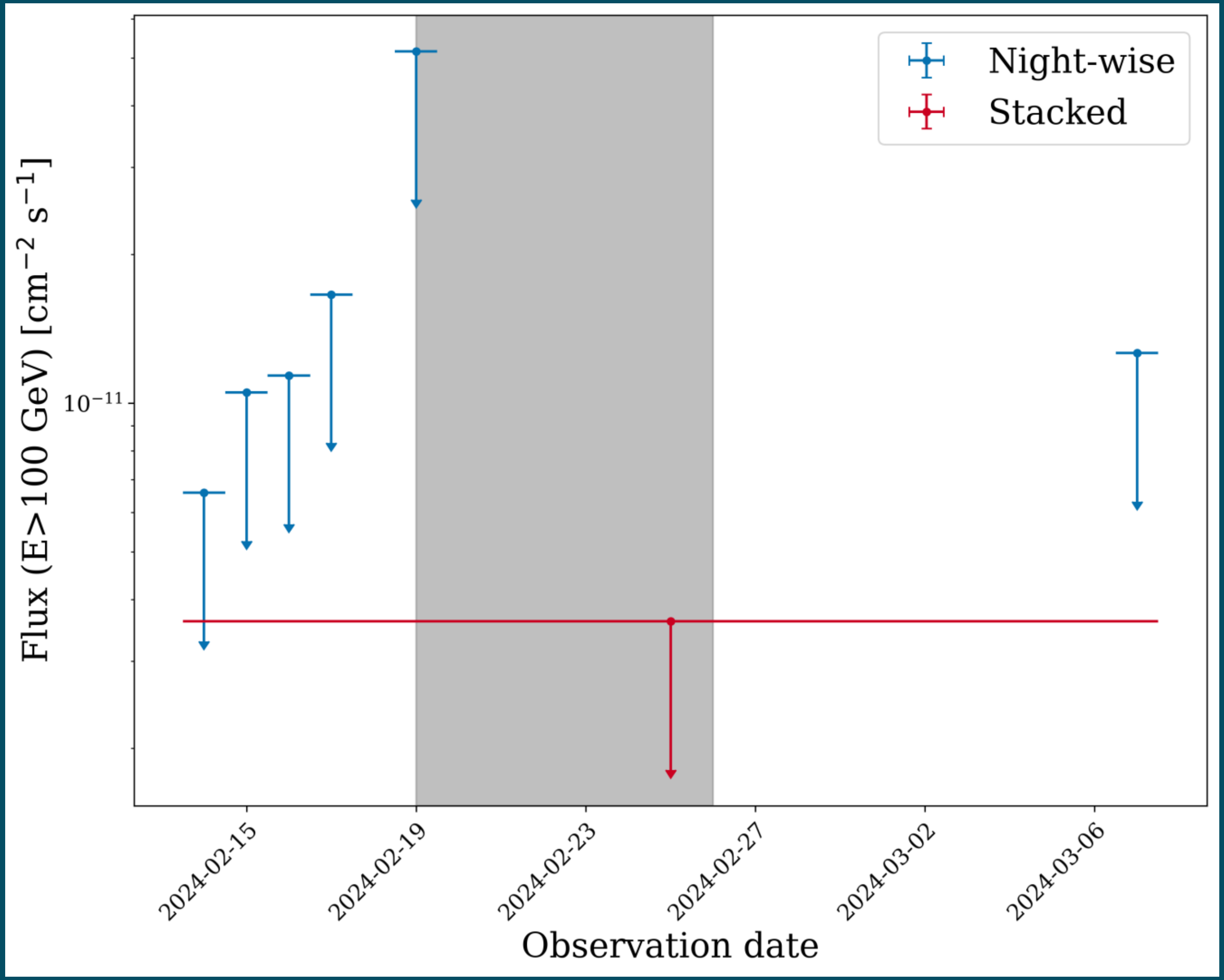
- CCSN of type IIn-L.
- T0 = Jan 28, 2024
- D = 17-20 Mpc
- 14 h of LST-1 over 6 nights.
- Our firsts:
  - ✓ First ULs on a IIn-L SN
  - ✓ First ULs down to 100 GeV



How to use ULs

We apply a <u>simple toy model</u> to derive physical parameters from our differential flux ULs.

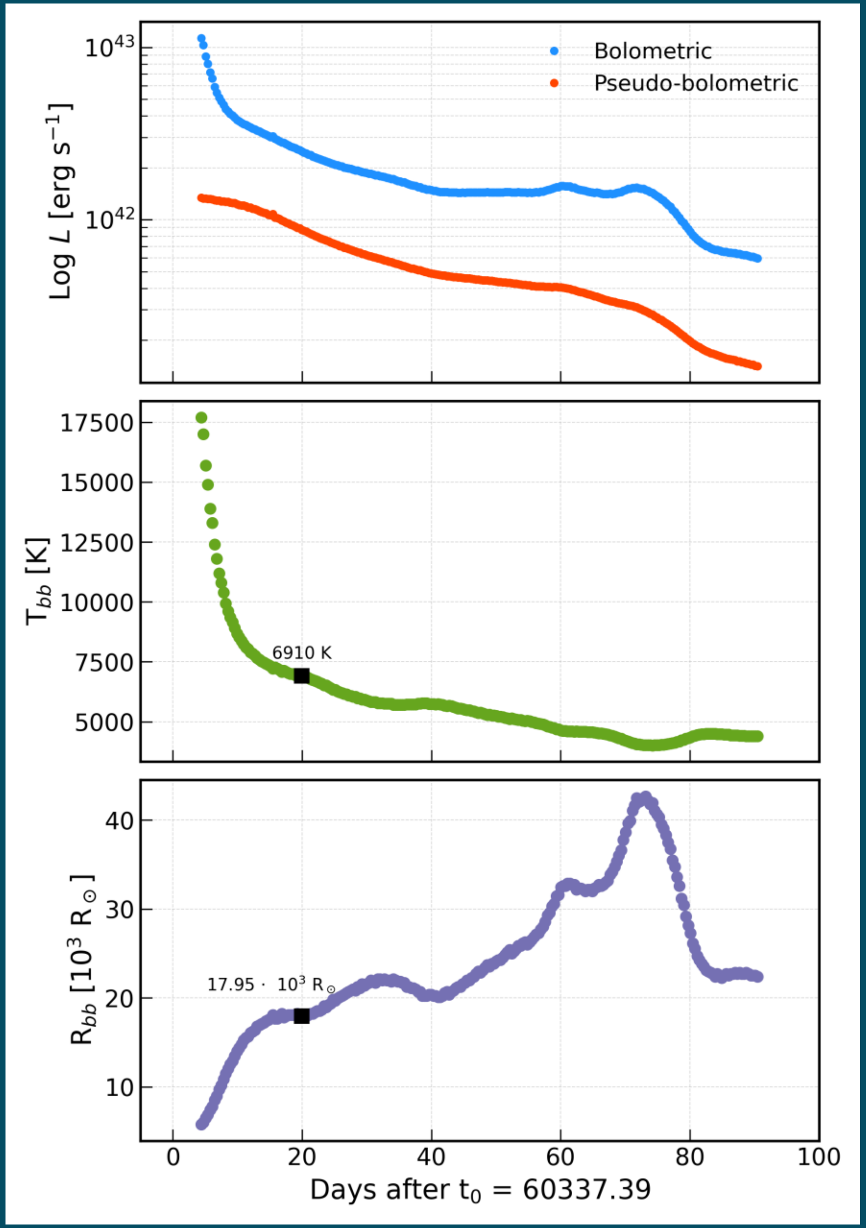
We use optical data to constrain the properties of the ejecta, the progenitor and the photosphere.



Modelling

$$\rho_{CSM} \propto \sqrt{F_{\gamma}(E_0, t, d)}$$

We derive the relative density of the CSM from our gamma-flux ULs. This puts constraints on the nature of the CSM and the pre-explosion mass ejection of the progenitor. The evolution of the photosphere is an indication of what to expect from gamma-gamma absorption.



Results

- We constrain $\rho_{CSM} \leq 10^{-4} \frac{M_\odot}{yr} \frac{s}{km}$ indicating a low density CSM.
- The photospheric evolution suggests that at the bulk of LST-1 observations (T0+20 days), the gamma-gamma attenuation could have had a minimum impact.
- From optical analysis we constrained progenitor's properties: combining optical + VHE results we conclude that the progenitor was a Red Super Giant.

Take-home message

Andrea Simongini
andrea.simongini@inaf.it

- VHE Supernovae are a new class of objects yet to be discovered.
- Past and present observations lay the foundations for future detection.
- The MWL approach is key to make real science, as demonstrated by the study of SN 2024bch.
- A dedicated ToO proposal on VHE supernovae is currently active (P.Is. A. Simongini, F. Acero) and we aim to detect the first event with MAGIC + LST-1 telescopes in joint configuration.

INAF ISTITUTO NAZIONALE DI ASTROFISICA
CTAO | LST COLLABORATION
TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA
MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescopes

Appendix

Acronyms

- CCSN = Core Collapse Supernova
- SLSN = Super Luminous Supernova
- UL = upper limit
- CSM = circumstellar material
- VHE = very high energy
- CTAO = Cherenkov Telescope Array Observatory
- LST-1 = first Large Sized Telescope
- MWL = multiwavelength
- T0 = time of explosion

Definitions

- II-P: hydrogen rich supernova with slowly decaying light curves
- II-L: hydrogen rich supernova with fast decaying light curves
- IIn: hydrogen rich supernova with narrow spectral lines
- IIn-L: supernova with IIL-like light curves and IIn-like spectra
- I-a: thermonuclear explosions of white dwarf
- SLSN: subspecies of CCSNe with Mag<-20, likely powered by magnetars.