Searching for high-energy neutrinos from interaction-powered supernovae with the IceCube Neutrino Observatory

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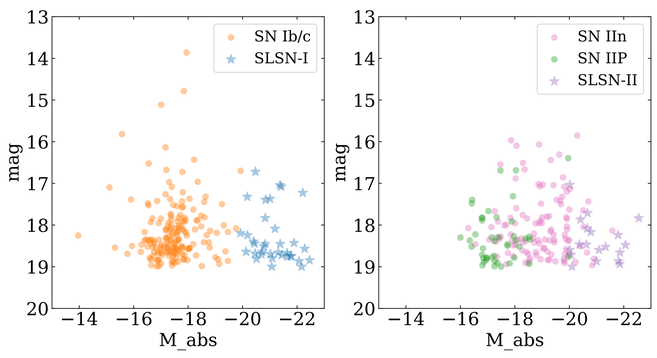
Motivation

- The sources of the **astrophysical diffuse flux** discovered by IceCube are still mostly unresolved;
- **extragalactic core-collapse supernovae (CCSNe)** have been suggested as potential sources of high-energy neutrinos;
- CCSNe showing strong **interaction with a dense circumstellar medium** (CSM) could be promising particle accelerators.

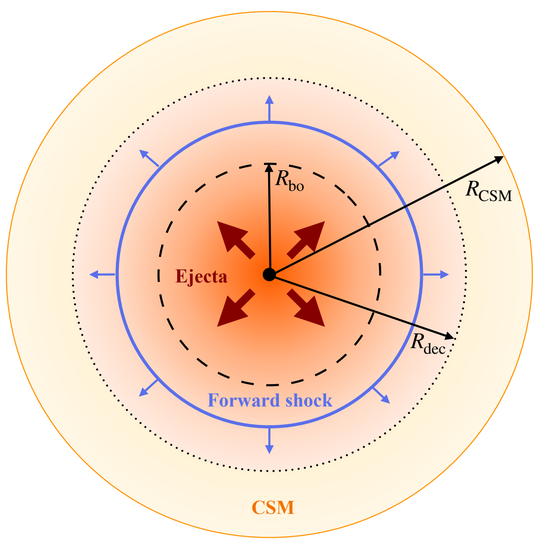
The CCSN population



Zwicky Transient Facility *Bright Transient Survey*.

- Type IIn SNe (right, green) and type II superluminous SNe (right, blue) are believed to be **interaction-powered (IPSN)**;
- in IPSNe, the majority of the optical emission comes from the **ejecta-CSM interaction**;
- a fraction of SLSN-I could also be interaction powered.

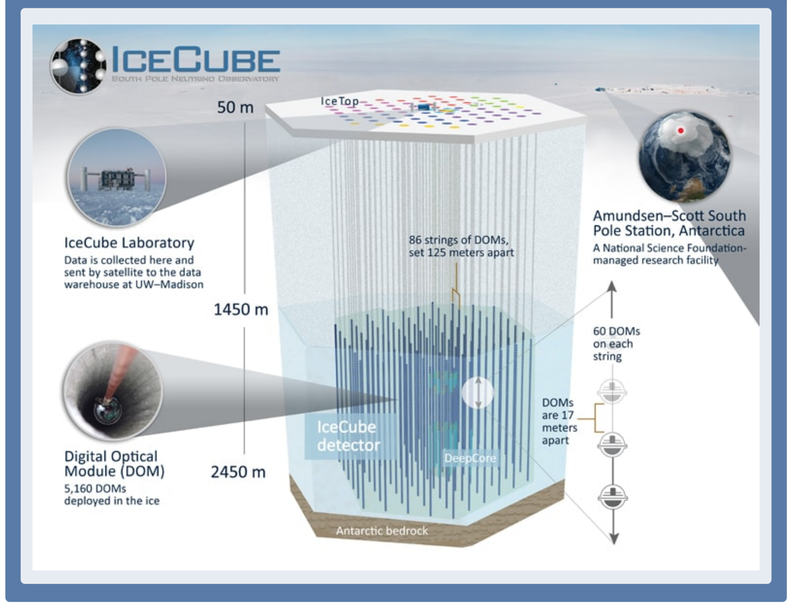
Shock-powered emission



Pitik et al., *Astrophys. J.* 929 (2022) 163

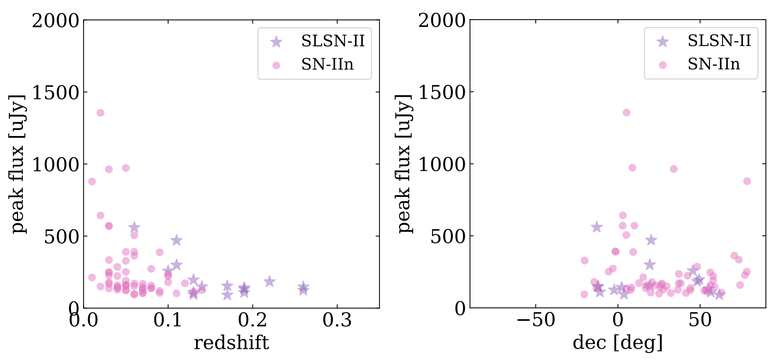
- **Protons are accelerated to relativistic energies** in the SN forward shock;
- **neutrinos can be produced in inelastic p-p collisions** between relativistic protons and the cold CSM material;
- optical properties reflect the ejecta-CSM configuration → neutrino luminosity and the SN optical properties are connected.

The IceCube Neutrino Observatory



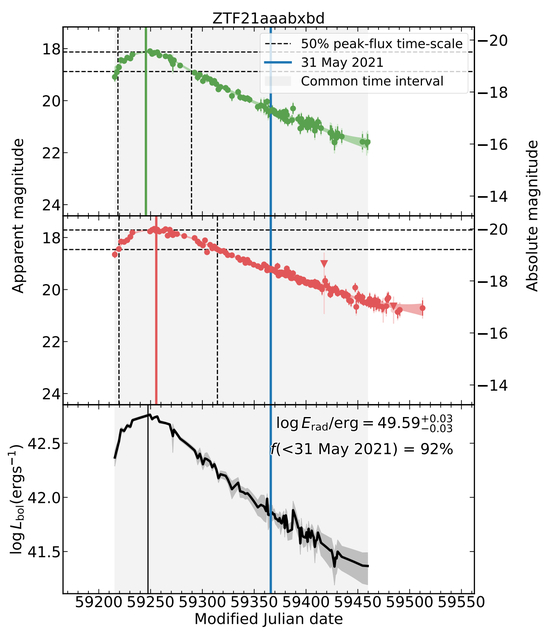
Building an IPSN catalogue

- A sample of SN IIn and SLSN-II is extracted from the Bright Transient Survey of ZTF;
- **quality selection** requires good classification and observation of the long-term evolution of the source.



74 SNe sources observed up to the end of the 2020-21 IceCube-86 season (May 31, 2021).

Lightcurve analysis



Lightcurve processing in collaboration with S. Schulze, ZTF.

- Gaussian-process interpolation of g- and r- band ZTF lightcurves;
- interpolated g+r is taken as lower limit on bolometric luminosity;
- characteristic properties (**peak luminosity**, **rise time**) are derived from the lightcurve.

Stacking analysis

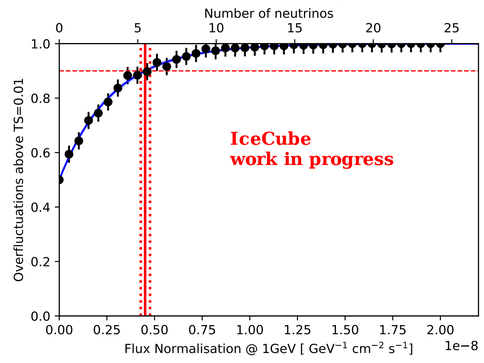
Unbinned likelihood stacking:

$$\mathscr{L}(n_s,\gamma) = \prod_{i=0}^{N}\left[\frac{n_s}{N}\sum_{j=0}^{M} w_j \mathscr{S}_j(\nu_i,\gamma) + \left(1-\frac{n_s}{N}\right)\mathscr{B}(\delta_i)\right]$$

$i \rightarrow$ neutrino event, $n_s \rightarrow$ number of signal events, $w_j \rightarrow$ source weight, $\mathscr{S}$, $\mathscr{B} \rightarrow$ signal, background PDFs, $\gamma \rightarrow$ spectral index, $\delta_i \rightarrow$ declination.

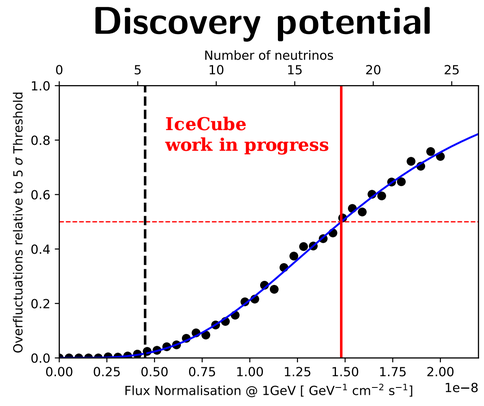
- Analysis based on **flarestack** (Stein *et al.*, 10.5281/zenodo.5497486);
- injection spectral index $\gamma = 2.0$;
- fixed **weights based on pseudo-bolometric time-integrated flux** at Earth.

Sensitivity



$\sim 4.5 \cdot 10^{-9}\,\mathrm{GeV^{-1}cm^{-2}s^{-1}}$

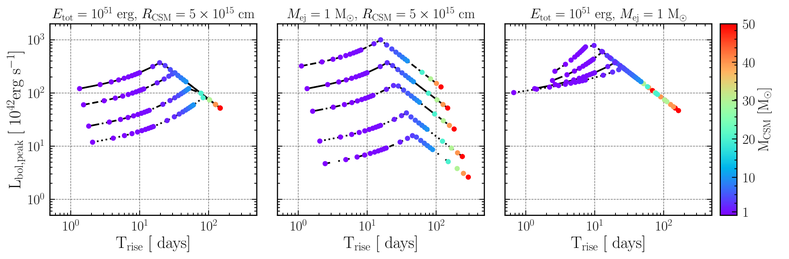
Discovery potential



$\sim 1.5 \cdot 10^{-8}\,\mathrm{GeV^{-1}cm^{-2}s^{-1}}$

Model-driven weighting

- Prospect to derive the source weighting from a theoretical model constrained by the SN optical properties (work in progress);
- the **properties of the ejecta-CSM interaction** can be partially derived from the **peak luminosity and the rise time** (*).



(*) Pitik, Tamborra, Lincetto, Franckowiak, Schulze, *in preparation.*

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