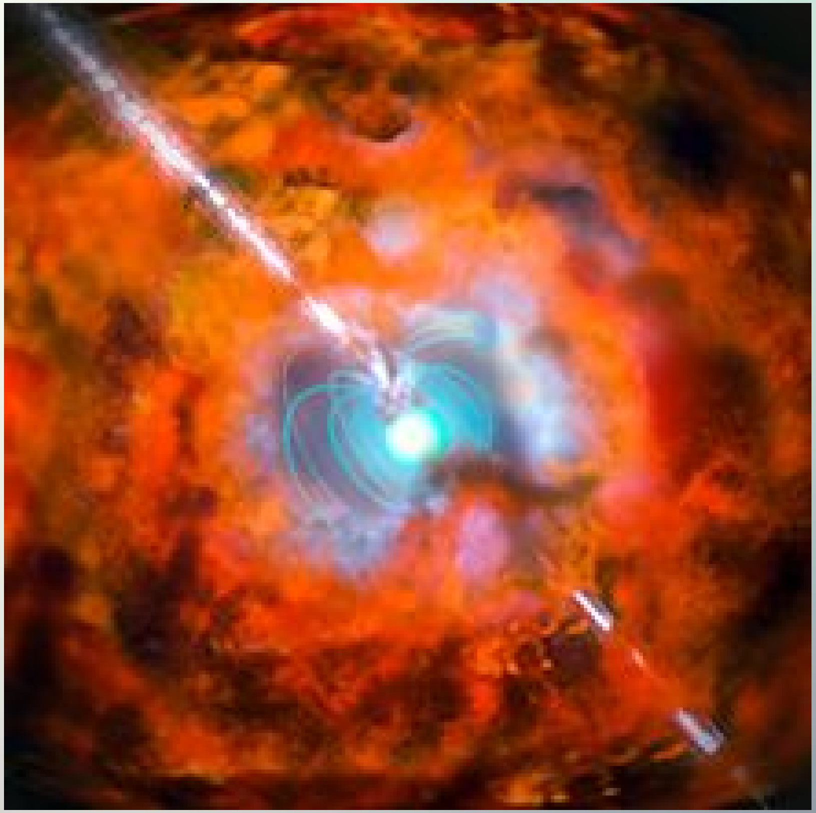
Probing for Magnetars with Late-Time, Multi-Wavelength Observations of SLSNe

Conor Omand

Astrophysics Research Institute
Liverpool John Moores University

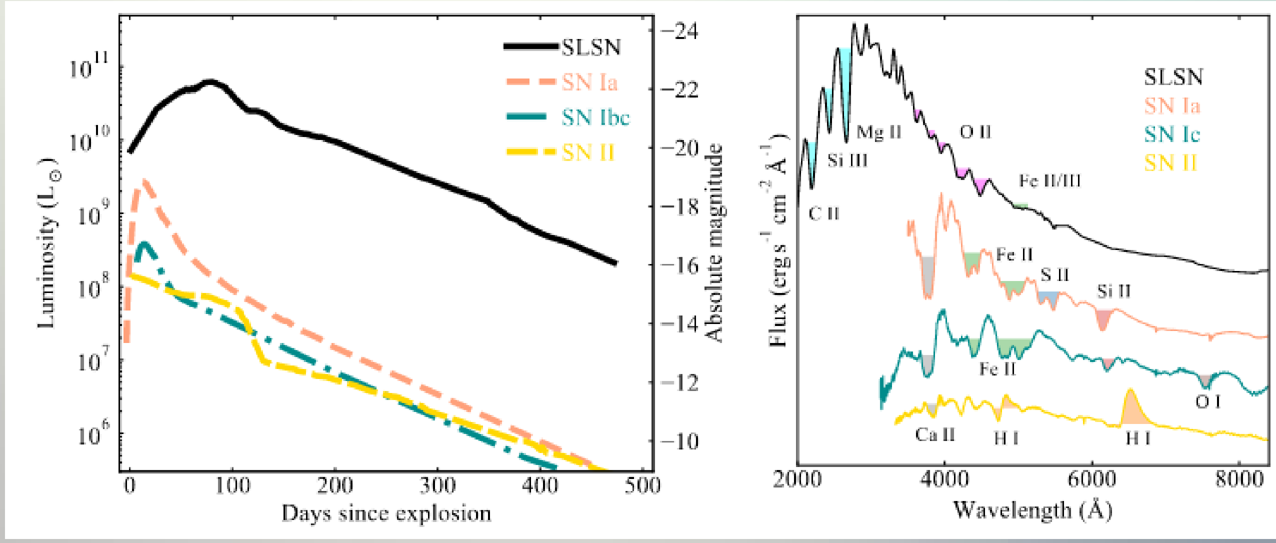


Credit: ESO

LIVERPOOL JOHN MOORES UNIVERSITY

Superluminous Supernovae (SLSNe)

- 10-100 times brighter than typical SNe – too powerful to be from conventional ^{56}Ni decay
- Classified according to hydrogen feature (SLSNe-I/SLSNe-II)
- Event rate: 0.01-0.1% of CCSNe
- Usually found in dwarf, metal-poor, star-forming galaxies



Nicholl 2021

Models for SLSNe

- Collision of ejecta with circumstellar material
- Pair instability or pulsational pair instability
- Fallback accretion onto a black hole or neutron star
- GRB-like jet
- Spin down of a rapidly-rotating (P ~ 1 ms) magnetar

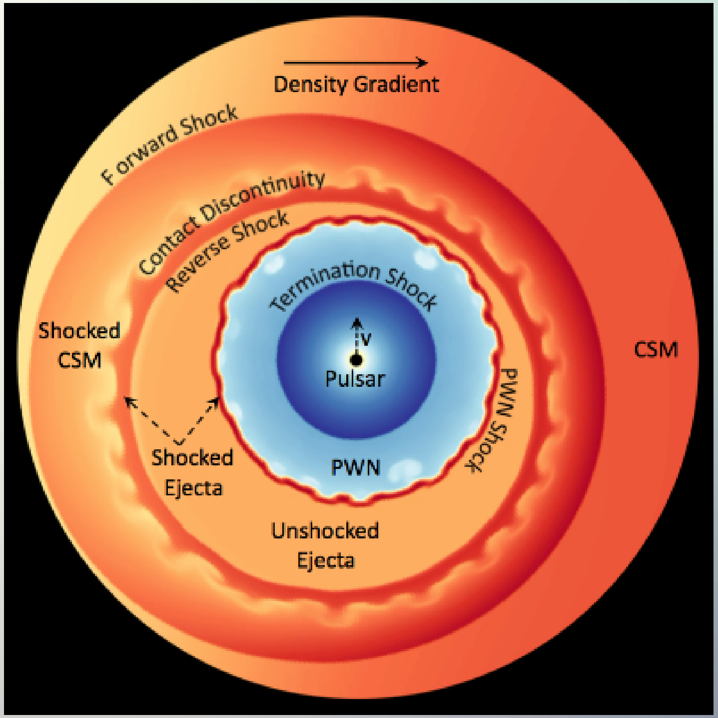
Can not be distinguished by optical light curve alone, need to test with other emission unique to model

Pulsars/Magnetars

- Pulsars: Rotating neutron stars with strong magnetic fields, loses rotational energy (spins down) as photons/particles are emitted
- Magnetars: Pulsars with extremely large magnetic field ($> 3 \times 10^{13}$ G)
- Characterized observationally by P and $\dot{P}$, $\dot{P}$ related to B
- Rotational energy: $\sim (P/1\text{ ms})^{-2} \times 2 \times 10^{52}$ ergs
- Spin-Down Timescale: $\sim (P/1\text{ ms})^{2}(B/10^{14}\text{ G})^{-2} \times 8$ hours
- Most energy goes into the PWN

Pulsar Wind Nebulae (PWNe)

- Pulsar spin-down generates energetic particles
- Confined particle wind produces termination shock, accelerating particles to ultrarelativistic energies
- Particles emit broadband synchrotron radiation and can ICS photons to gamma ray energies



Slane 2017

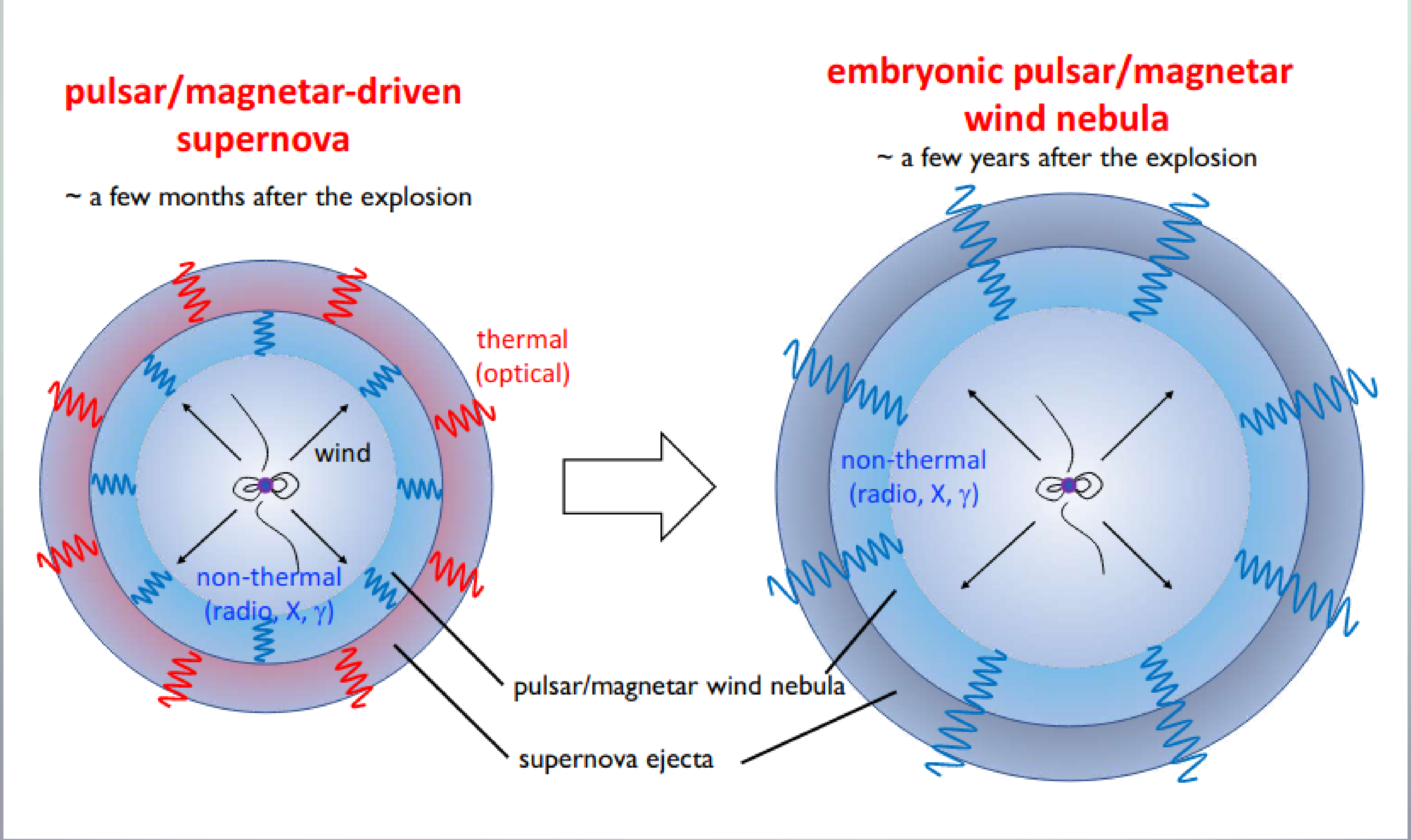
Signals from a Magnetar Engine

- Increasing the luminosity of the transient
- Accelerating the transient ejecta
- Direct detection of PWNe at high energy (x-rays, gamma-rays) or low energy (radio, millimetre)
- Indirect detection via dust re-emission (infrared)
- Nebular spectroscopy (optical/infrared)

Signals from a Magnetar Engine

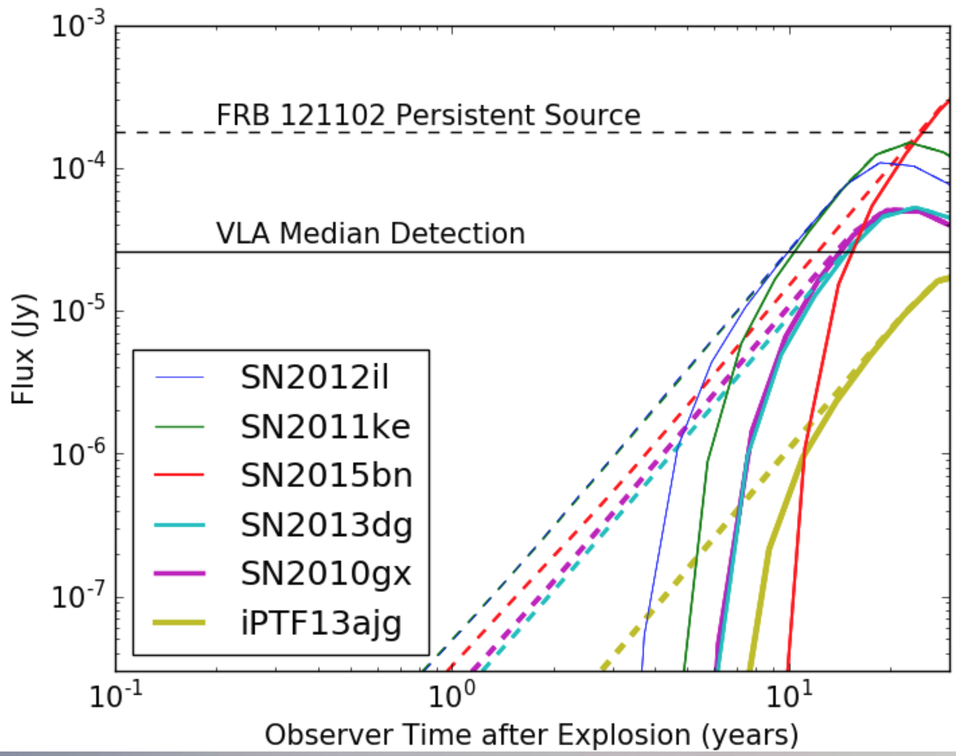
- Increasing the luminosity of the transient
- Accelerating the transient ejecta
- Direct detection of PWNe at high energy (x-rays, gamma-rays) or low energy (radio, millimetre)
- Indirect detection via dust re-emission (infrared)
- Nebular spectroscopy (optical/infrared)

PWN Detection in Radio

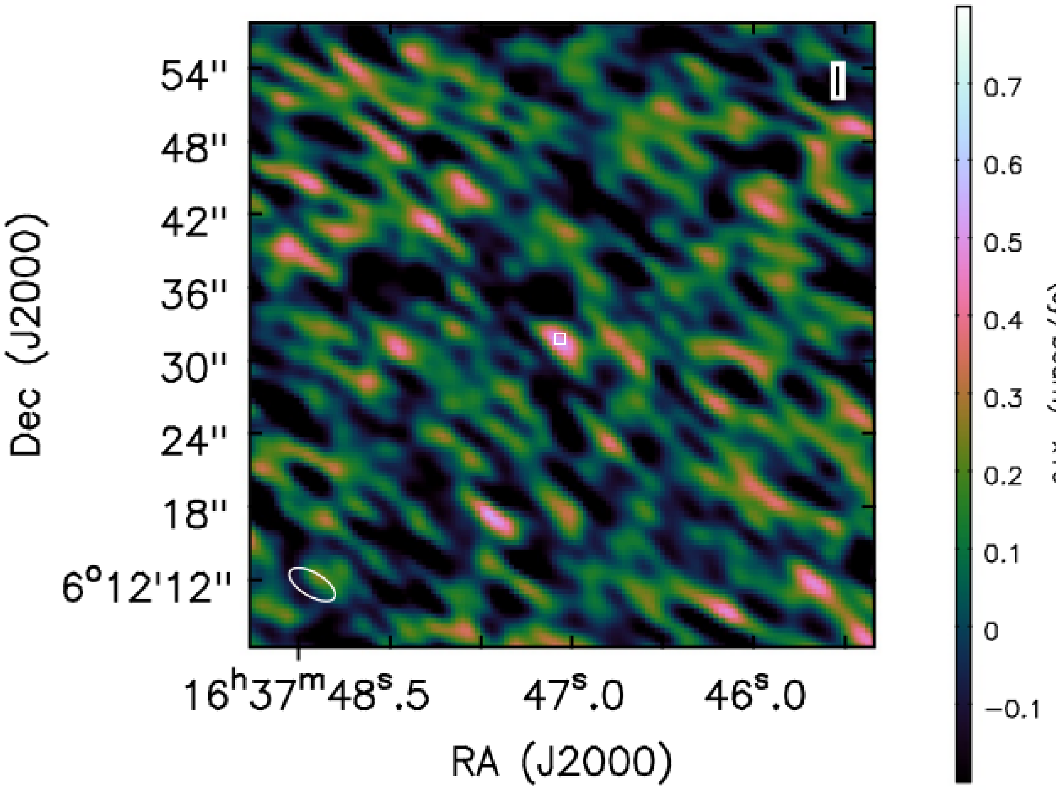


Murase, Omand+ 2021

Early Results

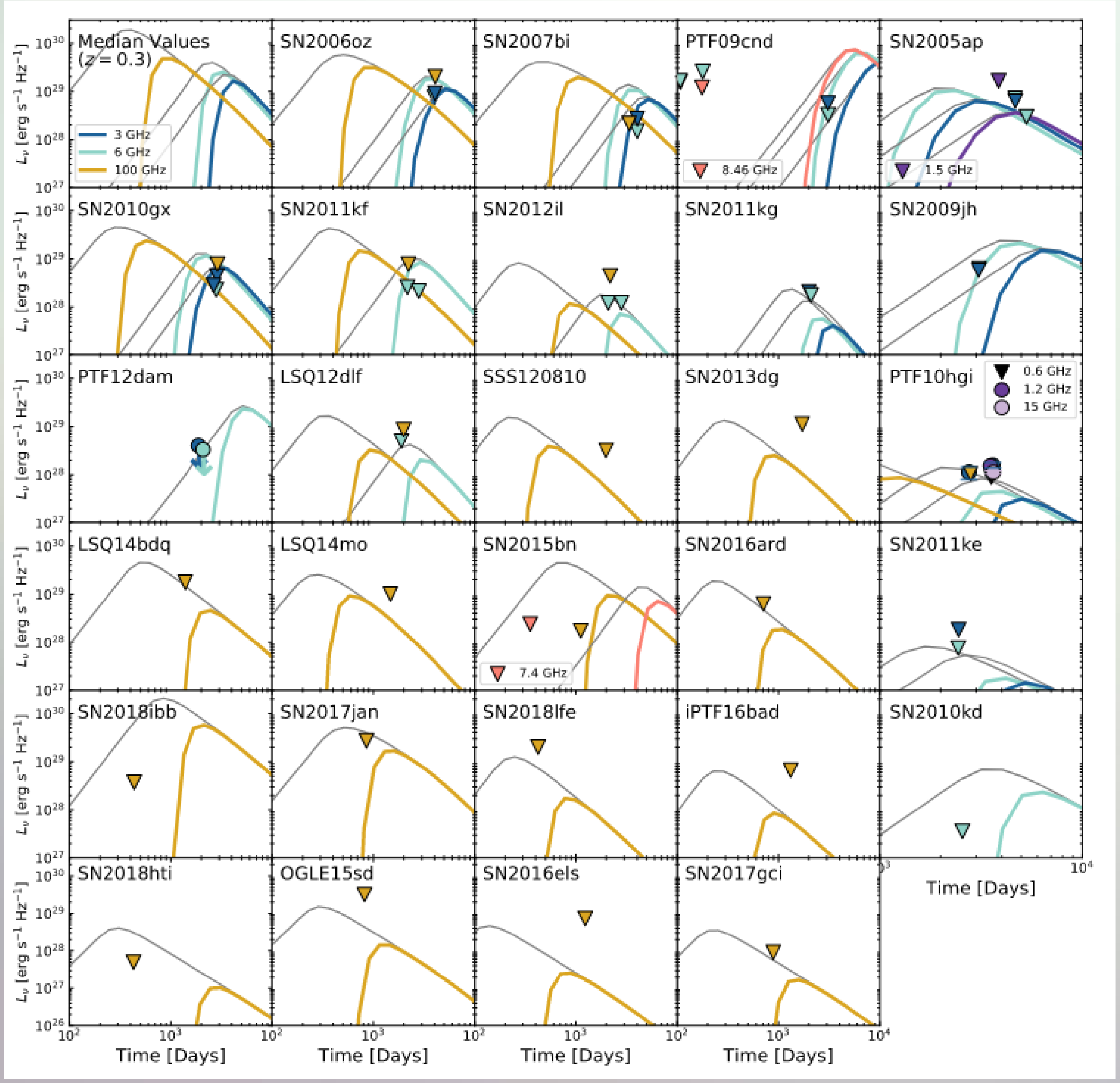


Omand+ 2018



Law, Omand+ 2019

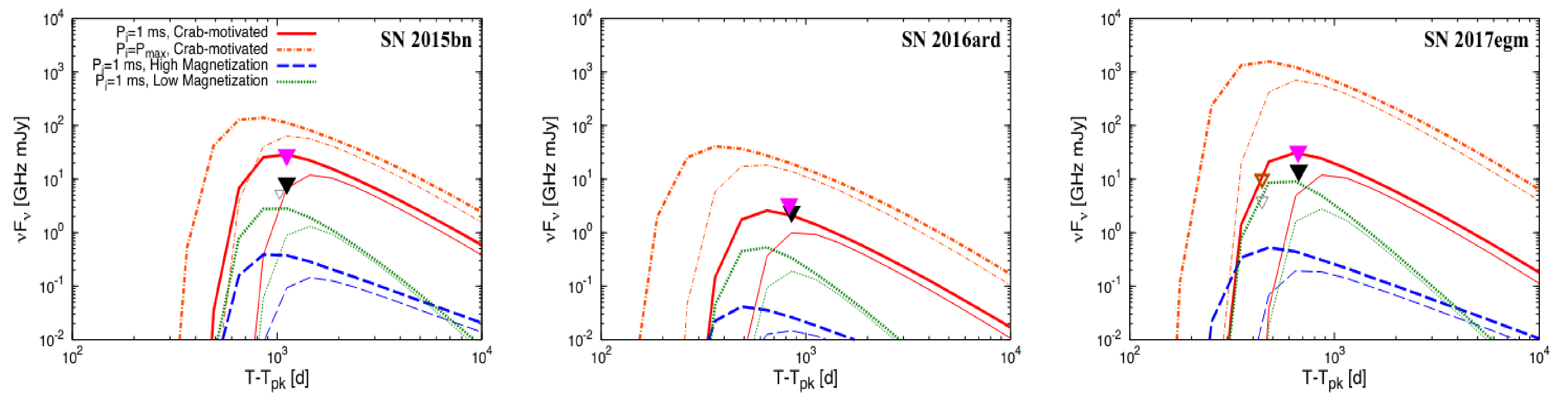
Lots of Constraints



Eftekhari, Margalit, Omand+ 2021

Millimetre Constraints

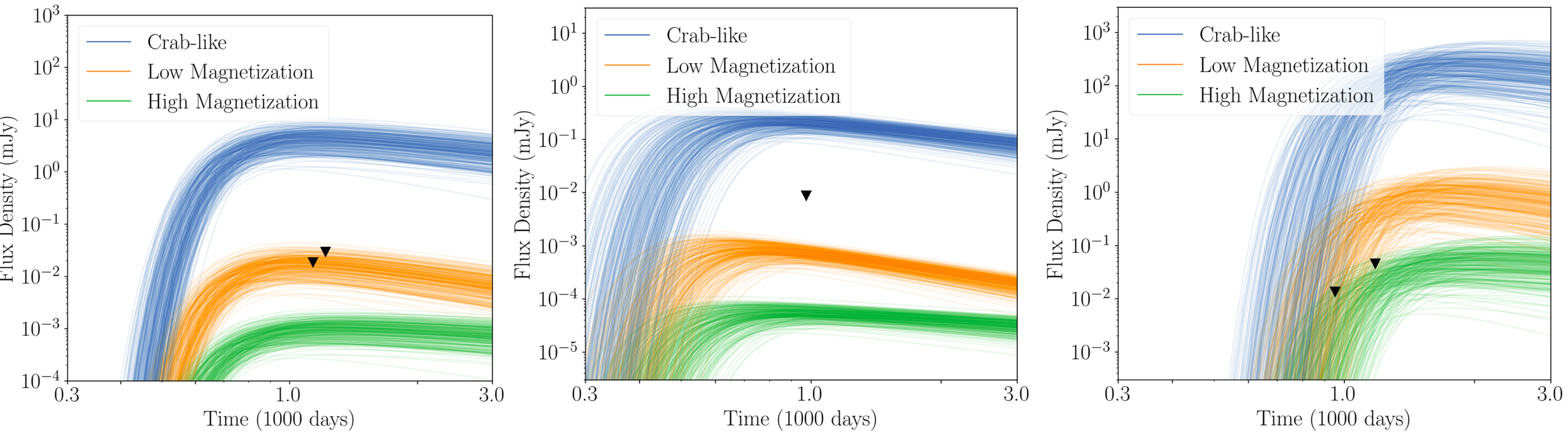
- Optical and radio models used for these were slow, which limited the statistics of these studies
- Difficult to tell how meaningful the constraints are, since there's no posterior on the optical models



Murase, Omand+ 2021

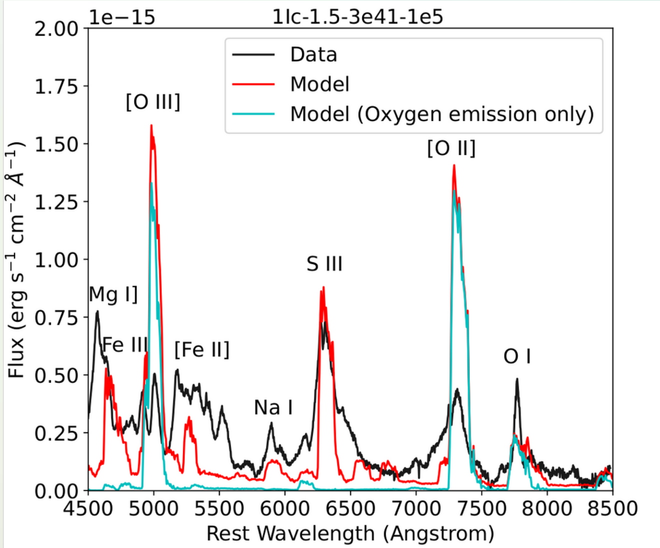
Millimetre Constraints Revisited

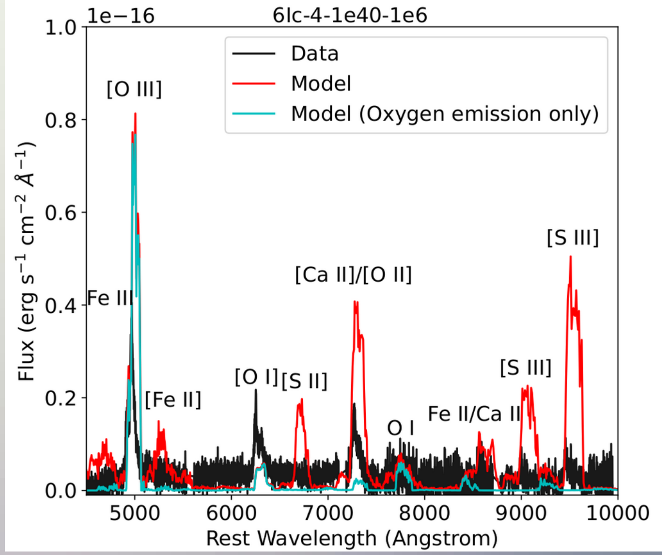
- Uncertainty from optical models give factor 3-10 uncertainty in radio emission, more during the rise.
- Crab-like PWN parameters are strongly excluded.
- DSA-2000 and ngVLA will improve sensitivity by a factor ~50, allow us to probe every physical model



Nebular Spectra

- Calculated a grid of radiative transfer models for magnetar-driven supernovae.
- Focused on optical emission (particularly oxygen lines) trying to explain SN 2012au.
- Radiative transfer was only ran up to 10 micron, not far enough for some IR lines with JWST.
- Identified NeII[12.8μm] as a particularly strong coolant.
- Can examine cooling properties as a proxy for line emission, make general conclusions.

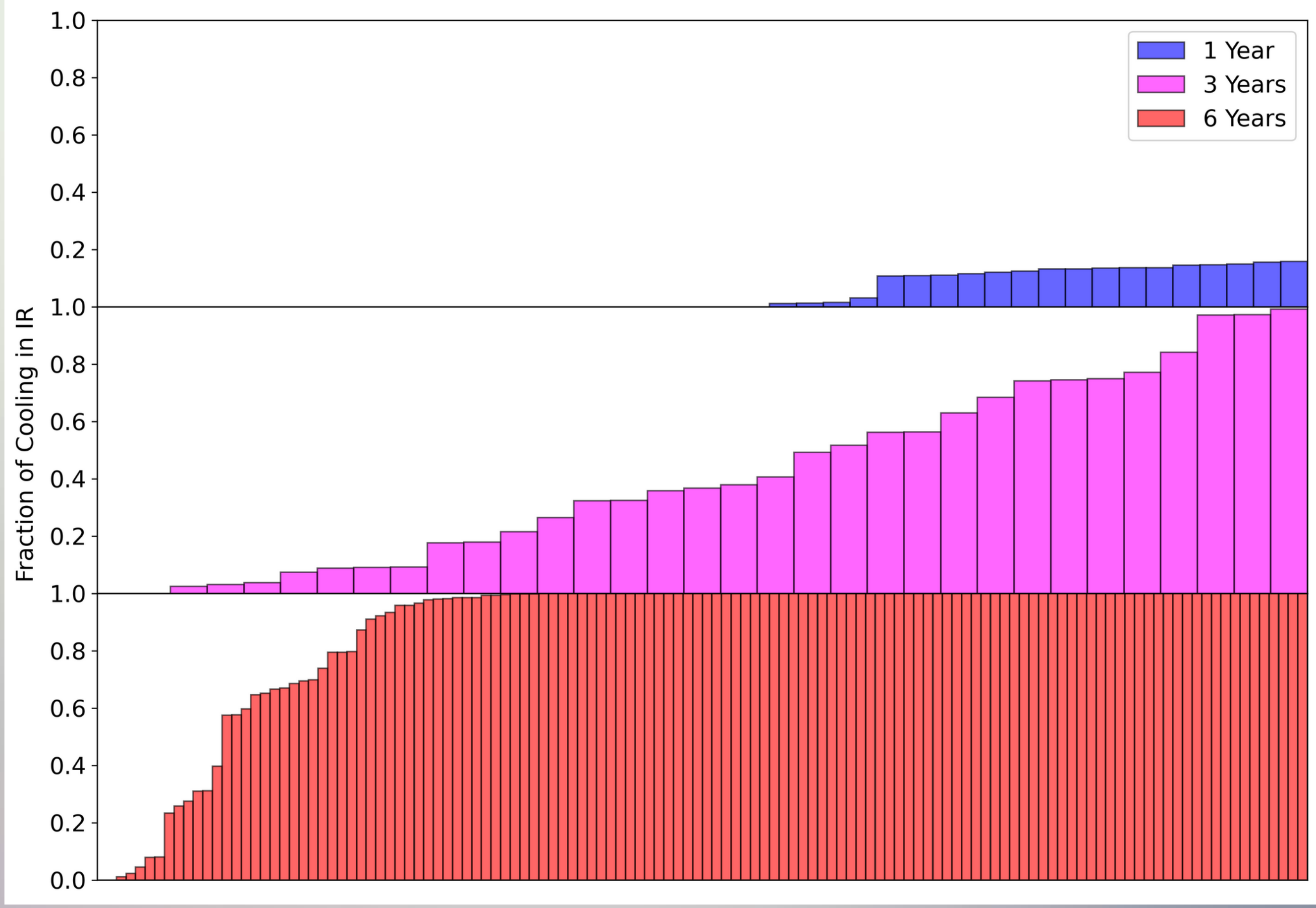




Omand & Jerkstrand 2023

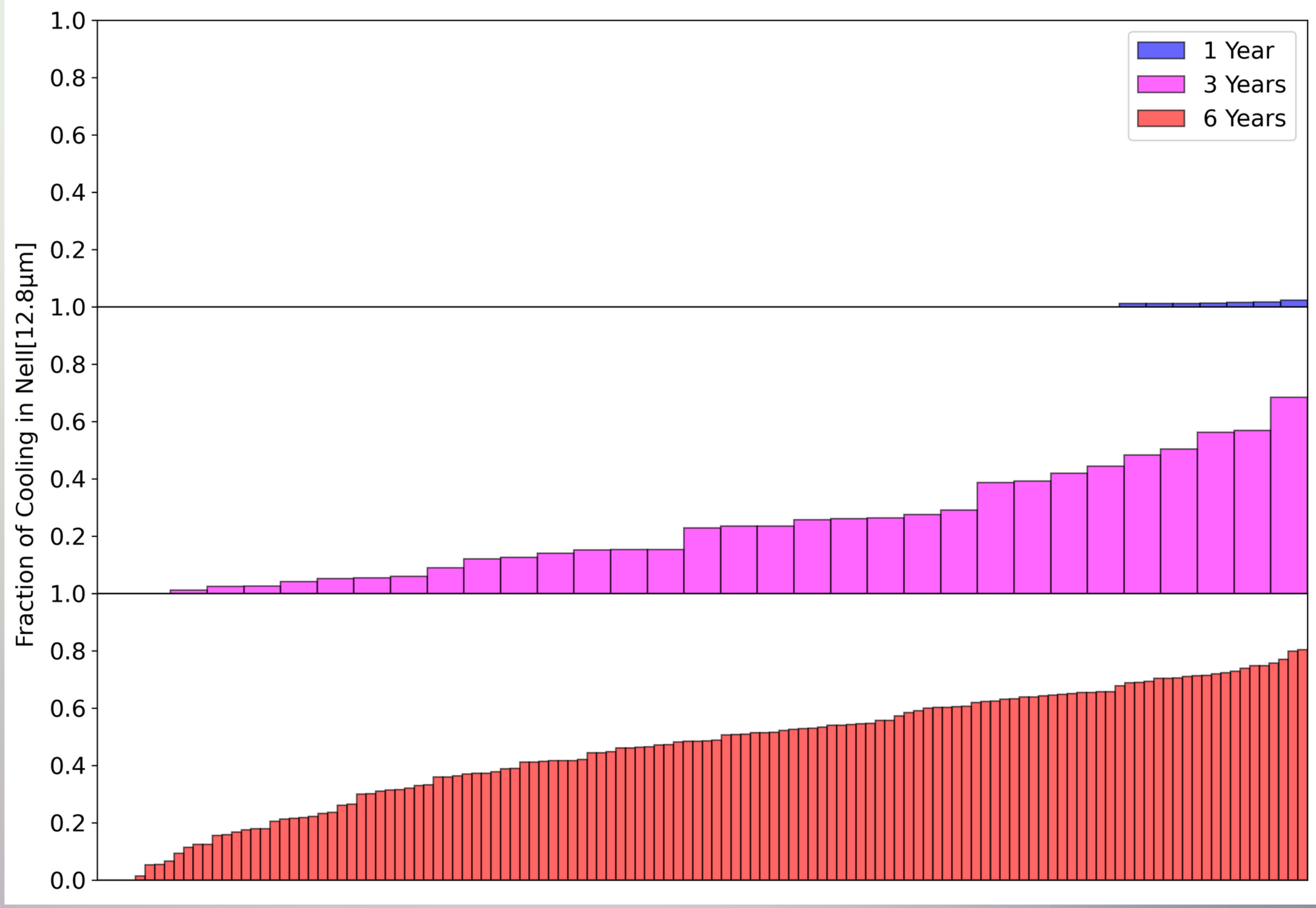
Total Cooling in the IR

- Find a transition between optically-dominated cooling and IR-dominated cooling. Lots of spread in models at intermediate times.
- No strong correlation with any model parameters.



The Strongest Coolant: NeII[12.8μm]

- One transition can sometimes dominate cooling at late times.
- Other strong IR coolants:
  - NiII[6.64μm]
  - ArII[6.99μm]
  - NiIII[7.35μm]
  - ArIII[8.99μm]
  - SiII[34.8μm]
  - OIII[51.8μm]



Summary

- Multiple multiwavelength signals for millisecond magnetars powering SLSNe
- Early radio programs showed little success, but faster models and better statistic can make constraints more meaningful
- NgVLA and DSA-2000 will be able to probe multiple physical scenarios
- Spectra transition from optically dominated to IR dominated, a few lines can be probed with JWST.
- Radio models and IR linelist are public, can be used for proposals.