LATE-TIME RADIO OBSERVATIONS OF SUPERNOVAE: PROBING PROGENITORS, OUTFLOWS, AND ENVIRONMENTS

TARRANEH EFTEKHARI
NASA HUBBLE EINSTEIN FELLOW

THE TRANSIENT AND VARIABLE UNIVERSE 2023
JUNE 22, 2023

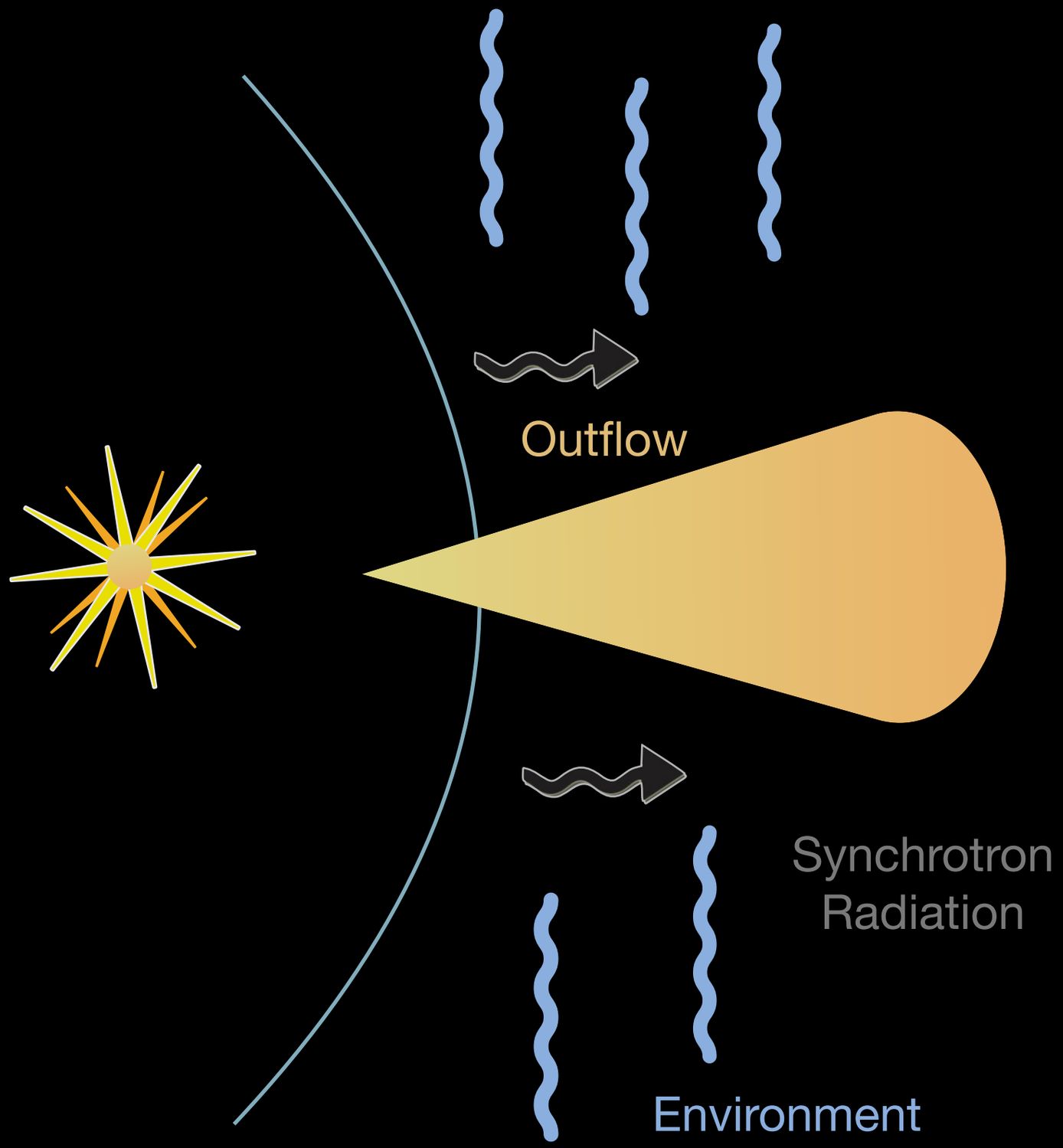
IMAGE CREDIT: NRAO

Northwestern

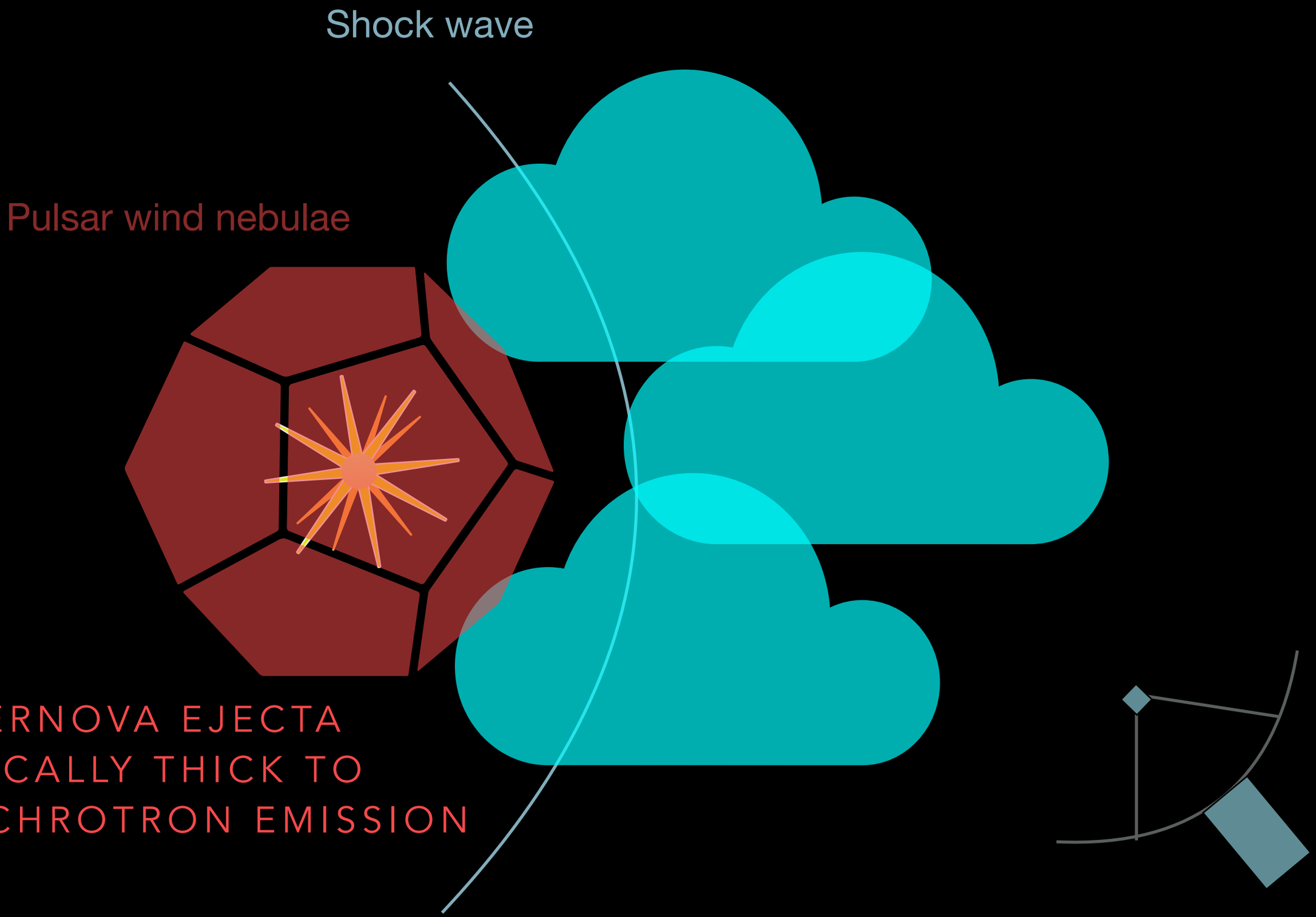
CIERA
CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

FAST & FORTUNATE
FRB FOLLOW-UP

RADIO OBSERVATIONS OF SUPERNOVAE: UNIQUELY PROBING THEIR PROGENITORS AND ENVIRONMENTS

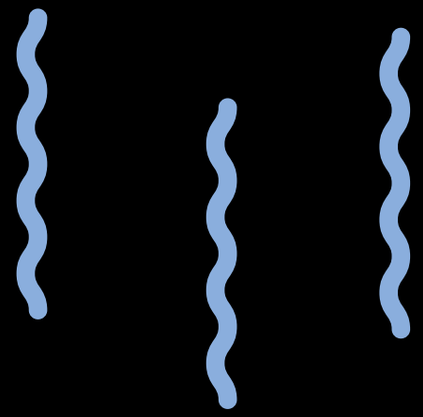


EARLY TIMES:

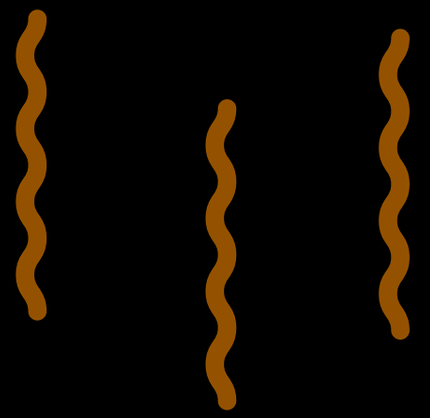

Shock wave
Pulsar wind nebulae
SUPERNOVA EJECTA
OPTICALLY THICK TO
SYNCHROTRON EMISSION

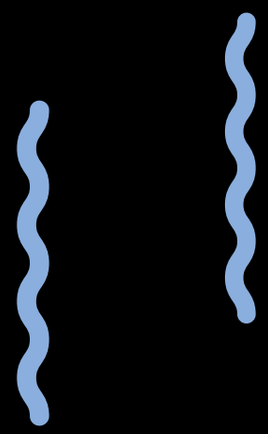
EARLY TIMES:

SUPERNOVA SHOCK FRONT
PROBING MATERIAL
EJECTED IMMEDIATELY
PRIOR TO EXPLOSION

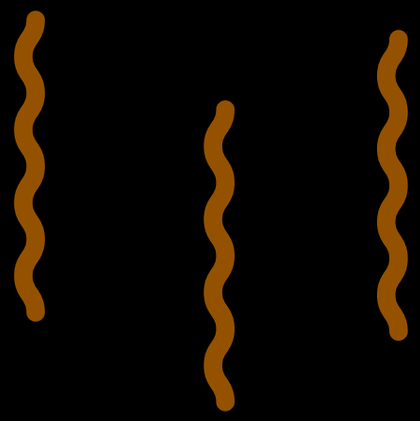


Material ejected
immediately
prior to explosion

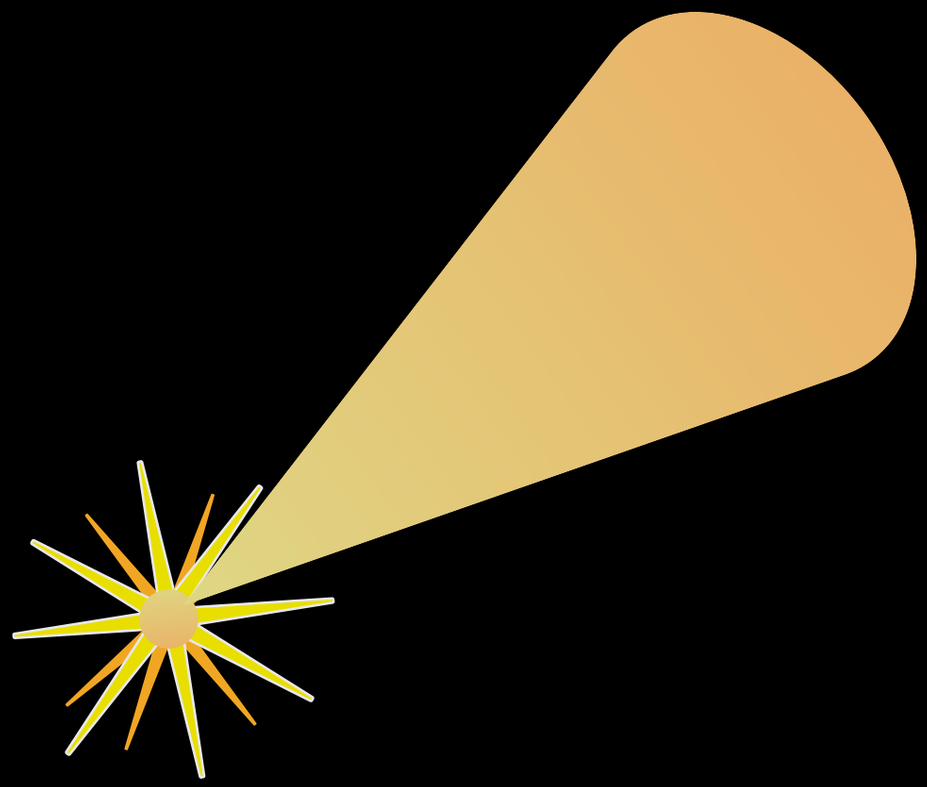




Material ejected in
the centuries prior
to explosion

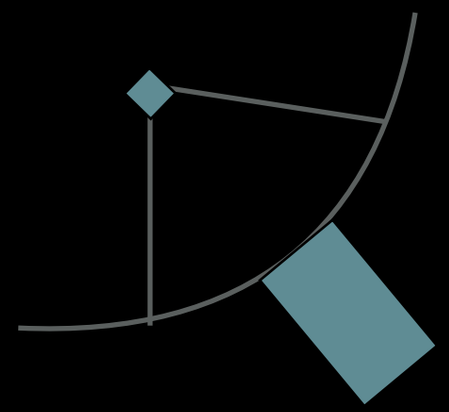


EARLY TIMES:



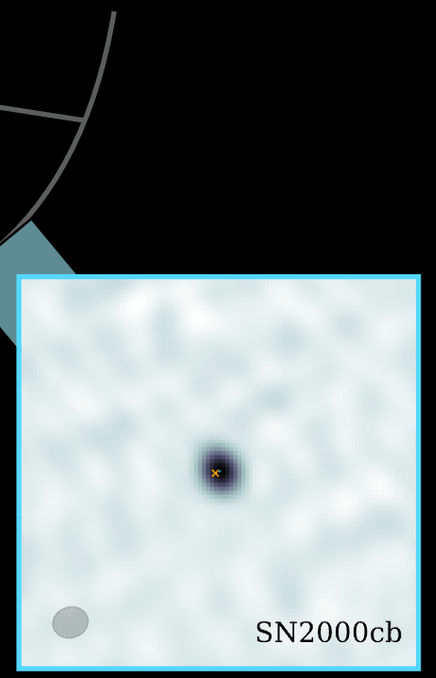
OFF-AXIS JETS HAVE NOT YET SPREAD INTO OUR LINE OF SIGHT

???



LATE TIMES (~5-100 YEARS):

SUPERNOVA EJECTA IS OPTICALLY THIN; JET HAS SPREAD; SHOCK FRONT HAS EXPANDED FURTHER OUT



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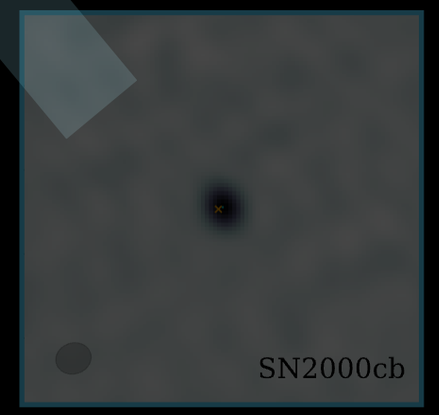
LATE TIMES (~5-100 YEARS):

WHAT ARE THE CENTRAL ENGINES RESPONSIBLE FOR POWERING RARE CLASSES OF SUPERNOVAE?

WHAT ARE THE MASS-LOSS HISTORIES AND CSM DENSITIES OF TYPE II SUPERNOVAE?



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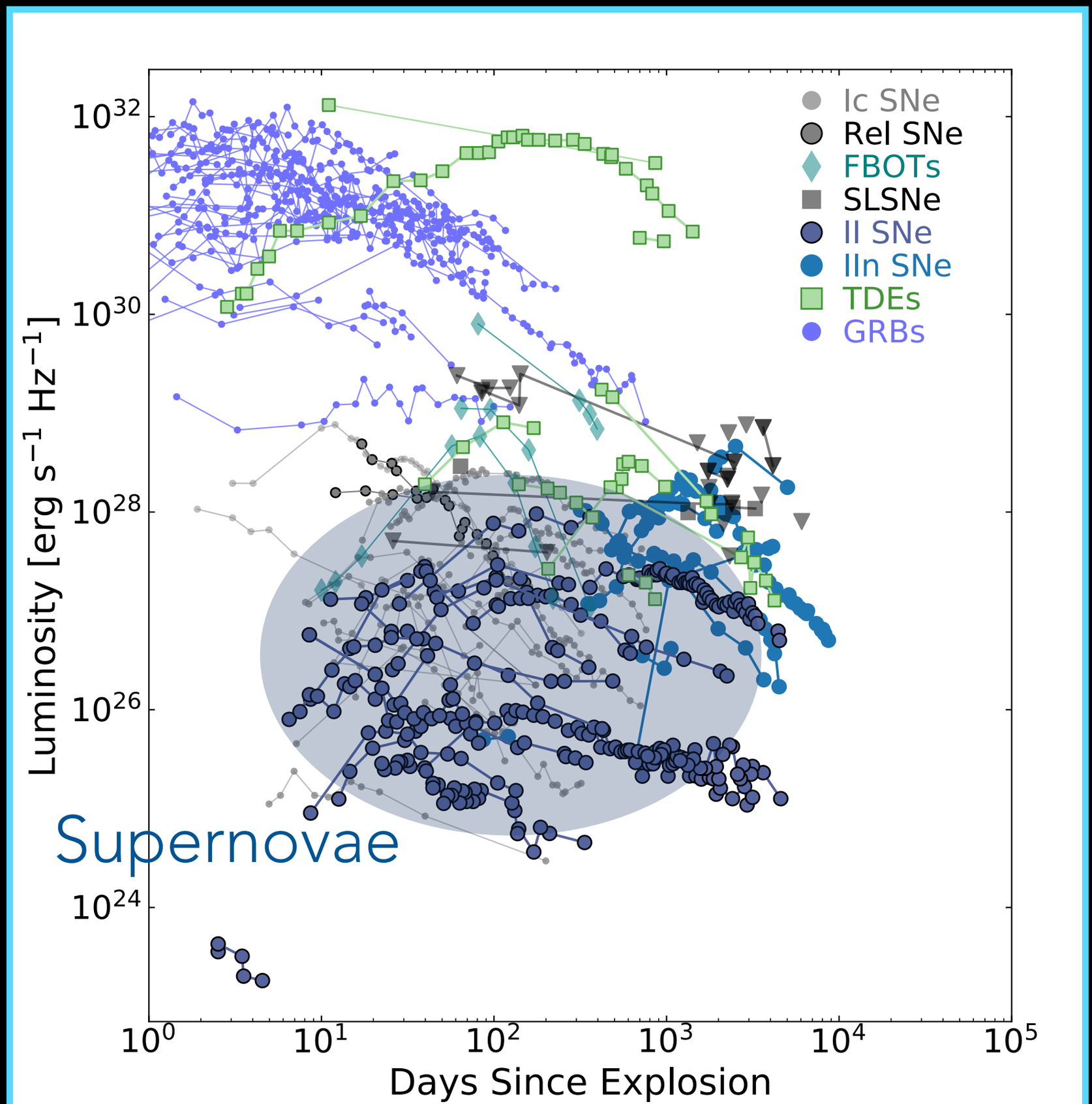

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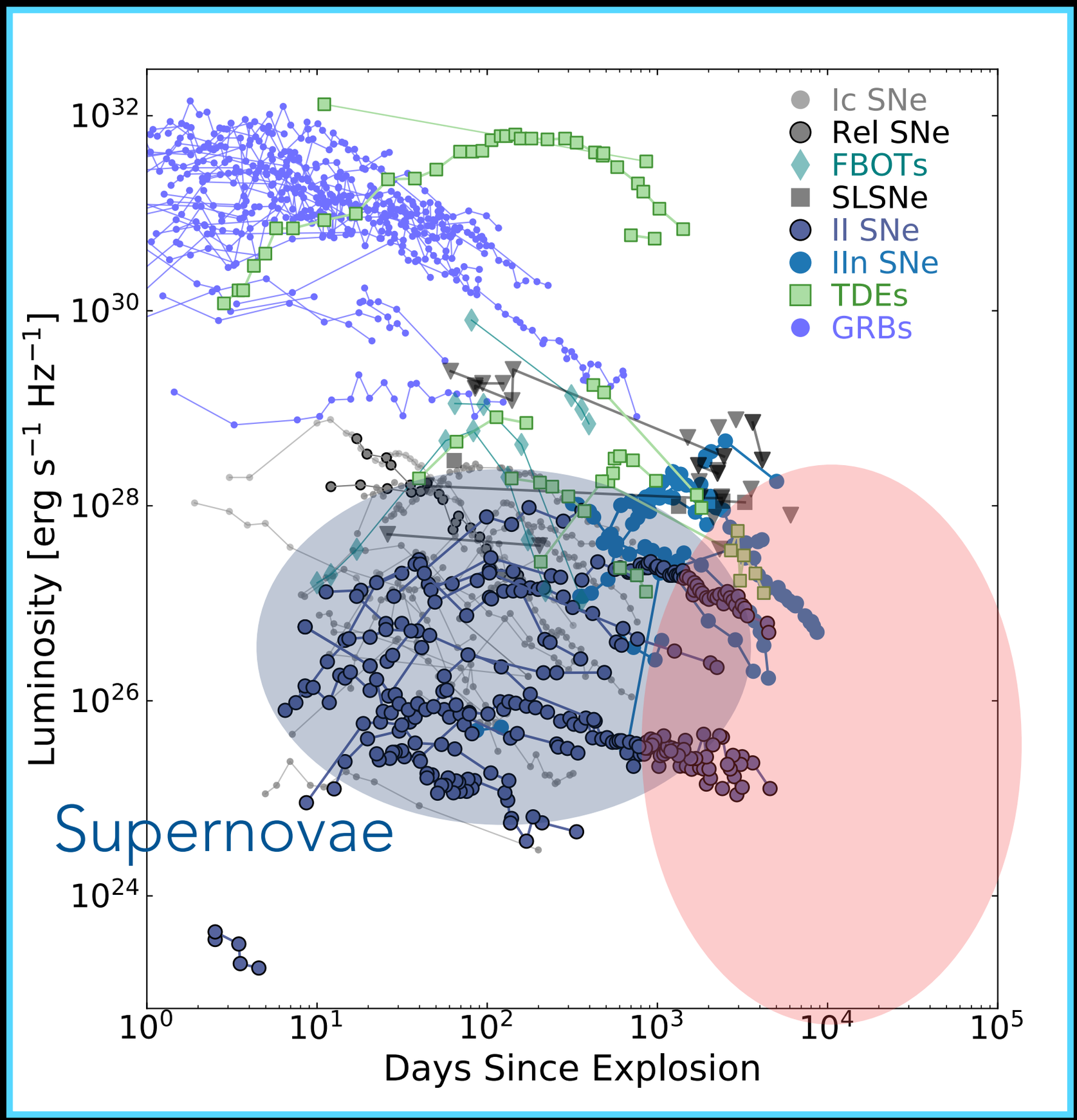

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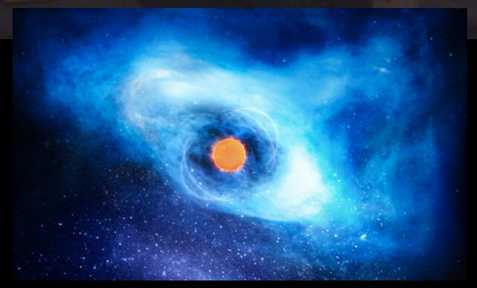
LARGE SURVEY OF SUPERLUMINOUS SUPERNOVAE WITH THE VLA AND ALMA

36 SLSNe with ages spanning 1 - 19 years *(Eftekhari+ 2021)*

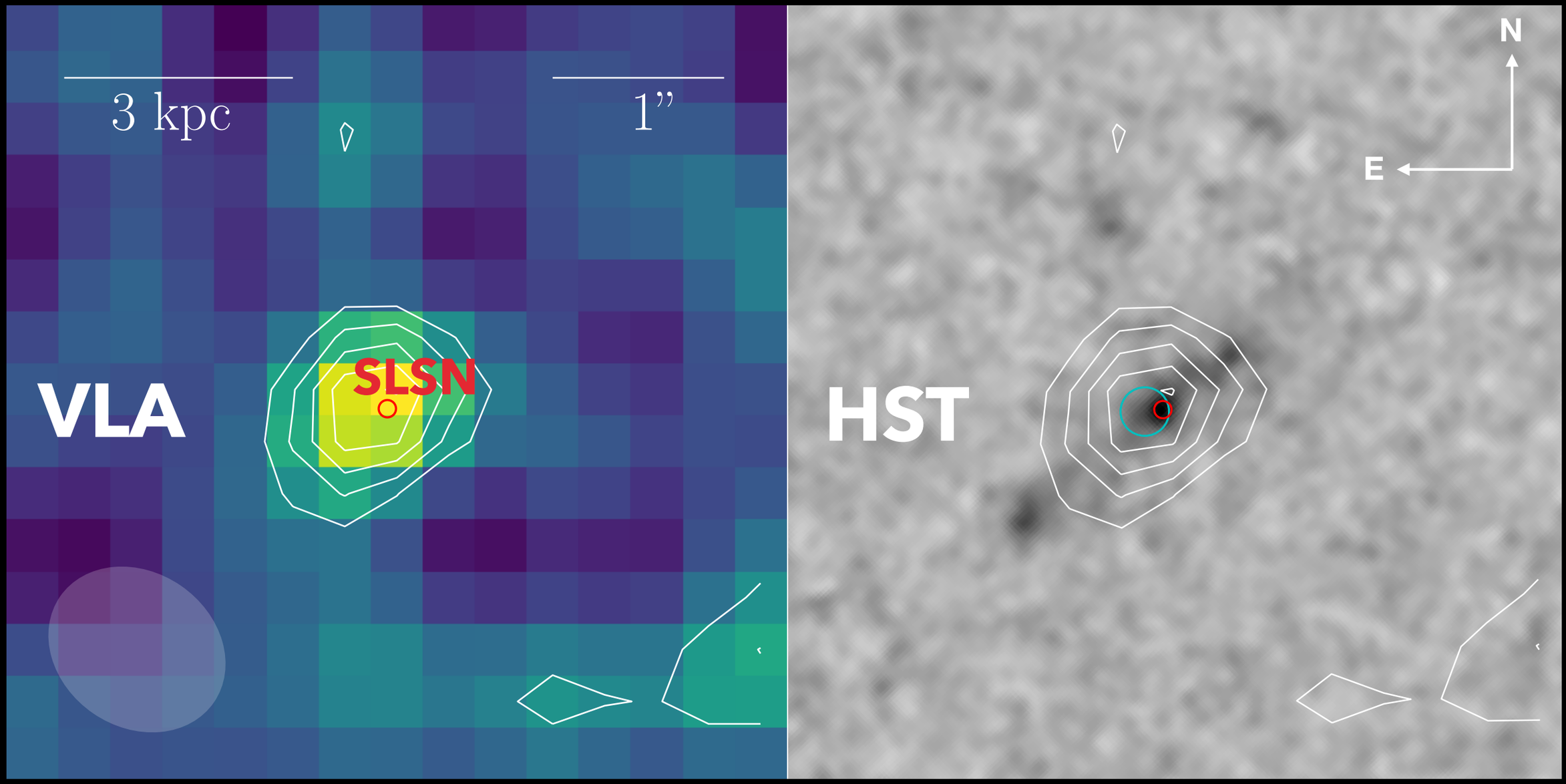


Implications for:

1. Connection to FRBs
2. Central engines: relativistic jets or magnetar wind nebulae
3. Obscured star-formation

A RADIO SOURCE COINCIDENT WITH A SUPERLUMINOUS SUPERNOVAE

PTF10HGI ~8 YEARS POST-EXPLOSION



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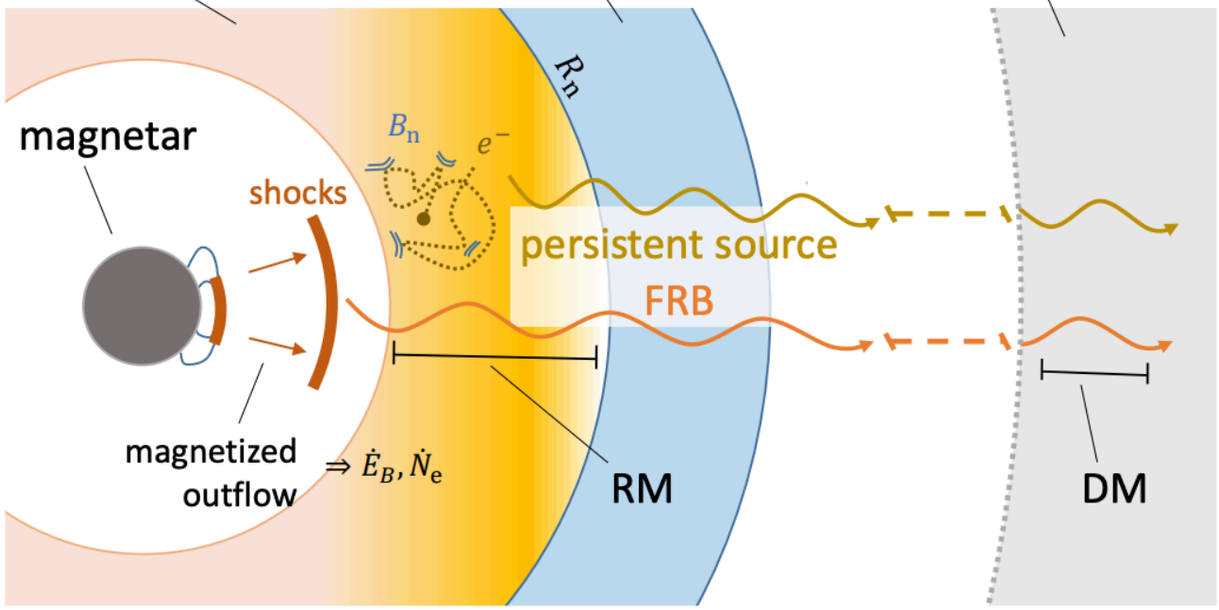
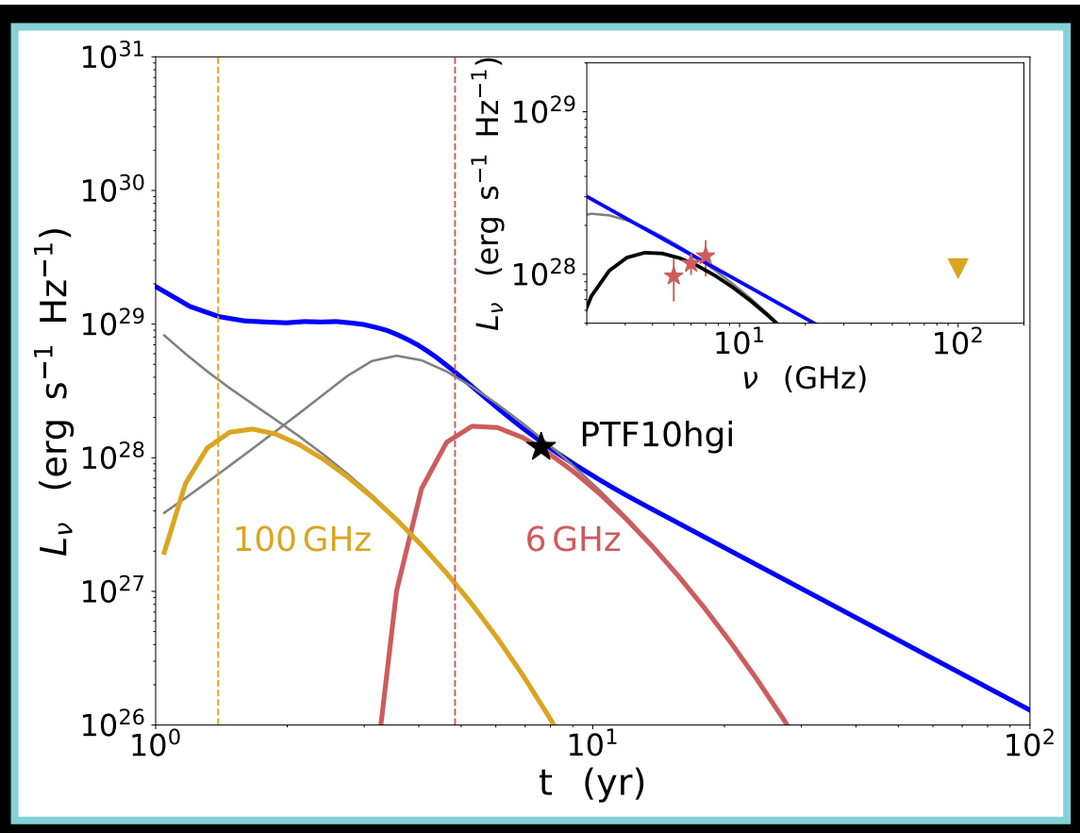
CENTRAL ENGINE MODELS

MAGNETAR NEBULA

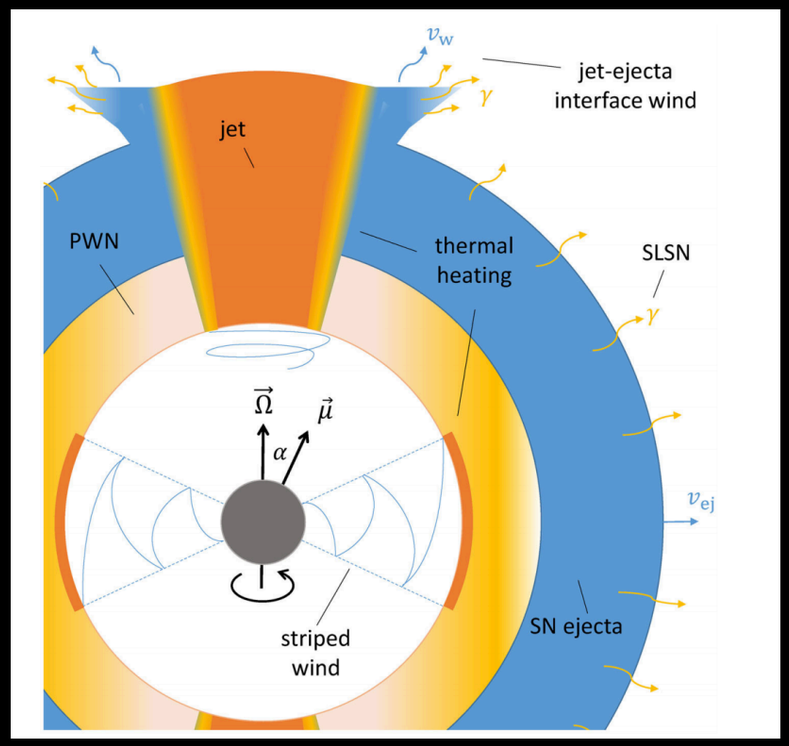
Margalit & Metzger 2018

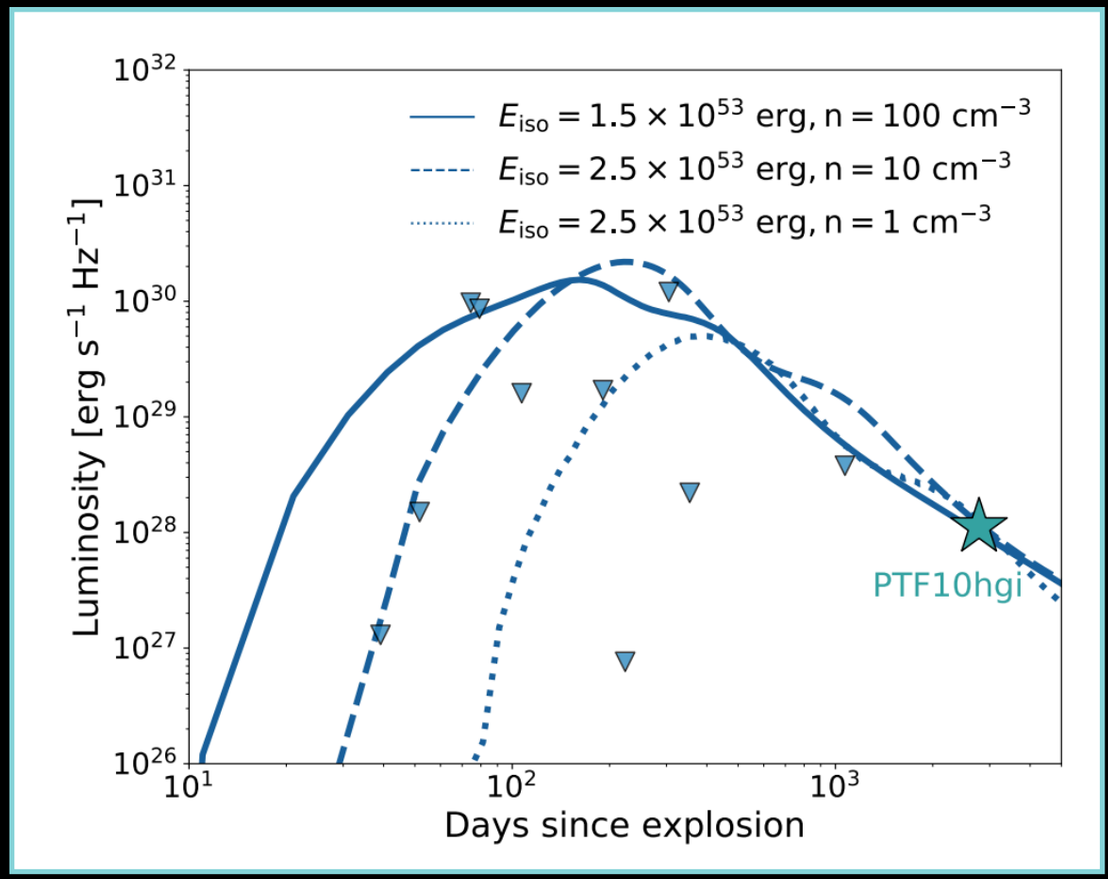




RELATIVISTIC JET

Margalit+ 2018

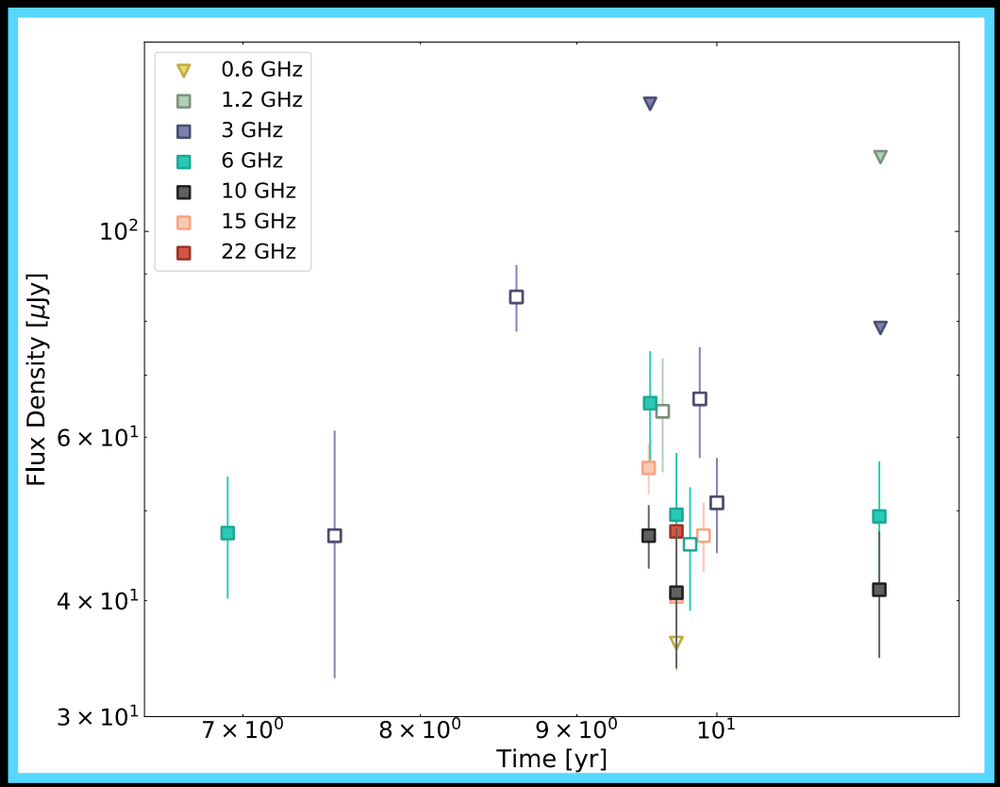




Eftekhari+ 2019

RADIO - X-RAY FOLLOW-UP OBSERVATIONS, INCLUDING AN ARECIBO SEARCH FOR FRBS!

Short timescale variability —
a scintillating compact object?



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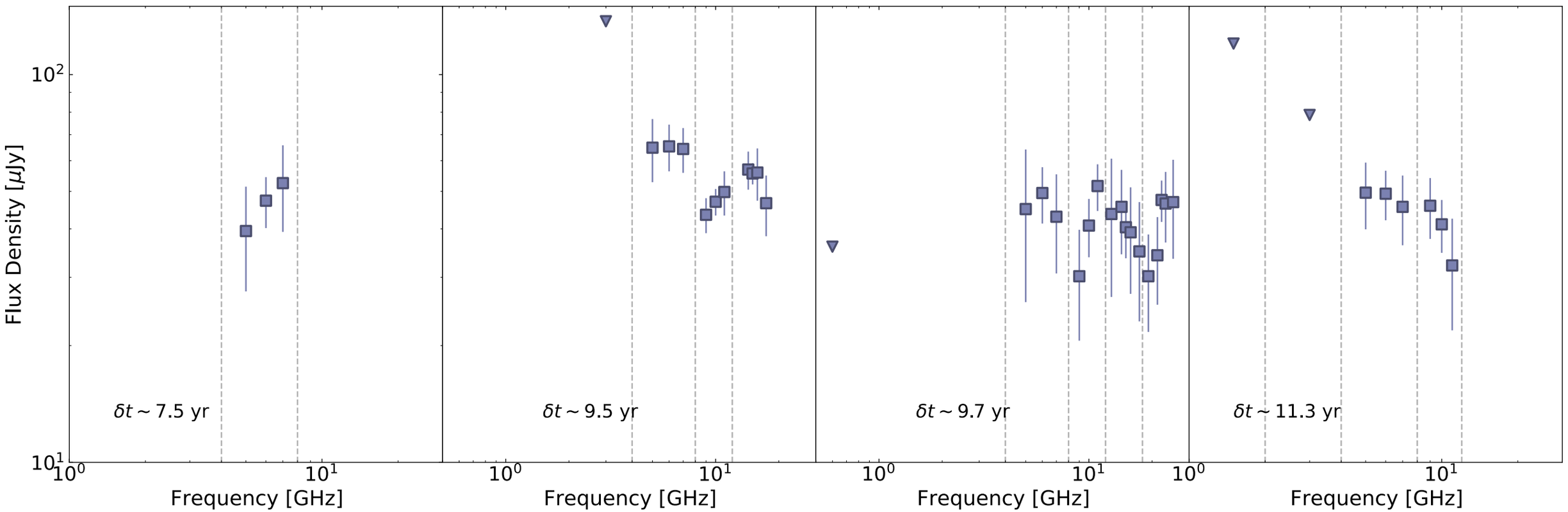
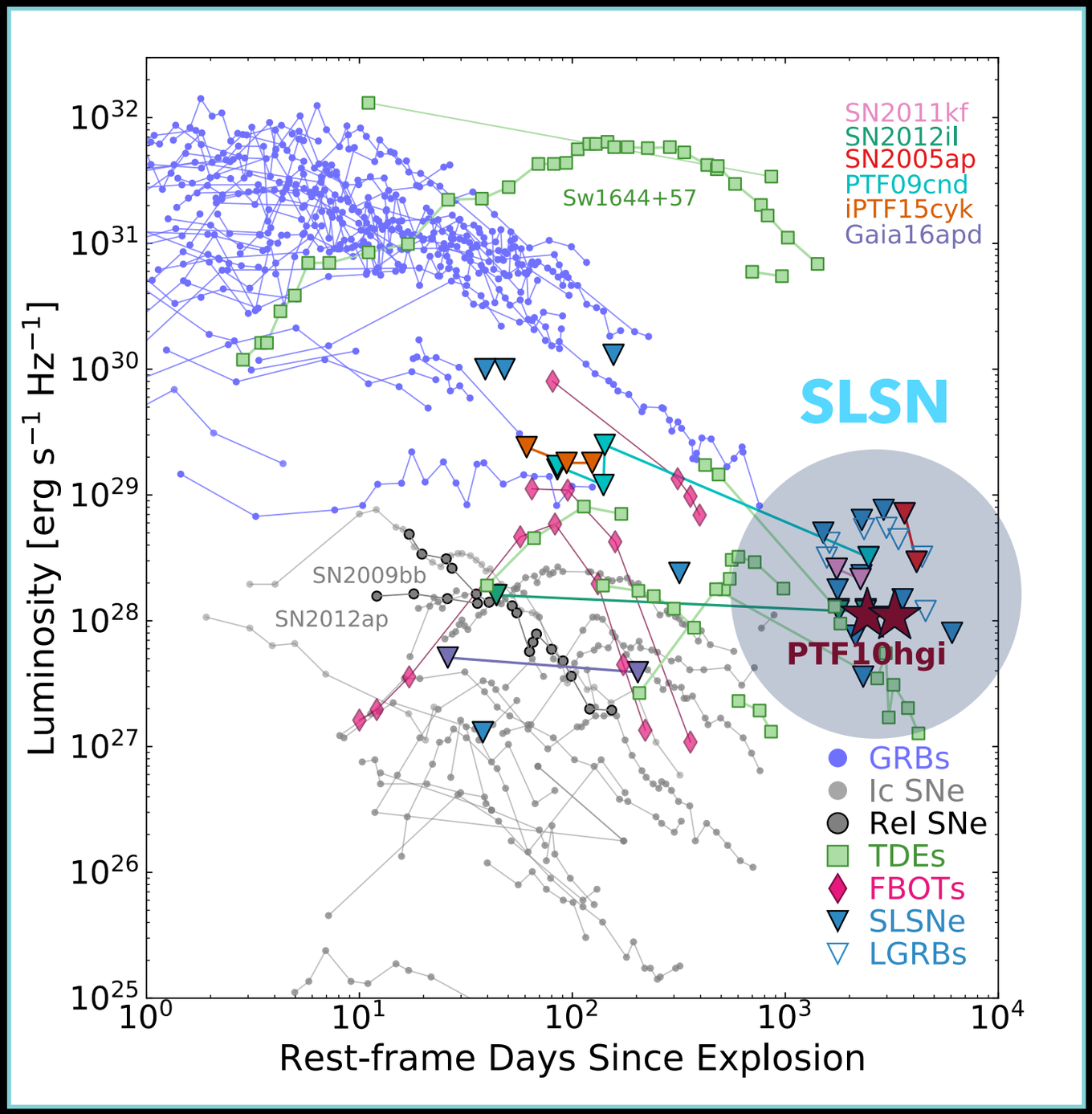


RADIO OBSERVATIONS AS PROBES OF CENTRAL ENGINES IN SUPERLUMINOUS SUPERNOVAE



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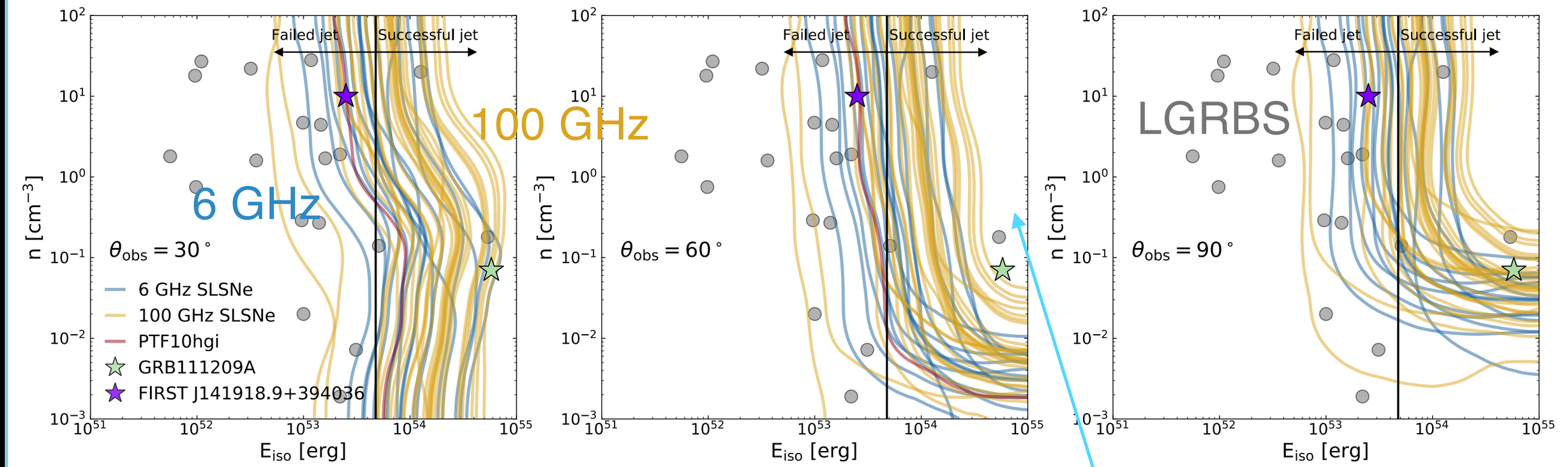
RULING OUT A POPULATION OF RELATIVISTIC JETS

$\theta_{\rm obs} = 30°$ $\theta_{\rm obs} = 60°$ $\theta_{\rm obs} = 90°$



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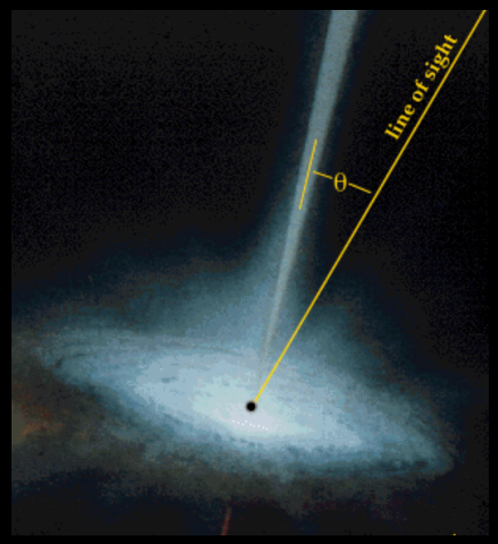
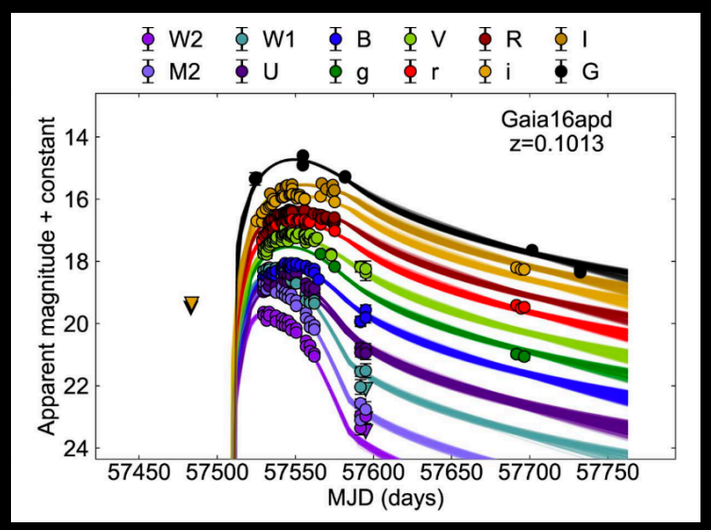
Region to right of curves ruled out



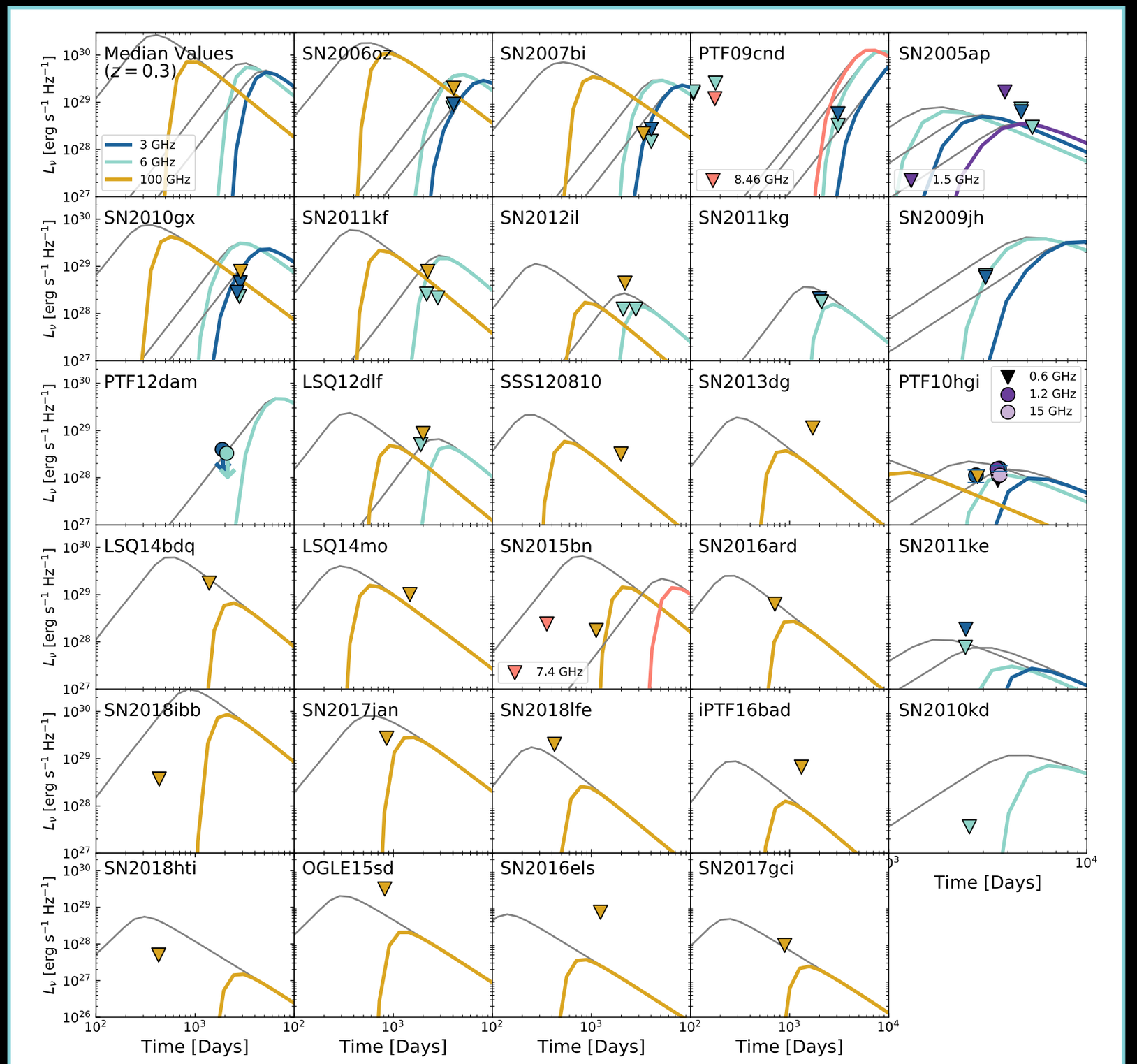
Jetted emission decelerates and spreads into the observer's line of sight at late times

RULING OUT A POPULATION OF RELATIVISTIC JETS

- Uncertainties on magnetar parameters from light curve fits
- Assume injection spectrum of electrons/positrons is consistent with that of Galactic PWNe MURASE+2016

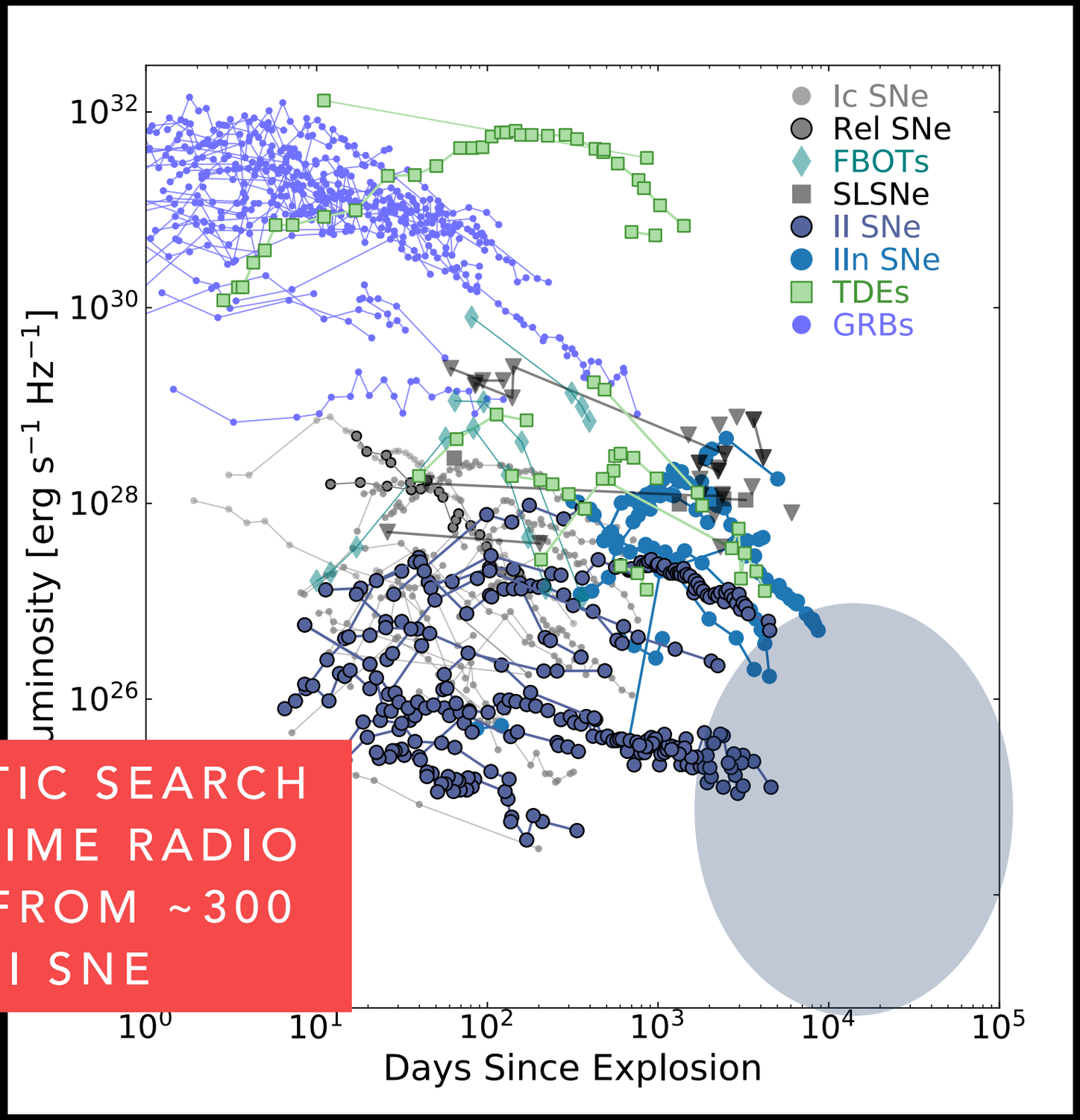


NICHOLL+2017



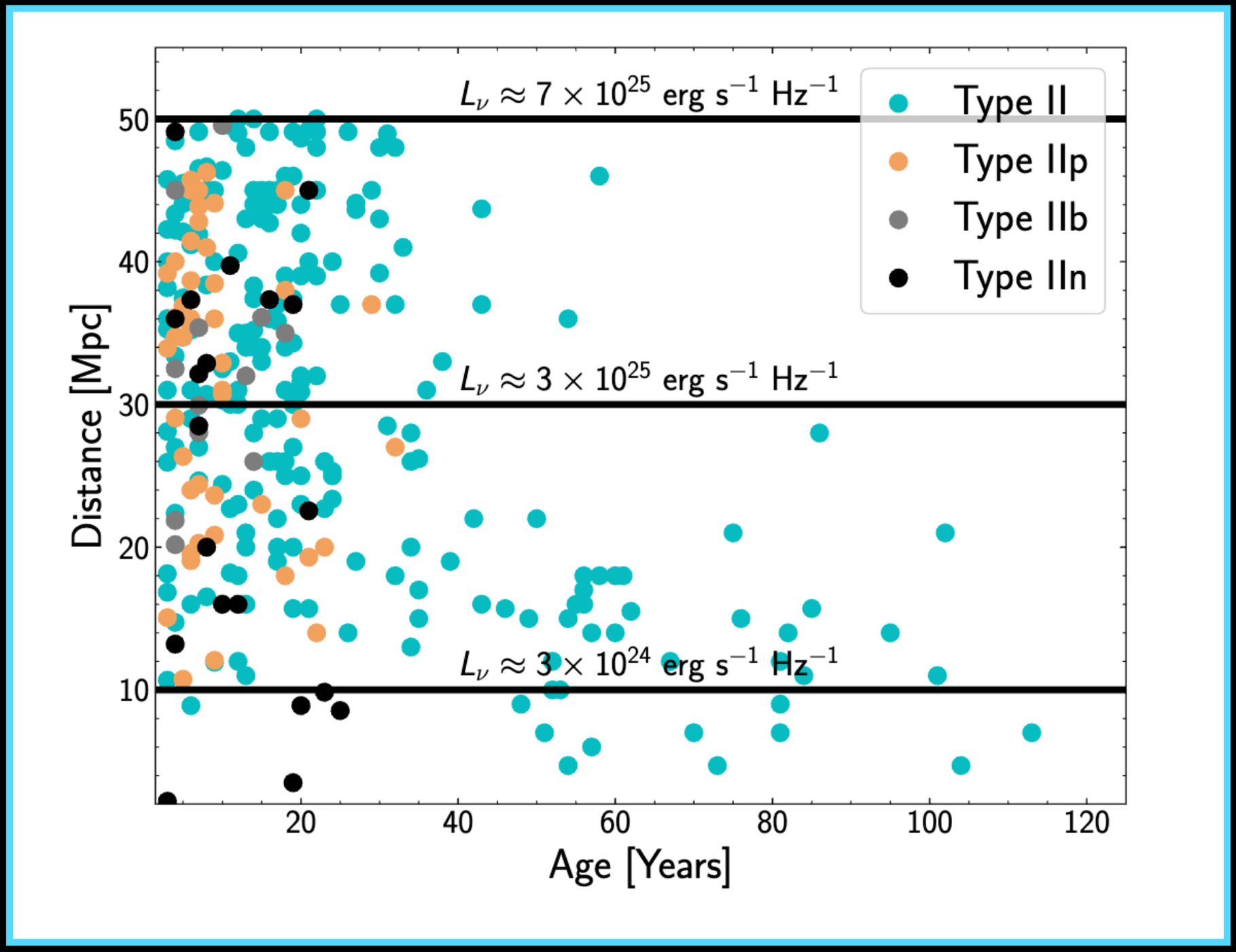
EFTEKHARI+2021

PROBING THE MASS-LOSS HISTORY AND CSM DENSITY OF TYPE II SUPERNOVAE



A SYSTEMATIC SEARCH FOR LATE-TIME RADIO EMISSION FROM ~300 TYPE II SNE

PROBING THE MASS-LOSS HISTORY AND CSM DENSITY OF TYPE II SUPERNOVAE



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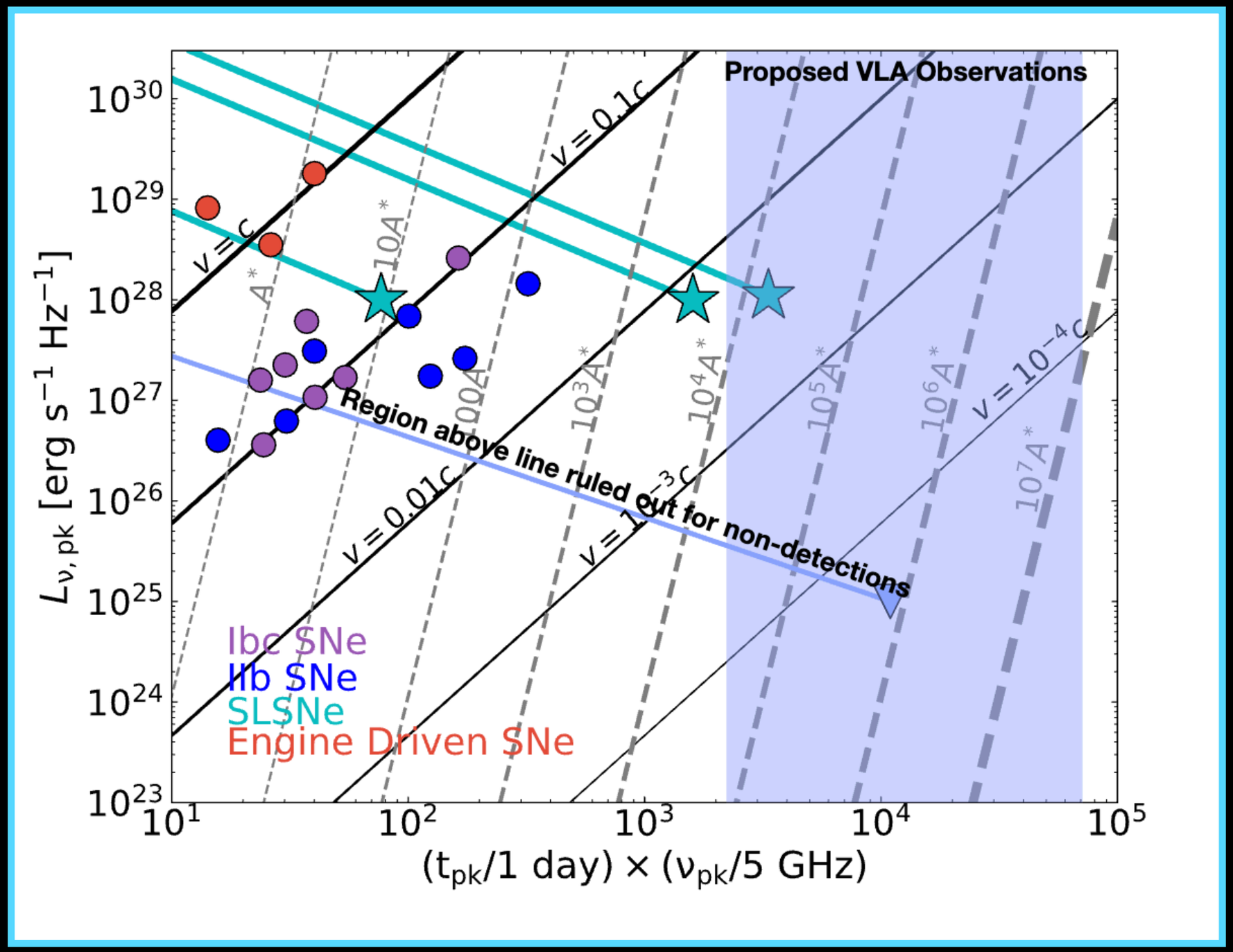

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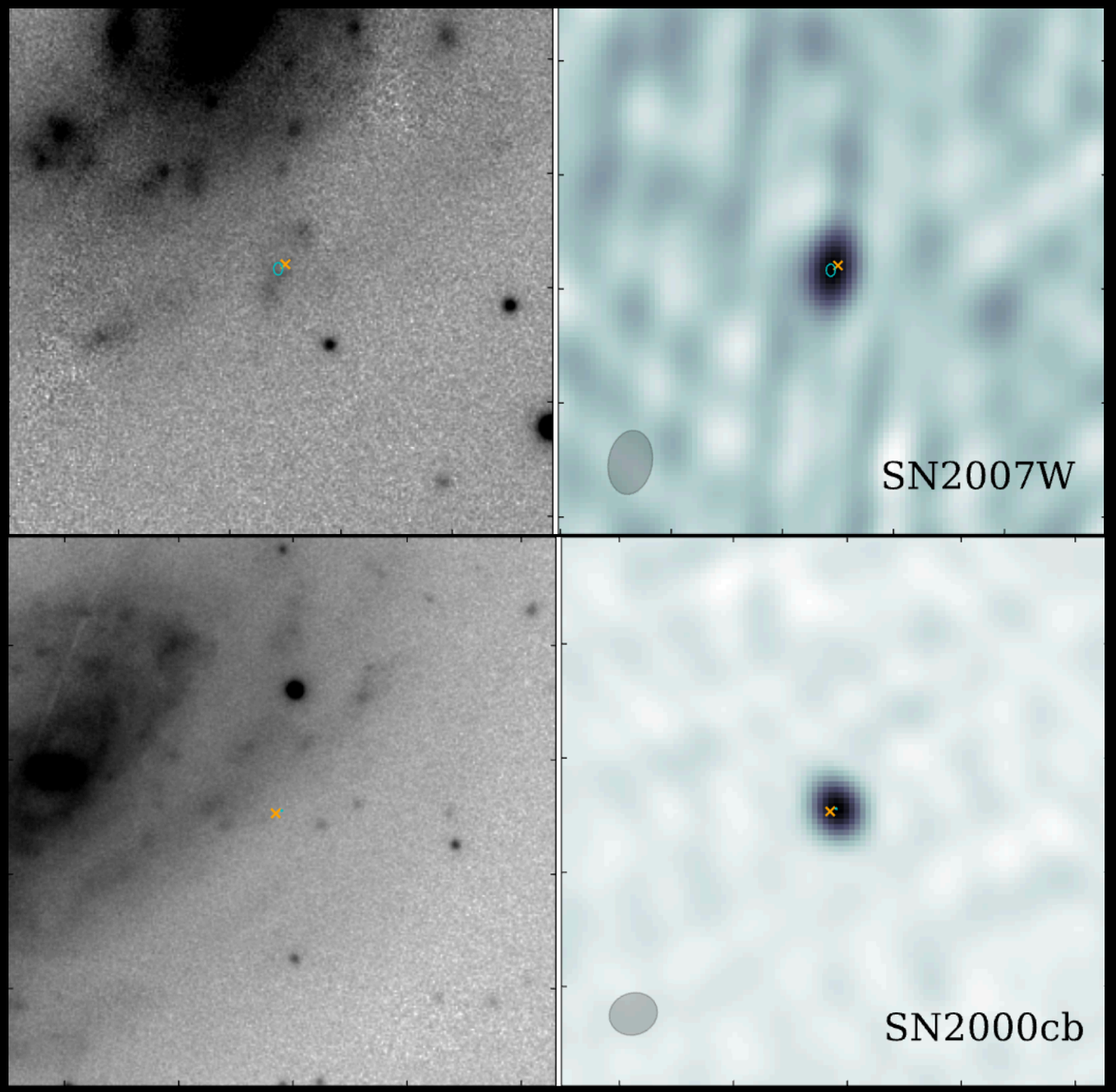

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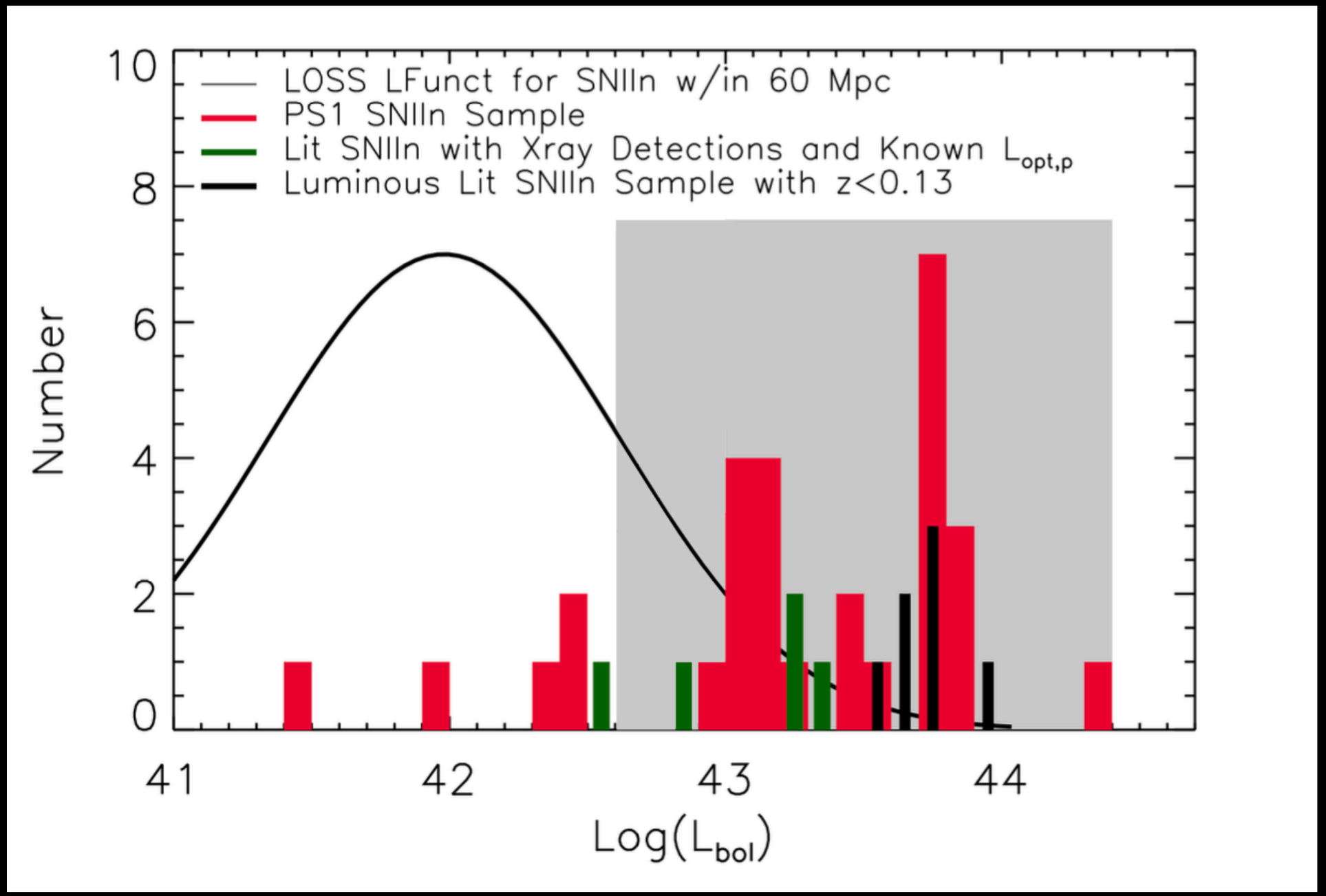
PROBING THE MASS-LOSS HISTORY FROM THE PROGENITORS OF LUMINOUS TYPE IIN SUPERNOVAE



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CONCLUSIONS

Late-time radio transient phase space is largely unexplored…until now! Such observations uniquely probe supernovae progenitors, outflows, and environments

Only one Superluminous Supernovae detected in the radio to date — evidence for a magnetar central engine

Radio limits for Superluminous supernovae rule out relativistic jets with energies comparable to the most energetic GRBs

Late-time (3-100 yr) radio observations of Type II supernovae will place the deepest limits on radio emission from supernovae to date and will probe the CSM densities on the largest physical scales