UNVEILING THE TRANSIENT SKY AT RADIO AND MILLIMETER WAVELENGTHS

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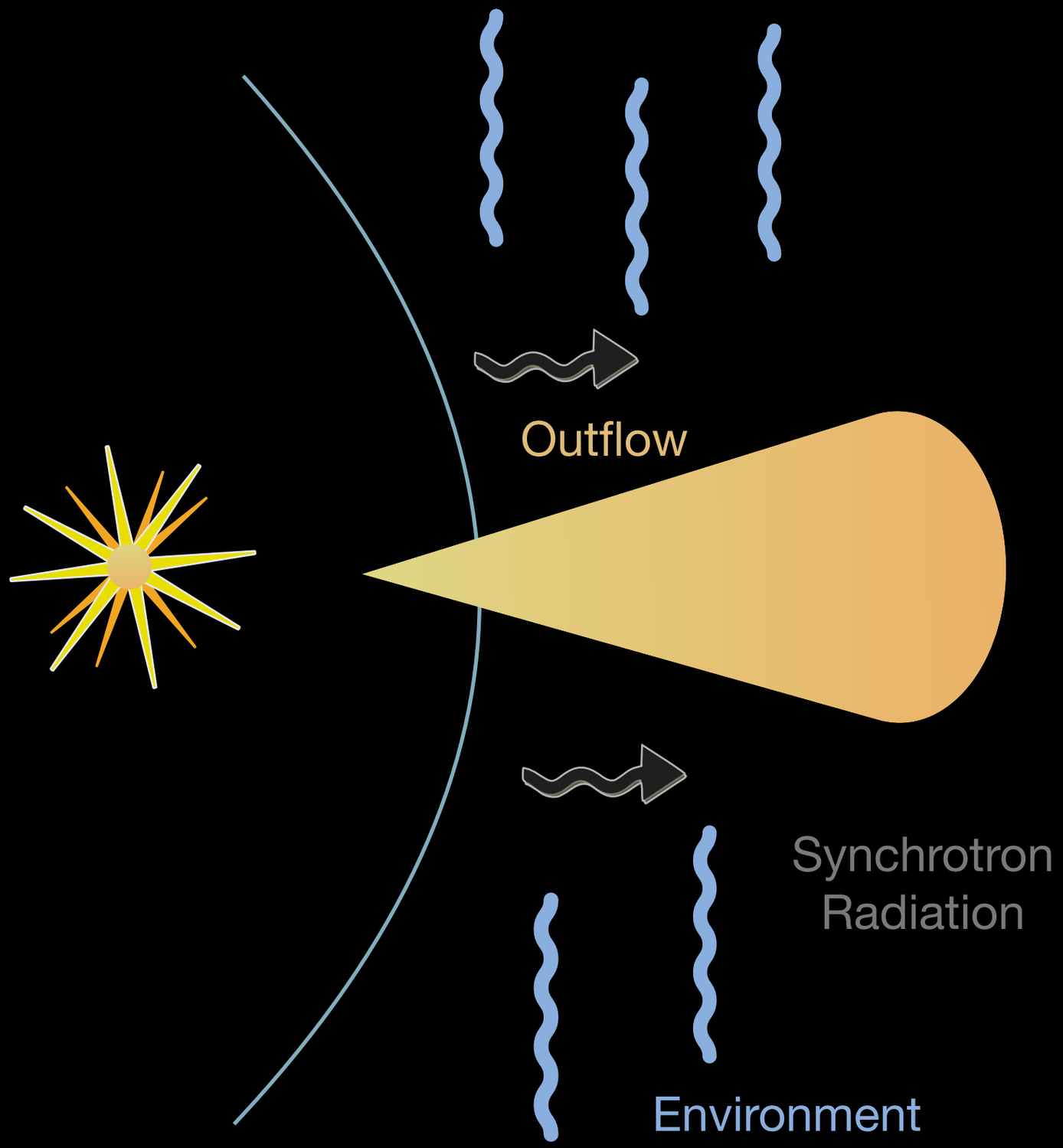
Northwestern

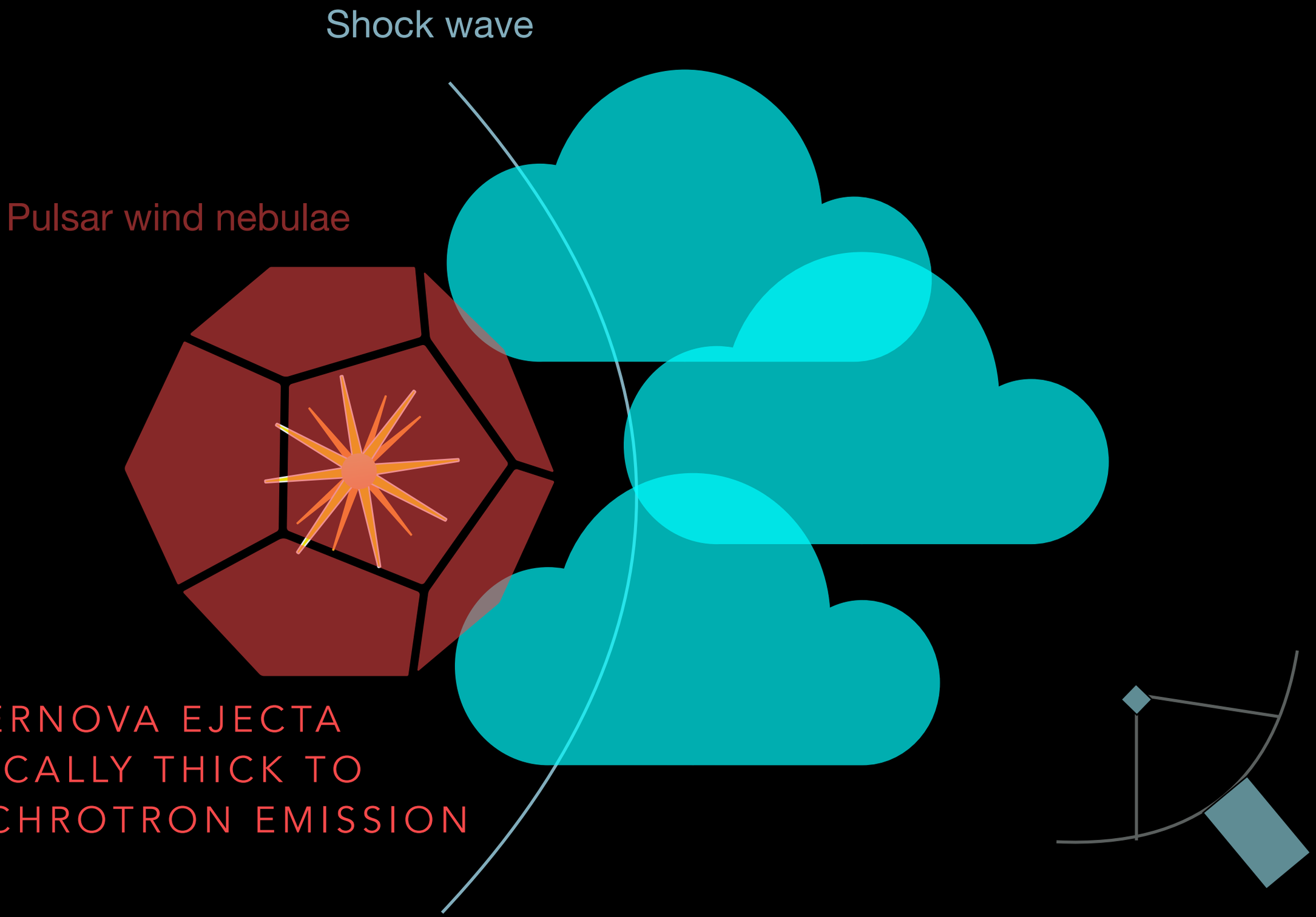
CIERA
CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

FAST & FORTUNATE
FRB FOLLOW-UP

RADIO OBSERVATIONS OF SUPERNOVAE: UNIQUELY PROBING THEIR PROGENITORS AND ENVIRONMENTS

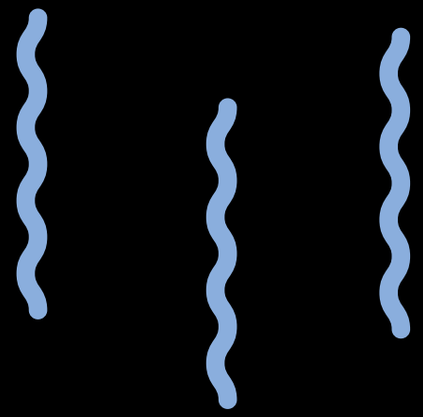


EARLY TIMES:

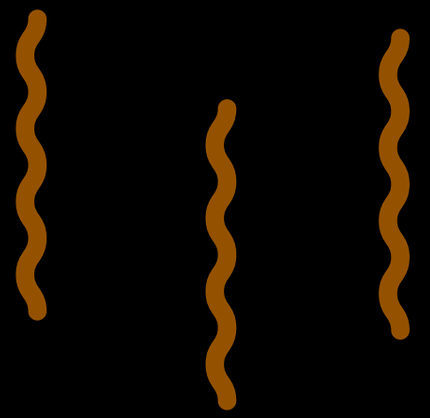

Shock wave
Pulsar wind nebulae
SUPERNOVA EJECTA
OPTICALLY THICK TO
SYNCHROTRON EMISSION

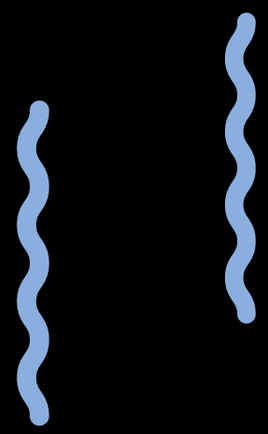
EARLY TIMES:

SUPERNOVA SHOCK FRONT
PROBING MATERIAL
EJECTED IMMEDIATELY
PRIOR TO EXPLOSION

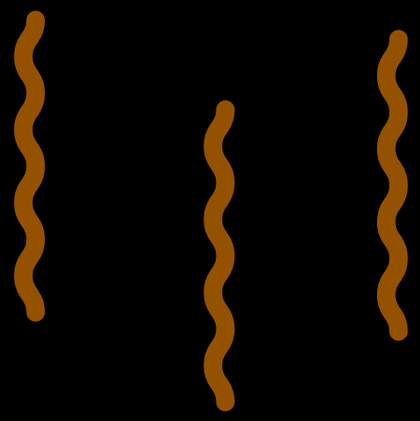


Material ejected
immediately
prior to explosion





Material ejected in
the centuries prior
to explosion



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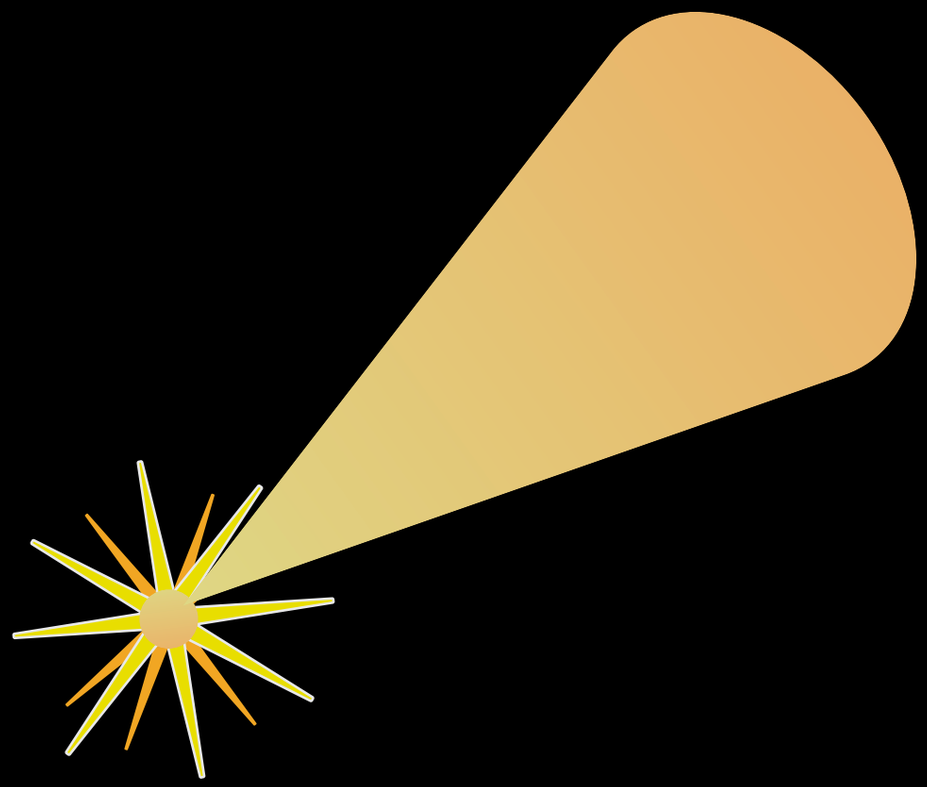
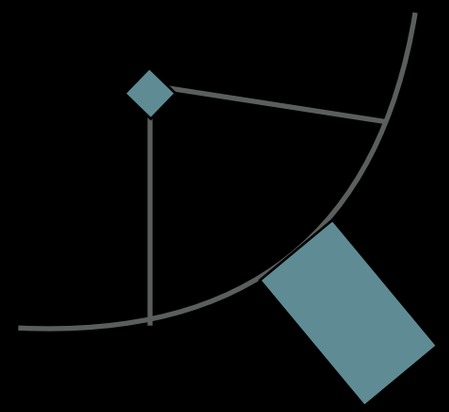


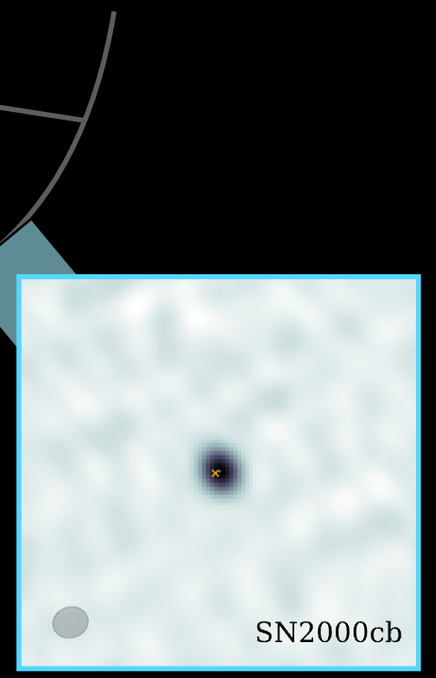
OFF-AXIS JETS HAVE NOT YET SPREAD INTO OUR LINE OF SIGHT

???



LATE TIMES (~5-100 YEARS):

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

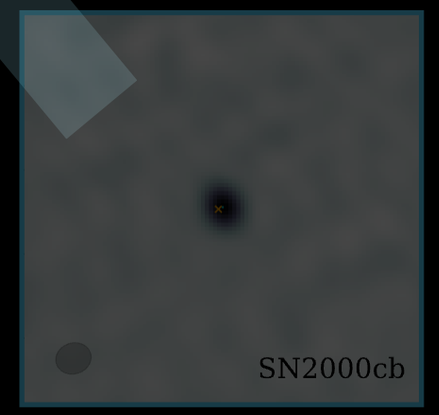


Eftekhari+ *in prep*

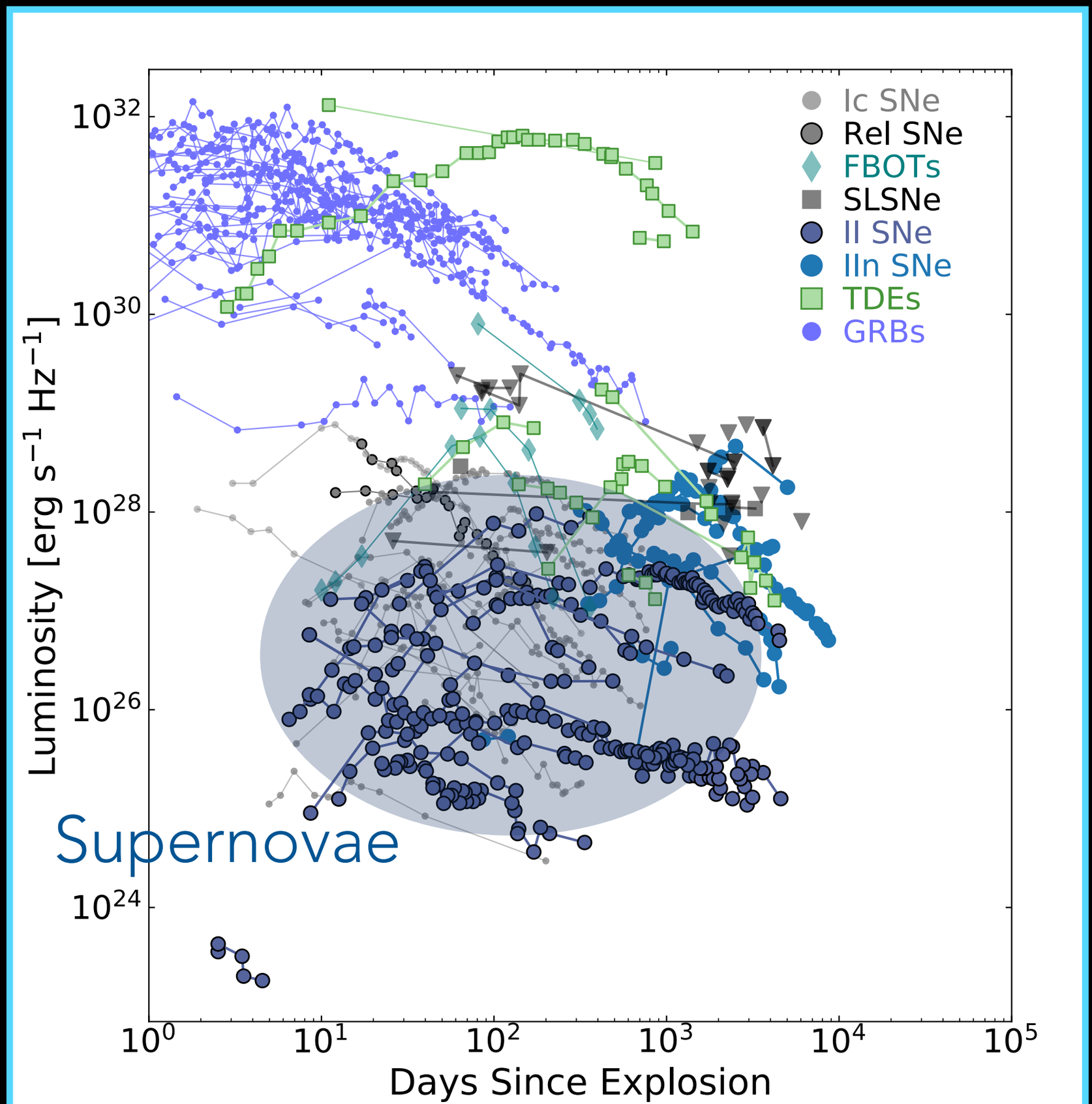
LATE TIMES (~5-100 YEARS):

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

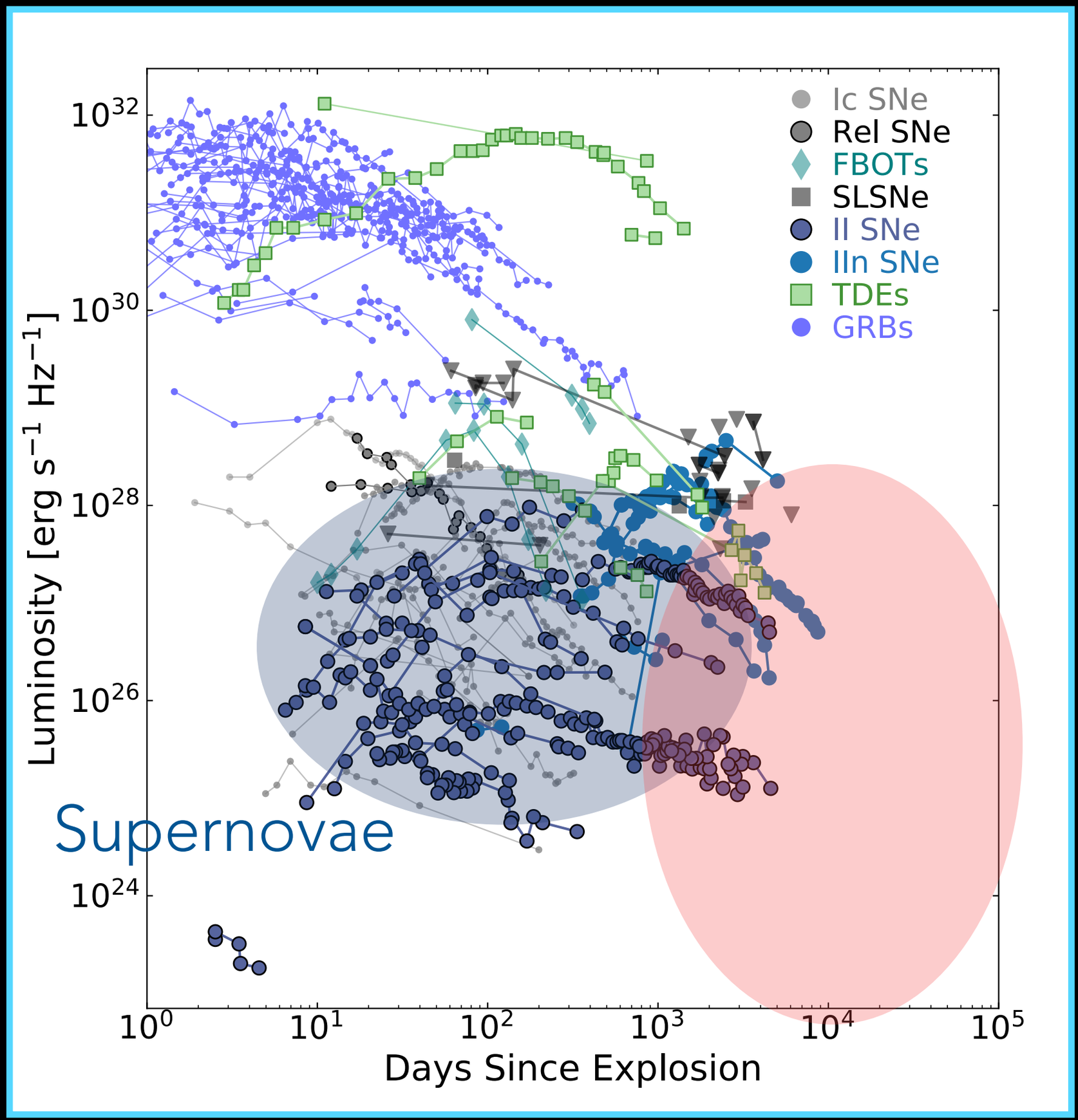
WHAT ARE THE MASS-LOSS HISTORIES AND CSM DENSITIES OF TYPE II SUPERNOVAE?



Eftekhari+ *in prep*



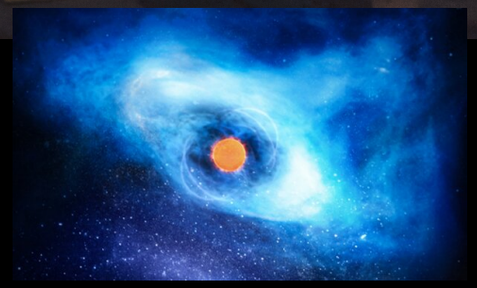
EFTEKHARI+2020



EFTEKHARI+2020

LARGE SURVEY OF SUPERLUMINOUS SUPERNOVAE WITH THE VLA AND ALMA

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



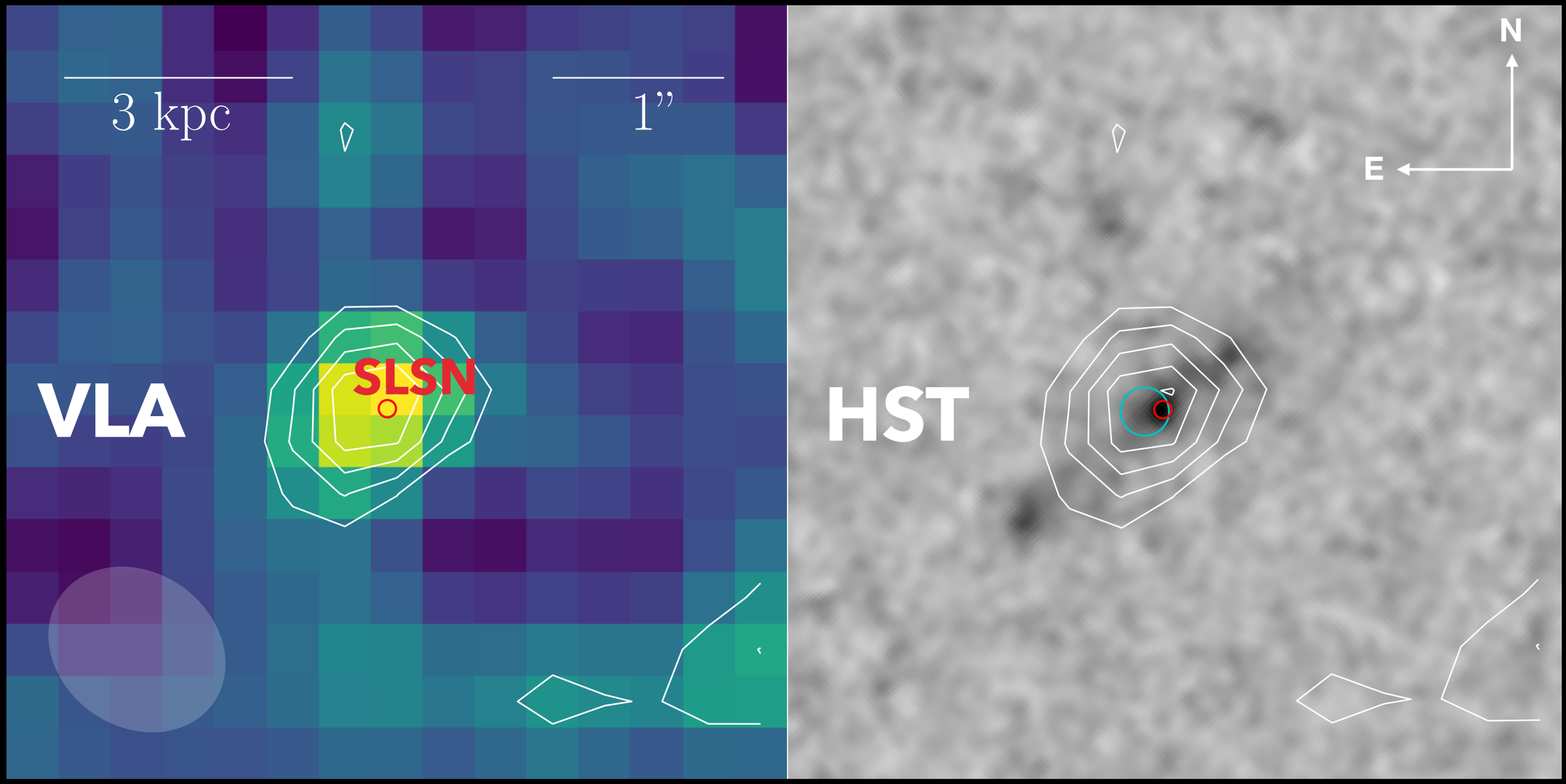
Implications for:

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

Evidence for central engine-powered emission?

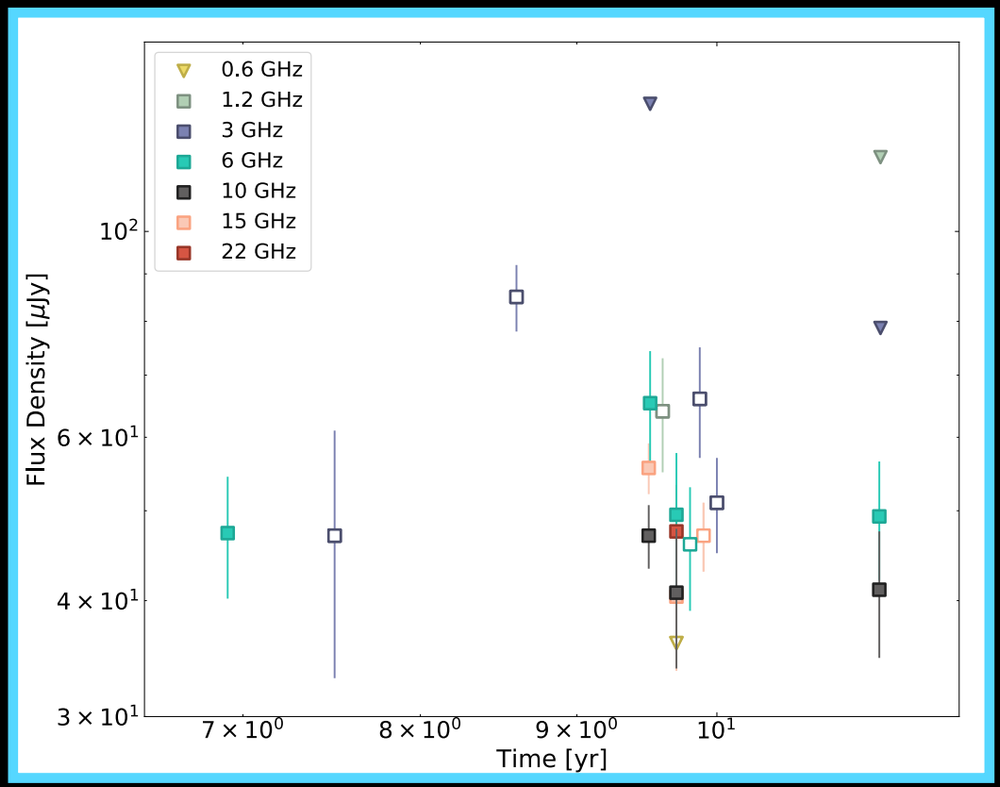
PTF10HGI ~8 YEARS POST-EXPLOSION



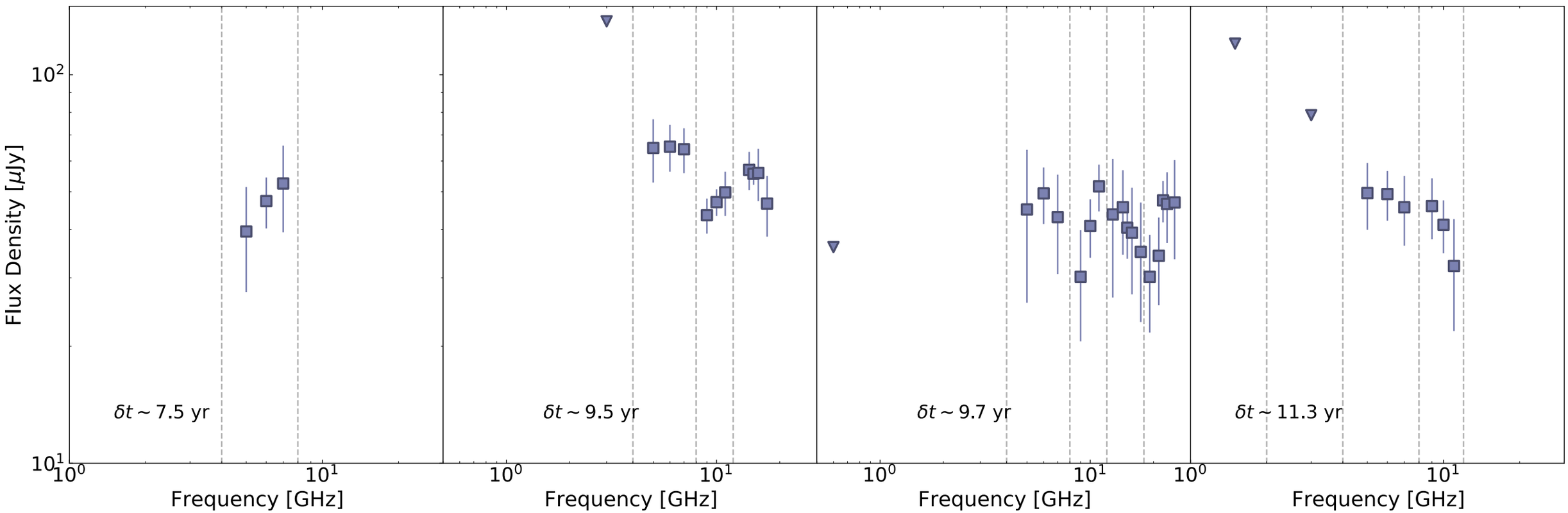
EFTEKHARI+2019

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

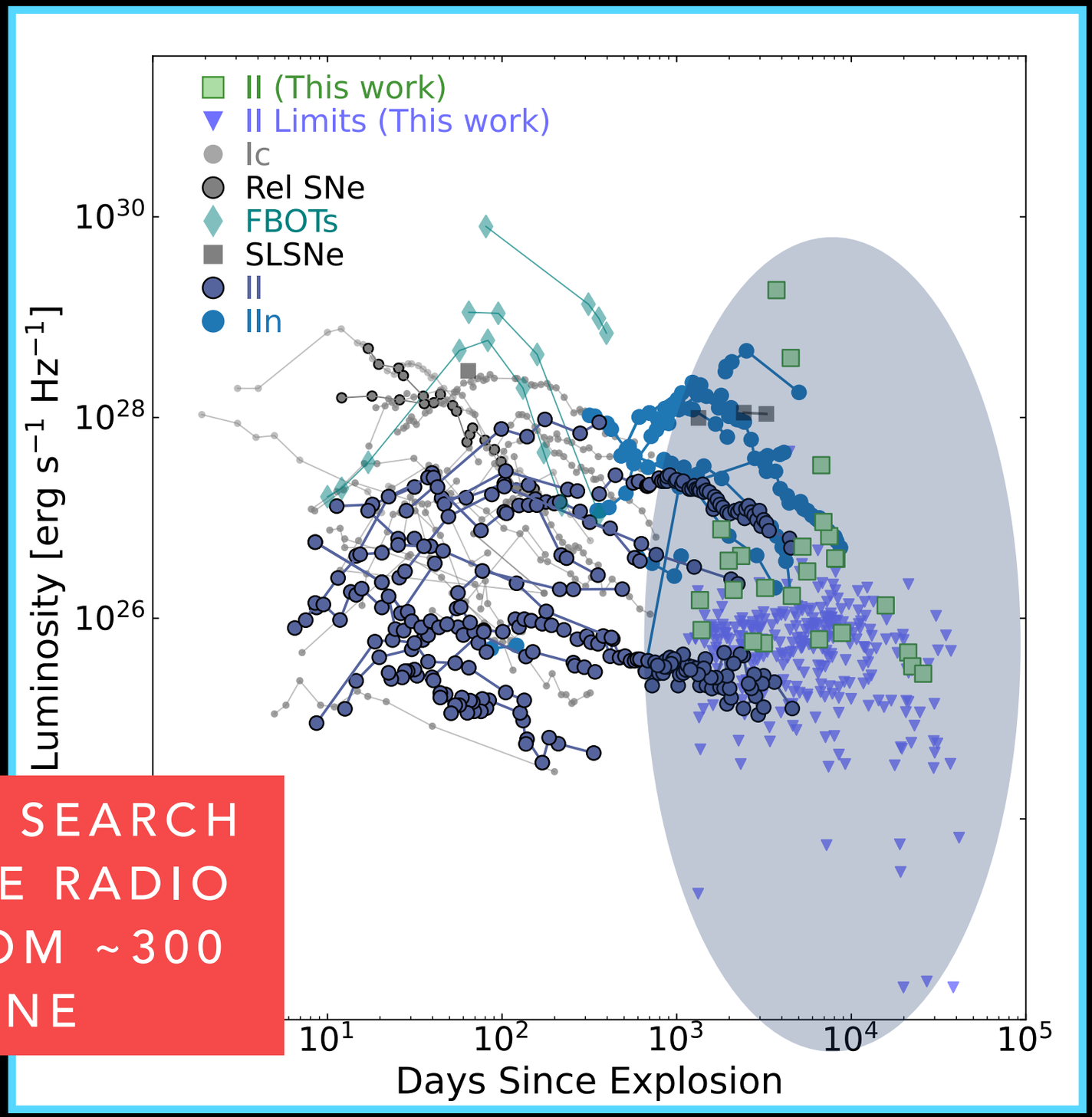
Short timescale variability —
a scintillating compact object?



EFTEKHARI+*IN PREP*



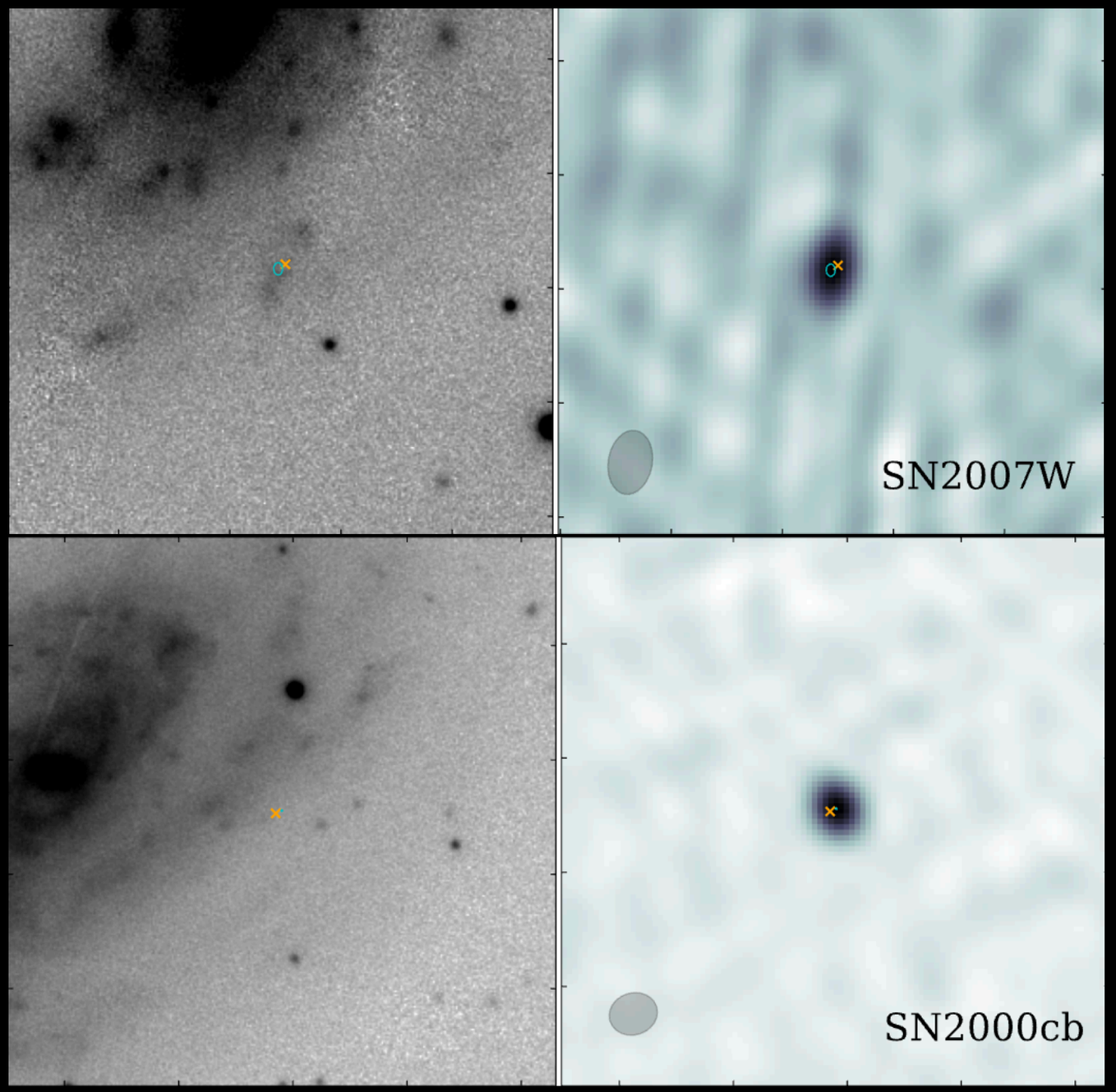
PROBING THE MASS-LOSS HISTORY AND CSM DENSITY OF TYPE II SUPERNOVAE



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

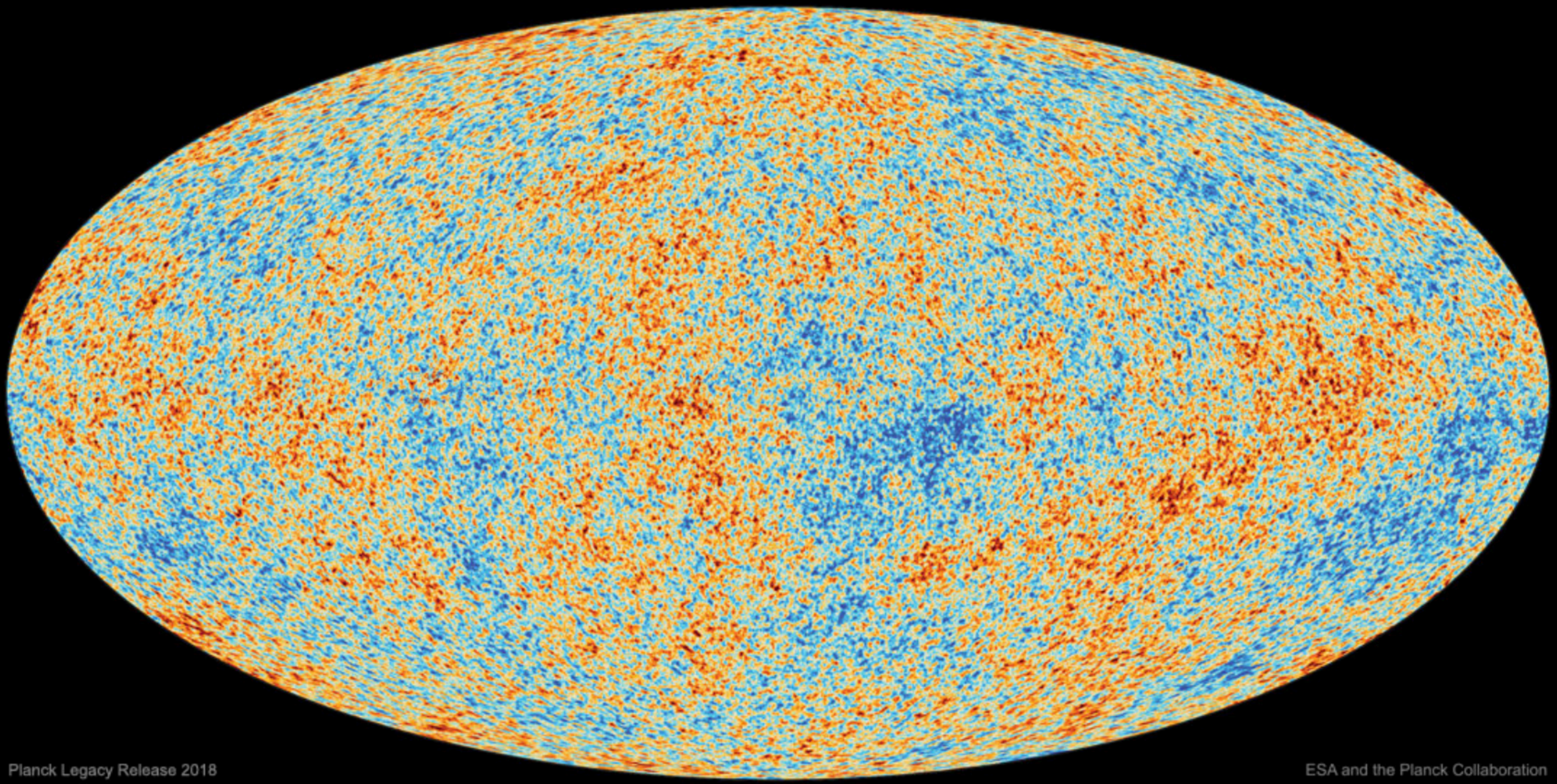
EFTEKHARI+*IN PREP*

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



EFTEKHARI+*IN PREP*

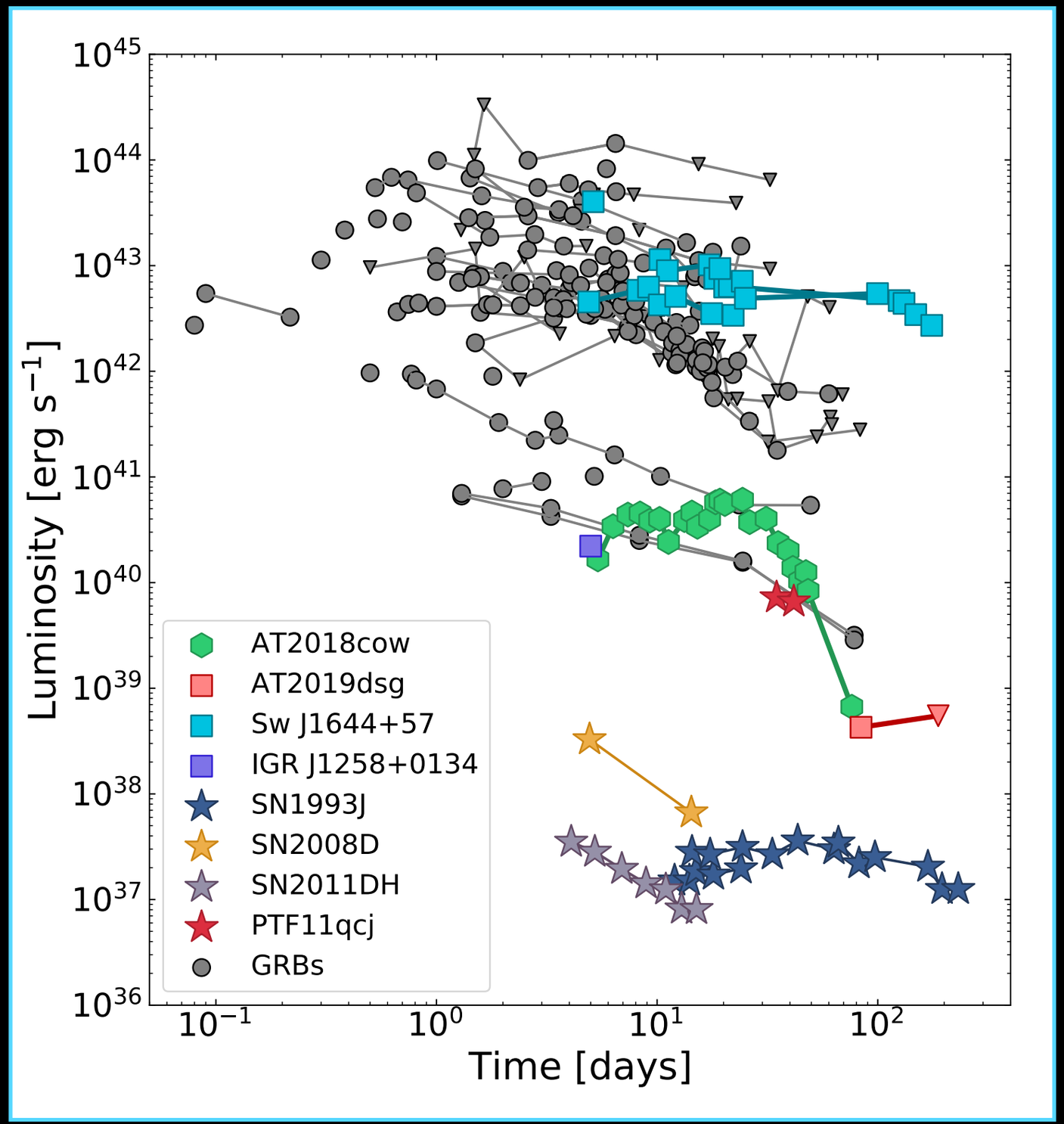
CMB EXPERIMENTS OFFER AN UNTAPPED VIEW OF THE MILLIMETER TRANSIENT SKY



Planck Legacy Release 2018

ESA and the Planck Collaboration

PRESENT DAY LANDSCAPE OF MM TRANSIENTS SPANS MANY ORDERS OF MAGNITUDE IN LUMINOSITY



EFTEKHARI+2022

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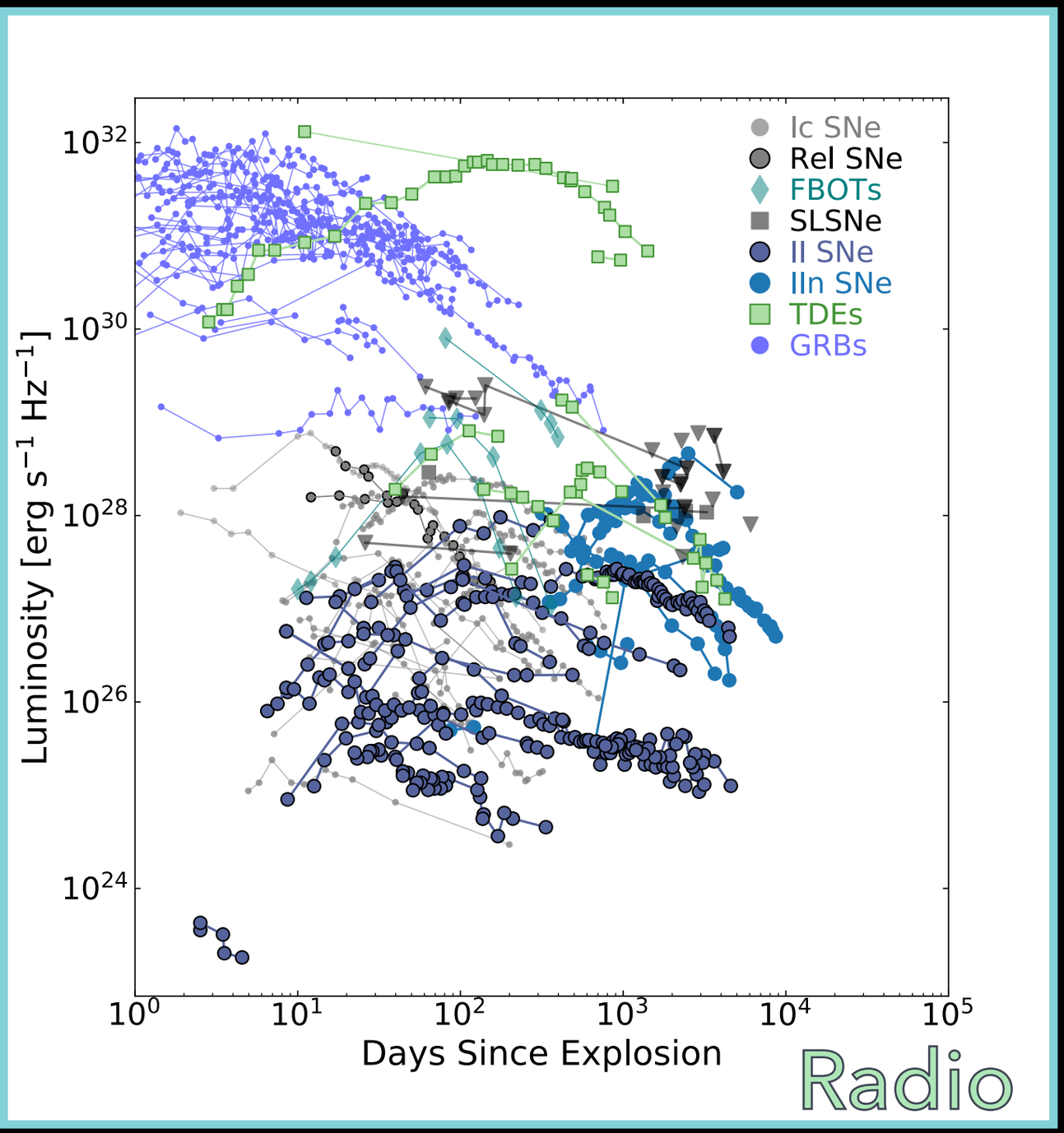
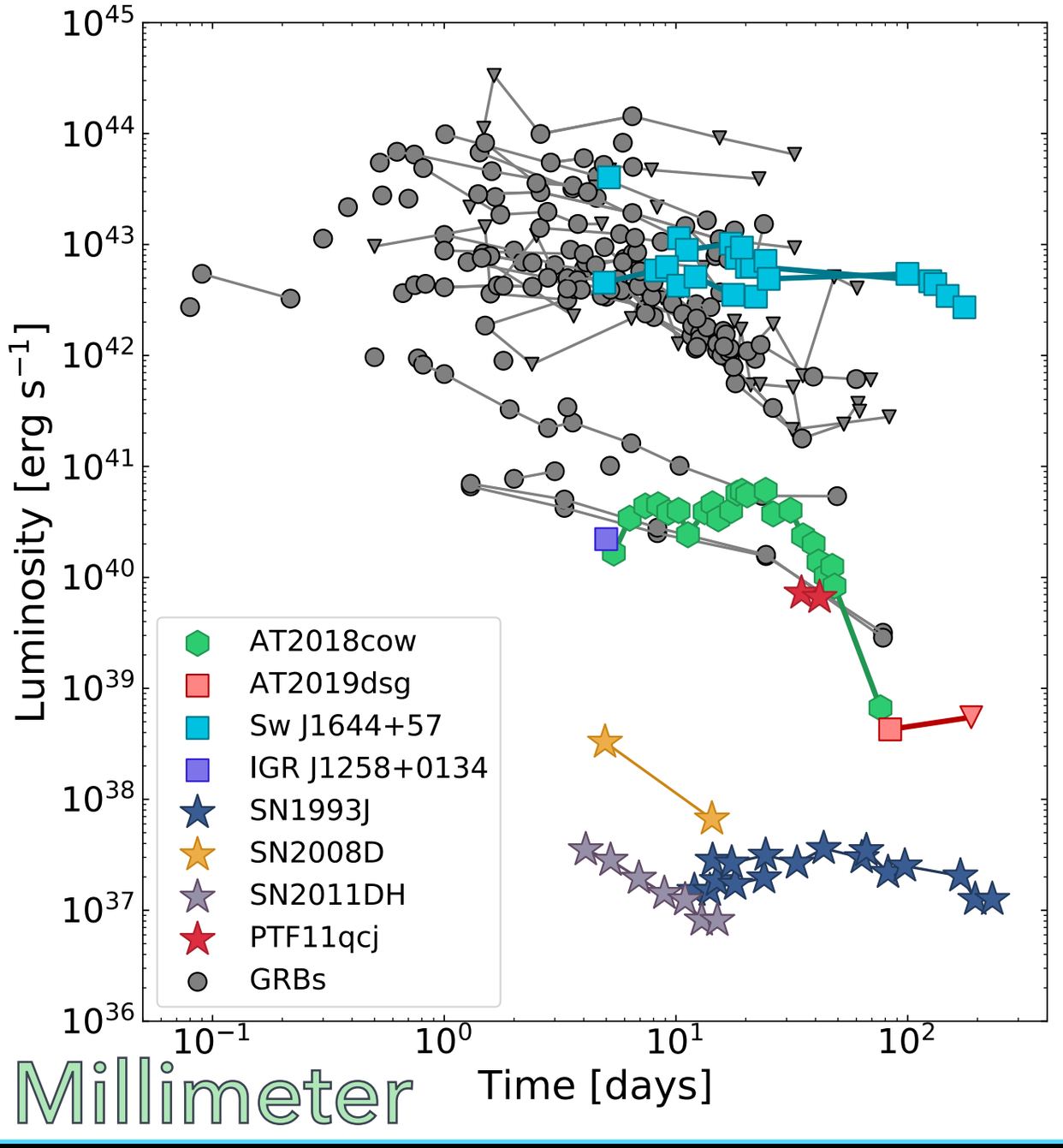


EFTEKHARI+2020



EFTEKHARI+2022

NEXT-GEN CMB SURVEYS OFFER WIDE-FIELD, DAILY CADENCE MAPS

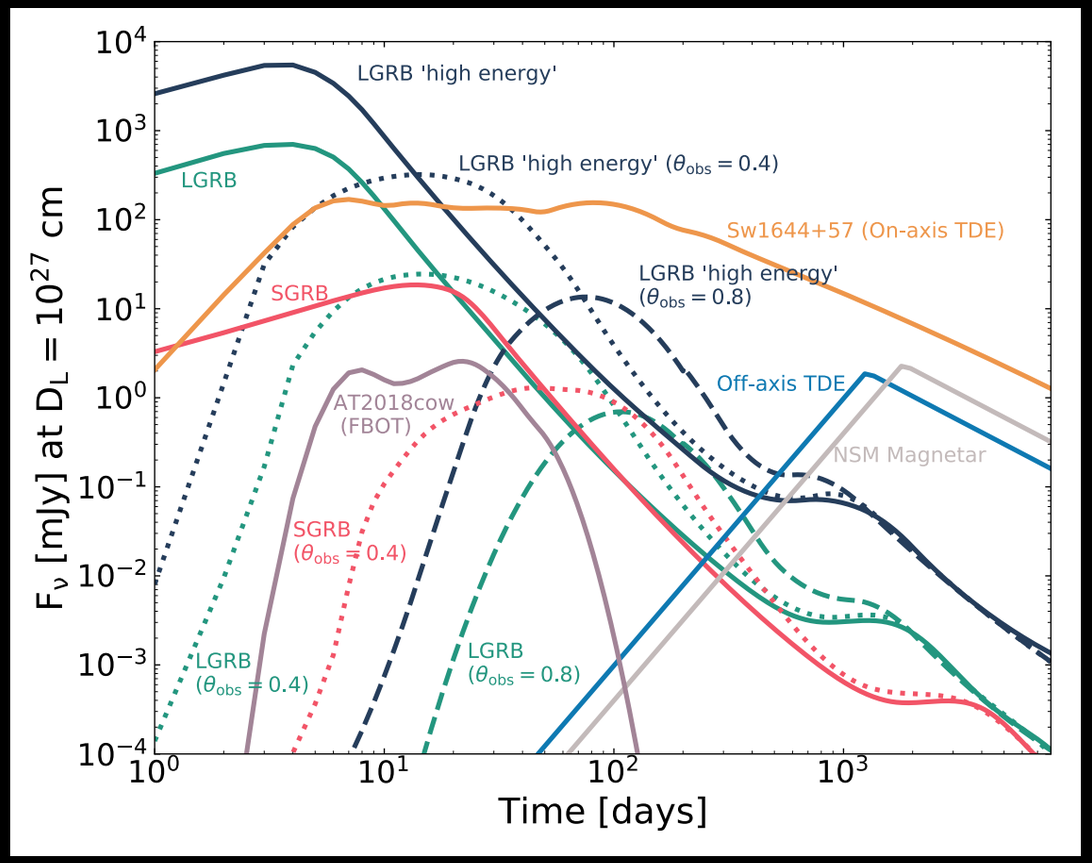
ACT (97 - 148 GHz; 40% of sky)
SPT-3G (95 - 220 GHz; 30% of sky)
SIMONS OBSERVATORY (90 - 150 GHz; 10 - 40% of sky)
CMB-S4 (30 - 270 GHz; 50% of sky, daily cadence!)

"Because of its great potential to advance general astrophysics and open discovery space, it is essential that CMB-S4 produce transient alerts…"

ASTRO2020 DECADAL

CHARACTERIZING THE TRANSIENT DETECTION LANDSCAPE WITH CMB SURVEYS

Transient	$\mathcal{R}\ (z=0)$ $(\mathrm{Gpc^{-3}\ yr^{-1}})$
LGRB, On-Axis	$\mathbf{0.2}^{+0.02\,a}_{-0.03}$
LGRB, $\theta_{obs} = 0.4$	$\mathbf{0.8}^{+0.1\,a}_{-0.1}$
LGRB, $\theta_{obs} = 0.8$	$\mathbf{3.0}^{+0.5\,a}_{-0.3}$
LGRB high energy, On-axis	$\mathbf{0.1}^{+0.01\,a}_{-0.01}$
LGRB high energy, $\theta_{obs} = 0.4$	$\mathbf{0.4}^{+0.04\,a}_{-0.04}$
LGRB high energy, $\theta_{obs} = 0.8$	$\mathbf{1.5}^{+0.2\,a}_{-0.2}$
SGRB, On-Axis	$\mathbf{1.3}^{+0.4\,a}_{-0.3}$
SGRB, $\theta_{obs} = 0.4$	$\mathbf{5.0}^{+1.7\,a}_{-1.0}$
TDE, On-Axis	$\mathbf{0.03}^{+0.04\,b}_{-0.02}$
TDE, Off-Axis (spherical)	$\mathbf{3}^{+4\,b}_{-2}$
NSM: stable remnant	2.5^{a}
FBOTs	70



EFTEKHARI+2022

CHARACTERIZING THE TRANSIENT DETECTION LANDSCAPE WITH CMB SURVEYS

- Detection rates dominated by long GRBs
- Small number of FBOTS/TDES
- Short GRBs

Transient	$\mathcal{R}\ (z=0)$ $(\mathrm{Gpc^{-3}\ yr^{-1}})$
LGRB, On-Axis	$\mathbf{0.2}^{+0.02\,a}_{-0.03}$
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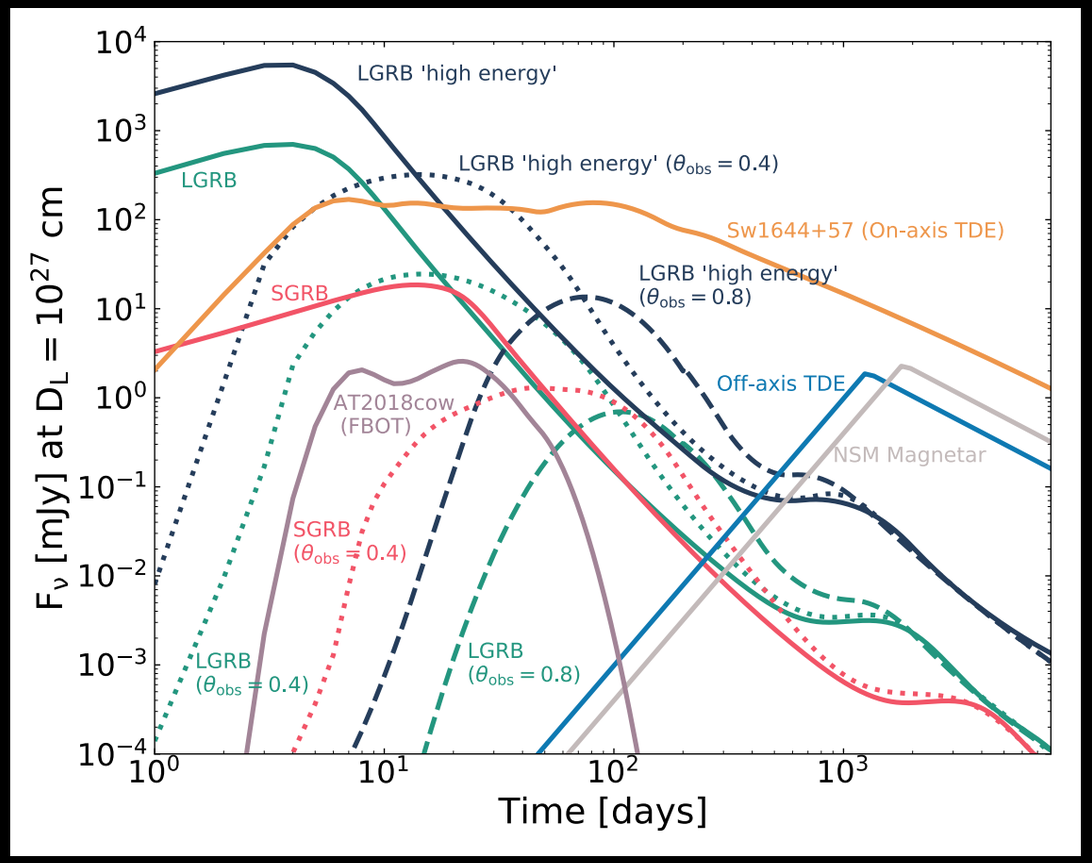


EFTEKHARI+2022

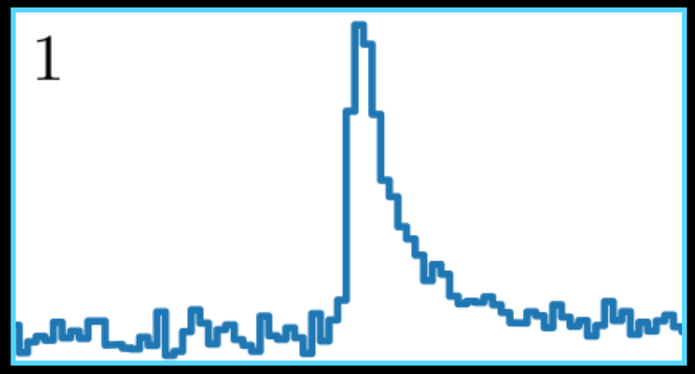
KEY SCIENCE QUESTIONS ADDRESSED WITH CMB SURVEYS

1) How common is reverse shock emission in long gamma-ray bursts?

2) What fraction of tidal disruption events produce relativistic jets?

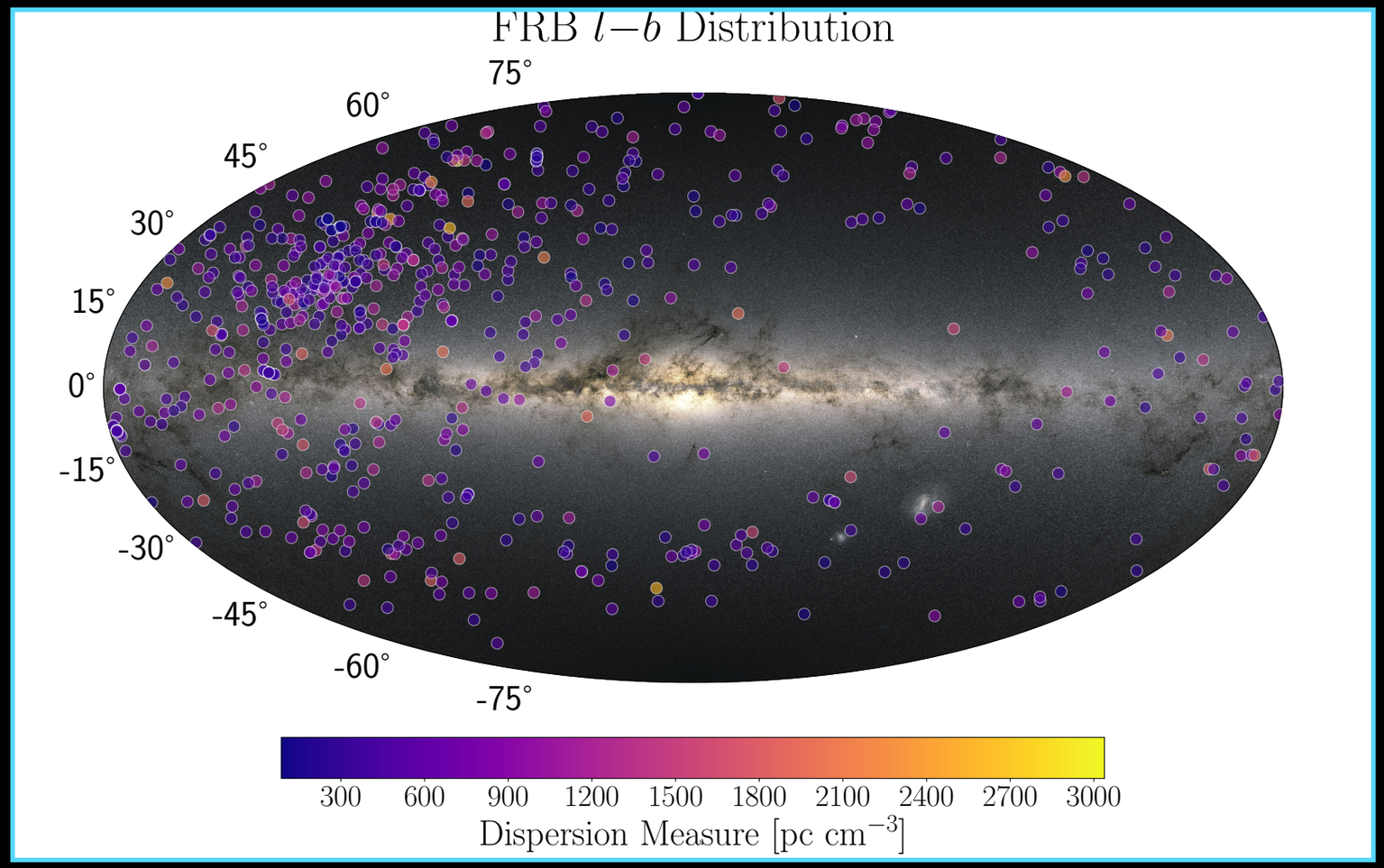
3) What drives the radio/millimeter diversity of fast blue optical transients?

FAST RADIO BURST KEY PROPERTIES



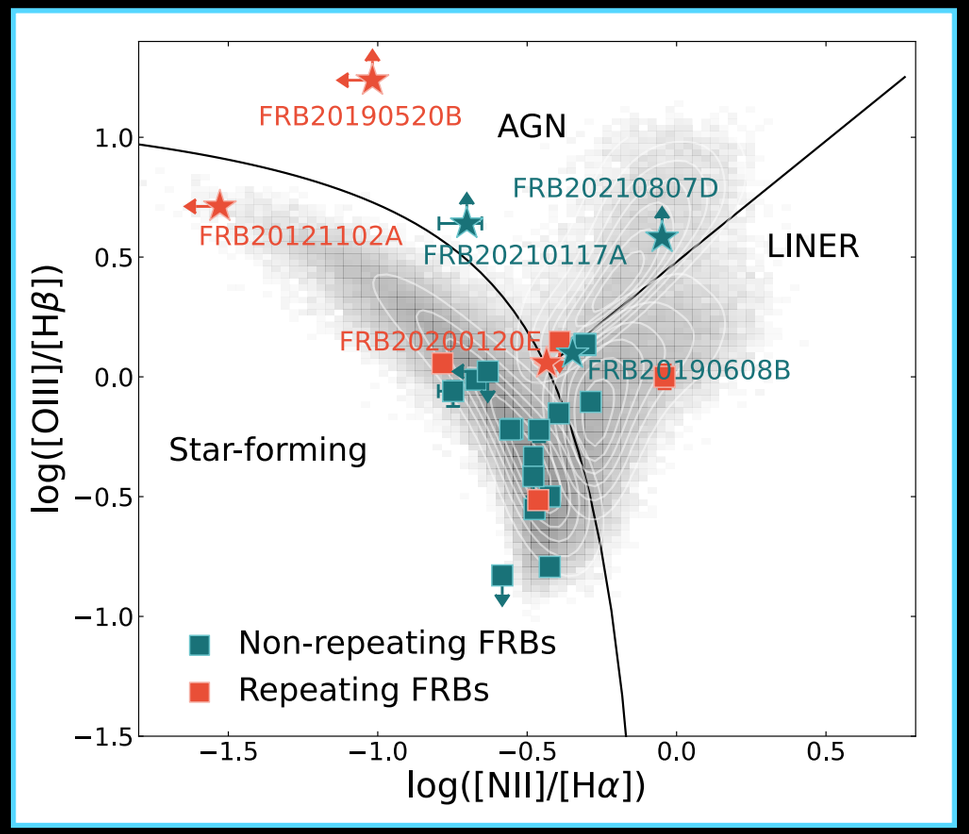
PLEUNIS+ 2021

- Millisecond duration bursts of radio emission
- All-sky rate >~1000 FRBs per day
- Repeating vs apparently one-off events
- Complex burst morphologies
- Some exhibit scatter broadening
- Energies spanning ~ $10^{35} - 10^{43}$ erg

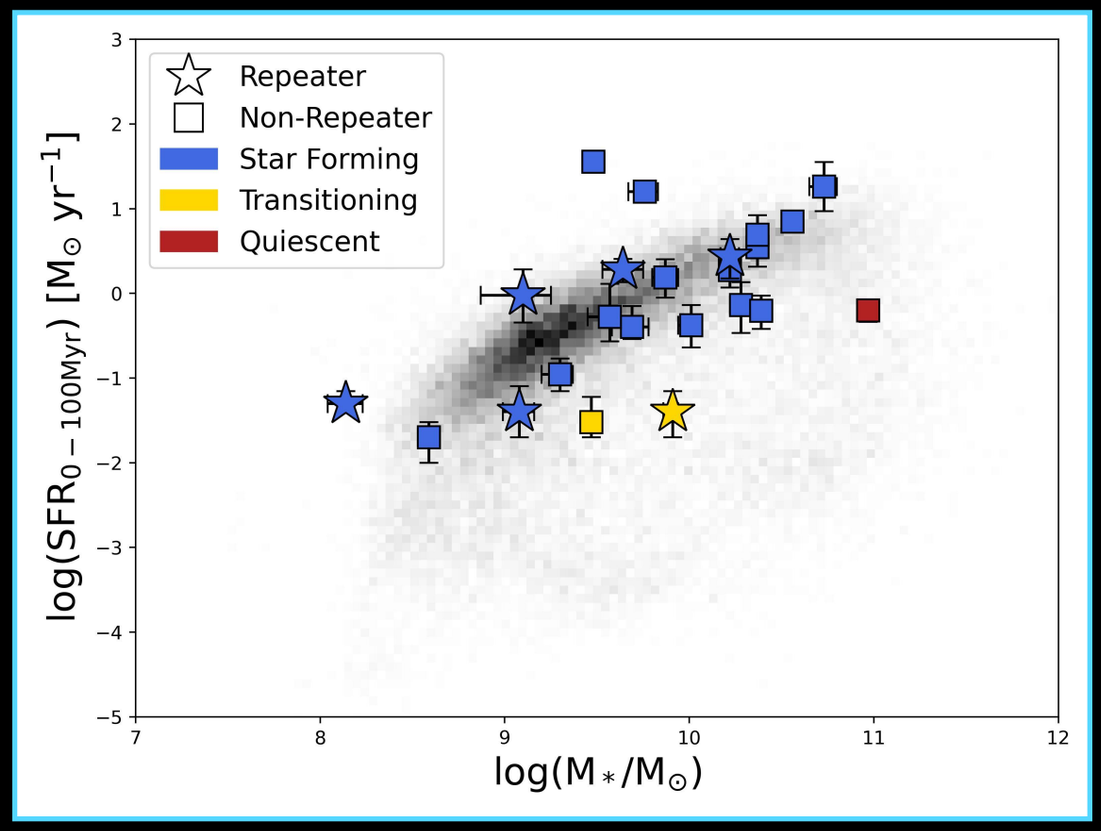


HERTA-EXPERIMENT.ORG/FRBSTATS/

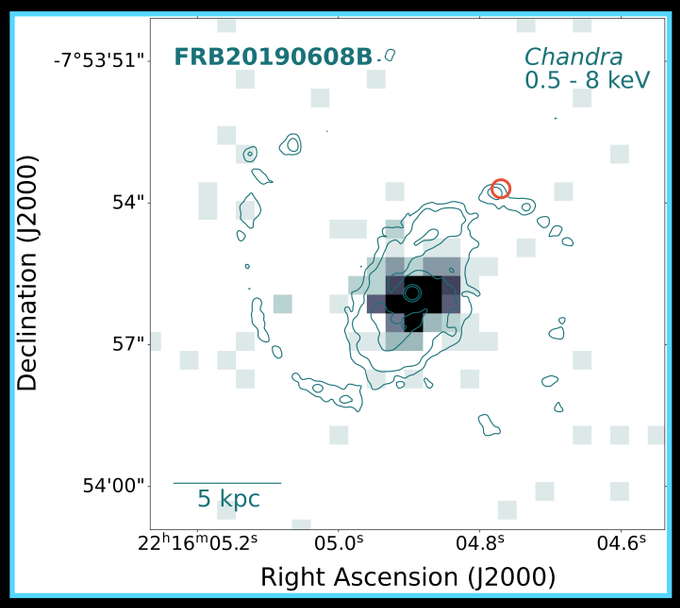
HOST ENVIRONMENTS PROVIDE INSIGHT INTO FRB PROGENITORS

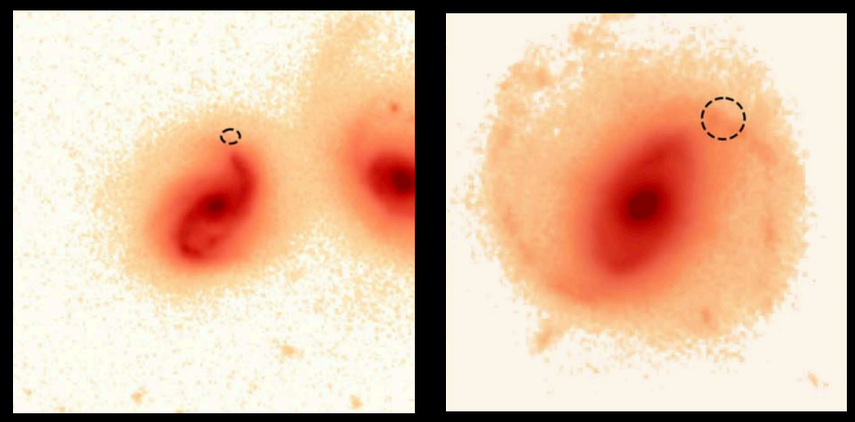


EFTEKHARI+ 2023

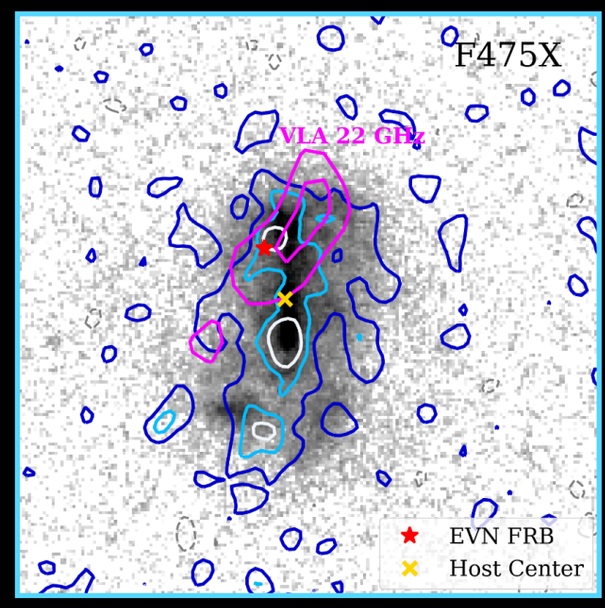


GORDON,...,TE,+ 2023





MANNINGS+ 2021



DONG, EFTEKHARI+ 2023

FAST AND FORTUNATE FOR FRB FOLLOW-UP (F^4)

FAST & FORTUNATE
FRB FOLLOW-UP

FRB-F4.ORG

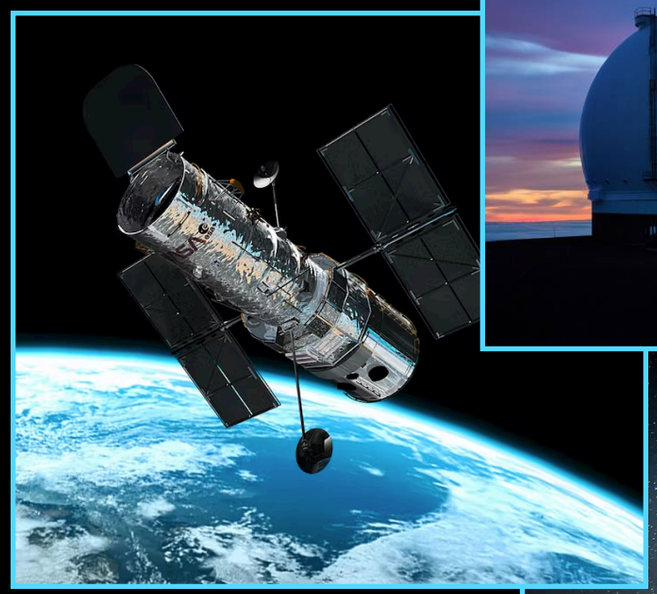
CRAFT

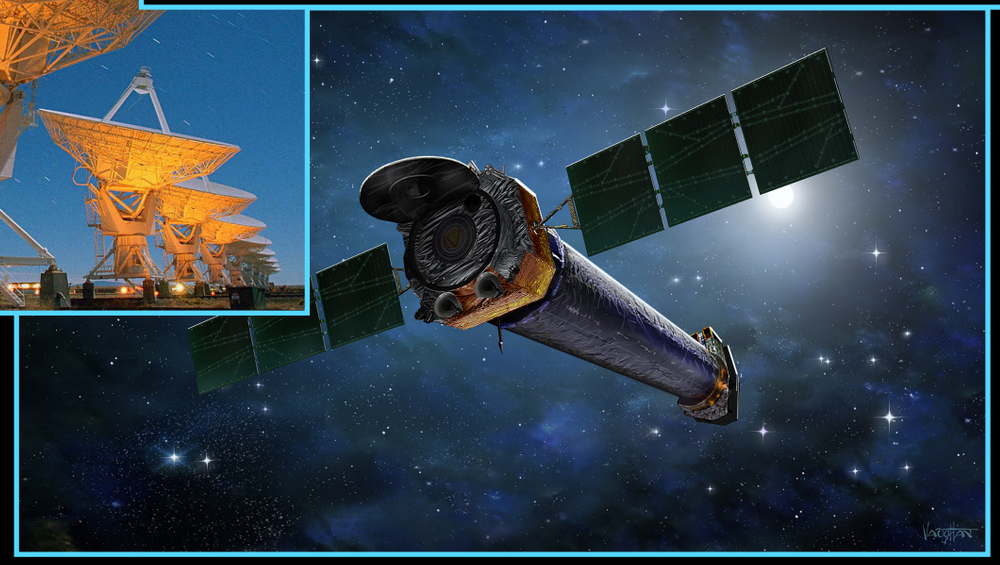
realfast

MEERTRAP

ASTROFLASH

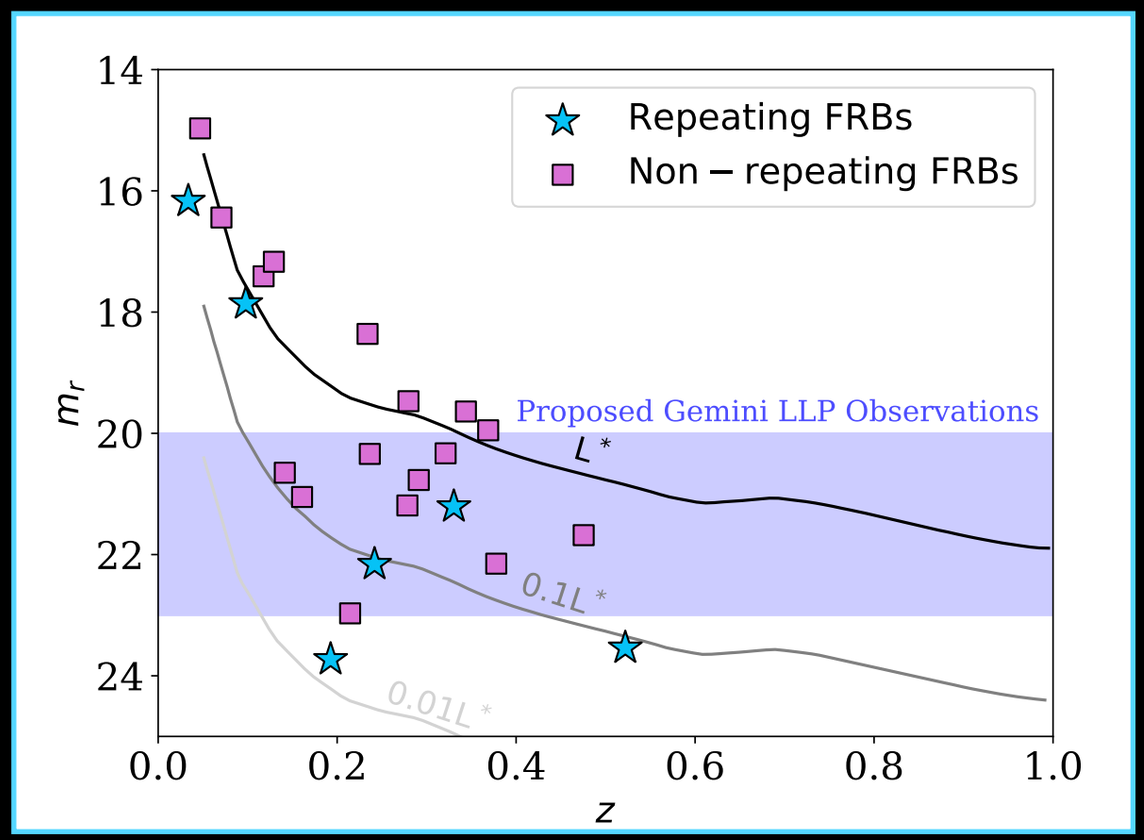
chime



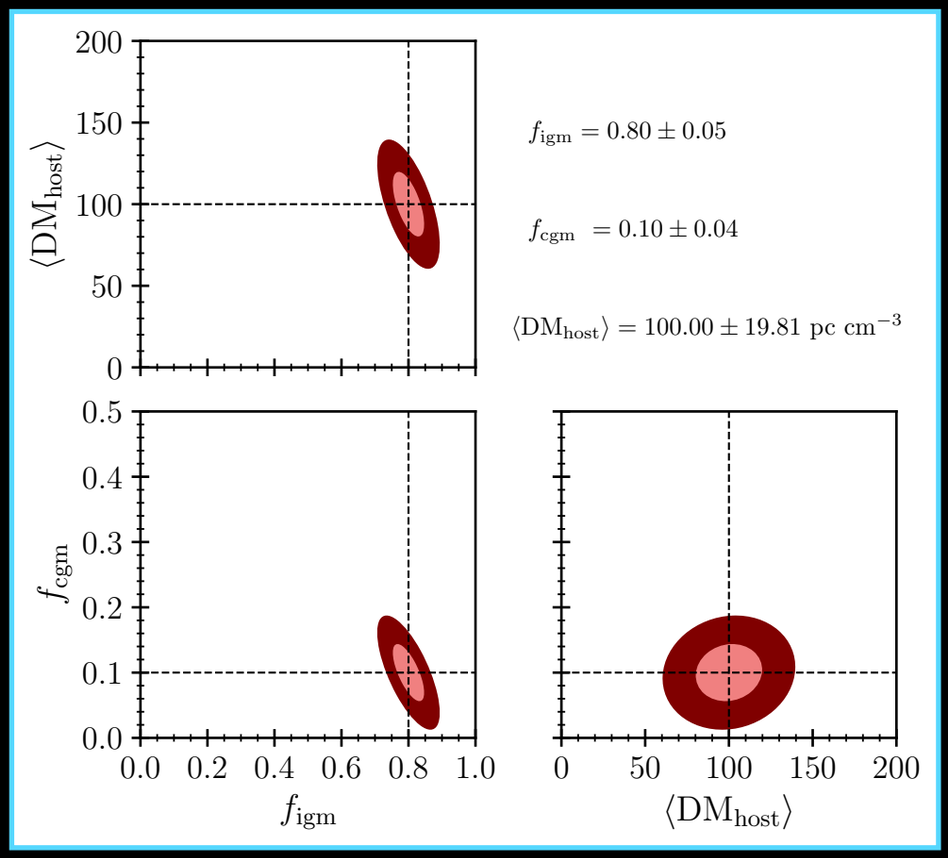


THE FIRST LARGE CENSUS OF FAST RADIO BURST HOST GALAXIES WITH GEMINI

Gemini Large and Long Program (PI: Eftekhari) to obtain redshifts for 200 FRB host galaxies!



Probing 0.01 L* to L* galaxies across a wide range of redshifts



Constraining the baryon content in the CGM and IGM to high-precision with well-mapped foreground structures

CONCLUSIONS

Late-time radio transient phase space is largely unexplored…until now!
Direct probes of central engines; constraints on massive star evolution

CMB surveys poised to open a new window into the transient sky at millimeter wavelengths; expect large numbers of long GRB detections, some TDEs, FBOTs, short GRBs

Host localizations are key for elucidating FRB progenitors; moving into the large *N* era where we can start to answer this question!

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