Core-collapse and Type Ia SNe with ThunderKAT

(A commensal perspective on CCSNe and a targeted one on Type Ia SNe)

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(For details, see Pérez-Torres et al. 2014, arXiv:1409.1827 and PT+2015 in "The Spanish SKA White Book")

IAA-CSIC (Granada) & CEFCA (Teruel), SPAIN

Brasenose Radio Transients / ThunderKAT meeting, Oxford
2015 September 14-16

CCSN searches

Lack of systematic searches of radio SNe

Targeted searches of some optically discovered CCSNe.
Optical searches miss a significant fraction of CCSNe.

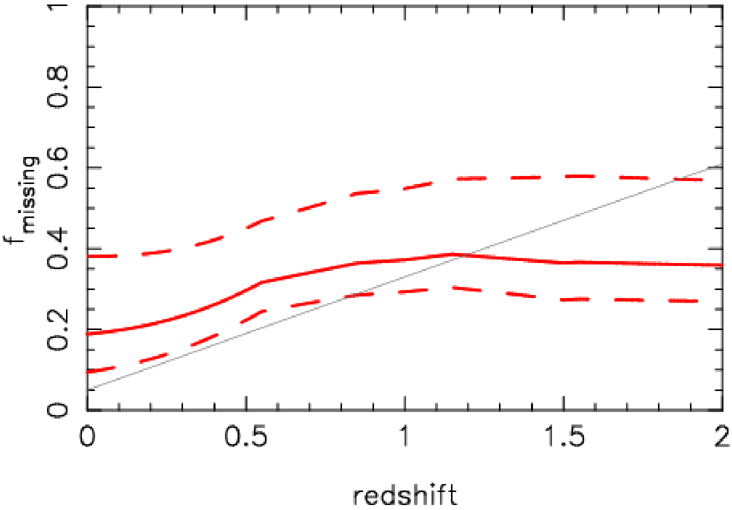
Radio SN searches more promising for yielding complete CCSN rates.

Obscuration is not an issue.

Survey commensalism

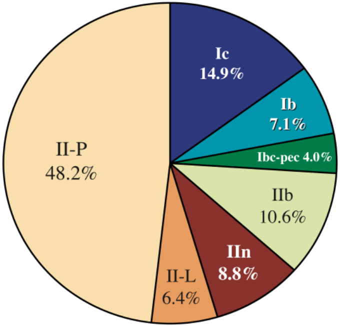
Planned radio surveys offer a free plate: VLASS, MeerKAT, SKA

Optical searches miss a significant fraction of CCSNe

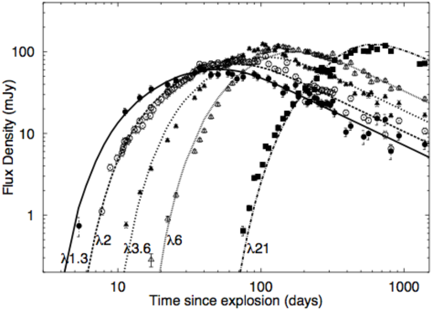


Mattila et al. (2012)

Synchotron radio emission from CCSNe



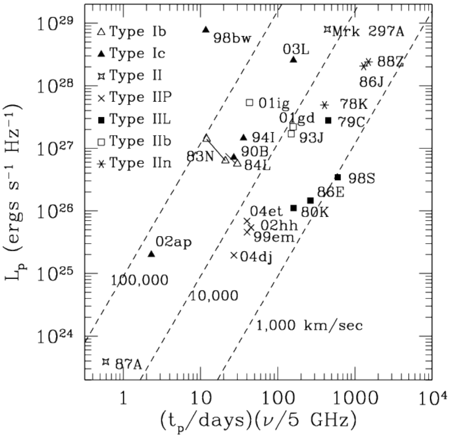
Smith et al. (2011)



Pérez-Torres et al. (2001)

- Supernovae evolve slowly at radio wavelengths
- Absorption delays the appearance of radio emission at low freqs

Peak luminosity vs. time to peak for CCSNe



Chevalier 2006

- All CCSNe are intrinsically radio emitters...
- ...but span more than five orders of magnitude in their radio peak luminosity
- $L_{\nu,\rm peak} \propto t_{\nu,\rm peak}$

CCSNe searches with the SKA and its pathfinders - **Why?**

Limited sensitivity and field of view of existing radio interferometers

- Observing bias towards brightest events
- No systematic radio follow-up of CCSNe
  (with the exception of nearby Type Ib/c SNe)
- → radio obs-ns of CCSNe are of limited use for characterizing CSM-shock interaction
- → prevents to type CCSNe from their radio light curves.
  (Important, as dust obscuration in the local universe prevents the detection of a significant fraction of CCSNe.)

Why commensal surveys?

It's a free plate! So the question is rather... why not?

CCSNe searches with the SKA? **How?**

CCSNe searches with the SKA? **How?**

SKA will allow for transient survey observations

BLINd Deep COmmensal Wide-field Surveys **(BLIND COWS)**

- BLINd - No bias introduced.
- Deep - Better sensitivity than any other radio facility.
- COmmensal - Uses data taken anyway by the array; doesn't harm
- Wide-field - Several thousand degrees' surveys.
- Survey Speed - Fast turnover for results.

BLIND COWS promises

- Unveiling the hidden CCSN population.
- Yielding the complete CCSN census in the local universe.
- → Massive SFR and CCSN rates.
- Obtain $\Re$, the volumetric CCSN rate in the local universe.
- Bridging the gap between Type Ibc SNe and (long) γ-ray bursts.
- Probing the SN-CSM interaction for all CCSNe types.
- Typing CCSNe from their radio behaviour.
- Correlating optical and radio properties.

BLIND COWS wish list

Wish list

- Sensitivity close to the μJy/b level
- Large instantaneous field of views
- Arcsecond (or sub-arcsec) angular resolution
- Frequencies around or above 1.5 GHz

SKA1-mid approaches those requirements

- Survey sensitivity of $\simeq 1.14\mu$Jy/b for 1-hr of on-source integration
- FoV $= 0.5$ deg^2
- Angular resolution of $\sim$0.3 arcsec
- Fiducial sensitivity of 1.7 GHz

Expectations from several commensal surveys

Table : Expectations for CCSN detections from commensal radio surveys for the VLASS, SKA1-MID, and SKA. (# CCSN/per year). $\mathrm{D}_{\max}$, in Mpc; $L_{\nu,26} = L_{\nu,\mathrm{peak}}/10^{26}$ erg/s/Hz; $\nu_5^{-1} = \nu/5$ GHz.

SN Type	$\Delta\, t_{\mathrm{peak}}\, \nu_5^{-1}$ [days]	$L_{\nu,26}$	VLASS		SKA1-MID		SKA	
			$\mathrm{D}_{\max}$	$\mathrm{N}_{\mathrm{det}}$	$\mathrm{D}_{\max}$	$\mathrm{N}_{\mathrm{det}}$	$\mathrm{D}_{\max}$	$\mathrm{N}_{\mathrm{det}}$
Ib/c	30	20	69	8	362	126	1145	3976
IIb, IIL	~150	10	49	1	256	21	422	654
IIP	40	0.5	11	0	57	1.1	94	33
IIn	1000	100	154	11	810	162	1334	5129
87A	2	0.04	3	0	16	0	27	0
Total				~20		~310		~ 9790

(For details, see Pérez-Torres et al. 2014, arXiv:1409.1827 and PT+2015 in "The Spanish SKA White Book").

Now compare SKA with ThunderKAT commensal

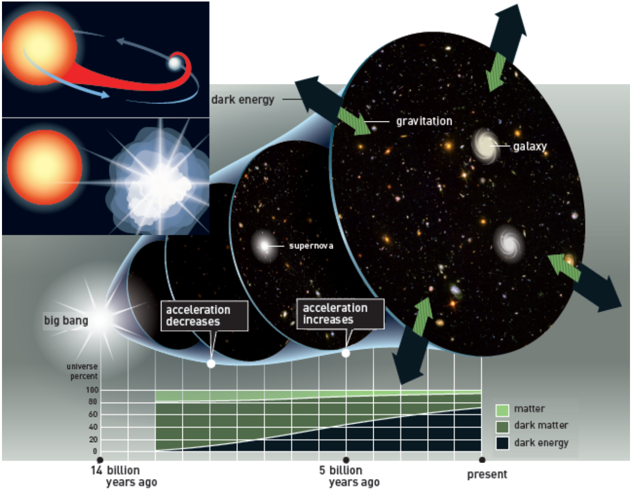
Table : Expectations for CCSN detections from commensal radio surveys for ThunderKAT, SKA1-MID, and SKA (# CCSN/per year).

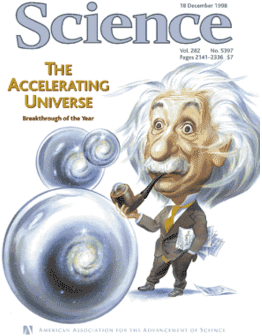
SN Type	$\Delta\ t_{\mathrm{peak}}\ \nu_5^{-1}$	$L_{\nu,26}$	ThunderKAT		SKA1-MID		SKA	
	[days]		$\mathrm{D}_{\mathrm{max}}$	$\mathrm{N}_{\mathrm{det}}$	$\mathrm{D}_{\mathrm{max}}$	$\mathrm{N}_{\mathrm{det}}$	$\mathrm{D}_{\mathrm{max}}$	$\mathrm{N}_{\mathrm{det}}$
Ib/c	30	20	218	10	362	126	1145	3976
IIb, IIL	∼150	10	155	2	256	21	422	654
IIP	40	0.5	35	0	57	1.1	94	33
IIn	1000	100	489	13	810	162	1334	5129
87A	2	0.04	10	0	16	0	27	0
Total				∼25		∼310		∼ 9790

CCSN commensalism: Bottom lines

- SKA to provide key science values in terms of CCSN rates, but still about 10 yr from real start
- ThunderKAT (365 sq. degrees per year) has similar expectations to the VLASS (10,000 sq. deg): 25 CCSNe after just one year.
- Requires ∼5 visits/yr, but requirement can be relaxed by implementing Martin's approach (get spectrum almost for free).
- Commensal use of other programmed surveys within MeerKAT will boost this number, so prospects are promising.
- Availability of simultaneous optical info (MeerLICHT) very useful.
- Main CAVEAT: the 4.7 arcsec angular resolution of MeerKAT can be an issue (source confusion and/or contamination from host galaxy)

SNe Ia and the accelerated expansion of the Universe





Science

18 December 1998

Vol. 282 No. 5397
Pages 2141–2336 $7

THE ACCELERATING UNIVERSE

Breakthrough of the Year

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

An uncomfortable truth

Type Ia SNe play a crucial role

- Primary cosmological distance indicators
- Major contributors to the chemical evolution of galaxies

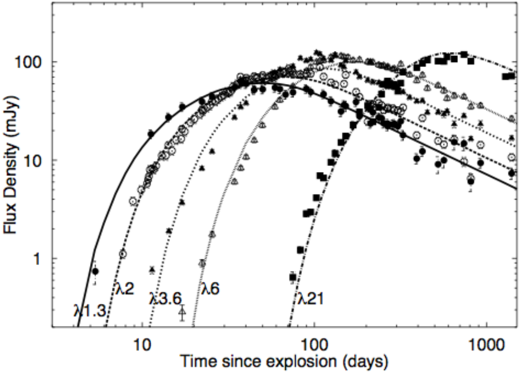
Yet we don't know what makes a Type Ia SN

- Plethora of Single Degenerate (SD) scenarios + DD scenario
- Observationally is tough to distinguish between them

Radio (and X-rays) is probably the most powerful observational tool

- SD $\Rightarrow$ measurable prompt radio emission
- DD $\Rightarrow$ no prompt radio

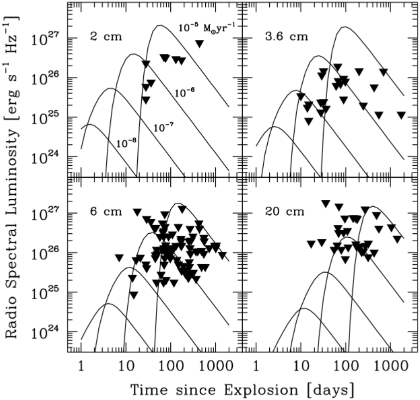
Radio luminosity traces the mass-loss rate of SNe



Radio luminosity traces the mass-loss rate of SNe

$$L_{\nu,\mathrm{thin}} \propto \left(\dot{M}/v_w\right)^{\omega}$$

Previous radio observations of SNe Ia



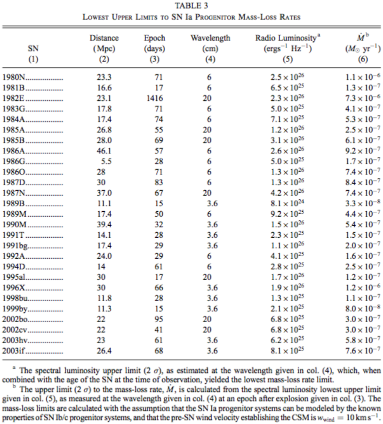


TABLE 3

LOWEST UPPER LIMITS TO SN Ia PROGENITOR MASS-LOSS RATES

SN (1)	Distance (Mpc) (2)	Epoch (days) (3)	Wavelength (cm) (4)	Radio Luminosity[a] (ergs^{-1} Hz^{-1}) (5)	$\dot{M}$[b] ($M_\odot$ yr^{-1}) (6)
1980N	23.3	71	6	2.5×10^{26}	1.1×10^{-6}
1981B	16.6	17	6	6.5×10^{25}	1.3×10^{-7}
1982E	23.1	1416	20	2.3×10^{26}	7.3×10^{-6}
1983G	17.8	71	6	5.0×10^{25}	4.1×10^{-7}
1984A	17.4	74	6	7.1×10^{25}	5.3×10^{-7}
1985A	26.8	55	20	1.2×10^{26}	2.5×10^{-7}
1985B	28.0	69	20	3.1×10^{26}	6.1×10^{-7}
1986A	46.1	57	6	2.6×10^{26}	9.2×10^{-7}
1986G	5.5	28	6	5.0×10^{25}	1.7×10^{-7}
1986O	28	71	6	1.3×10^{26}	7.4×10^{-7}
1987D	30	83	6	1.3×10^{26}	8.4×10^{-7}
1987N	37.0	67	20	4.2×10^{26}	7.4×10^{-7}
1989B	11.1	15	3.6	8.1×10^{24}	3.3×10^{-8}
1989M	17.4	50	6	9.2×10^{25}	4.4×10^{-7}
1990M	39.4	32	3.6	1.5×10^{26}	5.4×10^{-7}
1991T	14.1	28	3.6	2.3×10^{25}	1.5×10^{-7}
1991bg	17.4	29	3.6	1.1×10^{26}	2.0×10^{-7}
1992A	24.0	29	6	4.1×10^{25}	1.6×10^{-7}
1994D	14	61	6	2.8×10^{25}	2.5×10^{-7}
1995al	30	17	20	1.7×10^{26}	1.2×10^{-7}
1996X	30	66	3.6	1.9×10^{26}	1.2×10^{-6}
1998bu	11.8	28	3.6	1.3×10^{25}	1.1×10^{-7}
1999by	11.3	15	3.6	2.1×10^{25}	8.0×10^{-8}
2002bo	22	95	20	6.8×10^{25}	3.0×10^{-7}
2002cv	22	41	20	6.8×10^{25}	3.0×10^{-7}
2003hv	23	61	3.6	6.2×10^{25}	5.8×10^{-7}
2003if	26.4	68	3.6	8.1×10^{25}	7.6×10^{-7}

[a] The spectral luminosity upper limit (2 σ), as estimated at the wavelength given in col. (4), which, when combined with the age of the SN at the time of observation, yielded the lowest mass-loss rate limit.

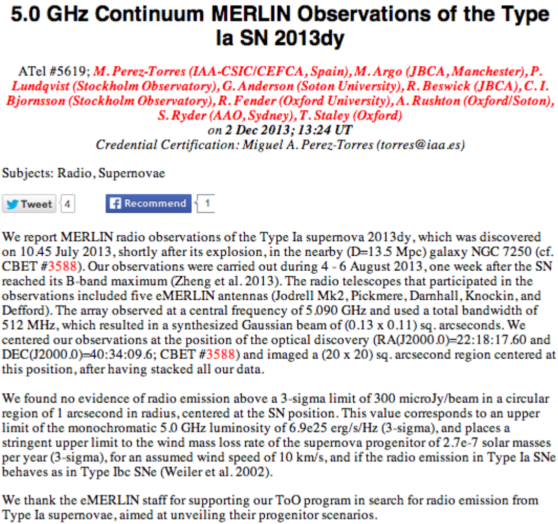
[b] The upper limit (2 σ) to the mass-loss rate, $\dot{M}$, is calculated from the spectral luminosity lowest upper limit given in col. (5), as measured at the wavelength given in col. (4) at an epoch after explosion given in col. (3). The mass-loss limits are calculated with the assumption that the SN Ia progenitor systems can be modeled by the known properties of SN Ib/c progenitor systems, and that the pre-SN wind velocity establishing the CSM is $w_{\rm wind} = 10$ km s^{-1}.

Panagia et al. (2006)

- Chevalier (1982) model + scaling of emission from SNe Ib/c

SN 1999by: $L_\nu \approx 2.0 \times 10^{25}$ erg s^{-1} Hz^{-1}; $\dot{M} \approx 1.2 \times 10^{-7}\,\mathrm{M_\odot\,yr^{-1}}$(3-$\sigma$)

Upper limits to the radio emission of SN 2013df



5.0 GHz Continuum MERLIN Observations of the Type Ia SN 2013dy

ATel #5619; ***M. Perez-Torres (IAA-CSIC/CEFCA, Spain), M. Argo (JBCA, Manchester), P. Lundqvist (Stockholm Observatory), G. Anderson (Soton University), R. Beswick (JBCA), C. I. Bjornsson (Stockholm Observatory), R. Fender (Oxford University), A. Rushton (Oxford/Soton), S. Ryder (AAO, Sydney), T. Staley (Oxford)***
*on **2 Dec 2013; 13:24 UT***
Credential Certification: Miguel A. Perez-Torres (torres@iaa.es)

Subjects: Radio, Supernovae

Tweet 4 Recommend 1

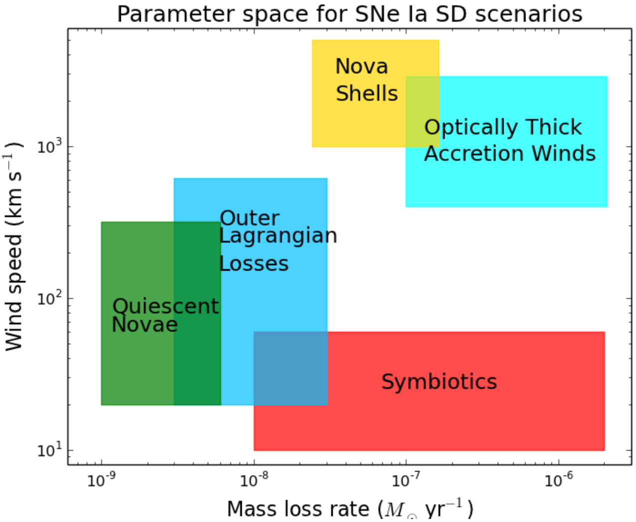
We report MERLIN radio observations of the Type Ia supernova 2013dy, which was discovered on 10.45 July 2013, shortly after its explosion, in the nearby (D=13.5 Mpc) galaxy NGC 7250 (cf. CBET #3588). Our observations were carried out during 4 - 6 August 2013, one week after the SN reached its B-band maximum (Zheng et al. 2013). The radio telescopes that participated in the observations included five eMERLIN antennas (Jodrell Mk2, Pickmere, Darnhall, Knockin, and Defford). The array observed at a central frequency of 5.090 GHz and used a total bandwidth of 512 MHz, which resulted in a synthesized Gaussian beam of (0.13 x 0.11) sq. arcseconds. We centered our observations at the position of the optical discovery (RA(J2000.0)=22:18:17.60 and DEC(J2000.0)=-40:34:09.6; CBET #3588) and imaged a (20 x 20) sq. arcsecond region centered at this position, after having stacked all our data.

We found no evidence of radio emission above a 3-sigma limit of 300 microJy/beam in a circular region of 1 arcsecond in radius, centered at the SN position. This value corresponds to an upper limit of the monochromatic 5.0 GHz luminosity of 6.9e25 erg/s/Hz (3-sigma), and places a stringent upper limit to the wind mass loss rate of the supernova progenitor of 2.7e-7 solar masses per year (3-sigma), for an assumed wind speed of 10 km/s, and if the radio emission in Type Ia SNe behaves as in Type Ibc SNe (Weiler et al. 2002).

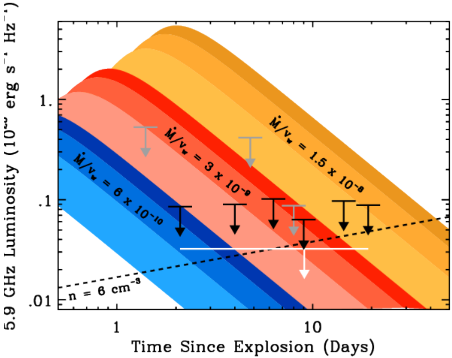
We thank the eMERLIN staff for supporting our ToO program in search for radio emission from Type Ia supernovae, aimed at unveiling their progenitor scenarios.

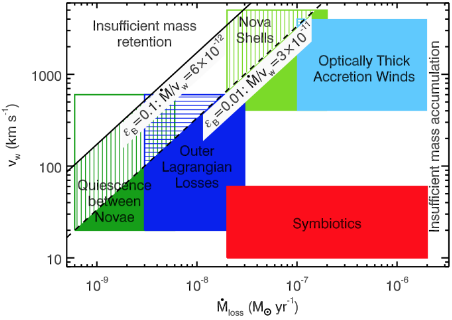
(Pérez-Torres et al. 2013, ATel No. 5619)

Mass-loss rate – wind-speed parameter space for SNe



Radio obs-ns of SN 2011fe (Chomiuk+12, Horesh+12)



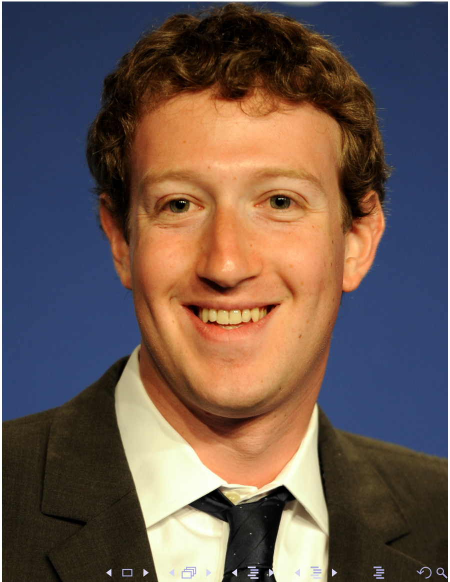


- $L_\nu \lesssim 8.0 \times 10^{23}$ erg s^{-1} Hz^{-1}(@ 2 days; early obs-ns are crucial)
- $\dot{M} \lesssim 7 \times 10^{-10}\,\mathrm{M_\odot\,yr^{-1}}$(3-$\sigma$)
- Most SD scenarios ruled out for SN 2011fe

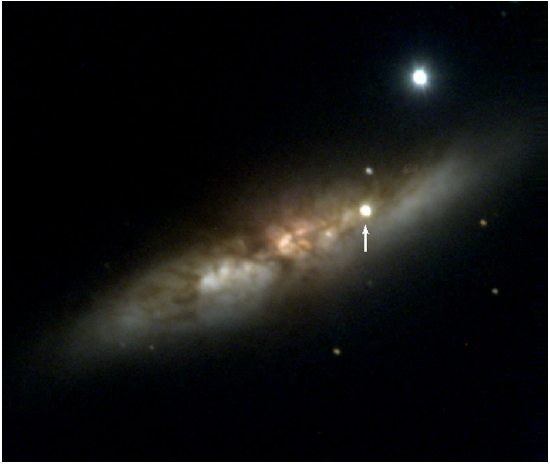
I hate to say this, but...

I hate to say this, but...

...Thanks, Mr. Zuckerberg

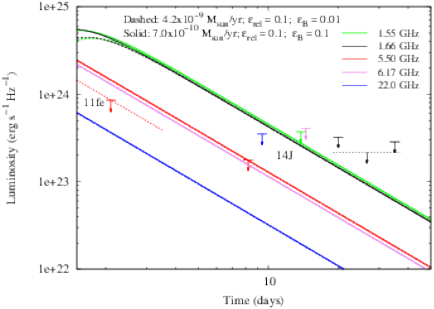


The Type Ia SN 2014J in M 82 (D = 3.5 Mpc)



Serendipitous discovery by Fossey et al. (2014)
Images by Itagaki $\Rightarrow t_{\mathrm{expl}} \approx 15.0$ Jan 2014

Radio obs-ns of SN 2014J - CSM wind constraints



Starting UT	T day	$t_{\rm int}$ hours	Array	ν GHz	S_ν μJy	$L_{\nu,22}$	$\dot{M}_{-9}$
Jan 23.2	8.2	–	JVLA	5.50	4.0	5.9	0.70
Jan 24.4	9.4	–	JVLA	22.0	8.0	11.7	3.7
Jan 28.8	13.8	13.6	eMERLIN	1.55	12.4	18.2	0.85
Jan 29.5	14.5	14.0	eMERLIN	6.17	13.6	19.9	2.7
Feb 4.0	20.0	11.0	eEVN	1.66	10.8	15.8	1.3
Feb 19.1	35.0	10.0	eEVN	1.66	9.5	13.9	2.2

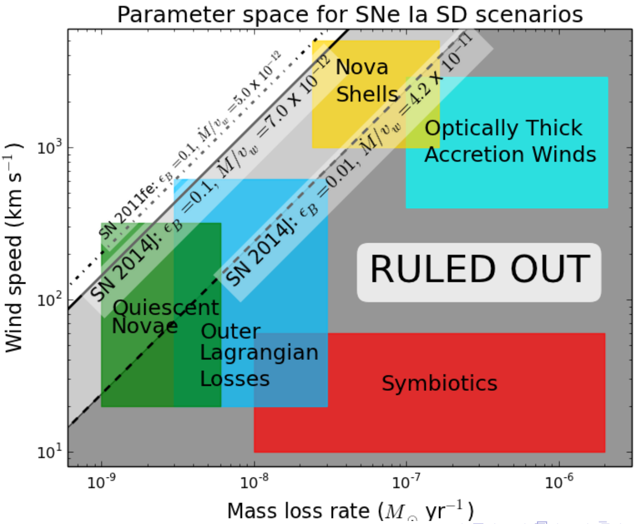
Pérez-Torres et al. (2014)

Most constraining upper limits to radio emission of SNe Ia together with those on SN2011fe

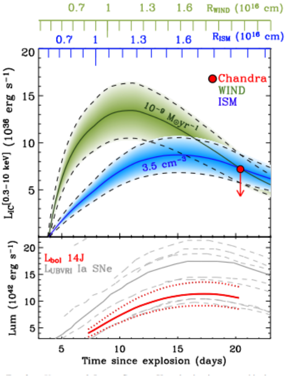
- $L_\nu \lesssim 2 \times 10^{23}$ erg s^{-1} Hz^{-1}; $\dot{M} \lesssim 7.0 \times 10^{-10}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$(3-$\sigma$)

Constraints on the progenitor system of SN 2014J

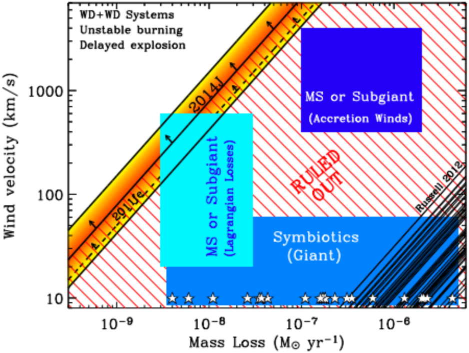
Pérez-Torres, Lundqvist et al. (2014)



Constraints from X-ray observations



Lack of X-rays from SN 2014J



$L_X \lesssim 7\times10^{36}$ erg s^{-1}; $\dot{M} \approx 3.6\times10^{-9}\,\mathrm{M_\odot\,yr^{-1}}$(3-$\sigma$), for $v_w = 100$ km s^{-1}(Margutti et al. 2014)

A promising future

JVLA

Upper limit of SN 2011fe/SN 2014J at 6 GHz was ∼6 μJy (1-σ)
Angular resolution heavily depends on EVLA configuration

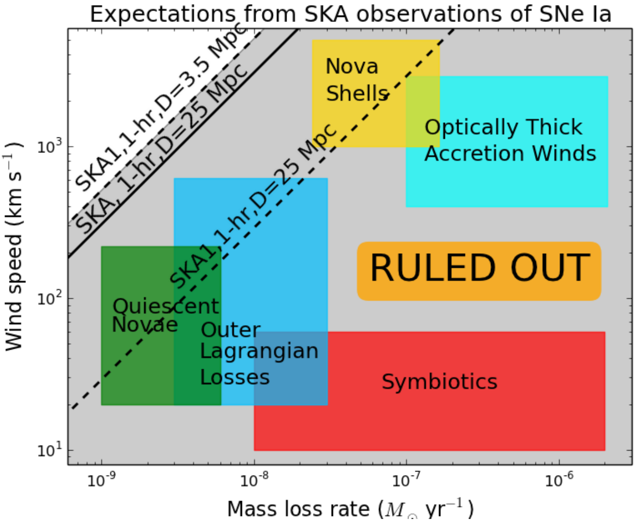
eMERLIN/EVN

Upper limit (1-σ) of SN 2014J was ∼10 μJy (1.7/5.0 GHz) Angular resolutions in the 20 mas to 150 mas range

SKA-mid promises to yield ∼700 nJy in 1-hr

- 350-1400 MHz; angular resolutions $\sim 0.3''$
- ⇒ Probe similar limits as for SN2011fe/SN2014J out to ∼20 Mpc (typically 1 SNe Ia/yr)
- ⇒ If at same distance as SN 2014J/SN2011fe: test all possible progenitor scenarios.

A promising future



What about ThunderKAT?

ThunderKAT

It's expected to yield similar constraints to that obtained for SN 2011fe/SN 2014J.

- Angular resolution doesn't depend on configuration
- Very useful to constrain SN Ia progenitors out to a distance of $\sim$ 25-30 Mpc
- CAVEAT No. 1: Host galaxy contamination
- Source confusion not an issue?