Electromagnetic observations of supernovae for gravitational wave searches

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SN2025gw: First IGWN Symposium on Core Collapse Supernova Gravitational Wave Theory and Detection, Warsaw, Poland, 21-25 July 2025

Core collapse supernovae (CCSNe) closer than 40 Mpc: candidate targets for gravitational wave (GW) searches

LVK observations exploring CCSN population, type Ib/Ic/II occurring during first three runs

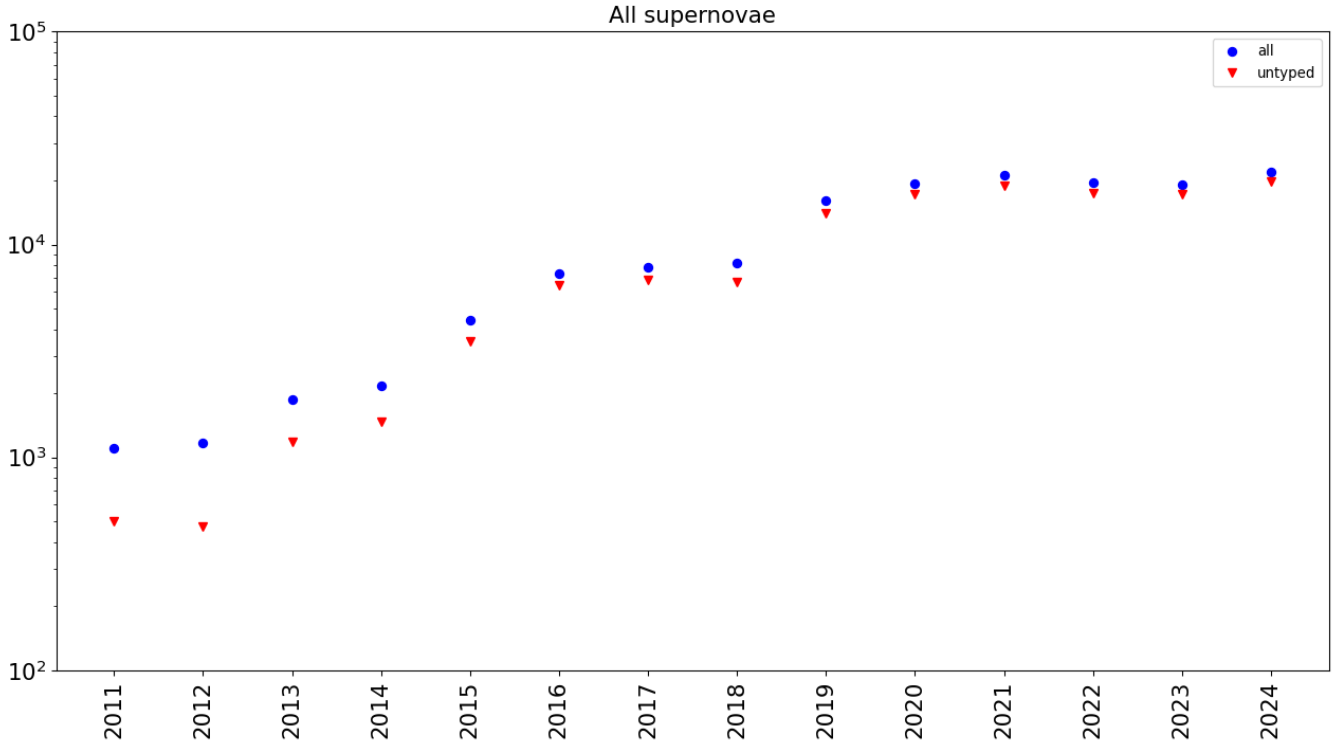
EM observations of CCSNe:

- Precise sky localization, extensive monitoring by astronomical community, including all sky surveys
- Information about explosion mechanisms
- Triggering searches for the associated GW emission
- Multiband photometric light curves constrain time interval for GW searches

Issues:

- Estimate of progenitor mass
- Distance of host galaxies
- CCSN with peculiar evolution

Supernovae: basic stats from https://www.rochesterastronomy.org/supernova.html



Impact of recent all sky surveys on number of discoveries

Majority of supernovae not classified

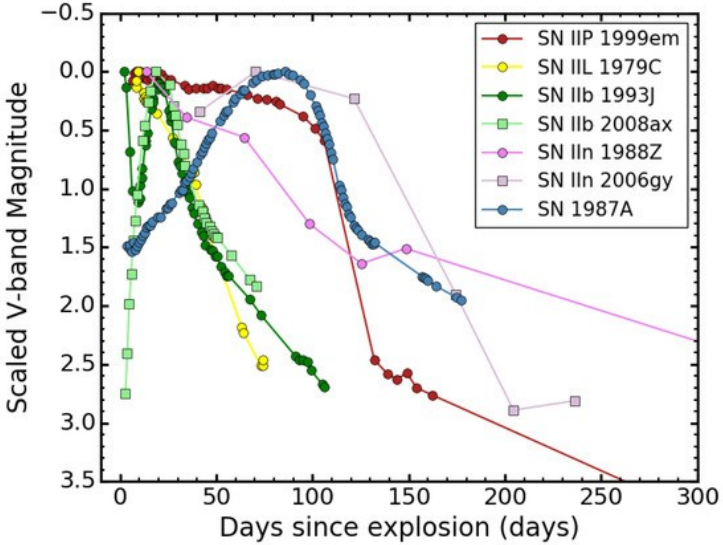
Discovery in photometric observations: limiting magnitude of telescopes

Survey	Band	Limiting magnitude
ASASS-N	V	17-18
ATLAS	o	19-20
DLT40	r	19-20
Gaia	G	~ 21
GOTO	L	~ 20
ZTF	g	~ 21

Impact on definition of the last non detection and the first detection

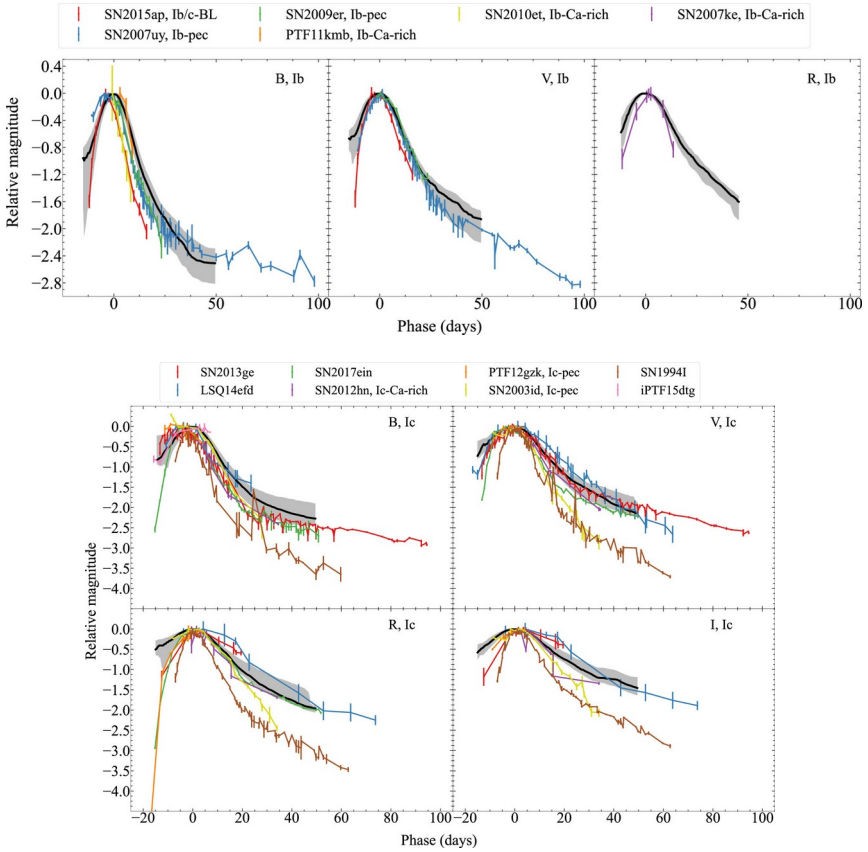
Impact of photometric error

Type II, Ib/c supernovae light curves



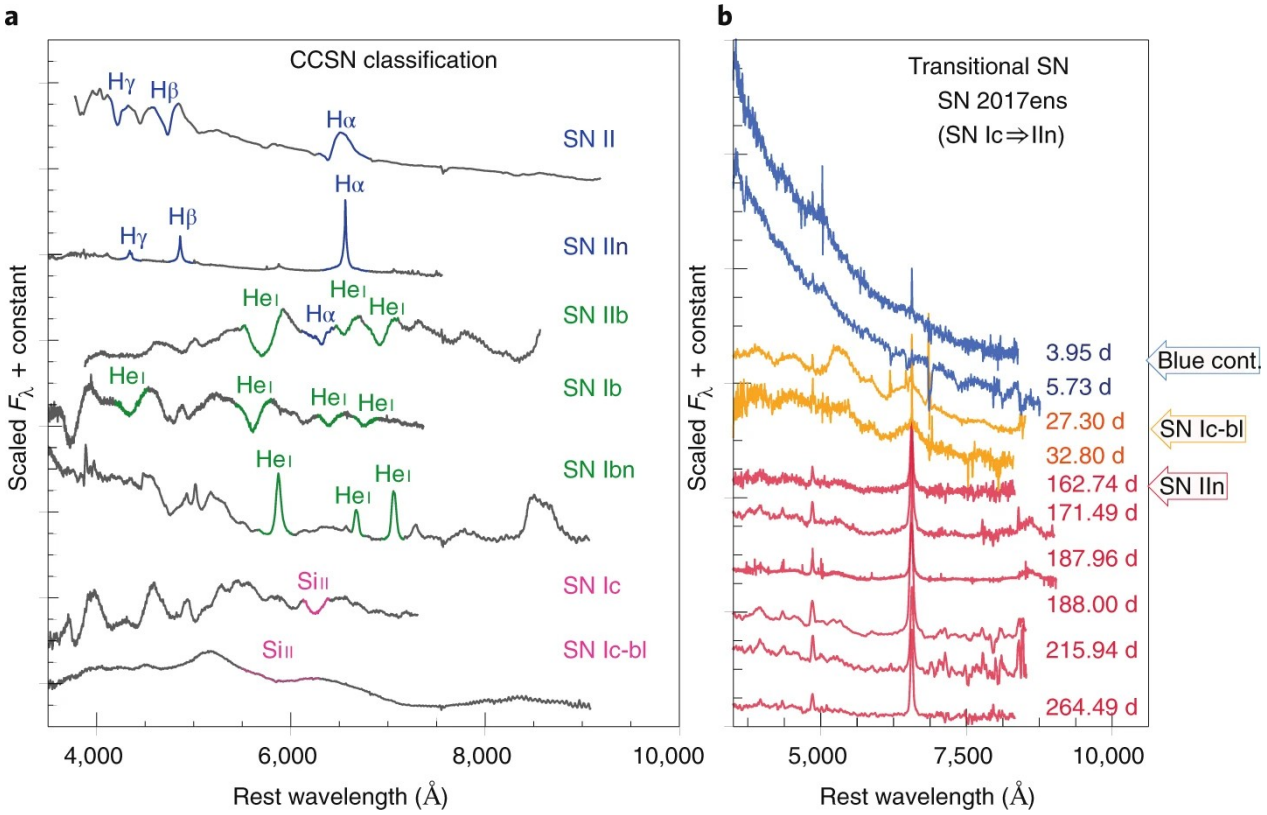
Lin+ 2023

Universality of shape up to the peak



Kakhpash+ 2024

Optical spectroscopy



Modjaz+ 2019

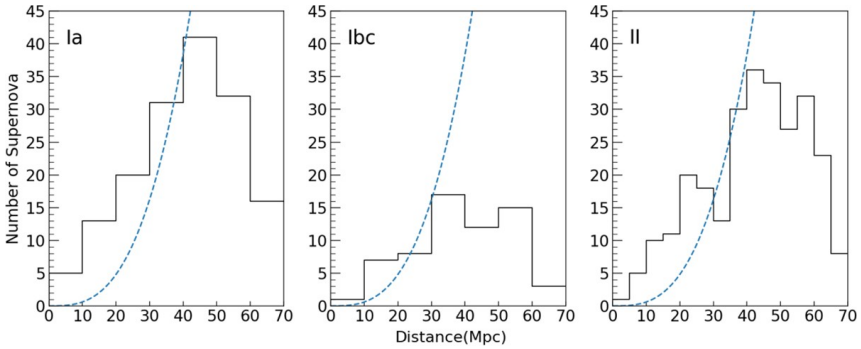
Key for classification

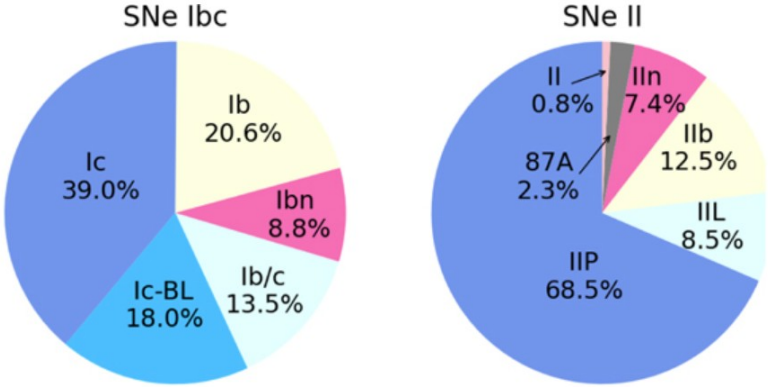
Evolution, interaction with environment….

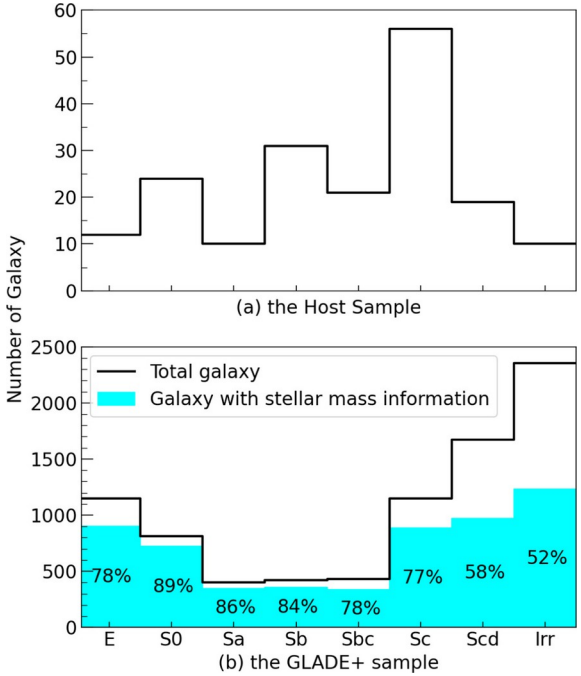
Statistics of close CCSNe (< 40 Mpc)

Ma+ A&A, 698, A305 (2025): supernova sample closer than 40 Mpc observed by wide field surveys from 2016 to 2023. Total: 211 SNe, including 109 SNe II, 33 SNe Ib/c, 69 SNe Ia

Volume limited sample corrected for Malmquist bias







Light curves and targeted GW searches

Gill+ 2022: optical observations to increase search sensitivity by narrowing relevant time interval, critical for the false alarm probability

Search window: $t_1 - t_2$

$t_1 = t_{nd} - \Delta t_{SB}$ $t_2 = t_{fd}$

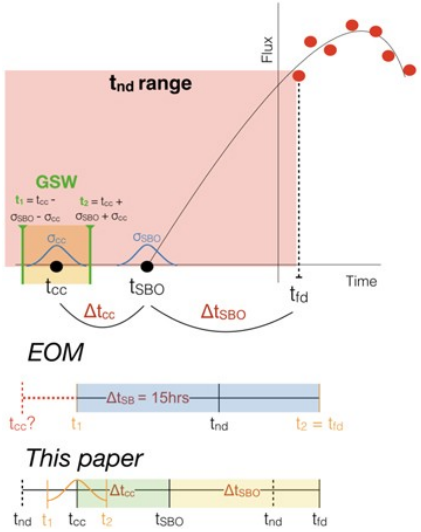
t_{fd} : time of first optical detection
t_{nd} : time of the last non detection
Δt_{SB} : shock propagation travel time between core collapse and SBO

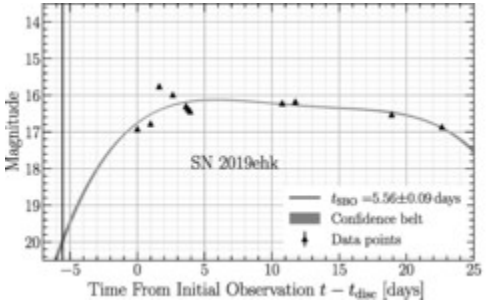
Details in Zanolin's talk

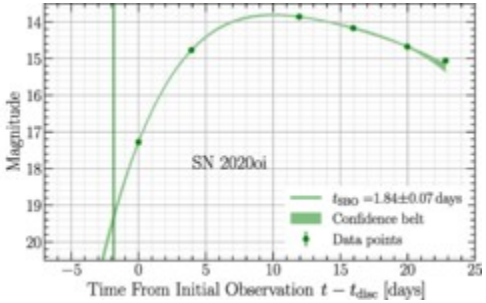
Early observations vs light curve interpolation
Good photometric coverage essential

O1, O2 LVK search (Abbott+ 2020)

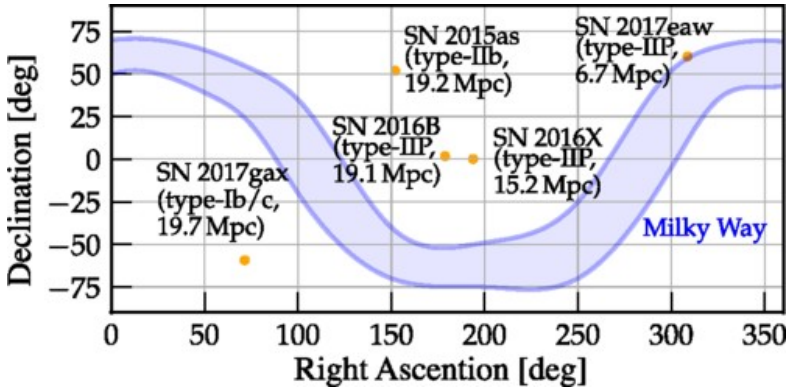
O3 search (Szczepańczyk+ 2024)







CCSNe during O1, O2 runs

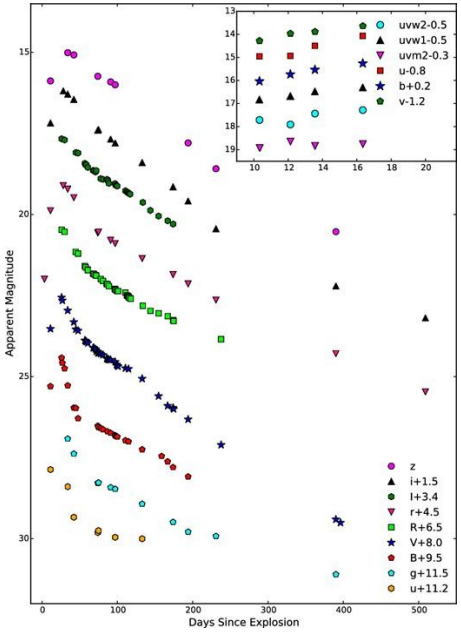


Supernova	Type	Host galaxy	Distance (Mpc)	t_1 (UTC)	t_2 (UTC)	Δt (days)	OSW method	Run	Active detectors	Coincident coverage (%)
SN 2015as	IIb	UGC 5460	19.2	Nov. 2015 14.77	Nov. 2015 16.23	1.47	Early	O1	H1,L1	34.2
SN 2016B	IIP	PGC 037392	19.1	Dec. 2015 23.51	Dec. 2015 27.55	4.03	Early	O1	H1,L1	34.3
SN 2016X	IIP	UGC 08041	15.2	Jan. 2016 17.72	Jan. 2016 20.56	2.86	Early	O1	H1,L1	14.4
SN 2017eaw	IIP	NGC 6946	6.72	Apr. 2017 26.56	Apr. 2017 27.96	1.39	EPM	O2	H1,L1	48.8
SN 2017gax	Ib/c	NGC 1672	19.7	Aug. 2017 14.28	Aug. 2017 16.15	1.66	Early	O2	H1,L1, V1	61.5 (H1L1) 60.8 (H1L1V1)

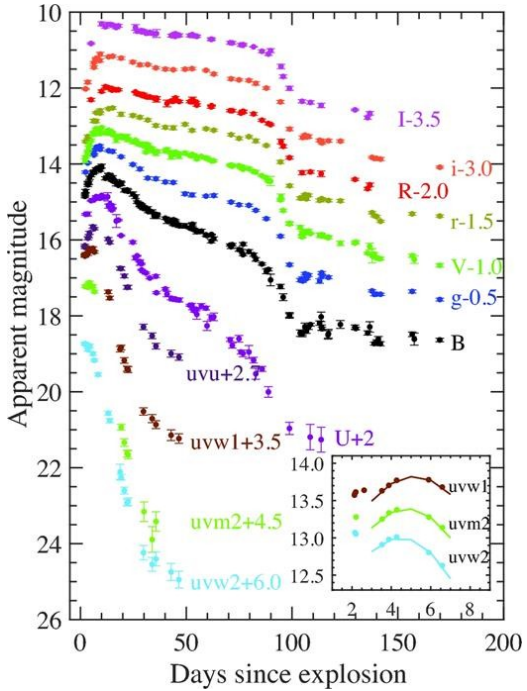
LVK, PRD 101 (2020) 084002

CCSNe during O1, O2 runs

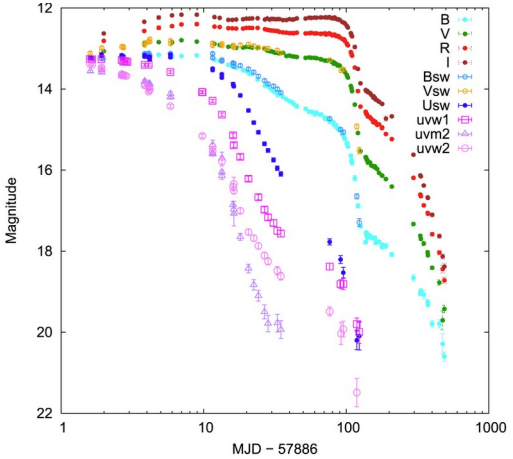
SN 2015as, Gangopadhyay+ 2018



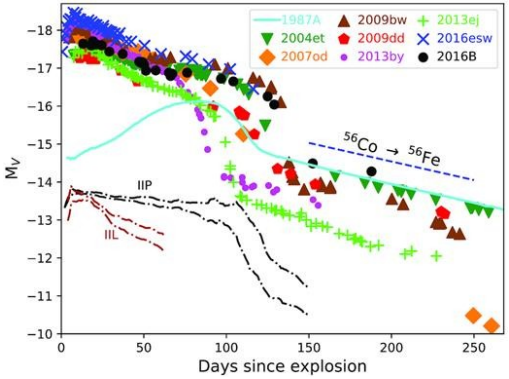
SN 2016X, Huang+ 2018



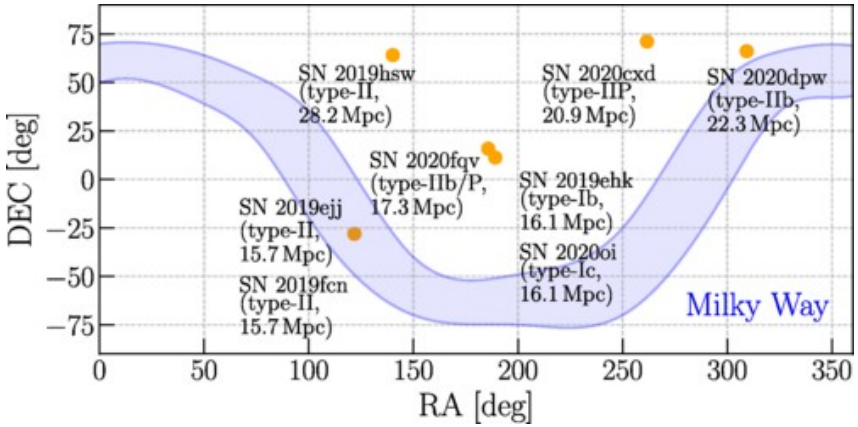
SN 2017eaw, Szalai+ 2019



SN 2016B, Dastidar+ 2019



CCSNe during O3

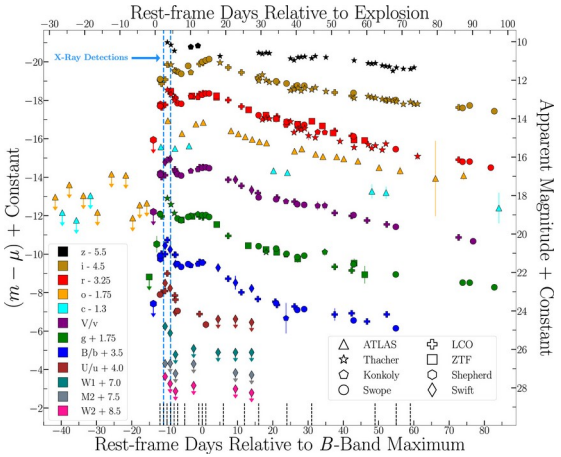


Supernova	Type	Host galaxy	Distance [Mpc]	t_1 [UTC]	t_2 [UTC]	Δt [days]	OSW method	T_{coinc} [days]
SN 2019ehk	IIb	NGC 4321	16.1	2019 Apr 23.10	2019 Apr 24.50	1.40	2	0.41 (29%)
SN 2019ejj	II	ESO 430-G20	15.7	2019 Apr 23.28	2019 Apr 30.86	7.58	3	1.25 (16%)
SN 2019fcn	II	ESO 430-G20	15.7	2019 May 03.02	2019 May 07.56	4.54	3	2.51 (55%)
SN 2019hsw	II	NGC 2805	28.2	2019 Jun 05.14	2019 Jun 13.14	8.00	1	5.08 (64%)
SN 2020oi	Ic	NGC 4321	16.1	2020 Jan 02.48	2020 Jan 06.18	3.70	2	2.56 (69%)
SN 2020cxd	IIP	NGC 6395	20.9	2020 Feb 16.53	2020 Feb 22.53	6.00	1	4.58 (76%)
SN 2020dpw	IIP	NGC 6952	22.3	2020 Feb 21.08	2020 Feb 25.08	4.00	1	3.06 (77%)
SN 2020fqv	IIb	NGC 4568	17.3	2020 Mar 22.00	2020 Mar 28.00	6.00	1	4.06 (68%)

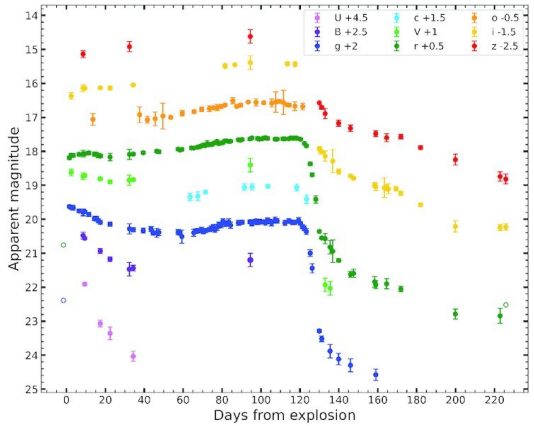
Szczepańczyk+, PRD 110 (2024) 042007

CCSNe during O3

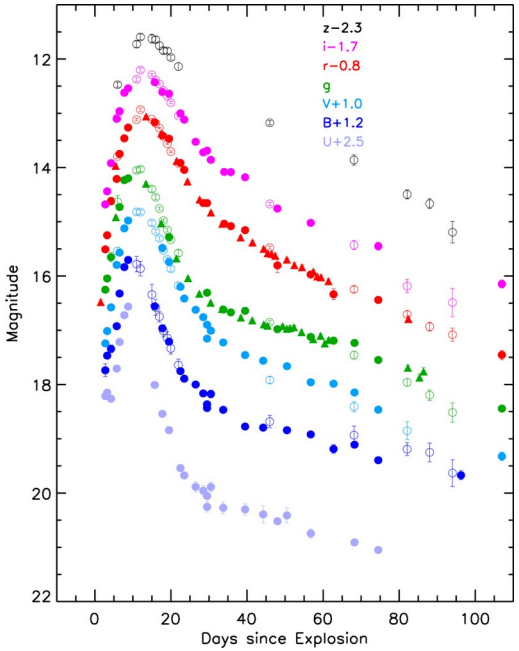
SN 2019ehk, Jacobson-Galan 2020



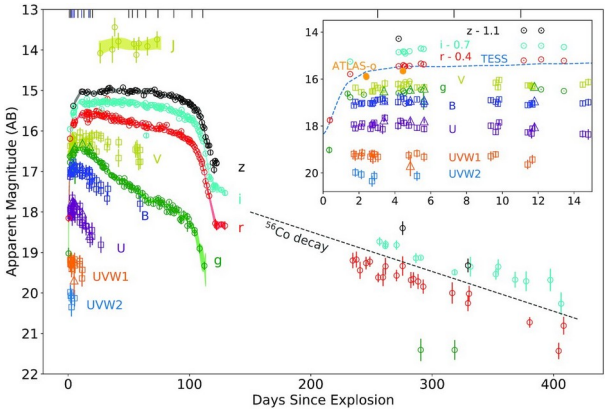
SN 2020cxd, Valerin+ 2021



SN 2020oi, Rho+ 2021



SN 2020fqv, Tinyanont+ 2022



CCSNe during ER15/O4a (within 40 Mpc)

Run	Name	Discovery	Host	Type	Discoverer
ER15	SN 2023ixf	2023-05-19	M101	II	Itagaki
O4a	SN 2023mut	2023-07-11	UGC 03174	IIb	ASAS-SN
O4a	SN 2023mpz	2023-07-09	GALEXASC J202049.64+092955.3	II	ALeRCE
O4a	SN 2023fyq	2023-04-17	NGC 4388	Ib-pec	ZTF
O4a	SN 2023rve	2023-09-08	NGC 1097	II	Odeh
O4a	SN 2023usp	2023-10-12	NGC 2848	II	ATLAS
O4a	SN 2023zcu	2023-12-08	NGC 2139	II	ATLAS
O4a	SN 2023zdx	2023-12-08	NGC 5630	IIp	ATLAS
O4a	SN 2023abdg	2023-12-24	NGC 7421	II	ATLAS
O4a	SN 2023wcr	2023-10-31	NGC4346	II	Itagaki
O4a	SN 2023rkg	2023-08-12	WISEA J214934.34 - 220718.2	Ib	ZTF

CCSNe during ER16/O4b (within 40 Mpc) I

Run	Name	Discovery	Host	Type	Discoverer
ER16	SN 2024ggi	2024-04-11	NGC 3621	II	ATLAS
O4b	SN 2024iss	2024-05-12	LEDA 1846725	II	GOTO
O4b	SN 2024jlf	2024-05-28	NGC 5690	II	ZTF
O4b	SN 2024phz	2024-07-11	NGC 4330	II	ATLAS
O4b	SN 2024phv	2024-07-10	NGC 3936	II	DLT40
O4b	SN 2024pxg	2024-07-23	NGC 6221	II	DLT40
O4b	SN 2024qvh	2024-08-01	NGC 2139	II	GOTO
O4b	SN 2024uwq	2024-09-07	NGC 6902	IIb	ATLAS
O4b	SN 2024abbv	2024-11-13	UGCA 006	II	ATLAS

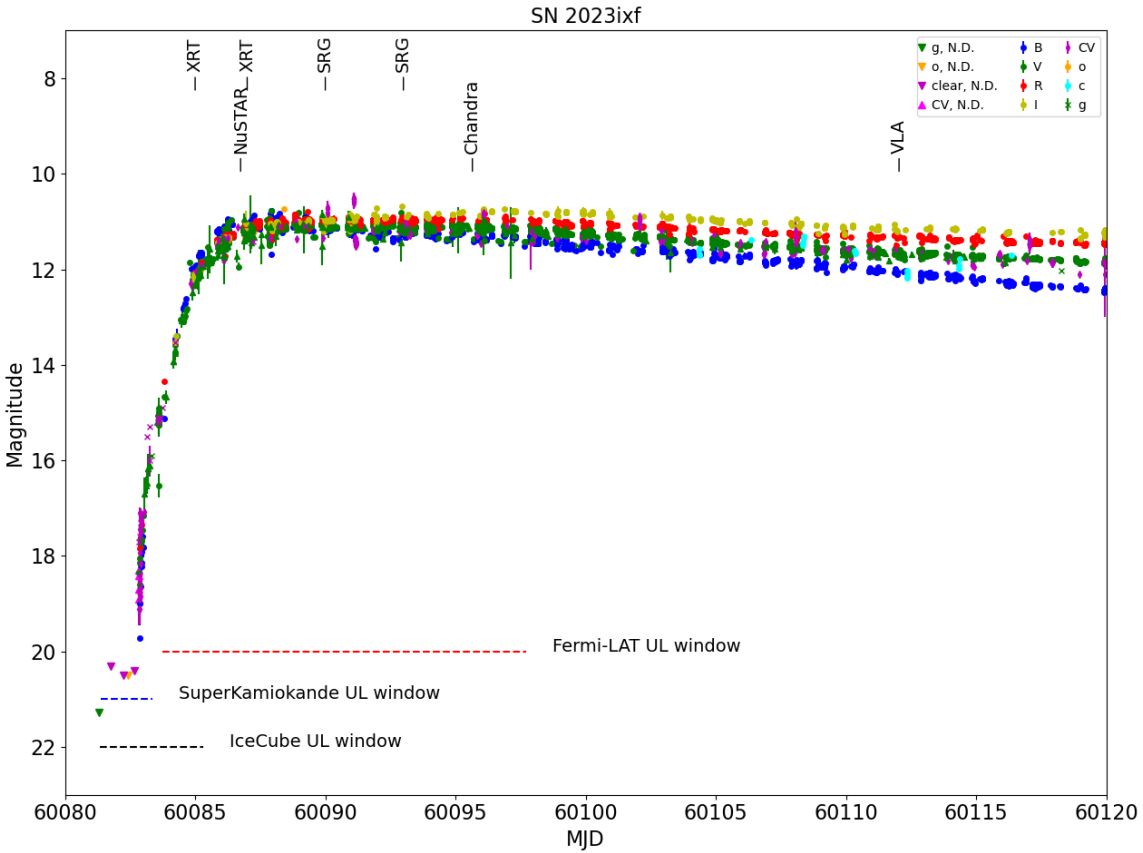
CCSNe during ER16/O4b (within 40 Mpc) II

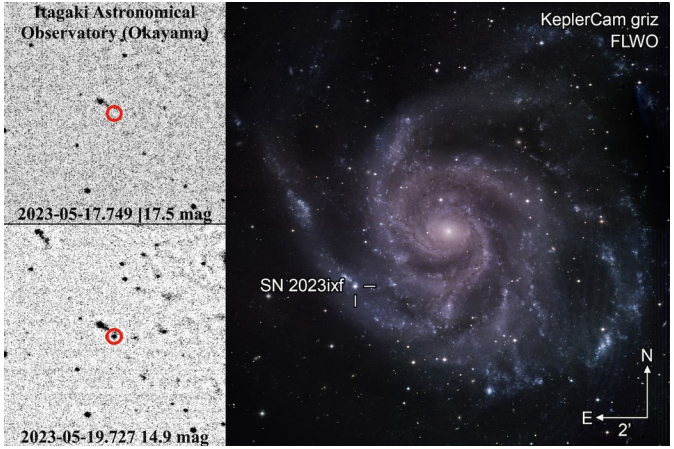
Run	Name	Discovery	Host	Type	Discoverer
O4b	SN 2024abfo	2024-11-15	NGC 1493	II	ATLAS
O4b	SN 2024abfl	2024-11-15	NGC 2146	II	Itagaki
O4b	SN 2024abup	2024-11-22	NGC 681	Ic-BL	ATLAS
O4b	SN 2024ablh	2024-11-18	NGC 4722	II	ZTF
O4b	SN 2024aecx	2024-12-16	NGC 3521	Ic	ATLAS
O4b	SN 2024xuo	2024-10-11	IC 2554	IIn	ATLAS
O4b	SN 2025bl	2025-01-04	Faint host	II	ATLAS
O4b	SN 2025kq	2025-01-12	UGC 10892	II	GOTO

Type Ib/Ic/II supernovae in O4a, O4b

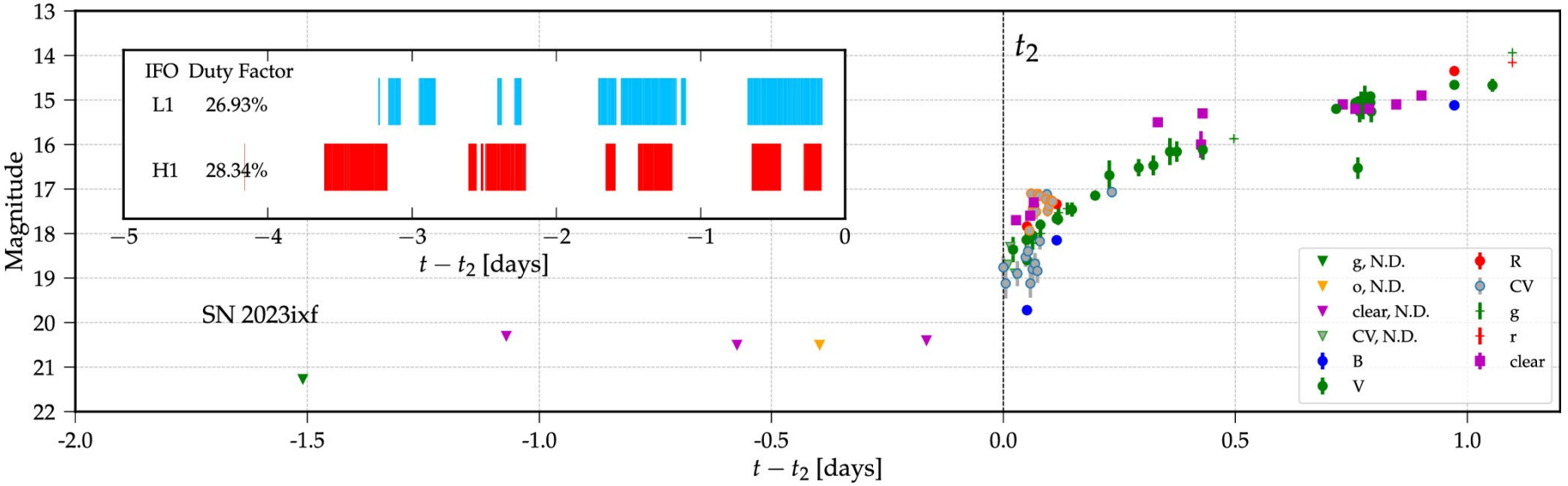
Photometric coverage variable

SN 2023ixf: a multi-messenger target

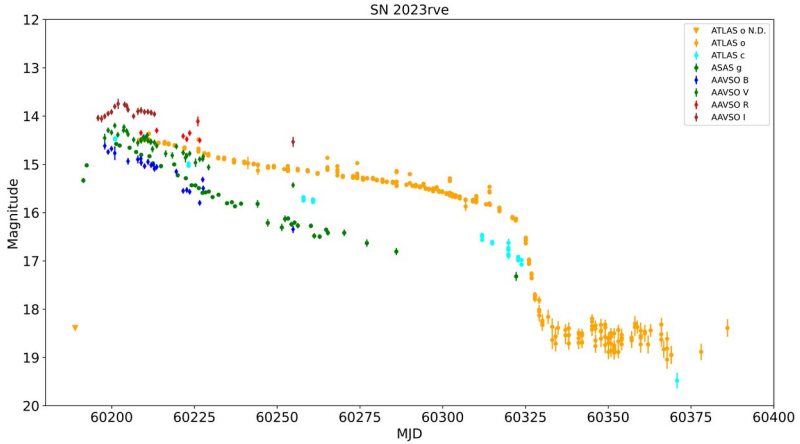


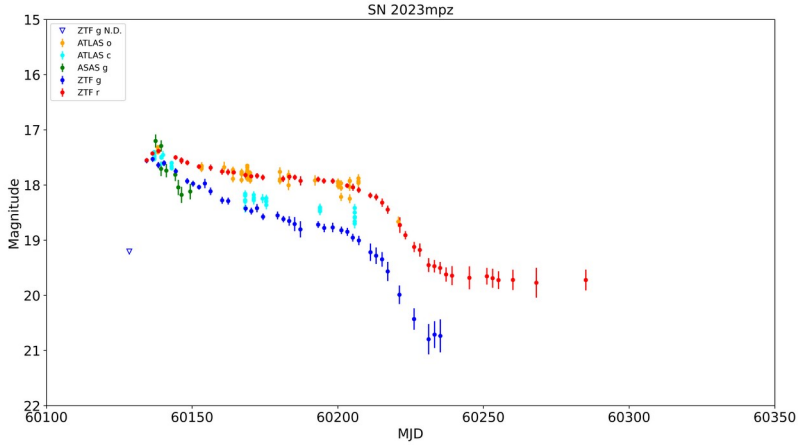


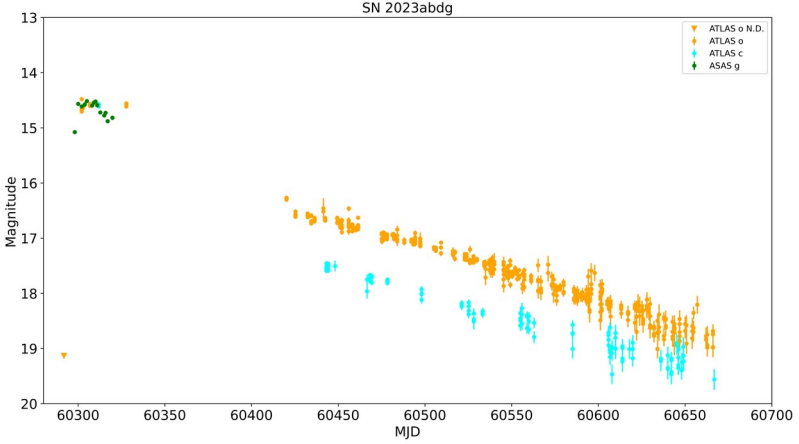
SN 2023ixf GW search window

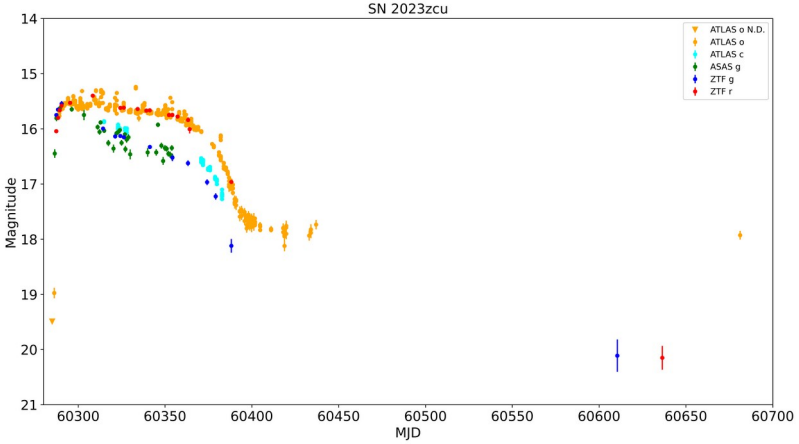


Abac+, ApJ 985 (2025) 183

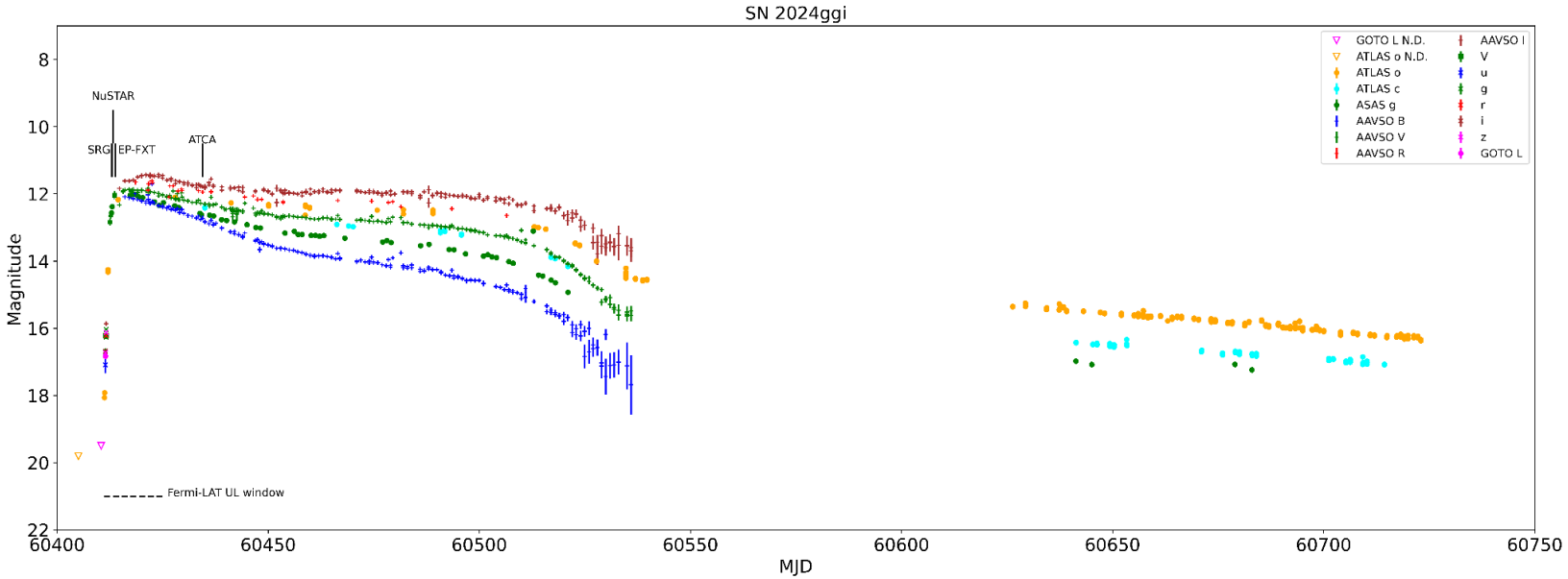

SN 2023rve
ATLAS o N.D.
ATLAS o
ATLAS c
ASAS g
AAVSO B
AAVSO V
AAVSO R
AAVSO I
Magnitude
MJD


SN 2023mpz
ZTF g N.D.
ATLAS o
ATLAS c
ASAS g
ZTF g
ZTF r
Magnitude
MJD


SN 2023abdg
ATLAS o N.D.
ATLAS o
ATLAS c
ASAS g
Magnitude
MJD

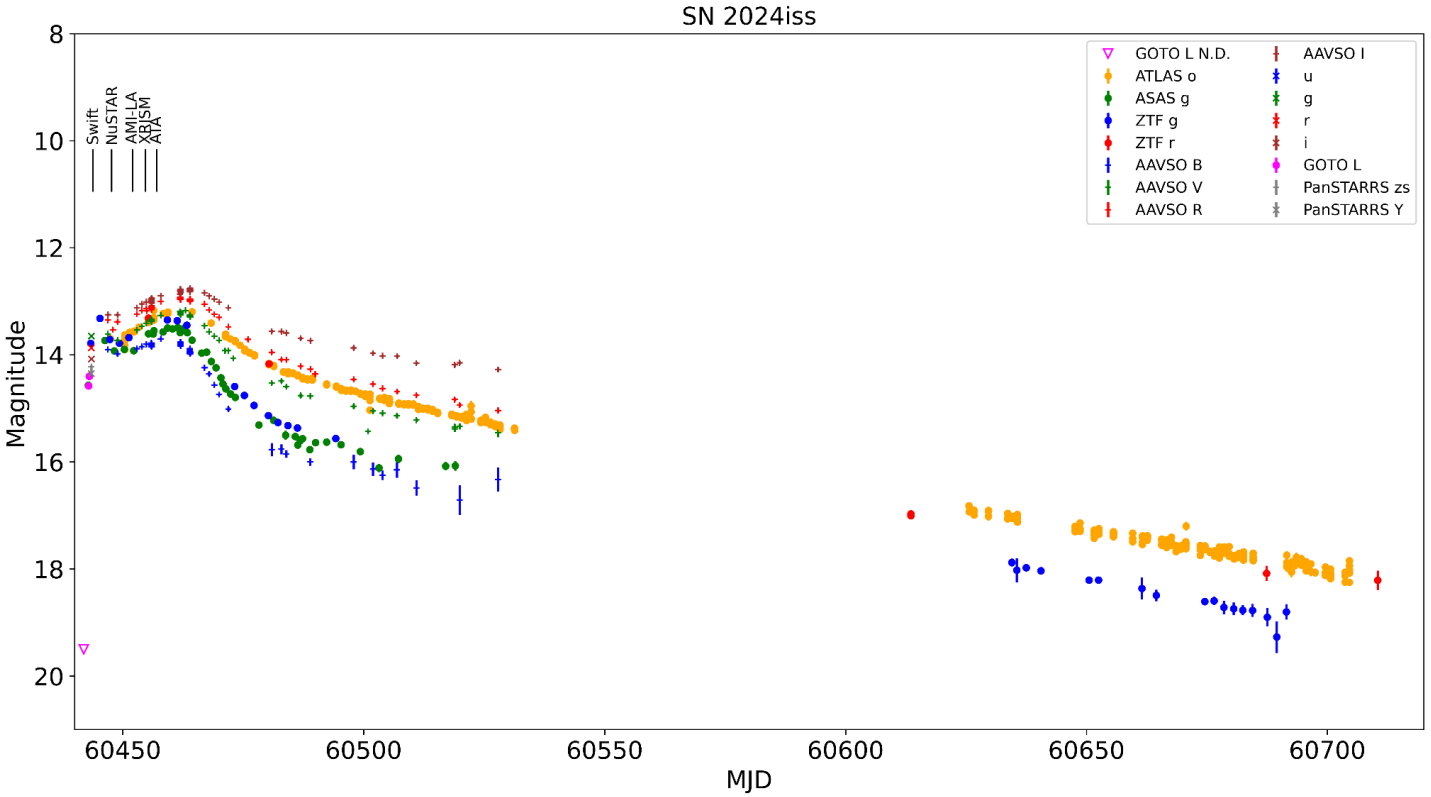

SN 2023zcu
ATLAS o N.D.
ATLAS o
ATLAS c
ASAS g
ZTF g
ZTF r
Magnitude
MJD

SN 2024ggi



Photometric and spectroscopic evolution similar to SN 2023ixf

SN 2024iss


SN 2024iss
Magnitude
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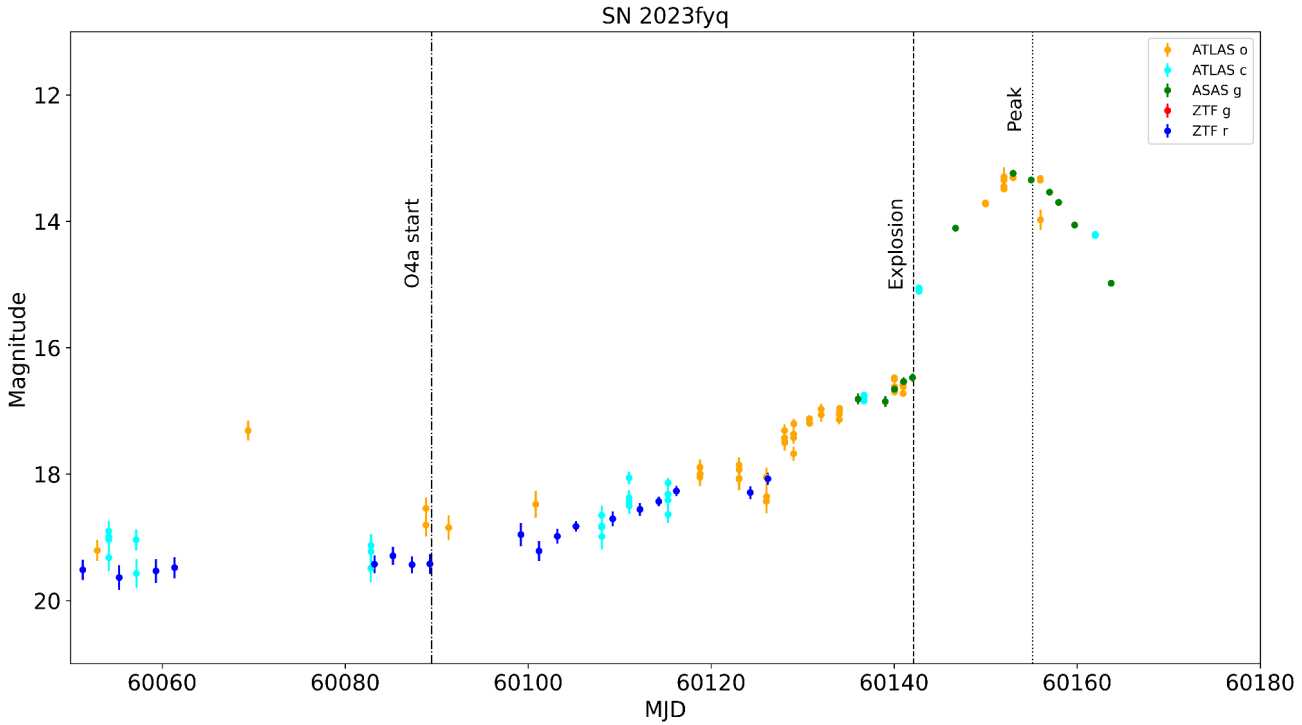
16
18
20
60450
60500
60550
60600
60650
60700
Swift
NuSTAR
AMI-LA
ATCA
ATA
GOTO L N.D.
ATLAS o
ASAS g
ZTF g
ZTF r
AAVSO B
AAVSO V
AAVSO R
AAVSO I
u
g
r
i
GOTO L
PanSTARRS zs
PanSTARRS Y

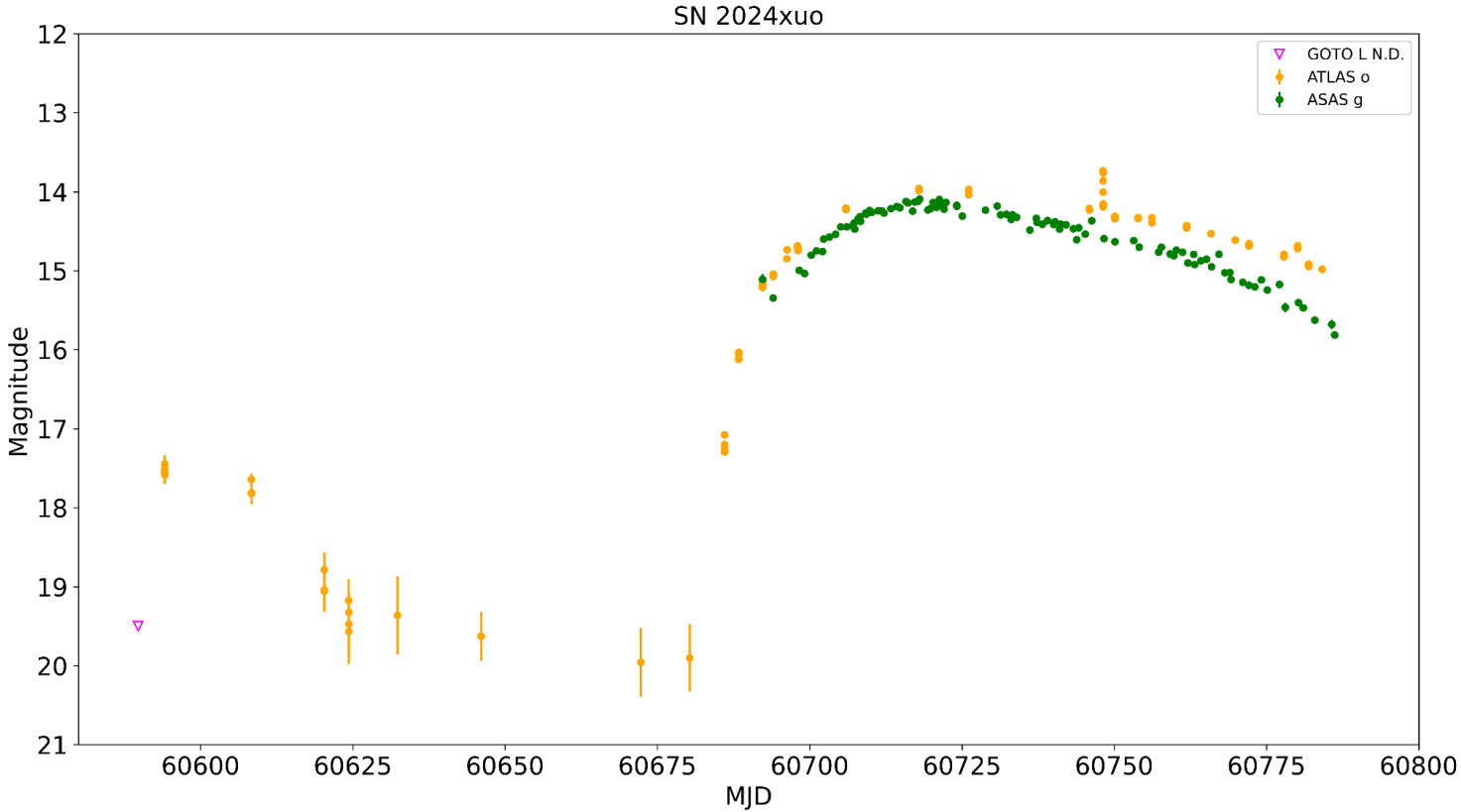
SN 2023fyq



Explosion and peak dates from A&A, 684, L18 (2024), reporting progenitor activity before type Ibn explosion

Impact of evolution previous to rise to maximum?

SN 2024xuo


SN 2024xuo
GOTO L N.D.
ATLAS o
ASAS g
Magnitude
MJD
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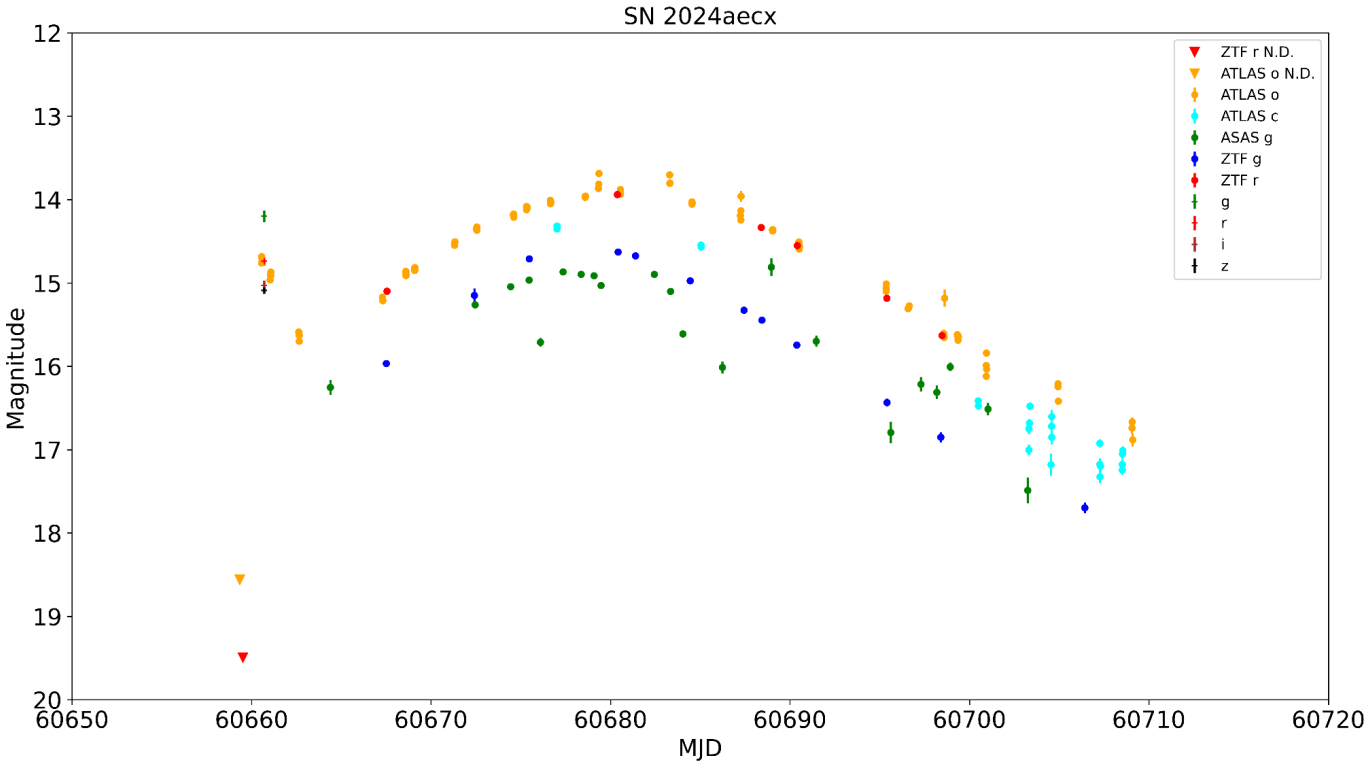
21
60600
60625
60650
60675
60700
60725
60750
60775
60800

SN 2024aecx


SN 2024aecx
Magnitude
MJD
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60690
60700
60710
60720
ZTF r N.D.
ATLAS o N.D.
ATLAS o
ATLAS c
ASAS g
ZTF g
ZTF r
g
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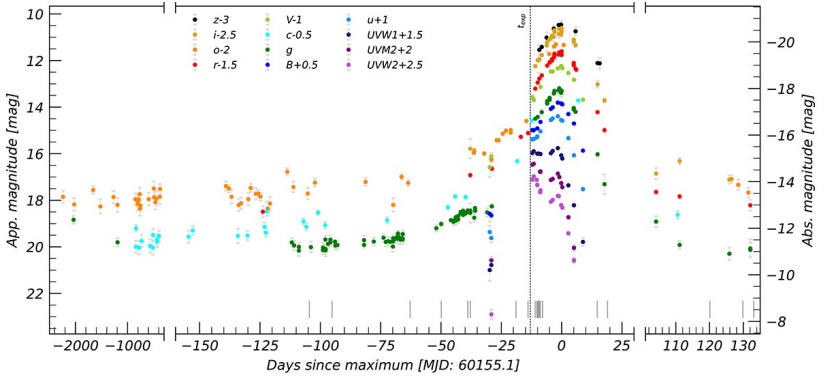
i
z

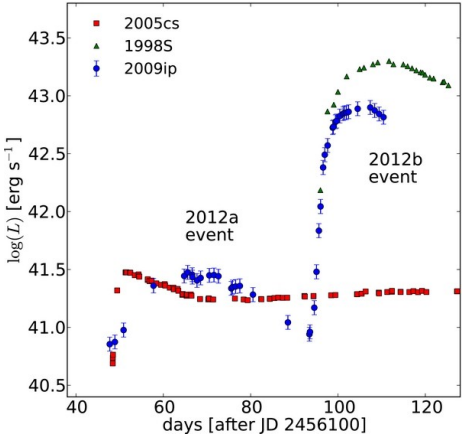
SN 2023fyq and CCSNs with precursor emission

Brennan+, A&A 684, L18 (2024):
- observations of He-rich progenitor before type Ibn explosion
- asymmetric He-rich material present both prior and after explosion
- double peaked post explosion light curve
- progenitor likely highly unstable before core collapse



Dong+, ApJ 977 (2024) 254:
- precursor activity explained by mass transfer in a binary system
- low mass He star + compact companion
- explosion triggered either by core collapse of He star or by merger of He star with compact object

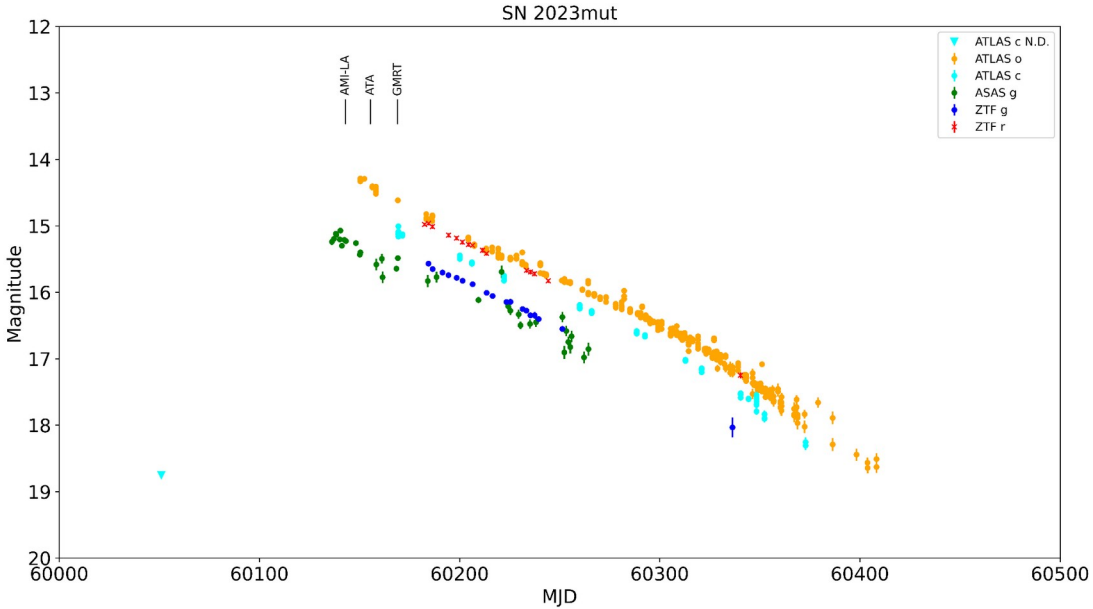
Tsuna+, ApJ 966 (2024) 30: progenitor in a binary system with a compact object, RSG-BH(NS), HeHighMass-BH(NS), HeLowMass-BH(NS), RSG models for type II Sne and He star models for type Ibn SNe



Precurson emission not uncommon, e. g. SN 2009ip
Pastorello+ ApJ 767 (2013) 1, Mauerhan+ MNRAS 430 (2013) 1801 ...

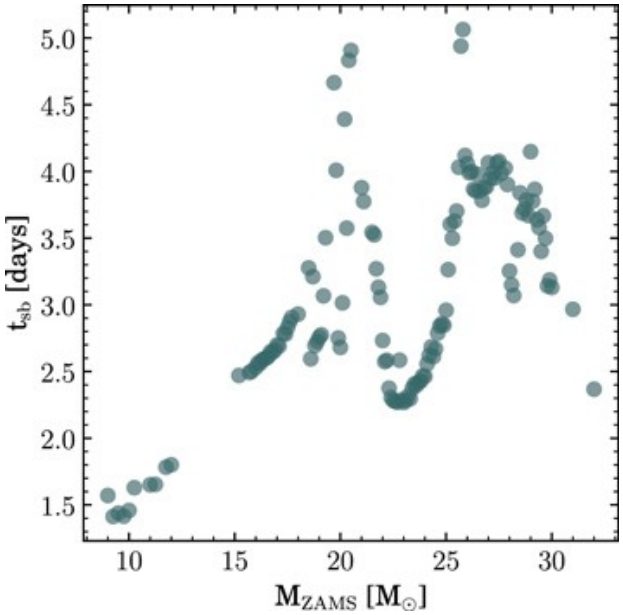
Supernovae with missing maximum

SN 2023mut, distance ~ 8.2 Mpc



Missed maximum: other methods to reconstruct the light curve?

Time for shock breakout and progenitor mass



Barker+, ApJ 934 (2022) 67

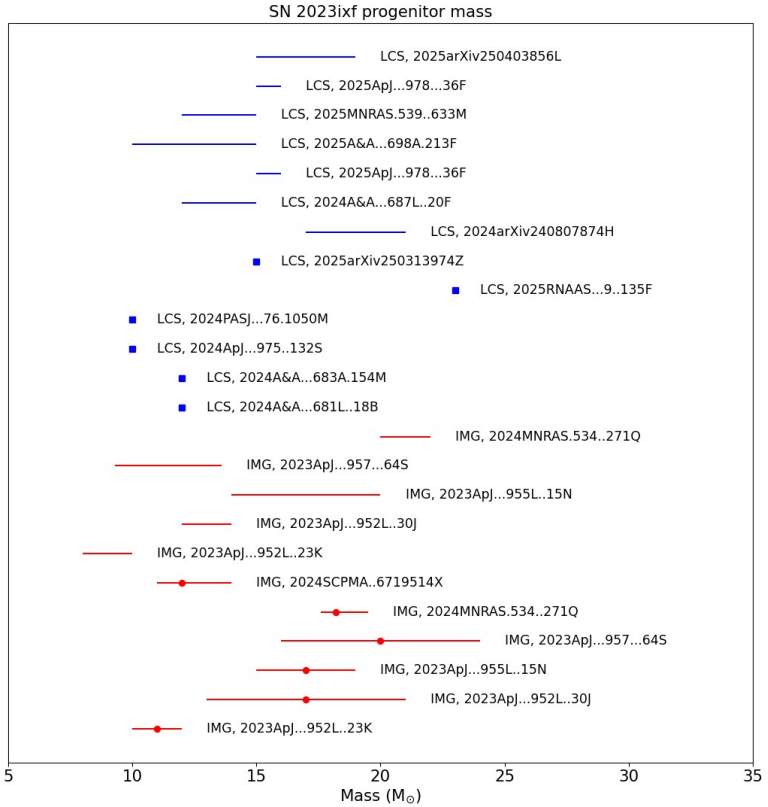
Progenitor mass: SN 2023ixf as a case study

Mass estimates with pre-explosion imaging (IMG) and light curves/spectroscopy (LCS)

Values/interval of values/values with error

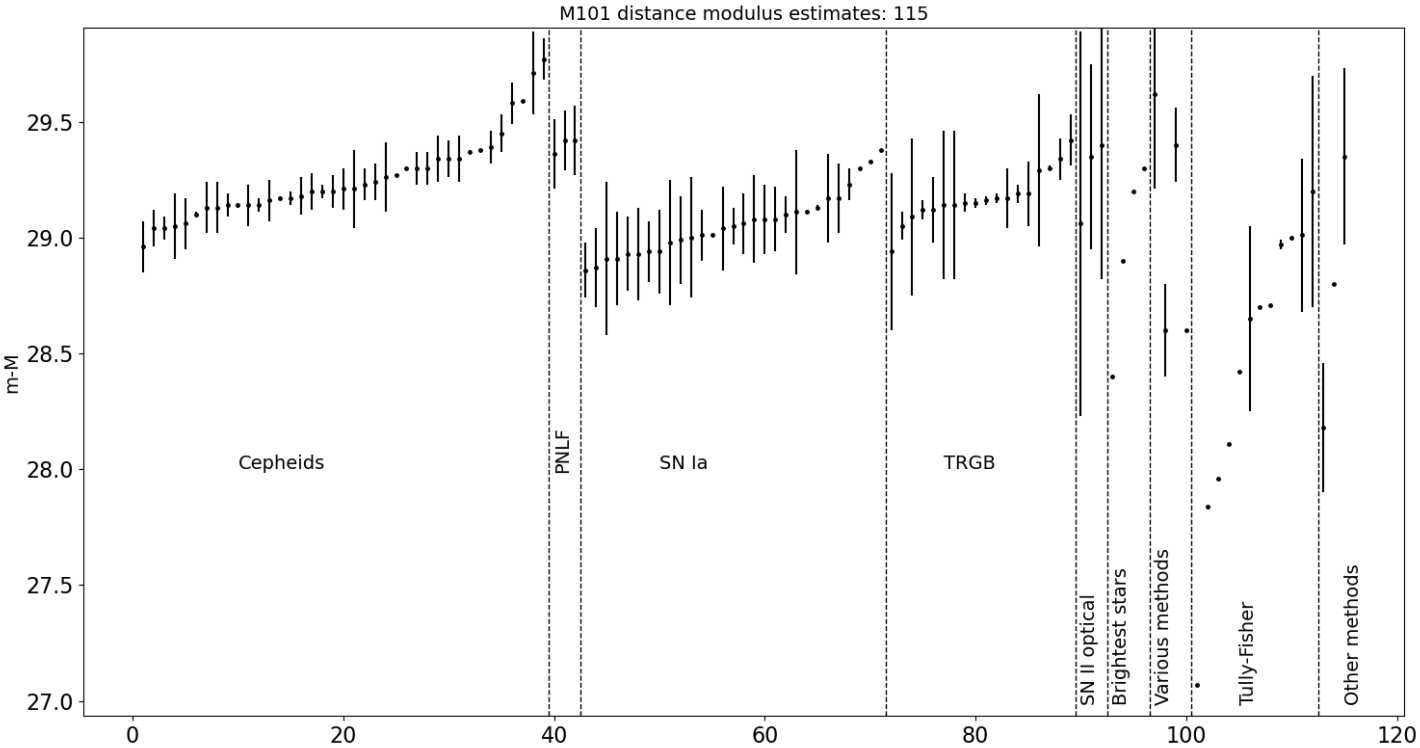
Large spread also within the same class of estimates

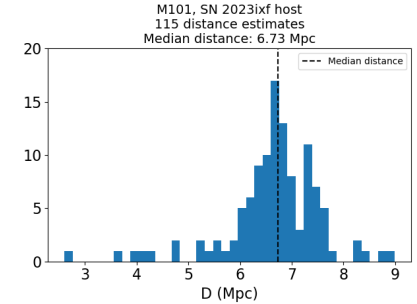
Discussion about stellar models

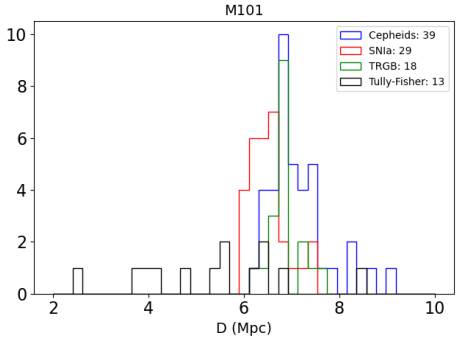


Distance of host galaxies

M101, host galaxy of SN 2023ixf (NED data): large spread in distance, also for each method







Sometimes redshift and non redshift distances unconsistent

Conclusions

Large number of supernovae discovered each year, mostly unclassified

Photometric coverage of close CCSNe unveven

Broad spectrum of progenitor mass estimates

Broad spectrum of host distance estimates

LIGO/Virgo/KAGRA exploring different types of CCSNe (Ib, Ic, II)