Probing the physics of bright SNe with high-cadence photometry

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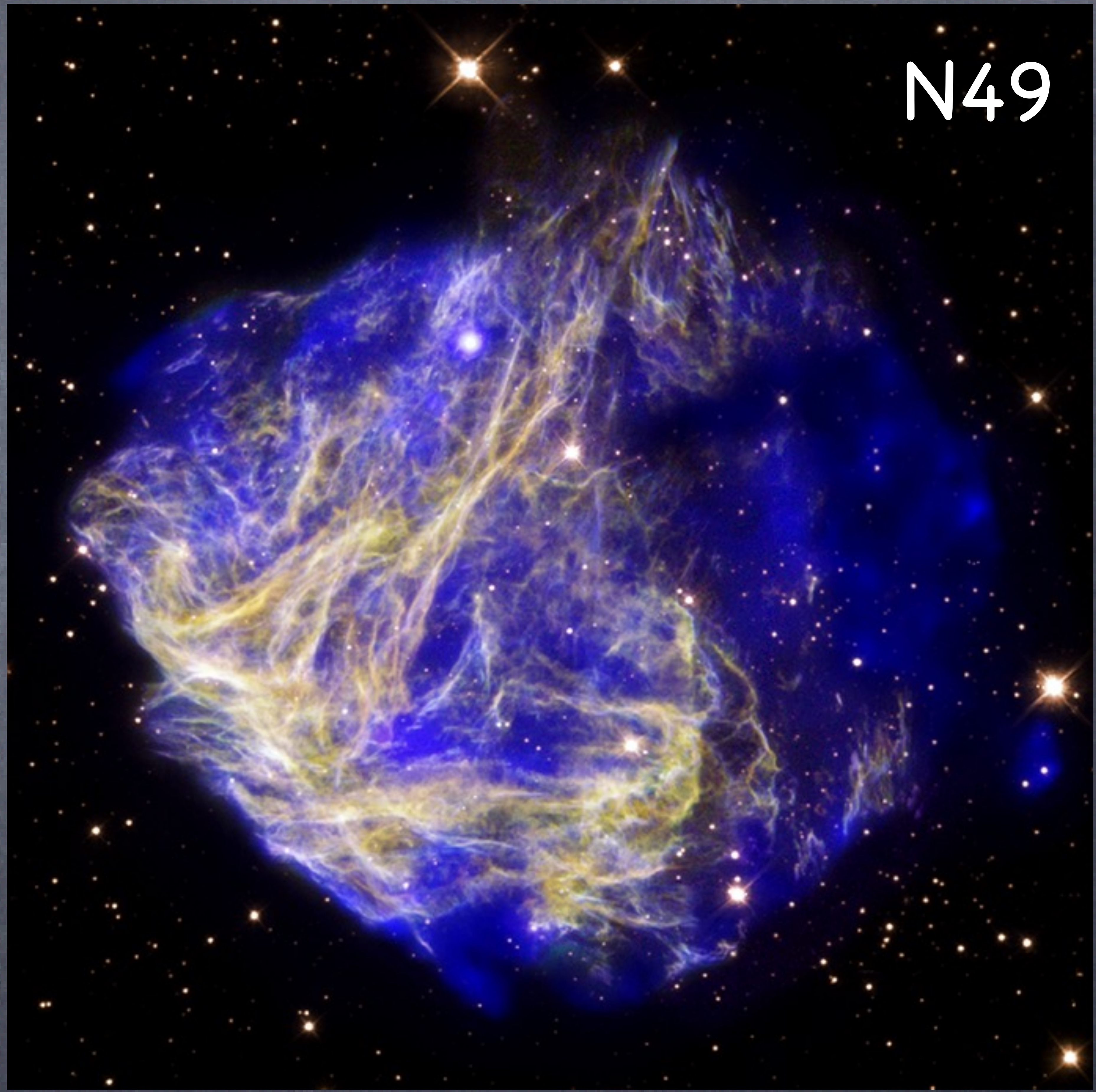
Motivation

- Explore short-timescale and low-amplitude variability properties of SN light curves
- Probe supernova physics (e.g. explosion, ejecta)
- Learn about SN progenitor system



X-ray: (NASA/CXC/Penn State/S.Park et al.)
Optical: NASA/STScI/UIUC/Y.H.Chu & R.Williams et al.

SN 2014J

SN 2014J in M82 (3.3 Mpc) reached V_{max}=10.6 mag (Foley et al. 2014)

High-cadence photometry obtained with the 2.3m Aristarchos telescope Helmos Observatory, Greece

http://helmos.astro.noa.gr/

"Fast variability is <u>not</u> expected from supernovae (because the shell is too large to change fast), but then no one has ever looked. Similarly, no one [expected] fast variations from novae during their optically-thick shell phase, but the first time anyone looked, for U Sco in 2010, the nova was seen to have many hour-long flares, with these still being completely unexplained."

B. Schaefer 2014, AAVSO Alert Notice 495

SN 2014J

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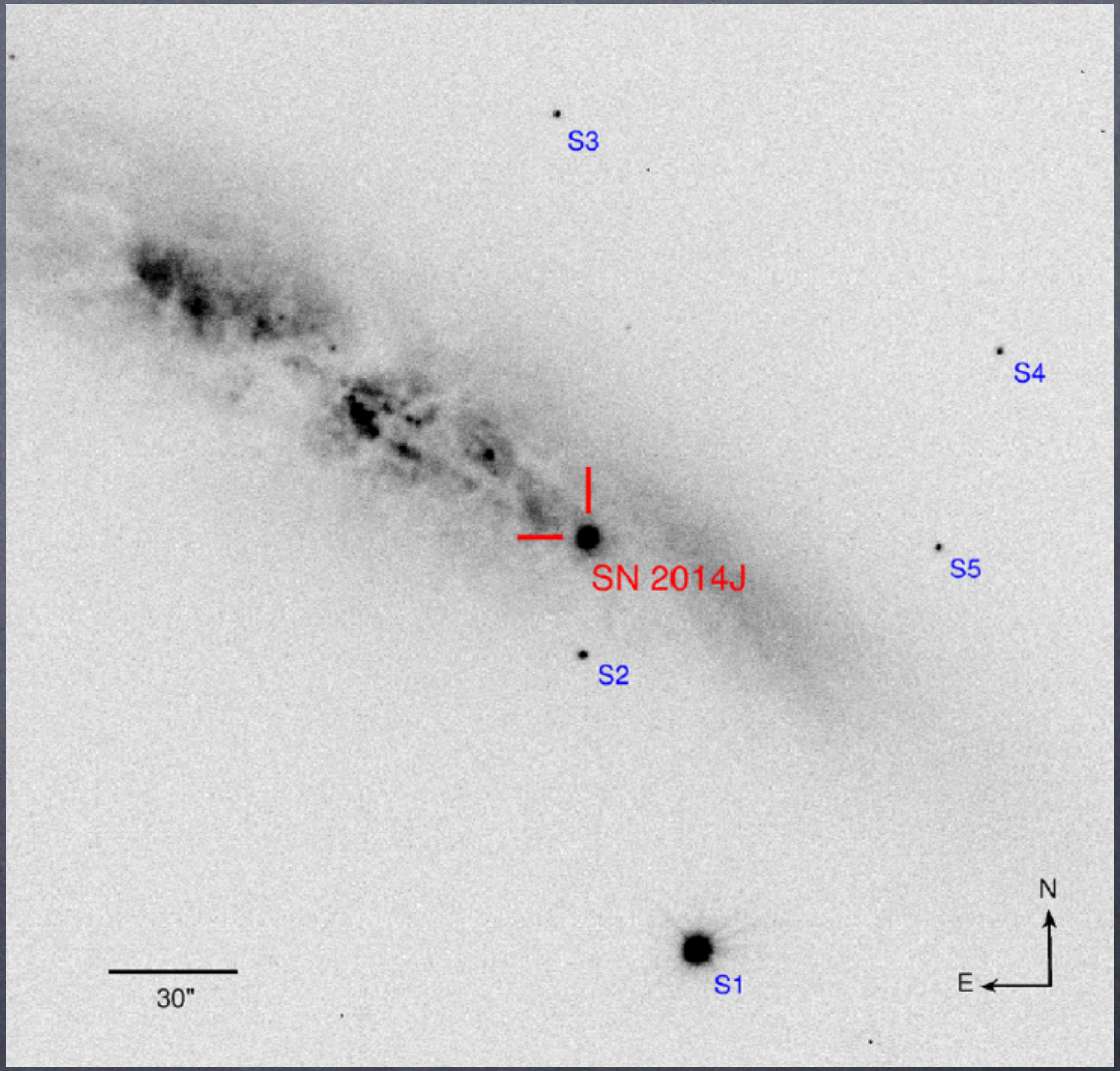
High-cadence photometry obtained with the 2.3m Aristarchos telescope Helmos Observatory, Greece

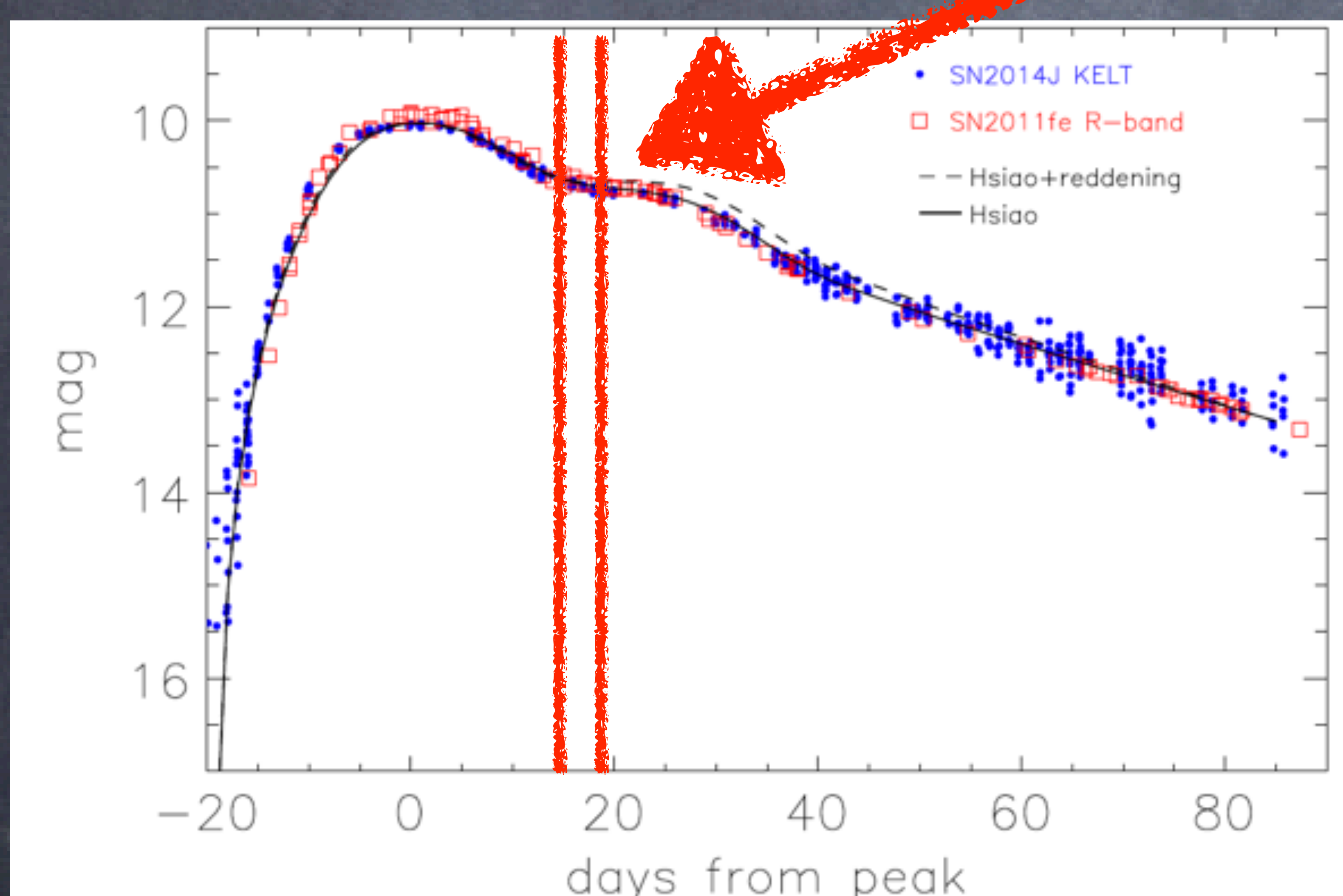
http://helmos.astro.noa.gr/

February 16-19, 2014
5 sec (V) & 20 sec (B) exposures
2 min cadence

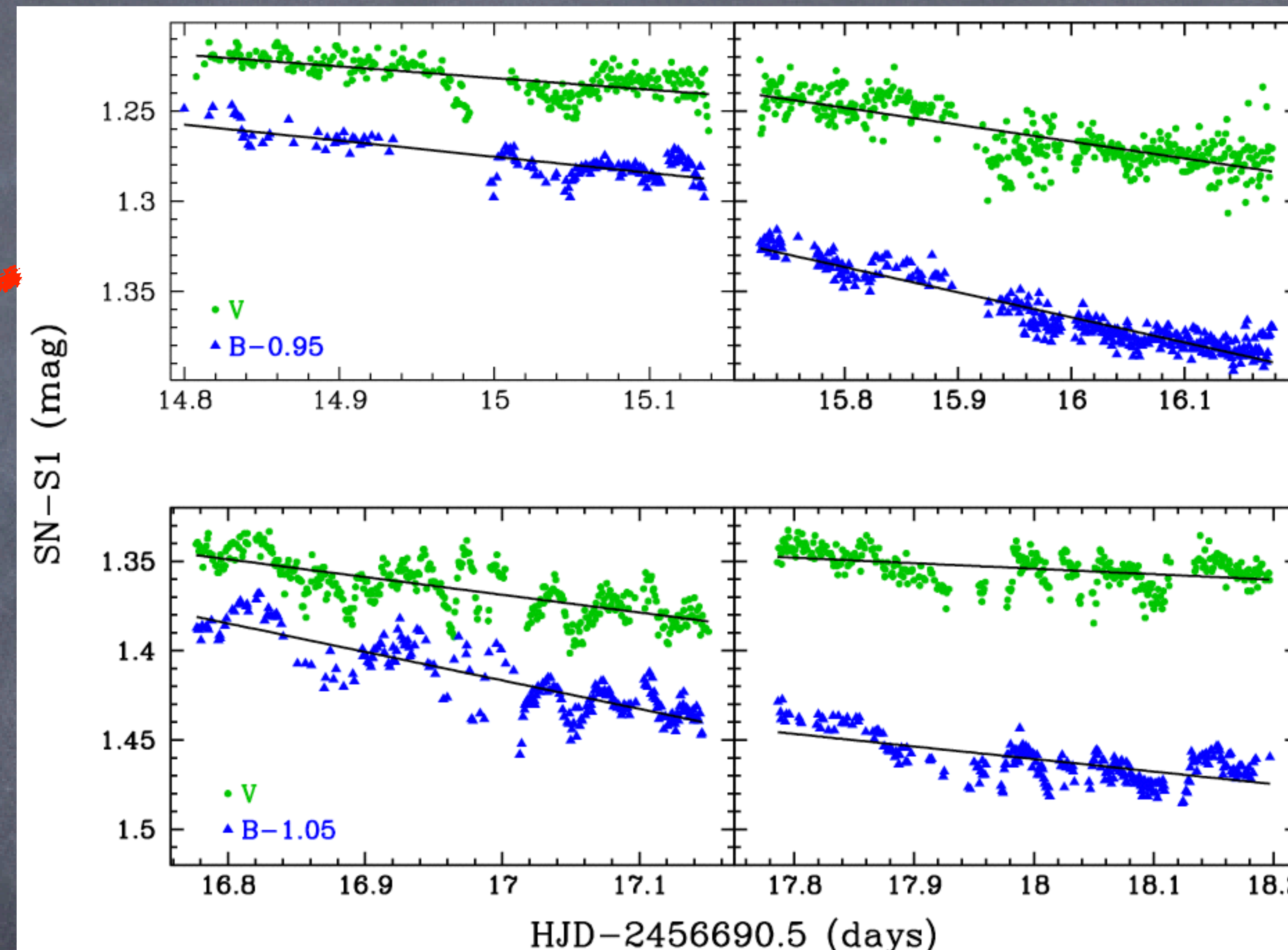


Results

evidence for rapid variability
amplitude: 0.02-0.05 mag
(2-5% in flux)
timescale: 15-60 min
precision: 3-6 mmag



Siverd et al. (2015)



Bonanos & Boumis (2016, A&A, 585, 19)

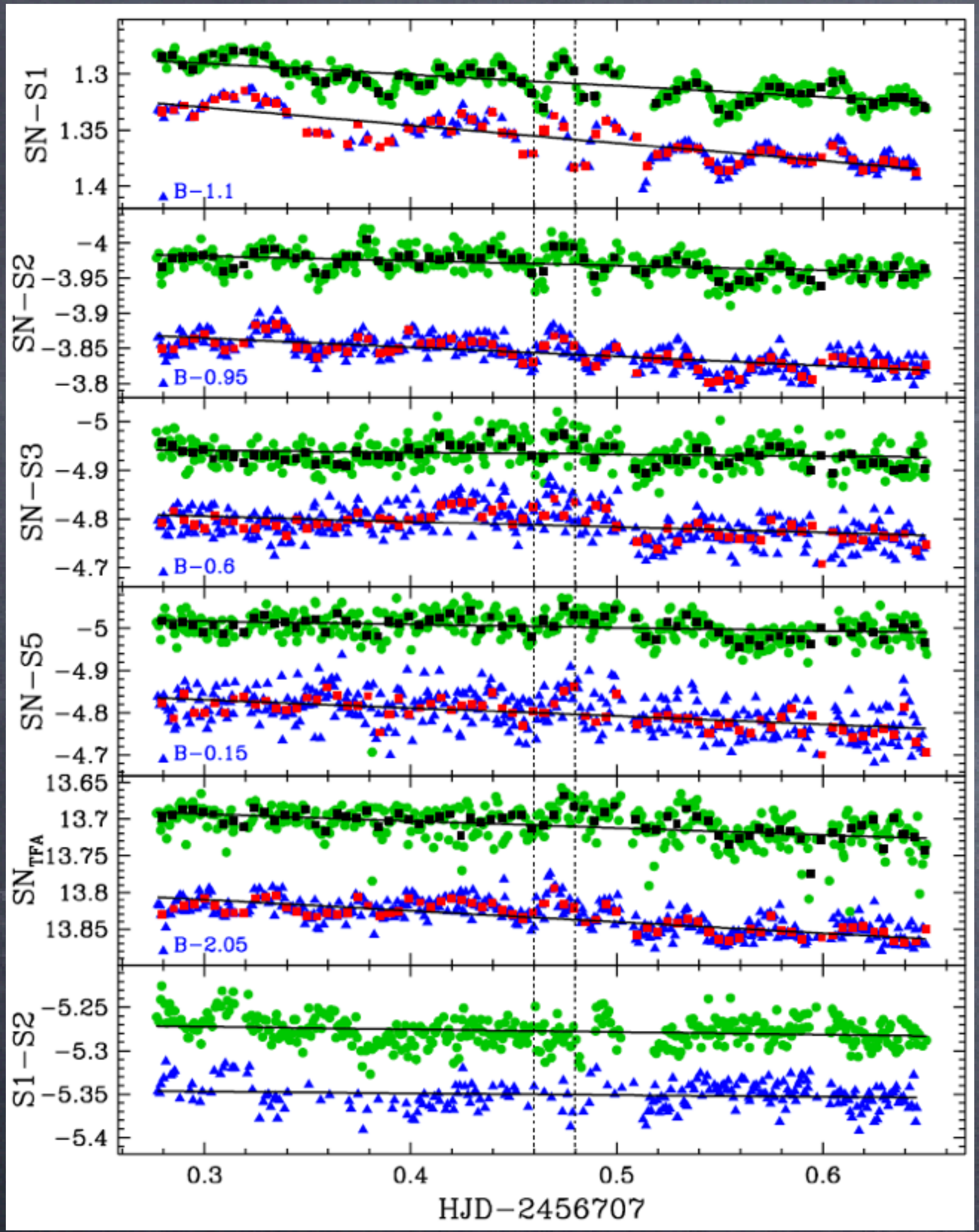
Results

Table 1. Decline rates α (mag day^{-1}) and values of σ_w, σ_r, σ_N (mag) based on SN–S1 of the *V*- and *B*-band light curves of SN 2014J.

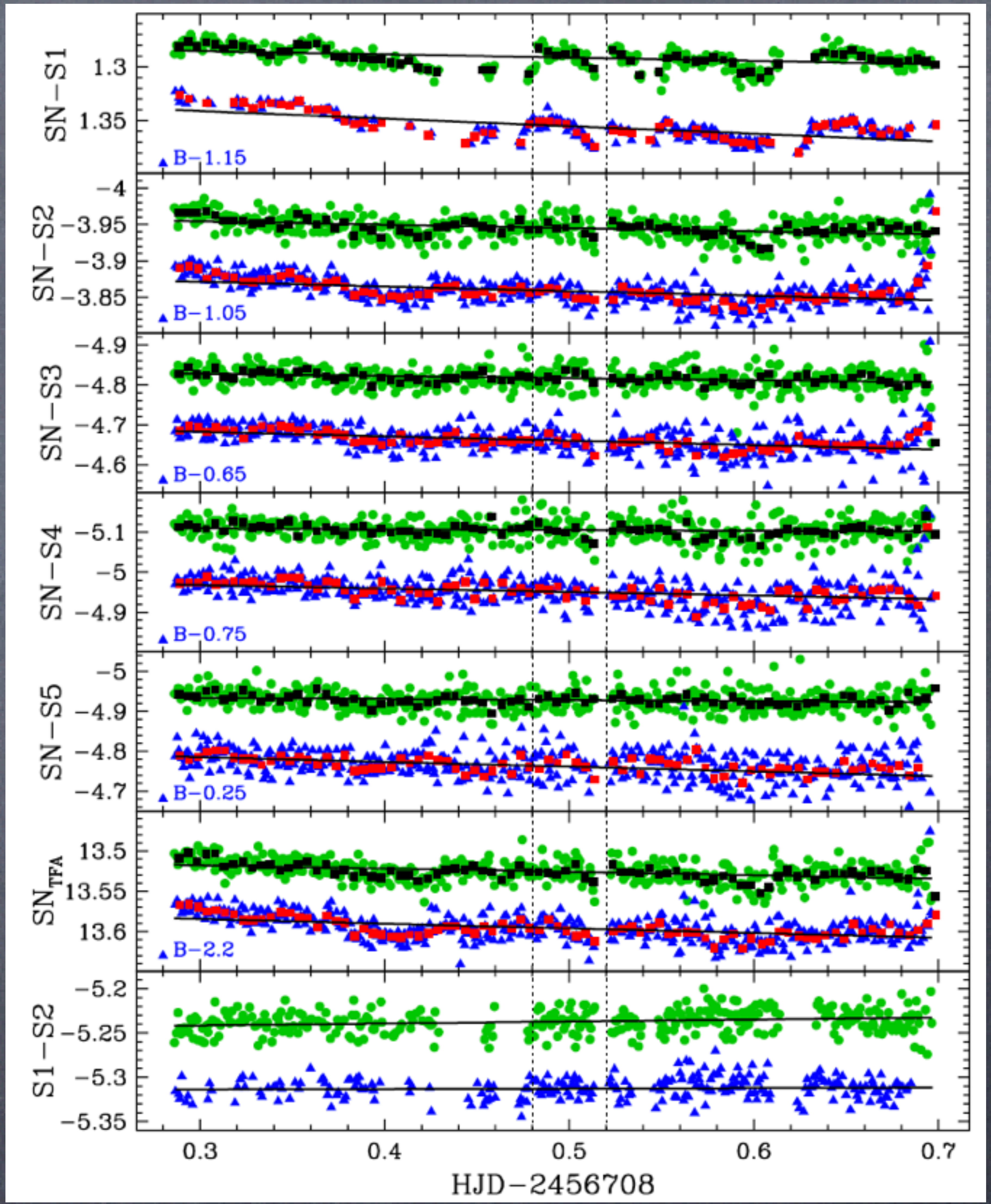
Night	Filter	α_{SN-S1}	α_{SN-S2}	α_{SN-S3}	α_{SN-S4}	α_{SN-S5}	$\alpha_{SN_{TFA}}$	σ_w	σ_r	σ_N
1	*V*	0.06 ± 0.01	0.15 ± 0.01	0.17 ± 0.02	0.15 ± 0.03	0.16 ± 0.02	0.14 ± 0.02	0.0086	0.0045	0.0048
2	*V*	0.09 ± 0.01	0.09 ± 0.01	0.10 ± 0.02	0.08 ± 0.03	0.07 ± 0.03	0.07 ± 0.01	0.0107	0.0050	0.0053
3	*V*	0.10 ± 0.01	0.07 ± 0.02	0.04 ± 0.03	...	0.08 ± 0.03	0.09 ± 0.04	0.0177	0.0052	0.0061
4	*V*	0.03 ± 0.01	0.04 ± 0.01	0.05 ± 0.02	0.02 ± 0.03	0.03 ± 0.02	0.04 ± 0.01	0.0131	0.0046	0.0052
1	*B*	0.09 ± 0.01	0.19 ± 0.01	0.24 ± 0.03	0.21 ± 0.03	0.17 ± 0.05	0.22 ± 0.05	0.0104	0.0025	0.0031
2	*B*	0.14 ± 0.01	0.12 ± 0.01	0.12 ± 0.03	0.10 ± 0.03	0.07 ± 0.04	0.09 ± 0.01	0.0074	0.0033	0.0036
3	*B*	0.16 ± 0.01	0.13 ± 0.02	0.11 ± 0.03	...	0.20 ± 0.04	0.15 ± 0.03	0.0186	0.0036	0.0050
4	*B*	0.07 ± 0.01	0.06 ± 0.02	0.11 ± 0.03	0.09 ± 0.04	0.12 ± 0.04	0.06 ± 0.01	0.0128	0.0059	0.0063

- Measured decline rate per night of a Type Ia SN for the first time
- 1σ error from aperture photometry is 1.4 mmag
- 3-6 mmag precision (based on red noise estimation, Pont et al. 2006) $\sigma_N^2 = \frac{\sigma_w^2}{N} + \sigma_r^2$
- 2-5% variability corresponds to a 1-2.5% fractional change in radius (104 AU on day 17) and is consistent with 4.5% (3σ) upper limit from Siverd et al. (2015)

Results



Night 3:
0.05 mag (8.2σ in V, 10σ in B)

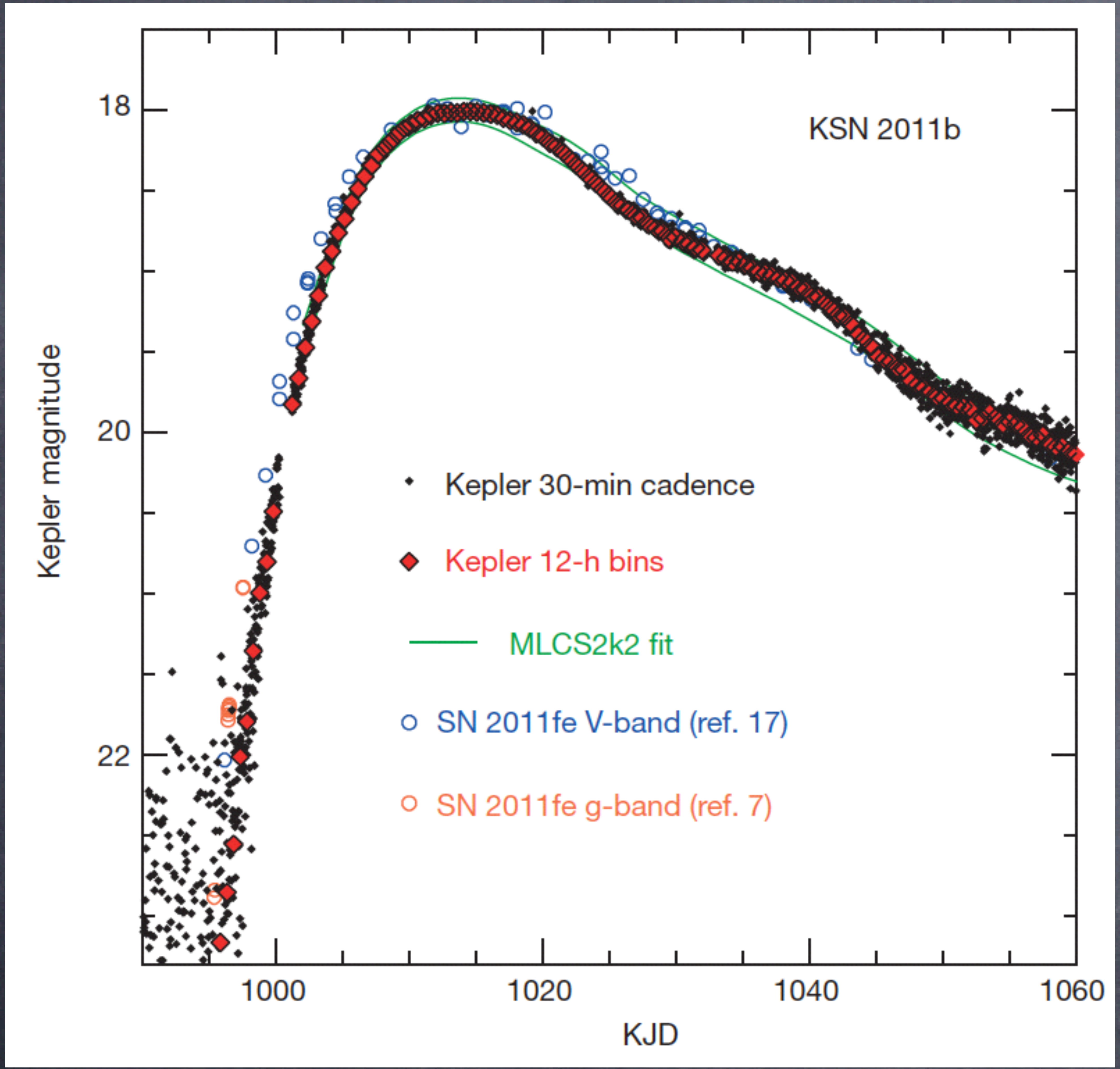


Night 4:
0.04 mag (7.7σ in V, 6.3σ in B)

Origin of variability in SN 2014J

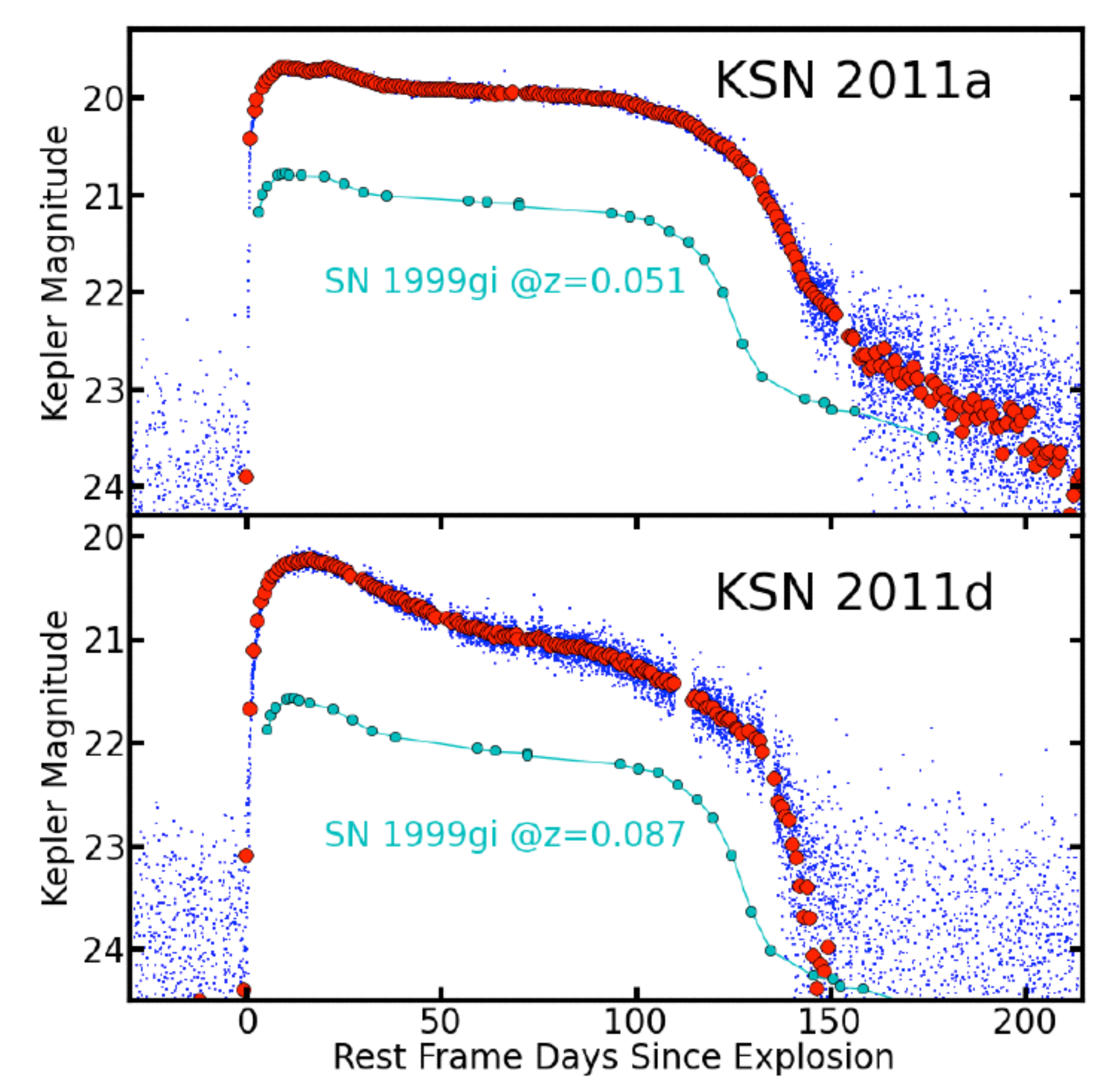
- clumping of ejecta, possibly caused by structures of intermediate mass elements in the outer layers (Hole et al. 2010)
- interaction of the ejecta with circumstellar material (Foley et al. 2014)
- asymmetry of the ejecta (non-spherically symmetric explosion, Wang & Wheeler 2008)
- onset of secondary maximum (Pinto & Eastman 2000)

SNe from the Kepler K2 mission



Olling et al. (2015, 3 Type Ia SNe)

no signature of ejecta interaction with companion



Garnavich et al. (2016, 2 Type IIp SNe)

detection of shock breakout in KSN 2011d

Bright supernovae

RA	DECL	Discovery Date	Last Mag	Last obs	Max Mag	Max Date	Type	z	Host	Link
17:43:05.20	-28:27:39.4	2011/08/01.000	12.8**	02/26	8.1	08/01	unk	n/a	Milky Way	VVV-WIT-05
09:55:42.14	+69:40:26.0	2014/01/21.810	18.0**	09/28	10.1	02/03	Ia-HV	0.000677	M82	2014J
12:45:09.10	-00:27:32.5	2014/12/09.610	15.3**	04/13	11.1	12/18	Ia	0.005101	NGC 4666	ASASSN-14lp
07:36:15.76	-69:30:23.0	2015/03/09.789	19.1**	10/02	12.9	03/22	Ia	0.004000	NGC 2442	2015F
03:08:48.44	-35:13:50.9	2015/09/27.160	19.6**	04/10	13.0	10/12	Ia	0.015000	ESO 357-G5	ASASSN-15pz
13:43:16.69	-31:33:21.5	2015/04/26.180	13.1**	05/11	13.1	05/11	Ia	n/a	anonymous	ASASSN-15hx
12:21:57.57	+04:28:18.5	2014/10/29.838	17.6**	04/22	13.2	10/30	Ia-pec	0.005200	M61	2014dt
11:49:25.48	-05:07:13.8	2015/06/29.773	13.4**	07/21	13.4	07/21	Ia	0.005600	IC 2963	PSN J11492548-0507138
15:05:30.07	+01:38:02.4	2015/03/16.490	17.1**	06/05	13.6	04/03	Ia-91bg	0.004069	NGC 5839	2015bp
11:57:44.44	-10:10:15.7	2014/03/12.400	15.5**	05/03	13.6	03/22	Ic	0.005700	PGC 37625	2014ad
11:14:11.04	+48:19:07.2	2015/11/08.620	13.9**	12/14	13.7	11/23	Ia	0.007125	NGC 3583	ASASSN-15so
12:24:30.98	+75:32:08.6	2014/06/18.880	17.6**	09/17	13.8	06/29	Ia	0.005594	NGC 4386	2014bv
12:04:51.50	+26:59:46.6	2014/10/28.875	17.0**	04/08	13.9	11/03	Ib	0.001890	NGC 4080	MASTER OT J120451.50+265946.6
12:55:15.50	+00:05:59.7	2016/01/20.586	15.9	04/13	13.9	02/11	IIP	n/a	UGC 8041	2016X
03:48:19.78	+70:07:54.5	2014/09/11.725	17.3**	01/31	13.9	09/29	Ia	0.004000	UGC 2855	2014dg
10:54:34.13	+54:17:56.9	2014/01/14.317	17.9**	05/25	13.9	01/31	IIL	0.004503	NGC 3448	2014G
10:52:53.26	-32:55:34.9	2015/01/08.300	14.6**	01/16	14.0	01/09	Ia	0.010921	NGC 3449	ASASSN-15aj
07:17:45.70	+23:20:40.6	2015/05/02.482	14.0**	05/19	14.0	05/19	Ia	0.007589	NGC 2357	2015I
03:44:23.99	-44:40:08.1	2014/06/03.182	14.7**	06/06	14.0	06/03	Ib	0.003000	NGC 1448	2014df
10:08:11.37	+51:50:40.9	2015/11/15.778	16.6	03/80	14.0	12/02	II	0.003600	UGC 5460	2015as
10:29:30.76	-35:15:35.2	2015/04/17.050	16.4**	06/13	14.2	05/03	Ia	0.005000	ESO 375-G41	ASASSN-15hf
15:46:58.69	+17:53:02.5	2015/02/15.580	14.5**	03/03	14.2	02/19	Ia	0.010998	NGC 5996	ASASSN-15db
09:18:31.05	+74:19:07.0	2015/06/05.280	14.4**	06/20	14.3	06/08	Ia	0.013000	UGC 4883	ASASSN-15kk
13:25:24.119	-43:00:57.90	2016/02/08.560	16.1**	02/11	14.3	02/08	IIb	n/a	NGC 5128	2016adj
00:59:47.83	-07:34:18.6	2014/09/02.572	16.5**	01/13	14.3	09/09	IIP	0.005490	NGC 337	2014cx
14:10:23.42	-43:18:43.7	2015/12/15.066	16.5**	02/17	14.4	12/15	Ib	0.006000	NGC 5483	PSN J14102342-4318437
09:10:39.53	+50:22:48.3	2014/10/12.610	15.0**	12/25	14.4	10/25	Ia	0.016855	NGC 2771	ASASSN-14iu
12:18:48.68	+14:24:43.5	2014/01/26.830	15.9**	05/03	14.4	02/06	Ic	0.008029	M99	2014L
21:50:50.94	-70:20:28.9	2015/11/27.871	14.5**	11/27	14.5	11/27	Ia	0.012000	NGC 7123	PSN J21505094-7020289
19:19:33.49	-33:46:02.0	2015/08/31.090	14.7**	09/06	14.5	09/03	II	0.007000	HIPASS J1919-33	ASASSN-15oz
23:33:13.90	-60:34:11.5	2014/10/21.12	15.1**	11/17	14.5	11/06	Ia	0.014800	PGC 128348	ASASSN-14jg
00:45:32.55	-14:15:34.6	2014/10/01.110	15.0**	01/09	14.5	11/09	IIn	0.022000	PGC 3093694	ASASSN-14il
23:44:48.00	-02:07:03.2	2014/05/20.590	15.5**	09/03	14.5	05/20	IIb	0.006700	PGC 1101367	ASASSN-14az
01:39:32.03	+33:49:36.0	2016/01/04.30	15.6**	02/04	14.5	01/14	Ia	0.016000	KUG 0136+335	2016F
00:43:21.14	+41:24:59.7	2015/09/19.974	17.0**	10/08	14.6	09/29	FeII	n/a	M31	Nova M31 2015-09c?
04:20:01.41	-54:56:17.0	2014/09/10.290	15.7**	12/28	14.6	09/10	II	0.005017	NGC 1566	ASASSN-14ha
11:20:59.02	+53:10:25.6	2016/03/13.974	16.0	04/11	14.6	03/24	Ib	0.003856	NGC 3631	2016bau
03:09:42.51	+40:58:29.3	2015/11/30.306	15.9**	12/18	14.6	12/08	Ia	0.020000	IC 290	2015az
22:09:09.64	-47:08:02.5	2015/12/29.030	14.7**	12/29	14.7	12/29	Ia	0.005839	NGC 7213	ASASSN-15us
02:48:59.57	+03:10:10.5	2015/07/05.610	15.9**	09/06	14.7	07/21	Ia	0.013900	UGC 2295	ASASSN-15mc
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11:55:04.25	+01:43:06.8	2016/01/03.620	15.6	04/12	14.7	01/03	IIP	0.004293	CGCG 12-116	2016B
08:24:15.02	-18:46:28.1	2015/09/13.150	19.5**	03/22	14.7	09/18	II-pec	0.008000	IC 2367	2015an
02:28:32.86	+20:17:07.7	2015/07/10.744	16.5**	09/06	14.7	07/18	Ia	0.013700	NGC 938	2015ab
23:27:40.86	+23:35:21.4	2014/08/09.517	14.9**	09/02	14.7	08/28	II	0.011000	NGC 7673	2014ce
22:55:01.97	-39:39:34.5	2014/05/07.758	15.3**	05/10	14.7	05/07	Ia-91bg	0.005800	NGC 7410	2014ba
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12:18:57.71	+47:18:11.3	2014/05/20	14.8**	05/20	14.8	05/20	IIP	0.001494	M106	2014bc
12:22:55.29	+15:49:22.0	2015/09/13	14.9**	09/13	14.9	09/13	unk	n/a	anonymous	SPIRITS15ud
00:42:42.53	+41:15:13.9	2015/06/03.047	14.9**	06/06	14.9	06/06	FeII	n/a	M31	Nova M31 2015-06a?
01:49:10.32	+05:38:23.3	2015/06/20.610	14.9**	06/21	14.9	06/21	Ia	0.017686	MRK 576	ASASSN-15lp
22:16:11.81	+37:28:26.1	2015/06/10.570	14.9**	09/06	14.9	09/06	Ia	0.018000	MCG +6-49-1	ASASSN-15kx
13:38:05.30	-17:51:15.3	2016/01/03.841	17.2*	03/04	14.9	01/04	IIP	0.004520	NGC 5247	2016C
09:25:44.53	+34:16:36.1	2015/09/21.072	17.9**	01/28	14.9	10/13	II	0.005400	UGC 5015	2015aq
07:28:53.87	+33:49:10.6	2015/02/13.338	14.9**	02/22	14.9	02/22	Ibn	0.013790	NGC 2388	2015U

http://www.rochesterastronomy.org/snimages/snmag.html

SNe with V_{max} < 15 mag

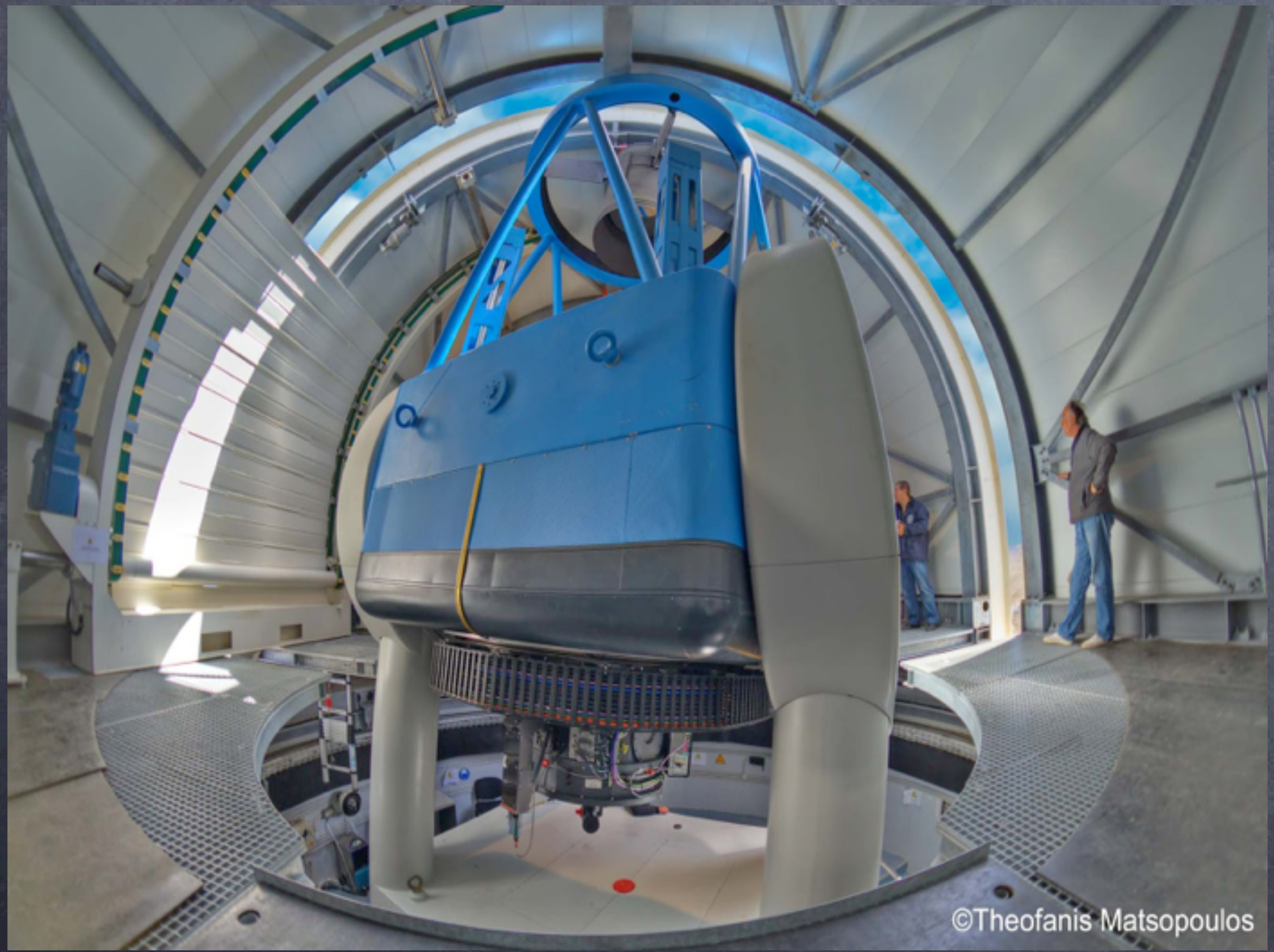
2014:
21 SNe (14 north)

2015: 28 SNe (18 north)

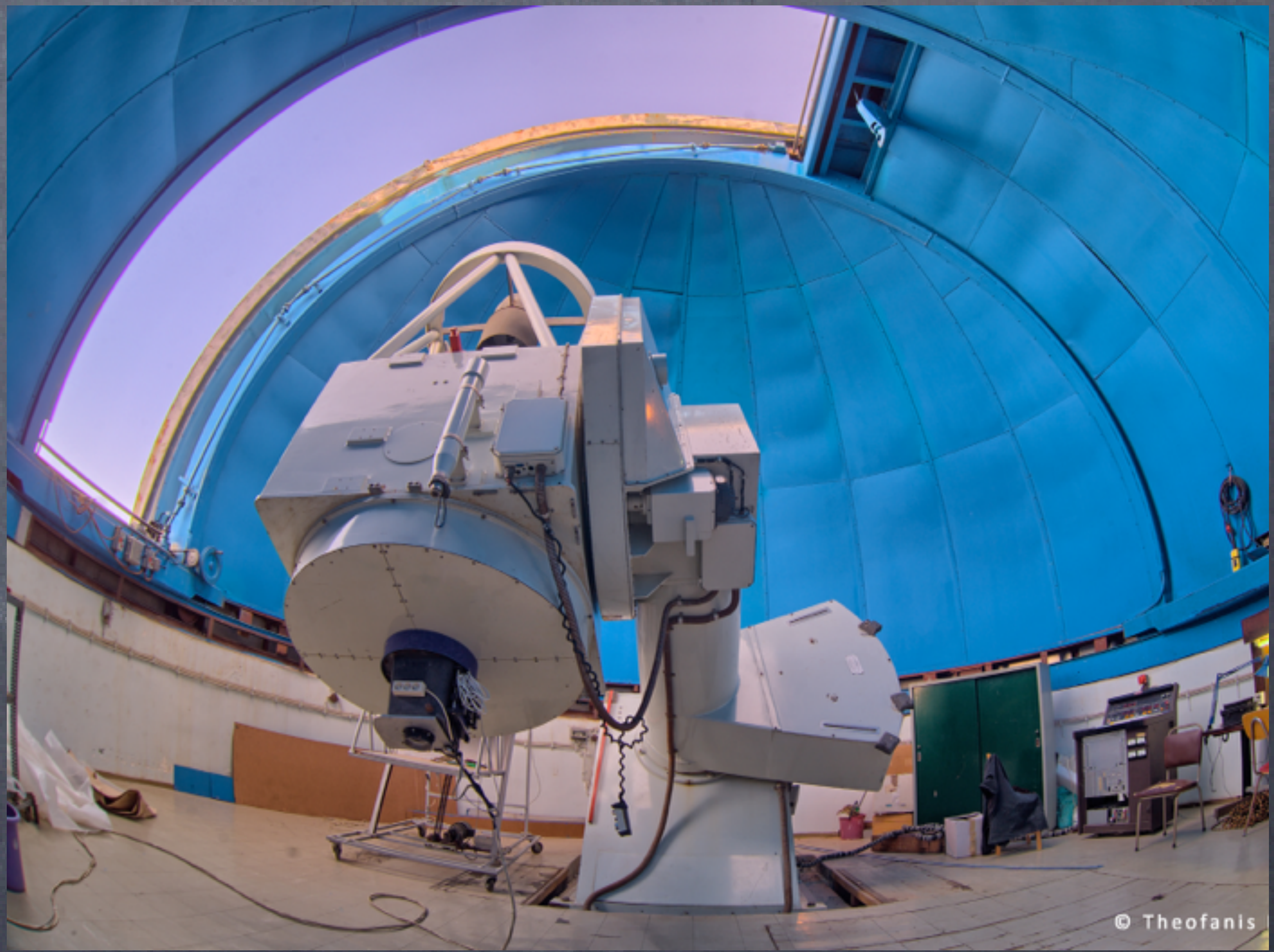
2016 (Jan-May):
8 SNe (5 north)

Future

- Follow-up future bright supernovae with 2.3m Aristarchos telescope (9 nights in Fall 2016)
- Use NELIOTA lunar imager on 1.2m Kryoneri telescope to monitor future bright supernovae (starting in Fall 2016)



2.3 m Aristarchos telescope



1.2 m Kryoneri telescope

NELIOTA lunar monitoring

NELIOTA is an ESA project aiming to establish an operational system at Kryoneri Observatory, Greece to conduct lunar monitoring. The goal is to determine the distribution and frequency of Near Earth Objects (NEOs) by detecting lunar flashes.

The Lunar Imager has a dichroic and 2 sCMOS Andor cameras and will observe in the R and I-bands at **30 fps**.

http://neliota.astro.noa.gr/

Kryoneri Observatory

Conclusions

- High-cadence photometry is a powerful tool for probing supernova physics (e.g. clumping, asphericity, shock breakout)
- Evidence for rapid variability at the 2-5% level on 15-60 min timescale detected in SN 2014J on 4 consecutive nights
- First measurement of intraday decline rate for a SN Type Ia
- Future monitoring of bright supernovae planned with 1.2m Kryoneri (NELIOTA Lunar Imager) and 2.3m Aristarchos telescopes

Stay tuned!