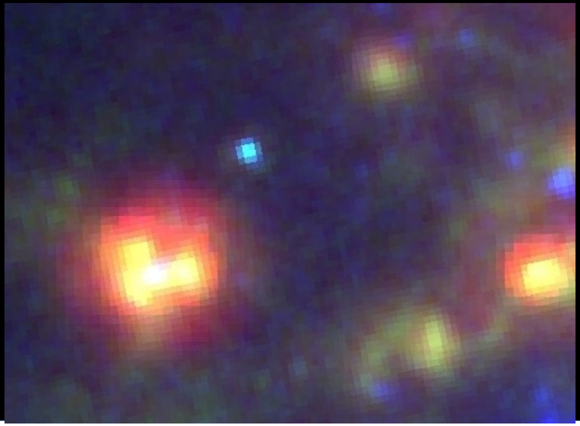
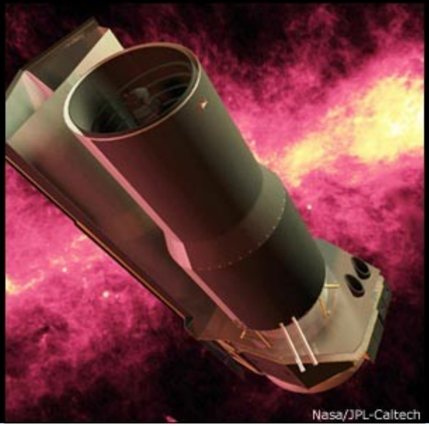
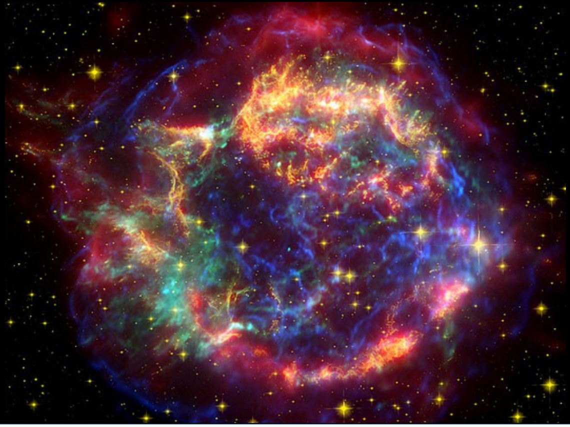
Searching for signs of circumstellar interaction in supernovae: a mid-IR investigation





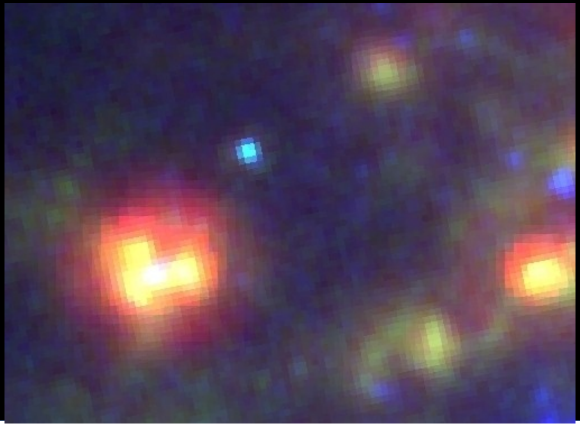


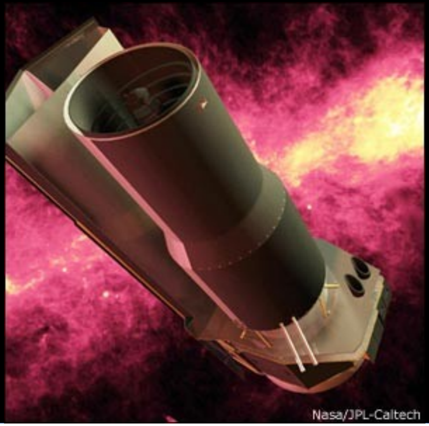
Tamás Szalai
University of Szeged, Hungary

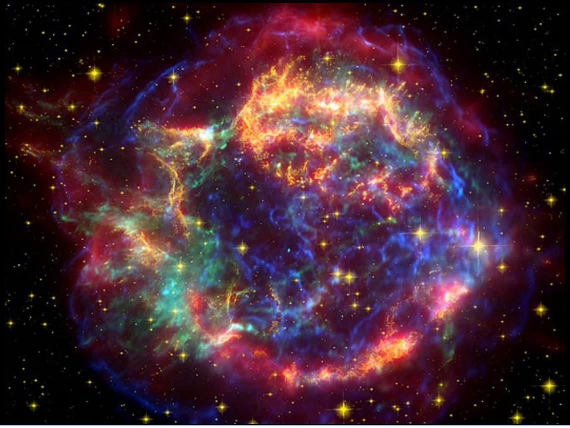
Deciphering the Violent Universe

Playa del Carmen, Mexico, 11–15 December 2017

Searching for signs of circumstellar interaction in supernovae: a mid-IR investigation







Tamás Szalai
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Ondrej Pejcha
U. of Princeton, UCSB

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Supernovae in the mid-IR

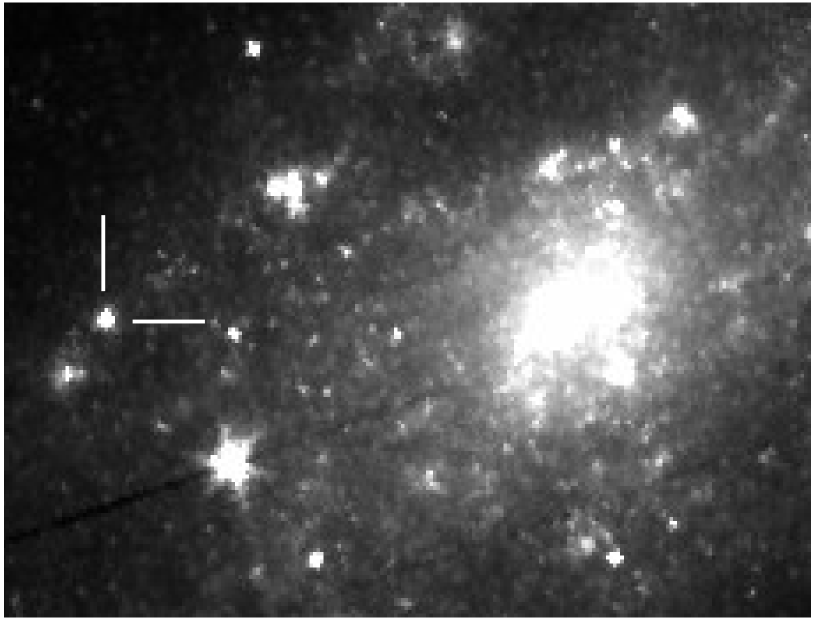
Why mid-IR?

An obvious and advantageous choice in following the late-time evolution of supernovae (Sne)

- peak of SED shifts toward the IR after the photospheric phase
- practically free of interstellar extinction

Extra: special astrophysical processes can be well traced

- warm (~200-1000 K) dust in the ejecta
- interaction between SN shock and CSM



SN 2004dj on Spitzer 3.6 micron image, ~120d after expl.(Szalai+11)

Supernovae in the mid-IR

Dust formation

- Dust content of galaxies → sources?
- Molecule formation
- Formation of stars and planets
- Light-matter interactions

CSM interaction

- Complex environment, various form and time-scale of interactions
- Insight to the progenitor systems and late phases of stellar evolution

Supernovae in the mid-IR

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↔

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Supernovae in the mid-IR

Dust formation

- Dust content of galaxies → sources?
- Molecule formation
- Formation of stars and planets
- Light-matter interactions

Main questions/problems

- Amount of observable (warm) dust: theory ↔ observations
- Large amount of cold dust? (SN 87A)
- Modelling of grains (types, sizes, survival rates etc.)

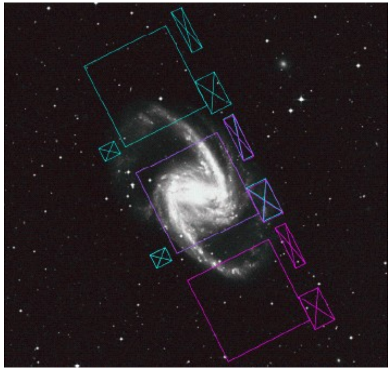
CSM interaction

- Complex environment, various form and time-scale of interactions
- Insight to the progenitor systems and late phases of stellar evolution

Main questions/problems

- Need special & lucky observations (X-ray, radio, H-alpha, ...)
- Evidences in progenitor debates? (e.g. SD vs. DD models of Type Ia Sne)
- Can we always detect interactions? (Time scales, sensibility...)

Spitzer – an effective tool in studying SNe



irsa.ipac.caltech.edu

<u>IRAC</u> (Infrared Array Camera):

4-channel imaging photometer

(3.6 μm; 4.5 μm; 5.8 μm; 8.0 μm)

256 x 256 pixels, FoV:5.2 x 5.2 arcmin

<u>MIPS</u> (Multiband Imaging Photometer for Spitzer):

3-channel imaging photometer

(24 μm; 70 μm; 160 μm)

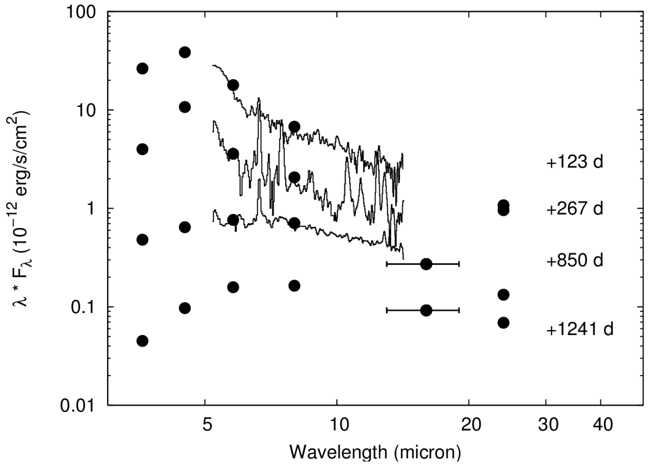
Low-res. spectrometer (R=15–20), 55-95 μm

<u>IRS</u> (Infrared Spectrograph):

Low-res spectrographs:

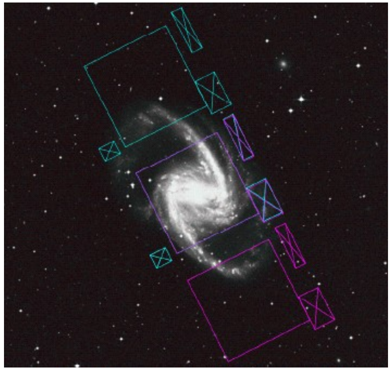
5-38 μm (R=60–120), 10-37 μm (R≈600)

Peak-up imager (13.3-18.7 & 18.5-26.0 μm



Mid-IR SEDs and spectra of SN 2004dj (Szalai+11)

Spitzer – an effective tool in studying SNe



IRAC (Infrared Array Camera):

(3.6 μm; 4.5 μm)

„Warm phase”
(since 2009)

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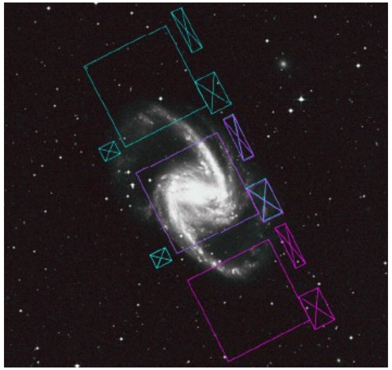
Spitzer – an effective tool in studying SNe



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IRAC (Infrared Array Camera):

(**3.6 μm; 4.5 μm**)

„Warm phase" (since 2009)

SPIRITS program (*Tinyanont+16*)
141 SNe (<20 Mpc)
44 positive detections (6 new)

Fox+11, Fox+13:
69 Type IIn SNe
10 positive detections

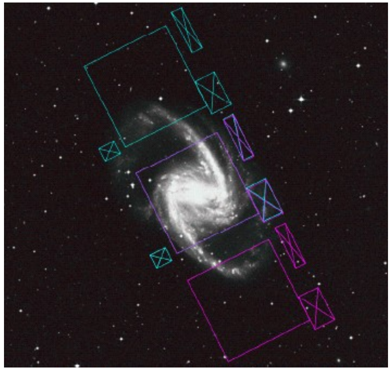
Szalai & Vinkó13:
12 Type II-P SNe
9 positive detections

Johansson+17:
9 Type Ia SNe
(positive detections)

Individual objects
(mostly multi-wavelength studies)

In total: ~200 studied SNe, ~70 positive mid-IR detections in the literature

Spitzer – an effective tool in studying SNe



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(positive detections)

Individual objects
(mostly multi-
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In total: ~200 studied SNe, ~70 positive mid-IR detections in the literature

But: many other objects could have detected during non-SN targeted surveys!

Collection of supernova data

<u>Object list</u>:

- Websites of *CBAT* & *ASAS-SN* → SNe discovered before 2015 (spectroscopic classification: at least as Type I or Type II objects)
- Further close (z<0.05) objects selected from the *Open Supernova Catalog*

  → **~4500 objects**

Search for SN coordinates using ***Spitzer Heritage Archive***

→ **~1100 objects** (only IRAC data)

Additional data of SNe + hosts: *Open Supernova Catalog, NED*

Photometry on IRAC images

Basic method: aperture photometry (IRAF) on PBCD images

- Original images
- Flux differences (multiple obs.)

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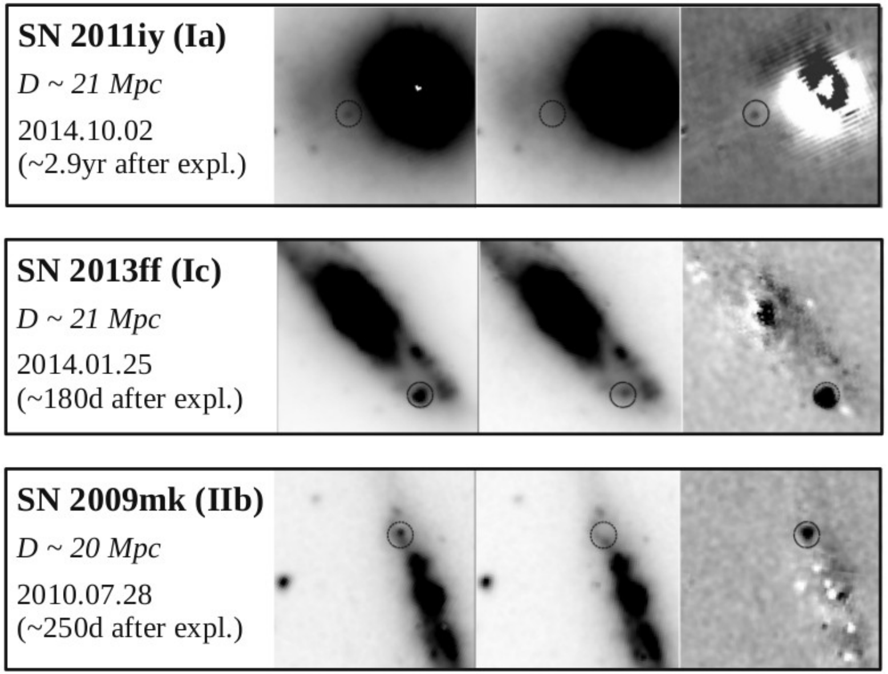
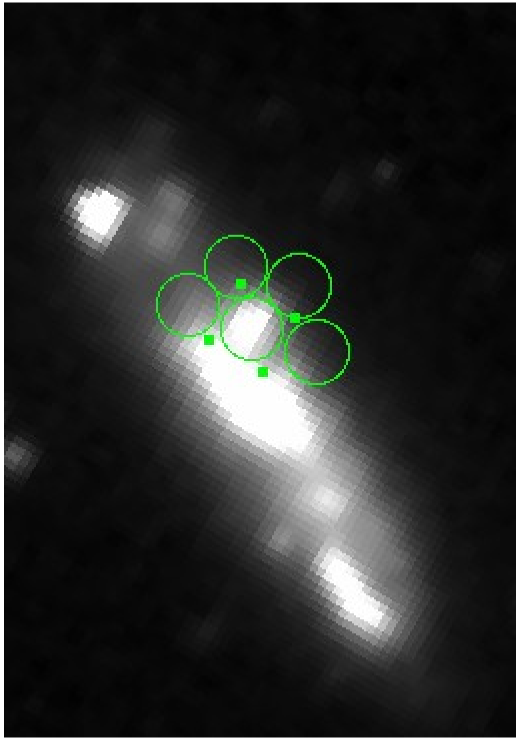


Photometry on IRAC images

<u>Basic method</u>: aperture photometry (IRAF) on PBCD images

- Original images
- Flux differences (multiple obs.)
- Image subtraction of pre-explosion or very late-time images (using HOTPANTS by A. Becker)
- „Fox+11” method

Repeated photometry of all previously published data



SN 2005kd, Spitzer 3.6 micron image

Statistics of the *Spitzer*/IRAC data regarding the sample of studied SNe.

	Thermonuclear SNe				Stripped-envelope CC SNe							Type II SNe				
	Ia	Ia-pec	Iax	Ia-CSM	Ib	Ib-pec	Ibn	Ib/c	Ic	Ic-pec	IIb	II-P	II-P pec.	IIn	II-L	Unclass. SN II
Total number of observed SN sites: 1131/683†																
Total number of observed SN sites	723/294†	25/23†	8	5	59/53†	1	2	1	73/63†	4/3†	24	36	2	93	4	71
SN sites with multiple observations: 549/332†																
SN sites with multiple observations	325/112†	9	4	5	27/25†	1	1	–	35/33†	2	13	32	2	36	4	53
SN sites with pre-explosion images: 110/86†																
SN sites with pre-explosion images	43/20†	3	2	–	10	–	1	–	9/8†	–	4	10	2	8	1	17
Total number of positive detections: 119																
Total number of positive detections	25	1	2	5	6	–	2	1	7	–	7	22	1	22	2	16
Unpublished positive detections: 49																
Unpublished positive detections	14	1	1	2	4	–	1	1	2	–	4	4	0	6	1	8

NOTE—† Total number of objects / Number of objects excluding SNe in distant, anonymous galaxies

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NOTE—†Total number of objects / Number of objects excluding SNe in distant, anonymous galaxies

In total: 1131 SN sites:

- 683 close (z<0.05) SNe
- 448 distant objects in anonymous galaxies (mostly Type Ia)

Statistics of the *Spitzer*/IRAC data regarding the sample of studied SNe.

~50% multiple observations

~10% pre-explosion images

	Ia	Ia-pec	Iax	Ia-CSM	Ib	Ib-pec	Ibn	Ib/c	Ic	Ic-pec	IIb	II-P	II-P pec.	IIn	II-L	Unclass. SN II
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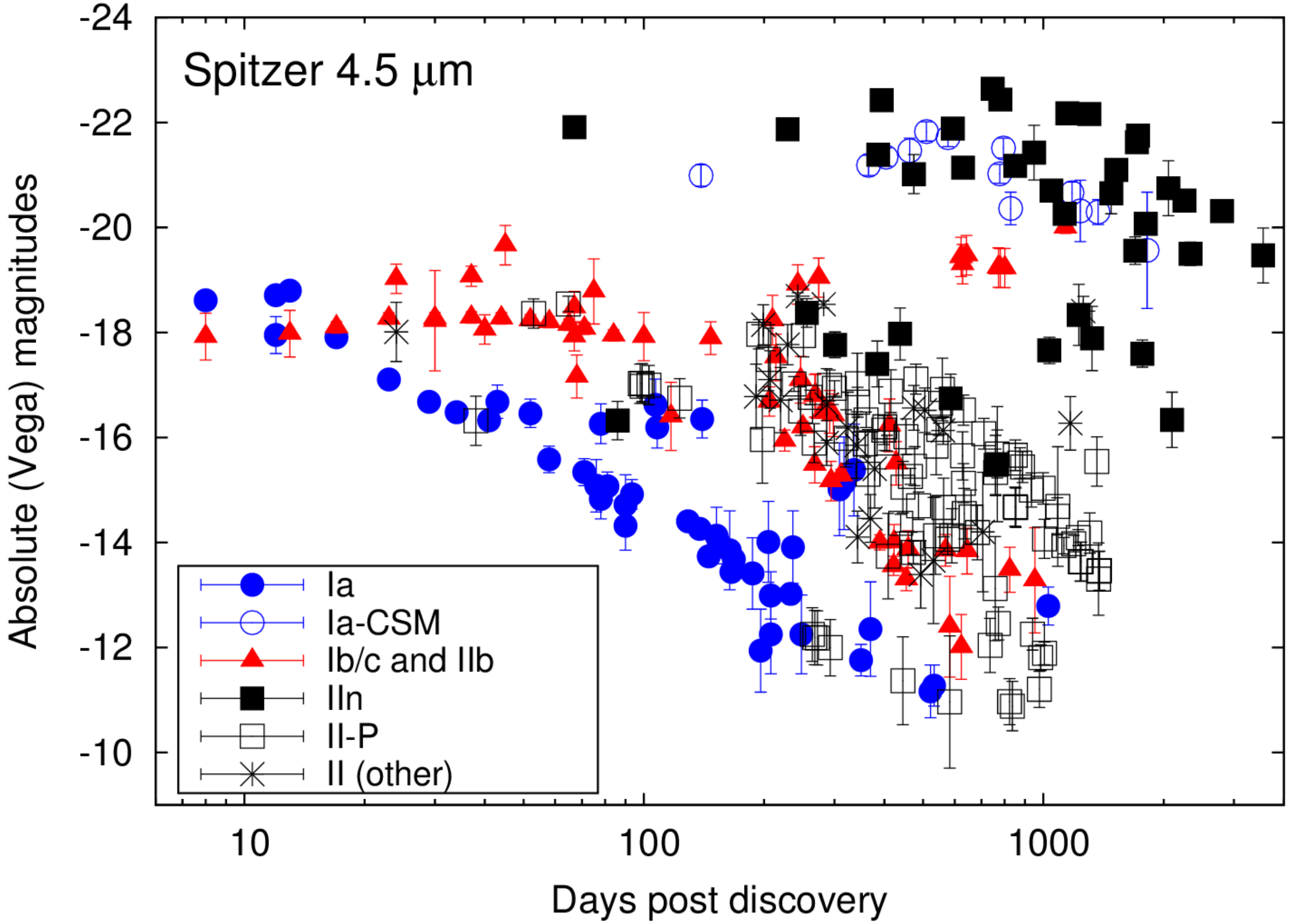
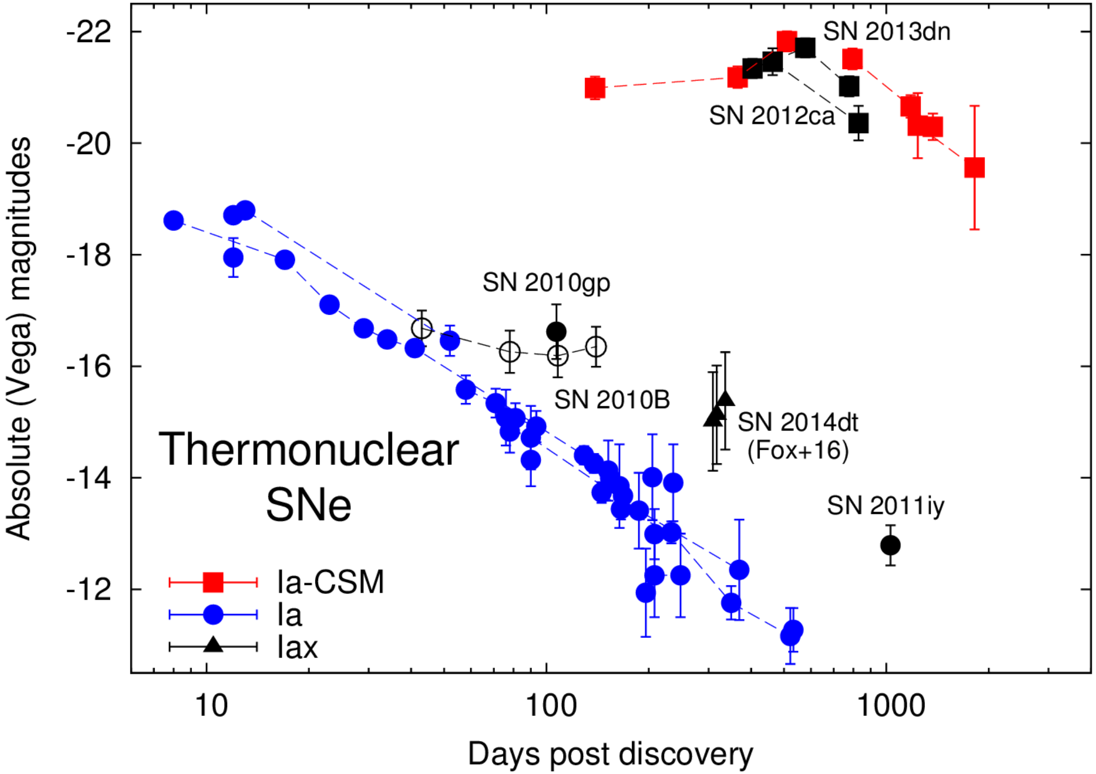
- 49 new objects with positive Spitzer-detections
- ~2x enlargement in both thermonuclear and SE CC SNe

NOTE—†Total number of objects / Number of objects excluding SNe in distant, anonymous galaxies


Spitzer 4.5 μm
Absolute (Vega) magnitudes
Days post discovery
-24
-22
-20
-18
-16
-14
-12
-10
10
100
1000
Ia
Ia-CSM
Ib/c and IIb
IIn
II-P
II (other)

Thermonuclear SNe



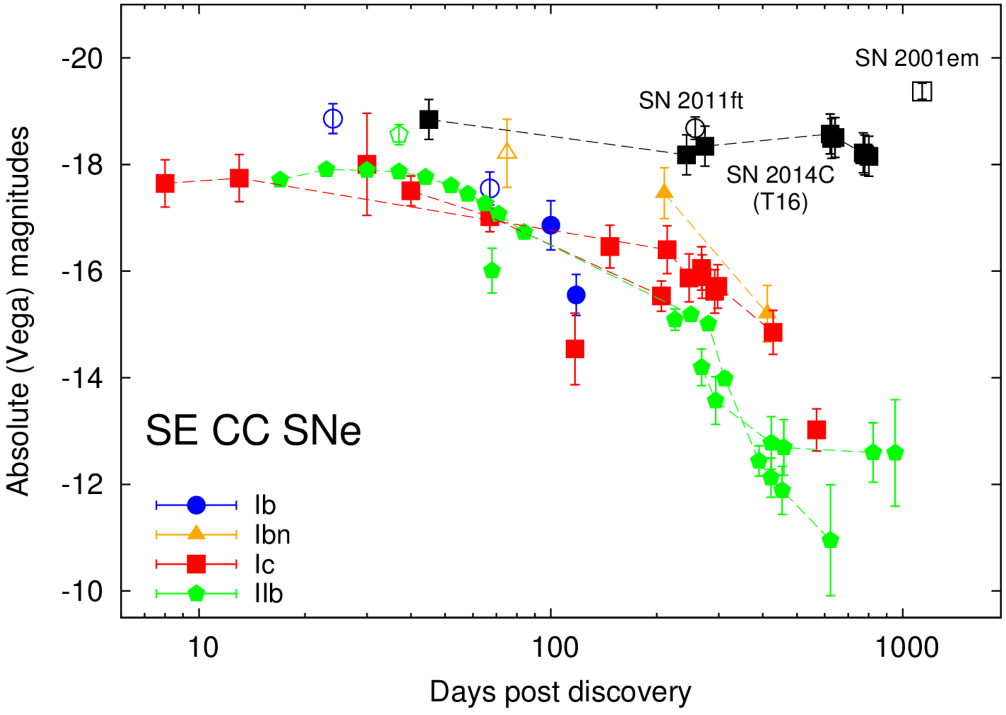
- SNe Ia-CSM: similar evolution? (still a small sample...)
- Basically no „intermediate" cases between „normal" SNe Ia and Ia-CSM

  → different progenitors?

  → distant shells of CSM?
- 2 (3) „normal" Type Ia with late-time mid-IR excess
- Special case: SN 2014dt, an Iax explosion (Fox+16)

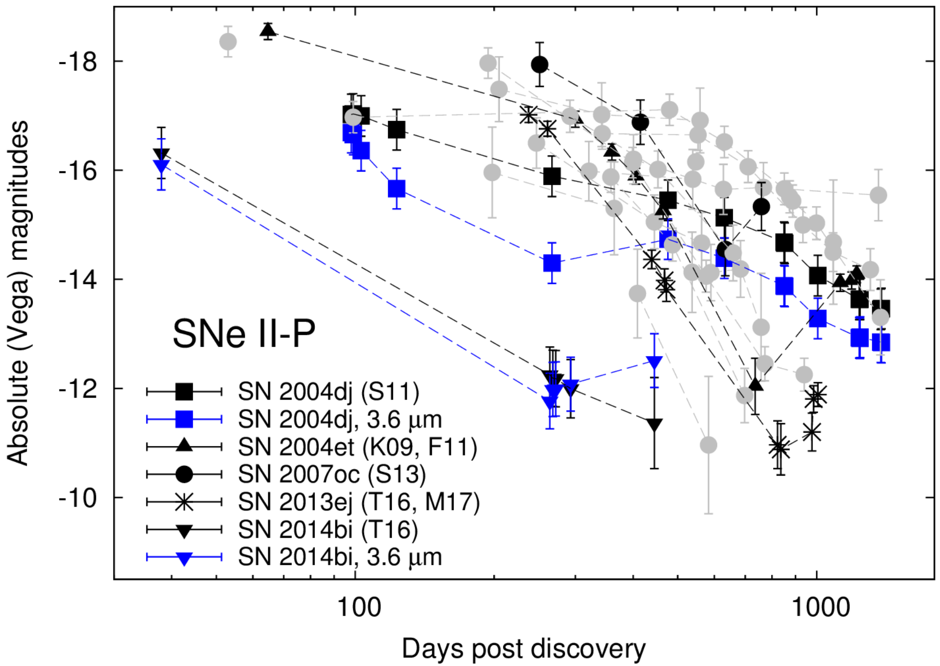
  → unfortunately, very few data of such kind of SNe

Stripped-envelope CC SNe



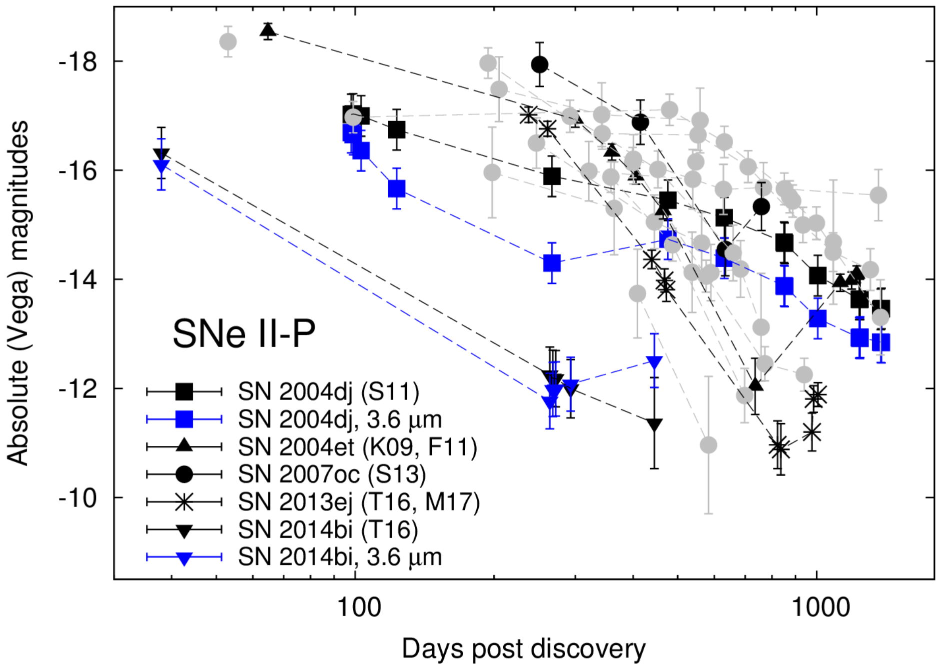
- Well-known interacting SNe (2014C, 2001em) are bright in mid-IR → fluxes of SN 2001em are first reported
- Only one new candidate for strong CSM-interactions: SN 2011ft (Type Ib)

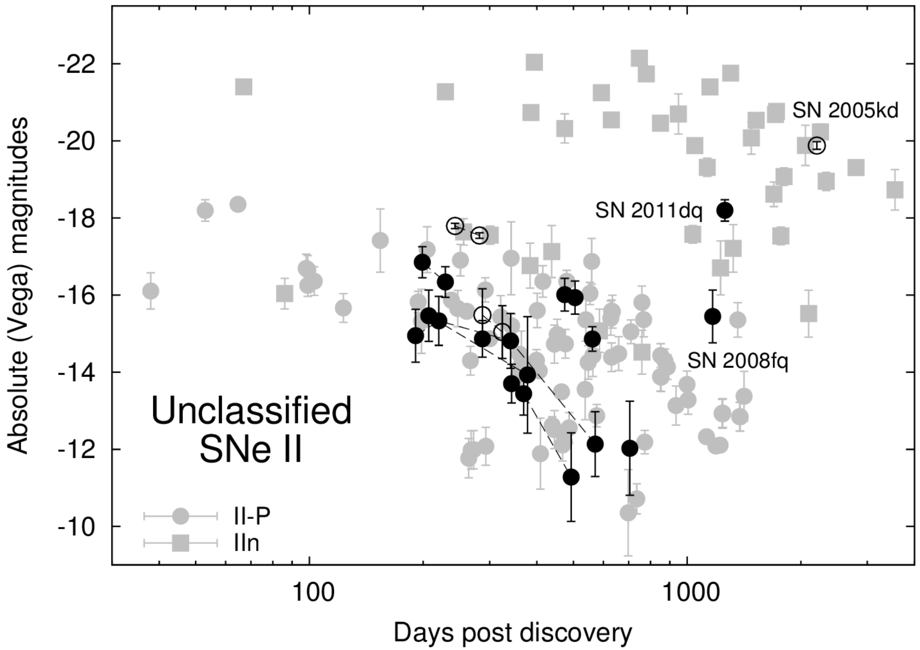
  → although, only a single-epoch, single-channel image



Type II-P SNe

- Mid-IR re-brightening:
    - Dust-formation in the ejecta (~300-500d)
    - CSM-interaction (~800-1000d)
- What is the reason of heterogeneity?





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  - Dust-formation in the ejecta (~300-500d)
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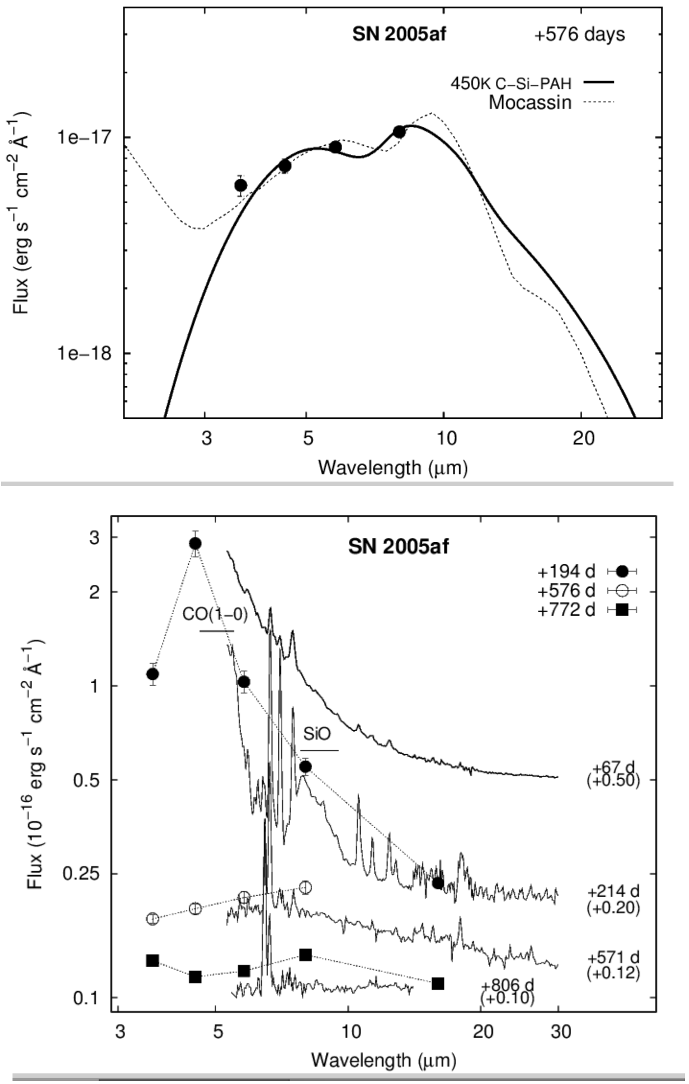
(Possible post-classification of Type II SNe ...)

Modelling of SEDs

- Spitzer/IRAC 4 channels (+ IRS + MIPS):

  Mid-IR SEDs are valuable at their own

  (dust composition, size and spatial distribution of grains, analytical / numerical dust models, ...)



Szalai & Vinkó 13

Modelling of SEDs

- Spitzer/IRAC 4 channels (+ IRS + MIPS):

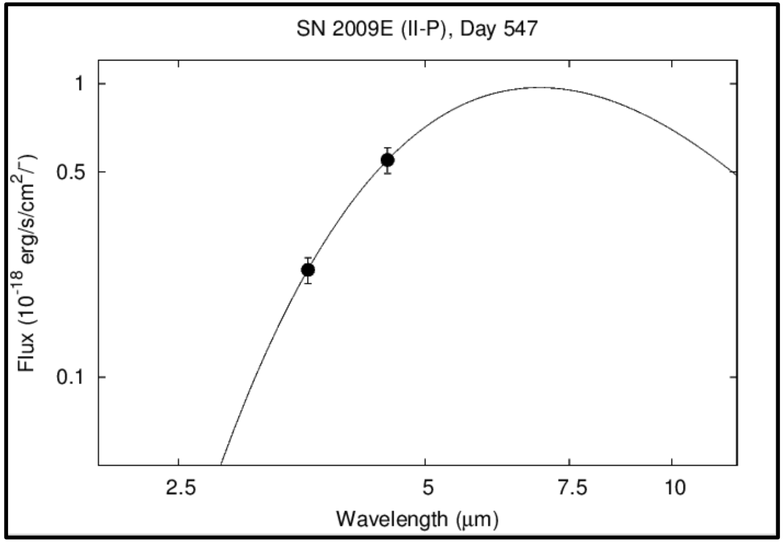
  Mid-IR SEDs are valuable at their own

  (dust composition, size and spatial distribution of grains, analytical / numerical dust models, ...)

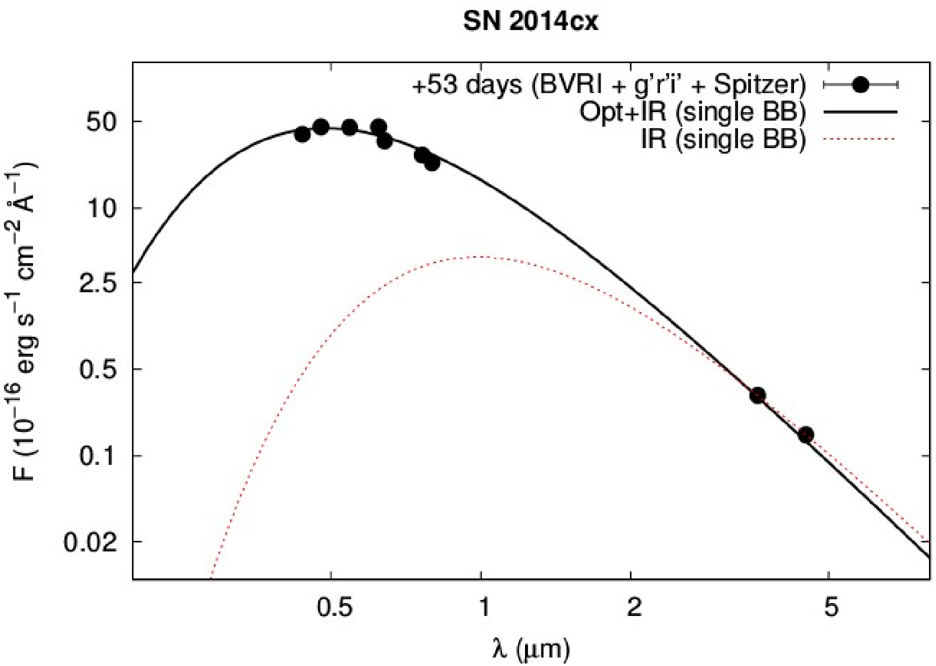
- Spitzer/IRAC 2 channels (since 2009):

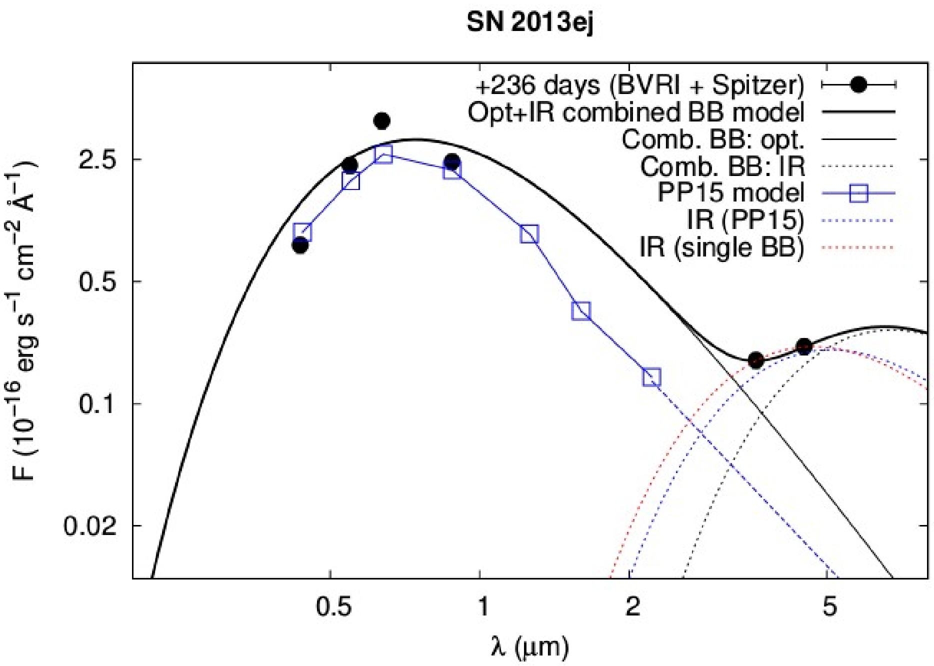
  Fitting blackbodies (or simple dust models)

  BB models → *minimum* size of dust forming region → disentangling btw. possible scenarios



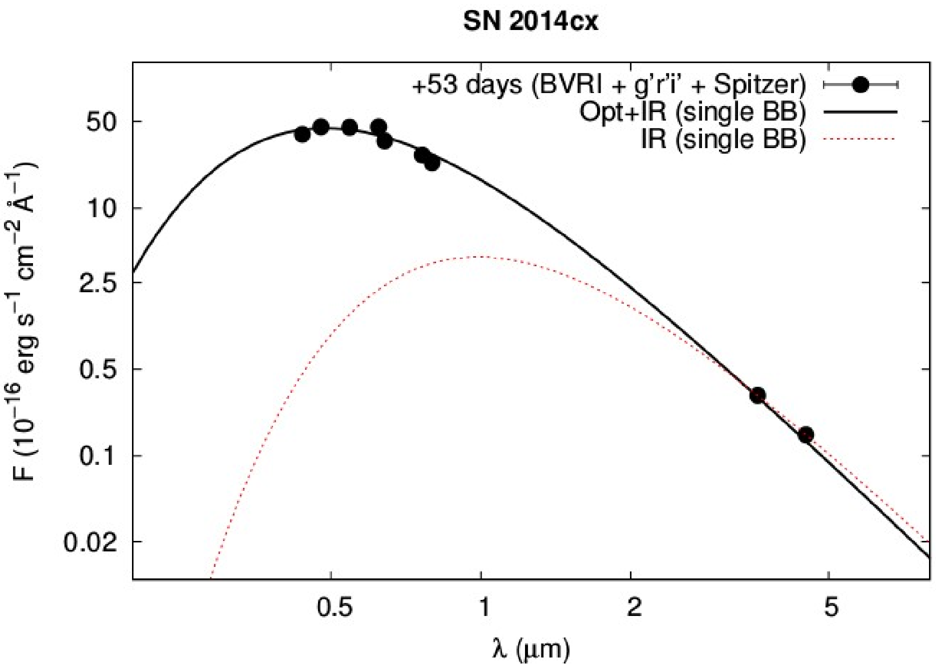
Further constraints on SED modeling

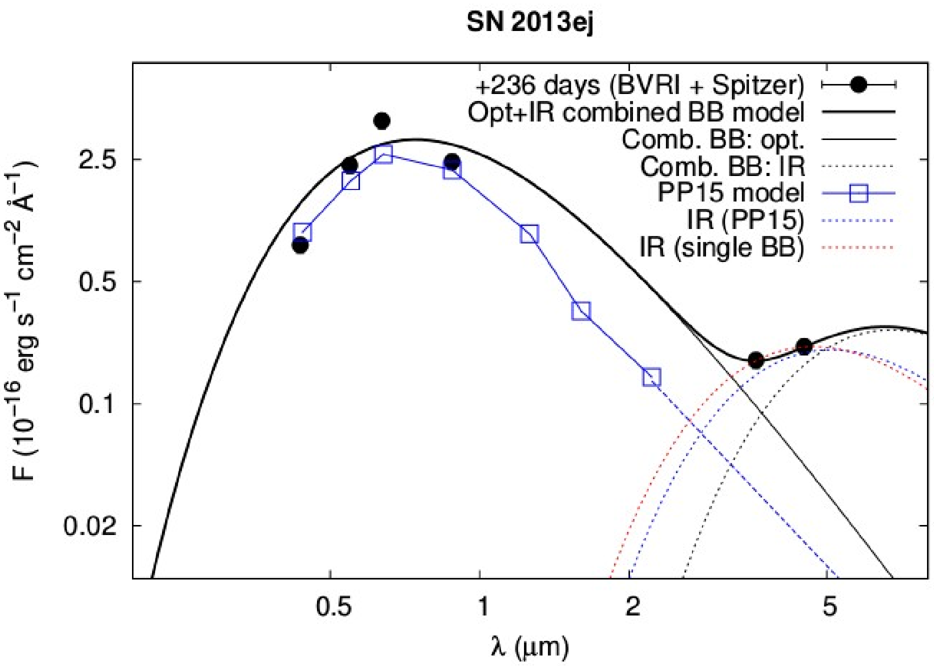




Opt-IR atmospheric model calculations based on Pejcha & Prieto (2015)

Constraints on SED modeling





Opt-IR atmospheric model calculations based on Pejcha & Prieto (2015)

Ideal case („dream"): simultaneous Opt-NIR-MIR datasets (photometry + spectra) → JWST?

Summary

- A comprehensive study on Spitzer/IRAC data of SNe, including high number of objects catched by non-SN targeted surveys (Szalai et al. in prep.)
- A **~5x enlargement** in number of studied SN sites (~200 → ~1100), an **~1.7x enlargement** in positive detections (~70 → ~120) (even larger rate regarding Type Ia and SE CC Sne)
- Photometric analysis / re-check of the complete sample
- **Number of identified CSM-interacting objects is still low (<10%); at the same time, each of such detections would be valuable**
- **Potential role of Spitzer in the future: trace for special devices (e.g. JWST) in observing CSM-interacting SNe**