Exploring the phase space of extra-galactic explosions

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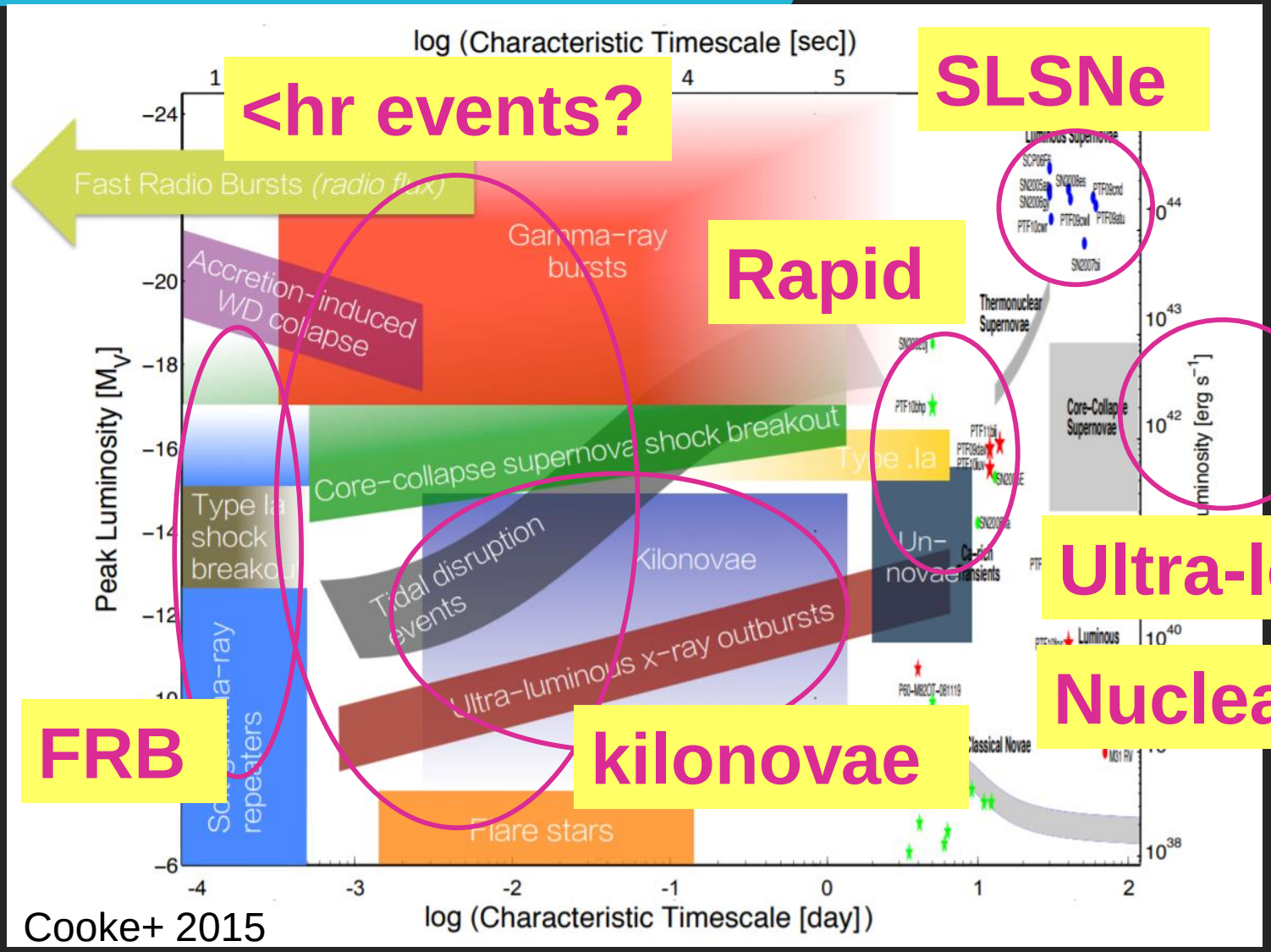
Phase Space



<hr events?

SLSNe

Rapid

Ultra-long

Nuclear

FRB

kilonovae

Cooke+ 2015

A Big Picture

- Census of energetic phenomena in stellar evolution.
- Toward Physics Understanding.

The SN rate in the local Universe

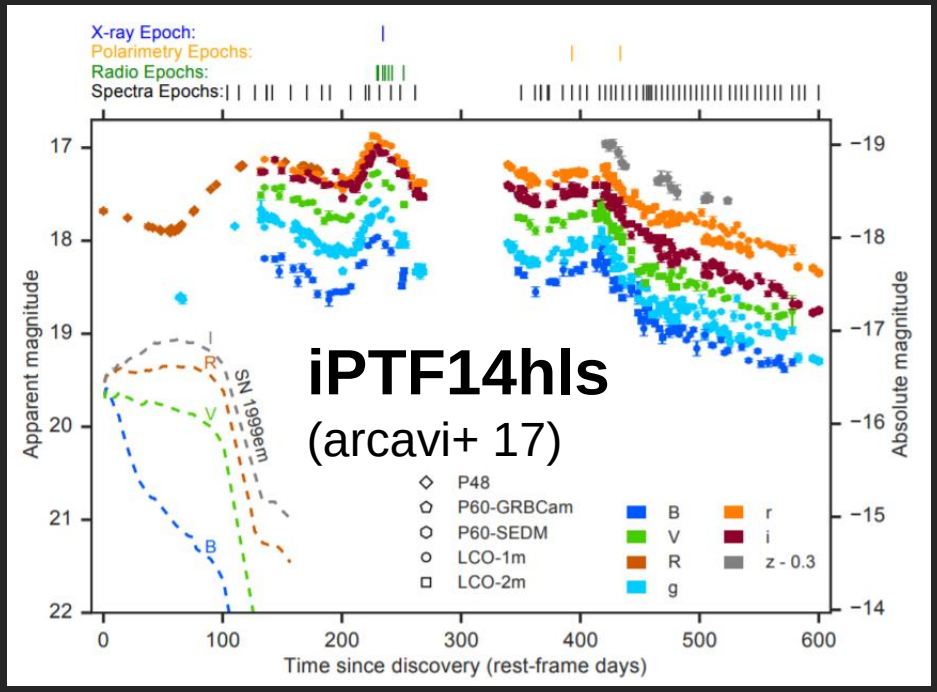
Some numbers

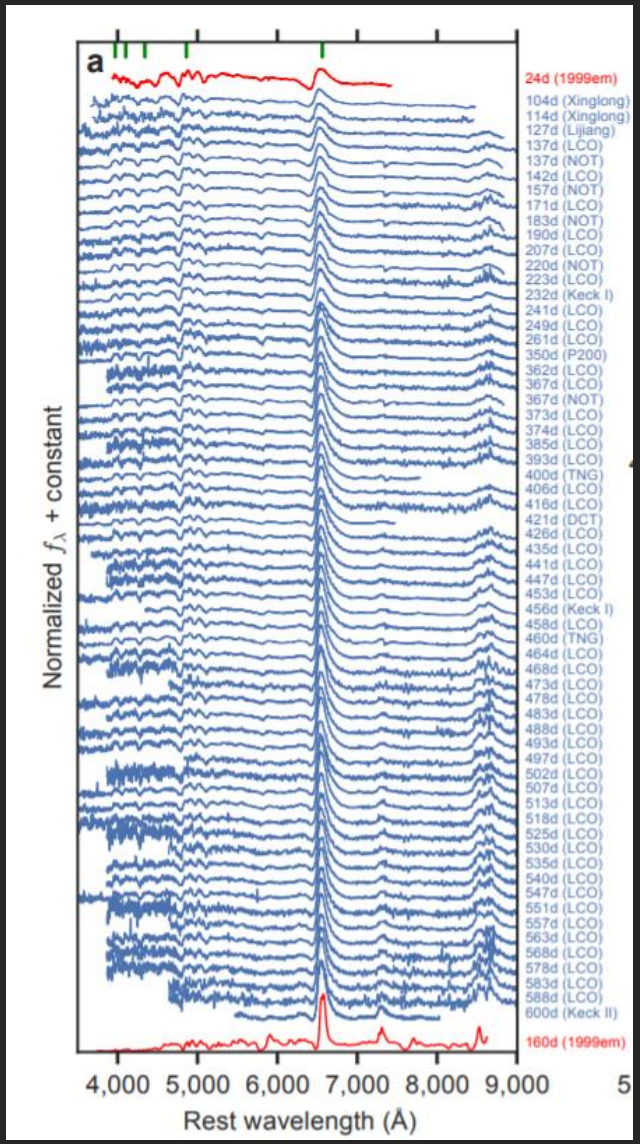
* Numbers for all sky

Distance (Mpc)	Volume (Mpc^3)	# of galaxies	# of SNe (yr^{-1})	mag (abs mag -15 mag)	mag (abs mag -13 mag)
10	4×10^3	40	0.4	15.0	17.0
30	1×10^5	10^3	10	17.4	19.4
50	5×10^5	5×10^3	50	18.5	20.5
70	1×10^6	1×10^4	100	19.2	21.2
100	4×10^6	4×10^4	400	20.0	22.0
200	3×10^7	3×10^5	3,000	21.5	23.5
500	5×10^8	5×10^6	50,000	23.5	25.5

From Masaomi's slide

Super/Ultra-long (14hls, IIn, …)





- "Impossible supernova".
- What are they?
- How common?
- Even longer duration?

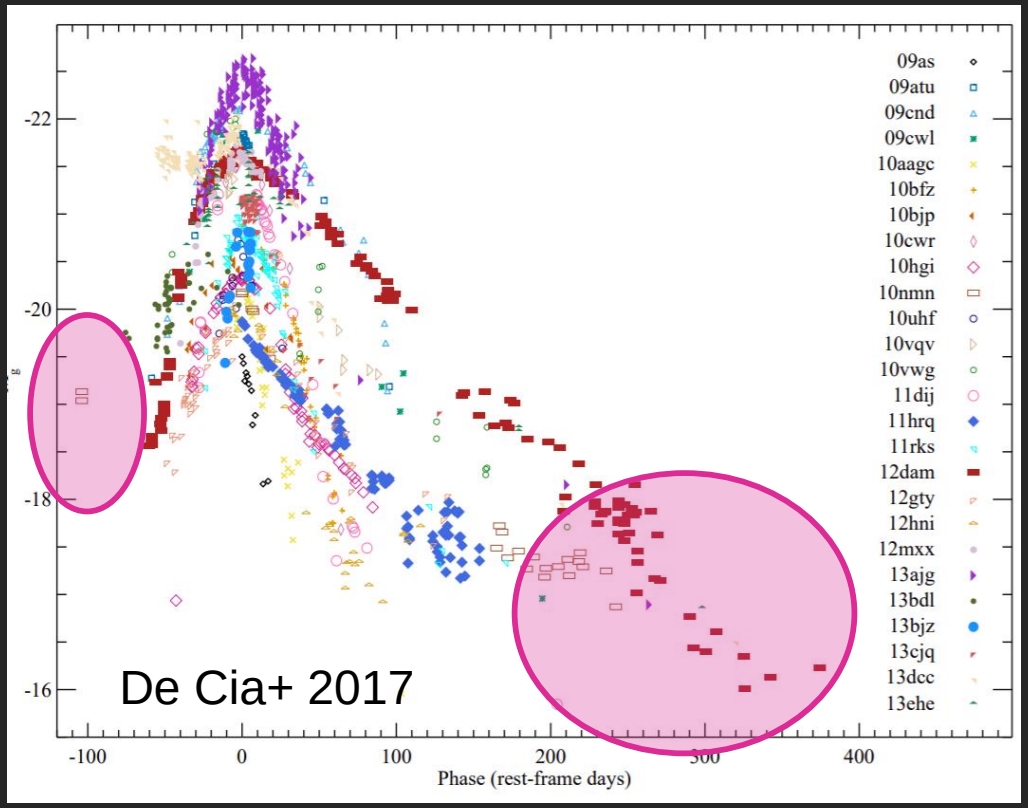
⇒ Still limited by the sample size.

Super/Ultra-long (14hls, IIn, …)

- **More sample needed. ZTF (HSC =>LSST but too deep?)**
- If -17 mag, then up to ~ 300 Mpc for m_{lim}=21 mag.
- If 0.1% of CCSNe, then ~ 5 / year expected by ZTF/public?
- **Co-add survey data? 1 mag deeper⇒ x4 efficiency.**
  - **Exercise with archival long-baseline data (OGLE, Catalina)?**

- **Need a good strategy for identification.**
  - IIn's are trivial if spectrum is taken.
  - 14hls-like. Simply rely on long-baseline light curve?
  - It might look like boring initially – unbiased classification important (but ~ 21-22 mag). Is low-resolution classification sufficient? (also for nuclear transients?)

Super-luminous SNe, especially of type-I



- What are they?

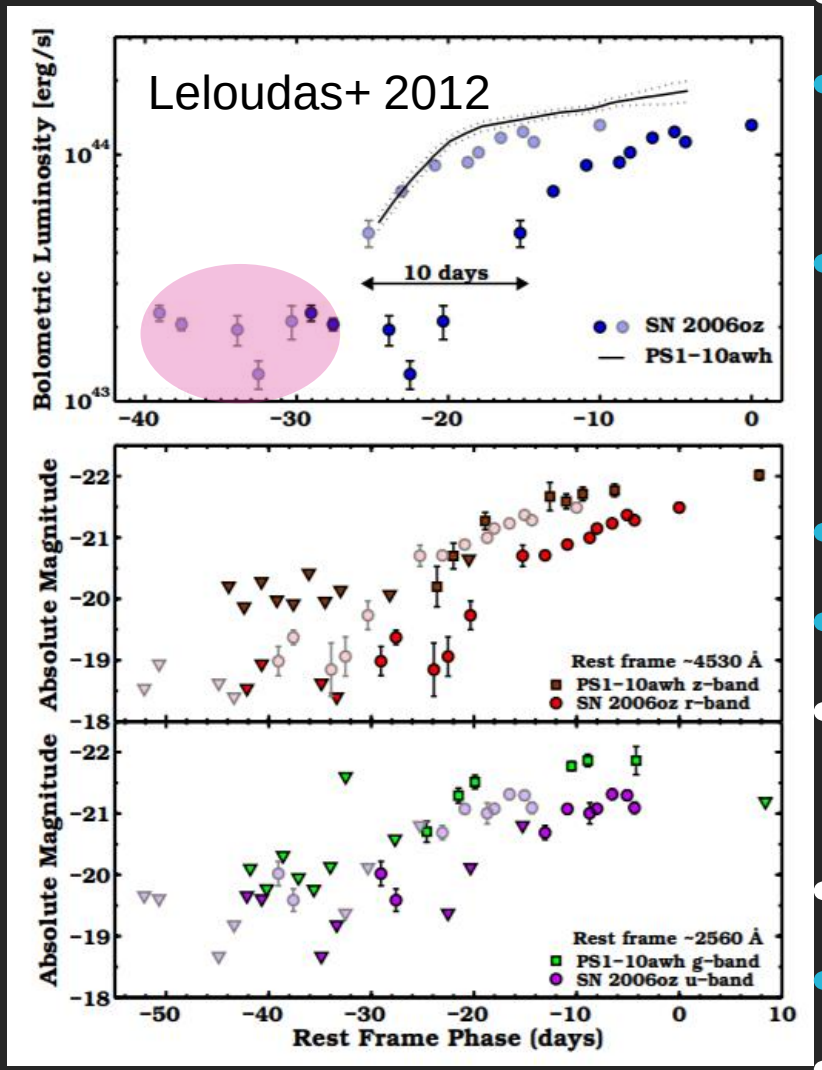
⇒ Central engine(s)?

  - Magnetar, BH, or anything?

- Light curve:
  - Any model can do it.
- (Maximum) Spectra:
  - No really robust model.

- Go for data quality, not quantity (just LSST).
  - Nebular (direct physics).
  - Non-optical (radio, X).
    - Follow-up.
  - Precursor.
    - Survey + follow-up.

Precursors in SLSNe-I (and IIn/SN imposter)



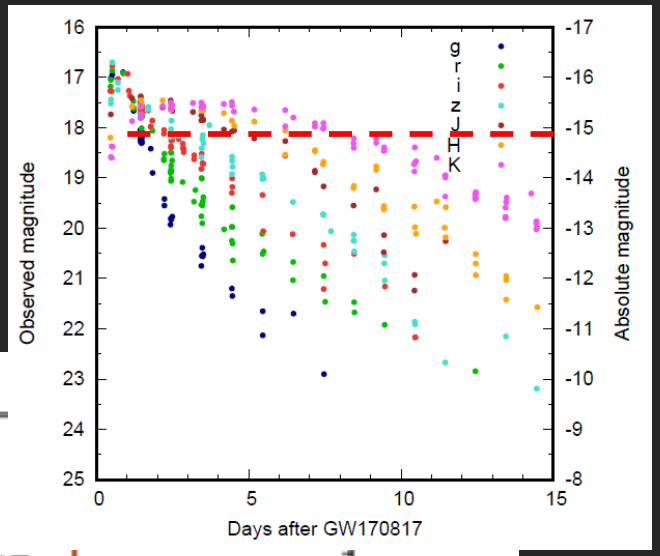
- ~50% of SLSNe-I (and most IIn?).
- Origin unclarified (pre-SN activity for IIn?).
- Unexplored – may contain key information.

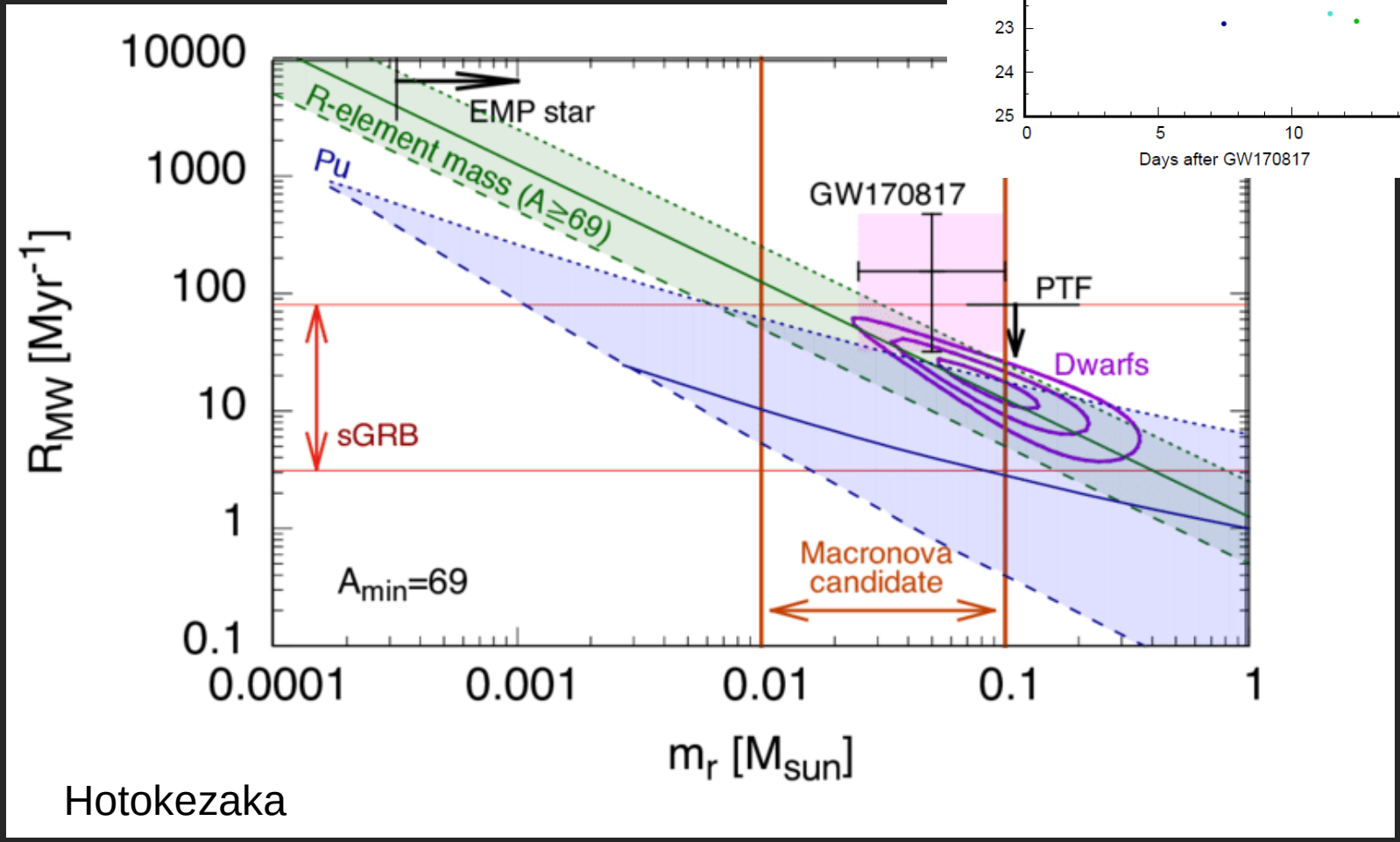
- -19 mag for 10 days (~ SNe Ia).
- SLSN-I rate/SN Ia ~ 0.1-1%.
- ZTF-public will likely be able to detect a few / year.
- Confusion with “boring” SNe Ia?
- Spectra unknown. Blue.
- Unbiased classification or color?

Kilonovae/Macronovae (NS-NS/BH mergers)

- **Diversity, with a goal to identify if this is enough for the r-process. NS-BH?**
- **Trivial direction: Get more samples.**
- Identify a robust candidate(s) without GW.
  - Even the ZTF-public survey is not enough?
  - Need (less-than) one-day cadence.
    - ZTF-private – 21 mag, 6000 deg. Up to 150 Mpc?
    - Tomo-e (18 mag / 2 hrs, 19 mag/ one day).
    - ~1000 SNe / year ⇒ ~ a few / year???
    - Identification and follow-up? Must be quick (and NIR).

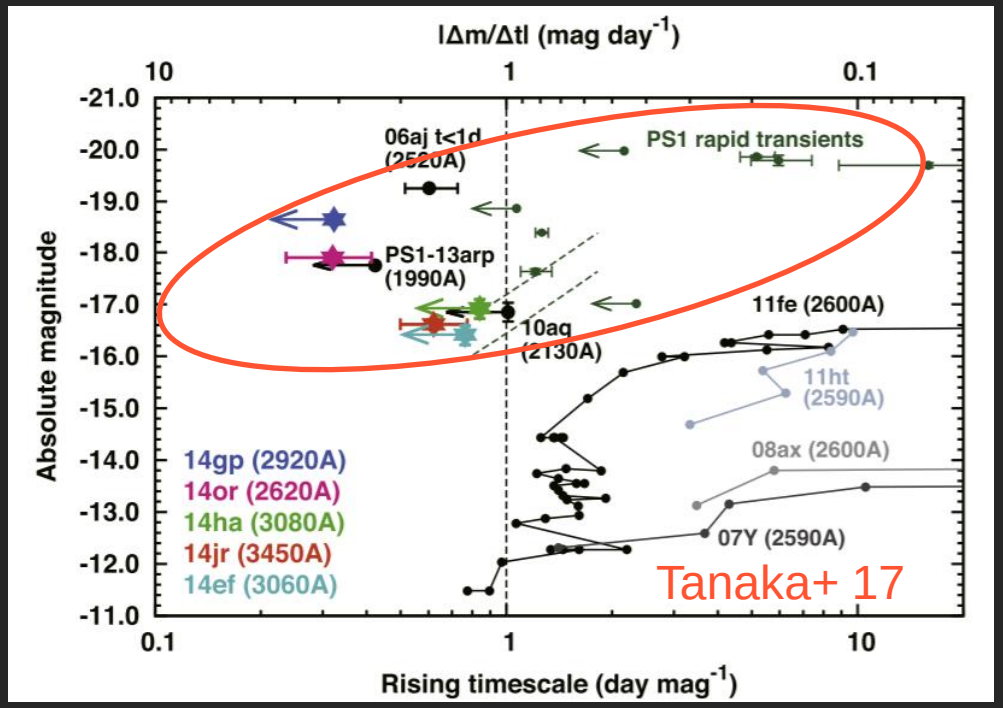
21 mag @ 150Mpc

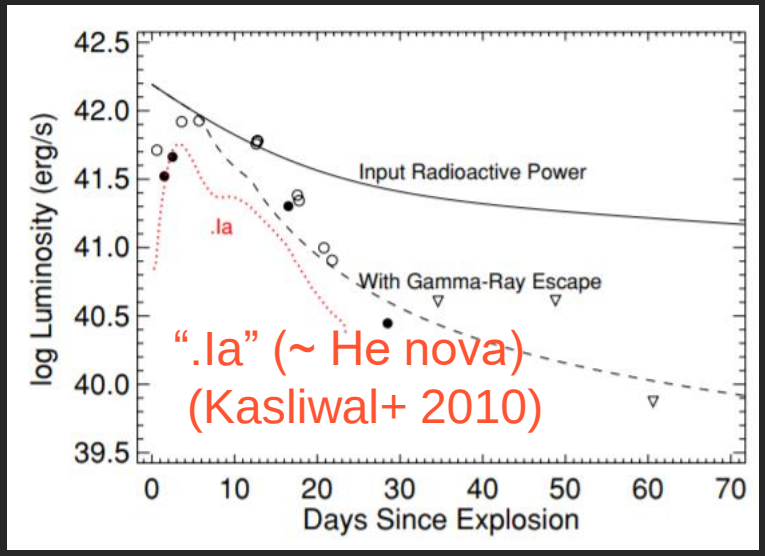


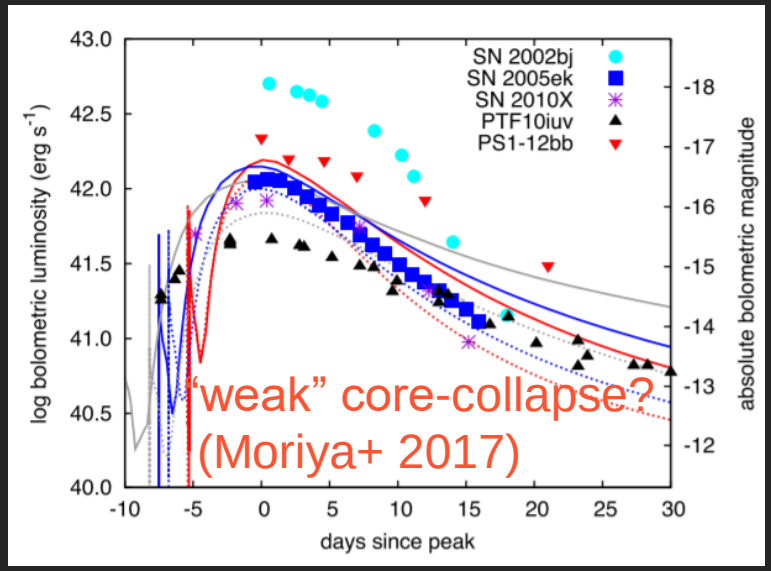


Hotokezaka

Rapid Transients (faint to luminos)







Origin(s)?

Multiple population?

Survey sufficient.

Quick follow-up key.

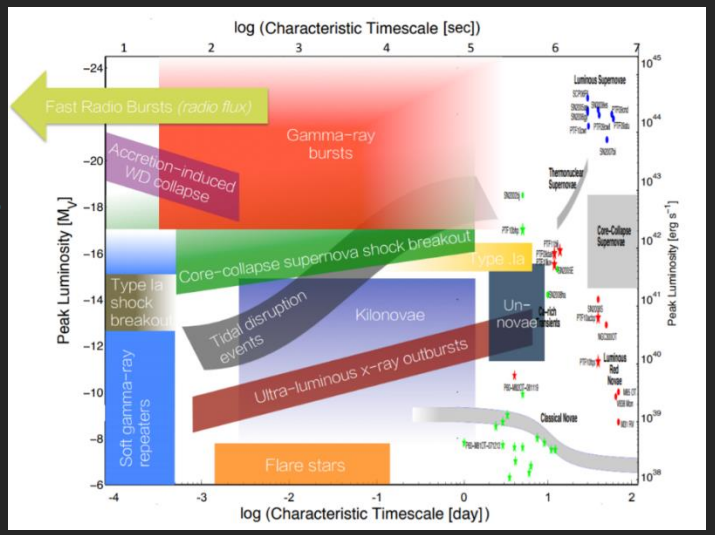
Rapid Transients

- **(Unbiased?) Spectroscopy in the discovery night.**
- A strategy NOT to miss these objects in rapid spectroscopic follow-up.
  - **Unbiased classification.**
  - **Use of galaxy catalog?**

+ Multi-phase + Multi-wavelength:

- Deeper follow-up in the later phase? 8m KECK/Subaru (⇒Thermonuclear vs. CC).
- UV, Radio and X-rays (⇒2018cow!).

Super-short duration



- **If 2 hr, R < ~10^{14}cm.**
- **If 1 min, R < ~10^{12} cm.**
- **New phase space.**
  - ZTF: 21 mag / 2hr.
  - Tomo-e (CMOS): 18 mag / 2hr.
  - Tsinghua (CMOS, simulataneous 4 bands): 16 mag / 2hr.
- **Once “repeating” objects are identified, go deeper.**
  - Kyoto-Seimei: 3-band simultaneous CMOS to come.
  - CMOS on 8m?
  - Example: FRB (even simultaneous radio/optical).

Further unknowns for unexplored space

- **Long and faint as another direction (weak, SN imposters, …).**
- **Non-optical yet another direction (?).**

- ZTF-like surveys should work, but we may further want dedicated surveys.
  - Failed-SN survey-like discovery strategy (deep and local)? LSST should in principle be able to do it.
  - NIR/IR wide-field survey (probably they are cool, may form dust)? WFIRST, PRIME, ULTIMATE-Subaru Etc.

Projects/Strategies (as a Summary)

	mag	Survey	Follow-up	Non-optical	Note
Ultra-long (e.g., 14hls-like)	21 22	ZTF-pub, 5 / yr Co-add 20 / yr	Unbiased 8m-class	-- --	“Boring” IIp --
SLSNe, precursor	21	ZTF-pub, a few / yr	Unbiased or color	If possible	“Boring” Ia
SLSNe, main-late		--	8m	yes	Rare nearby
Kilo/Maclonovae	21	ZTF-private, a few / yr?	Unbiased or color	If possible	+GW trigger
Rapid transients	19	--	Unbiased or galaxy	yes	Deeper for Later-phase
Shortest	?	ZTF-private 2hr Tomoe even shorter	To see? CMOS	?	To see
Faint (and long)	>21	ZTF LSST	8m TMT/GMT	-- --	To see
Non-optical (NIR)	?	PRIME WFIRST, Ult.-Subaru	8m, JWST TMT/GMT	Radio? --	To see