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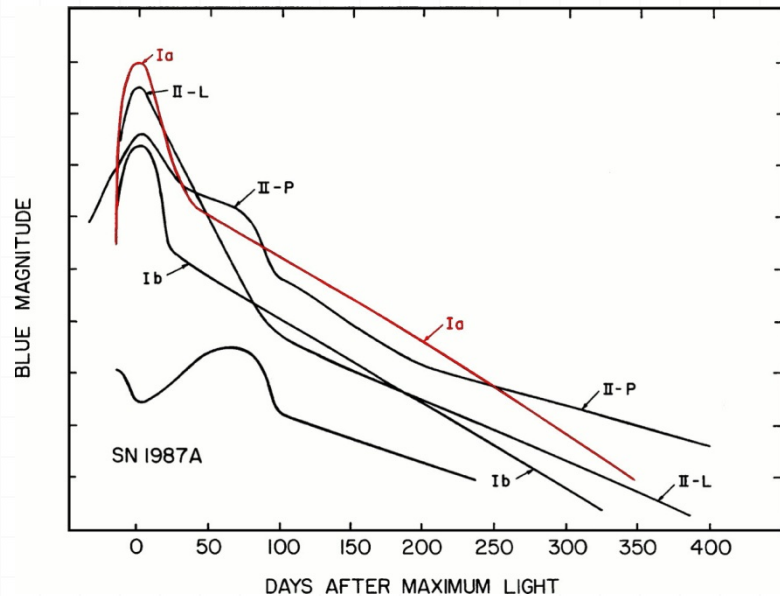
Type Ia SN Light Curves:

Slow Decliners,
Super-Ch Candidates,
and Super-Ch-Mass Models

Type Ia Supernovae (SNe Ia)

Observations

- light curves (LCs)
 - rising time ≈ 20 days
 - $M_{V,\text{peak}} \approx -19.3$ mag



(Filippenko '97, ARAA, 35, 309)

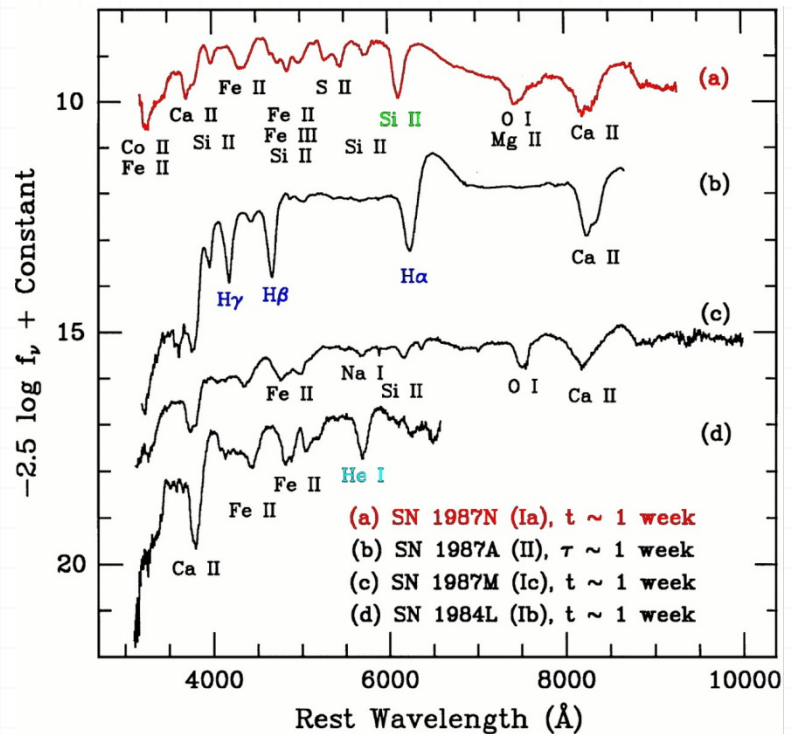
Type Ia Supernovae (SNe Ia)

Observations

- (early-time) spectra

- absence of H & He

- presence of strong Si



(Filippenko '97, ARAA, 35, 309)

SNe Ia

o Theory

o explosion

o thermonuclear

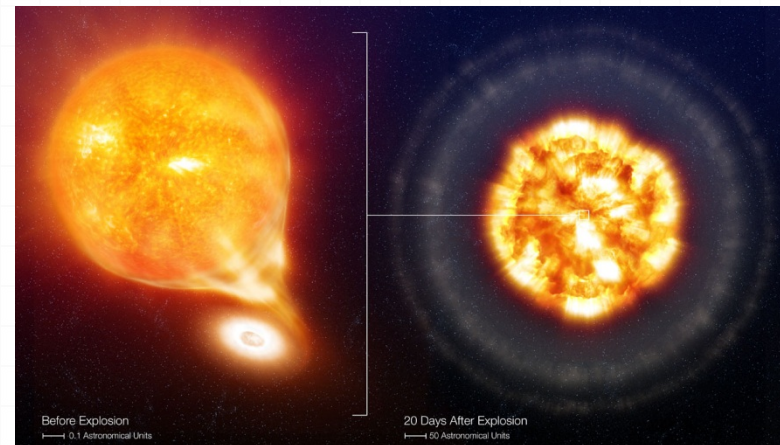
o $E_{\text{kin}} \approx 10^{51}$ erg

o progenitor

o CO white dwarf (WD)

o in a close binary system

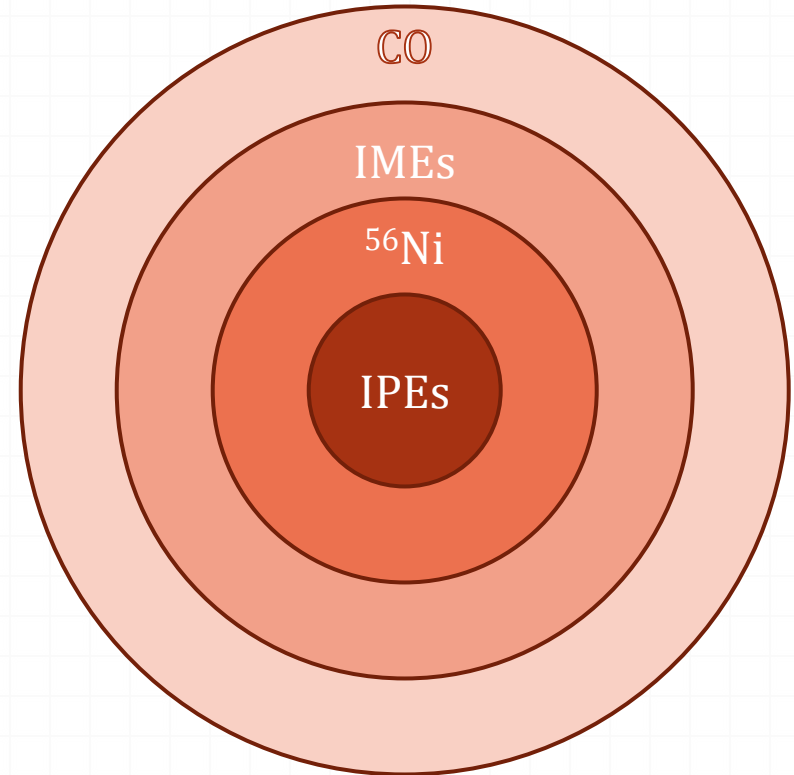
o $M \approx$ Chandrasekhar mass
($M_{\text{Ch}} \approx 1.4 M_{\text{Sun}}$)



(<http://www.eso.org/public/news/eso0731/>)

SNe Ia

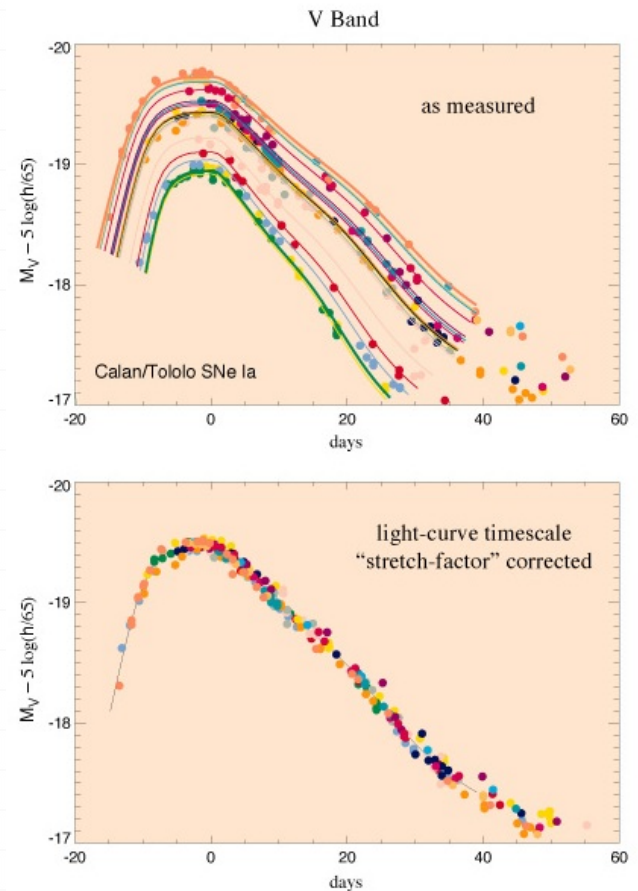
- Theory
 - nucleosynthesis
 - Fe-peak elements (IPEs)
 - ^{56}Ni
 - heating source
 - $\approx 0.6 M_{\text{Sun}}$
 - Intermediate mass elements (IMEs)
 - unburnt CO



Pskovskii-Phillips Relation

- Inhomogeneous LCs
 - renormalization
 - cosmological use
 - correlation between peak magnitudes & LC shapes
 - e.g., Pskovskii ('77), Phillips ('93)
 - *empirical*

(Perlmutter+ '98, arXiv:astro-ph/9812473)

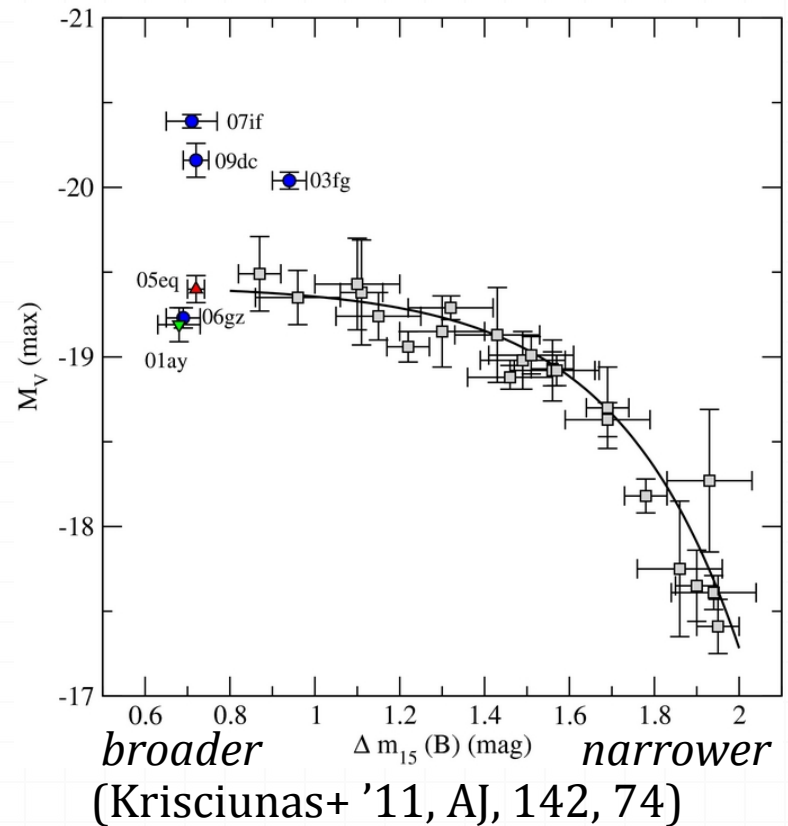


Pskovskii-Phillips Relation

○ $M(X)_{\text{peak}}$ vs. $\Delta m_{15}(X')$

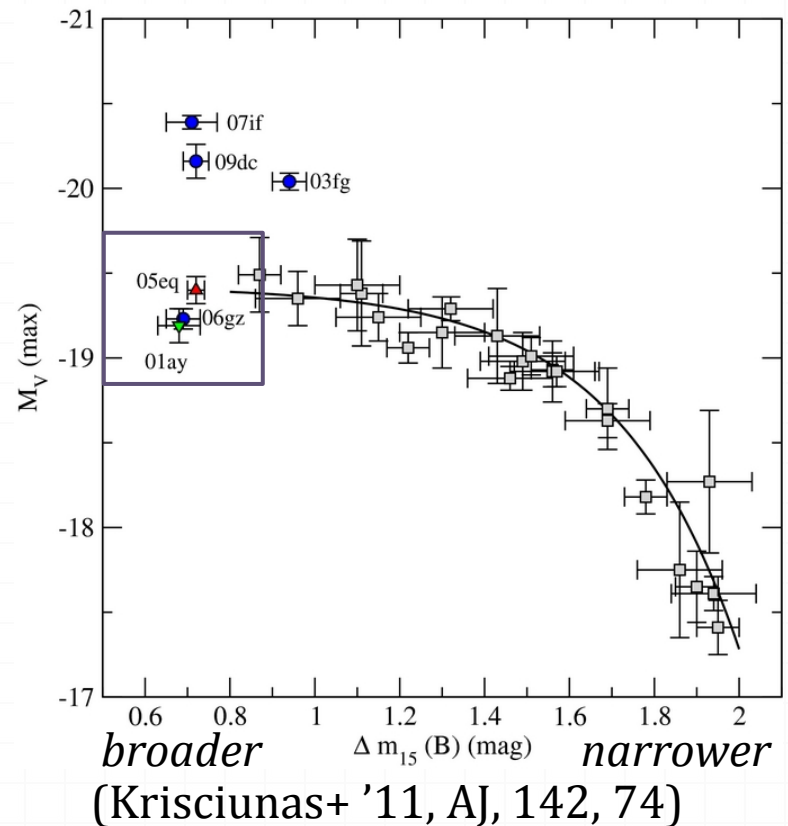
○ $\Delta m_{15}(X') \equiv$

$$m(X')_{\text{peak+15days}} - m(X')_{\text{peak}}$$



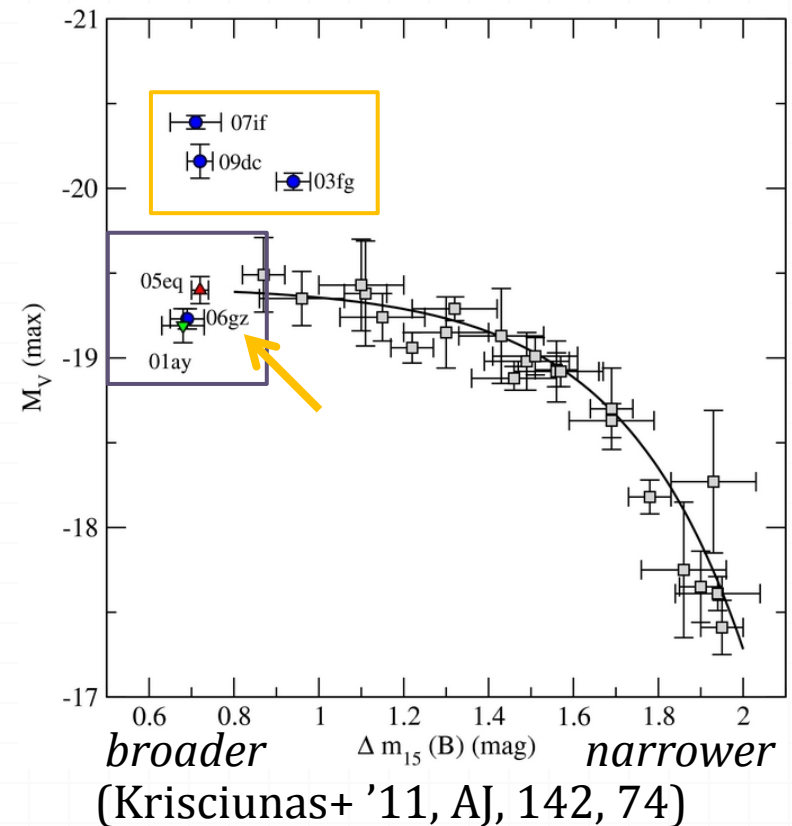
Pskovskii-Phillips Relation

- $M(X)_{\text{peak}}$ vs. $\Delta m_{15}(X')$
- $\Delta m_{15}(X') \equiv m(X')_{\text{peak}+15\text{days}} - m(X')_{\text{peak}}$
- “slow decliners”
- SNe '01ay, '05eq, '06gz, ...



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- $\Delta m_{15}(X') \equiv m(X')_{\text{peak+15days}} - m(X')_{\text{peak}}$
- “slow decliners”
 - SNe '01ay, '05eq, '06gz, ...
- super-Chandrasekhar (super-Ch) candidates
 - SNe '03fg, '06gz, '07if, '09dc



Pskovskii-Phillips Relation

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- $\Delta m_{15}(X') \equiv m(X')_{\text{peak}+15\text{days}} - m(X')_{\text{peak}}$

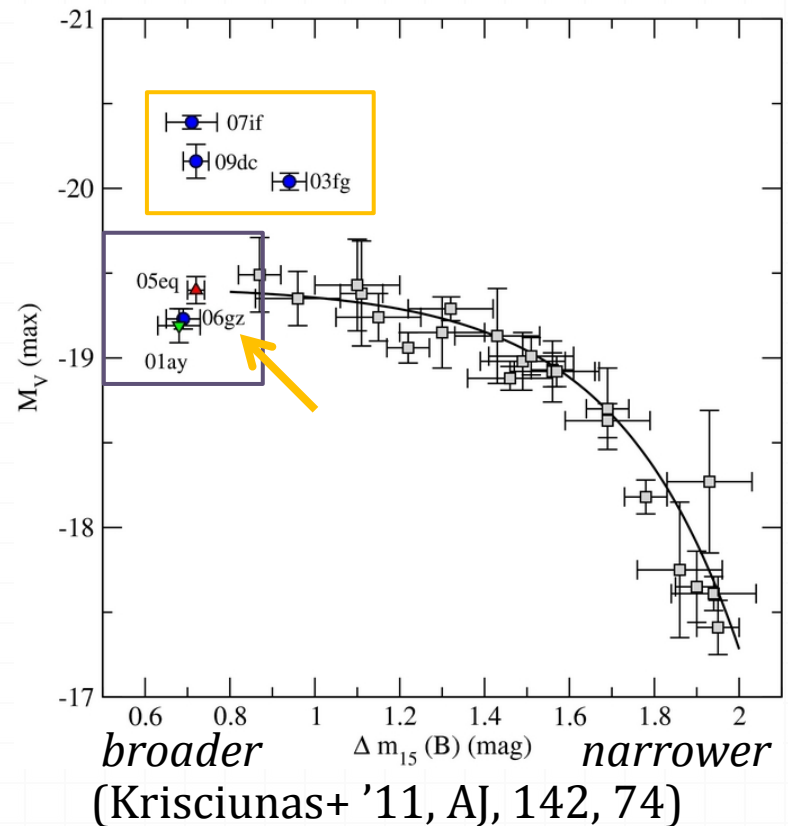
○ “slow decliners”

○ SNe '01ay, '05eq, '06gz, ...

○ super-Chandrasekhar (super-Ch) candidates

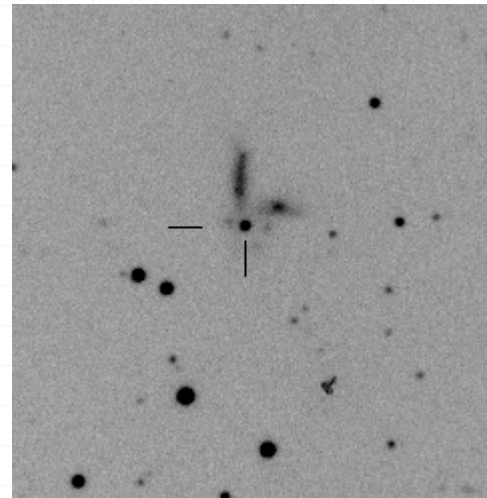
○ SNe '03fg, '06gz, '07if, '09dc

Related?



Another One

- o SN 2011aa
 - o Type Ia
 - o discovered on Feb. 6
(CBET 2653)
 - o host galaxy = UGC 3906
 - o pair of PGC 021381
& PGC 021386 (cf. ATEL 3164)
 - o $\mu = 33.56$ mag
($d_L = 51.4$ Mpc; NED)



(<http://www.rochesterastronomy.org/sn2011/sn2011aa.html>)

Another One

o SN 2011aa

o phot. data

o Sahu (pers. comm.)

o $V_{\text{peak}} = 14.7 \text{ mag}$

o $\Delta m_{15}(B) = 0.65 \text{ mag}$

o extinction

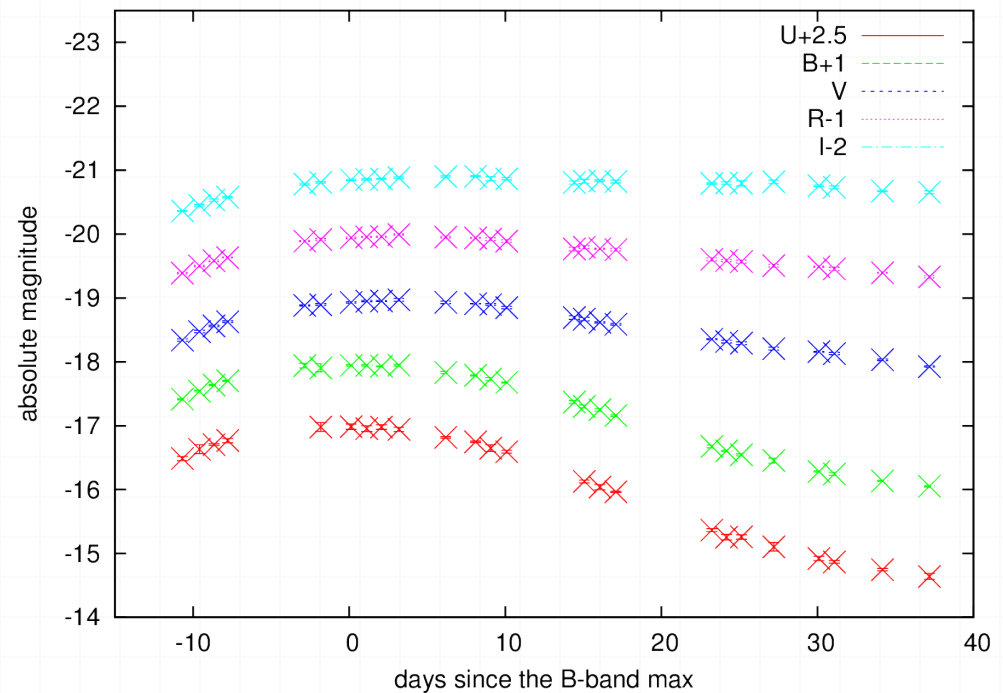
o Galactic

o $E(B - V)_{\text{Gal}} = 0.029 \text{ mag}$
(NED)

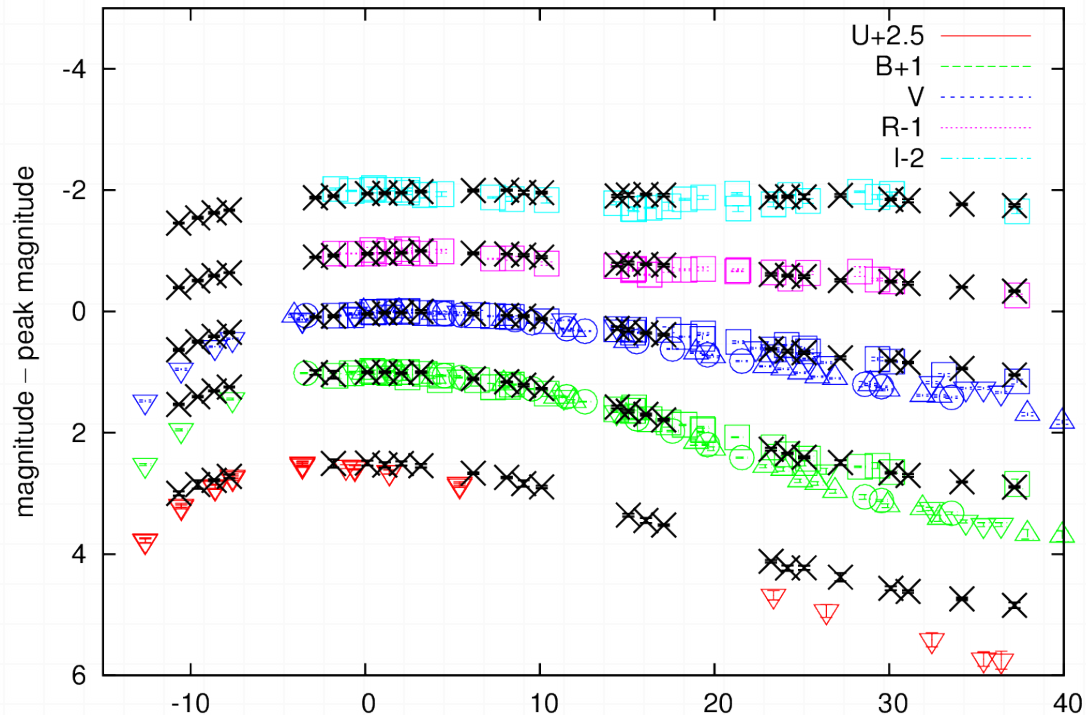
o $R_{V,\text{Gal}} = 3.1$

o host = unknown

→ $M_{V,\text{peak}} \leq -19.0 \text{ mag}$



Another One



× SN 2011aa (Sahu) days since the B-band maximum

□ SN 2001ay (Krisciunas+ '11)

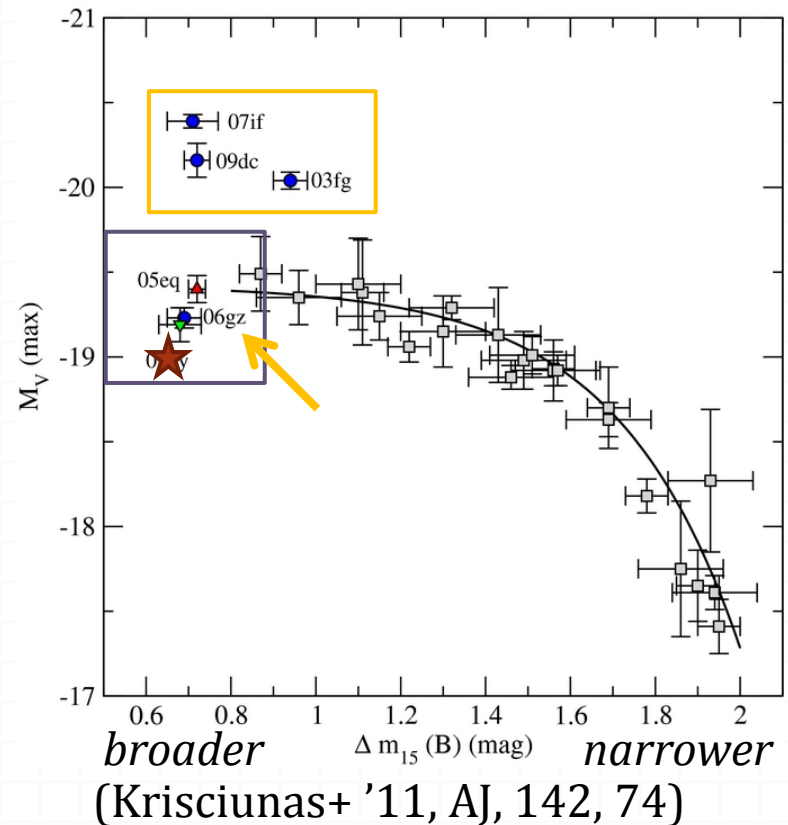
▽ SN 2006gz (Hicken+ '07)

△ SN 2004gu ○ SN 2005eq

(Folatelli+ '10, Contreras+ '10)

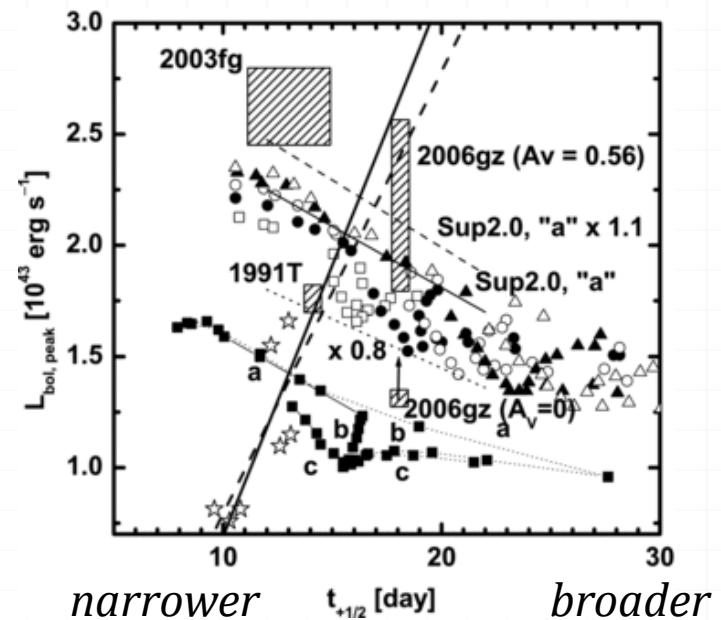
Another One

- SN 2011aa
 - another “slow decliner”
 - $M_{V,\text{peak}} \leq -19.0$ mag
 - $\Delta m_{15}(B) = 0.65$ mag
 - SN 2001ay-like?
 - pulsational delayed detonation?
(Baron+ '12)
 - related to SN 2006gz?
 - super-Ch!



(Super-)Ch-Mass Models

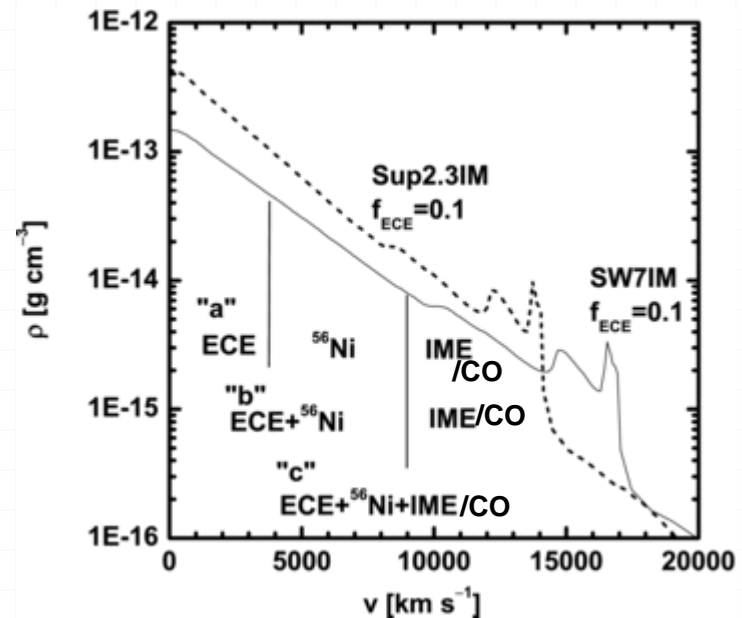
- o Maeda & Iwamoto ('09)
- o SN 2006gz = super-Ch



(Maeda & Iwamoto '09, MNRAS, 294, 239)

(Super-)Ch-Mass Models

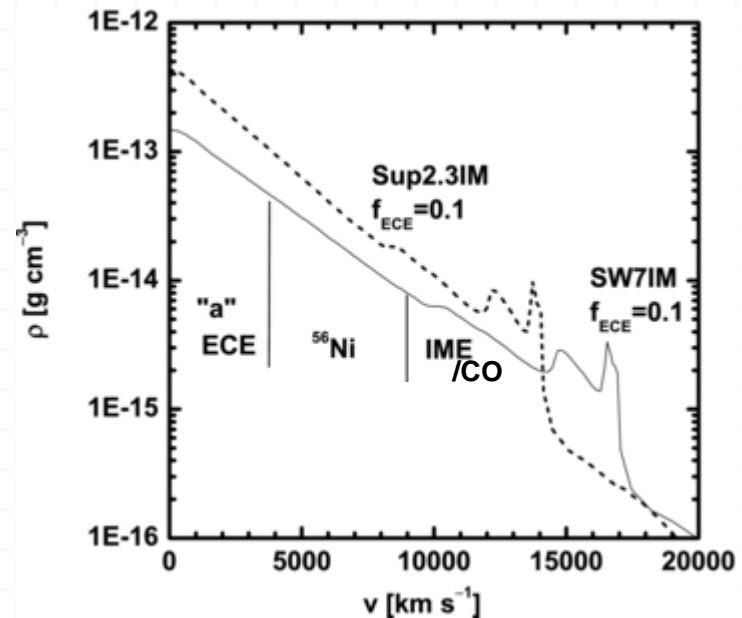
- o Maeda & Iwamoto ('09)
 - o SN 2006gz = super-Ch
 - o 1D models of *exploding WDs*
 - o parameters
 - o {WD, IPE, ^{56}Ni , IME, CO} mass
 - o WD: 1.38, 1.7, 2.0, ..., 2.6 M_{Sun}
 - o ^{56}Ni : 0.6("SW7")/1.0 M_{Sun}
 - o no IME/CO assumed
 - o mixing



(Maeda & Iwamoto '09, MNRAS, 294, 239)

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 - o no IME/CO assumed
 - o ~~mixing~~
 - stratified (onion-like) only for this talk



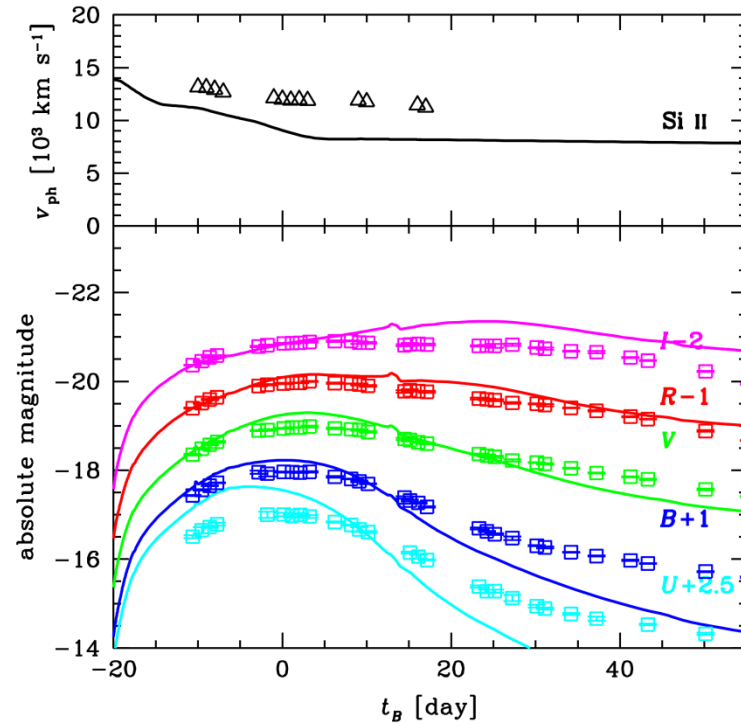
(Maeda & Iwamoto '09, MNRAS, 294, 239)

(Super-)Ch-Mass Models

Model sequence	WD mass [M_{Sun}]	^{56}Ni mass [M_{Sun}]	IPE mass [WD mass]	Assumption
SW7IM	1.38	0.6	0, 0.1, ..., 0.5, 0.57	no CO, no mixing
LW7IM	1.38	1.0	0, 0.1, 0.2, 0.28	no CO, no mixing
Sup17IM	1.7	1.0	0, 0.1, ..., 0.4, 0.41	no CO, no mixing
Sup20IM	2.0	1.0	0, 0.1, ..., 0.5	no CO, no mixing
Sup23IM	2.3	1.0	0, 0.1, ..., 0.5, 0.57	no CO, no mixing
Sup26IM	2.6	1.0	0, 0.1, ..., 0.6, 0.62	no CO, no mixing
SW7CO	1.38	0.6	0, 0.1, ..., 0.5, 0.57	no IME, no mixing
LW7CO	1.38	1.0	0, 0.1, 0.2, 0.28	no IME, no mixing
Sup17CO	1.7	1.0	0, 0.1, ..., 0.4, 0.41	no IME, no mixing
Sup20CO	2.0	1.0	0, 0.1, ..., 0.5	no IME, no mixing
Sup23CO	2.3	1.0	0.1, 0.2, ..., 0.5, 0.57	no IME, no mixing
Sup26CO	2.6	1.0	0.2, 0.3, ..., 0.6, 0.62	no IME, no mixing

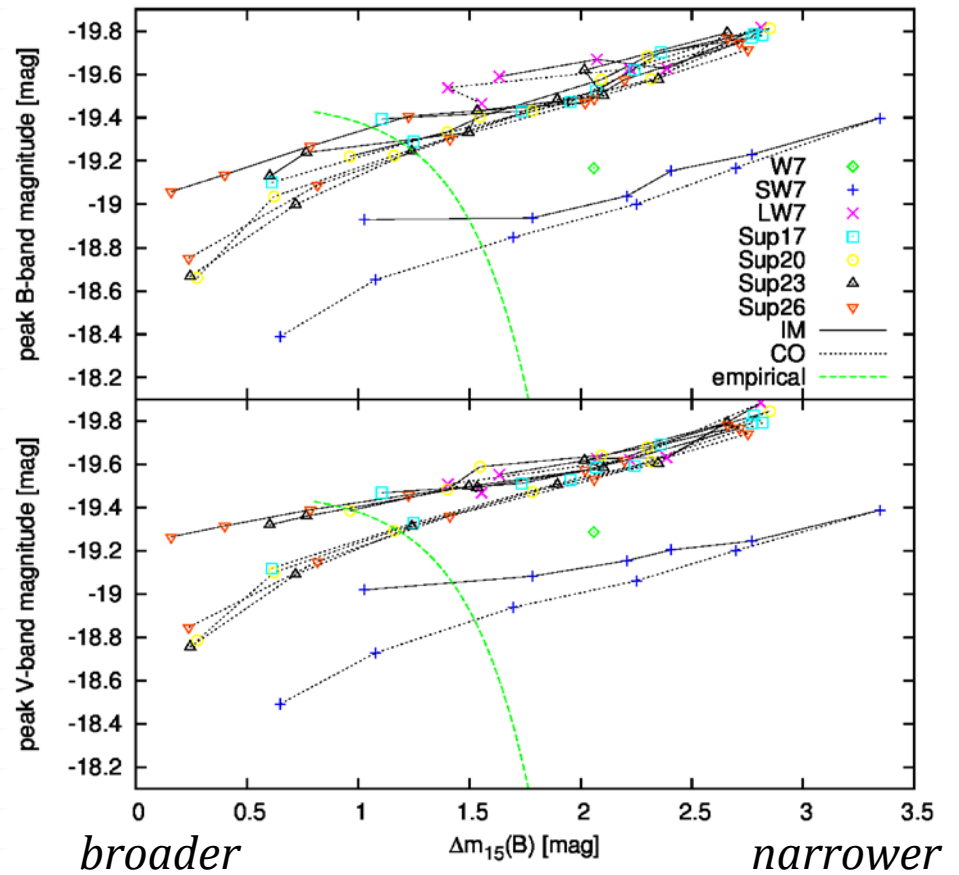
LC Calculations

- o This work
 - o STELLA code
 - o e.g., Blinnikov+ ('06)
 - o bolometric & *UBVRI*



(one of the stratified $2 M_{\text{Sun}}$ WD models)

Preliminary Results



Preliminary Results

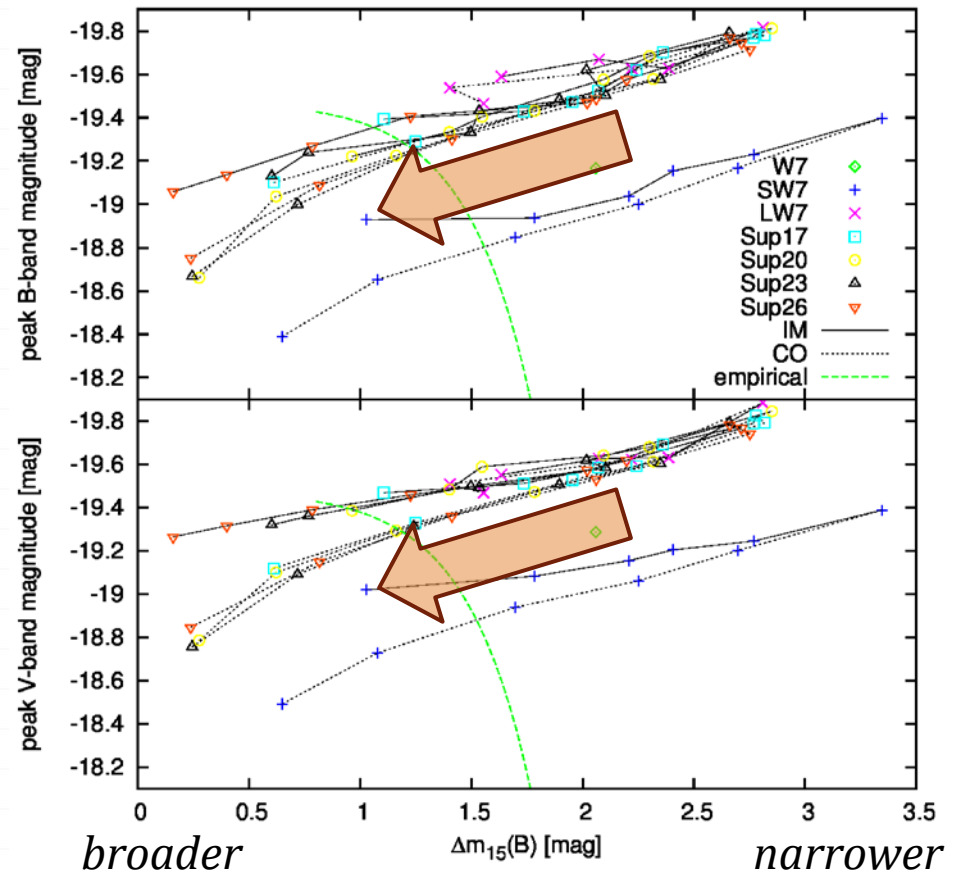
Trends

○ for the same WD mass

○ more IMEs/CO
(less IPEs)

➔ broader & fainter

○ $\tau_{LC} \propto \kappa^{1/2} M_{WD}^{3/4} E_{kin}^{-1/4}$
(Arnett '82)



Preliminary Results

Trends

○ for the same WD mass

○ more IMEs/CO
(less IPEs)

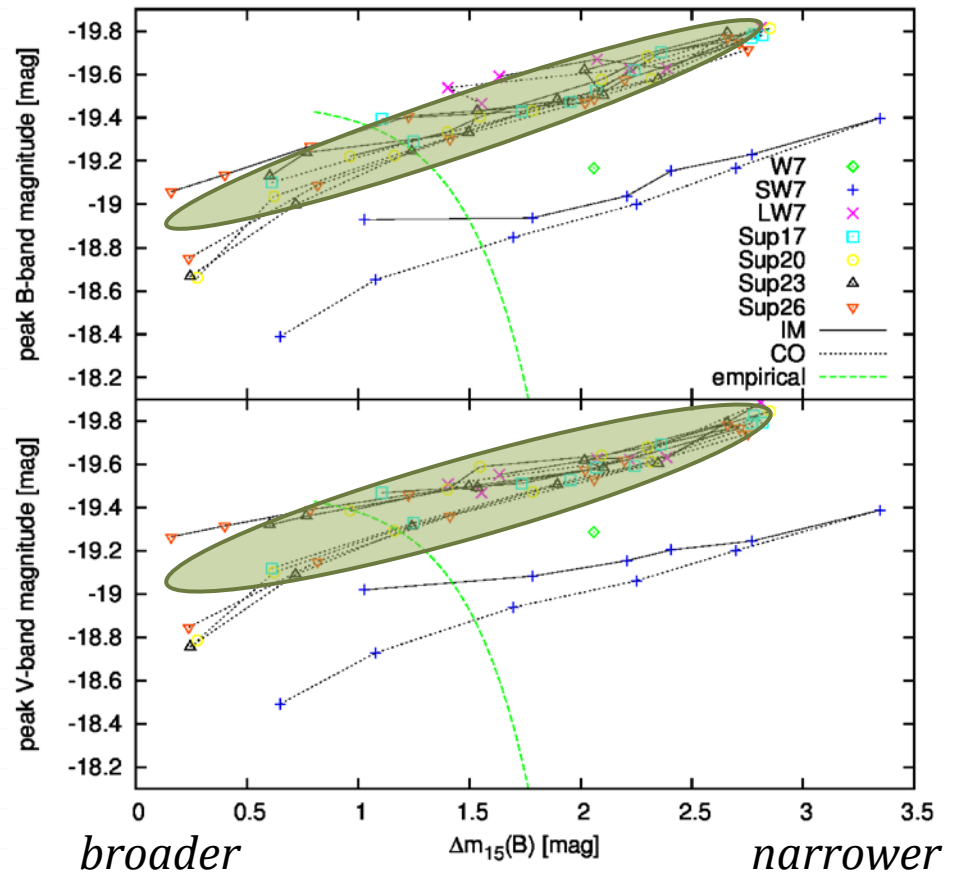
➔ broader & fainter

$$\tau_{\text{LC}} \propto \kappa^{1/2} M_{\text{WD}}^{3/4} E_{\text{kin}}^{-1/4}$$

(Arnett '82)

○ for the same ^{56}Ni mass

○ somewhat degenerate



Preliminary Results

○ Comparison to the obs.

★ SN 2011aa

◆ SN 2001ay

▲ SN 2006gz (super-Ch)

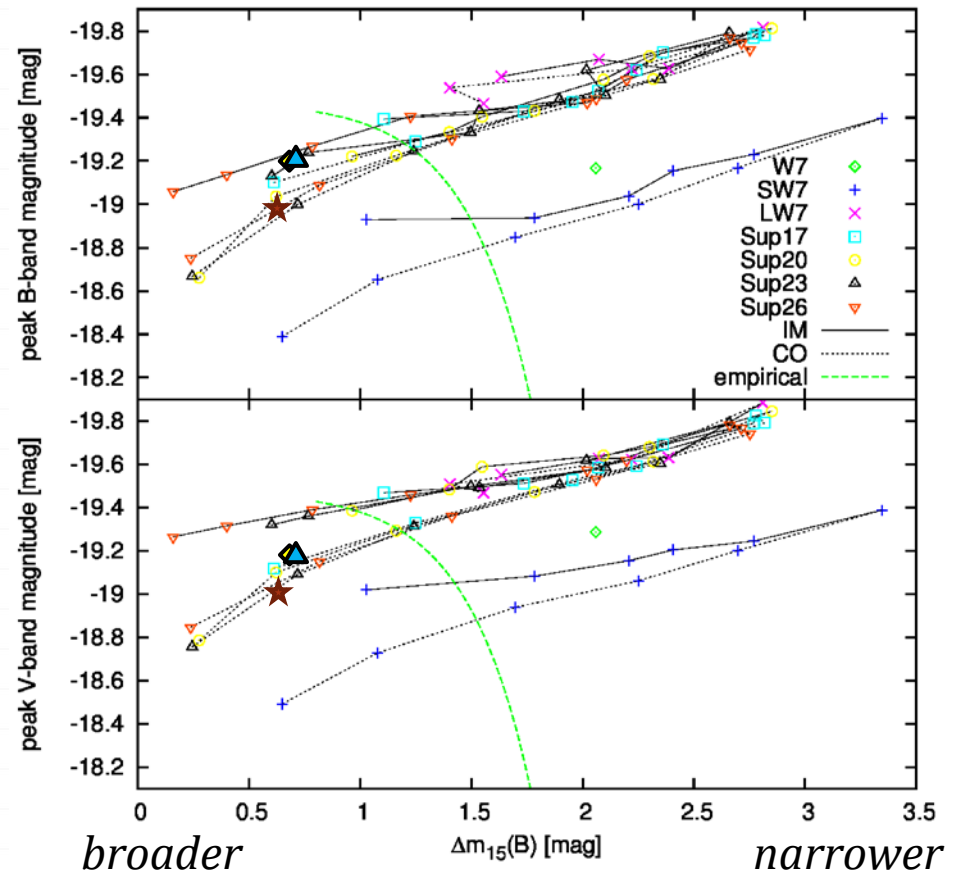
○ Ch-mass models (“SW7”)

○ lying relatively away
from “slow decliners”

○ cf. SN 2001ay

○ PDD model (Ch-mass)

○ $M_{\text{Ni}} \approx 0.5 M_{\text{Sun}}$



Summary

- o “Slow decliners”
 - o at the tip of Pskovskii-Phillips relation
 - o related to (one of) the super-Ch candidates?
- o LC calculations for (super-)Ch-mass models

- o What about ...?
 - o mixing (→ broader)
 - o more detailed obs. data (host-galaxy extinction)

*Thank you very much
for your attention.*