studying the circumstellar medium of SNe Ia in the near-infrared

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DOE CSGF

most SNe Ia do not have CSM

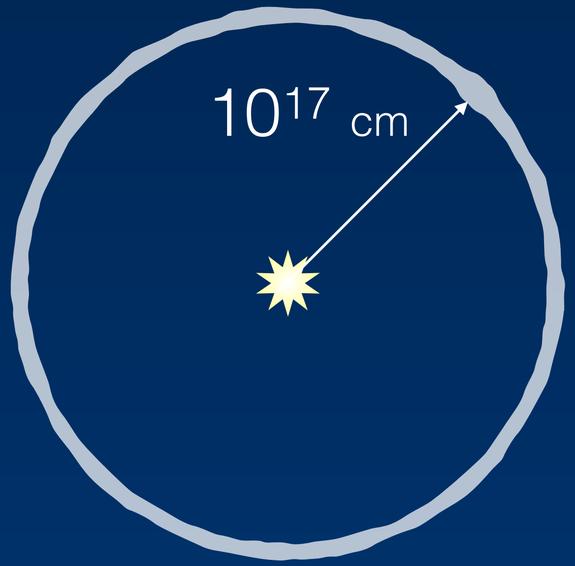
- radio limits (e.g. Chomiuk+ 2016)
- nebular spectra: no H (e.g. Maguire+ 2016)
- delay time distribution (esp. Maoz, loads of papers)
- SN 2011fe: completely normal and very clean environment (Chomiuk+ 2012, Bloom+ 2012, Nugent+ 2012…)

but some do!

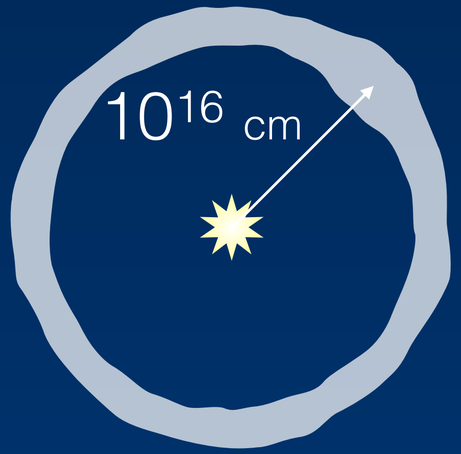
somewhat distant CSM

delayed interaction (DI)

e.g. PTF11kx



distant CSM … or ISM?
Na D absorption
~20% SNe Ia?



SN 2015cp
Graham+ (2018)
Harris+ (2018)
in prep

Ia-CSM
dense CSM
immediate vicinity of SN
e.g. SN 2002ic

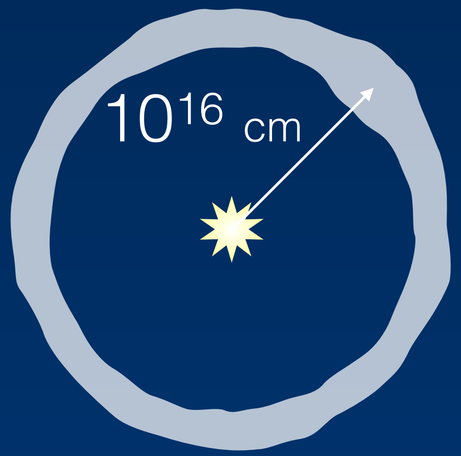
(hypothetical)
within $\leq 10^{13}$ cm
blip in early LC

but some do!

somewhat distant CSM

delayed interaction (DI)

e.g. PTF11kx



Ia-CSM

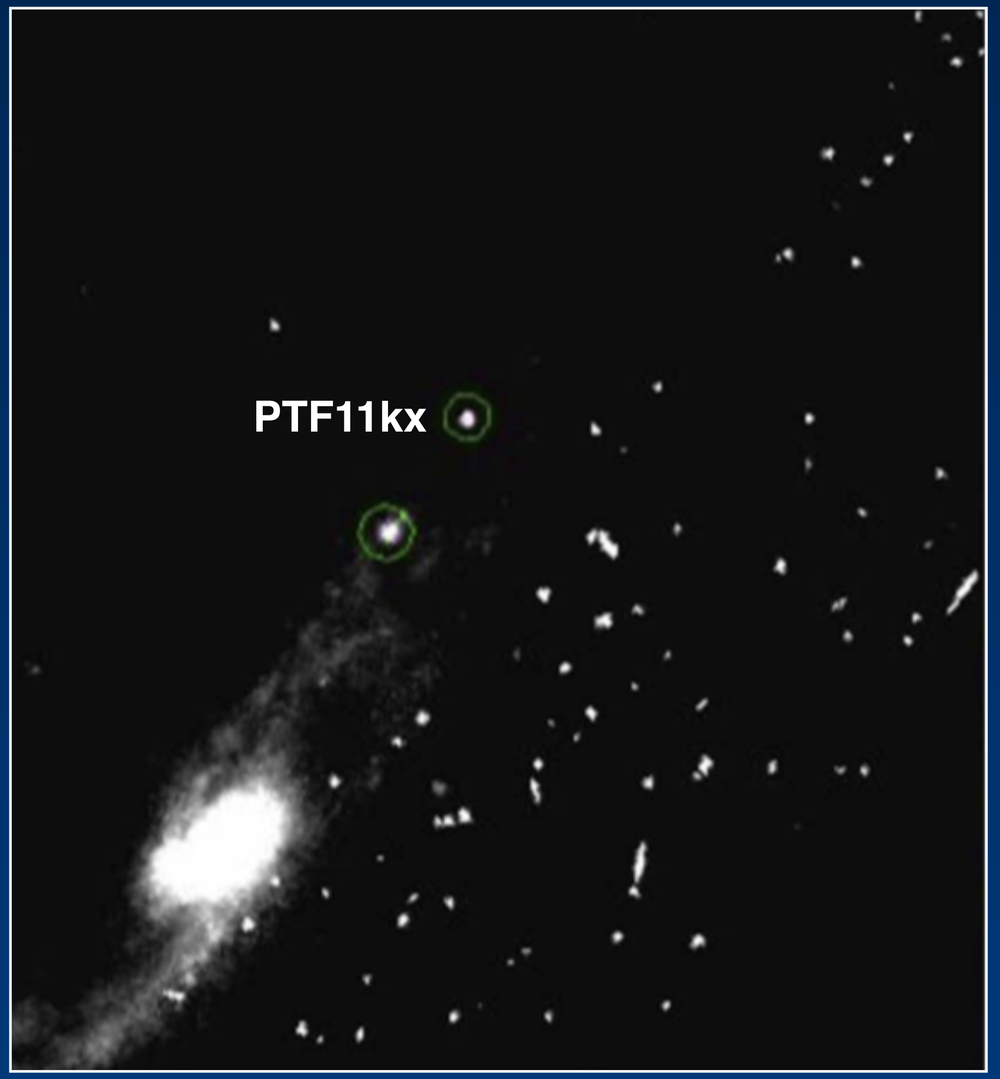
dense CSM

immediate vicinity of SN

e.g. SN 2002ic

let’s find more interacting SNe Ia!

- **Models**. I simulated SNe Ia interacting with distant, thin shells of CSM.
- **Survey**. We looked for this in nearby SNe Ia and found what may have been a PTF11kx “twin”.
- **Future**. The NIR can help by giving a “historical record” of the interaction and showing He I.



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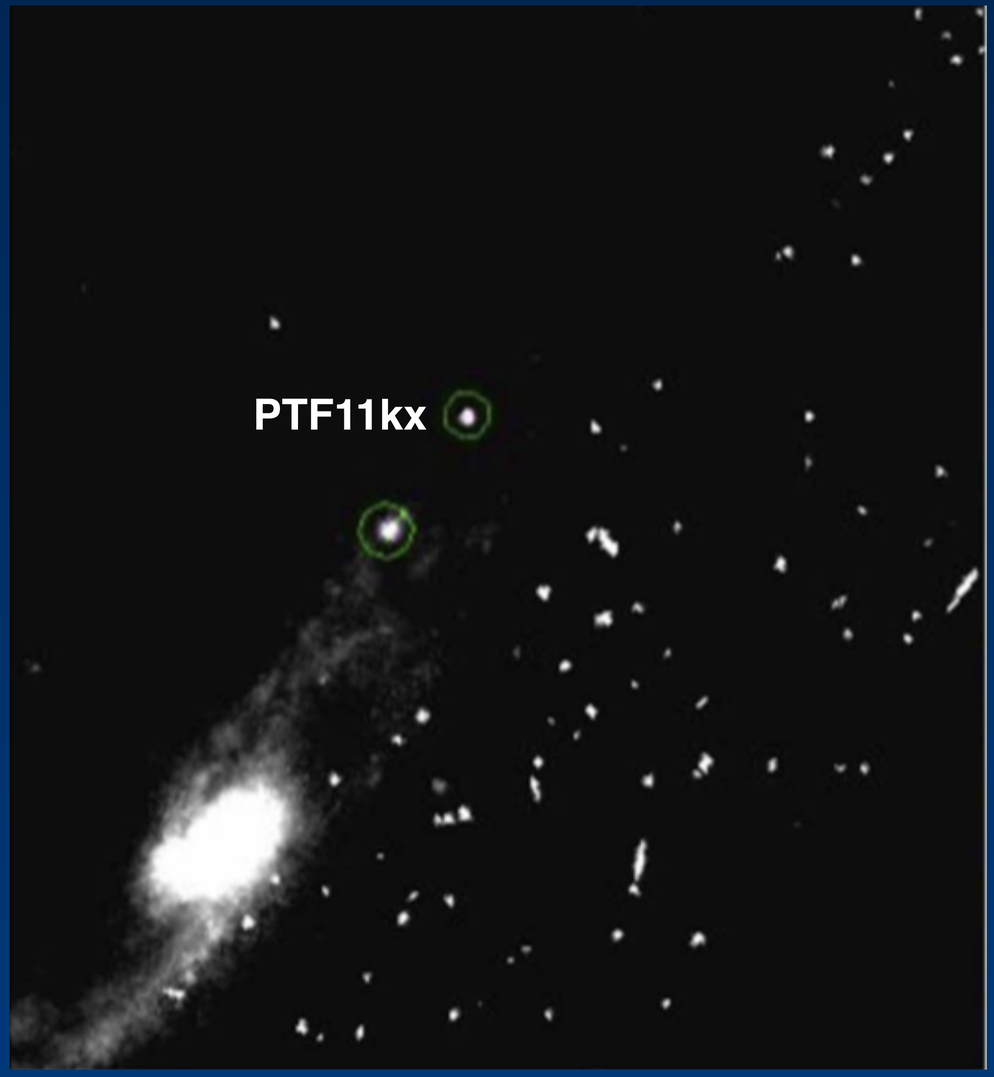
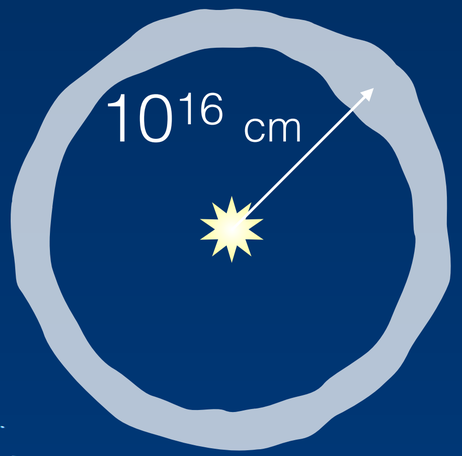


we lacked equivalent of wind models

e.g. SN 2002ic

- observation start time » interaction start time
  - interaction is described by self-similar/mini-shell evolution (Chevalier 1982)
  - easy tools for reading CSM density from radio or x-ray data

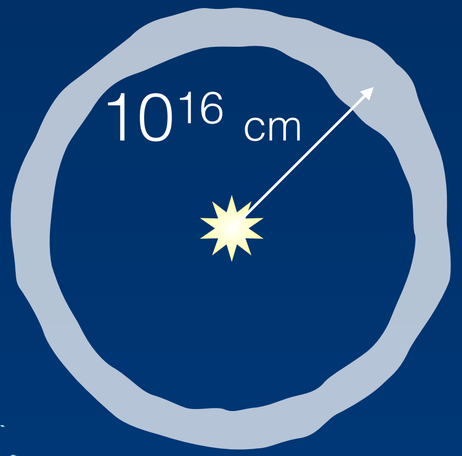


e.g. PTF11kx

- observation start time ~ interaction start time
  - state of hydrodynamic transition
  - no tools (predictions, when made, were for specific model)

we lacked equivalent of wind models

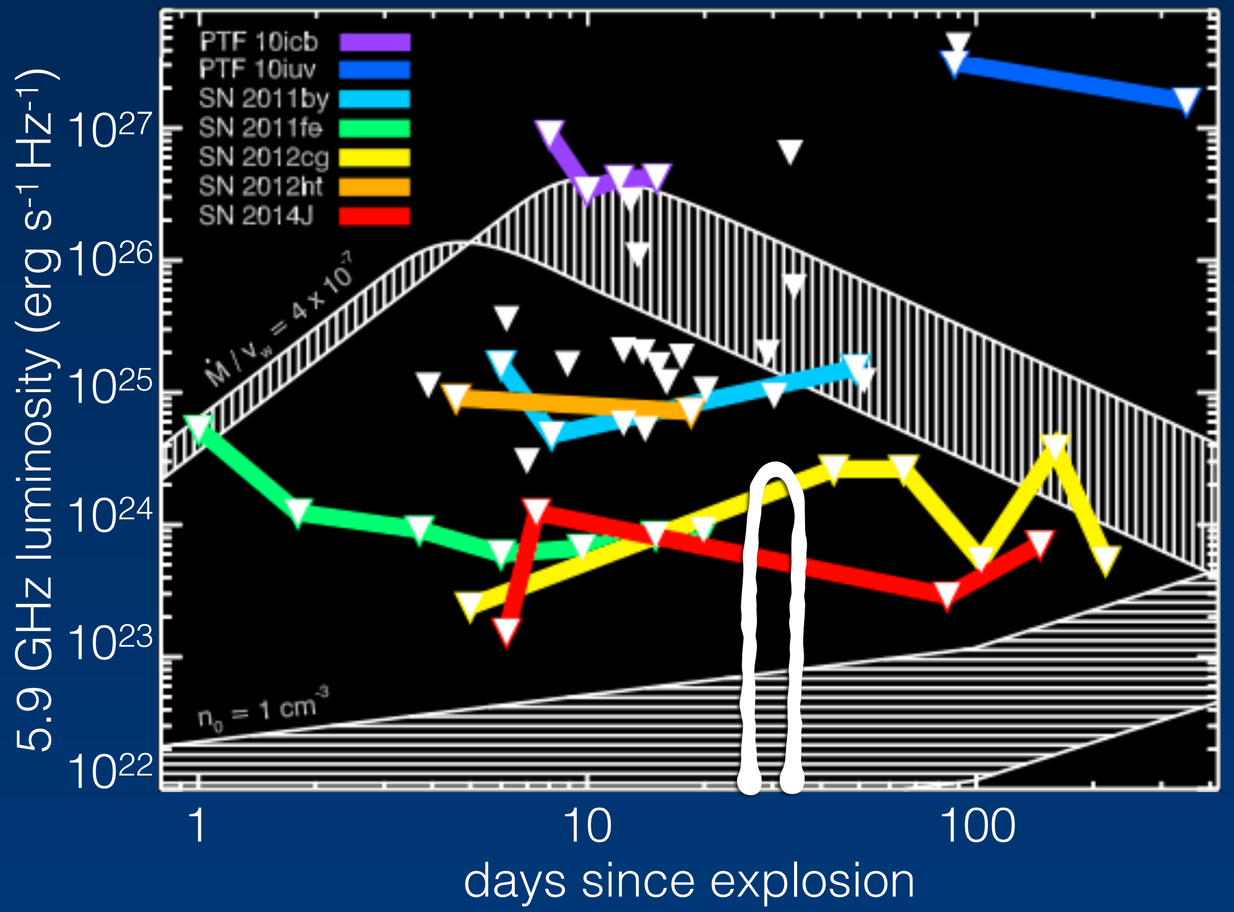
e.g. SN 2002ic



e.g. PTF11kx

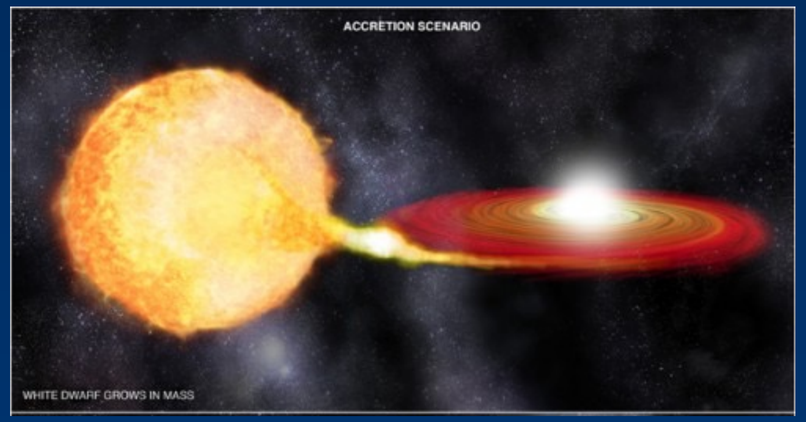
radio

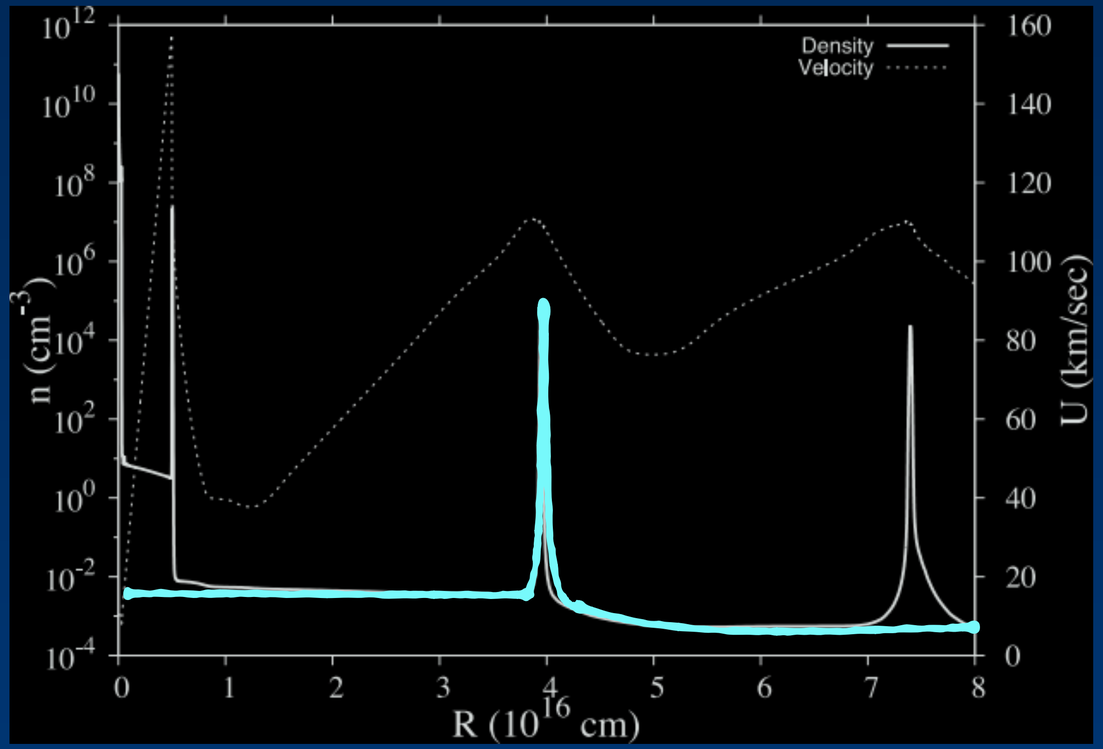
Chomiuk+ (2016)



shells would be nova/outburst products!

and we had no predictions for what they, generally, look like



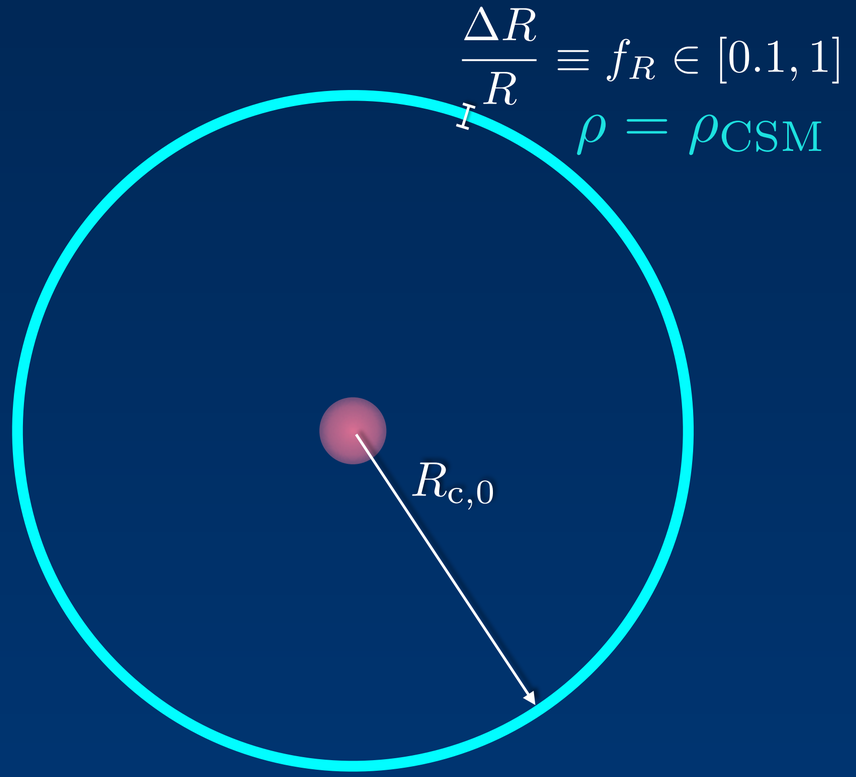


Dimitriadis+ (2014)

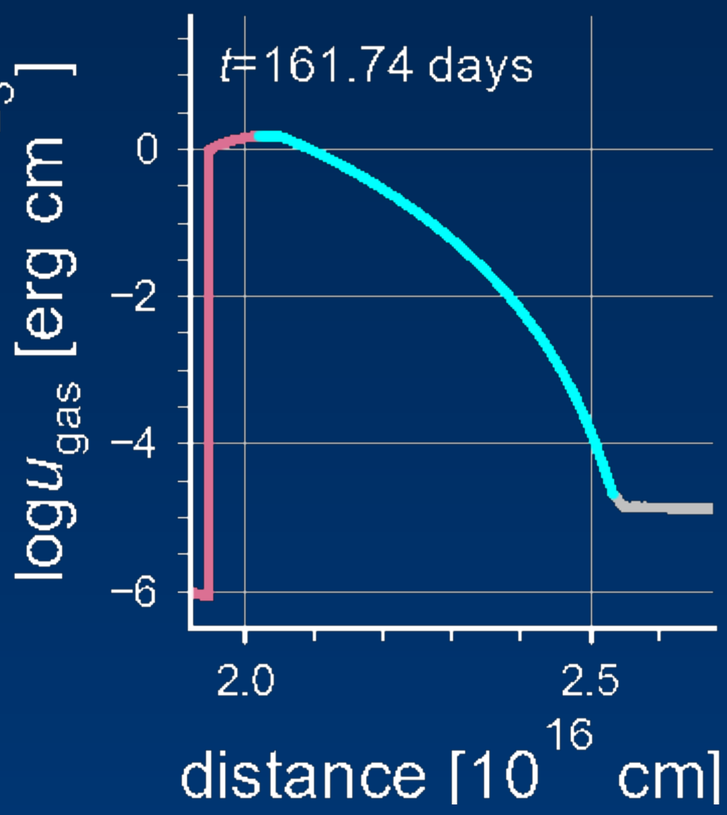
Harris+ (2016)

so I developed “delayed interaction” models

CSM structure

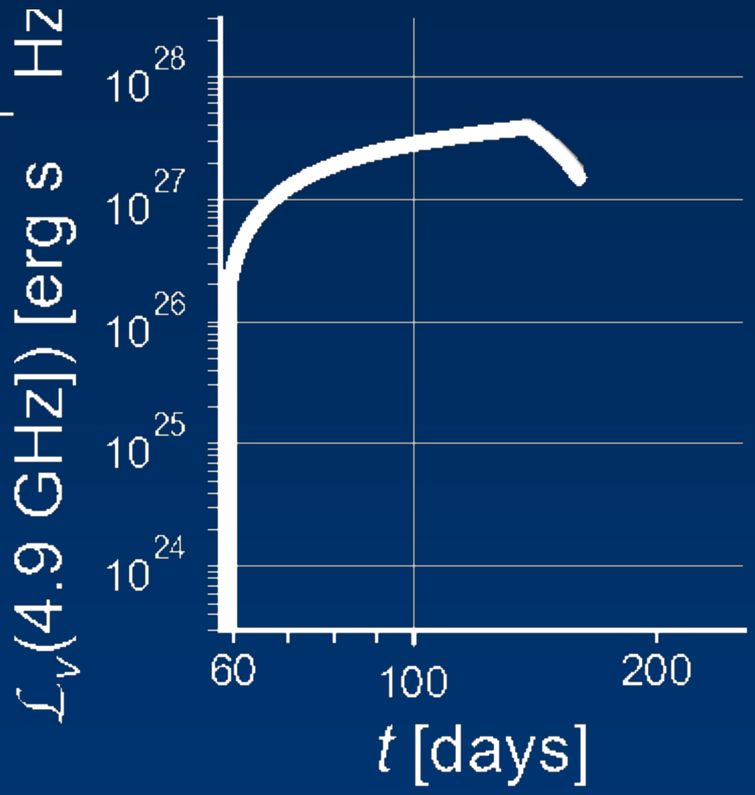


hydro



low density → no cooling
(adiabatic shock)

radio light

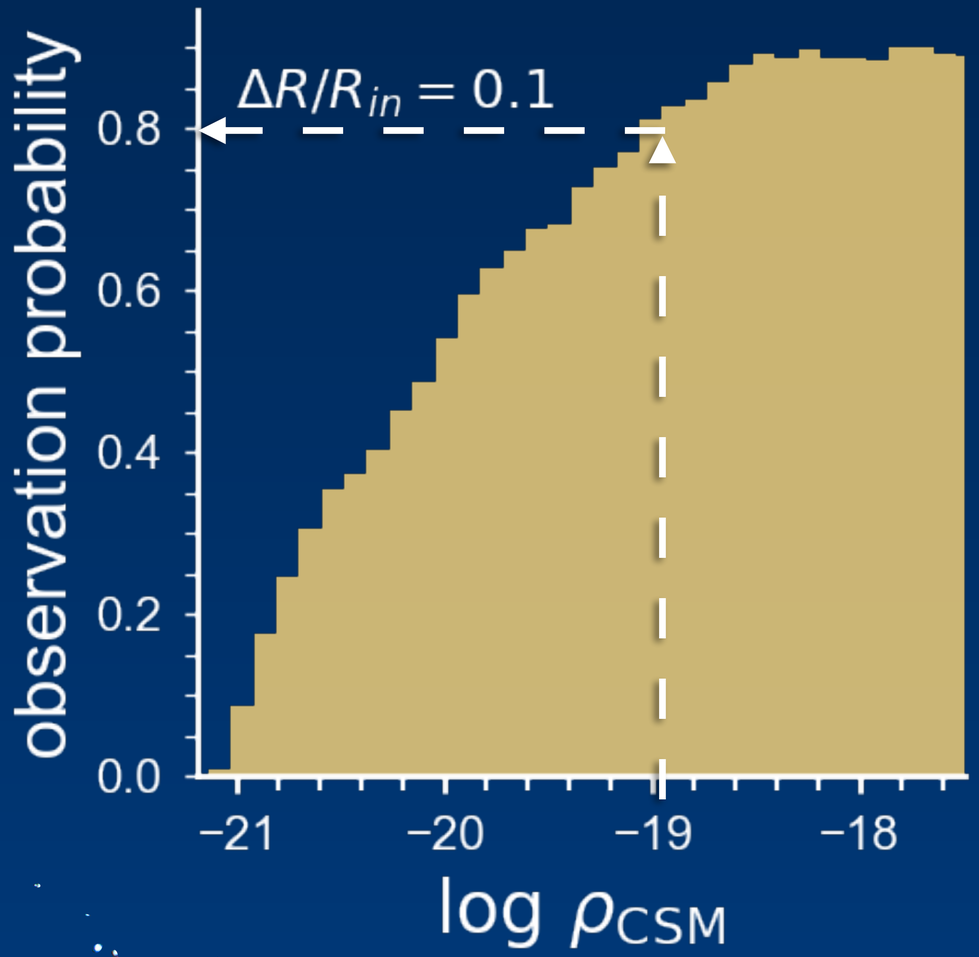


CSM only (standard)

CSM + ejecta

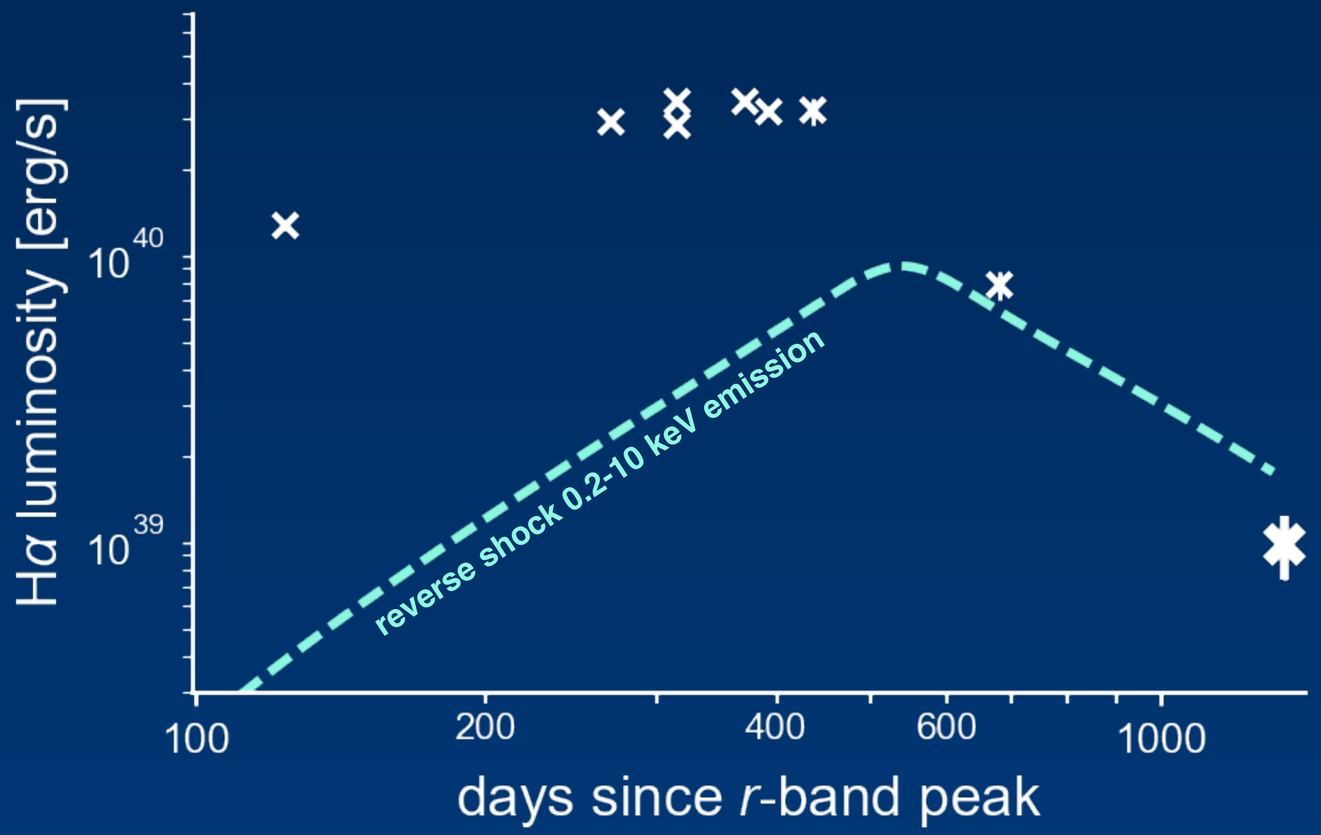
and use DI models to interpret observations

SN 2014J



Harris+ (2016); Pérez-Torres+ (2014)

PTF11kx ($\Delta R/R_{in} \approx 4$, $\rho_{csm} \sim 10^{-18}$ g cm^{-3})



Graham, Harris+ (2017); Silverman+ (2013)

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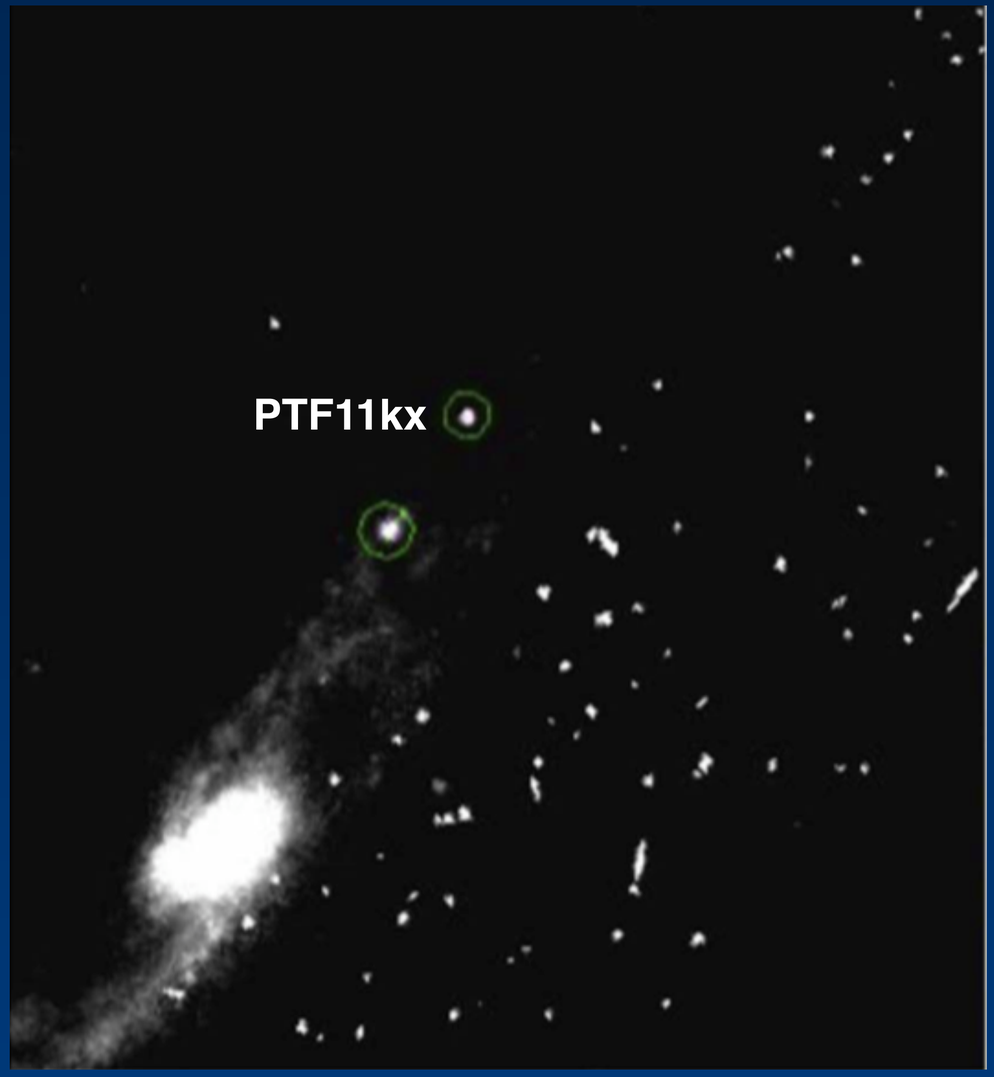


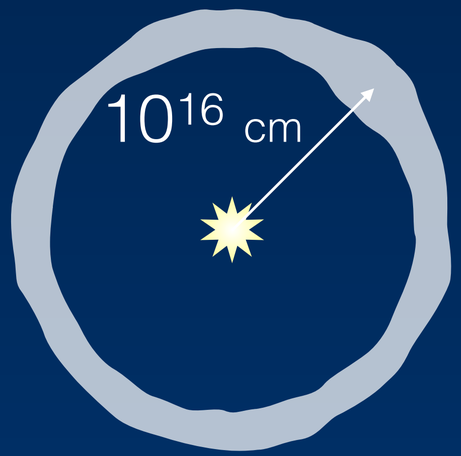
HST NUV snapshot program

PI M. Graham

- 1-3 years old as of Oct 1 2016
- distance ≤ 300 Mpc

interaction is associated with the “91T” subclass

Leloudas+ (2015); Dilday+ (2012); Graham+ (in prep; inc. CEH)



the “91T” subclass:

- ~10% of SNe Ia (Li+ 2011)
- from younger stellar pops (low-mass/star-forming hosts)
- bright
- slow-declining
- hot (Fe III, **R_{Si}**)
- evolve toward normal spectrum
- on M_B-Δm_{15} relation

bad for CSM studies:

- dusty
- host narrow Hα

HST NUV snapshot program

PI M. Graham

- 1-3 years old as of Oct 1 2016
- distance ≤ 300 Mpc
- prefer targets
  - bright, Na D, high velocity, “91T” spectrum
  - good early-time data coverage
- reject targets
  - deeply embedded in their host galaxy or with severe extinction
  - in regions of high UV surface brightness (reviewed GALEX/Swift/HST)
- control: SNe IIn and Ia-CSM, <100 Mpc normal SNe Ia
- **result: 80 targets, of which 71 were observed!**

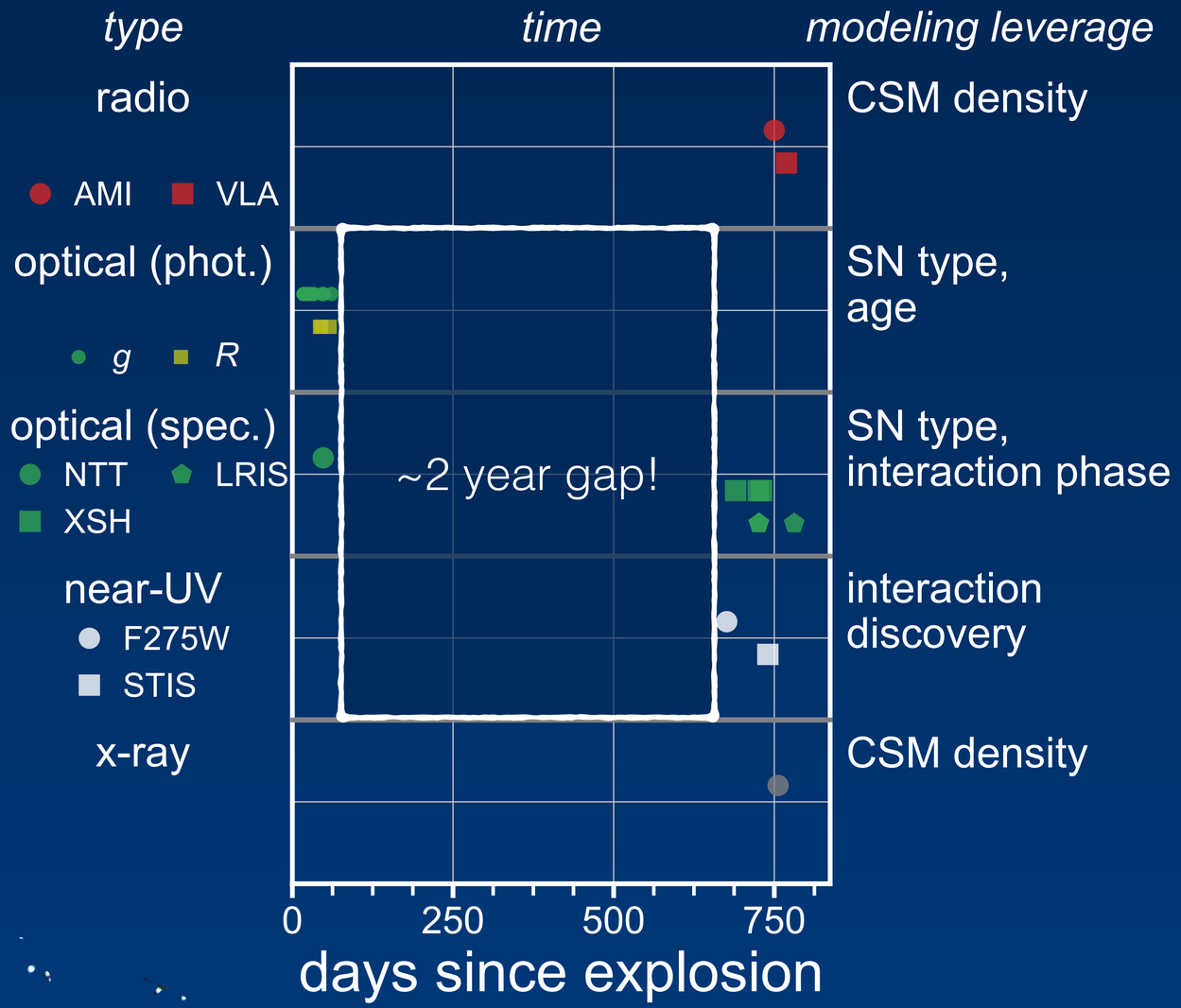
mostly non-detections … except one!

Graham+ (2018; in prep)

- discovered post-interaction
- D_L ~ 170 Mpc
- from non-detection rate, est. 10-25% of all targets could have been like SN 2015cp
  - assuming 250-day interaction time

Preliminary!

follow-up allowed a mass constraint



- model constraint (primarily radio):
  - if peak at 500 days: **$M_{csm} < 2\ M_\odot$**
  - if peak at 670 days (discovery): **$M_{csm} < 0.5\ M_\odot$**
- consistent with PTF11kx properties
- main uncertainty: start of interaction!
- suggestion: follow every z < 0.08 "91T"-like SN Ia with optical spectroscopy at a 6-month cadence
  - Hα at $L_\lambda \sim 10^{37}$ erg s^{-1} Å^{-1}

Harris+ (2018; in prep)

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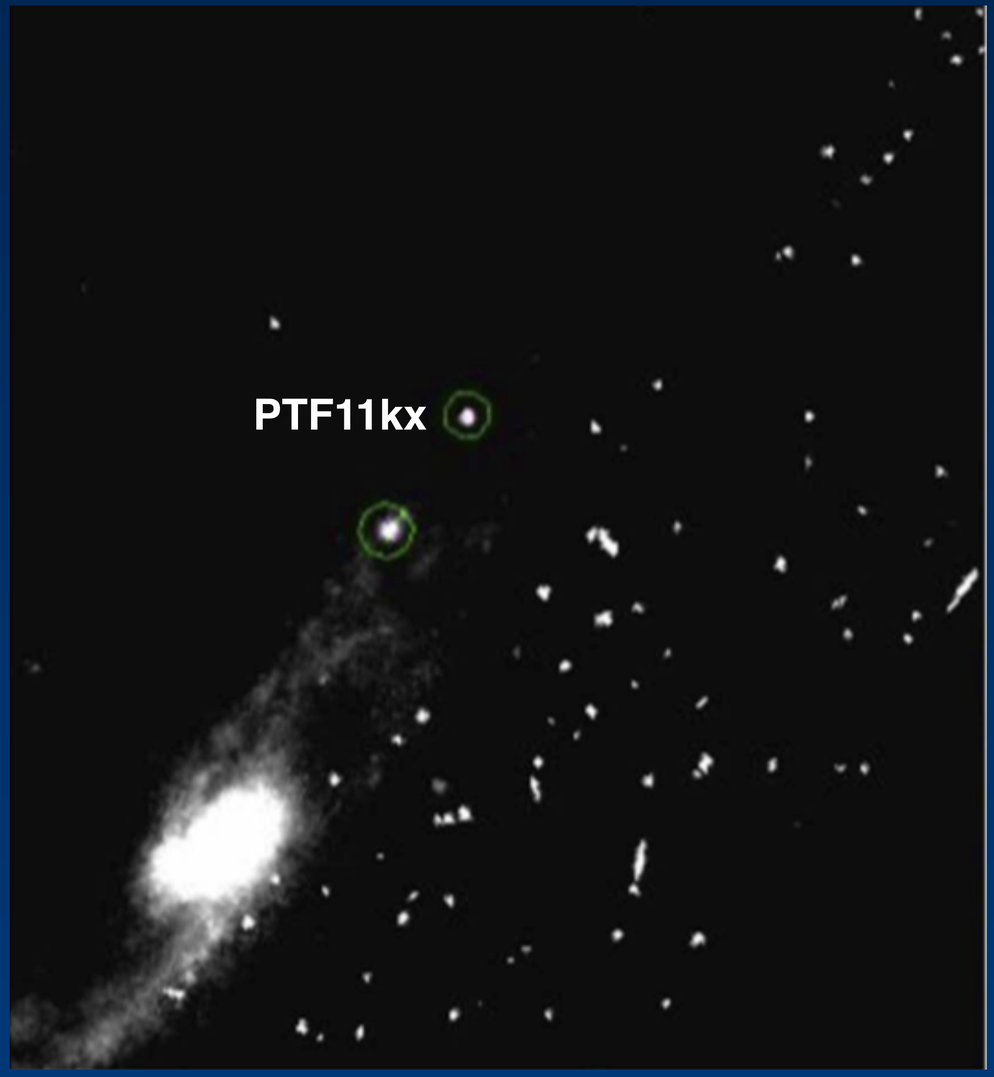
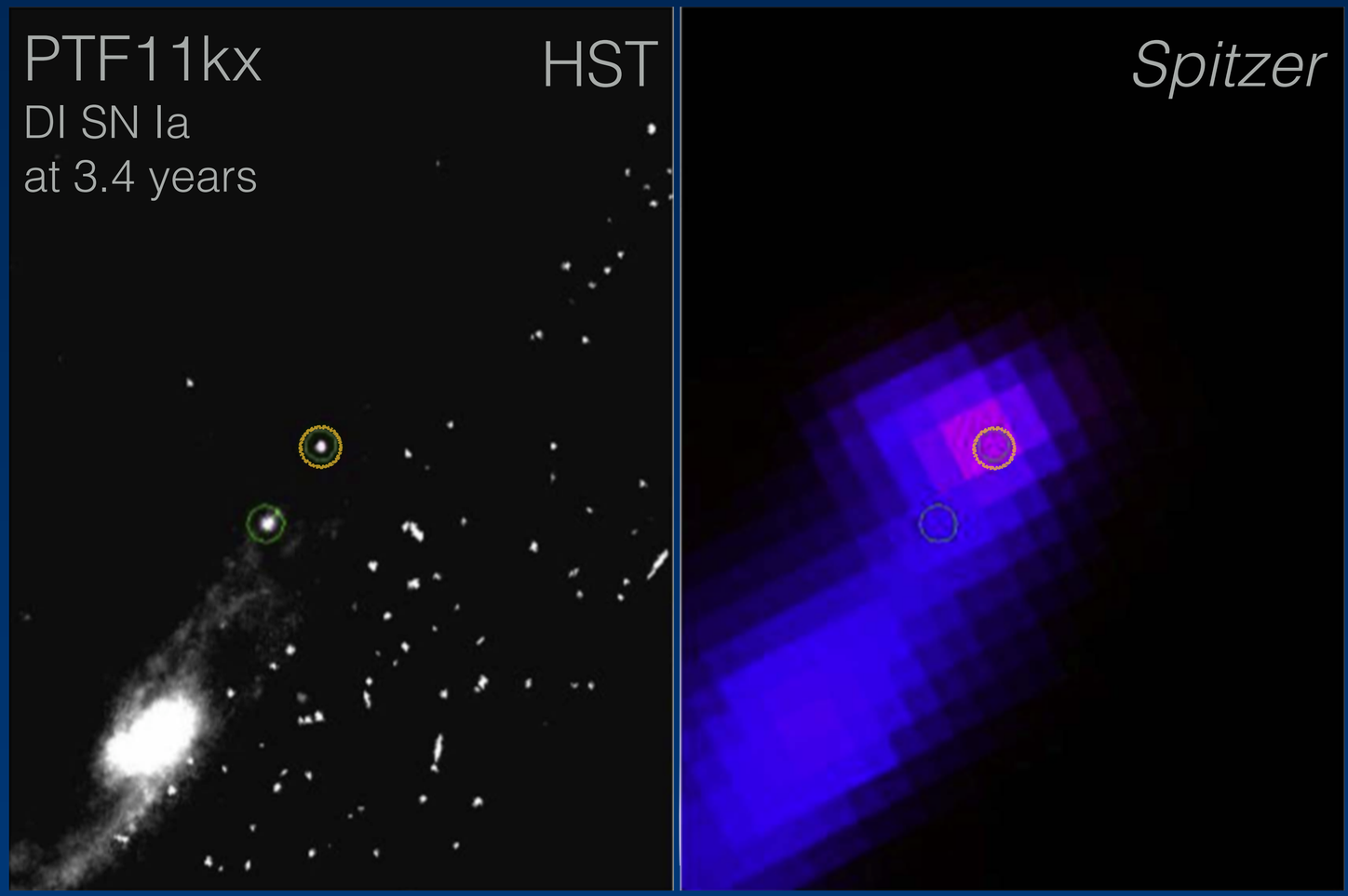


studying CSM in the NIR

- dust heating : interaction luminosity
- dust creation : cooling rate
- the He I NIR emission line

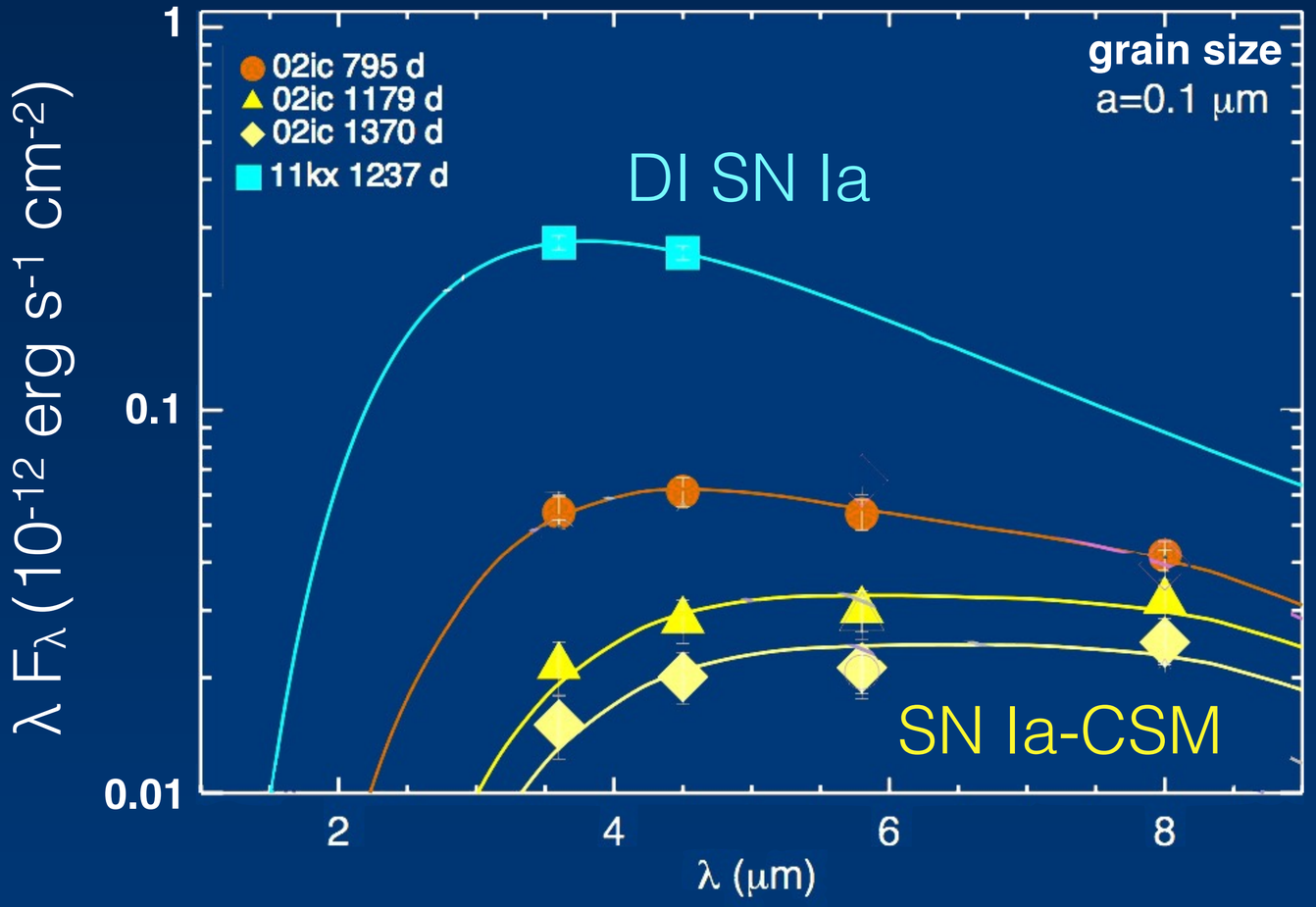


Graham, Harris, Fox+ (2017); IC: **O. Fox**

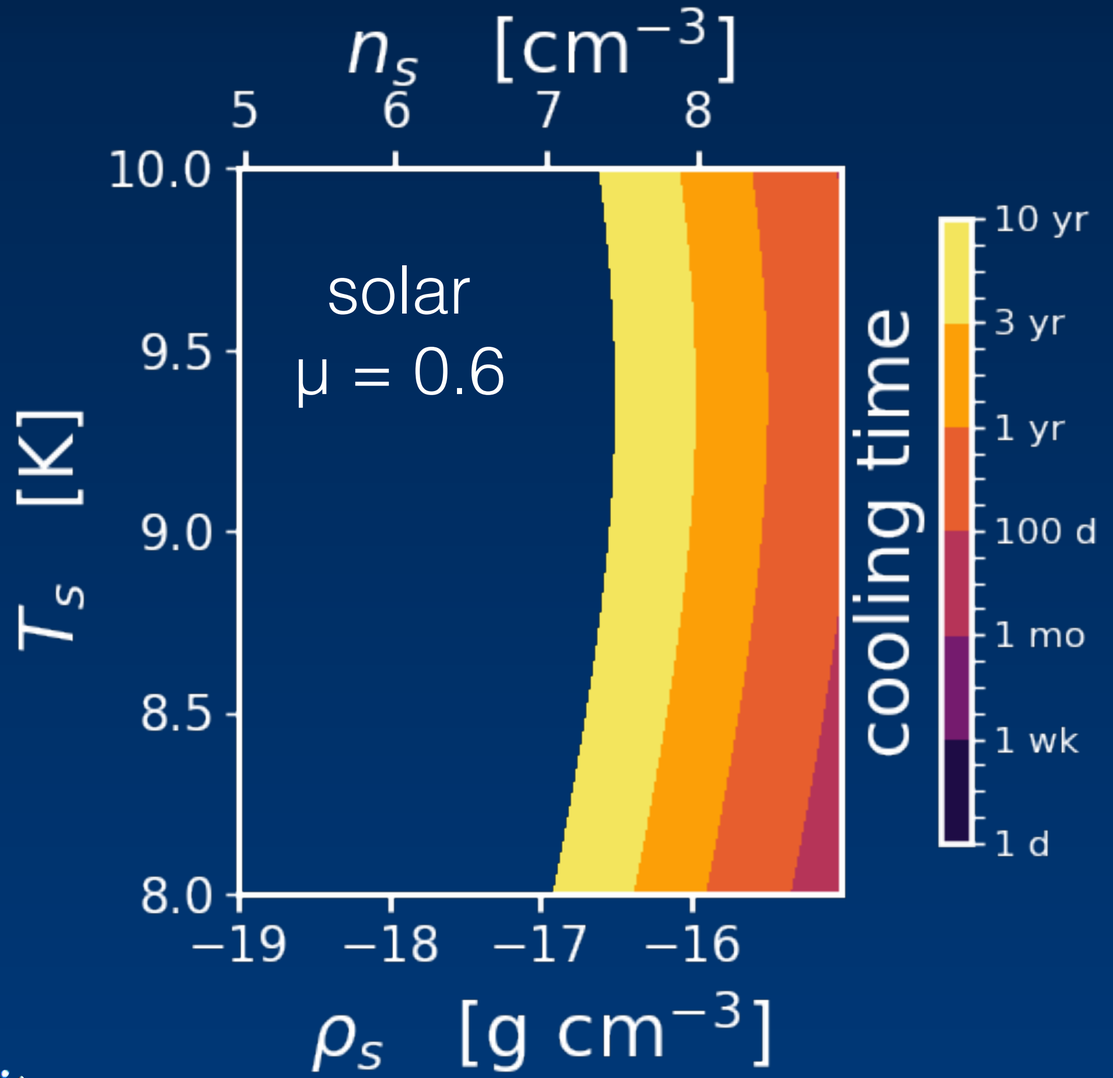
NIR in interacting SNe Ia

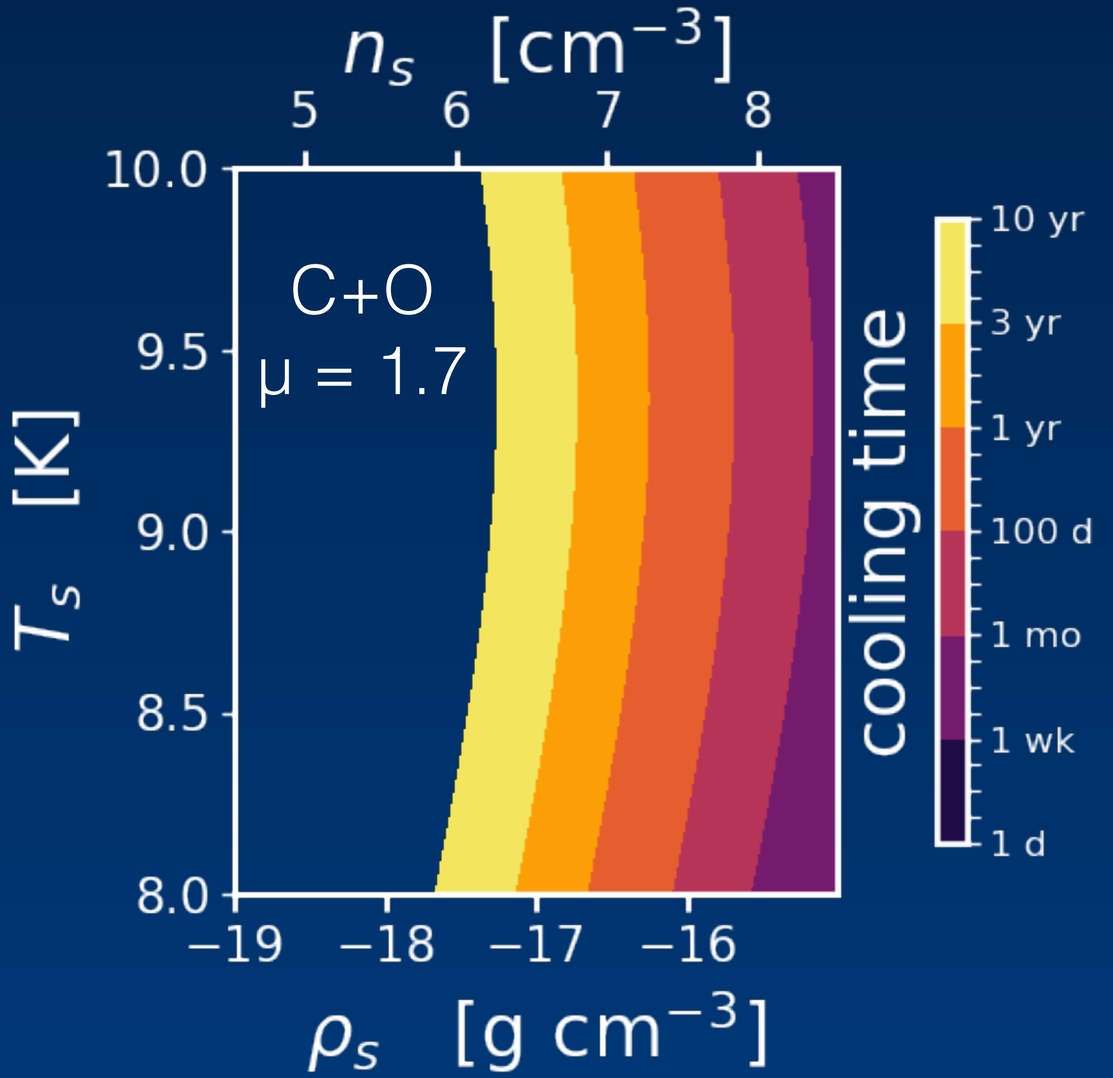
- dust may be pre-existing **or** newly formed
- dust may be heated by local gas OR outside radiation field

- SN 2002ic: (blackbody) radii 10^{17} cm→ existing dust heated by radiation field from interaction
  - **get L_{shock} from heating model** (Fox+ 2013)
- PTF11kx: radius 5×10^{16} cm → collisional heated



difficult to form new dust? hard to cool

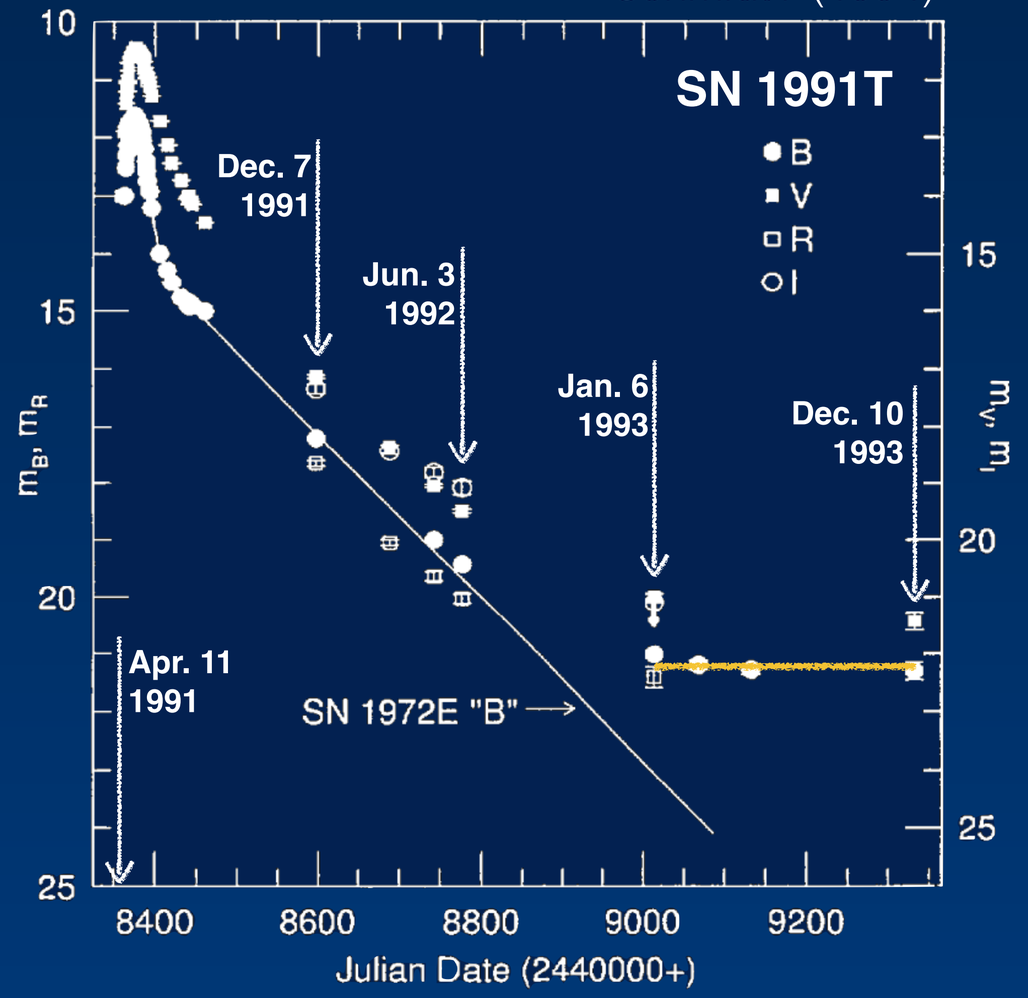




light echoes / NIR “echoes”

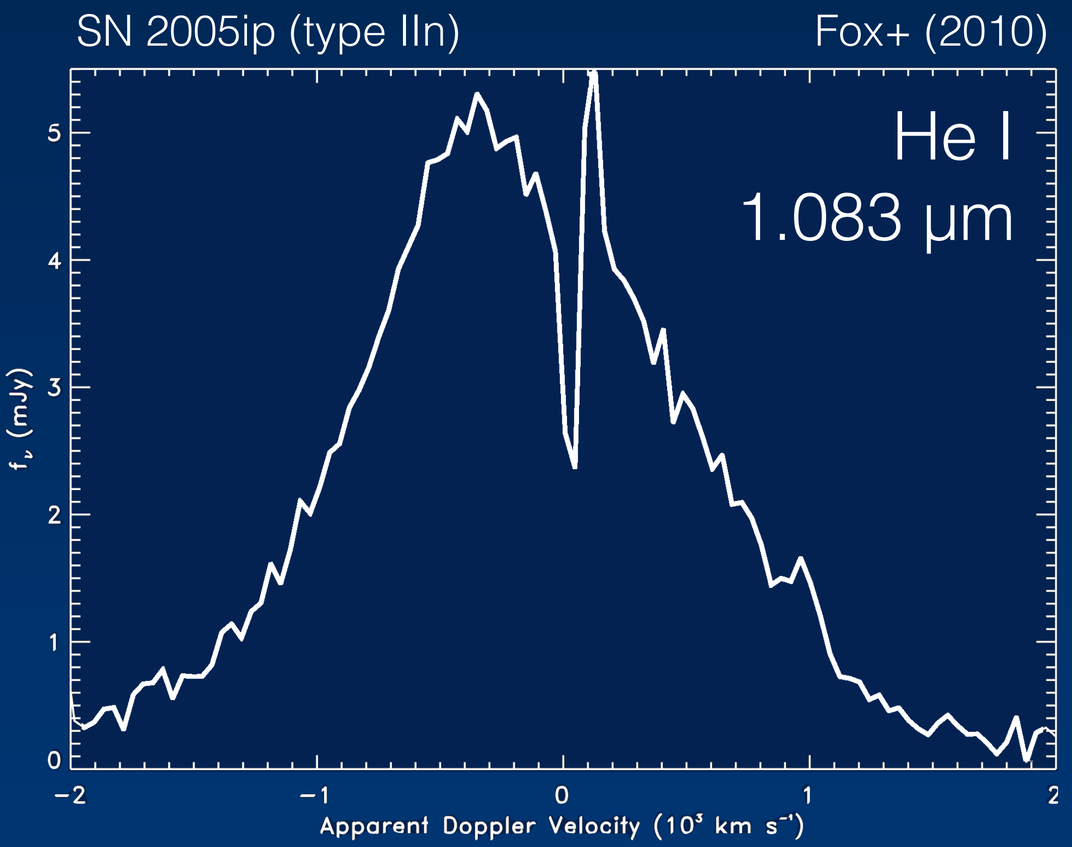
- distant pre-existing gas/dust
- light crossing time ~years
  - **late-onset + long-duration**
- flatten light curve (in all bands)
- **L_{flat}/L_{peak} ~ 9 mag** (SN 1987A, 1991T)
- optical spectra are convolution of SN time series (dust scattering)
- NIR light from far-side heated dust

Schmidt+ (1994)



NIR He I line

- for SNe Ia, He is in CSM
- distinguishes light echo from interaction



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