14th North American CV Workshop

Unstable He Shell Burning in AM CVn Systems: SNe .Ia

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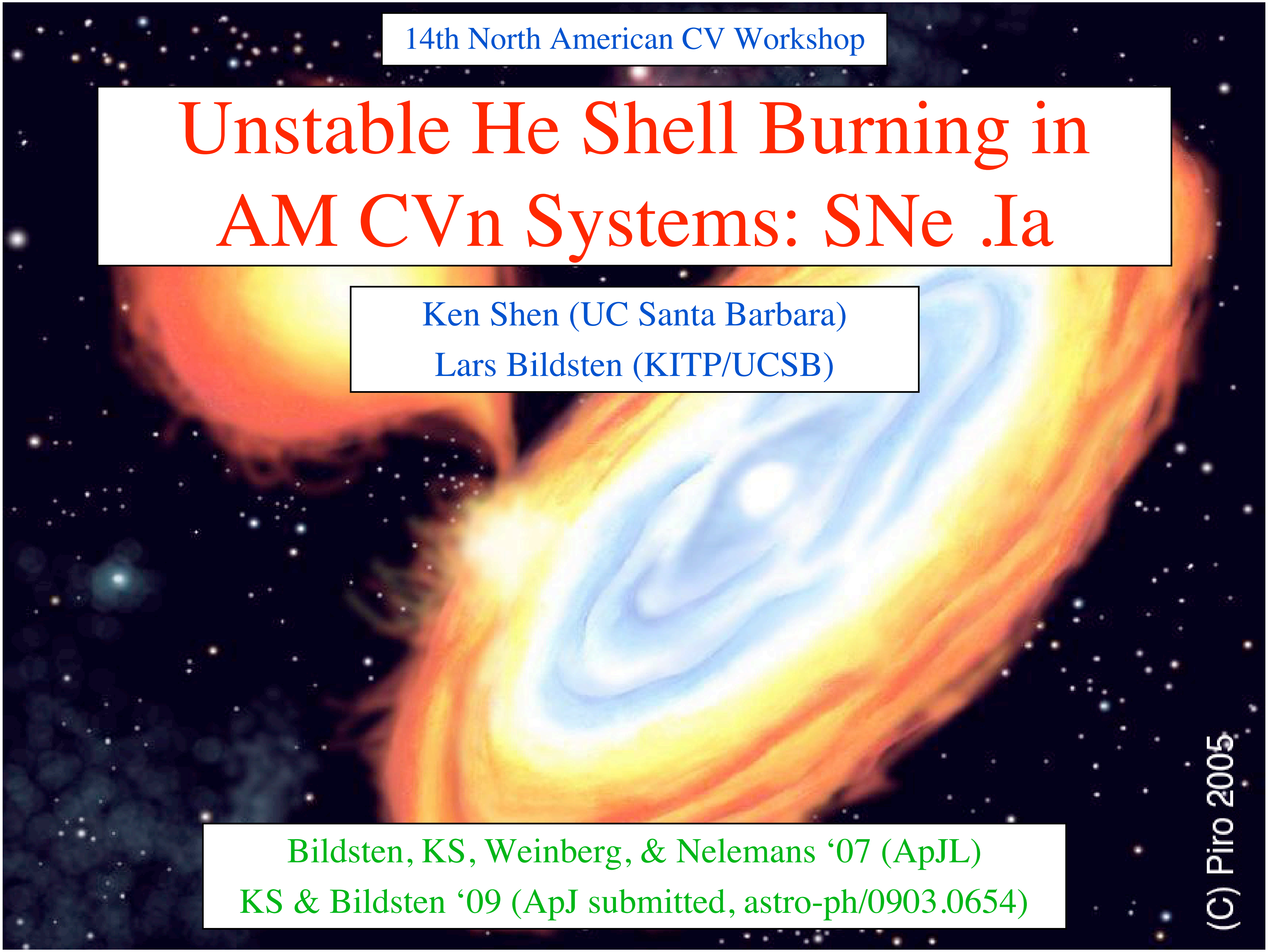
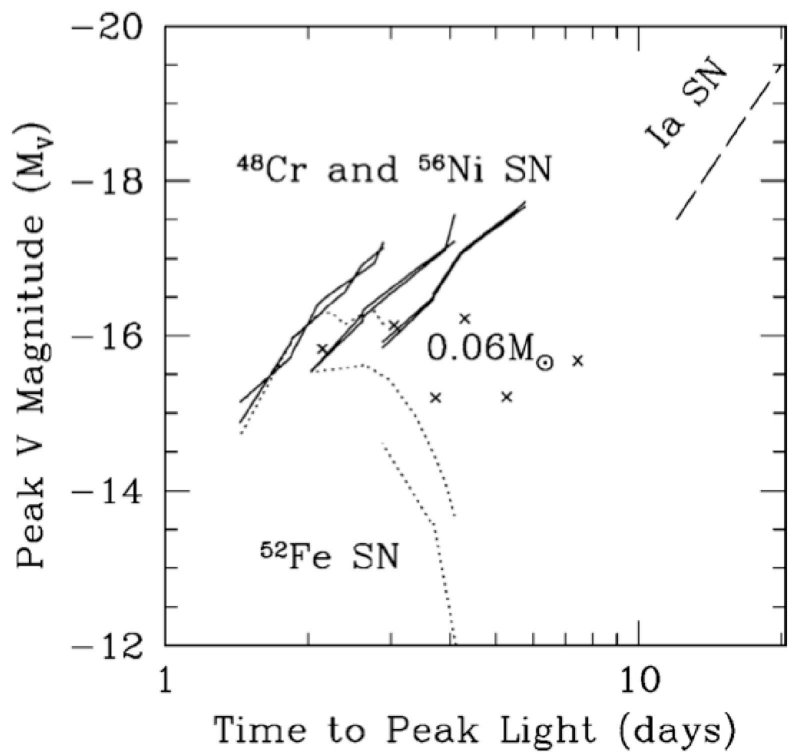


Bildsten, KS, Weinberg, & Nelemans '07 (ApJL)
KS & Bildsten '09 (ApJ submitted, astro-ph/0903.0654)

SNe .Ia: A Brief Overview

(Bildsten, KS, Weinberg, & Nelemans '07)

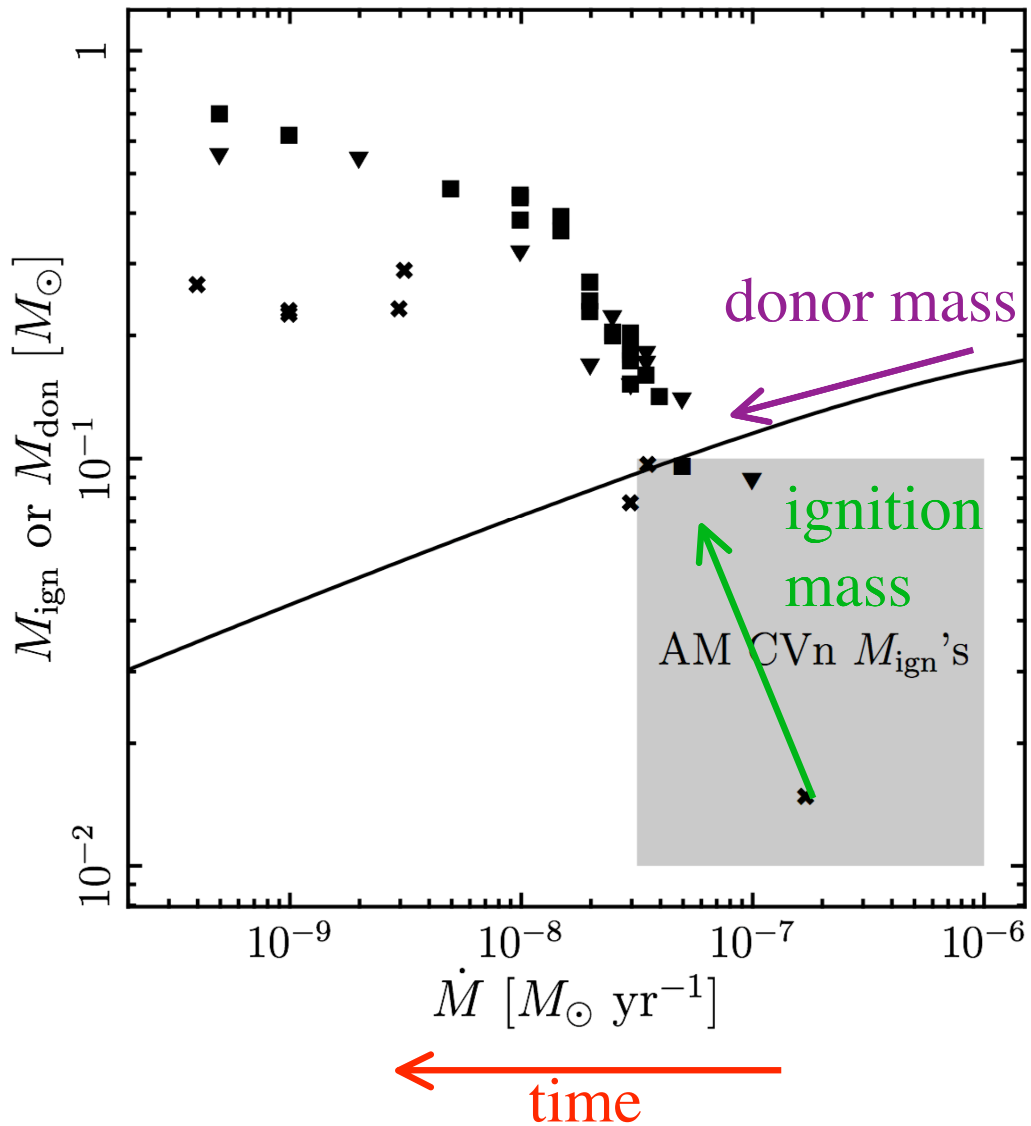
- AM CVn evolution naturally yields unstable He-burning shells of ~ 0.1 Msol
- Hydrostatic calculation shows these shells burn hydrodynamically, potentially yielding He detonations; the majority of the talk will go into detail
- Small ejecta mass → short lifetimes (~5-10 days), 10% as bright as SNe Ia



- .Ia rate is few percent of Ia rate in an old population
- SDSS SN (r = 22.5; 280 deg^2; 2 day cadence) gets 0.5 – 7 .Ia/yr
- PS-1 medium-deep survey (V = 24; 50 deg^2; 4 day cadence) gets 1 – 10 .Ia/yr

AM CVn accretion outcome: He-burning

- Initially, very low P_{orb} < 4 min & high Mdot > 10^{-6} Msol/yr: stable He-burning (Tutukov & Yungelson '96; KS & Bildsten '07; SSSs)
- Binary evolves to lower Mdot: ~10 unstable helium novae (Iben & Tutukov '89)
- Eventually, $M_{donor} < M_{ign}$:
  - No novae < 10^{-8} Msol/yr and above 10 min, just He accretion
  - Last flash has largest M_{ign} ~ 0.1 Msol

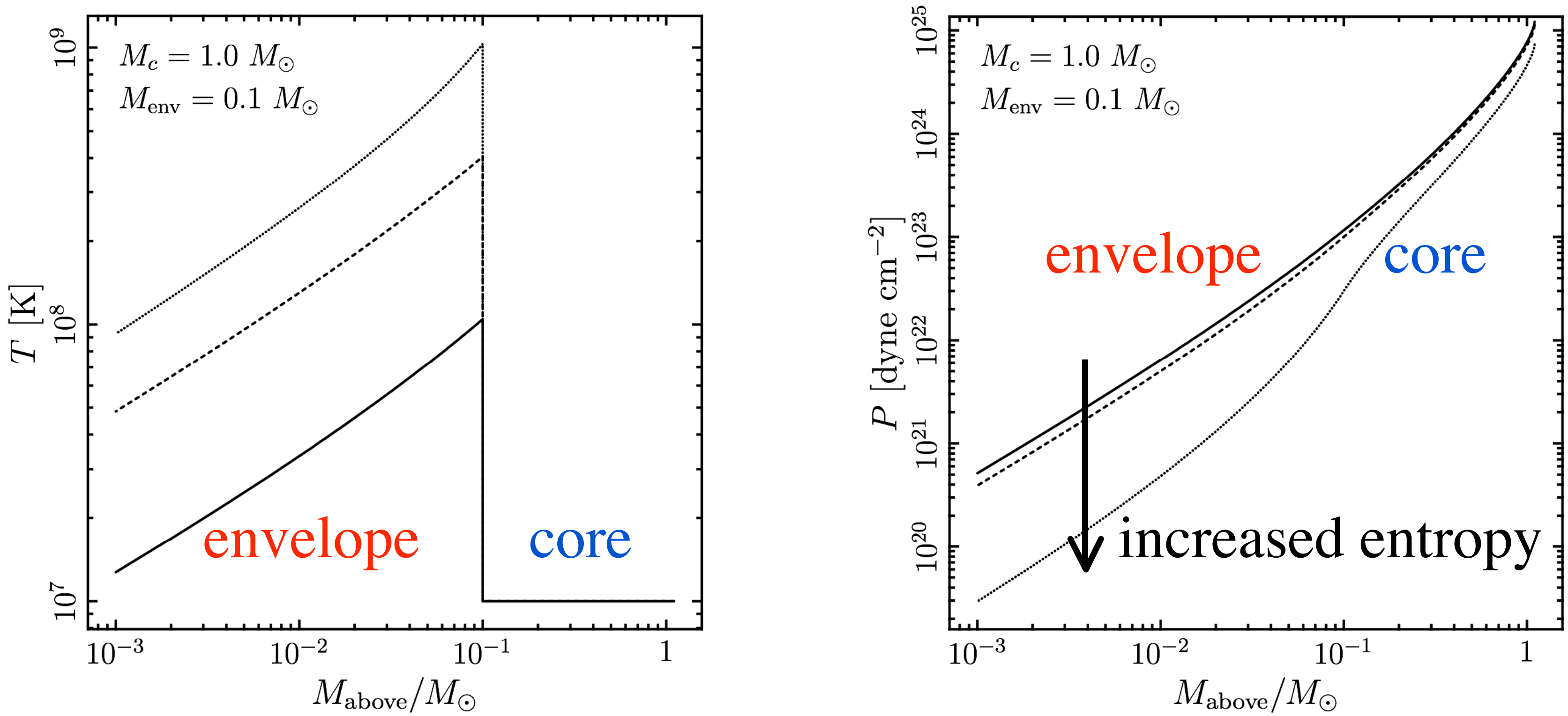


Progress of the convective phase

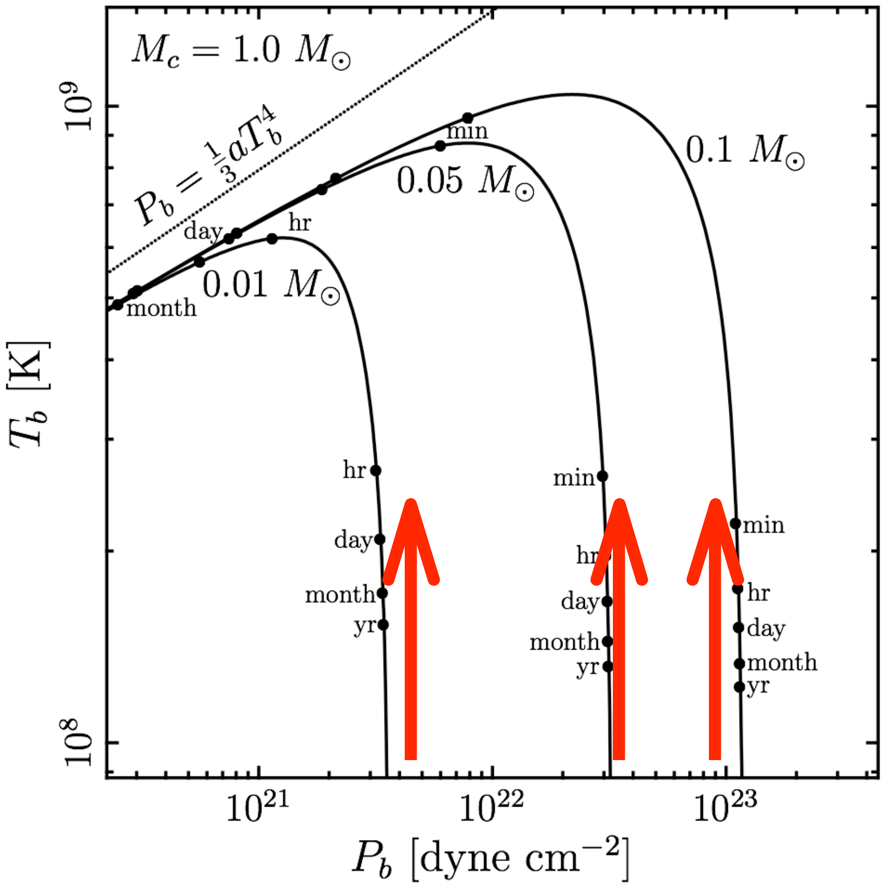
- He-burning injects entropy into the convective (isentropic) shell, raising T:

$$Tds = du + PdV$$

- Need to be consistent with hydrostatic equilibrium because $M_{\rm env}$ can be large
- Initially no expansion work done b/c $P_b \sim GM_cM_{\rm env}/4\pi R^4$, but then $T_b \sim T_{\rm virial}$



Small M_{ign}: He nova



- For smaller envelopes < 10^{-2} Msol, entropy increase eventually leads to expansion. Like a hydrogen classical nova in a regular CV: helium nova (e.g., V445 Pup)

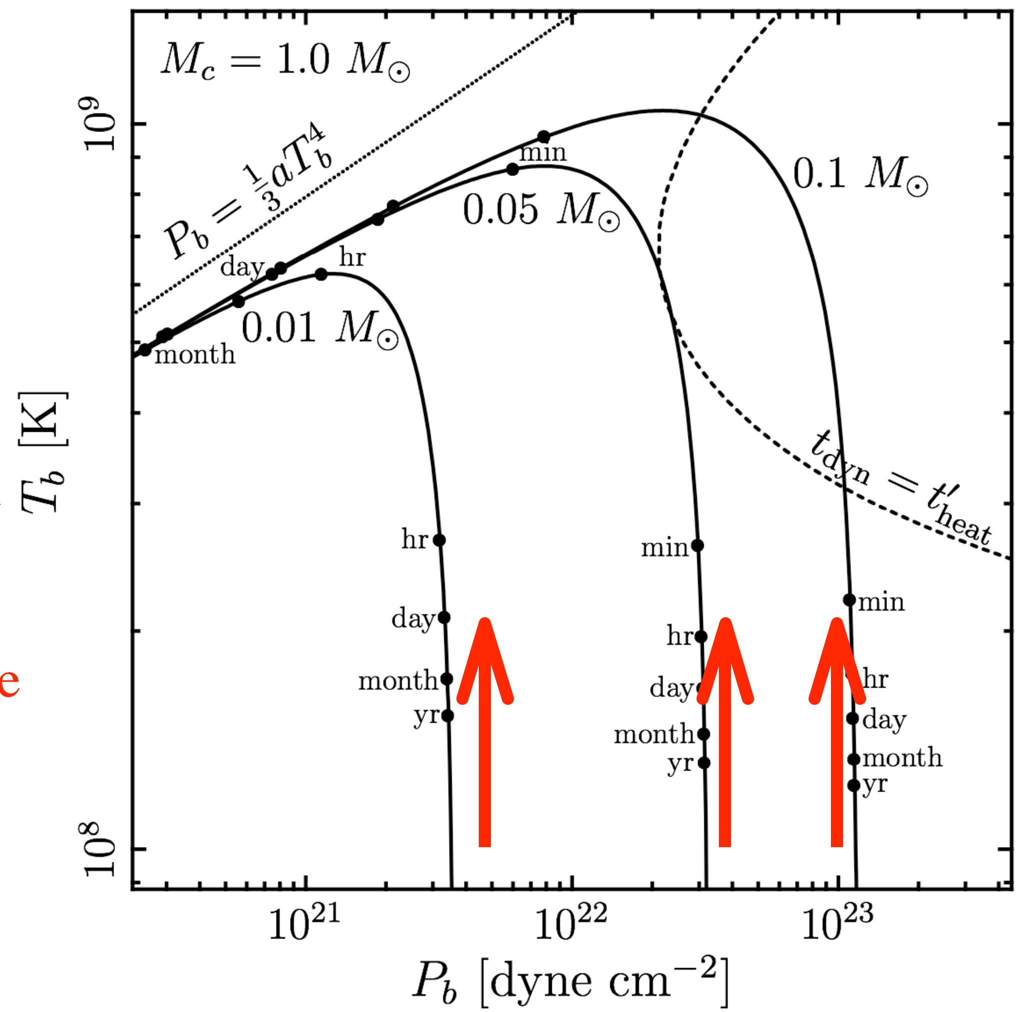
- What about bigger envelopes?

Large M_{ign}: He shell detonation!

- For larger envelopes, the heating timescale can become shorter than the dynamical timescale:

$$t_{\text{heat}} = \frac{c_P T}{\epsilon_{\text{nuc}}}$$

$$t_{\text{dyn}} = \frac{H}{c_s} = \sqrt{\frac{P}{\gamma \rho g^2}}$$

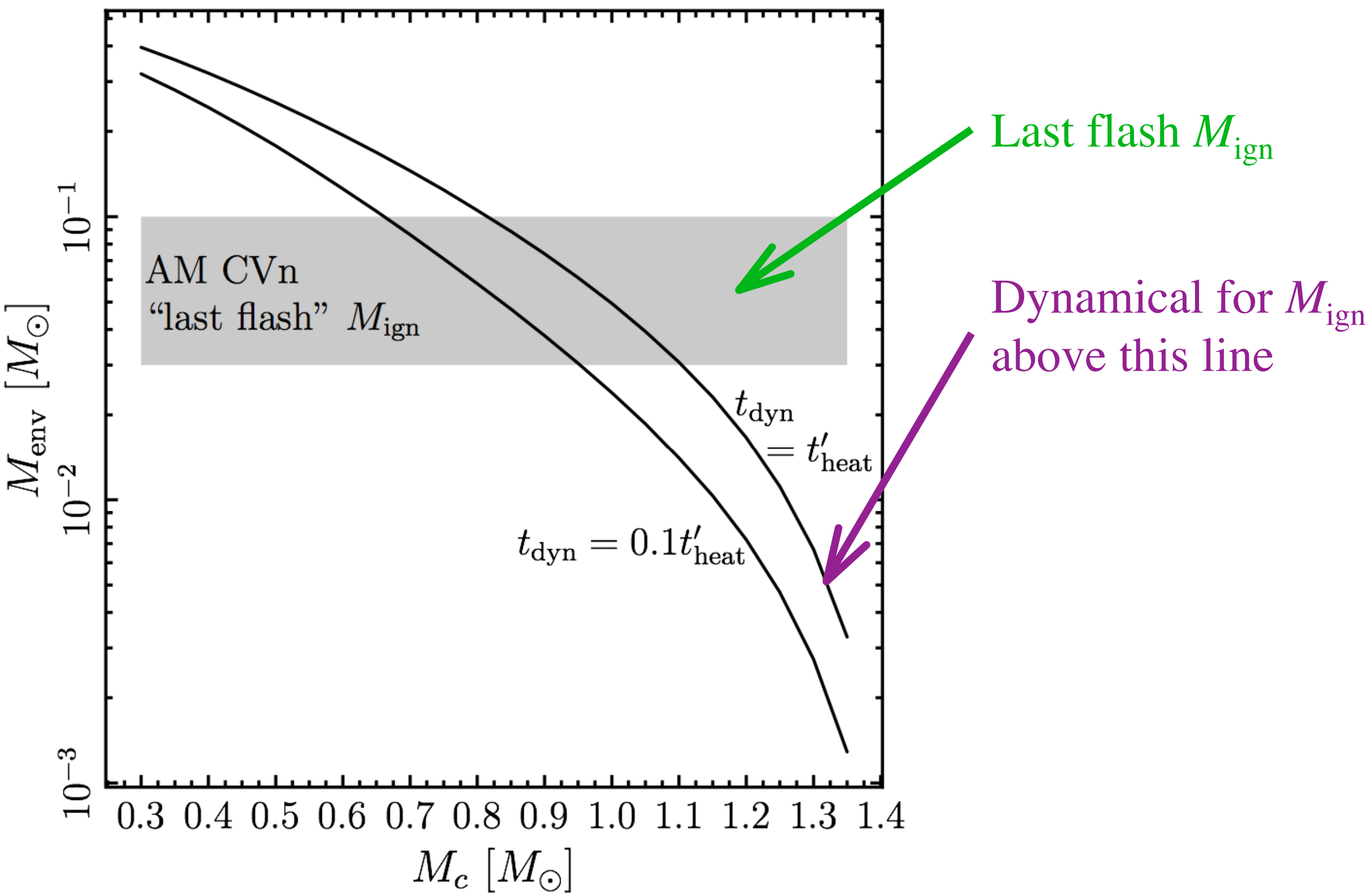


- Heat is injected faster than shell can respond and maintain hydrostatic equilibrium: large overpressure, dynamical explosion: likely outcome is a detonation!

- There is a minimum M_{env} that can detonate

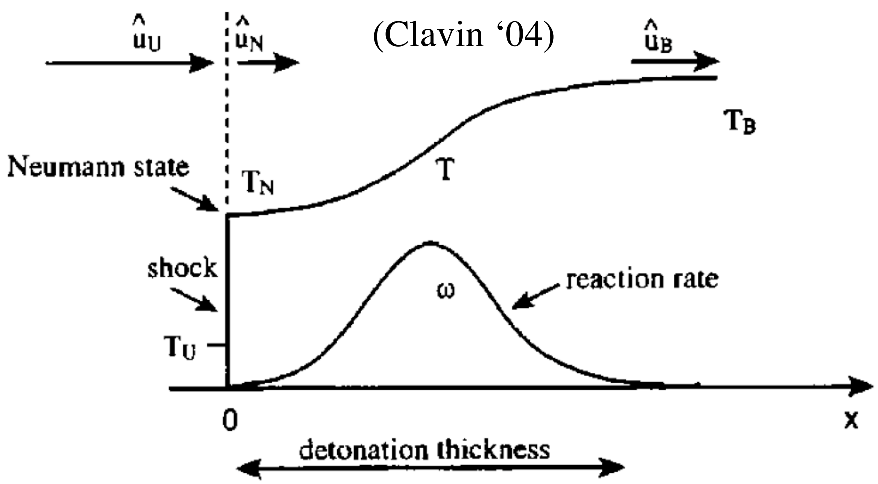
Many AM CVn's should undergo He detonations

- Last flash for each system is the biggest
- For $M_{acc} > 0.8$ Msol, last flash should be dynamical / detonation

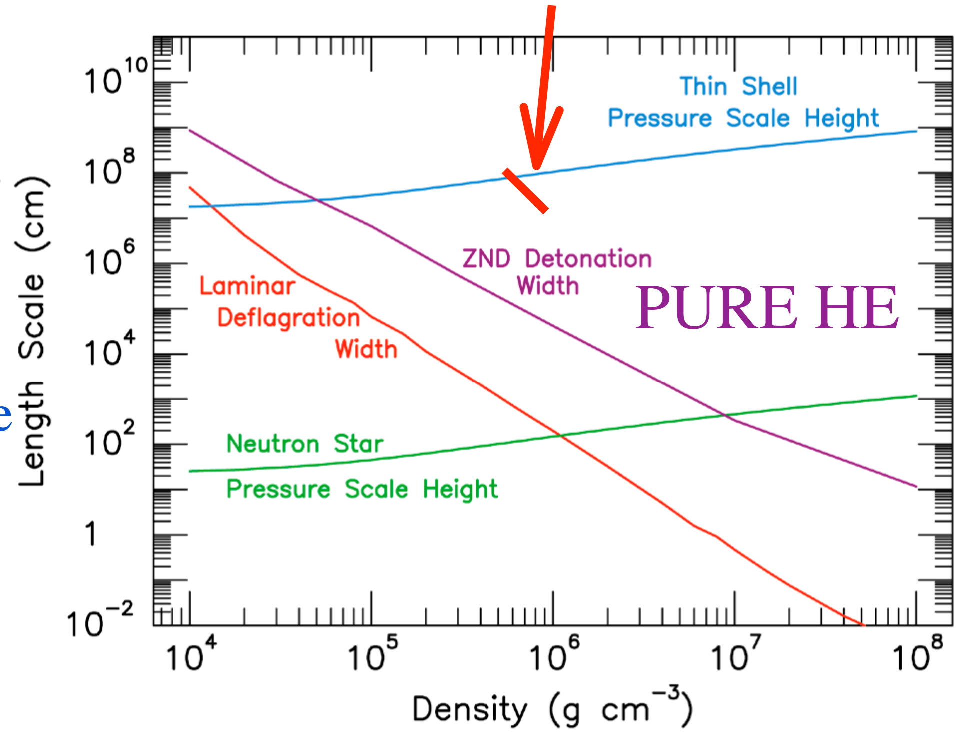


Initial abundances for detonation

- Determines:
  - neutron-to-proton ratio / $Y_e \rightarrow$ isotopic yield
  - likelihood that detonation will propagate (ZND length)



Scale height for min M_{env} at onset of detonation for 0.6 - 1.35 Msol

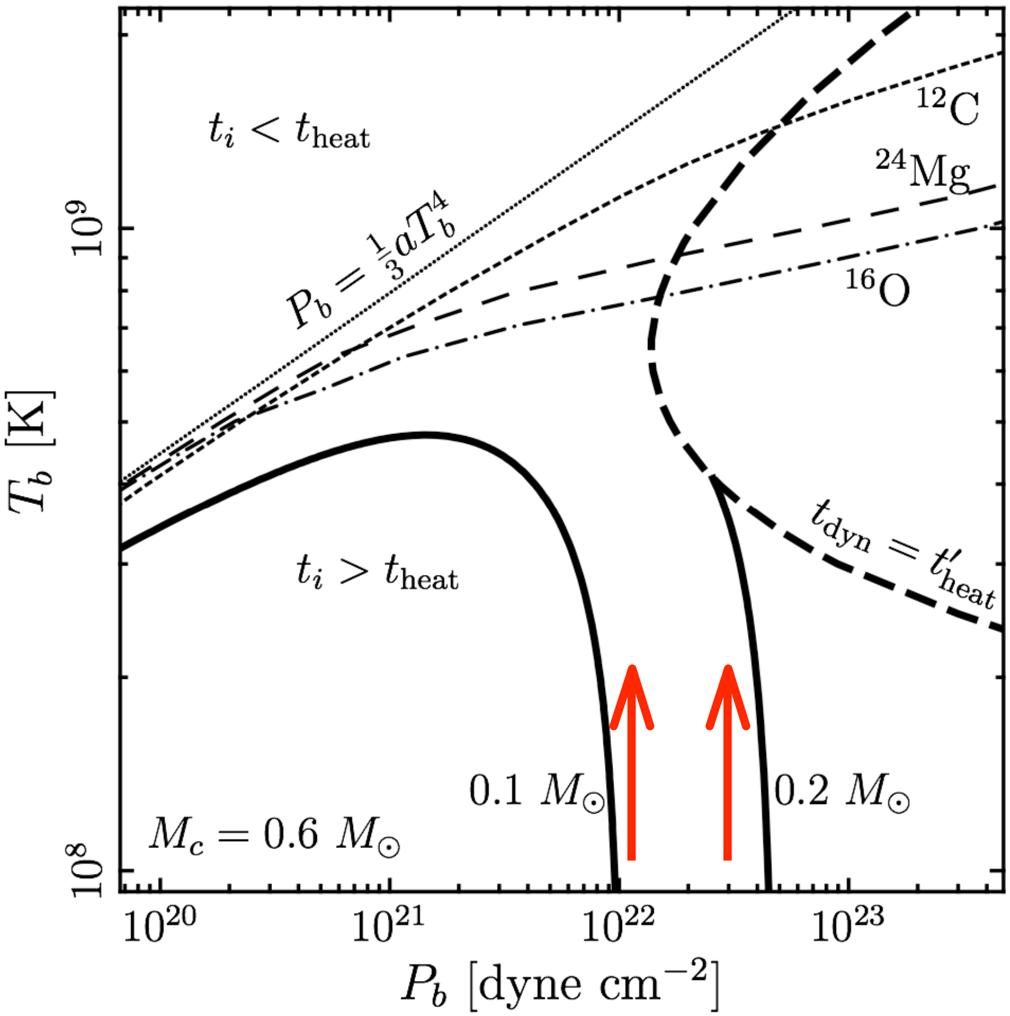


(Timmes & Niemeyer '00)

- The smaller ZND length is compared to scale height, the more likely a detonation will propagate
- Pure He ZND length 10^2 - 10^3 times smaller than scale height

α-chain elements (^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, etc.)

- Lower limit set by triple-α burning → $X_{12C} \sim 0.01$-0.05
- But dredge-up may yield $X_{12C/16O/20Ne} \sim 0.1$ (depending on WD core)



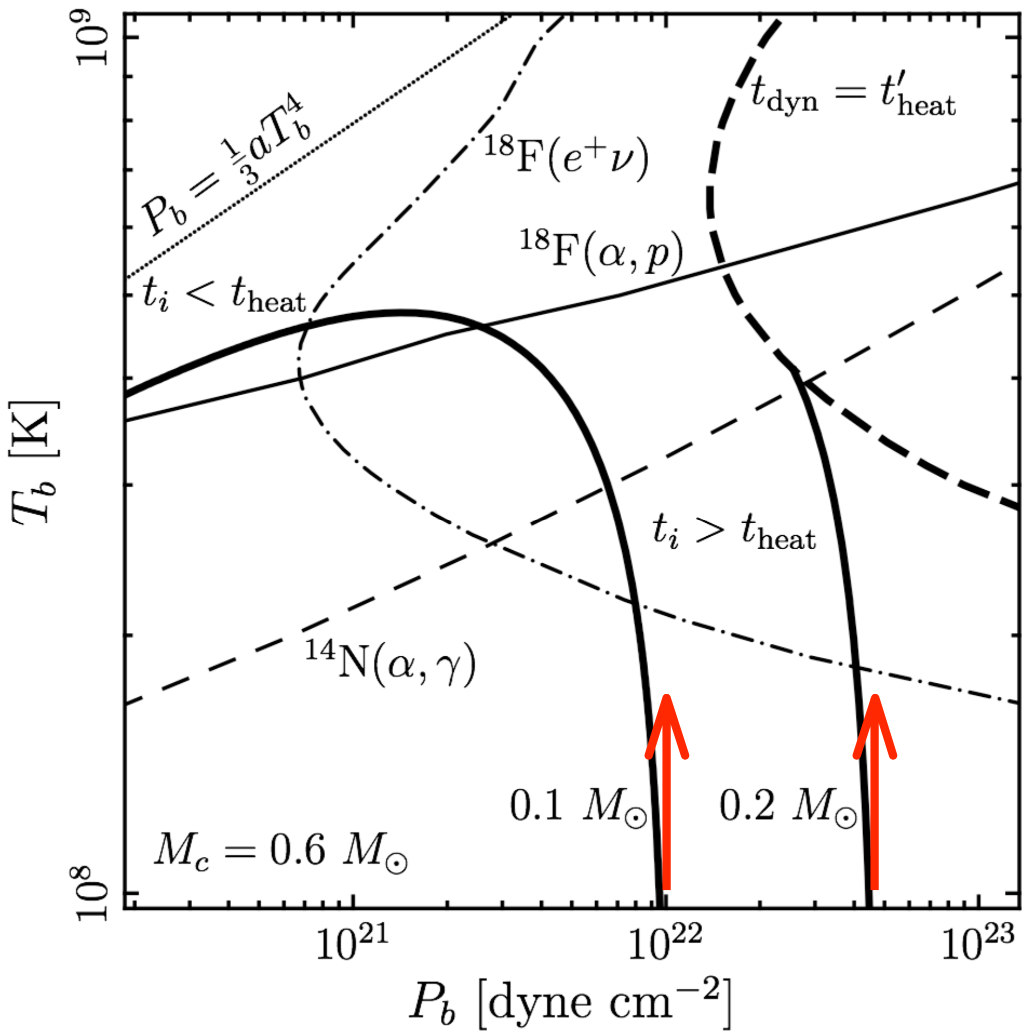
- To see if given isotope hangs around, want to compare $t_{\rm heat}$ to t_i

$$t_i \equiv \left| \frac{d \ln X_i}{dt} \right|^{-1}$$

- α-chain elements unburned when detonation begins
- At post-shock $T > 10^9$ K, α-chain elements burn as fast as or faster than triple-α
- So ZND length is shorter than for pure He

$^{14}N(\alpha, \gamma)^{18}F(\alpha, p)^{21}Ne$

- Majority of accreted metals are ^{14}N due to donor's CNO-processing → $X_{14N} \sim 0.01$
- Timescales too short for ^{18}F to β-decay ($\tau_{1/2}$ = 110 min) → Y_e unchanged



- Post-shock α-capture on ^{18}F yields proton
- Proton catalyzes slow step of α-chain via $^{12}C(p, \gamma)^{13}N(\alpha, p)^{16}O$ (Weinberg et al. '06)
- Further reduces ZND length!

- Self-propagating detonation more likely
- Hydrodynamic studies must include these elements

Conclusions

- AM CVn evolution leads to dynamical He shell explosions: .Ia supernovae
  - Quick rise of a few days, 10% as long as SNe Ia, allowing short-lived radioactivity to be seen
  - Peak of M_V = -17 to -15, 10% as bright as SNe Ia
  - AM CVn birth rate gives upper limit of a few percent of the Ia rate
  - Upcoming (and maybe current) optical surveys should see a few every year! (And SN2008ha [Foley et al. '09] is close…)

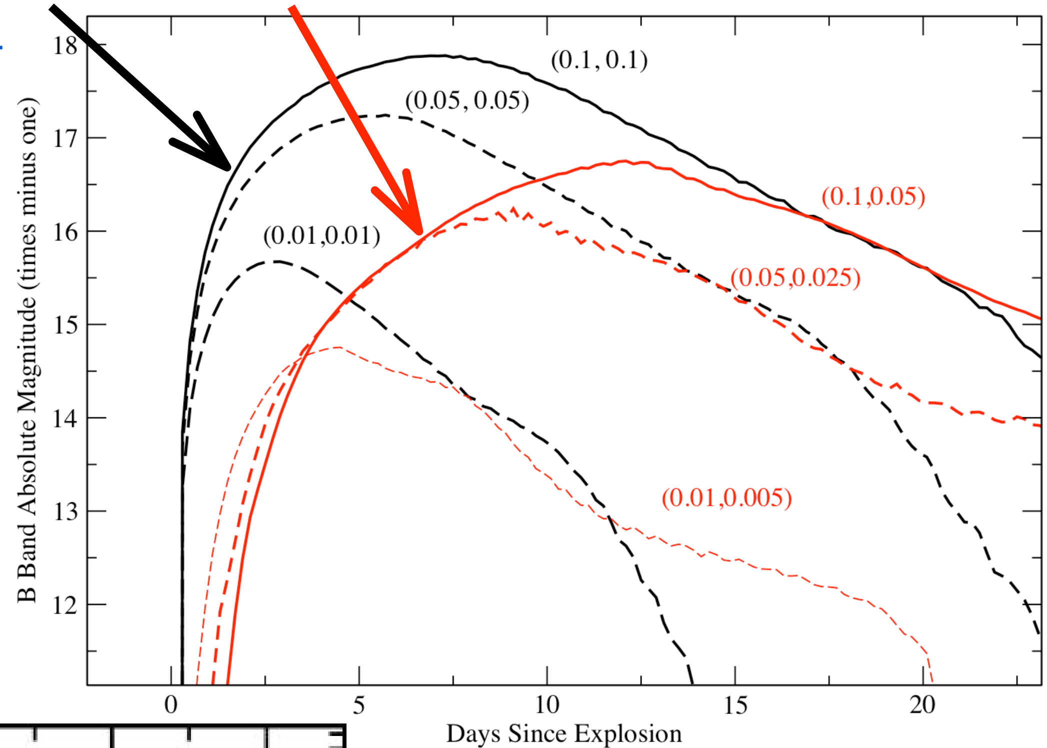
- Trace elements (^{12}C/^{16}O/^{20}Ne & ^{14}N) important for detonation
  - Won't change Y_e and isotopic yield
  - BUT can significantly affect ZND length and likelihood of propagation
  - Future hydro simulations must take these into account

- Calculation also applicable to He core flash; see paper for more details

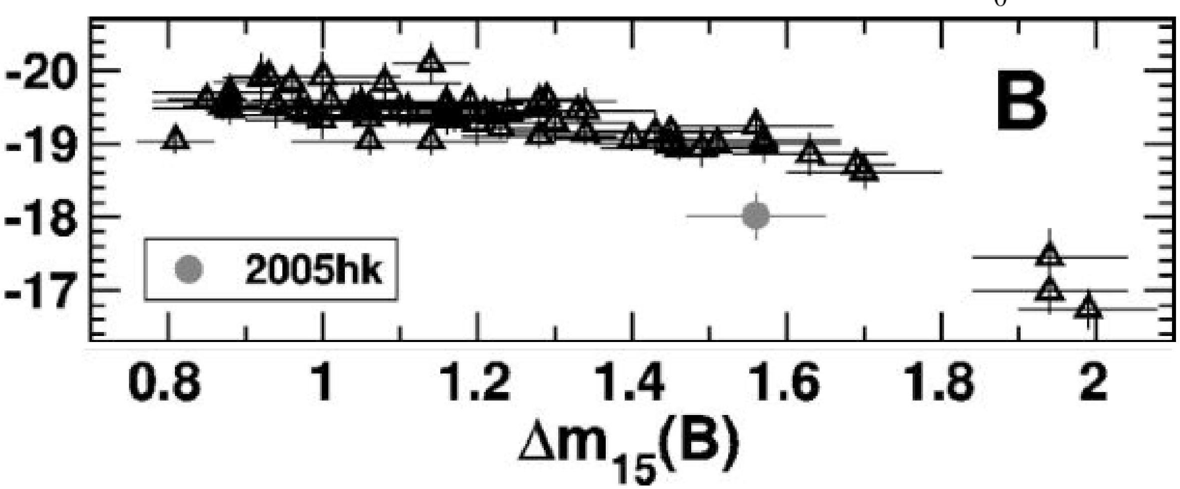
- Many thanks to Lars Bildsten and our collaborators

.Ia Light Curves (courtesy of D. Kasen [UCSC])

- Radiative transfer of expanding ^{56}Ni and ^{56}Ni/^{28}Si balls
- $M_{peak,B}$ = -18 to -15, Δm_{15} = 3 – 4



- Compare to SNe Ia, including subluminous ones, from Phillips et al. (2007):



Bright .Ia, 0.1 Msol of ^{56}Ni
$M_{peak,B}$ = -17.5, Δm_{15} = 3