Faint (.Ia)* Thermonuclear Supernovae from AM CVn Binaries

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Pure helium accretion onto the C/O WD in an AM CVn binary leads to unstable burning and helium shell flashes:

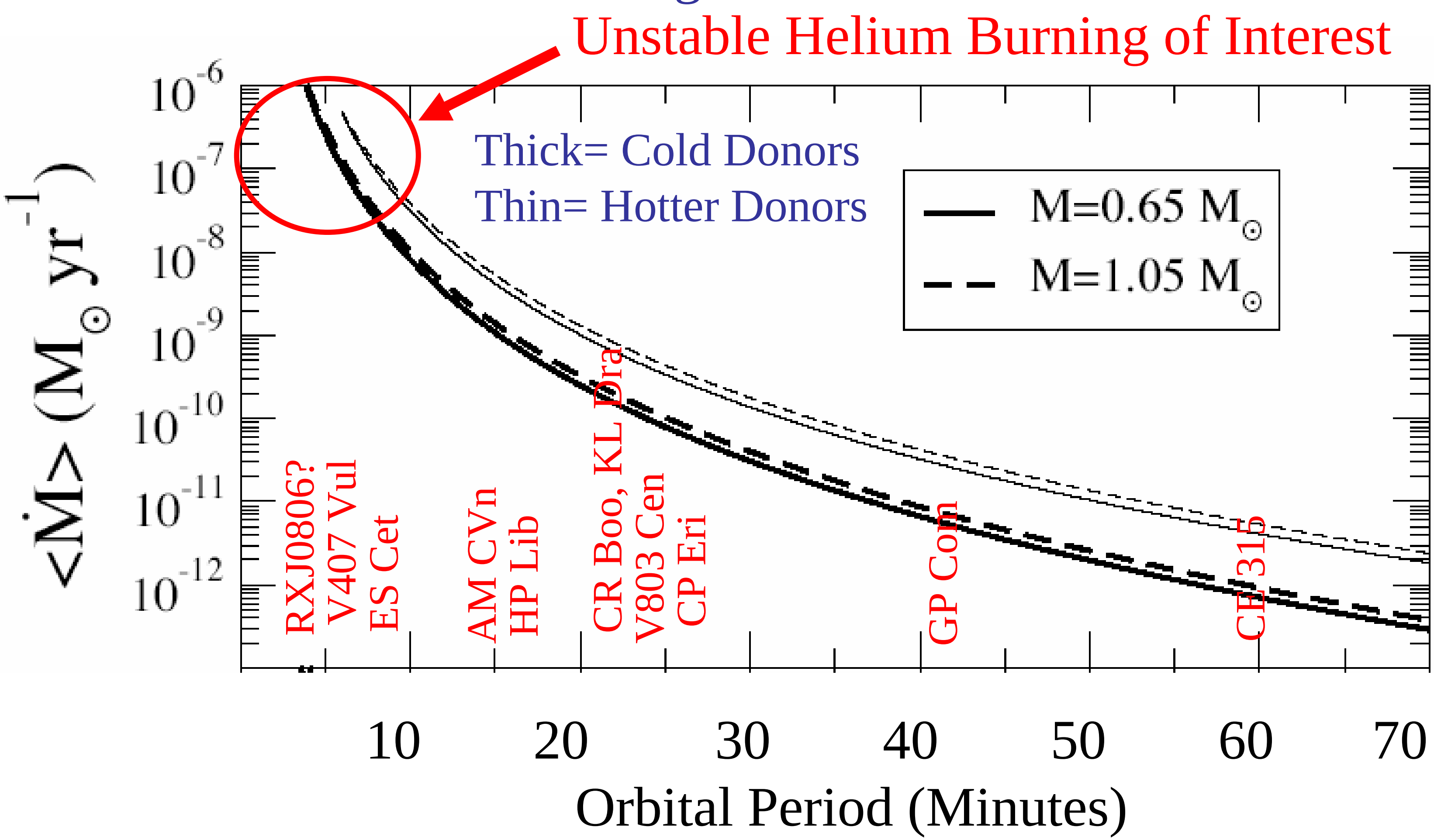
- The last flash is an explosion and ejection of 0.02-0.1 solar masses of radioactive 56Ni, 52Fe, and 48Cr
- This yields a Type I supernova with absolute V magnitude of -16 to -18 for 3-5 days.
- If every AM CVn has one such explosion, the .Ia rate in old stellar populations would be ~1/10th the Type Ia rate.

L.B., Shen, Weinberg & Nelemans 2007, Ap J Letters, submitted

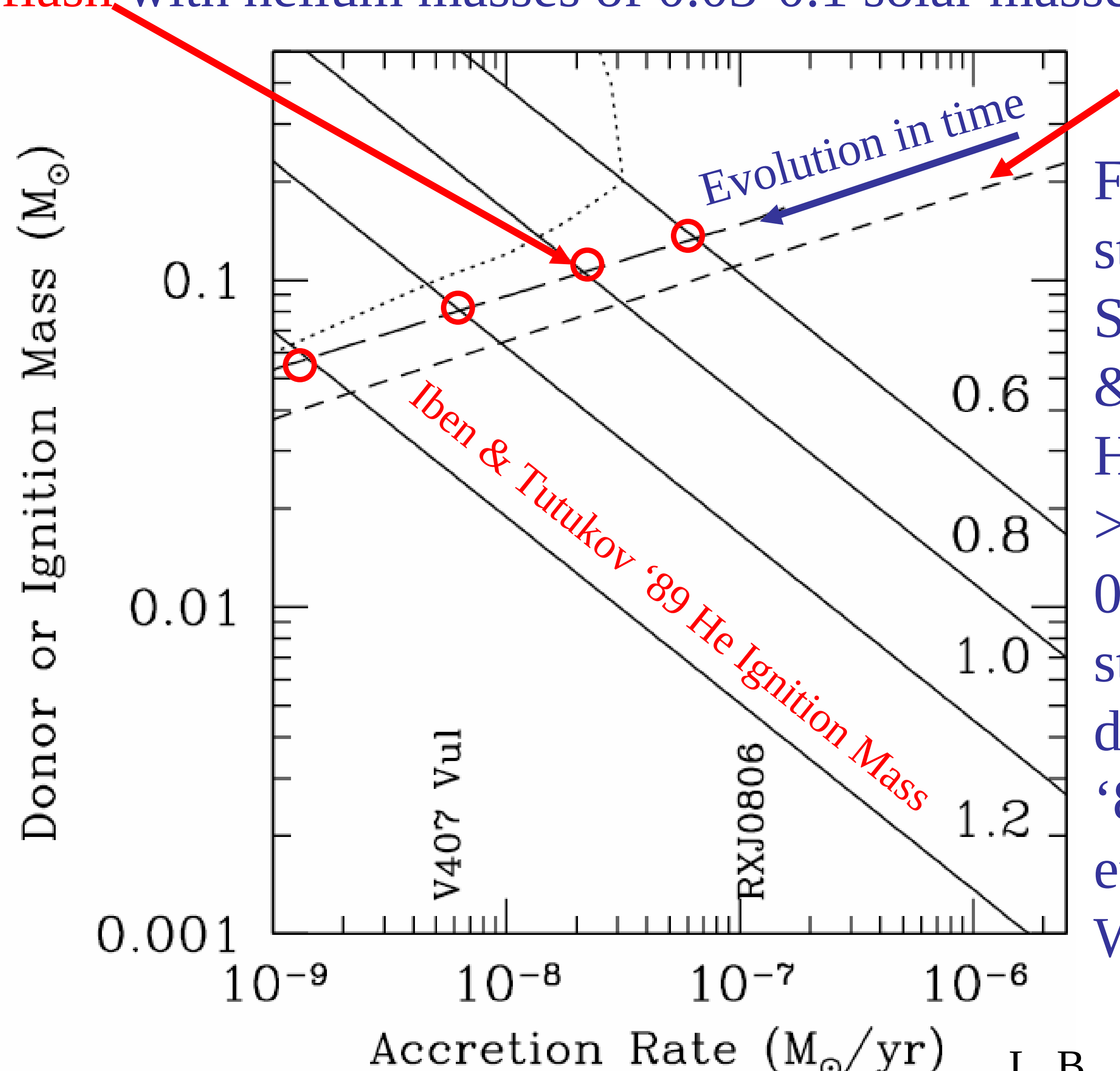
*thanks to Chris Stubbs for name!

Helium Ignitions in AM CVns

He burning is thermally stable when donor mass is 0.2-0.27, with orbital periods of 2.5-3.5 minutes (Tutukov & Yungelson '96). However, as the accretion rate drops, it becomes thermally unstable, and there remain orders of magnitude of accretion rates to traverse…



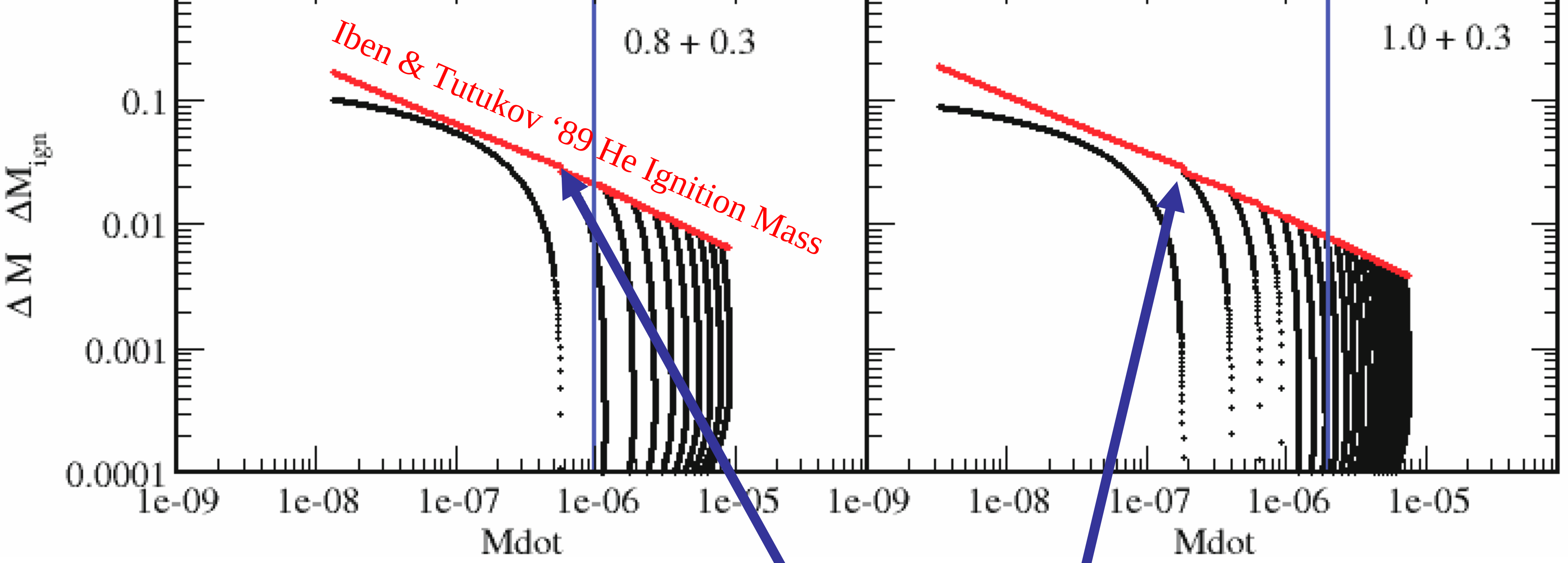
For a degenerate (or semi degenerate) donor (dashed lines) there will be many He novae at early times, followed by one last explosive flash with helium masses of 0.03-0.1 solar masses. .



Helium Donor Mass

For a Helium burning star donor (dotted line; Savonije et al 86; Ergma & Fedorova '90), Helium ignition masses >0.2 naturally occur on 0.6 WDs and were studied as double detonations (Nomoto '82, Livne '90, Woosley et al '86, Woosley & Weaver '94).

L. B., Shen, Weinberg & Nelemans '07



• Early in the evolution, many flashes with masses less than 0.01

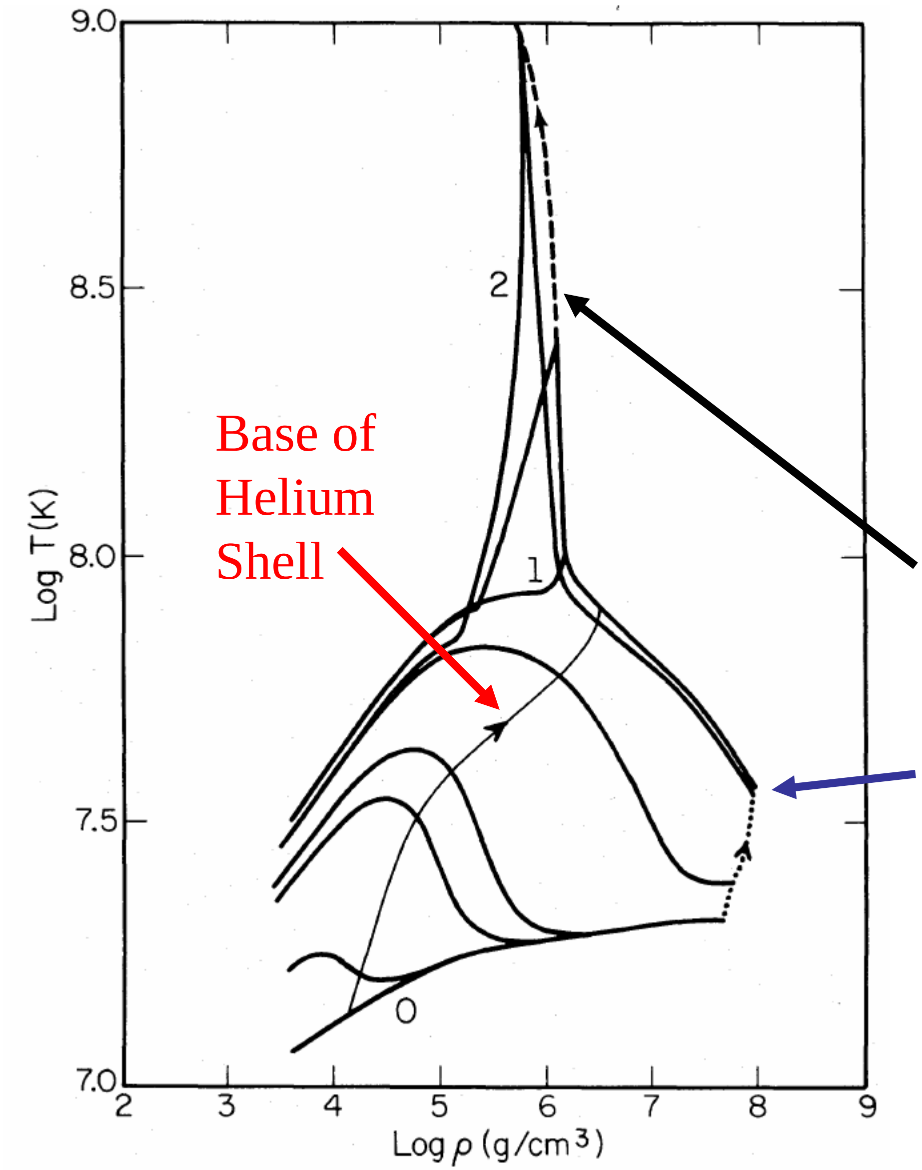
• The last flash has the largest mass (0.03 in these cases), and occurs at 1e-8--1e-7 Msun/year (depending on the accreting WD mass)

• Last flash mass is sensitive to the binary evolution and ignition mass under changing M_dot . . the 0.8 case nearly ignited at 0.08..

• After last flash, the accreted Helium simply accumulates, so all AM CVns with P_orb> 10 minutes are building He envelopes (Bildsten et al '06)

Previous Helium Shell Flash Work

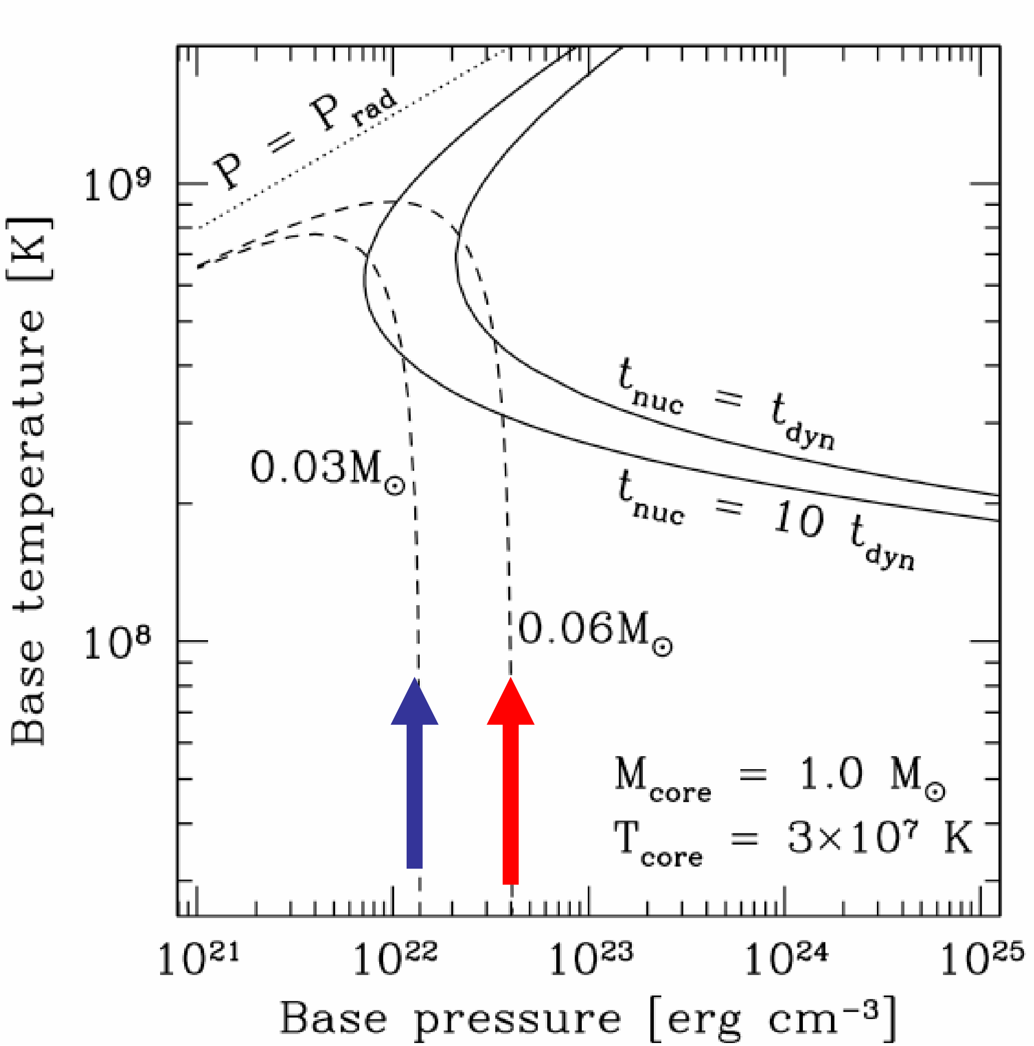
Fujimoto & Sugimoto '82



- A 1.076 M_sun C/O WD accreted Helium at a rate of 3.5e-8
- Ignition occurred after 0.097 solar masses was accreted
- Due to cold core, the ignition point was at 0.043 solar masses
- Convection zone develops and grows in time
- Core decompresses slightly during convective burning
- He Burning became so rapid that heating timescale was on sound travel time across scale height.

Path to Helium Shell Detonations

The radial expansion of the convective region allows the pressure at the base to drop. For low shell masses, this quenches burning. For a massive shell, however, the heating timescale set by nuclear reactions:



$$t_{\rm nuc} = \frac{C_P T}{\epsilon_{\rm nuc}}$$

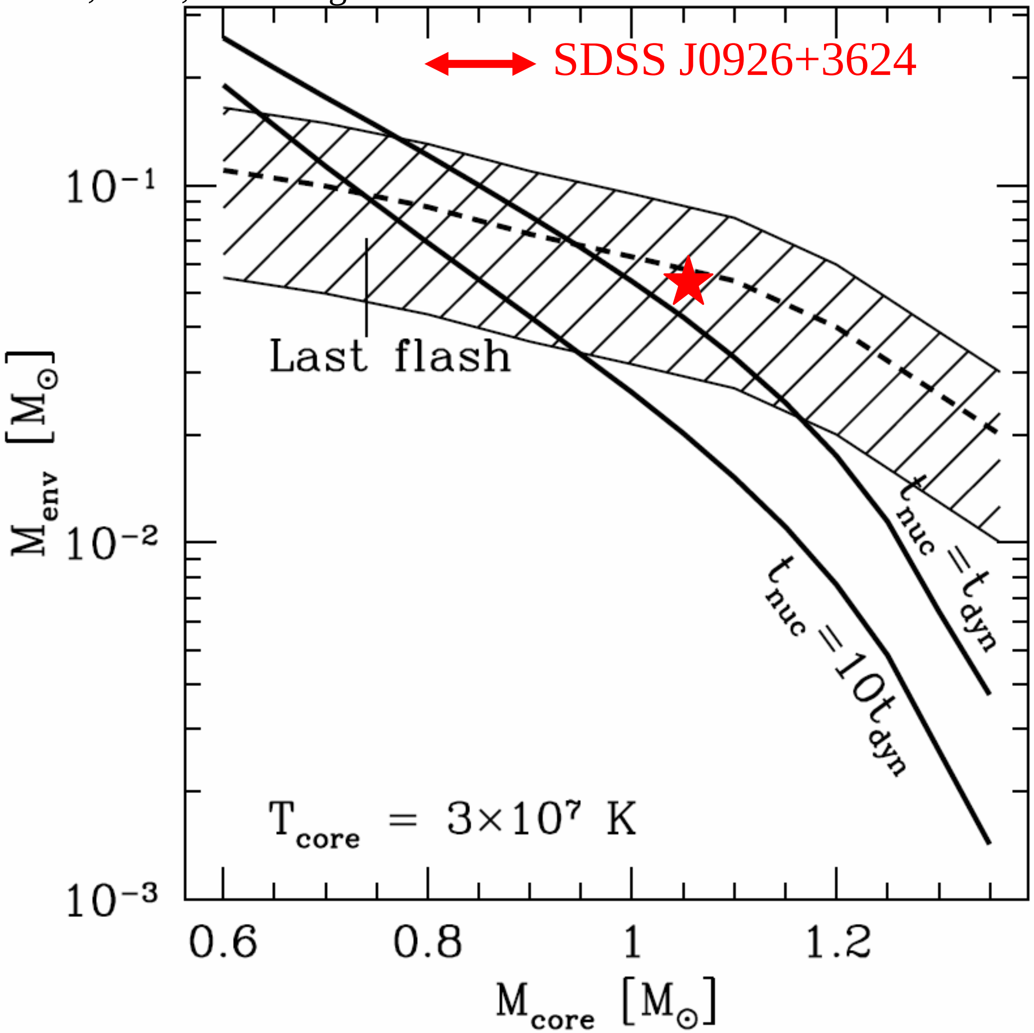
will become less than the dynamical time,

$$t_{\rm dyn} = \frac{H}{c_s} = \frac{P}{\rho g c_s}$$

So that the heat cannot escape during the burn, likely triggering a detonation of the helium shell. This condition sets a minimum shell mass.

Binary Evolution Naturally Yields Detonations

L. B., Shen, Weinberg & Nelemans ‘07

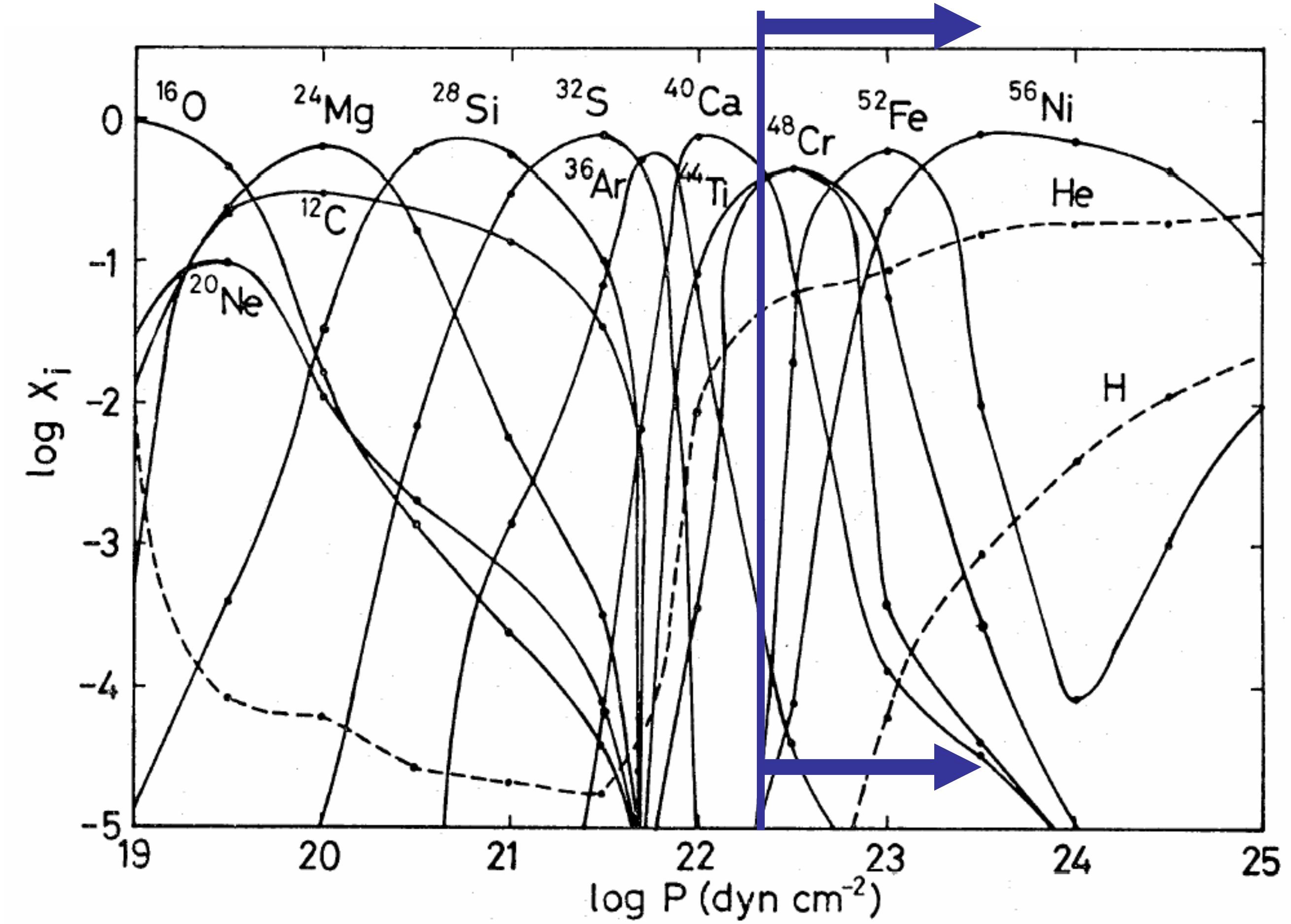


The intersection of the ignition masses with that of the donor yields the hatched region, most of which lie above the dynamical event line ==>

- For WD masses >0.9, likely outcome is detonation
- For lower WD masses, the outcome may be less violent, further work needed

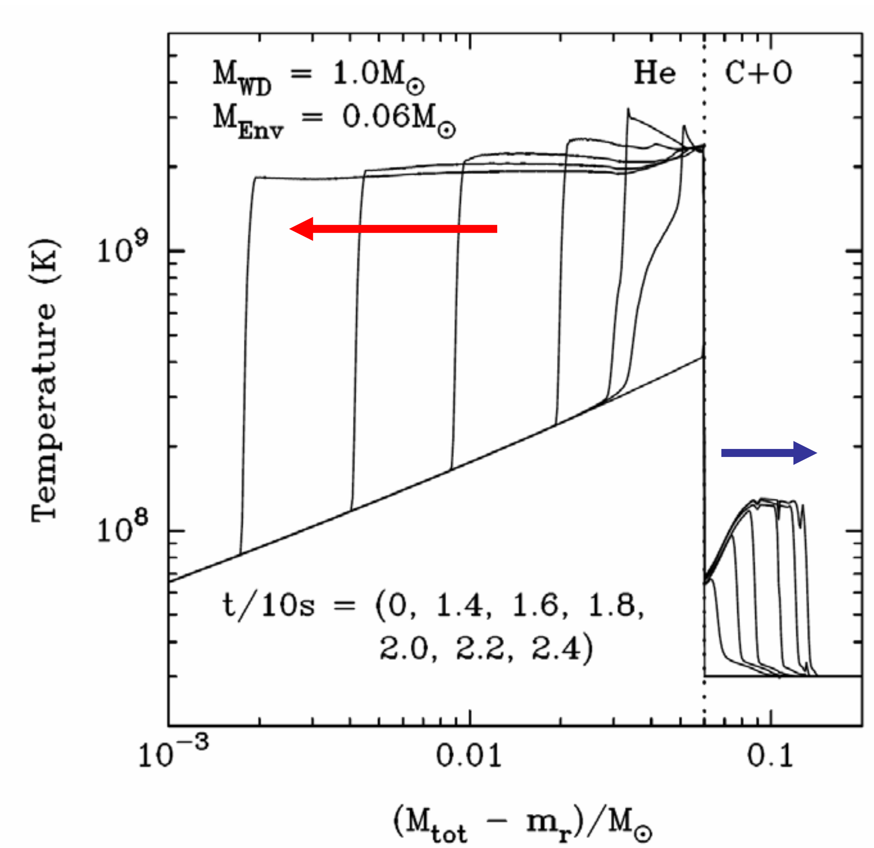
Must understand the dynamic outcome and nucleosynthetic yields from these low pressure detonations.

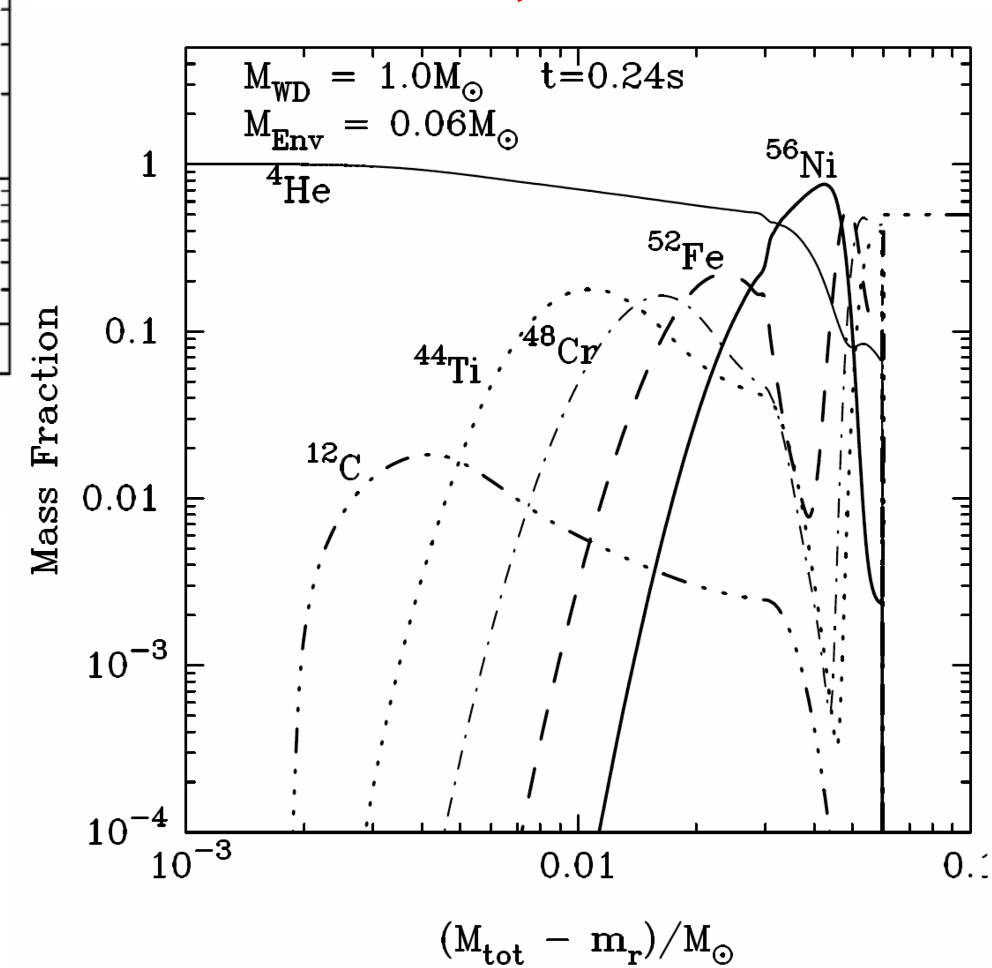
The pressures for the first dynamical cases are in the 2e22-6e22 range.. Naturally leading to an expected production of radioactivities



Hashimoto et al. 1983

Yields at this point in time (0.24 seconds) are 0.012 M_sun of 56Ni, 0.0071 of 48Cr, and 0.0076 of 52Fe, much helium still not burned, but it will later.





Shock goes down (blue arrow) into the C/O and the He detonation (red arrow) moves outward.

Outcome of Helium Detonations

• Helium shell detonation on a WD has been studied previously (Nomoto, Woosley, Weaver, Livne, Arnett. . .) for much larger ignition masses, where it easily detonates and sends a strong enough shock into the underlying C/O WD to ignite the Carbon==> complete disruption

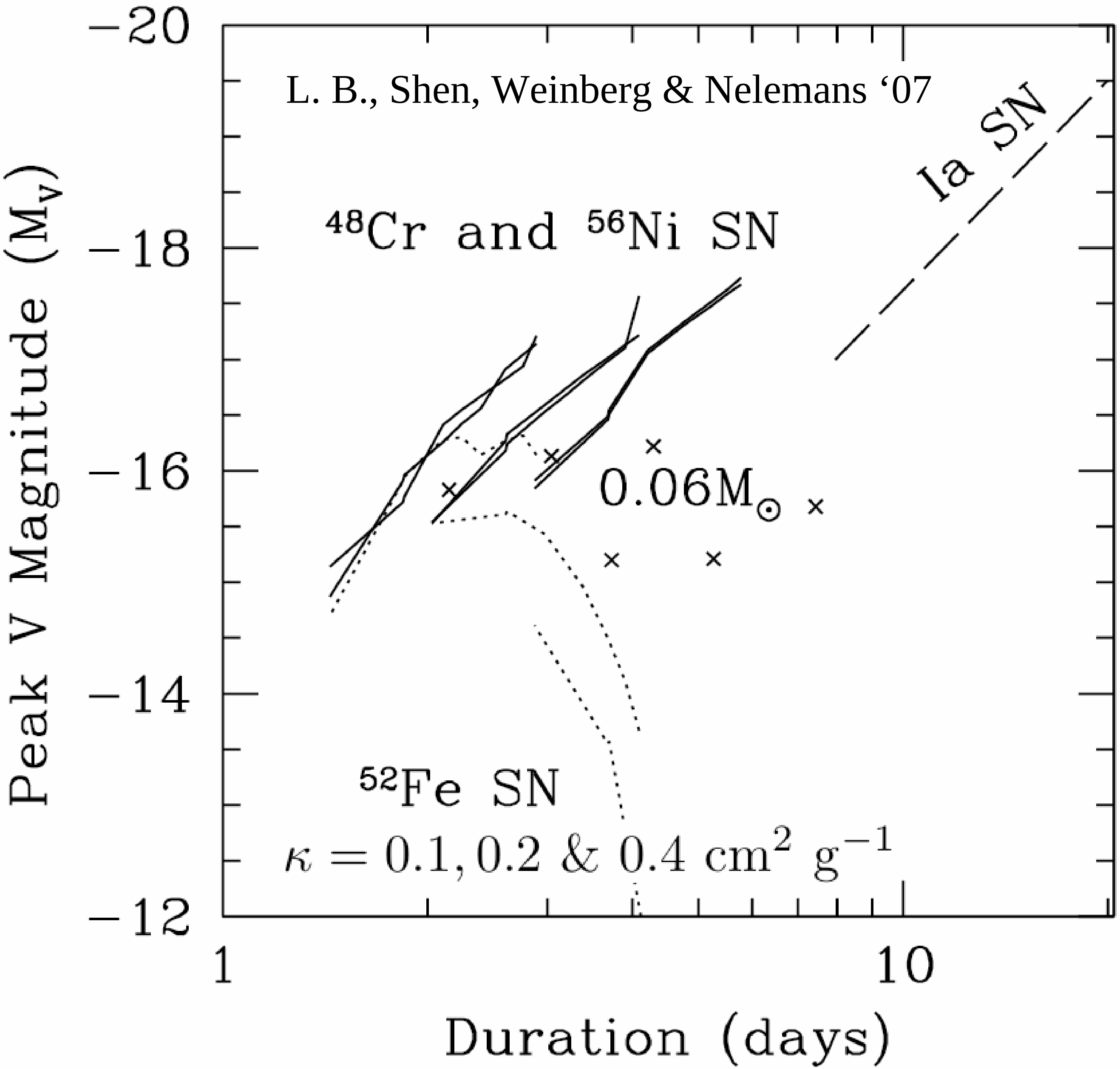
• Double detonations certainly occur, but their lack of large amounts of intermediate mass elements (Si, Ca) in the outer regions eliminate them as the dominant cause of most Type Ia SN.. BUT SHOULD BE THERE!

• Our ignition (and ejection) masses are small (0.02-0.1), so we only detonate helium, which leaves the WD at 10,000 km/sec

$$\tau_m = \left(\frac{\kappa M_e}{7cv}\right)^{1/2} \approx 3-5 \text{ days}$$

• The radioactive decays of the fresh 48Cr (1.3 days), 52Fe (0.5 d) and 56Ni (8.8 days) will provide the power on this rapid timescale!!

.Ia Supernovae



- Typical event remains radiation dominated at maximum light
- We use Arnett's rule to find peak magnitude for the last flash mass ranges
- At maximum light, Teff=10,000-15,000 K. . Except for the 52Fe events, which are much cooler
- Crosses show the 0.06 model…

.Ia Supernovae Rates

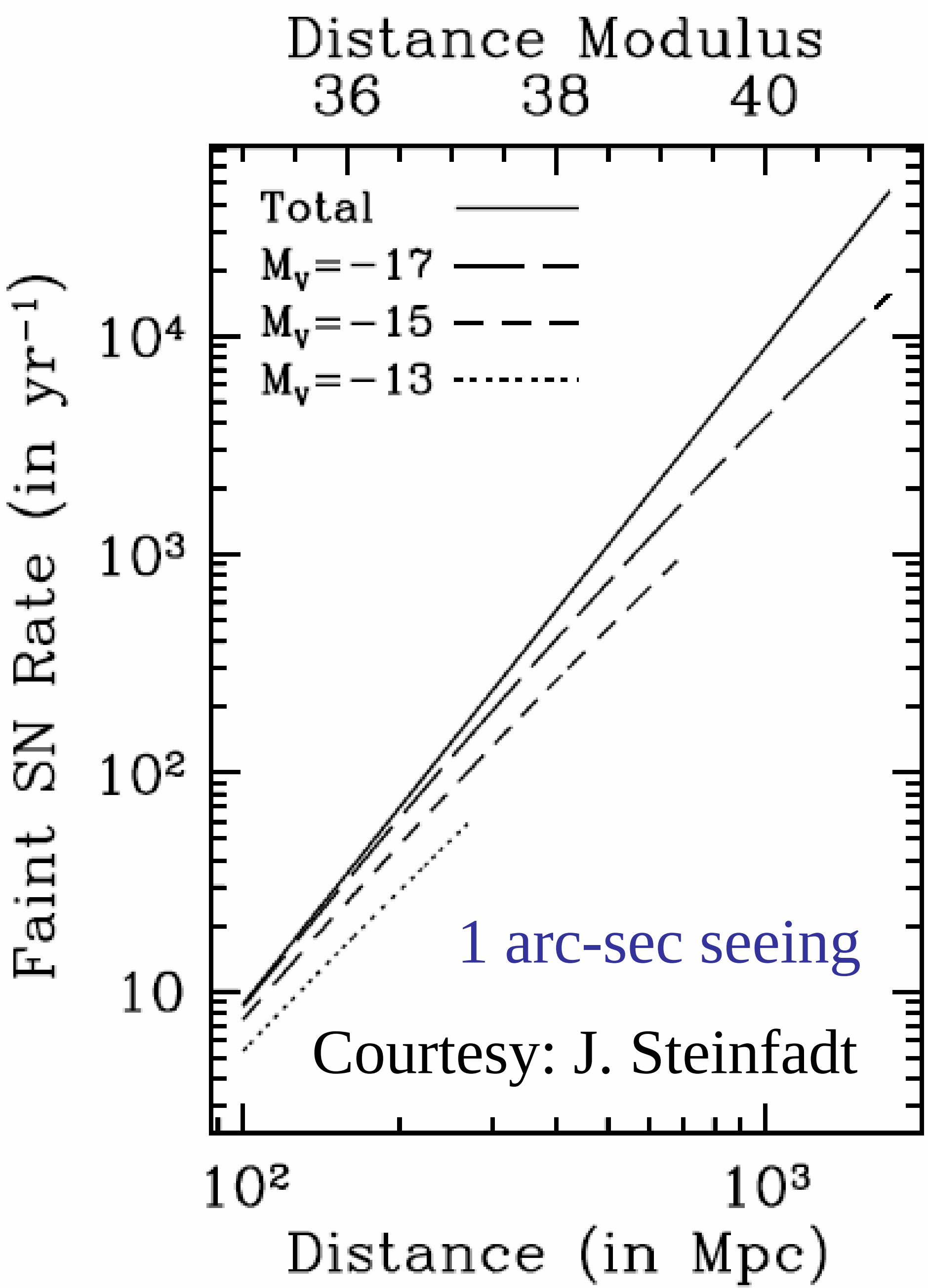
• Nelemans et al ‘04 and Roelofs et al ‘07 give a rough AM CVn birthrate

$$(1-3)\times 10^{-4}\mathrm{yr}^{-1} \text{ in a } 10^{10} L_{\odot,K} \text{ Galaxy}$$

• If every AM CVn gives a .Ia SN, their rate would be 1/4 the Type Ia rate in an Elliptical Galaxy. Likely an upper limit to what is possible.

• .Ia Discoveries would reveal distant AM CVns, and may well have been missed in SN surveys due to rapid decline.

• Volume rate in the nearby universe says that upcoming optical transient surveys with rapid cadences should find many. . . Daily survey 1/2 sky (LSST) to V=24 would give up to 1000 .Ia’s per year.



- Solid line shows number per year if .Ia's have a volume rate 1/10'th of Ia's.
- Some events are lost in the light of the Elliptical host, which depends on peak .Ia brightness (-13,-15,-17 shown)
- Lines show resulting all-sky detection rate assuming all ellipticals are L* and survey depth of V=24

==> at -17, we get over 1000 a year all sky…

==> Rates need to be evaluated for SNLS, SDSS, PS1, PS4, SkyMapper, including cadences.

Conclusions and Future Work

- Binary evolution with helium donors naturally lead to helium shell detonations, many too weak to detonate carbon/oxygen WD
- The combination of a lower ejecta mass and more rapidly decaying radioactive elements makes the .Ia supernovae bright enough to be studied in nearby galaxies (PLEASE FIND THEM!)
- Much theoretical work remains to be done, including

1. Better calculations of Helium ignition masses for changing accretion rate, including 14N electron captures… etc..
2. Hydrodynamic calculations to give full yields and velocity profiles (how much energy is lost to shocking the C/O WD?)
3. Lightcurve calculations, more robust rate estimates . . . .

- Detection would provide a census of AM CVn binaries in distant galaxies.. And nuclear flashes are the only way to see them.