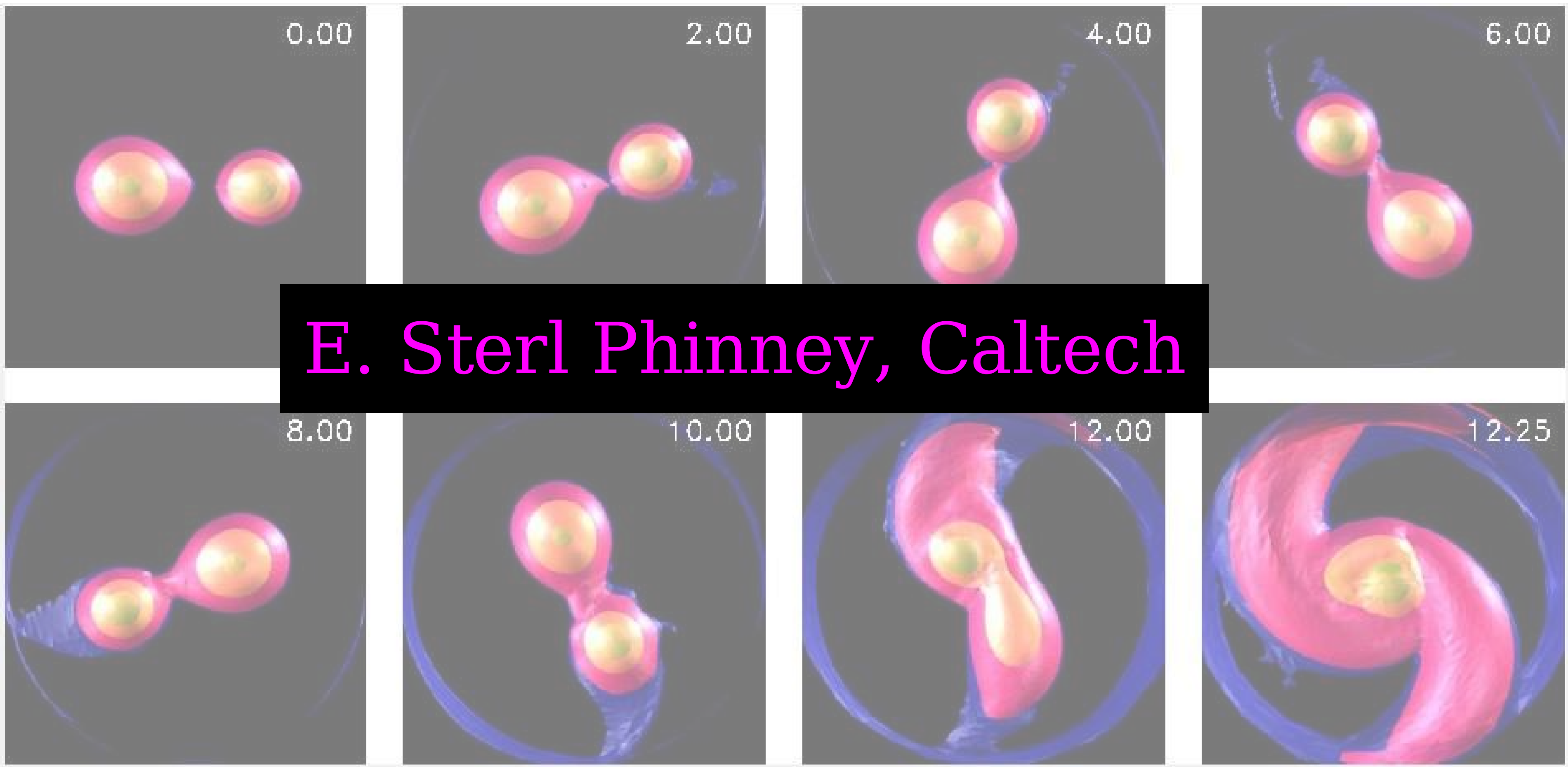
Coalescing White Dwarfs:

Rates, Precursors, EM signatures and Aftermaths



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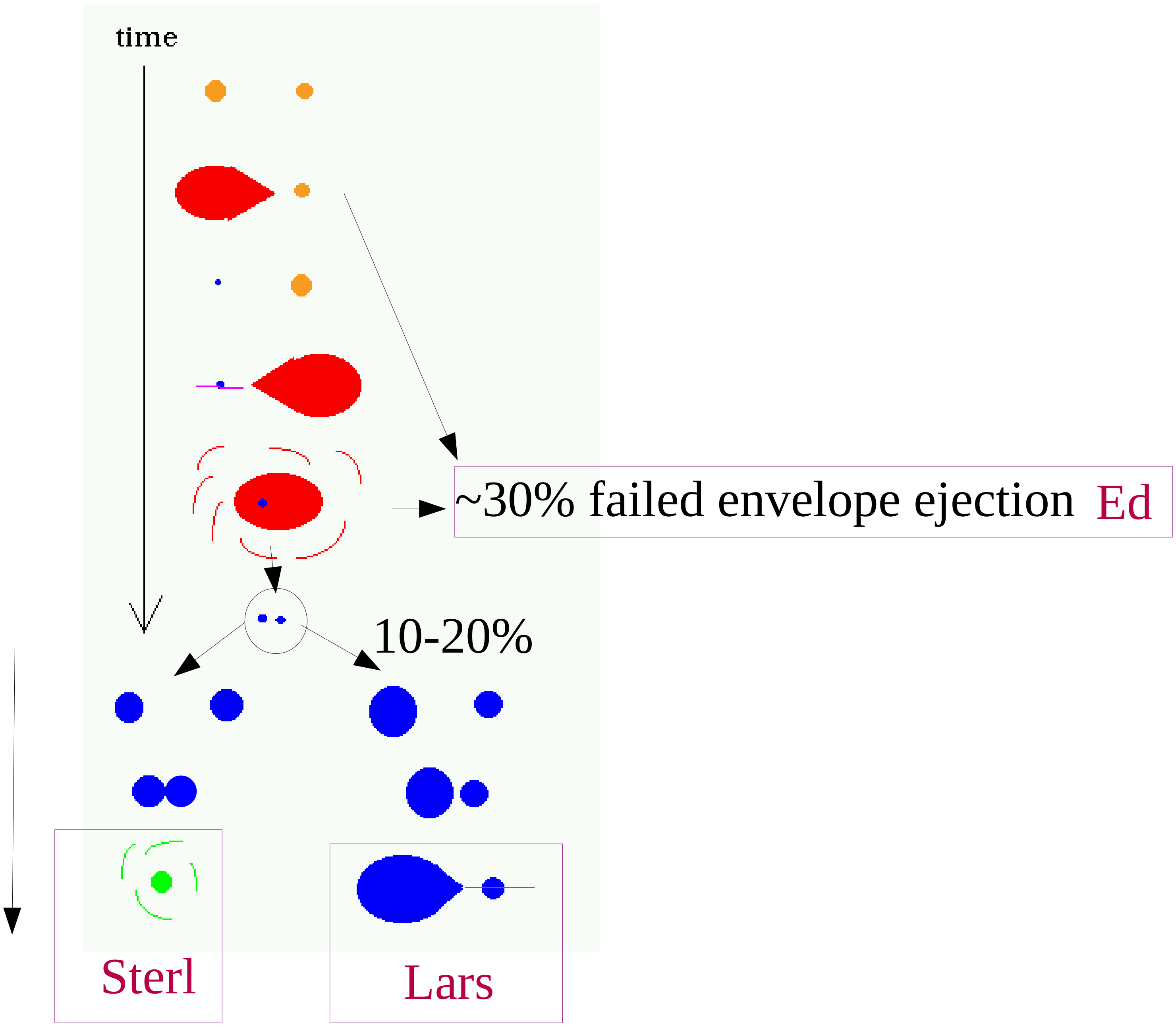
TU 2006, UCSB: 13 Mar 2006

Relation of this talk to the next two



Rates of WD-WD merger

- fairly well determined (factor of few) by both
  - theory: created by common envelope inspiral of initially wide binaries. Depends on
    - binary fraction & mass ratio distribution as function of M_1
    - common envelope ejection efficiency α_{CE} (weakly sensitive). $\alpha_{CE}|\Delta E_{orbit}| > |E_{b,envelope}|$ for CE ejection.
    - angular momentum transport (e.g. by tides) and mass loss $\Rightarrow$ mass transfer stability
  - observation: we see many WD-WD pairs that will merge (esp. recent SPY survey), plus likely aftermaths. Observational rates agree roughly with theoretical ones.

WD-WD merger rates in the Milky Way

Conventional wisdom for merger rates in Milky Way, predicted from single star evolution:

He+He WD (~0.6 $M_\odot$): R=0.006/y

He+CO WD (~1$M_\odot$): R=0.02/y

CO+CO WD (~1.5$M_\odot$): R=0.006/y

of which ~50% have $M_1+M_2>1.4M_\odot$ (SNIa or AIC candidates)

Comparable numbers of long (3Gyr) and short (0.3Gyr) delay cases, consistent with large variation of SNIa rates with galaxy type: Mannucci et al astro-ph/0411450, 2005 ASPC 342, 140.

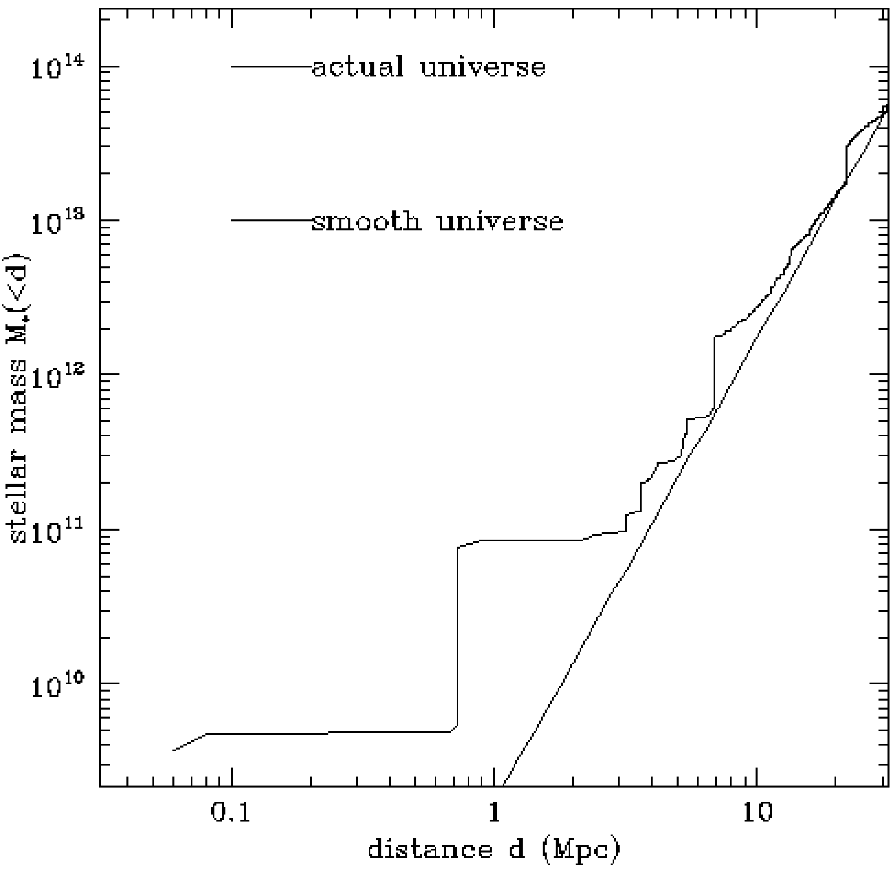
Han 1998 MNRAS 296, 1019

Nelemans et al 2001 astro-ph/0010457

Webbink 1984 ApJ 277, 355

But note Shara & Hurley astro-ph/0202179: open star clusters can produce 15x more CO+CO via exchanges and hardening than single star evolution!

WD-WD merger rates in the universe



Scaling to the rest of the universe gives volume-average z=0 rates

He+He: $4x10^{-5}Mpc^{-3}y^{-1}$

He+CO: $2x10^{-4}Mpc^{-3}y^{-1}$

CO+CO: $6x10^{-5}Mpc^{-3}y^{-1}$

Given the Virgo enhancement above the mean density, these rates give D(1/y)~7-10Mpc.

Mergers: theory

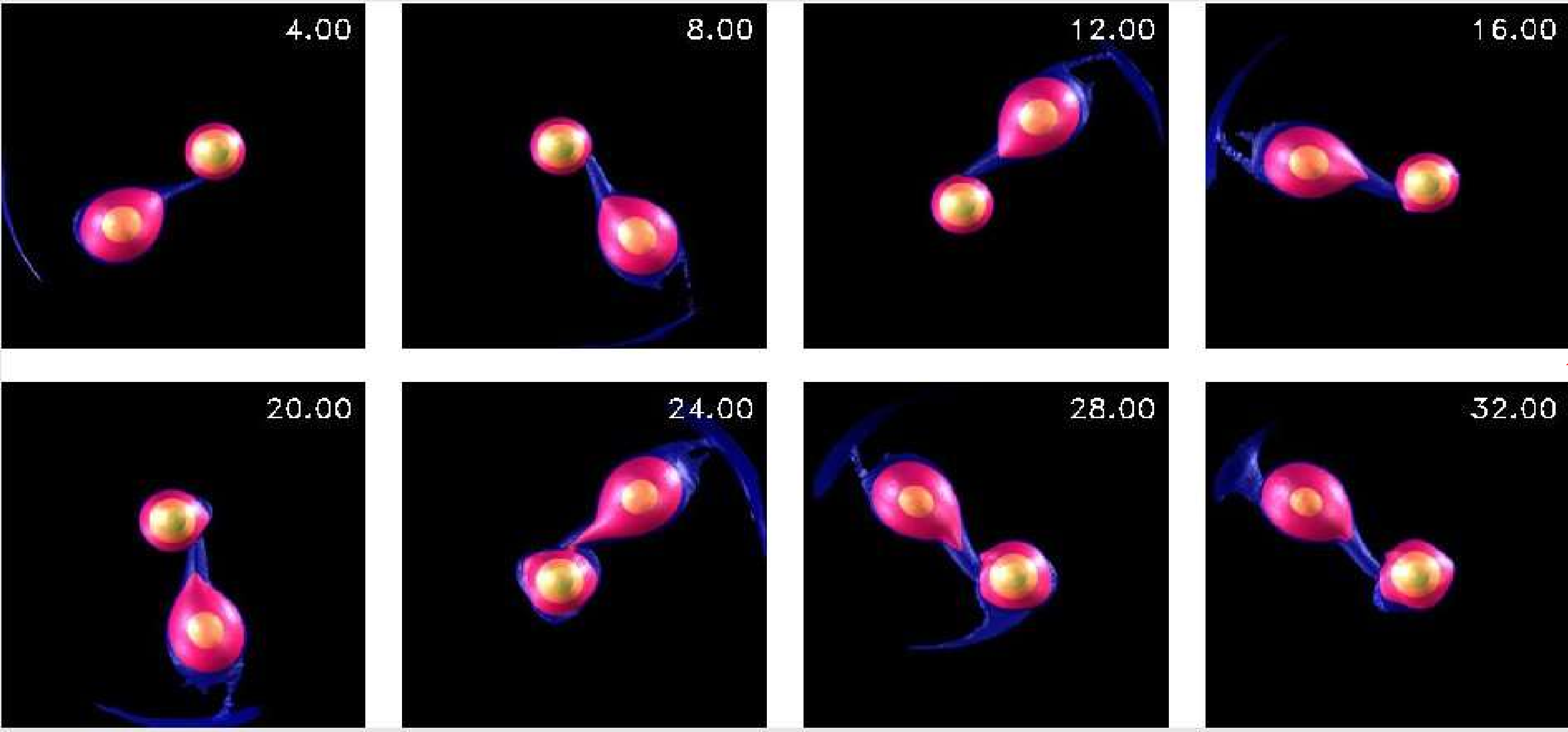
- Degenerate stars: less massive bigger, fills Roche lobe first. $q=M_{loser}/M_{gainer}$. WDs not subject to tidal instability as are stiffer NS's (cf. Lai et al 1993 ApJ 406, L63)
- If angular momentum of accreted material conserved (no mass loss) and transferred back to orbit (by disk tides or stellar tides)
  - When mass transfer starts, if $q>0.6$ mass loser swells faster than Roche lobe: dynamical instability.
  - If $q<0.6$, mass loser swells more slowly than growing Roche lobe: dynamically stable.
  - If $q<0.22$, stable even without tides to transfer angular momentum back to orbit.
  - Limiting understanding: white dwarf tides, mass loss, disk dynamics and direct impact physics. Affects stability (Soberman et al 1997 AA 327, 620) of transfer and dM/dt.

The skeleton in the closet:

RXJ0806.3+1527, P_b=5min, direct impact. dP_b/dt right magnitude, wrong sign for conservative GR-driven evolution. L_X too low by orders of magnitude. Must be below equilibrium transfer rate. Also V407 Vul. Note that tides can dissipate rotation energy ~WD's grav binding energy! Need to understand tides in white dwarfs!

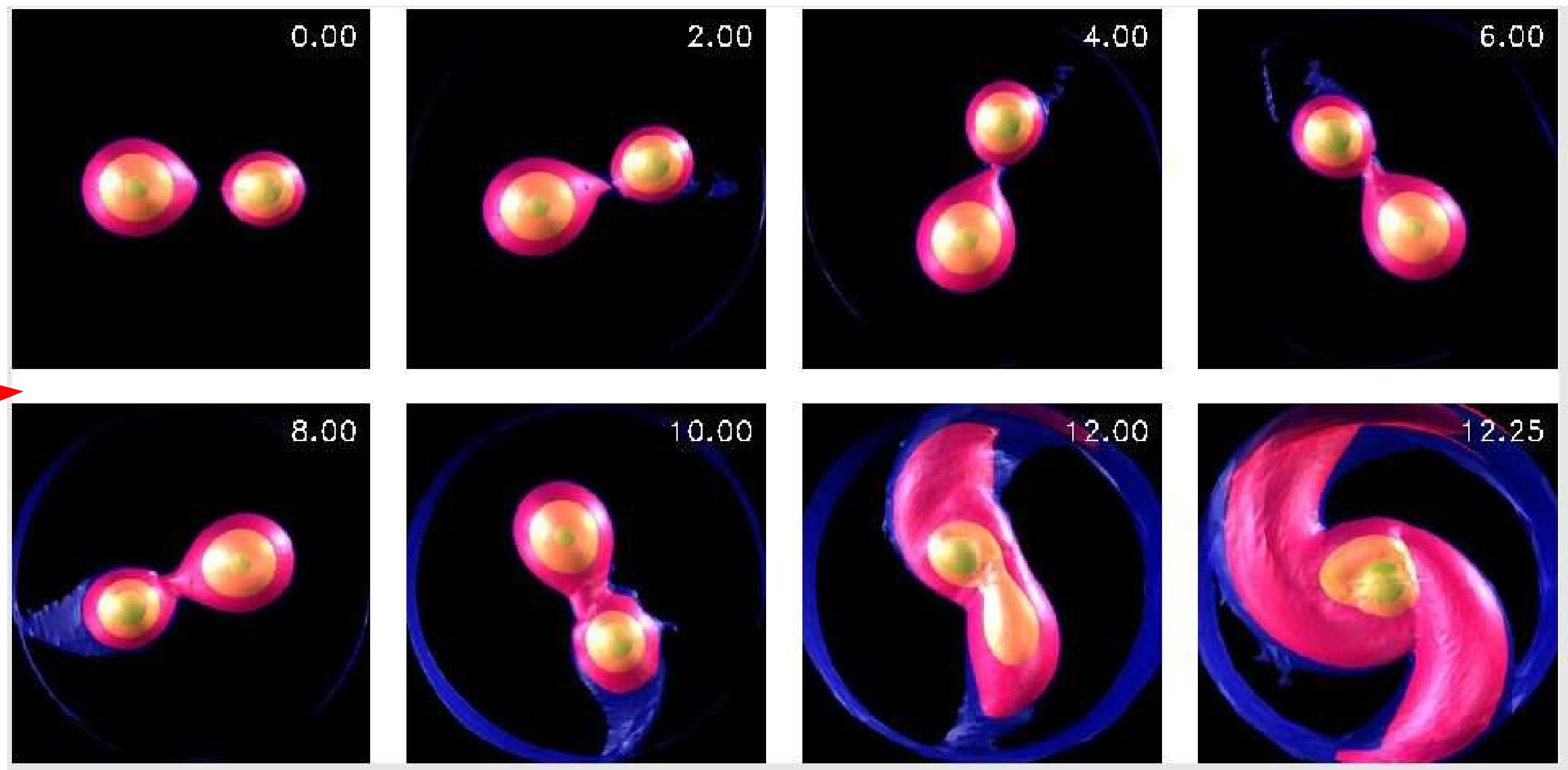
Mergers: simulations

- Smooth Particle Hydro (SPH) simulations seem to make everything disrupt (even q=0.5: Rasio & Shapiro 1995 ApJ 438, 887 and q=0.33: Guerrero et al 2004 A&A 413, 257).
- More accurate Eulerian hydro simulations (D'Souza et al astro-ph/0512137) disrupt q=1.3 as expected, but find q=0.5 to be dynamically stable as expected theoretically and in contrast to the SPH results.
- In no case (SPH or Eulerian) is a significant >2% fraction of the total mass ejected.



q=0.5

MOVIE TIME



q=1.3

D'Souza et al
astro-ph/0512137

Electromagnetic appearance 1

- Conventional (Nova, SNIa) modellers assume all of disrupted WD disk accretes at Eddington rate
  - $dM_{Edd}/dt = 1.7x10^{-5} (R_{wd}/10^9 cm) M_{\odot}/y$
  - $L_{Edd} = 5x10^4 L_{\odot}$, $M_{bol} = -6$
  - Lasts $t \sim 10^3$-10^4 years! Hot, high Mdot $\Rightarrow$ stable He burning.
- Magnetic alternatives:
  - Photon bubble instability (Ruszkowski & Begelman 2003 ApJ 586, 384; Gammie 1998 MN 297, 929) allows $L \sim 100 L_{Edd}$. Mass loss also! $M_{bol} = -11$, $t \sim 1$ y. Thomson thick wind $\tau_T \sim 4x10^3\, dotM_{-3}\, R_9^{-1}$

Proposed aftermaths of WD-WD merger

- Single subdwarf OB (sdB, sdO) stars: He+He
- R Coronae Borealis (R CrB) stars: He+CO
- EUVE J0317-85.5 rapidly rotating 1.35Msun, magnetic white dwarf: CO+CO
- Most single white dwarfs with M>0.7Msun.
- Neutron stars: accretion induced collapse CO+ONeMg, ONeMg+ONeMg
  - single msec pulsars (weakly magnetised WDs)
  - magnetars/AXPs/SGRs (strongly magnetised Wds)
- Type Ia Supernovae.
  - Ib/c ???

Aftermaths: sdB/sdO stars

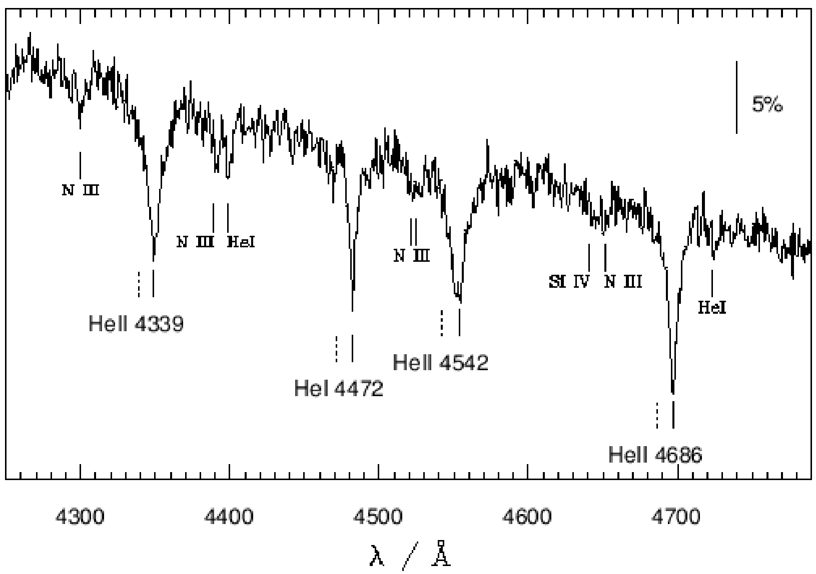
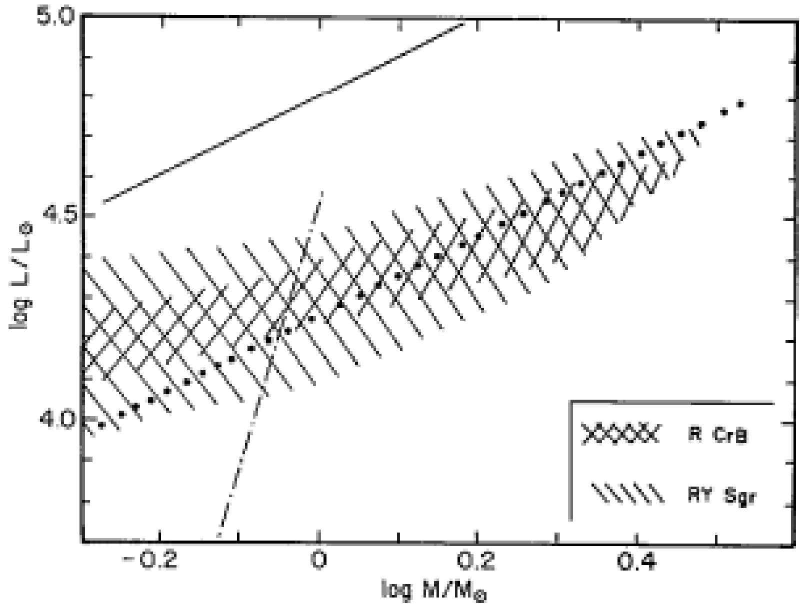


Fig. 1. Section of the spectrum of US 708. Rest-wavelengths of the strongest lines are marked as dashed lines. Note the large redshifts.

- Extreme Horizontal Branch stars $\sim 0.5 M_\odot$; core He burning, $<10^{-2} M_\odot$ H envelope too thin to burn. Evolve directly to cooling WDs. Han et al 2003 MNRAS 341, 669
- One interesting new case: Usher 708. 14kpc above plane, V>750km/s hypervelocity star. Orbit traces back to GC 32Myr ago. Hirsch et al astro-ph/0511323.

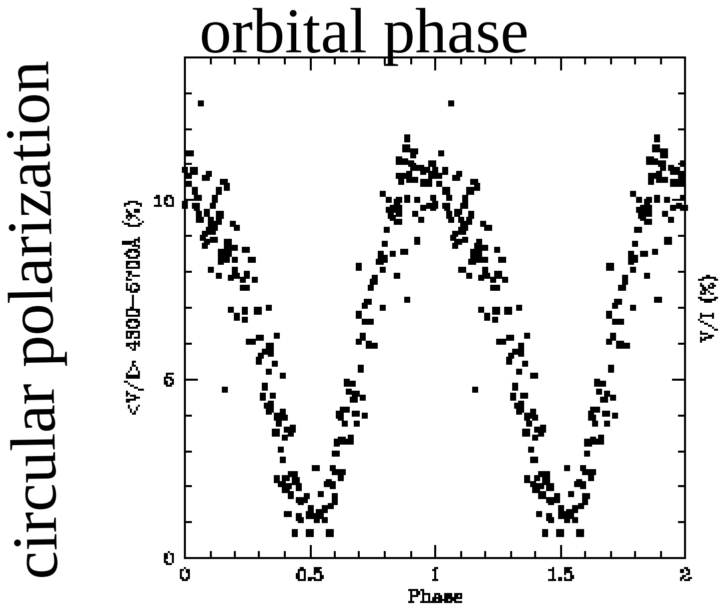
Aftermaths: R CrB stars



Saio & Wheeler 1983 ApJ 272 L25
pulsation (P=44d and 39d) constraints on M,L.

- Cool (~3500-10,000K) helium stars. $L_V \sim 10^4 L_\odot$, $M \sim 1 M_\odot$
- [H/He]<-4
- transient fadings due to dust formation in stellar wind.
- Formation models
  - final He shell flash just after planetary nebula.
  - CO+He merger
- Iben et al 1996 ApJ 456, 750.

Aftermaths: EUVE J0317-85.5



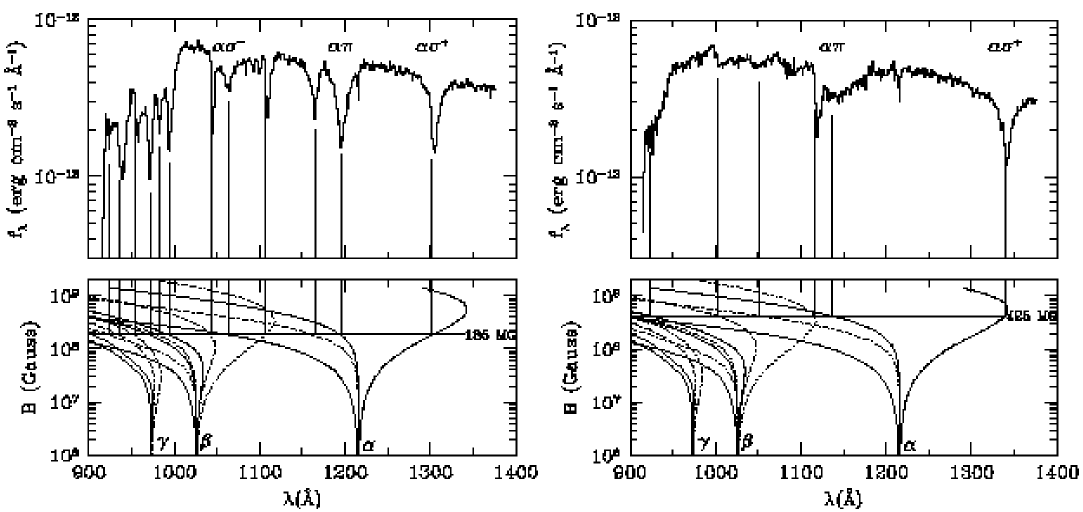
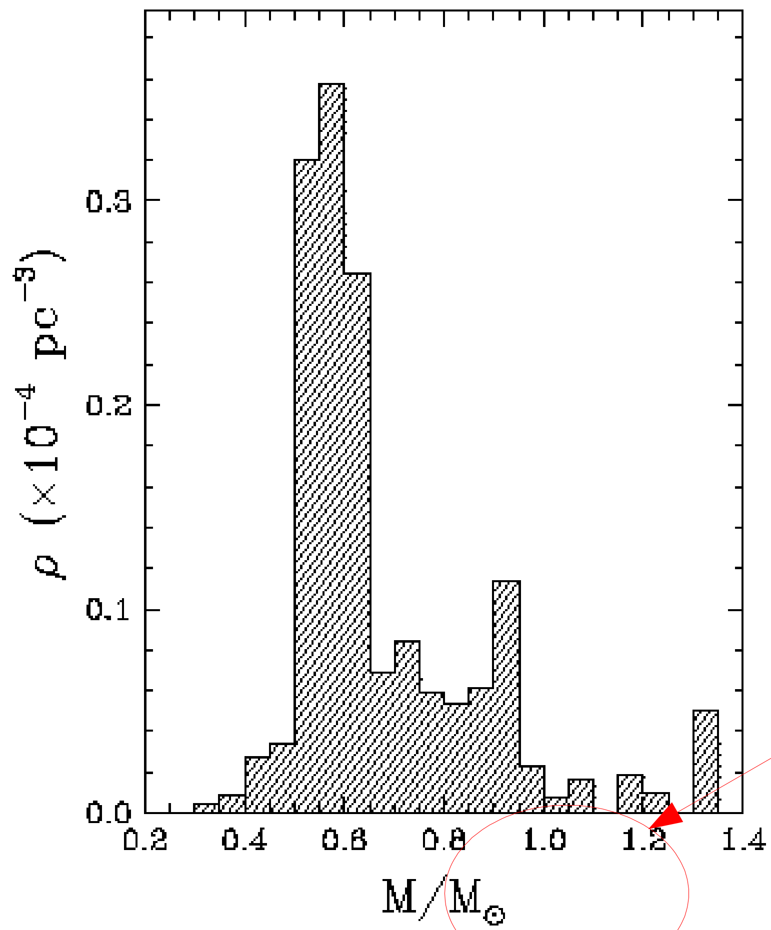


FIG. 3.—Phase-resolved *HST* FOS/*FUSE* spectroscopy at $\phi = 0$ (*left*) and $\phi = 0.5$ (*right*). The FOS and *FUSE* data are merged at $\lambda = 1175$ Å. The spectra t both phases are compared to predicted line positions for permitted (*solid lines*) and forbidden lines (*dashed lines*), showing that $\phi = 0$ is characterized by a ield strength of $B = 185$ MG, while $\phi = 0.5$ is characterized by a field strength of $B = 425$ MG.

- M=1.35Msun, log *g*=9.3
- P_{rot}=725.7s
- Teff=33,000K, H rich
- B_{dipole}=450MG
- Cooler, less massive non-magnetic companion at 200AU.
- Vennes et al 2003 ApJ 593, 1040; Ferrario et al 1997 MNRAS 292, 205.

Aftermaths: Massive single WDs??

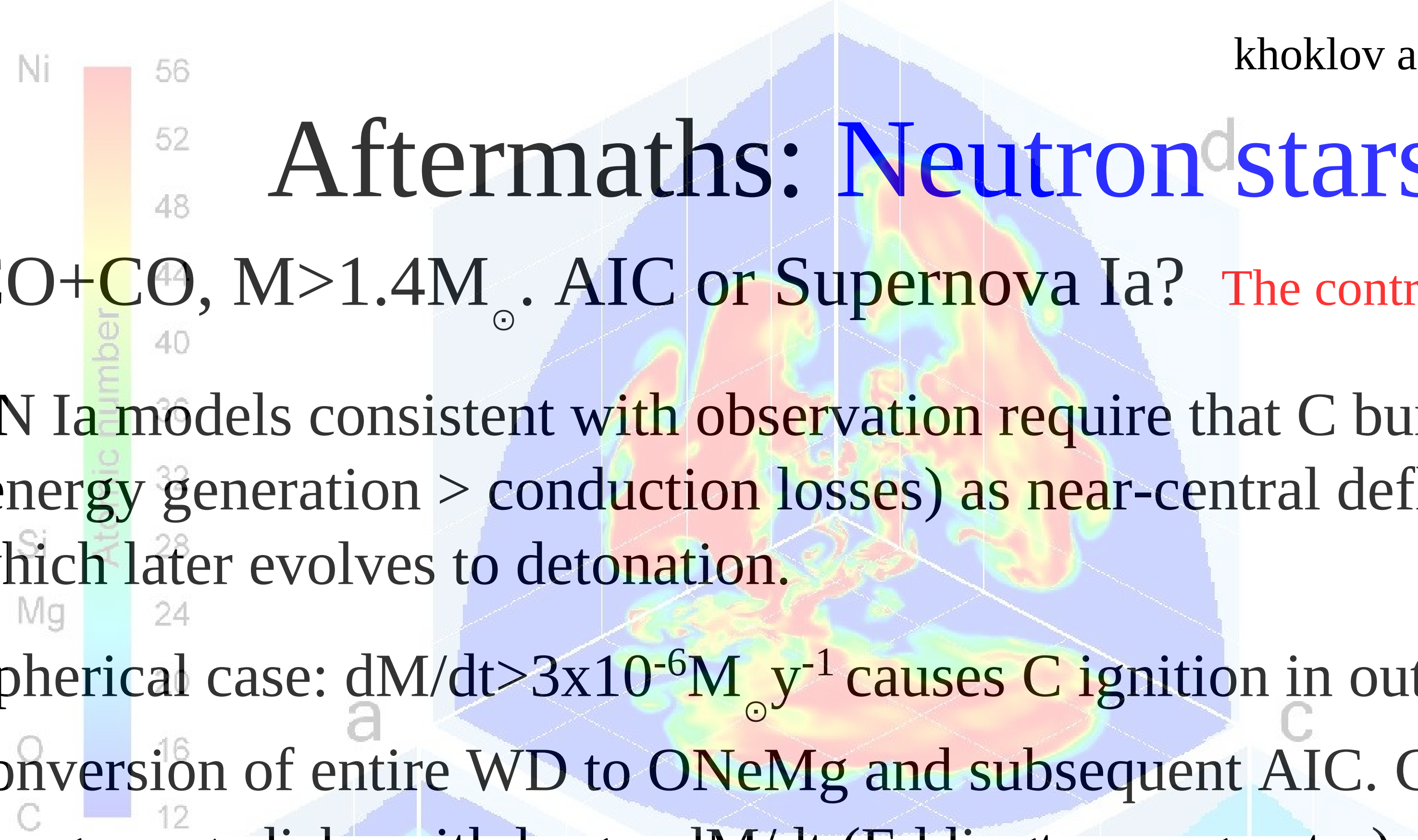


Maybe some comets/planets form in the disk? cf. Phinney & Hansen 1993 ASP CS 36, 37; Menou et al 2001 ApJ 559, 1032; vs G29-38 and Hansen et al astro-ph/0511094, Debes & Sigurdsson 2002 ApJ 572, 556

- With some IMFs and initial mass-final mass relations, only ~20% of the white dwarfs in the 0.8Msun peak can be produced by single-star evolution. cf Liebert et al astro-ph/0406657. Rest due to WD-WD mergers?
- But with other im-fm relations, no problem! cf Ferrario et al 2005 MN 361, 1131. Maybe just rapid rotators like EUVE J0317?

khoklov astro-ph/0409598

Aftermaths: Neutron stars



- CO+CO, $M>1.4M_\odot$. AIC or Supernova Ia? The controversy continues.
- SN Ia models consistent with observation require that C burning “ignites” (energy generation > conduction losses) as near-central deflagration, which later evolves to detonation.
- Spherical case: $dM/dt>3x10^{-6}M_\odot y^{-1}$ causes C ignition in outer layer and conversion of entire WD to ONeMg and subsequent AIC. CO+CO mergers ⇒ disks with larger dM/dt (Eddington or greater), so AIC not Ia.
- Piersanti et al 2003 consider spinup of WD -assume accretion rate drops as star reaches mass-shedding limit, find central ignition; SNIa, not AIC.
- Saio & Nomoto astro-ph/0401141: accretion continues across boundary layer of spunup WD (Popham & Narayan 1991), assume constant dM/dt. Get outer ignition due to large dM/dt, so AIC, not SNIa.
- But models are spherical(!), do not actually compute boundary layer/disk dM/dt and torques....

Electromagnetic appearance 2

- More Magnetic alternatives for CO+CO mergers $>1.4M_\odot$ which turn out to be AIC, not SNIa:
  - Winding of magnetic field: jets, magnetars. Very short and bright!
  - Magnetar hypothesis natural given EUVE 0317-85.5: rapidly rotating $1.35M_\odot$ magnetic $B=4\times10^8$G white dwarf. Slightly more massive merger would have led to accretion-induced collapse to a neutron star, flux conservation $B_{NS}=B_{WD}(R_{WD}/R_{NS})^2=10^{14}$G.
  - Proposed by King et al 2001 MNRAS 320, L45 and as source of short GRBs from giant SGR flares by Levan et al astro-ph/0601332. Expect about 10% CO+CO mergers magnetic enough.
  - Usov 1992 Nature 357, 472 proposed as GRB model. Middleditch 2004 ApJ 601, L167 proposes AIC also for long GRBs, and Type Ib, Ic and IIp SNae.
  - Winding of B by differential rotation(disk or accreting WD) could produce even stronger B enabling relativistic jet expulsion: e.g. slight modification of Dai et al 2006 Science 311, 1127 astro-ph/0602525, or Spruit 1999 A&A 341, L1.

Conclusions

- White dwarf mergers ~1/y in Virgo.
- Non-magnetic mergers limited by thermal-time escape of radiation, and Eddington/photon-bubble accretion rates/luminosities. Probably M_{bol}>-11, timescales >year.
- Magnetic mergers potentially much more spectacular, and if they result in AIC could plausibly create magnetars and some GRBs.