UNIVERSITY OF CAMBRIDGE

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Institute of Physics of the Czech Academy of Sciences

OVERLY LUMINOUS TYPE IA SUPERNOVAE FROM SUPER-CHANDRASEKHAR MASS HIGHLY MAGNETISED WHITE DWARFS

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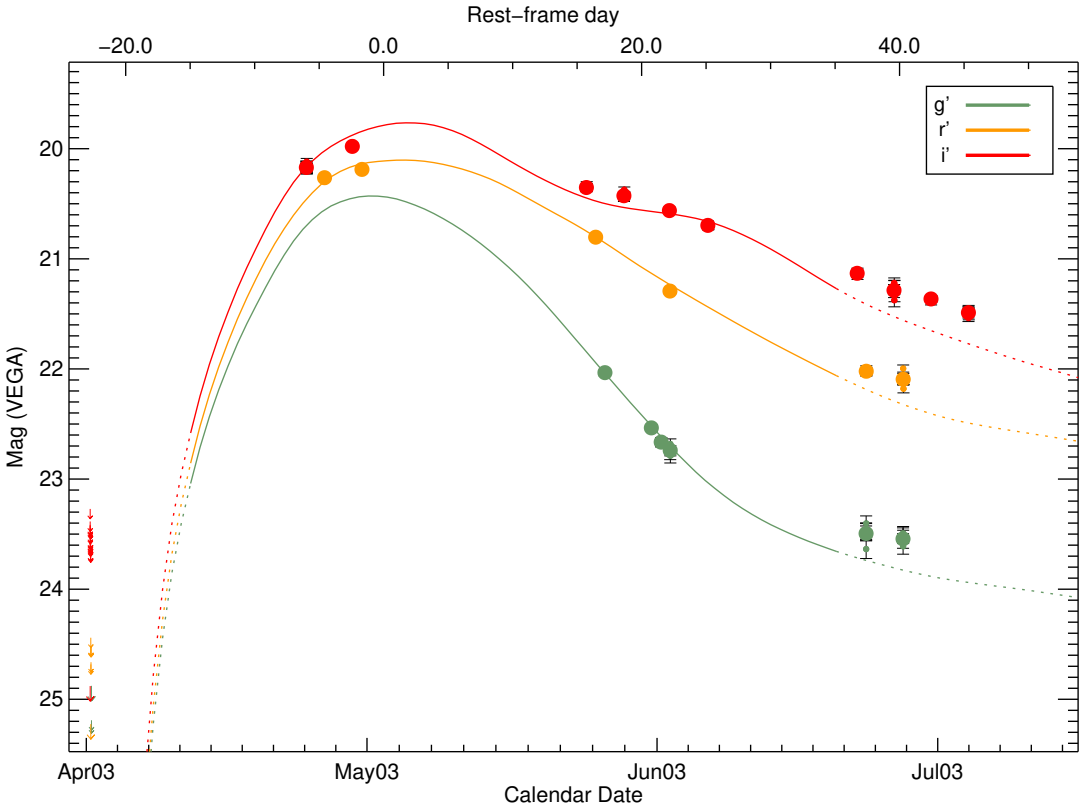
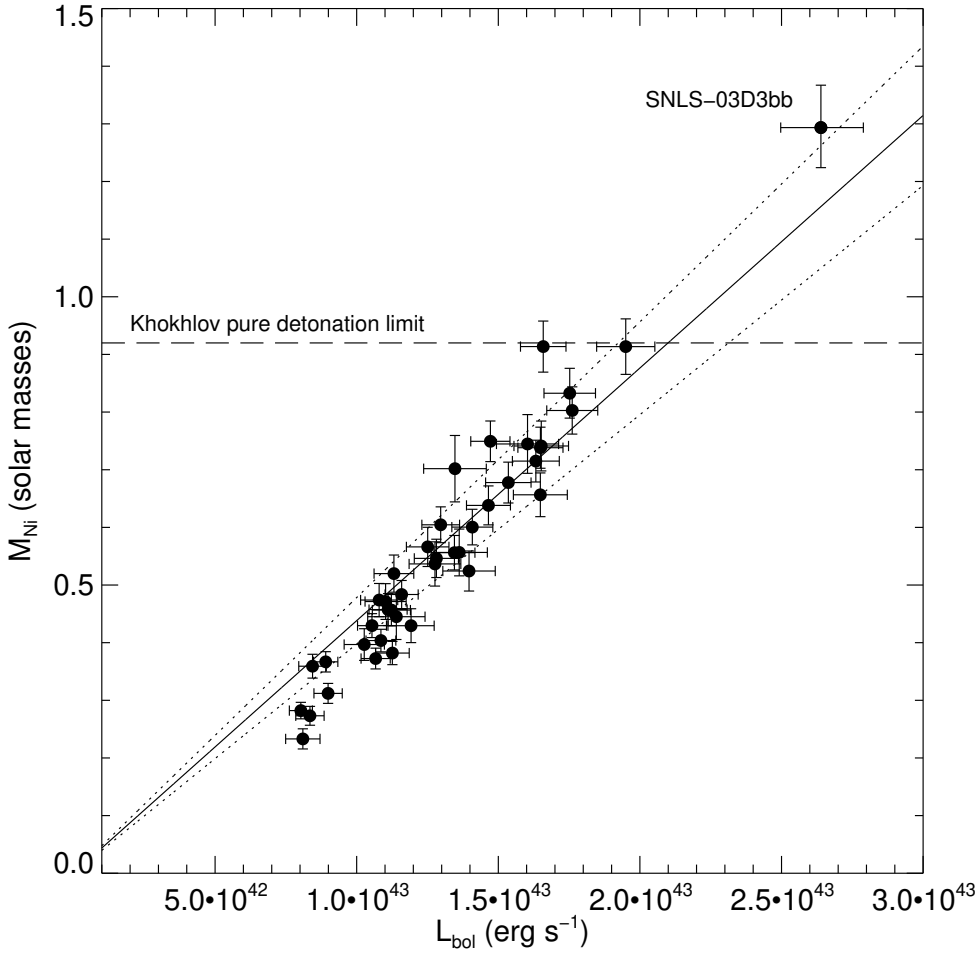
Champagne Supernova?

This isn’t Manchester…

SN2003fg “The Champagne Supernova”

(Branch06)





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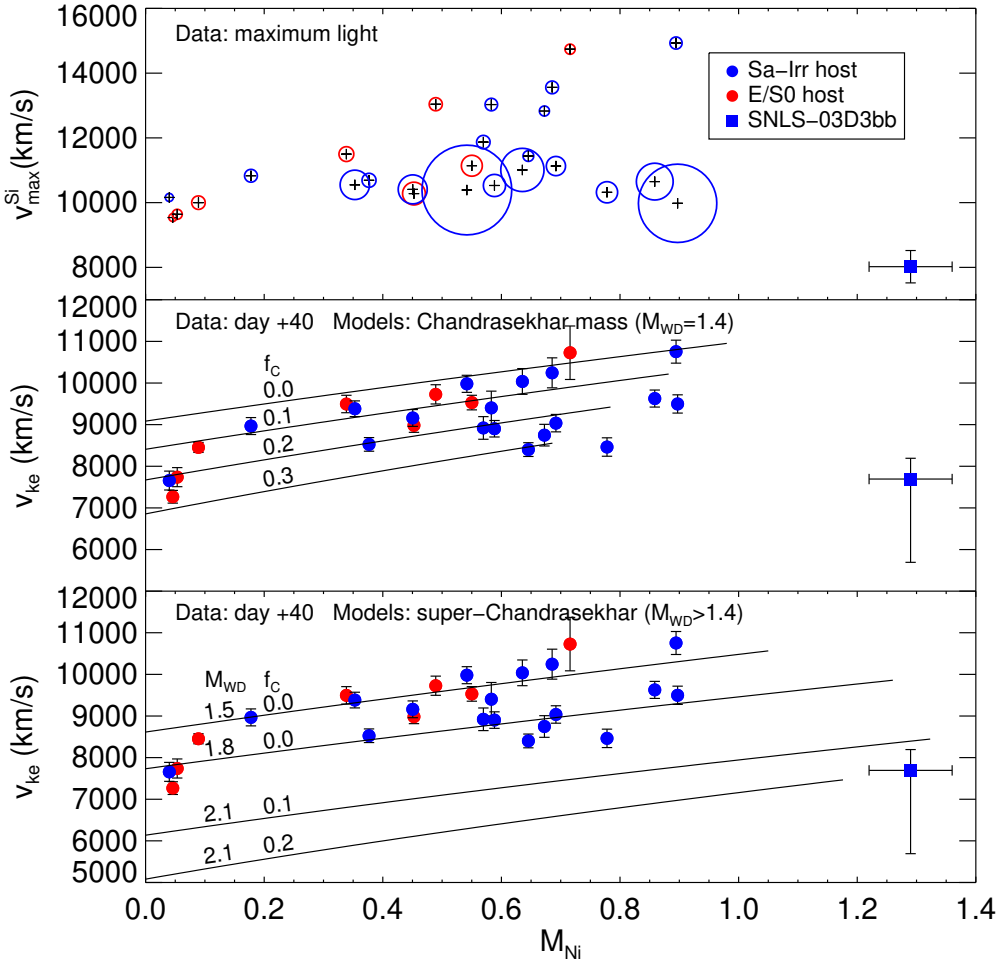
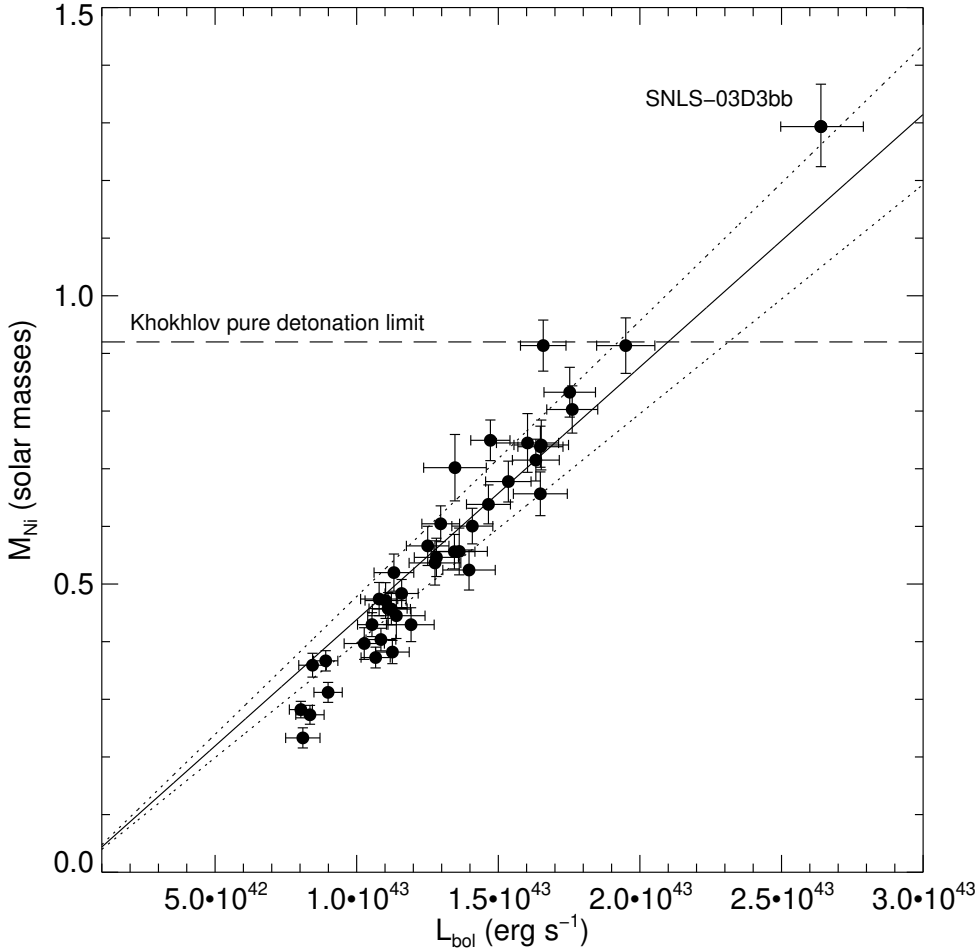
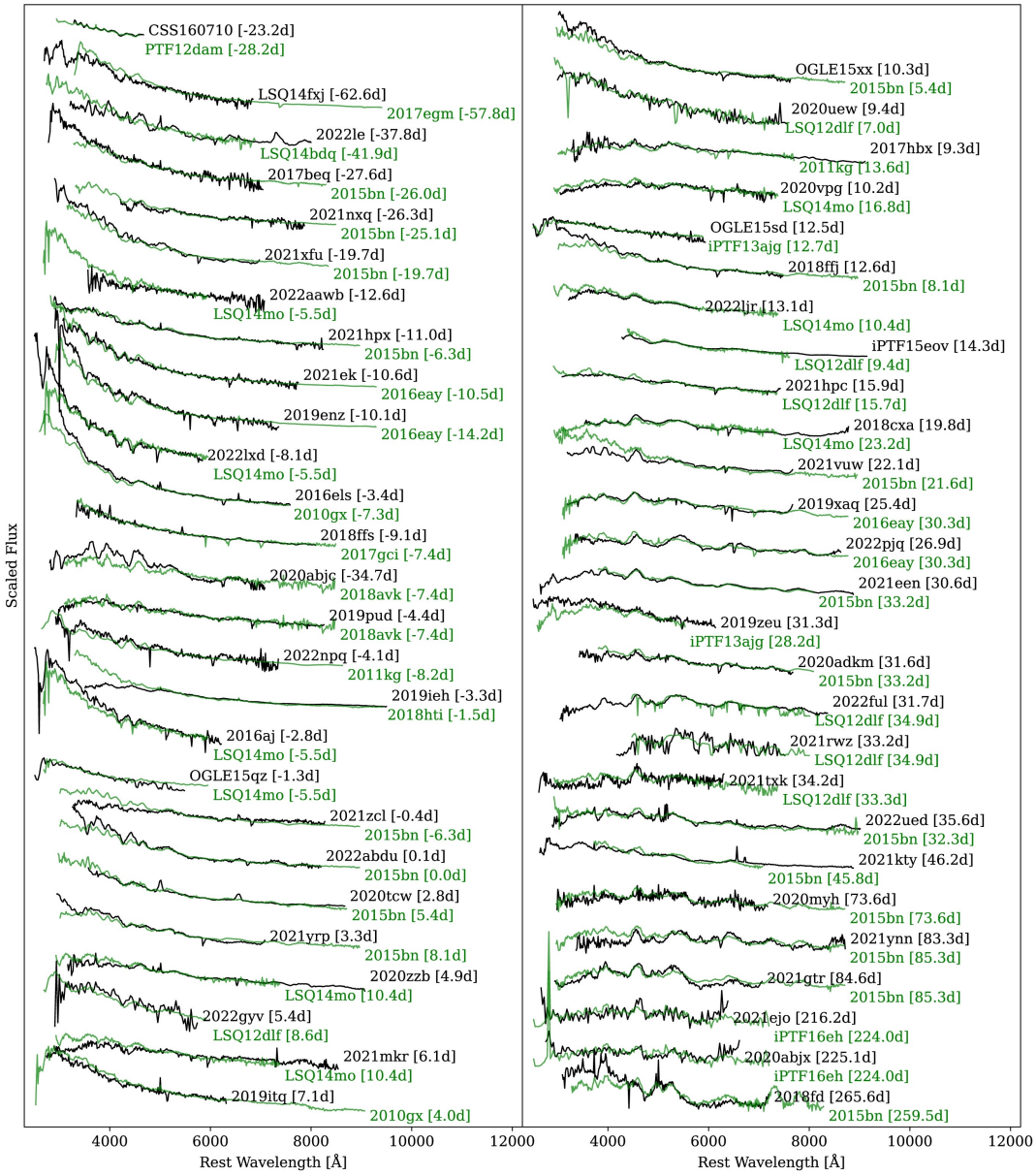






Gomez+24

Overluminous SNe Ia

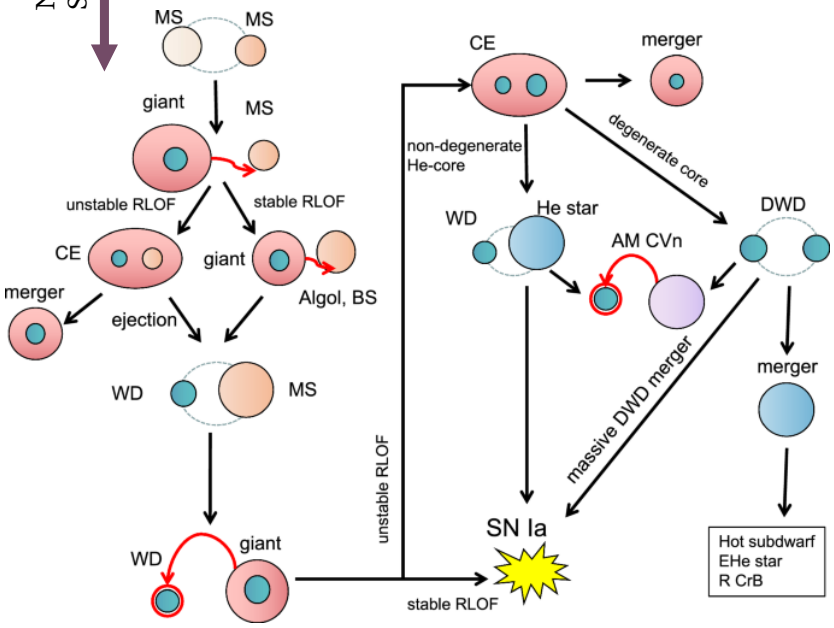
2018ffj, 2018ffs, 2018gbw, 2018gft, 2018hpq, 2018hti, 2018ibb, 2018kyt, 2018lfd, 2018lfe, 2018lzv, 2018lzx, 2019aamp, 2019aamq, 2019aamr, 2019aams, 2019aamt, 2019aamu, 2019aamv, 2019aamx, 2019bgu, 2019cca, 2019cdt, 2019cwu, 2019dgr, 2019dlr, 2019enz, 2019eot, 2019gfm, 2019gqi, 2019hno, 2019itq, 2019kcy, 2019kwq, 2019kws, 2019kwt, 2019kwu, 2019lsq, 2019neq, 2019nhs, 2019otl, 2019pud, 2019qgk, 2019sgg, 2019sgh, 2019szu, 2019ujb, 2019vvc, 2019xaq, 2019xdy, 2019zbv, 2019zeu, 2020abjc, 2020adkm, 2020afag, 2020afah, 2020ank, 2020aup, 2020auv, 2020dlb, 2020exj, 2020fvm, 2020htd, 2020iyj, 2020jii, 2020kox, 2020qef, 2020qlb, 2020rmv, 2020tcw, 2020uew, 2020vpg, 2020wnt, 2020xga, 2020xgd, 2020xkv, 2020zbf, 2020znr, 2020zzb, 2021bnw, 2021een, 2021ejo, 2021ek, 2021fpl, 2021gtr, 2021hpc, 2021hpx, 2021kty, 2021mkr, 2021nxq, 2021txk, 2021vuw, 2021xfu, 2021ynn, 2021yrp, 2021zcl, 2022abdu, 2022ful, 2022le, 2022ljr, 2022lxd, 2022npq, 2022pjq, 2022ued, DES14S2qri, DES14X2byo, DES14X3taz, DES15E2mlf, DES15X1noe, DES15X3hm, DES16C2aix, DES16C3dmp, DES17X1amf, DES17X1blv, iPTF13ajg, iPTF13ehe, iPTF15eov, iPTF16eh, LSQ12dlf, LSQ14bdq, LSQ14mo, OGLE15qz, PS110awh, PS110bzj, PS110ky, PS110pm, PS111afv, PS111aib, PS111ap, PS111bdn, PS112bqf, PS112cil, PS113or, PS114bj, PS15cjz, PTF09atu, PTF09cnd, PTF10uhf, PTF10vqv, PTF12dam, PTF12mxx, SCP06F6, SNLS06D4eu, SNLS07D2bv…

- Most objects here implies a SuperChandrasekhar Mass Progenitor…
- Some are certainly lensed
- Some are almost certainly not…

Do we need a SC Progenitor?

Yes, even with alternate scenarios, some of these progenitors have implied masses above $2M_{\odot}$

No, we have alternate SN Ia Scenarios



How to make a super-Chandrasekhar mass WD?

Spin it up to (nearly) critical

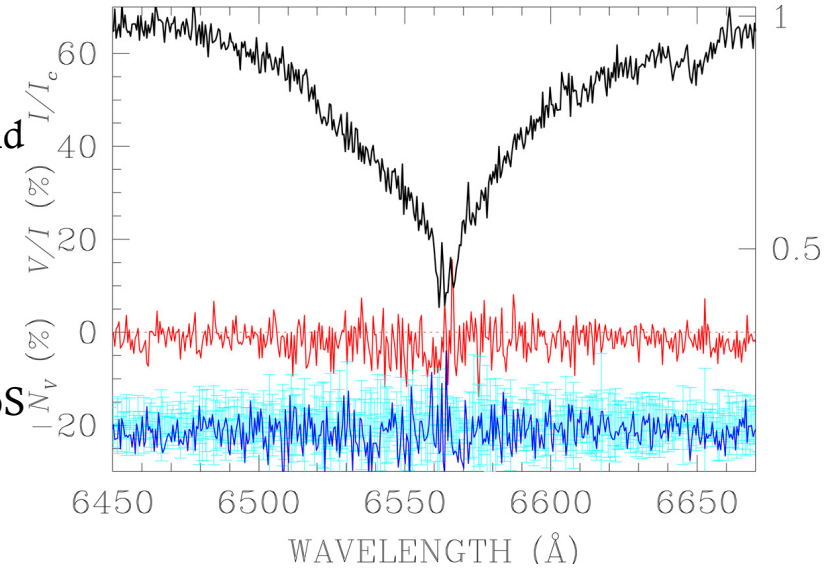
Permeate it with an extreme magnetic field

Can we model this?

Das+12 shows new EoS from Landau quantization

Can implement without needing GR if $\zeta \leq 0.01$
(where ζ is the ratio of magnetic field mass-energy density to matter density)

Roughly corresponds to
$B_c \approx 10^{14} G$



Landstreet+19 found kilogauss fields in WD 1105–340 – very close by!

Our implementation?

EoS

Opacity

$$\kappa_B \approx 5.5 \times 10^{31}\, \rho\,/\,\mathrm{g\,cm^{-3}}\,(T\,/\,\mathrm{K})^{-3/2}\,(\mathrm{B}\,/\,\mathrm{G})^{-2}\,\mathrm{cm^2\,g^{-1}}$$

Potekhin magnetic opacity (Potekhin+01, Ventura+01) Add to ordinary (OPAL) opacity in reciprocal

Radial magnetic field profile (Gupta+20)
Modified with cutoff radius

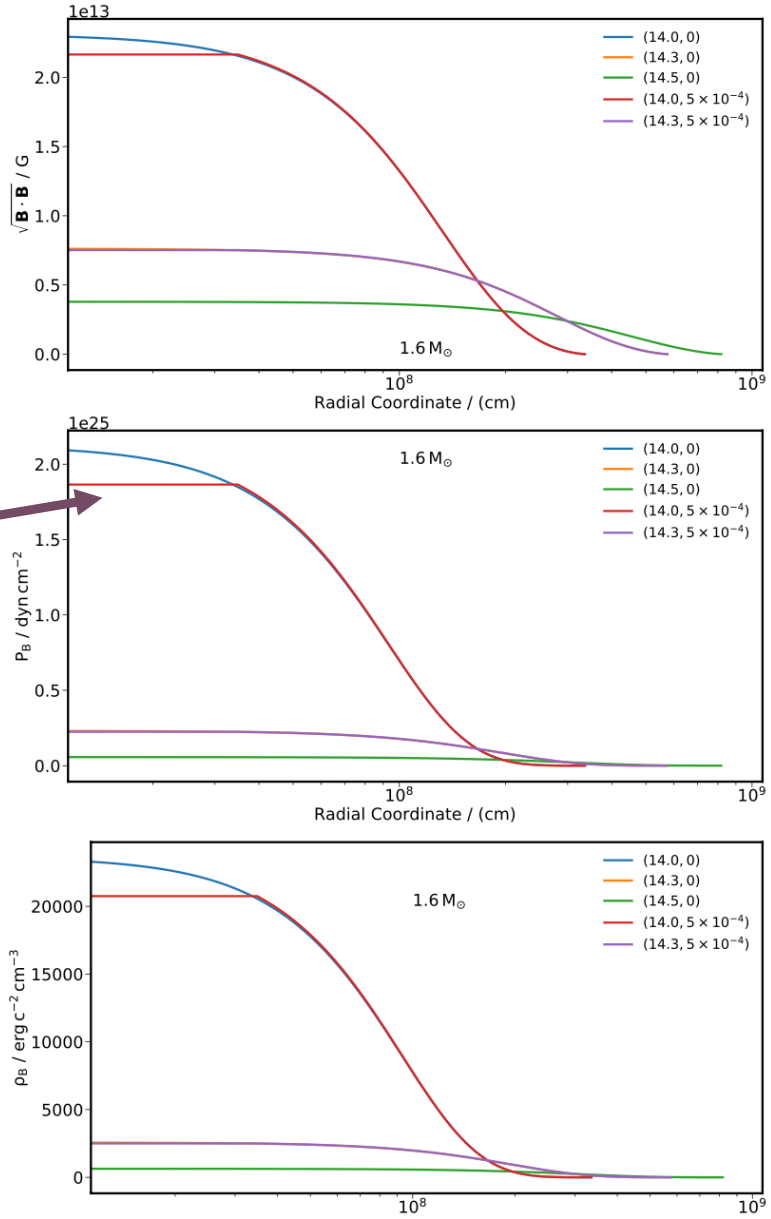
$$B\left(\frac{\rho}{\rho_0}\right) = \begin{cases} B_S + B_0\left[1-\exp\left(-\eta\left(\frac{\rho}{\rho_0}\right)^{\gamma}\right)\right] & r \le R_c \\ B_S + B_0\left[1-\exp\left(-\eta\left(\frac{\rho_c}{\rho_0}\right)^{\gamma}\right)\right] & r > R_c \end{cases}$$

Why cutoff?

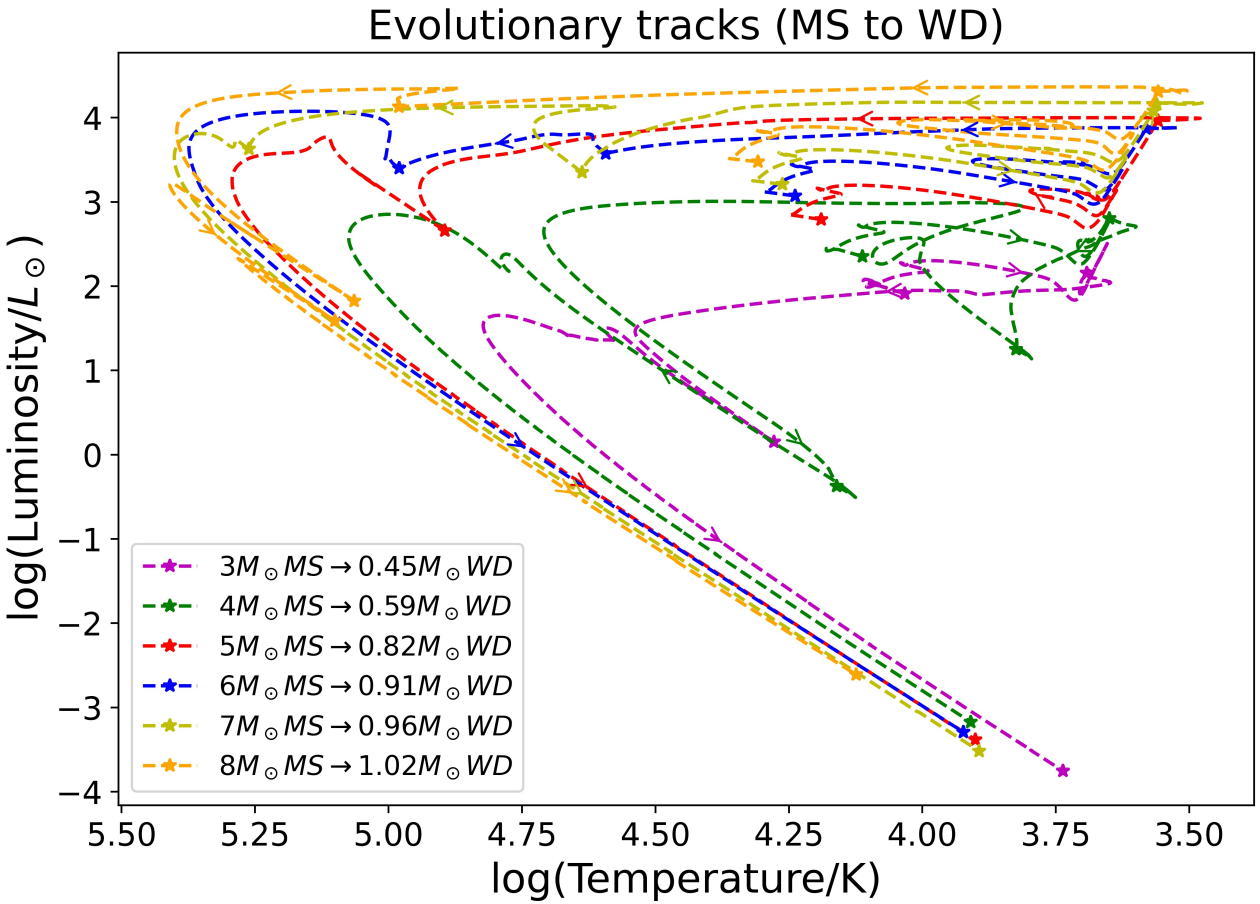
Chatterjee+17 – all positive radial field gradient →

Unphysical current sheath at small radii

It works: even with large cutoff radii – surface observables retained!

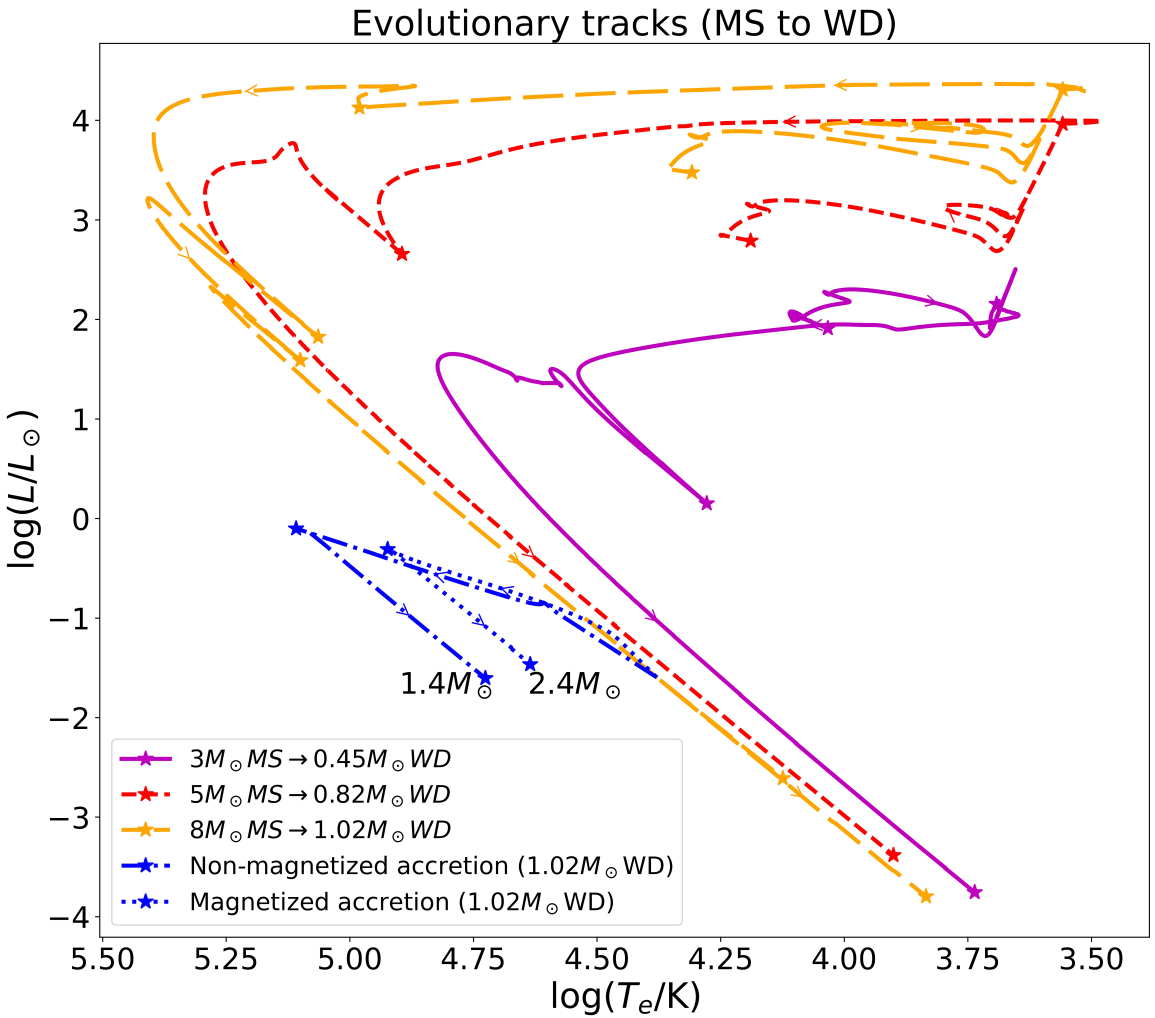


From First Principles – Evolve our BWDs from MS to WDs



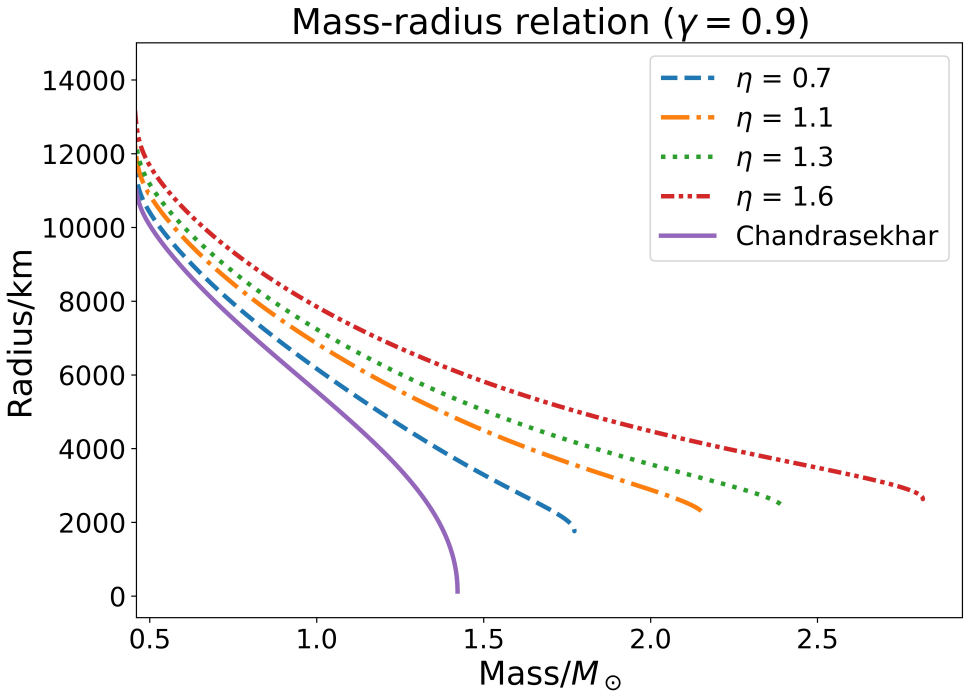
- We modify the error and convergence routines of the STARS code
- We can now run a star from the MS to the WD in a single simulation run
- The magnetic field is seeded at the PMS
- Followed self-consistently all the way to the WD

From First Principles – Now with Accretion!



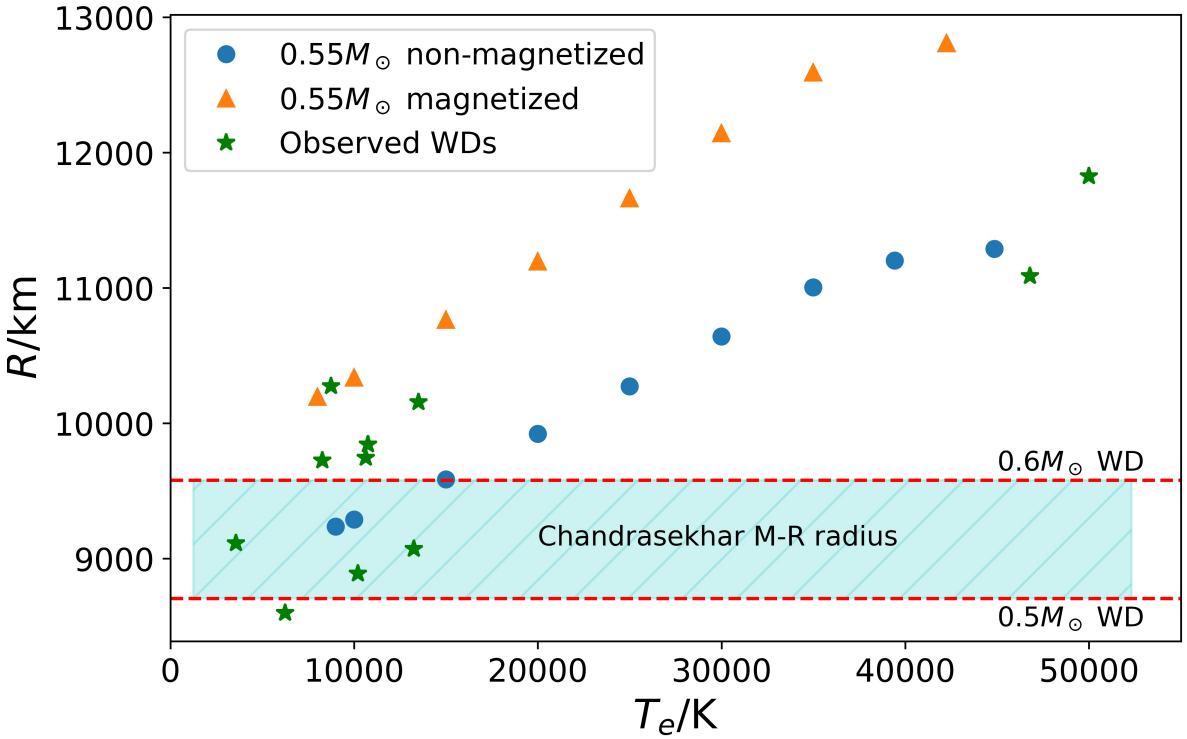
- Taking a high mass white dwarf – we allow it to accrete companion material
- WDs not seeded with a field in the PMS reach a maximum mass at the Chandrasekhar mass
- Those seeded with fields in the PMS grow to well above 2 solar masses
- Central fields grow to around 8×10^{13} G at 2.4 solar masses – enormous, but not theoretically problematic…

Some Preliminary Results



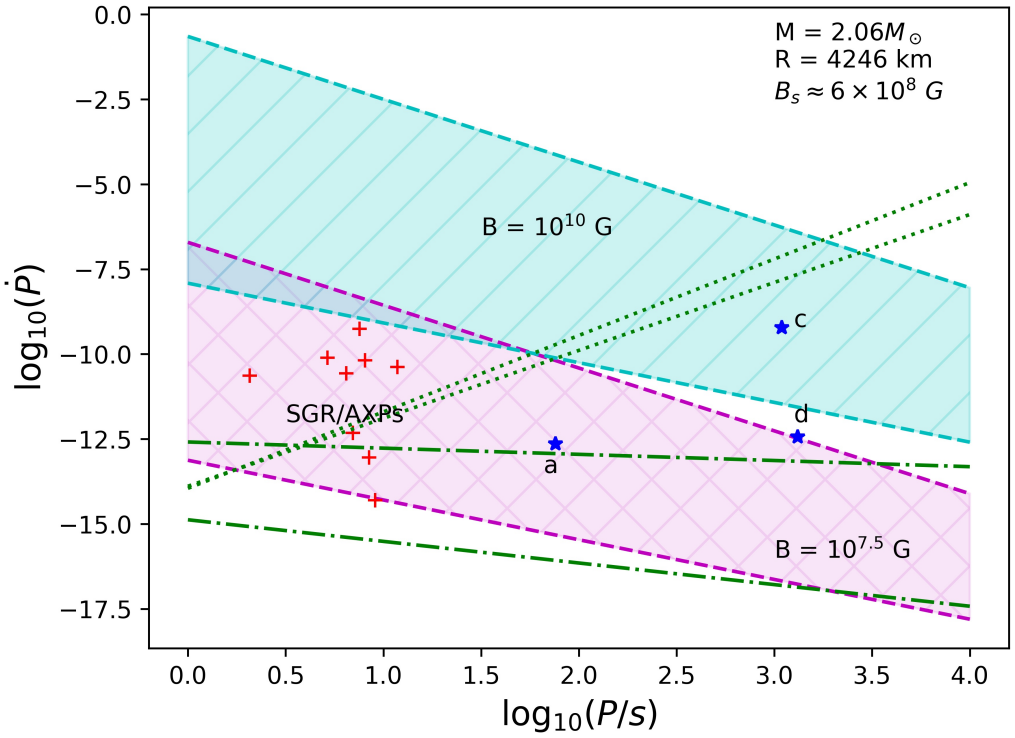
- Observed WDs are consistent from zero field models, to those with even larger fields than we allow for

- Mass radius relationships split from non-magnetised, as expected



Some Implications

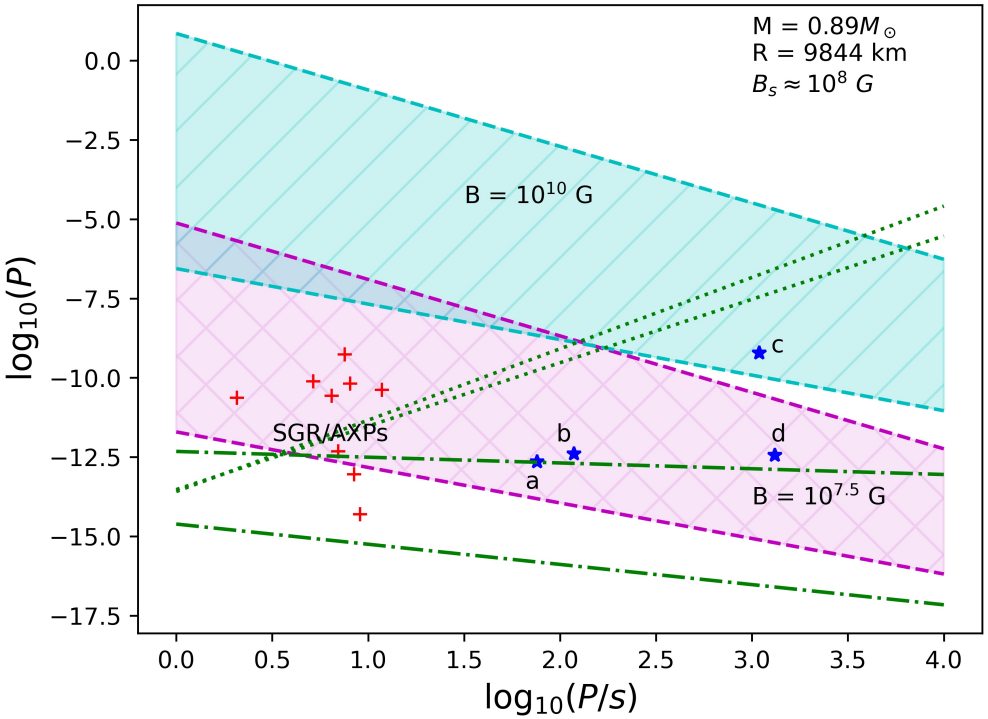
(Zuraiq+ Submitted)



Perhaps – but much more simulation and observational work needed

Can some AXPs/SGRs be ascribed to BWDs?

(Mukhopadhyay&Rao16)



CONCLUSIONS