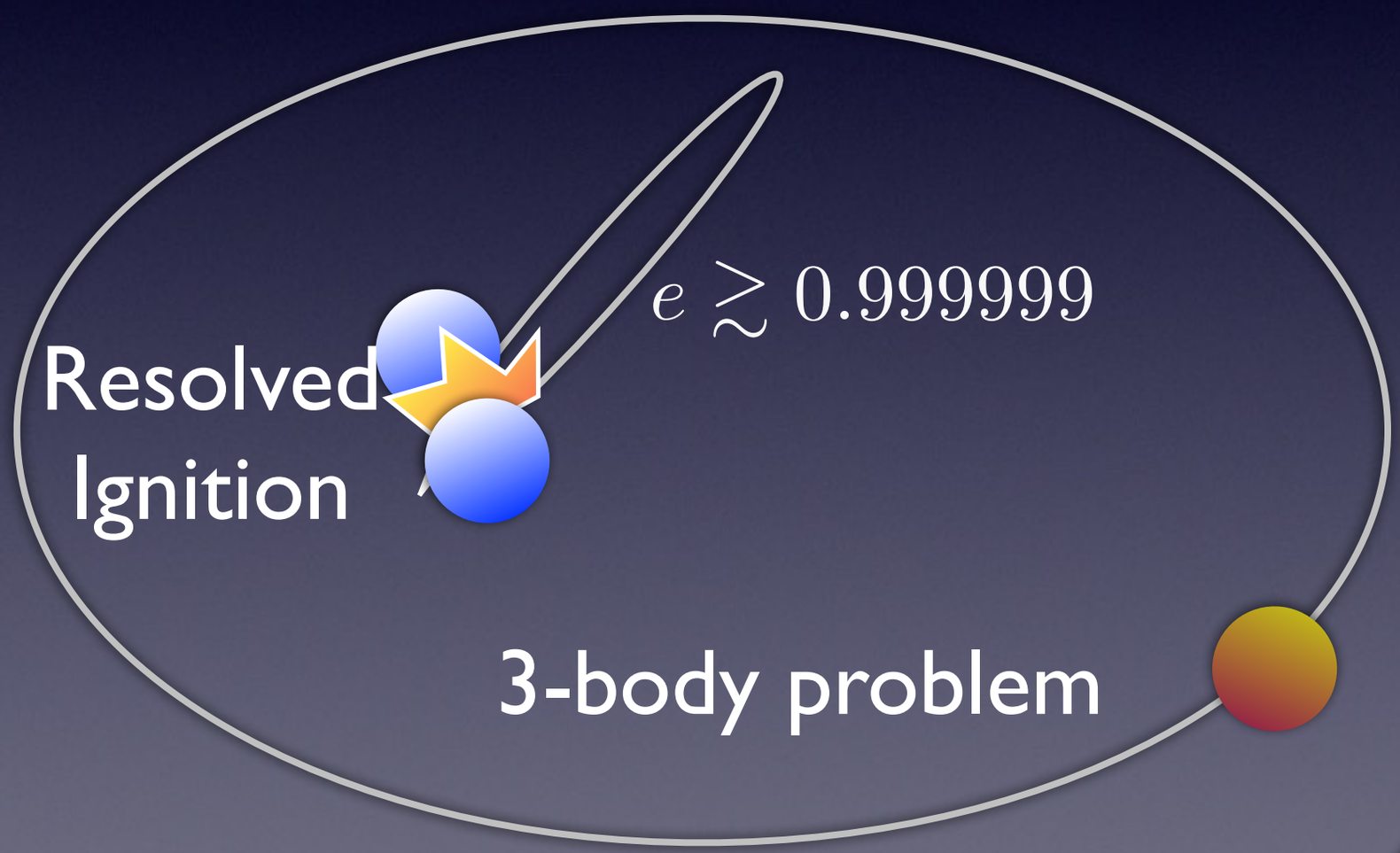
We believe type Ia SNe are direct collisions of WDs

Boaz Katz, Subo Dong, Doron Kushnir



Please
try at home

If you detonate a White Dwarf you get a type Ia supernovae

detonate (0.9-1.15 Msun) WDs sub chandra

e.g. Sim et. al. 2010

torture Chandrasekhar WD chandra

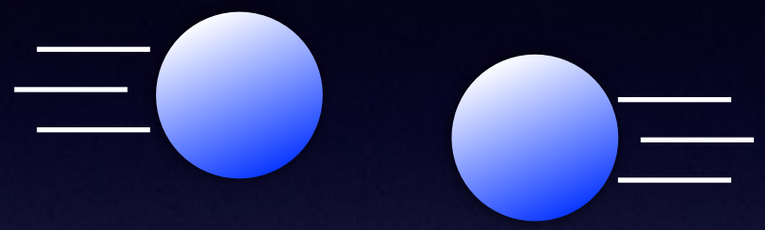
Main challenge:

Detonate ~1% of White Dwarfs

We think it is WD collisions

1.

2.



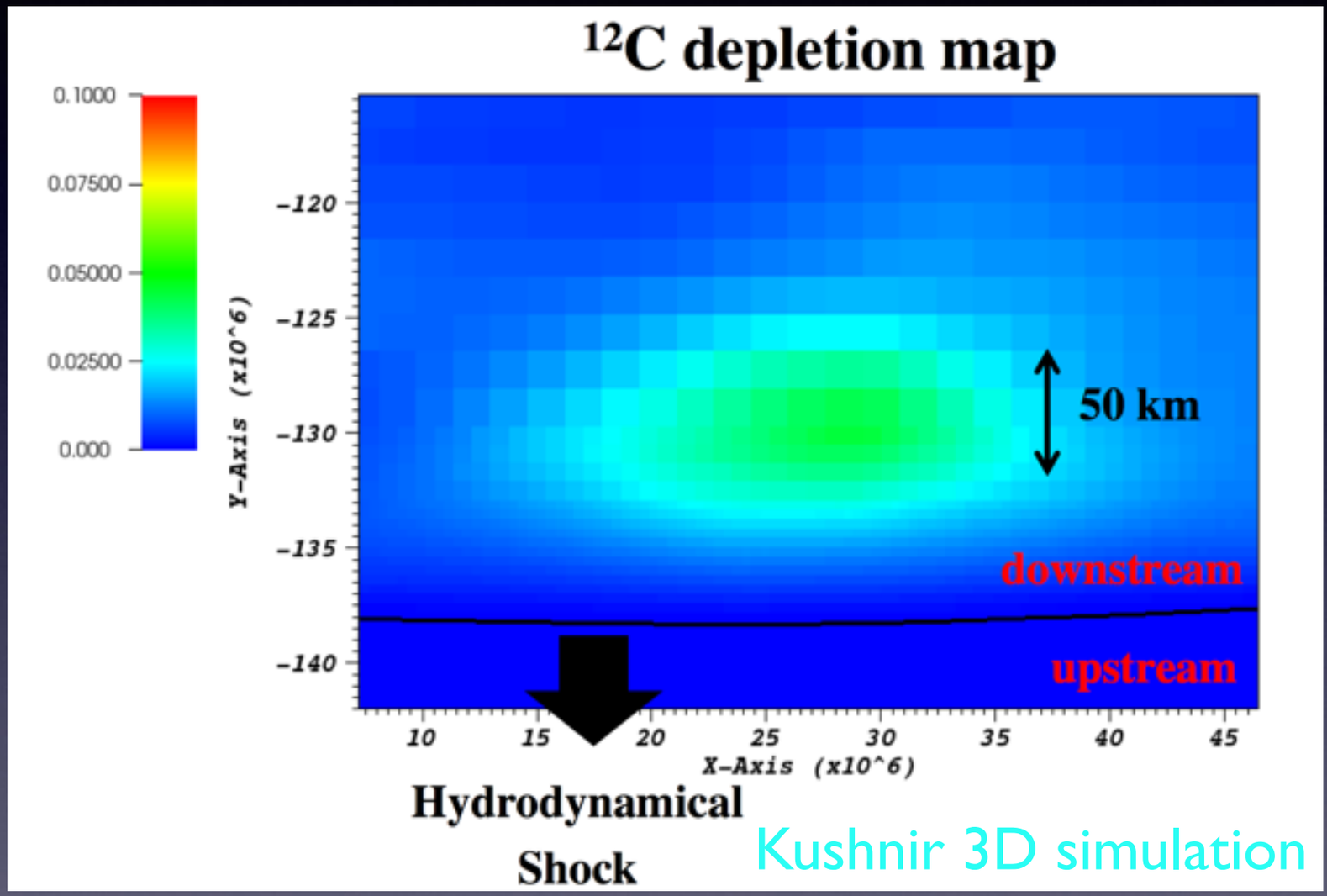
3.

4.

Kushnir et. al 2013, Rosswog et. al. 2009, Raskin et. al. 2010

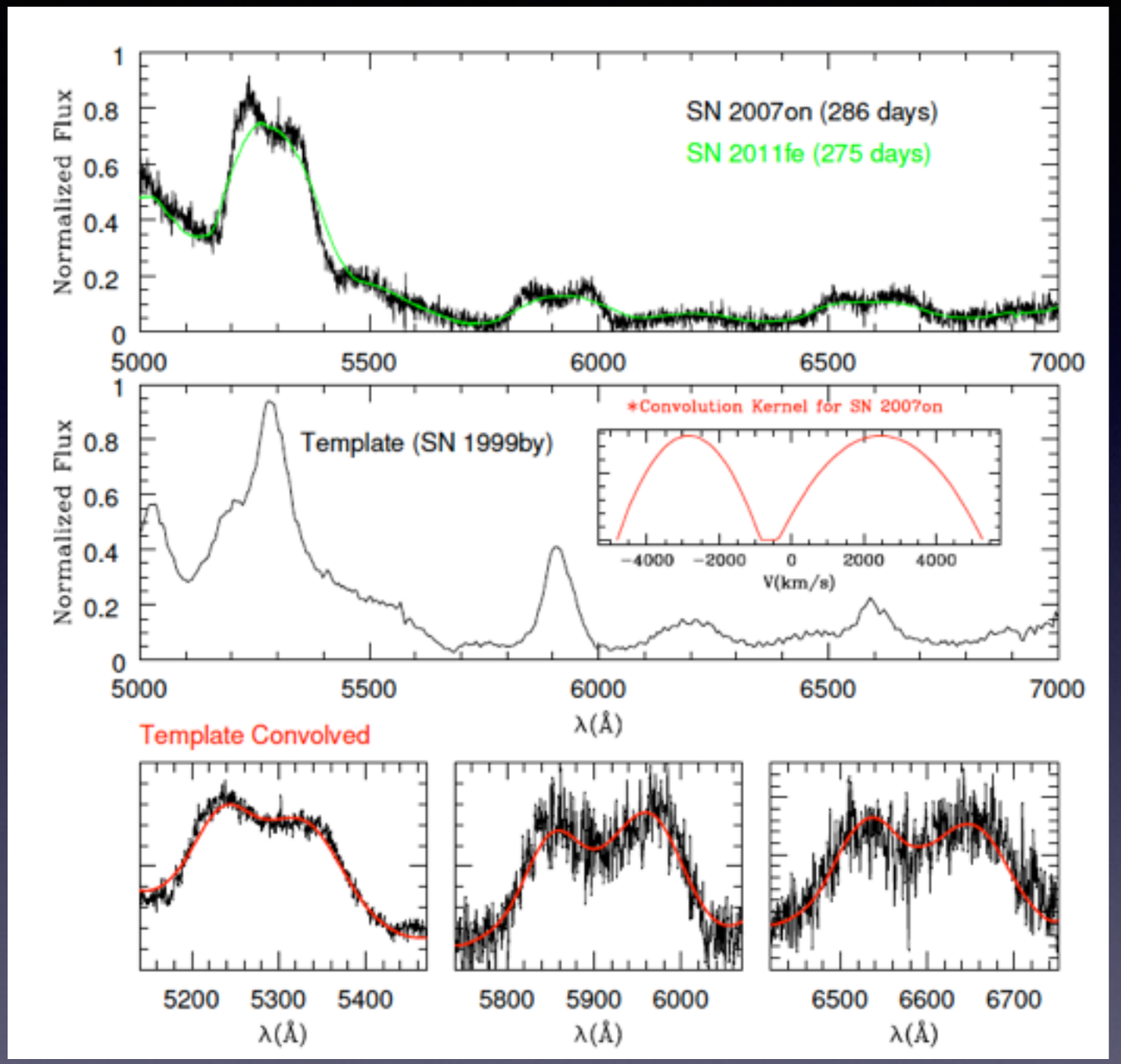
Collisions robustly detonate WDs

Kushnir et. al 2013, Rosswog et. al. 2009, Raskin et. al. 2010



Kushnir 3D simulation

Direct Evidence for collision

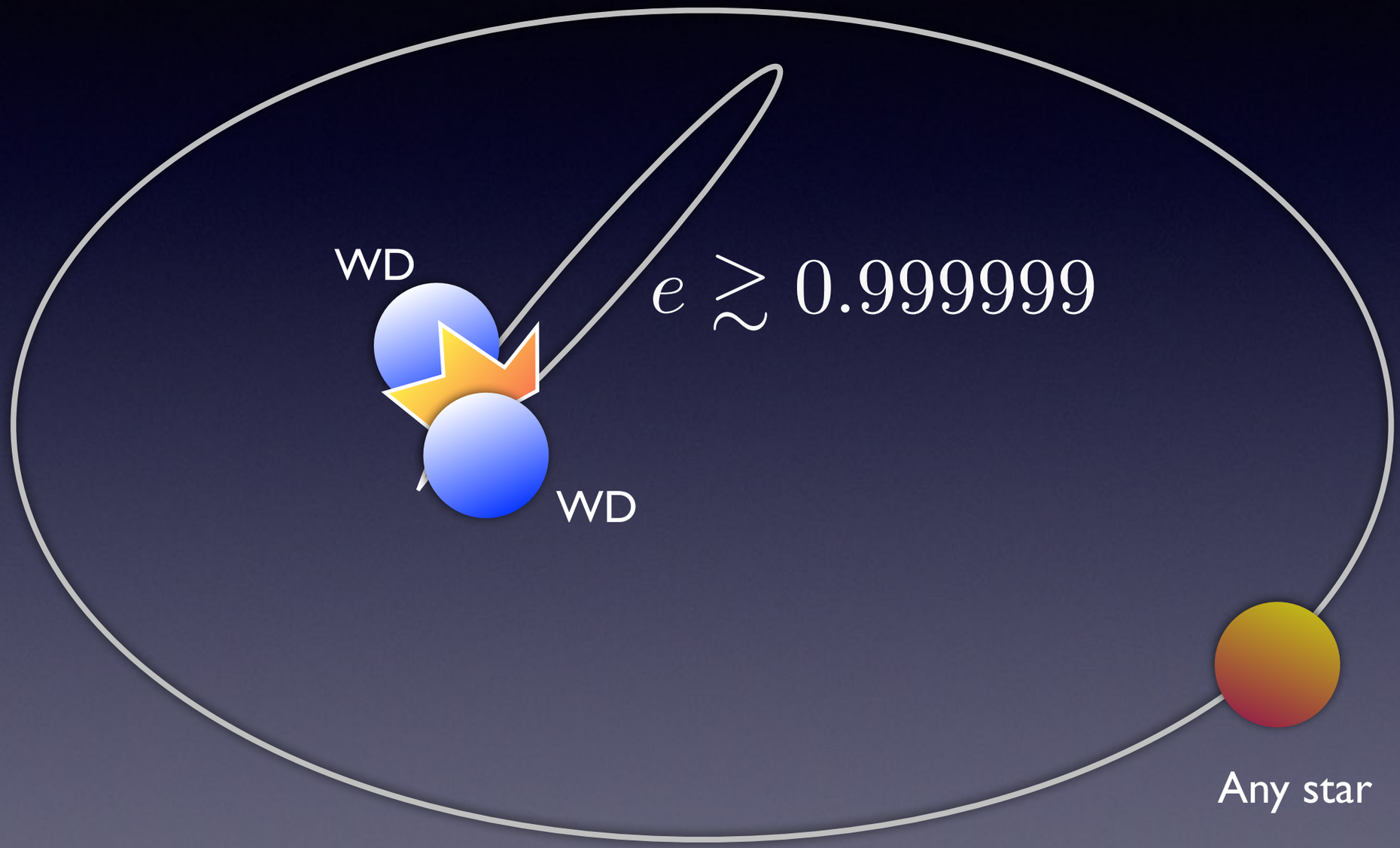


Dong et. al. 2014

Stars are so small,
they practically
never collide.

WDs are 100 times
smaller!

cartoon multiple system



Katz &Dong 12

Real system in scale (10-1000 AU)

Field triples are (naively) hopeless

$$\frac{a_{\rm in}}{R} \sim \frac{100{\rm AU}}{10^9{\rm cm}} \sim 10^6$$

Kozai: 10^{-6} → 10^{-3}

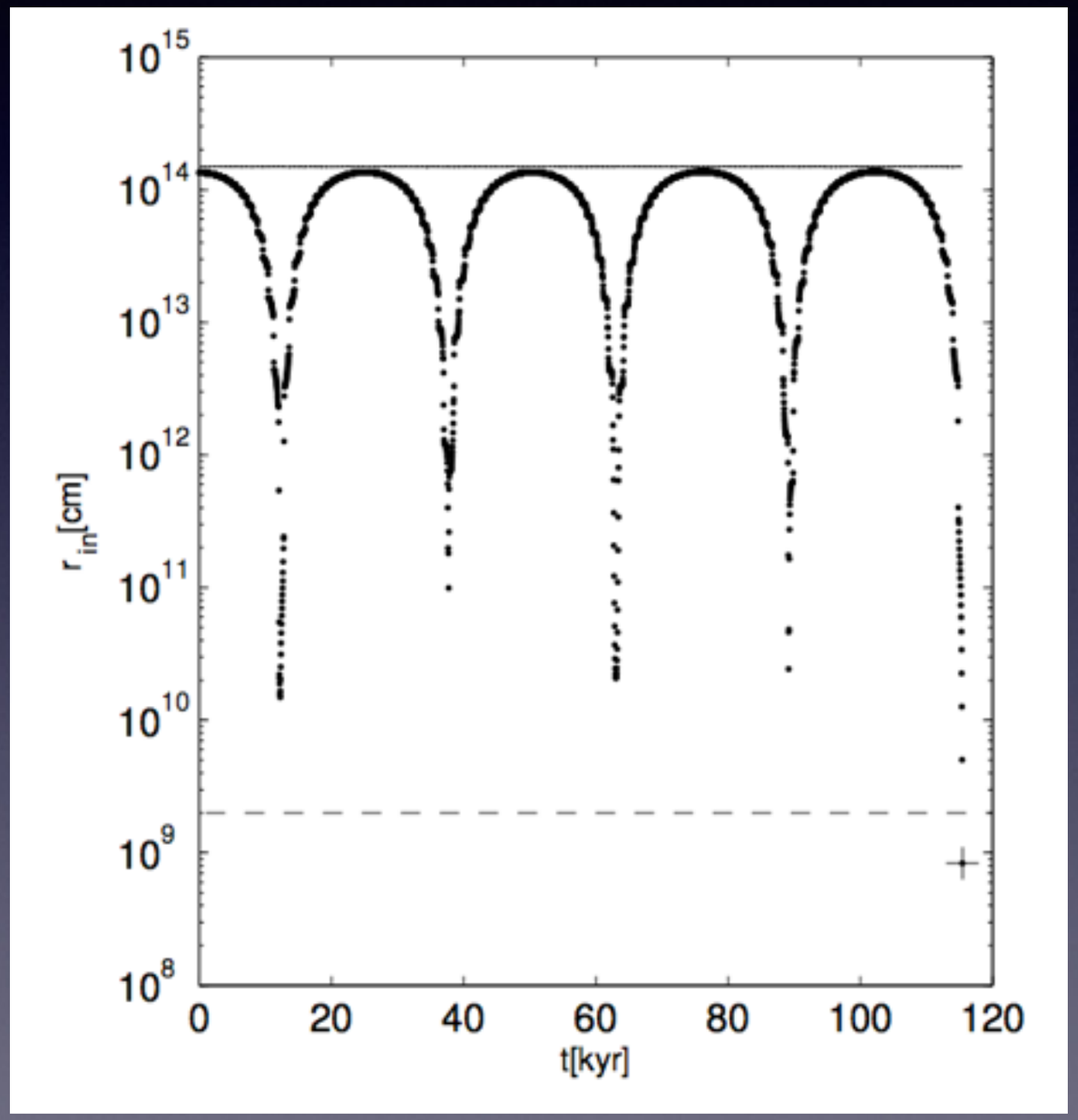
Maybe some collisions in compact triples,

$$a_{\rm in} \lesssim 0.1{\rm AU}$$

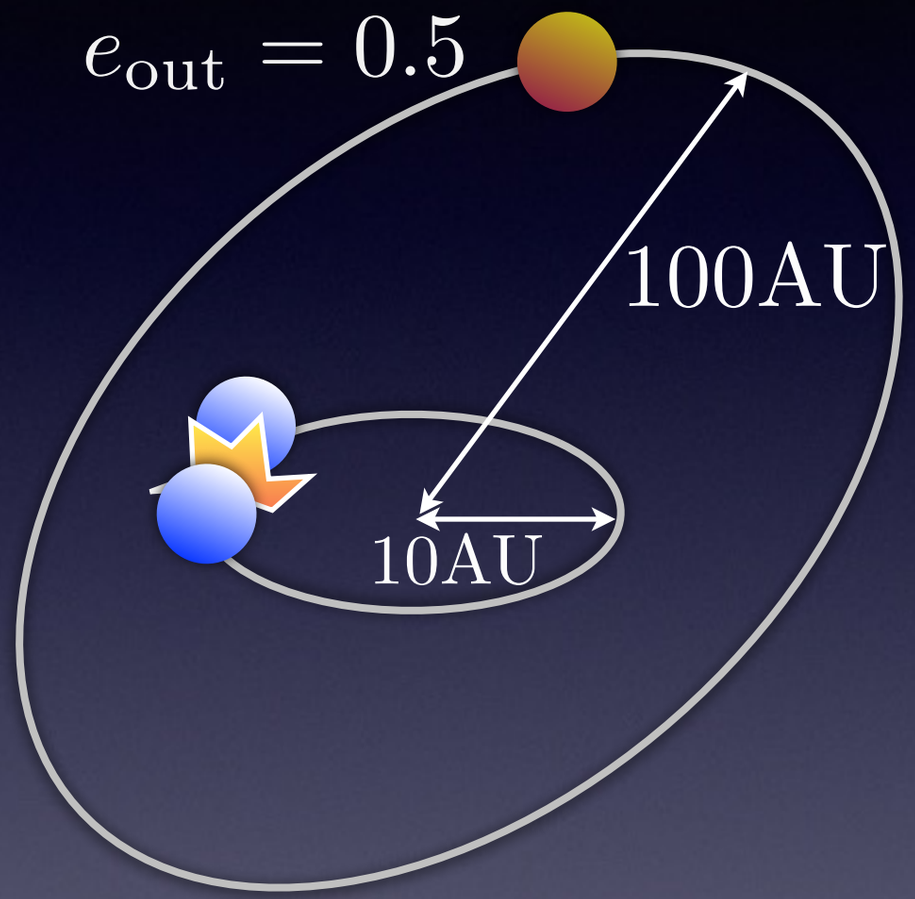
mainly in globular clusters Hut&Inagaki 85, Sidgerson&Phinney 93, Fregeau et. al. 04, Thompson 11

More problems GR, Tides, a grazing encounter first?

Moderate Hierarchy leads to 'clean' collision

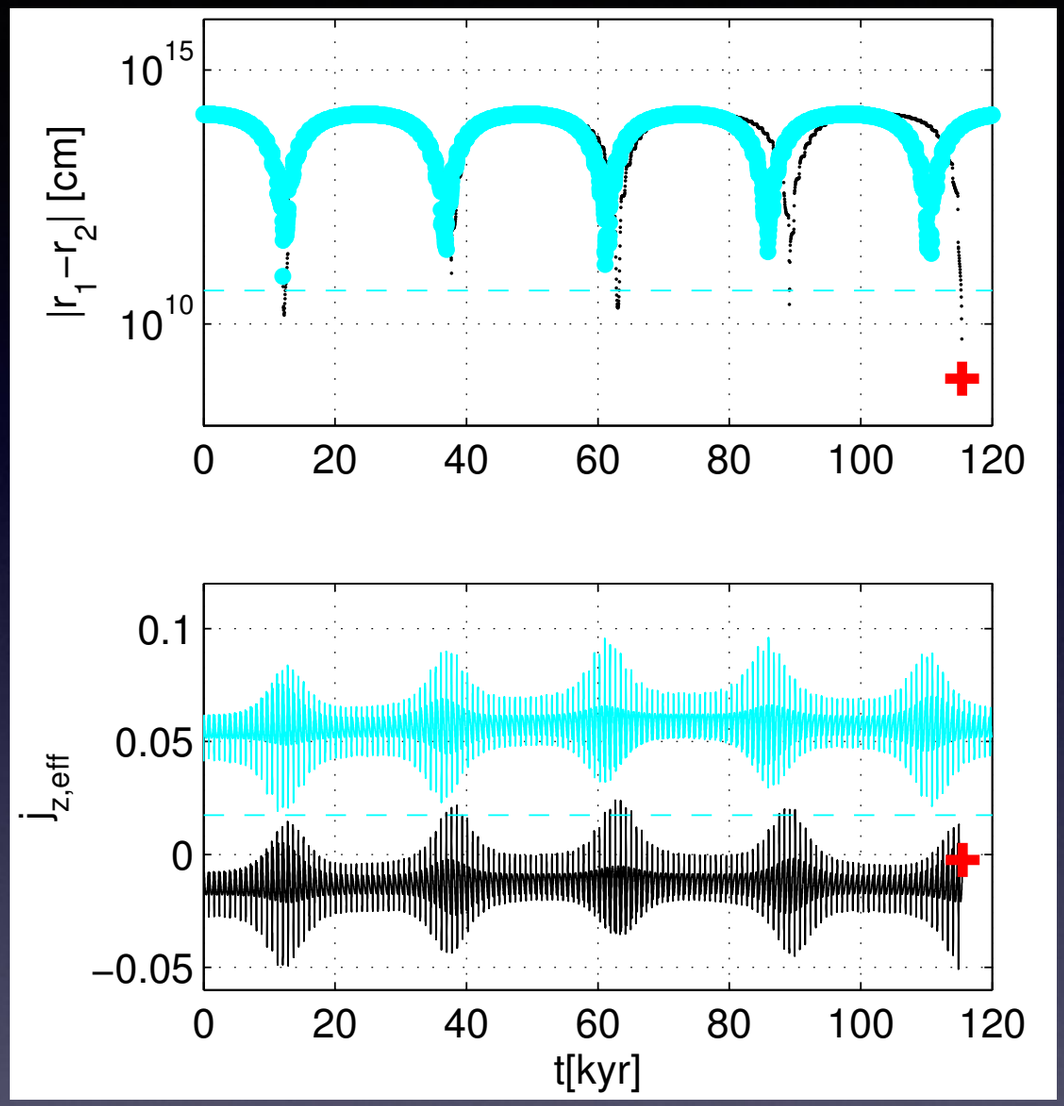


Katz &Dong 12



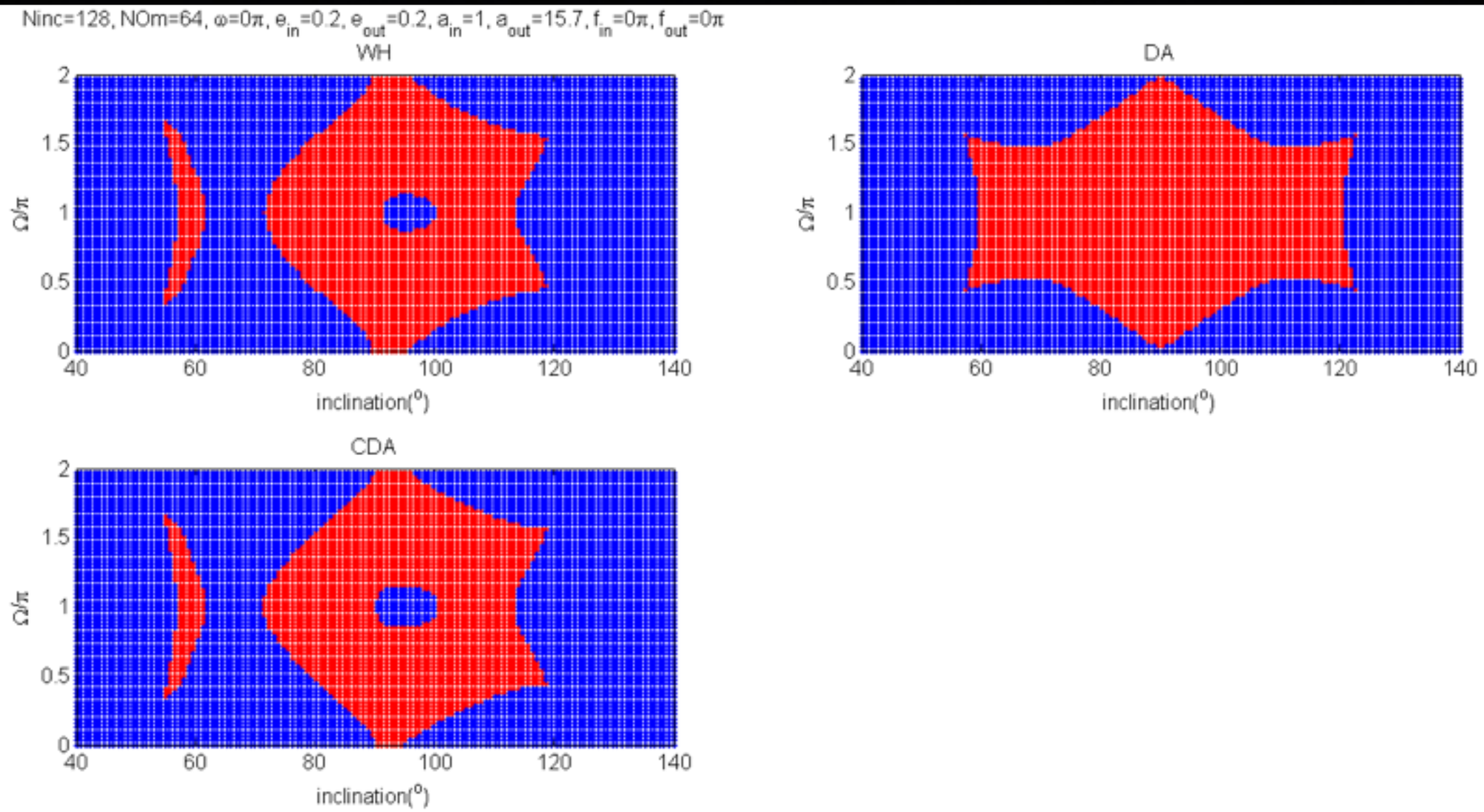
$$m_1 = m_2 = m_3 = 0.5 M_\odot$$

Double Averaging breaks down



$$j_{z,\mathrm{eff}} \equiv \frac{|J_{\mathrm{tot}}|^2 - |J_{\mathrm{out}}|^2}{2\,|J_{\mathrm{out}}|\,J_{\mathrm{circ}}}$$
$$= j \cdot \hat{J}_{\mathrm{out}} + j^2 \frac{J_{\mathrm{circ}}}{2\,|J_{\mathrm{out}}|}$$

Long term error in double averaging



Liantong Lou et. al. in prep

Single orbit 'Jumps' (req. for clean colls.)

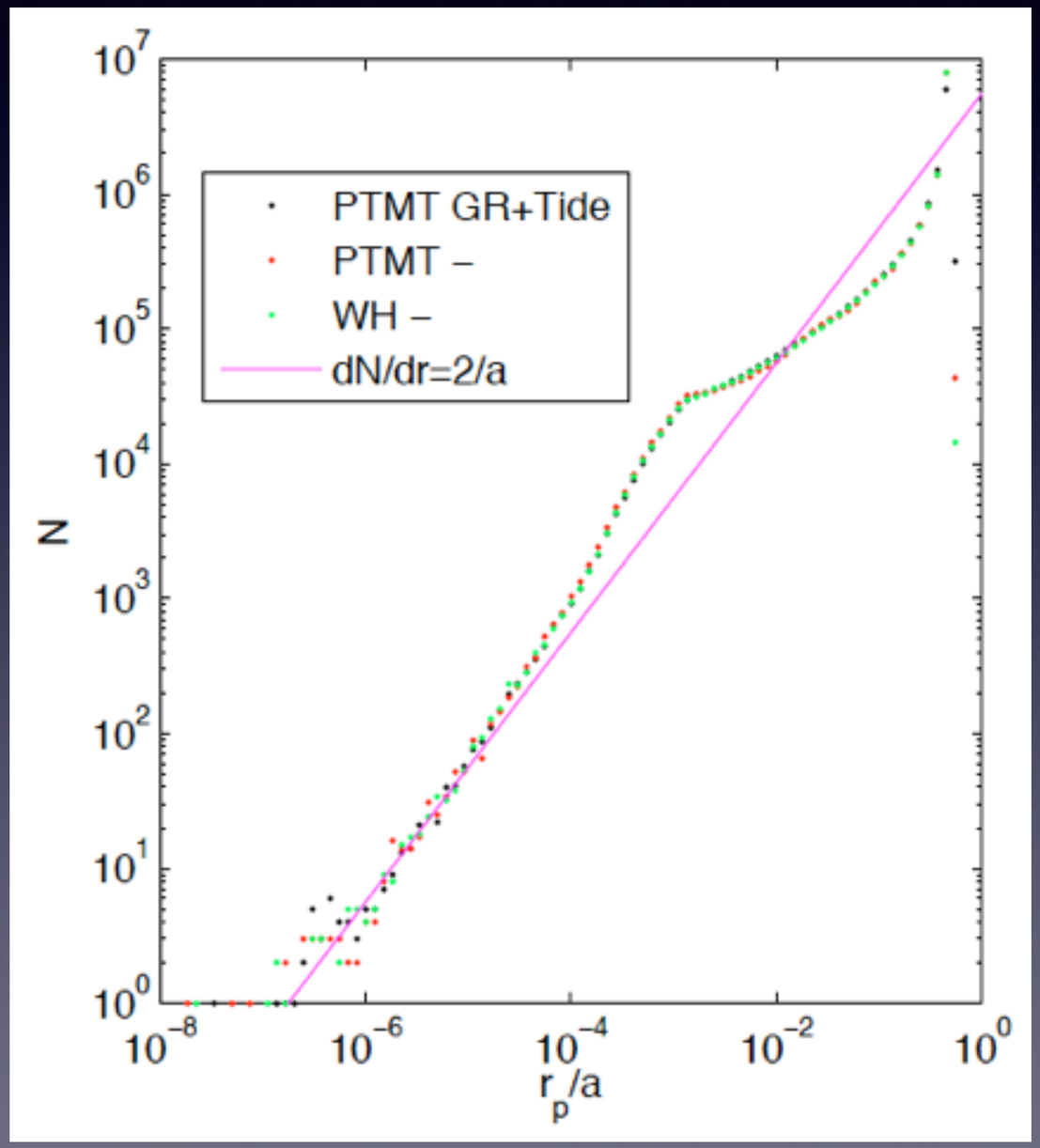
$$\text{Torque} \times \text{Period} = \Delta J$$

$$4R \to 0$$

$$\frac{r_{p,\text{out}}}{a_{\text{in}}} \lesssim 14$$

$$\times \left(\frac{m_3}{m_1+m_2}\right)^{1/3} \left(\frac{a_{\text{in}}}{30\text{AU}}\right)^{1/6} \left(\frac{R}{10^9\text{cm}}\right)^{-1/6}$$

Stochastic +gravitational focusing $N \propto J^2 \propto r$



$$J^2 = v_p^2 r_p^2 \propto r_p$$

Typical time for collision

For $a_{\rm in} = 100{\rm AU}$

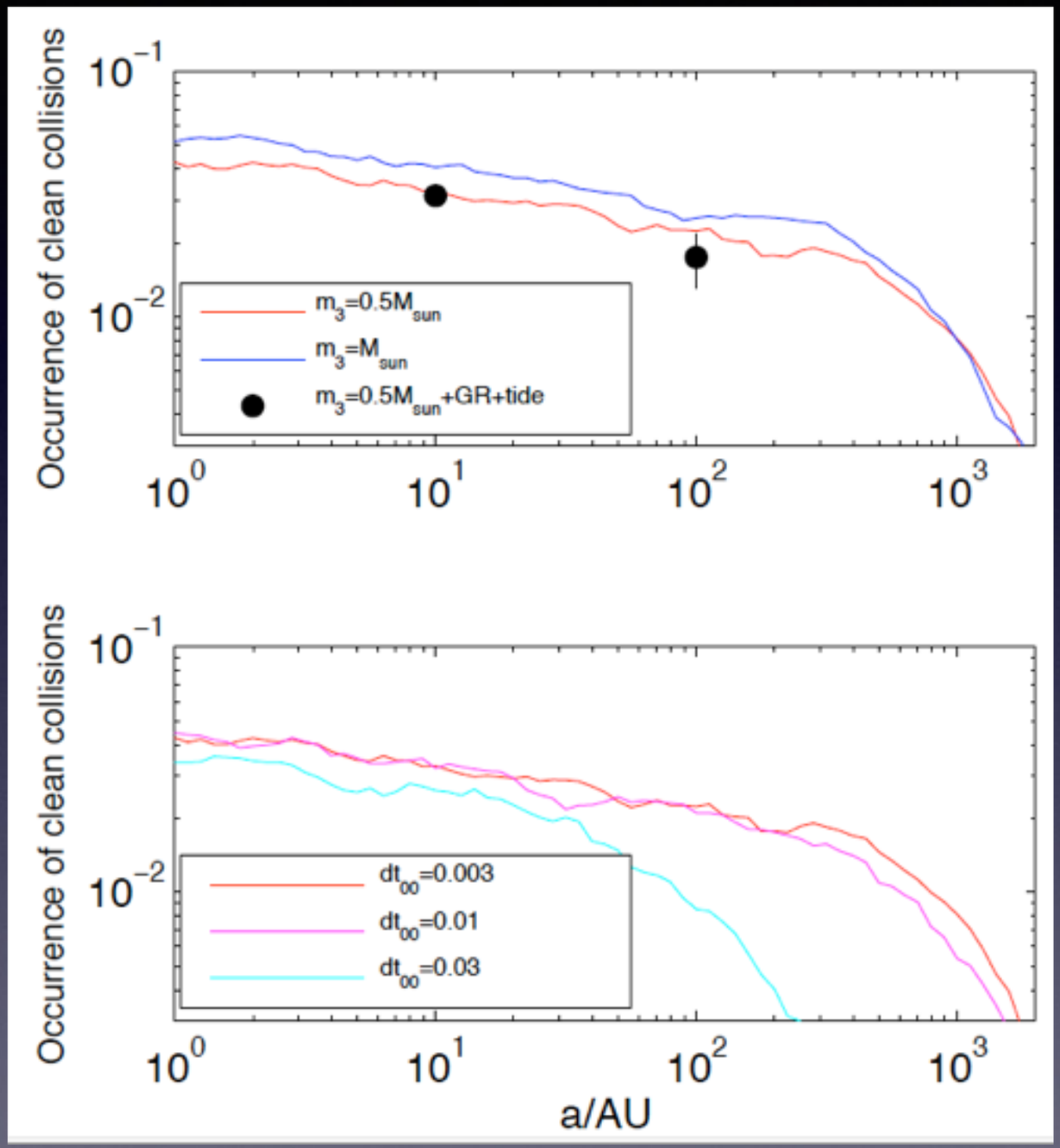
An orbit takes $1000{\rm yr}$ $\propto a_{\rm in}^{3/2}$

Need $\frac{a_{\rm in}}{R} \sim 10^6$ orbits $\propto a_{\rm in}$

total ~1 Gyr $\propto a_{\rm in}^{5/2}$

Available ~5 Gyr

Few percent clean collisions



$$3 < \frac{r_{p,\mathrm{out}}}{a_{\mathrm{in}}} < 10$$

10,000 3-body simulations

Katz &Dong 12

Rate could be sufficient:

~30% triples

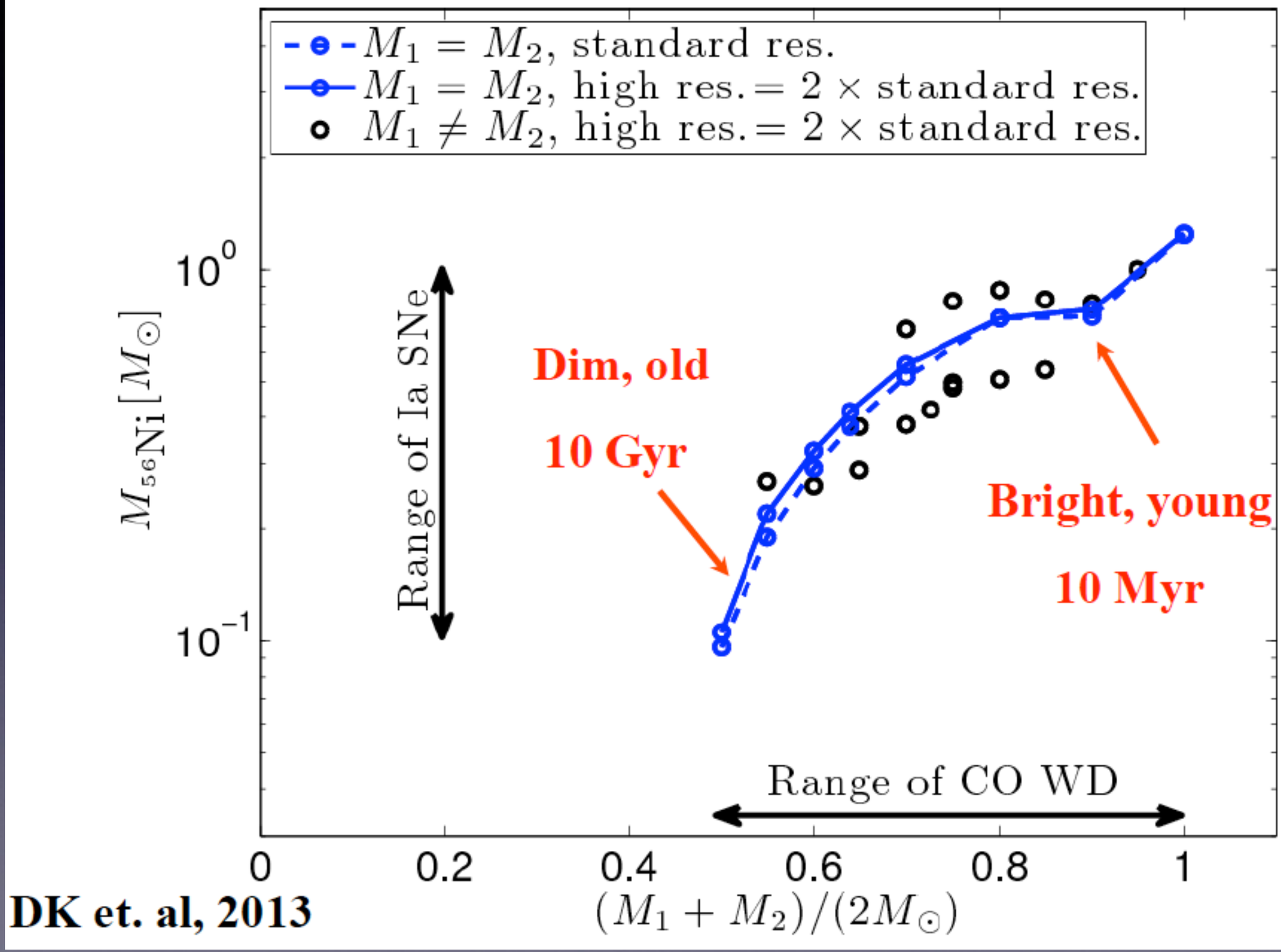
collision in ~3 % of triples

~1 % collide = SNe Ia

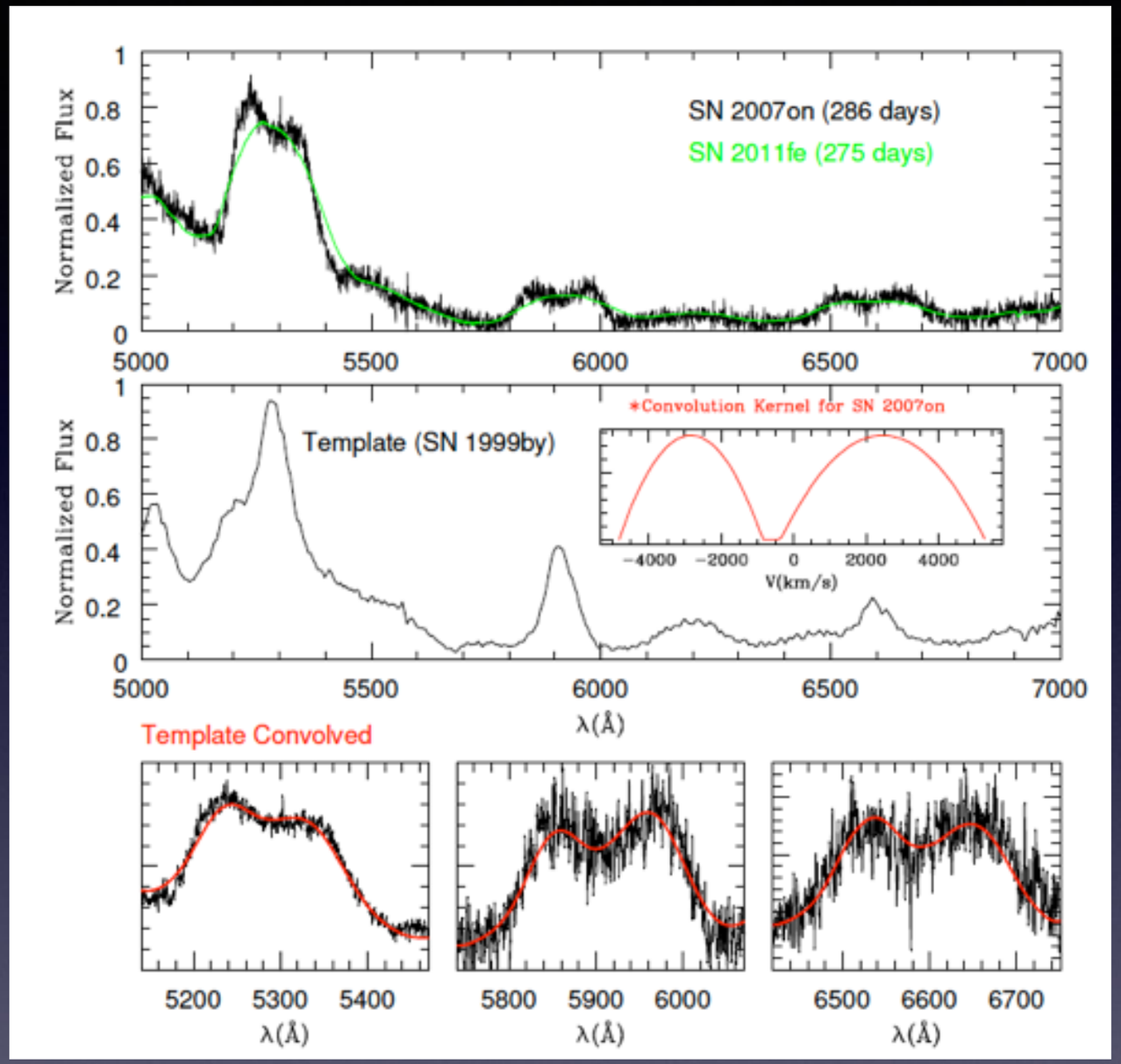
Katz &Dong 12

Explains some central la observations

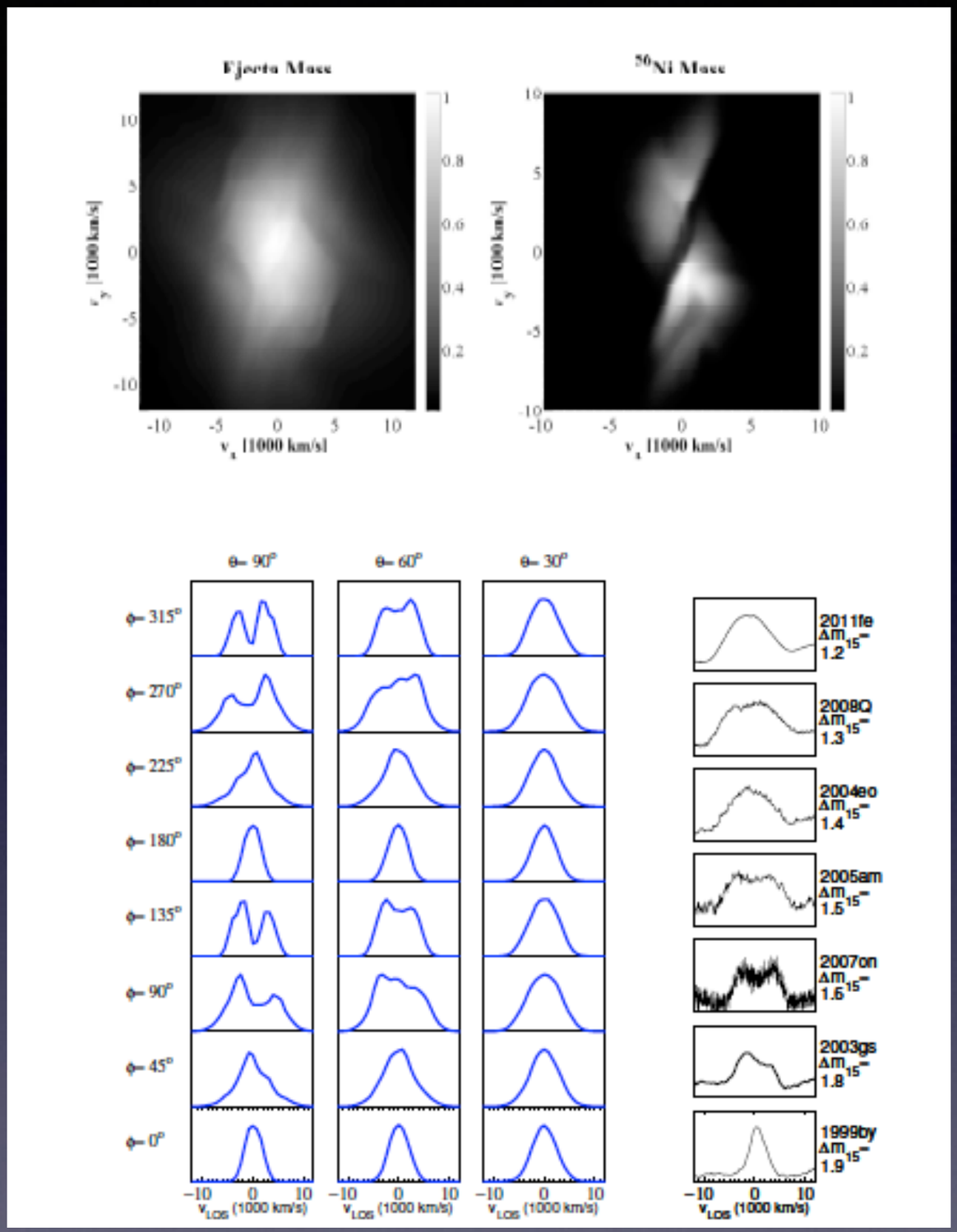
Converged ^{56}Ni range is produced by WD range



DK et. al, 2013



Dong et. al. 2014



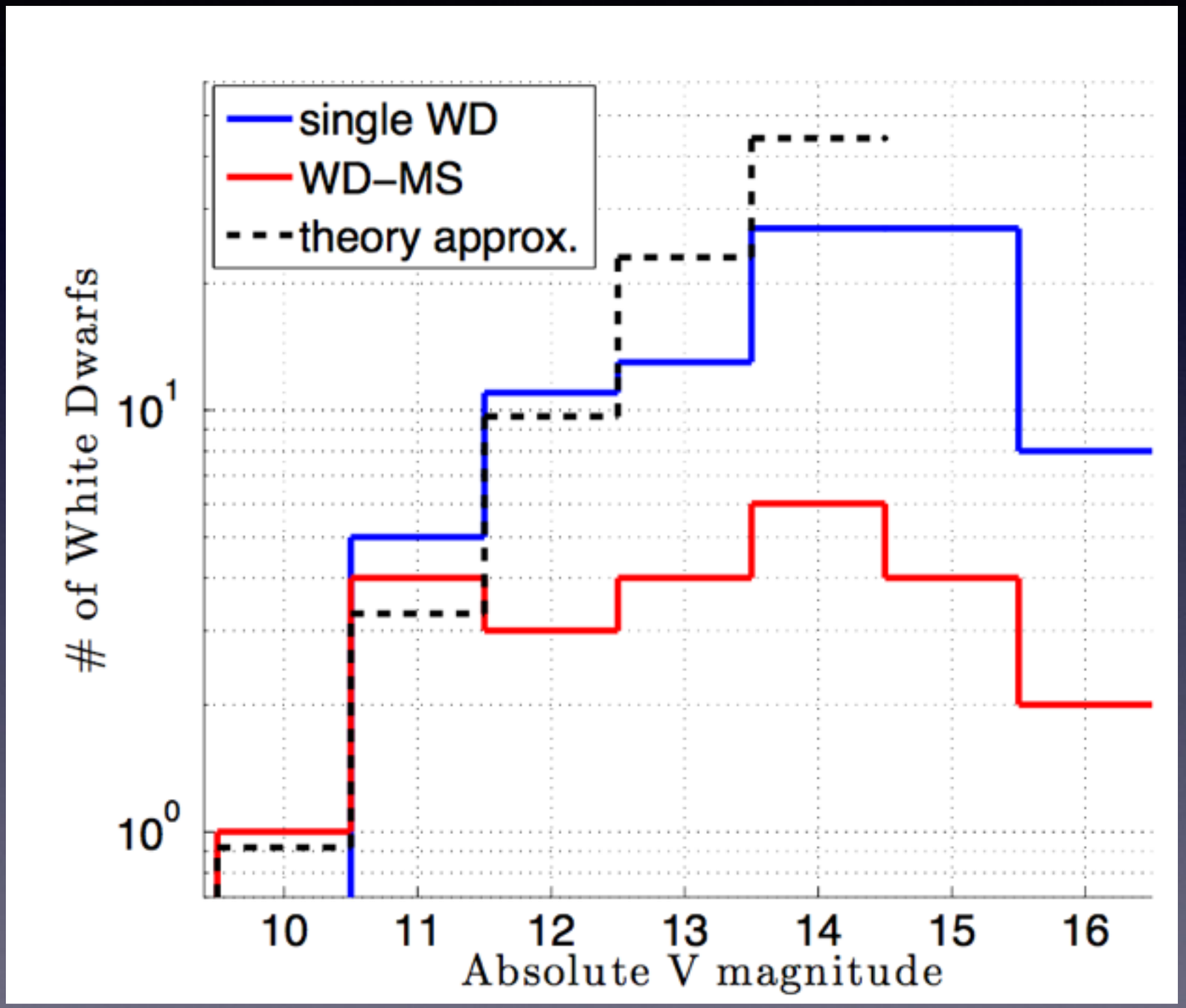
Collision at non-zero impact parameter

0.64 Msun WDs

Dong et. al. 2014

Conclusions

- Works: agrees with obs. so far
- Simple, Robust
- Main uncertainty - amount of triples


single WD
WD–MS
theory approx.
# of White Dwarfs
10^1
10^0
10
11
12
13
14
15
16
Absolute V magnitude

Ignition of detonation resolved?? imposible

White Dwarf ~ 10,000 km

Detonation front width ~ 1mm

Would need 10^30 numerical cells!

At ignition, temperatures are lower

burning time*speed of sound ~ 50km

Kushnir et al. 13,14

Only need ~10^8 cells

Ignition resolved in global 2D and 3D simulations