

Double white dwarf mergers and type Ia supernovae

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Sept. 8 2023

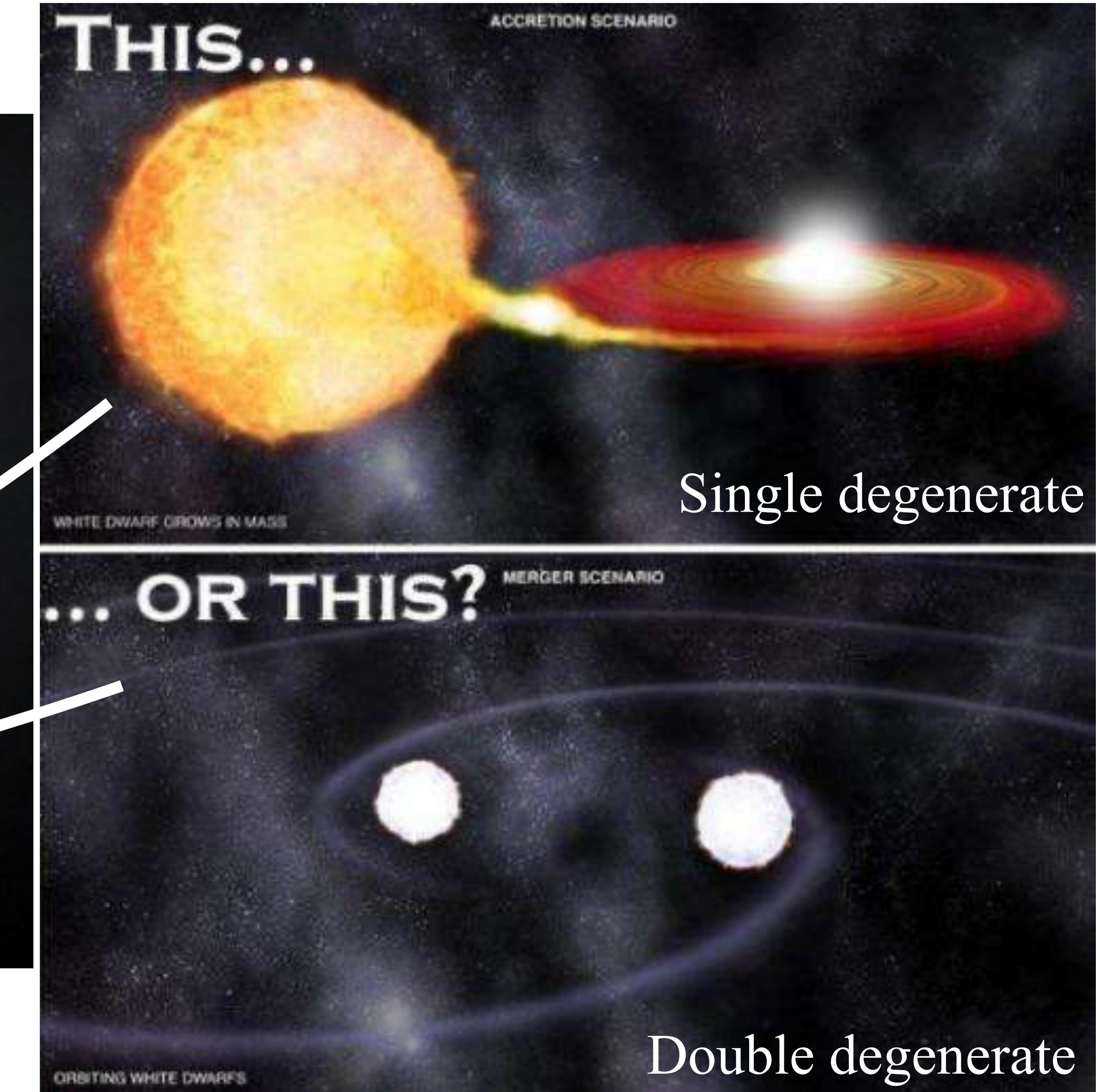
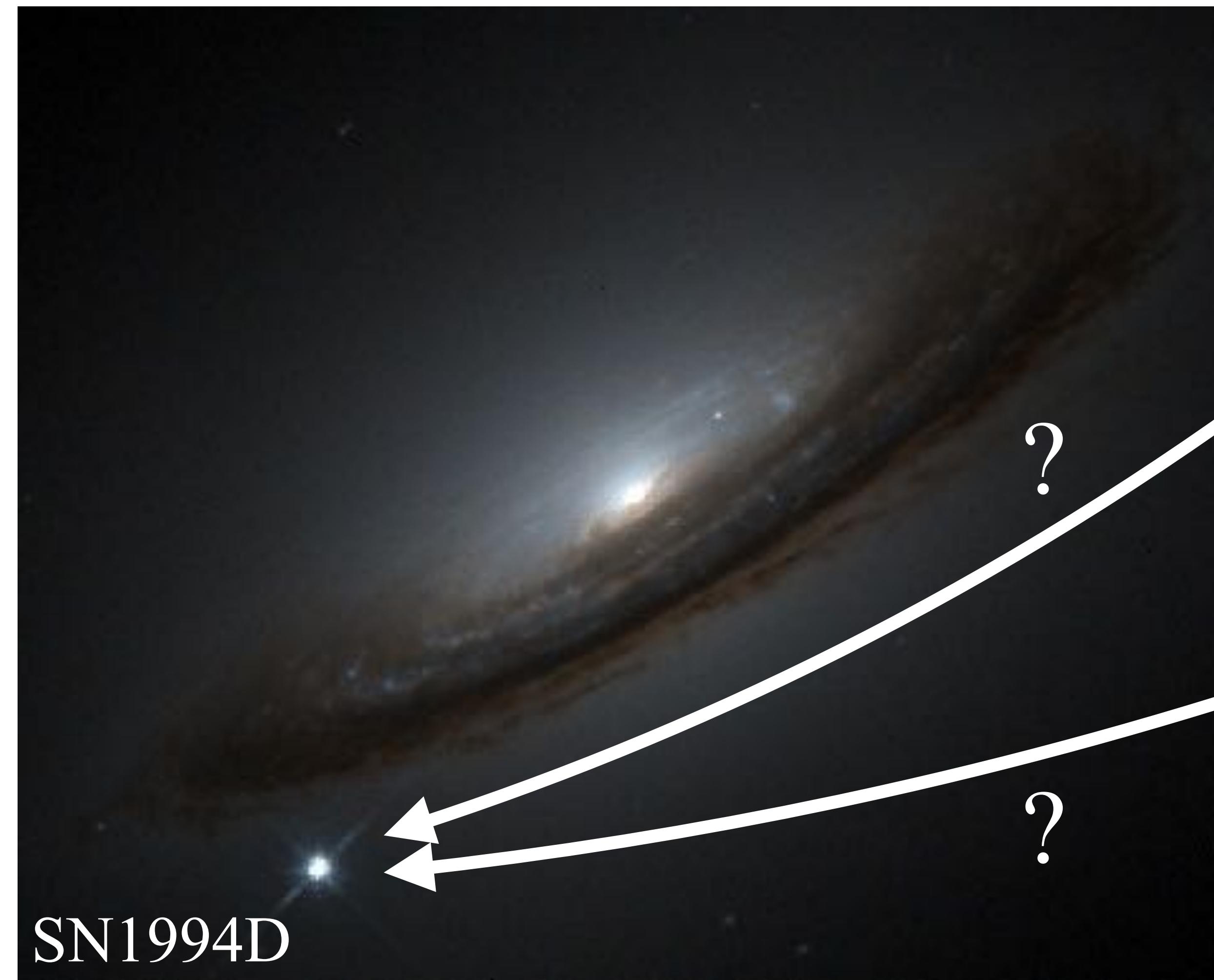
The Golden Age of Cataclysmic Variables and
Related Objects VI, Palermo, Italy

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- Motivation
- D⁶ explosion simulation
- D⁶ SNR simulation
- Multi-messenger astronomy for type Ia supernovae

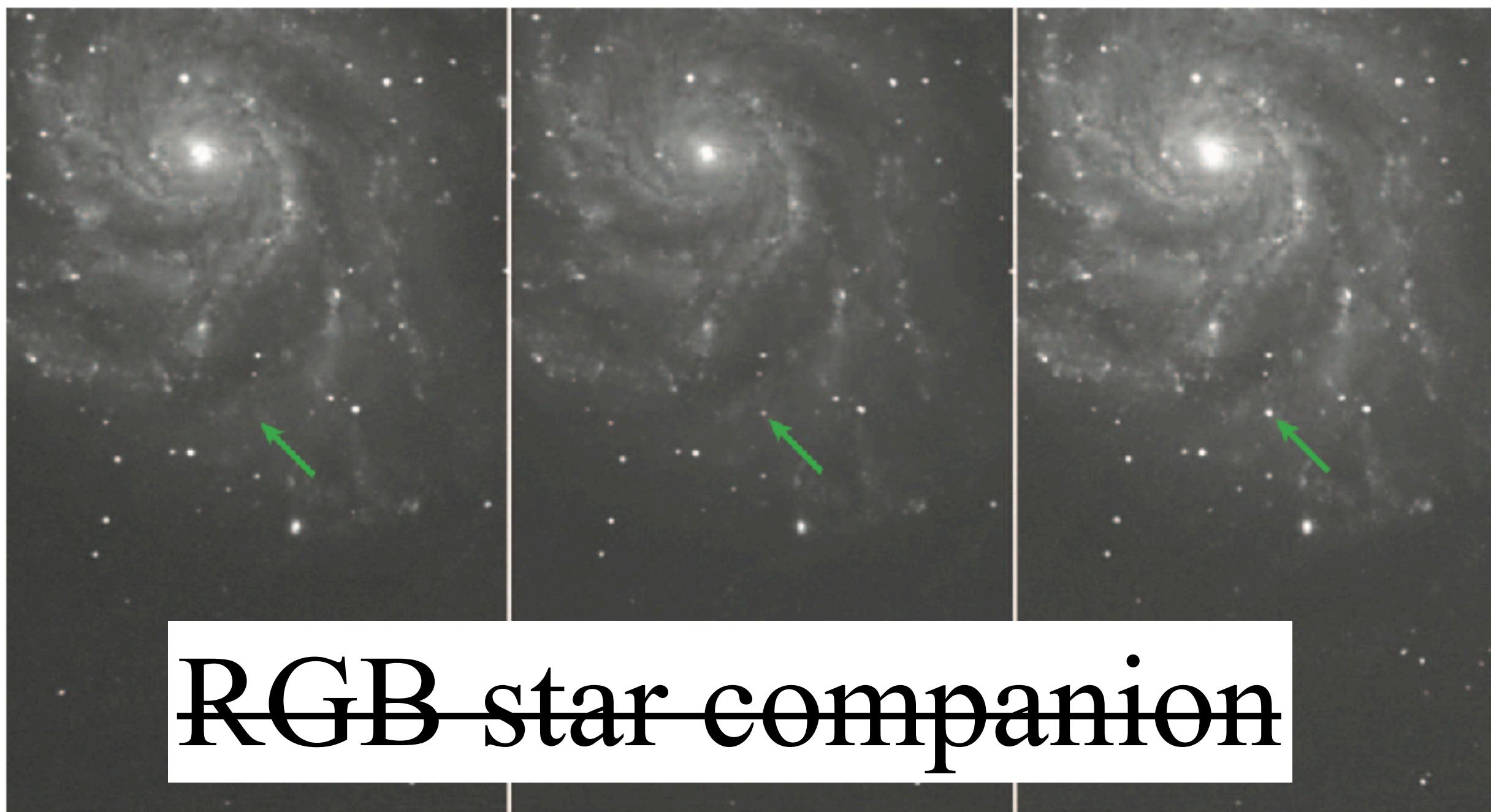
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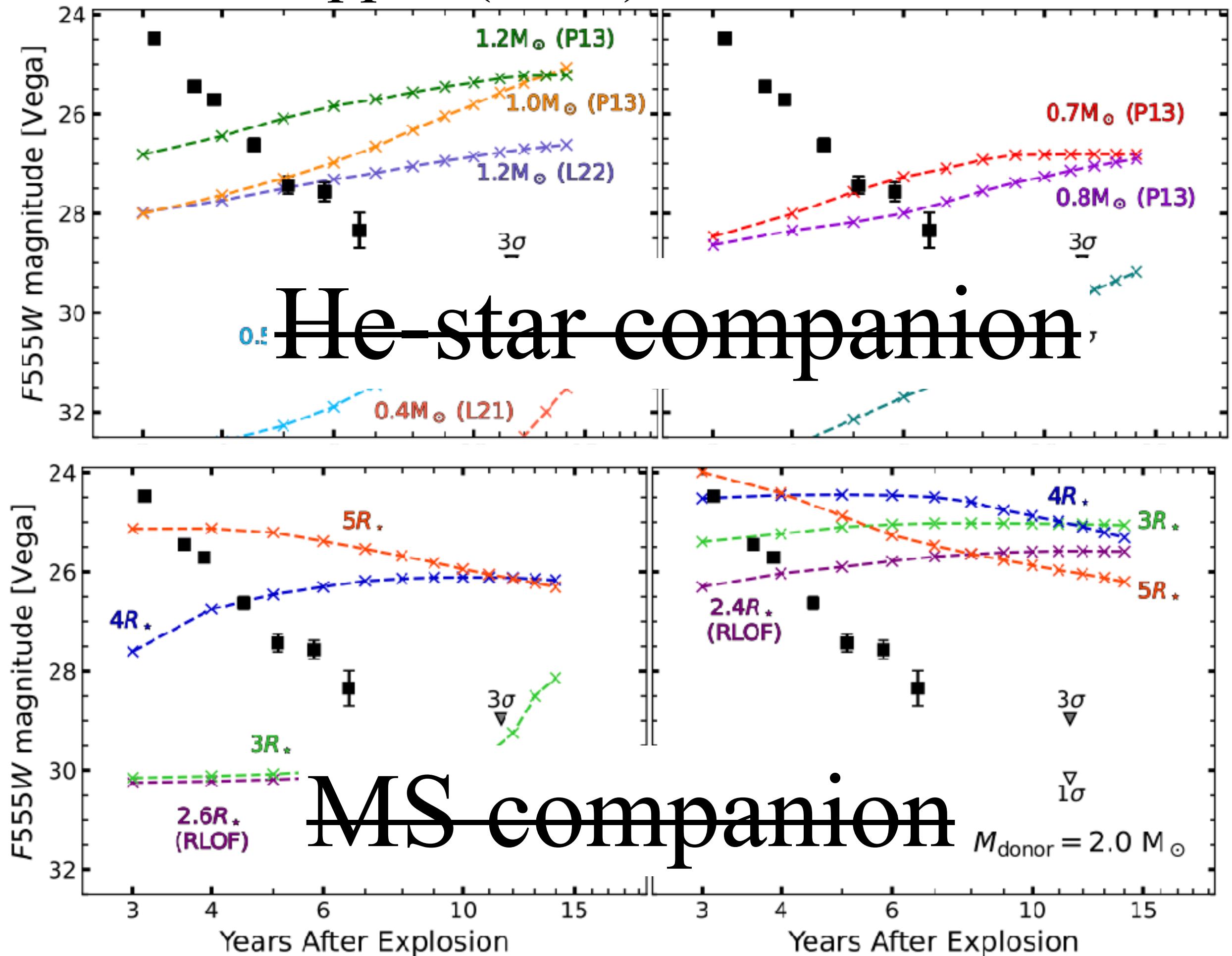


Strong constraints on SD

Nugent et al. (2011)

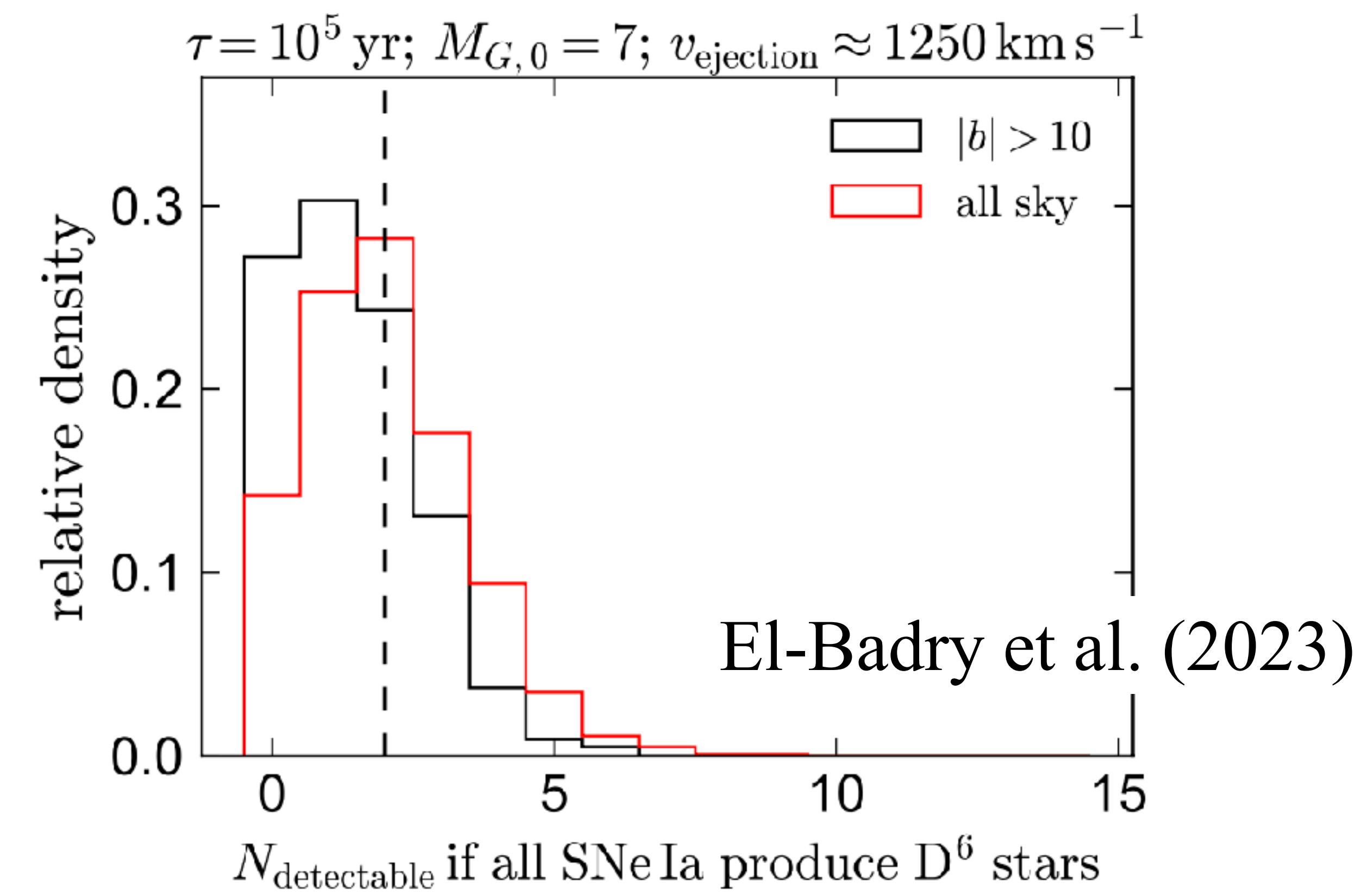
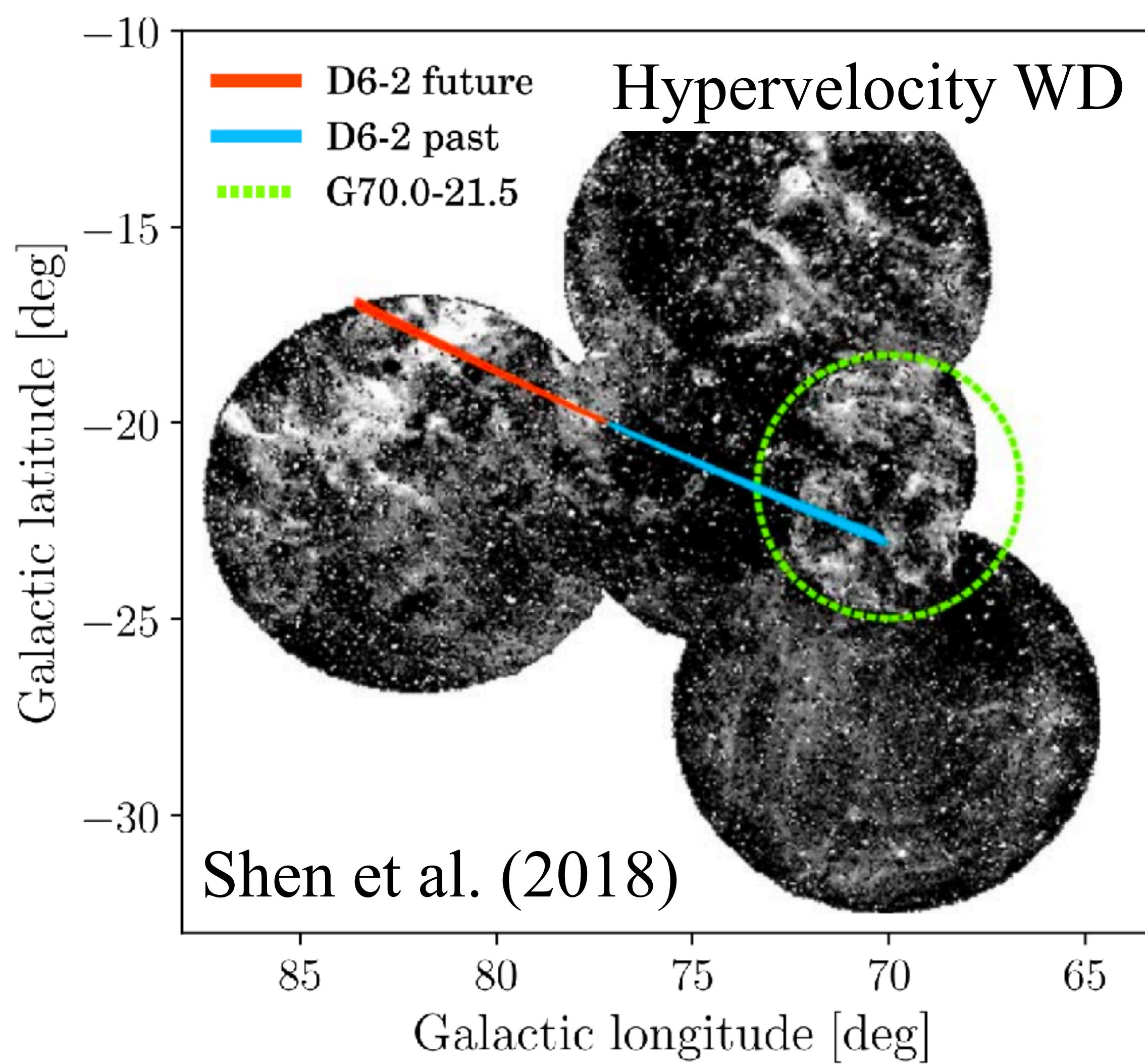


Tucker, Shappee (2023)



Ruling out SD \implies Searching for the positive evidence of DD

Positive evidence for DD



Piling up positive evidences for DD

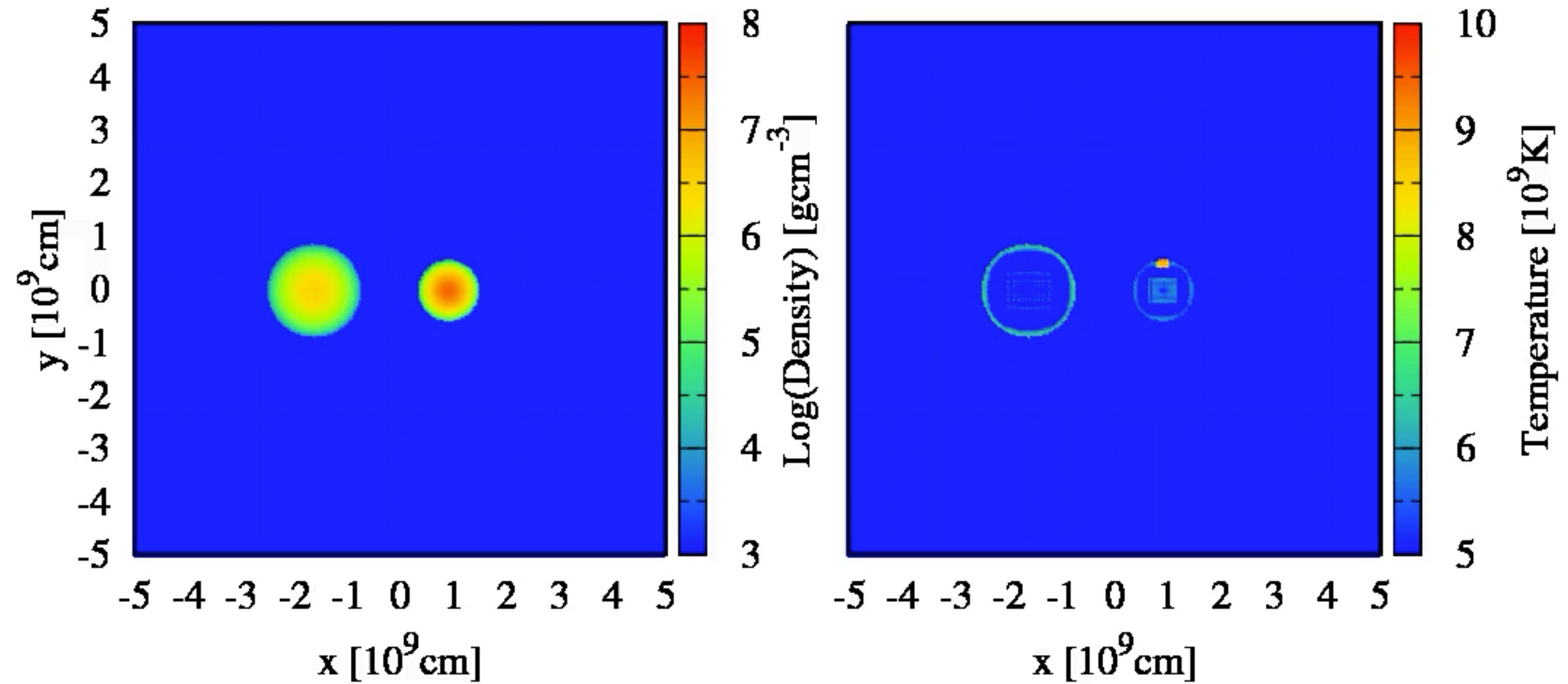
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Overview of the simulation

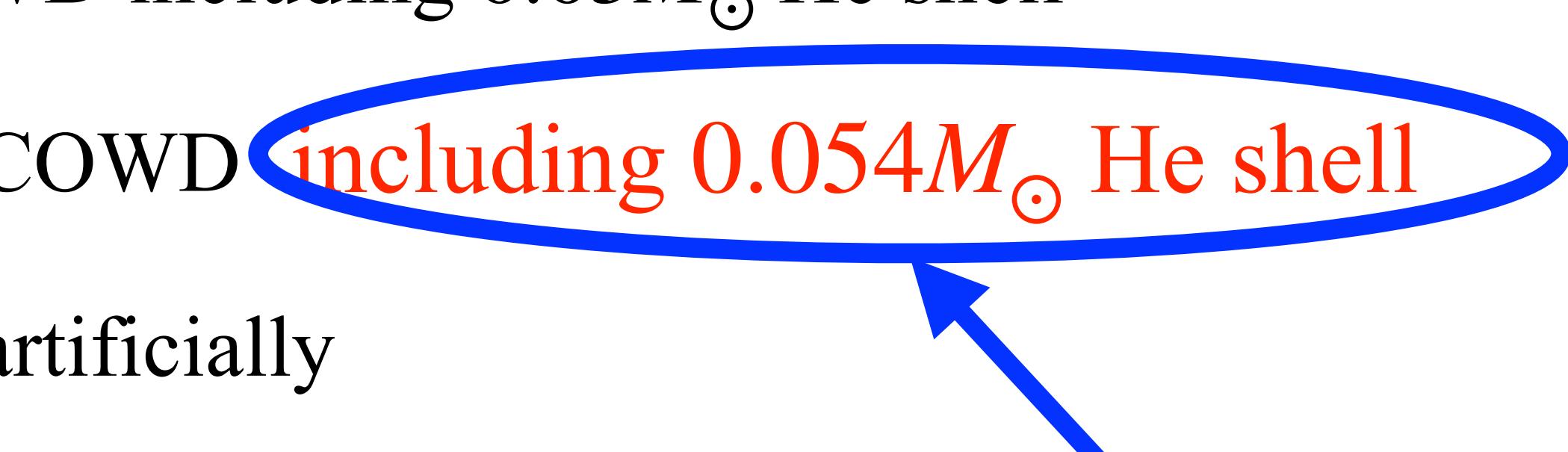
- Initial setup
 - $1.0M_{\odot}$ COWD including $0.05M_{\odot}$ He shell \implies Exploding WD
 - $0.6M_{\odot}$ COWD \implies Surviving and hypervelocity WD
 - Hot spot set in the He shell artificially
- Method
 - Hand-made SPH simulation with 67 million particles
- Final results
 - ^{56}Ni : $0.54M_{\odot}$, Si: $0.15M_{\odot}$, O: $0.07M_{\odot}$, Kinetic energy: 1.1Foe

D^6 explosion



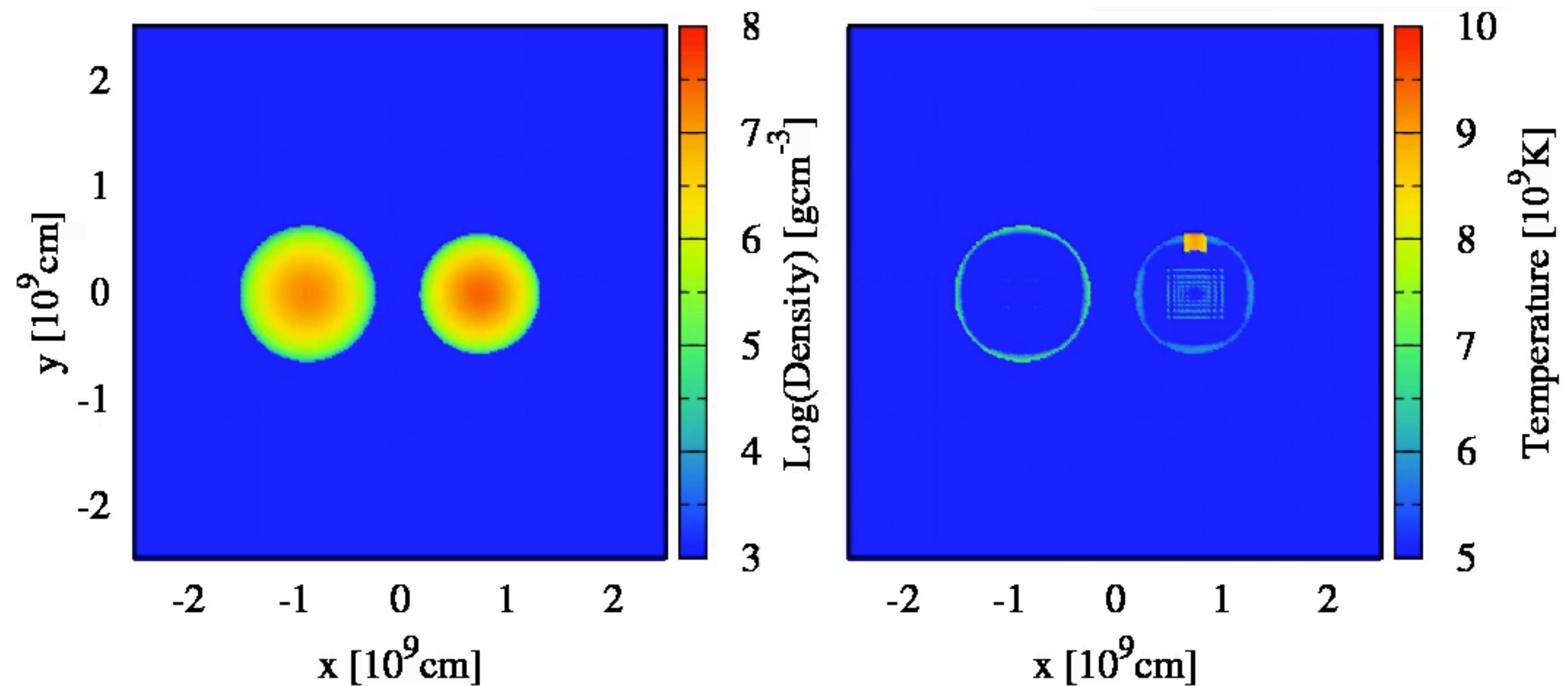
Tanikawa et al. (2018, ApJ, 868, 90)

Overview of another simulation

- Initial setup
 - Exploding WD: $1.0M_{\odot}$ COWD including $0.05M_{\odot}$ He shell
 - Exploding $0.90M_{\odot}$ WD: $0.6M_{\odot}$ COWD **including $0.054M_{\odot}$ He shell**

Unrealistically thick shell
 - Hot spot set in the He shell artificially
- Method
 - SPH simulation with ~~67~~ million particles
- Final results
 - ^{56}Ni : $0.54M_{\odot}$, Si: $0.15M_{\odot}$, O: $0.07M_{\odot}$, Kinetic energy: 1.1Foe
 $1.01M_{\odot}$ $0.28M_{\odot}$ $0.16M_{\odot}$ 2.1Foe

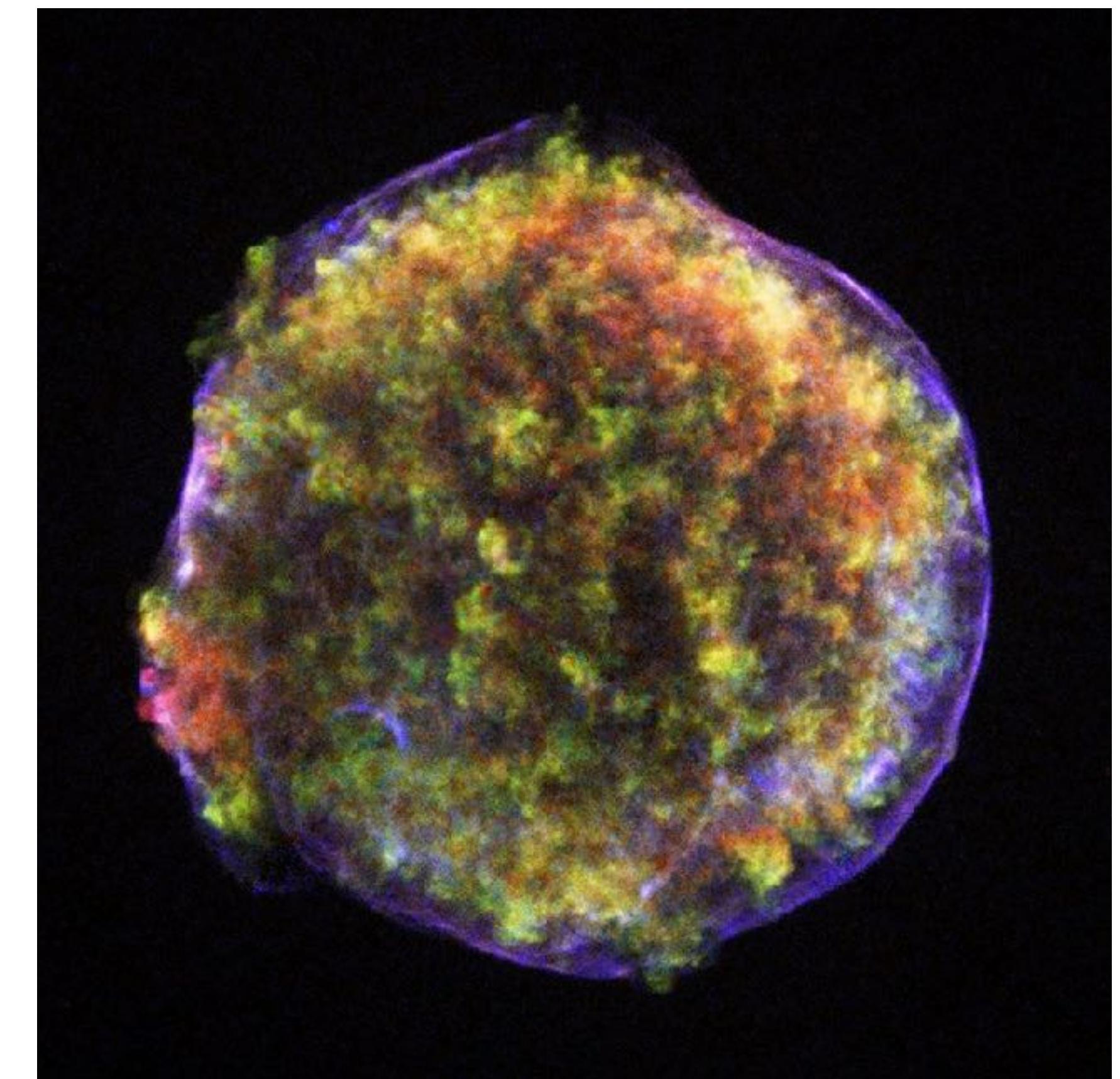
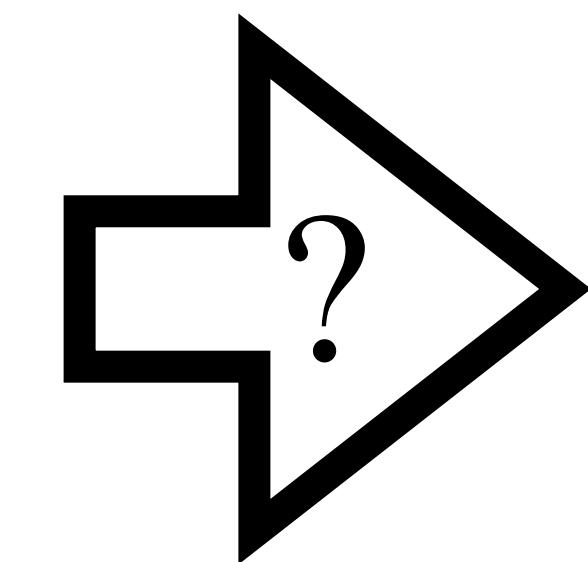
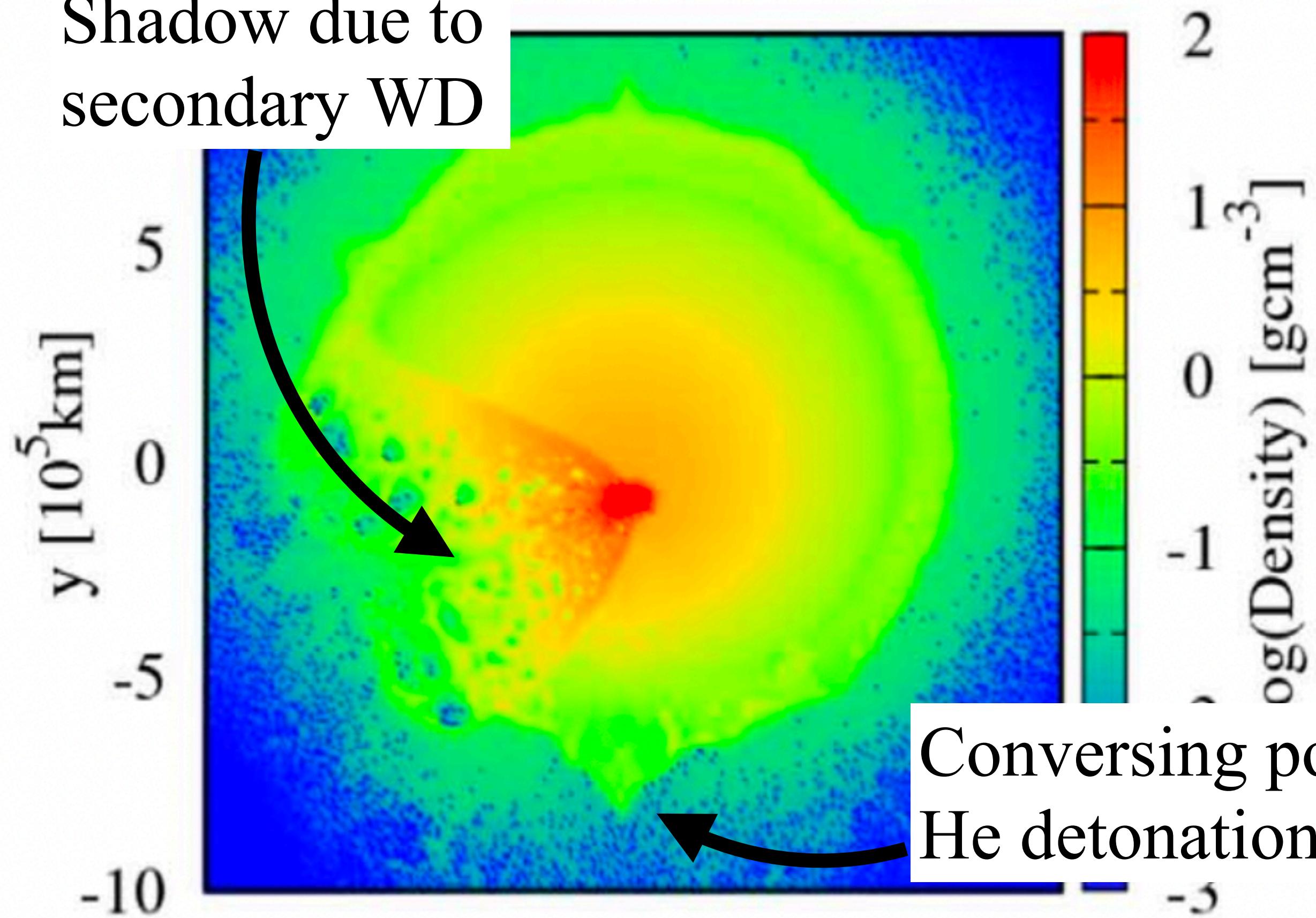
Secondary explosion



Tanikawa et al. (2019, ApJ, 885, 103)

D^6 supernova to SNR?

Shadow due to
secondary WD



Tycho's supernova remnant

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SNR simulation



G. Ferrand



D. C. Warren



S. Nagataki



S. Safi-Harb

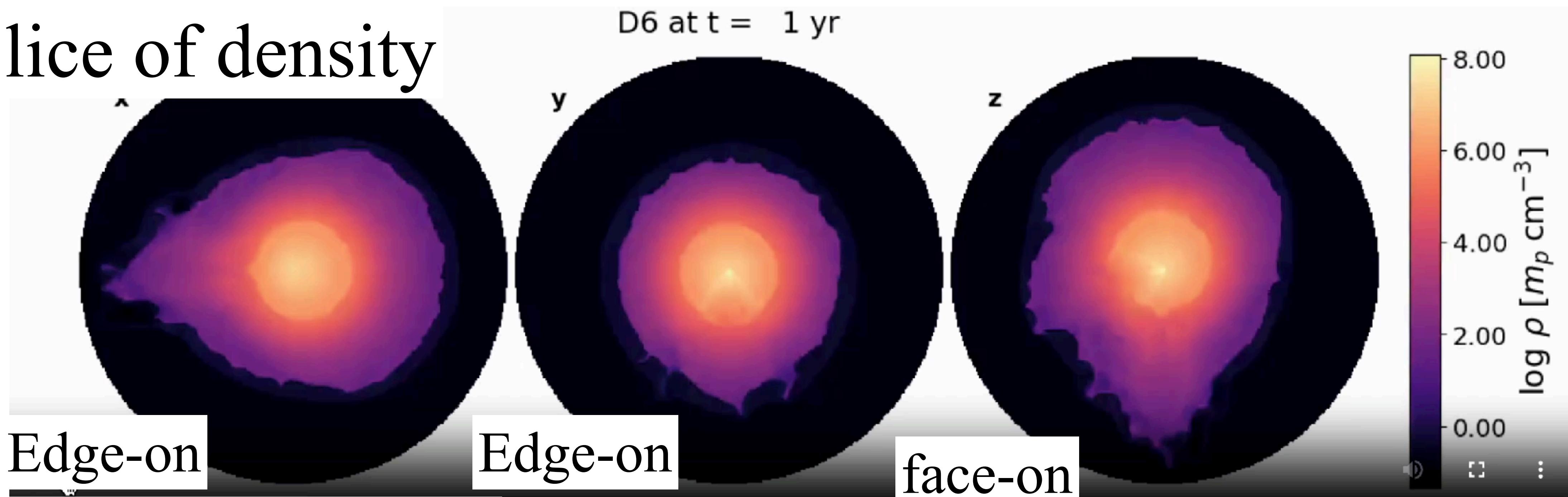


A. Decourchelle

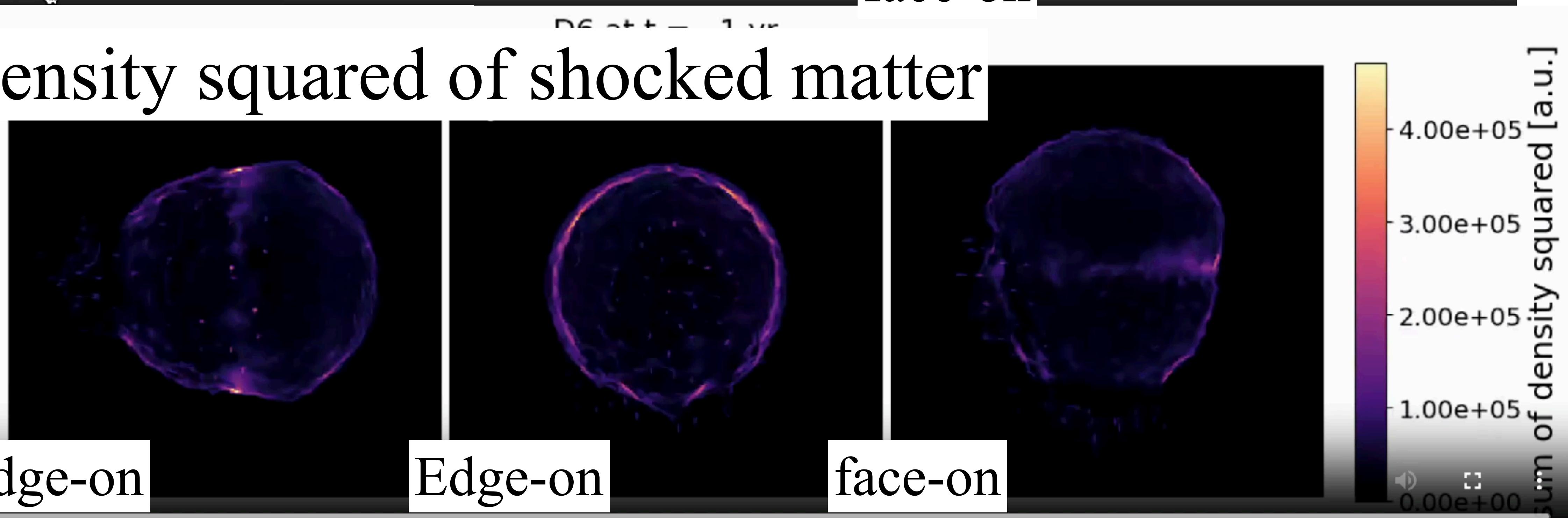
- Initial condition: 1 day after explosion
- Pure hydrodynamics simulation with Ramses for 4000yr
 - Snowplow phase starts 50000yr after.
- Grid number: 256^3
- Comoving grid: 4.5×10^{-4} pc at 1day, 5.6 pc at 100yr, 40 pc at 4000yr
- Homogeneous ISM of 0.1 cm^{-3}

Ferrand, AT, et al. (2022, ApJ, 930, 92)

Slice of density

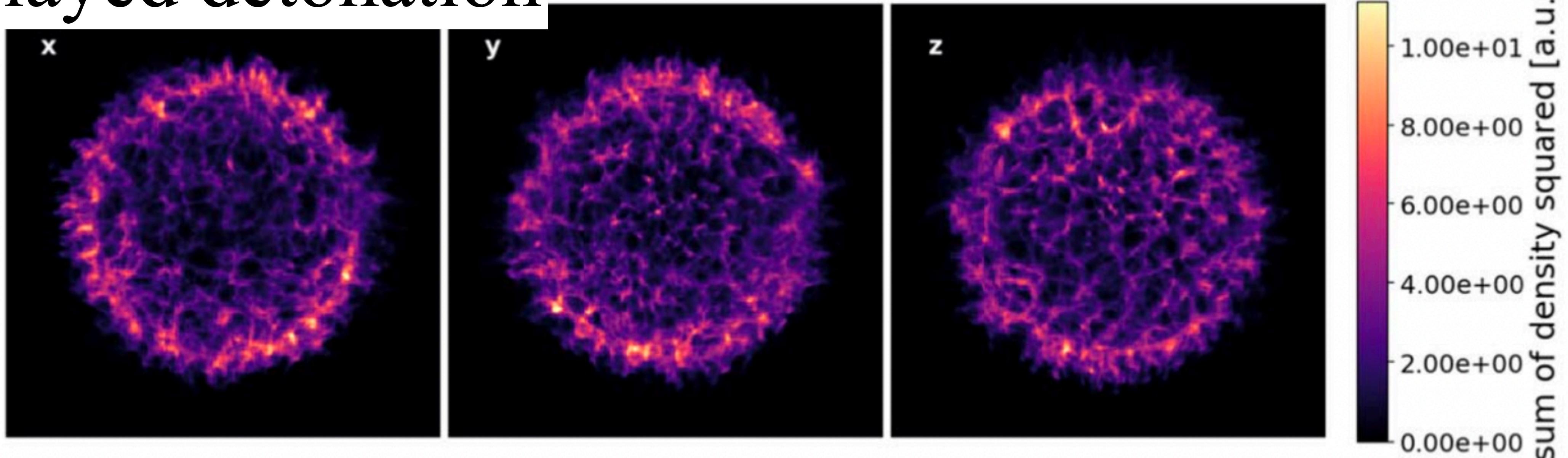


Density squared of shocked matter



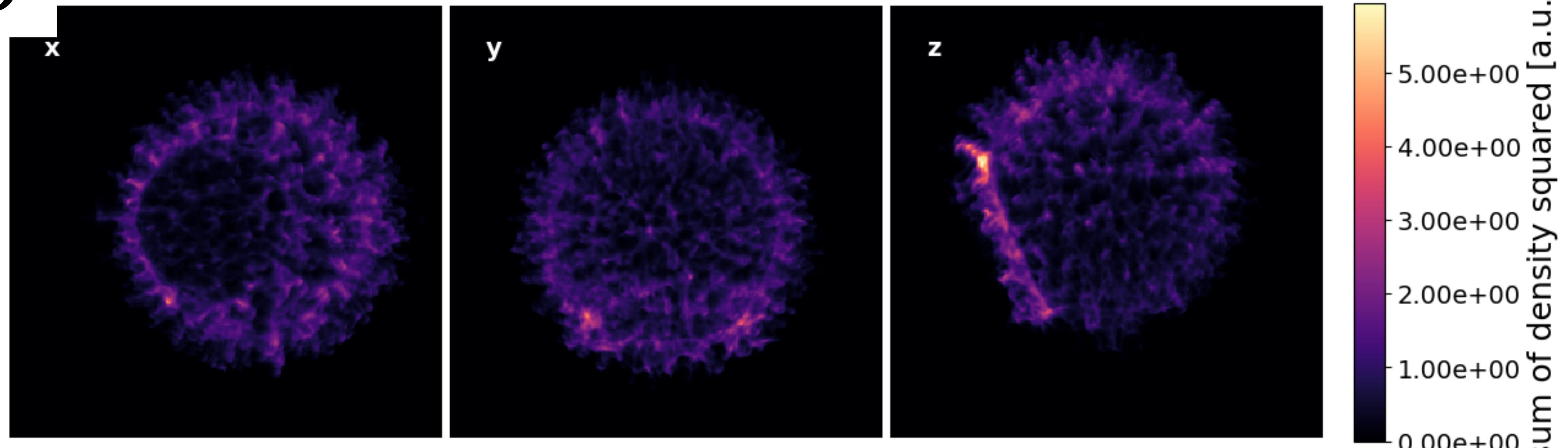
Delayed detonation

$\partial \rho / \partial t$ at $t = 500$ yr

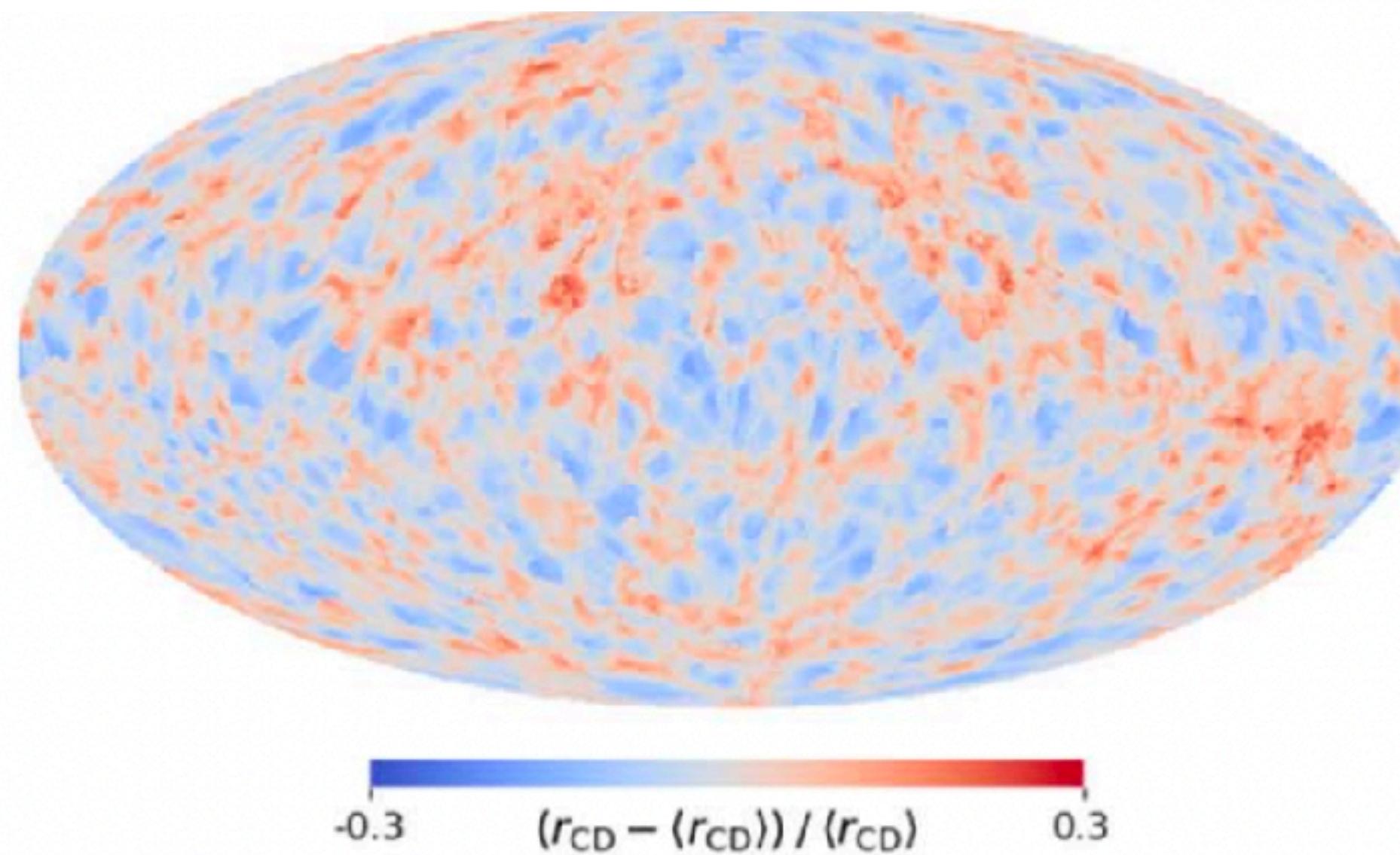


D^6

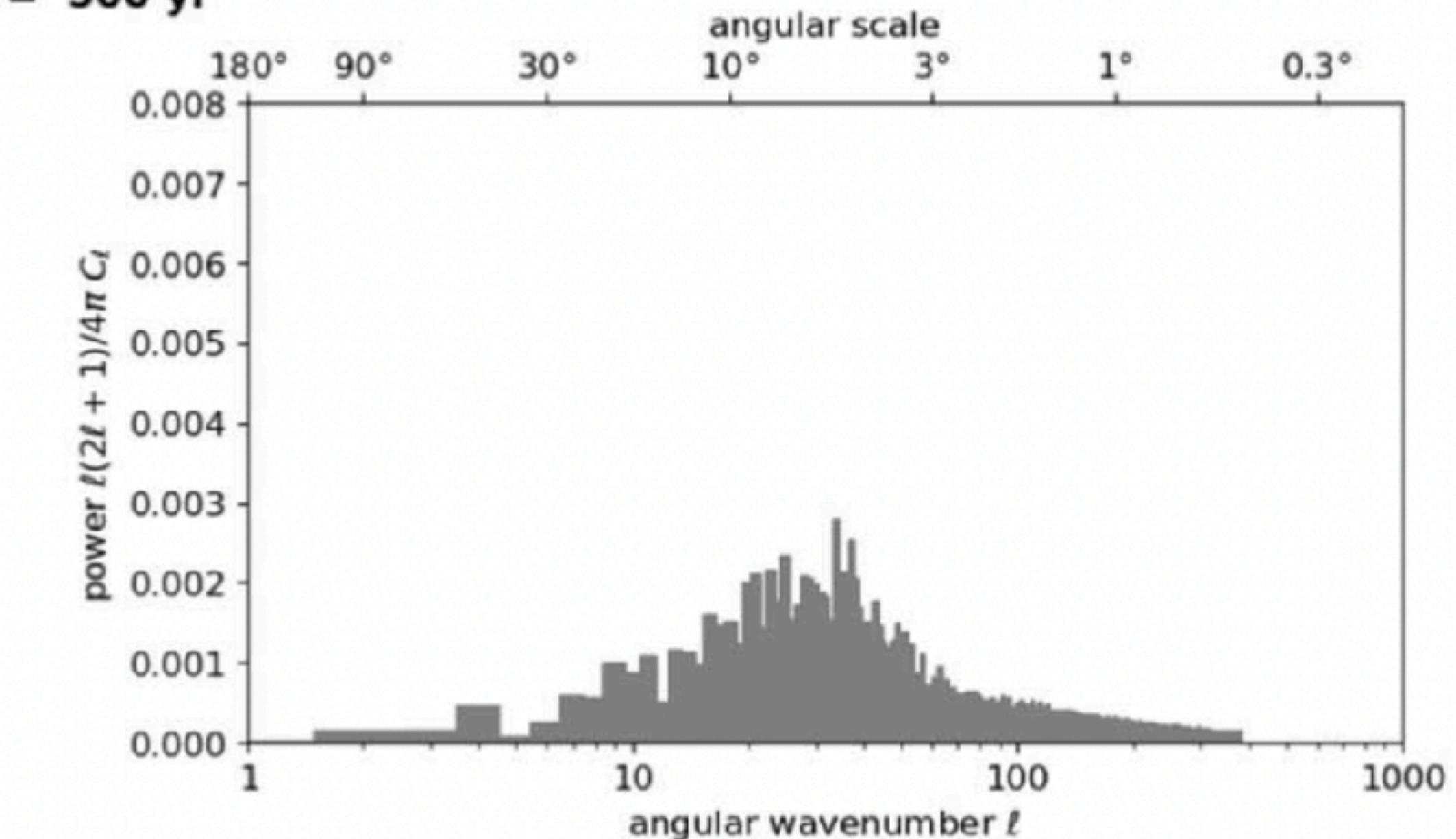
D^6 at $t = 500$ yr



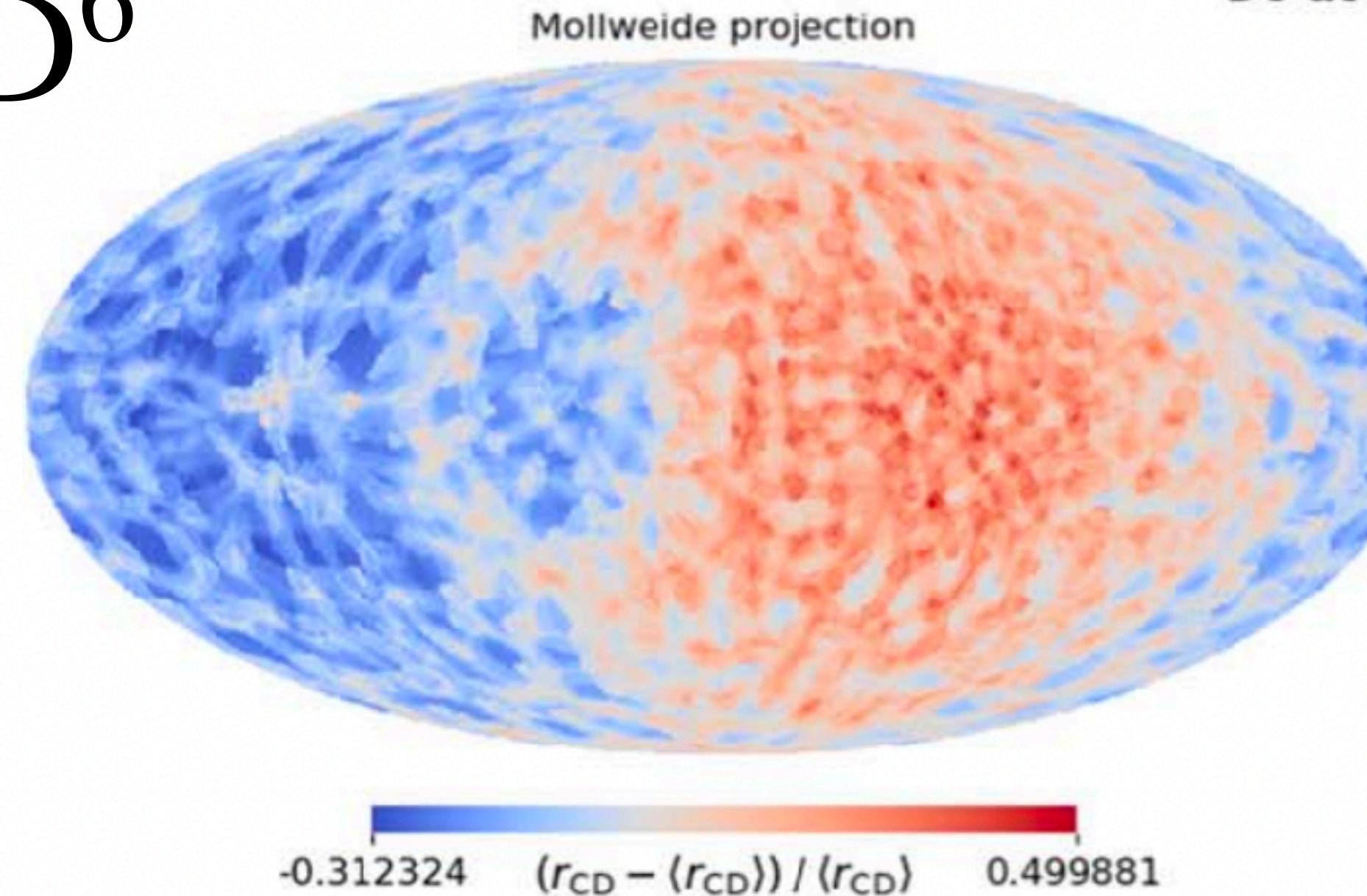
Delayed detonation



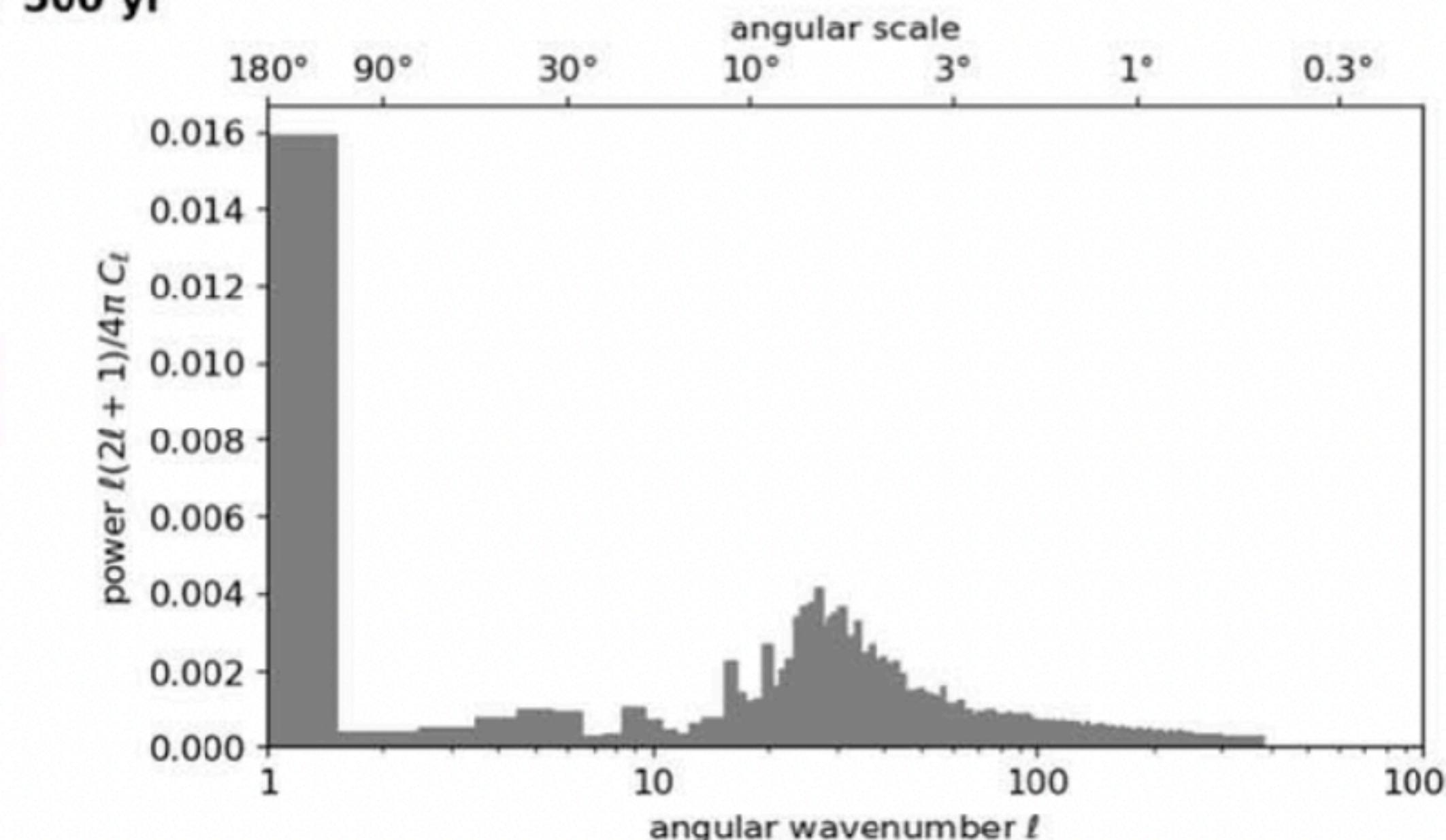
N100ddt at $t = 500$ yr



D^6



D6 at $t = 500$ yr

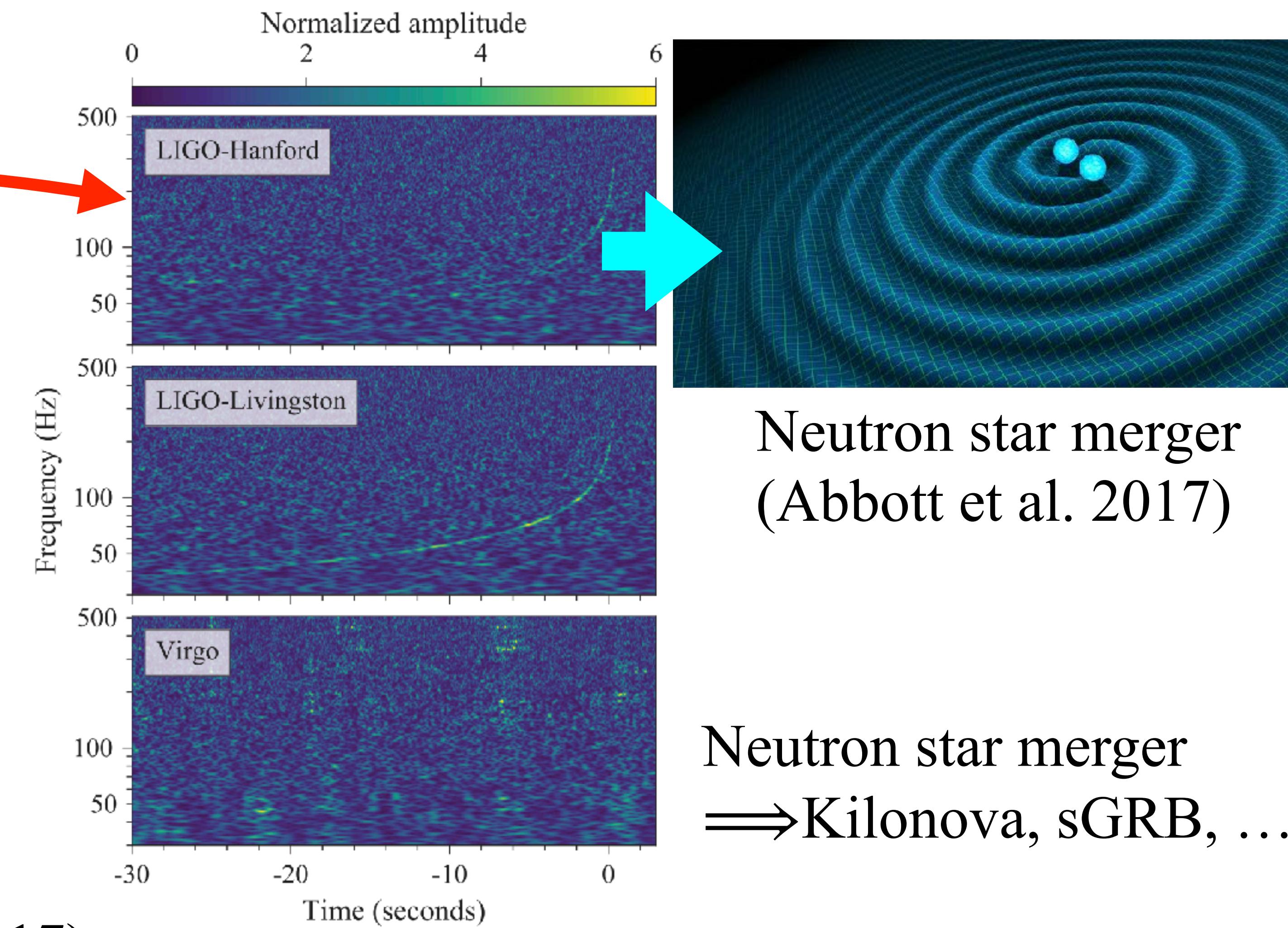
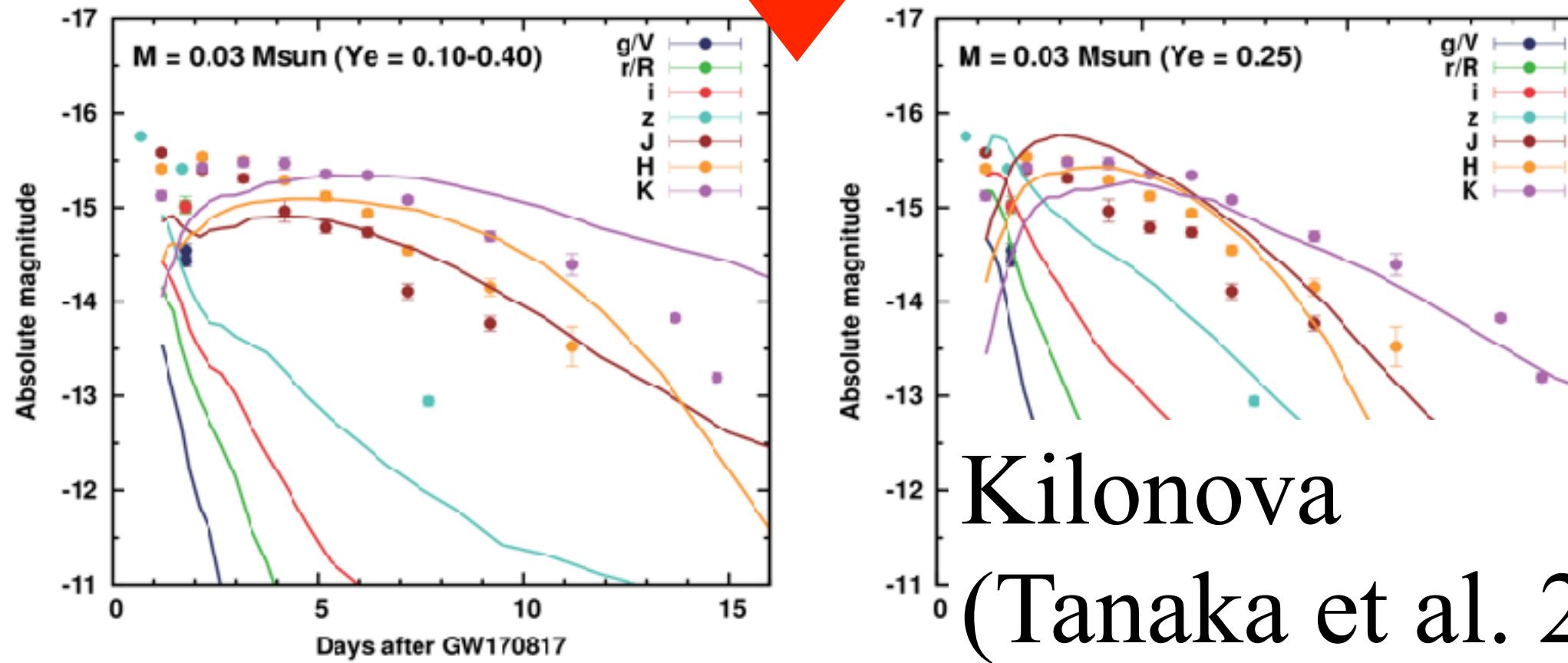
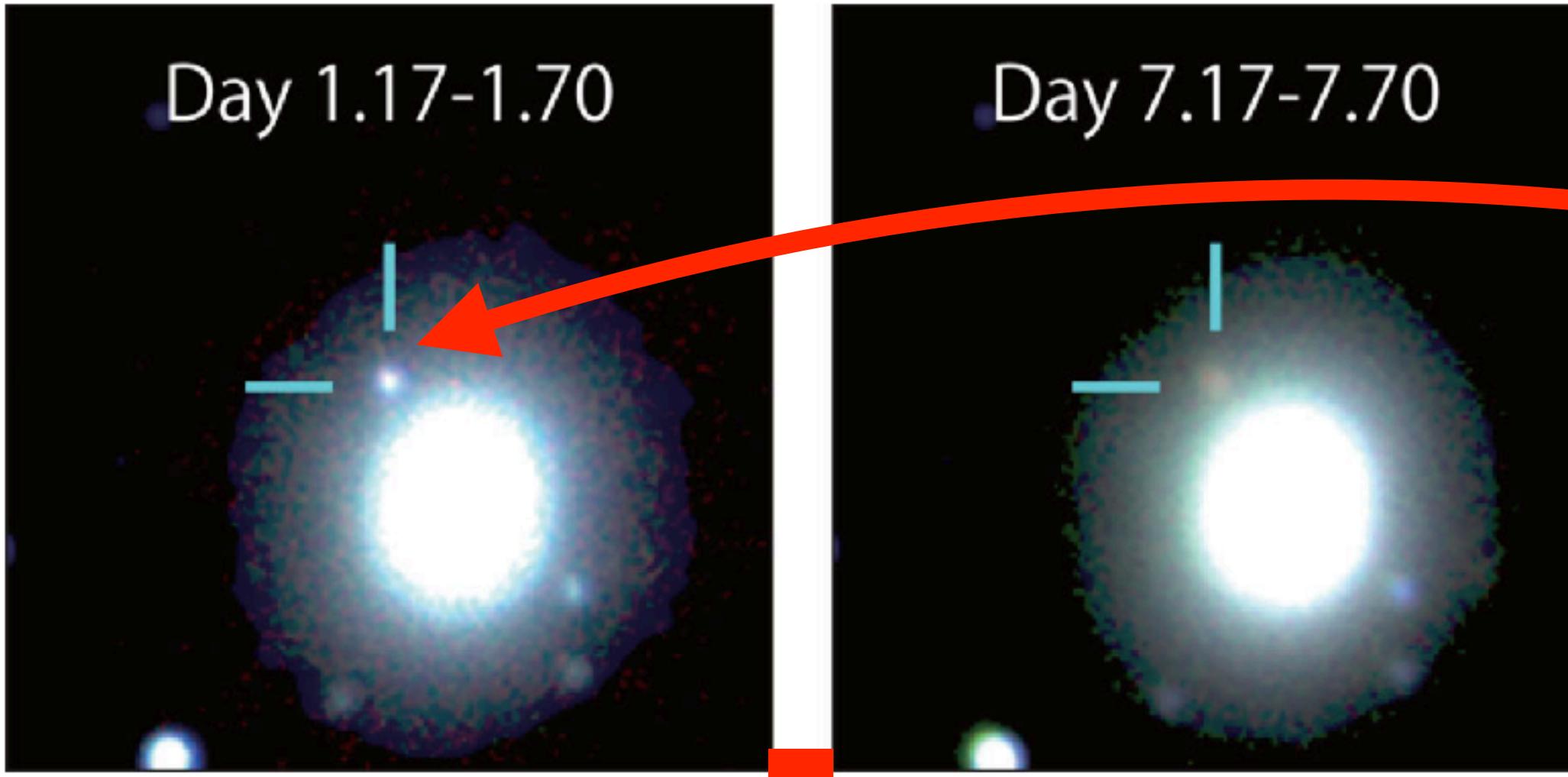


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A success case of multi-messenger astronomy

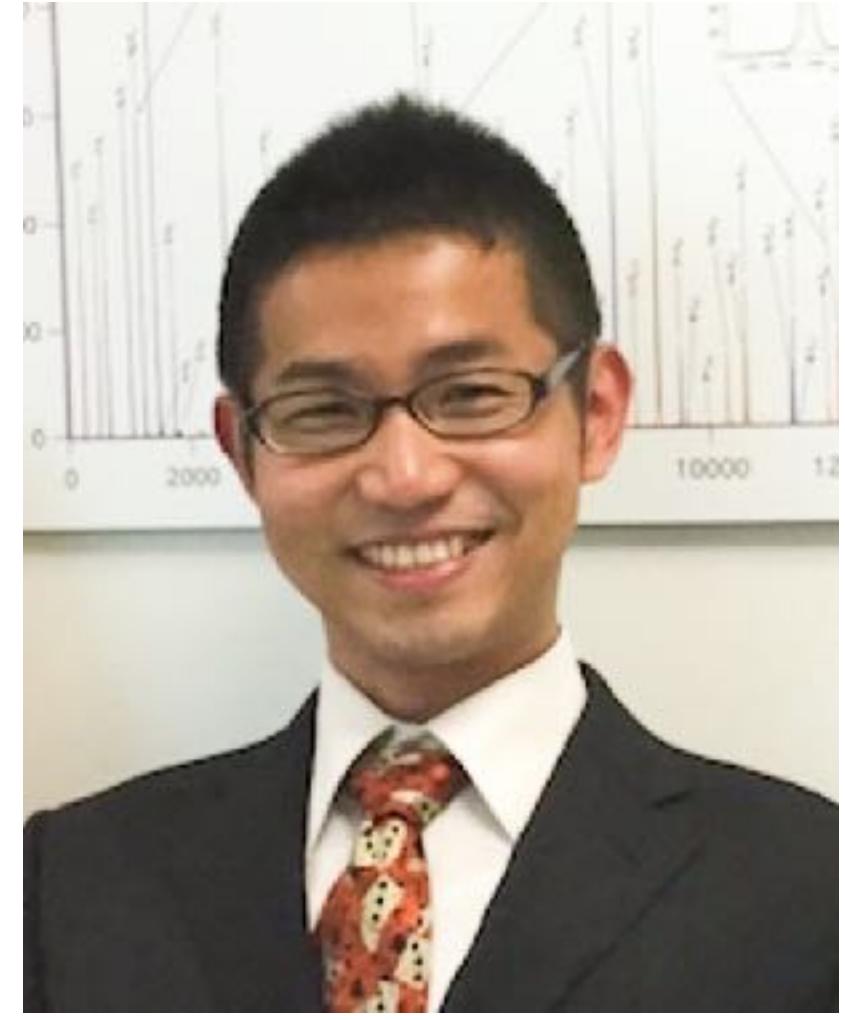
Utsumi et al. (2017)



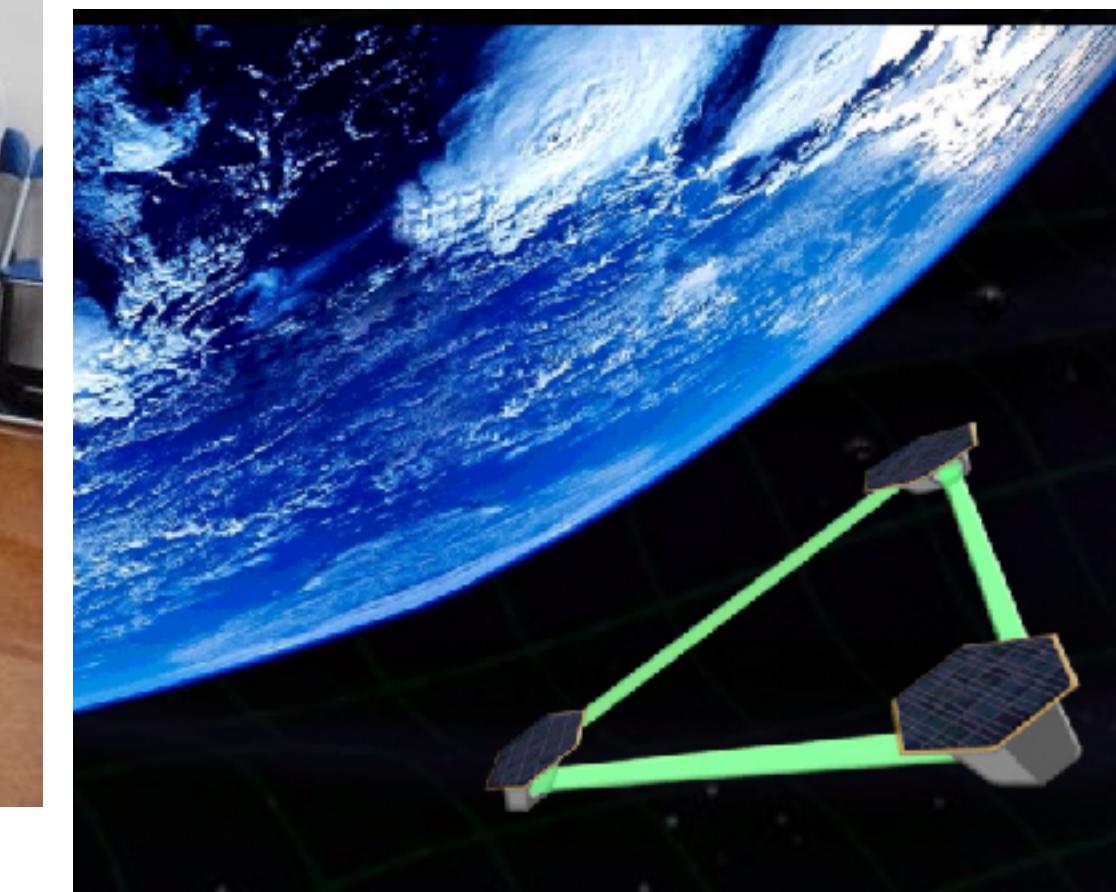
H. Takeda



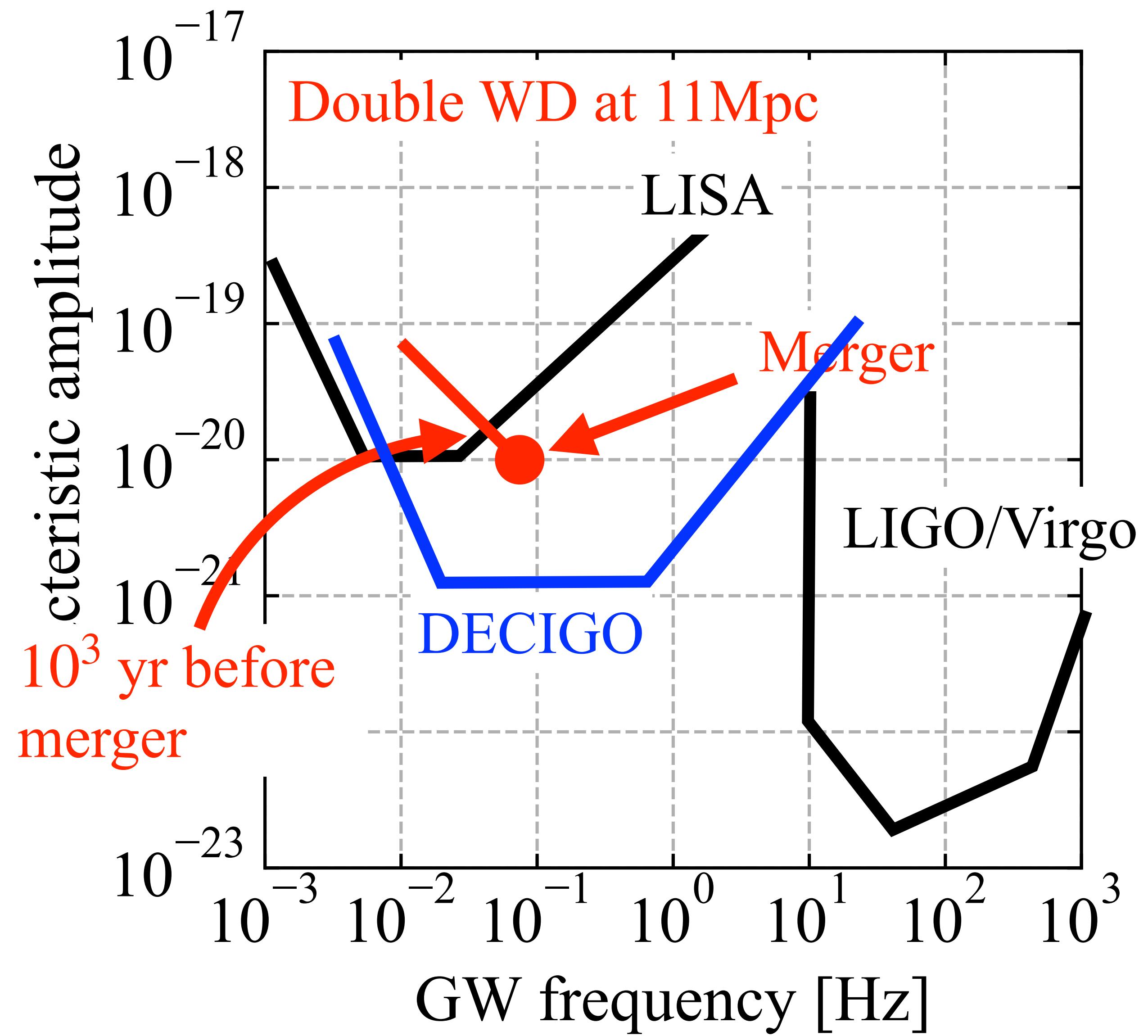
H. Yamaguchi



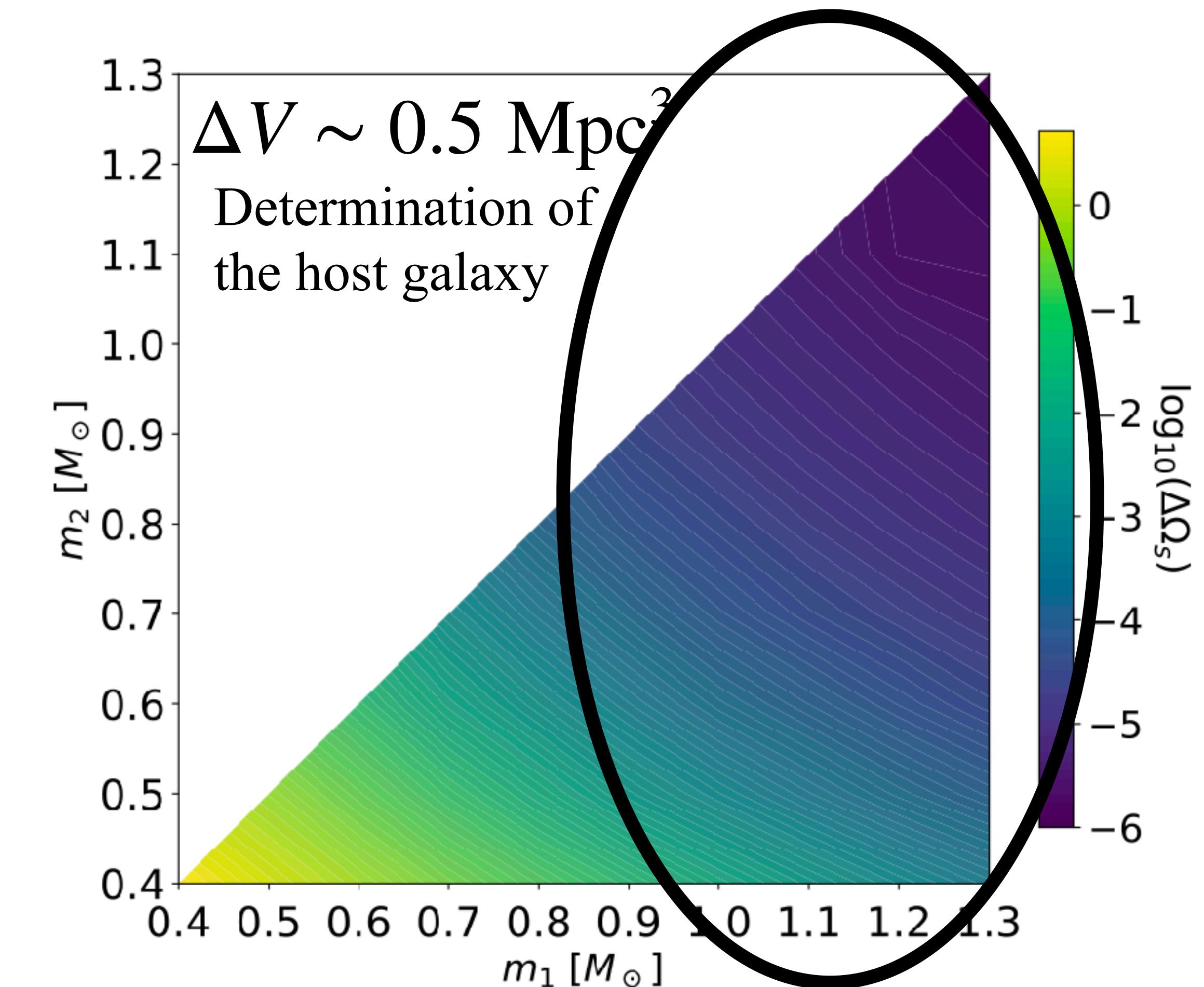
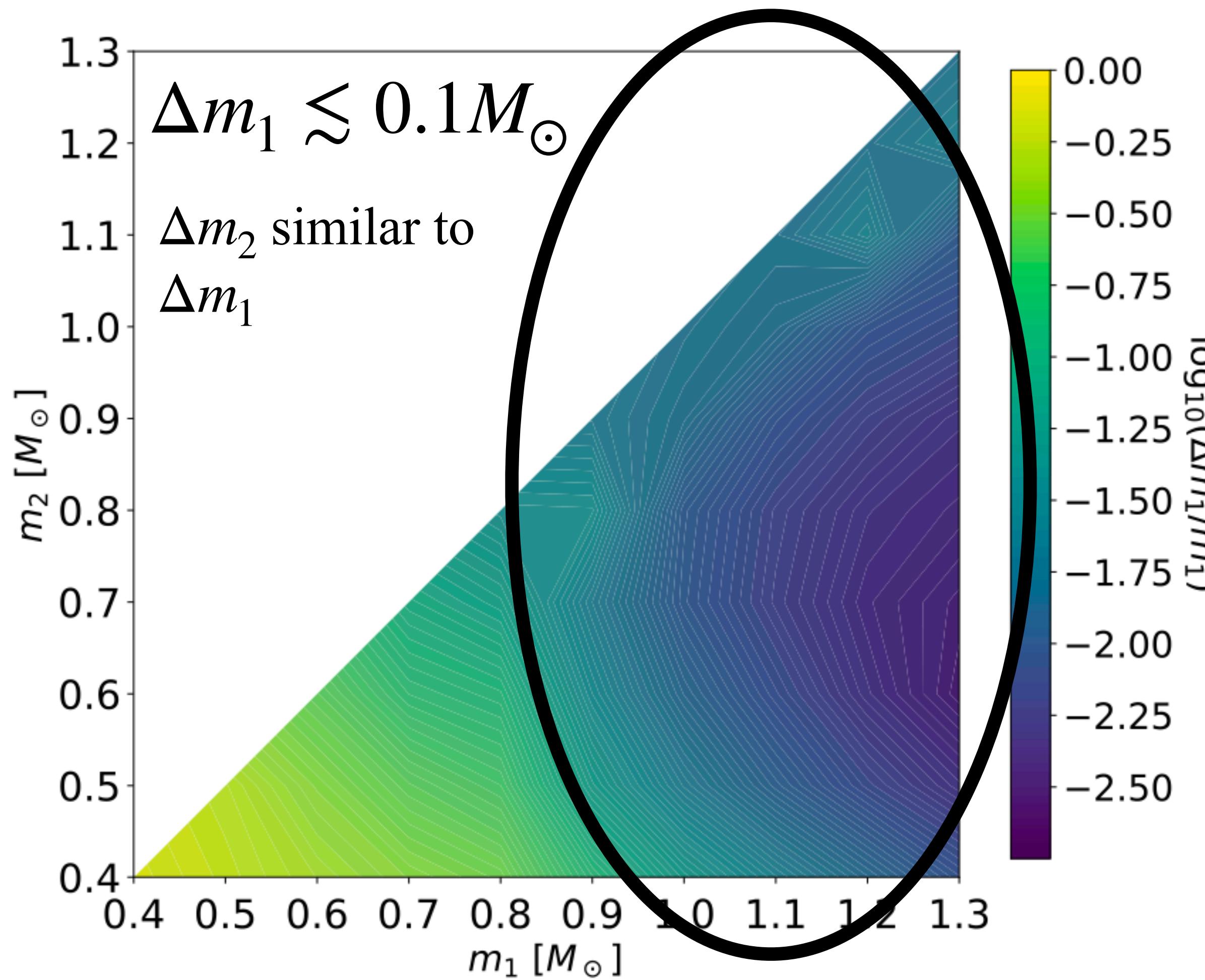
T. Kinugawa



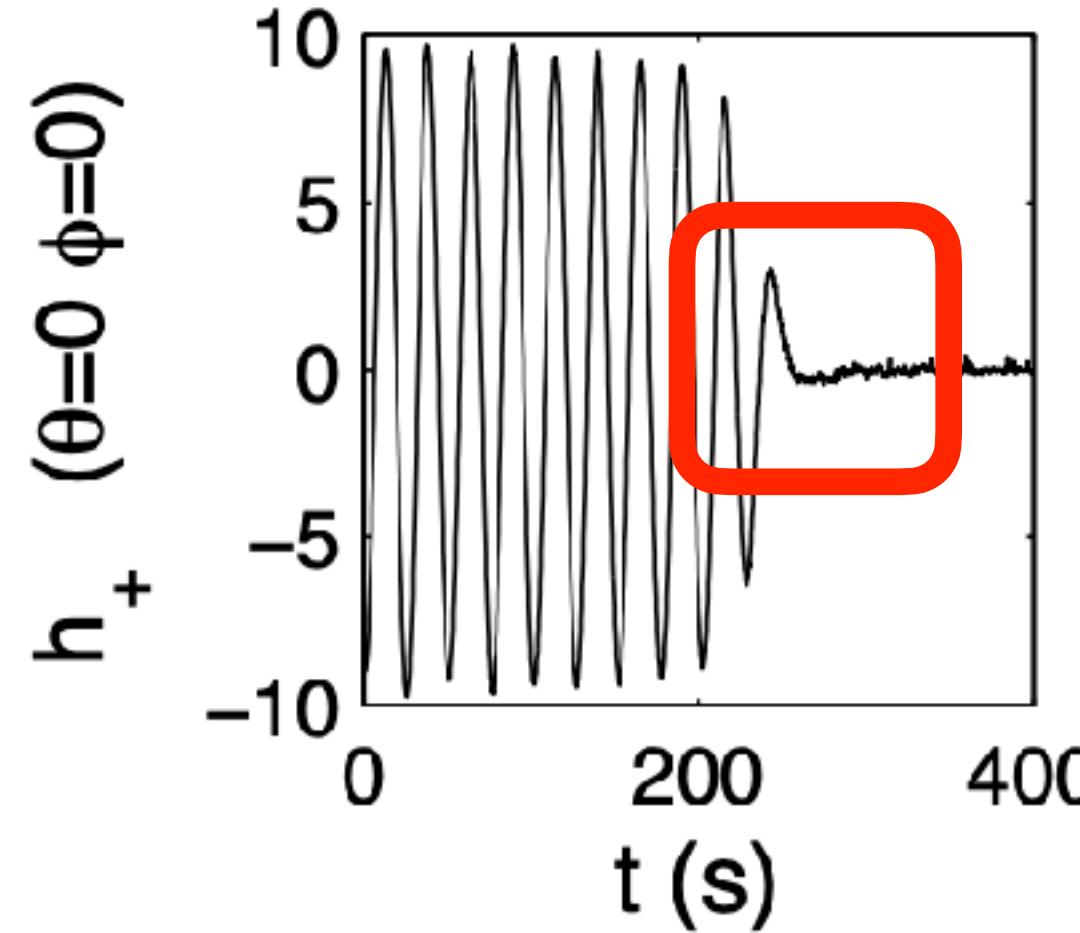
Gravitational wave obs.
“DECIGO”



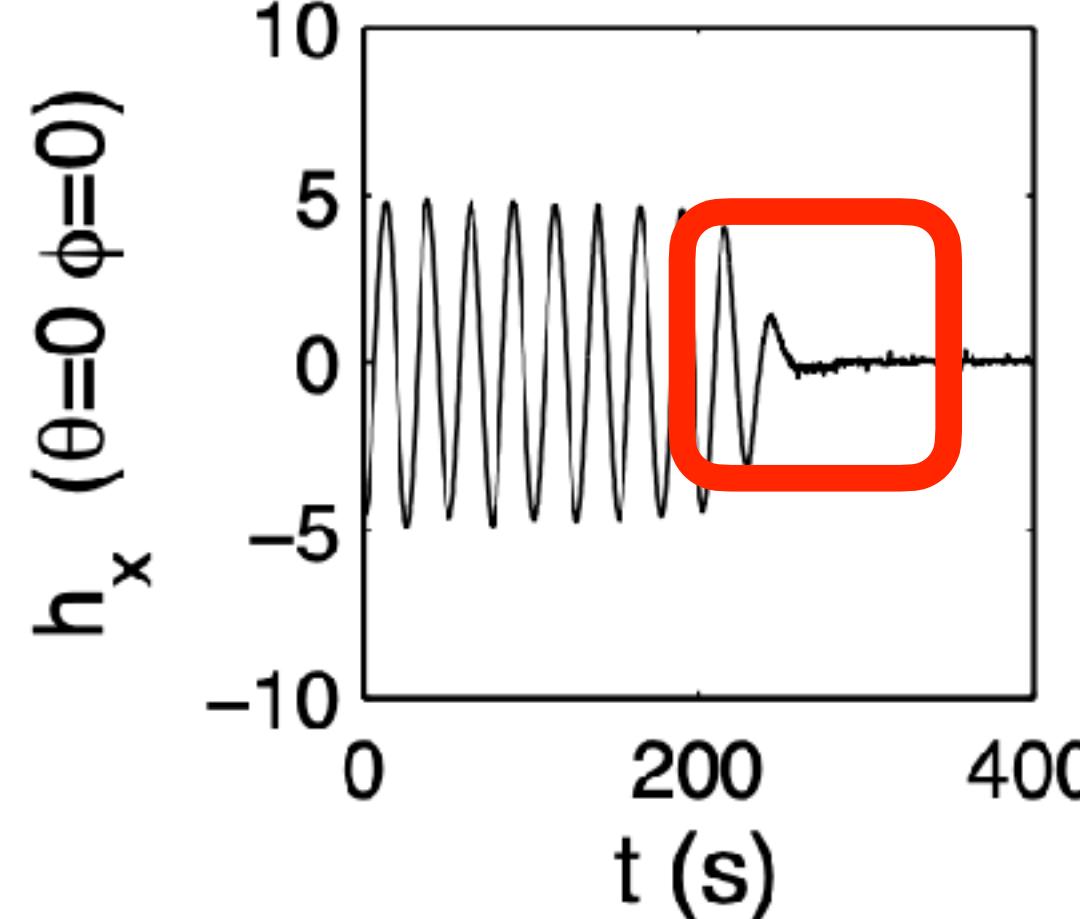
Accuracy of parameter estimate



1.4WD + 0.6WD

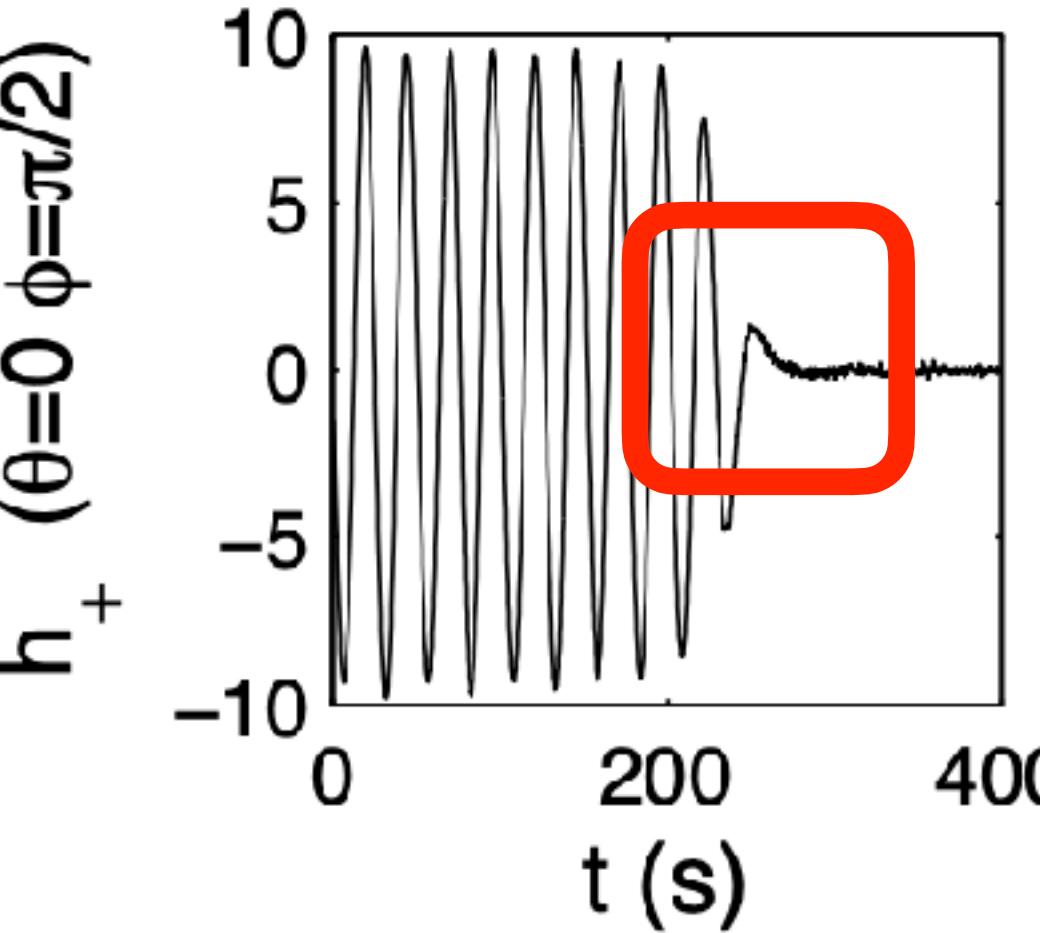


GWs disappear at the merger moment.

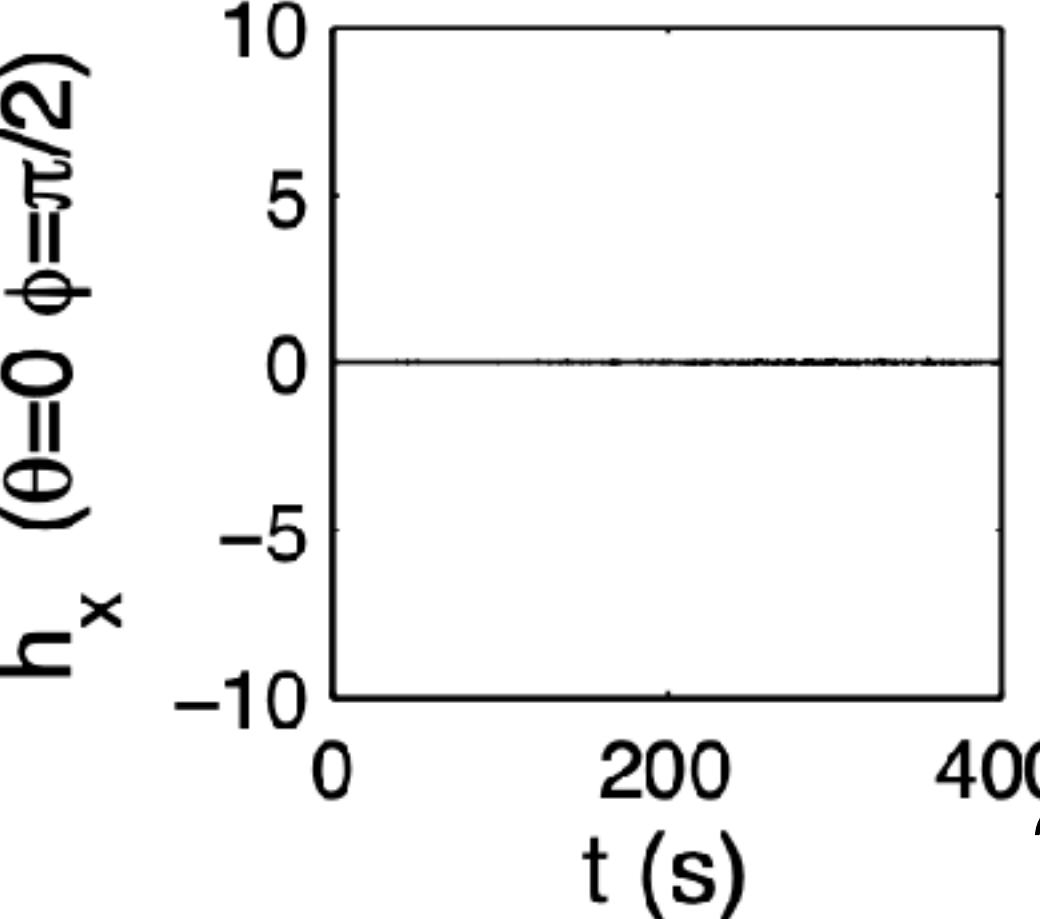


Garcia-Berro et al. (2007)

0 day



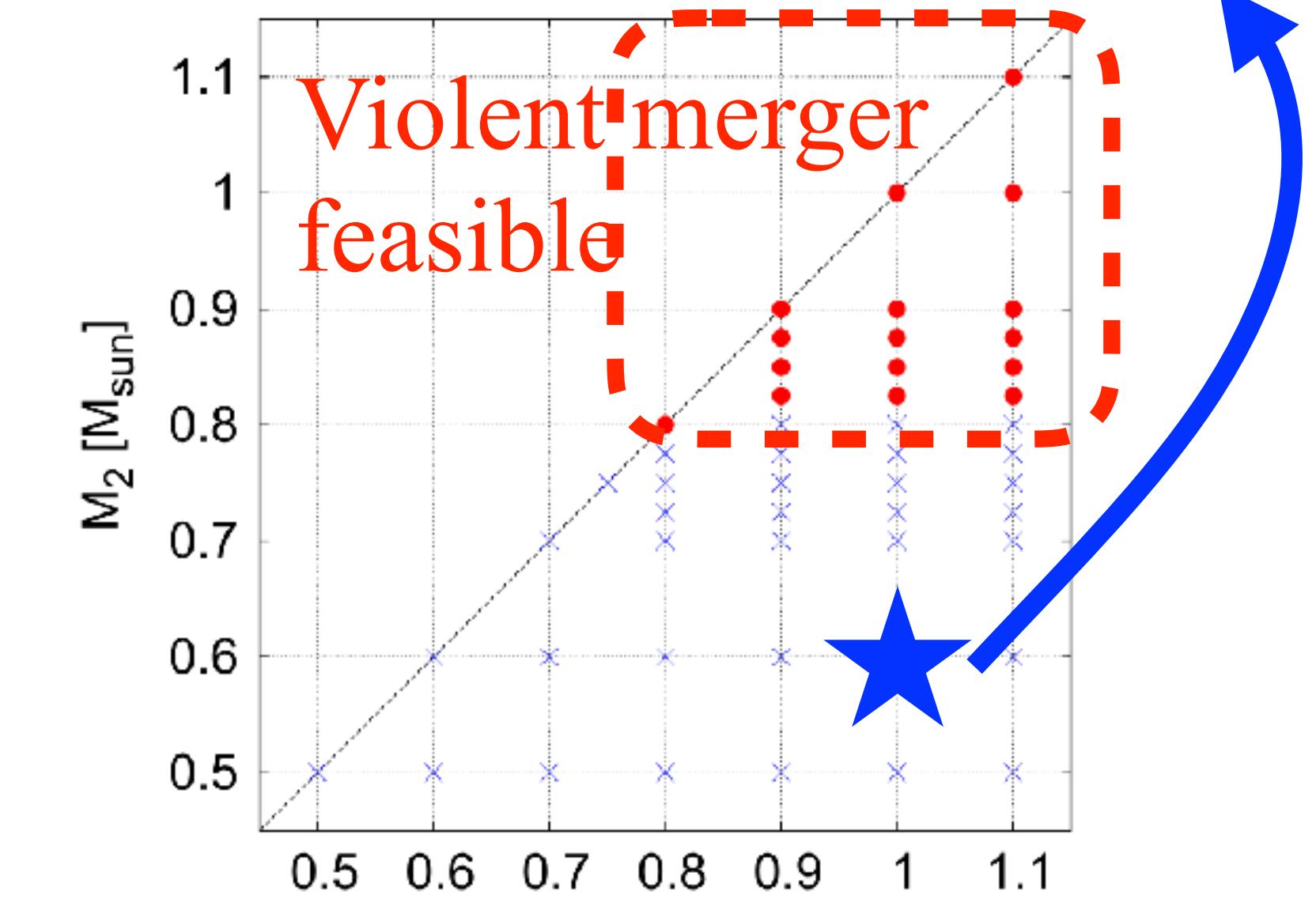
~ 3 day



~ 1 month

Disappearance of GWs

EM signals supporting prompt explosion (violent merger, D⁶)



Sato+(2016)

EM observations determining if prompt explosion points to normal Ia or Ia subclass.

Summary

- We try to search for positive evidences of DD scenario.
- D⁶ explosion can leave footprints (bright ring or dark hole) in its SNR because of the presence of hypervelocity WD.
- Distinguishable from the spin-up/down model and slow-merger model.
- Deci-hertz GWs will elucidate type Ia progenitors if type Ia supernovae happen from prompt explosions of double WDs.