Electromagnetic Counterparts of Advanced LIGO Binary Black Hole Mergers

LIGO 2017 SURF Program

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Source: LIGO Caltech

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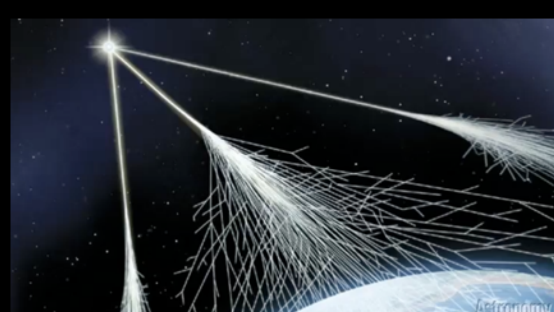
What is multimessenger astronomy?

electromagnetic radiation

gravitational waves

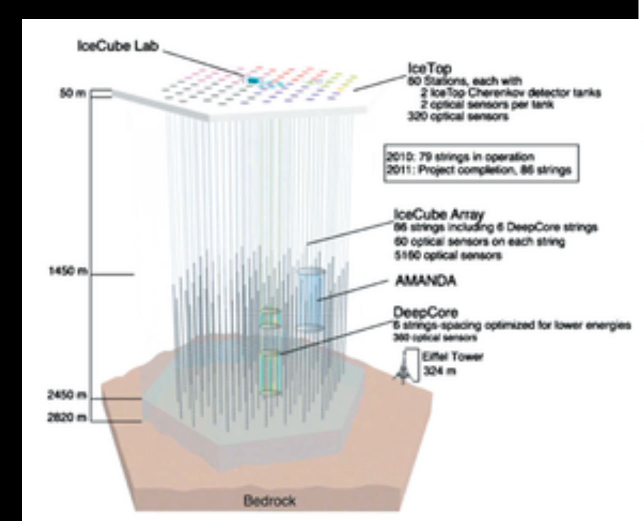
multimessenger astronomy

cosmic rays



Dangerous Cosmic Rays Will Pass Close to Earth 'Tonight'?
www.snopes.com/dangerous-cosmic-gamma-rays/ ▾
Claim: Dangerous cosmic rays will pass near Earth tonight, causing bodily harm if you keep personal electronics near you.
Claimed by: Internet
Fact check by Snopes.com: FALSE

neutrinos



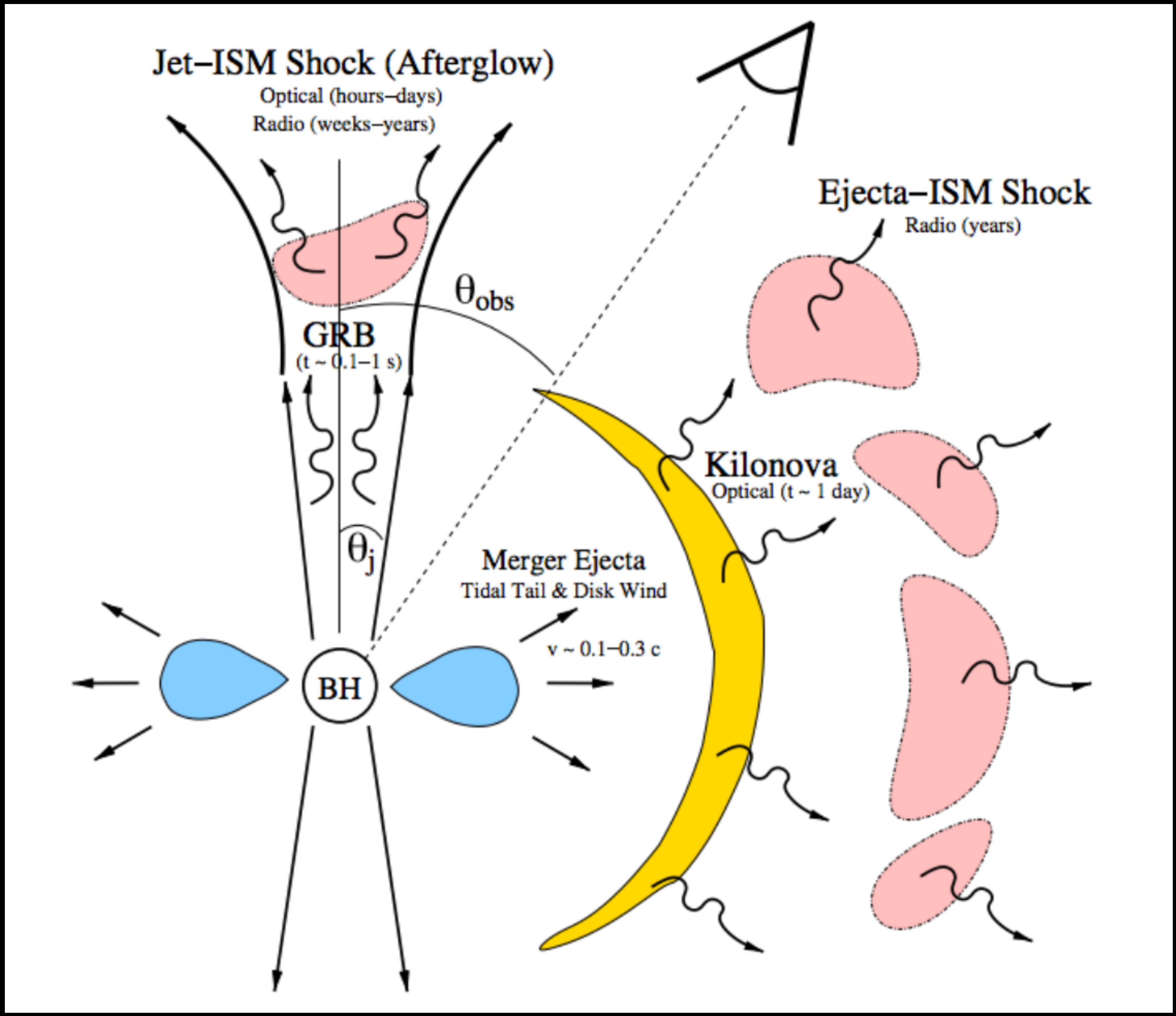
LIGO’s role in multimessenger astronomy

We believe that some events which produce gravitational wave signals also produce electromagnetic counterparts.

To find any potential counterparts, astronomers conduct follow-up campaigns after LIGO’s GW triggers, searching for associated

- gamma rays
- X-rays
- optical signals
- radio signals
- neutrinos

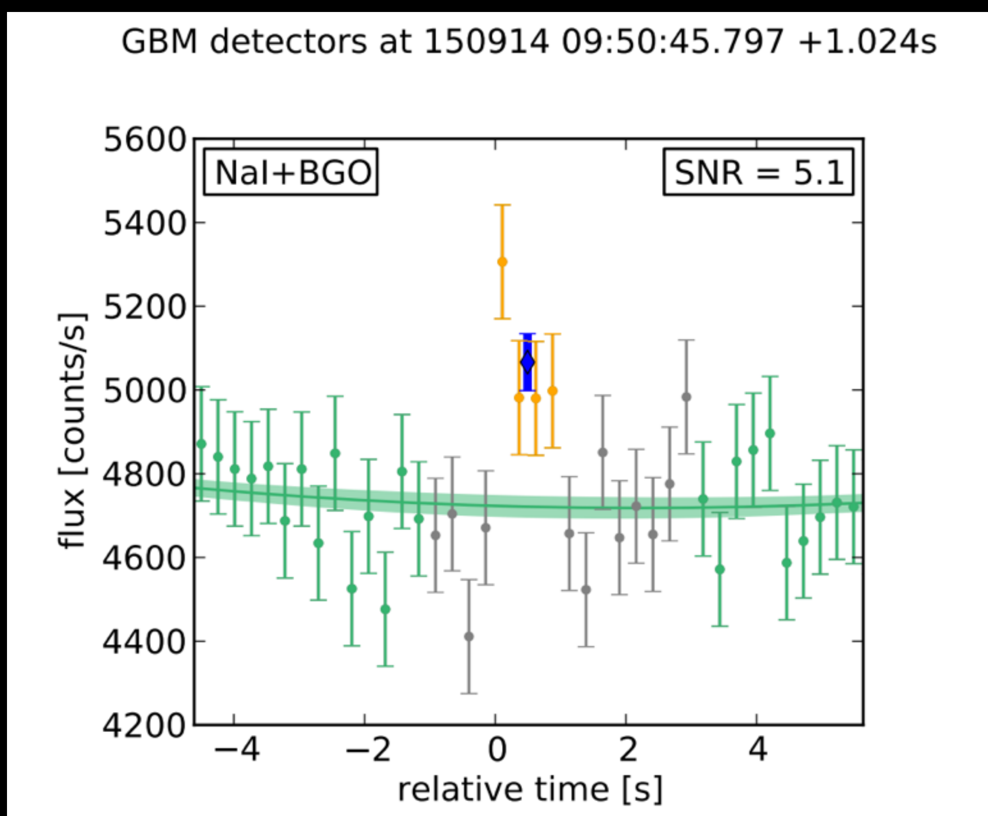
For merger events involving neutron stars:



Source: Metzger & Berger 2012

GW150914 and a gamma ray transient

On September 14, 2015, LIGO detected for the first time the coalescence of binary black holes! In an EM follow-up campaign, Fermi detected a gamma ray transient in the localization of GW150914.



Source: Connaughton, V., Burns, E., Goldstein, A. et al.

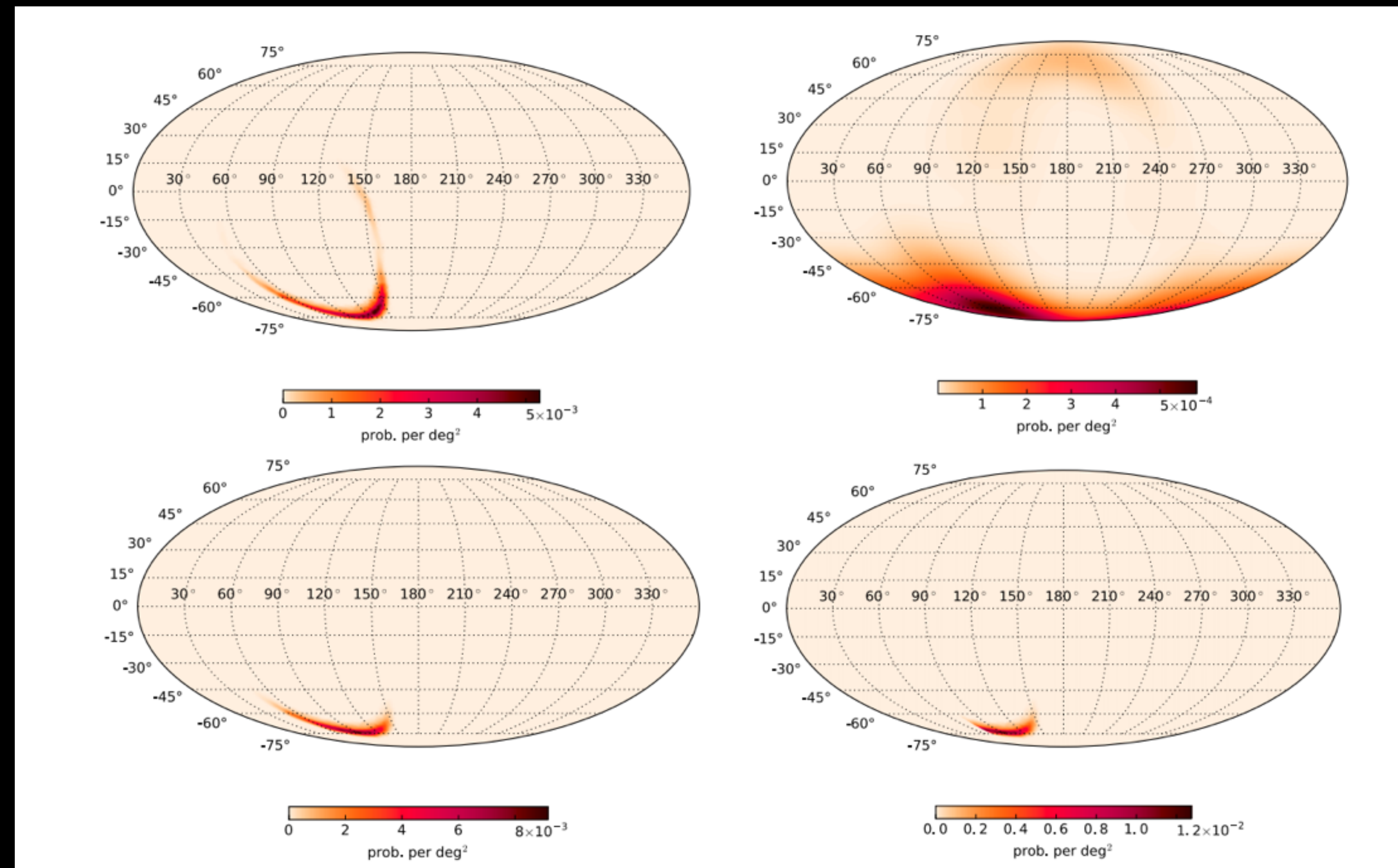


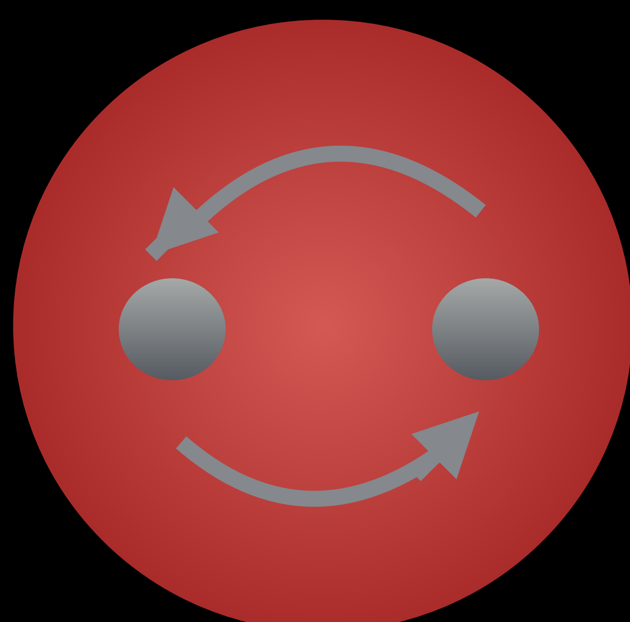
Fig. 4.— The LIGO localization map (top left) can be combined with the GBM localization map for GW150914-GBM (top right) assuming GW150914-GBM is associated with GW150914. The combined map is shown (bottom left) with the sky region that is occulted to *Fermi* removed in the bottom right plot. The constraint from *Fermi* shrinks the 90% confidence region for the LIGO localization from 601 to 199 square degrees.

Motivation: do binary black hole mergers have electromagnetic counterparts?

Binary black hole progenitor models

rapidly rotating star

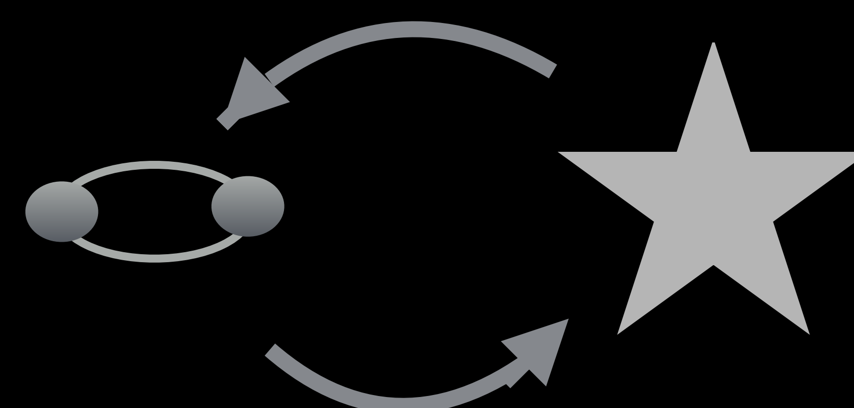
A rapidly rotating massive star breaks apart into two dumbbell shapes, whose cores eventually collapse to form two black holes.



Source: Loeb 2016

hierarchical triple system

Two black holes are in a tight binary, and this system is in a larger binary with a white dwarf star.



Source: Rosswog et al. 2009

White Dwarf stars

Equations of Hydrostatic Equilibrium

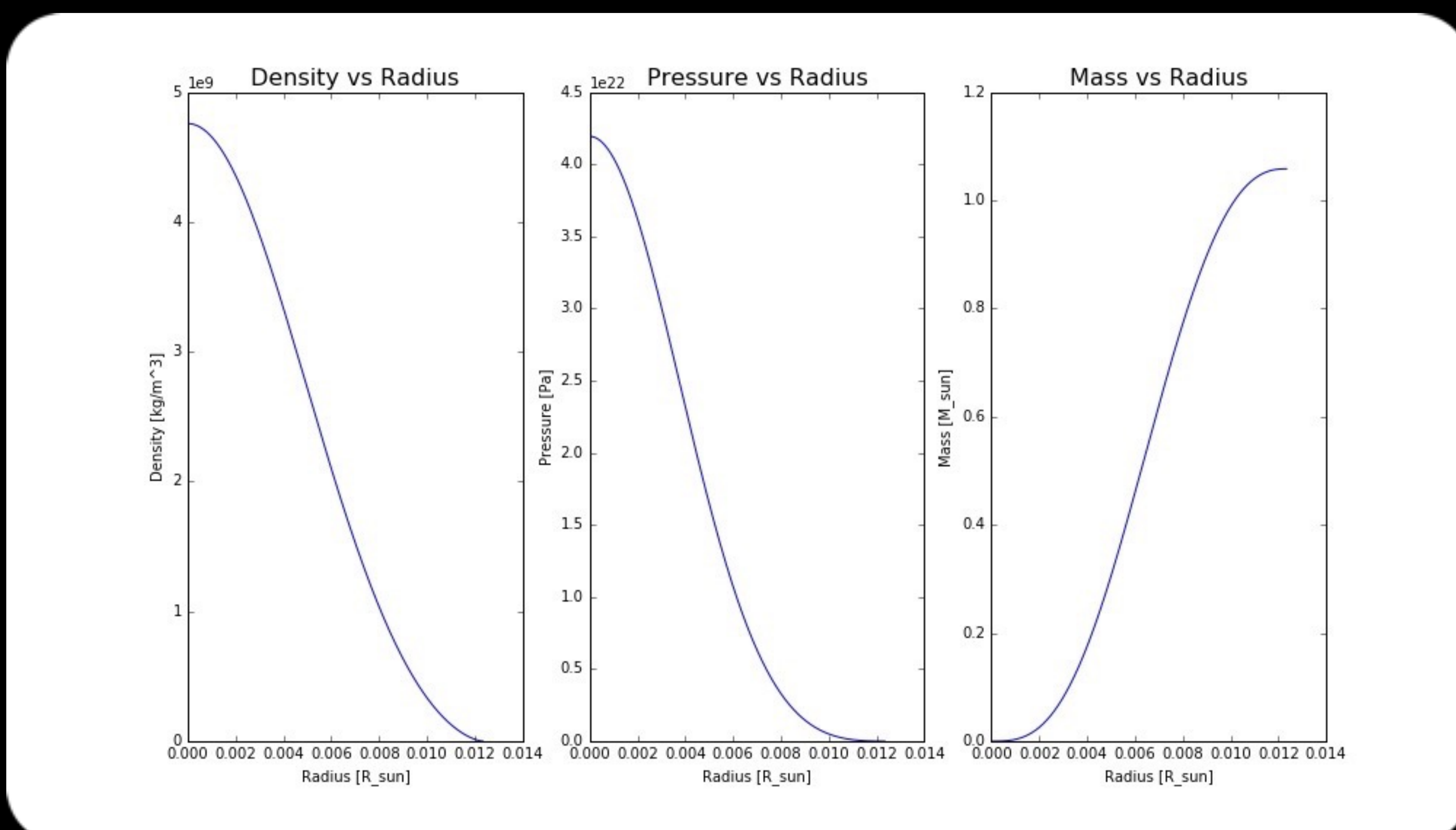
$$\frac{dP}{dr} = -\frac{G}{r^2}\rho(r)m(r)$$

$$\frac{dm}{dr} = 4\pi r^2 \rho(r)$$

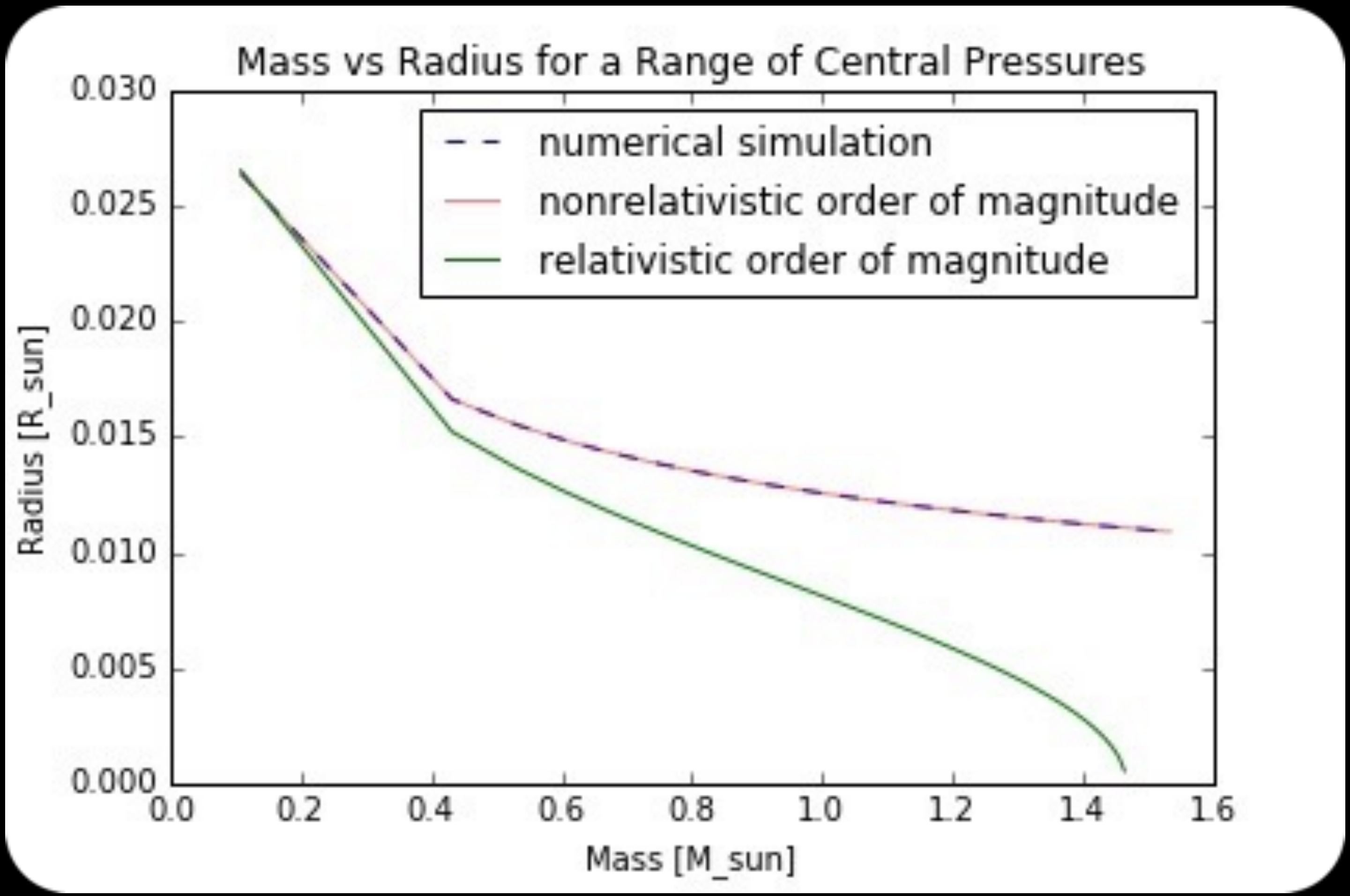
Equations of State

$$P = K_1 \rho^{\gamma_1}$$

$$P^{-2} = (K_1 \rho^{\gamma_1})^{-2} + (K_2 \rho^{\gamma_2})^{-2}$$



White Dwarf stars cont.



Based on simulations, the WD radius is constrained to 0 - .03 R_sun, while the WD mass is constrained to 0 - 1.4 M_sun.

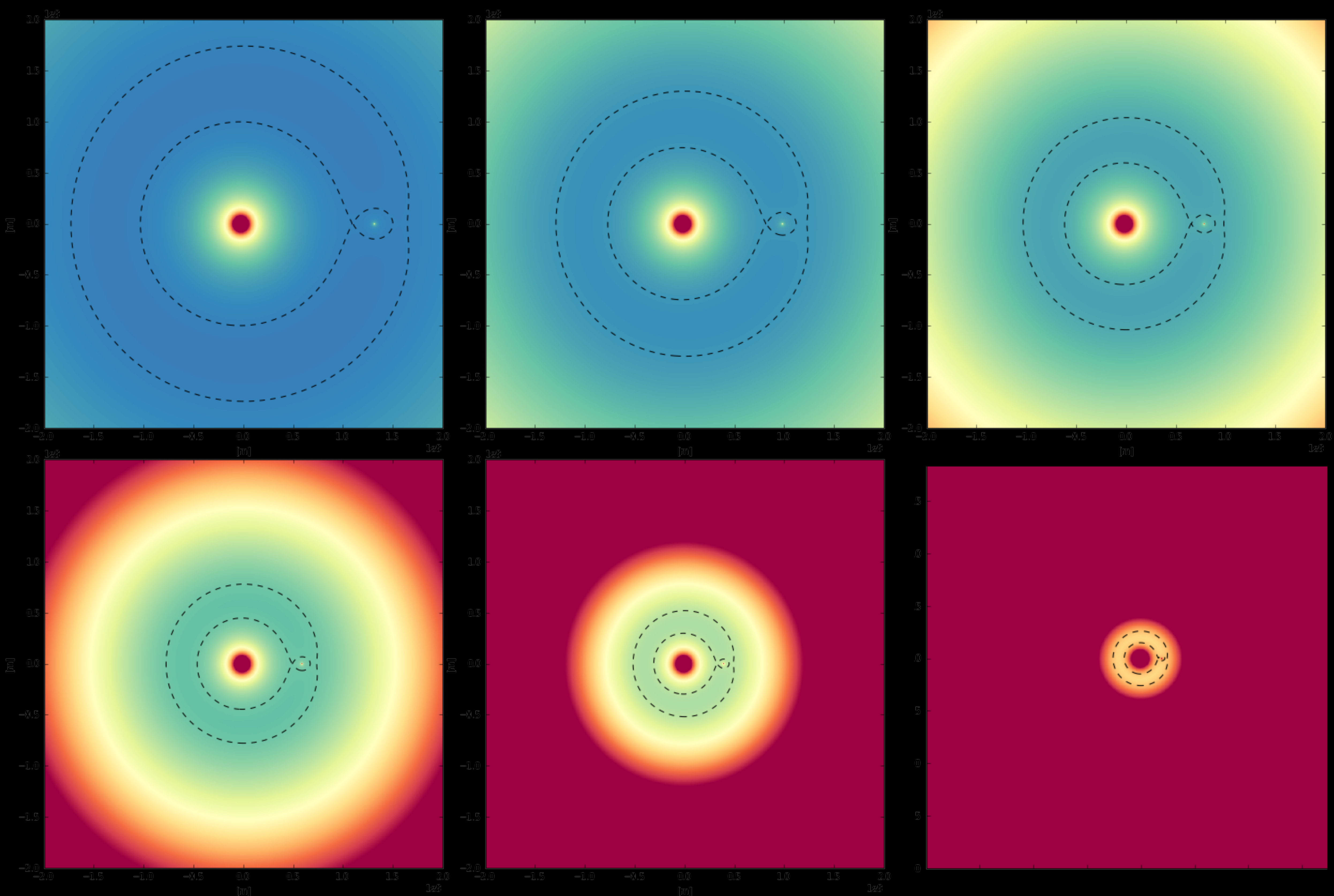
Tidal Forces

$$\Delta F(R) = -GM_1M_2[(R - r_{WD})^{-2} - (R + r_{WD})^{-2}]$$

Tidal forces start to take effect at around R = 1.34e6 km.

Since 1.34e6 km >> .03 R_sun, we can't rule out this theory yet!

Roche potential



goals & future work

Modeling

- Update Roche lobe model to describe 3D system
- Model tidal disruption effects and EM emission

Statistical Analysis

- Find a posterior distribution for expected emission from this kind of system
- Compare the expected emission to observed data from GW150914