

# Stars and Stellar Evolution

## Astro2010 Science Frontier Panel

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- **Questions:**

**How do Rotation and Magnetic Fields Affect Stars?**

**What are Type Ia Supernovae?**

**How do Massive Stars End Their Lives?**

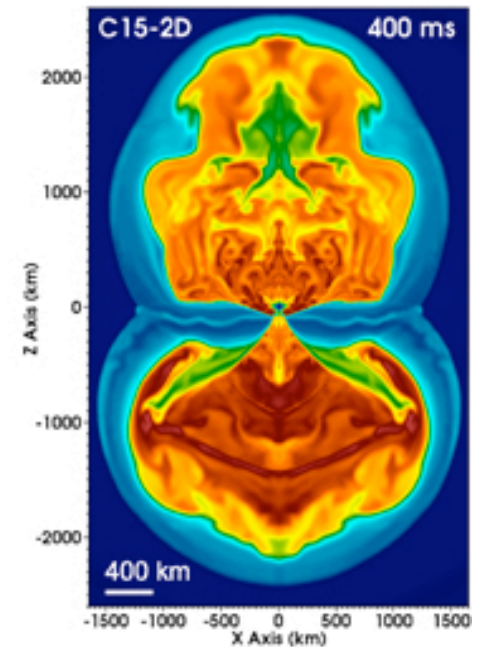
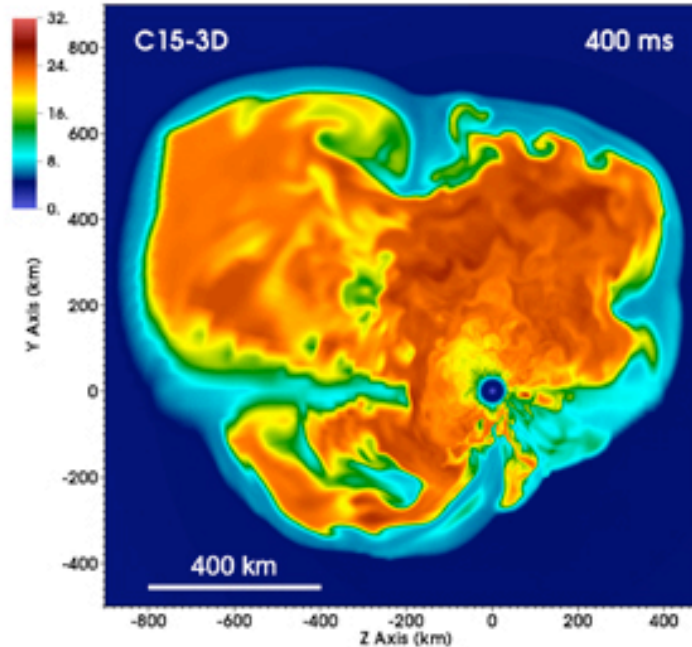
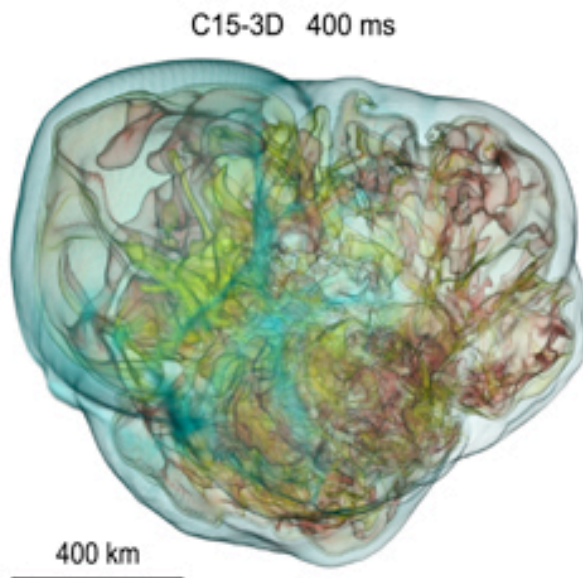
**What Controls the Masses, Spins, and Radii of Compact Stellar Remnants?**

- **Discovery Area:**

**Time Domain Surveys**

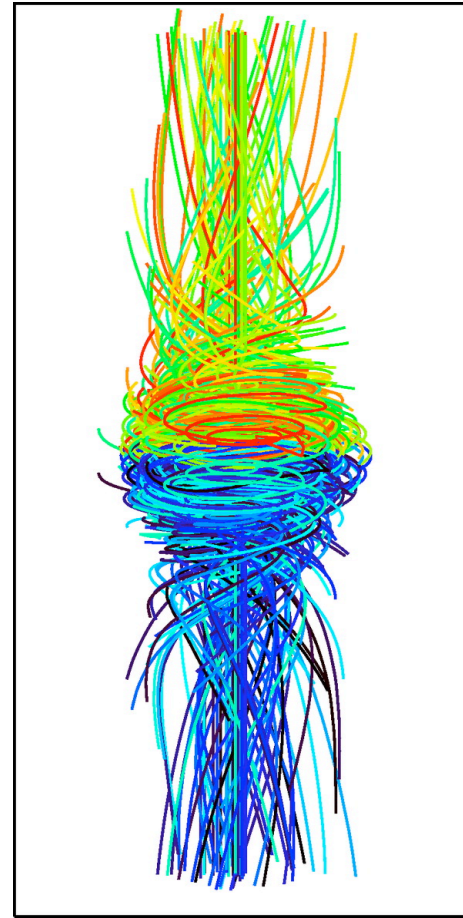
# How do Massive Stars End Their Lives?

- Neutrino explosion mechanism still plausible, but no consensus model



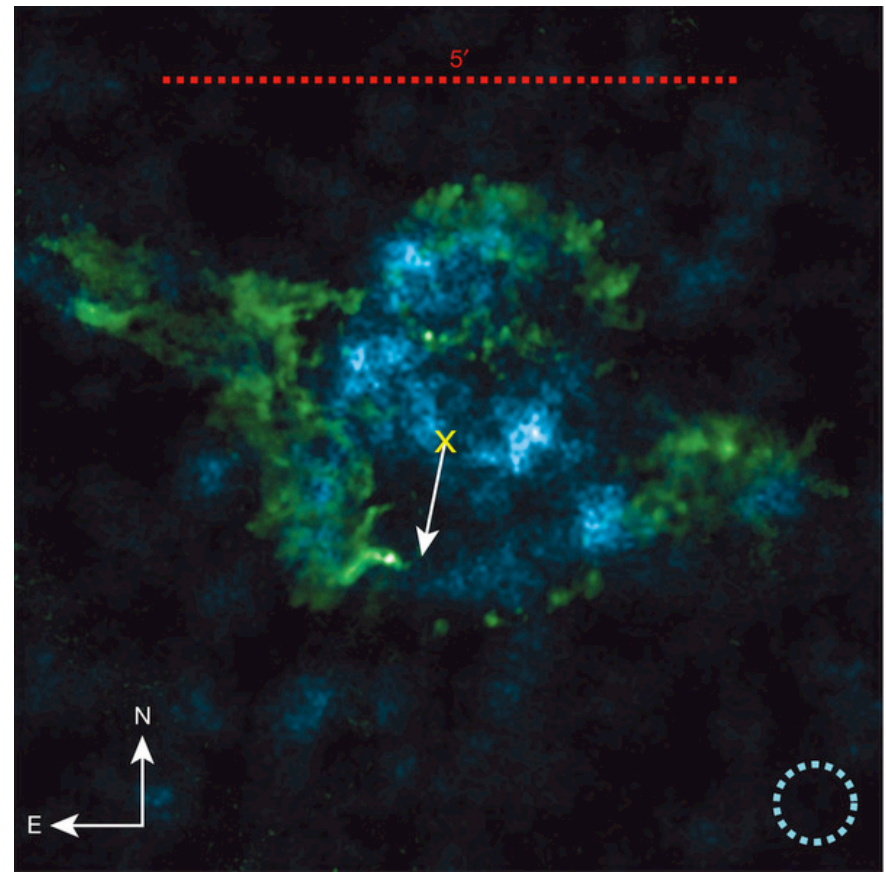
Lentz et al. 2015

- Possible that common,  $\sim 10^{51}$  erg, explosions are by neutrinos and energetic,  $\sim 10^{52}$  erg, explosions are from rotation energy of compact object tapped by magnetic field



Particle trajectories  
Burrows...

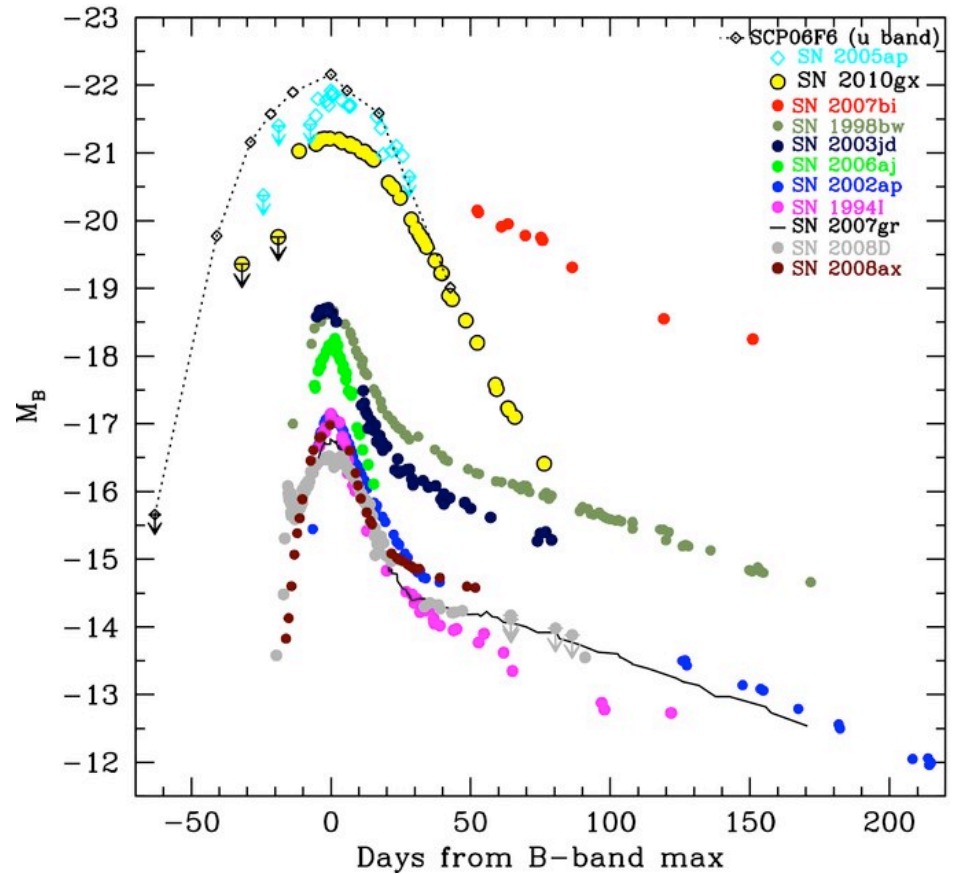
- Cas A:
  - Blue –  $^{44}\text{Ti}$ , 68 and 78 keV lines
  - Green – X-ray, hot Si
- Inner ejecta ( $^{44}\text{Ti}$ ) asymmetric, but not jet-like



NuSTAR

# Diverse ends

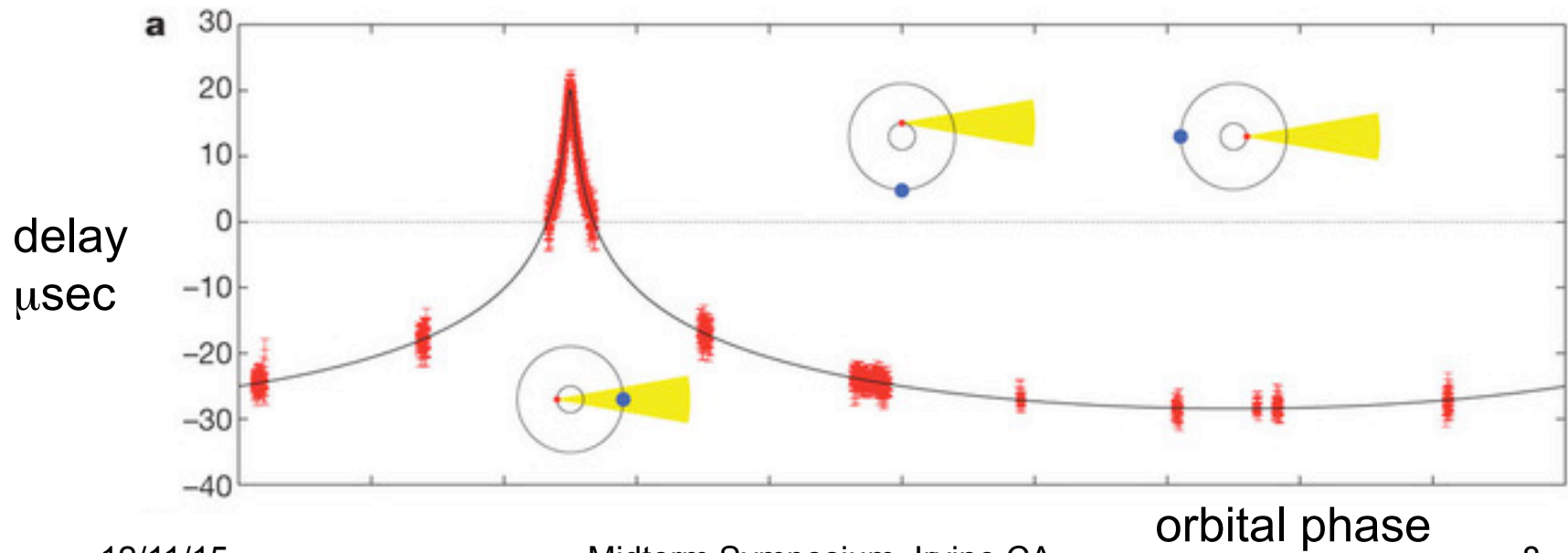
- Superluminous SN
  - Magnetar power or circumstellar interaction favored over  $^{56}\text{Ni}$
- Interaction (SN 2010jl)
  - Lost  $0.1 M_{\odot}/\text{yr}$  in 10s of yrs leading to explosion
- Black hole formation
  - Faint explosion
  - Search for disappearing stars in progress



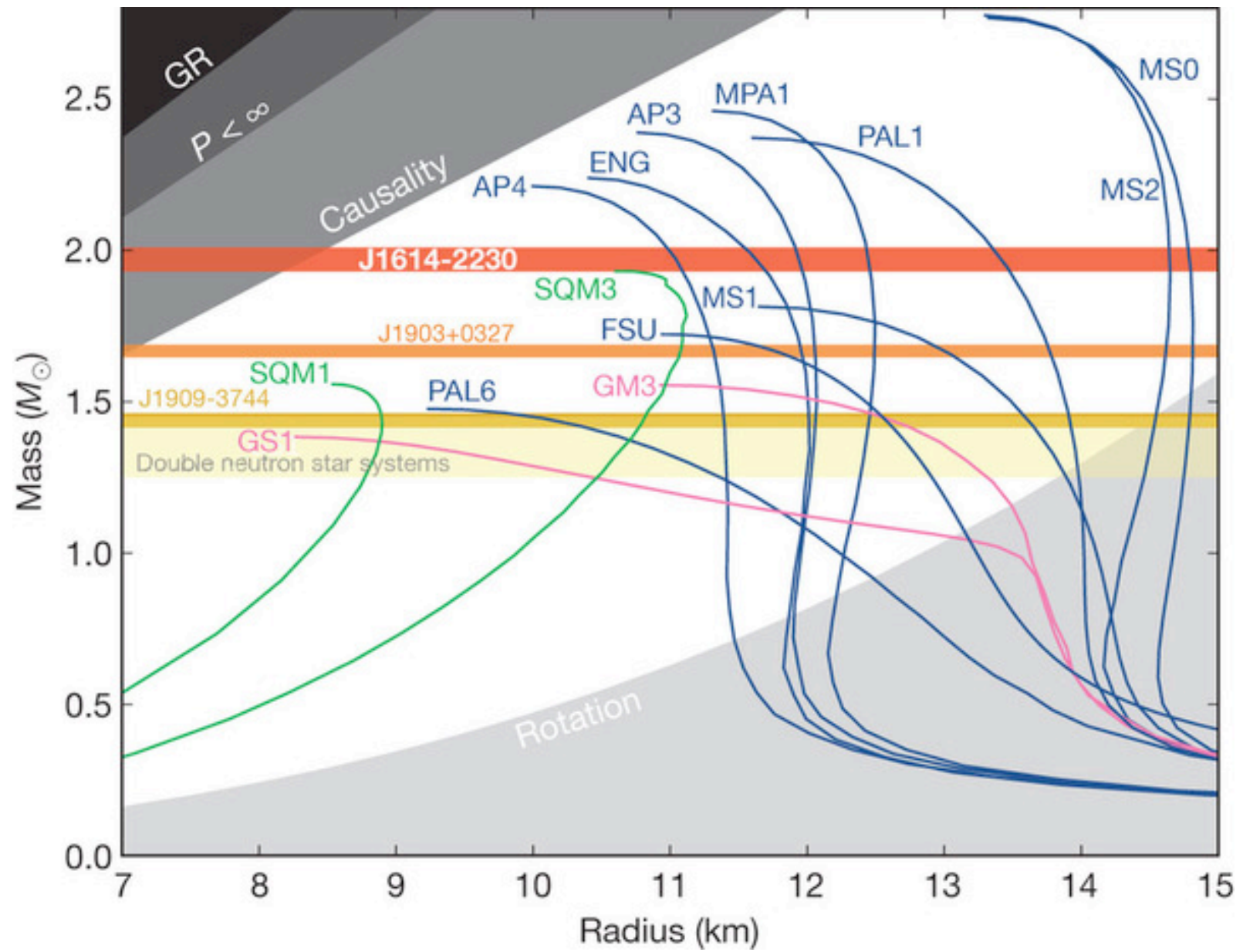
# **What Controls the Masses, Spins, and Radii of Compact Stellar Remnants?**

# NS masses

- $1.97 \pm 0.04 M_{\odot}$  (J1614+2230), from Shapiro delay
- $2.01 \pm 0.04 M_{\odot}$  (J0348+0432), in compact relativistic binary



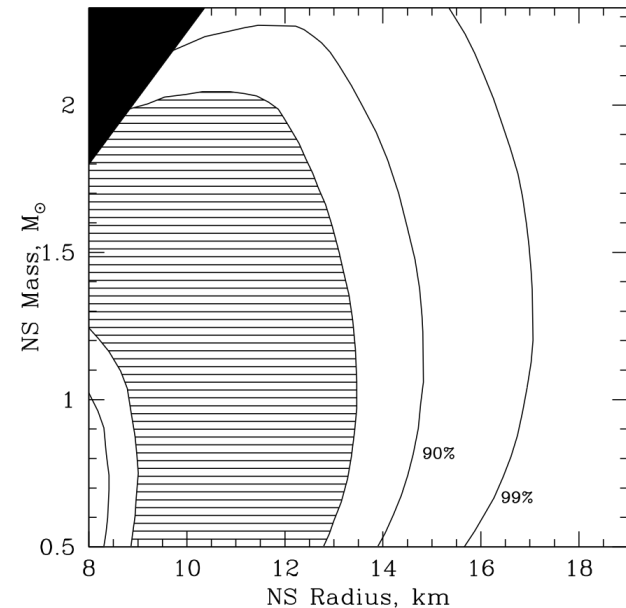




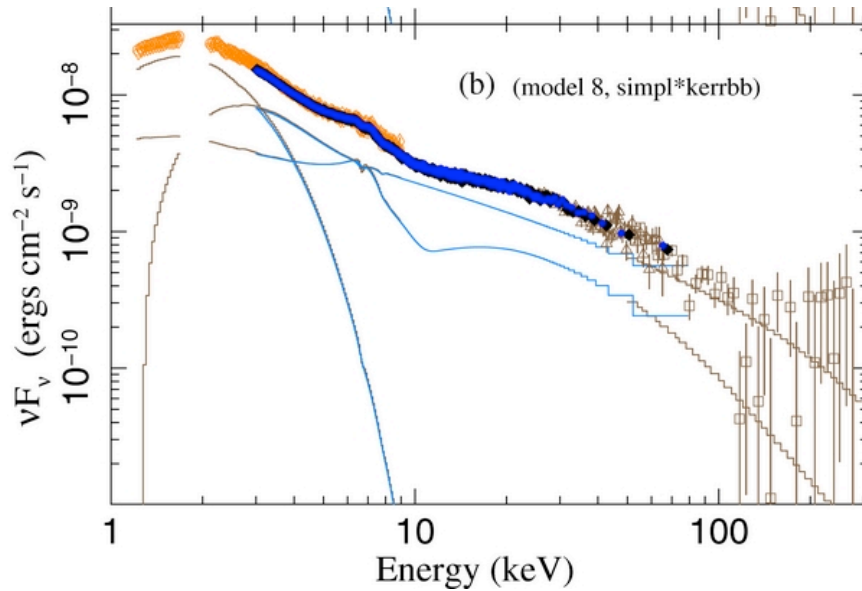
# Modeling of NS atmospheres

- Spectra of quiescent NS in globular clusters give  $R$  of 10-13 km for typical  $M$  (Heinke et al. 14)

Systematic uncertainties:  
atmosphere model  
(composition...),  
interstellar medium,  
distance, instrument  
calibration



# Spin of BH from relativistically broadened Fe line



Cyg X-1, Tomsick+ 2014

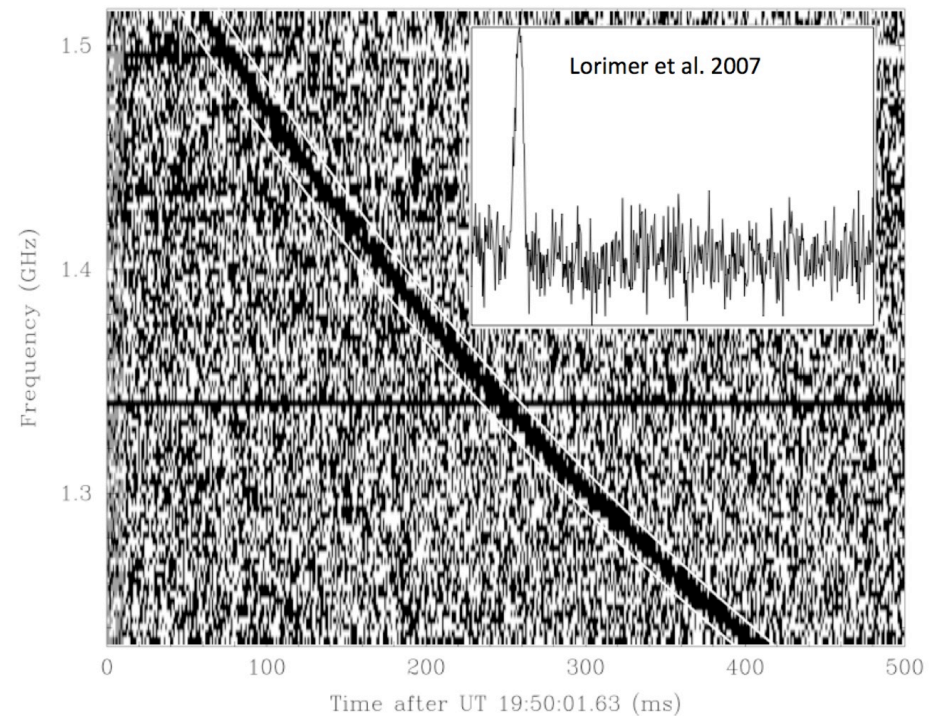
- NuSTAR, Suzaku important to get the higher energy continuum
- Near maximal rotation
- Better models are needed to interpret the data

# Discovery: Time domain

- Examples of areas that have developed in last 5 years
- Facilities

# Fast radio bursts

- msec timescale
- High dispersion measure
- Distances unknown
- Many models



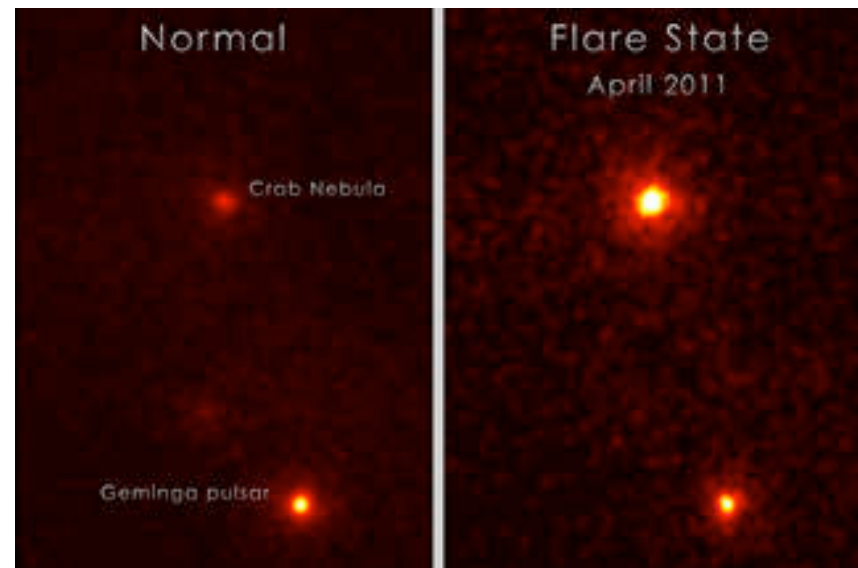
# Tidal disruption events

- Star disrupted by nuclear black hole
- Form disk around BH
- Can generate jets and high energy emission (e.g., Sw J1644+57)



# Crab Nebula $\gamma$ -ray flares

- GeV photons (AGILE, Fermi)
- Hours
- Not seen at other wavelengths

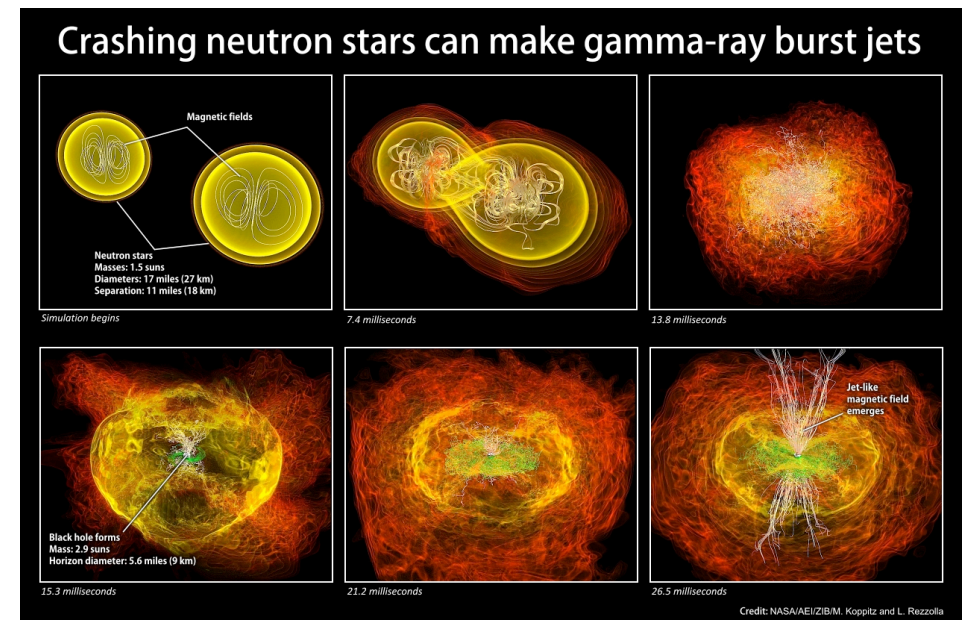


Fermi



# Optical/IR signal of neutron star merger associated with short GRB

- Radioactive isotopes in lost mass power fast supernova-like event
- May have been observed in a short GRB





# Facilities

- Transient search
  - now: ASAS-SN optical; has discovered relatively nearby supernovae and TDEs
  - near future: ZTF (Zwicky Transient Facility)
  - future: LSST
  - multiwavelength
- Time domain accurate photometry (SSE1)