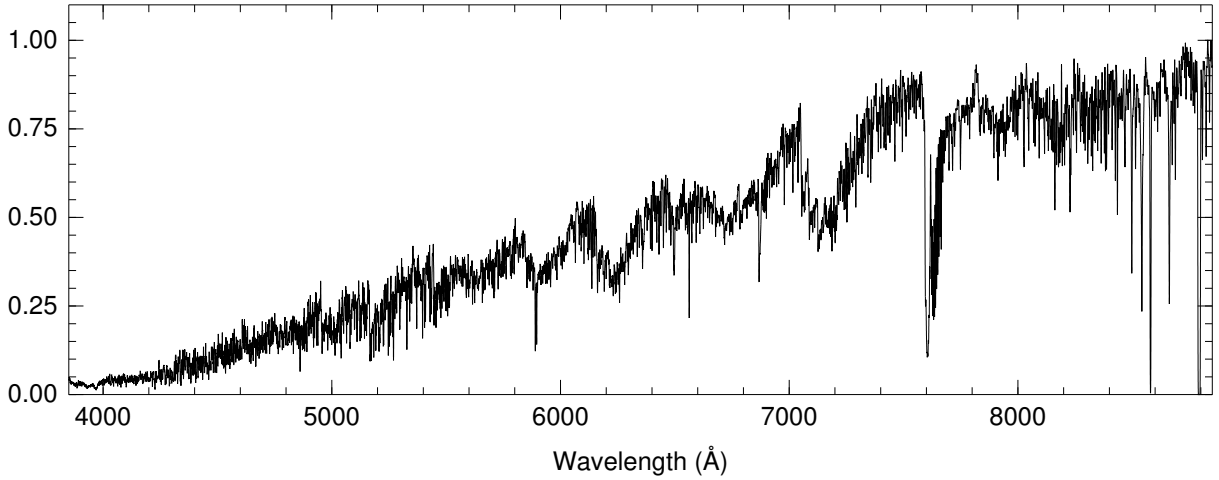

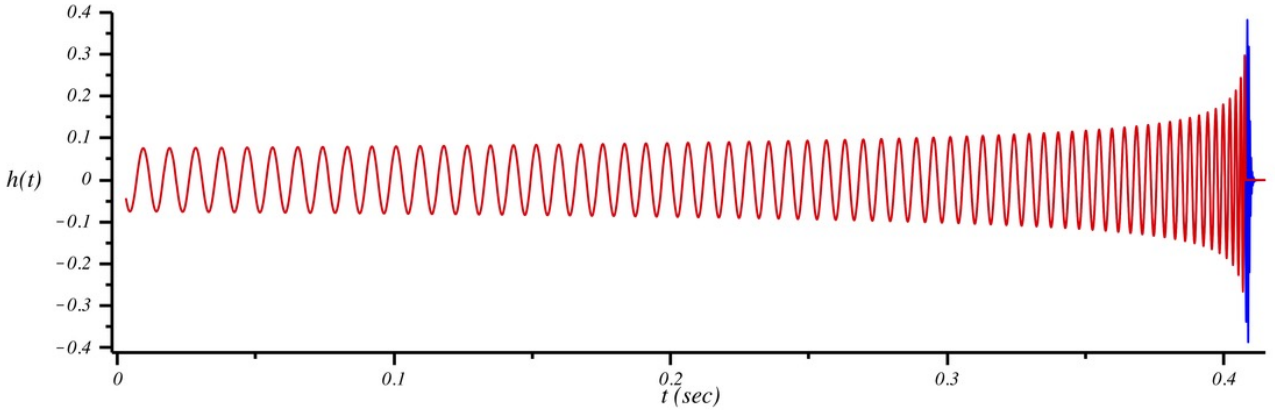

Prospects for Multi-messenger Observations of Thorne-Żytkow Objects

DeMarchi[1] et. al. 2021

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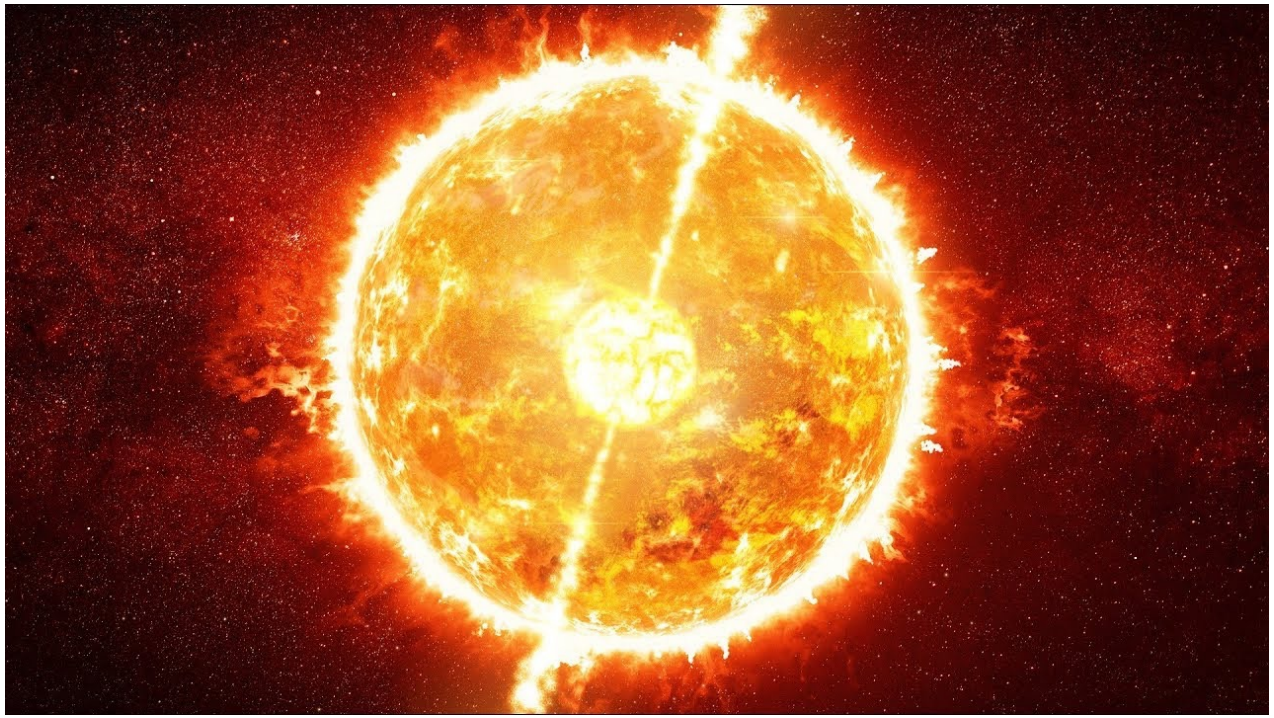
Outline

- Motivation
- What are Thorne-Żytkow Objects (TŻOs) ?
- Formation
- Electromagnetic Signature
- Gravitational Wave Signature
- Where to look for them?
- Wrapping Up

Motivation



An artist render of a TŻO

Kip Thorne

Anna Żytkow

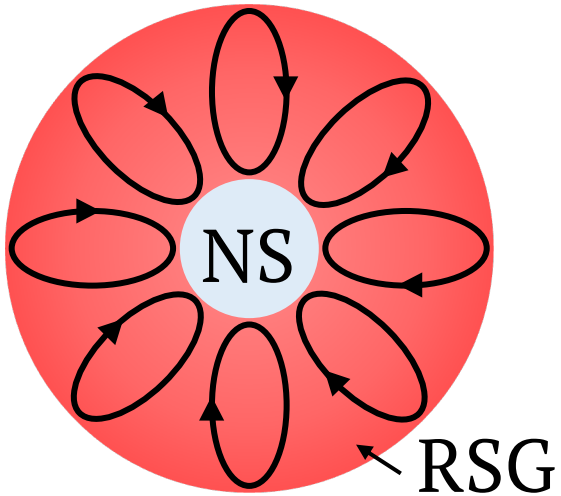
Emily Levesque

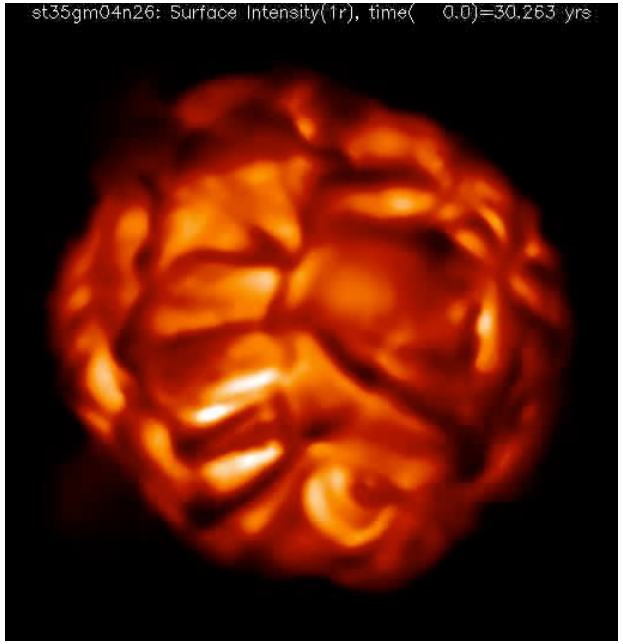
So, what are Thorne-Żytkow Objects?

- **TŻO:** class of stellar object comprised of a neutron star core surrounded by a large and diffuse envelope
- **Formation:**
  - RSG - NS pair (major contributor)
  - Failed Supernova
- **Lifetimes:** 10^5 - 10^6 yrs

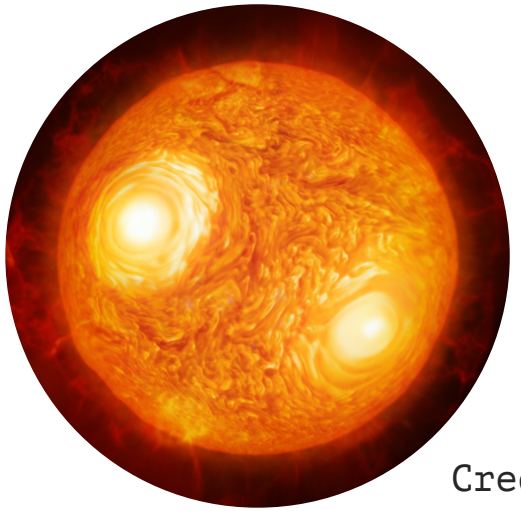
- *Visually indistinguishable from RSGs*
- Unusual chemical abundances in atmosphere due to *irp-process*
- Emit faint Gravitational Waves

- Most promised candidate: **HV 2112** in SMC



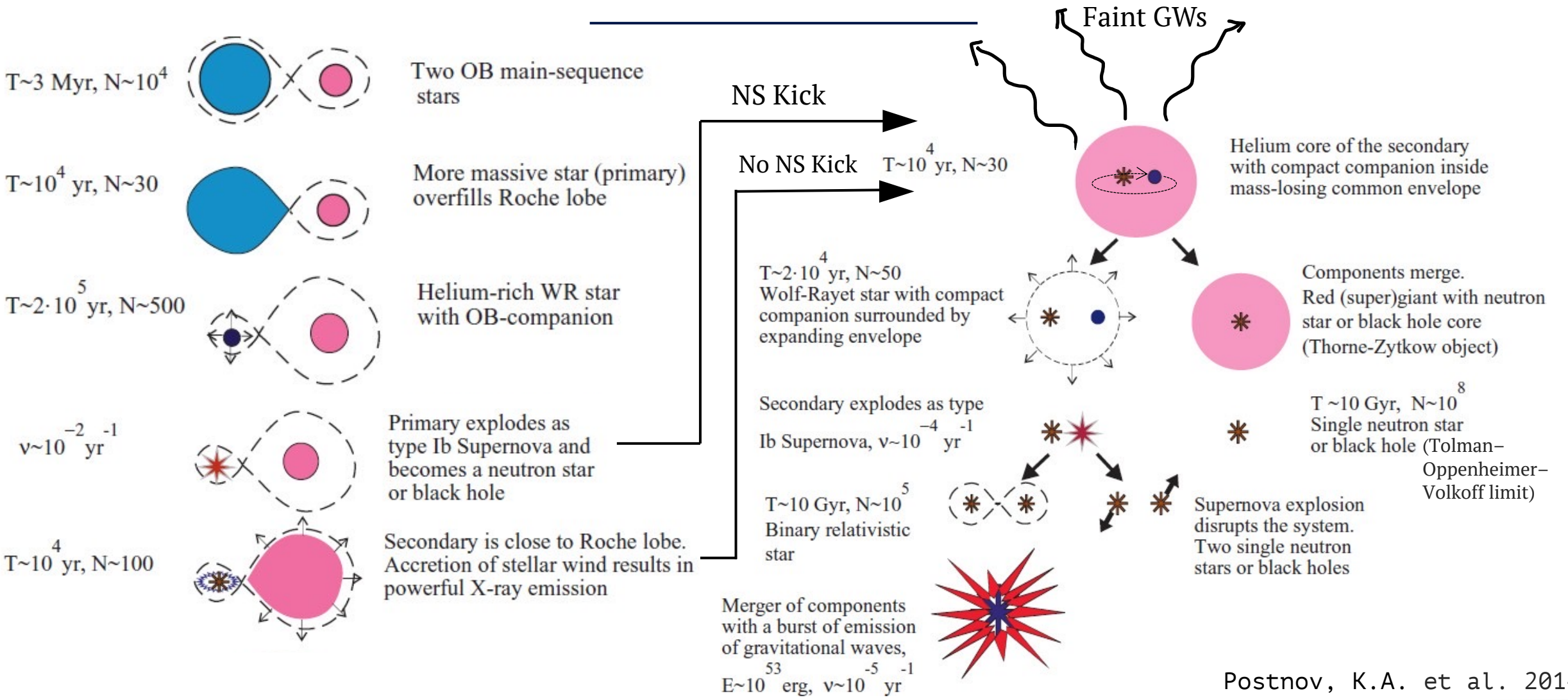


Credits - Dr. Freytag, UU



Credits - ESO

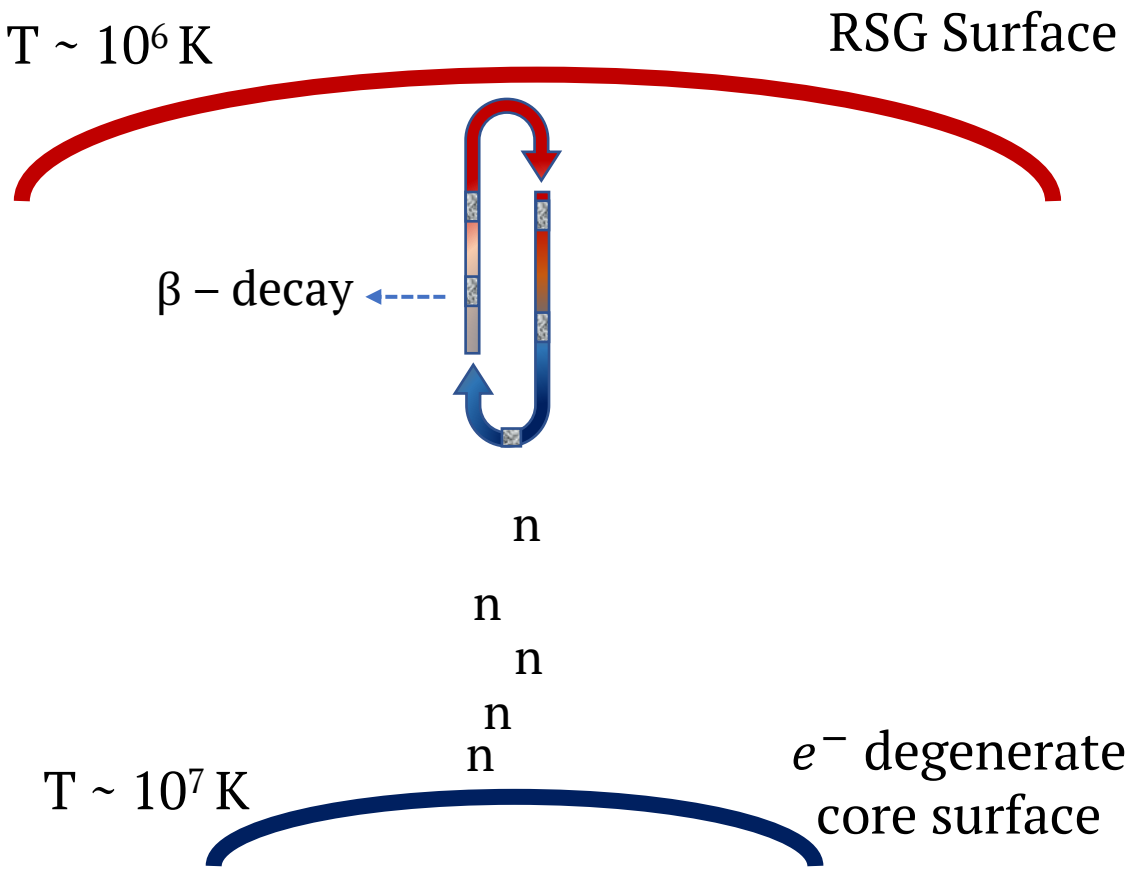
Formation



Postnov, K.A. et al. 2014

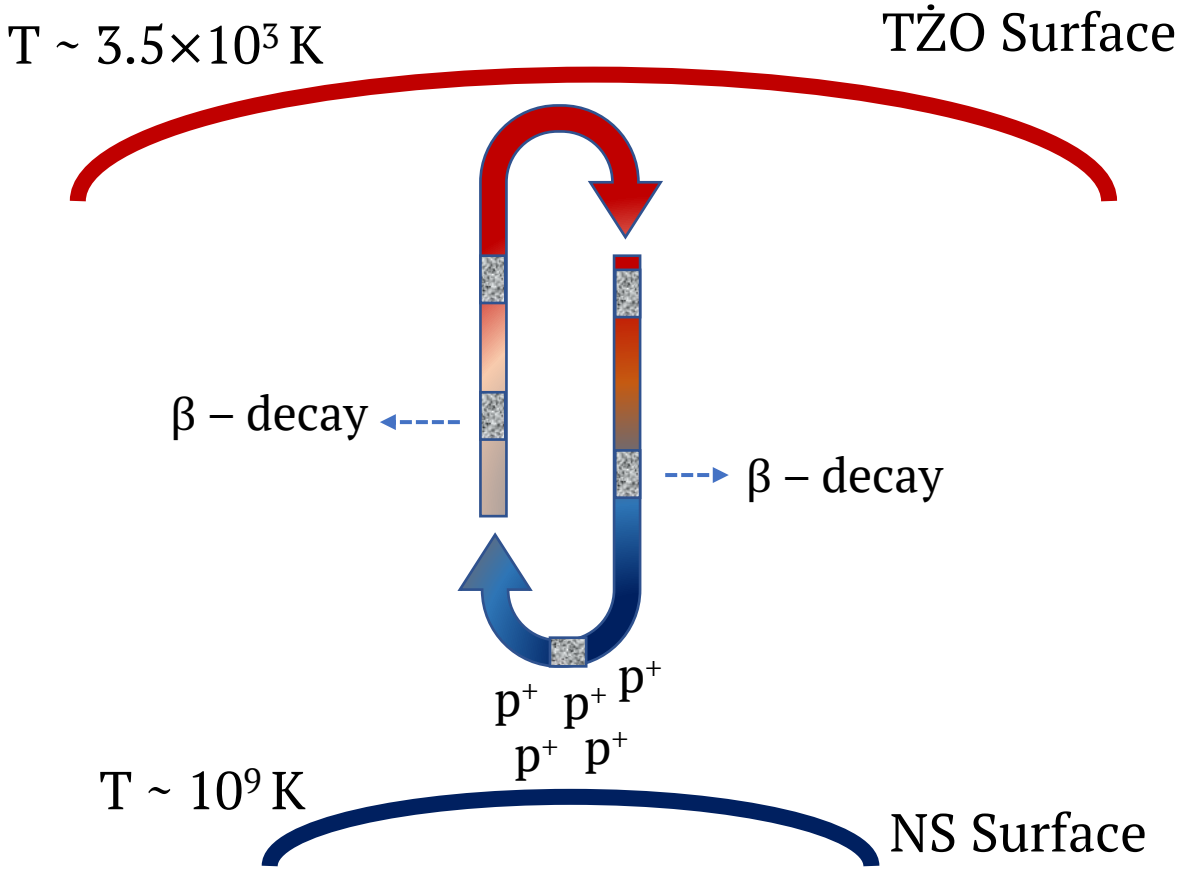
Electromagnetic Signature

- *slow neutron capture process (s-process)*
  - parcel bombarded with neutrons near the core
  - as it leaves the region, β – decay starts
  - β – decay completes when parcel reaches near the core again and gets irradiated again
- Usual chemical abundance we see in the RSG stars



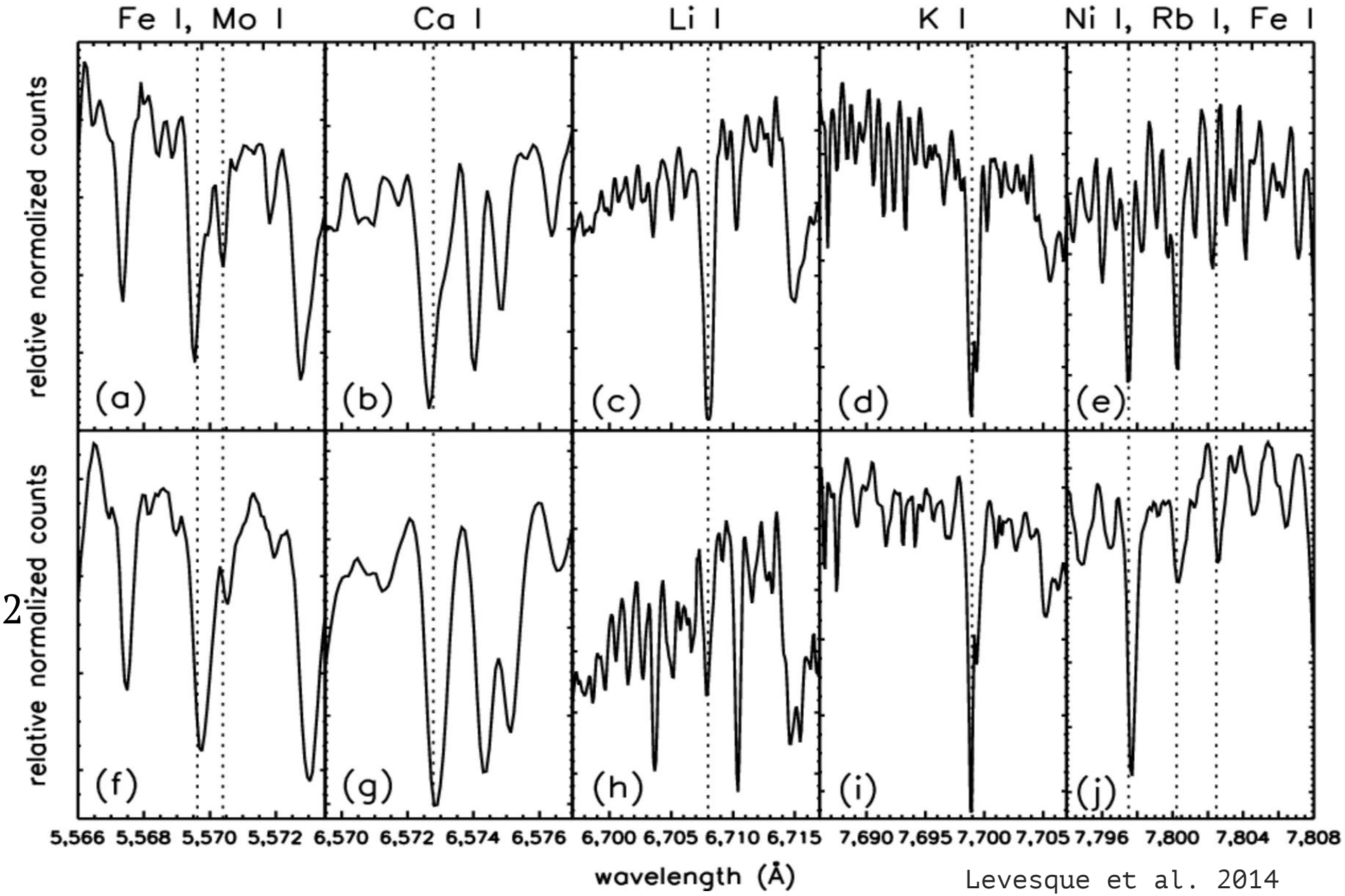
Electromagnetic Signature

- Extremely high temperatures at the core's surface combined with the completely convective surrounding envelope
- Gives rise to *'interrupted rapid-proton' – process (irp-process)*
  - parcel bombarded with protons near the core
  - as it leaves the region, β – decay starts
  - β – decay still ongoing when parcel reaches near the core again and gets more irradiated
- Enhanced lines of Mo I, Rb I, Li I and Ca I
- RSG: Mo I, Rb I, Ni I, very trace amounts of Li I
- HV 2112, a TŻO or SAGB?



HV 2112
TŻO Candidate

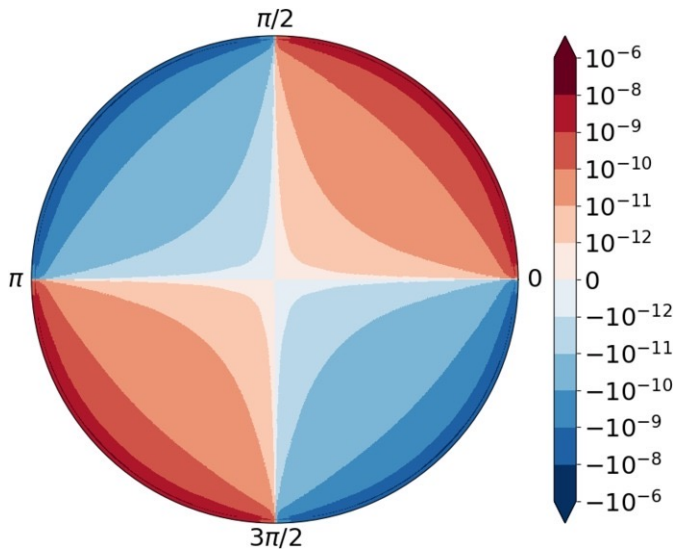
[M2002] SMC 005092
Typical RSG



Levesque et al. 2014

Gravitational Wave Signature

- TŻO core start as an extremely rapid rotator
- Accretion from C/O core & envelope induces asymmetries in the NS
- Spin downs dramatically over the lifetime – lost angular momentum becomes gravitational waves



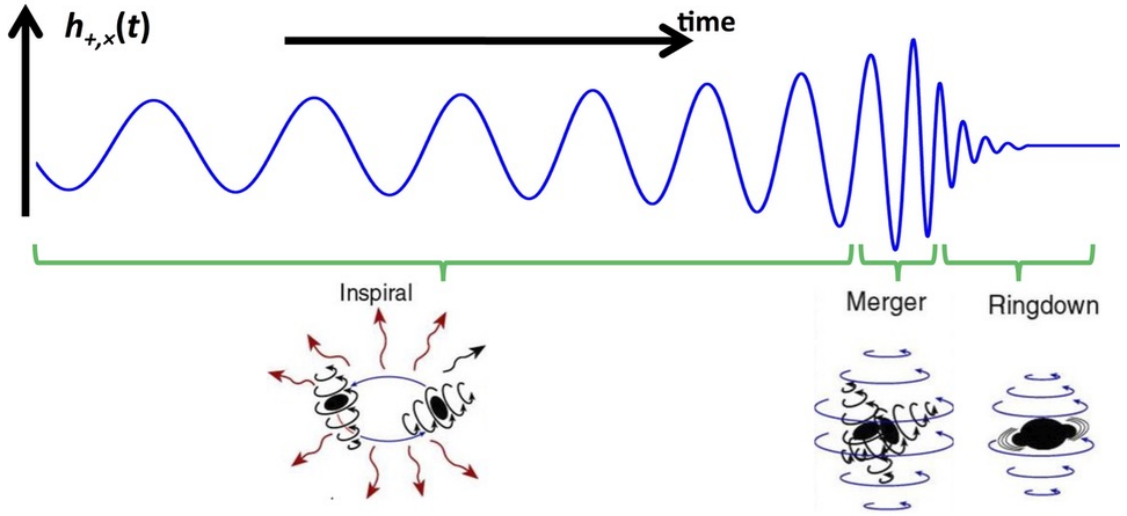
Relative Density Distribution of NS (Rui Xu et al. 2020)

- Spindown limit (obs. $\Delta\omega$ due to energy loss from GW emission):

$$h_{spindown} = \frac{1}{D}\left(5GI_{zz}\left(-\dot{f}\right)/2c^3 f\right)^{0.5}$$

where,

$h_{spindown}$ - GW strain tensor amplitude
I_{zz} - zz component of inertia tensor
$\dot{f}$ - spindown, df/dt
f – rotational frequency
D – distance to source



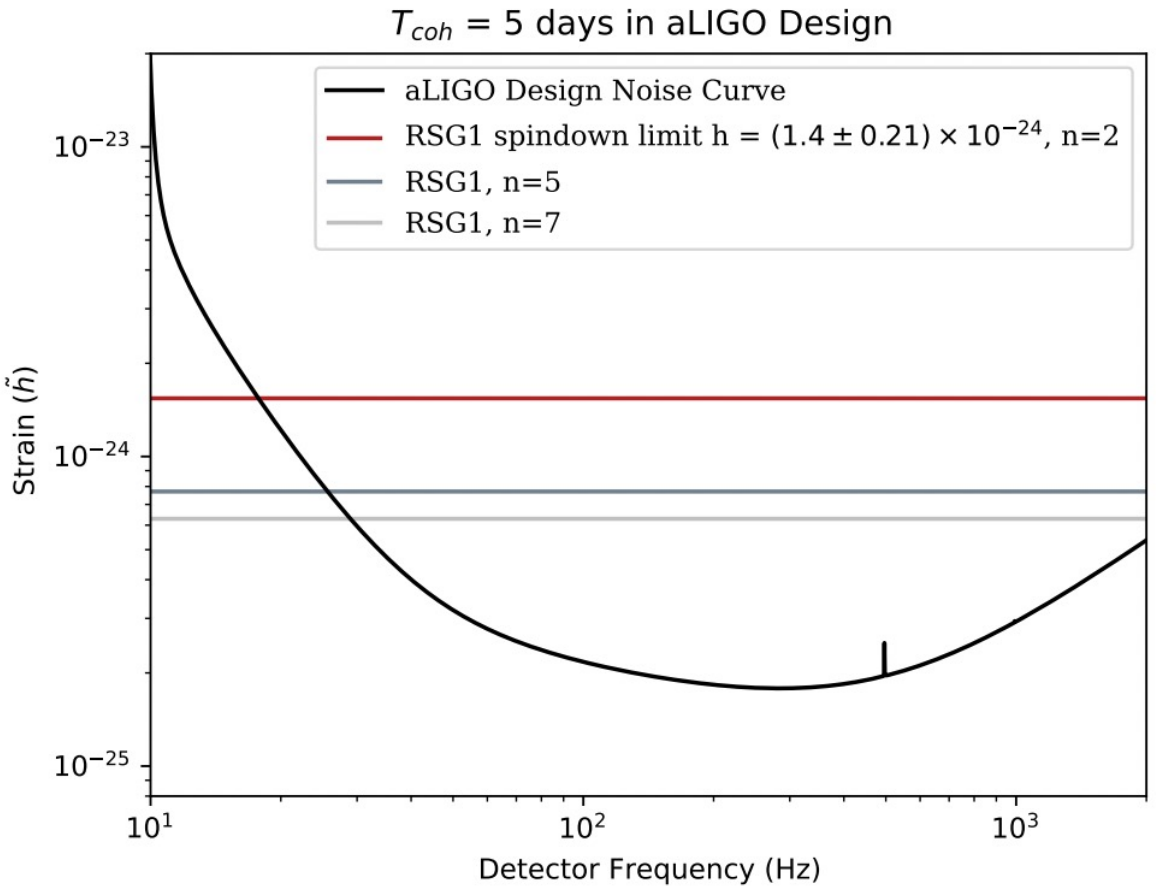
Credits: M. Favata/SXS/K. Thorne

Gravitational Wave Signature

- $\dot{f} \propto f^n, \qquad n = Braking\ Index$
- Theoretical models:
  - $n = 2 \rightarrow$ pure dipole radiation
  - $n = 5 \rightarrow$ gravitational emission from a mass quadrupole
  - $n = 7 \rightarrow$ exotic treatments of magnetic fields
- Obs. value: n = 2-3
- For $n = 2$ and $T_{coh} = 5\ days$, RSGC1 ($D = 6.6\ kpc$) gives upper limit of,

$$h = 1.54 \pm 0.21 \times 10^{-24}\ m$$

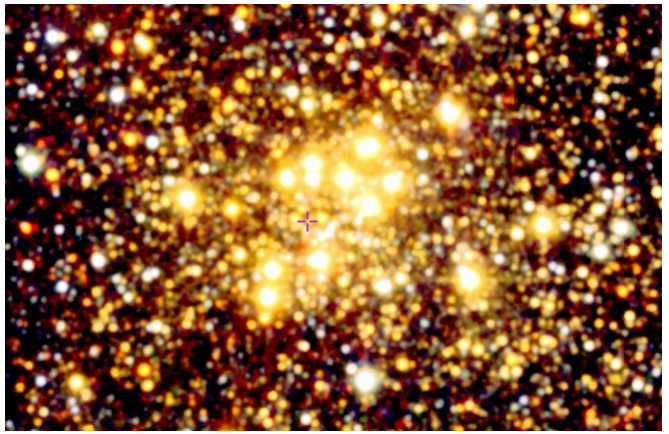
- Extremely computationally intensive;
  - $computing\ cost \propto T_{coh}^{7}, senstivity \propto T_{coh}^{1/2}$



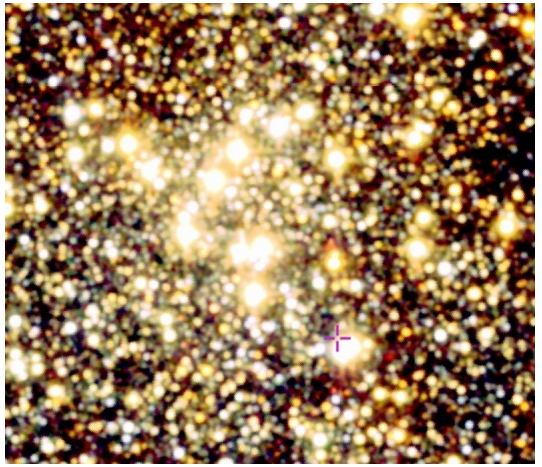
DeMarchi et al. 2021

Where to look for them?

- RSG-rich regions or clusters
- Old enough to host NS but not too much old to be done with TŻO
- For EM Signature,
  - M-type RSGs
- For GW signature, we are limited by distance,
- 6 RSG-rich clusters near the base of the Scutum-Crux arm:
  - RSGC1 (D = 6.6 ± 0.89 kpc)
  - RSGC2 (D = 5.83+1.91 −0.76 kpc)
  - RSGC3 (D = 5.9 ± 0.3 kpc)
  - Alicante 10 (D = 5.1 ± 0.2 kpc)
  - RSGC4 (D ~ 6.6 kpc)
  - RSGC5 (D ~ 6 kpc)



RSGC1 (2MASS)

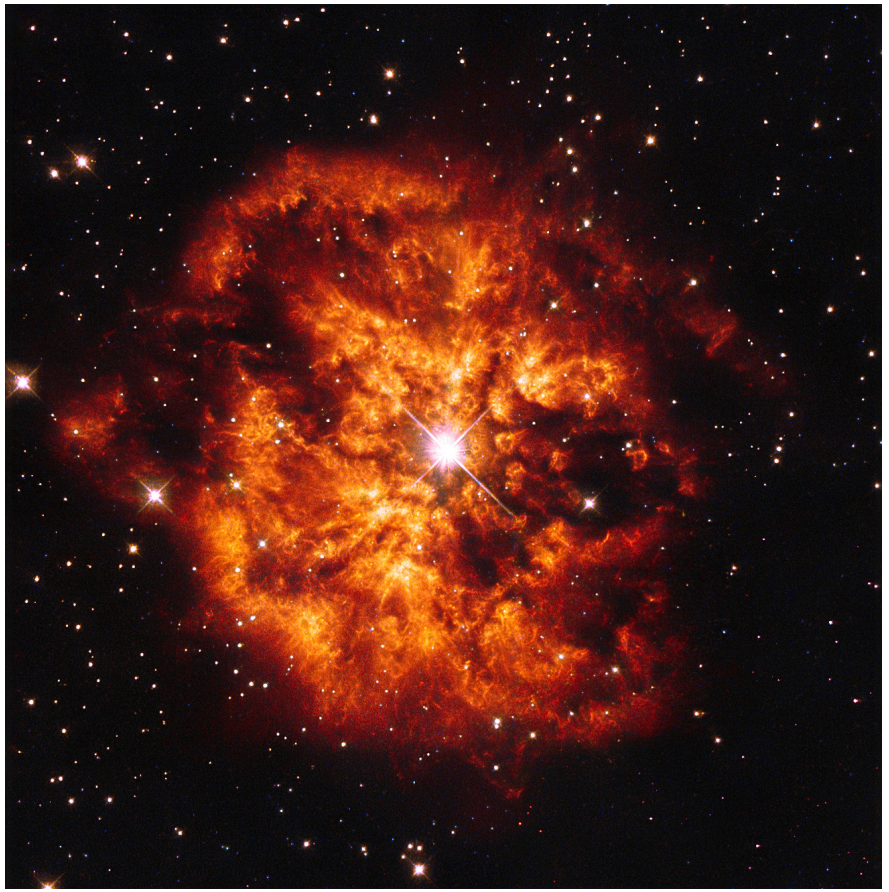


RSGC3 (2MASS)

Wrapping up

- Challenges:
  - GWs from HV 2112 in SMC (~60kpc) below detection limits of current detectors
  - RSG clusters subjected to high extinction hence less efficient spectroscopy

- Why to find and study them?
  - Testing the extremes of Stellar Evolution theories and models
  - Motivation of making more sensitive GW detectors
  - Solidifying fundamentals of Neutron Star structures
  - Possible progenitors for
    - Wolf-Rayet Stars but with NS core
    - Rotating Stellar-mass Black Holes with accretion disks



Hen 2-427 (STScI)

Thank you for your patience

Questions?

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