A FIRST TASTE OF MESA

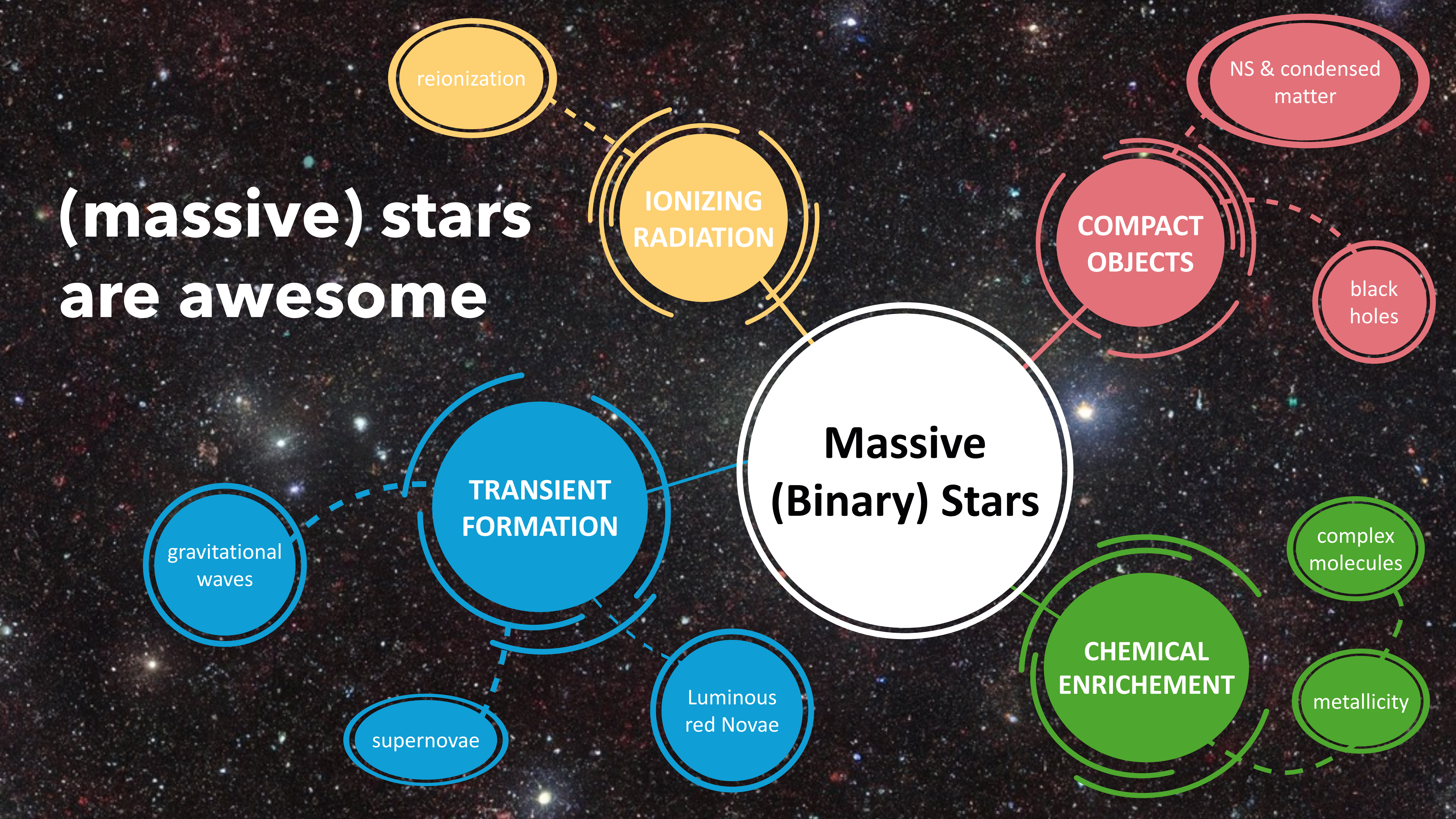
★ Created by: Lieke van Son, Aleksandra Olejak, and Shelley Cheng ★

Meet the MESA-hack Organizers

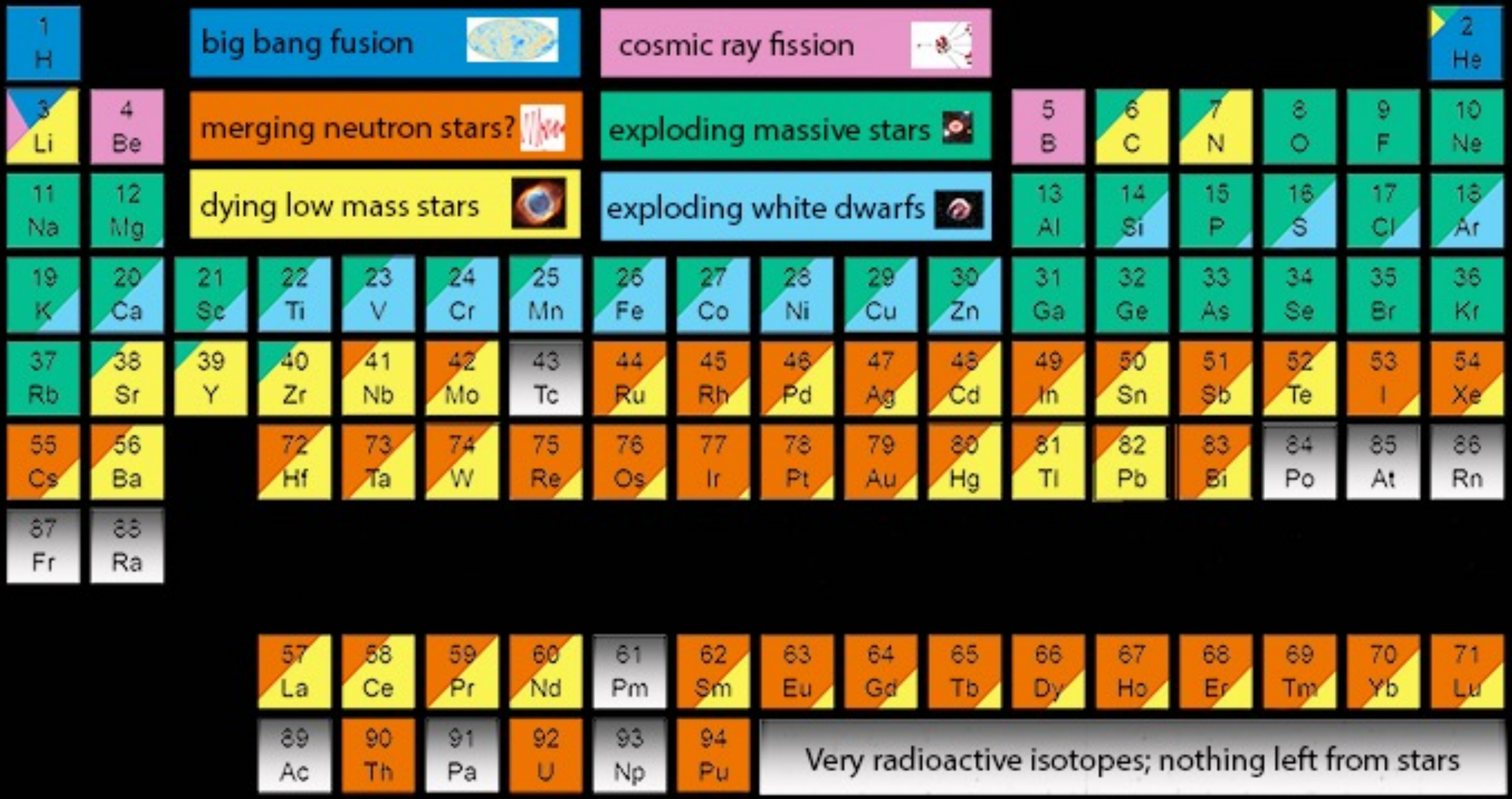
Lieke van Son
lvanson@flatironinstitute.org

Aleksandra Olejak
aolejak@mpa-garching.mpg.de

Shelley Cheng
shelley.cheng@cfa.harvard.edu


(massive) stars are awesome
Massive (Binary) Stars
IONIZING RADIATION
reionization
COMPACT OBJECTS
NS & condensed matter
black holes
TRANSIENT FORMATION
gravitational waves
supernovae
Luminous red Novae
CHEMICAL ENRICHEMENT
complex molecules
metallicity

The Origin of the Solar System Elements



Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

Astronomical Image Credits:
ESA/NASA/AASNova

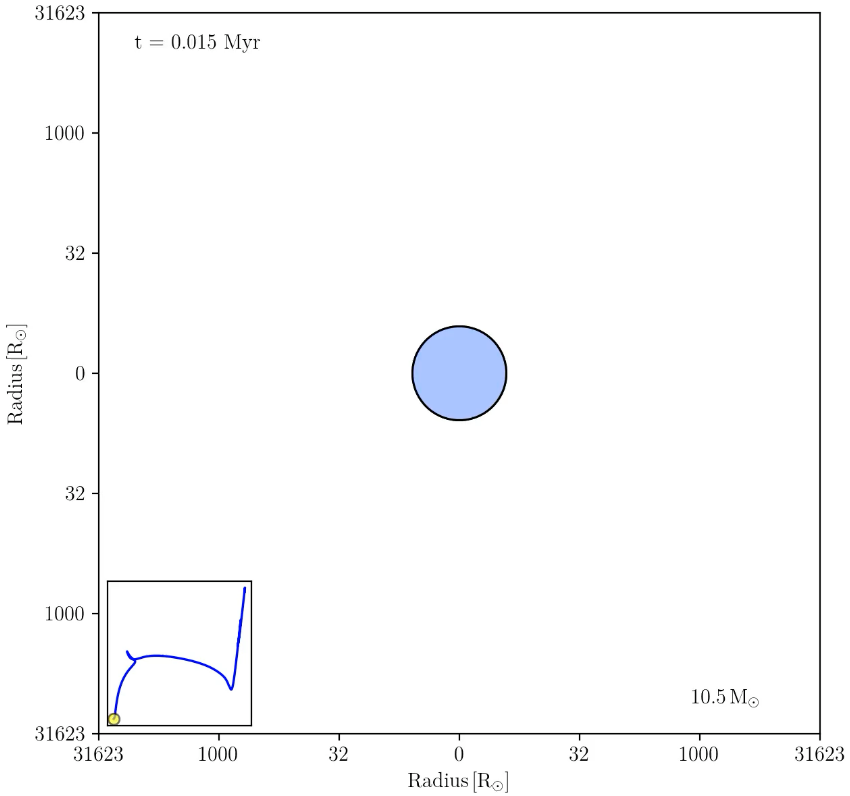
The challenge:

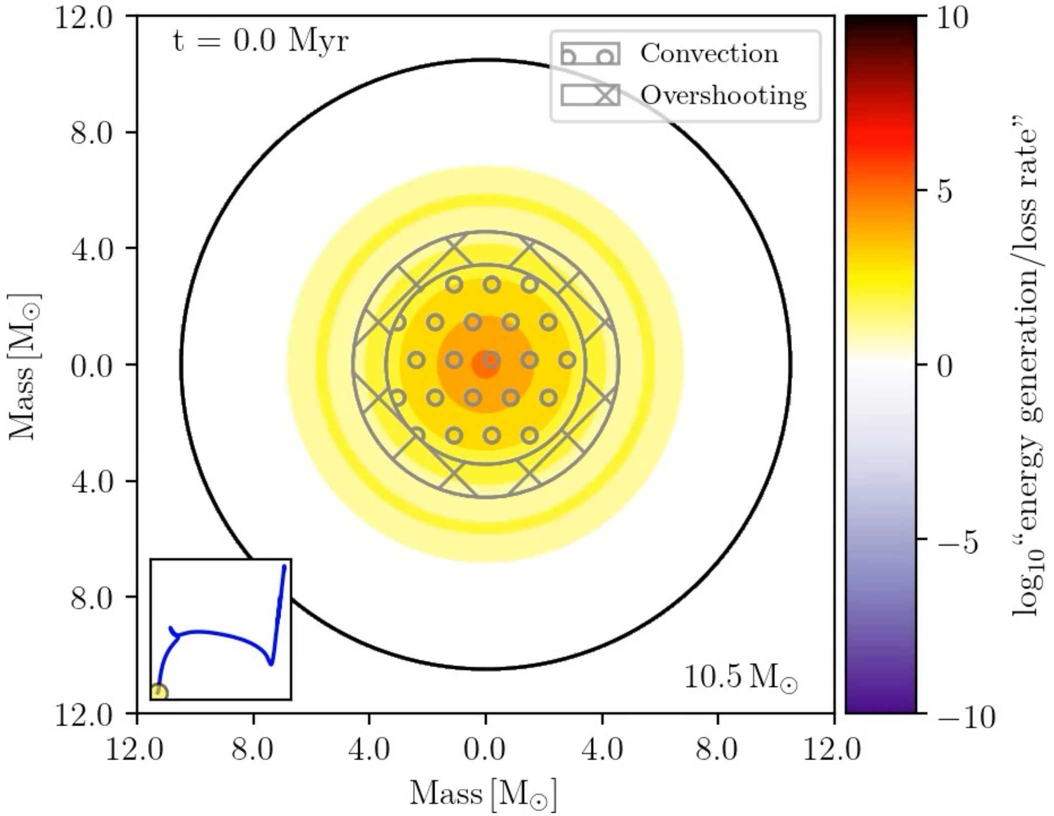
Massive binary stars are complicated

Uncertain: wind mass loss, size of the core, nuclear reaction rates, formation of convective regions, mass transfer stability, mass transfer efficiency, common envelopes, birth metallicity, angular momentum transport within the star, birth spin, remnant-mass function, supernova birth kick, tidal interactions, luminous blue variable mass loss, etc..

What is MESA?

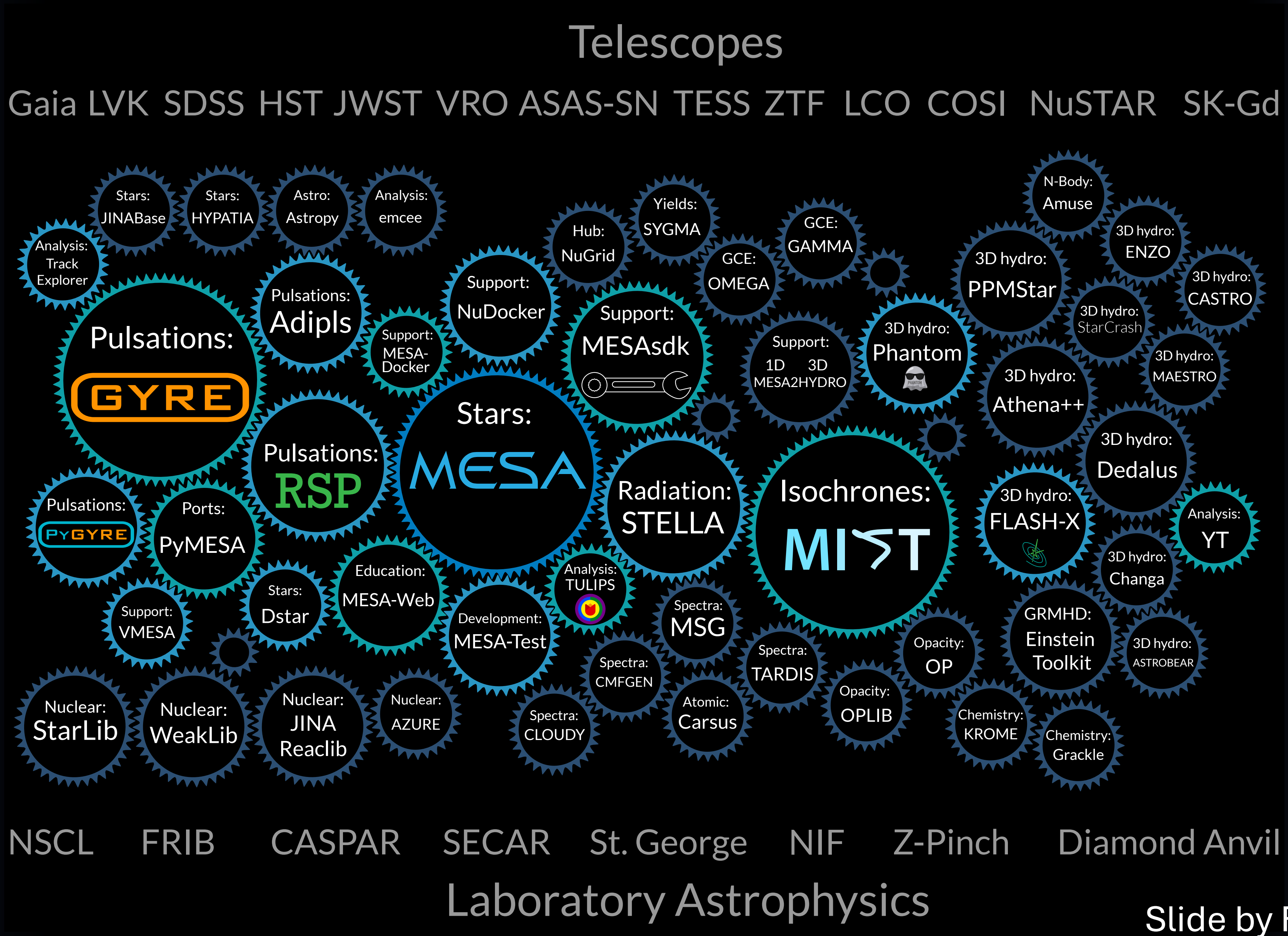
Modules for **E**xperiments in **S**tellar **A**strophysics





Made using TULIPS Laplace et al. (2021)


MESA == Table mountain



Slide by Frank Timmes

Solving the stellar structure equations

1) Hydrostatic equilibrium

$$\frac{\partial P}{\partial M_r} = -\frac{GM_r}{4\pi r^4} - \frac{1}{4\pi r^2}\frac{\partial^2 r}{\partial t^2},$$

2) Mass conservation

$$\frac{\partial r}{\partial M_r} = \frac{1}{4\pi r^2 \rho},$$

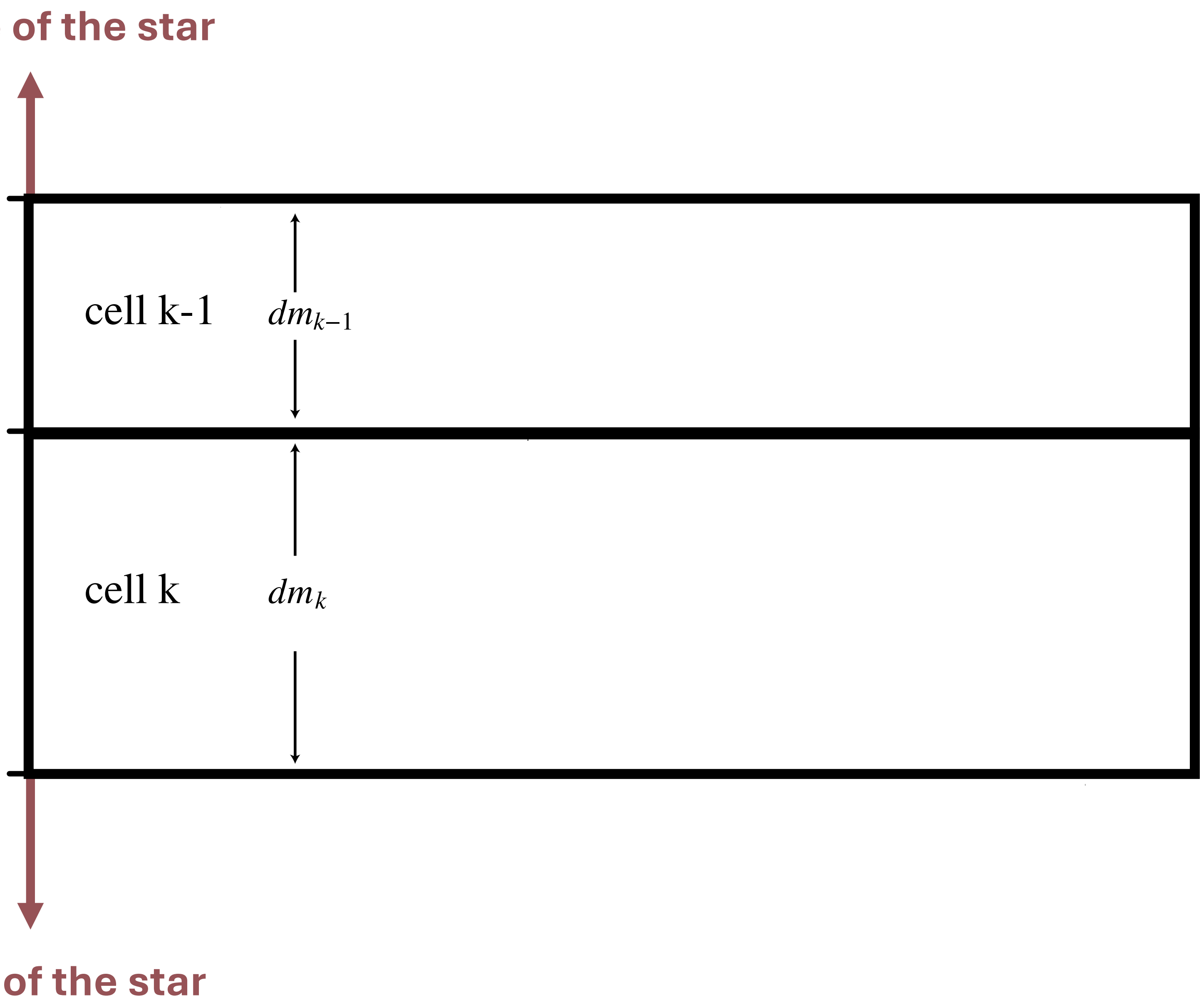
3) Radiative transport

$$\frac{\partial T}{\partial M_r} = -\frac{3\kappa L_r}{64\pi^2 ac T^3 r^4},$$

4) Thermal equilibrium

$$\frac{\partial L_r}{\partial M_r} = \epsilon - T\frac{\partial S}{\partial t}.$$

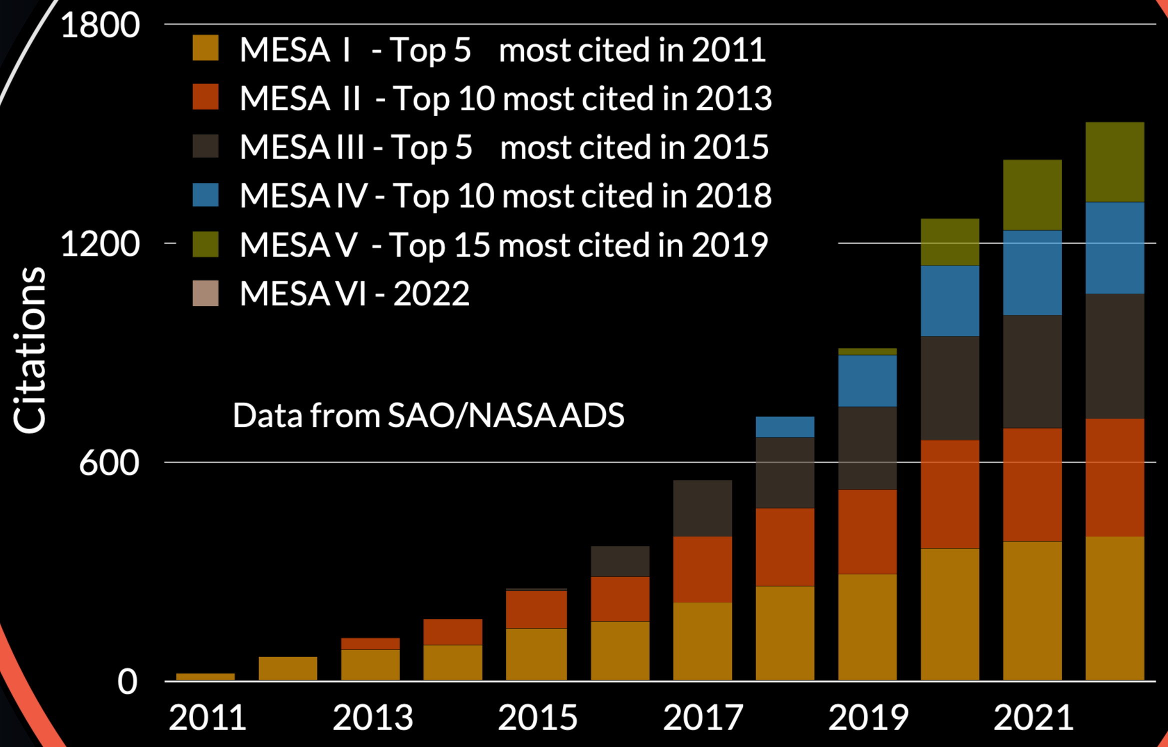
Structure divided into cells (spherically symmetric)



Six instrument papers to date

1. **Modules for Experiments in Stellar Astrophysics (MESA)**
   Paxton, Bill; Bildsten, Lars; Dotter, Aaron et al. (2011) ApJS..192....3P
2. **~ (MESA) Planets, Oscillations, Rotation, and Massive Stars**
   Paxton, Bill; Cantiello, Matteo; Arras, Phil et al. (2013) ApJS..208....4P
3. **~(MESA): Binaries, Pulsations, and Explosions**
   Paxton, Bill; Marchant, Pablo; Schwab, Josiah et al. (2015) ApJS..220...15P
4. **~ (MESA): Convective Boundaries, Element Diffusion, and Massive Star Explosions**
   Paxton, Bill; Schwab, Josiah; Bauer, Evan B. (2018) ApJS..234...34P
5. **~ (MESA): Pulsating Variable Stars, Rotation, Convective Boundaries, and Energy Conservation**
   Paxton, Bill; Smolec, R.; Schwab, Josiah (2019) ApJS..243...10P
6. **~ (MESA): Time-dependent Convection, Energy Conservation, Automatic Differentiation, and Infrastructure**
   Jermyn, Adam S. ; Bauer, Evan B. ; Schwab, Josiah (2023) ApJS..265...15J

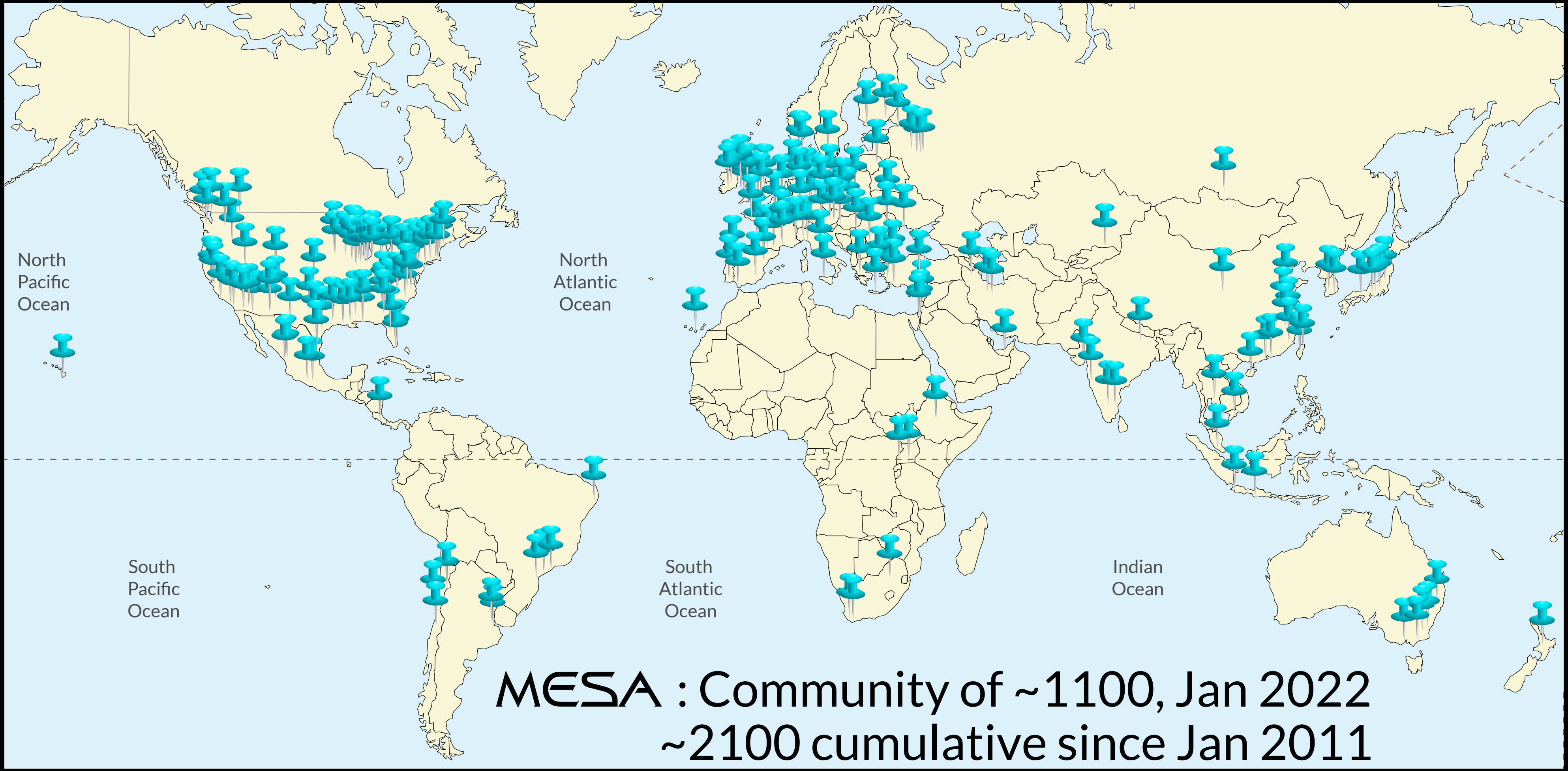
MESA



Citations: 11019

Slide by Frank Timmes
VAST 18 Jan 2022

The MESA community



Slide by Frank Timmes VAST 18Jan202

MESA = open source

APPENDIX A

MANIFESTO

MESA was developed through the concerted efforts of the lead author over a six year period with the engagement and deep involvement of many theoretical and computational astrophysicists. The public availability of MESA will serve education, scientific research, and outreach. This appendix describes the scientific motivation for MESA, the philosophy and rules of use for MESA, and the path forward on stewardship of MESA, and advanced development of future research and education tools. We make MESA openly available with the hope that it will grow into a community resource. We therefore consider it important to explain the guiding principles for using and contributing to MESA. Our goal is to assure the greatest usefulness for the largest number of research and educational projects.

Paxton et al, ApJS, 193, 3, 2011

Useful links

Documentation:
https://docs.mesastar.org

MESA market (tools & inlists):
https://cococubed.com/mesa_market/

py_mesa_reader by Bill Wolf:
https://github.com/wmwolf/py_mesa_reader

Github repository:
https://github.com/MESAHub

Zenodo repository:
https://zenodo.org/record/7983526

Annual MESA summer school!

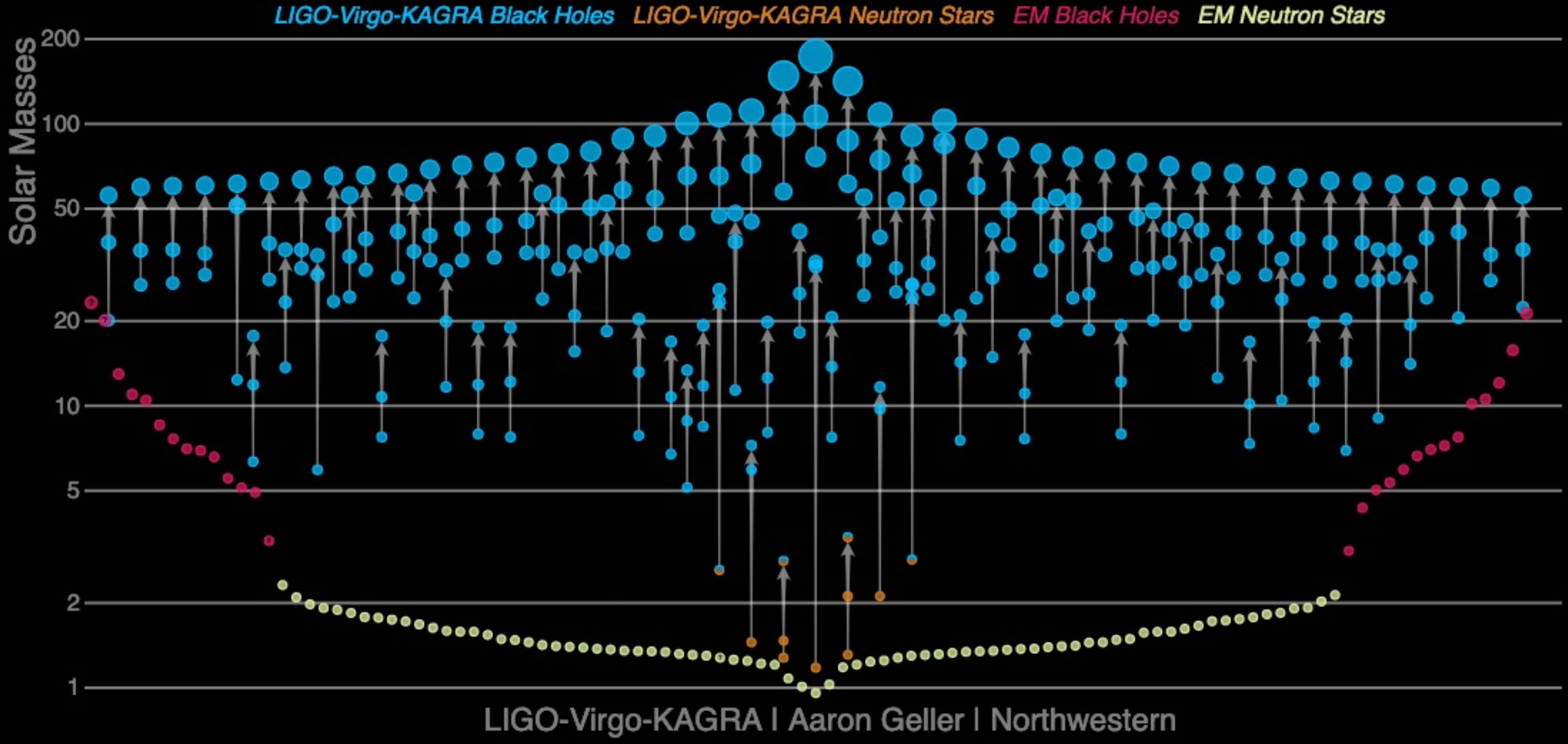
To dive deeper into the subject!

More than 10 year of MESA Summer School lectures & labs
(including solutions):
https://cococubed.com/mesa_market/education.html

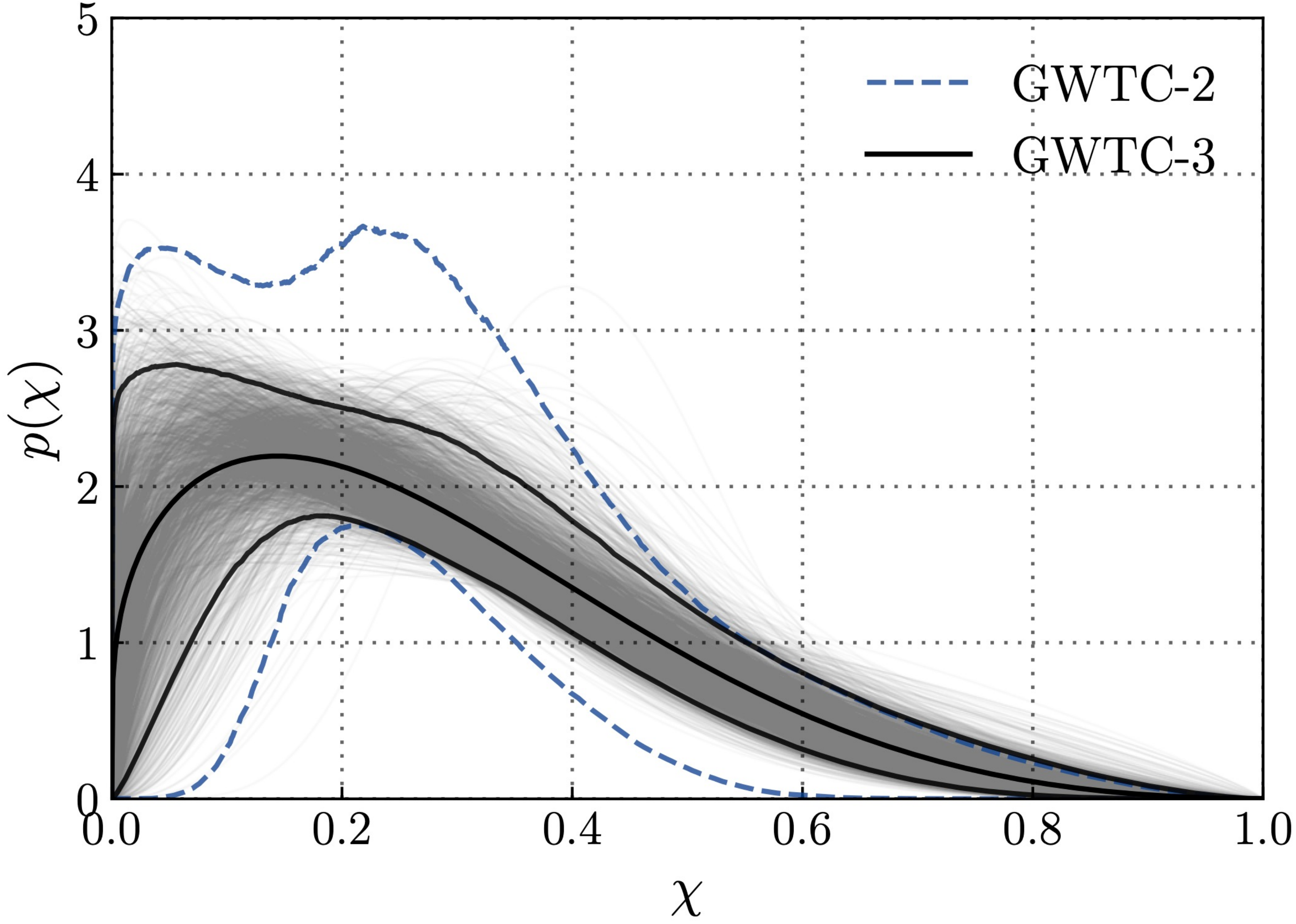
A first taste of MESA

Rotating stars and black holes

Masses in the Stellar Graveyard



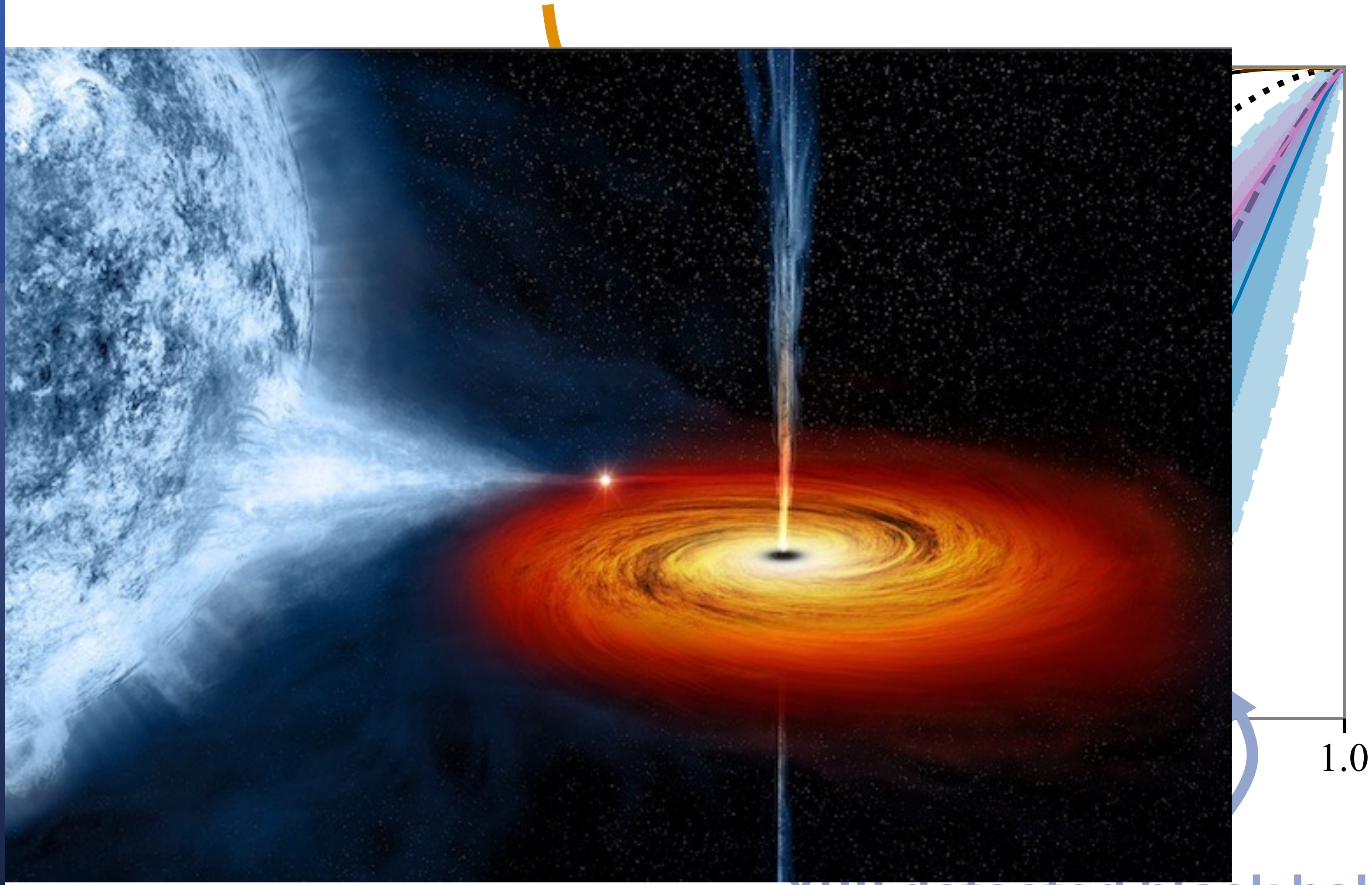
These BHs spin slowly



GWTC-3, LVK collaboration 2023

X-ray binaries spin fast?

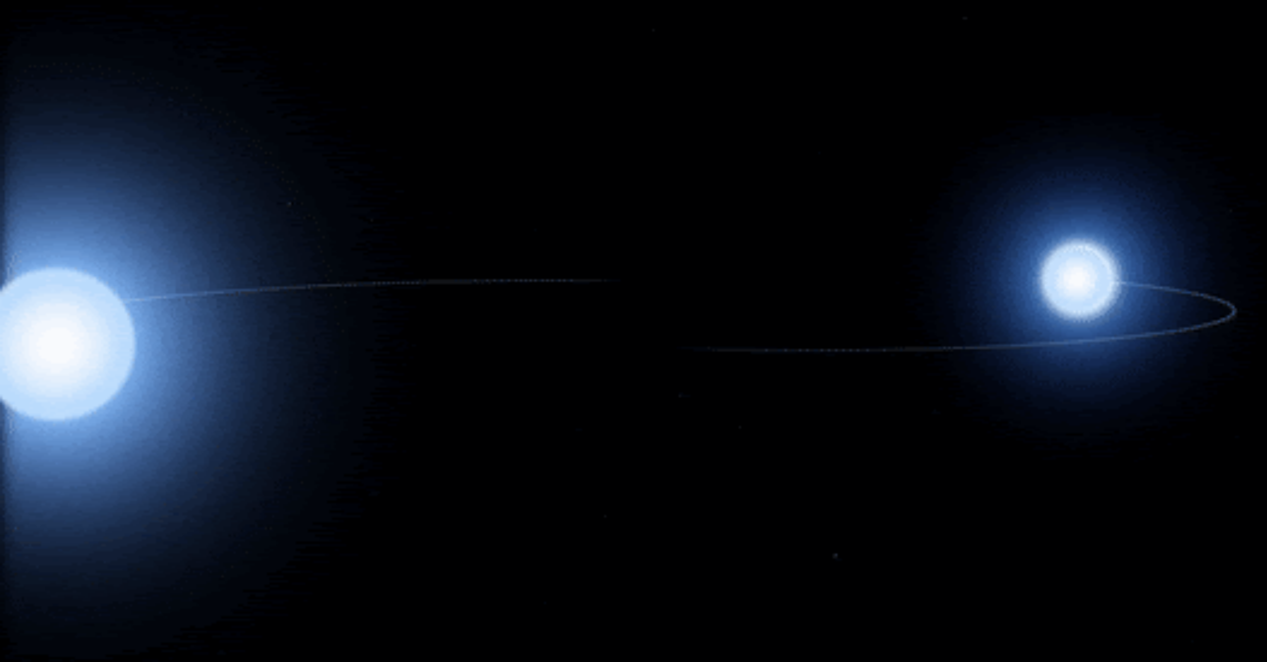
GW-detected black holes

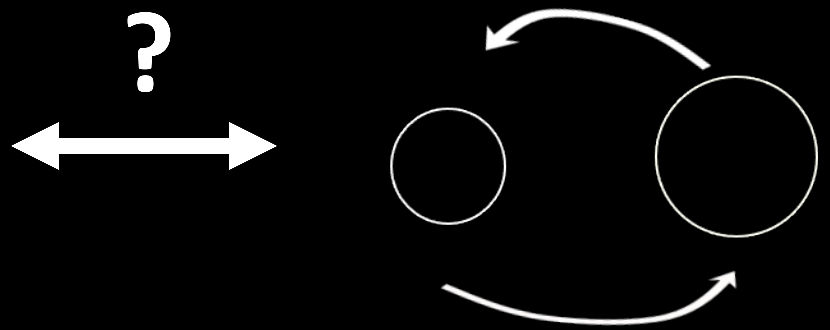


XRB detected black holes

Fishbach & Kalogera 2022

How do black holes get their spin?



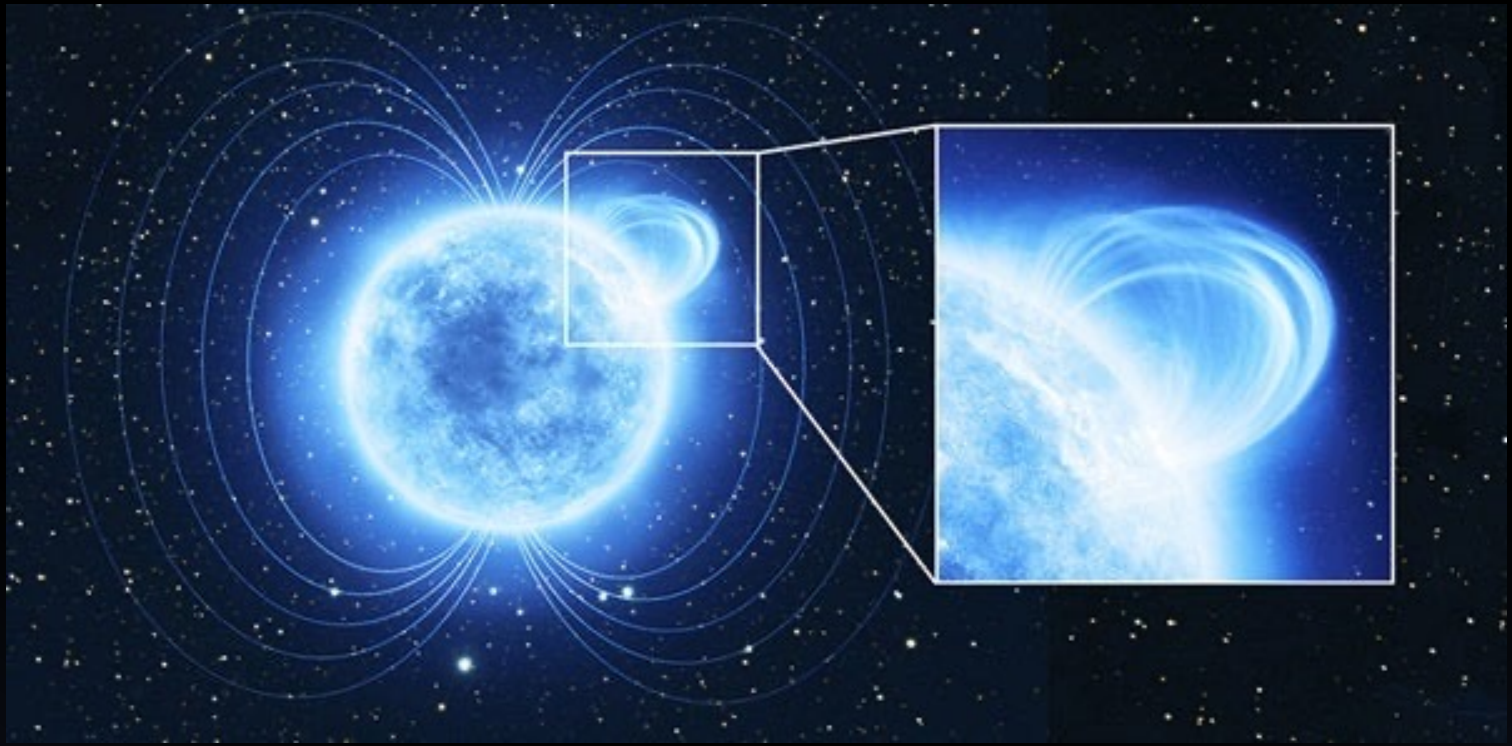


What affects the rotation of a star and its core?

Birth rotation

Protostar forming inL1527
JWST NIR Cam

Magnetic fields
(Angular momentum transport)



Magnetic loop on magnetar SGR 0418. // *ESA*

Stellar Winds

The 'bubble nebula
Credit: NASA, Hubble Space Telescope

Logistics

Hackathon: “A first taste of MESA”

This MESA hackathon

MESA hack	Sunday 4th August	Monday 5th August
9:00-10:00		Part 2.0 continued
10:00-10:30	Welcome/Guidelines/intro/Icebreaker	Birth rotation
10:30-11:00	Tea Break	Birth rotation
11:00-11:30	Lecture: Introduction to MESA	Tea Break
11:30-12:00	Getting started / Running MESA	AM transport
12:00-13:00	Running MESA	AM transport
13:00-14:00	Lunch	Lunch
14:00-15:00	MESA output	Winds
15:00-15:30	MESA output	Winds
15:30-16:00	Tea Break	Tea Break
16:00-17:00	Start on part 2.0	Final proj. / begin preparing presentations
17:00-18:00	Team updates and questions	Final Presentations

slido

Please download and install the
Slido app on all computers you use

How comfortable do you feel with **python?**

ⓘ Start presenting to display the poll results on this slide.

slido

Please download and install the Slido app on all computers you use

How comfortable do you feel with **working through the terminal?**

ⓘ Start presenting to display the poll results on this slide.

slido

Please download and install the Slido app on all computers you use

How comfortable do you feel with running MESA?

ⓘ Start presenting to display the poll results on this slide.

Hack Teams

3 people per team
Sharing one Virtual Machine (VM)
Produce a joint final presentation

Spin it as you like!

What affects the rotation of a star and its core?

With your group, calculate the final **dimensionless spin** of a compact object for different initial conditions

→ **can you get it to spin like the GW-observed black holes?**

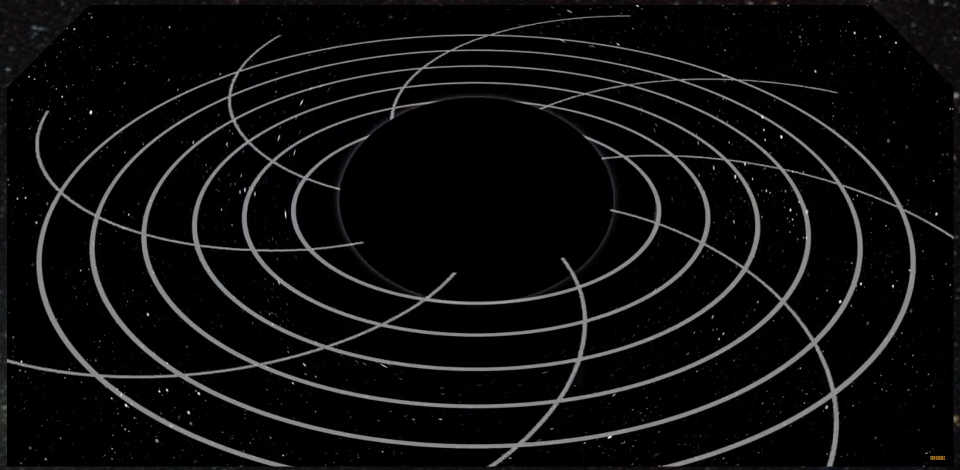


Image credit: Science Asylum

Questions?

Getting started

go to:

https://liekevanson.github.io/IAUhackathon/home.html