Some Astrophysics

of relevance to the Low Energy Community (LEC)

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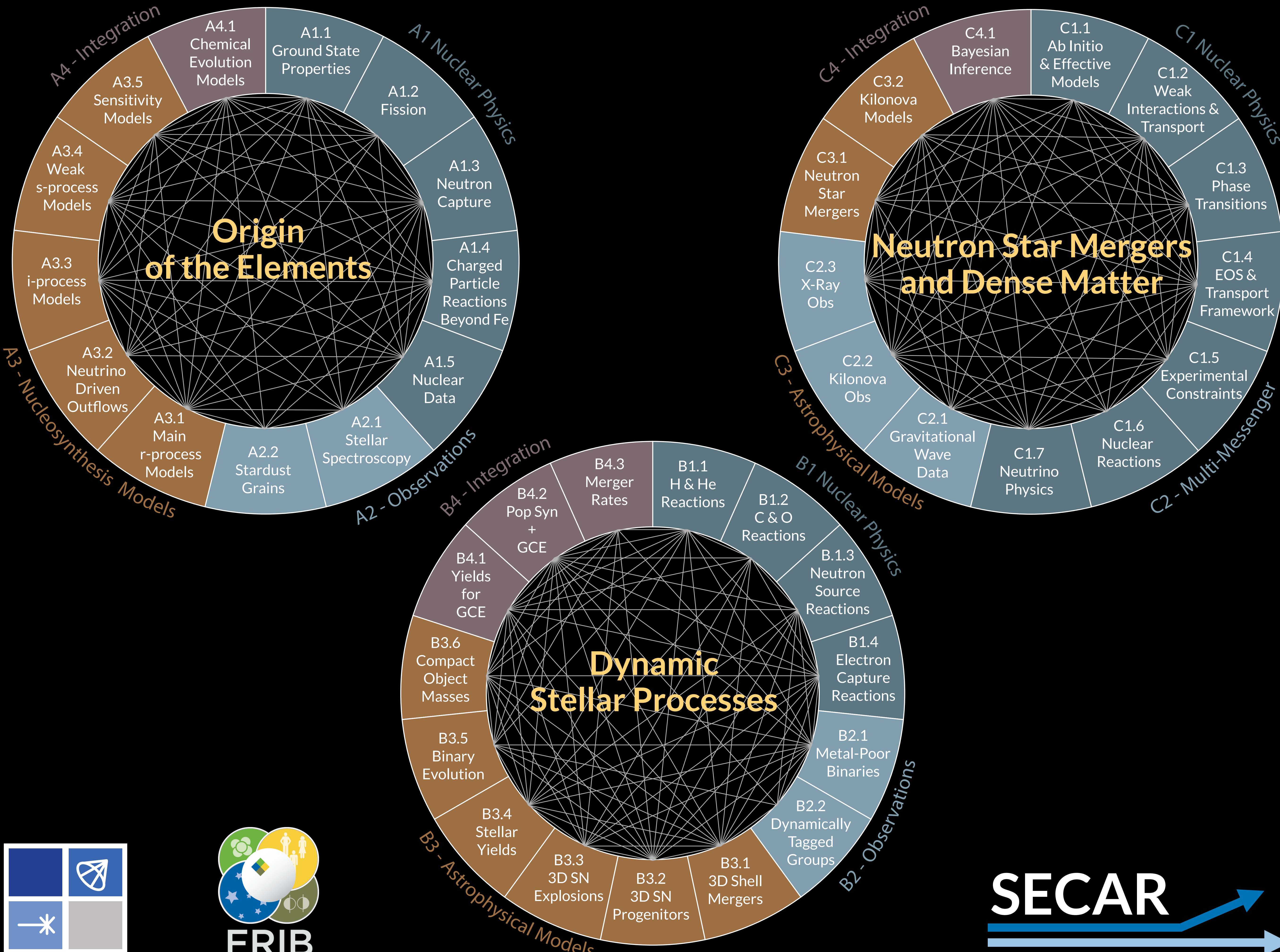
Origin of the Elements
A1 Nuclear Physics
A1.1 Ground State Properties
A1.2 Fission
A1.3 Neutron Capture
A1.4 Charged Particle Reactions Beyond Fe
A1.5 Nuclear Data
A2 - Observations
A2.1 Stellar Spectroscopy
A2.2 Stardust Grains
A3 - Nucleosynthesis Models
A3.1 Main r-process Models
A3.2 Neutrino Driven Outflows
A3.3 i-process Models
A3.4 Weak s-process Models
A3.5 Sensitivity Models
A4 - Integration
A4.1 Chemical Evolution Models
Neutron Star Mergers and Dense Matter
C1 Nuclear Physics
C1.1 Ab Initio & Effective Models
C1.2 Weak Interactions & Transport
C1.3 Phase Transitions
C1.4 EOS & Transport Framework
C1.5 Experimental Constraints
C1.6 Nuclear Reactions
C1.7 Neutrino Physics
C2 - Multi-Messenger
C2.1 Gravitational Wave Data
C2.2 Kilonova Obs
C2.3 X-Ray Obs
C3 - Astrophysical Models
C3.1 Neutron Star Mergers
C3.2 Kilonova Models
C4 - Integration
C4.1 Bayesian Inference
Dynamic Stellar Processes
B1 Nuclear Physics
B1.1 H & He Reactions
B1.2 C & O Reactions
B.1.3 Neutron Source Reactions
B1.4 Electron Capture Reactions
B2 - Observations
B2.1 Metal-Poor Binaries
B2.2 Dynamically Tagged Groups
B3 - Astrophysical Models
B3.1 3D Shell Mergers
B3.2 3D SN Progenitors
B3.3 3D SN Explosions
B3.4 Stellar Yields
B3.5 Binary Evolution
B3.6 Compact Object Masses
B4 - Integration
B4.1 Yields for GCE
B4.2 Pop Syn + GCE
B4.3 Merger Rates
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Roadmap

17 Slides

1) Tools for the Low Energy Community
2) Frontiers - Multi-Messenger Neutrinos
3) Frontiers - Seismology
4) Frontiers - Isomers
5) Frontiers - First Stars
6) Current and potential NASA missions

Tools for the Low Energy Community

The community may find it useful to have free, open tools for *rapid and painless* exploration of the astrophysical impact of a new measurement.

PAIN MEASUREMENT SCALE

Reaction networks.

Stellar evolution models.

3D, general relativistic, radiation, magnetohydrodynamics.

Engaging a developer / theorist.

Frontiers - Multi-Messenger Neutrinos

Recent results provide new targets for stellar neutrino detectors, new estimates of the stellar neutrino background signal, and new opportunities for nuclear physics that can make sizable differences in stellar evolution.

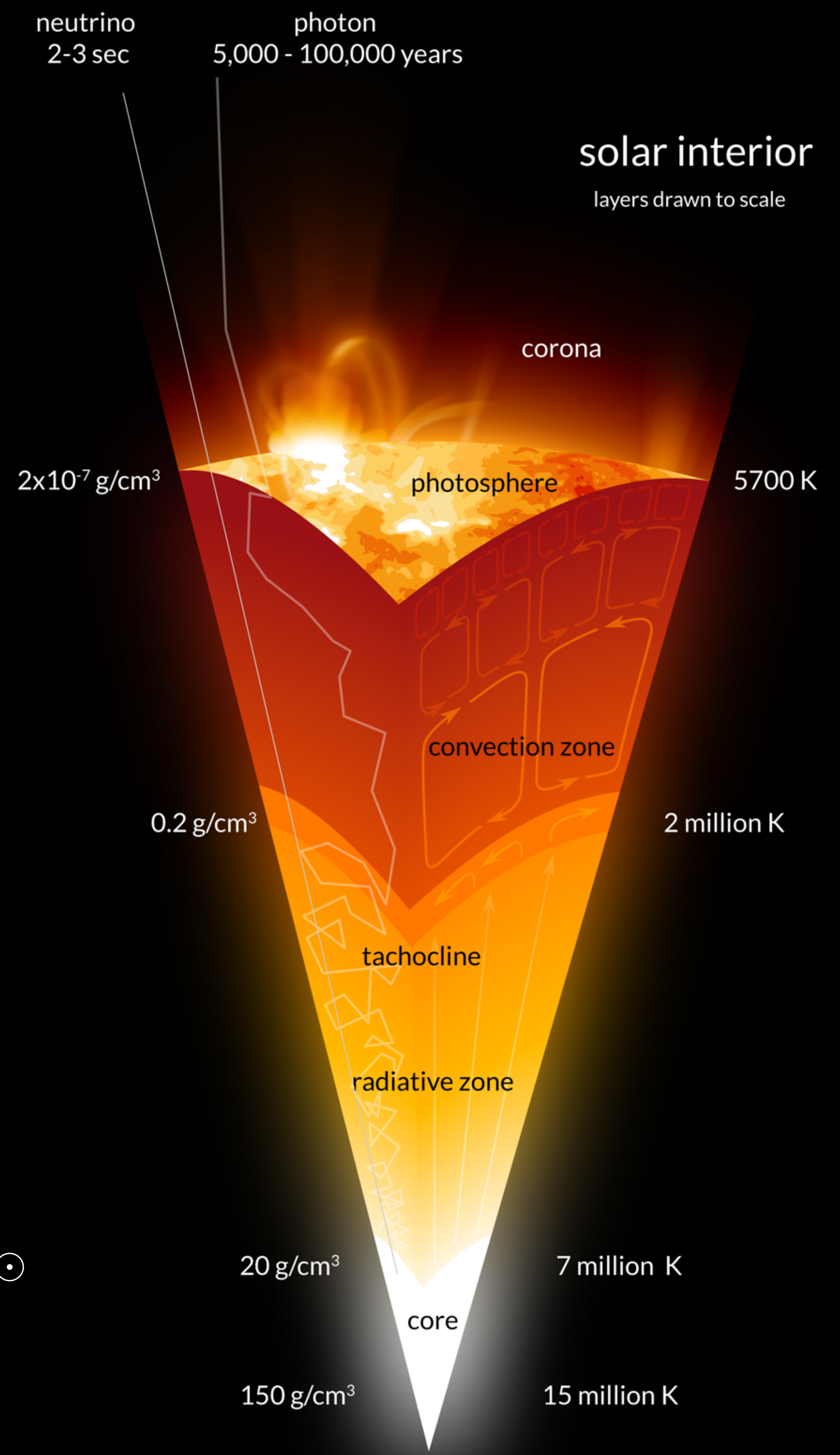
Stars radiate energy by releasing photons from the stellar surface and neutrinos from the stellar interior.

$$\sigma_\nu \simeq (E_\nu/m_e c^2)^2 \cdot 10^{-44}\ \mathrm{cm}^2$$

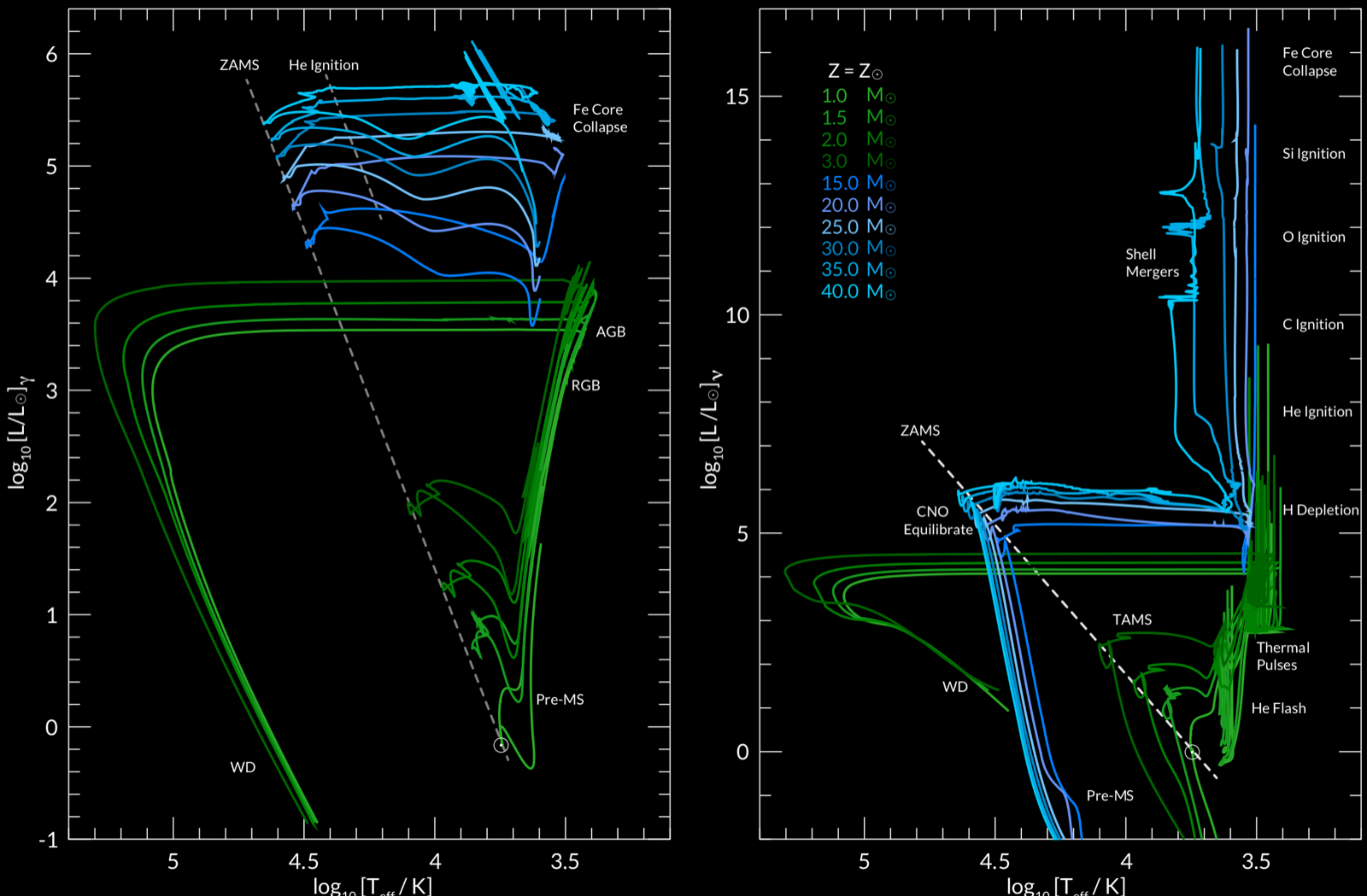
$$\sigma_\gamma = \frac{8\pi}{3}\left(\frac{\alpha\hbar c}{m_e c^2}\right)^2 \simeq 10^{-24}\ \mathrm{cm}^2$$

$$\lambda_\nu = \left.\frac{\mathrm{m_u}}{\rho\cdot\sigma_\nu}\right|_\odot \simeq 3\cdot 10^{19}\mathrm{cm} \simeq 10\mathrm{pc} \simeq 4\cdot 10^9 R_\odot$$

$$\tau_\nu \simeq R_\odot/c \simeq 2\ \mathrm{s}$$

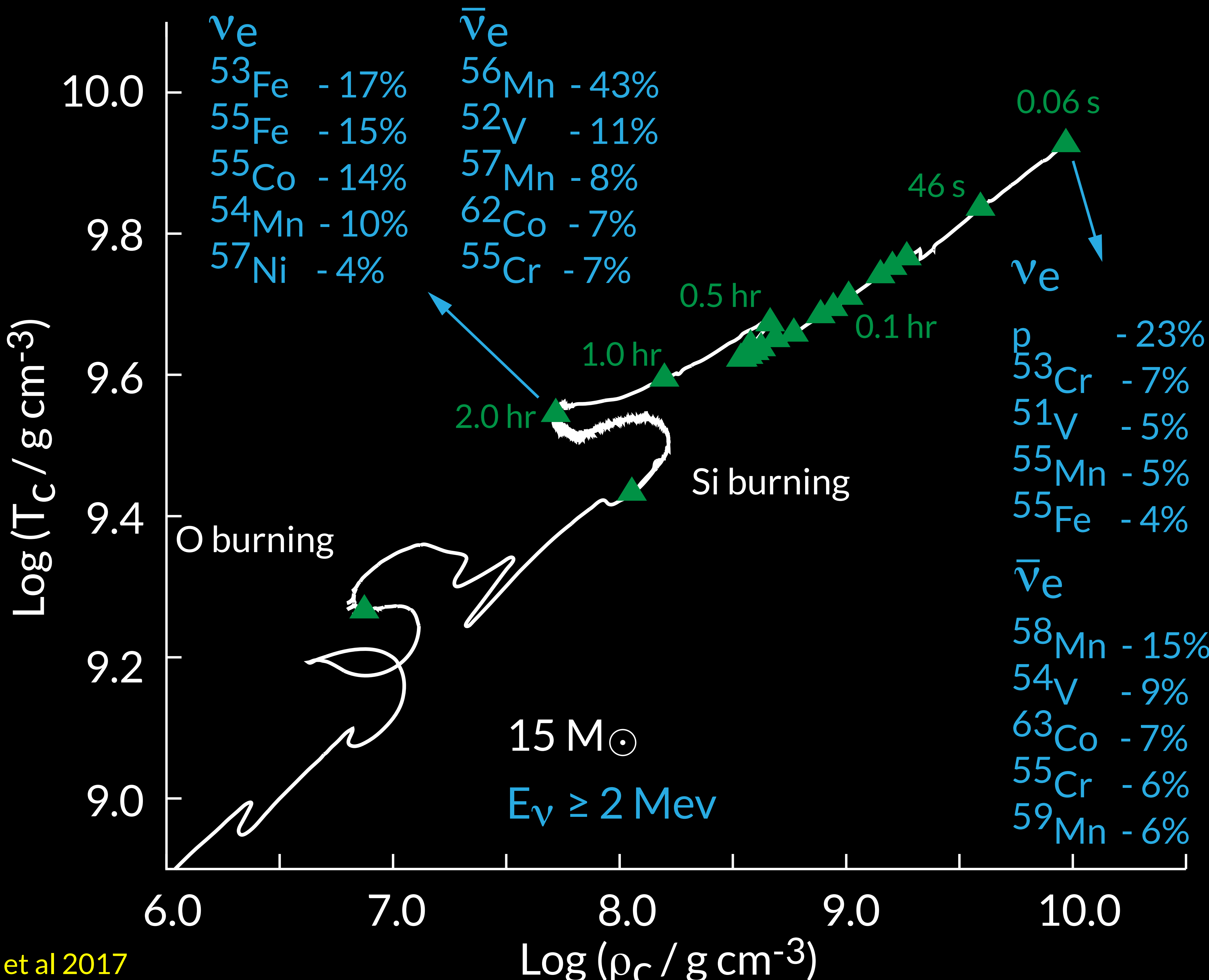


A neutrino HR Diagram!



Farag et al 2020

β-process rates that matter. Isotopes listed for neutrinos are mainly electron captures, those for antineutrinos are mainly β^- decay.



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Patton et al 2017

Sensitivity of Super-Kamiokande with Gadolinium
to Low Energy Anti-neutrinos from Pre-supernova Emission

C. Simpson et al, The Super-Kamiokande Collaboration

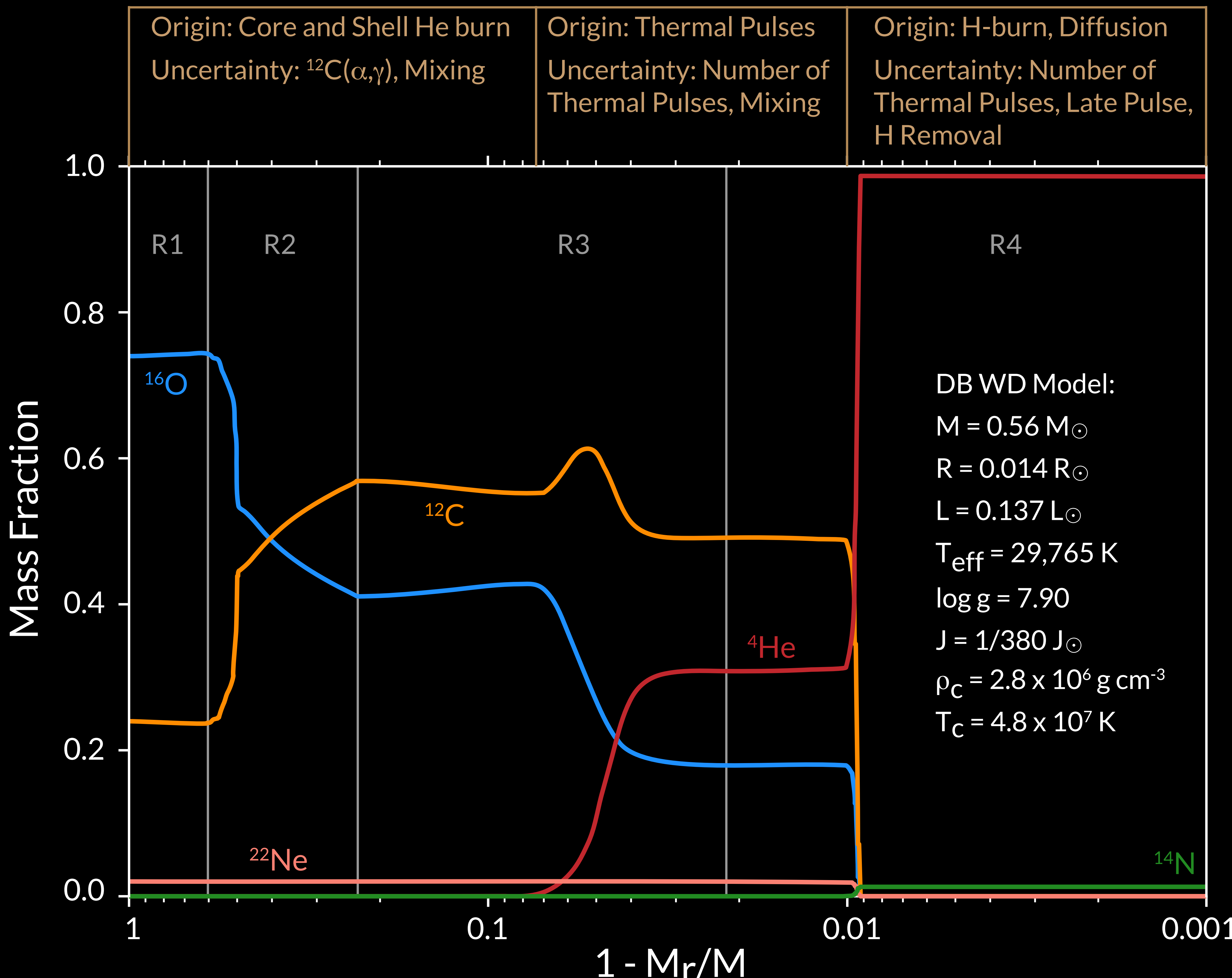
ABSTRACT

Supernova detection is a major objective of the Super-Kamiokande (SK) experiment. In the next stage of SK (SK-Gd), gadolinium (Gd) sulfate will be added to the detector, which will improve the ability of the detector to identify neutrons. A core-collapse supernova will be preceded by an increasing flux of neutrinos and anti-neutrinos, from thermal and weak nuclear processes in the star, over a timescale of hours; some of which may be detected at SK-Gd. This could provide an early warning of an imminent core-collapse supernova, hours earlier than the detection of the neutrinos from core collapse. Electron anti-neutrino detection will rely on inverse beta decay events below the usual analysis energy threshold of SK, so Gd loading is vital to reduce backgrounds while maximising detection efficiency. Assuming normal neutrino mass ordering, more than 200 events could be detected in the final 12 hours before core collapse for a 15-25 solar mass star at around 200 pc, which is representative of the nearest red supergiant to Earth, α-Ori (Betelgeuse). At a statistical false alarm rate of 1 per century, detection could be up to 10 hours before core collapse, and a pre-supernova star could be detected by SK-Gd up to 600 pc away. A pre-supernova alert could be provided to the astrophysics community following gadolinium loading.

ApJ, Nov 2019

Frontiers - Multi-Messenger Seismology

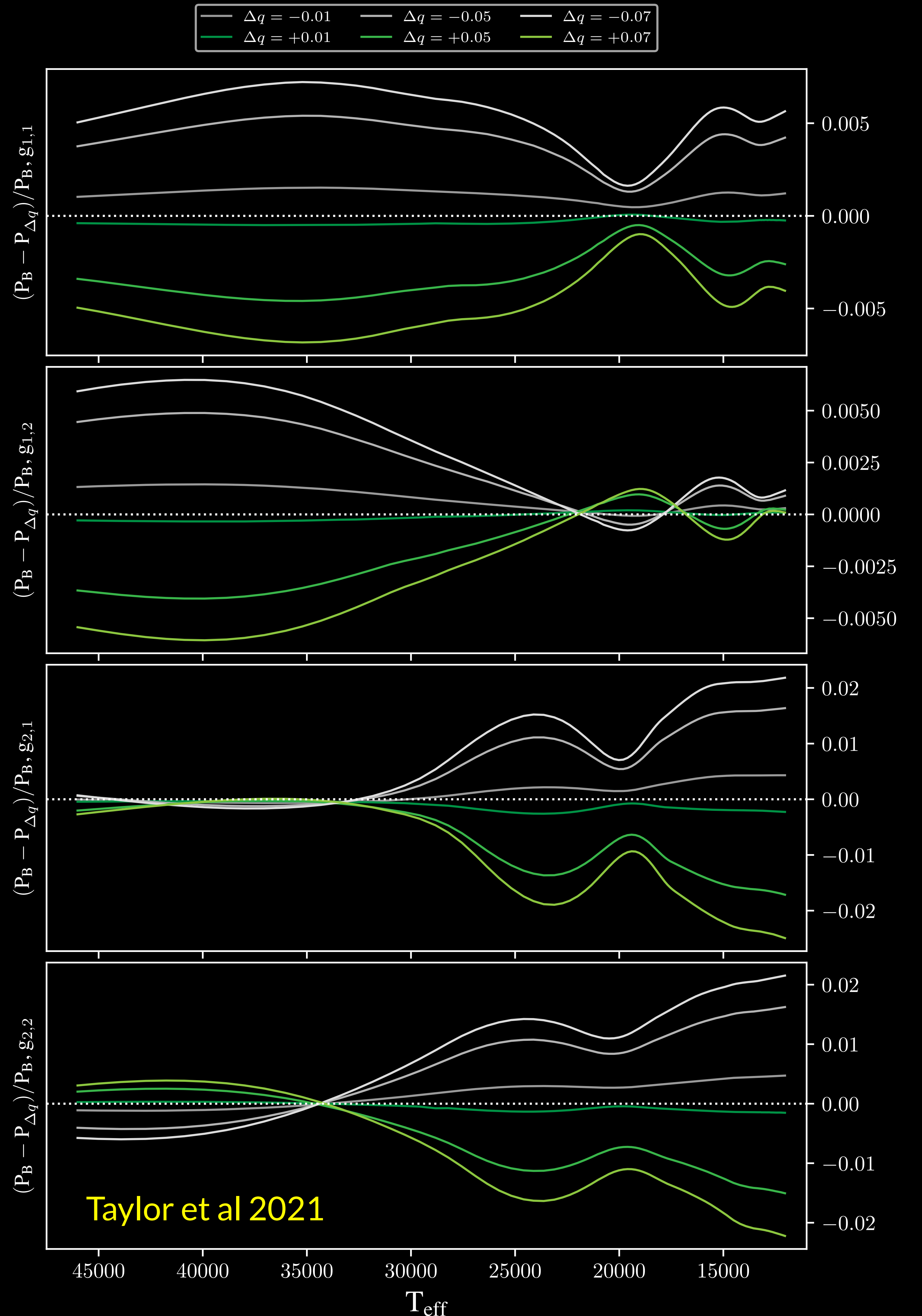
Stellar seismology can probe the abundance profiles of carbon-oxygen white dwarfs, their prior evolution history, and thus place bounds on key reaction rates such as $^{12}C(\alpha,\gamma)^{16}O$.



Taylor et al 2020

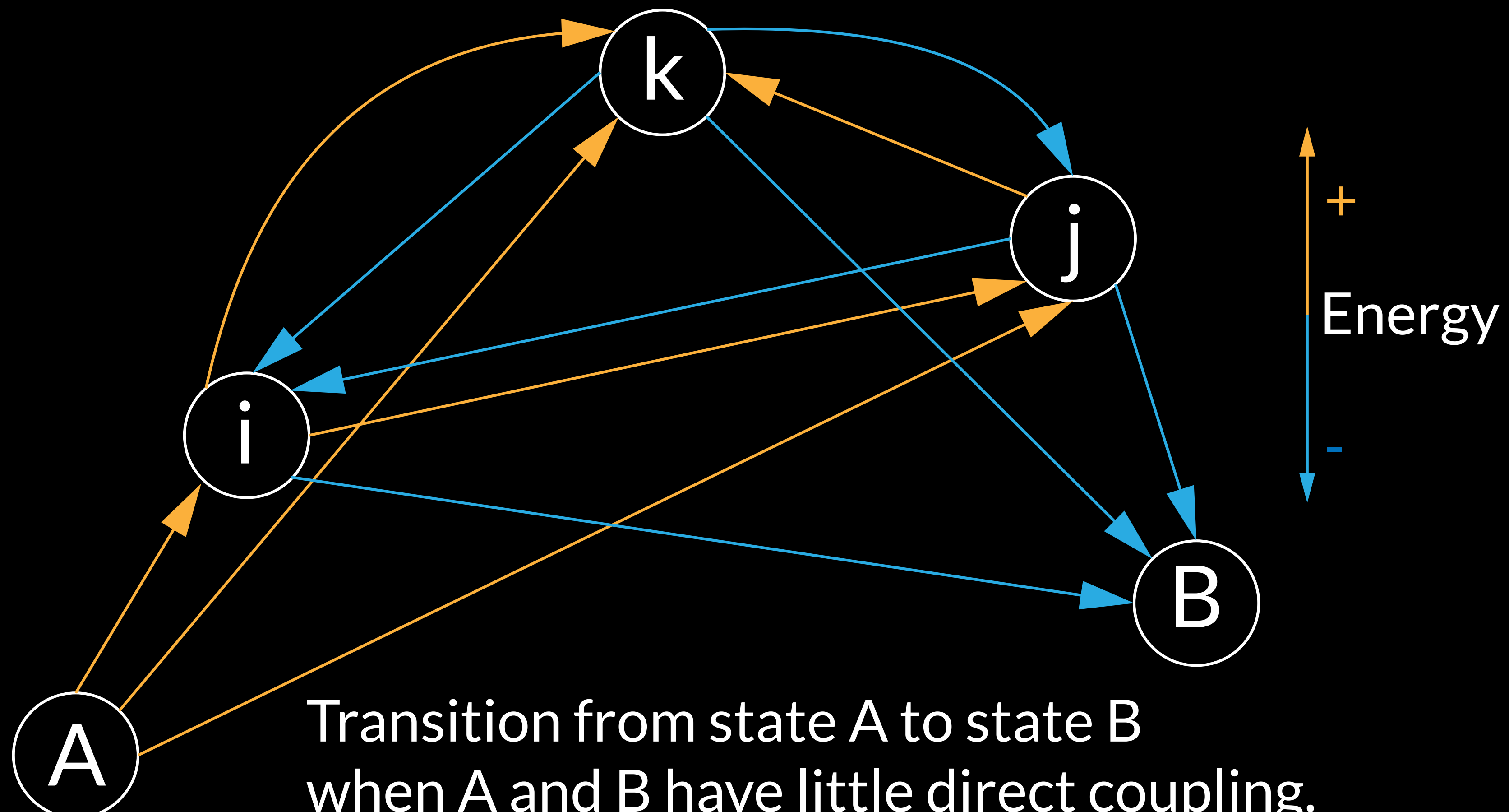
Translating the CO mean molecular weight gradient mimics changes in the reaction rate $^{12}C(\alpha,\gamma)^{16}O$ at lower temperatures and the convective boundary mixing prescription.

The ultimate goal of this project is to constrain key helium burning reactions from a stellar seismology determinations of white dwarf abundance profiles.

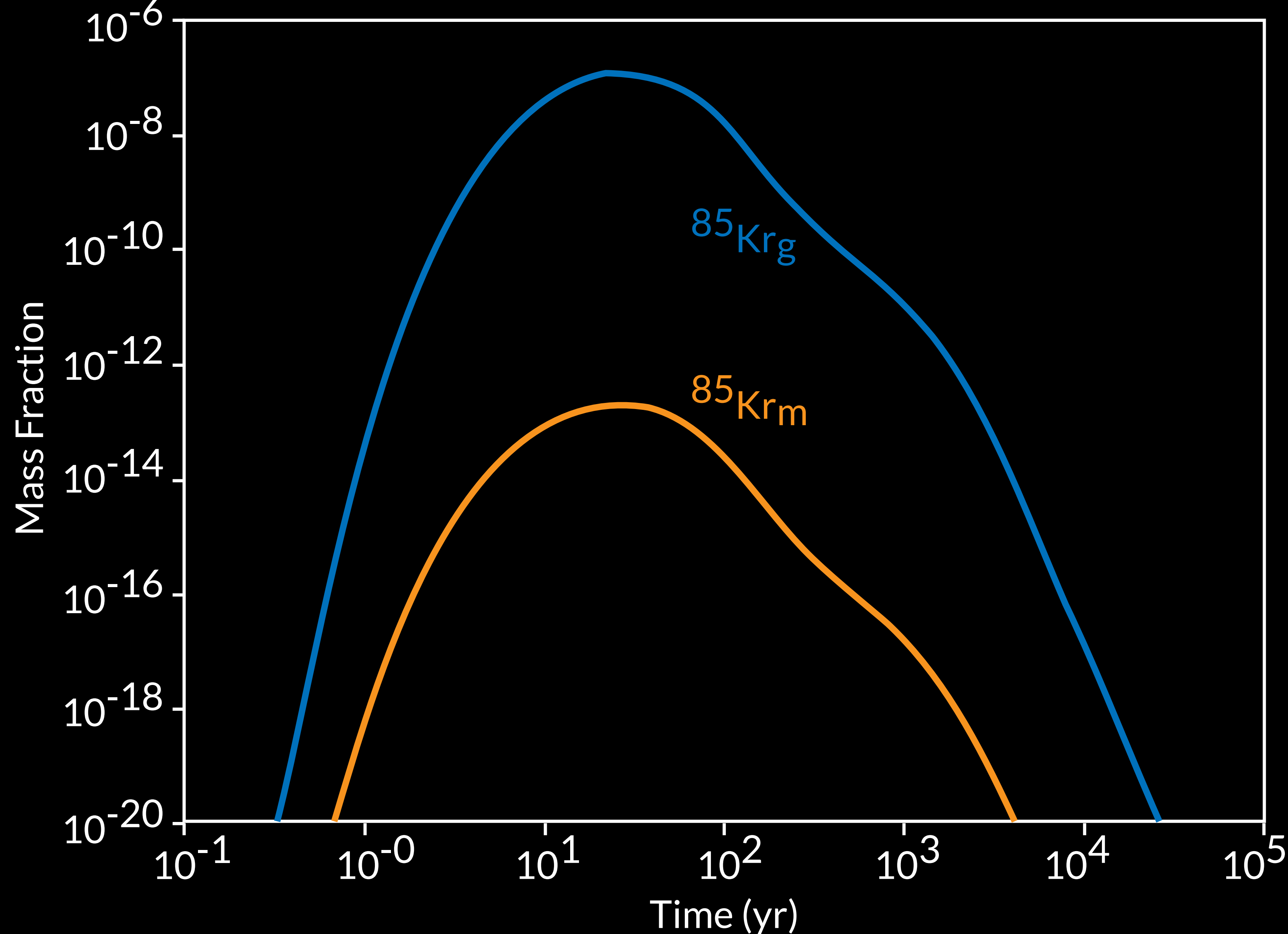


Frontiers - Isomers

Excited nuclear states with lifetimes longer than 1 ns are considered metastable isomers. Isomers do not behave the same as the associated ground states, and some isomers can play an influential role in nucleosynthesis.



Transition from state A to state B
when A and B have little direct coupling.



Meyer et al 2021

A new comprehensive effort to explore the N-Z plane for interesting astro and medical isomers has begun.

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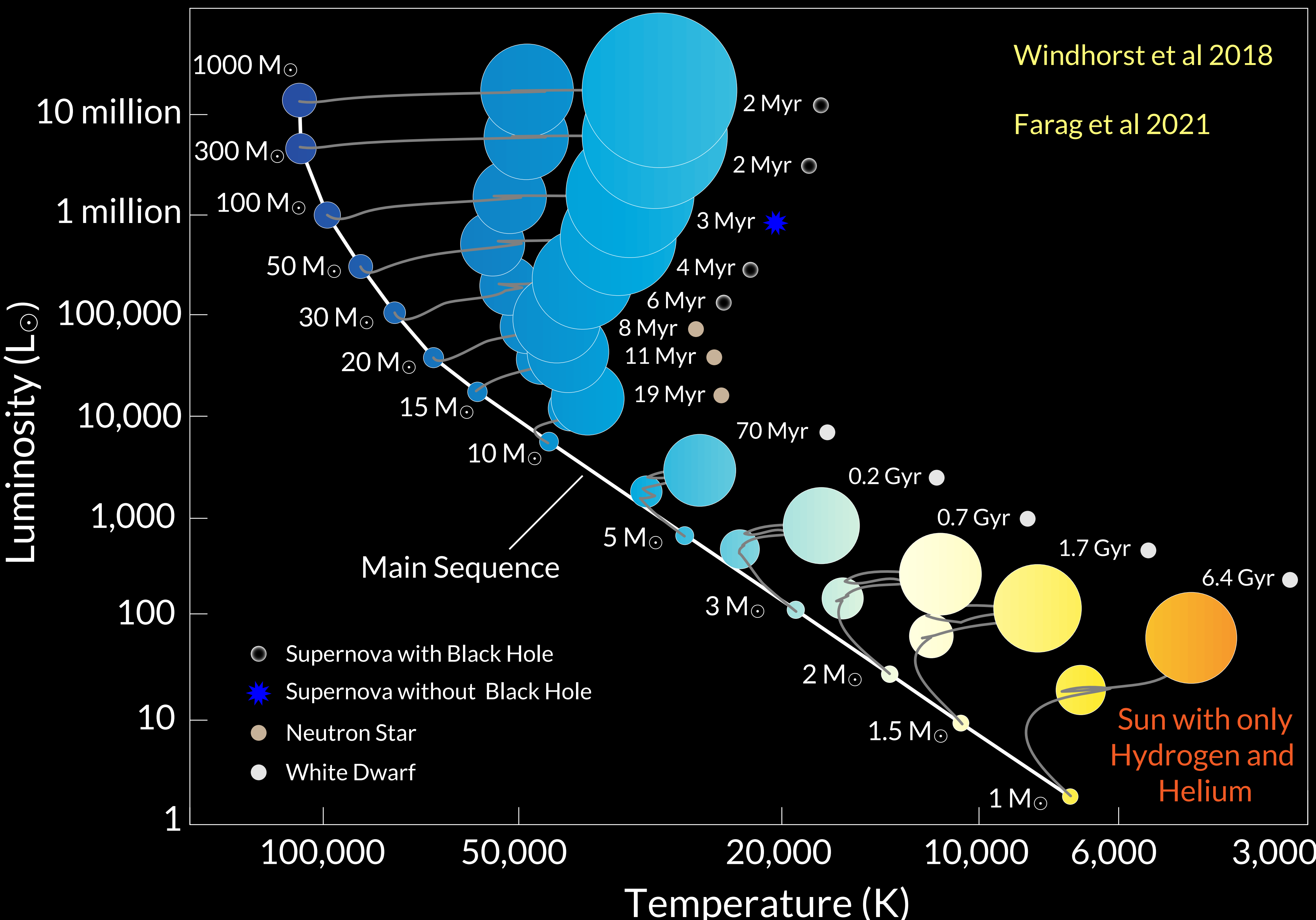
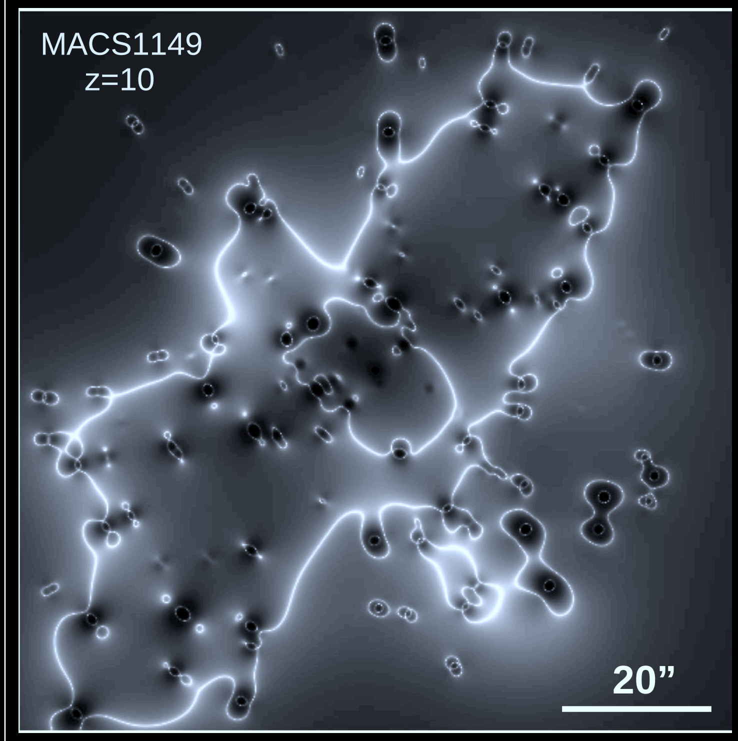
First Stars

Explore the impact of $^{3}He(\alpha,\gamma)^{7}Be$, $^{7}Li(\alpha,\gamma)^{11}B$, $^{11}B(\alpha,n)^{14}C$, $^{10}B(\alpha,n)^{13}N$ and $^{10}B(p,\alpha)^{7}Be$ in concert with new experimental and JWST studies.

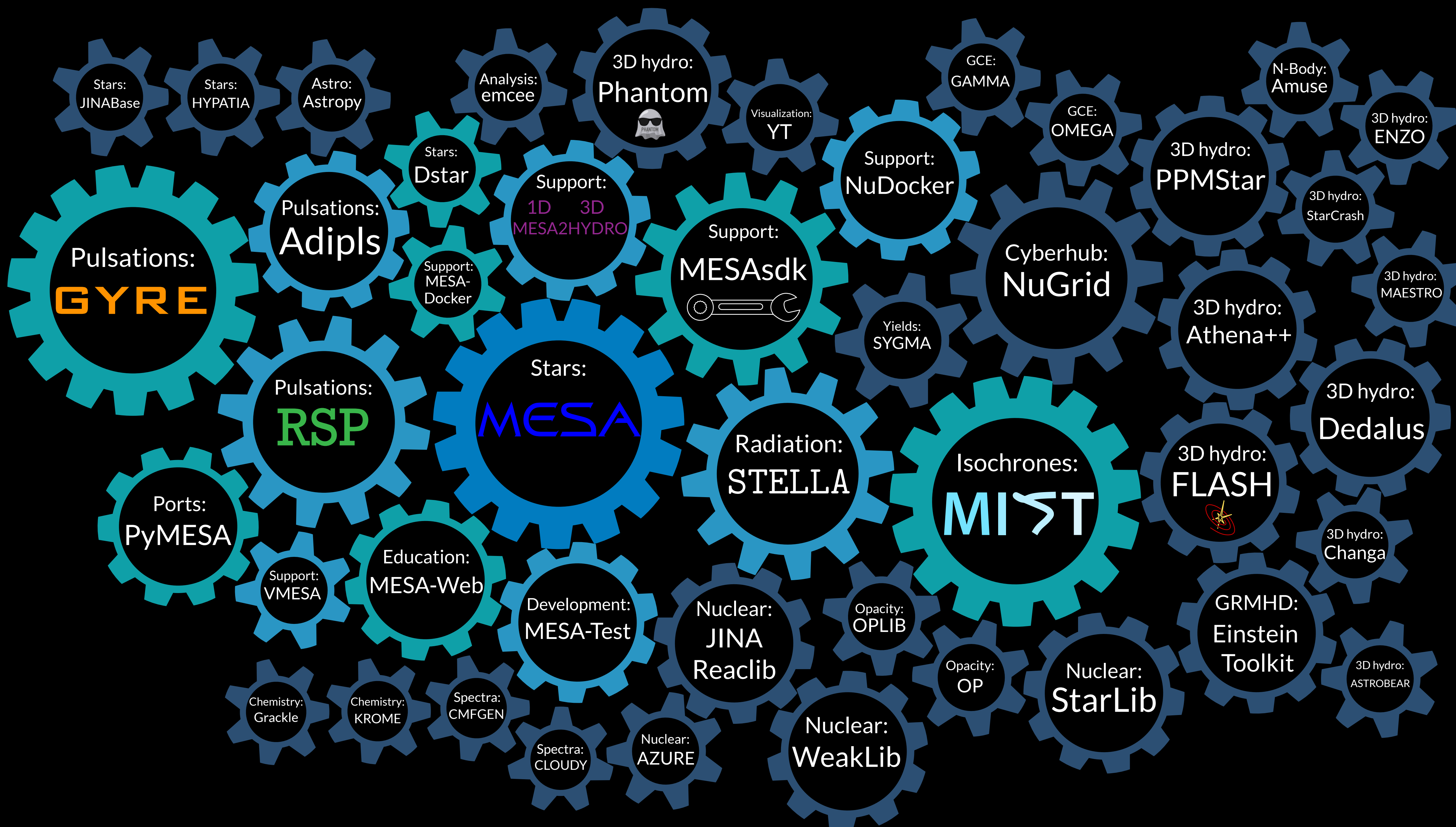




Current and potential NASA missions

Telescopes

Gaia LIGO SDSS Hubble JWST VRO ASAS-SN TESS ZTF LCO NuSTAR SK-Gd



NSCL FRIB CASPAR SECAR St. George Z-Pinch Diamond Anvil

Laboratory Astrophysics

Catching Element Formation In The Act

The Case for a New MeV Gamma-Ray Mission: Radionuclide Astronomy in the 2020s

A White Paper for the 2020 Decadal Survey

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Among my current favorite 2020 astrophysics targets are the production and destruction channels of

1	Big Bang	^{7}Li
2	H burn	^{3}He, ^{7}Be, ^{7}Li, ^{10,11}B, ^{12,13}C, ^{13,14}N, $^{15\text{-}17}$O, ^{17,18}F
3	He burn	^{4}He, ^{12}C, ^{16,18}O, ^{18}F, ^{20,22}Ne, ^{25,26}Mg, ^{44}Ca, ^{47}Ti, ^{51}V
4	C burn	^{12}C, $^{20\text{-}22}$Ne, $^{21\text{-}23}$Na, $^{23\text{-}26}$Mg
5	Ne burn	^{20}Ne, $^{24\text{-}26}$Mg, ^{27}Al, ^{31}P, ^{29,30}Si
6	O burn	^{16}O, ^{31}S,^{30,31}P,^{28}Si, ^{32,34}S, ^{35}Cl,^{36,38}Ar
7	Si burn	^{24}Mg, ^{28,30}Si, 32,^{34}S, ^{36,38}Ar, ^{40}Ca, $^{54\text{-}56}$Fe, ^{57}Co, ^{58}Ni
8	s-process	^{12}C, ^{13}C, ^{13}N , ^{22}Ne, ^{48}Ca, ^{50}Ti, ^{54}Cr ^{85}Kr
9	i-process	^{10}B, ^{11}B, ^{18}O, ^{21}Ne, ^{25}Mg, ^{26}Mg
10	r-process	^{89}Y,^{89}Sr, ^{90}Zr,^{130}Cd, ^{195}Th, ^{247}Cm, ^{127,129,132}I, ^{232}Th, ^{235,248}U, ^{244}Pu
11	rp-process	^{72}Kr, $^{103\text{-}106}$Sn, ^{105,107}Sb, ^{107,108}Te
12	νp-process	^{78}Kr, ^{84}Sr, ^{92,94}Mo, ^{96,98}Ru
13	p-process	^{31}P, ^{35}Cl, ^{45}Sc, ^{39}K
14	Radionuclides	^{7}Be, ^{22}Na, ^{26}Al, ^{45}V, ^{44}Ti, ^{53}Mn, ^{60}Fe, ^{56,57,60}Co, ^{56,57}Ni
15	Fission recycling	^{254}Cf, ^{254}Pu, ^{260}Fm
16	ν astronomy	^{11}B, ^{19}F, ^{53}Fe, ^{55}Co, ^{54}Mn, ^{54}Mn, ^{57}Mn, ^{52}V
17	Cosmic-ray spallation	^{6}Li, ^{9}Be, ^{10}B
18	Pyconuclear	^{12}C,^{40}Mg, ^{56}Fe, ^{56}Cr, ^{56}Ti, ^{56}Ca, ^{56,62}Ar
19	Isomers	^{26}Al, ^{34}Cl, ^{85}Kr, ^{58}Mn, ^{121,123,125,127}Sn , ^{113}Cd, ^{128}Sb, ^{176}Lu, ^{182}Hf + new ones!

Time for an LEC Cocktail