Frank Timmes

JINA-CEE

SPIDER

SCORPION

MESA

Starlib

100 isotopes project

edX

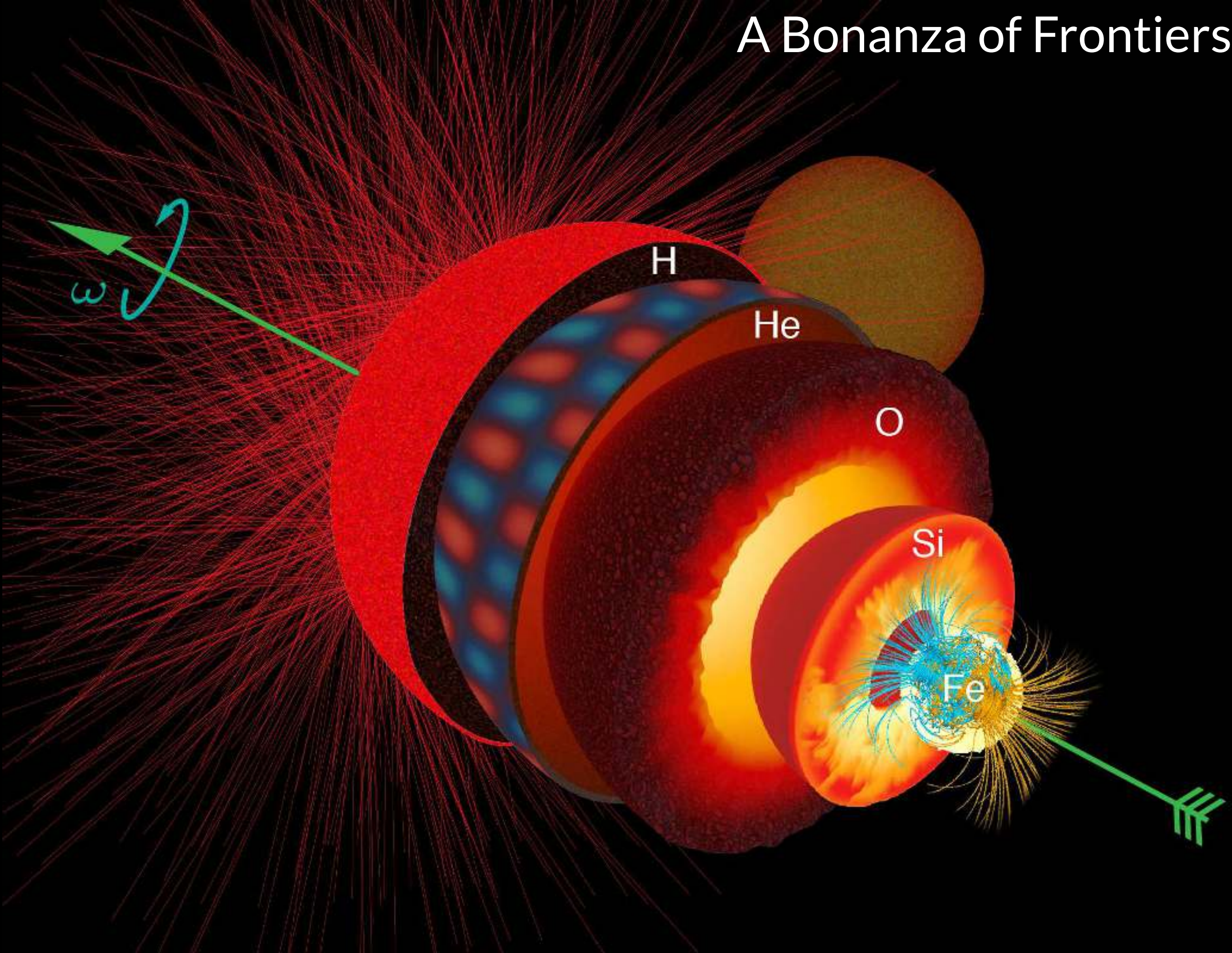
NSF

THE ASTROPHYSICAL JOURNAL

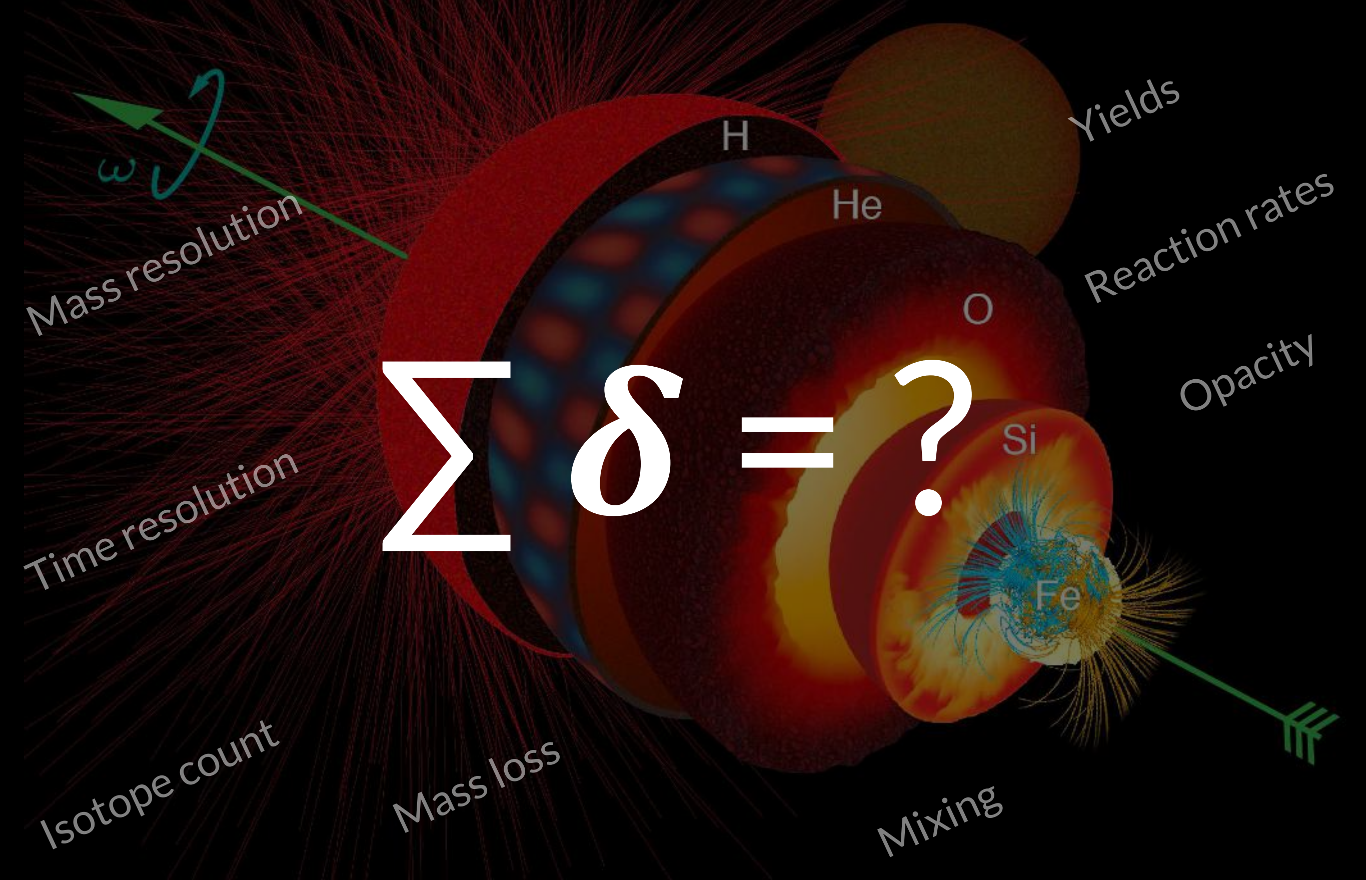
SIMONS FOUNDATION

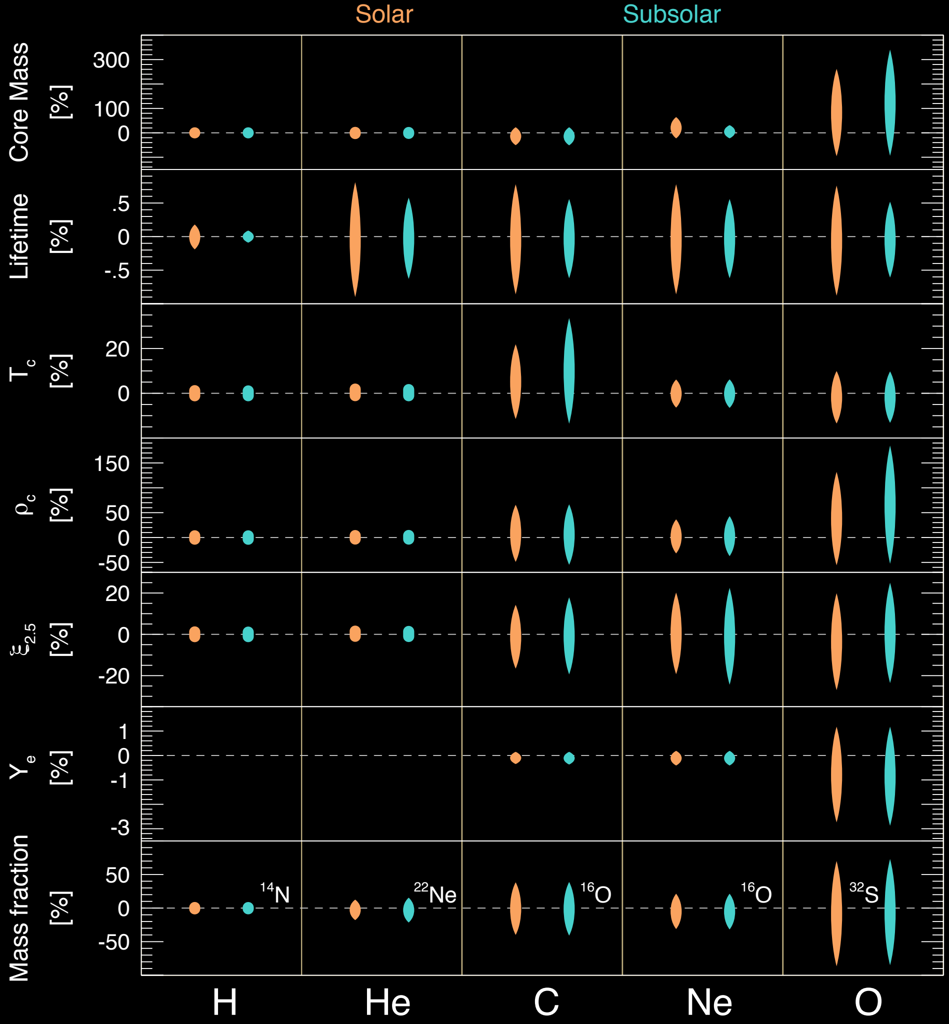
NASA

A Bonanza of Frontiers



How do the properties of our model stars vary with respect to the composite uncertainties?





Fields et al 2018

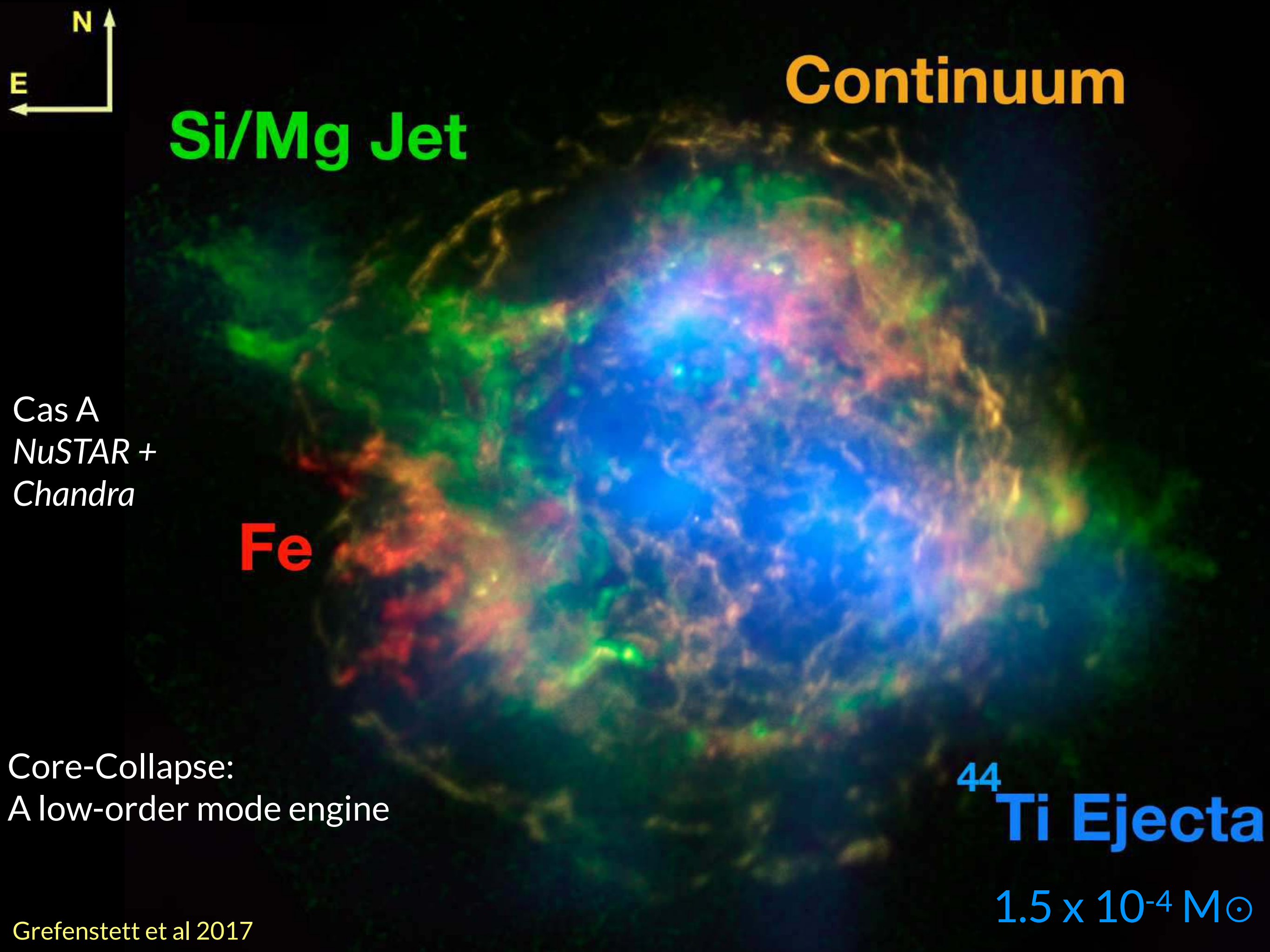
$$\sum \delta = ?$$

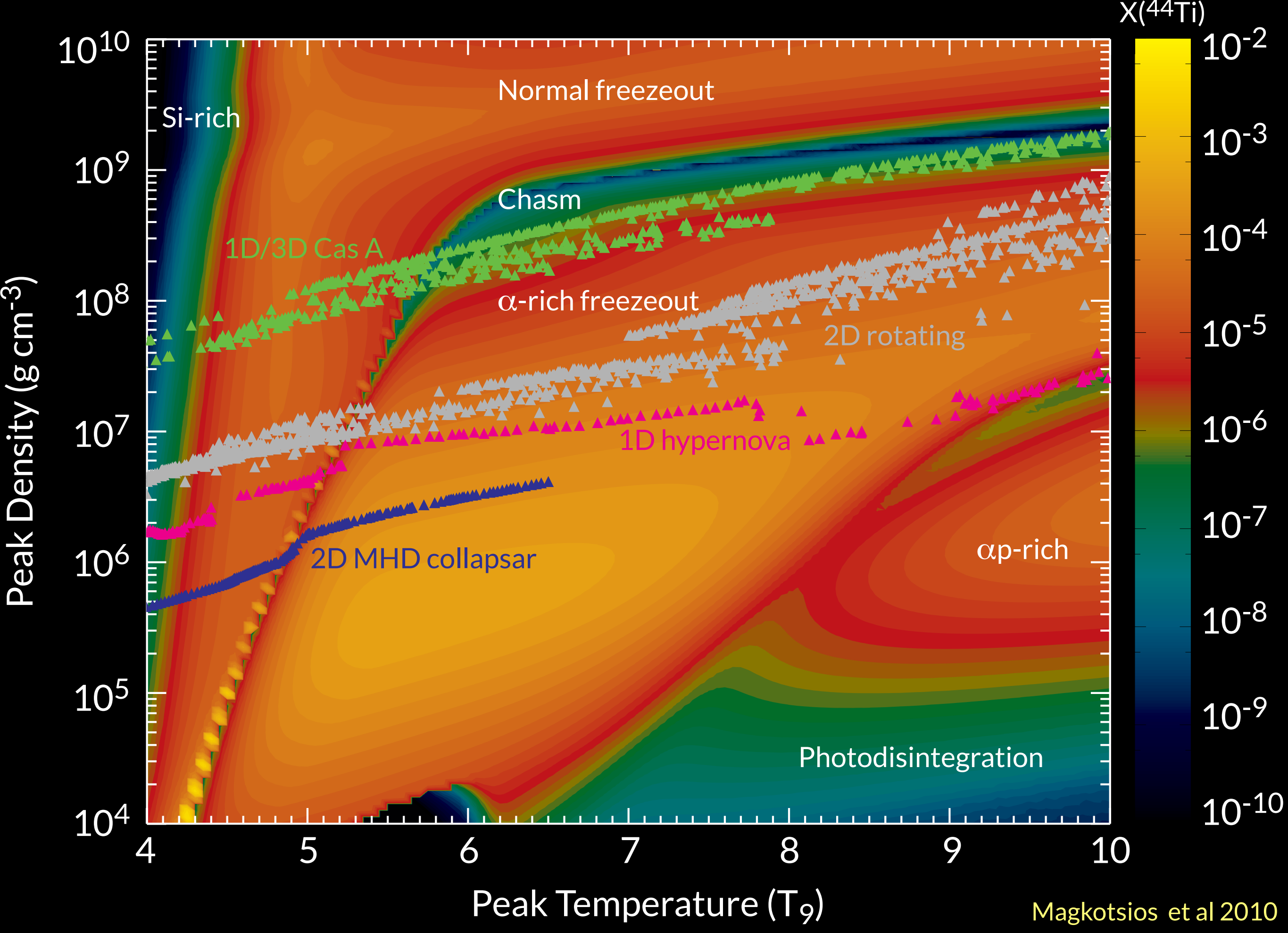
Property	15 $M_\odot$		20 $M_\odot$	
	$\dot{M} = 0$	$\dot{M} \neq 0$	$\dot{M} = 0$	$\dot{M}$
He_{core} $[M_\odot]^{a,b}$	$2.82^{2.82}_{2.79}$	$2.77^{2.78}_{2.72}$	$4.67^{4.70}_{4.59}$	4.
C_{core} $[M_\odot]$	$2.51^{2.58}_{2.49}$	$2.44^{2.53}_{2.43}$	$4.19^{4.75}_{4.04}$	4.
O_{core} $[M_\odot]$	$1.41^{1.43}_{1.35}$	$1.40^{1.42}_{1.32}$	$1.54^{2.47}_{1.43}$	1.
Si_{core} $[M_\odot]$	$1.15^{1.38}_{1.02}$	$1.15^{1.39}_{1.08}$	$1.38^{1.65}_{1.30}$	1.
$Ye_{c,He}{}^{b}$	$0.505^{0.505}_{0.505}$	$0.505^{0.505}_{0.505}$	$0.505^{0.505}_{0.505}$	0.
$Ye_{c,C}$	$0.499^{0.500}_{0.499}$	$0.499^{0.500}_{0.499}$	$0.499^{0.500}_{0.499}$	0.
$Ye_{c,O}$	$0.499^{0.500}_{0.498}$	$0.499^{0.500}_{0.498}$	$0.499^{0.500}_{0.498}$	0.
$Ye_{c,Si}$	$0.486^{0.498}_{0.475}$	$0.486^{0.498}_{0.475}$	$0.488^{0.498}_{0.483}$	0.

We don’t know the full answer yet,
but we have useful partial answers.

These γ-ray lines are interesting in astrophysics because they have a decay time larger than the source dilution time and/or have enough produced to overcome instrumental sensitivities:

Isotope	Mean Lifetime	Decay Chain	Energy (keV)	Source
^{7}Be	77 d	$^{7}Be \rightarrow {}^{7}Li^{*}$	478	Nova
^{56}Ni	111 d	$^{56}Ni \rightarrow {}^{56}Co^{*} \rightarrow {}^{56}Fe^{*} + e^{+}$	158, 812; 847, 1238	Supernova
^{57}Ni	390 d	$^{57}Co \rightarrow {}^{57}Fe^{*}$	122	Supernova
^{22}Na	3.8 y	$^{22}Na \rightarrow {}^{22}Ne^{*} + e^{+}$	1275	Nova
^{44}Ti	89 y	$^{44}Ti \rightarrow {}^{44}Sc^{*} \rightarrow {}^{44}Ca + e^{+}$	76, 68; 1157	Supernova
^{26}Al	1.04×10^{6} y	$^{26}Al \rightarrow {}^{26}Mg^{*} + e^{+}$	1809	Stars, SN, Nova
^{60}Fe	2.0×10^{6} y	$^{60}Fe \rightarrow {}^{60}Co^{*} \rightarrow {}^{60}Ni^{*}$	59, 1173, 1332	Stars, SN
e+	$\sim 10^{5}$ y	$e^{+} + e^{-} \rightarrow Ps \rightarrow \gamma\gamma$	511	SN,Nova, ...


N
E
Continuum
Si/Mg Jet
Cas A
NuSTAR +
Chandra
Fe
Core-Collapse:
A low-order mode engine
^{44}Ti Ejecta
1.5 x 10^{-4} M$_\odot$
Grefenstett et al 2017

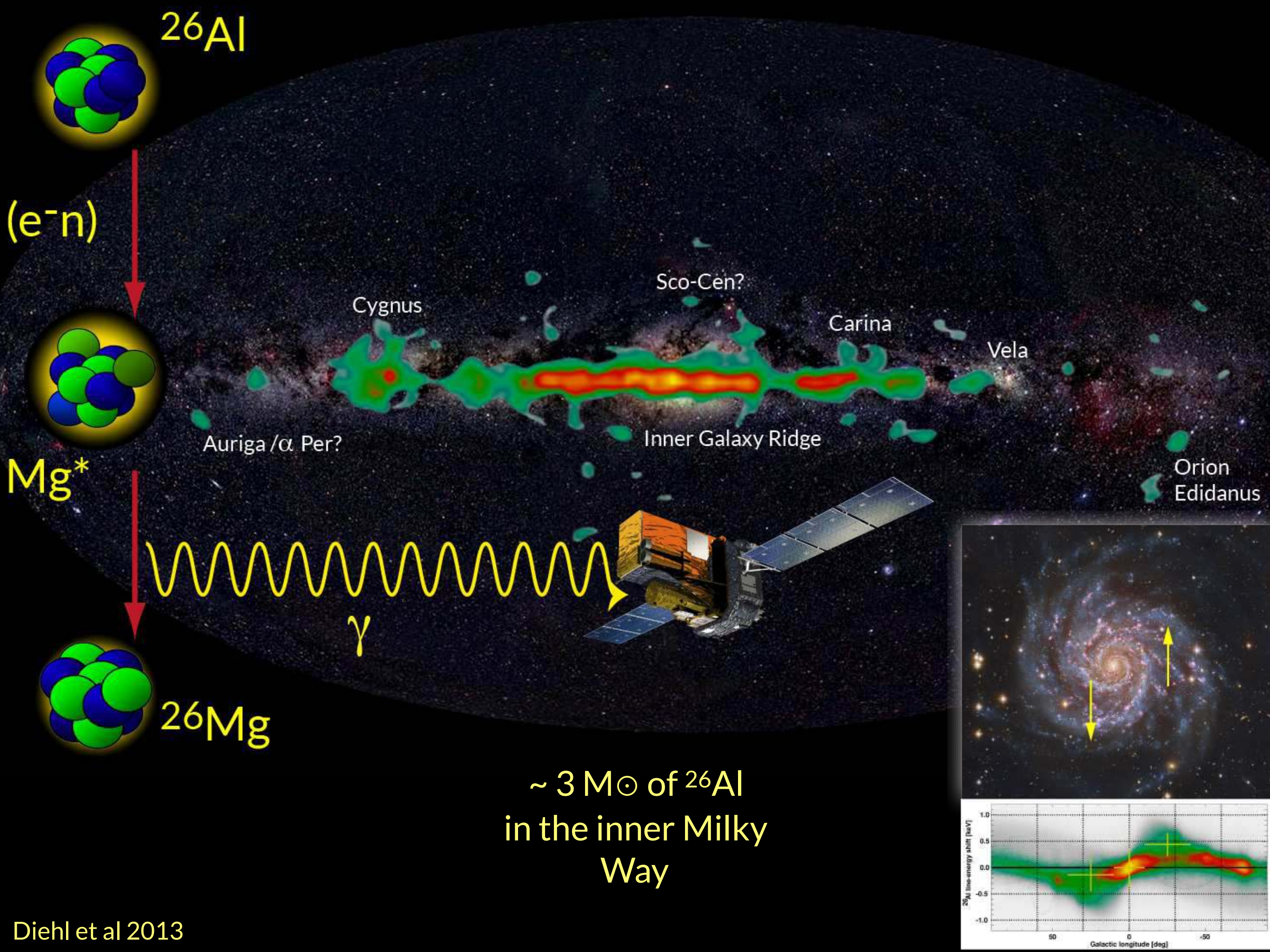


X(^{44}Ti)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
Normal freezeout
Si-rich
Chasm
1D/3D Cas A
α-rich freezeout
2D rotating
1D hypernova
2D MHD collapsar
αp-rich
Photodisintegration
Peak Density (g cm^{-3})
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
4
5
6
7
8
9
10
Peak Temperature (T_9)
Magkotsios et al 2010

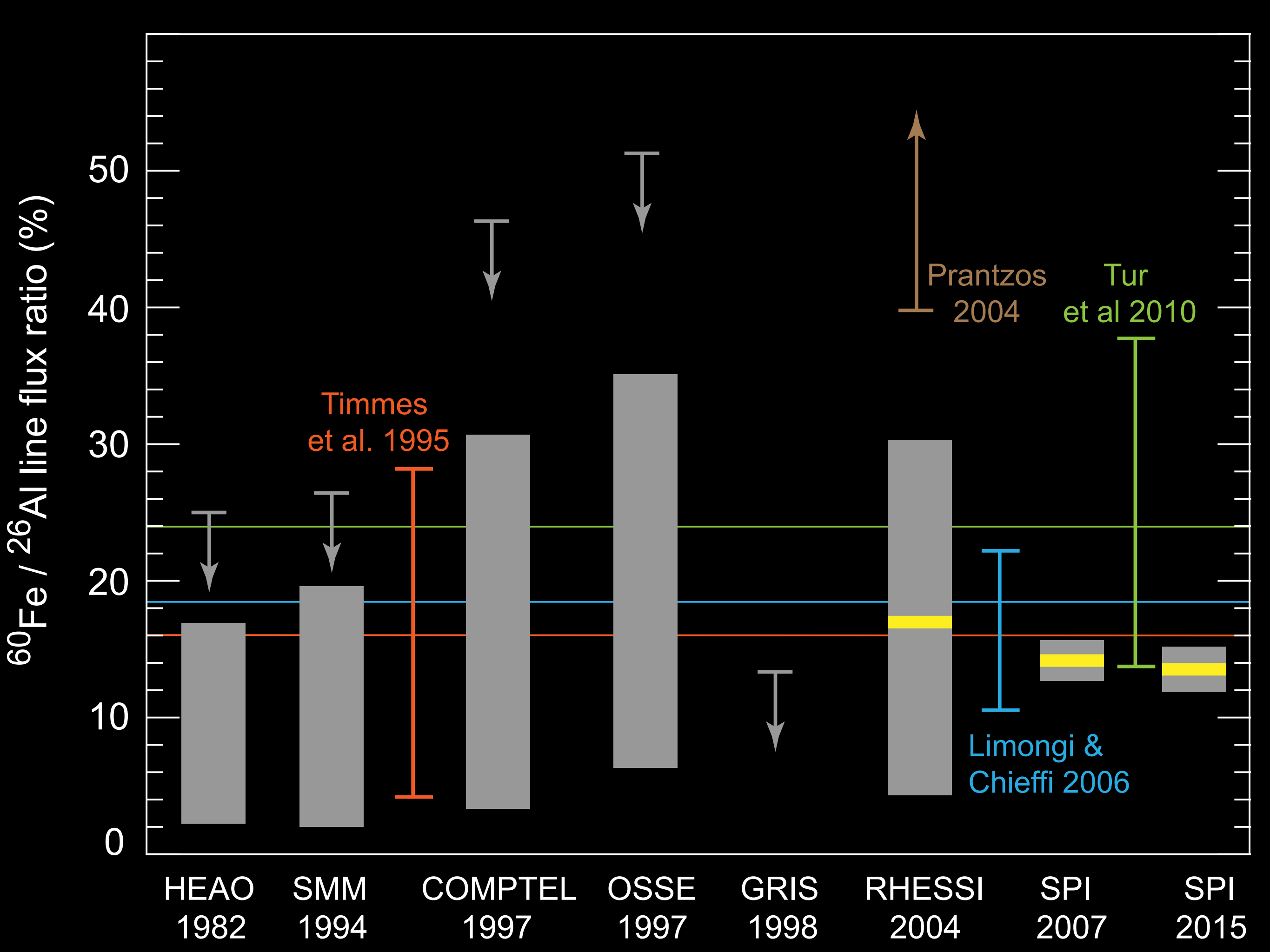
Critical laboratory astrophysics needs for NASA missions

Progress in a ^{44}Ti metric depends upon, but not solely upon, improvements in reaction rate measurements of

$^{44}Ti(\alpha,p)^{47}V$	$^{40}Ca(\alpha,\gamma)^{44}Ti$
$^{45}V(p,\gamma)^{46}Cr$	$^{40}Ca(\alpha,p)^{43}Sc$
$^{17}F(\alpha,p)^{20}Ne$	3α



26Al
(e⁻n)
Mg*
γ
26Mg
Cygnus
Sco-Cen?
Carina
Vela
Auriga /α Per?
Inner Galaxy Ridge
Orion
Edidanus
~ 3 M⊙ of 26Al
in the inner Milky
Way
Galactic longitude [deg]
Diehl et al 2013

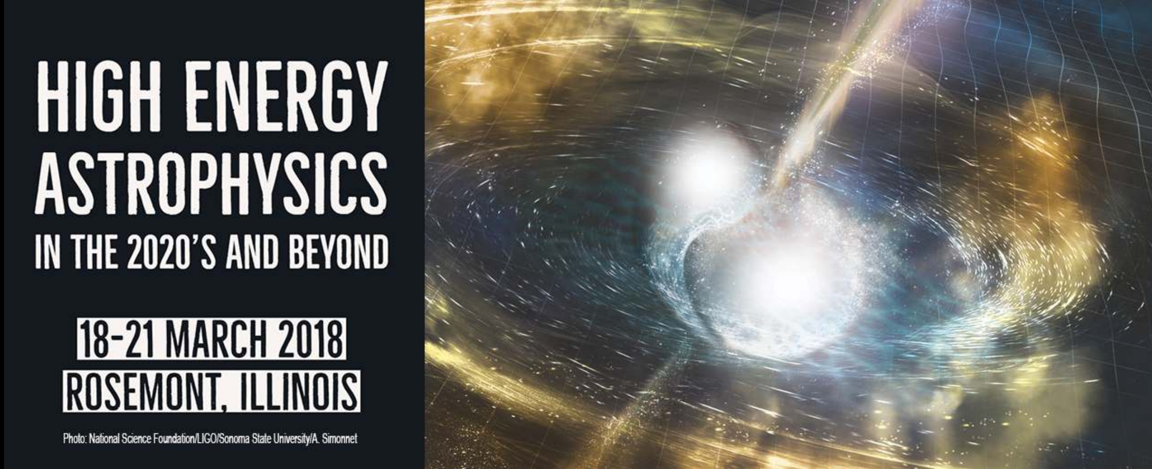

60Fe / 26Al line flux ratio (%)
0
10
20
30
40
50
Prantzos
2004
Tur
et al 2010
Timmes
et al. 1995
Limongi &
Chieffi 2006
HEAO
1982
SMM
1994
COMPTEL
1997
OSSE
1997
GRIS
1998
RHESSI
2004
SPI
2007
SPI
2015

Critical laboratory astrophysics needs for NASA missions

Progress in ^{26}Al and ^{60}Fe depends upon, but not solely upon, improvements in reaction rate measurements of

^{26}Al(n,p)^{26}Mg	^{26}Al(n,α)^{23}Na
^{59}Fe(n,γ)^{60}Fe	^{60}Fe(n,γ)^{61}Fe
^{22}Ne(α,n)^{25}Mg	^{59}Fe(e^{-} ν_e)^{50}Co

Also see Debra Richman’s presentation.



August 20-22, Los Alamos, NM

Also revisit Robert Petre's presentation.

LOX

Lunar Occultation Explorer

LOX is a New Paradigm that is…

- Inherently scalable, low-risk, and cost-effective
- Capable of achieving competitive game-changing sensitivity
- Relevant as an *Explorer*- or *Probe*-class mission, or on the *Deep Space Gateway*

with Science Goals that Address Decadal Review Findings and Areas of Unusual Potential Discovery…

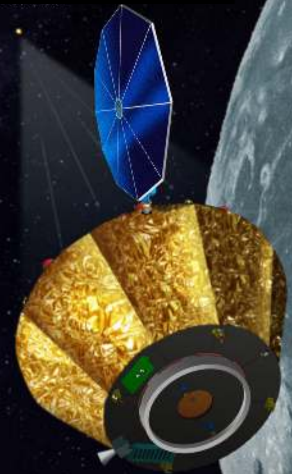
- Time-domain (nuclear) astrophysics & surveys
- What are the Progenitors of SNeIa and how do they explode?
- Why is the Universe accelerating?
- How do stars form?
- What controls the mass-energy-chemical cycles within galaxies?

and Establish the Moon as a Platform for Science…

- Employs the Lunar Occultation Technique
- Benefits from the unique lunar environment
- Leverages 20+ years of lunar nuclear science & operations

by Deploying the BAGEL Spectrometer to Lunar Orbit

- The Big Array for Gamma-Ray Energy Logging (*BAGEL*) contains high-TRL phoswich gamma-ray spectrometer modules
- Configured to operate as a single instrument
- Energy: 0.1-10 MeV, <10% FWHM @ 0.662 MeV

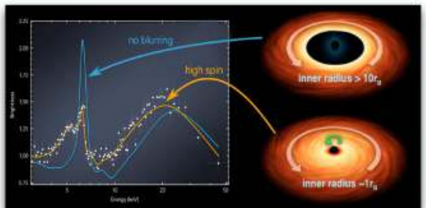


Johns Hopkins Applied Physics Laboratory
Richard S. Miller (PI)
richard.s.miller@jhuapl.edu
(240) 592-1576

HEX-P: The High-Energy X-ray Probe

- Probe-class hard X-ray focusing observatory
- NuSTAR heritage
- Cost: ~$600M

	HEX-P	NuSTAR
bandpass	2-200 keV	3-79 keV
angular resolution	15″	60″
spectral resolution	200 eV @ 6 keV 0.8 keV @ 60 keV	600 eV @ 6 keV 1.2 keV @ 60 keV
timing resolution	1 µsec	1 µsec
field of view	13′ × 13′	13′ × 13′
Focal Length	20 m	10 m



Key Science Topics

Physics of neutron stars and black holes (stellar mass and supermassive)

- Black hole spin
- Physics of the X-ray emitting corona
- Relativistic outflows + feedback
- X-ray reverberation studies to measure geometry of central engine
- Super-Eddington accretion

Resolving the CXB

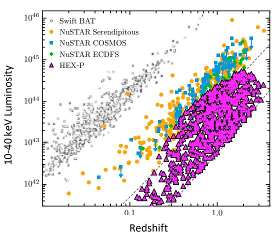
- HEX-P will resolve 90-95% of the CXB at its 20 keV peak
- Study the dominant population of heavily obscured AGN

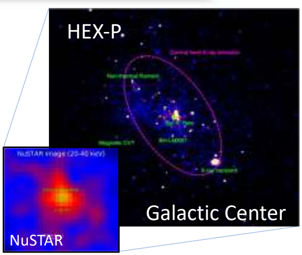
Supernova physics

Dark matter decay

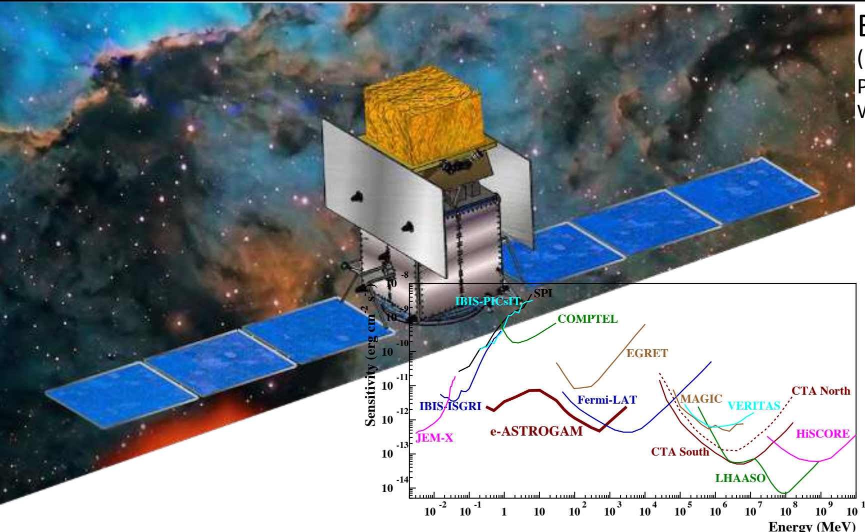
Galactic Center and Sgr A*

Hard X-ray population studies of nearby galaxies

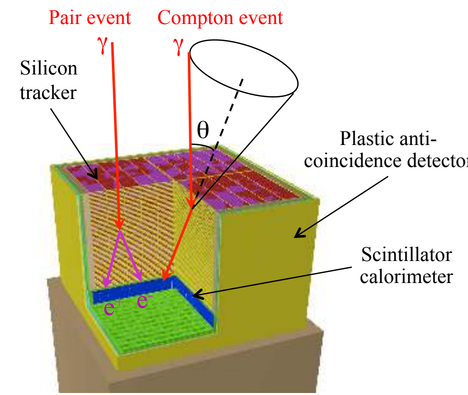




e-ASTROGAM Mission proposed for ESA M5



ESA Selection for phase A: May 2018
(13 proposals short-listed with eAstrogam)
PIs: A. de Angelis, V. Tatischeff; ~150 groups in EUR
WhiteBook: arxiv 1710.01265V2 16Mar2018

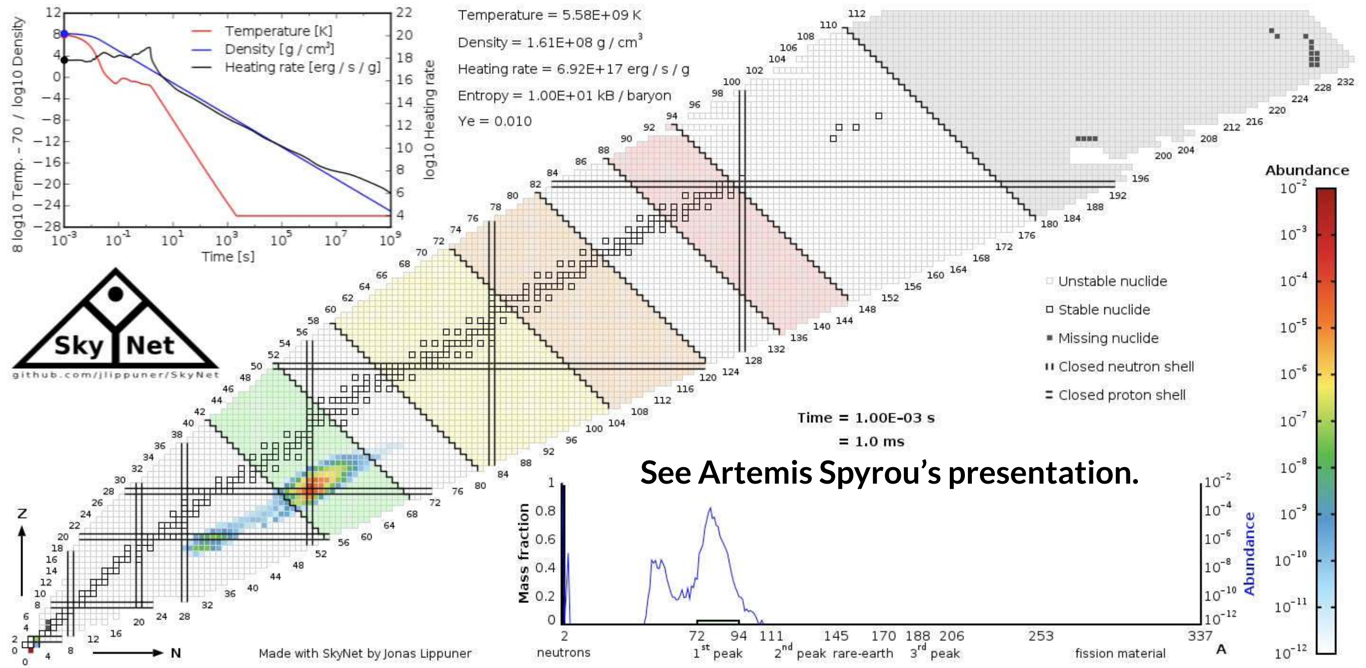


- **Tracker** → Double-sided Si strip detectors (DSSDs) for excellent spectral resolution and fine 3-D position resolution → 56 layers, 5600 DSSDs, 500 mm thick and 240 mm pitch, bonded strip to strip to form 5×5 ladders, 4 stacks
- **Calorimeter** - High-Z material to absorb scattered photon → 33 856 CsI(Tl) bars coupled at both ends to low-noise Silicon Drift Detectors for better energy resolution
- **Anticoincidence detector** to veto charged-particle induced background → plastic scintillators readout by Si PMTs

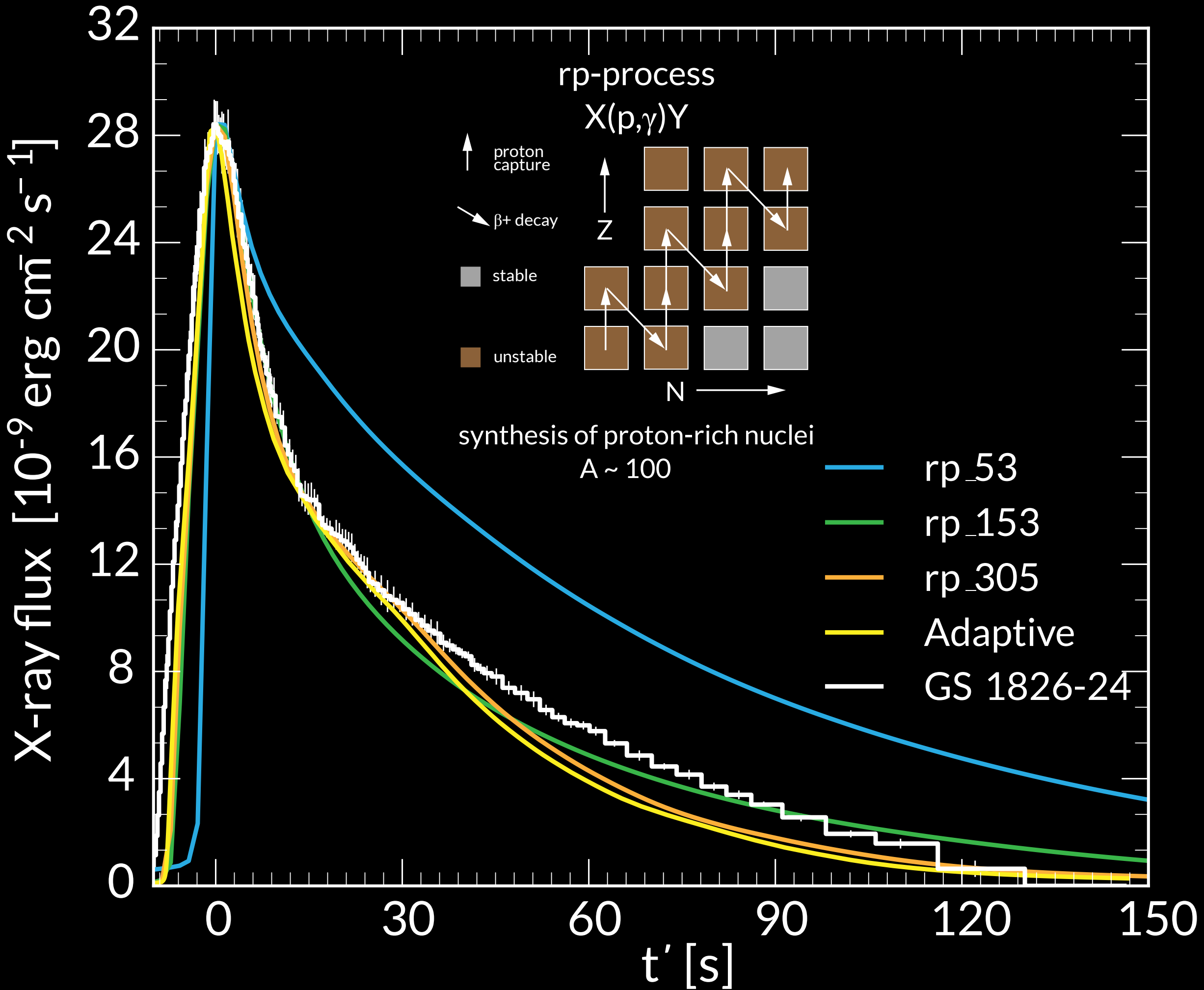
Parameter	Value
Energy bands:	0.3 MeV – 3 GeV (Gamma-ray imager: Tracker + Calorimeter) 30 keV – 200 MeV (Calorimeter burst search)
Gamma-ray imager FOV (at 100 MeV)	$\geq$ 2.5 sr
Gamma-ray imager Continuum flux sensitivity at 3σ confidence level	$< 2\times10^{-5}$ MeV cm^{-2} s^{-1} at 1 MeV ($T_{obs} = 10^6$ s effective observation time) $< 5\times10^{-5}$ MeV cm^{-2} s^{-1} at 10 MeV ($T_{obs} = 10^6$ s, high-latitude source) $< 3\times10^{-6}$ MeV cm^{-2} s^{-1} at 500 MeV ($T_{obs} = 10^6$ s, high-latitude source)
Gamma-ray imager Line flux sensitivity at 3σ confidence level	$< 5\times10^{-6}$ ph cm^{-2} s^{-1} for the 511 keV line ($T_{obs} = 10^6$ s effective obs. time) $< 5\times10^{-6}$ ph cm^{-2} s^{-1} for the 847 keV SN Ia line ($T_{obs} = 10^6$ s) $< 3\times10^{-6}$ ph cm^{-2} s^{-1} for the 4.44 MeV line from LECRs ($T_{obs} = 10^6$ s)
Gamma-ray imager angular resolution	$\leq$ 1.5° at 1 MeV (FWHM of the angular resolution measure) $\leq$ 1.5° at 100 MeV (68% containment radius) $\leq$ 0.2° at 1 GeV (68% containment radius)
AC particle background rejection efficiency	> 99.99 %
Polarization sensitivity	MDP < 20% (99% c.l.) for a 10 mCrab source (0.3-2 MeV, T_{obs} = 1 yr) Detection of a polarization fract. ≥ 20% in more than 20 GRBs per year
ΔE/E (Gamma-ray imager)	3.0% at 1 MeV 30% at 100 MeV
ΔE/E (Calorimeter burst)	< 25% FWHM at 0.3 MeV < 10% FWHM at 1 MeV < 5% FWHM at 10 MeV
Time tagging accuracy	1 microsecond (at 3 sigma)

Critical laboratory astrophysics needs for NASA missions

For r-process abundances, the properties of $^{132-136}$Cd, $^{134-138}$In, $^{136-140}$Sn have the largest impact globally. Nuclei near $^{159-161}$Nd have the largest impact locally on the rare earth peak.



See Artemis Spyrou's presentation.



rp-process
X(p,γ)Y
proton capture
β+ decay
stable
unstable
Z
N
synthesis of proton-rich nuclei
A ~ 100
rp_53
rp_153
rp_305
Adaptive
GS 1826-24
X-ray flux [10-9 erg cm-2 s-1]
t′ [s]
0
4
8
12
16
20
24
28
32
0
30
60
90
120
150

Critical laboratory astrophysics needs for NASA missions

Progress in the rp-process depends upon, but not solely upon, improvements in reaction rate measurements of

$^{15}O(\alpha,\gamma)^{19}Ne$ - a flow bottleneck

$^{22}Mg(\alpha,p)^{23}Al$ - to assess theoretical rates

(p,γ) vs (p,α) branching - at ^{59}Cu

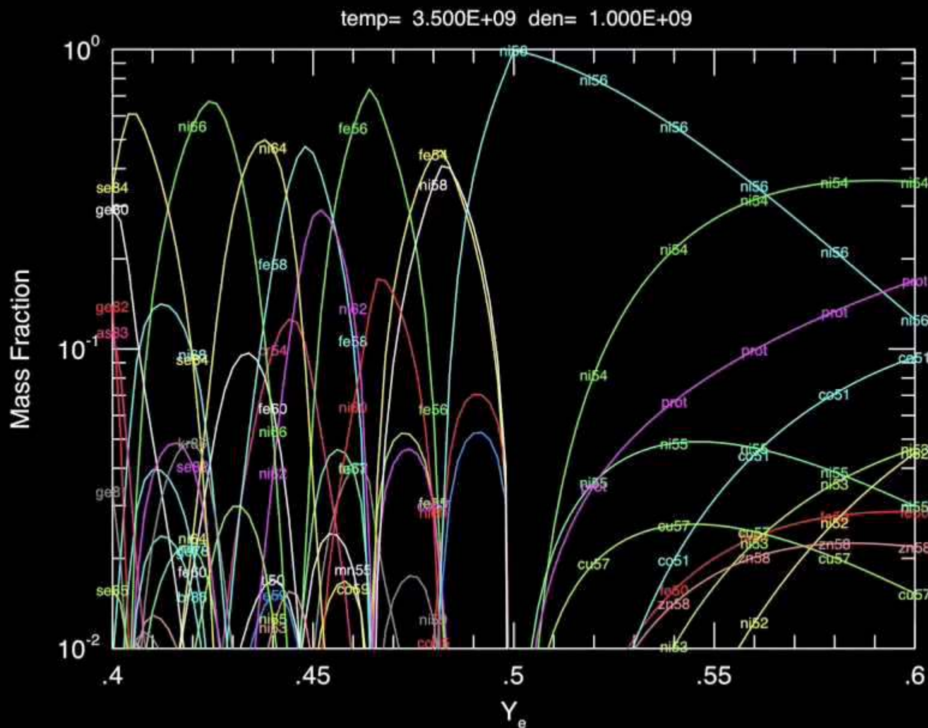
$^{30}P(p,\gamma)^{31}S$

See Christopher Fontes' presentation.

Critical laboratory astrophysics needs for NASA missions

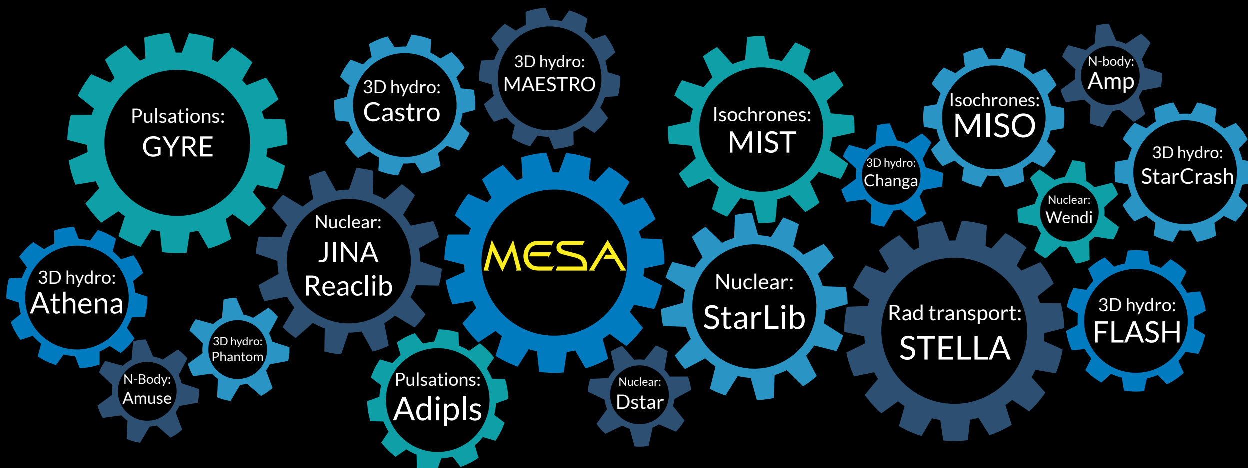
Improved weak reaction rates to advance the accuracy of the neutron/proton ratio in stellar models:

- ^{33}S
- ^{35}Cl
- $^{52-53}$V
- $^{53-55}$Cr
- $^{53-58}$Mn
- $^{55-64}$Co
- $^{53-59}$Fe
- $^{56-61}$Ni



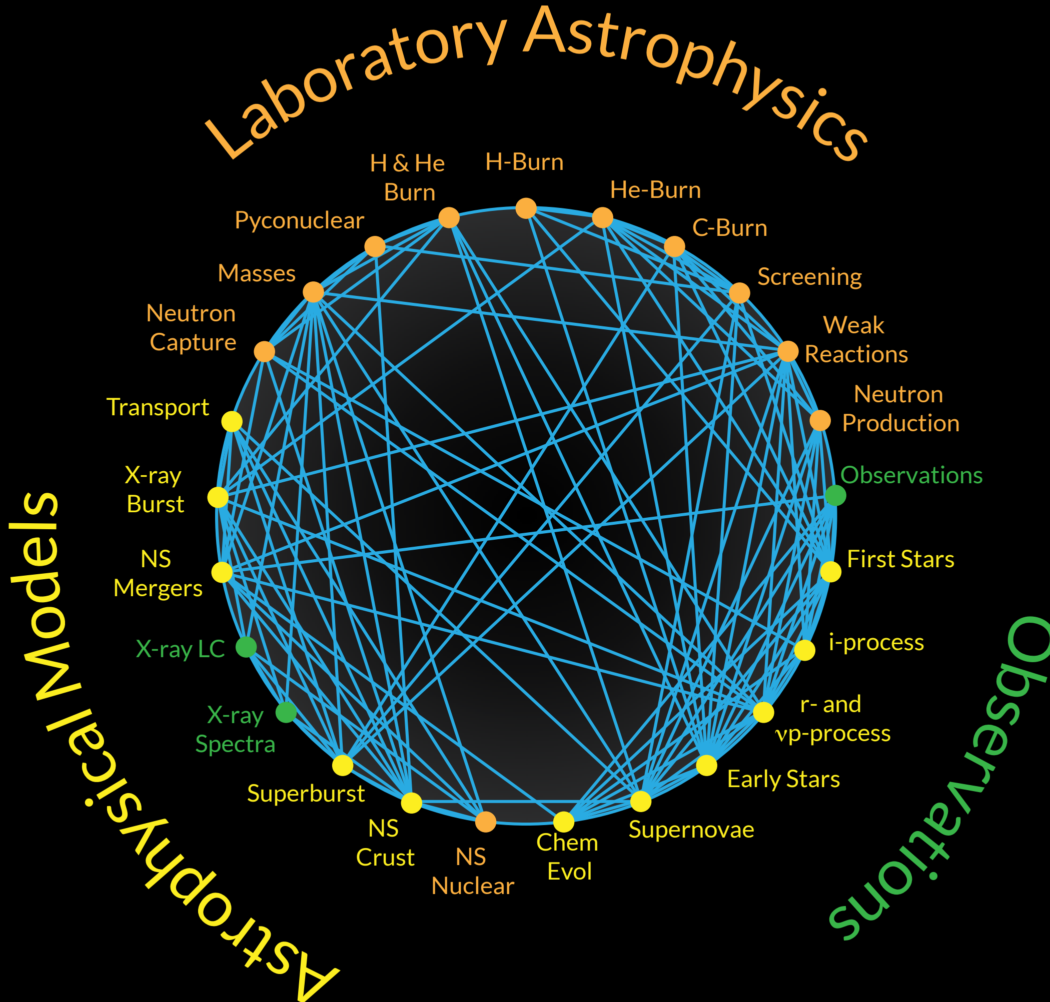
Critical community-driven software and data infrastructure for NASA missions.

LIGO Kepler SDSS Zwicky NuSTAR



GAIA LSST LCO JWST Pan-STARRS1

See Keith Arnaud’s and Marie-Lise Dubernetand’s presentations.



Laboratory Astrophysics
Astrophysical Models
Observations
H & He Burn
H-Burn
He-Burn
C-Burn
Screening
Weak Reactions
Neutron Production
Observations
First Stars
i-process
r- and νp-process
Early Stars
Supernovae
Chem Evol
NS Nuclear
NS Crust
Superburst
X-ray Spectra
X-ray LC
NS Mergers
X-ray Burst
Transport
Neutron Capture
Masses
Pyconuclear

The SOC would like to ask you to give an overview of the critical needs in laboratory astrophysics as related to r-process and other nuclear reactions, and sensitivities to models due to nuclear input uncertainities. In particular, the focus should be on modeling observations from NASA current and near-term high-energy (X-ray, Gamma-ray, etc.) astrophysics missions. We request you consult with the nuclear astrophysics modeling and observational communities and attempt to be as inclusive as possible with particular attention to high priority laboratory needs (e.g., lanthanide r-process rates). The talk will be 25 minuts in length with an additional 5 minutes for questions.

The goal of the workshop is to identify and prioritize critical laboratory astrophysics needs to enable NASA to maximize the scientific return from its current and future astrophysics missions. To that end, the meeting will also involve panel discussions with the speakers and break-out sessions in order to allow for community input and to aid the SOC in writing a report on recommendations to NASA. We hope that you can participate in these important activities as well.