Modelling uncertainty of the Rhenium-Osmium cosmic clock

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Svein Rosselands hus 209

What is a cosmic clock?

Why use ${}^{187}_{75}$Re-${}^{187}_{76}$Os?

$^{187}_{75}$Re-$^{187}_{76}$Os

Advantages

Halflife	$T_\beta = 43.3$ Gyr[1] $(\lambda_\beta = \frac{\ln 2}{T_\beta})$
Different sources	Slow and rapid neutron capture process

[1] IAEA Nuclear Data Service Livechart

Nucleosynthesis

How was the nuclear elements created?

- Big bang nucleosynthesis
- Fusion of lighter elements (up to iron)
- Neutron capture processes

  slow β^--decays before succesive neutron capture
  rapid capture multiple neutrons before β^--decay

Slow and rapid neutron capture around ${}^{187}_{75}$Re-${}^{187}_{76}$Os

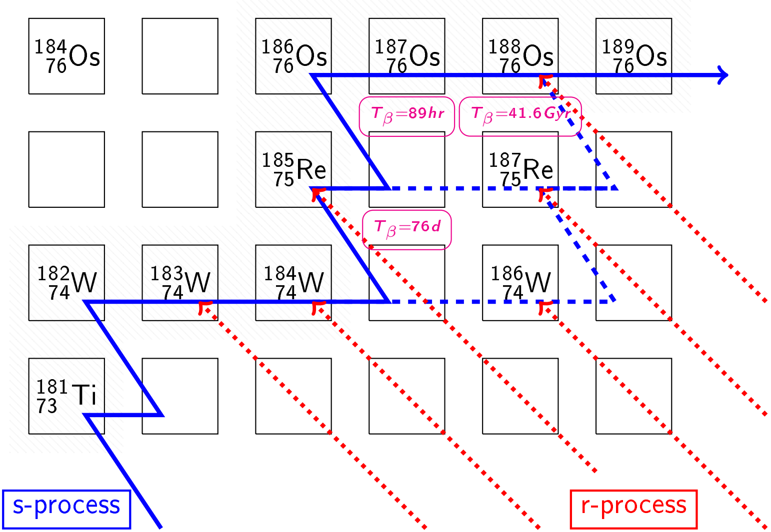


Figure: Adopted from fig.1 in Clayton (1964)

Analytical models of ${}^{187}_{75}\mathrm{Re}$-${}^{187}_{76}\mathrm{Os}$ cosmic clock

$$\frac{dN}{dt} = -\lambda N$$

$${}^{187}_{76}\mathrm{Os}_{\odot} = {}^{187}_{76}\mathrm{Os}_s + {}^{187}_{76}\mathrm{Os}_p + {}^{187}_{76}\mathrm{Os}_c$$

$$\frac{d}{dt}\left[{}^{187}_{76}\mathrm{Os}_c\right] = \lambda_\beta\, {}^{187}_{75}\mathrm{Re}$$

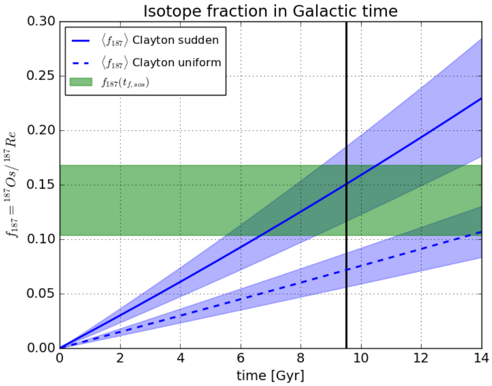
$$\frac{d}{dt}\left[{}^{187}_{75}\mathrm{Re}\right] = A(t) - \lambda_\beta\, {}^{187}_{75}\mathrm{Re}$$

Using the analytical model from Clayton (1964)

$$A(t) = A_0 e^{-\lambda_r t}$$

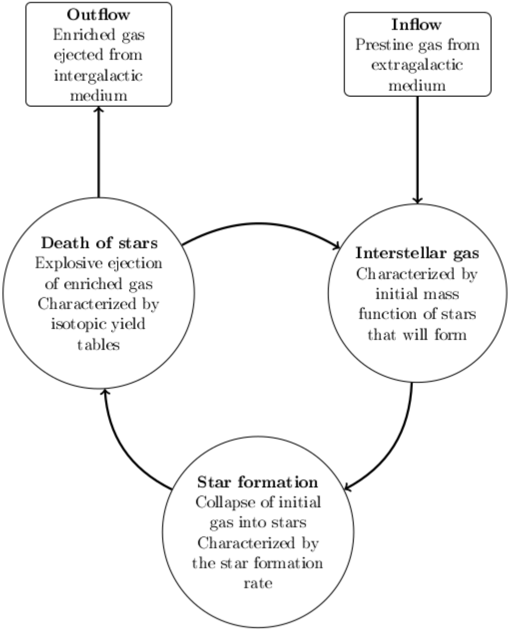
$$f_{187} \equiv \frac{{}^{187}_{76}\mathrm{Os}_c}{{}^{187}_{75}\mathrm{Re}} = \frac{\frac{\lambda_\beta}{\lambda_r}(1 - e^{-\lambda_r t}) - (1 - e^{-\lambda_\beta t})}{e^{-\lambda_r t} - e^{-\lambda_\beta t}}$$

Observed isotope fraction from meteorites and solar atmosphere



Observed isotope fraction from meteorites (Shizuma, T. et al. 2005, Bouvier, A. et al. 2010, Snelling, A.A. 2015)

Chemical enrichment of galactic medium

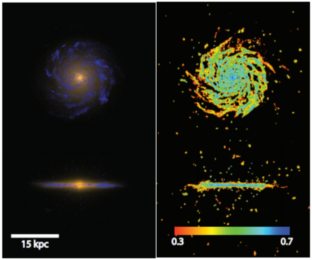


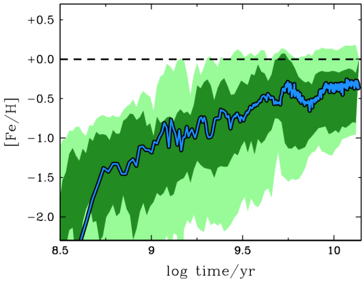
Explosive events

- Asymptotic giant branch stars (not really explosive)
- Core collapse supernovae
- Type 1a supernovae
- Neutron star mergers

Eris simulation

THE ASTROPHYSICAL JOURNAL, 742:76 (10pp), 2011 December 1





- Smoothed particle hydrodynamics simulation (Guedes et al. 2011)
- 3D
- 18.6 million particles
- Postprocessing to add rapid neutron capture elements from neutron star mergers (Shen et al. 2015)

Figures/images from Guedes et al. (2011) and Shen et al. (2015)

Omega semianalytical model (Côté 2016)

- SFR + timestep $\rightarrow$ stellar mass formed
- stellar mass formed $\rightarrow$ stellar population
- stellar population + yield tables + delay-time $\rightarrow$ isotopic yields recycled into ISM + remnant
- remnants $\rightarrow$ secondary events

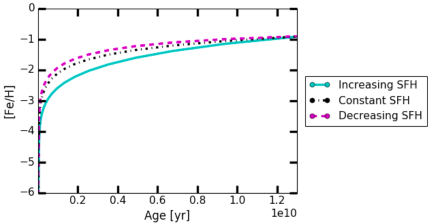
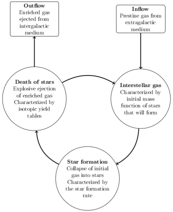


Figure: Image from `github.com/NuGrid/NuPyCEE/`



Modelling uncertainty of the Rhenium-Osmium cosmic clock

Methods

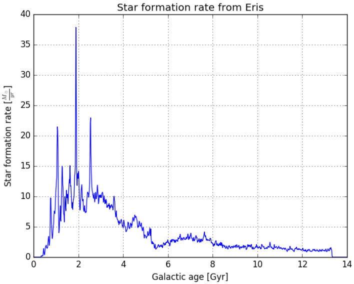
- Fitting `Omega` to data from `Eris`
- Manipulate yields in `Omega`
- Main experiments
- Postprocessing

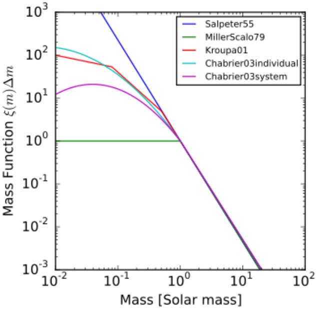
Fitting Omega to data from Eris

- Rough model
- "χ^2-by-eye"
- Star formation rate, stellar mass, total mass, [O/H], [Fe/H], [Eu/H]

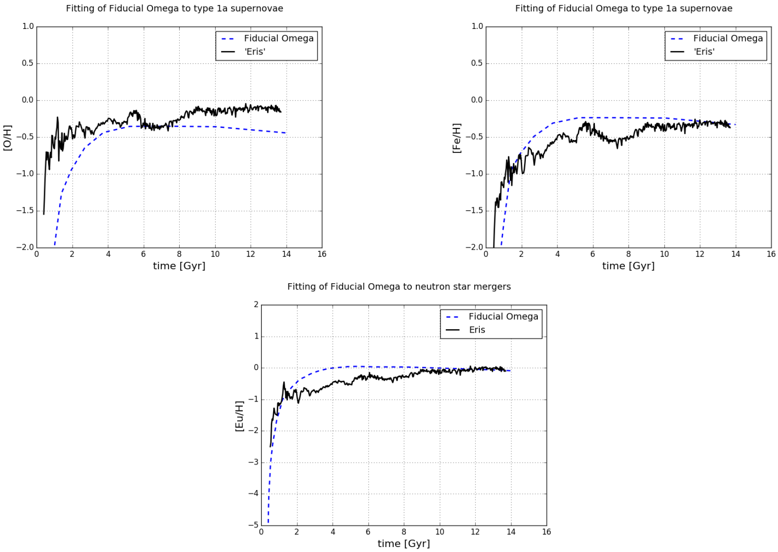
- Direct insertion
- Mass content
- type 1a supernovae
- Neutron star mergers
- Size of timesteps

Fitting Omega to data from Eris

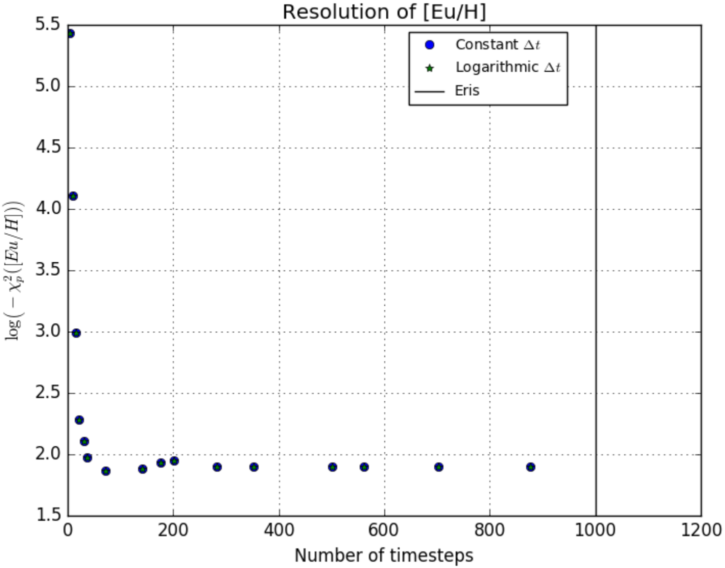




Fitting Omega to data from Eris



Size of time steps



Manipulate yields in Omega

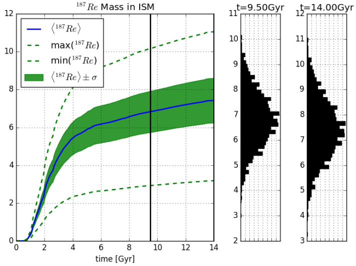
isotope	standard	min	max	σ_{lower}	σ_{upper}
Re-187	0.0318	0.027	0.0359	-0.1509	0.1289
Re-185	0.0151	0.011	0.0176	-0.2715	0.1656
Os-188	0.0707	0.0633	0.0781	-0.1047	0.1047
Os-189	0.103	0.0961	0.109	-0.067	0.0583
Os-190	0.152	0.137	0.168	-0.0987	0.1053
Os-192	0.273	0.252	0.289	-0.0769	0.0586
Eu-151	0.0452	0.0267	0.0482	-0.4093	0.0664
Eu-153	0.0495	0.046	0.0526	-0.0707	0.0626

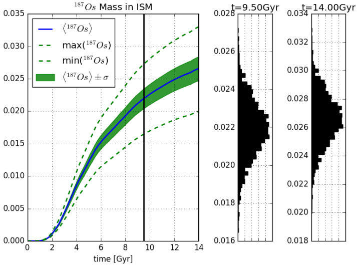
Table: Values and uncertainties of r-process nuclei near $^{187}_{75}$Re from (Arnould et al. 2007)

Main experiments

- Draw random "fudge-factor" from gaussian distribution
- 1500 individual calculations
- **Yields**
- **Yields+IMFslope**
- **Yields+IMFslope+NSM**

Results - **Yields** without postprocessing





Postprocessing

β^--decay

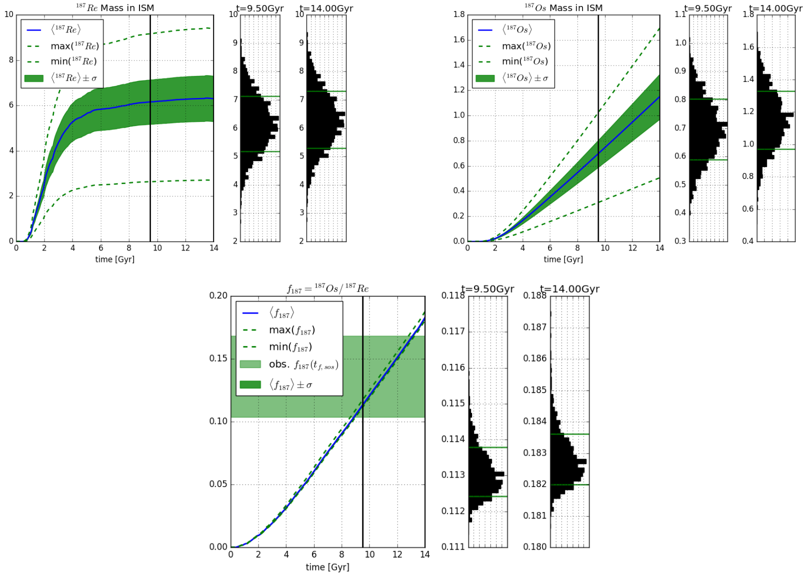
$^{187}_{75}\mathrm{Re} \rightarrow {}^{187}_{76}\mathrm{Os} + e^- + \bar{\nu}_e$

- $\Delta\mathrm{Re} = -\lambda_{\mathrm{Re}}\mathrm{Re}\Delta t$
- $\Delta\mathrm{Os} = \lambda_{\mathrm{Re}}\mathrm{Re}\Delta t$

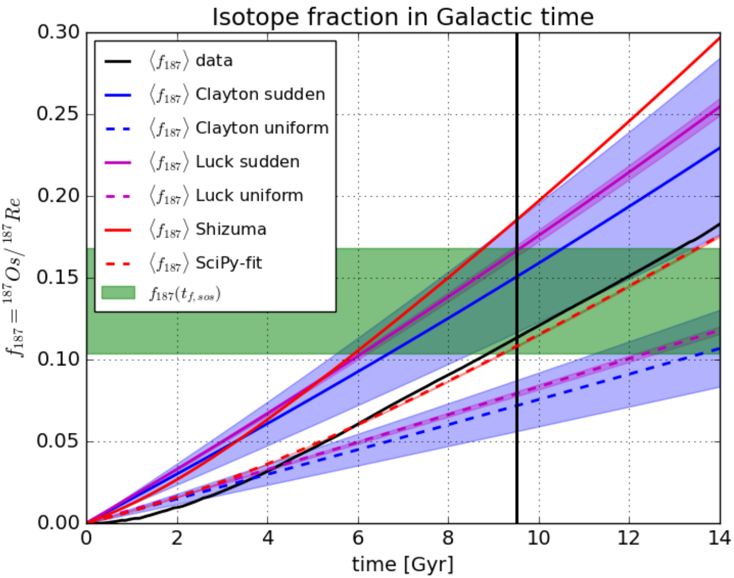
Removing negative negative yields

- $\hat{Y} \leq 0 \rightarrow$ Do not consider calculation

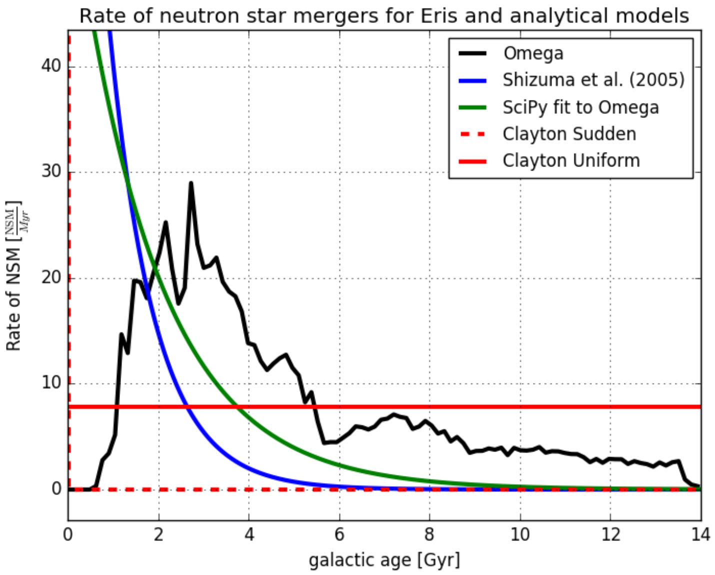
Results - **Yields** with postprocessing



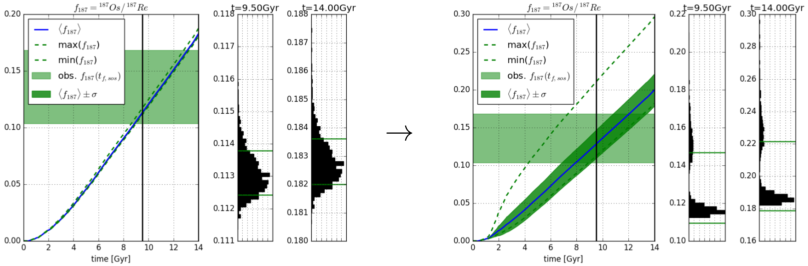
Comparing models



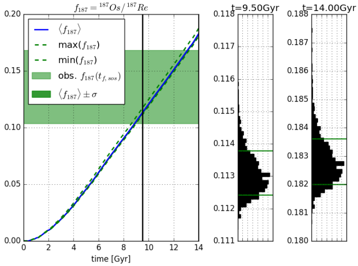
Comparing models



Results - Uncertainties of **Yields+IMFslope**



Results - Uncertianties of **Yields+IMFslope+NSM**



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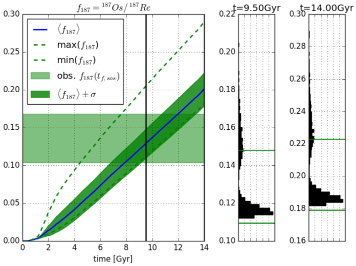
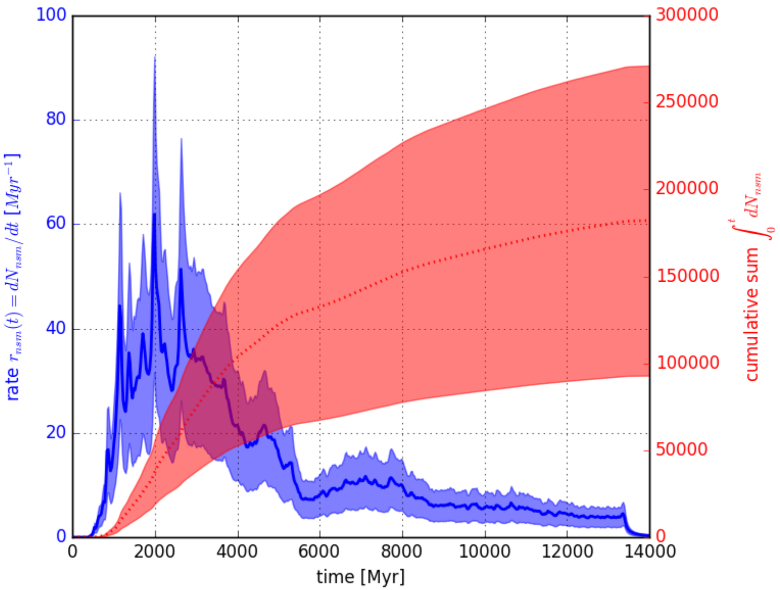


Results - Uncertianties of **Yields+IMFslope+NSM**



Conclusions/summary

- **Yields**
- **Yields+IMFslope**
- **Yields+IMFslope+NSM**

- Uncertainties with and without β^--decay
- Uncertainties of models and observations
- Little uncertainty from nuclear r-process abundance
- Additional uncertainties from the slope of the *Initial Mass Function*
- Additional uncertainties from *Neutron Star Mergers*