Modelling uncertainty of the Rhenium-Osmium cosmic clock

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Svein Rosselands hus 209

Intro

Theory (10 min)

- basics of nuclear physics and reactions
- neutron capture processes
- stellar evolution and galactic enrichment
- Omega
- Eris

Nuclear physics

atom + chart of nuclides
shell-model
reaction rates + β^--decay
neutron-capture reactions
slow and rapid neutron capture
climbing in the chart of nuclides
Re-Os system + analytical model

Stellar environments

AGB + massive + SN2

SN1a + BNSM + BHNSM

yield-tables

Galaxies

gravitational collapse of gas and dark matter
star formation from GMC
inflow from surrounding medium
outflow from supernovae

Eris

SPH

properties

postprocessing

sfr + total mass + [O/H] + [Fe/H] + [Eu/H]

Omega

SFR + timestep -> stellar mass formed

stellar mass formed -> stellar population

stellar population + yield tables + delay-time -> isotopic yields

recycled into ISM + remnant

remnants -> secondary events

What is a cosmic clock?

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

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

Halflife: TODO! Different sources: slow and rapid neutron capture process

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

TODO! insert tikz-figure from clayton

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

TODO! calculations and citations to appendix A

Observed isotope fraction from meteorites and solar atmosphere

TODO! calculatations and citations from appendix A

Chemical enrichment of galactic medium

TODO! insert tikz-figure of recycling

Explosive events

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

Eris simulation

TODO! insert eris-image

- Smoothed particle hydrodynamics simulation *[?]*
- TODO! Add more simulation details? number of particles etc.
- Postprocessing to add rapid neutron capture elements from neutron star mergers *[?]*

Omega semianalytical model [?]

- 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

Modelling uncertainty of the Rhenium-Osmium cosmic clock

Methods

- Fitting `Omega` to data from `Eris`
- Manipulate yields in `Omega`
- Main experiments TODO! rewrite this
- Postprocessing

Fitting Omega to data from Eris

- TODO! rough model
- TODO! chi2-by-eye
- TODO! data available
- Steps

Direct Insertion

Mass

Stellar parameters

Neutron star mergers

Time steps

Final model

Manipulate yields in `Omega`

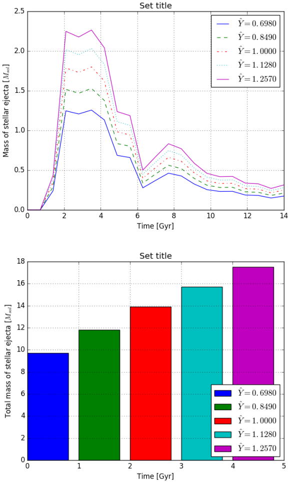
- Yields from arnould and other TODO!
- Fudge-factors TODO!
- Linear relationship

Table of observed abundances

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 *[1]*. The relative uncertainty, σ-values, are calculated on the assumption that min/max are the one-sigma standard deviations in either direction.

Chemical evolution of $^{187}_{75}\text{Re}$



Statistical deviation of $^{187}_{75}\mathrm{Re}$

σ_{init}	$\sigma_{ISM}(z=0)$	$\Sigma\sigma_{ISM}$	$\sigma_{\dot{m}}(z=0)$	$\Sigma\sigma_{\dot{m}}$
-0.302	-0.301887	-0.301887	-0.301887	-0.301887
0.128	0.128931	0.128931	0.128931	0.128931
0.257	0.257862	0.257862	0.257862	0.257862
0	0	0	0	0
-0.151	-0.150943	-0.150943	-0.150943	-0.150943

Main experiments TODO! rewrite this

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

Postprocessing

β^--decay

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

Removing negative negative yields

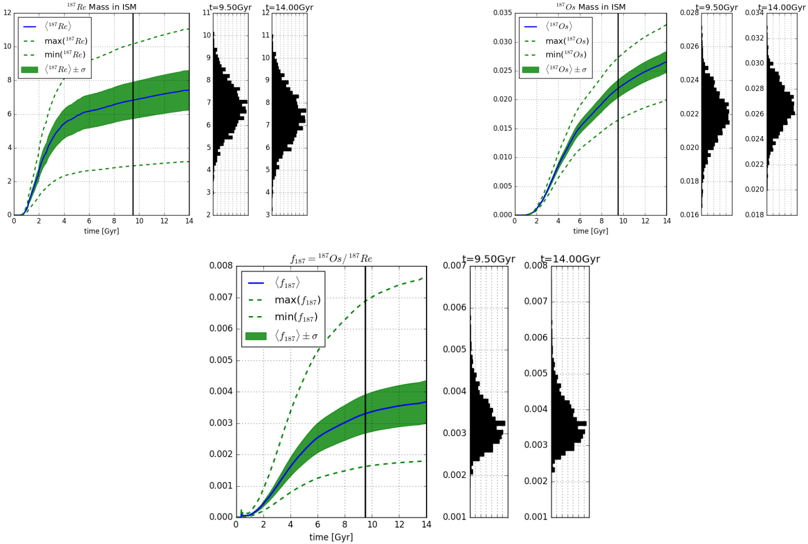
- $\hat{Y} \leq 0 \rightarrow$ Do not consider calculation

Results

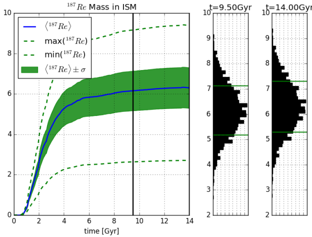
- ${}^{187}_{75}$Re in interstellar gas
- ${}^{187}_{76}$Os in interstellar gas
- $f_{187} = \frac{{}^{187}_{76}\mathrm{Os}}{{}^{187}_{75}\mathrm{Re}}$
- Rate of neutron star mergers

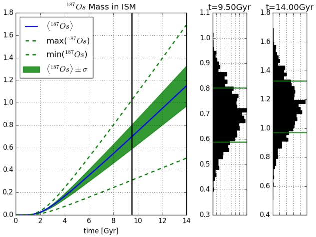
- **Yields**
- **Yields+IMFslope**
- **Yields+IMFslope+NSM**

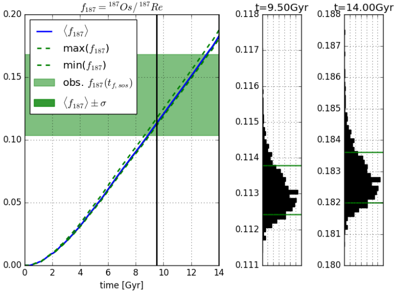
Yields without postprocessing



Yields with postprocessing



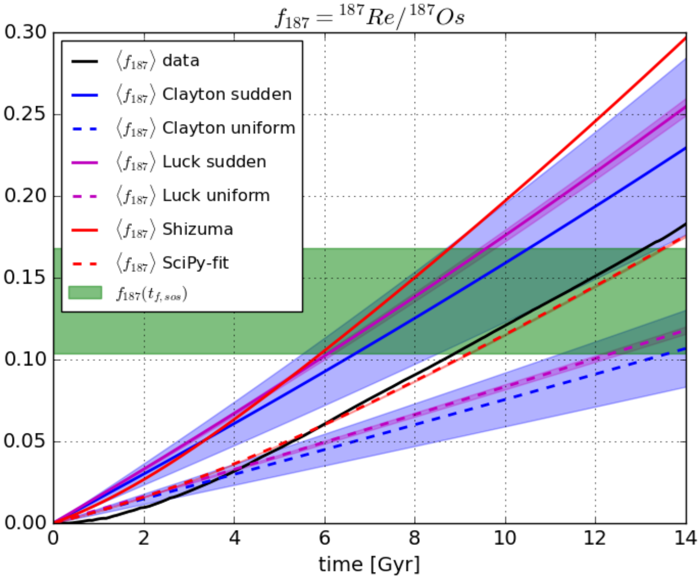




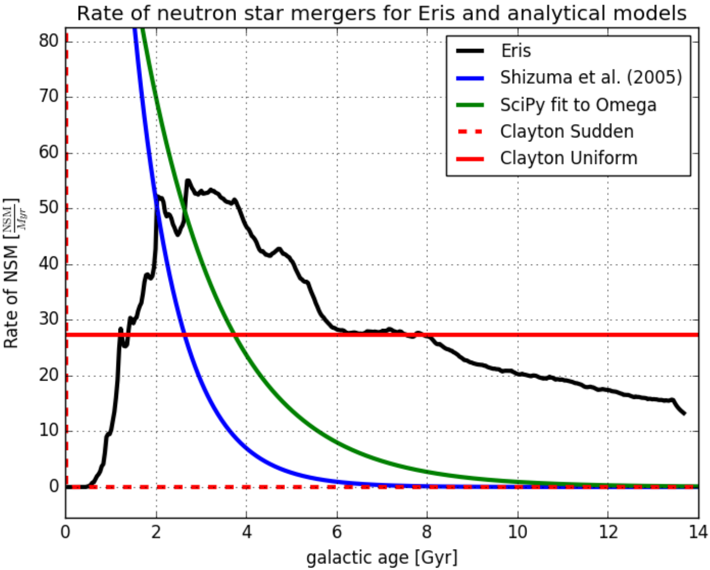
Comparing models

Model	${}^{187}_{76}\mathrm{Os}_c / {}^{187}_{75}\mathrm{Re}$	λ_{Re}	λ_{rncp}
Clayton	$\frac{\Lambda-\lambda}{\lambda} e^{\lambda t} \frac{1-e^{-\Lambda t}}{1-e^{-(\Lambda-\lambda)t}} - 1$	$\lambda = \frac{\ln 2}{\tau_{Re}}$	Λ
Clayton Sudden synthesis	$e^{\lambda t} - 1$	$\tau_{Re} = 47 \pm 10 Gyr$	$\Lambda \to \infty$
Clayton Uniform synthesis	$\frac{\lambda t}{1-e^{-\lambda t}} - 1$	——〃——	$\Lambda \to 0$
Luck	$\frac{\lambda_{Re}/\beta(1-e^{-\beta t})-(1-e^{-\lambda_{Re} t})}{e^{-\beta t}-e^{-\lambda_{Re} t}}$	$\lambda_{\mathrm{Re}} = \begin{array}{l} 1.62 \pm 0.08 \\ \times 10^{-11} yr^{-1} \end{array}$	β
Luck Sudden synthesis	——〃——	——〃——	$\beta = 10^{-6} yr^{-1}$
Luck Steady state	——〃——	——〃——	$\beta = 10^{-12} yr^{-1}$
Shizuma	$\frac{(1-e^{-\lambda_\beta^{\mathrm{eff}} t})-(1-e^{-\lambda t})\lambda_\beta^{\mathrm{eff}}/\lambda}{e^{-\lambda_\beta^{\mathrm{eff}} t}-e^{-\lambda t}}$	$\lambda_\beta^{\mathrm{eff}} = \frac{1.2 \ln 2}{\tau_{Re}} = 2.00 \times 10^{-11} [yr^{-1}]$	$\lambda \in [0, 2] Gyr^{-1}$
SciPy curvefit to *Fiducial* `Omega`-*model*-data	——〃——	1.33×10^{-11} $\pm 2.767 \times 10^{-14}$ $[yr^{-1}]$	5.42×10^{-10} $\pm 5.79 \times 10^{-12}$ $[yr^{-1}]$

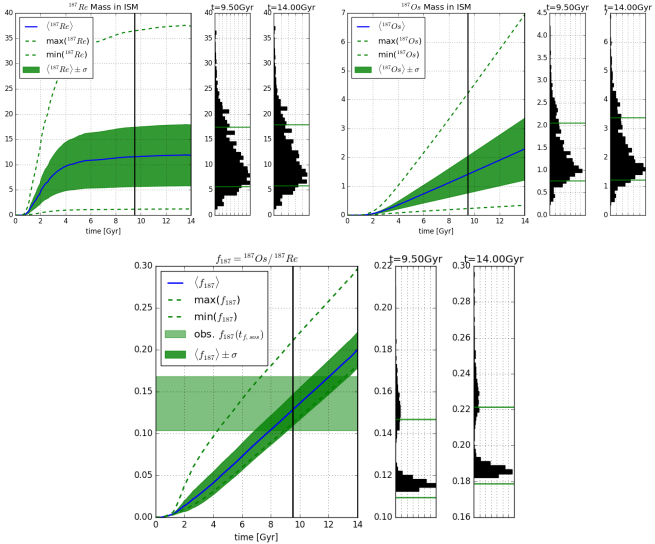
Comparing models



Comparing models



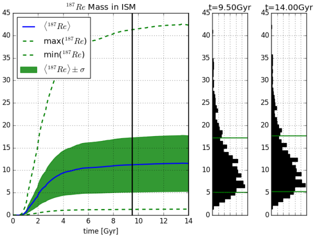
Uncertainties of **Yields+IMFslope**

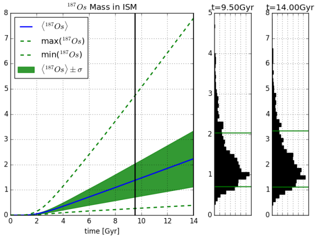


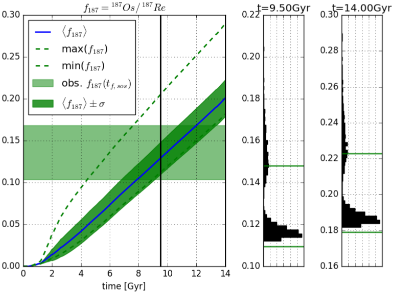
Uncertainties of **Yields+IMFslope**

TODO! insert plot of rates here

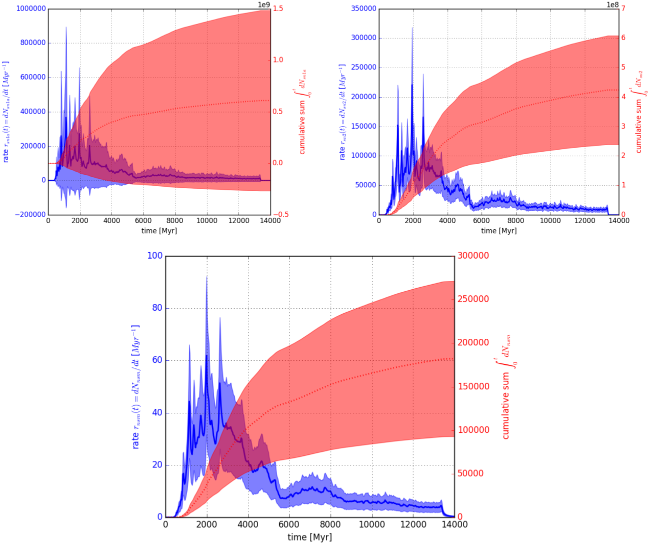
Uncertianties of **Yields+IMFslope+NSM**







Uncertianties of **Yields+IMFslope+NSM**



Conclusions/summary

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

- Uncertainties with and without β^--decay
- Uncertainties of models and observations
- Additional uncertainties from the slope of the *Initial Mass Function*
- Additional uncertainties from *Neutron Star Mergers*

References I

[Arnould et al. (2007)] Arnould, M. and Goriely, S. and Takahashi, K.
The r-process of stellar nucleosynthesis: Astrophysics and nuclear physics achievements and mysteries
Phys.Rep. TODO! add shen15 TODO! add cote16a TODO! add guedes11 TODO! add clayton