The Joint Institute for Nuclear Astrophysics

Neutron-Capture Elements in Globular Cluster M15

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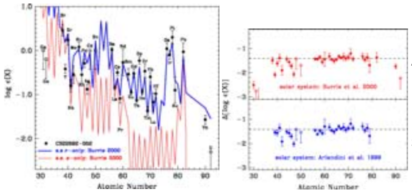
Abstract

We have observed six giants in the metal-poor globular cluster M15 using the Subaru Telescope to measure neutron-capture elemental abundances. There is star-to-star scatter in the heavy neutron-capture elements (e.g., Eu) but no significant s-process contribution as found in previous studies. We have found that there are anticorrelations between the abundance ratios of light to heavy neutron-capture elements ([Y/Eu] and [Zr/Eu]) and the abundance of heavy neutron-capture elements (e.g., Eu). Our results suggest that the light neutron-capture elements in those stars cannot be explained by only a single r-process. There was another process that contributed significantly to the light neutron-capture elements in M15. Our results also indicate that the heavy r-process elements were less dispersed than those light neutron-capture elements when M15 stars were formed.

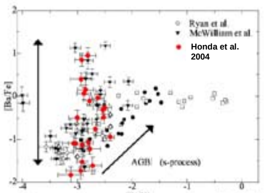
r-process elements in field stars

- Universal abundance pattern for elements Z>56.

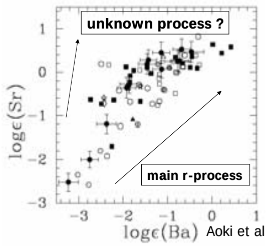


Abundance distribution of metal-poor star CS22892-052 (from Sneden et al. 2002). Dozens of other metal-poor stars have the same abundance pattern.

- A scatter of heavy r-process elements to Fe ratio at [Fe/H]<-2.5.



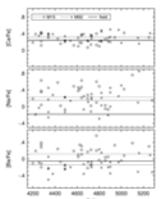
- The ratios of light neutron-capture elements to heavy r-process elements varies in each metal-poor stars.

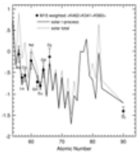


Aoki et al. 2005

Previous studies (Sneden et al. 1997,2000)

[Ba/Fe] scatter in M15 stars
→chemical inhomogeneity of progenitor?





Abundance distributions for elements Z>56 agree with solar r-process abundance pattern.
→pure r-process.

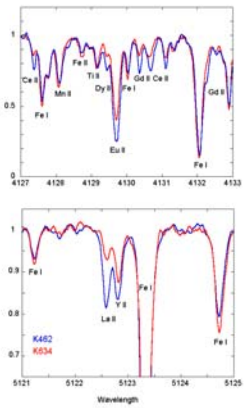
✓Observational uncertainties of Ba abundance.
✓light neutron-capture elements has not been studied.

Observation

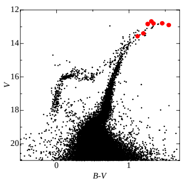
July 24-25, 2004
Subaru/HDS, 3550-5250A, R=50000
S/N~100 at 4300 Å

Subaru Telescope & HDS (High Dispersion Spectrograph)

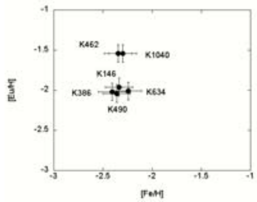
Three high-Ba stars and four low-Ba stars from Sneden et al. (1997,2000)
(K479 is excluded because of its broadened spectral lines.)



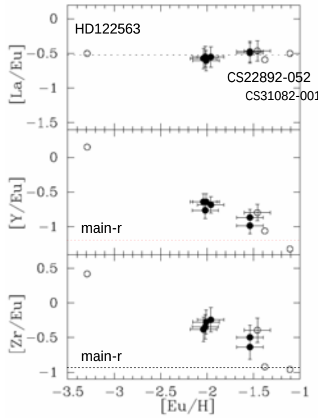
Examples of spectra



Observed stars.



[Eu/H] vs. [Fe/H]
We confirmed that there is the star-to-star abundance variation in heavy neutron-capture elements.



(Otsuki et al. 2006)

(Up) [La/Eu] vs. [Eu/H]
There is no significant s-process contribution.
(Middle) [Y/Eu] vs. [Eu/H]
(Bottom) [Zr/Eu] vs.[Eu/H]
There are anticorrelations between [Y,Zr/Eu] and [Eu/H].

Species	n	σ	log ε(X)							
			Sun*	K146	K386	K462	K490	K634	K1040	HD221170
T_{eff} (K)				4450	4200	4225	4350	4225	4450	4475
log g				1.25	0.35	0.50	1.00	0.60	1.20	1.00
v_{turb}				2.00	2.25	2.25	2.05	2.05	2.40	1.70
Fe (Fe I)	54–81	0.133	7.45	5.12	5.05	5.10	5.09	5.20	5.15	5.41
Fe (Fe II)	9–13	0.148	7.45	5.11	5.04	5.11	5.09	5.21	5.15	5.41
Sr	1		2.92	0.11	0.20	0.16	−0.14	0.09	0.26	0.55
Y	5	0.041	2.21	−0.43	−0.57	−0.31	−0.47	−0.44	−0.20	−0.06
Zr	5	0.137	2.59	0.39	0.23	0.41	0.17	0.31	0.56	0.74
Ba	3	0.060	2.17	−0.34	−0.60	−0.31	−0.53	−0.45	−0.11	0.33
La	6	0.098	1.13	−1.25	−1.43	−0.96	−1.38	−1.41	−0.84	−0.79
Eu	3	0.110	0.52	−1.44	−1.50	−1.02	−1.52	−1.49	−1.02	−0.94

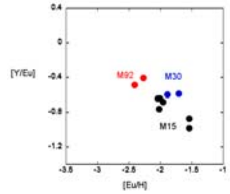
Multiple lines are detected.
We adopted the latest line data for the abundance analyses.

Discussion

- There are star-to-star abundance variations in heavy r-process elements (e.g., Eu) in M15.
- There is an anti-correlation between the abundance ratio of light to heavy neutron-capture elements (e.g., [Y/Eu], [Zr/Eu]) and the abundance of heavy r-process elements.
  - ➤Two different sources of neutron-capture elements contributed to M15 progenitor.
- Heavy r-process elements show a larger scatter than light neutron-capture elements
  - ➤uniform contamination of light neutron-capture elements and insufficient mixing of main r-process elements.

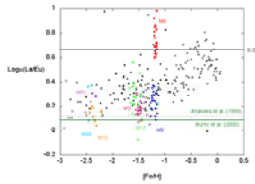
If we assume a simple correlation between time and the degree of mixing, this scatter can be realized if light neutron-capture elements enriched the progenitor of M15 earlier than the main r-process elements which were not mixed completely before star formation. In this case, the astrophysical origin of those light neutron-capture elements could be related to more massive stars than the main r-process.
Strongly concentrated main r-process elements (e.g., jet) could also explain our results. Since very little about mixing of SNe ejecta and ISM is known, it is difficult to reach a definitive conclusion. The theoretical studies of such dynamics are now ongoing.

neutron-capture elements in other metal-poor globular clusters



Our preliminary results
[Y/Eu] in M92 & M30
the abundance ratios of light to heavy neutron capture elements varies in each GCs

Logε(La/Eu) in GCs



Field stars: Simmerer et al. 2004(black closed triangles), Wolf et al. 1995 (black open triangle), Honda et al. 2004(crosses)
GCs: M15: Sneden et al. 2000b(circles), Our new data (squares), M68: Lee et al. 2005, M92: Our new data, M13 & M3: Sneden et al.2004 (closed circles), Cohen & Melendes 2005 (open circles), M5: Ivans et al. 2001 (closed circles), Ramirez & Cohen 2003 (open circles), M4: Ivans et al. 1999.

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