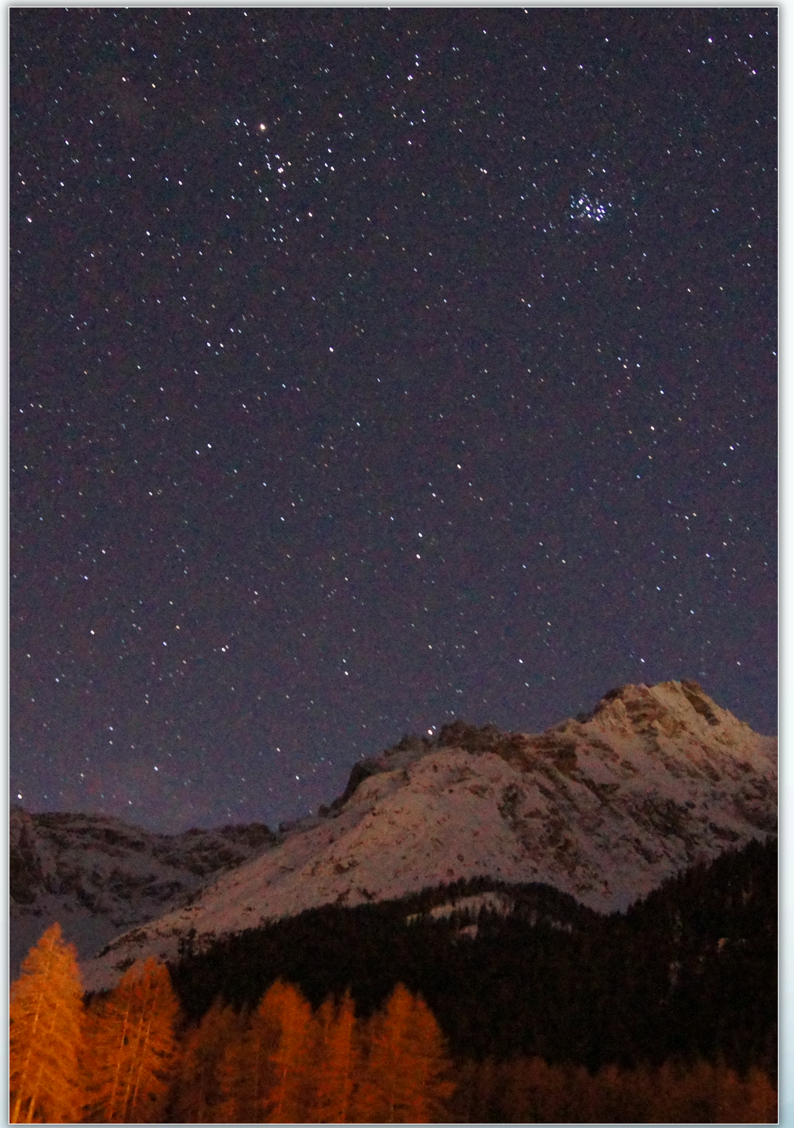
# Galactic Evolution of Eu: NSM vs. SNe

In collaboration with A. Romano,
G. Cescutti, A Arcones, O. Korobkin
and S. Rosswog

Sexten Center for Astrophysics

January 23, 2015



# Chemical Evolution Model (Matteucci+2014)

- The chemical evolution model we adopt is an updated version of the two-infall model (Chiappini et al. 1997) as presented in Romano et al. (2010)
- It computes in detail the evolution of the abundances of 37 elements including Europium
- It relaxes I.R.A but it assumes instantaneous mixing
- The SN II and Ia rates are computed in details
- The halo and disk form by means of independent gas accretion episodes

# Europium production

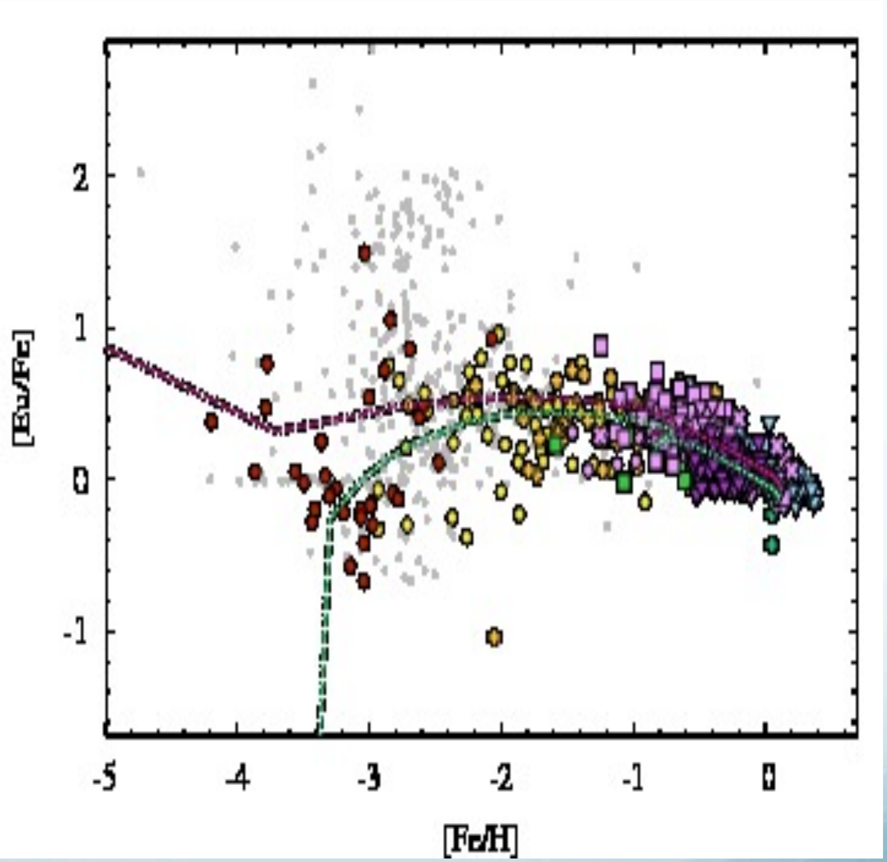
- Two main sites have been proposed for Eu production:
- SN II, either of low (8-10 $M_{sun}$) and high (>20 $M_{sun}$) mass, during explosive nucleosynthesis (Cowan et al. 1991; Woosley et al. 1994; Wanajo et al. 2001) but many uncertainties are still present in the physical mechanisms involved in Eu production
- Merging NS producing Eu ( Freiburghaus et al. 1999, Rosswog et al. 1999;2000): ($10^{-3}$ – $10^{-2}$ Msun total mass ejected in the event). The Eu mass produced is $10^{-7}$ – $10^{-5}$ Msun (Korobkin et al. 2012)

# The NS merging rate

- We assume that the binary NS are a fraction of all NS and that the rate of NS merger is a fraction (alpha) of the NS formation rate. All stars between 9 and 30 $M_{sun}$ are assumed to leave a NS
- This fraction alpha =0.02 is a free parameter and is fixed by reproducing the present time NS merging rate of 83 $Myr^{-1}$
- Another important parameter is the delay between the formation of the NS and their merger, $t_d$
- This time delay can be as short as 1 Myr but it can be also 100 Myr and more. It depends on the common envelope phase

# Eu only from NS: Matteucci+2014

- We run a model where we assumed that neutron stars form from 9 to 50 $M_{sun}$ and not only to 30Msun and that Eu comes only from NSM with a minimum $t_d$ = 1Myr and $M_{eu}$=3x10$^{-6}$ $M_{sun}$
- The result is shown by the violet line and it demonstates that Eu can indeed be entirely produced by NSM if these conditions are fulfilled
- Predicted solar Europium is alsoin agreement with observations



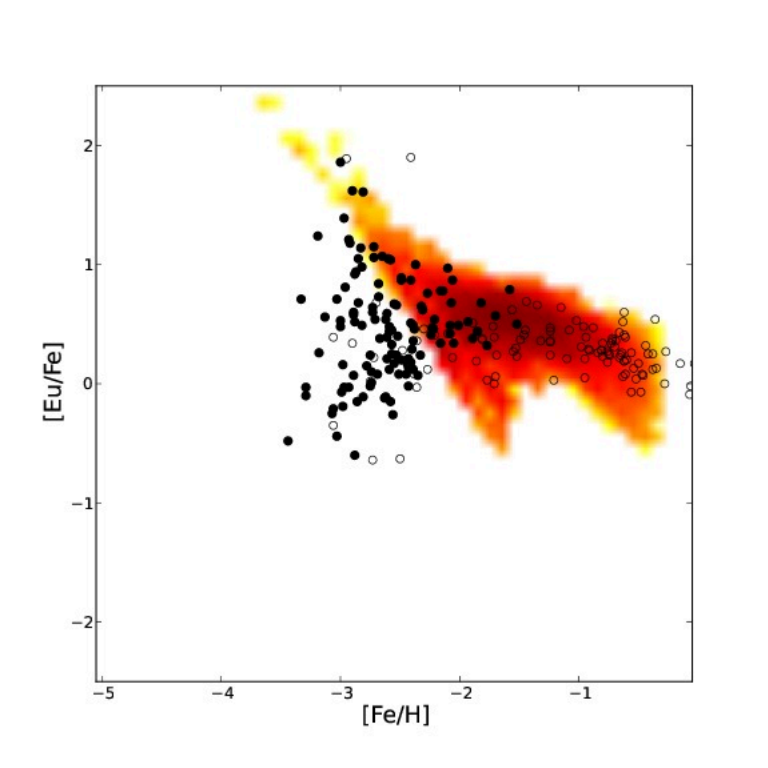
# Conclusions

- Europium production only from NSM can reproduce the evolution of Eu abundance as well as its solar value if the NS systems explode with a delay of 1 Myr and each event produces $M_{eu} = 3x\ 10^{-6}\ M_{sun}$ and all stars with masses in the range 9-50 Msun leave a NS as a remnant
- An alternative situation suggests that both SNeII and NSM can produce Eu. The best model in this case assumes that in NSM is produced $M_{eu} = 2x\ 10^{-6}\ M_{sun}$, the delay times can be various. The SNe II should produce Eu in a range 20-50 Msun
- NSM produce much more Eu than core-collapse SNII
- It is very important to have Eu sources acting at early times to reproduce observations at low [Fe/H]

# Europium production in the halo: a stochastic model (Cescutti et al. 2015, submitted)

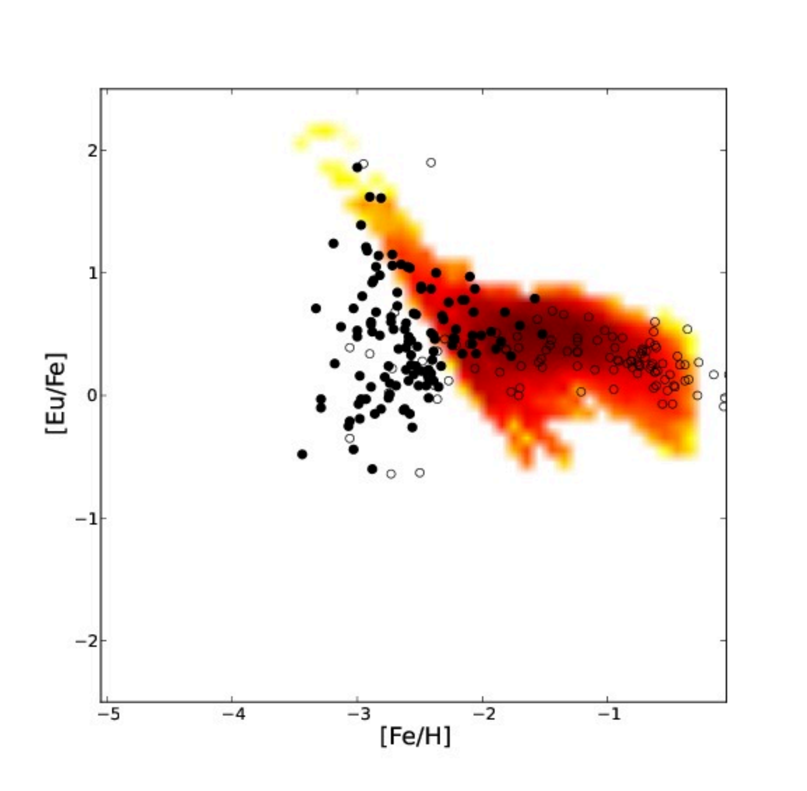
- In order to reproduce the large spread observed in the [Eu/Fe] ratio in halo stars we adopted a stochastic inhomogeneous model
- The model is from Cescutti (2008) and assumes incomplete mixing in the first stages of galaxy evolution
- The halo in divided in several regions not interacting: each region has a volume with radius of 90 pc
- In each regions stars form by means of a random function weighted on the assumed IMF (Scalo 1986)

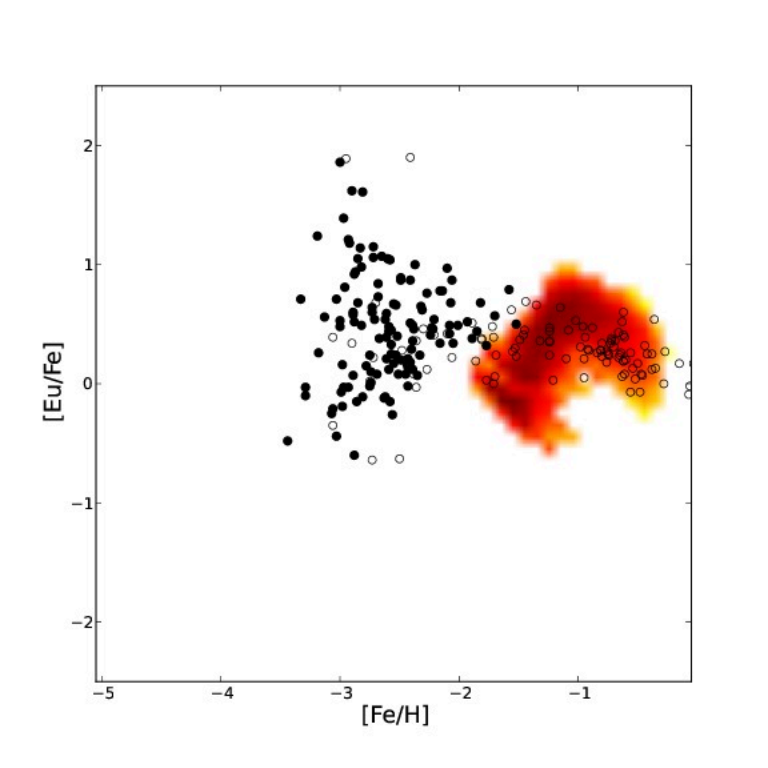
# Results for the halo: Eu from NSM




- Results for NSM with a delay of 1Myr and a yield of $5x10^{-6}$ Msun per event. Prescriptions like in the homogeneous model of Matteucci et al. (2014) with NS progenitors in 9-30Msun range
- No Europium production from core-collapse SNe
- The data are those of Frebel (2010)

# Results for the halo: delay of 10 and 100Myr

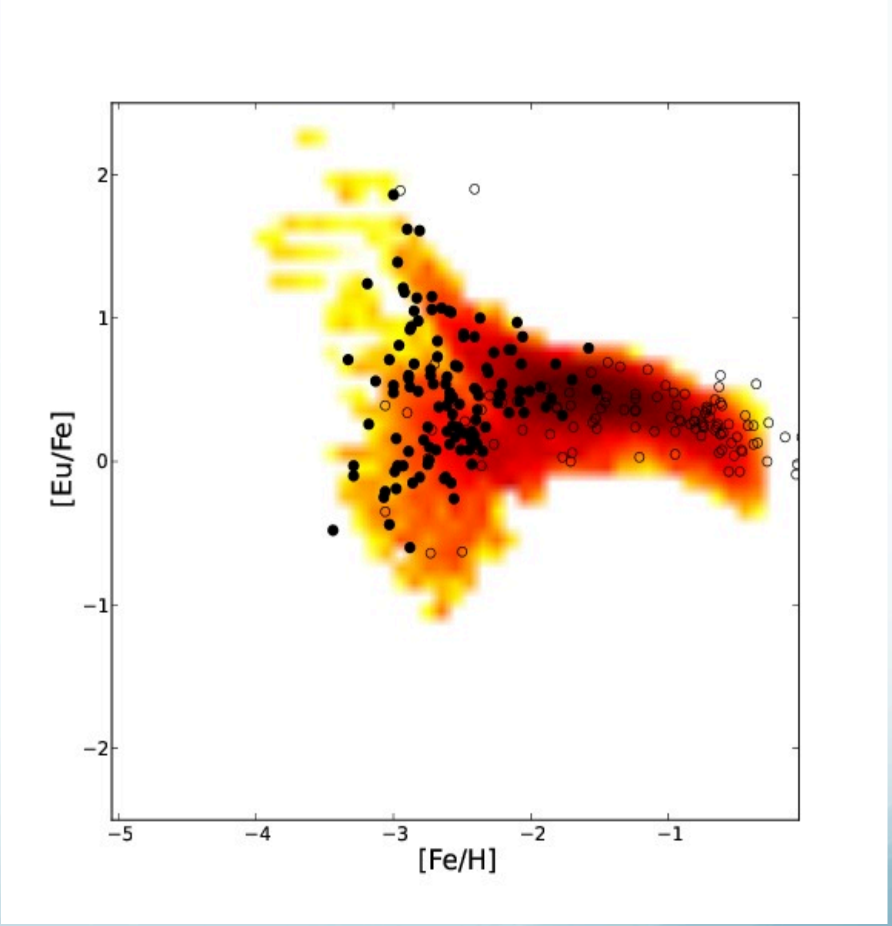


# Results: NSM+SNe

- Europium from NSM plus SNe. The prescriptions for SNe are like Model2SNNS of Matteucci et al.(2014)

- Model2SNNS assumes 10 Myr delay and Eu yield of $2x10^{-6}$ Msun plus SNeII in the range 20-50Msun



# Summary

- We can reproduce the large spread observed in [Eu/Fe] in halo stars by means of an inhomogeneous stochastic model of chemical evolution of the halo
- We confirm the results of Matteucci et al. (2014) although a better agreement with data arises if only a small fraction if massive core-collapse SNe produce Eu at early times
- Uncertainties still present in the rate of NSM and the delay time distribution function
- Encouraging results obtained for Sgr (Vincenzo's talk) and Fornax (paper in preparation)

# Results:NSM+MRD SNe

- Here Europium originates from NSM plus magneto rotational (MRD) SNe
- The merging events have a fixed delay of 100Myr
- The MRD SNe are assumed to be 10% of the total number of SNe II but only for $z<10^{-3}$