CEMP, GALAH - Summary

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Melbourne, November 2017

CEMP stars and GALAH

GALAH will find a few thousand halo stars, and might identify some halo CEMP stars.

CEMP star studies are aimed at unravelling the events starting from the formation of the first stars into the 2nd and later generations.

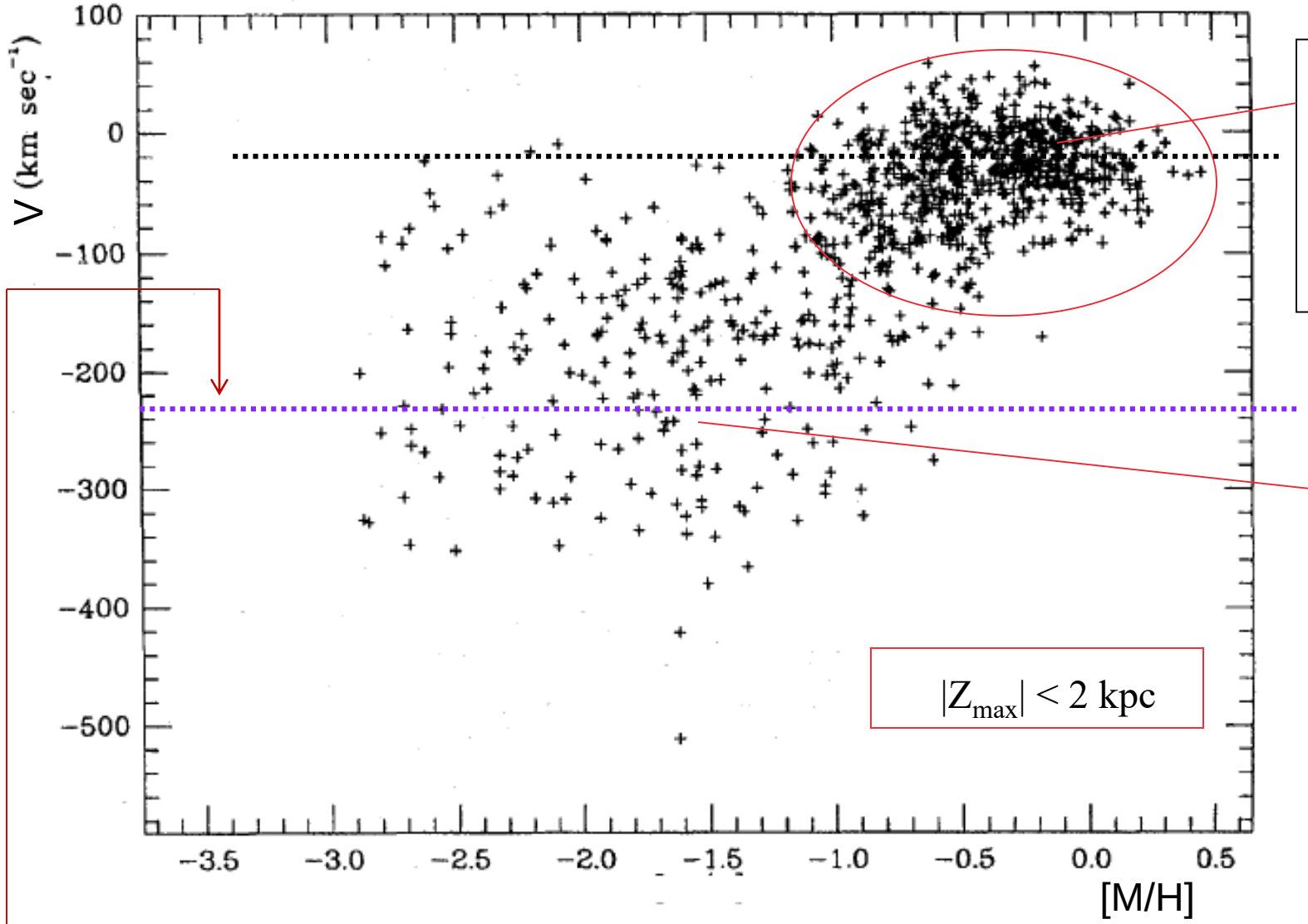
GALAH is primarily a disk survey, aimed at understanding the assembly of the Galactic disk which contains most of the Galactic stellar baryons.

CEMP stars are probably associated with low metallicity star formation in (very) small dwarfs/minihalos at high redshift. which later become part of the Galactic stellar halo (Hanson, Yoon, Frebel, Bland-Hawthorn).

How important are these small subhalos to the Milky Way ?

The stars of the Galactic stellar halo are a very small fraction (~1%) of the Galactic stellar baryons.

The stellar halo may tell us more about the evolution of dwarfs in tiny sub-halos than it tells about the evolution of the Milky Way.



Rotational velocity of nearby stars relative to the sun vs [M/H]

(V = -232 km/s is zero angular momentum)

LSR has V = 0

(Carney et al 1990)

The Carney diagram shows how halo and disk (thin and thick) are dynamically very different entities. But we do see some metal-poor stars with disk angular momentum.

Maybe EMP stars are not so irrelevant to the rest of the Milky Way.

The disk may have had its its own brief first and second generation EMP epoch, and these metal-poor stars with apparent disk kinematics may be the remnants.

(We know that the chemical evolution of the disk was very fast because of the high star formation rate at z = 2-3 when large disks were assembling.)

It may be worth looking at GALAH and other survey data for nearby EMP stars in the disk. Gaia DR2 will help.

If finding EMP stars in the halo is hard, finding them in the disk will probably be harder.

Now try to summarise main points of what we heard on

- CEMP stars
- Galah and Galactic Archaeology

CEMP stars and their pre-enrichment

Nice reviews of CEMP stars by Beers, Aoki.

The real insights to be gained from CEMP stars are about the first generation stars. Search for their chemical signature which is diluted by later population II stars.

Goswami : study of the kinematics and chemistry of a large sample of CH and CEMP stars which could be kinematically assigned to their Galactic components (thin and thick disk, halo).

Carlos : used Mg isotope abundances to identify the metallicity at which AGB stars began to appear in the Galactic halo.

CEMP-no stars have charactistic light element abundance patterns: C, N, Mg, Al, Si.

Heger : the nucleosynthetic origin of this light element abundance pattern.

Choplin : the various options for generating CEMP-no stars: mixing and fallback, spinstars. These are not exclusive - both may be needed.

The CEMP-no stars fall into two groups in the A(Ca)-[Fe/H] plane.

Gen Chiaki proposed that these two groups are defined by the conditions required to form the carbon and silicate dust grains. These grains enable cooling and fragmentation of the clouds from which these stars formed.

The CEMP-s stars have high binary fraction, possibly as high as 100% (Pols).

Several people spoke on forming single-star CEMP-s stars via spinstar and SN routes.

Hansen reviewed the diagnostics for different routes to single star and binary star CEMP-s stars, and how one might discriminate between these routes.

Stancliffe : some of the dynamical problems in accreting mass and angular momentum in binary CEMP-s stars.

Nice reviews and discussions of massive star nucleosynthesis (Heger, Ishigaki, Nomoto, Tominaga, Sarmento).

Prominent themes of mass cuts, mixing and fallback, asymmetric explosions.

Limited role of more massive stars in first generation nucleosynthesis. Need for hypernova and faint SN. Asymmetric explosions to get Fe-peak abundance distributions right.

Hartwig : on finding the chemical signatures of 2nd generation stars that have been enriched by just a single enrichment event.

Karakas and Hampel reviewed the astrophysics of the s-process and i-process as related to the CEMP-s and CEMP-i stars. The i-process (10^{15} cm^{-3} neutron densities) gives a good representation of the abundance distributions in CEMP-i stars.

Proton ingestion was the dominant theme, to enable the n-generating reactions. Bannerjee and Campbell discussed n-capture sites and relation to proton ingestion. Henkel spoke on the thermohaline mixing in metal-poor red giants.

Cseh gave a related tak on the s-process in binary Ba stars which are metal rich analogs of the CEMP-s stars.

Observational studies

Roederer : on observations of CEMP-i stars, noting the two groups of s-enhanced CEMP stars in the [Ba/Fe]-[Eu/Fe], with correlations within each group.

The two large surveys for EMP stars:

Da Costa : on the southern SkyMapper survey for EMP stars (the very EMP Keller star)

Starkenburg : on the northern Pristine survey with CFHT with related goals.

Reminder that the most metal-poor stars may not be the oldest stars (e.g. Tumlinson 2010).

GALAH and Galactic Evolution

Martell introduced the GALAH project. The goal is to derive the history of the MW. GALAH has close links to the Kepler 2 asteroseismology survey, which provides prospects for accurate gravities and ages, particularly for the red giants. Ages are vital for Galactic Archaeology because they enable us to study the evolution of the MW directly.

Red giants are useful for Galactic Archaeology with GALAH, because we can observe them out to several kpc. Stello described the huge progress in red giant asteroseismology, driven by CoRoT, Kepler and K2.

The combination of Gaia and GALAH will deliver accurate 6D phase space data and ~30D chemical space data for about a million stars.

One of the primary drivers of the GALAH project is the prospect of using chemical tagging to reconstruct the debris of dispersed star formation events like clusters. Not everyone thinks that chemical tagging will work.

Ting discussed the limitations and prospects of success for chemical tagging.

Simpson described his work on the chemical tagging of co-orbiting stars.

Spina described an exciting study using solar twins to study the temporal evolution of n-capture elements in the Galactic disks. Finds that the thick disk is somewhat r-enhanced but not s-enhanced. From gradients of r, s-process elements, the main n-capture evolution in the thin disk is via s-process. Y/Mg and Y/Al have steep dependence on age and are good clocks for solar-type stars at sub-Gyr level.

Koch talked about finding obscured low mass GC, using the Na/O anticorrelation as a tag for GCs.

Lim reviewed the multiple stellar populations in the bulge and GCs.

Buder presented new results from the analysis pipeline for GALAH. Now giving [X/Fe] values for up to 30 elements, for about 0.5M stars. See trends with age for various element groups, in good agreement with independent results that we have heard about here.

The combination of GALAH and Gaia will be transformational for Galactic archaeology and chemical tagging. I think the recovery of cluster debris via CT will benefit greatly from having abundance and phase space data, even for clusters that dispersed many Gyr ago.

Gao spoke about non-LTE effects in M67. Their study shows that the [X/Fe] distributions become much tighter in M67 with NLTE analysis for Na, Al, Mg, Si. This will benefit CT.

Galactic chemodynamic evolution models are our main route for interpreting survey data and testing our basic galaxy formation narratives.

Kobayashi and Gibson reviewed these models from different points of view.

Chiaki's focus was on the stellar physics of nuclear evolution and the predicted [X/Fe]-[Fe/H] relations.

Brad discussed the subtleties of comparing the models with data. The physics in the models is calibrated on a small number of scaling laws. The models predict a vast range of physical properties of galaxies. The resolution of the models is still at the 10^3 star level, and comparing the models with survey data requires a number of assumptions which are as significant as the subgrid physics involved in the models.

Many thanks to the organisers for a great conference,

and all the best to Tim