Spectroscopic approach to Galactic Archaeology with Subaru

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NAOJ
Progress of searches for most metal-poor stars

Norris (2005, in Proc. OMEG05)

Fe abundances (relative to the solar value)
Searches for metal-poor stars
Roederer et al. (2014, AJ 147, 136)

- Bond (1981) “Where is population III?”
- Bidelman & MacConnel (1973) Curtis Schmidt (CTIO)

- Catalogue:
  - Henry Draper (HD) e.g. HD122563
  - Bonner Durchmusterung (BD) e.g. BD+44 493
  - Córdoba Durchmusterung (CD) e.g. CD-38 245
  - Lowell Proper Motion survey (G) e.g. G64-12

Honda et al. (2006)
Ito et al. (2009, 2013)
Searches for metal-poor stars

- HK survey (1980s-)
  *Beers et al. 1985, 1992, etc.*
  - objective prism survey for Ca II H and K lines (R~800)
  - $B\sim<15$

  - Curtis Schemidt (CS) CTIO, e.g. BPS CS22892-052
  - Burell Schmidt (BS) KPNO, e.g. BPS BS16934-002

- HK-II: re-analysis of the plates of HK survey
Objective prism survey of metal-poor stars (1980s~)

① wide-field spectroscopic survey

② follow-up medium resolution spectroscopy
Follow-up spectroscopy with Subaru/HDS for HK survey sample

- First Light of Subaru/HDS in 2000

Topics:
- $r$-process-enhanced stars (Honda et al. 2004)
- CEMP stars: $s$-process from CEMP-$s$, and establishing “CEMP-no” class (Aoki et al. 2002)
**Searches for metal-poor stars**

- Hamburg/ESO survey (1990s-)
  - stellar content: Christlieb et al. 2001 etc.
  - → e.g. HE0107-5240 ([Fe/H]= -5.3, Christlieb et al. 2002)

Follow-up with Subaru/HDS (2003~)

**Topics:**
- most metal-poor stars (Frebel et al. 2005)
- CEMP stars (Aoki et al. 2007)
- Li (Aoki et al. 2009)
The 2\textsuperscript{nd} HMP star HE1327-2326

*Frebel et al. (2005)*

very weak Fe lines
→[Fe/H]=-5.4

detection of CH molecular bands
→excess of carbon
Origins of Carbon-Enhanced Metal-Poor stars (CEMP)

Aoki et al. (2007)

- Definition of CEMP
- Classification into CEMP-s (Ba-rich) and CEMP-no (Ba-normal)
- Metallicity and carbon-abundance distributions of CEMP-s and CEMP-no

... different origins of the two classes

CEMP-s $\rightarrow$ binary mass transfer

CEMP-no $\rightarrow$ formed from C-rich cloud?
Searches for very/extremely metal-poor stars by SDSS/SEGUE

- Imaging/spectroscopic surveys
- Surveys of Galactic stars 240,000

The 2.5m telescope at Apache Point Observatory
Follow-up high resolution spectroscopy with Subaru for selected SDSS objects

Follow-up with Subaru/HDS for 150 objects (2008-2009)
Topics:
- chemical compositions of 137 very/extremely metal-poor stars
- binary frequency

→ see poster by Matsuno et al.: Most metal-poor main-sequence turn-off stars
Discovery of a low-mass star with peculiar chemical composition

SDSS J001820.51-093939.2

• $[\text{Fe/H}]=-2.5$
• Low C, Mg, Co, Ba etc. abundances → excess of Fe
• A low-mass main-sequence star

Taken from SDSS

Aoki, Tominaga, Beers, Honda, Lee (2014, Science)
SDSS J0018-0939 -- a low-mass star with a peculiar abundance pattern

The abundance pattern is not explained by normal core-collapse supernovae

*Aoki, Tominaga, Beers, Honda, Lee (2014)*

- **SDSS J0018-0939**
- **comparison star (G39-36)**
- **core-collapse supernova model**
SDSS J0018-0939 -- a low-mass star with a peculiar abundance pattern

Aoki, Tominaga, Beers, Honda, Lee (2014)

Recording yields of a very-massive star?

- SDSS J0018-0939
- Pair-Instability Supernova
- core-collapse supernova of very-massive stars
Exploring the early chemical evolution of the Milky Way with LAMOST and Subaru

H.N. Li, Wako Aoki, T. Suda, G. Zhao, S. Honda, N. Christlieb
LAMOST survey

- $R=1800$
- 4000 fibers
- $r<19$

- LAMOST Experiment for Galactic Understanding and Exploration (LEGUE)

- Target selection: random selection for a given magnitude/temperature range
  cf. SDSS/SEGUE

- Data Release 3 (DR3): 5.7 million spectra including 4 million AFGK stars

Fibers on the focal plane
Target selection from LAMOST sample

LAMOST medium resolution spectra

Subaru high-resolution follow-up spectroscopy

J1253+0753 \([\text{Fe/H}]=-4.0\) main-sequence turn-off
Exploring the early chemical evolution of the Milky Way with LAMOST and Subaru

- Programs in 2014-15 + Intensive program in 2016-17: ~300 stars to date
- Searches for rare but key objects:
  - signature of first stars
  - neutron-capture element-enhanced stars
- Statistics of very metal-poor stars:
  - metal-poor tail of the metallicity distribution function
  - binary frequency from double-lined binaries
  - trend and scatter (or clustering) of elemental abundance ratios
Li in stars from main-sequence to giant branch traced by globular cluster stars

Constant Li in main-sequence turn-off

Depletion of Li in red giants

Lind et al. (2009)
Early result 1. new ultra metal-poor stars

The second example of Li detection in Ultra Metal-Poor ([Fe/H]<-4) stars

*Li, Aoki et al. (2015, PASJ)*

→Li depletion in the most metal (iron)-poor stars ([Fe/H]<-4)
Li in stars from main-sequence to giant branch traced by globular cluster stars

Constant Li in main-sequence turn-off

Depletion of Li in red giants

Lind et al. (2009)
Early result 2. Super Li-rich red giant!

\[ [\text{Fe/H}] = -3.3, \quad T_{\text{eff}} = 5200 \text{K}, \quad \log g = 2.2, \quad A(\text{Li}) \sim 3.0 \]
Li in stars from main-sequence to giant branch traced by globular cluster stars

Constant Li in main-sequence turn-off

Depletion of Li in red giants  

Lind et al. (2009)
Summary and future prospect

• High resolution follow-up spectroscopy have been conducted for candidates of metal-poor stars discovered by large surveys (HK, HES, SDSS/SEGUE)

• LAMOST is providing huge samples of metal-poor stars and other chemically/kinematically interesting objects. We are conducting follow-up spectroscopy with Subaru for 500 stars

◆ LAMOST objects studied with Subaru are relatively bright, providing good sample for detailed abundance studies.

◆ Combining kinematics data provided by Gaia