Subaru partnership WS
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Chemical abundances, kinematics and ages of stars in the Milky Way halo and satellite galaxies

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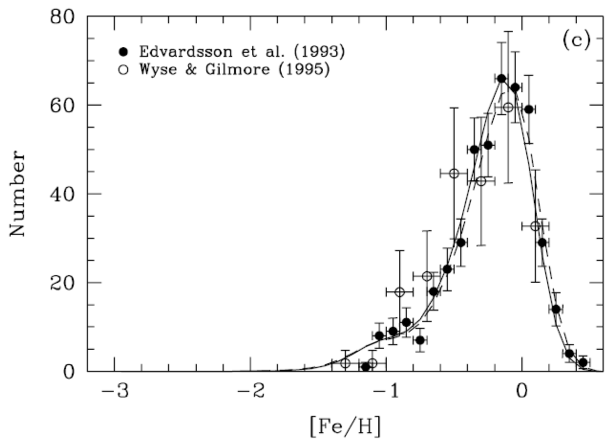
Chemical abundances, kinematics and ages of stars in the Milky Way halo and satellite galaxies

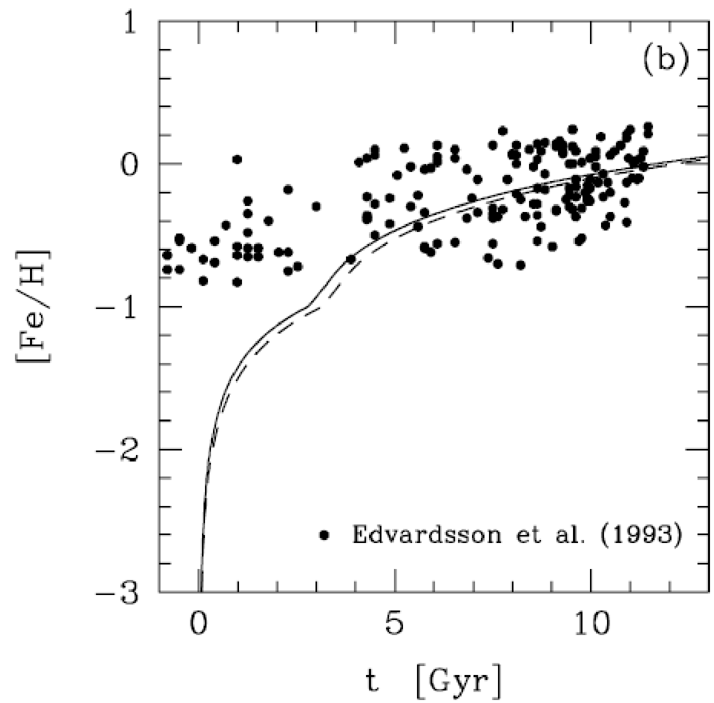
- Previous and ongoing studies on abundance measurements
- New era of observational studies on chemical evolution of the Milky Way (MW): abundances, kinematics and ages for large sample
- Studies of MW halo and satellite galaxies with PFS

Key observables in studies of chemical evolution

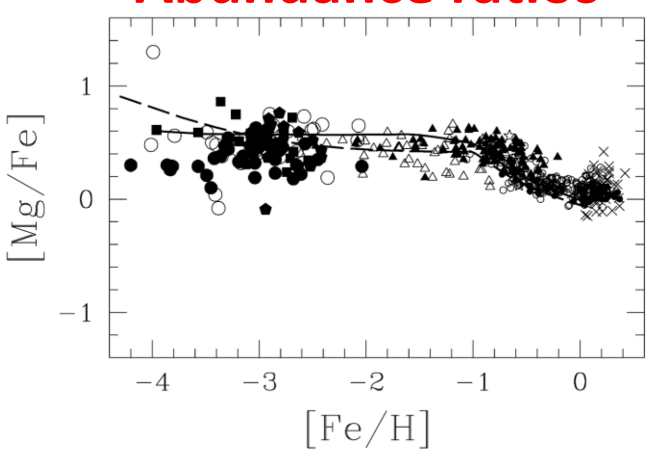
Metallicity distribution function



Age metallicity relation



Abundance ratios

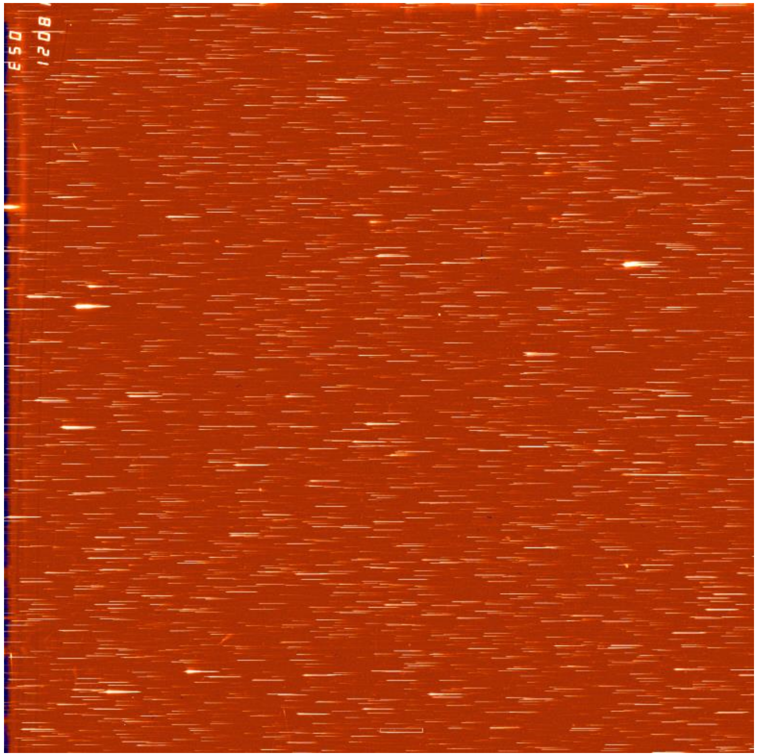


Kobayashi et al. (2006)

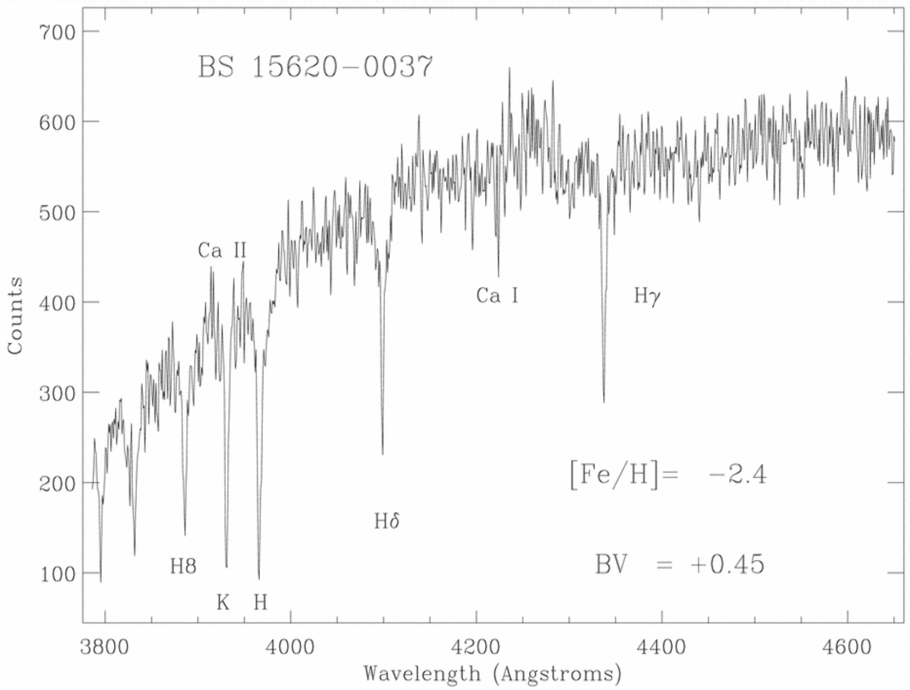
Metallicity and chemical abundance ratios of metal-poor stars

Objective prism survey of metal-poor stars (1980s～)

①wide-field spectroscopic survey



②follow-up medium resolution spectroscopy



Follow-up spectroscopy with Subaru/HDS for metal-poor star candidates

- First Light of Subaru/HDS in 2000

Topics:
-signature of first stars
-r-process-enhanced stars
-Li problems
-trend and scatter of abundance ratios

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*~<15

T.C. Beers

- **Hamburg/ESO survey (1990s-)**
  stellar content: *Christlieb et al. 2001* etc.

N. Christlieb

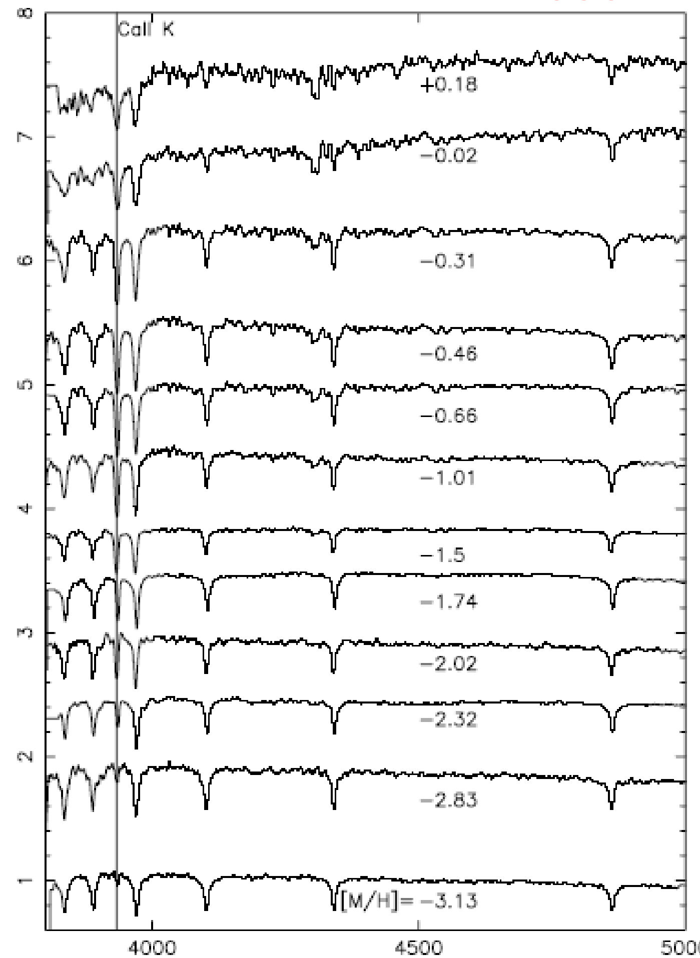
Searches for very/extremely metal-poor stars by SDSS/SEGUE

The 2.5m telescope at Apache Point Observatory

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

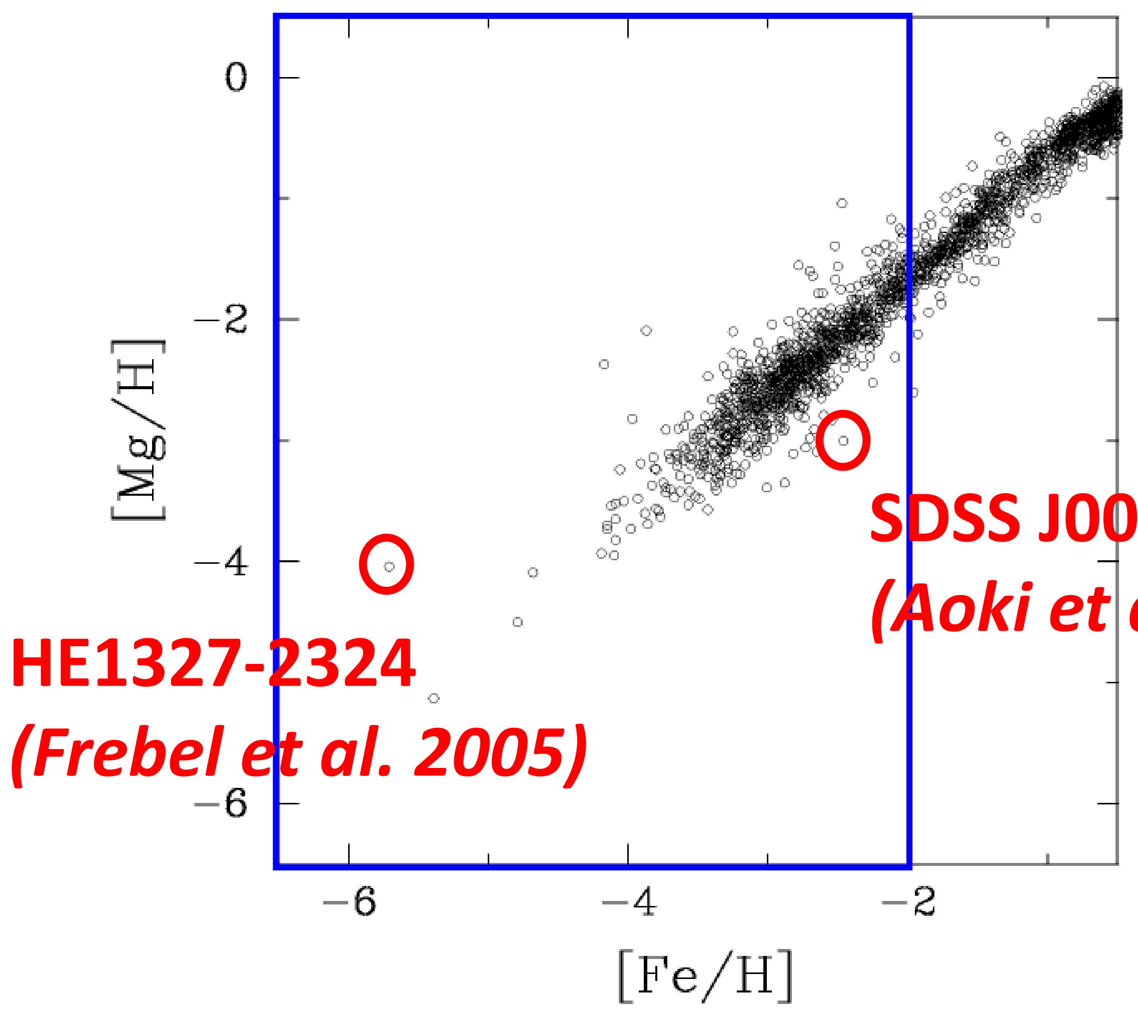
Intensive program: Follow-up with Subaru/HDS for 150 objects (2008-2009)

R~2000



Abundance trend and scatter: α-elements

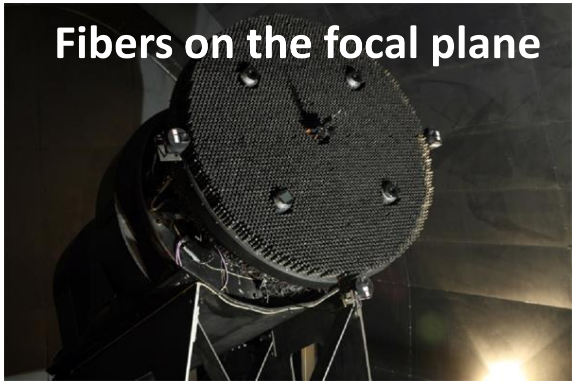
SAGA database (Suda et al. 2008)



LAMOST survey and follow-up with Subaru/HDS

talk by H-N. Li

-R=1800
-4000 fibers
-r<19



- Target selection: random selection for a given magnitude/temperature range
- Data Release 4 (DR4): 6 million spectra including 4.2 million AFGK stars

Subaru intensive program:
LAMOST/Subaru study for 500 very metal-poor stars

Spatial distribution, kinematics and age of stars

Astrometry and Seismology

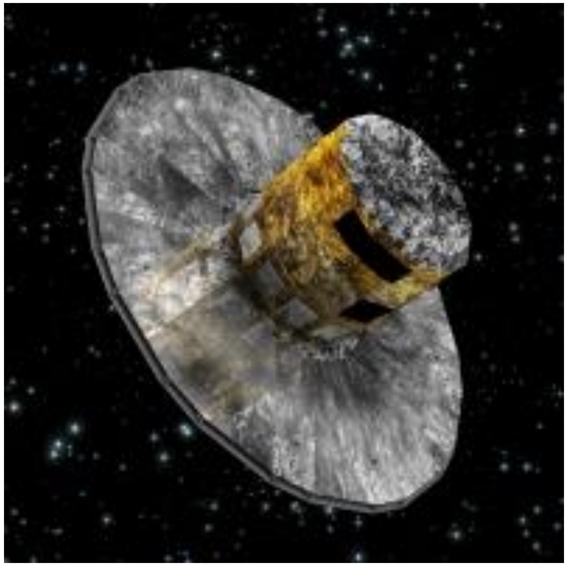
Astrometry with Gaia

- Parallax → Distance to stars
  → Stellar parameters
  → Ages of *main-sequence turn-off stars*
- Proper motion + radial velocity + distance
  → Kinematics

Seismology with CoRoT, Kepler, and TESS

- Mass of *red giants* → Ages

Astrometry with Gaia



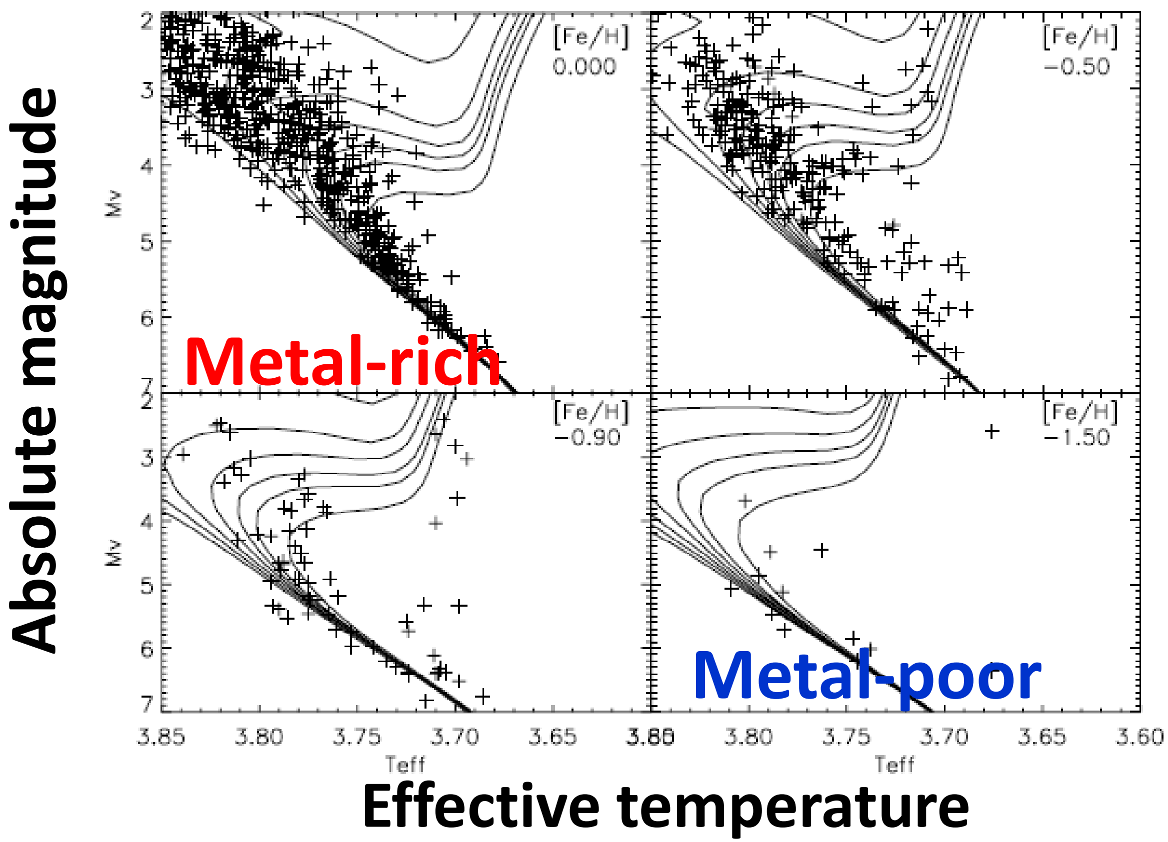
- ESA's mission
- Launch in December 2013
  (5 year observation planned)

- Targets: 1 billion stars (V<20)
- Accuracy: 20 micro arcsec
- Spectroscopy for bright stars
  → radial velocity (V<16)

1st data release : Sep. 2016
Final release ~2022

Age estimate by HR diagram with accurate distance measurements

Nordstrom et al. (2004)



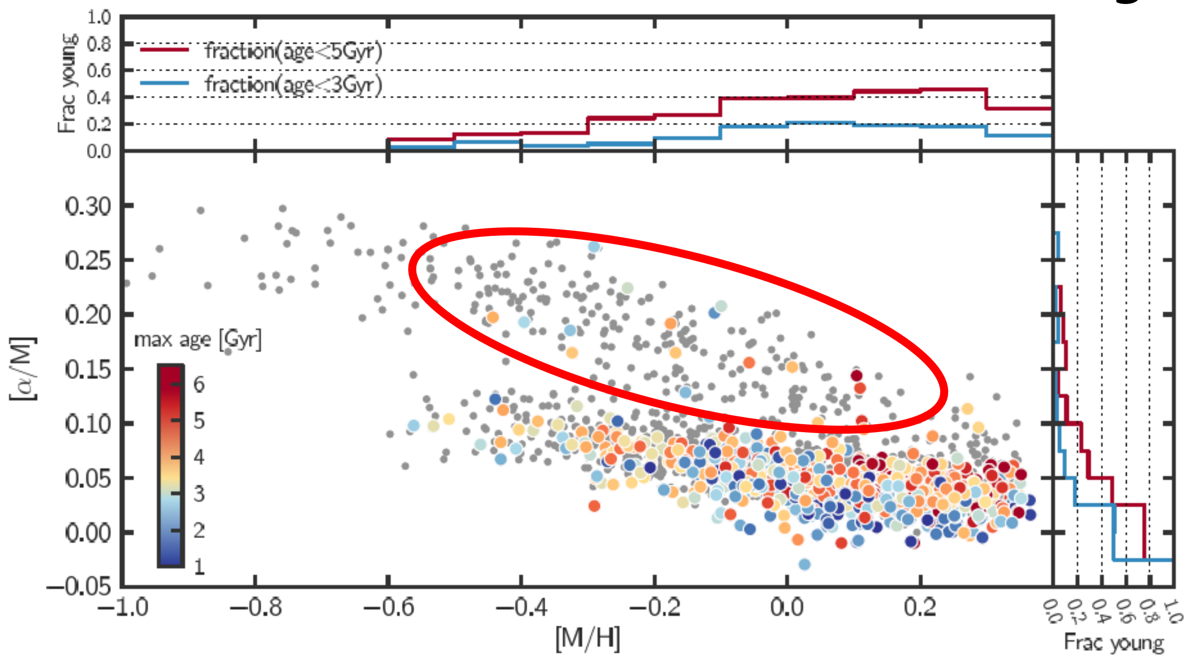
Isochrones for 0-15 Gyr

CoRoT and SDSS/APOGEE

- **Seismology with CoRoT → Age estimates for red giants**
- **Spectroscopy with SDSS/APOGEE**

Young (ages of a few Gyr) alpha-rich stars?

Martig et al. 2015



Gaia-ESO survey

- VLT FLAMES (multi-object, R~20,000)
  300 nights

- Spectroscopy for 100,000 Milky Way stars (V<19)
  - Inner Galaxy (Bulge) : ~14,000
  - Thick disc, Halo and Outer Galaxy : ~24,000
  - Thin disc : ~20,000
  - Open clusters : ~40,000

Many publications, in particular on discs and open clusters

What should we do now and near future?

Halo stars with low metallcity

Studies of MW Halo with Subaru/PFS

PFS white paper (Takada et al. 2015)

The main questions we seek to address in our dedicated GA survey are summarized as follows:

1. *What is the merging history of the Milky Way?* *(addressing the role and nature of dark matter in galaxy formation)*
2. *How did the old Galactic components (thick disk and stellar halo) form?* *(addressing baryonic physics at early epochs)*
3. *How does M 31 differ from the Milky Way?* *(contrast merging and baryonic processes on small scales in two systems)*

Decomposition of halo stars in the phase space and examination by chemical abundance ratios

PFS white paper (Takada et al. 2015)

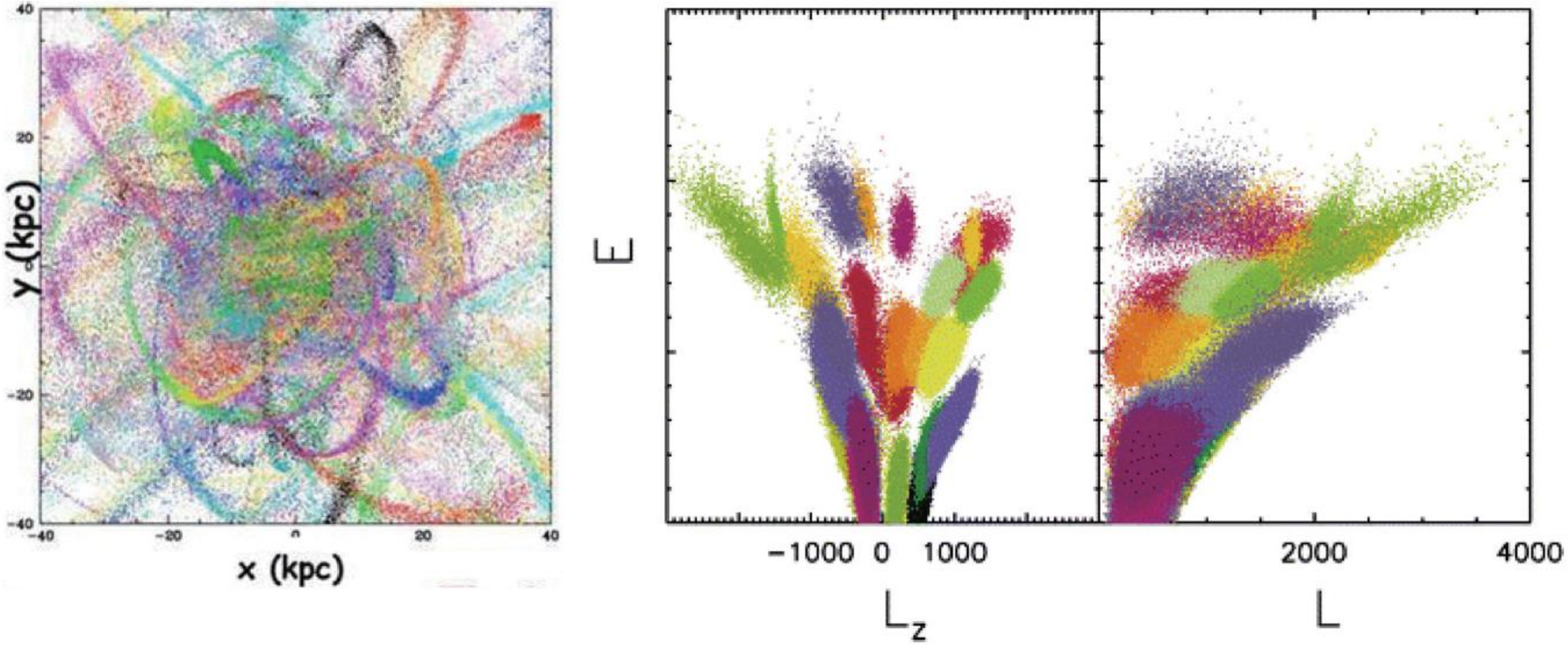
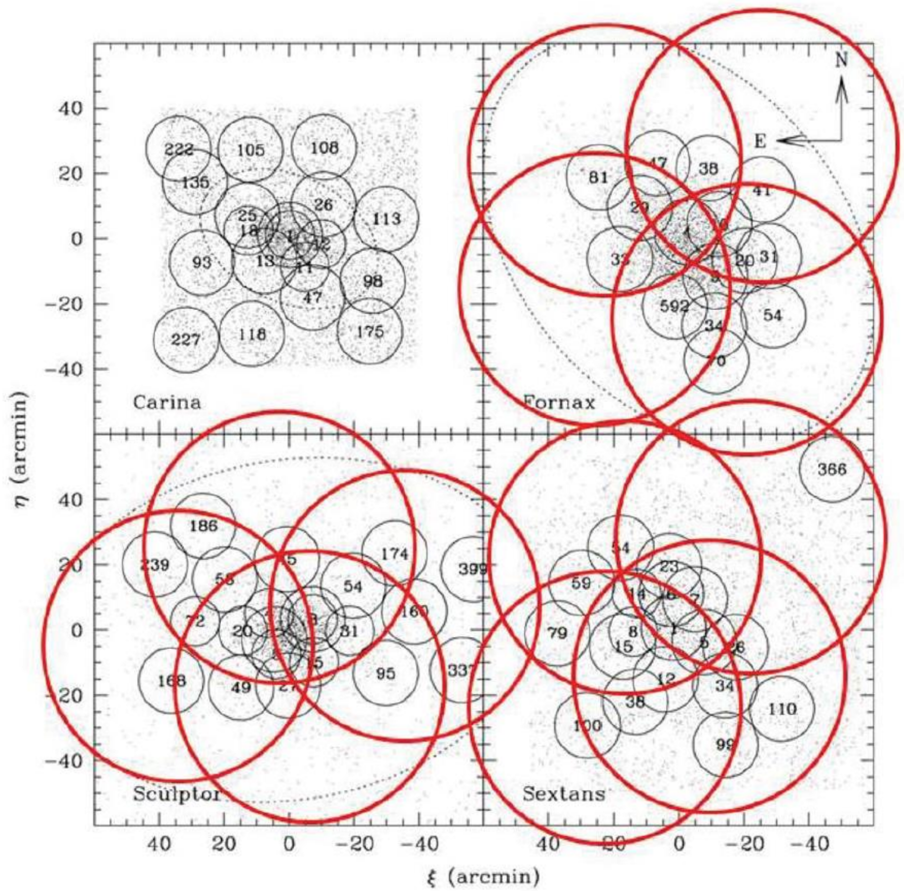


Fig. 12. Left: Model distribution of tidal streams in a Milky Way-like galaxy in spatial coordinates where the different colors represent different satellites (from Freeman & Bland-Hawthorn 2002). These stream-like features disappear after several dynamical times. Right: Model distribution of nearby stars in the integrals of motion space, i.e., E vs. L_z and E vs. L, based on numerical simulations of satellites falling into the Milky Way (from Helmi & de Zeeuw 2000). The different colors represent different satellites. Shown is the final distribution of stars after 12 Gyr within about 6 kpc from the Sun, after convolution with the errors expected for Gaia. It is clear that each of the progenitor galaxies can be traced via the current phase space distribution. (Color online)

Studies of dwarf (satellite) galaxies with PFS

Measurement of velocity dispersion covering outer region
→ constraint on the nature of dark matter



PFS white paper (Takada et al. 2015)

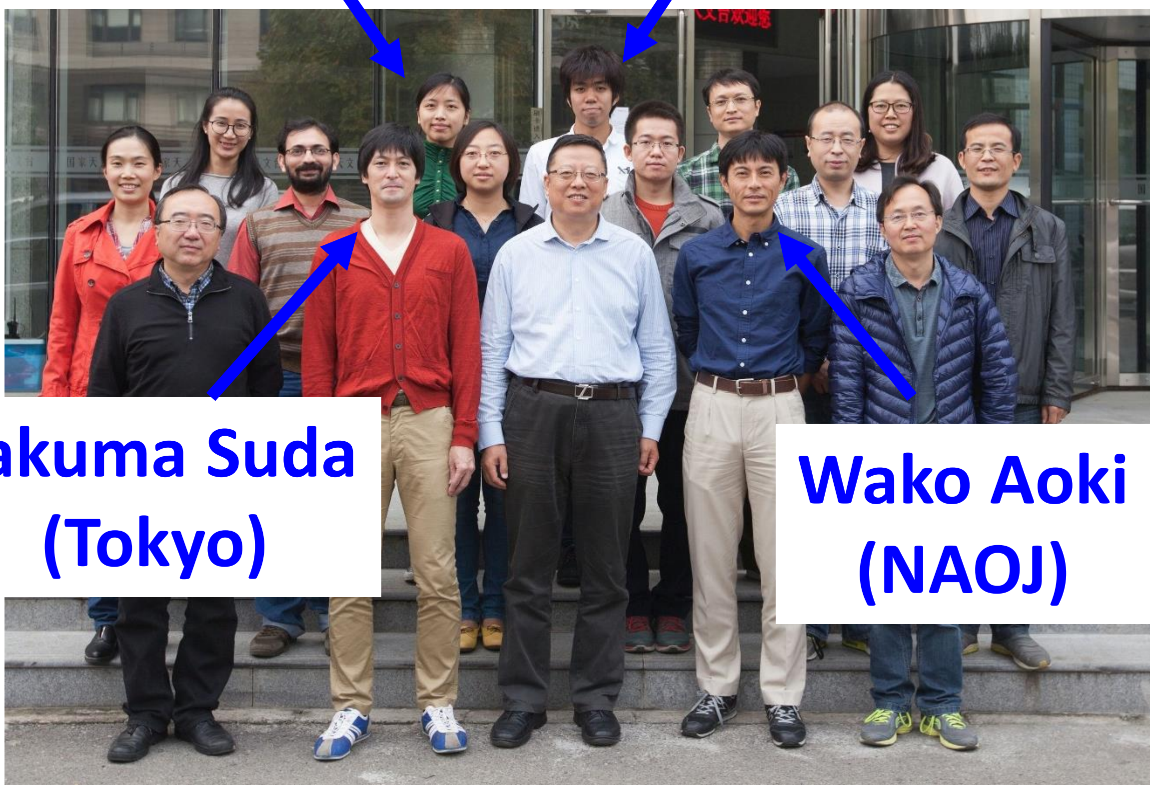
Red circles: FoV of PFS
Black circles: previous studies

People working on spectroscopy for halo stars in Japan

Misa Aoki
(ICU)

Tadafumi Matsuno
(NAOJ/SOKENDAI)

Miho Ishigaki
(Kavli-IPMU)



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