Towards Galactic Archaeology with PFS

PFSによる銀河考古学に向けて

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Galaxy formation in CDM paradigm

Assembly of CDM

Galactic dark halo

Bright parts are centrally concentrated
Main issues in GA

1. Formation of Galactic structures
   ✓ Merging history of the Milky Way?
   ✓ Formation process of each Galactic component?
   ✓ Is MW different from M31? If so, why?

2. Nature of galactic dark matter
   ✓ Missing satellites problem?
   ✓ Properties of luminous satellites? How many there?
   ✓ Dark matter profiles? Cuspy or cored?

All are recorded in old stellar populations
Fossil records of galaxy formation

Debris of building blocks

- Space and velocity distributions of ancient stars
  - Past collapse and merging events
  - Tracer of dark matter profiles
- Chemical abundance of ancient stars
  - Star formation and chemical evolution

Phase space

A building block

Thick disk

Thin disk

\( [\text{Mg/Fe}] \)

\( [\text{Fe/H}] \)
Galactic astronomy through resolved stars

- **Photometry**:
  - mag., color (→ color-mag. diagram)

- **Spectroscopy**:
  - metallicity (→ age), $V_{rad}$ (kinematics)
  - abundance pattern (→ SF & chemical evol.)

- **Astrometry**:
  - proper motion, distance (→ 6d phase space)

Structure, dynamics, star formation and chemical evolution

⇒ galaxy formation and evolution
Substructures in the M31 halo

Northern Spur

G1 Clump

Stream

Ferguson+02
Several stellar halos in CDM models (Johnston+08)
Extracting merging history in M31

Identify and count the number of streams delineated by $\mu$, [Fe/H], and $V_{rad}$

$\Rightarrow$ Probability distribution of streams
HSC photometric survey of M31’s halo using optimized NB515 filter (g<22.5)

Metallicities and RVs of substructures and satellites with PFS

$I_{TRGB}=20.5$
Substructures in the MW halo (tidal debris of building blocks)
Metal-poor stars in angular momentum space (Hipparcos sample)

- measurement error of a few 100 (kpc km/s) smears out substructures

Astrometry with Gaia
- precise distances and proper motions
- resolves each of substructures (Building blocks of the stellar halo)
Gaia

Astrometry:
- $V = 15$, 12~25 $\mu$as
- $V = 20$, ~300 $\mu$as

Photometry:
- $V < 20$

RV measurement:
- $V < 17$ (150M stars)
- $R \sim 10000$, $\lambda = 8450$-8750A (CaT)
- $\Delta V_{rad} \sim 15$ km/s

[Fe/H] measurement:
- $V < 13$

Cf. Hipparcos
- $V < 12$, 1mas
Constraints on accretion time of a satellite
(McMillan & Binney 2008, Gomez et al. 2010)
⇒ Extracting merging history in the MW

Orbital freq.
\(\Omega r-\Omega \phi\)  \(\Omega r-\Omega \phi\)

\(\Omega \sim \Omega_0\)  \(\Omega \phi\)

\(P(k\phi)\)

\(L_z\)

7.9 Gyr  8.9 Gyr  7.6 Gyr
DSphs as ideal sites for DM study (via. velocity dispersion profiles)

Gilmore+07

$\sigma \sim$ a few to 10 km/s

DM dominated

Cuspy or core?
PFS
(Prime Focus Spectrograph)

FOV: 1.77 sq deg
(1.5 deg diameter)
2400 to 3000 fiber positioners
40 sec reconfig. time
λ: 600~1000nm +more?
R: 3000 +more?
Requested performance of PFS

1. Ability to measure RVs and [Fe/H] for many stars at the same time
   - Best synergy with Gaia, i.e., 15<V<20
   - Enable to determine $\sigma$ of dSphs and streams accurately, i.e., $\Delta V_{\text{rad}} < 2 \text{ km/s}$
   - Enable to observe M31 stars with $I_{\text{TRGB}} = 20.5$, i.e., $V_{\text{lim}} \sim 21.5$

2. Ability to follow up high-res. spectroscopy for reasonable number of stars at the same time
   - $R=3-40000$, $\lambda < 9000A$, a few 100 fibers, $V<17$
WFMOS study
Team A & B

1. **LR mode** for metallicities and kinematics
   A) $V < 21.5$, $\Delta[Fe/H] \sim 0.2$, $\Delta V_{\text{rad}} \sim 10$ km/s, S/N$\sim 50$,
      $R \sim 1800$, $\lambda=3900-9000$A using SEGUE pipeline
   B) $V < 20$, $\Delta[Fe/H] \sim 0.1$, $\Delta V_{\text{rad}} \sim 2$ km/s, S/N$\sim 10-15$,
      $R \sim 5000$, $\lambda=4800-5500$A (Mgb) & 8150-8850A (CaT)

2. **HR mode** for chemical tagging
   $V < 17$, $\Delta[Fe/H] < 0.1$, S/N$\sim 100-150$
   A) $R \sim 30000$, (1) $\lambda=6280-6593$A (2) 5015-5268A (3) 6456-6608A (4) 8380-8804A (5) 4112-4322A
   B) $R \sim 20000$, $\lambda=4800-6800$A

1000-2000deg$^2$, 100-280nights for each mode
Ca II triplet as [Fe/H] indicator

Reduced EW $W'(\Sigma Ca, V_{HB} - V)$

Valid for RGBs with $-4 < \sim [Fe/H] < -0.5$
Ca II HK as $[\text{Fe/H}]$ indicator

Valid for both dwarfs and giants with $-4.0 < [\text{Fe/H}] < 0.5$

Beers+99
Chemical tagging?

De Silva+07

Abundance variation in an open cluster

ΔMg ~0.05 dex
ΔFe  ~0.02 dex

Very precise spectroscopy for many stars (million stars) is required!

すばるでやるか?
恐らくNo
Best step towards GA with PFS

1. PFS LR in perfect synergy with Gaia
   - $R=5000$, $\lambda=3900-9000\text{A}$, ~3000 fibers
   - RVs and [Fe/H]s for million stars with $17<V<21.5$, $\Delta[\text{Fe/H}]/\sim0.1$, $\Delta V_{\text{rad}}/\sim2$ km/s
   - Discover many substructures and identify merger history

2. PFS HR for follow-up studies
   - $R=40000$, (1) $\lambda=6280-6593\text{A}$
     (2) 5015-5268A (3) 6456-6608A (4) 8380-8804A
     (5) 4112-4322A , ~200 fibers, with $V<17$
   - Chemical history of each merging progenitor

| Table 5. Predicted Log star counts per square degree in the V-band |
|------------------------|-----------------|----------------|---------------|-----------------|----------------|
| $V$        | $|b|=20^\circ$ | $30^\circ$ | $60^\circ$ | $90^\circ$ |
| 17         | 3.36            | 3.12         | 2.67         | 2.55          |
| 18         | 3.61            | 3.35         | 2.87         | 2.74          |
| 19         | 3.85            | 3.56         | 3.05         | 2.92          |
| 20         | 4.06            | 3.75         | 3.23         | 3.09          |
| 21         | 4.24            | 3.91         | 3.39         | 3.25          |
| 22         | 4.38            | 4.05         | 3.54         | 3.38          |

~1400 stars/PFS field @ $V=17, b=|45|$
Photometry to $V=20$
End