MSE and Stellar Astrophysics

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MSE and Stellar Astrophysics

MSE’s primary roles in Stellar Astrophysics:

1. **Discovery Space**, increasing sample size & sample quality unlocks new phenomena, new environments, hard-to-reach populations.

2. **Supporting** imaging surveys and help **target selection** for exoplanet surveys

Discovery space
Discovery space

What is there left to discover?

(1) Outer halo, e.g.,
   - Accreted stars that sample the non-surviving dwarf galaxies & GCs; thus, ages, kinematics, with compositions, and possibly host masses & SFHs.
   - Halo white dwarfs, halo dwarf stars, RR Lyrae, thus ages & kinematics.

(2) Dwarf galaxies, e.g.,
   - $g < 20.4$ permits full stellar census of nearby northern dwarf galaxies & UFDs to compare to the outer stellar halo and other stellar populations.

(3) Faint Bulge, e.g.,
   - SFH in the Bulge, comparison of dwarf stars & giants.
   - Significant numbers of metal-rich, old stars.
Discovery space

What is there left to discover – II?

(3) Outer disk, e.g.,
   - recent star formation & different conditions in outer disk ISM
   - young, metal-poor stars.

(4) Rare stars, e.g.,
   - metal-line white dwarfs, solar twins, Li rich giants, CEMP-no, peculiar AGB stars …
   - new chemically peculiar stars, alpha-rich young stars, First Star remnants …

(5) The unknown, e.g.,
   - In studies of the diversity of a population of butterflies, Fisher (1943) proposed a simple relationship linking the sample size, \( N \), and the number of species present, \( S \), such that
     \[
     S = A \times \ln(1 + N/A)
     \]
   - where \( A \) the diversity index, parameterizes the tendency of the population to produce separate subspecies.

\[
\begin{align*}
\text{If } A &= 1 : & S &= 7 \quad \text{for } N=10^3 & \text{which seems ~astro-like.} \\
\text{Adopting } A &= 1 : & S &= 12 \quad \text{for } N=10^5 & \text{seems ~similar to known number of stellar populations, i.e., current & planned surveys.} \\
\text{With MSE}, & \quad S &= 15 \quad \text{for } N=5\times10^6 & \text{What will those ~3 new populations be !?}
\end{align*}
\]
Baseline specs: 370 nm to 1.7 microns

Nearly all chemical species are available in this wavelength range, e.g., Starkenburg plot (optical) →

In addition:
- Eu II 3819, 4129 (stronger!)
- Pb I 4057 (s-process)
- Dy II 4077, 3944 / Er II 3830, 3896 (nucleosynthesis)
- U II 3859, Th II 4019-4095 (cosmochronology)

In the near-IR:
the APOGEE survey has made enormous improvements in synthesizing 1.5-1.7 microns:
- isotopic ratios, 13C/12C, etc.
- precision from OH, CH, CO, CN bands.
- comparison of optical and IR elemental abundances to examine systematic errors (NLTE, stellar models, atomic/molecular data, etc.)
Support Surveys
Target density (g<20)

Figure 2: Sky density (per deg$^2$) up to G=20 visible from MSE ($\delta > -30^\circ$), aitoff projection. Input data credit: Gaia DPAC CU2.
Support Surveys

Existing surveys:

(1) Imaging surveys: e.g., Gaia, PanStarrs, MegaCam surveys, Skymapper
   - Photometric indices alone can be used to select interesting targets, e.g., metal-poor.
   - PanStarrs limiting magnitudes already deeper than MSE limits.
   - Spectroscopy complements Gaia proper motions for full 6D phase space.

(2) Medium-to-Low resolution spectroscopic surveys: e.g., Gaia, DES, Lamost, SDSS
   - At R=20,000, [Fe/H], [alpha/Fe], and 5-10 additional elements with precision ~0.15 dex.
   - At R=40,000, more chemical elements and higher precision, ~0.1 dex.
   - Also needed for de-blending lines (e.g., few & critical lines, or cool & metal-rich stars.).

(3) Planet search surveys: e.g., Kepler, CORALIE
   - Need high resolution spectroscopy to confirm candidates/ false positives, e.g., binaries.
   - Need high resolution spectra for radial velocity precision (<100 m/s) for orbits & masses.
Binaries

Binary is important:

Some stellar astrophysics directly due to binary characteristics;
- e.g., CVs, HMXB, LMXB, Novae, CEMP, AGB, blue stragglers

Non-detection can bias stellar parameters, continuum placement, & abundances determinations,
- Erspamer & North (2003) find undetected binaries can cause $\Delta v \sin i = 10$ km/s and affect abundance determinations by up to 0.1 dex.

Non-detection can boost the radial velocity dispersions, and thereby dSph galaxy mass estimates;
- Erspamer & North (2003) find undetected binarity can increase velocity dispersions by 9 km/s in stellar groups.
- McConnachie & Cote (2010) estimated a boost in binary fraction could increase velocity dispersions in dwarf galaxies by 4.5 km/s.
- Geha et al. (2013) suggest $f(\text{bin}) \sim 0.47$ in Leo IV and Hercules UFD, though had little effect on mass estimate.
- Walker et al. (2009) show global velocity dispersions vs half light radius for dSph galaxies, and best-fitting mass profiles.
Imagine an MSE targeted project for the spectral follow-up to the Kepler field:

- 115 deg$^2$ Kepler survey area covered in 84 MSE pointings

Now imagine long term MSE monitoring (10 years, ~50 epochs)

- RVs at R=40,000 of exoplanet candidates
- determine stellar multiplicity
- determine precision stellar parameters
- also rotational velocities, ages, orbits, Galactocentric orbits, etc.
Binaries

Note: MSE radial velocity accuracies are ~150 m/s, thus not meant to compete with VLT ESPRESSO’s ~10 cm/s

MSE provides wide field and long term monitoring
Support Surveys

**Planned surveys:**

(1) Imaging surveys: **LSST, Euclid**
- Spectroscopic follow up on objects, transients.
- 60% of the LSST footprint available at Maunakea.

(2) Low resolution surveys: **DESI, PFS**
- High resolution for higher precision in stellar parameters of faint objects.

(3) Future planet finding missions: **TESS, PLATO**
- Target selection; stellar parameters & binarity, *a priori*
Time Domain
MSE will also have the unique ability to \textit{spectroscopically} monitor time variable objects:

- Serendipitous discoveries of variable stars expected with LSST, \sim 100’s per night (Ridgway et al. 2014).
- binary stars
- pulsating stars
- eclipsing variables
- novae, XRBs, & eruptive stars
- supernovae
- transit-selected planet hosts

Searching for Time Variable objects requires attention to \textit{cadence}:

- $\log(\text{time})$ displacements is one way to avoid aliasing period determinations.
- or SDSS-MARVELS uses a baseline cadence of 33 visits over 18 months, e.g., 15 visits within a two-month period to resolve short period variations, 5 more over the first year, and two per month in the second year to resolve longer periods, phases, and amplitudes (Ge et al. 2008, Lee et al. 2011).

Currently, only SDSS-APOGEE uses multiple observations:

- spaced over two years (to reach their SNR requirements),
- enables the search for variability, or at least binarity (e.g., Deshpande et al. 2013).
MSE and Stellar Astrophysics

MSE’s primary roles in Stellar Astrophysics:

(1) Discovery Space: new stars & stellar populations, rare stars.
(2) Supporting surveys and target selection: e.g., exoplanet hosts.
(3) Time domain astronomy, spectroscopic monitoring.