Probing the IMF

Star Formation in Massive Clusters

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GSMT SWG
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Probing the IMF: Goals

- Quantify the IMF in rich, dense star-forming regions
  - dominant contributor to total stellar content of galaxies
- Understand the relationship between IMF; initial conditions
  - explore linkage to density; thermal + turbulent pressure
    - e.g. Elmegreen and Mohsen (2003)
      - locate the stellar birthline
      - link to mass accretion rate

Critical to modeling star-formation in the early universe
• JHK photometry
  – MCAO images at high Strehl (~ 0.7 at K-band)
• IFU spectroscopy at R ~ 1000 provides spectral types
• Spectral types + photometry yield:
  • N(A_v)
  • statistical model of N(K)
  • N (M) for assumed age
Probing the IMF: Measurements

Galactic Center Superclusters: $d = 10$ kpc

Stellar density $\sim 100x$ Orion Nebula Cluster
Probing the IMF: Measurements

LMC Massive Cluster: $d = 200 \text{ kpc}$

Stellar density $\sim 10\times$ Orion Nebula Cluster
Probing the IMF: Measurements

M82 Superclusters: $d = 4$ Mpc
Probing the IMF: Measurements

Stellar Birthlines for Differing $dM_{\text{acc}}/dt$

How is $dM_{\text{acc}}/dt$ related to $[\text{Fe/H}]$; stellar density?
• Best available data: HST probes of Arches (MWG); R136 (LMC)
  – IMF range limited to $M > 2 \, M_{\sun}$

• With JWST or MCAO on 8-m telescopes
  – IMF can be probed down to hydrogen-burning limit in MWG
  – Studies in more distant galaxies in Local Group (~1 Mpc) not feasible
    • Crowding limits photometric measurements
Key issue is crowding (not photon collection):
  • See MCAO simulations by K. Olsen (this meeting)

With a 30m GSMT, K-band diffraction limit is 15 mas
  • R136-like clusters can be studied throughout the M33 disk
    – Probe birthlines; IMF for wide range of metallicities
  • R136-like clusters can be studied out to M82 (upper end of IMF)
Estimating GSMT Performance

- Assume MCAO system that delivers Strehl of 0.7 at K
- Use as input a composite K-band luminosity function
  - Arches IMF from Blum et al. (2002) [upper end]
  - Orion IMF from Hillenbrand & Carpenter (2000) [lower end]
- Derive crowding from observed central surface densities
  - Arches cluster
  - R136
- Estimate crowding limit ($\sigma_K < 0.1 \text{ m}$) for $R/R_{1/2} = 0.5, 1, 2, 5$
- Convert K-limit to mass limit using $t = 1$ Myr isochrone
Lower Mass Limit for IMF Studies: Arches-Like Cluster in M33

\[ \Sigma_k = 13.6 \text{ mags arcsec}^{-2} \]

\[ (m-M)_0 = 24.5 \text{ (M33)} \]

\[ \text{slope} = 0.23 \text{ mag/meter} \]

\[ L_{\text{lim}} = A e^{0.2d} \]
Lower Mass Limit for IMF Studies: R136-Like Cluster in M33

\[ L_{\text{lim}} = A e^{0.2d} \]

slope = 0.23 mag/meter
Probing the IMF: Requirements

- MCAO-fed near IR imager with ~0.5’ -1’ FOV
  - Deliver Strehl ~ 0.7 at K-band
- MCAO-fed IFU spectrograph with R ~ 3000
Probing the IMF: Trades

- Ability to probe IMF to larger distances; lower masses increases as (aperture)$^2$
  - Directly linked to reduced crowding
- Adequate sampling of IMF requires MCAO field $r \sim 15''$
## Results: 30-m GSMT

<table>
<thead>
<tr>
<th></th>
<th>Limiting $M_K$</th>
<th>Limiting mass</th>
<th>Exposure time</th>
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<tbody>
<tr>
<td></td>
<td>LMC</td>
<td>M33</td>
<td>M82</td>
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<tr>
<td>0.5$R_{1/2}$</td>
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<td>$R_{1/2}$</td>
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### Results: 20-m

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<td>$R_{1/2}$</td>
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### Results: 8-m

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<th>Exposure time</th>
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<tr>
<td></td>
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<td>M82</td>
</tr>
<tr>
<td>0.5R&lt;sub&gt;1/2&lt;/sub&gt;</td>
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Example Program

- **Milky Way**
  - Observe rich clusters from galactic center to Perseus arm
    - Probe N(M) down to hydrogen-burning limit
    - Define role of metallicity on birthline; IMF
- **LMC & SMC**
  - Extend understanding to lower metallicities
- **M33**
  - Probe N(M) for $M > 4 M_{\text{sun}}$ for super-rich clusters across the galactic disk
- **Total time to complete program ~ 10s of nights**
• Quantify the spatial distribution for stars of different masses & ages
  – Do massive stars form preferentially near the cluster center?
  – If so, does this imply a different formation mechanism?
    • e.g, mergers in dense cluster core
• Quantify stellar multiplicity in dense clusters
  – How do dynamical interactions influence multiplicity?
  – What are the relevant timescales and environmental conditions?
Probing the IMF: Additional Simulations Needed

- Simulate variable extinction & nebular background
- Understand Strehl vs photometric precision trade
- Understand IFU spectrograph performance requirements
- Understand spectroscopic sample needed to derive \( N(A_v) \)
Conclusions

• GSMT can establish the link between emerging stellar populations and initial conditions in star-forming regions
  – Fundamental to understanding star-formation process
  – Essential to understanding galactic evolution

• Size matters!
  – Crowding limits photometric accuracy
  – Crowding limit scales as $d^2$
  – Telescope diameters of 30m or greater are needed

• The IMF example is representative of a large class of problems that require superb image quality over ~1’ FOV