THE ROLE OF SMALL TELESCOPES IN STUDIES OF STAR-FORMING REGIONS AND YOUNG STELLAR CLUSTERS

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Outline:

Telescopes $\lesssim 2$ m in Size are Valuable for:

- self-contained, targetted research appropriate to small apertures
- enabling/supporting observations with larger apertures
- monitoring of well-studied or bright objects
- dedicated large-scale and/or long-term surveys
- follow-up on objects detected with space-based observatories
- teaching and instrument/technique development

An Example of a Major Program Enabled by Small Telescopes

Studying the stellar population, star-forming history, and structure/dynamics of the Orion Nebula Cluster (ONC) is a hybrid of small aperture applications.

The ONC is forming stars of all masses in the range $< 0.1 - 50\mathcal{M}_{\odot}$ and is the nearest, richest example of the clustered mode of star formation thought to dominate in the Galaxy.

- The goals of this long-term project are to derive the:

  – initial distribution of stellar masses

  – initial distribution of stellar angular momenta

  – initial distribution of circumstellar disk properties

- Motivation:

  – to understand factors (initial conditions, environment, etc) which influence masses, angular momenta, and disk properties

  – to utilize derived initial distributions in investigations of the evolution of mass, angular momentum, and disk property distributions via comparison with older open clusters

Complement of Instruments/Facilities Utilized in ONC Study:

[a 0.5 x 0.5 deg^2 region ($r_{projected} < 2.5$ pc) has been analyzed thusfar, with study of larger 3.5 x 3.5 deg^2 region underway]

- optical imaging at VI; N$\approx$ 1600 stars

  – KPNO 0.9m CCD
  – HST in central crowded/nebulous region (Prosser *et al.* , 1994)

- infrared imaging at JHK; N$\approx$ 700 optical + 225 infrared stars

  – KPNO 1.3m OTTO for brighter stars
  – KPNO 1.3m SQIID
  – MDM 2.4m with UMass/NICMASS in central region

  K-band only from literature for several thousand others

  – OSIRIS (Ali & DePoy, 1995)
  – MAGIC (McCaughrean *et al.* , 1994)

- optical spectroscopy over 5000-9000 Å; N $\approx$ 450+ stars

  – KPNO 4m/WIYN HYDRA multiobject spectrograph
  – KPNO 4m RC spectrograph with multi-slit masks
  – a few spectral types from the older literature

The combination of low- and high- spatial resolution observations plus the low- and high- sensitivity of these various instruments allows the stellar population of the ONC to be studied at all cluster radii over its full dynamic range of > 20 mag at V and > 10 mag at K.

Brief Summary of Results on the ONC:

- masses
- ages
- disks
- rotation
- radial gradients

These *are* the directly measureable initial conditions of cluster-mode star formation.

The Need to Build an Open Cluster Database:

- test star-formation / cluster-formation models:

  – universality of initial mass distributions

  – fraction of total cluster mass in brown dwarfs

  – fraction of stars born in binary systems; binary evolution

  – circumstellar disk accretion rates and lifetimes, with mass (*i. e.*, planet-building timescales)

  – all of above as a function of environment

- test angular momentum evolution models:

  – pre-main sequence star/disk magnetic locking

  – relationship between disk dissipation and stellar spin-up

  – solid-body rotation vs. core-envelope decoupling

- refine the currently uncertain calibrations of observational → theoretical quantities:

  – pre-main sequence tracks and isochrones, with age

  – color- and spectral-type-to-T_{eff} conversions

Why one or two clusters isn't enough:

- need a range of star-forming environments (*e. g.* small cores *vs.* GMC's; low- *vs.* high- stellar density aggregates/clusters)

- need a range of cluster ages, especially since stellar and circumstellar evolution occurs on different timescales for stars of different mass

- need a range of metallicities, to ensure that small metallicity variations don't dominate over evolution

- need to remove random cluster-to-cluster variations

The Current Open Cluster Database:

- At least some data exist (or studies are underway) for:

  - Small aggregates associated with Herbig Ae/Be stars
  - NGC 2024 (<1 Myr; d = 470 pc)
  - Orion Nebula Cluster (1 Myr; d = 470 pc)
  - Mon R2 (<1 Myr; d = 830 pc)
  - NGC 7000 / IC 5070 ($\lesssim$ 3 Myr; d = 600 pc)
  - NGC 2264 (3-20 Myr; d = 800 pc)

  - IC2602/IC2391 (30 Myr; d = 150 pc)
  - Alpha Per (50 Myr; d = 170 pc)
  - Pleiades (70 Myr; d = 125 pc)
  - Hyades (500 Myr; d = 45 pc)
  - Praesepe (700 Myr; d = 175 pc)

- We need to know, down to the hydrogen burning limit:

  - membership
  - photometry
  - spectral types
  - rotational velocities
  - lithium measurements
  - chromospheric / coronal activity measures

BUT EXISTING DATABASES ARE SURPRSINGLY SPARSE!!!

Next Steps on "Initial" Clusters:

- Current Status:

  – no modern optical data at all exist for many important regions

  – only reconnasaince-level near-infrared imaging surveys exist for a few small cloud cores, and none at all for many larger GMC complexes

  – only spectra of the brightest and the bluest stars exist in most star-forming regions

- Action Items:

  – acquire optical imaging data for large regions like NGC 7000 and all of the Orion GMC complex, to study cloud surface populations (1m)

  – conduct comparable near-infrared imaging surveys to study embedded populations (1-2m)

  – extend near-infrared surveys to depth suitable for detection of young brown dwarfs (2m)

  – carry out follow-up observations of young stellar objects identified in satellite surveys (*i. e.* IRAS, ROSAT) (1m + 4m)

  – build databases for carrying out multi-object spectroscopic programs

Expected Return for Telescope Commitments:

- optical imaging:
  - moderate spatial-resolution
    - photometry over large fields (23' at KPNO 0.9m)
    - coordinates for spectroscopy
    - rotation periods and binary discovery though monitoring

    (2 hours for $3/4 \times 3/4$ deg^2 field at VRI)
  - high spatial-resolution
    - photometry in central, dense, nebulous region
    - statistics of visual binary frequency
- infrared imaging:
  - moderate spatial-resolution

    (1 night at JHK with SQIID; 3 nights with any other imager)
  - high spatial-resolution
- optical spectroscopy:
  - moderate-resolution
    - spectral classification
    - identification of stars with emission lines

    (10 nights with fibers plus 2-3 nights with slits for entire ONC)
  - high-resolution
    - rotational and radial velocities
    - lithium measurements
    - emission-line profiles indicating infall/outflow
    - continuum veiling measurements
- infrared spectroscopy of embedded populations

Next Steps on "Older" Clusters:

- Current Status:

  – no membership lists exist below $\sim 1\mathcal{M}_\odot$ for more distant open clusters (ie, M67); nearby southern clusters are poorly known

  – $\sim$50% of the Pleiads do not have photoelectric photometry, 75% of Praesepe

  – rotation period data exist only for small samples of early-type (G-K) stars, mostly in the Pleiades, Alpha Per

- Action Items:

  – complete stellar photometry in Pleiades and Praesepe (1m)

  – survey to R=25, I=23 to identify brown dwarfs to 0.02 $\mathcal{M}_\odot$ in the Pleiades and show they are not present in Praesepe due to cooling (4m)

  – establish membership lists for more distant (m-M $\lesssim$ 10) clusters to fill in age gaps (1m + 4m)

  – extend rotation period studies to early M dwarfs in Alpha Per, Pleiades, Hyades, IC2602 IC2391 (1m, 0.5% photometry)

  – obtain near-infrared photometry for $\lesssim$ 30 Myr old populations (1m)

Concluding Thoughts:

- there is much to be done both on establishing the initial distributions of fundamental stellar parameters and on following the evolution with time of these distributions

- this is basically small telescope science, although not small science!!

  (in fact, big telescopes can be proven to be actually "too big")

- for the youngest clusters, building merged opt/ir photometric and opt/ir spectrosopic databases necessitates data gathering, analysis, and interpretation over timescales of ~ 5 years

- infrastructure provided by a national observatory (NOAO) allows, for either an individual or a team:

  – use of a single proposal for multiple telescopes/instruments to be presented as coherent project to the TAC

  – access to well-documented, reliable facilities

  – uniform data acquisiton format

  – well-supported data reduction/analysis software

  – feedback mechanism for the benefit of both other users and the observatory

- the ONC study would not have been possible on its current timescale without this infrastructure