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SENIOR CAPSTONE PROJECT 2026

Research Proposal:

Mapping Nebular Gas Structure Through Stellar Population Filtering in the Orion Nebula.

Author: Koen Schenck
Supervisor: Dr. David Harris

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INTRODUCTION

Star-forming nebulae such as M42 offer a rare opportunity to investigate the transition between molecular gas and ionized plasma under the influence of newly formed massive stars. The interplay between feedback, extinction, and gas kinematics defines the architecture of the surrounding interstellar medium (ISM) and regulates subsequent star formation.

In the Orion Nebula Cluster (ONC), the dominant O- and B-type stars within the Trapezium have carved a cavity of ionized gas within the molecular cloud. However, disentangling stellar light from nebular emission remains a key challenge: continuum from thousands of stars, reflected and scattered light, and spatially variable extinction all complicate direct measurement of the gas emission.

This project therefore focuses on producing **clean, extinction-corrected emission-line maps** and **correlating them with molecular gas and dust distributions.** Color–magnitude diagrams (CMDs) will serve as a diagnostic tool to remove stellar contaminants and build extinction maps, allowing accurate recovery of nebular surface brightness. The ultimate goal is to quantify the gas distribution, emission, and ionization across the ONC, relating them to the structure of the molecular cloud!

Methods

Overview This project integrates optical photometry, narrowband emission-line imaging, and astrometric data to characterize the nebular gas structure in M42. CMDs and Gaia-based membership analysis will be used primarily for extinction mapping and foreground/background separation, while the main science focus lies on emission-line morphology and gas diagnostics. Observations will be complemented with public CO and far-infrared data to link the ionized, atomic, and molecular components of the nebula.

Data Acquisition Broadband photometry (B, V, or Gaia G/BP/RP) will be used to construct CMDs for extinction mapping and star–gas separation. Narrowband imaging through filters centered on (). These data will be acquired through the Skynet and FIT telescope networks. All data will be registered to a \textbf{World Coordinate System (WCS)} to permit multi-instrument comparison and overlay with external surveys.

Spectroscopic and Ancillary Data. Spectroscopic data (archival or new) will probably aid in separating stellar and nebular line emission, providing velocity and excitation diagnostics.

Image Processing and Calibration All images will undergo bias, dark, and flat-field corrections, with photometric calibration derived from standard stars or cross-matched Gaia magnitudes. PSF-fitting photometry (\texttt{photutils}) will be used to identify and subtract stellar sources, particularly in the crowded Trapezium region.

Continuum subtraction may employ the medium-band F547M filter: each narrowband frame will be scaled to match the stellar continuum flux across the field and subtracted to isolate pure emission-line maps. The scaling factor will be spatially variable to account for filter transmission and scattered light differences. Residual stars or strong H\$$\alpha\$emitterswillbemaskedormodeledindividually.$

CMB and Extinction Mapping CMDs will be constructed to estimate gas color and line-of-sight extinction. Rather than serving as a stellar classification tool, the CMD analysis will provide:

- a map of $E(B-V)$ and A_V across the field derived from stellar colors relative to a fiducial ridge line;
- identification of foreground (blue) and embedded (red) stellar populations for masking or weighting in extinction interpolation;
- a spatially smoothed extinction map via the NICER or NICEST algorithms, which will be used to correct emission-line surface brightness.

This extinction map will be validated against Herschel dust emission maps and used to correct Hα, [N II], and [O III] images for differential reddening.

Nebular Emission Mapping and Analysis After stellar and continuum subtraction, extinction-corrected line maps will be used to derive:

1. **Surface Brightness and Emission Measure (EM)**
2. **Line-Ratio Diagnostics** — such as [O III]/Hα, [N II]/Hα, and [O I]/Hα, to map ionization, shocks, and photoevaporation;

3. **Spatial Correlations** — cross-correlation between ionized-gas brightness, CO column density, and dust optical depth to quantify feedback-driven structures.

Emission-line maps may be converted to physical units (erg s^{1} cm^{2} $arcsec^{2}$) and compared directly with molecular and dust maps in WCS-aligned coordinates.

Cluster Membership and Contamination Control Foreground/background stars may be filtered using Gaia parallaxes, proper motions, and RUWE quality cuts. Stars consistent with ONC membership would inform extinction mapping; others will be excluded from the analysis. Probabilistic membership classification will further be refined with infrared excess (disk-bearing YSOs) and Hα excess indicators where available.

Spatial and Structural Analysis Using the WCS-aligned catalogs, spatial density maps and radial surface-density profiles will be generated for each PMS sequence. Profiles will be compared between the ONC and Trapezium subregion to evaluate cluster concentration and possible sequential star formation. Foreground and background differentiation will be visualized through two-panel maps—one for blue (foreground) and one for reddened (embedded) sources—following the approach of **?**].

Reproducibility and Software All reduction and analysis pipelines will be implemented in `Python` using `astropy`, `photutils`, and `emcee`. Scripts and calibration files will be version-controlled in a public Git repository to ensure transparency and reproducibility.

Expected Outcomes This project will deliver:

1. Extinction-corrected emission-line maps (Hα, [O III], [N II], [O I]) for the Orion Nebula;
2. Stellar-subtracted, continuum-corrected images in WCS coordinates suitable for multiwavelength overlay;
3. Spatial distribution analysis between ionized gas, molecular gas, and dust emission;
4. A documented, reproducible pipeline for CMD-based extinction correction and nebular mapping applicable to other H II regions.

Scientific Impact By shifting the CMD's role from direct stellar classification to a tool for extinction and contamination correction, this work bridges stellar and nebular analyses. The resulting maps will provide new insights into how massive-star feedback sculpts the surrounding ISM, and how extinction and geometry shape our perception of star-forming regions. This integrative approach lays the groundwork for comparative studies of nebular kinematics, which this project will not outline, and structure across different H II regions, using both archival and new ground-based data.

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