A STUDY OF THE AGE OF THE ORION NEBULA CLUSTER

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Abstract

We present a new HR diagram of the Orion Nebula Cluster (ONC), obtained using the broad-band photometry taken for the HST Treasury Program on the ONC, an expanded set of spectral types and the most recent estimate of the cluster's distance. We compare the source distribution in the HR diagram with the theoretical isochrones derived by different groups to derive the mean cluster age, the age dispersion and to search for evidence of evolutionary trends of the age against the stellar mass or source distance from the cluster center.

The age predicted for the Orion Nebula Cluster in Hillenbrand 1997 is lesser than 1 Myr, but recent estimates of the distance have moved the estimated age to values greater than 1 Myr. However several lines of evidence support a very young age for the ONC:

- the position of the stars well above the ZAMS (Zero Age Main Sequence)
- the intrinsic variability of the stellar objects
- IR excess observed in emission from circumstellar material
- the presence of circumstellar disks and mass loss phenomenology

In principle, the ONC may allow an extremely accurate estimate of the stellar parameters despite the observational difficulties related to the non-uniform background and dust extinction.

ONC and HST Treasury Program

The Orion Nebula Cluster (ONC) plays a fundamental role in Astronomy as the prototype of young stellar clusters. The Hubble Space Telescope Treasury Program on the ONC carried out multicolor photometry of this region using in parallel the Advanced Camera for Surveys (ACS) Wide-Field/Planetary Camera (WFPC2) and the Near Infrared and Multi Object Spectrograph (NICMOS) in 11 filters from the U-band to the near IR, in order to obtain the most accurate estimates of stellar parameters.

Our sample

To study the age of the ONC cluster, we have selected in the ACS catalogue 487 stars with known spectra type from Hillenbrand 1997 (LAH97). For 475 of them we have complete four-bands photometry, which allows us to accurately estimate the extinction using Chorizos. For 336 of these stars Herbst et al. (2002) provide an estimate of photospheric variability.

- In order to reduce the uncertainties on the luminosity, we have selected the sources with low variability (σ<0.1 mag).
- We have also rejected 31 sources with high accretion luminosity revealed by the presence of anomalously blue F435W-F555W (B-V equivalent) colors.

Our final sample includes 258 sources.

Method

EXTINCTION

We have used the Chorizos package (Maiz Apellániz 2004) to derive the extinction toward each source given the LAH97 temperature and two different effective temperature and bolometric correction models. For the spectral type – effective temperature relation we have used the NEXTGEN models. The corresponding error in stellar luminosity and age is 0.04 (σ(logL)=0.04).

EFFECTIVE TEMPERATURE and BOLOMETRIC CORRECTION

For the spectral type – effective temperature relation we have used the relation of Luhman (1999), which improves at the low mass end over the relation originally assumed by LAH97. Bolometric Corrections have been derived from direct integration of the NEXTGEN atmosphere model atmospheres as seen through the ACS photometric system. We used the following formula for the F850LP bandpass:

\[
\log (\frac{L}{L_\odot}) = 0.4 \cdot \left( M_{\text{2,85}} - M_{\text{1,90}} + A_{\text{F435W}} + A_{\text{F555W}} - BC_{\text{DMAMMLL}} \right)
\]

For our sample of 258 sources with low variability and accretion, the estimated average error on the stellar luminosity is σ(logL)=0.03.

RESULTS: 1) HR DIAGRAMS

The figures below represent the HR diagrams for ONC with isochrones and tracks from different models:

- Siess
- Baraffe-Chabrier
- Palla-Stahler
- D'Antona-Mazzitelli

Rv=3.1

Rv=5.5

RESULTS: 2) CLUSTER AGE

These histograms show the distribution of the ages for:

1. Our original sample of 336 sources (solid line on top)
2. Our selected sample of 258 sources (yellow area)
3. A more conservative sample of 94 sources with variability Δm<0.06 mag (dashed area)

The cluster age depends on the assumed PMS models and on the reddening law. In general, ages derived assuming a reddening law of Rv=3.1 are larger than those derived assuming Rv=5.5. This is expected, since high values of R imply higher extinction values and therefore higher intrinsic stellar luminosity and younger age.

Siess model shows the lowest age scatter both in the case of Rv=3.1 and in the case of Rv=5.5.

Remarkably, cleaning the samples from stars having significant photospheric variability or accretion luminosity does not reduce the age spread.

Discussion

Hartmann (2001) discusses the age spread in star forming region finding that observational and theoretical uncertainties probably preclude any robust inferences of the detailed variation of star formation rates as a function of time. The main sources of error are:

1. distance
2. spectral type
3. extinction
4. photometric variability
5. unresolved binary companions
6. accretion

In the case of Orion, however:

1. the distance has been recently measured using VLBI techniques to d=414±17pc. Since the error is large than the extension of the cluster, we can assume all stars are at the same distance. This corresponds to an average error on the luminosity σ(logL)=0.015
2. spectral types have been obtained by Hillenbrand (1997) at visible wavelengths and they are typically accurate to within one sub-type. The corresponding error in stellar luminosity and age (σ(logL)=0.02) turns out to be negligible (see also Hartmann 2002)
3. we have used a Bayesian code to estimate the extinction toward individual stars on the basis of extremely accurate ACS photometry, and factorizing the uncertainties due to the assumed reddening law. The resulting error on the stellar luminosity is less than σ(logL)=0.014
4. we have selected a sample of sources with variability Δm<0.06 mag, corresponding to σ(logL)=0.04
5. our ACS data allow to resolve all sources with separation larger than ~0.5 AU. According to the standard distribution of binary companion separations, this corresponds to ~2% of the total number of binaries present in the cluster; correcting by this factor we estimate that the total fraction of binaries is ~0.9%. The corresponding error on the luminosity is σ(logL)=0.008
6. sources with evidence of significant mass accretion (3% of the total) have been removed from the sample.

The average error in the luminosities of our HR diagrams is therefore σ(logL)=0.04, This is significantly less than the observed scatter, indicating that the cluster is not coeval and that the star formation event may have occurred over a period of time of the order of the cluster age, i.e. ~1Myr.