Stellar Clusters as Probes of the Local Volume: A HEXA Program

Emilio J. Alfaro on behalf Stellar Systems Group (IAA-CSIC)

Antecedents and Main Objectives

1) **Star Formation and Cluster Dynamics**

Most of the visible matter in the universe is condensed into stars, with densities more than 30 orders of magnitude higher than the average density of the universe and more than 20 orders of magnitude higher than the densities of the interstellar clouds in which they form (Larson 2007). Thus, the fundamental question is not how baryons end up as stars, but how some of them form stars and others remain as hot, low-density interstellar gas. This enigma lies at the core of a predictive theory of star formation, one of the main goals of modern astronomy. We are still far away from a global solution to this complex problem, whose answer depends very much on the existence of a well-structured and complete set of empirical data, as well as on the building of reliable and precise simulation tools.

Nowadays, it is widely accepted that stars form in highly hierarchical stellar systems that mimic, in some way, the stepped structure of the interstellar medium or, at least, the morphology of the densest regions. This hierarchical pattern, both spatial and temporal, presents singular condensations, the stellar clusters, whose main physical characteristics make them reliable tracers of the star forming processes in galaxies. Hierarchical structure extends from star complexes (or large portions of spiral arms in flocculent galaxies) through embedded clusters to individual young stars inside those embedded clusters. The cluster scale appears to be the best metric to measure and analyze the whole spatial range in the formation of stellar systems.

In this project we tackle the study of the formation, evolution and destruction of star clusters and its not-so-lineal connection with the forming processes that lead to the generation of stars.

Theories of cluster formation range from the highly dynamic through to quasi-equilibrium and slow contraction scenarios. These different routes lead to different initial cluster structures and kinematics. Subsequent evolution depends on many factors, including the initial conditions, star formation efficiency and tidal interactions (Chen, de Grijs & Zhao 2007; Lamers & Giele 2008; Konstantopoulos et al. 2010; Smith et al. 2011). Whilst hydrodynamic and N-body simulations are developing, a fundamental requirement is an extensive body of detailed observations. A complete comparison requires precise position and velocity phase-space information to resolve the internal cluster kinematics (~0.5km/s), which can be provided by the spectroscopy proposed here. Even more sophisticated studies will follow from combination with Gaia astrometry. The velocity fields within the youngest clusters betray their formation history, whilst the kinematics of the older clusters and the age dependence of their mass functions test theories of cluster destruction.

In this way, then, the radial velocity of the stars of the cluster, obtained with a resolving power between R ~ 20000 – 40000, will provide fundamental data for the analysis of the internal dynamics of the cluster and, therefore, of the mechanisms of its own destruction.

2) **PMS Stars in Clusters**

Let us not forget that stellar clusters are the best natural laboratory for the study of stellar evolution. The colour-magnitude diagrams obtained in different spectral ranges represent, and have represented, the best observational constrictions for models of stellar evolution. Almost all our knowledge about how stars are born and evolve is based on the feedback between HR observational and theoretical diagrams. High resolution spectroscopy plays an important role here, for on the one hand the radial velocity of the stars allows us to carry out an analysis of their membership to the cluster and, on the other hand, the estimation of their chemical abundance provides us with a fundamental variable for the study of its evolutionary state. In this context, the pre-main sequence phase is perhaps the least known. Various factors influence this fact: the majority of young clusters are still found surrounded by the cold material from which they formed, which impedes their observation in the visible range; low mass stars that have not yet reached main sequence have an intrinsic low brightness that limits its study in the optical to clusters that are nearby and almost free of interstellar extinction; and the transformations of the HR diagram from theoretical to observational are not known for PMS stars and, as first approximation, the corresponding transformations for main sequence stars are used, a functional hypothesis that requires verification (Kenyon & Hartmann 1995).

Our project deals with YOCs of ages around 10 Myr, which offer some clear advantages to the study of the star formation process in clusters. These objects are not usually embedded in the remnants of the dust and gas clouds where they formed, and can be studied with multiwavelength photometric observations, covering the optical range. For these clusters, reliable determinations of distance and absorption are possible, which greatly help in further determinations of physical parameters of the PMS cluster members, such as mass and age.

In recent years, detailed new observations of some particular YOCs have enlarged the data available to test and constrain model predictions. Primarily, X-ray detections and Hα emission, together with spectroscopically determined spectral types, provide assessment of cluster members, and, subsequently, models are used to obtain masses and ages (Flaccomio et al. 2006, F06 in the following; Dahm et al. 2007, D07 in the following). In this context, several sets of PMS isochrone models have been published, which cover different ranges in star mass and other physical parameters (see Hillenbrand & White 2004, H04 in the following).

Recent studies have compared models to observations on the basis of synthesized clusters, simulated from different models and with assumed contributions from the expected sources of uncertainty (Hillenbrand et al. 2008). Another approach to assess age determinations of theoretical models has been advanced recently, based on the analysis of stellar pulsation of PMS stars and comparison with predictions of model interiors (Zwintz et al. 2008).

The measurement of physical parameters such as mass and age is achieved through the comparison of observations with evolutionary stellar interior models in the HR diagram. This comparison between models and observations can be performed in two ways. The first consists of calculating luminosity and effective temperature from observed colours, and afterward the physical parameters are read from the theoretical isochrones in the HR diagram (examples for NGC2264 by Rebull et al. 2002, R02 in the following; F06). This approach is used in the methods for age measurement reviewed by Naylor et al. (2009). This procedure has the advantage of a more accurate consideration of extinction for the individual stars. But the comparison to models needs additional information, such as spectral types and, most important, membership confirmation, which is usually lacking. The second approach consists of translating the theoretical isochrones to colours and absolute visual magnitudes, and of comparing to observations in the photometric diagrams (D07, also for NGC2264). For a general sample of clusters, the conversion from theoretical luminosity and effective temperature to photometric colours is preferred, in particular if the extinction does not show values or degree of variability that are too high. The transformed isochrones can then be used as reference lines to measure colour excess and distance. Interestingly, this approach allows the simultaneous study of three issues, a) assignment of cluster membership, b) determination of the physical parameters for the candidate members, and c) test of the performances of different evolutionary calculations.

The results obtained up to now are highly promising (see DAY-I) but require systematic comparison for different ranges of age, distance and reddening with the spectroscopic data from a selected sample of objects in different clusters. The ideal tool for this scientific case is HEXA, with a field of view greater than one square degree, some 500 fibres per field and resolving power between 20000 and 40000.

References

Chen, L., de Grijs, R., Zha, J. L. 2007, AJ, 134, 1368
Lamers, H. J. G. L. M., Gieles, M. 2008, ASPC, 388, 367
van den Berk, J., Portegies Zwart, S. F., McMillan, S. L. W. 2007, MNRAS, 379, 111
Converse, J. M., Stahler, S. W. 2010, MNRAS, 405, 666
Rolffs, R., Schilke, P., Wyrowski, F., Menten, K. M., Güsten, R., Bisschop, S. E. 2011, A&A, 527, A68
Konstantopoulos, I. S., Bastian, N., Gieles, M., Lamers, H. J. G. L. M. 2010, IAUS, 266, 433
Smith, R., Fellhauer, M., Goodwin, S., Assmann, P. 2011, MNRAS, 601
Vesperini, E., McMillan, S., Portegies Zwart, S. 2009, Ap&SS, 324, 277
Dahm, S. E., Simon, T., Proszkow, E. M., et al. 2007, AJ, 134, 999 (D07)
Delgado, A. J., Alfaro, E. J., & Yun, J. L. 2007, A&A, 467, 1397 (DAY-I)
Flaccomio, E., Micela, G., & Sciortino, S. 2006, A&A, 455, 903 (F06)
Hillenbrand, L. A., & White, R. J. 2004, ApJ, 604, 741 (H04)
Hillenbrand, L. A., Bauermaister, A., & White, R. J. 2008, in "Cool Stars, Stellar Systems and the Sun XIV", ASPC, 384, 200
Kenyon, S. J., & Hartmann, L., 1995, ApJS, 101,117
Lada, E. A., & Lada, C. J. 1995, AJ, 109, 1682
Larson, R. B. 2007, Reports on Progress in Physics, 70, 337
Naylor, T. 2009, MNRAS, 399, 432
Naylor, T., Mayne, N. J., Jeffries, R. D., et al. 2009, I.U.Symp. 258 "The ages of stars". Eds. E. Mamajek, D. R. Soderblom, R.Wyse., Cambridge University Press. p. 103
Yi, S., Demarque, P., Kim, Y.-Ch., et al. 2001, ApJS, 136, 417 (Y01)
Zwintz, K., Guenther, D., & Kallinger, T. 2008, CoAst, 157, 256