Convocatoria de ayudas de Proyectos de Investigación

MEMORIA TÉCNICA PARA PROYECTOS DE LA CONVOCATORIA DE I+D TIPO A ó B

1 RESUMEN DE LA PROPUESTA (Debe rellenarse también en inglés)

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PROJECT TITLE: Star Formation in Stellar Systems

SUMMARY:
The scientific objectives in this project aim to improve our knowledge of the physical processes underlying star formation, both at Galactic and stellar scales. On the one hand, we are interested in understanding how individual stars are formed, which processes are common to the whole mass range, and which processes are specific for low- and high-mass stars. On the other hand, we also want to increase our knowledge of the behavior of star formation at different spatial scales: which variables govern star formation in clusters as opposed to the isolated star case? How is the observed hierarchy configured in star forming regions? Stellar systems, clusters, and stellar complexes, will be used as environments that constrain the number of relevant variables in the process, and also, in the case of compact clusters, as probes to determine the history and rates of star formation in other galaxies. This project will be undertaken from three specific points of view that we understand are also linked to different physical processes: 1. **Molecular clouds** 2. **Stars** • **Low-mass Pre-Main Sequence (PMS) stars (e.g. T-Tauri and Post T-Tauri stars)** • **Intermediate-mass PMS stars (e.g. Herbig AeBe stars)** • **O-type stars** 3. **Stellar complexes** Among the expected results, besides the foreseen increment in the knowledge in the field of star formation, we include the production of several catalogs and data bases and the creation of different tools for the analysis of astronomical data that will be made available to the astronomical community.

2. INTRODUCTION

- This section should include: project aims, antecedents, and current status of the knowledge in this scientific-technical field, including the most relevant literature and national or international teams working on the same specific subject or in similar matters.

2.1 Project aim and organizing antecedents

The study of the first stages of star formation currently constitutes one of the most active research fields in Galactic and Extragalactic Astronomy. On the one hand, we are interested in learning how individual stars are formed, which processes are common to the whole range of masses, and which are specific for low- and high-mass stars. On the other hand, we also want to know the mechanisms of stellar formation at different spatial scales: Which variables control star formation in clusters as opposed to the formation of isolated stars? What is the hierarchical structure of the observed star-forming regions? These matters, though apparently unrelated, actually represent different scales of a same phenomenon: **Star Formation**, the process that keeps the Universe visible to our eyes through the continuous transformation of gas into stars that can be seen everywhere in the Cosmos.
The **Stellar Systems** research group has been working on these subjects for more than a decade, focusing on different aspects of the process, at different scales. During the last five years we have oriented and organized our research through two PNAyA (Spanish National Plan for Astronomy and Astrophysics) projects: one of them has been devoted to study of the first stages of the formation of low-mass stars, and the other centered on the analysis of the hierarchical aspects of star formation in our Galaxy and in external galaxies. The second project was framed into the “Estallidos de Formación Estelar” (Starbursts) consortium through its node at Granada (led by Dr. Vílchez), while the first group was designed and entirely performed by our research team.
Several current circumstances suggest the convenience of joining forces and taking advantage of synergies: the addition of new personnel to our team; the results obtained during the last years, both by us and by other colleagues; the promising prospects opened by the incorporation of Spain to ESO and by the first light of GTC; and the current dynamics of Spanish Astrophysics, with the creation of powerful consortia and big research groups. Plainly said, pulling out all the stops and grouping together all the team members with a common set of objectives as part of the natural development that has arisen during the last years from the research performed by the team members working in our two different PNAyA projects.
Therefore, this project has the double aim of advancing in the knowledge of the different physical mechanisms and the phenomenology implicit in the words **Star Formation** and, also, of establishing our group at the forefront of the research on **Star Formation in Stellar Systems.**
We will undertake this project from three points of view that we understand are linked to different equations of state and different physical processes:

1. **Molecular clouds**
2. **Stars**
   - **PMS Stars in the low-mass range (e.g. T Tauri and post-T Tauri)**
   - **Intermediate-mass PMS Stars (e.g. Herbig AB stars)**
   - **O-type Stars**
3. **Stellar Complexes**

2.1.1 Project aims and priority objectives of the Spanish National Plan for Astronomy and Astrophysics (PNAyA)

The four PNAyA priority objectives are:

1 Basic research in Astronomy and Astrophysics
2 Design and development of astronomical instrumentation
3 Scientific and technological exploitation of astronomical resources
4 Research and development in technologies related to astronomy

As we will show in Section 3, the specific aims of this project naturally match three of the PNAyA priority objectives. Firstly, our activities belong to the basic research category, i.e., their main goal is to widen and improve our knowledge of star formation (PNAyA first priority objective). Secondly, to reach our goals we need to exploit the astronomical resources and facilities available to us that range from the 1m-class telescopes at Sierra Nevada Observatory to the intermediate resolution spectrographs at our disposal at ESO telescopes and also include the Virtual Observatories databases (PNAyA third priority objective). Thirdly, we are proposing three scientific and technical aims that are related to the PNAyA fourth priority objective: a) building, maintaining, and servicing a data base for PMS stars in clusters to be implemented into the Spanish Virtual Observatory; b) implementing the analysis of PMS stars into the CHORIZOS software (designed and written by J. Maíz-Apellániz); and c) developing massive calculation algorithms to perform “laboratory” analysis of the structure of molecular clouds. Furthermore, even though this is not specified among the PNAyA priority objectives, it is recommended for all R+D+i projects to include a **public outreach plan**. We have designed such a plan to spread the obtained results to the general public.

2.2 Antecedents

2.2.1 The structure of molecular clouds: Fractals and star formation

One of the most relevant features of the interstellar medium (ISM) is the fact that it apparently shows a **fractal structure through a wide range of spatial scales.** This holds true for the interstellar cirrus observed by IRAS (Bazell & Dessert 1988), molecular clouds (Dickman et al. 1990; Falgarone et al.1991, Lee 2004), high-velocity clouds (HVC) (Vogelaar & Wakker 1994), and also for the distribution of neutral hydrogen (Westpfhal et al. 1999). One of the main problems with this kind of research is related to the determination of the fractal dimension of the clouds, using a precise and homogeneous method that would allow comparing the results obtained by different authors from different data sets. There are several estimators for the fractal dimension of an object: the so-called perimeter-area relation (D_{per}), the correlation dimension (D_{cor}), or the mass dimension (D_{mas}). All of them can be used in astronomy, applied to the clouds projected on the celestial sphere. All of them are 2D-estimators of a 3D dimension (D_f). How to transform the obtained dimensions from 2D into 3D? Traditionally, it has been considered that $D_f = D_{per} + 1$ (e.g. Elmegreen & Falgarone 1996), which seems to be mathematically valid for slices or layers, but could be false for projections. There are other problems related to the real measure of D_f, arising from different causes related to the data e.g. spatial resolution, signal-to-noise ratio, optical depth of the clouds, etc.

In 2004, **Néstor Sánchez Doreste** joined our group and we undertook a project to analyze these issues in detail. The results have been clarifying and successful, and they have provided us with a set of codes that allow analyzing real data for different chemical species. We now have a “laboratory” at our disposal for the analysis of the physical processes that induce or are induced b, the internal structure of the clouds. There are several outstanding results obtained by our group related to the determination of precise 3D fractal dimensions and to the general properties of the interstellar medium as deduced from these methods (Sánchez et al. 2005, 2006a, b). One of these results indicates that **the fractal dimension of the interstellar medium** (for different gas states) seems to be larger than traditionally considered, with values **between 2.6 and 2.8.**

Is this geometry transferred to the distribution of the stars born from the cloud? Does the fractal dimension of the stellar distribution evolve with time? What is the dominant factor that determines the distribution of the young stellar population in spiral galaxies? And in irregular galaxies?
Fractal clouds generated in our "laboratory" have been created from a nesting process. In this procedure, spheres are randomly nested inside others for a given number of hierarchies. This way, the only free parameter is the fractal dimension. But the question arises: Do the physical properties of the cloud depend only on this parameter, as it is currently assumed in the astronomical literature? Or, do they depend, also, on the mechanism leading to their generation? In other words, does geometry characterize the physical properties of a cloud in an univocal way? This project intends to tackle these questions.

2.2.2 Stars

2.2.1.1 Intermediate and low-mass PMS stars

In the course of the work done during the last years, **we have developed a methodology** that allows: a) obtaining the physical parameters of a star cluster, b) assigning a membership code to each star, and c) distinguishing PMS from main-sequence stars (Delgado et al. 1998, 2000). The code requires multicolor photometry with a minimum of three different bands and a*U*-band filter among them. We have applied this method to a sample of clusters for which we have obtained a homogeneous set of photometric data. As a result, we have produced a **photometric catalogue (DAY-I)** in 5 colors $(UBVR_cI_c)$ with 950 **low-mass PMS candidate stars**, selected from a total number of more than 25 000 observed stars in 10 young (< 10 Ma) clusters in the southern hemisphere (Delgado et al. 2006). 85% of these objects also have JHK_S photometry from the 2MASS catalogue. It is worth noting that our team has centered this research on clusters with ages below 10 million years, but with a color excess *E(B-V)* typically under 0.75 magnitudes. These conditions make possible to study these clusters both in the optical and infrared bands, but IR observations are not necessarily required for their detection. In this age range, PMS stars of F spectral type and later appear clearly separated from main-sequence stars on color-magnitude diagrams. However, the evolutionary tracks of the heavier PMS stars (Herbig AB stars) are mixed with those of the main sequence. For this reason, the classification of these stars requires obtaining narrow-band photometry centered on some of the possible emission features, and also infrared photometry to detect a possible color excess in this range. Alternatively, spectra obtained at different resolutions can be used for the same purpose.
Having produced this catalogue places our team at a vantage point, compared to other research groups, for the analysis of different subjects related to the process of stellar formation. The information contained in the catalogue, the models of PMS stellar evolution and a well-suited methodology, allow us to estimate **masses and ages** for PMS stars, and to compare them with those derived for main-sequence stars in the same clusters. This yields valuable information on the **initial mass distribution**, **age spread** inside the clusters, and **average ages** for different mass bins. But we should not forget that this study produces an important by-product: 8-color photometry (JHK_S included) for almost 25 000 stars, all of them having the membership to their groups determined. Now we are ready to produce a similar catalogue of **Herbig AB stars**, using the IR color excesses. Such a catalogue has been lacking up to now, and is needed to undertake the analysis of the **emission line mechanisms in B stars.**

2.2.2.2 High-mass stars

Maíz-Apellániz et al. (2004) compiled the first catalog of Galactic O-type stars ever built that relies exclusively on uniform and precise spectral types. Similar previous attempts had used very inhomogeneous sources, and were done before the revolution caused by the availability of multiple data bases through Internet. When building this catalog, we used these resources to gather data of different kinds (astrometric, photometric, and others), and to make them available to the astronomical community at a web site. In the two years since its publication, the Galactic O star catalog has become the most-cited reference for spectral types of its kind. Now

we intend to enlarge the current **Galactic O star catalog** to (critically) include all the existing spectral classifications done by different authors to reinforce its leadership position in the massive star community. At the same time, we plan to process the photometric data by means of the CHORIZOS software, using the new zero-points deduced for the most widespread photometric systems in the optical and the IR (Maíz-Apellániz 2006, 2007), with the aim of precisely determine the intrinsic colors of these stars, a subject still affected by uncertainties of the order of 2-3% (Martins & Plez 2006).
As a complement to the catalog described in the previous paragraph, we plan to construct a photometric catalogue of early-type stars (O-type, Wolf-Rayet, hot white dwarfs and, specially, early B-type stars), from the **Tycho-2 and 2MASS** databases. Both catalogs will be used to do a thorough and consistent analysis of the extinction law and to build an elaborate map of the extinction distribution in the solar vicinity free of the biases that have affected previous attempts.

2.2.2.3 Variability of PMS stars: accretion, flares and pulsation

The study of variability of PMS stars in clusters can provide relevant information on two fundamental subjects: the internal structure of stars and their interaction with their surroundings.
PMS stars frequently display variations due to different causes, both intrinsic and extrinsic. Among the first group we find pulsation; stellar activity as winds or jets; and also the different phenomena related to chromospheric activity and to the physical interaction with the medium (accretion processes). The extrinsic causes of variability include binarity and absorption due to the interposition of masses of variable opacity, both in the immediate surroundings of the stars (accretion disks) or in the neighboring interstellar medium.
Non-periodic variability provides important information on the physical properties of the stellar atmosphere and on the interaction of the star with the medium. During the last years, it has been observationally confirmed that there are sometimes noticeable differences among the optical and infrared variabilities for young stars still surrounded by accretion disks (classical T Tauri stars). The optical emission comes, mainly, from the stellar surface, while the inner areas of the disk dominate the IR emission. Up to now, there is only one published work including a simultaneous follow-up of both wavelength intervals (Eiroa et al. 2002). For this reason, we have decided to perform a systematic study of a sample of classical T Tauri stars in order to check the relationship between both kinds of variability.
For solar-type stars where the accretion processes have faded, the variability is associated to the characteristic phenomena linked to magnetic activity. Observations recently performed at the "Observatorio de Sierra Nevada" (OSN) have shown that the flares found in solar-type stars with ages of just one million years release huge amounts of ultraviolet radiation, enough to contribute to the formation of primary atmospheres around possible Earth-like planets around them (Fernández et al. 2004). It is not yet known with precision what is the duration of the formation phase for an Earth-like planet. That is why we have decided to study the flare frequency for a sample of solar-like stars with ages in the range from 5 to 100 million years, thus covering the time interval predicted by different theoretical models for the formation or rocky planets. We have selected star clusters for this study, because this will allow monitoring the variability of many stars at the same time, all of them having the same age and chemical composition.
Typical time-scales for pulsations comprise from tenths of minutes to less than ten hours, with amplitudes from several thousandths to several hundredths of a magnitude in the *V* band. In contrast, variations due to other causes usually show larger time scales and, also, wider amplitudes. This circumstance combined with the periodic shape of pulsations (as opposed to the non-periodic character of other effects) and with the chromatic analysis of the variations allows to distinguish pulsations from other kinds of variability.
Most variability studies performed up to now on PMS stars have been centered on detecting high-amplitude variations, since they are easier to detect. However, it has been shown in practice (Kurtz & Marang 1995) that it is possible to decouple the variations due to pulsation from those due to other reasons, even when the amplitude is small, if the data have good temporal sampling and high S/N.
With this aim, we will undertake specific observational campaigns during which we will obtain well-sampled,

long photometric series with several wide-band filters, reaching the maximum precision allowed by differential photometry with a careful selection of the comparison stars. The telescopes accessible to this research group in both hemispheres, with classical CCD detectors and diameters of 1-2 m are enough for this purpose. The main effort to reach this goal is to perform a careful planning of the observations, and to apply the finest techniques for the subsequent processing of the data. In spite of the efforts done by this group and other teams during the last few years (Mochejska et al. 2003; Paunzen et al. 2004; Zwintz et al. 2005; Zwintz & Weiss 2006), less than ten PMS stars are known to display pulsations.
We have designed an observational procedure for the variability analysis of PMS stars in clusters. We will re-observe several clusters already studied by Zwintz's team with the aim of comparing the results yielded by both methods. We estimate that for a sample of 8 clusters distributed over both hemispheres we could double the current catalog of pulsating PMS stars.

2.2.3 Stellar Complexes

Stellar complexes represent the largest scale in the **hierarchical structure** of star formation within a galaxy (**Efremov** 1978, 1995). These complexes consist of associations of gas and stars with sizes of the order of 1 kpc and with an age spread that can reach up to 100 million years. They show coherent patterns of star formation but can display different morphologies depending on the amount of gas available and on the proportion of clusters found among their stellar content. There are galaxies whose cluster population is huge and others where they are seldom found. Which physical variables control the isolated and clustering modes of star formation? Elmegreen & Efremov (1997) proposed that an additional pressure exerted on the star-forming material would induce a preferential formation of clusters. Is this the only relevant variable? Which are the main mechanisms responsible for this extra pressure? The analysis of a stellar complex in the galaxy **NGC 6946** has already produced interesting results by our team. The history of star formation inside the complex during the last 60 million years shows that both star formation modes appear alternatively. After a spatially extended starburst giving rise to isolated field stars, all the subsequent stellar formation is concentrated in super-massive star clusters (**Larsen et al**. 2002). We have selected several stellar complexes in a galaxy with a rich cluster population (M83), to analyze these issues in depth. Connected to this subject, we also want to study the details of the cluster population associated to the **Gould Belt**, supposedly the stellar complex closest to the Sun.

2.2.4 Software tools

As commented in the previous section, we have designed our own method to analyze photometry of young clusters, and to search for PMS stars inside them. The new members joined to the team have brought interesting contributions to our set of software tools. **CHORIZOS** is a code specifically developed to compare observational and synthetic photometry, deriving the last from stellar models and allowing to derive physical parameters for the stars (Maíz-Apellániz 2004). The precision of the results depends on the precision of the observational photometry, on the number of bands used, and on the extinction affecting the objects. Applying this code to several objects of interest has made its potential clear (Maíz-Apellániz et al. 2004, Arias et al. 2006). It is obvious that this software can be very useful for the individual analysis of AB stars in the observed clusters, specifically to determine their physical properties and IR excess. As an example we show two fits done with CHORIZOS for two main-sequence stars in the cluster **NGC 3293**, with 8-band photometry. One of them displays a good fit with a model with solar metallicity and $T_{\rm eff}$ = 10 000 K (Fig. 1a). However, the other one yields a worse fit, mainly in the IR part of the spectrum, with a clear **excess in the *H* band** (Fig. 1b). This shows the utility of CHORIZOS to evaluate color excesses in the infrared for members of clusters, and to distinguish their PMS or MS nature. **Extending CHORIZOS to PMS low-mass stars** is the natural continuation of this work and, as we will show in section 3, one of the specific aims of this project.

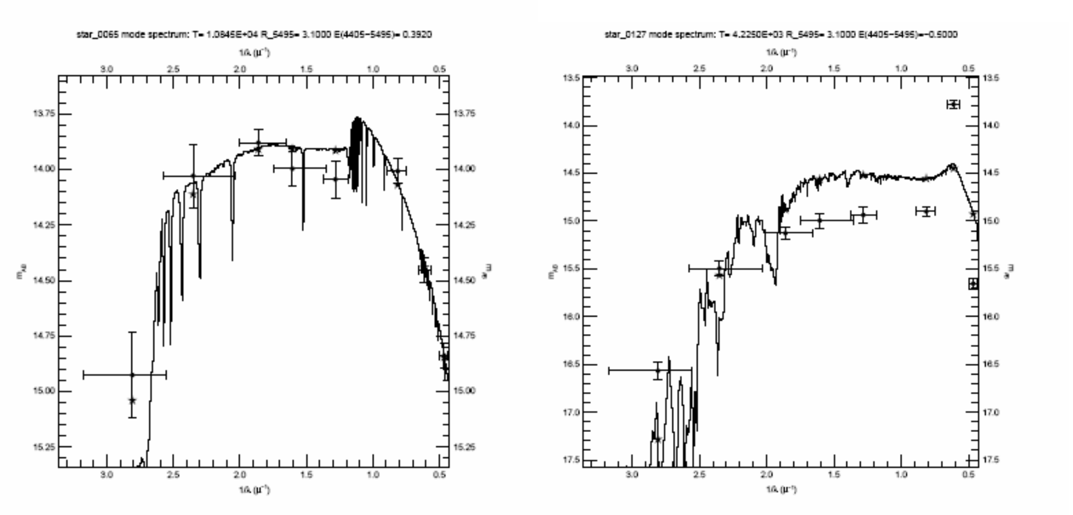

Fig.1.-**CHORIZOS** applied to two main-sequence stars in NGC 3293. a) Left. Best SED fit with 7 colors to a model with $T_{\rm eff}$ = 10 000 K and *E(B-V)* = 0.39. The observed photometry is shown with error bars while the stars indicate the corresponding synthetic photometry. b) Right. No combination of a main-sequence model and standard reddening can reproduce the photometry for this star. A large *H*-band excess is observed.

Bibliography (Here are included all the references cited in the whole text)

- Alfaro, E. J. 2006, Publications de l'Observatoire Astronomique de Beograd, 80, 29
- Anders, P., Bissantz, N., Fritze-v. Alvensleben, U., & de Grijs, R. 2004, MNRAS, 347, 196
- Arias, J. I., Barbá, R. H., Maíz-Apellániz, J., Morrell, N.I., & Rubio, M. 2006, MNRAS, 366, 739
- Balaguer-Núñez, L., Jordi, C., Galadí-Enríquez, D., & Zhao, J. L. 2004, A&A, 426, 819
- Balaguer-Núñez, L., Jordi, C., Galadí-Enríquez, D., & Masana, E. 2004, A&A, 426, 827
- Balaguer-Núñez, L., Jordi, C., & Galadí-Enríquez, D. 2005, A&A, 437, 457
- Bazell, D., & Desert, F. X. 1988, ApJ, 333, 353
- Bouy, H., Moraux, E., Bouvier, J., Brandner, W., Martín, E.L., Allard, F., Baraffe, I., & Fernández, M. 2006, ApJ, 637, 1056
- Broeg, C., Fernández, M., & Neuhäuser, R. 2005, Astronomische Nachrichten, 326, 134
- Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
- Comerón, F., Fernández, M., Baraffe, I., Neuhäuser, R., & Kaas, A.A. 2003, A&A, 406, 1001
- Comerón, F., Reipurth, B., Henry, A., & Fernández, M. 2004, A&A, 417, 583
- Delgado, A. J., & Alfaro, E. J. 2000, AJ, 119, 1848
- Delgado, A. J., Alfaro, E. J., Moitinho, A., & Franco, J. 1998, AJ, 116, 1801
- Delgado, A. J., González-Martín, O., Alfaro, E. J., & Yun, J. 2006, ApJ, 646, 269
- Delgado, A. J., Miranda, L. F., Fernández, M., & Alfaro, E. J. 2004, AJ, 128, 330
- Dickman, R. L., Horvath, M. A., & Margulis, M. 1990, ApJ, 365, 586
- Efremov, Y. N. 1978, SvAL, 4, 66
- Efremov, Y. N. 1995, AJ, 110, 2757
- Efremov, Y. N., et al. 2002, A&A, 389, 855
- Efremov, Y. N., Alfaro, E., Hodge, P., Larsen, S., & Muñoz-Tuñon, C. 2004, Astronomical and Astrophysical Transactions, 23, 95
- Eiroa, C., et al. 2002, A&A, 384, 1038
- Elias, F., Alfaro, E. J., & Cabrera-Caño, J. 2006b, AJ, 132, 1052
- Elias, F., Cabrera-Caño, J., & Alfaro, E. J. 2006a, AJ, 131, 2700

- Elmegreen, B. G., & Efremov, Y. N. 1997, ApJ, 480, 235
- Elmegreen, B. G., & Falgarone, E. 1996, ApJ, 471, 816
- Falgarone, E., Phillips, T. G., & Walker, C. K. 1991, ApJ, 378, 186
- Fernández, M., et al. 2004, A&A, 427, 263
- Fernández, M. 2005, Protostars and Planets V, 8089
- Fernández, M., Torne, M., Garcia-Castellanos, D., Vergés, J., Wheeler, W., & Karpuz, R. 2004, Earth and Planetary Science Letters, 221, 131
- Franco, J., Kim, J., Alfaro, E. J., & Hong, S. S. 2002, ApJ, 570, 647
- Kaas, A. A., et al. 2004, A&A, 421, 623
- Kurtz, D. W., & Marang, F. 1995, MNRAS, 276, 191
- Larsen, S. S., Efremov, Y. N., Elmegreen, B. G., Alfaro, E. J., Battinelli, P., Hodge, P. W., & Richtler, T. 2002, ApJ, 567, 896
- Lee, Y. 2004, JKAS, 37, 137
- Maíz-Apellániz, J. 2004, PASP, 116, 859
- Maíz-Apellániz, J. 2005, PASP, 117, 615
- Maíz-Apellániz, J. 2006, AJ, 131, 1184
- Maíz-Apellániz, J., Walborn, N. R., Galué, H. Á., & Wei, L. H. 2004, ApJS, 151, 103
- Marconi, M., & Palla, F. 1998, ApJ, 507, L141
- Martins, F., & Plez, B. 2006, A&A, 457, 637
- Mochejska, B. J., Stanek, K. Z., & Kaluzny, J. 2003, AJ, 125, 3175
- Mugrauer, M., et al. 2004, A&A, 417, 1031
- Mugrauer, M., Neuhäuser, R., Mazeh, T., Fernández, M., & Guenther, E. 2004, AIP Conf. Proc. 713: The Search for Other Worlds, 713, 31
- Paunzen, E., Zwintz, K., Maitzen, H. M., Pintado, O. I., & Rode-Paunzen, M. 2004, A&A, 418, 99
- Reed, B. C. 2003, AJ, 125, 2531
- Sánchez, N., Alfaro, E. J., & Pérez, E. 2005, ApJ, 625, 849
- Sánchez, N., Alfaro, E. J., & Pérez, E. 2006a, ApJ, 641, 347
- Sánchez, N., Alfaro, E. J., & Pérez, E. 2006b, ApJ, accepted (astro-ph/0610613)
- Stelzer, B., et al. 2003, A&A, 411, 517
- Subramaniam, A., Sahu, D. K., Sagar, R., & Vijitha, P. 2005, A&A, 440, 511
- Ubeda, L., Maíz-Apellániz, J., & MacKenty, J.W. 2004, ASP Conf. Ser. 322: The Formation and Evolution of Massive Young Star Clusters, 322, 221
- van Leeuwen, F., & Fantino, E. 2005, A&A, 439, 791
- Vogelaar, M. G. R., & Wakker, B. P. 1994, A&A, 291, 557
- Westpfahl, D. J., Coleman, P. H., Alexander, J., & Tongue, T. 1999, AJ, 117, 868
- Zwintz, K., Marconi, M., Reegen, P., & Weiss, W. W. 2005, MNRAS, 357, 345
- Zwintz, K., & Weiss, W. W. 2006, A&A, 457, 237

3. PROJECT AIMS

- **3.1** Brief description of the reasons why this research is considered convenient and, if suited, the **hypothesis underlying** to the project aims **(maximum 20 lines)**

Star formation is one of the central subjects of modern astronomy. There are many possible approaches to this problem: from the detailed analysis of the lightest stars (e.g. brown dwarfs) to the study of the interaction of the interstellar medium with hot stars or of the spatial distribution of massive young clusters in galaxies of the Local Group. All these are different facets of the same physical process, the transformation of gas into stars. What makes this problem interesting is that: a) it comprises phenomena happening at very different scales, b) it requires studies performed over a wide spectral range, and c) it postulates a multidisciplinary effort.
In this project we deal with three different aspects of star formation associated to different physical mechanisms:
a) The physics and geometry of giant molecular clouds.
b) The origin, structure, and history of star formation in several selected stellar complexes.
c) Detecting, cataloguing and analyzing low and intermediate-mass PMS stars in stellar clusters of our Galaxy, and cataloguing and calibrating O-type stars.
Items a) and b) are closely related, since we plan to use the structural features of the clouds for the analysis of the main physical interactions governing the stellar distribution in complexes. Items b) and c) also show contact points, because we will use intermediate-scale systems (star clusters) to study both how stars are formed inside them, and how they shape the structure of star formation in galaxies at larger scales.
Beside these purely scientific aspects, our project will provide new analysis tools, and new catalogs and stellar data bases.

- **3.2** State the **antecedents and previous results** obtained by this research team, or by others, supporting the validity of the underlying hypothesis

a) ISM structure: First of all we need to verify the main hypothesis underlying all the research done in this field, that **clouds having the same fractal dimension have, also, the same physical properties, independently of their generation process**. Second, this dimension needs to be determined
and compared to 3D models of fractal clouds. During recent years, the team has shown that it is capable of producing codes that model cloud creation and that analyze the different factors that could affect the determination of the fractal dimension for real and for simulated data. Currently, there is no other Spanish group working on this kind of analysis, but there is one applying this approach to the structure of star-forming regions (**Sánchez et al**. 2005, 2006a,b).
b) PMS stars in clusters: Since the late 90's, a part of this group began the search for PMS stars in young clusters from optical photometry. The hypotheses underlying this search are very well established by our team and by others. Our team has made the original contribution of elaborating a systematic method to determine membership and to discriminate MS, PMS and post-MS stars. The method has been systematically applied to star-forming regions in the Galaxy. Now we want to use our observational background to include Herbig AeBe stars (see e.g. **Subramian et al.** 2005), and to enlarge the low-mass PMS star catalog covering other star-forming regions in the Galaxy (**Delgado et al**. 1998, 2000, 2004, 2006a,b;**Kaas** et al. 2004)
c) OB stars: Similarly, the aims in this matter do not require big hypotheses, but good data and a good knowledge of stellar physics and photometry. Members of our team are currently forefront leaders in this

field, as shown by their recent publications.

d)Variability of PMS stars in clusters: The underlying hypotheses are that we can find two sources of variability (periodic and non-periodic) for a given star, that those two sources can be decoupled (**Kurtz & Marang 1995**), and that from the variability we can infer properties about their internal structure (pulsation) (**Marconi & Palla 1998; Zwintz et al. 2005, 2006**) and about their interaction with the surrounding medium (flares, accretion) (**Eiroa et al.** 2002; **Fernández et al.** 2004)

e) Stellar complexes: This matter comprises two subjects, one being the history recorded into the star forming regions, which is related to the original structure of the parent clouds. The other subject is the mechanism(s) pushing star formation towards an isolated or a clustering mode. In the first subject the underlying hypothesis is that in a star-forming region born from a single cloud, the distribution of young stars should preserve some memory of the original structure of the cloud. There are several previous studies based on this hypothesis, but with uncertain results: some of the surveyed areas are larger that the typical sizes of supergiant clouds, thus probably mixing elements from different origins. Other studies use too few objects inside individual complexes, which affects the precision of the derived fractal dimension. Our working hypothesis is quite simple and we want to test it in a well-known complex that harbors many stars, **Gould's Belt**. In relation to the characterization of the star forming history in stellar complexes, there is abundant literature and the singularity of our proposal relies on the selection of galaxies containing the stellar complexes. We have chosen those with a bigger density of star clusters and placed at distances where they can be resolved with HST.

- **3.3** Brief enumeration and clear, precise and realistic description (according to the duration of the project) of the **concrete objectives** pursued.

1. Fractal structure of molecular clouds. Geometry and physics

1.1. - Simulate 3D interstellar clouds using Fractal Brownian Motions and compare the results with those obtained from our generator of geometric fractals. This test is fundamental to check the hypothesis (so often assumed) that clouds with the same fractal dimension have similar internal physical properties.

1.2. - Analyze the nature of Gould's Belt from the study of the fractal dimension of their OB stars in different age bins.

2.PMS stars in clusters

2.1. - Extend the search for PMS stars to other stellar complexes in the northern hemisphere.

2.2. - Characterize and catalog Be and Herbig AeBe stars in these clusters from existing data.

2.3. - Begin the taxonomic study of PMS stars and look for possible correlations between the PMS and MS populations and age, age spread in the clusters, etc.

2.4.- Spectroscopic characterization of PMS stars

2.5. - Transform of the DAY-I catalogue (PMS stars in clusters) into a dynamic data base that could be incorporated to the Spanish Virtual Observatory.

3.Optical and near-IR variability of PMS stars in clusters

3.1. - Search for pulsating PMS stars.

3.2. - Study the optical and near-IR variability of classical T Tauri stars.

3.3. - Study the variability of solar-type stars with ages from 5 to 50-100 million years, with the aim of determining the frequency of flares and, as a by-product, obtaining the distribution of rotation periods.

3.4. - Develop free software for the reduction and analysis of time series obtained on rich stellar fields.

4.OB stars

4.1. - Expand the Galactic O-star catalog.

4.2. - Generate a catalog of Galactic early-type stars from the Tycho-2 and 2MASS data bases and publish it as a second web site.

4.3. - Use the two catalogs to test the intrinsic colors of OB stars, precisely determine the Galactic extinction law, and obtain the spatial distribution of massive stars and dust in the solar vicinity.

5.Stellar complexes

5.1. - Determine the star formation history in the stellar complexes of M83.

6.CHORIZOS

6.1. - Adapt CHORIZOS to the analysis of PMS stars.

6.2. - Introduce several improvements in the CHORIZOS code.

4. METHODOLOGY AND WORKING PLAN

Given the diversity of the specific objectives, this project will deal with a great variety of theoretical, observational and numerical techniques. For the objectives listed in Section 3, the tasks are:

Objective 1.1

a) Implement the code for fractal generation based on the Fractal Brownian Motion technique (FBM).**(Sánchez**)
b) Generate clouds with different fractal dimensions by means of both techniques (nesting and FBM). (**Sánchez**)
c) Compare different internal structure parameters such as density, mass and radius distribution of clumps, etc. (**Sánchez and Alfaro**)

Objective 1.2

a) From previous work by Elías et al (2006a,b) on the spatial and kinematic structure of Gould's Belt, we will select different age groups for both systems (local Galactic disk and GB). (**Elías and Alfaro**)
b) Afterwards, the fractal dimension of different subsamples will be determined and compared to those deduced for molecular clouds. (**Sánchez)**
c) Analysis and discussion of the results. (**Alfaro, Sánchez and Elías)**

Objective 2.1

a) Selection of the sample of 10 clusters to enlarge the set studied in the northern hemisphere. These clusters will be mostly in Cygnus (summer) and towards the anticenter (winter). (**Delgado, Galadí and Alfaro**)
b) Observation of the clusters in 3-5 bands *($UBVR_cI_c$)* at the OSN. **(Delgado and Galadí)**
c) Photometric reduction (**Galadí and Delgado**)
d) Selection and cataloguing of the low-mass PMS stars. (**Delgado and Galadí)**

Objective 2.2

a) For the clusters already studied, 14 in total, and for those selected in objective 2.1, we will use the color excess derived fromJHK_s2MASS photometry to detect Herbig AeBe stars in the sample. (**Yun, Delgado and Alfaro**)
b) Construction of the catalog. (**Delgado and Cantero**)

Objective 2.3

a) Using the ages of PMS stars from the DAY-I catalogue (Delgado et al. 2006b) deduced from different sets of isochrones, we will evaluate the age spread for low-mass stars and we will analyze this dispersion parameter in relation to the physical parameters of the cluster. (**Delgado and Alfaro**)
b) From the determination of the spatial densities of PMS and MS member stars in the clusters, we will analyze their possible variations with cluster position in the Galactic plane and with age. (**Delgado, Alfaro and Yun**)

Objective 2.4

a) Characterization of PMS stars in clusters. Telescopes of the 3-4 m class will be needed to reach the magnitude limit of our faintest candidates in both hemispheres. The working plan will require requesting time at Roque de los Muchahos, Calar Alto, and La Silla. Observational campaigns are foreseen for the 3 years of the project. (**All the team is involved, except from Sánchez and Cantero**)
b) Obtaining spectra with resolution *R*=5000 or above (in Hα) to characterize spectral types and to measure radial velocities to derive kinematic memberships. (**Djupvic, Delgado and Yun)**
c) Data reduction and analysis of the results. Determination of the fraction of photometric candidates that are "bona-fide" PMS members after the spectroscopic characterization. Evaluation of the photometric method as a function of cluster distance and reddening. (**Djupvic, Delgado, Yun and Alfaro)**

Objective 2.5

a) Determination of the database protocol to be used. (**Cantero and Cabrera-Caño**)
b) Definition of the user interface. (**Cantero and Cabrera-Caño**)
c) Implementation of the catalog. (**Delgado**,**Cantero and Cabrera-Caño)**

Objective 3.1

a) Selection of the clusters with high probability of having a large number of pulsating PMS stars. This selection will be done on the base of the population found in the pulsational instability zone theoretically predicted for PMS stars in each cluster. (**Galadí, Fernández and Delgado**)
b) Selection of the best suited fields, according to the presence of candidate PMS members of the right kind. (**Galadí, Fernández and Delgado)**
c) Definition of the observational campaigns: filters, exposure times, and time sampling. (**Galadí, Fernández, Delgado and Alfaro)**
d) Construction of the algorithms needed to reduce and analyze the data in three modules: reduction of precision differential photometry, construction of the light curves, and detection of variability among member stars and field population. (**Fernández and Galadí)**
e) If necessary, determination of the periods through classical frequency analysis. (**Fernández and Galadí)**
f) Identification of the pulsating PMS stars for a subsequent detailed spectroscopic and spectrophotometric follow-up. (**Fernández, Galadí and Delgado)**

Objectives 3.2 and 3.3

a) The tasks involved in these objectives are similar to those listed for 3.2. (**Fernández, Galadí and Delgado)**

Objective 3.4

a) It could be considered a task, more than an objective, in the sense that the code and the programs have to be operational to reach objectives 3.1, 3.2 and 3.3. It is an objective on its own implementing the code on the web, writing a manual and making it public. (**Fernández, Galadí, Cantero, new technician)**

Objective 4.1

a) Expand the Galactic O-star catalog by critically including all published O-star classifications. (**Maíz-Apellániz and Walborn)**

b) Reform the catalog web site (http://www.stsci.edu/~jmaiz/GOSmain.html) to include database queries, on-line submissions of new spectral classifications, and new additional information for each star.(**Maíz-Apellániz and new technician)**

Objective 4.2

a) Build a photometric catalog of Galactic early-type stars in the solar neighborhood (O, WR, early-B, plus a few very close white dwarfs) by combining the Tycho-2 and 2MASS catalogs and processing the result through CHORIZOS to select the early-type objects.(**Maíz-Apellániz)**
b) Publish the results in a new web site.(**Maíz-Apellániz and new technician)**

Objective 4.3

a) The photometric data will be processed using CHORIZOS and the new zero-points for the photometric systems in the optical and the IR (Maíz-Apellániz 2006, 2007) to get a precise determination of the intrinsic colors of the stars. (**Maíz-Apellániz and Walborn)**.
b) After completing the previous step, we will check the validity of the galactic extinction law of Cardelli et al. (1989), and we will combine the results with the (soon to be available) reanalyzed data from the astrometric mission Hipparcos (van Leeuwen & Fantino 2005) to deduce precise absolute magnitudes for O stars, a quantity currently affected by significant uncertainties. (**Maíz-Apellániz and Walborn).**
c) The two (O and early-type) catalogs will be correlated between them and with the spectroscopic catalogue by Reed (2003), to verify the completeness of the three in relation to extinction and distance. (**Maíz-Apellániz)**
d) Finally, obtain a complete analysis of the distribution of massive stars and of extinction in the solar neighborhood. (**Maíz-Apellániz and Walborn).**

Objective 5.1

a) Measure the HST photometry in three bands for a set of selected stellar complexes in M83. (**Bastian and Larsen**)
b) From the HST photometry, estimate the stellar reddening map in the disk of the galaxy around the complexes. (**Alfaro and Larsen**)
c) Separate clusters from isolated stars. Determine ages and luminous masses for the clusters. From the extinction-corrected photometry, evaluate the history of star formation in the complex. (**Larsen and Bastian**)
d) Compare the age and mass of the clusters with the diagram of star formation rate vs. time. (**Alfaro and Efremov**)

Objective 6.1

a) Add models for PMS stars to the data libraries of CHORIZOS (**Maíz-Apellániz, Delgado)**
b) Search for the best combinations of photometry and/or spectrophotometry for the study of the properties of PMS stars. The code has the capability of combing through filters and/or spectral bands combinations to deduce which is suited to suppress possible multiple solutions. Our ultimate goal is to select the optimum combinations to analyze PMS stars, in a similar way to that followed by Anders et al. (2004) for star clusters. **(Maíz-Apellániz & Alfaro)**
c) Do a similar analysis to select the optical/UV filter combinations which are more appropriate to separate PMS from MSD stars using the CHORIZOS test modes. (**Maíz-Apellániz)**

Objective 6.2

a) Including spectrophotometric and color indices as possible inputs in CHORIZOS. (**Maíz-Apellániz)**
b) Extension of CHORIZOS to generic Bayesian priors and multidimensional solution searches. (**Maíz-Apellániz)**
c) Adapt CHORIZOS to a web-based interface.**(New technician)**

Justification for the requested contract for a PhD at the "Juan de la Cierva" level

Objectives 1.1 and 1.2, related to **the creation and evaluation of tools for the analysis of the fractal structure of molecular clouds**, as well as to the determination of the monoparental origin of different star forming complexes (an idea proposed for the very first time in this project) rely exclusively on **Néstor Sánchez**. Nowadays, there is no other active research group in Spain working on cloud models and in the connection to cloud geometry with the physics of the interstellar medium. The results obtained up to now have been well received and are having impact, as can be deduced from the citations of the publications by colleagues, and from conversations maintained with different research teams. This makes us excited about the prospects for this new research line. Other groups recently created in Spain are using fractal methods to get answers on star formation in galaxies and in other stellar systems, but none of them are developing nor checking their own tools.

All of us are aware of the fast projection of Spanish observational astronomy during the last 30 years, but we also know the need (that could be described as urgent) for a bigger development in theoretical and numerical modeling matters, fields where we are still several steps behind the first astronomical powers. Our group is advancing in this field and we expect not having to go back to the starting gate.

In this same sense, it is worth noting that Federico Elías has presented his PhD dissertation in June 2006. He is now in Mexico with a post-doctoral contract of UNAM. His project, supervised by José Franco and Serguéi Silich, aims to the development of magnetohydrodynamic codes to model the properties of ionized gas in star forming complexes. Saying this, we only want to indicate that this team is raising the stakes for the development of such tools. We already know how to observe, how to compare with models and theories... produced by others and even getting conclusions from that. Now we want, and we must, propose our own models.

4.1 TENTATIVE TIME SCHEDULE

The name of the responsible person for each task is underlined.

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<table>
<tr><th>Activities/Tasks</th><th>Center</th><th>Researches</th><th>First year (*)</th><th>Second year(*)</th><th>Third year(*)</th></tr>
<tr><td rowspan="3">Fractal structure of molecular clouds.
Geometry and physics</td><td rowspan="3">IAA
IA-UNAM</td><td rowspan="3"><u>Sánchez</u>, Alfaro,
Elías</td><td></td><td></td><td></td></tr>
<tr><td>X|X|X|X|X|X|X|X|X|X|X|</td><td>X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X|X|X|X|X|X|X</td></tr>
<tr><td>Task 1.1</td><td>Tasks 1.1 y 1.2</td><td>Task 1.2</td></tr>
<tr><td rowspan="3">PMS stars in clusters</td><td rowspan="3">IAA
NOT, Lisboa
Univ. Sevilla</td><td rowspan="3"><u>Delgado</u>, Galadí,
Alfaro, Djupvik, Yun,
Cantero, Cabrera-Cañ</td><td></td><td></td><td></td></tr>
<tr><td>X|X|X|X|X|X|X|X|X|X|X|</td><td>X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X|X|X|X|X|X|X</td></tr>
<tr><td>Tasks 2.1, 2.2, 2.4</td><td>Tasks 2.1- 2.5</td><td>Tasks 2.3 y 2.5</td></tr>
<tr><td rowspan="3">Visible and near infrared variability of PMS stars in clusters</td><td rowspan="3">IAA</td><td rowspan="3"><u>Fernández</u>, Galadí,
Delgado, Alfaro,
Cantero</td><td></td><td></td><td></td></tr>
<tr><td>X|X|X|X|X|X|X|X|X|X|X|</td><td>X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X|X|X|X|X|X|X</td></tr>
<tr><td>Tasks 3.1, 3.2, 3.3</td><td>Tasks 3.1, 3.2, 3.3</td><td>Tasks 3.1-3.4</td></tr>
<tr><td rowspan="3">OB stars</td><td rowspan="3">IAA
STSCI</td><td rowspan="3"><u>Maíz-Apellániz</u>
Walborn</td><td></td><td></td><td></td></tr>
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<tr><td>Task 4.1</td><td>Tasks 4.1 -4.2</td><td>Task 4.2-4.3</td></tr>
<tr><td rowspan="3">Stellar complexes</td><td rowspan="3">IAA
Kaptein Inst.
Stenberg Inst.</td><td rowspan="3"><u>Alfaro</u>, Bastian,
Larsen, Efremov</td><td></td><td></td><td></td></tr>
<tr><td>X|X|X|X|X|X|X|X|X|X|X|</td><td>X|X|X|X|X|X|X|X|X|X|X</td><td>X|X|X|X|X|X|X|X|X|X|X</td></tr>
<tr><td>Task 5.1</td><td>Task 5.1</td><td>Task 5.1</td></tr>
<tr><td rowspan="3">CHORIZOS implementation</td><td rowspan="3">IAA</td><td rowspan="3"><u>Maíz-Apellániz</u>
Cantero</td><td></td><td></td><td></td></tr>
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<tr><td>Task 6.1</td><td>Task 6.1-6.2</td><td>Task 6.1-6.2</td></tr>
<tr><td rowspan="3">(**) The detailed sequence of Tasks is shown in sec.7</td><td rowspan="3"></td><td rowspan="3"></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td></tr>
</table>

(*) Mark with X the number of corresponding months

5. BENEFITS FROM THE PROJECT, DIFFUSION AND EXPLOITATION OF THE RESULTS

Expected benefits and suitability of the project to the priorities of the program

The net benefit that can be expected from this project is to widen and improve our knowledge of the Universe in the specific field of Star Formation, following the aims specified in section 3. This is mainly a basic science project **(PNAyA priority objective 1)**. Nevertheless, some of the aims of the project have a singular component that could be described as "scientific service", because we intend to provide the astronomical community not only with ideas and results, but also with catalogues, data bases, computational tools and analysis software. In this sense, we can underline the following expected results:

- **Expand the catalogue of low-mass PMS stars in clusters (DAY-I; Delgado et al 2006b)**
- **Create a catalog of Herbig Be and AeBe stars in clusters**
- **Expand the catalogue of O-type stars (Maíz-Apellániz et al. 2004)**
- **Create a catalog of early-type stars in the Galaxy from the Tycho-2 and 2MASS data bases**
- **Convert the DAY catalog into a data base publicly available from the web pages of the "Stellar systems" group, implemented into the Spanish Virtual Observatory**
- **Add PMS stars to the current SED libraries in CHORIZOS**
- **Generate and make available to the community, via web, the software package developed for the analysis of variability in rich stellar fields**
- **Design robust estimators of fractal dimensions for the systematic analysis of the interstellar medium in our Galaxy and in external galaxies**

The EPO (Observing and Promoting Entity) BFI-Optilas has shown interest for the outcome of these results. The technician we are requesting would receive formation, mainly, in the application of data base protocols, and in the creation of user-friendly interfaces. Benigno Cantero (computing engineer) would be the supervisor of this work. Finally, we want to stress that reaching our objectives implies the exploitation of a considerable part of the set of telescopes accessible to the Spanish astronomical community **(PNAyA priority objective 3)**.

Plan for the diffusion of the results and public outreach

The results of this project will be disseminated through the usual ways in the scientific community, as articles in specialized journals, and oral and poster contributions to conferences. With respect to the diffusion among the general public, we foresee the following actions:

- Participate in the public outreach activities organized by the research institutions to which the team members are ascribed.

- Participate in external public outreach activities in form of talks and conferences.

- Preparing popular science articles that will be published in the most important media for amateur astronomers in Spanish. Versions of these texts, with accompanying images, will be available at the web pages of the Stellar Systems group of the IAA.

- Prepare collective monographs, with the collaboration of all the members of the research team. In principle we consider the production of a monograph on "Open Star Clusters", with general contents but special emphasis on the subjects related to this project. This monograph, addressed firstly to amateur astronomers but also to the general public, will be published in the best suited way, preferentially as a book: the necessary contacts with the specialized publishers will be done to reach this goal. We want to underline that several members of the research team are frequent consumers and producers of popular science products in different forms. Now we have before us a new challenge, this monograph, a high-level essay on popular science, focused on a cultivated reader with interest for astronomy but written by professionals specialized on the subject: a cultural product not too much frequent in our scientific community.

6. PREVIOUS EXPERIENCE OF THE TEAM IN THE SUBJECT MATTER
(maximum **two** pages)

Indicate the previous activities of the team and the achievements reached in the subject matter:

> If this project is the continuation of other previously funded, the already achieved objectives have to be stated clearly, as well as the corresponding results.
>
> If this project opens a new line, the antecedents and previous contributions of the team have to be stated, to justify its capability to perform the new project.

This section, together with section 3, has the aim of determining the suitability and capability of the team on this subject (and, thus, determining the viability of the proposal).

During the last five years, the members of the "**Stellar Systems**" group have focused their research on two key projects: (a) the detection and characterization of PMS stars in clusters and the analysis of the interaction of classical T Tauri stars with the interstellar medium; and (b) the study of the origin and structure of several stellar complexes, including the structural analysis of the parent molecular clouds. Other members that haver recently joined the team have taken part or led a number of projects related to subjects that are central to this proposal. Among them we can mention the participation in HST projects devoted to processes of star formation in galaxies, massive stars, and the structure of the young stellar component of our Galaxy. Some new members have, also, a long experience in instrumentation and in the study of star clusters and associations.

Since 2002, the following results have been obtained in relation to this proposal:

a) Structure of the ISM

- Determination of the 3D fractal dimension from the 2D dimension of projected clouds (Sánchez et al. 2005).
- Analysis of the influence of spatial resolution, number of pixels, signal-to-noise ratio and self-absorption on the measurement of the fractal dimension in real clouds (Sánchez et al. 2005, 2006b).
- Analysis of the inner structure of the clouds (density distribution, mass function, and size of the different clumps) as a function of fractal dimension and of the density thresholds used to define the clumps (Sánchez et al. 2006a).
- The mass distribution follows a power law only when the densest clumps are selected, which represents a 10% of the total mass of the clouds: a value very close to the average star formation efficiency. Under these conditions, the mass distribution follows a power law with an exponent close to Salpeter's. (Sánchez et al. 2006a)
- It is observed that the fractal dimension of the ISM adopts values from 2.6 to 2.8, higher than previously assumed (~2.35). This value seems to describe both the atomic and molecular components (as deduced from different data) (Sánchez et al. 2005, 2006b).
- We have proposed a mechanism to generate giant molecular clouds in the spiral arms of galaxies with magnetized medium through Parker instabilities (Franco et al. 2002).

b) Stars and star clusters

- We have analyzed more than 14 clusters with ages younger than 10 Ma searching for low-mass PMS stars. We have published more than one thousand candidates up to now (Delgado et al. 2004).

- ●We have performed a detailed study of the cluster NGC 2362 with multiband data (*$UBVR_CI_C$;JHK_s* from 2MASS; H-alpha; X-ray emission from Chandra). We have found X-ray emission along the whole mass range covered by the cluster, from early B-type stars to G-K PMS stars, with significant differences among MS and PMS stars both in total X-ray luminosity and in the spectral properties of this emission. A correlation is found for PMS stars linking X-ray emission and bolometric magnitude. (Delgado et al. 2006a).
- ●During this period, a number of studies on stellar variability, accretion and flares, led by or with participation from team members have been published (Broeg et al. 2005, 2004a,b; Fernández et al. 2004, Comerón et al. 2003, 2004, Stelzer et al. 2004; see Matilde Fernández's CV for further details).
- ●The most precise catalog ever produced of Galactic O-type stars has been published (Maíz-Apellániz 2004).
- ●We have participated in the study of a selected sample of open clusters of different ages, applying innovative tools for their analysis from astrometric and photometric (intermediate band) data (Balaguer-Núñez et al. 2004a,b; Balaguer-Núñez et al. 2005).

●c) Stellar complexes

- ●We have analyzed Gould's Belt (GB) in detail, designing a method to distinguish the members of the local Galactic disk (LGD) relying only on the spatial structure (Elías et al. 2006a).
- ●GB kinematics is clearly different to that of the LGD, as deduced from both its vertex deviation and its Oort constants. The classical negative vertex deviation shown by early OB stars in the solar neighborhood seems to be due to contamination by the GB. Once the groups are separated, the LGD shows a positive vertex deviation. (Elías et al. 2006b).
- ●We have studied in detail a big stellar complex containing, probably, the biggest known star cluster (several millions of solar masses) in the galaxy NGC 6946 (Alfaro et al. 2006, Efremov et al. 2002, 2004, Larsen et al. 2002).

d) Software packages

- ●We have produced the package **CHORIZOS**, a Bayesian code to compare spectral energy distribution models with observational magnitudes, sampling the parameter space to generate a likelihood distribution (Maíz-Apellániz 2004).

As we have shown, the team has a long experience in the research of the different aspects of star formation, including the following abilities:

Alfaro, E. J.(research direction and management, Galactic structure, star formation, star clusters, optical photometry, 2D spectroscopy)

Cabrera-Caño J.(data bases, statistics, numerical methods, synthetic photometry, MATLAB)

Cantero, B.(creation and maintenance of data bases, creation and support of computer networks).

Delgado, A. J.(binary stars, star clusters, PMS stars, optical and IR photometry)

Elías, F.(OB stars, stellar kynematics, stellar complexes)

Fernández, M.(star formation, T Tauri stars, accretion processes, optical and IR photometry, stellar variability)

Galadí-Enríquez, D.(star clusters, stellar variability, optical photometry, astrometry)

Djupvik, A. (formerly Kaas, A.)(star formation, clusters and associations, very low-mass stars, IR photometry and spectroscopy)

Maíz-Apellániz, J.(O stars, Galactic structure, massive young star clusters, extinction, photometric calibration, statistics, numerical methods, IDL)

Sánchez, N.(molecular clouds, fractal geometry, numerical methods, FORTRAN)

Sánchez-Gil, C.(getting trained on: optical 2D and 3D spectroscopy, multiobject spectroscopy, photometry with tunable filters)

Walborn, N.(spectral classification of early-type stars, fundamental properties of massive stars, variability of O-type stars, induced star formation)

6.1 PUBLIC GRANTS RECEIVED BY THE TEAM MEMBERS IN THE LAST FIVE YEARS

Título del proyecto o contrato	Relación con la solicitud que ahora se presenta (1)	Investigador Principal	Subvención concedida o solicitada EURO	Entidad financiadora y referencia del proyecto	Periodo de vigencia o fecha de la solicitud (2)
Estudio de la viabilidad de una misión precursora del Interferómetro Infrarrojo Espacial (C)	2	B. Montesinos (IAA-CSIC; LAEFF)	39000	DGICyT ESP98-1339-C02-02	1998-2001
Poblaciones Estelares en el Grupo Local (C)	2	E. J. Alfaro (IAA-CSIC)	21000	DGICyT PB97-1438-C02-02	1998-2001
OSIRIS- Instrumento de día 1 para GTC (C)	3	J. Cepa (IAC)	2019400	MCyT AYA2000-0333-P4-02	2001-2004
Estallidos de formación estelar en galaxias (C)	1	J. M. Vílchez (IAA-CSIC)	100796	MCyT AYA2001-3939-C03-02	2001-2004
Caracterización observacional de estrellas de pre-secuencia principal (C)	1	E. J. Alfaro (IAA-CSIC)	103675	MCyT AYA2001-1696	2001-2004
Estudio en los rangos visible e infrarrojo de estrellas de pre-secuencia principal (C)	1	E. J. Alfaro (IAA-CSIC)	62500	MEyC AYA2004-05395	2004-2007
Estallidos de formación estelar en galaxias	1	J. M. Vílchez (IAA-CSIC)	180400	MEyC AYA2004-8260-C03-02	2004-2007
Sistemas Estelares (V)	0	E. J. Alfaro (IAA-CSIC)	25000	Junta de Andalucía: PAI-TIC-101	2000-2004
Explotación de la primera luz del GTC (Proyecto CONSOLIDER) (V)	2	J. M. Rodríguez-Espinosa	5500000	MEyC CSD2006-70	2007-2011

(1) Escríbase 0, 1, 2 o 3 según la siguiente clave: 0 = Es el mismo proyecto; 1 = está muy relacionado; 2 = está algo relacionado; 3 = sin relación
(2) Escríbase una C o una S según se trate de una concesión o de una solicitud.

7. FORMATIVE CAPACITY OF THIS PROJECT AND OF THE APPLYING TEAM

This section should be filled in only if an affirmative answer was given to the corresponding question in the application form.
It is required to show that the applying team is capable of hosting graduate students (from the Researcher Formation Program) associated to this project, and arguments should be given illustrating the team's formative ability.

The Instituto de Astrofísica de Andalucía (IAA, the institution to which the graduate student would be associated) has resources enough to host students from the Programa de Formación de Investigadores (Researcher Formation Program). As it is stated in the project proposal, the team has access to the different telescopes and instrumentation required to pursue the research. The techniques to be applied are very well known by different members of the group. Given the current interest in this research subject and considering the diversity and quality of the team members, we conclude that this project is very well suited to the formation of a doctor on astronomy, who could receive a complete instruction on several observational techniques in different spectral ranges.

The formative capacity of the applying team is demonstrated by the number of PhD thesis and Master-degree equivalents (DEA) it has produced, by the courses for graduate students given by its members, and by their frequent participation in PhD dissertation evaluation committees.

The team members have supervised 7 PhD dissertations, 11 Master-degree equivalents (DEA), and they are currently supervising another 3 graduate students. Doctors Alfaro, Cabrera-Caño, Delgado, Fernández, Galadí-Enríquez, Djupvic, Maíz-Apellániz, and Walborn have given courses addressed to undergraduate and graduate students at several universities and research centers.

We consider that the incorporation of new students is crucial to hold and further develop the research lines open by the team.

Among the 3 PhD dissertations currently in progress, only one (that by María del Carmen Sánchez-Gil) is funded by the Spanish Ministry of Education and Research (Ministerio de Educación y Ciencia) via FPU grant. Alfredo Sota, supervised by Maíz-Apellániz, works under contract funded by a NASA grant at the Space Telescope Science Institute. The graduate student supervised by Matilde Fernández, Edwind Pelegrina Rodríguez, is a secondary school teacher.