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Complementing Gaia from the ground

The DANCe survey

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Abstract. The DANCe survey aims at complementing Gaia by providing proper motion measurements with a comparable accuracy 4 magnitudes fainter. These measurements are used to identify sub-stellar members of young nearby clusters and associations down the planetary mass regime.

Key words. Proper motions, Stars: kinematics and dynamics, Stars: luminosity function, mass function

1. Introduction

The Gaia satellite will provide astrometric, spectroscopic and photometric measurements for a billion stars in the Galaxy. The unprecedented astrometric accuracy will allow for the first time to perform detailed study of the internal dynamics of young nearby clusters and associations, providing unique and novel constrains to the theories of stellar and sub-stellar evolution. Unfortunately, Gaia will have two important limitations for the specific study of star formation. Its detection limit (G =20 mag) will not allow it to study the least massive brown dwarfs (see Sarro's contribution to this meeting). Additionally, because it will operate in the visible, Gaia will be strongly affected by extinction and nebulosities, which are often present in the core of young clusters and associations. The DANCe project aims at complementing Gaia in the embedded cores of young nearby associations and clusters and beyond its limit of detection down to the least massive objects.

2. The DANCe survey

2.1. Description

The DANCe survey was originally motivated by the availability in public archives of many multi-epoch wide field images of nearby clusters and associations. These images were obtained over periods covering 10 to 15 years, allowing accurate proper motion measurements for all the sources in their field of view.

The Pleiades was the first cluster targetted by the DANCe survey. Because of its proximity and relative youth, the Pleiades has been studied extensively over the past hundred years. As a consequence, a large number of archival observations were available in various astronomical archives, making it the perfect test bench for the project. Figure 1 shows the footprints of the various datasets downloaded from public astronomical archives, as well as our own CFHT MegaCam images. The entire UKIDSS (Lawrence et al. 2007) survey of the Pleiades was included and re-analyzed.

2.2. Results

The large number of epochs and the long time-baseline allowed us to derive proper motions with an accuracy as good as 0.3 mas yr^{-1}. Figure 2 shows the estimated uncertainty on the proper motion measurements as a function of magnitude and of the time baseline. Gaia and LSST predicted accuracy are also overplotted for comparison. At the faint end, the results obtained by the DANCe survey are similar to Gaia's expected performances, and remain below the millarcsecond per year 3 to 4 magnitudes beyond Gaia's detection limit. The accuracy achieved by DANCe is similar to that expected for LSST.

To select the Pleiades members among the catalog, we developed a novel multi-dimensional probabilistic analysis. First, the best (in a statistical sense) combination of colors and luminosities are selected among all available photometric measurements using the Bayesian information criterion. Second, the locus of Pleiades candidate members from the literature (Stauffer et al. 2007) is fitted in the multi-dimensional space. Mixture of gaussians are used to fit the Pleiades locus in the proper motion diagram, while principal curves are used to fit the cluster's locus in the various color-magnitude diagrams (see Figure 3). This model allows us to compute the membership probability for all sources in the catalogue. New high probable members are selected (probability greater than 99.5%), contaminants in the original sample of candidate members of Stauffer et al. (2007) are rejected, and a new model is computed. The procedure is repeated until it converges.

Applying the same procedure to the Tycho-2 catalogue, we recovered 206 members of the Pleiades including 86 new candidate members. The final sample of Pleiades includes 2 216 high probability candidates members, of which ≈50% are new.

The method presents several advantages. First, it includes the treatment of missing or censored data. Because our survey is based on archival images, the astrometric and photometric coverage is not homogeneous (see Figure 1). It was therefore important to be able to take censoring in a statistically satisfying way. Second, the method takes into account measurement uncertainties, ensuring coherent and homogeneous membership probabilities over the entire luminosity range.

Figure 4 shows a $(i, i - K)$ color-magnitude diagram with the members overplotted in red. Gaia's detection limit is represented as well, assuming the typical color predicted by the BT-Settl models (Allard 2014) for Pleiades members of the corresponding luminosities.

We are now in the process of gathering new epochs and analyzing a number of nearby clusters. Our list of targets includes clusters and associations closer than 1 kpc, and with ages in the range 1-5 000 Myr. Preliminary results in IC2391, IC2602 and CygOB2 show that the DANCe survey successfully complements Gaia beyond its detection limit and, for

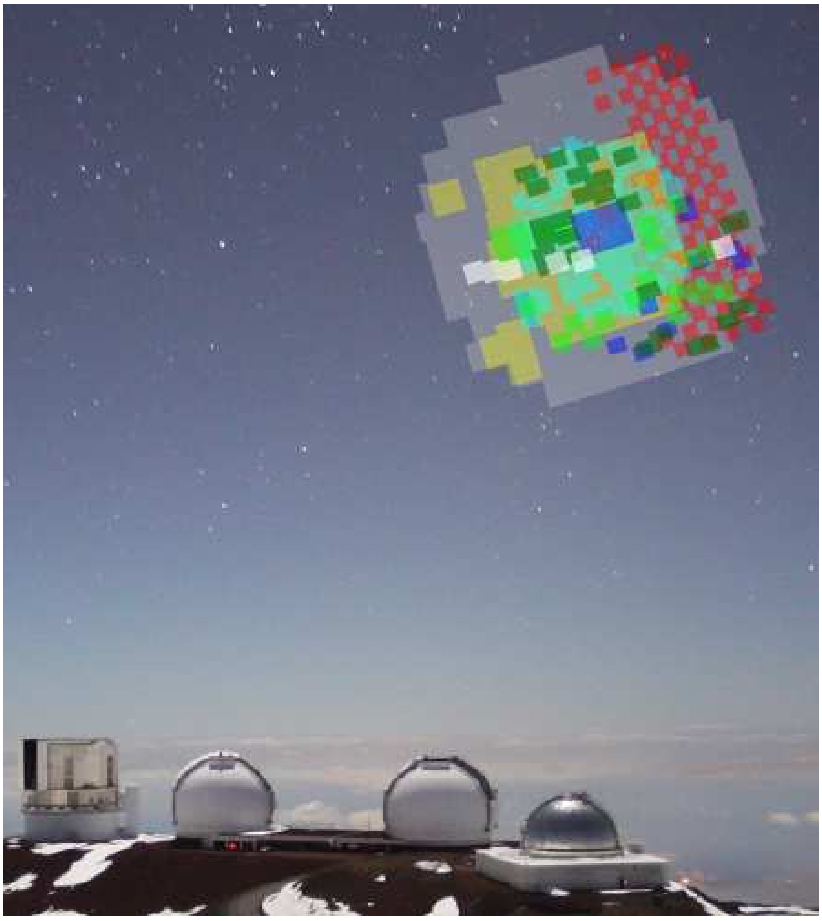

Fig. 1. Coverage of the DANCe survey in the Pleiades. The footprints of the various datasets are overplotted in the hawaiian sky over the Keck, Subaru and IRTF telescopes. The UKIDSS survey defines the largest area and is represented in white. Our CFHT/MegaCam images are represented in yellow.

the nearest and youngest associations, down to the planetary mass regime.

3. Conclusions

We have successfully designed a survey to complement Gaia's astrometry beyond its detection limit. The survey is based on archival and new wide field images, and provide proper motion measurements with a precision as good as 0.3 mas/yr, depending on the observational history. The data processing software, astrometric analysis tools and selection methods developped for the DANCe project should be readily applicable to the Gaia catalog, ensuring a complete an coherent analysis of the content and properties of nearby clusters from their most massive members down to the least massive brown dwarfs and, in some cases, planetary mass objects.

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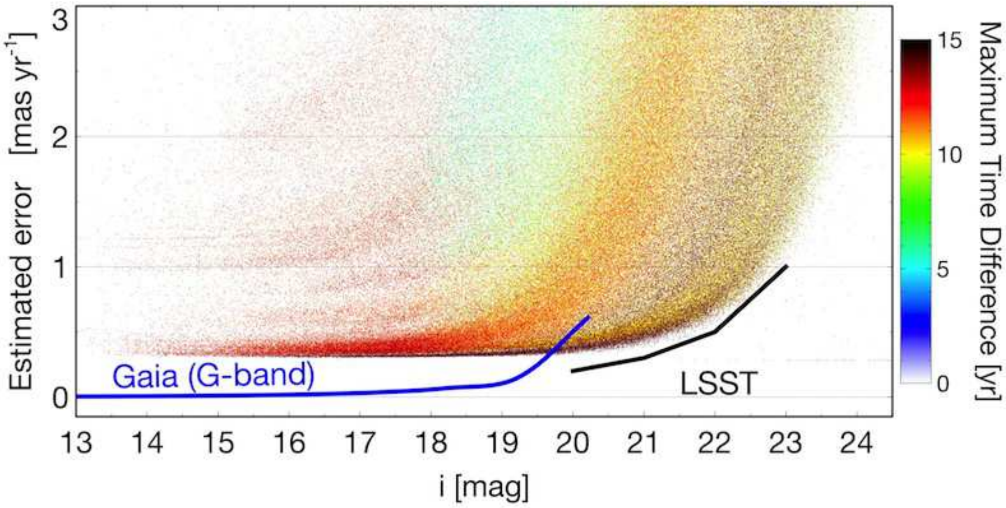

Fig. 2. Estimated error on the proper motion as a function of luminosity (in the i-band) and time baseline (color scale). The Gaia and LSST expectations are overplotted for comparison.

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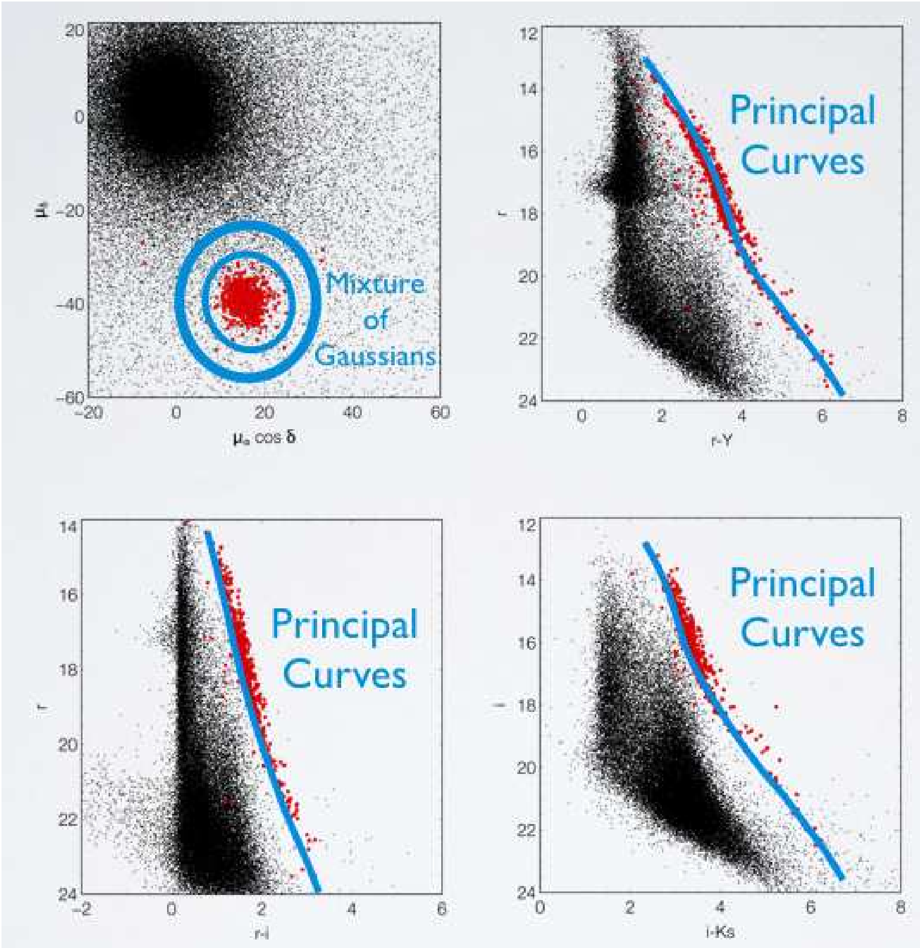

Fig. 3. Selection of members in the DANCe catalogue. The locus defined by clusters members is fitted with a mixture of gaussian in the proper motion diagram, and principal curves in the color magnitude diagrams.

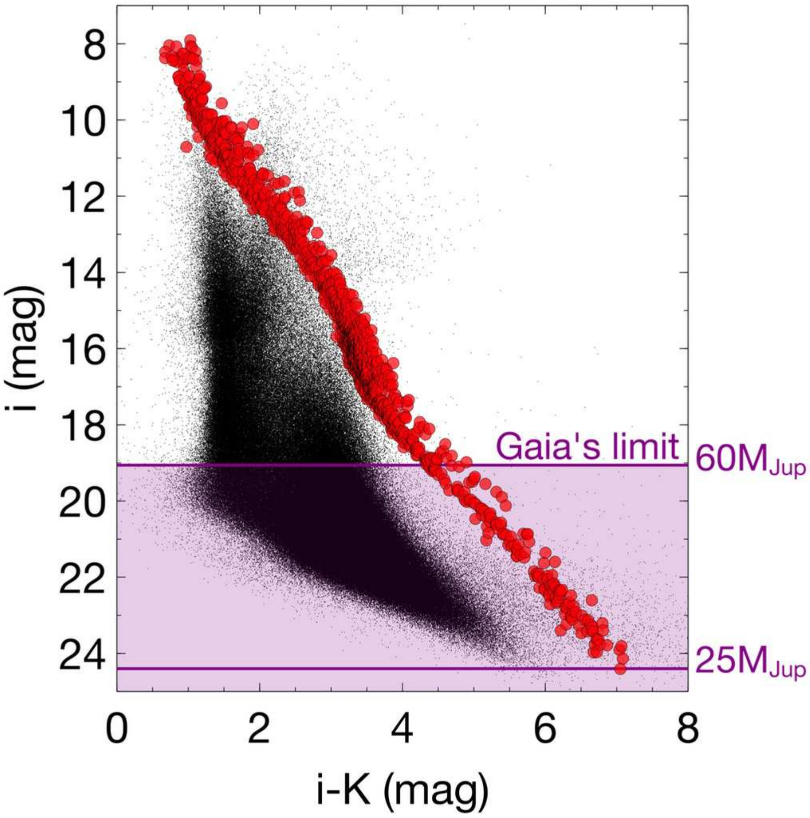

Fig. 4. $(i, i-K)$ color magnitude diagram of the DANCe Pleiades survey. The members are indicated in red, and Gaia's detection limit is represented.