Mem. S.A.It. Vol. 85, 715

Memorie della

Prospects for the BANYAN search of low-mass moving group members with Gaia, and the importance of magnetic fields for isochronal age determination

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Abstract. Using the BANYAN I and BANYAN II tools, we identified more than 500 candidate members in nearby young kinematic groups. As part of the follow-up programs, we measured radial velocity and confirmed signs of youth (Hα, X-ray emission, low surface gravity, lithium) for more than 150 red objects using optical and near-infrared spectroscopy. An accurate determination of the age of those objects requires a comparison of their fundamental properties to those of evolutionary models, which take into account the impact of their fully convective interior. As young low-mass objects display strong magnetic activity, the inclusion of magnetic fields in evolutionary models is a key step towards the accurate determination of their fundamental properties. We present the isochronal age determination of β Pictoris moving group members using the Dartmouth magnetic evolutionary models, and show that including magnetic fields generally increases the isochronal age, which better agree with the lithium depletion boundary method.

Key words. Stars: low-mass objects – Stars: fundamental properties – Galaxy: young moving groups

1. Introduction

Low-mass stars and brown dwarfs constitute the majority of the Galactic stellar population. Their study has bloomed in the two decades thanks to large-scale far-red and infrared surveys and the advent of a new generation of infrared instruments. This is motivated in part by the search for habitable exoplanets, since recent results have shown that a significant fraction of them host exoplanets (Barnes et al., 2014; Bonfils et al., 2013). Ultimately, our understanding of the properties of these exoplanets relies on our knowledge of the fundamental properties of their host stars, namely their masses, effective temperatures, radii, and their age. Age is probably the most difficult fundamental parameter to constrain because its determination inevitably relies on models (e.g. isochrone fitting, gyrochronology, and the Li depletion boundary) or kinematic traceback techniques, in the case of members of young co-moving groups (Soderblom et al., 2013).

Realistic stellar evolutionary and atmosphere models are crucial to precisely determine the ages of such objects. Young low-mass stars are known to display rapid rotation, as well as high chromospheric and coronal activity, all these pointing to strong magnetic fields which are driven by a dynamo arising in their fully convective interiors. Considering such magnetic fields in evolutionary models is therefore important for the age determination of young red objects.

2. Method and analysis

In order to quantitatively assess membership of stars in young moving groups (YMGs), Malo et al. (2013) developed Bayesian Analysis for Nearby Young AssociatioNs (BANYAN), a tool which derives membership probabilities by combining Bayesian inference to empirical models for seven observables characterizing the kinematics (U,V,W,X,Y,Z) and photometry of known members. Such models were built for the seven closest and youngest well-defined moving groups : TW Hydrae, β Pictoris, Tucana-Horologium, Columba, Carina, Argus and AB Doradus. In addition to a membership probability, this tool provides statistical predictions for its radial velocity (RV) and distance, given its membership to each moving group.

Gagné et al. (2014) developed BANYAN II, which include more sophisticated kinematic models (ellipsoids with arbitrary rotation) and use NIR color-magnitude diagrams to specifically target the identification of brown dwarfs in these moving groups. Moreover, expected field and moving group populations are taken into accounts as prior probabilities, and an extensive false-positive and hit rate analysis is performed based on a Besançon Galactic model Robin et al., 2012, Robin et al. inprep.

We used the BANYAN I and BANYAN II tools to identify new 200 K5V-M5V, 175 M4-L7 candidate members to YMGs, and 39 previously known brown dwarfs with signs of youth (Gagné et al., 2014, Gagne et al. inprep).

2.1. Kinematic and youth confirmation

Confirming the membership of these candidates require measurements of RV, parallax as well as indications of youth. For this reason, Malo et al. (2014) presented RV measurements for 130 K7–M5 candidate members, using high resolution spectroscopy. Furthermore, a collaboration with A. Riedel (Riedel et al., 2014) and the CTIOPI, as well as recent parallax measurements in the literature (Dupuy & Liu, 2012; Shkolnik et al., 2012; Liu et al., 2013; Dittmann et al., 2013) confirmed statistical distance predictions from BANYAN for 30 candidate members.

In order to confirm the youth of low-mass star candidates, we measured chromospheric and coronal activity indicators such as Hα, X-ray and UV emission. In the case of brown dwarfs, spectroscopic indicators of low-gravity are preferred, such as the equivalent width of Na I, K I, the depth of VO band-heads, as well as the shape of the H-band continuum. Another widely used technique for age dating require the use of atmospheric and evolutionary models to compute isochrones and compare them to the observed fundamental parameters of the red dwarfs. For objects with spectral types later than M3, this method has yielded ages which were consistently underestimated the ages compared to more massive objects into the same group or from the lithium depletion boundary. Episodic accretion rates, rapid rotation and the presence of magnetic fields were often proposed as potential solutions to solve this problem. Feiden & Chaboyer (2013, 2014) recently developed pre-main sequence Dartmouth magnetic evolutionary models. This inclusion of these magnetic fields (B_f = 2.5kGauss) has the effect of increasing the bolometric luminosity of synthetic models by $\sim$ 0.5 dex in the case of objects with effective temperatures below 3200 K.

We used these magnetic models to derive the isochronal age of 15-28 Myrs for K5–

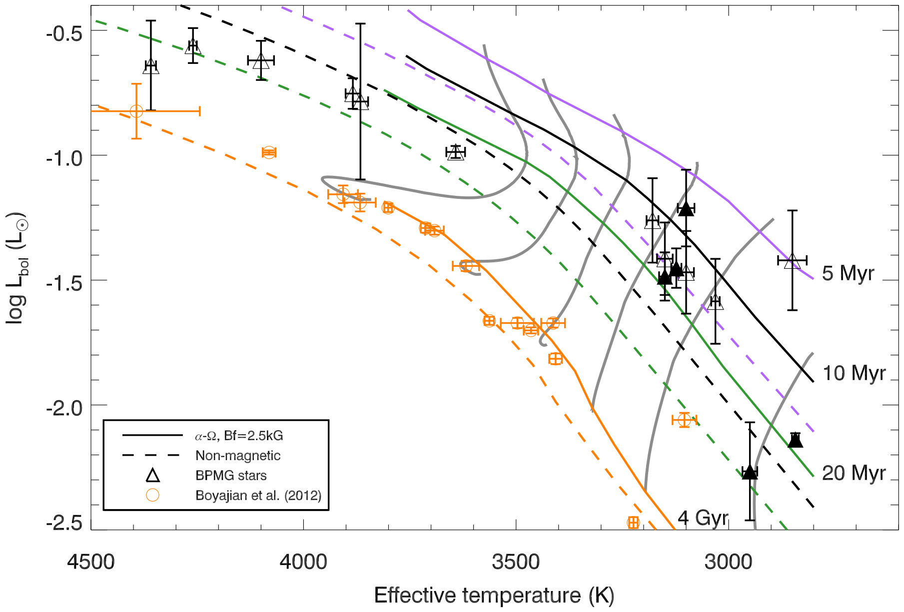

Fig. 1. Bolometric luminosity as a function of effective temperature for members of βPMG (Pecaut & Mamajek, 2013; L. Malo et al., submitted). Field dwarfs are represented by orange circles (Boyajian et al., 2012). Binary stars are displayed with filled symbols and their luminosity was reduced by a factor of two. Magnetic $\alpha-\Omega$ Dartmouth models with field strengths 2.5 kG are represented with solid lines. The magnetic Dartmouth isochrones of 5, 10, 20 Myr and 4 Gyr are represented with purple, black, green and orange color lines, respectively. Tracks of constant masses are represented with grey lines; their values from right to left vary from 0.1 to 0.6 $M_{\odot}$.

M5 bona fide members to βPMG by adjusting the Dartmouth magnetic evolutionary models to observed fundamental properties (L_{bol} and T_{eff}) from Pecaut & Mamajek (2013) and Malo et al. (submitted). This age estimate is in agreement with the age infered from the Lithium depletion boundary method for βPMG members (21±4 Myr; Binks & Jeffries, 2014). In Figure 1, we show bolometric luminosity as a function of effective temperature for our sample of βPMG members.

Since the inclusion of magnetic fields shifts isochrones to larger bolometric luminosities and cooler effective temperatures, ages derived from those are systematically older than those derived from non-magnetic models. Considering magnetic fields with strengths of 2.5 kGauss which is typical for early to mid-M dwarfs (Reiners, 2012) yields median age of 14 Myr for βPMG, in contrast with the age of 5 Myr which was obtained from non-magnetic models.

3. Future prospects

The main limitation of the current BANYAN tool is that it does not include young association members located beyond 100 pc such as the Scorpius-Centaurus complex (de Zeeuw et al., 1999) and the Pleiades (Jeffries, 1995). The main reason for this is that the construction of reliable spatial and kinematic models for these associations requires precise measurements of RV and distance for a significant set of credible members. The *GAIA* mission will provide such an opportunity by providing measurements of trigonometric distance for objects with $V \leq 20$. However, RV measurements from *GAIA* mission will be limited to a precision higher than ~ 1 kms^{-1} for faint low-mass stars and brown dwarfs. This brings out the important role that ground-based RV surveys reaching precisions of ~ 1 kms^{-1} will play in characterizing the kinematics of red objects. With accurate RV and parallax measurements for all stars in hand, the determination of the UVW, XYZ) for young group members beyond 100 pc will become possible.

The global parametrization of the brightness of these young members will be improved with the *GAIA* results, as it will provide photometry and astrometry of unprecedented precision for most stars brighter than V = 20. Binary stars will be more easier detected, leading fewer false positives from old field binaries. As red objects emit most of their light at red and NIR wavelengths, their characterization using NIR spectrographs is more efficient. Current and next generations instruments such as CARMENES (Quirrenbach et al., 2010) and SPIRou (Delfosse et al., 2013) are opening the door to a precise characterization of these red objects, as well as making possible the search for exoplanet companions. SPIRou will provide an opportunity of measuring magnetic field strengths, which as discussed above, is an important parameter in the accurate determination of an objects' age. This will also allow a better understanding of the evolution of magnetic fields as a function of age for these objects.

Acknowledgements. We thank our collaborators: Jackie Faherty, Adric Riedel and Kelle Cruz. This work was supported through grants from the Canada-France-Hawaii Telescope, the Fond de Recherche Québécois - Nature et Technologie and the Natural Science and Engineering Research Council of Canada.

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