Short Visit Grant ☐ or Exchange Visit Grant ☒

Scientific Report

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Proposal Title: Formation and early evolution of young clusters with the Gaia-ESO survey

Application Reference N°: 4645

1) Purpose of the visit

The Gaia-ESO Survey is a large public optical spectroscopic survey of Milky Way stars in the field and in clusters (Gilmore et al. 2012, Randich & Gilmore. 2014). The aim of the survey is to provide radial velocities (RVs), stellar parameters and abundances of 10^5 Galactic stars. This data will complement the astrometric and photometric catalog provided by Gaia space mission.

The Gaia-ESO survey started on the 31 December 2011 and will last for five years for a total of 300 observing nights. Observations are carried out with the multi-object optical spectrograph FLAMES at the Very Large Telescope. This instrument is composed of a robotic fibre positioner that feeds the medium resolution (R~17,000) spectrograph GIRAFFE and the high resolution (R~47,000) spectrograph UVES with 132 and 8 fibres, respectively. The spectra of the Gaia-ESO Survey are processed and analysed homogeneously by twenty working groups composed of about 400 astronomers. After 27 months from the starting of the survey, nearly half of the targets have been observed and all the spectra observed during the first 18 months have been fully analysed.

The recipient of this Exchange Visit Grant, Germano Sacco, is one of the Co-I of the Gaia-ESO Survey and collaborates both to the analysis and the interpretation of the data, and to the scientific

explotation of the results, with a specific interest on the young clusters. He is leading the group, based at the Osservatorio Astrofisico di Arcetri, which performs the data reduction and the calculation of the RVs and the projected rotational velocities for all the spectra of the survey taken with UVES (Sacco et al. 2014). He is also part of the working group in charge of the analysis of the spectra of Pre-main sequence stars and he is leading some of the scientific projects focused on the study of star formation processes. The astrophysics group at the University of Keele, the host istitution, is also deeply involved in the Gaia-ESO Survey. The group leader, R. Jeffries is a member of the steering committee of the survey and, together with R. Jackson, is collaborating to the data reduction and to the calculation of the RVs for all the stars observed with the GIRAFFE spectrograph. Furthermore, R. Jeffries is leading some of the scientific projects aimed at the interpretation of the results from the observations of young clusters and he is the first author of the first paper published by the Gaia-ESO consortium on the topic of cluster formation (Jeffries et al. 2014).

The five weeks visit of Germano Sacco at the University of Keele had mutiple aims:

1. Performing the scientific analysis and the interpretation of the latest observations of young clusters fully analysed by the workflow of the Gaia-ESO Survey;

2. Reviewing the procedure used for the calculation of the radial velocities for GIRAFFE and UVES with the aim of improving the accuracy and precision of the values provided by the Gaia-ESO Survey;

3. Planning future collaborations to maximize the scientific output of the Gaia-ESO Survey.

2) Description of the work carried out during the visit

2.1) Analysis of the Gaia-ESO Survey observations of NGC 2547

As discussed in the last section, the first aim of the visit was to analyse the latest products of the Gaia-ESO observations of young clusters. Specifically, the work was focussed on the analysis of the observations of the cluster NGC 2547. This is a 35 Myr cluster (Oliveira & Jeffries 2005) located at a distance of about 400 pc in the Vela region. The cluster is just two degrees (the projected distance at 400 pc is 11 pc) south of Gamma Velorum, namely the first young cluster

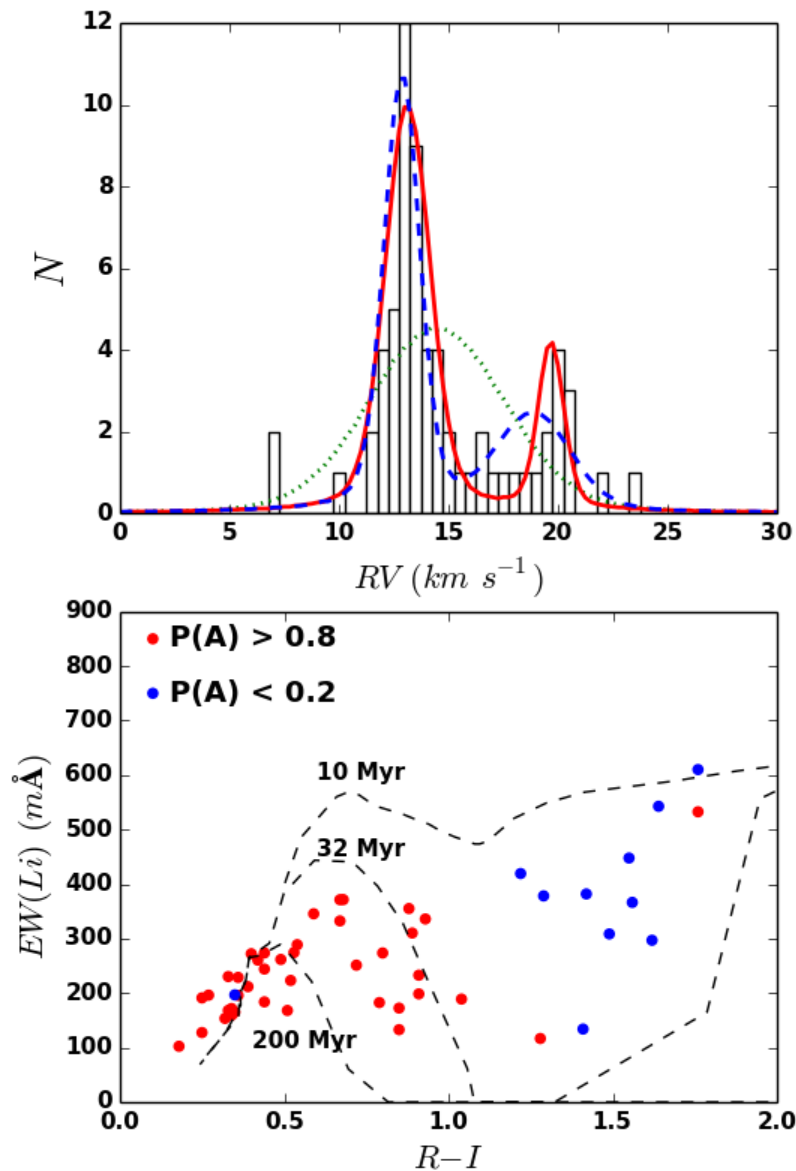observed by the survey, where Jeffries et al. (2014) discovered two kinematically distinct populations.

Figure 1. Top panel: distribution of RVs for all the stars with EW (Li) > 100 mÅ of NGC 2547. The dotted (green), the dashed (blue) and the continuous (red) lines represent the model which best fit the distribution when considering only one population, two populations with the parameters of the second one fixed at given values (see the text) and two populations with all parameters free to vary, respectively. Bottom panel: equivalent width of the Li line at 607.8 nm as function of R-I for all the stars to population A (red dots) and population B (blue dots) of NGC 2547.

The cluster NGC 2547 has been observed in January and February 2013, during two separate runs. A total of 450 targets distributed over

an area of about 1 deg^2 and divided in 16 fields of view of FLAMES (diameter ~25 arcminutes) have been observed, using the GIRAFFE spectrograph.

The first goal of the analysis was to investgate the kinematical properties of the cluster, using the RV distribution of a sample of cluster members. As discussed in Jeffries et al. (2014), the most efficient method to remove field stars from whole sample is to select only the Li rich objects. The top panel of Fig. 1 shows the RV distribution of the Li rich stars (Li equivalent width > 100 mÅ). Two peaks are clearly present in the RV distribution. The first and most prominent is centred at the velocity quoted in the literature for NGC 2547, while the second peak (which will be called population B) is located, approximately, at the same velocity of the secondary population discovered in Gamma Velorum by Jeffries et al. (2014).

This suggests that the secondary population of Gamma Velorum and population B of NGC 2547 have a common origin. To test this hypothesis, we fitted the RV distribution with three models (see Fig 1): a) a model which assumes the presence of only one population (green dotted line in the plot in Fig 1); b) a model assuming the presence of two populations, one of which with the same central velocity and dispersion of the secondary population of Gamma Velorum (blue dashed line in the top panel of Fig. 1); c) a model assuming two populations with both central velocity and dispersion free to vary (red continuous line in the top panel of Fig. 1). A statistical analysis of the three fits based on the Bayesian Information Criterion proved that the distribution is better described by two populations and the central velocity and dispersion of the second one are consistent with the secondary population of Gamma Velorum.

To investigate the age discrepancy between the two populations of NGC 2547, we plotted in the bottom panel of Fig. 1 the Li EWs as function of R-I, together with isochrones from the Baraffe et al. (1998) models. The plot clearly shows that population B (blue dots in the plot) is younger than NGC 2547, for which we confirm the age of ~35 Myr. In particular the age of the secondary population is consistent with population B of Gamma Velorum.

2.2) Analysis of the precision and accuracy of the radial velocities of the Gaia-ESO Survey

The second aim of the visit was to analyse the procedure for the calculation of the RVs to correct the systematic shift between GIRAFFE and UVES, discussed in Sacco et al. (2014), and improve the precision. We performed a detailed comparison of the procedures developed in Keele and in Florence, arriving to the conclusion that the origin of this systematic shift is the wavelength calibration. In fact, the GIRAFFE data are calibrated with a simultaneous arc lamp taken during the

night, while the UVES spectra are calibrated using a arc lamp taken in daytime.
Since no simultaneous calibration is available for the UVES spectra, the emission lines from the sky spectrum will be used to correct the calibration based on the arc lamp.

3) Description of the main results obtained

During the 5 weeks visit, the recipient of this grant worked with the Gaia-ESO team in Keele both to the scientific analysis and interpretation of the observations of the young cluster NGC 2547 and to the procedure used to derive the RVs of the Gaia-ESO survey. The following results have been obtained:

1. The discovery of the presence of a double populations towards the young cluster NGC 2547. The kinematical properties as well as the distribution of the equivalent width of the Li lines support the hypothesis that this secondary population has been formed together with the secondary population discovered by Jeffries et al. (2014) around Gamma Velorum. It is not clear if these stars towards NGC 2547 formed near Gamma Velorum and then migrated or if the parental cloud of this young population was much more extended than previously thought.
2. The definition of a strategy to correct the systematic shift between the RVs calculated from UVES and GIRAFFE spectra and improve the precision.

4) Future collaboration with host institution

The reaserch teams based at the Osservatorio Astrofisico di Arcetri and at the University of Keele are two main contributors of the Gaia-ESO Survey, since they are both involved in the data processing and analysis, and in the interpretation of the results. This visit helped to strenghten the collaboration between these two groups, that will pursue during the rest of the survey.

5) Projected Publications

The results of this visit have been presented at the GREAT workshop held in Palermo "Young clusters in the Gaia-ESO Survey" on the 20-22 of May and will pubblished in a paper that will be submitted on the journal *Astronomy & Astrophysics.*