Searching for new members of stellar kinematic groups:
kine-chemical tagging FGK stars with GES/UVES data

D. Montes[1], H. M. Tabernero[1], J.I. González Hernández[2]

[1]Departamento de Astrofísica, Universidad Complutense de Madrid (UCM), Spain;
[2]Instituto de Astrofísica de Canarias (IAC), Spain.

Abstract

Using the large amount of data provided by the **Gaia ESO Survey** (GES) we intend to perform a **chemical and kinematic analysis** of the **FGK field stars of the Milky Way** observed with **UVES**. Using the radial velocities provided by the survey, the astrometry available in the literature and an estimation of the distance using our derived spectroscopic stellar parameters (***T***T_{eff}, log***g***, ξ and **[Fe/H]**) we will make a first kinematic selection of possible members to **stellar kinematic groups** (moving groups and associations) of difference ages. For these subsamples of stars we will perform a detailed differential abundance analysis (**chemical tagging**) and use additional information derived from the spectra (rotational velocities, Lithium abundance and chromospheric activity) that will allowed us to discern between real physical structures of coeval stars with a **common origin** (debris of star-forming aggregates in the disk) and **field-like stars** (structures formed by resonance interactions, associated with dynamical resonances (bar) or spiral structure).

Stellar kinematic groups

Classical Old Moving Groups: **Table 1** and **Fig. 1** show the oldest moving groups (MG) located outside the boundaries (dotted line) that determine the young disk population as defined by Eggen (see Montes et al. 2001MNRAS.328...45) except Groomb 1830 and Kapteyn groups that have very high velocities. In **Fig. 1** it is also plotted in dashed line the velocity ellipsoid determined by Francis & Anderson 2009NewA...14..615 to eliminated high velocity stars.

Classical Young Moving Groups: The youngest (age < 650 Myr) and best documented MG in the solar vicinity (see **Table 2** and **Fig. 2**) are the **Hyades**, **Ursa Major** (UMa), **Local Association** (LA), **IC 2391** and **Castor** (see Montes et al. 2001MNRAS.328...45 and references therein). Substructures in these MG have been found like the B1-B4 subgroups of the LA (Asiain et al. 1999A&A...341..427) and some possible new MG as **Hercules-Lyra** has been identified more recently (López-Santiago et al. 2006ApJ...643.1160).

Young Nearby Loose Associations: Several nearby associations of young stars have been identified in the last years, and a large number of then have U, V velocities in the region of the Local Association (Pleiades MG). In **Table 3** and **Fig. 3** we compile the more recent results from Torres et al., 2008hsf2.book..757; Zuckerman & Song 2004, ARA&A, Vol. 42, 685, and some other authors. Some initially indentified groups like HD 199143 later result to be part of the β Pic. Some recently identified associations result to be part or to be related with known MG or open clusters (like Argus = IC 2391).

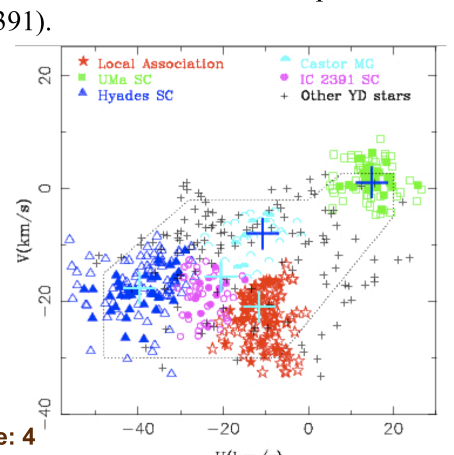


Figure: 4

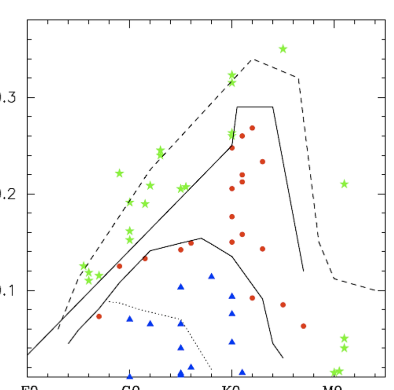


Figure: 5

High resolution echelle spectroscopy (see our previous work, Montes et al. 2001 MNRAS, 328, 45; López-Santiago et al. 2010 A&A, 514, A97; Figs. 4 and 5) allowed us to analyse in more detail the membership of these stars to the different young MG: using **age-dating methods** for late-type stars such as the chromospheric activity level and the lithium absorption line. See also the ***chemical tagging*** method (Tabernero et al. 2012, A&A, 547, A13).

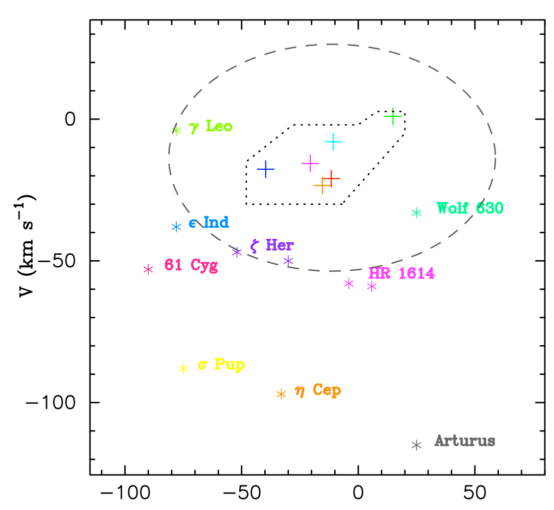


Figure: 1

Name	U (km/s)	V (km/s)	W (km/s)
γ Leo	-78.0	-4.0	-1.0
Wolf 630	25.0	-33.0	13.0
ε Ind	-78.0	-38.0	4.0
ζ Her "	-52.0 -30.0	-47.0 -50.0	-27.0 -
61 Cyg	-90.0	-53.0	-8.0
HR 1614 "	-4.0 5.8	-58.0 -59.0	-11.0 -
σ Pup	-75.0	-88.0	-21.0
η Cep	-33.0	-97.0	10.0
Arturus	25.0	-115.0	-3.0
Groombridge 1830	277.0	-157.0	-14.0
Kapteyn´s star	19.0	-288.0	-53.0

Table 1: Classical Old Moving Groups
http://www.ucm.es/info/Astrof/invest/actividad/skg/old_skg.html

Name	Clusters	Age (Myr)	U (km/s)	V (km/s)	W (km/s)
Local Association (Pleiades moving group) (Stream 0)	Pleiades (M45, Melotte 22) α Persei (Melotte 20) M34 (NGC 1039) delta Lyr (Stephenson 1) NGC 2516 (Mel 82) IC 2602 (theta Carinae)	20 - 300	-11.6	-21.0	-11.4
Hercules-Lyra	-	150 - 300	-15.4	-23.4	
IC 2391 supercluster	IC 2391 (o Velorum)	35 - (80 - 250)	-20.6	-15.7	-9.1
Castor Moving Group	-	~200	-10.7	-8.0	-9.7
Ursa Major group (Sirius supercluster) (Stream II)	Ursa Major (Collinder 285) M39 (NGC 7092)?	300 - 500	+14.9	+1.0	-10.7
Hyades supercluster (Stream I)	The Hyades (Melotte 25) Praesepe (M44) NGC 1901 (Bok 1)	~650	-39.7	-17.7	-2.4

Table 2: Classical Young Moving Groups
http://www.ucm.es/info/Astrof/invest/actividad/skg/skg.html

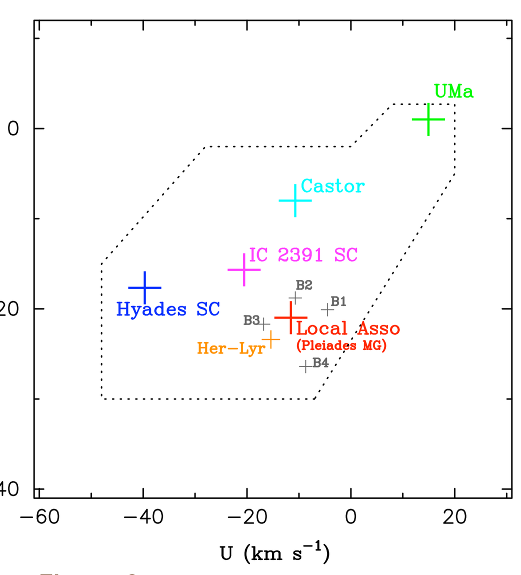


Figure: 2

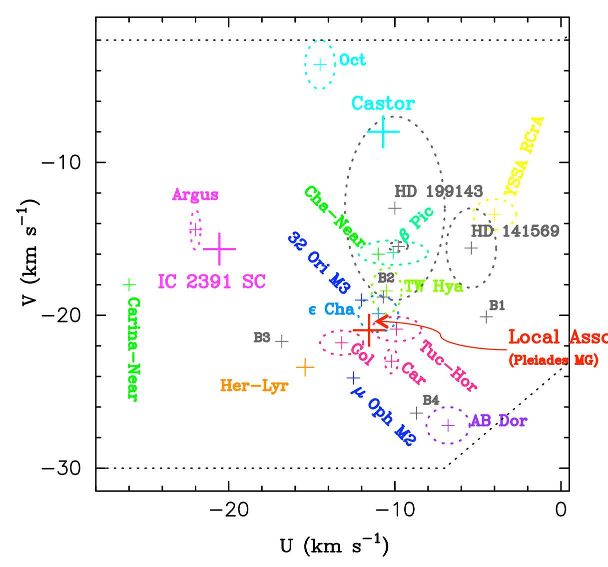


Figure: 3

Name	d (pc)	Age (Myr)	U (km/s)	V (km/s)	W (km/s)
TW Hydrae	~50 (48+-13)	~10 (8)	-10.5	-18.0	-4.9
ε Chamaeleontis η Chamaeleontis Cluster	~110 (108+-9) ~97	6 8 (4-9)	-11.0	-19.9	-10.4
β Pictoris HD 199143 (Capricornius Asso) "	~36 (36+-21) ~48 "	~12 (10) ~12 (10) "	-10.1 -10.0 -9.8	-15.9 -13.0 -15.5	-9.2 -13.0 -11.1
Great Austral Nearby Young Asso (GAYA) Tucanae - Horologium Columba Carina	 (48 +- 7) (82 +- 30) (85 +- 35)	 40 (30) 30 (30) (30)	 -9.9 -13.2 -10.2	 -20.9 -21.8 -23.0	 -1.4 -5.9 -4.4
Octans	(141 +-34)	(20?)	-14.5	-3.6	-11.2
Argus = IC 2391	(106 +-51)	(40)	-22.0	-14.4	-5.0
AB Doradus	(34 +-26)	50-120 (70)	-6.8	-27.2	-13.3
YSSA, Young Sco-Sgr Asso (ρ Oph & R CrA)	~100	8	-4.0	-13.4	-8.0
HD 141569	~100	~5	-5.4	-15.6	-4.4
μ Oph Cluster (Mamajek 2)	~170	~120	-12.5	-24.1	-4.9
32 Ori (Mamajek 3)	~92	~25	-12.0	-19.0	-9.0
Carina-Near	~30	~200	-26.0	-18.0	-2.0
Cha-Near	~90	~10	-11.0	-16.0	-8.0

Table 3: Young Nearby Loose Associations
http://www.ucm.es/info/Astrof/invest/actividad/new_associations_ys.html

Stellar parameters

Stellar atmospheric parameters (T_{eff}, log***g***, ξ and **[Fe/H]**)

StePar (Tabernero Montes, González Hernández, **2012**, A&A, 547, A13):

- 2002 version of the MOOG code (Sneden 1973).
- a grid of Kurucz ATLAS9 plane-parallel model atmospheres (Kurucz 1993) and MARCS.
- The EW determination of the Fe lines with the ARES code (Sousa et al. 2007) and TAME.
- 263 Fe I and 36 Fe II lines (Sousa et al. 2008).

The code iterates until obtain:
- **excitation equilibrium**:
  the slopes of **χ** *vs* log(*ε*(**Fe I**))
  and log(*EW*/λ) *vs* log(*ε*(**Fe I**)) where zero
- **ionization equilibrium**:
  log(*ε*(Fe I)) = log(*ε*(Fe II)).

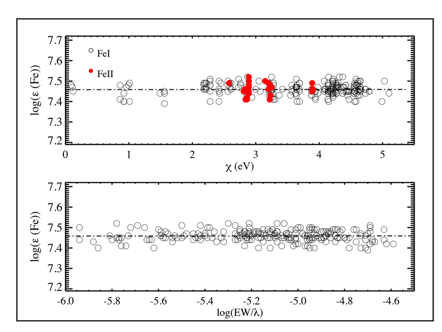
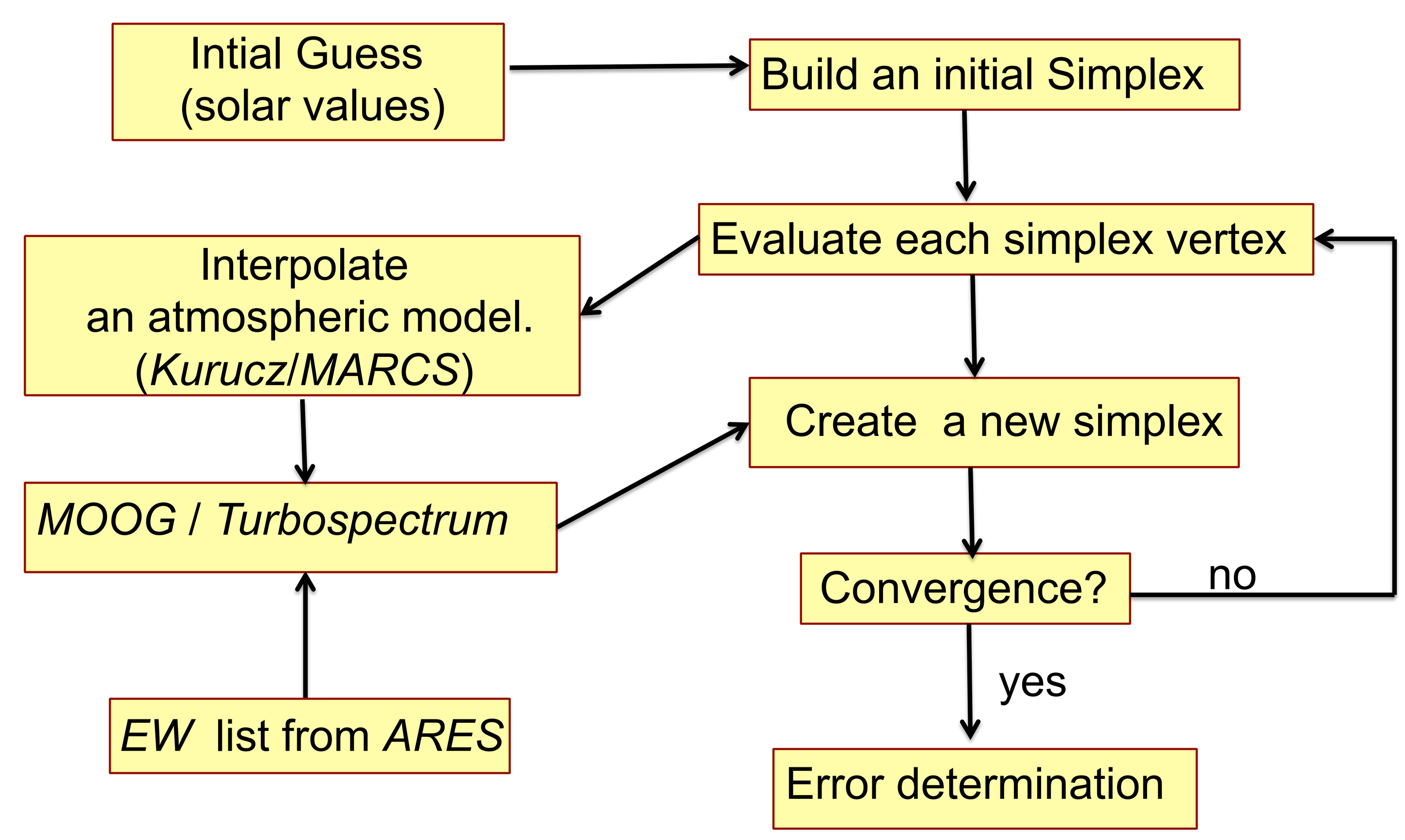


Figure: 6

- 2-σ rejection of Fe I and Fe II lines after a first determination of the parameters
- **Limitations**: spectral types F6 to K4, slow rotators, no veiling.

StePar internal workflow

StePar (Tabernero Montes, González Hernández, **2012**, A&A, 547, A13) employs the 2002 version of the *MOOG* code (Sneden 1973) and a grid of Kurucz *ATLAS9* plane-parallel model atmospheres (Kurucz 1993). The atmospheric parameters are obtained from the *EWs* of Fe I and Fe II lines iterating until the excitation and ionization equilibrium are fulfilled. *StePar* uses a Downhill Simplex method (Press et al. 1992) that minimizes a quadratic form composed by the excitation and ionization equilibrium conditions. Atmospheric parameters determined by *StePar* are independent of the stellar parameters initial-guess for the problem star, therefore we employ the canonical solar values as initial input. *StePar* can only deal with FGK stars from F6 to K4, also it can not work with fast rotators, veiled spectra, very metal poor stars or signal to noise ratio below 30. Optionally *StePar* can operate with *MARCS* models (Gustafsson et al. 2008) instead of Kurucz ATLAS9 models, additionally Turbospectrum (Álvarez and Plez 1998) can replace the *MOOG* code and play its role during the parameter determination.



Chemical abundances

Fe, the α-elements (Mg, Si, Ca, and Ti),
Fe-peak elements (Cr, Mn, Co, and Ni),
odd-Z elements (Na, Al, Sc, and V)
s-process elements (Cu, Zn, Y, Zr, Ba, Ce and Nd)

- EW method in a line-by-line basis with *ARES* code (Sousa et al. 2007).
- Line lists and atomic parameters from (Neves et al. 2009; González Hernández et al. 2010) and GES line list.
- Abundance analysis with *MOOG* (Sneden 1973) using our determined atmospheric parameters and a solar spectrum taken with the same instrumental configuration.

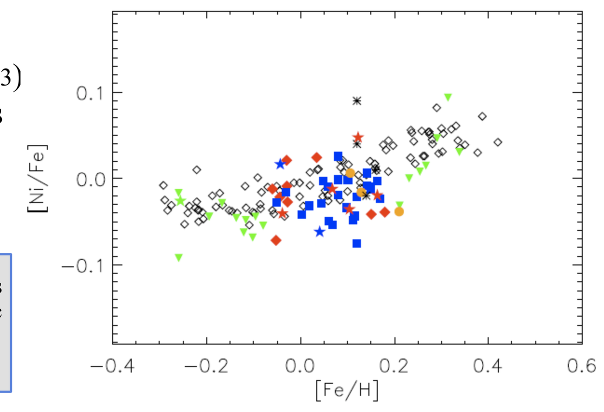


Figure: 7

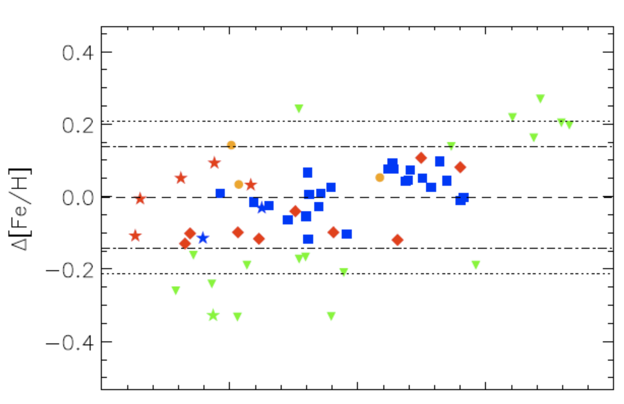
[Ni/Fe] vs [Fe/H] for our sample of stars in the Hyades Supercluster (coloured symbols) compared with the thin disc data (González Hernández et al. 2010, open diamonds). See Tabernero et al. (2012).

Differential Abundances and Chemical tagging

Elemental abundances for several chemical elements have been derived taking into account stellar parameters derived with ***StePar*** using high-resolution spectra of several samples of FGK stars possible members Stellar Kinematic Groups. **Differential abundances Δ[X/H]** are determined by comparison with a reference star known to be member of the analysed MG in a line-by-line basis. A first candidate selection within the sample has been determined by applying a 1-rms rejection for the Fe abundance results. In this way we have applied the ***chemical tagging*** method to test the common origin of these stars. We have already analysed the **Hyades Supercluster** (Tabernero et al. 2012, A&A, 547, A13, **Figs. 8 & 9**) and the **Ursa Mayor moving group** (Tabernero et al. 2014, A&A, in press, **Fig. 10**). See also Tabernero 2014, PhD Thesis, UCM.

Figure: 8

Δ[Fe/H] differential abundance vs T_{eff}. Dashed-dotted lines represent **1-rms** over and below the median for our sample, whereas dotted lines represent the **1.5-rms** level. Dashed lines represent the mean differential abundance. Red diamonds are our stars compatible to within 1-rms with the Fe abundance but not for all elements, blue squares and blue starred symbols are the candidates selected to become members of the Hyades Supercluster. Green downward-pointing triangles show no compatible stars. BZ Cet, V683 Per, and ε Tau Hyades cluster members stars are marked with orange circles.



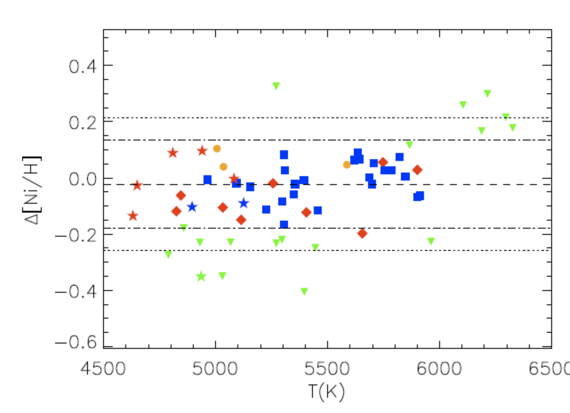


Figure: 9, Hyades Supercluster

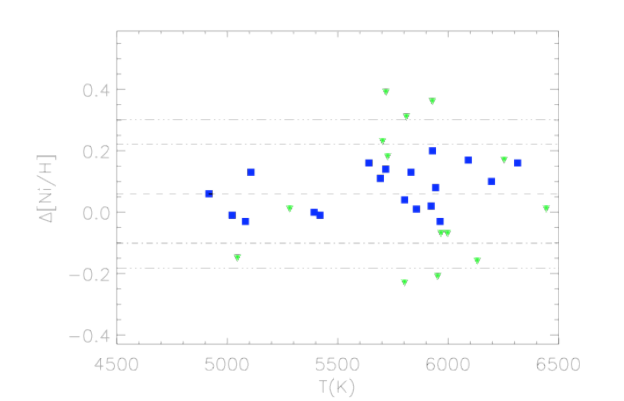


Figure:10, Ursa Mayor moving group

Kine-chemical analysis of the FGK stars observed with GES/UVES: Membership to the different MGs

- **Kinematic selection** of possible MGs members using the radial velocities provided by the survey, the astrometry available in the literature and an estimation of the distance using our derived spectroscopic stellar parameters (T_{eff}, log***g***, ξ and **[Fe/H]**).
- Detailed differential abundance analysis (**chemical tagging**).
- Additional information derived from the spectra (rotational velocities, Lithium abundance and chromospheric activity).

Name	S_{Tp}	T_{eff} (K)	log *g*	ξ (km/s)	[Fe/H]	[X/H]	Li	*vsini* (km/s)	V_r (km/s)	*UVW* (km/s)	Activity Hα,CaII…
HD 142267	G2V	5768 ±35	4.42 ±0.08	1.00 ±0.05	-0.38 ±0.03	…	…	…	…	…	…
HD 82885	G8V	5536 ±37	4.43 ±0.09	1.32 ±0.06	0.27 ±0.03	…	…	…	…	…	…
HD 3651	K0V	5282 ±45	4.35 ±0.10	1.16 ±0.08	0.11 ±0.03	…	…	…	…	…	…

Kine-chemical

Allowed us to confirm the membership to each MG and in this way discern between real physical structures of coeval stars with a **common origin** (debris of star-forming aggregates in the disk) and **field-like stars** (structures formed by resonance interactions, associated with dynamical resonances (bar) or spiral structure).

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