Chemically peculiar A/F stars in open clusters of the Milky Way – Results and needs

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Introduction

Chemically peculiar A stars have received much attention for abundance studies because of their slow rotational velocities which facilitate abundance determinations. In contrast, little is known about the chemical composition of normal A stars. Abundance variations were found from star to star among a few normal A field dwarfs (Lemke 1990, Hill & Landstreet 1993 and Hill 1995). The few stars analyzed definitely do not have a solar chemical composition. Hui-Bon-Hoa et al. (1997), Monier (2005), Gebran et al. (2008), Gebran & Monier (2008) and Gebran et al. (2009) found similar behavior for a larger number of A stars in a few open clusters.

Elemental radiative diffusion is the main process to account for anomalous abundances in Am stars. However turbulence, mass loss, accretion and meridional circulation may play a role as well.

Recent work by Royer et al. (2007) shows a pronounced double peaked distribution of rotational velocities for normal A stars. The peak at low $v_e$sini is not due to chemically peculiar stars as they have been removed from the sample.

Gaia's RVS and Astrometric Field will give us valuable information concerning the statistics of Am and A stars in the Galaxy. This will also broaden our knowledge concerning the formation and the evolution of these stars. Slowly rotating early A-type stars could originate from phenomena of angular momentum loss and redistribution undergone during pre-main-sequence phases.

The stars

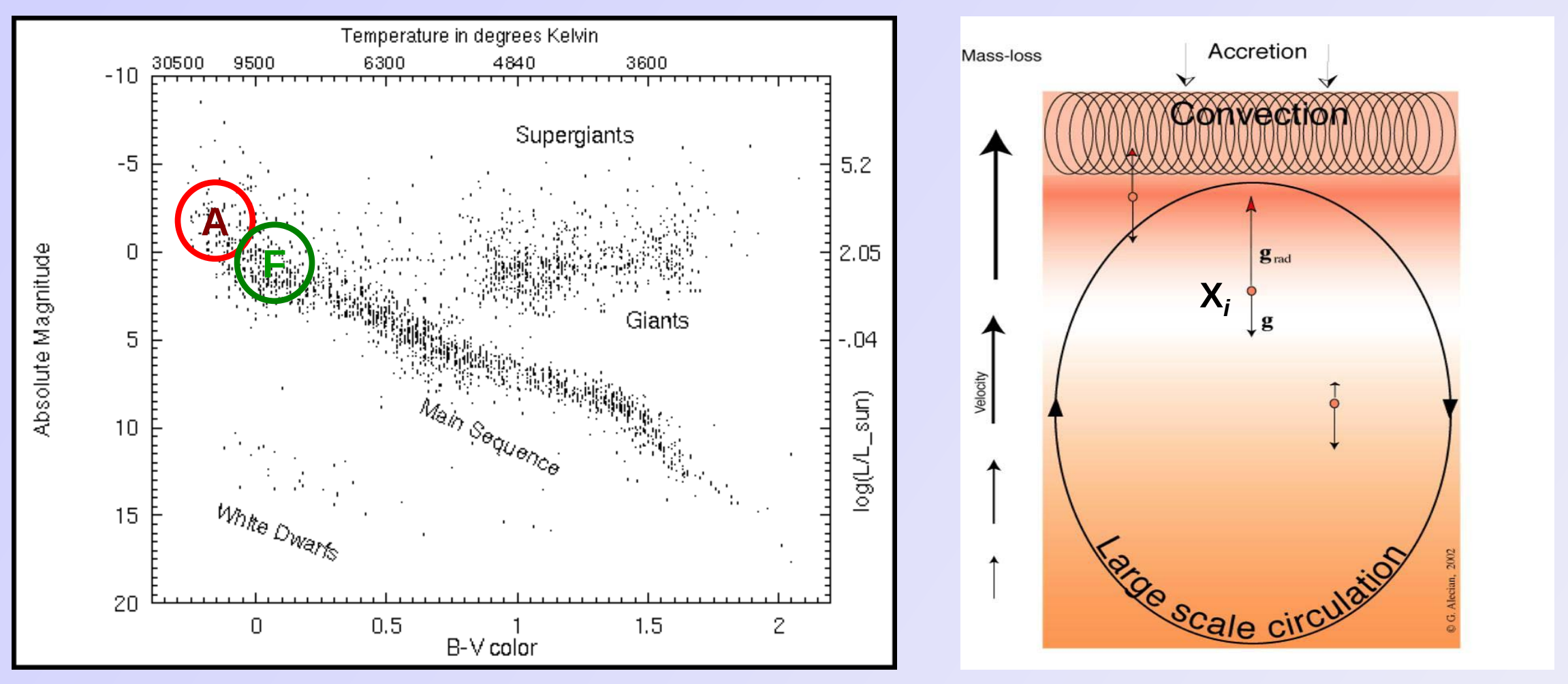


Fig. 1: Position of A and F stars in the HR diagram (left panel). Competing processes occurring in the envelope of the star (right panel)

	A	F
$T_{\rm eff}$ (K)	7100-10000	5900-7100
M ($M_\odot$)	1.6-2.4	1.1-1.6
R ($R_\odot$)	1.5-1.9	1.1-1.5
Envelope	Radiative	Convective

Am stars represent ~12% of A stars and are characterized by an overabundance of iron peak elements and heavy elements and/or underabundance of scandium and/or **calcium**. These stars are also characterized by a slow rotational velocity: <$v_e$sini> smaller than 50 km/s, and a high probability to be member of a binary or multiple system.
Abundance determinations of A and F dwarfs in open clusters and moving groups of known properties aim at elucidating the mechanisms of mixing at play in the interiors of these main-sequence stars. The derived abundances for these stars help us to set constraints on self-consistent evolutionary models of these objects including various particle transport processes. Indeed stars in open clusters originate from the same interstellar material (i.e. they have the same age and the same initial chemical composition) and as such are very useful to test the predictions of evolutionary models.

Abundances (surface) ➔ Understand the physics in the atmospheres and the interiors of these stars.
The abundances depend on the vertical distribution of the elements and thus depend on the hydrodynamical processes occurring in the atmospheres and the envelopes.

Two types of competing processes:
- Separation processes (gravitational settling/radiative)
- Mixing (micro-/macroscopic)

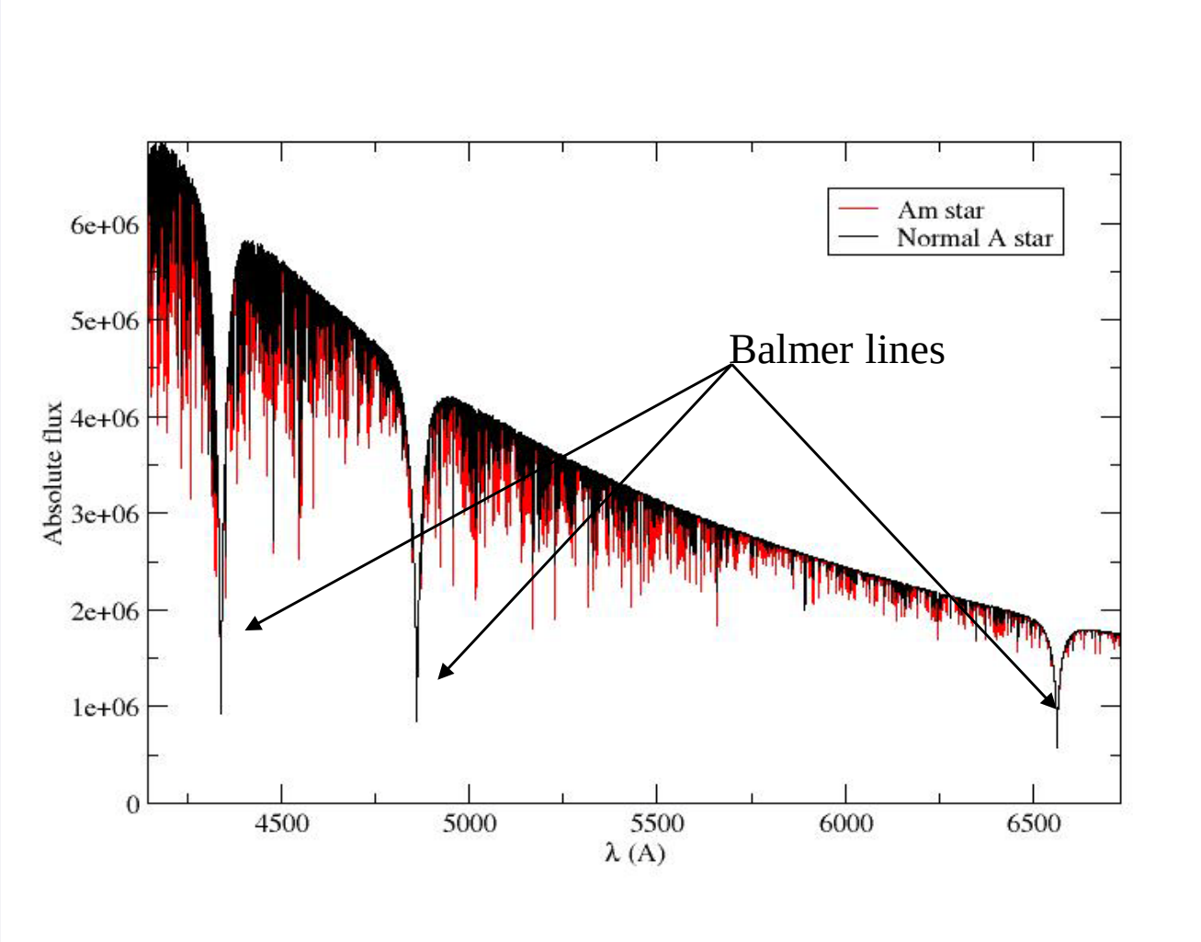


Fig. 7: Typical spectra of a normal A (black) and a peculiar Am star (red). The iron lines are enhanced with a factor of 10 in the Am star.

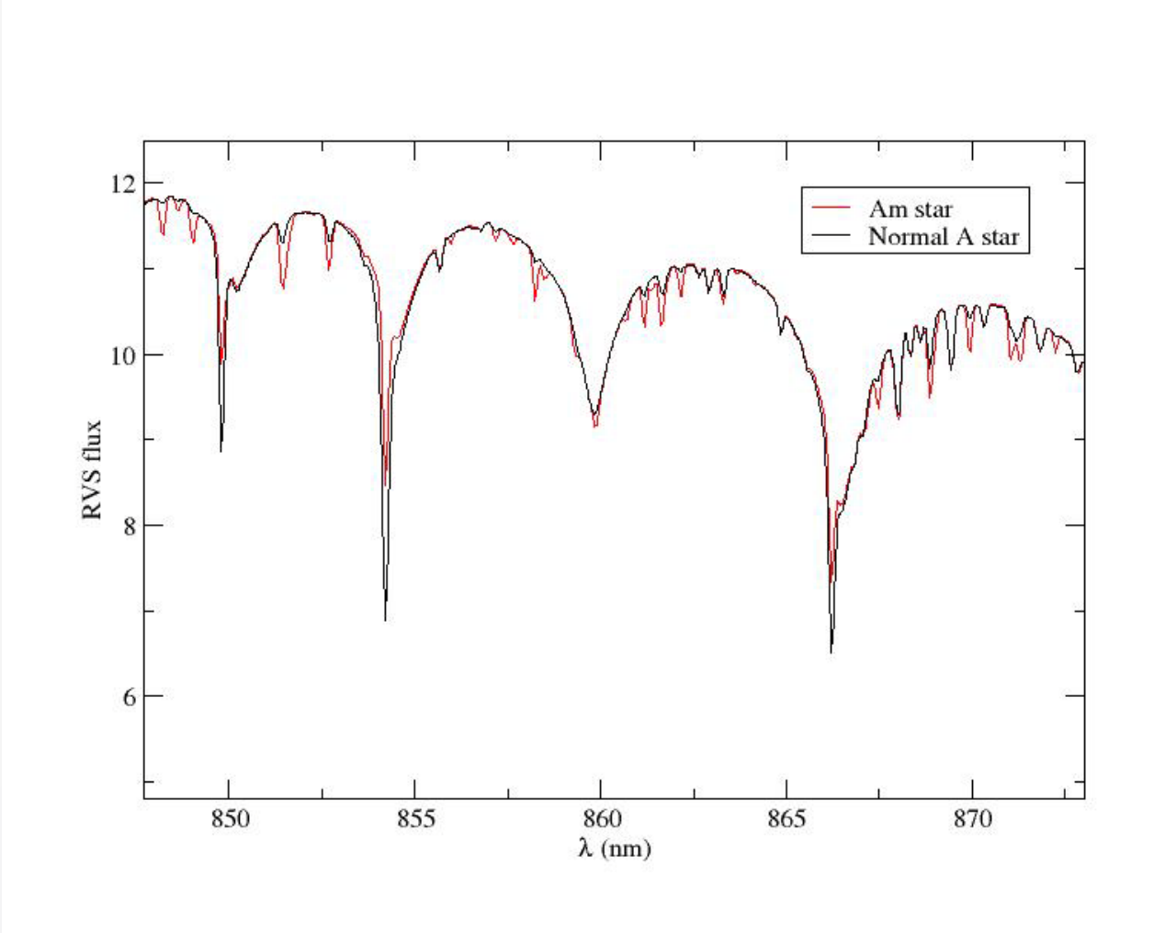


Fig. 8: Gaia RVS spectra at G=12 of the normal A type star and Am star displayed in Fig. 7. These spectra were computed using GOG5 data.

Rotational velocities

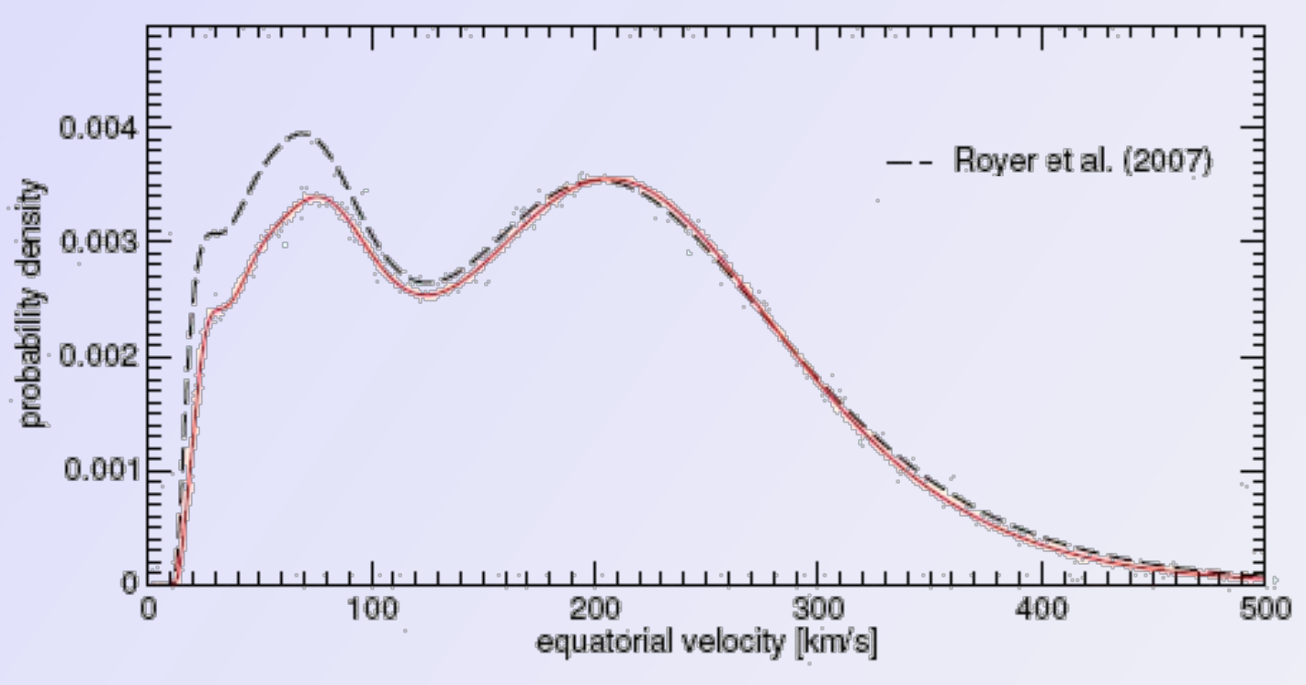
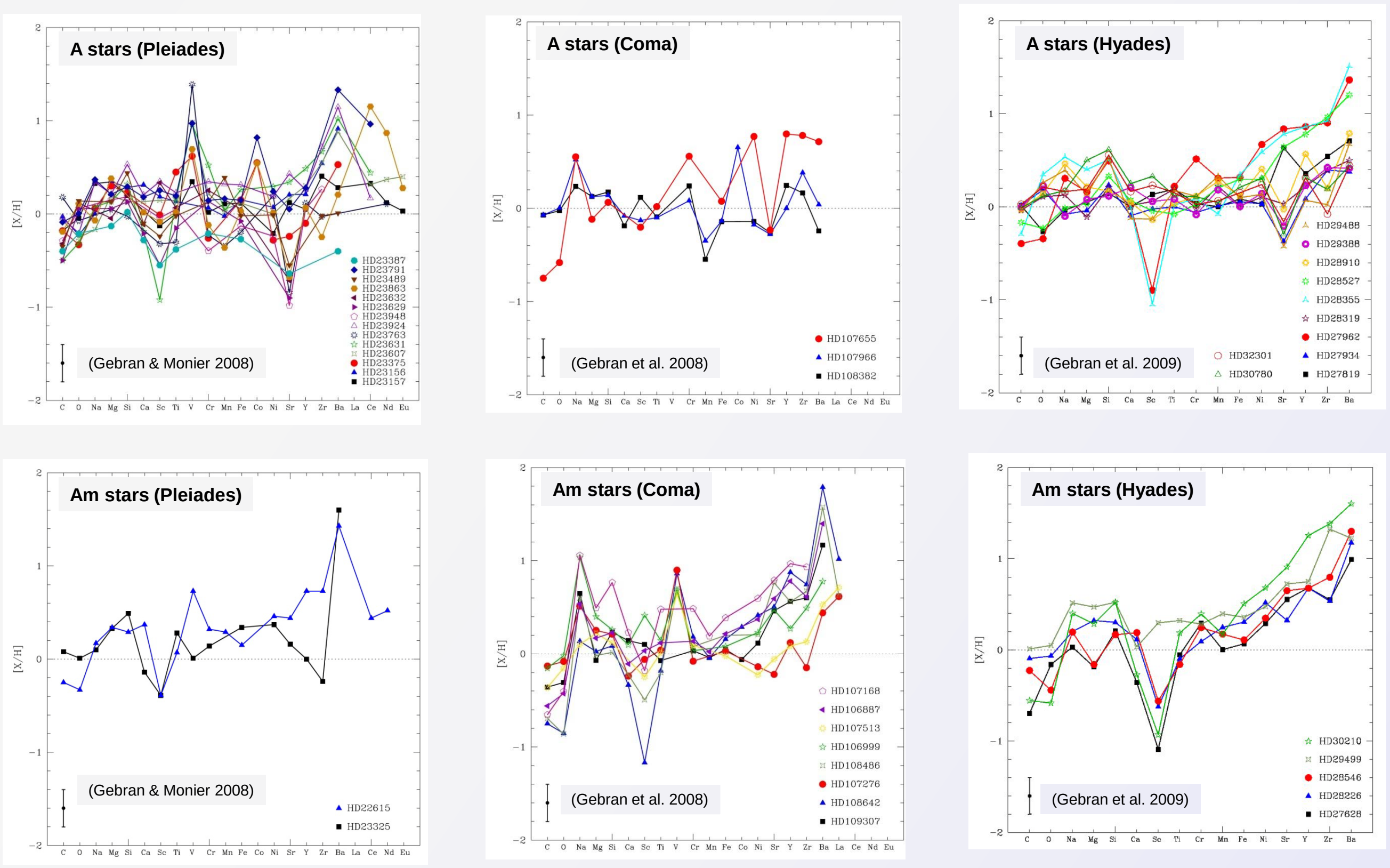


Fig. 2: Distribution of the true equatorial velocities for A0–A1 type stars from Royer et al. (2007) (dashed line) and the update of the distribution (solid line) when the newly detected chemically peculiar stars as well as the spectroscopic binaries are discarded. The updated distribution is normalized so that its high rotator mode fits the previous one. One can notice that the low rotator mode still persists.

Why are there slow rotators among normal A-type stars?
Are these slowly rotating stars young Am/Ap binaries?
Magnetic field? Ap(SrCrEu)?....

The observed rotation of stars undergoing the early main sequence evolutionary stages is the result of a long process of global angular momentum loss and redistribution inside the star. This process begins with the stellar formation phases which encompass the fragmentation of rotating clouds and the angular momentum losses required to solve the angular momentum problem through the initial magnetic braking and bipolar overflows. Further pre-main sequence processes of angular momentum exchange and/or magnetic locking with the accretion disc, angular momentum losses by stellar winds, and internal angular momentum redistribution phenomena shape the internal structural patterns and rotational characteristics of stars on the zero-age main sequence. Guthrie (1982) found that late B-type stars in clusters have bimodal rotational velocity distributions whereas the distributions are uni-modal for the same class of field stars. Bi-modality was also observed for the rotation of young solar mass stars in Orion (Herbst et al. 2001; Barnes 2003). Abt & Morrell (1995) found bimodal-like distributions among field A0–F0 objects on the main sequence where the component due to slow rotators was ascribed to the chemically peculiar Am and Ap stars. **Recently, Royer et al. (2007) found that the bimodal velocity distribution of field early A-type stars remains when chemically peculiar and binary stars are removed (see Fig. 2)**. They found that the A0–A1 type stars have a bimodal distribution of equatorial velocities v_e, contrary to previous findings (Abt & Morrell 1995). **In light of Royer et al.'s results the nature of the peak at low projected rotational velocities seems very much open again.**

Chemical properties



Abundance patterns of A/Am stars members of 3 open clusters: Pleiades, Coma Berenices and Hyades.

Main Results:

1- Large star-to-star variations in [X/H] among A stars (with respect to F stars)

2- No correlations between [X/H] and $T_{\rm eff}$ nor between [X/H] and $v_e$sin*i*

3- In young clusters, the number of Am stars is low with respect to the ones in old clusters.

Cluster	Age (*M*yrs)	Distance (pc)	[Fe/H]
Pleiades	100	140	0.06 dex
Coma Ber	450	95	0.07 dex
Hyades	620	46	0.05 dex

Gaia mission

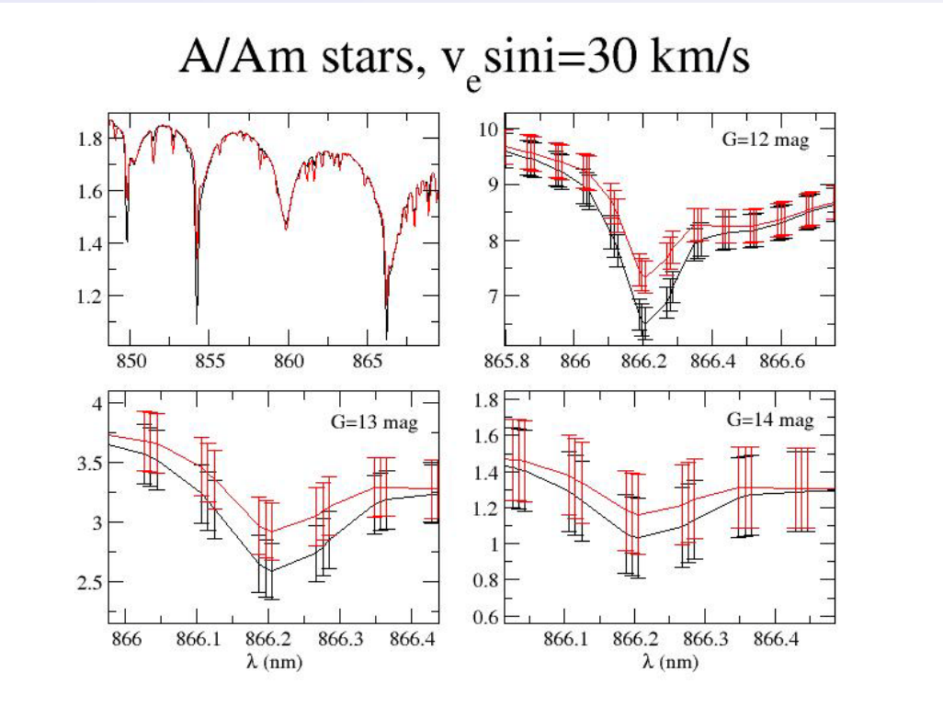


Fig. 3: RVS spectra of one A and one Am stars with effective temperature of 8000K and gravity of 4.0 dex computed using GOG cycle 5. The equatorial rotational velocity is 30 km/s which is typical for an Am star. The Am star has an overabundance of iron of about 10 times the solar one and an underabundance of calcium of about 1/10 the solar one. The end-of-mission error bars represent the flux errors as implemented in GOG cycle 5 simulator.

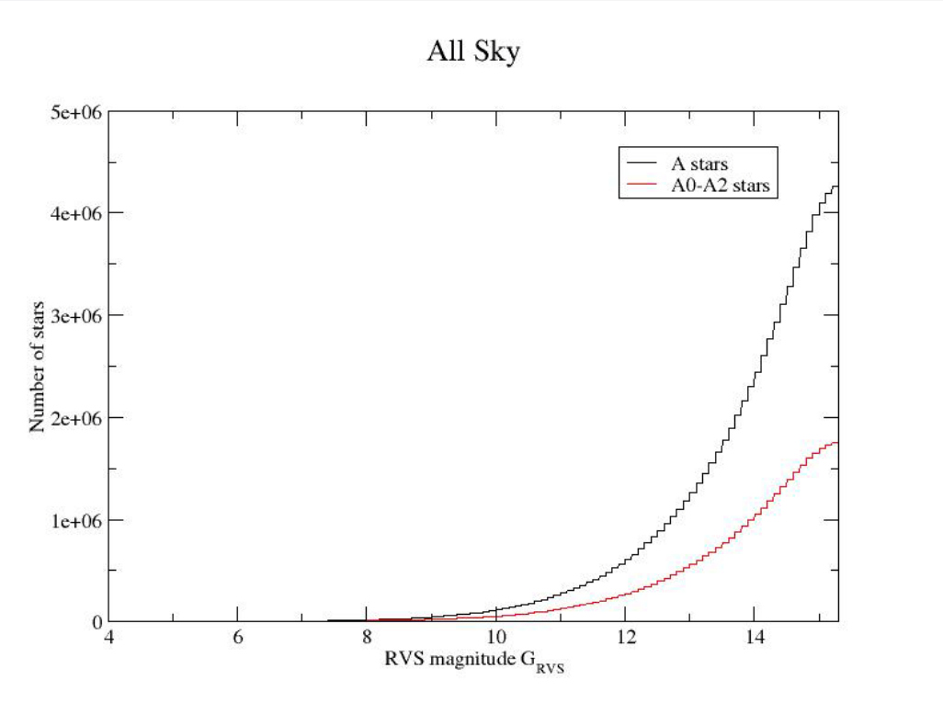


Fig. 4: G_{RVS} magnitude distribution of A-type stars (black line) and for A0-A2 stars only (red line) as derived with **GUMS** cycle 6.

GOG cycle 5 simulations of RVS spectra show that we can disentangle between a normal A star and an Am star up to magnitude G_{RVS} ~12-13 mag (Fig. 3). This is due to the difference between the intensities of the calcium line in normal A and Am stars. At this magnitude, we will have medium resolution spectra (R~11500) for more than 1 million A stars (Fig. 4). Among these stars, a group of Am stars (the one with low calcium abundances) can be identified. Once these stars are identified, on-ground observations will be needed to acquire high resolution and high signal-to-noise spectra in order to have a detailed elemental abundances determination. On the other hand, using the astrometry data, the distance to these stars and specially for **open clusters** will be determined with better accuracies. Then, using isochrones, we will have new estimation about the ages of the clusters ➔ more **constraints for the evolutionary models**.
For a magnitude V~12-13 mag and for an A type star with a temperature of 8000 K, we can go up to a distance of ~3 kpc. There are ~900 open clusters with d<3 kpc according to the WEBDA database. Most of these clusters are in the galactic plane as displayed in Fig. 5.

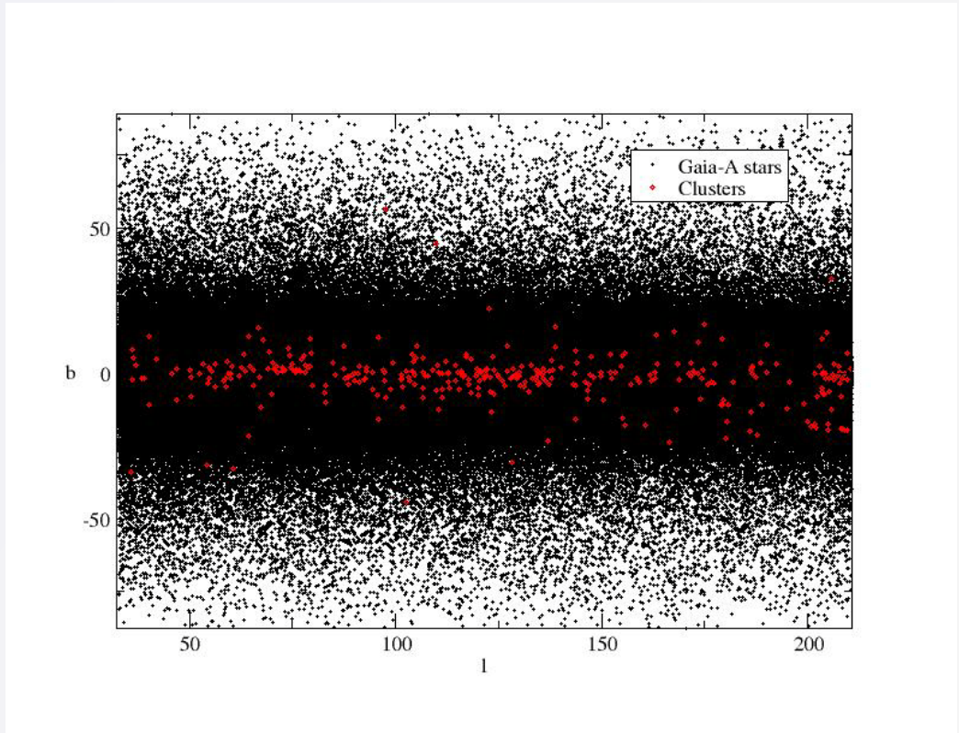


Fig. 5: Galactic coordinates of the clusters with a distance smaller than 3 kpc (red circles) and of the A stars simulated by GUMS with G< 16 mag (black circles). Galactic coordinates l and b are in degrees.

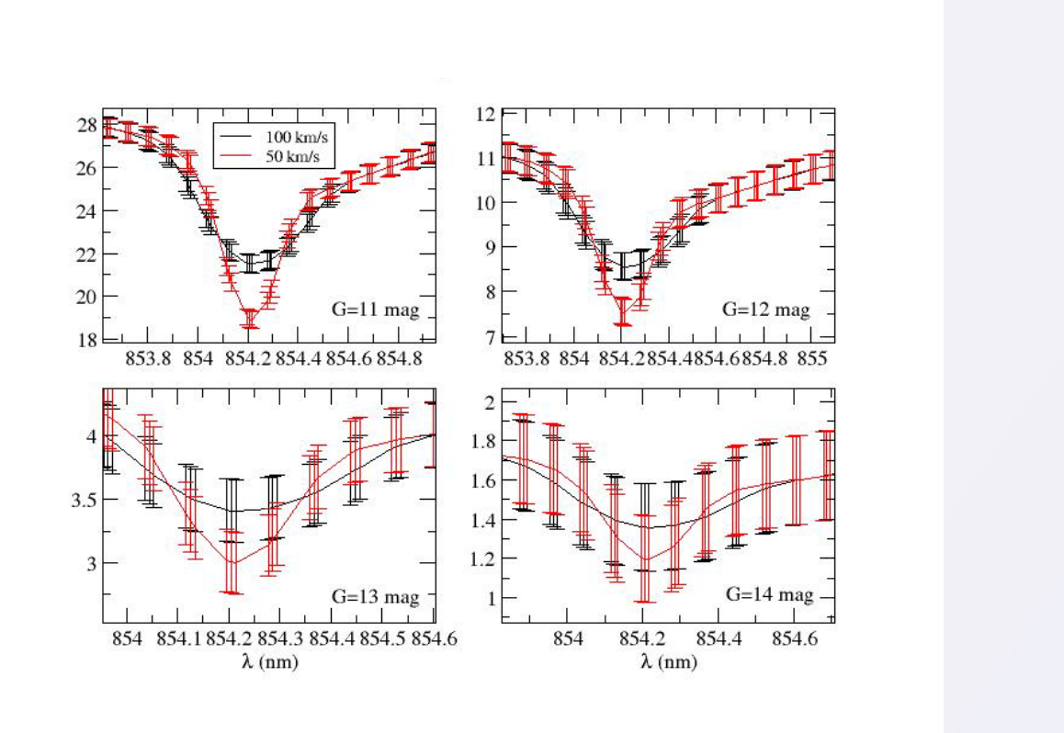


Fig. 6: RVS spectra of two A stars with different rotational velocities and different magnitude. The red spectrum is for the slow rotator at 50 km/s and the black spectrum is the fast one at 100km/s. These spectra are computed for a A0 dwarf star ($T_{\rm eff}$=10000 K and log*g*=4.00 dex). The end-of-mission error bars represent the flux errors as implemented in GOG cycle 5 simulator.

On the other hand, the RVS spectra of A type stars (in the field and in open clusters) will provide us, to a certain degree, information about the rotational velocities of the stars. The idea is to detect A0-A2 stars with slow rotational velocities (*ie*. $v_e$sin*i*<50 km/s). Once the star is detected, a check of the peculiarity should be done in order to remove the star from the sample. Fig. 6 displays two stars with the same effective temperature (10000 K) but with different $v_e$sin*i* (50 and 100 km/s).
For the end of mission spectra (~40 transits), an estimation of the accuracy on the rotational velocity for a slowly rotating A0-A2 star is around 20-30 km/s for G=12 (GAIA-C6-TN-OPM-PS-006-I). With these error bars, we can still disentangle between fast and slowly rotating A stars up to magnitude ~11-12 mag. This will enlarge drastically the statistics of A stars and specially slowly rotating A stars with respect to our current knowledge.
On-ground observations with high signal-to-noise will be needed in order to verify the non-peculiarities of the slow rotator stars and to analyze the line profiles of these stars. We aim at detecting peculiar profile due to the temperature gradient over the photosphere when the star is rapidly rotating. Then, we will be able to disentangle v_e and *i* using the high signal-to-noise (~300-400) spectra (Hill et al. 2004). Moreover, Reiners (2003) showed that in spectra of fast rotators the unprojected rotational velocity is measurable directly from the line shape in the Fourier domain. Both methods will be used to analyze the line profiles of the normal stars, and derive a direct distribution of equatorial velocities.

Acknowledgments: This work makes use of Gaia simulated data and we thank the members of the Gaia DPAC Coordination Unit 2 for their work. These data simulations were done with the MareNostrum supercomputer at the Barcelona Supercomputing Center – Centro Nacional de Supercomputacion (The Spanish National Supercomputing Center).

Evolutionary models

Chemical evolution of stars in the presence of microscopic diffusion and other mixing processes.

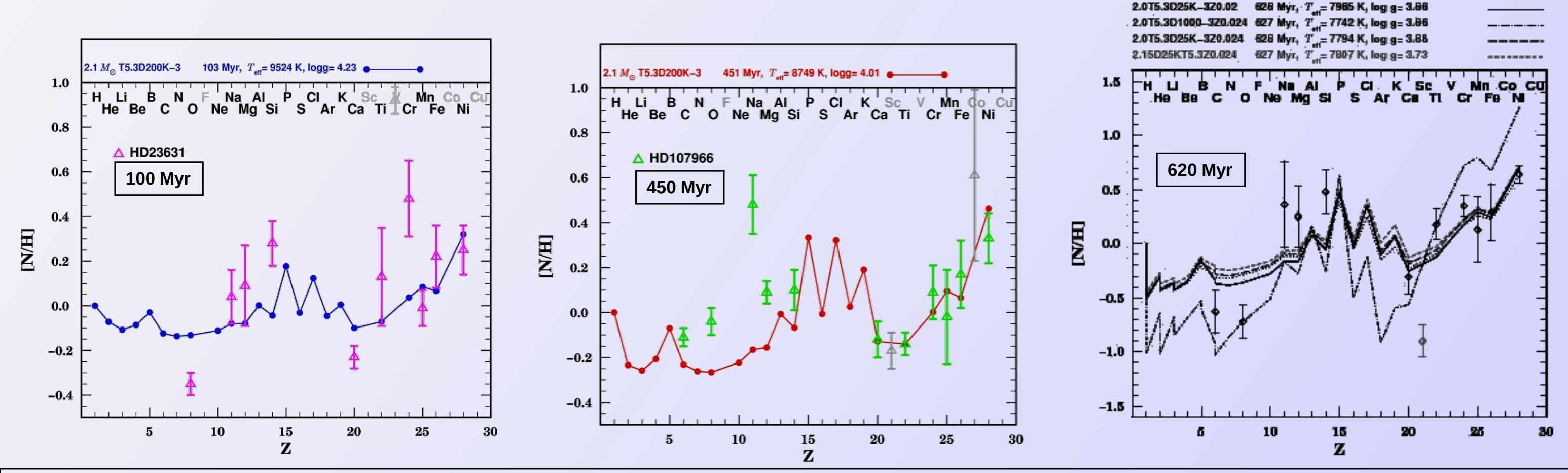
- Diffusion velocity: (Richer et al. 2000 and Richard et al. 2001)

$$v_{pi} = \underbrace{-D_{pi}}_{\text{Diffusion coefficient}}\left[\frac{\partial \ln c_i}{\partial r} + \underbrace{\left(\left(A - \frac{Z}{2} - \frac{1}{2}\right)g - Ag_{rad,i}\right)}_{\text{Balance between gravity and radiative levitation}}\frac{m_p}{k_B T} - k_T\frac{\partial \ln T}{\partial r}\right]$$

➔ In stars with similar fundamental parameters, the diffusion velocities have to be identical ➔ Same abundance anomalies?

These models contain a turbulent mixing coefficient in order to lower the effects of chemical separation and better fit the abundances of AmFm stars.

The aim is to follow, with the best model, the chemical evolution of an A star with time:
HD23631 (A2V, 100 Myr) ➔ **HD107966** (A3V, 450 Myr) ➔ **HD30210** (A5V/Am, 620 Myr)



Main conclusions:

- If microscopic diffusion was the only process at work within the radiative zone ➔ we do not expect star-to-star variations, especially in stars having close $T_{\rm eff}$ and log*g*.
- Disagreement between the observations and the models (None of the models can reproduce the observed patterns).

➔ There are hydrodynamical processes acting within the radiative zone of these stars that hinder the effects of microscopic diffusion (mixing processes/mass loss)

Summary

Gaia's contribution:
- **Detection of over ~4.000.000 A type stars for G<16**
- **Distance (π) and ages of open clusters (isochrones)**
- **Detection of calcium deficient Am type stars until G~13**
- **Detection of slowly rotating normal A0-A2 type stars until G~12**
- **G, G_{BP} and G_{RP} magnitudes, interstellar absorption for these stars**

Gaia's impact:
- **Understanding the physics occurring in the envelope and atmosphere of these stars. Constraints on the evolutionary models**
- **Distribution of the true equatorial velocities and process of stellar formation**
- **Variability**
- **Chemical evolution**

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