The Metallicity of Post-T Tauri Stars: A preliminary approach to the understanding of the metal enrichment of stars harboring planets

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Abstract.
The metallicity of young low mass Post-T Tauri stars in coeval associations is practically unknown. This work is the beginning of a systematic measurement of these metallicities based on high resolution spectra of low rotating members of these associations. Here, we present an application by examining the behavior of the Iron abundance with stellar mass and temperature of some members of an association 30 Myr old. This will test the possibility of explaining the high metallic content of stars with planets by means of injection of planetesimals during this early stage of evolution.

1. Introduction

A challenging and unexpected puzzle appeared with the discovery of exo-planets. A large majority of stars with planets (SWP) present an important excess of metallicity of the mean order of 0.25 dex (see review of Gonzales 2003). At present time there is not a clear explanation for this. The problem can be expressed this way: is metallicity the cause of planets, or are planets the cause of metallicity? The investigations are essentially based on the two following conceptions: primordial explanation - SWP are preferentially formed in natal clouds already metal enriched; and self-enrichment produced by accretion onto the star of different bodies deficient in H and He (e.g. asteroids, planets). Due to the potential diversity of mechanisms involving the self-enrichment or pollution processes, this explanation has received a large interest in the literature. The primordial scenario appears today, only as an explanation when the self-enrichment eventually fails. As we will see, the key of the self-enrichment process resides in the behavior of the stellar convective layers. In fact, the small con-
vective layer of a hot and more massive F star will preserve the new incoming material and will therefore be more easily detected. This is not the case for a cooler and less massive K star, in which the convective layer can be ten times larger. Other processes that can dilute the fresh material are mixing by rotation, mass loss, diffusion and gravitational settling; these are, however, less important than convection.

2. Our approach

The self-enrichment scenario has been invoked in the literature to occur after the star has arrived on the main sequence (MS). At this stage of evolution the star’s convective layers have attained a stable minimum configuration. However, here the accretion mechanism is likely to be inefficient, because few planetesimals are expected to fall into the relatively old MS stars. One way to solve this consists of invoking the infall of entire planets (this has been mentioned several times in the literature with few details except for the case of giant stars). This possibility seems, however, strange from a dynamical point of view. In fact, planets have stable orbits, even in the case of large eccentricities. Also, in this stage the stellar radius remains constant and the natural stellar mass loss, even modest will, on the contrary, provoke the planets to move away.

Our approach is different. It consists of invoking a maximum fall of planetessimals at the epoch when the latter were being formed and were probably accumulating to form terrestrial planets or the cores of giant planets. It is at that time that they were numerous and they were able to bombard the star due to an effect produced by internal migration of a young planet in the disk. This stage is supposed to be that of Post-T Tauri stars with ages between 10 and 40 Myr. For this, we choose an association of ~30 Myr because it is at this age that stars with masses between 0.9 to ~1.2 \( M_\odot \), which are the stars of interest here (see Figure 1), begin to establish their convective layers (see for example D’Antona & Mazzitelli, 1994). Our test will then consist of detecting the presence of the pollution signature in the form of an increase in metallicity for the hot and massive members of a coeval association.

2.1. The GAYA Association

During our Southern Hemisphere survey SACY (Search for Associations Containing Young stars) based on ROSAT X-ray sources, several associations were discovered (Torres et al. 2003; Quast et al. 2003). Two of these are important in this context; GAYA (Great Austral Young Association) with an age around 30 Myr and YSSA (Young Scorpio-Sagittarius Association) with an age of ~10 Myr. GAYA consists of two structures: GAYA1 (~30 Myr) which contains the members of the known associations Tucana (Zuckerman et al. 2001) and Horologium (Torres et al. 2000). GAYA 1 is located at a mean distance of ~45 pc. GAYA2, which appears to be somewhat younger (~20 Myr), has a mean distance of ~85 pc.

Here, we present the initial metallicity determinations of some low rotating members of GAYA1 and GAYA2. Their projected rotation velocities vsini are less than 40 km s\(^{-1}\) corresponding to a mean equatorial velocity of 20±5 km s\(^{-1}\) (de la Reza & Pinzon 2004). Some very few members of YSSA are considered
for comparison. To consider low rotation is important in order to avoid the blending of spectral lines, especially those of the scarce Fe II lines. All these measurements have been made using high resolution FEROS spectra having a large spectral coverage, obtained at the 1.52 m telescope at ESO.

2.2. Methodology

For each star, we have measured equivalent widths of nearly 50 Fe I lines and 11 lines of Fe II. Calculations were performed by means of usual LTE procedures. A constant microturbulence (see Table 1) has been maintained in all cases in order to disentangle the thermal effects. In fact, temperature is a good indicator of surface convection in FGK stars (Pinsonneault, DeFoy & Coffee, 2001). Note that these spectral types are those of SWP. The initial $T_{\text{eff}}$ values, before any iteration, have been obtained from observed $UBV(IR)_c$ photometry, using pre-MS models (Siess, Dufour & Forestini, 2000) for the corresponding age. Some gravity values were obtained from Hipparcos parallaxes when available.

| N | Name       | $T_{\text{eff}}$ (K) | [Fe/H] | log g | Li EW (mA) | Micro | $M/M_\odot$ | Assoc. |
|---|------------|----------------------|--------|-------|------------|-------|-------------|--------|
| 1 | HD47875    | 5833                 | 0.28   | 4.3   | 210        | 2.0   | 1.2         | GAYA   |
| 2 | HD987      | 5625                 | 0.31   | 4.4   | 201        | 2.0   | 1.0         | GAYA1  |
| 3 | T9217 0417 | 4675                 | 0.085  | 4.2   | 330        | 2.0   | 0.9         | GAYA   |
| 4 | HD81544    | 5437                 | 0.05   | 4.4   | 340        | 2.0   | 1.1         | GAYA2  |
| 5 | T8584 2682 | 5625                 | 0.12   | 4.1   | 245        | 2.0   | 1.1         | GAYA2  |
| 6 | HD26980    | 5773                 | 0.13   | 4.2   | 183        | 2.0   | 1.2         | GAYA2  |
| 7 | HD49855    | 5701                 | 0.17   | 4.4   | 233        | 2.0   | 1.2         | GAYA2  |
| 8 | HD222259   | 5714                 | 0.14   | 4.4   | 231        | 2.0   | 0.9         | GAYA   |
| 9 | HD55279    | 5373                 | 0.019  | 4.4   | 275        | 2.0   | 1.0         | GAYA2  |
| 10| HD202917   | 5631                 | 0.27   | 4.4   | 227        | 2.0   | 1.1         | GAYA1  |
| 11| T9243 1332 | 5833                 | 0.15   | 4.3   | 220        | 2.0   | 1.1         | GAYA   |
| 12| HD274561   | 5250                 | 0.15   | 4.0   | 270        | 2.0   | 0.9         | GAYA2  |
| 13| HD32372    | 5833                 | 0.21   | 4.4   | 215        | 2.0   | 1.2         | GAYA2  |
| 14| T7044 0535 | 5185                 | 0.01   | 3.9   | 300        | 2.0   | 1.1         | GAYA2  |
| 15| HD160682   | 5640                 | 0.25   | 4.4   | 260        | 2.1   | 1.5         | YSSA   |
| 16| T7415 0284 | 5630                 | 0.23   | 4.4   | 272        | 2.1   | 1.5         | YSSA   |

3. Results and Conclusions

In Figure 1 and Table 1 we present the results of our measurements together with theoretical enrichment models for MS stars by Pinsonneault et al. (2001). The three curves correspond to accretion of 1, 3 and 10 Earth masses of Fe for an initial solar abundance. Similar curves for initial values corresponding to [Fe/H] = +0.2 and [Fe/H] = −0.2 can be shifted up and down respectively. We notice a better adjustment if a solar initial value is chosen. This solar basis appears to be more appropriate to these young stars than the [Fe/H] =
Figure 1. Behavior of [Fe/H] abundances with stellar temperatures for some members of GAYA. Spectral types and mean masses are shown. The label numbers correspond to those of Table 1. The curves are the MS enrichment models of Pinsonneault et al. (2001) for three different Fe pollution accretions.

−0.2 value, which corresponds to the peak of the distribution of dwarfs in the solar neighborhood. Recently, Cody & Sasselov (2004) studied the long term evolution of polluted stellar models without rotation. The main effects are the expansion of the convective zone and downward shift of $T_{\text{eff}}$. In that study the effects of surface pollution require significantly larger amounts of the injected material than in the Pinsonneault et al. case. For instance, to replicate the 3 terrestrial masses of Fe in Figure 1, the calculations of Cody & Sasselov require 40 Earth masses of Fe! In any case, these models were introduced for comparison to the metallicity of SWP with temperature and no considerations were made on the eventual time variations of the pollution mechanisms. In the case of Pinsonneault et al. they showed that accretion produces a much too high Fe abundance for stars hotter than 6000 K. The recent work of Cody & Sasselov appears to have solved this point. Also, following other considerations, Murray & Chaboyer (2002) indicate that a smaller injection of Fe of the order of 3 to 6 Earth masses can be compatible with SWP metallicities.

Even if this preliminary exploration seems to show a positive indication of the pollution process at ∼30 Myr, we must confirm this trend by extending our measurements to more members of GAYA as well as field stars for comparison.
Also, we note that a more detailed model must be constructed for the first
100 Myr of evolution to interpret our observations. Especially, this model must
consider the dilution produced by rotation mixing. A first approach in this sense
has been made by Pinsonneault et al. who obtained a dilution of 0.22 dex for
a $\sim$6050 K star and 0.1 dex for a cooler star at $\sim$5040 K produced by rotation
with a mean velocity.

We will follow up on our measurements for other elements such as Li (see
Table 1), Si and Ni, which are refractory elements as Fe, and CNO volatile
elements. This will enable us to test the existence of “hot” (near the star) or
cool accretion scenarios (Smith, Cunha & Lazzaro, 2001).

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