Ionization states and abundances for various chemical elements in the atmosphere of 68 Tauri

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Introduction

68 Tauri (HD 27962) is a member of the Hyades open cluster (age about 700 Myrs). Previous analyses of the spectrum of HD 27962 have revealed a distinct under-abundance of scandium and over-abundances of the iron-peak and heavy elements. The last abundance analysis dates back from 2003 (Pintado & Adelman., 2003). The purpose of this study is to study the ionization ratios of as many elemental abundances as possible in the atmosphere of the star, from the spectrum secured by one of us (RM) with SOPHIE spectrograph, using the High Resolution (R =75000) mode, at Observatoire de Haute Provence. Using a synthetic spectrum generated by SYNSPEC49 and based on on an ATLAS model of 72 layers, we could also determine the abundances of several elements, including those defining the Am phenomenon. We also provide several new abundance determinations using updated accurate atomic data retrieved from the NIST database.

Observed spectrum

The observed spectrum of HD 27962 was obtained with the SOPHIE spectrograph at Observatoire de Haute Provence using the High Resolution (R =75000) mode. There are about 60 high resolution spectra of 68 Tauri in the SOPHIE archive.

Atmospheric parameters

The Table below lists the effective temperature and surface gravity we derived for 68 Tauri. We used Napiwotzki et al. (1993) UVBYBETA code and the observed uvby data of Hauck & Mermilliod (1998) for 68 Tauri.

	Teff	*log g*
68Tau	9025K ± 200K	3.95 ± 0.25 dex

Conclusion

The abundance analysis of 68 Tauri shows a significant under-abundance of Sc and over-abundances of V, Cr, Ni, Dy and Ba. These anomalies are characteristic features of hot Am stars. Pintado and Adelman (2003) obtained the abundances of 32 elements in 68 Tau. They used the same atmospheric parameters as in this work. Their results coincide with ours within $\pm 0.25 dex$ for Mg, Ni, Sc, Ca, Fr, Ti, and Ba. However, the abundances of Vanadium disagree, probably because of the difference in the *log gf* value of VII adopted in this work and in Pintado & Adelman (2003). Indeed we have used more recent updated *log gf* values from the NIST data base.

References

- Pintado, O. I.; Adelman, S. J, *Elemental abundance analyse The late B and early A stars vec xi Octantis, alpha Sextantis, and 68 Tauri*, Astronomy and Astrophysics, v.406, p.987-994, 2003
- David F. Gray, *The Observation and Analysis of Stellar Photospheres*, Cambridge University Press.
- http://simbad.u-strasbg.fr/simbad/sim-id?Ident=HD+27962
- https://www.nist.gov/pml/atomic-spectra-database
- Okyudo, Masami; Sadakane, Kozo, *Spectroscopic analyses of two A-type stars - Pi Draconis and 68 Tauri*, Astronomical Society of Japan 1990.

The ionisation profiles

In order to determine the abundance of a chemical element, it is preferable to analyse the absorption lines of the ion corresponding to the major ionisation state in the atmosphere. To determine this ionisation state, we used the Saha equation which yields the fraction between the number of ions in two successive ionisation states for an element versus optical depth:

$$\frac{n_j(\tau)}{n_{j-1}(\tau)} = \frac{\phi_j(T)}{P_e}$$

Where:

$$\phi_j(T) = 0.665 \frac{u_j(\tau)}{u_{j-1}(\tau)} T(\tau)^{\frac{5}{2}} 10^{\frac{-5040I}{kT(\tau)}}$$

Using the temperature profile $T(\tau)$ of the model atmosphere, the partition function (u) of each ions and the ionisation potential (I), we could plot the ionisation profiles of the various elements.
The Figure 1 represent the ionisation ratio of once ionised iron FeII versus the total number of neutral and ionised iron with depth in the atmosphere of 68 Tauri.

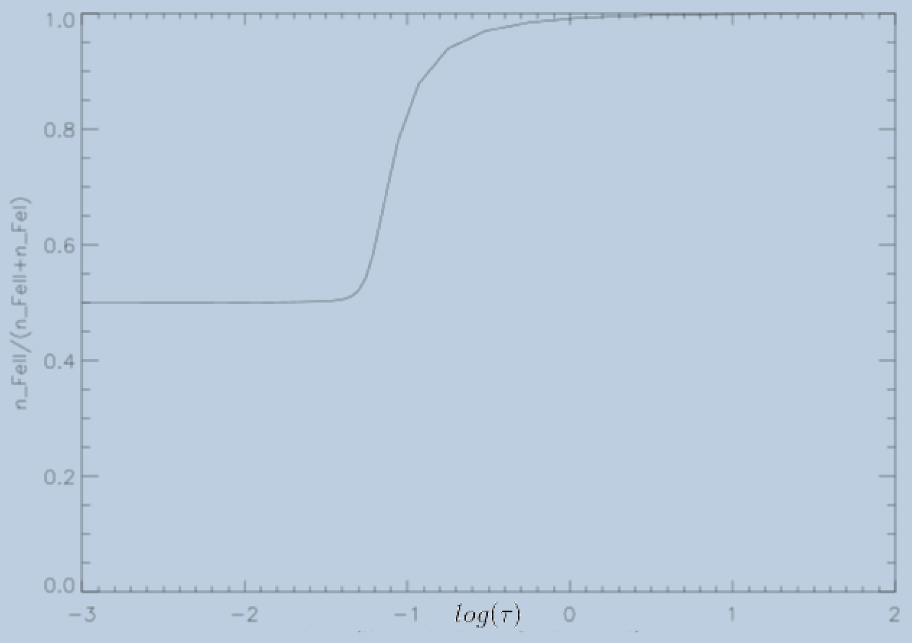


Figure 1: Ionisation profile of FeII

Abundances determination method and results

After preparing the input data: model atmosphere (ATLAS9 code, *Kurucz, 1992*), atomic and molecular line (NIST) and continuum opacities, we used the spectral synthesis code SYNSPEC49 (Hubeny & Lanz) to compute synthetic spectra for different abundances to determine the abundance which reproduces best selected absorption lines with reliable atomic parameters for each chemical element. This process requires several iterations to yield the chemical composition that best matches the observations. The figure 2 illustrates the application of this method to find the abundance of baryum in 68 Tauri.

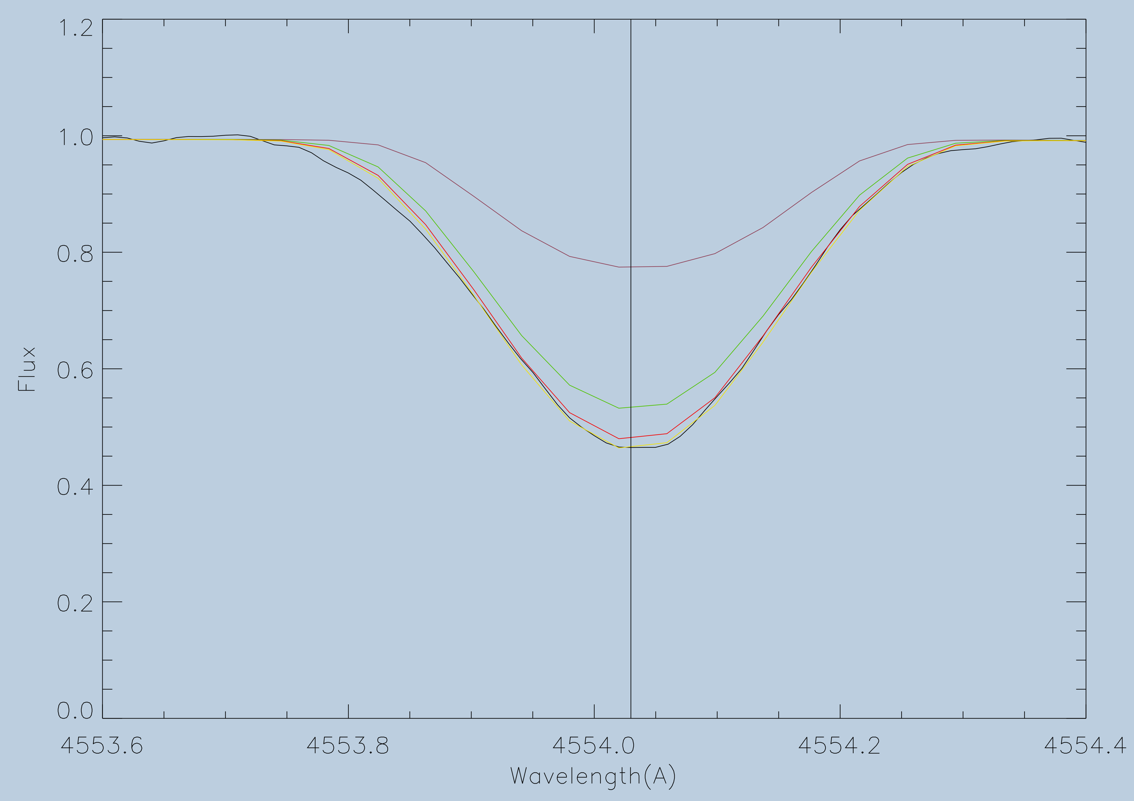


Figure 2: Iterating the calculation of the synthetic spectra (*coloured lines*) to arrive at the baryum's abundance value ($\epsilon = 23\odot$) that best matches the observation(*dark line*).

Using this method we could determine the abundance of 12 elements, our results are displayed in the table below, we compare our results with those found by the last two analysis.

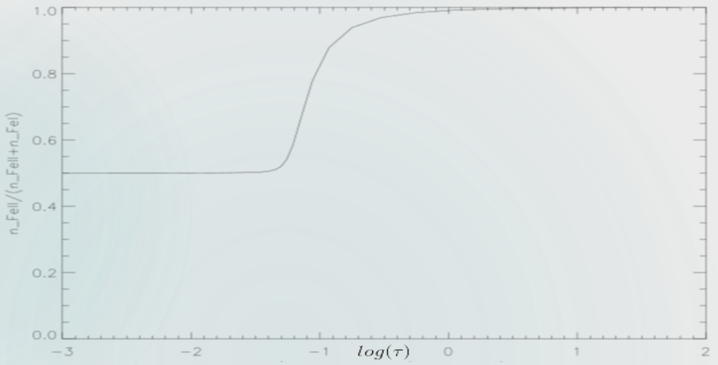
	O&S (1990)	Adelman (2003)	This work
Fe	0.81 $\odot$	1.51$\odot$	2.18$\odot$
Ti	1.31$\odot$	1.77$\odot$	2.68$\odot$
Cr	4.67$\odot$	3.98$\odot$	3.41$\odot$
Mg	1.41$\odot$	1.62$\odot$	1.50$\odot$
Ca	0.34$\odot$	0.88$\odot$	0.70$\odot$
V	5.37$\odot$	0.69$\odot$	4.42$\odot$
Ba	9.33$\odot$	21.87$\odot$	23.00$\odot$
Ni	0.75$\odot$	8.91$\odot$	8.50$\odot$
Sc	0.08$\odot$	0.12$\odot$	0.06$\odot$
Dy	$\times$	2.01$\odot$	1.60$\odot$
Sm	$\times$	2.10$\odot$	2.40$\odot$
Ce	$\times$	1.90$\odot$	1.71$\odot$

Observed spectrum

- SOPHIE spectrograph at Observatoire de Haute Provence
- High Resolution (R =75000) mode.

The ionization profiles:

- Saha equation : $\frac{n_j(\tau)}{n_{j-1}(\tau)}P_e = 0.665\frac{u_j(\tau)}{u_{j-1}(\tau)}T(\tau)^{\frac{5}{2}}10^{\frac{-5040I}{kT(\tau)}}$



Results :

- Significant underabundance of Sc 0,06⊙
- Overabundances of V, Cr, Ni, Dy and Ba (Iron peak and heavy elements)
- New abundance determinations using updated accurate atomic data retrieved from the NIST database

68 Tauri (HD27962) :

- Member of the Hyades open cluster (age about 700 Myrs).
- Am star
- The last abundance analysis : Pintado & Adelman, 2003

Atmospheric parameters

- Napiwotzki et al. (1993) UVBYBETA code
- uvby data of Hauck & Mermilliod (1998)
  - ❖ $T_{eff} = 9025\,K \pm 200$ K
  - ❖ $log\ g = 3,95 \pm 0,25\ dex$

Abundances determination method:

Method of synthetic spectra :

- ✓ Model of atmosphere (ATLAS9 code, Kurucz, 1992)
- ✓ Atomic and molecular line (NIST)
- ✓ Spectral synthesis code SYNSPEC49 (Hubeny & Lanz)
- Iterate on abundances to reproduce the selected absorption lines