Why are G and K Giants Radial Velocity Variables?

Michaela Petronilla Döllinger[1]
Luca Pasquini[1]
Artie Peter Hatzes[2]
Johny Setiawan[3]
Licio da Silva[4]
Jose Renan de Medeiros[5]
Oskar von der Lühe[6]
Leo Girardi[7]
Maria Pia Di Mauro[8]
Achim Weiss[9]
Markus Roth[6]

[1] ESO
[2] Thüringer Landessternwarte Tautenburg, Germany
[3] Max-Planck-Institut für Astronomie, Heidelberg, Germany
[4] Observatorio Nacional, Rio de Janeiro, Brazil
[5] Departamento de Fisica, Universidade Federal do Rio Grande do Norte, Natal, Brazil
[6] Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
[7] INAF – Osservatorio Astronomico di Trieste, Italy
[8] INAF – Istituto di Astrofisica Spaziale e Fisica Cosmica, Roma, Italy
[9] Max-Planck-Institut für Astrophysik, Garching bei München, Germany

G and K giants are low- and intermediate mass stars that have evolved off the main sequence. Almost 20 years ago they were shown to be Radial Velocity (RV) variables with amplitudes of up to 300 ms^{-1}. After several years of observations with ESO's Fibre-fed, Extended Range, Echelle Spectrograph (FEROS) at La Silla and with the Tautenburg 2-m telescope, we have found that three mechanisms (pulsations, planetary companions, rotational modulations) contribute to the RV variability of these stars.

In the last two decades, the dramatic increase in RV precision from several hundreds to a few ms^{-1} has led to the discovery of RV variability in stars previously thought to be constant. G-K giants are excellent examples of this transformation. These stars occupy a wide region of the cool portion of the Hertzsprung-Russel (H-R) diagram. Low- and intermediate-mass (1–5 $M_\odot$) stars that have migrated off the main sequence will spend some hundred million years in this region, either evolving along the Red Giant Branch (RGB), burning helium in the core (clump stars), or climbing the Asymptotic Giant Branch (AGB). In the past, many G-K giants were used as RV standard stars, but over 15 years ago it was discovered that several of them were RV variable. Subsequent investigations of a few objects have established that they show multiperiodic variability on large time scales, from one day to over 600 days.

Are all G-K giants RV variable? Why do these objects vary with such diverse periods?

The short-period (1–10 days) variations are certainly due to oscillations where pressure is the restoring force (p-mode oscillations). The long-period variations can be explained by the presence of stellar/substellar companions orbiting around the giant star. However, this is not the only possible explanation since the variations may also result from so-called rotational modulation. If a large surface inhomogeneity (for instance a starspot) passes the line-of-sight of the observer as the star rotates, distortions of the spectral line profile may result which will be detected as an RV variation with the rotation period of the star. The fact that RV variability in giants has higher amplitudes (50–500 ms^{-1}) than that commonly seen in main-sequence stars suggests that this may be related to some specific characteristics of these stars. For instance, giants have lower surface gravities and more extended atmospheres than main-sequence stars, and this may result in pulsations with higher amplitudes.

Although K giant RV variability can be complicated, it is possible to distinguish between these three mechanisms (pulsations, rotational modulation, or companions) by analysing other stellar parameters. For instance, the characteristics of stellar oscillations are expected to vary with stellar gravity. The presence of large inhomogeneities is expected to produce additional spectral features, such as the variation of chromospheric activity indicators in phase with the RV period and asymmetries in the line spectral shape (bisector). RV variations due to companions, on the other hand, should not produce changes in the line shape or spectral features measuring the level of chromospheric activity.

In October 1999 we started a spectroscopic survey of a sample of 83 G and K giants with the high-resolution (R = 48 000) spectrograph FEROS at the ESO 1.5-m telescope (1999–2002). Observations have continued on a less regular basis under Max-Planck-Gesellschaft (MPG) time on the 2.2-m MPG/ESO telescope at La Silla. The long-term FEROS RV accuracy at the 1.5-m telescope over these years is of 23 ms^{-1}, well within the instrument specifications of 50 ms^{-1}. The large spectral coverage of the spectrograph also allowed us to record chromospheric indicators such as the *H*- and *K*-lines of Ca II.

This survey covers a large part of the cool section of the H-R diagram, including a broad region of the red giant branch (RGB) from the stars of luminosity class IV to II, including RGB stars, and clump giants. This programme found 13 new spectroscopic binaries. The majority of the other stars in the sample (63 %) showed RV variability above the measurement error that seemed to increase with stellar luminosity. About 20 % of the sample was constant within the measurement accuracy.

Accurate distances to stars as measured by the HIPPARCOS satellite allowed us to derive absolute magnitudes, and in Figure 1 we plot the degree of variability observed (as measured from the scatter of the RV variations) versus absolute visual magnitude (from Setiawan et al. 2004). In this picture the stars with low-mass companions (planets or brown dwarfs) are indicated with filled symbols. Confirmed binaries have been excluded. The trends of increasing RV variations with absolute magnitude are clearly seen.

Rotational modulation of stellar surface inhomogeneities

In order to unveil the nature of the RV variations we measured the changes in the photospheric line shapes by measuring the line bisector. In addition, we measured chromospheric activity using the asymmetry of the Ca II K line core, which is an excellent chromospheric indicator (see e.g. Pasquini et al. 1988).

We found eight G and K giants whose RV variations correlate with changes in the asymmetry in the spectral line profiles (line bisectors) and with changes in the chromospheric Ca II K line emission core. The bisector velocity span versus radial velocity is shown in Figure 2 for one of these objects: HD 81797.

Several of these stars have large diameters, up to 20 milliarcseconds, which could be easily resolved by the ESO Very Large Telescope Interferometer (VLTI). They are therefore excellent candidates for VLTI observations, in which the effect of the surface inhomogeneities can be detected from detailed investigations of the fringe contrast as a function of wavelength.

AMBER, the near-infrared/red focal instrument of the VLTI, can use three telescopes (thereby yielding information on spot geometry in addition), with baselines providing up to 1 mas angular resolution, and a spectral resolution up to 10 000.

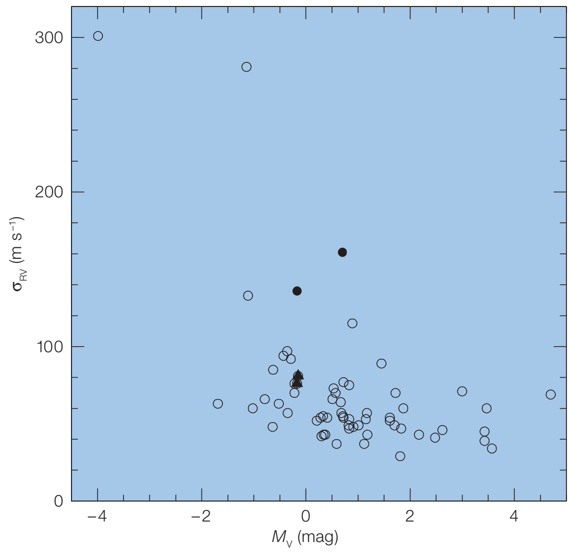

Figure 1: RV variability versus M_V for FEROS giants. The sample has been cleared of binaries. Stars which are candidates to host exoplanets are shown as filled triangles. Two stars hosting brown dwarfs are shown as filled circles. They stand out of the main "low level variation" group. A fraction of the stars shows no variability at the accuracy of 23 ms^{-1}. Spread and amplitude of the variations seem to increase for more luminous stars.

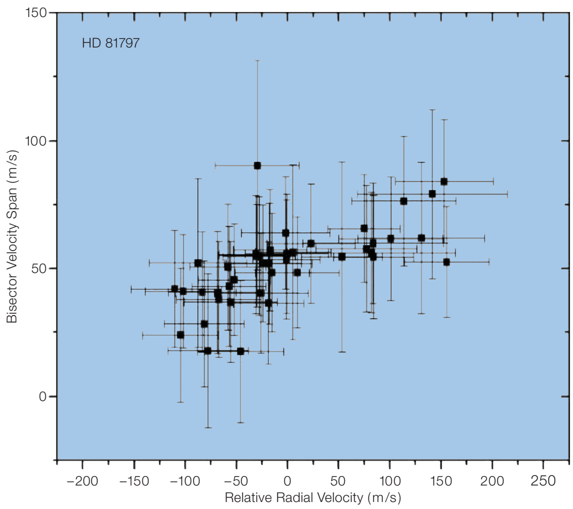

Figure 2: Bisector velocity span versus radial velocity for a K giant from our target sample. A clear correlation is present, indicating the presence of large surface inhomogeneities.

Low-mass companions

Doppler shifts of spectral lines caused by low-mass companions are neither expected to induce any variations in the spectral line shape nor to be accompanied by variations in stellar activity indicators. By measuring the projected rotational velocity of the stars and estimating their radius we can also derive the rotational period and check whether it differs substantially from the orbital period of the companion. This will further enable us to exclude rotational modulation as a possible cause of RV variations. We have so far identified three stars which possess companions (Setiawan et al. 2005).

These cool evolved stars lie in the clump region, where stars undergo core helium burning after having ascended the RGB. Clump giants spend 10–20 % of their main-sequence lifetime in this evolutionary stage. The comparison with theoretical evolutionary tracks allows a precise determination of the stellar mass, which we determined to be about 1.9 $M_\odot$.

This result is very interesting, because it shows that by analysing evolved stars we are able to explore planet formation in a different range of stellar masses than what is sampled in radial velocity surveys around main-sequence stars, which is limited to stars less massive than ~ 1.3 $M_\odot$.

Our high-quality FEROS data allow us to derive quite accurate metallicities for our sample stars. In addition to the metallicity [Fe/H], the effective temperature and surface gravity (log *g*) have been determined. Surprisingly, we found that the three stars proposed to host planets are not metal-rich. Studies of host stars of exoplanets around main-sequence stars show that these tend to have higher metallicites than stars that do not possess exoplanets (e.g. Santos et al. 2004). G-K giants seem to go against this trend. However, a much larger sample of planets harbouring K giant stars is needed to establish any trend with metallicity.

Pulsations

Asteroseismology is a powerful tool that uses stellar oscillations to probe the internal structure (e.g. sizes of convective cores) of stars and thus provides tests of stellar structure and evolution theory. Asteroseismology is expected to provide further information about stellar ages and masses in the near future. Although great advances have been made in helioseismology, asteroseismology is still in its infancy and it has been applied with success to some solar-type stars, white dwarfs, and rapidly oscillating Ap stars. More recently, precise stellar radial-velocity measurements with a precision of better than 1 ms^{-1} have discovered solar-like pulsations in η Bootis (Kjeldsen et al. 2003), a G0 subgiant. Current investigations have detected quite short periods in K giants. There exists evidence that oscillations as short as a few hours are possible. Frandsen et al. (2002) detected oscillation periods as short as 2–5 hours in the giant ξ Hya.

We also do not know the lowest amplitude for oscillations in K giants. The RV precision of FEROS may have just been insufficient to probe the lowest RV amplitudes, because about 20 % of our investigated sample showed no variations above the measurement error (23 ms^{-1}). Since the K giant α Ari (Kim et al., submitted) has recently been shown to be a pulsating star with a period of 0.84 day and an amplitude of only 20 ms^{-1}, our "constant" K giants may just be low-amplitude variable stars. We have indeed indications that some of our stars may have short-period variability.

In order to be effective for asteroseismology we must detect as many pulsation modes (periods) as possible (the so-called oscillation spectrum). This requires a higher radial-velocity accuracy than has been obtained with FEROS as well as better time sampling of the observations. Oscillation modes reach down to different depths in the stellar atmosphere depending on the period. If we detect many frequencies we can sound the interior of the star and determine stellar fundamental parameters such as its mass and evolutionary status. These can be used to directly test theoretical models.

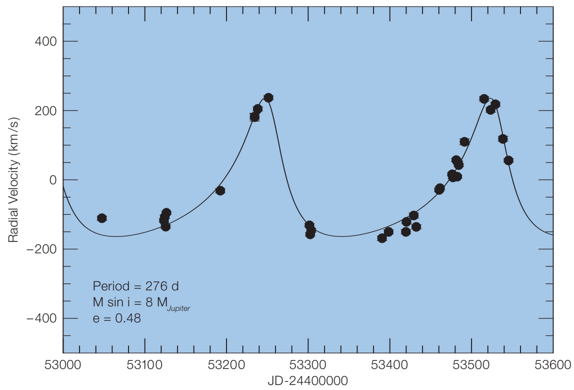

Figure 3: Example of long-term variability for one giant observed at the TLS observatory. The fit represents an orbital solution for an exoplanet companion with P = 276 d, e = 0.48 and M sin i = 8 $M_{Jupiter}$.

Beyond FEROS

We have shown that by determining the long-term and short-period RV variations in a sample of evolved stars we can learn about planet formation, surface structure, and pulsations in intermediate-mass stars. Our southern sample of G-K giants is sufficiently large to establish what fraction of G-K giants are short-period variable stars. Those showing significant night-to-night variations will form a group suitable for more detailed investigations by multi-site campaigns with increased time resolution and coverage. For some of our purposes a substantial increase in accuracy with respect to what has been obtained with FEROS at the 1.5-m telescope is needed; the high-resolution spectrograph HARPS, the High Accuracy Radial velocity Planet Searcher, at the 3.6-m at La Silla is the ideal instrument for this follow-up.

Work is also being undertaken in the northern hemisphere. In February 2004 we started a programme to observe a sample of 62 K giants from Tautenburg Observatory (TLS), in Germany. Precise stellar radial-velocity measurements were made using the echelle spectrograph of the 2-m telescope and an iodine absorption cell. We have continued our programme for these stars with observations typically made every other month. After 19 months of observations we have some preliminary results.

These show a typical RV precision of 3–5 ms^{-1} which is considerably better than our FEROS survey. So far 60 % of the sample shows short-period (night-to-night) variations. About 15 % of the sample exhibit long-term low-amplitude variations and several of these may be due to planetary companions. As an example, Figure 3 shows the long-term variability for one giant observed at the TLS observatory. The fit represents a solution with an exoplanet companion having P = 276 d, e = 0.48 and M sin i = 8 $M_{Jupiter}$.

In the TLS sample only 9 % of the stars seem to be constant. We interpret this as an evidence that most G-K giants indeed are RV variable and that the higher accuracy of the Tautenburg survey is the reason for the difference with the FEROS statistics. 11 stars (16 %) belong to binary systems.

In spite of our progress, we would still like to answer the important question: What makes a G-K giant pulsate and Radial Velocity variable?

References

Frandsen, S., Carrier, F., Aerts, C. et al. 2002, A&A 394, L5

Kim, K. M., Mkrtichian, D. E., Lee, B. C., Han, I., and Hatzes, A. P., A&A, submitted

Kjeldsen, H., Bedding, T. R., Baldry, I. K. et al. 2003, AJ 126, 1483

Pasquini, L., Pallavicini, R., Pakull, M. 1988, A&A 191, 253

Santos, N. C., Israelian, G., Mayor, M. 2004, A&A 415, 1153

Setiawan, J., Pasquini, L., da Silva, L., 2004, A&A, 421, 241

Setiawan, J., Rodmann, J., da Silva, L. et al. 2005, A&A 437, L 31