Stars as Suns: Activity, Evolution, and Planets
IAU Symposium, Vol. 219, 2004
A. K. Dupree and A. O. Benz, Eds.

VINCI / VLTI observations of Main Sequence Stars

Pierre Kervella

ESO, Alonso de Cordova 3107, Casilla 19001, Santiago 19, Chile

Frédéric Thévenin, Pierre Morel, Janine Provost, Gabrielle Berthomieu

Observatoire de la Côte d'Azur, BP 4229, F-06304 Nice, France

Damien Ségransan, Didier Queloz

Observatoire de Genève, CH-1290 Sauverny, Switzerland

Pascal Bordé

Observatoire de Paris, 5, pl. Jules Janssen, F-92195 Meudon, France

Emmanuel Di Folco

ESO, Karl-Schwarzschild-Str. 2, D-95748 Garching, Germany

Thierry Forveille

CFHT Corporation, PO Box 1597, Kamuela, HI 96743, USA

Abstract. Main Sequence (MS) stars are by far the most numerous class in the Universe. They are often somewhat neglected as they are relatively quiet objects (but exceptions exist), though they bear testimony of the past and future of our Sun. An important characteristic of the MS stars, particularly the solar-type ones, is that they host the large majority of the known extrasolar planets. Moreover, at the bottom of the MS, the red M dwarfs pave the way to understanding the physics of brown dwarfs and giant planets. We have measured very precise angular diameters from recent VINCI/VLTI interferometric observations of a number of MS stars in the K band, with spectral types between A1V and M5.5V. They already cover a wide range of effective temperatures and radii. Combined with precise *Hipparcos* parallaxes, photometry, spectroscopy as well as the asteroseismic information available for some of these stars, the angular diameters put strong constraints on the detailed models of these stars, and therefore on the physical processes at play.

1. Scientific rationale

The modeling of the MS stars benefits strongly of the additional constraint provided by the linear photospheric diameter. Thanks to high precision inter-

https://doi.org/10.1017/S0074180900181987 Published online by Cambridge University Press

ferometric measurements with the VLTI (Glindemann et al. 2000), equipped with the VINCI beam combiner (Kervella et al. 2000; Kervella et al. 2003a), we are in the process of producing a coherent list of angular diameters of nearby MS stars. The goal of our program is to refine our knowledge of their basic properties: age, metallicity, helium content, etc...

2. Interferometric observations

For all our measurements, we used the VLT Interferometer with its commissioning instrument, VINCI, a two telescopes beam combiner operating in the K band (2.0-2.2 μm). This instrument measures the squared visibility (V^2) of the interferometric fringes. V^2 is related to the angular diameter of the star through the Zernike-Van Cittert theorem. Fig.1 illustrates the V^2 measurements that we obtained on Sirius A, and the best-fit model that allowed us to derive its limb darkened angular size: $\theta_{\rm LD} = 6.039 \pm 0.019$ mas (Kervella et al. 2003c). Coupled with the Hipparcos parallax of $\pi = 379.22 \pm 1.58$ mas (Perryman et al. 1997), this translates into a radius of $R_\star = 1.711 \pm 0.013\,{\rm R}_\odot$. Among the other stars that we have measured (Table 1) figures Proxima (Ségransan et al. 2003), that is only slightly larger than Jupiter ($R_\star = 0.145 \pm 0.011\,{\rm R}_\odot$). The linear radii listed in Table 1 were deduced using the *Hipparcos* parallaxes.

Table 1. Physical parameters of the stars of our sample.

Name	Spect.	Mass ($M_\odot$)	$T_{\rm eff}$ (K)	$\theta_{\rm LD}$ (mas)	R ($R_\odot$)
Proxima	M5.5V	0.123 ± 0.006	3006 ± 100	1.04 ± 0.08	0.145 ± 0.011
GGJ191	M1V	0.281 ± 0.014	3419 ± 100	0.69 ± 0.06	0.291 ± 0.025
GGJ887	M0.5V	0.503 ± 0.025	3645 ± 100	1.39 ± 0.04	0.491 ± 0.014
GGJ205	M1.5V	0.631 ± 0.031	3894 ± 100	1.15 ± 0.11	0.702 ± 0.063
ϵ Eri	K2V	0.830 ± 0.100	5100 ± 100	2.14 ± 0.03	0.738 ± 0.010
α Cen B	K1V	0.907 ± 0.006	5250 ± 50	6.00 ± 0.03	0.863 ± 0.005
τ Cet	G8V	0.820 ± 0.030	5250 ± 100	2.05 ± 0.03	0.804 ± 0.010
α Cen A	G2V	1.100 ± 0.006	5750 ± 30	8.51 ± 0.02	1.224 ± 0.003
Procyon A	F5IV-V	1.420 ± 0.050	6530 ± 50	5.45 ± 0.05	2.048 ± 0.025
β Pic	A5V	1.750 ± 0.100	8200 ± 200	0.84 ± 0.06	1.732 ± 0.123
Fomalhaut	A3V	2.000 ± 0.200	8750 ± 200	2.22 ± 0.02	1.870 ± 0.032
Sirius A	A1V	2.070 ± 0.060	9900 ± 200	6.04 ± 0.02	1.711 ± 0.013

3. Modeling using the CESAM code

To retrieve the properties of these stars ($0.9\,{\rm M}_\odot$ and heavier) we use the CESAM evolutionary code (Morel 1997), constrained by the widest possible range of observations: spectroscopy, photometry, astrometry (for binary stars, giving the mass), interferometry, asteroseismology (when available). For the nearest stars, combining all these constraints together yields narrow uncertainties on the model outputs, in particular the age of the stars. This process benefits strongly of the interferometric constraint provided by the linear diameter. As shown on Fig. 2, the uncertainty domain defined for Sirius A in the HR diagram

https://doi.org/10.1017/S0074180900181987 Published online by Cambridge University Press

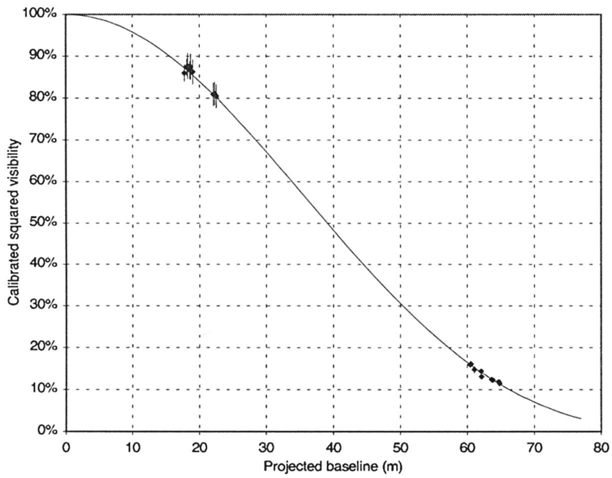

Figure 1. Squared visibilities of Sirius A measured with VINCI, and the adjusted limb-darkened disk model.

is reduced in surface by more than a factor 4, from this constraint alone, as compared to the classical parameters of temperature and luminosity. On this figure, the dashed rectangle delimits the uncertainty domain in luminosity and effective temperature, while the shaded area represents the uncertainty on the interferometric radius. The continuous line corresponds to a model with overshoot and the dashed-dot line to a model without overshoot, both with a mass of $2.12\,M_\odot$ and ages of roughly 200 Myr. The dashed line corresponds to a model with a mass of $2.07\,M_\odot$ and an age of 243 Myr. The modeling of this star is described in details in Kervella et al. (2003c).

For the very low mass stars (M dwarfs), the evolution is so slow that we currently cannot deduce precisely their properties by direct modeling of their evolution. However, we have compared the theoretical Mass-Radius relation predicted for this type of stars to our measurements (Ségransan et al. 2003), and the agreement is good even for very low mass stars ($\lesssim 0.5\,M_\odot$). This is an important indication that the equation of state used for these theoretical models is satisfactory, and that the source of the residual discrepancy lies probably in an imperfect modeling of the energy transport (convection and opacities).

4. Perspectives

One important limiting factor in the determination of linear diameters is the precision of the *Hipparcos* parallax. Though satisfactory in absolute, this precision can be insufficient compared to the interferometric angular diameter measurement. For α Cen A in particular, both error sources are of the same order of magnitude, $\pm 0.2\,\%$, and the parallax error contributes significantly to the final uncertainty on the linear size. In this context, very high precision parallaxes,

https://doi.org/10.1017/S0074180900181987 Published online by Cambridge University Press

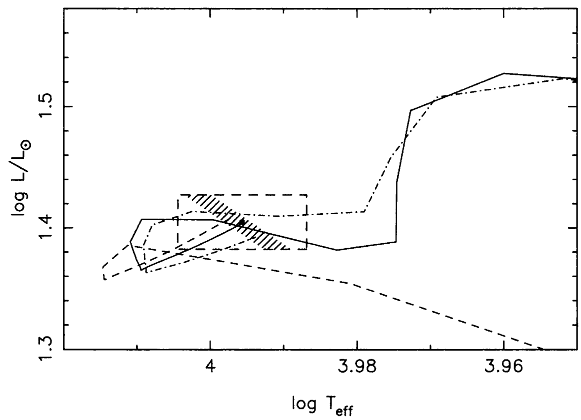

Figure 2. Evolutionary tracks of three models of Sirius A in the HR diagram, computed using the CESAM code (see text and Kervella et al. 2003c for details). The dashed rectangle delimits the uncertainty domain in luminosity and effective temperature, while the shaded area represents the uncertainty on the interferometric radius.

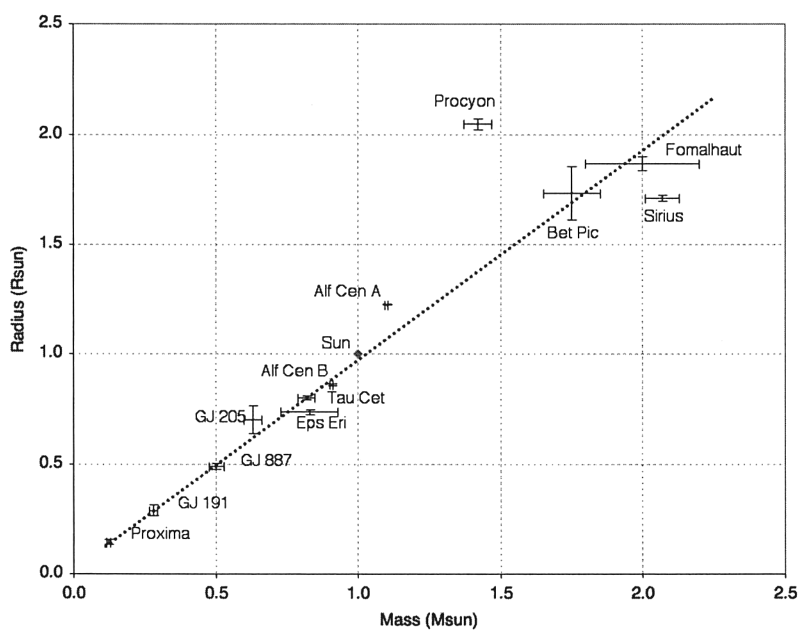

Figure 3. Mass-Radius diagram of the MS stars measured with VINCI/VLTI. The dispersion is due to the different evolutionary state of each star. α Cen A is already evolved and will soon leave the Main Sequence.

https://doi.org/10.1017/S0074180900181987 Published online by Cambridge University Press

beyond *Hipparcos*, are highly desirable. Currently, we rely on models of the atmospheric limb darkening to derive the true photospheric size of the stars, e.g. by Claret (2000). While their precision is relatively good (approximately $\pm 0.1\,\%$ of the total diameter), they start to be a limiting factor in the case of the highest precision diameter measurements. Our objective is to directly measure the limb darkening of nearby dwarf stars in order to avoid this modeling step. This implies that we sample the visibility function beyond its first minimum, and therefore presents particular observational difficulties. Aditionnally, we are in the process of bridging the gap in terms of spectral types between α Cen A and Sirius A through the observation of nearby F dwarfs.

References

Claret, A. 2000, A&A, 363, 1081

Di Folco, E., Kervella, P., Thévenin F., et al. 2003, IAU Symp. 219

Glindemann, A., Abuter, R., Carbognani, F., et al. 2000, SPIE, 4006, 2

Kervella, P., Coudé du Foresto, V., Glindemann, A., & Hofmann, R., 2000, SPIE, 4006, 31

Kervella, P., Gitton, Ph., Ségransan, D., et al. 2003a, SPIE 4838, 858

Kervella, P., Thévenin, F., Ségransan, D., et al. 2003b, A&A, 404, 1087

Kervella, P., Thévenin, F., Morel, P., et al. 2003c, A&A, 408, 681

Morel, P. 1997, A&AS, 124, 597

Perryman, M. A. C., Lindegren,L., Kovalevsky,J., et al. 1997, A&A, 323, 49

Ségransan, D., Kervella, P., Forveille, T., & Queloz, D. 2003, A&A, 397, L5

https://doi.org/10.1017/S0074180900181987 Published online by Cambridge University Press