CORAVEL RADIAL VELOCITY SURVEYS OF LATE-TYPE STARS OF THE HIPPARCOS MISSION

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ABSTRACT

Two large radial velocity surveys have been conducted during the last years with the two CORAVEL spectrometers. Up to now, more than 140 000 radial velocity measurements were obtained for some 40 000 late-type stars of the Hipparcos mission ($Sp \geq F5$). These surveys have been conducted at La Silla (ESO, Chile) on the 1.54-m Danish telescope and at the Haute-Provence Observatory (France) on the 1-m Swiss telescope. These ground-based complementary observations provide the third component of the space velocity, mandatory to most studies in Galactic dynamics. The cross-correlation functions measured for the stars not only give access to radial velocities but also to rotational velocities and metallicities. Not the least interesting part of these radial velocity surveys is the data obtained for the so-called Hipparcos 'survey'.

Key words: radial velocity; Hipparcos survey.

1. INTRODUCTION

Throughout the contributions to this meeting, an urgent need of radial velocities (V_r) for Hipparcos stars was expressed. The radial velocity information reveals itself to be fundamental from several points of view. First, the complementary third component of the space velocity very often proves to be mandatory to satisfactorily achieve most of kinematical studies. Many problems related to Galactic (determination of the halo parameters, etc.) or local ($\rho_\odot$, k_z, etc.) kinematics just remain inconclusively solved without the radial velocity information. Another aspect of the radial velocity relevance resides in its capacity of detecting binaries. As expressed by Dommanget: *Double stars are trouble stars*. Each time a star sample has to be 'cleaned up', V_r measurements bring an irreplaceable help to remove the binaries that are undetectable by astrometric methods because of the small separation between the components.

Very well aware of the restriction in the use of the Hipparcos data induced by the lack of radial velocities, several members of the Hipparcos consortium, in collaboration with radial velocity providers, set up a new consortium to get, from the ground, the complementary radial velocities for a large number of southern stars of the Hipparcos mission through an ESO key-programme. Thanks to its efficiency in rapidly getting accurate radial velocities, the CORAVEL spectrovelocimeter (Baranne et al. 1979) mounted on the 1.54-m Danish telescope in La Silla (Chile) proved to be the adequate instrument to reach this goal.

A subgroup of the radial velocity consortium members running the twin northern counterpart of the CORAVEL spectrograph installed on the 1-m Swiss telescope at the Observatoire de Haute-Provence (OHP, France) decided to complete the northern complementary part from France.

2. SAMPLE SELECTION

The star sample selection was driven by several contingencies related to the instrumentation and available observational time. Due to the large number of stars followed by the Hipparcos satellite, it was not possible to observe the complete Hipparcos sample within a reasonable period of time. Moreover, the main restriction for the sample selection was inherent to CORAVEL itself. To get the radial velocity, an optical cross-correlation (cc) over more than 1500 spectral lines is performed between the star spectrum and a physical mask optimized for a K2 giant (Arcturus). Because of the strong stellar rotation for early-type stars (and the paucity of absorption lines in their spectra), the technique becomes ineffective for most stars with spectral types earlier than $\sim$ F2–F5 (except for metal-rich stars).

The sample to be measured in radial velocity was thus selected to be the so-called Hipparcos 'survey'

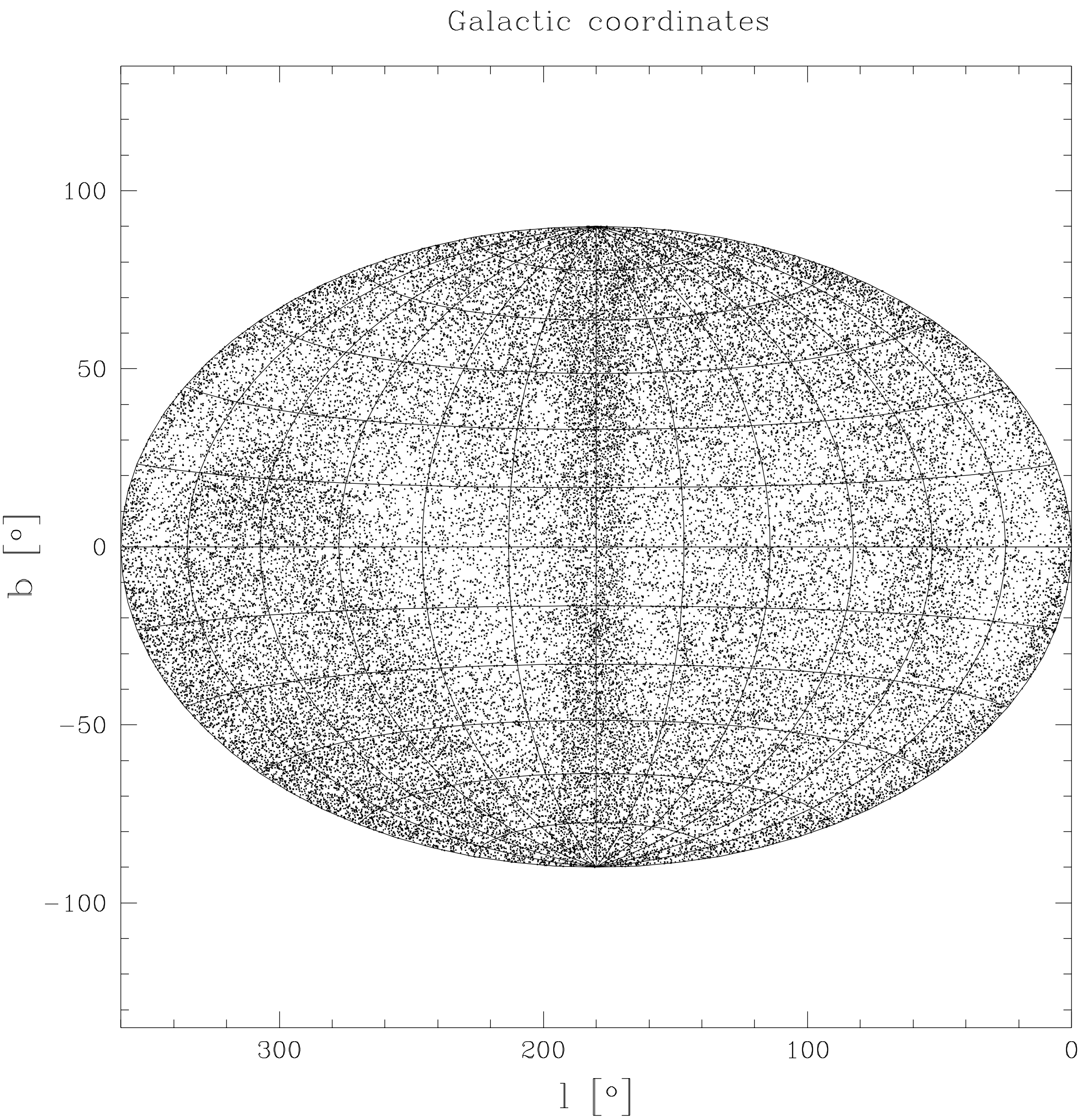

Figure 1. Repartition on the sky of the selected sample of stars measured in radial velocity with the CORAVEL *spectrovelocimeters.*

for stars with a spectral type later than $F5$. Several other particular programmes requiring radial velocities for stars not in the Hipparcos were added to the sample. Together the northern (22 349 stars) and southern (22 914 stars) sets include 45 263 stars. These numbers are summarised in the first part of Table 1.

An overall view of the distribution on the sky of the selected stars, in galactic coordinates, is given in Figure 1. In addition to the homogeneous coverage of the Hipparcos, some of the special programmes clearly stand out in the diagram (e.g. stars in the meridional plane, the Galactic poles).

3. OBSERVATIONAL STRATEGY

In order to get a fair rate of binary detection at a minimum observational cost, two short measurements per star were planned with a time interval (ΔT) of at least one year between the observations. We will see in Section 5 that, in practice, this time interval proved to be rather around 2–3 yr. Simulations adapted to our case show that two measurements per star separated by a time interval of two years lead to a detection rate of binaries larger than 50 per cent (Section 5).

Stars with at least two earlier measurements in the CORAVEL database were considered as completed and were therefore not reobserved.

Table 1. Summary of the sample sizes, observational effort and present status of the surveys. Columns 3 and 4 provide the numbers of selected (N_s) and effectively observed (N_o) stars, respectively. Column 5 gives the total number of measurements ($N_{\rm mes}$) for stars with at least one observation. In columns 6 and 7 are indicated the numbers of stars with 0 or 1 observation and finally, the last column gives the completeness rate of the samples (percentage of stars with the 2 required measurements).

Hemisphere	Tel. time [yr]	N_s selected	N_o observed	$N_{\rm mes}$	N_* $n=0$	N_* $n=1$	Completeness rate [%]
S	1	22 914	21 892	70 012	1 022	508	93.3
N	1.5	22 349	17 363	72 626	4 239 + 747	6 133	77.7
Total		45 263	39 255	142 638			

4. RESULTS AND COMPLETENESS

A huge observational effort has already been accomplished by now to get the desired radial velocities. Table 1 summarizes the sample sizes, the dedicated telescope time and the present status of the programmes.

For the southern part of the sample, about 6 months of telescope time were attributed by ESO to the key-programme, to which about 6 additional months from the Danish telescope-time were granted. All stars were observed at least once and the programme has been completed (observation + reduction) for 21 384 stars among the 22 914 selected ones. The overall completeness is thus of 93.3 per cent. The remaining stars consist of candidates with only one observation (508 stars, 2.2 per cent) or for which no or no satisfactory cross-correlation function was found (1022 stars, 4.5 per cent). Most of the stars with zero or one measurement belong to a faint complement of fast-rotating F2–F5 stars, difficult to handle with CORAVEL (see Section 2), for which no additional observations are planned.

In the northern hemisphere, things are going more slowly because of the smaller size of the telescope mirror and the worse seeing situation. These restrictions imply longer typical exposure times than at La Silla. However, we estimate that more than 1.5 yr of telescope time was already dedicated to the observation of Hipparcos stars. Up to now, only stars with HD numbers (18 110 stars among 22 349, 81 per cent of the sample) are on the observation list. The faint complement (4 239 stars) has not been observed yet. Among the HD stars, 747 are still to be observed or present no convincing cross-correlation dip and 6 133 have only one measurement, which gives a global completeness rate of 77.7 per cent for the northern sample.

The overall completeness of the two programmes is already very good. The picture displaying the coverage on the sky of the effectively observed stars would be indistinguishable from Figure 1 and is thus not included here.

The large sustained observational effort put into these programmes is illustrated as well by the distribution of the time intervals (in days) between the first and last observations (ΔT) of each star. These distributions for the northern and southern samples are presented in Figure 2. Typical values of ΔT are between 2 and 3 yr.

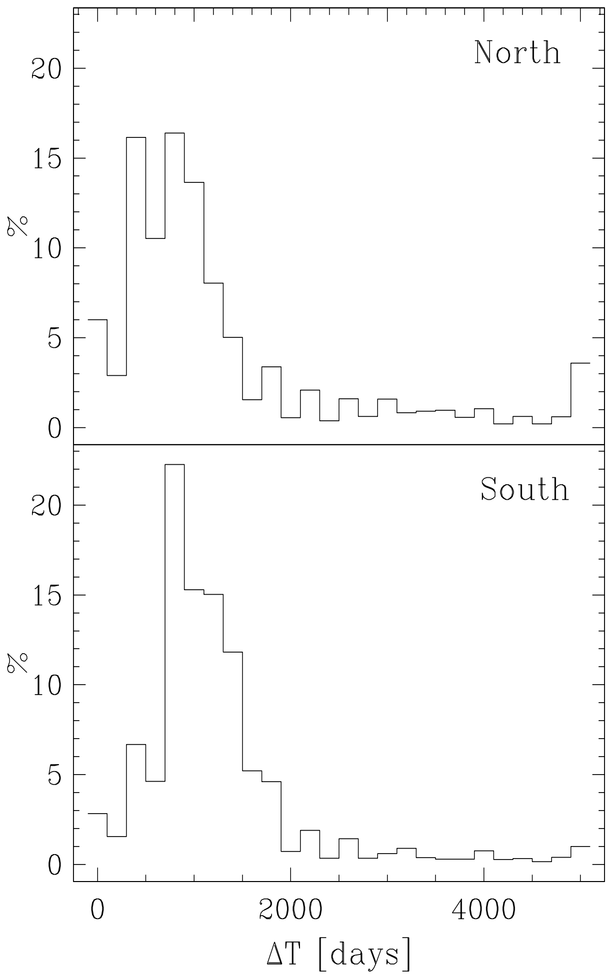

Figure 2. Distributions of the time intervals (in days) between the first and last observations, for the northern and southern samples.

5. QUALITY OVERVIEW OF THE SURVEYS

Despite of the short exposure time required for the observations, the quality of the obtained measurements is very satisfying. This is illustrated in Figure 3 displaying the distribution of the individual measurement uncertainties ε_i for the combined northern and southern samples. The typical value of ε_i is 0.3 $\mathrm{km\,s^{-1}}$ and 84 per cent of the observations provide radial velocity estimates with an accuracy better than 0.5 $\mathrm{km\,s^{-1}}$ (better than 1.0 $\mathrm{km\,s^{-1}}$ for 95 per cent of the measurements). In addition to the CORAVEL reliability, the quality of the results is also due to the high visual brightness level of the stars of the surveys.

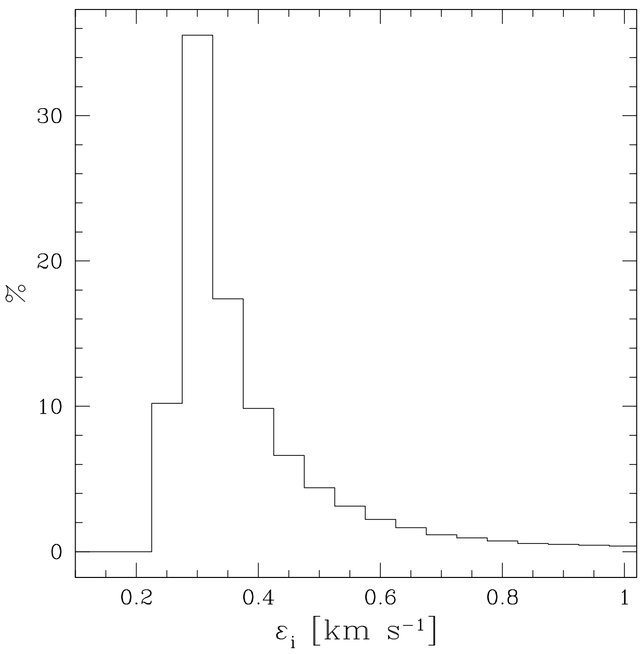

Figure 3. Distribution of the errors ε_i on the individual measurements of the radial velocity, for the combined northern and southern samples.

The right-hand tail of the distribution in Figure 3 is populated by a few faint stars and mainly by stars with large rotational velocities making the cross-correlation profile larger (see Section 6) and thus the radial velocity determination less accurate.

The estimate of the error on a CORAVEL measurement depends on several parameters: photon count (magnitude of the star), scintillation (integration time) and instrumental effect. An efficient tool for checking how well the errors are controlled is provided by the χ^2 statistics. For a star with N independent measurements of the radial velocity $V_{r,i}$, the χ^2 variable is defined as:

$$\chi^2 = \sum_{i=1}^{N} \left(\frac{V_{r,i} - \overline{V_r}}{\varepsilon_i} \right)^2 \qquad (1)$$

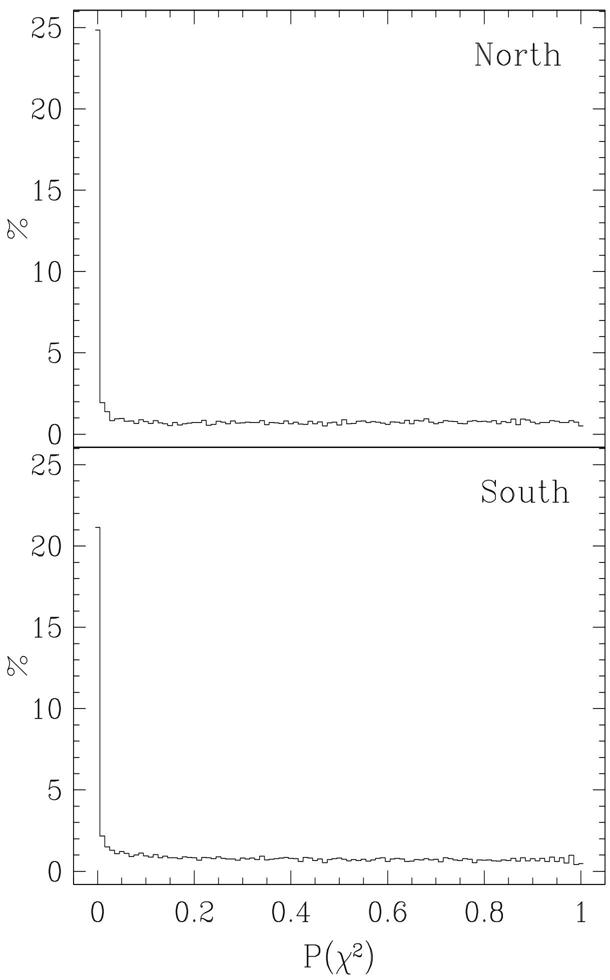

Figure 4. Distributions of the χ^2 probabilities of the stars in the northern and southern samples.

The probability of the χ^2:

$$P(\chi^2) = \frac{1}{\sqrt{2},\,(\frac{1}{2})} \int_{\chi^2}^{\infty} z^{-\frac{1}{2}} \exp{(-\frac{1}{2}z)} dz \qquad (2)$$

gives then the probability that the distribution of the uncertainties (ε_i) of the N measurements comes from a Gaussian distribution i.e. that it is purely statistical. In case $P(\chi^2) = 0$, the radial velocity variation is due to non-statistical (physical) causes such as binary motion or stellar atmospheric processes (pulsation, jitter). If the errors are correctly estimated, non-zero $P(\chi^2)$ values distribute themselves according to a uniform distribution.

The $P(\chi^2)$ distributions for the stars of the northern and southern samples are displayed in Figure 4. The flat right-hand side parts of the diagrams show that the errors are well controlled for the considered samples. The peaks at $P(\chi^2) = 0$, mainly due to binary stars, indicate a binary detection rate of about 25 per cent. This value is compatible with simulations of detection completeness (performed in the same way as in Raboud 1996 but for $N = 2$, $\Delta T = 2$ yr, a mass interval of $[0.1 - 1.5 M\odot]$ and a limit amplitude for binary detection of 1.5 $\mathrm{km\,s^{-1}}$) combined with the observed duplicity frequency among solar-type stars (Duquennoy & Mayor 1991).

6. SUPPLEMENTARY AVAILABLE INFORMATION

In addition to the desired radial velocities, the use of the CORAVEL spectrographs provides useful complementary information on the observed stars.

As already mentioned in Section 2, the CORAVEL spectrovelocimeter measures the radial velocity using a cross-correlation technique involving 1500 spectral lines of neutral and ionized iron-group species from the spectrum of Arcturus. The obtained cross-correlation function is almost exactly Gaussian in most cases. An example (cc-dip + a fitted Gaussian) for an observation of HD 190 is given in Figure 5.

The measured cross-correlation function reflects, in an average way, the information contained in all the spectral lines used. In particular, the position of the cross-correlation dip gives the average shift in wavelength (i.e. in radial velocity) of the lines with respect to a fixed reference (Baranne et al. 1979). Its width provides an indicator of line broadening that can be related to stellar rotation (Benz & Mayor 1981, 1984) or atmospheric turbulence (Bersier & Burki 1996), depending on the type of stars considered. Finally, the surface of the cross-correlation dip is related to the abundance in elements responsible for the spectral lines and consequently to the metallicity of the stars (Pont et al. 1997).

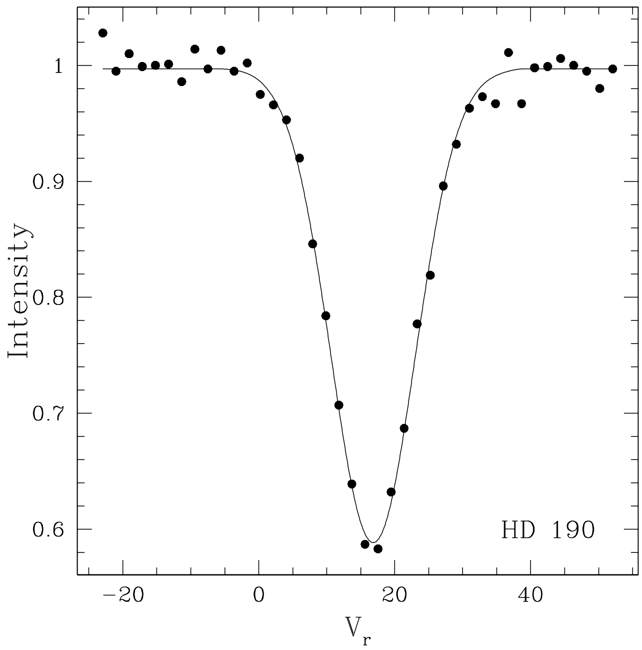

Figure 5. Cross-correlation function obtained for an observation with CORAVEL *of the star* HD *190 (points) and the corresponding fitted Gaussian profile (solid line).*

7. SCIENTIFIC PROGRAMMES

Even if the observing programmes are not fully completed yet, several studies in progress take advantage of the information supplied by the CORAVEL measurements in combination with the Hipparcos data. A few presentations, in this volume, describe preliminary results of some of these studies. They are just briefly mentioned here.

The radial velocity as third component of the space velocity is used in kinematical studies including several thousands of stars with CORAVEL measurements: In *Kinematics of disk stars in the solar neighbourhood*, Gomez et al. examine the evolution with age of the velocity ellipsoid using Hipparcos parallaxes and proper motions, and radial velocities of several thousands of $B-F$ stars ($\sim$ 3000 with CORAVEL data). The *Determination of the escape velocity in the solar neighbourhood* by Meillon et al. includes more than 4 700 CORAVEL stars. The CORAVEL velocity information is used as well in the dynamical study of Ursa Major (Soderblom et al.). The 'metallicity' information available through CORAVEL measurements has been exploited by Pont et al. for their subdwarf sample.

Other large programmes including CORAVEL radial velocities combined with Hipparcos data are under way. A collaboration between the Geneva Observatory (M. Mayor, F. Pont) and the Niels Bohr Institute (J. Andersen, B. Nordström, E. Olsen) is interested in the study of the kinematics and chemical evolution of the Galaxy using a sample of about 10 000 $F-G$ stars for which astrometric (distance, proper motion), spectroscopic (radial velocity), photometric and age information are available. The project is described in Nordström et al. (1996). Another large study, leaded by M. Grenon, using about 8000 stars from the NLTT survey for which Geneva multicolour photometry and radial velocities are available, will address the questions of the evolution of the Galactic thick disk and the age of the oldest Galactic structures.

Finally, an interesting aspect of the radial velocity catalogue of Hipparcos stars resides in its size and diversity, providing statistical comparison samples in various particular situations. For example, the cumulative distribution of velocity *rms* holds information on the binary content and on the intrinsic radial velocity variations of stars in a selected sample. Such a cumulative distribution will thus provide a good tool for a comparison between giant M-stars of the Hipparcos survey and dwarf-galaxy populations to be observed with the VLT.

8. RADIAL VELOCITY CATALOGUES

For the southern sample catalogue (Mayor et al. 1998), according to the present progression of the work, we hope to be able to make our data available to the scientific community within the year following the release of the Hipparcos Catalogue. Some work is still needed to have the CORAVEL visual binary components match the Hipparcos ones.

Concerning the northern sample catalogue (Udry et al. 1999), about one additional year is needed to complete the programme. It is hoped that the second catalogue will not follow the first one by more than 1 yr.

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