Press Release

Resolving the controversy about the Pleiades distance?

Released on November 19th, 2004

This press release is based on four articles published in *Astronomy & Astrophysics:*

"The distance to the Pleiades from orbital solution of the double-lined eclipsing binary HD 23642", by U. Munari et al. (published)
"The distance to the Pleiades: Main sequence fitting in the near infrared", by S. Percival et al. (to be published)
"Eclipsing binaries as standard candles: HD 23642 and the distance to the Pleiades", by J. Southworth et al. (to be published)
"A purely geometric distance to the binary star Atlas, a member of the Pleiades", by N. Zwahlen et al. (published)

A&A Press Release Homepage

***Astronomy & Astrophysics* is now publishing four new estimates of the distance to the Pleiades, one of the most famous and brightest stellar clusters in our Galaxy. These new measurements are the results of the independent work of four European groups led respectively by Susan Percival, Ulisse Munari, John Southworth, and Nicolas Zwahlen. Over the past few years, the distance to the Pleiades has become a crucial astrophysical problem. In 1997, the Hipparcos astrometric catalogue was released and provided astronomers with the most precise stellar distance measurements ever obtained. But the Hipparcos measurement of the Pleiades' distance was 12% smaller than the previous measurements. Since then, many attempts have been made to measure the distance to the Pleiades; they have confirmed the earlier measurements and not the Hipparcos ones, although doubts still exist in the astrophysics community. The new measurements now published may help resolve the controversy about the Pleiades' distance.**

The Pleiades are one of the most famous and brightest stellar clusters in our Galaxy. One might imagine that the distance to such an important object would be well-known and no longer poses a problem for astrophysicists. For several years, however, determining the distance to the Pleiades has been a crucial and complicated problem.

The Pleiades stellar cluster. Copyright Robert Gendler.

For several decades, the distance to the Pleiades was determined by methods relying on our knowledge of stellar physics that was assumed to be rather well advanced. In 1989, the European astrometric satellite Hipparcos was launched. Hipparcos was able to measure the astrometric parameters of more than 100 000 stars, i.e. their positions, parallaxes, and proper motions, with the best accuracy ever obtained. Distances could then be directly inferred from the parallax measurements. About 50 of the brightest stars from the Pleiades cluster were Hipparcos targets. When the results from Hipparcos were released in 1997, it soon appeared that there was a 12% difference between the new Hipparcos measurement of the Pleiades' distance and the previous estimates. The Hipparcos team found that the distance to Pleiades was about 118 parsecs or pc (385 light-years), whereas the previous measurements gave values of about 132 pc.

This situation presents a crucial astrophysical problem. If Hipparcos is right, it would mean that the stellar physics models relied upon for years may be wrong. If Hipparcos is wrong, there may be problems in calculating distances in the Universe, as distances of remote galaxies rely upon the determination of nearby stars' distances, such as that of the Pleiades. Therefore, fixing the discrepancy is of major importance for astronomers.

Many attempts have been made to resolve the inconsistency. Since the beginning of the year, several new results, based on various techniques, have been published that confirm the oldest value of 132 pc. *Astronomy & Astrophysics* is now publishing four new estimates of the distance to the Pleiades obtained by independent research teams.

The team [1] led by Susan Percival (Liverpool John Moores Univ.) developed an improved technique based on the so-called "main sequence fitting" method that has long been used to determine the distance of stellar clusters. This technique is supported by the relationship that exists between the colour of a star and its absolute brightness. If one plots the colour of many stars vs. their brightness, most of them appear to be gathered in the so-called "Main Sequence" phase. Stars spend the majority of their life in this phase, during which they fuse hydrogen into helium in their cores. Such stars are called "Main Sequence stars". The Main Sequence part of the graph represents the relationship between colour and brightness of stars while they are in this phase.

The principle of the main sequence fitting technique as applied to the Pleiades stars is as follows. First, a template colour-brightness relationship is established. The colours of the Pleiades stars are then measured. Applying the relationship, one can determine the absolute brightness of the Pleiades, and then their distance. Of course, the key difficulty of the method is determining an appropriate template relationship for the observed cluster. Historically, it was established from the nearby Hyades cluster, whose distance can be determined by geometrical means. However, the Hyades stars were discovered to be rather different from the Pleiades stars and so this cluster is no longer used as a template for the Pleiades. In recent years, template relationships have been computed from stellar physics models, and therefore obviously rely on theoretical assumptions. Most of the "pre-Hipparcos" measurements of the Pleiades distance were based on this technique.

Susan Percival and her team then took a new step to improve this technique. They built the template colour-brightness relationship using observations of selected nearby stars. These selected stars were all chosen from the Hipparcos catalogue, with particular care being taken to assure that their individual parallax measurements had very low errors. This method relies on observational data instead of on theoretical assumptions. However, some physical assumptions are still needed, the key one being the role of metallicity. Metallicity measures the heavy element content in stars and in the interstellar medium; that is, it measures the abundance of the elements heavier than hydrogen and helium (such as carbon, oxygen, iron, …). One of the key bases of stellar physics is that the colour of a Main Sequence star depends on its metallicity: the lower the metallicity, the bluer the colour of the stars. The metallicity of the Pleiades is rather well-known from spectroscopic measurements: it is close to the solar metallicity. Once the colour-brightness relationship is built for nearby stars, it is modified to account for the difference in metallicity between the nearby stars and the Pleiades. Then, the template relationship can be applied to the colours of the Pleiades. The brightness of the Pleiades can be computed, and their distance is inferred.

The team used this technique in four different wavelength ranges, from optical to near-infrared. They were the first ones to do so. The use of near-infrared data is of particular interest since the metallicity, as a key parameter, has a less important role in this wavelength range. They obtained consistent results in each wavelength range, with a distance to the Pleiades of around 133.8±3 pc.

The method proposed by the teams led by U. Munari and J. Southworth is very different from the one described above. This other method relies on the discovery of a detached eclipsing binary, named HD 23642, among the Pleiades last year. Detached eclipsing binaries are very powerful tools for determining distances in the Milky Way and in nearby galaxies such as Andromeda or the Magellanic Clouds. Eclipsing binaries are binary systems in which the orbital plane is oriented so that one star passes in front of the other, thus completely or partially blocking the light from the other star during each orbital period. To be a useful tool in determining distances, the binary system must also be well "detached": both stars must be far enough apart for there to be no material exchange between them. Thus, they can be considered separate bodies that orbit around each other. Unfortunately, this latter characteristic makes such systems difficult to detect as their orbital period is much longer than that of close binary systems.

So far, HD 23642 is the only such binary star known in the Pleiades cluster. The HD 23642 binary system was observed by Ulisse Munari and his team [2] who obtained its light curve and its radial velocity curve. They applied the classic method to determine the distance to detached eclipsing binaries. Combining both curves, one can calculate the orbital parameters (period, inclination, eccentricity) as well as the radii of both stars. At this stage, the technique is purely geometrical. Next, some stellar physics calibrations must be included to determine the temperature of each star, using colour or spectral measurements. The calibrations used illustrate a novel concept: firmly anchored in observations from the ground and from space that are performed over a wide wavelength range from the ultraviolet to the infrared, the calibrations are in accordance with the analysis of high resolution spectra of the binary itself. Finally, the absolute brightness of each component is computed, and their distances from the Earth inferred. Ulisse Munari's team found that the Pleiades member HD 23642 is at 132±2 pc from us.

Re-analyzing Munari's data, the British team led by John Southworth [3] explored other techniques of estimating the distance to eclipsing binaries. In particular, one major limitation of the classic method is that the determination of the star's temperature relies on stellar physics models. As stars may have peculiar behaviours not accounted for by models, it is difficult to quantify the uncertainties that the models introduce in this determination. The goal of John Southworth's group was to quantify the uncertainty of the traditional technique as much as possible. They also developed a new, almost entirely empirical technique to determine the distance to HD 23642. Their method relies on new empirical relations between the temperature and brightness of a star that have recently been established thanks to interferometric measurements of Main Sequence stars. Using this new empirical technique, John Southworth's team estimated the distance of about 139±3.5 pc.

A third, purely geometric, technique has been applied by N. Zwahlen and his team [4], to measure the distance to the binary star Atlas, one of the brightest Pleiades stars. Atlas is indeed a binary system: both stars revolve around one another with a period of 291 days; the average distance between the stars is about 259 million km. Atlas is visible to the naked eye, but appears as a single speck of light even through telescopes because both stars are close to each other and far from us. However, the pair can be distinguished using interferometers. In this case, the technique consists of measuring the angular size of the orbit of the binary system on the one hand, and its absolute size on the other hand, so that a simple division of the latter by the former gives the distance (indeed, for such small angles, the angular size is equal to the true size divided by the distance). The angular size was known from interferometric measurements published earlier this year by an American group, combined with additional data obtained by C.A. Hummel (ESO), who collaborated with N. Zwhalen. The absolute size can be determined from the radial velocities of the system and from Kepler's third law. The main difficulty is measuring the radial velocities of the system as both stars are very hot (about 12500 K) and present very few absorption lines. In addition, they rotate rapidly, making the spectral lines broad and shallow, so that a sophisticated method has to be used to disentangle the contribution of each star to the observed spectra. Applying this technique, N. Zwahlen and his colleagues measured that Atlas is 132±4 pc from us.

In short, Susan Percival estimated the mean distance to the Pleiades (133.8±3 pc), whereas Ulisse Munari and John Southworth measured the distance to an individual star in the cluster, HD 23642 (they found 132±2 pc and 139±3.5 pc, respectively), and N. Zwahlen determined the distance to Atlas, one of the brightest Pleiades stars (132±4 pc). These four new measurements are fully consistent with other results that have been published earlier this year. For instance, new parallax measurements of three Pleiades stars obtained with the Hubble Space Telescope also support past distance estimates. However, it is important to point out that the measurements of the distance to HD 23642 and Atlas, of which Southworth, Munari, and Zwahlen provided estimates, are the measurements of the distance to individual stars, not the mean distance to the Pleiades, as we do not know where the stars are situated in the cluster. The new measurements of the distance to HD 23642 or Atlas should therefore be compared to the Hipparcos measurement of HD 23642 (110±14 pc) or Atlas (117±16 pc), instead of to the mean cluster distance.

Since the first publication of the Hipparcos catalogue, global tests on the Hipparcos astrometric results have been made and all have indicated the very good reliability of the published Hipparcos catalogue. In fact, the Pleiades' case is the only one for which there is such a discrepancy between Hipparcos measurements and other estimates. According to the Hipparcos data processing expert Floor van Leeuwen, *"the Pleiades problem is most likely a local problem, resulting from extreme observing conditions that were not fully appreciated in the analysis of the data."* However, the Pleiades discrepancy must be solved, as Hipparcos provides the only way to test the crucial assumption of most of the ground-based techniques: that is, these techniques imply that the characteristics of the neighbouring stars can be compared to the Pleiades' ones. At least one of these characteristics is very different in the two samples: the nearby stars are much older than the Pleiades. The only technique that is an exception is the purely geometrical technique applied to measure Atlas' distance, which does not rely on any assumption. But currently, this technique can only be used to measure Atlas' distance, and does not provide, strictly speaking, a measurement of the mean cluster distance. Even though, given what we know about the shape of the Pleiades cluster, the distances to Atlas and to HD 23642 are likely to be representative of the mean cluster distance, two objects are not enough to define reliably the center of the Pleiades. Therefore, the parallax technique, as applied by Hipparcos on a large number of stars, is the only one to provide a fully independent and rigorous determination of the mean cluster distance, that does not assume at any stage that the Pleiades are similar to our neighbouring stars. Hipparcos provides the only way to obtain independent confirmation of these assumptions. Floor van Leeuwen and his colleague Elena Fantino are now working on a new processing of the raw Hipparcos data, *"taking into account the problems which may have caused the Pleiades discrepancy."* Indeed, the problem comes from a correlation of errors for stars close together in the sky. This problem was expected and corrected, but it recently appeared that it is worse for bright stars than for faint ones. Taking into account this new correlation effect, Floor van Leeuwen provided a first corrected estimate of the Hipparcos mean distance for the Pleiades that is between 117 and 133 pc. This new estimate, which still must be refined, is not significantly different from the new ground-based measurements. The reprocessed Hipparcos data should be published in the next months, and might solve this crucial problem definitely, allowing astrophysicists the confirmation that they can rely on the properties of our nearby stars to establish the theories of stellar physics.

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[1] S.M. Percival, M. Salaris (Liverpool John Moores Univ., UK), and M.A.T. Groenewegen (Leuven, Belgium).
[2] U. Munari (Padova, Italy), S. Dallaporta (Italy), A. Siviero (Padova, Italy), C. Soubiran (Obs. Bordeaux, France), M. Fiorucci (Padova, Italy), P. Girard (Obs. Bordeaux, France).
[3] J. Southworth, P.F.L. Maxted, B. Smalley (Keele Univ. UK).

[4] N. Zwahlen, P. North, Y. Debernardi (Lausanne, Switzerland), L. Eyer (Obs. Genève, Switzerland), F. Galland (Obs. Grenoble, France), M.A.T. Groenewegen (Leuven, Belgium), C.A. Hummel (ESO, Chile).

A&A acknowledges Drs. Michael Perryman (ESA) and Floor van Leeuwen (Cambridge Univ., UK) for their kind help in the preparation of this press release.

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Full article available in PDF format

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To be published in Astronomy & Astrophysics (DOI number: 10.1051/0004-6361:20041694)
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Published in Astronomy & Astrophysics, 2004, vol. 425, p. L45
Full article available in PDF format

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