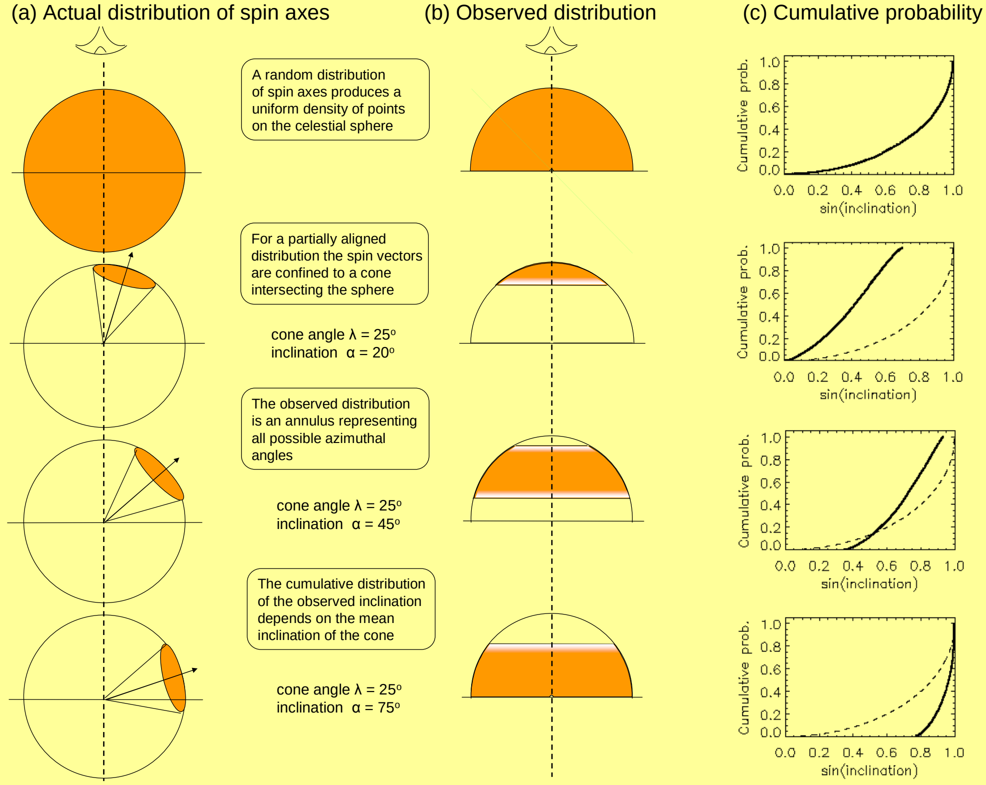
Are the spin axes of stars randomly aligned in young clusters?

Richard Jackson and Robin Jeffries*, Astrophysics Group, Keele University, UK * rdj@astro.keele.ac.uk

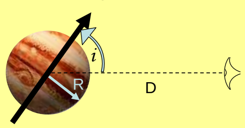
ABSTRACT

If the spin axes of stars in young clusters are randomly orientated in space, then it becomes possible, with measurements of period and projected equatorial velocity, to obtain accurate estimates of distance, mean age and age dispersion of the cluster (Jeffries 2007a,b). A new technique is presented which can be used to test this assumption. The inclination of a set of stars, found from their projected equatorial velocity, period and angular diameter is analysed to determine whether their spin axes are randomly distributed in space or if there is a preferred direction of rotation. The method is used to assess the degree of alignment of stars in the Pleiades and Alpha-Persei clusters. Both clusters show results consistent with a uniform distribution. Using period and Vsin*i* data to estimate distance to the Pleiades gives a result consistent with main sequence fitting and higher than the value found from Hipparcos measurements.

(a) Actual distribution of spin axes (b) Observed distribution (c) Cumulative probability



Measuring the inclination of spin axes in nearby clusters



$$\sin i \propto \frac{\text{Projected velocity (V}\sin i\text{)} \times \text{Period (P)}}{\text{Angular diameter (A)} \times \text{Distance (D)}}$$

The sin*i* distribution of a group of stars is the set of numbers specifying the angles between their axes of rotation and the line of sight. For stars in nearby clusters the sin*i* distribution can be determined by combining

(i) estimates of projected radius, R.sin*i*, found from measurements of projected equatorial velocity, Vsin*i*, made using high resolution spectrographs and period,P, measured from light curves,

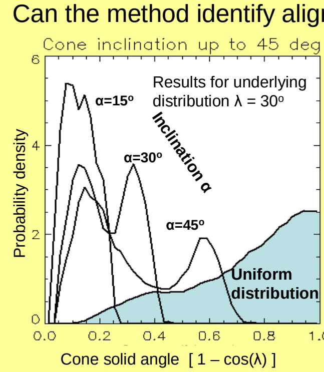
(ii) estimates of angular diameter, A = R/D, found from photometric data, magnitude, V and colour (V-K), using a Barnes-Evans relation derived for main sequence stars of similar metallicity;

$$\log (A) = 0.531 - 0.2V + 0.272(V\text{-}K) - 0.126\, E_{B\text{-}V}$$

(iii) an independent measure of distance, D, to the cluster, based on multi-colour main sequence fitting or parallax measurements.

This technique is valid for older clusters (>30Myr) where the radii of stars are reasonably stable and where a colour magnitude diagram can be used to identify probable binaries which are excluded from the data set. In practice there is a lower limit of inclination at which the period can be measured and therefore a lower limit to the value of sin*i* include in the data set. There is also an uncertainty in individual sin*i* measurements of ~15% due to measurement uncertainties in period, projected velocity and estimated angular diameter.

Can the method identify alignment of spin axes within a cluster?



To test the discrimination of the proposed technique a Monte-Carlo method is used to model two scenarios:

(i) the case where stars in a cluster are randomly aligned giving a uniform distribution of spin axes (λ = 90º).

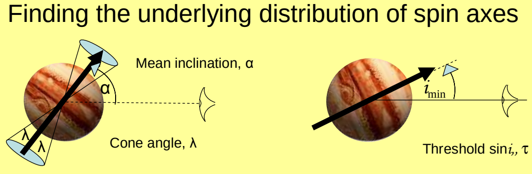
(ii) the case where there is significant alignment of spin axes of stars in a cluster described by a cone semi-angle of λ = 30º,

Sin*i* distributions are modelled for sets of stars with typical levels of measurement uncertainty. These are then analysed to determine the probability density of cone angle which should ideally reflect the underlying distribution of spin axes.

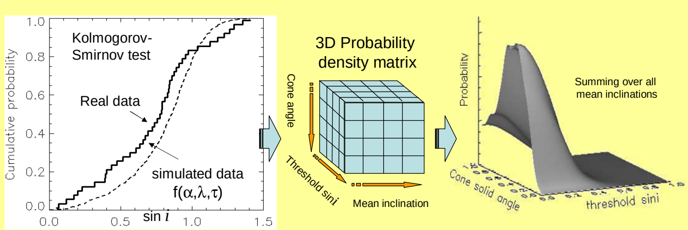
A uniform distribution shows an increase in probability density with cone angle, peaking at λ = 90º. For an aligned distribution the result depends on mean inclination,α. If this is less than 45º then the probability density shows two peaks, one reflecting the underlying cone angle and the second at a higher cone angle. For inclinations above 45º the probability density becomes fairly uniform indicating that the measured sin*i* distribution could result from almost any underlying distribution.

Repeated simulations for different sample sizes showed that whilst a fairly uniform distribution of spin axes can be identified by a strong increase in probability density with cone angle it is less easy to identify a well aligned distribution of spin axes. If the mean inclination, α, is 45º or less, then a well aligned distribution can be clearly identified; otherwise the result can be indeterminate since the case of a partially aligned distribution becomes degenerate with the case of uniform distribution observed with a high level of cut off in sin*i*, τ.

Finding the underlying distribution of spin axes



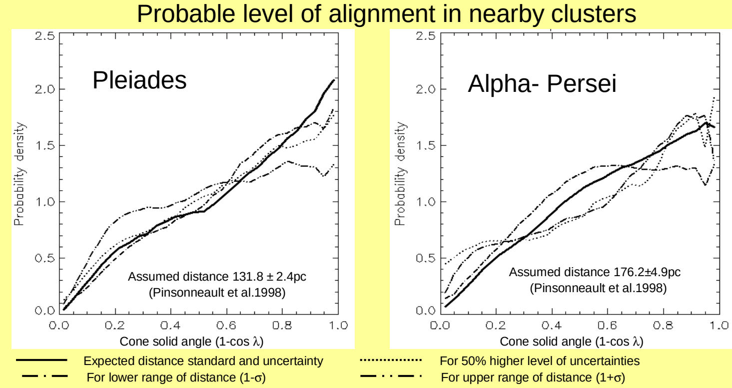
The measured sin*i* distribution is analysed to determine an underlying distribution of spin axes, i.e. the size and inclination of the cone containing the spin axes of the stars in the cluster. To do this the cumulative probability distribution of the measured data is compared with a simulated distribution calculated for a known cone angle, λ, mean inclination, α, and threshold in sini, τ. The simulated distribution includes the effects of the expected uncertainties in measured parameters, P, Vsin*i*, A and D and the practical limit of resolution of Vsin*i*.



A Kolmogorov-Smirnov test is used to estimate the probability that the measured sin*i* distribution is drawn from the same distribution as the simulated data set. In practice there is no unique combination of parameters that gives a perfect fit to the measured data. Instead, the probability is evaluated over all possible values of α, λ, and τ to produce a probability matrix that defines the probability of different underlying distributions.

Results can be visualised by summing the probability density matrix over one parameter, say mean inclination, to produce a surface plot of probability density as a function of cone solid angle (1-cos λ) and threshold in sin*i*.

Probable level of alignment in nearby clusters



The method was used to determine the likely distribution of spin axes for sets of stars in Pleiades and Alpha-Persei. Eliminating probable binaries there were 35 stars in each cluster where simultaneous measurement of Vsin*i* and period were available. Pleiades showed a probability density consistent with a random distribution of spin axes. Integrating under the curve shows a cone semi-angle greater than 42º at 90% confidence. This result is relatively robust being insensitive to small changes in measurement uncertainty or distance. Data for Alpha-Persei also indicates a uniform distribution although this result is less robust due to the greater uncertainty in assumed distance to the cluster.

If as indicated, the distribution of spin axes in Pleiades is uniform, then period and Vsin*i* data can be used to estimate distance to the cluster. This gives a distance of 130±6pc which is consistent with the value given by main sequence fitting but higher than the value found from Hipparcos data,122±1.9 pc (van Leeuwen, 2007) albeit at a low level of significance.

References : Jeffries R.D. 2007a MNRAS, 376, 1109
Jeffries R.D. 2007b MNRAS, 381, 1169
Pinsonneault M. H., Stauffer J., Soderblom D.R., King J.R., Hanson R.B., 1998, ApJ, 504, 170
van Leeuwen F.,ed.2007 Hipparcos, the New Reduction of Raw Data Vol 250 of Astrophysics and Space Science Library