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A Search for Nemesis: Current Status and Review of Theory

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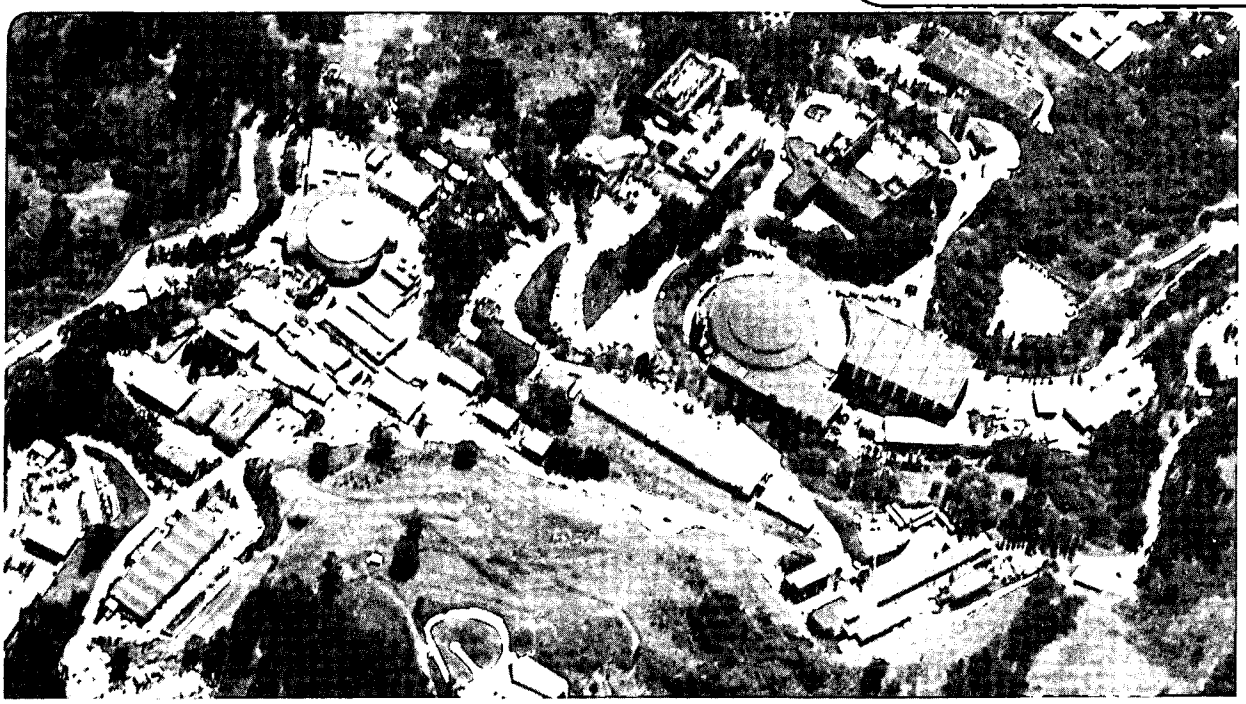

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Abstract

Otherwise unrelated geophysical and astrophysical observations can be consistently accounted for by postulating that the earth has been subjected to comet storms. The phenomena include features of the fossil record, impact craters and glass, geomagnetic reversals, and cosmic ray exposure ages of H-chondrite meteorites. Monte Carlo analyses of both the extinction data and the crater data suggest that these data are periodic. Theoretically, periodicity in impacts on the earth requires that the impacting bodies arrive in large numbers as in a comet storm. A number of causes have been suggested for periodic showers of comets, but presently only the Nemesis hypothesis of a solar companion star is consistent with all the known data. We are searching for this star by measuring the parallax of faint red stars that would have been missed in catalogues of bright and nearby stars. So far, we have rejected about 20% of the 2,691 stars in our list of candidates in the northern hemisphere.

Motivation: Comet Storms and Periodicity

Comet storms have been suggested as a possible explanation for diverse geophysical observations, including the fossil record of family and genus extinctions (Davis, Hut and Muller 1984, Rampino and Stothers 1984), impact craters and glass (Rampino and Stothers 1984, Alvarez and Muller 1984, Hut et al. 1987), and geomagnetic reversals (Muller and Morris 1986). We have recently proposed that the cosmic ray exposure ages of H-Chondrites can also be understood in terms of the same comet-storm model (Perlmutter & Muller, 1988). Figure 1 shows the distribution of these ages, plotted under error bars

——Figure #1 near here——

representing the times for which there is evidence of comet storms on the Earth. The bars agree with the ages of the peaks in the H-chondrite ages, within the systematic uncertainties of the age determinations. This agreement suggests that the H-chondrite meteorites were created during comet storms, perhaps from impacts of comets on asteroids. (The L-chondrites presumably come from a different source, e.g. asteroid-asteroid collisions.)

Are the physical phenomena that we are discussing here periodic? Monte Carlo analyses of both the extinction data and the crater data suggest that they are (Rampino and Stothers 1984, Alvarez and Muller 1984, Raup and Sepkoski 1984), although this has been a source of much statistical controversy (Grieve et al. 1985, Lutz 1985). Weissman (1986) has argued that the craters that contribute power to the periodicity show melt compositions that indicate impact from differentiated meteorites rather than comets. However this interpretation is ambiguous for all but two of the craters cited, and neither of these contribute significantly to the periodicity since the one-standard-deviation uncertainty in the ages of each covers a span of 20 Myr, comparable to the observed periodicity.

Nemesis Hypothesis

A number of explanations have been given for periodic comet storms—if they are in fact periodic. These explanations include the oscillations of the sun in the galactic plane (Rampino and Stothers 1984), a companion star, "Nemesis," orbiting the Sun (Davis, Hut, and Muller 1984, Whitmire and Jackson 1984), and a tenth planet, "Planet X," orbiting the

Sun (Whitmire and Matese 1985). Not all of these mechanisms, however, provide a periodic pulse of comets sufficiently narrow in time to account for the extinction data.

For *galactic oscillations*, the percentage modulation of the comet impact rate would be about 50%, and sinusoidal. This estimate is based on known motion of the sun, and known densities of stars and molecular clouds (Thaddeus and Chanan 1985). The measured modulation of extinction data is about 80%, and not sinusoidal.

Planet X perturbs the inner comet cloud that is necessary for it to cause comet showers. This lengthens the expected duration of these comet showers to about 5 to 10 Myr. The measured duration of extinction peaks is $\leq$ 3 Myr (J. Sepkoski, private communication, 1988).

Nemesis would give a comet shower with a 1 to 2 Myr duration (Hut 1984, Muller 1985). Passing stars would perturb its orbit, adding a jitter of 1 to 3 Myr to the times of comet storms (Davis, Hut, and Muller 1984, Hut et al. 1987). Both of these consequences of the Nemesis hypothesis are consistent with the extinction data.

Nemesis Lifetime

There has been a great deal of confusion in the literature about the lifetime of the Nemesis orbit, in large part because of a few mistakes and misinterpretations of the calculations. In the original theory, the lifetime of Nemesis in its present orbit was estimated to be on the order of 2 x10^9 years. Since this is too short a time to allow Nemesis to have survived since the formation of the solar system, it was assumed that "this orbit has probably evolved through a stochastic process, perturbed by random passing stars, from an initial orbit with a shorter period and smaller semi-major axis" (Davis, Hut, and Muller 1984). Thus the original, closer, orbit's lifetime would have been much greater than the current orbit's lifetime. This difference is often misunderstood. It is important to note that a current orbit lifetime of ~10^9 years suggests that the original orbit would have survived since the formation of the solar system.

The orbit must be stable for 10^9 years for another reason: a substantially shorter period would conflict with the observed regularity of the mass extinctions, which show only a 12% (3 Myr) RMS deviation from perfect periodicity (J. Sepkoski, private communication, 1988). (Stothers, 1989, points out that the mass extinctions appear this periodic only if the Harland timescale is used.) A subsequent detailed Monte-Carlo

simulation carried out by Hut (1984) concluded that half of all possible Nemesis orbits have a lifetime greater than 10^9 years. Bailey (1984), in a review of this calculation, missed the distinction between the current orbit lifetime and the original orbit lifetime discussed above, and interpreted Hut's paper as a "virtual retraction" of the theory.

Similar values (0.5 to 1.0 $\times 10^9$ years) were calculated by Torbett and Smoluchowski (1984) and by Weissman (1984 and private communication), although these authors also interpreted this as too short to be compatible with the Nemesis theory. Weissman predicts that the Nemesis orbit should vary in length by about 35% from the first period to the last; in fact the observed change was 31% (the interval between the first two mass extinctions on the Raup and Sepkoski data is 26.7 Myr, and the interval for the earliest two extinctions was 35 Myr). Clube and Napier (1984) concluded that the survival time of Nemesis was considerably less, approximately 50 Myr, and therefore incompatible with the observed regularity in the extinction record, but this small value was due to a mistake in the way they calculated the effects of large molecular clouds. They took the full mass of these clouds to be concentrated in a region small compared to the Sun-Nemesis orbit (3 light-years); in fact the clouds are so large that their effect on the orbit of Nemesis is negligible, as was shown by Morris and Muller (1986). With the molecular clouds left out, Clube and Napier give the lifetime as 10^9 years, in agreement with the other authors.

What to Look for? Red Dwarfs

We have thus chosen to look for a solar companion star, Nemesis. This is not the first time that a search for a solar companion star has been suggested (Davidson 1975, Reynolds, Tarter, and Walker 1980). It has been known for a while that such a star would probably have escaped cataloging in standard astronomical surveys for nearby stars (van de Kamp 1982). Nearby stars are usually found by their high proper motion, or by their brightness. A star bound to the sun, however, would not have high proper motion. Furthermore, the most common type of star, the red dwarf, would be too dim to draw attention, even if it were the closest star in the sky. Figure 2 shows the absolute brightness (magnitude) range covered by the Yale Bright Star Catalogue (Hoffleit 1982) for a star 1 pc from the sun. The cool

——Figure #2 near here——

red dwarfs and white dwarfs would not be in the catalogue. There are ten times as many red dwarfs as white dwarf candidates, and we have begun our search with the red dwarfs.

The Dearborn Observatory Catalogue of Faint Red Stars (Lee, Baldwin, and Hamlin 1943, Lee and Bartlett 1944, Lee, Gore, and Bartlett 1947) lists 2,691 stars in the northern hemisphere red enough to have escaped the Yale catalogue. The distances to these stars have not been measured, since these are mostly distant bright red giant stars. One of them, however, may be a nearby faint red dwarf star. We are trying to find this one.

How to Search? Parallax

A nearby star will appear to move with respect to distant background stars as the earth moves about the sun—this is parallactic motion. We are collecting digitized images of a 13 arcmin × 8 arcmin field around each of the candidate stars from the Dearborn catalogue to compare with images taken some months later. We align the two images to each other using the background stars in the field, and look for parallactic motion. An automated telescope system observes the candidate stars; it was originally designed by our group for a supernova search that is currently in operation (Perlmutter et al. 1988, Kare et al. 1988).

To account for a 26 Myr periodicity, a companion star must have a major axis of about 0.8 parsecs (2.4 light years) in its orbit about the sun. At this distance the star would exhibit ≥2.5 arcsec of motion peak-to-peak in six months. The telescope optics gives a scale of 2.45 arcsec per pixel on the CCD camera, so Nemesis should be the one star in our sample that moves 1 pixel (in the right direction) in six months. If we find such a star, we can track its parallactic motion in the course of a year, thus easily distinguishing it from a more distant star with proper motion that coincidentally appears to be in the direction and magnitude expected for Nemesis.

Current Results

We have collected 789 "first look" images so far. Figure 3 shows the results of the

——Figure #3 near here——

analysis of 579 "second look" images, matched against the "first looks." As expected, the distribution of apparent motion clusters around zero, since (almost?) all of these stars are distant red giants. Figure 4 shows the same data projected on the direction of parallactic

——Figure #4 near here——

motion, and normalized to the magnitude of parallactic motion expected between the dates of the first and second looks, for a star at 0.8 parsec. If we find Nemesis, it will appear near the right edge of the parallel motion histogram (Figure 4b). The width of these histograms reflects the uncertainty in the apparent motion measurement seen in Figure 3, divided by the expected motion between observations.

We can reject nearly all of the stars shown in Figure 4 from our Nemesis search, although the stars in the right-hand tail of the parallel distribution (Figure 4b) will be remeasured in case one is a downward fluctuation from the expected Nemesis motion. We have thus completed approximately 20% of the search through the Dearborn catalogue's candidates.

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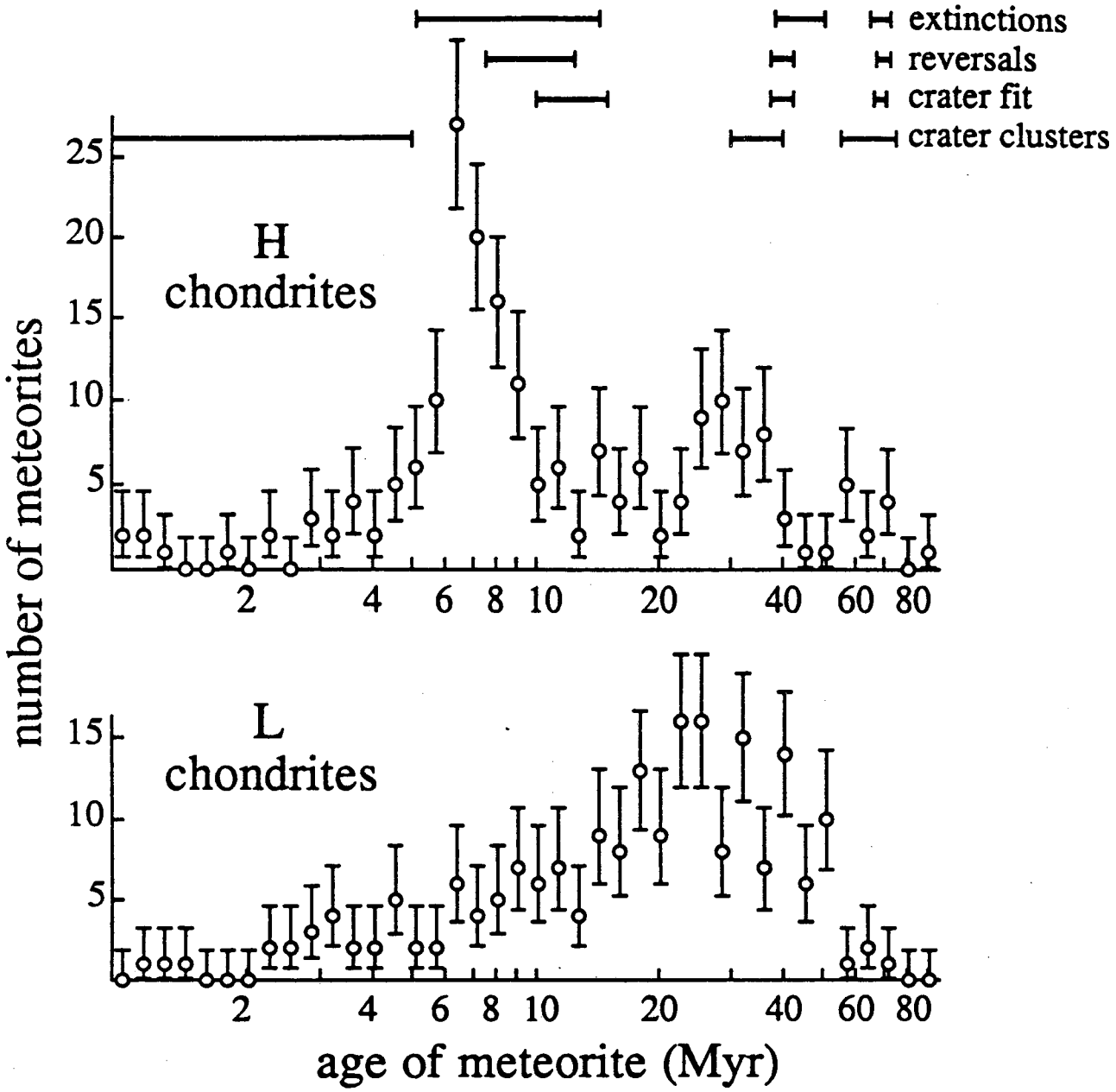
Figure Captions

Figure 1. The cosmic ray exposure ages of chondritic meteorites (from Perlmutter and Muller, 1988). Since the meteorites are all recent falls, the age indicates the time that the meteorite was created. The bars indicate the times for which there is independent evidence of comet showers, based on extinctions of fossil families (Raup and Sepkoski 1984), rates of geomagnetic reversals (Raup 1985), and impact cratering (and impact glass) on the Earth (Alvarez and Muller 1984, Hut et al. 1987).

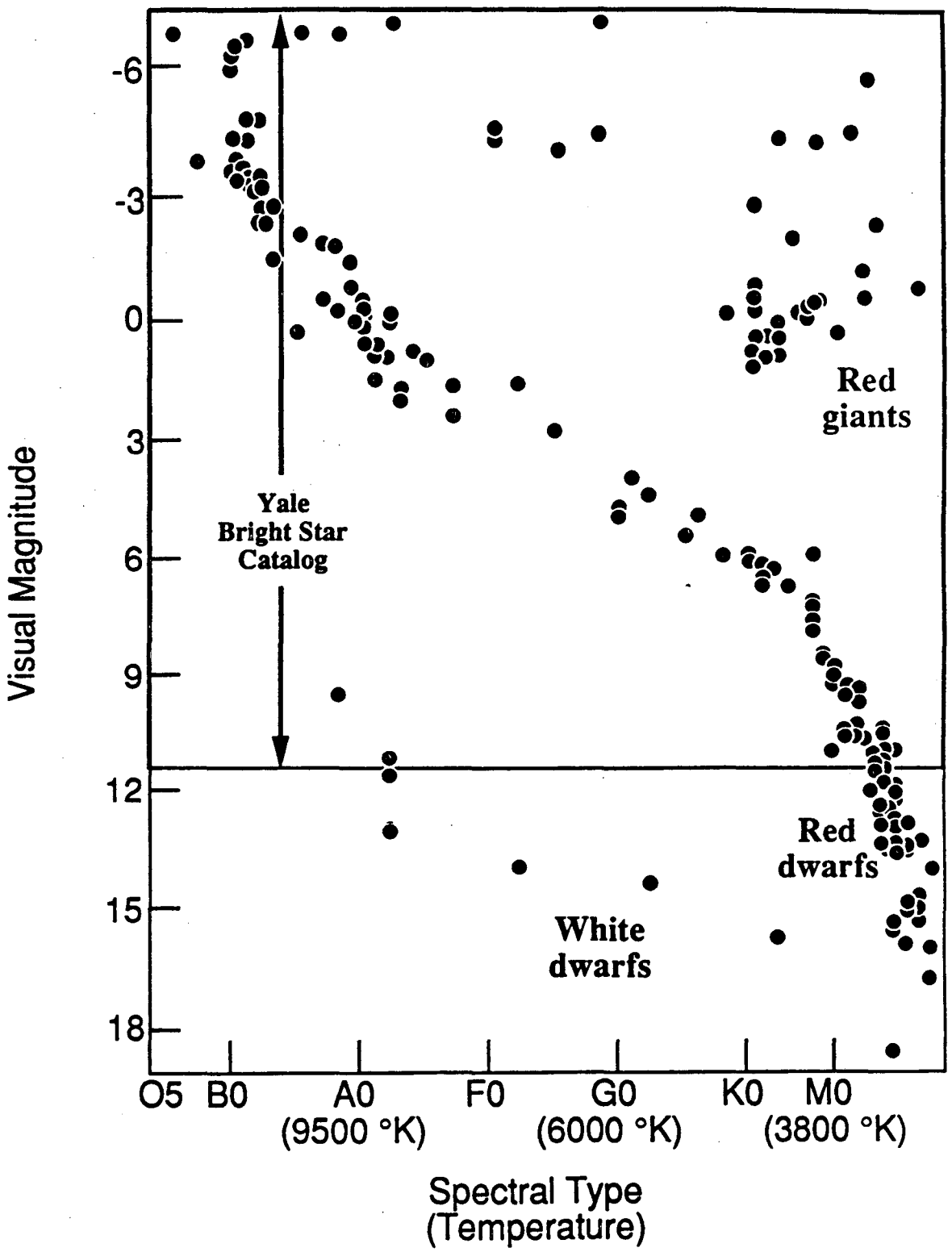
Figure 2. H-R diagram of 100 brightest and 100 nearest stars, showing the coverage of the Yale Bright star catalog for a star at a distance of 1 pc.

Figure 3. Histogram of apparent parallactic motion for the 579 candidate stars measured so far. Since almost all of these stars are very distant giants, the actual parallactic motion should be very close to zero. The width of these distributions thus indicates the measurement uncertainty.

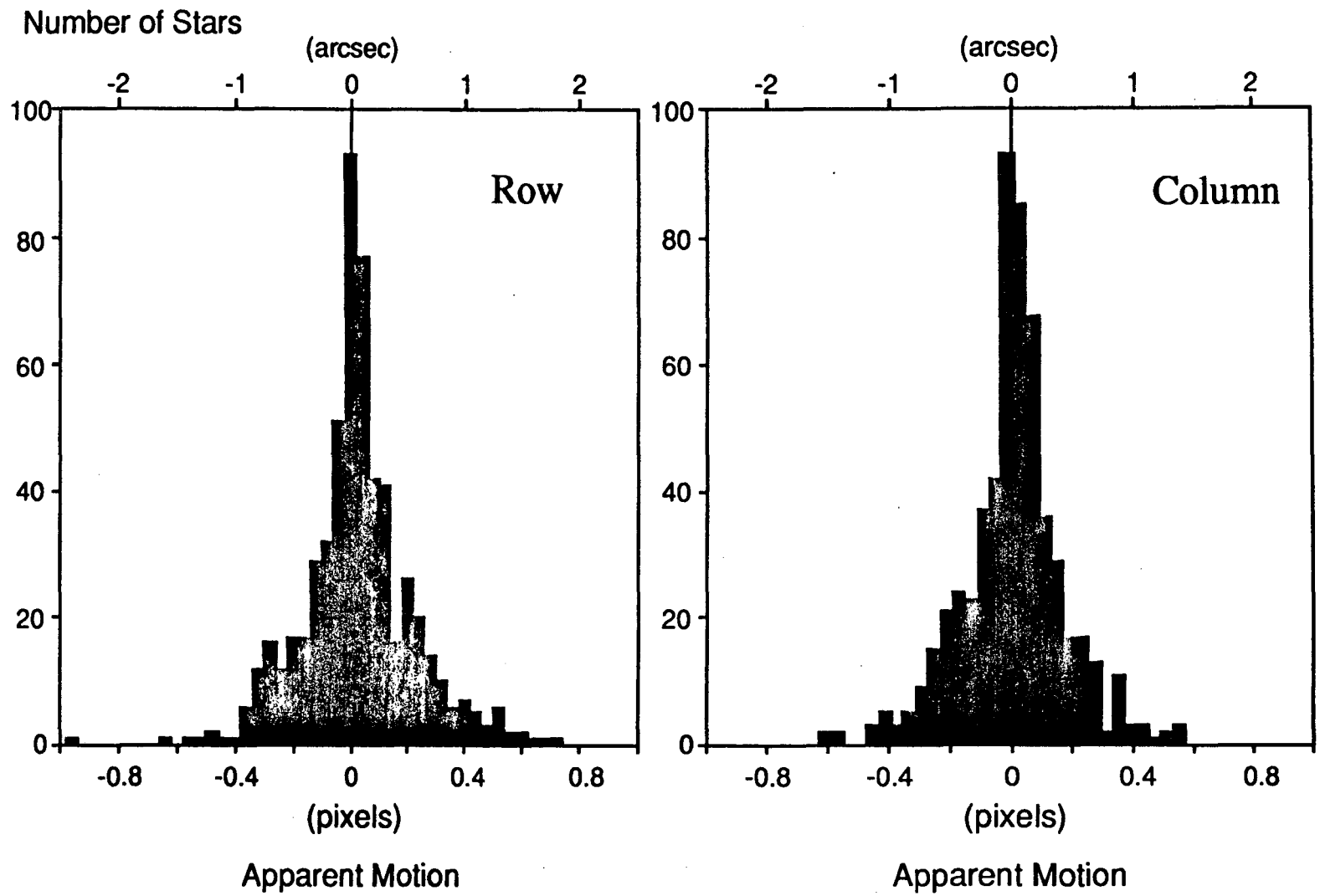
Figure 4. Histogram of apparent motion as in Figure 3, except that the motion has been projected perpendicular (a) and parallel (b) to the calculated motion of the star if it is at 1 pc distance, and normalized by the calculated magnitude of this motion. Nemesis would appear as a star with zero perpendicular motion and 1.0 parallel motion.



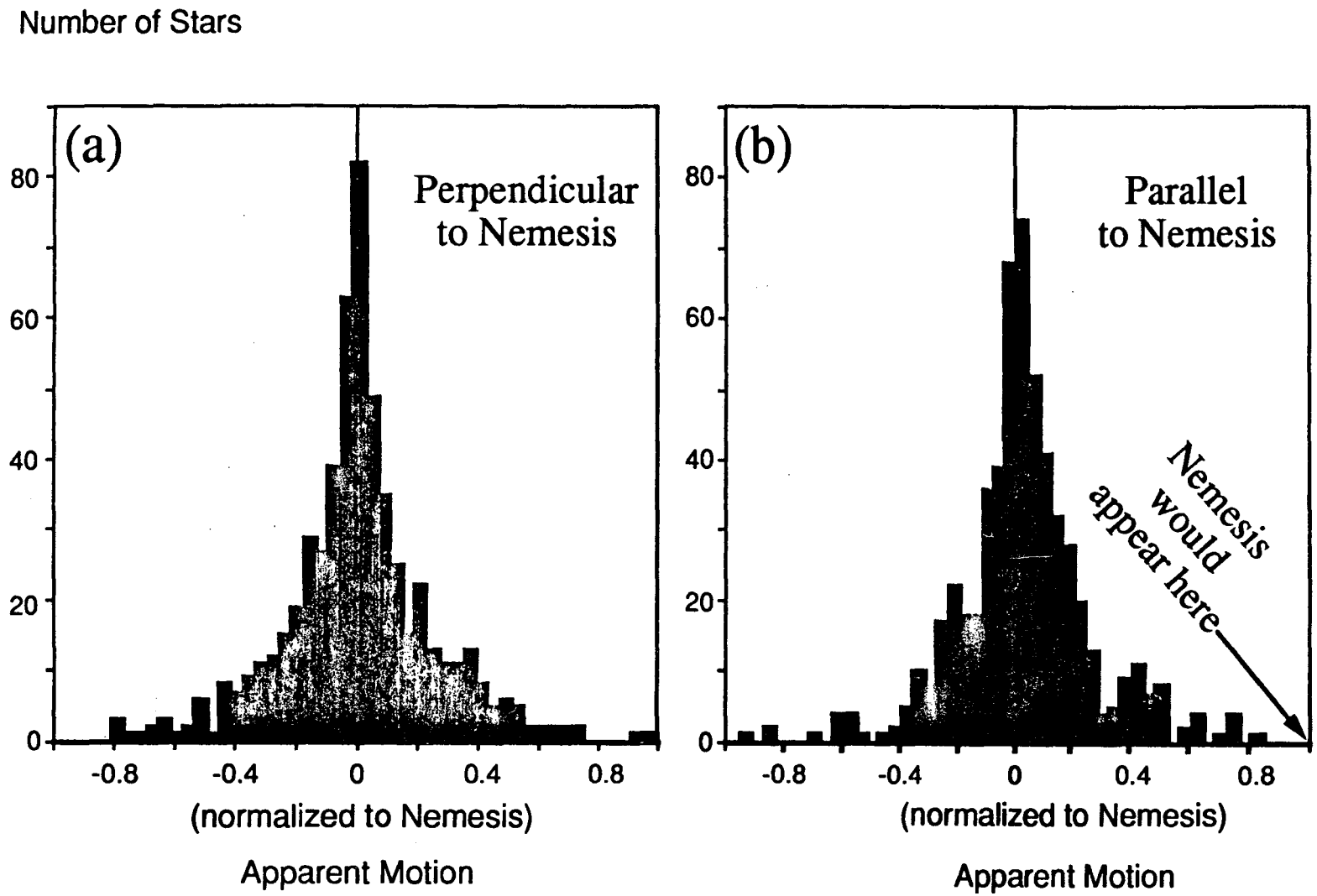
Perlmutter, et al., Figure 1



Perlmutter, et al., Figure 2



Perlmutter, et al., Figure 3



Perlmutter, et al, Figure 4

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