Young Stars Near Earth: Progress and Prospects
ASP Conference Series, Vol. ???, 2001
Ray Jayawardhana and Thomas Greene, eds.

Search for Nemesis Encounters with Vega, ϵ Eridani, and Fomalhaut

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Abstract. We calculate the space motions of 21,497 stars to search for close stellar encounters with Vega, ϵ Eridani and Fomalhaut during the past 10^6 yr. We discover that ϵ Eridani experienced three <2 pc encounters over the past 10^5 yr. Within the uncertainties, ϵ Eridani is having a close encounter with Kapteyn's star near the present epoch, with a 42.2% probability that the closest approach distance is <1 pc. Vega and Fomalhaut experienced four and six <2 pc encounters, respectively, over the past 10^6 yr. Each had one encounter with a ~2% probability that the closest approach distance is less than 0.5 pc. These encounters will not directly influence the debris disks observed around Vega, ϵ Eridani and Fomalhaut, but they may pass through hypothetical Oort clouds surrounding these stars. We find that two other Vega-like stars, HD 17848 and HD 20010, experienced rare, <0.1 pc stellar encounters that are more likely to directly perturb their circumstellar disks.

1. Introduction

Objects orbiting a star may be redistributed or ejected over their lifetime due to the close passage of another star with the system. "Nemesis encounters" may produce interstellar comets (Weissman 1996), free-floating planets (Laughlin & Adams 1998; Smith & Bonnell 2001), comet showers (Heisler et al. 1987) and periodic extinctions (Davis et al. 1984). Though nemesis encounters are short-lived and rare, these events may manifest as relatively long-lived phenomena. Comet showers may increase the dust content close to the star and produce an observable signature that decays on dust destruction timescales. Also, the direct dynamical influence of the perturber on an extant debris disk may generate significant asymmetries in the disk morphology (Larwood & Kalas 2001).

Here we use data from the Hipparcos catalog and the Barbier-Brossat & Figon (2000) catalog of stellar radial velocities to determine the U, V, W space velocities of 21,497 stars and trace their trajectories 10^6 yr into the past. We search for the closest stellar encounters experienced by three nearby stars – Vega, ϵ Eridani, and Fomalhaut – that have asymmetric debris disks (Holland et al. 1998; Greaves et al. 1998).

2. Search for Nemesis Encounters

The sample selection and method are identical to recent work that tests for nemesis encounters with β Pic (Kalas, Deltorn & Larwood 2001). In Table 1 we show those encounters with Vega, ϵ Eri, and Fomalhaut that have closest approach distance, $D_{ca} < 2$ pc. We use a Monte-Carlo routine to propagate the standard deviations for the observables (position, proper motion, parallax, and radial velocity), resulting in a spread of final results for D_{ca} and the closest approach time, t_{ca}. Columns 2 and 3 in Table 1 give the maxima and 1-σ values for these distributions, and Fig. 1 shows the spread of values as isocontours. The contours trace the confidence level for finding a star at a specific location in the (D_{ca},t_{ca}) plane. For each encounter, Table 1 gives the probability of closest approach at the 95.4% confidence level, $P_{95.4\%}$, for $D_{ca} < 1$ pc and $D_{ca} < 0.5$ pc (columns 5 and 6, respectively). These probabilities are computed by dividing the distribution below $D_{ca} < 1$ pc and $D_{ca} < 0.5$ pc by the total distribution in the (D_{ca},t_{ca}) plane (Fig. 1).

Table 1. Closest Approach Parameters for the Stars with $\bar{D}_{ca} < 2$ pc

Hipparcos No.	t_{ca} (kyr)	D_{ca} (pc)	ΔV_{ca} (km/s)	$P_{95.4\%}^{(D_{ca}<1pc)}$ (%)	$P_{95.4\%}^{(D_{ca}<0.5pc)}$ (%)
Vega:					
21421	$-620.1^{+26.6}_{-26.4}$	$1.84^{+0.68}_{-0.48}$	38.6±0.8	0.0	0.0
34603	$-337.9^{+29.5}_{-28.9}$	$1.50^{+0.68}_{-0.61}$	31.6±2.1	17.8	1.9
85665	$-318.0^{+36.5}_{-33.2}$	$1.49^{+0.36}_{-0.33}$	18.0±1.4	1.0	0.0
86974	$-52.3^{+10.1}_{-9.9}$	$1.08^{+0.21}_{-0.20}$	41.1±0.3	31.0	0.0
ϵ Eri:					
24186	$-12.5^{+12.2}_{-9.8}$	$1.02^{+0.22}_{-0.20}$	297.8±1.0	42.2	0.0
30920	$-62.3^{+6.7}_{-6.6}$	$1.15^{+0.18}_{-0.17}$	41.9±1.5	11.3	0.0
32349	$-72.3^{+3.3}_{-6.1}$	$1.83^{+0.06}_{-0.13}$	21.4±0.2	0.0	0.0
Fomalhaut:					
12777	$-474.0^{+20.0}_{-19.1}$	$1.15^{+0.41}_{-0.34}$	28.8±0.5	21.8	0.0
31626	$-490.6^{+43.2}_{-46.5}$	$1.77^{+0.61}_{-0.68}$	76.8±1.1	10.5	1.6
53767	$-394.3^{+73.0}_{-89.6}$	$1.84^{+0.54}_{-0.61}$	34.5±4.9	1.4	0.0
102485	$-281.4^{+16.6}_{-13.2}$	$1.63^{+0.34}_{-0.27}$	30.3±0.6	0.0	0.0
106440	$-185.2^{+17.3}_{-15.8}$	$1.78^{+0.47}_{-0.55}$	17.9±0.4	1.2	0.0
116745	$-102.1^{+7.8}_{-7.5}$	$1.90^{+0.18}_{-0.18}$	75.3±1.2	0.0	0.0

The dynamical influence of each encounter depends on the relative velocity (ΔV_{ca}, Table 1) and mass (Table 2) of each perturber. Following Kalas et al. (2001), we use the impulse approximation to compute the average change of velocity, Δv_{avg}, and eccentricity, Δe_{avg}, for comets in a hypothetical, 10^5 AU radius Oort cloud around each star (Table 2).

3. Discussion

Our search for nemesis encounters shows that Vega, ϵ Eri, and Fomalhaut experienced several <2 pc encounters over the past 10^6 yr, comparable to the rate of encounters for the Sun (García-Sánchez et al. 1999). The most recent encounters are interesting because their dynamical influence on circumstellar disks may still be evident in observations (e.g. Kalas et al. 2000). Within the uncertainties, ϵ Eri's $D_{ca} \sim 1$ pc encounter with HIP 24186 (Kapteyn's star) is occurring at the present epoch. There is a 42.2% probability that the Kapteyn-ϵ Eri encounter has $D_{ca} < 1$ pc (Table 1). However, the large relative velocity of this encounter and the low mass of Kapteyn's star combine to give the smallest dynamical influence in our study (Table 2).

Table 2. Dynamical Influence on Objects Orbiting at 10^5 AU Radius

Hipparcos No.	Mass ($M_\odot$)	Δv_{avg} (10^{-3} m/s)	Δe_{avg} (10^{-3})	R_{eq} (pc)
Vega:				
21421	0.67	20.39±6.35	0.25±0.08	$1.13^{+0.42}_{-0.29}$
34603	0.21	17.61±10.31	0.22±0.20	$1.11^{+0.50}_{-0.45}$
85665	0.45	40.62±7.09	0.51±0.09	$0.98^{+0.24}_{-0.22}$
86974	0.95	81.30±8.60	1.01±0.11	$0.62^{+0.12}_{-0.11}$
ϵ Eri:				
24186	0.5	6.05±0.22	0.15±0.01	$0.57^{+0.12}_{-0.11}$
30920	0.2	14.17±1.78	0.35±0.04	$0.77^{+0.12}_{-0.11}$
32349	2.9	167.87±5.52	4.20±0.14	$0.63^{+0.02}_{-0.04}$
Fomalhaut:				
12777	1.3	129.92±22.14	1.82±0.31	$0.51^{+0.10}_{-0.09}$
31626	0.67	17.16±14.64	0.24±0.20	$0.92^{+0.21}_{-0.18}$
53767	0.3	10.22±0.79	0.14±0.01	$1.14^{+0.38}_{-0.42}$
102485	1.4	68.60±9.25	0.96±0.13	$0.70^{+0.15}_{-0.12}$
106440	0.45	33.12±16.46	0.46±0.23	$1.02^{+0.27}_{-0.31}$
116745	0.7	10.57±1.05	0.15±0.01	$0.98^{+0.09}_{-0.09}$

The ϵ Eri encounters are distinguished by the fact that all three occurred recently, $t_{ca} < 10^5$ yr (Vega and Fomalhaut each have one encounter with $t_{ca} \lesssim 10^5$ yr). Also, ϵ Eri's encounter with HIP 32349 (Sirius) gives the strongest dynamical influence on hypothetical Oort clouds in our group (Table 2). These results partly reflect the fact that at the present epoch ϵ Eri has a smaller heliocentric distance (3.3 pc) than Vega (7.8 pc) or Fomalhaut (7.7 pc). As a star enters a volume with greater observational completeness, the likelihood of finding recent close encounters increases (García-Sánchez et al. 1999). However, Vega and Fomalhaut may have experienced the closest stellar encounters in this study, with a ~2% probability that $D_{ca} < 0.5$ pc. (Table 1, Fig. 1).

None of these encounters will directly influence the observed circumstellar disks, which appear confined to <0.001 pc radius (Holland et al. 1998; Greaves et al. 1998). However, an undetected assembly of comets weakly bound to each star with semi-major axis ~1 pc may experience a dynamical perturbation.

Table 2 gives the distance, R_{eq}, where the gravitational forces between Vega, ϵ Eri and Fomalhaut, and each of their respective stellar perturbers, are equal at t_{ca}. The estimated values of R_{eq} are less than the maximum radius of a gravitationally bound cloud of comets around each star. Stars that pass through an Oort cloud can erode the comet population by ejecting members into interstellar space or by producing comet showers near the star that may briefly increase the circumstellar dust content (Weissman 1996). Another source of perturbation for Fomalhaut is its probable binary stellar companion (Barrado y Navascues et al. 1997). In principle the close encounters identified here may pump the orbital eccentricity of the companion such that Fomalhaut's debris disk experiences periodic close encounters with the companion.

Establishing whether or not the dust debris around Vega, ϵ Eri, and Fomalhaut is enhanced because of these recent ~1 pc encounters requires a comprehensive study using a control sample. Two more Vega-like stars that should also be studied closely are HD 17848 and HD 20010 (Sylvester & Mannings 2000; Walker & Wolstencroft 1988). We have discovered that HD 17848 and HD 20010 encountered each other with D_{ca} = 0.081 pc, t_{ca} = -351.2 kyr, and ΔV_{ca} = 44.2 km s^{-1}. The 1-σ uncertainty for D_{ca} is (-0.0488,+0.6250) pc.

Presently the greatest limitation in conducting these studies lies with the radial velocity catalogs, which have less than a third of the stars in the Hipparcos catalog. A definitive study of nemesis encounters will be possible after an all-sky radial velocity survey, such as the one proposed for GAIA, is completed, and after more sensitive astrometric catalogs become available, such as the one expected in ~2006 from the FAME mission.

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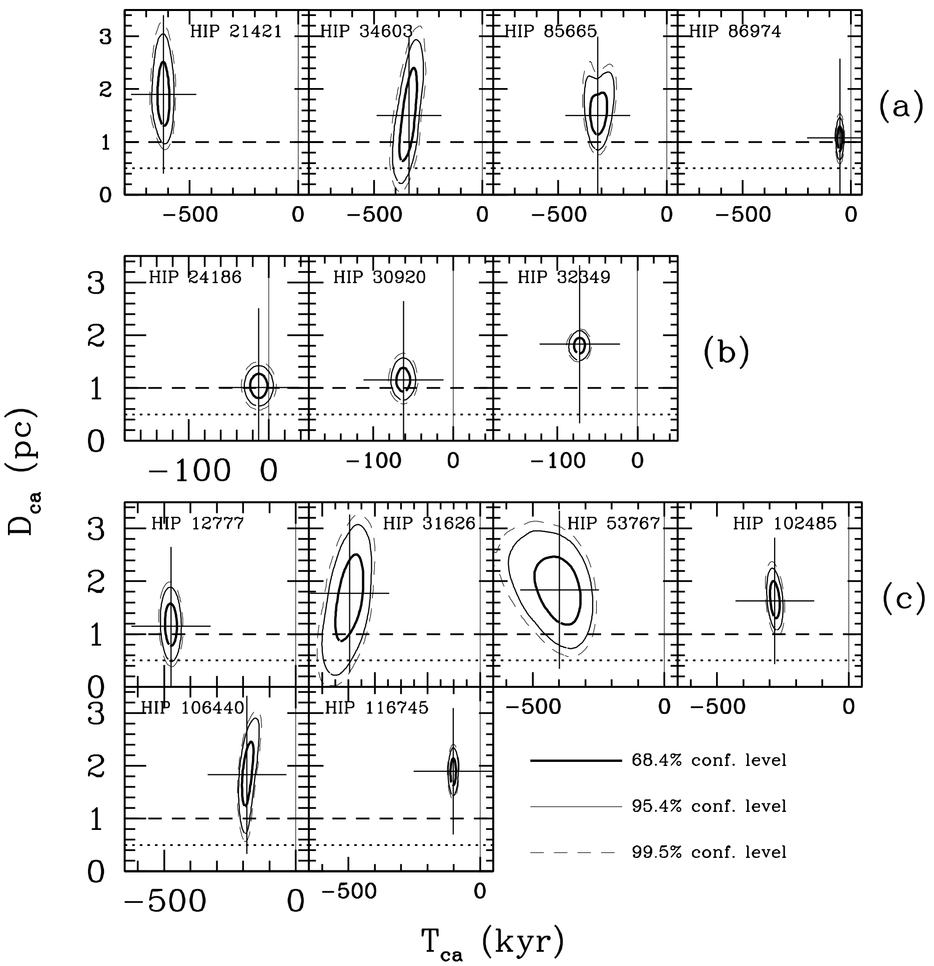

Figure 1. Isocontours for the Monte-Carlo distributions in the closest approach plane, (D_{ca}, t_{ca}), for the stars with $\bar{D}_{ca} < 2$ pc during the past 10^6 yr relative to: a) Vega, b) ϵ Eridani, and c) Fomalhaut. Bold contour: 68.3% confidence level, thin contour: 95.4%, and dashed contour: 99.5% confidence level. The contours outline the decreasing probability of finding the star at a more specific location at a given time due to uncertainties in position, proper motion, radial velocity, and parallax. Each cross marks the maximum of the probability distribution derived from the Monte Carlo simulation (the size of the cross has no significance). For a fixed uncertainty in the observables, the area of contours will grow the farther back in time an encounter occurs. Horizontal lines mark $D_{ca} = 1$ pc and $D_{ca} = 0.5$ pc. Note that the nemesis search extended to t_{ca} = -1000 kyr, but here we plot each x-axis only as far back in time as required to encompass the oldest <2 pc encounter within the 10^6 yr timeframe.