MONITORING NEARBY STARS FOR TRANSITS BY EXTRASOLAR JOVIAN PLANETS

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Presented at the 84th AAVSO Spring Meeting, May 13, 1995

Abstract

Periodic temporary dimmings of a star caused by transits (passages between the star and the Earth) of a Jovian planet orbiting it offer possibilities for discovering extrasolar planets (planets orbiting stars other than the Sun). This paper investigates such transits for 10 nearby stars: the magnitude changes (Δm) expected, probabilities for occurrence, and total transit durations are calculated for transits by Jovian planets of 70,000 km and 25,000 km radii. Methods for detecting transits are discussed. The possibility of AAVSO involvement in searches for transits of nearby stars by extrasolar Jovian planets is discussed in connection with flare star monitoring and the AAVSO's education program. Finally, 21st century searches for extrasolar planets with spacecraft, including unmanned interstellar spacecraft launched towards some nearby stars, are briefly mentioned.

1. Introduction

The nearby stars Gliese 144, 406, 411, 445, 551, 699, 820A, 820B, 882 (51 Pegasi, for which a Jovian-mass planet was recently detected), and Gliese 905 have been selected for investigation. Transits are investigated for (a) a planet with the size (radius $R_p = 70{,}000$) and mass of Jupiter, and (b) a planet with a size ($R_p = 25{,}000$ km) and mass near those of Uranus and Neptune.

The second smaller Jovian planet is included because planets of Jupiter's mass may be rare; only one such planet has been detected orbiting one (Gliese 882) of the 31 nearby main-sequence stars for which Marcy and Butler (1995) have made accurate radial velocity measurements and analyses (see also Lissauer 1995; Wetherill 1994).

2. Procedure

A star's luminosity L_s, effective temperature T_{eff}, and radius R_s are related by the equation

$$L_s = 4\pi R_s^2 \, \sigma \, T_{eff}^4 , \qquad (1)$$

where σ is the Stefan-Boltzmann constant for black body radiation. Thus, estimates of L_s and T_{eff} values for a star allow its radius R_s to be estimated from equation (1). The magnitude changes Δm caused by non-partial transits of a planet of radius R_p across a star's uniform disk is found from the equation

$$\Delta m = -2.5 \log (1-(R_p/R_s)^2). \qquad (2)$$

Probabilities were calculated for the occurrence of transits by Jovian planets (assuming random orientations for their orbits) for star-planet distances from 0.17

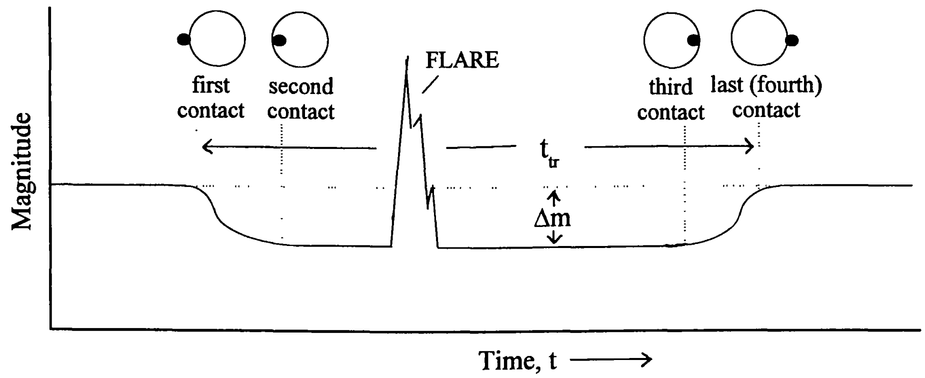

Figure 1. Diagram of a light curve for the transit of an extrasolar Jovian planet across the disk of its star. This diagram also shows the effect on the light curve of a flare occurring during transit.

astronomical unit (a.u.), which was taken from Benedict *et al.* (1994) for a possible Jovian planet of Gliese 551, to 5 a.u. (the approximate Sun-Jupiter distance). The 0.17 a.u. star-planet distance now seems more plausible since the recent discovery of a Jovian-mass planet at about 0.05 a.u. from Gliese 882, a star with about the Sun's luminosity and density.

The expected total times of transit (from first to last contact; see Figure 1) were calculated for transits by Jovian planets at star-planet distances from 0.17 a.u. to 5 a.u. for the stars considered here.

3. Results

Values of Δm calculated from equation (2) for the Jovian planets considered transiting the disks of the stars considered are shown in Table 1. Their Gliese numbers

Table 1. Results of calculations of magnitude changes Δm during non-partial transits.

Star				Estimated				
Gliese No.	Other Designation	V mag.	Distance r_o, pc	$(L_s/L_\odot)$	T_{eff}, K	R_s, km	Δm, magnitude R_p=70,000 km	R_p=25,000 km
882	51 Pegasi	$5^m.50$	14	1.00	5750	700,000	$0^m.011$	$0^m.0014$
144	ε Eridani	3.73	3.27	0.30	4800	580,000	0.016	0.002
820A	61 Cygni A	5.21	3.46	0.15	4400	470,000	0.024	0.0031
820B	61 Cygni B	6.03	3.46	0.09	4100	420,000	0.030	0.00385
411	Lalande 21185	7.48	2.53	0.019	3500	260,000	0.082	0.0101
445	AC+79 3888	10.48	5.22	0.0056	3300	160,000	0.231	0.0268
699	Barnard's star	9.55	1.83	0.004	3100	155,000	0.248	0.0286
905	Ross 248 HH And	v12.29	3.17	0.0018	2600	145,000	0.288	0.0328
551	Proxima Cen α Cen C V645 Cen	v11.05	1.30	0.0017	2700	132,000	0.358	0.0397
406	Wolf 359 CN Leo	v13.45	2.39	0.0013	2500	130,000	0.372	0.041

Note: The letter "v" before a V-magnitude value indicates that the star, and so the magnitude, is variable.

(Gliese and Jahreiss 1991) and other designations are shown in columns 1 and 2, respectively. Column 3 shows the star's visual magnitude V, while column 4 shows its present distance r_o in parsecs (pc). The estimated ratio of the star's luminosity to that of the Sun ($L_s/L_\odot$) and its estimated T_{eff} and R_s are shown in columns 5, 6, and 7, respectively. The Δm values found are shown in columns 8 and 9 for transits by planets with radii of 70,000 km and 25,000 km, respectively.

We see that a Jupiter-size planet can, while transiting the red dwarf stars Gliese 445, 699, 905, 551, or 406, dim the star enough ($\Delta m \geq 0.2$ magnitude) for the transit to be detectable by visual telescopic observation. However, there are two difficulties associated with observing these stars: first, they are quite faint (V = magnitude 9.55 or fainter), thus requiring use of a telescope with at least a 15-cm aperture; and second, Gliese 406, 551, and 905 are variable stars with the designations CN Leo, V645 Cen, and HH And, respectively (see Table 1). This complication will be discussed below.

The largest Δm value predicted for a Uranus-size planet ($\Delta m \approx 0.04$ magnitude) transiting Gliese 406 requires photoelectric or CCD photometry under good sky conditions with a large telescope to detect transits reliably.

The probabilities found for the occurrences of transits are all low, 0.0088 or less, for all stars except Gliese 882, whose recently discovered planet had a ~0.1 probability of transiting it. Because the predicted dimming of Gliese 882 is very slight ($0.0014 \leq \Delta m \leq 0.011$ magnitude), transits of it by its planet should be searched for using the most accurate photometry available, preferably with the High Speed Photometer of the Hubble Space Telescope. Planets 5 a.u. from their stars all have low probabilities (from 0.0002 [Gliese 406] to 0.001 [Gliese 882]) for transiting them. Probabilities for catching planets actually transiting their stars are somewhat less (0.00007 to 0.0025) than those found for their possible occurrences. The probability for catching the planet of Gliese 882 transiting it is 0.03 or less, but the times of possible transits should be able to be predicted quite accurately from the radial velocity curve of Gliese 882.

The durations found here for transits are from a few hours to 1.4 days. A transit of Gliese 882 by its planet would last 3 hours or less.

4. Discussion

The results above and in Table 1 show that ground-based observers with small- and medium-aperture telescopes can detect transits of Jovian planets across nearby stars, and that they can visually detect transits of Jupiter-size planets across low-luminosity red dwarfs. The total transit times found (several hours or longer) indicate that the flares which occur on many red dwarfs, such as Gliese 406 and 551, can usually be allowed for, since flare stars will usually return to their normal brightnesses after at most 10 minutes (see Figure 1).

The situation is different for transits of Uranus-size planets, which may be much more common than Jupiter-size ones, as noted above. Their reliable detection requires the use of photoelectric or CCD photometry.

Accurate light curves for transits of extrasolar planets across the disks of their stars will enable one to distinguish between a short transit duration caused by a far off-center transit of a distant planet from one caused by a nearly central transit of a much closer planet, which is shown in Figure 1. Methods of interpreting eclipsing binary light curves should find many applications in interpreting the light curves of transiting extrasolar planets. Information which could be extracted from light curves includes a planet's radius relative to the star's radius, the star-planet distance, and possibly to the star's limb darkening.

Table 2. Some stars which will come closest to the Sun during the next 50,000 years

Gliese Number	Predicted minimum distance from the Sun r_{min}		Predicted year of minimum distance, Gregorian calendar year
	parsecs	a.u.	
411	1.28	292,000	22,000
445	0.977	201,000	45,900
551	1.078	222,000	26,800
699	1.152	238,000	11,800
905	0.945	195,000	38,300

5. The next century

One expects searches for extrasolar planets in the 21st century to be made mainly from spacecraft. Some space-based methods for detecting extrasolar planets will probably be using large opaque plates in deep space to block a star's light so that any planets near it can be detected, using interferometry, and using gravitational microlensing. Finally, unmanned robot interstellar spacecraft launched toward nearby stars could become future observatories to search for extrasolar planets during fly-bys of those stars. A conference on the feasibility of interstellar spaceflight was held in New York City in September 1994.

Gliese 411, 445, 551, 699, and 905 are approaching the Sun and will pass closest to it during the next 50,000 years; they are listed in column 1 of Table 2. Their predicted minimum distances from the Sun (r_{min}) are given in parsecs and a.u. in columns 2 and 3, respectively, and the predicted years for their minimum distances are given in column 4. At least two unmanned interstellar missions have been suggested for launch within the next 50 years. The Thousand Astronomical Unit (TAU) mission was suggested for launch in 2005, and while not aimed toward any particular star, it is intended to reach a distance of 1,000 a.u. from the Sun by 2055 (Meinel and Meinel 1986; Nock *et al.* 1986). West (1985) suggested launching a spacecraft between 2025 and 2030 which, after fly-bys of Jupiter (2041) and Pluto (2052), will eventually fly by Gliese 905 about the year 37,200, when Gliese 905 will be close to its minimum distance from the Sun.

6. Conclusions

(a) The low probabilities found for the occurrence of transits by extrasolar planets indicate that an enormous amount of telescope time will probably be needed before even one extrasolar planet is discovered by this method of monitoring nearby stars.

(b) Low-luminosity red dwarf stars will permit easier detection of transits by Jovian planets, since they produce larger values of Δm during transits of red dwarfs than of more luminous solar-type stars.

(c) Searches for transits of extrasolar planets across the disks of their stars seem to be ideal tasks for automated patrol telescopes.

(d) The monitoring of nearby stars for transits by extrasolar planets seems to be a suitable method for their discovery (along with astrometry and precise radial velocity spectroscopy). The AAVSO could consider monitoring nearby stars, especially red dwarfs (which include many flare stars), for transits by extrasolar Jovian planets. This project could be used in the AAVSO's educational program to interest young people in the search for extrasolar planets, which will continue for centuries and perhaps even for millennia.

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