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LAMBDA TAURI: A PROBE OF ANGULAR MOMENTUM LOSS IN ALGOL BINARIES

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ABSTRACT

The stability of the orbits of the triple system λ Tau is considered at various points during the evolution of the mass-transferring binary. A surprisingly low upper limit of 50% for the orbital angular momentum loss of the inner (Algol-like) binary is derived from the requirement that the system was stable when the mass ratio of the inner binary was unity.

Subject headings: stars: eclipsing binaries — stars: individual

The triple system λ Tau (Fekel and Tomkin 1982) contains an apparently fairly normal semidetatched binary of Algol type ($P = 3^{\mathrm{d}}.95$) and a third invisible component orbiting the Algol with $P' = 33^{\mathrm{d}}$. The masses are approximately 7.2 and 1.9 $M_\odot$ for the Algol pair (the cooler star being the less massive, and presumably Roche-lobe-filling) and 0.7 ± 0.2 $M_\odot$ for the third component. Fekel and Tomkin (1982), using the criterion of Harrington (1975), find the triple orbit to be far from unstable. However, Harrington (1977) has pointed out that this formula is inappropriate for these masses. Recently the revised formula of Harrington (1977) has been criticized and a new formula for stability proposed (Black 1982). This formula is accurate for most masses, but in the area of nearly equal masses disagrees with the analytic results of Szebehely and Zare (1977) by what amounts to a factor of 2 in the crucial parameter q/a, where q is the periastron of the outer orbit and a is the semimajor axis of the inner orbit. The calculations of Harrington (1975), however, agree more closely with the analytic results than with Black's criterion (Black 1982), as do our integrations for this specific case.

Using an N-body code kindly supplied by Dr. Aarseth (Aarseth 1972; Ahmad and Cohen 1973), we investigated the stability of the λ Tau system numerically, in its present configuration and at various hypothetical epochs during its past and future evolution. At each epoch, several three-body integrations were performed for different periods of the Algol pair. Each integration started with all three bodies in a straight line, and with coplanar velocities perpendicular to the line. The Algol pair were given velocities and separations which would put them in a circular orbit of the chosen period in the absence of the third body. The third body was placed in a position and given a velocity which would put it in a circular prograde orbit with the Algol pair, considering the latter as a single point. The second orbit was always given a period of 33^{d}. We followed each model for 150 orbits of the Algol binary, looking for dynamical instability. This was defined in the usual way as a secular change in the orbits. In practice it was always obvious, resulting in ejection of the outer body or the formation of a highly eccentric long period outer orbit, over a few tens of Algol orbits. The integrations were accurate to one part in 10^6 over one Algol orbit; increased accuracy made no difference to the results reported here.

The present configuration was found to be stable, although the Algol orbit was found to have a variable eccentricity in the neighborhood of 0.005. We expect that this must be reflected in the mass transfer rate, an effect which may be observable. In order to damp this eccentricity, tidal friction would have to operate on a time scale of a few orbits. Variations in the period of the Algol were also found, again of magnitude 0.5%. We hope to explore the possible consequences of such a varying eccentricity and period in an Algol binary in a future paper.

We also modeled several future epochs, increasing the mass ratio of the Algol and hence its period ($P^{-1} \propto m_1^3 m_2^3$) on the assumption of conserved orbital angular momentum. We found that the three-body orbit will become unstable if (or when) the loser in the Algol has reduced its mass to about 1.3 $M_\odot$, corresponding to $P \sim 10^{\mathrm{d}}$ on the conservative assumption. More importantly, we also examined the system at the epoch of equal masses. Again on the conservative assumption, the period of the Algol would have been shortest ($P = 1^{\mathrm{d}}.12$) at this epoch. Such a system is (predictably) stable. However, the system may have undergone loss of angular momentum, and so the period at equal masses may have been longer. We tried various periods for the inner orbit and found that instability set in for $P \geq P_{\mathrm{crit}} \sim 9^{\mathrm{d}}.9$. In the neighborhood of P_{crit}, models with initial inner periods differing from each other by $0^{\mathrm{d}}.1$ were tried, and we found stability for $P < 9^{\mathrm{d}}.9$. P_{crit} therefore appears to be a well-defined upper limit on P at the epoch of equal masses. This corresponds to an upper limit on the orbital angular momentum of the Algol at that time, and

TABLE 1

ORBITAL PERIODS FOR VARIOUS MASS RATIOS

Epoch	m_1 ($M_\odot$)	m_2 ($M_\odot$)	P_{cons} [a] (days)	P_{crit} [b] (days)
Hypothetical initial conditions ...	2.27	6.80	2.68	10.2
	3.07	6.00	1.58	10.1
Equal masses	4.535	4.535	1.12	9.9
Present	7.18	1.89	3.95	10.2
Future dynamical instability	7.80	1.27	10.16	10.2

[a] Period of inner (Algol) orbit given angular momentum conserved.
[b] Maximum orbital period for dynamical stability of triple system.

hence an upper limit on the loss of angular momentum between then and now. Since angular momentum varies as $P^{1/3}$ for given masses, this gives a maximum angular momentum loss of 52%, while the loser must in the same interval have transferred 60% of its mass. To have lost more angular momentum, the Algol would have had to be sufficiently wide in the past that the third body's orbit would have been disrupted. This is clearly an upper limit, since the system cannot have started with equal masses. We explored hypothetical initial mass ratios of 2:1 and 3:1, and redetermined P_{crit} as described above. The limits on angular momentum loss in these cases are 45% and 35%, respectively.

Table 1 shows the masses m_1 and m_2 of the gainer and loser of the Algol at various hypothetical points during its evolution. For each epoch the period P_{cons} of the Algol is given using the conservative assumption. P_{crit} is the smallest period for which dynamical instability sets in in our three-body computations, given the inner masses, and the third body of mass 0.7 $M_\odot$ orbiting the Algol barycenter with $P' = 33^d$ and (initially) zero eccentricity. Harrington's (1977) formula correctly predicts that the present system is stable, and also predicts that it will become unstable at $q/a = 3.3$, which for circular orbits corresponds to a period ratio of 5.9 or less. Harrington remarks that systems with eccentricity of the inner orbit of less than 0.2 will tend to be somewhat more stable than his formula predicts, as is borne out by our calculations.

The limits derived for the orbital angular momentum loss in the Algol can be modified if one supposes that mass as well as angular momentum was lost by the Algol pair. Eccentricity in the outer orbit, for which Fekel and Tomkin (1982) found $e = 0.15 \pm 0.08$, would tend to tighten our limits, since the important parameter q/a (Harrington 1975) would be smaller for a given outer period. These limits could of course be rendered meaningless if one supposes that the outer orbit has shrunk by some considerable amount. We believe the latter is rather contrived and implausible.

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