resonance condition for bump Cepheids. Possible resolutions to these problems include a deep Fe convection zone whose effect would be to lower the period ratios (Cox 1993), and/or an opacity increase near 1 x 10^6K, which could extend the blue loops (Stothers & Chin 1994). Each of these schemes require more research.

Finally, we point out a difficulty involving the long-period Cepheids, $P_0>20$d. Because these stars do not seem to be exceedingly rare, either in the Galaxy or Magellanic clouds, they should correspond to "slow" evolutionary timescales, which are generally associated with the tips of the blue loops. However, for $M>7M_\odot$ (high masses are necessary to give the long periods in question, for reasonable values of T_{eff}), the evolutionary tracks display loops which are too long, so that the tips occur well blueward of the instability strip. This means that for the requisite masses, passage through the instability strip is so rapid that few long-period Cephids ought to be seen. At metallicities corresponding to those of the LMC and SMC, respectively, all of the long-period Cepheid sample in the Clouds is to be accounted for, a way will be needed to slow the evolution of high mass models through the strip.

Andrievsky, S.M., Kovtjukh, V.V. Makarenko, E.N. & Usenko, I.A. 1993, MNRAS, 265,257
Bressan, A., Fagotto, F., Bertelli, G. & Chiosi, C. 1993, A & AS, 100, 647
Buchler, J.R., Moskalik, P. & Kovacs, G. 1990, ApJ, 351, 617
Cox, A.N. 1993, in New Perspectives on Stellar Pulsations and Pulsating Variable Stars, ed. J.M. Nemec & J.M. Matthews (Cambridge: Cambridge University Press), 261
El Eid, M.F. 1994, A&A, 285, 915
Kanbur, S.M. & Simon, N.R. 1994, ApJ 420, 800
Moskalik, P., Buchler, J.R. & Marom, A. 1992, ApJ, 385, 685
Schaller, G. Schaerer, D., Meynet, G. & Maeder, A. 1992, A&AS, 96, 269
Simon, N.R. & Kanbur, S.M. 1994, ApJ, in press (July 10)
Simon, N.R. & Schmidt, E.G. 1976, ApJ, 205, 162
Stothers, R.B. & Chin, C.-W. 1991, ApJ, 381, L67
Stothers, R.B. & Chin, C.-W. 1994, preprint

CEPHEID VARIABLES: PERIOD AND MASS DETERMINATION

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Determination of masses has been a long standing problem in the Cepheid research. Since the early days of Cepheid modeling different methods of mass calibration have lead to conflicting results, implying serious discrepancies between the evolution and pulsation theories (see Cox 1980 for a review). In recent years this situtation has been mostly remedied, and the Baade-Wesselink masses, pulsation masses and evolutionary masses are now in good agreement with each other (e.g., Gieren 1989). However, both the bump

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masses inferred from the position of the secondary bump on the lightcurve and the beat masses obtained from the period ratios of the double mode Cepheids turned out to be very resilient to a reconciliation.

There are 13 Cepheids in the Galaxy in which two vibrational modes are simultaneously excited (e.g., Szabados 1988). The period ratios measured in these variables can be used in conjunction with the linear pulsation theory to infer the masses of these stars. The method was first applied by Petersen (1973) who obtained masses ranging from $1M_\odot$ to $3M_\odot$ for Cepheids with fundamental mode periods between 2.1 d and 6.3 d. Such "beat" masses are 2—4 times smaller than the evolutionary or Baade-Wesselink masses for these objects.

Numerous classical Cepheids display a secondary bump on their light and velocity curves. For short periods the bump appears on the descending branch of the lightcurve. With increasing period the bump shifts to progressively earlier phases, and finally moves to the ascending branch. The switch-over occurs at a period of about 10 days. When the first hydrodynamical Cepheid models became available (Christy 1968; Stobie 1969ab) it was immediately realised that the location of the bump depends on the stellar radius and therefore can be used to infer Cepheid radii and then masses. The "bump" masses derived in this way turned out to be about 30-50% too low as compared to other mass determinations for the same stars.

The advent of the OPAL (Iglesias, Rogers & Wilson 1992) and OP (Seaton, Yu Yan, Mihalas & Pradhan 1994) opacity tables has a profound impact on the Cepheid beat and bump mass problem (Moskalik, Buchler & Marom 1992; Moskalik & Buchler 1993; Kanbur & Simon 1994). The new metal bump in the opacities around $T = 2 — 5 \times 10^5$K modifies the structure of the Cepheid models in such a way that the period ratios become significantly reduced as compared to those obtained with the Los Alamos tables. The size of this effect depends on the overall metallicity Z.

The new beat masses for the Galactic double mode Cepheids ($Z = 0.02$) are between $3.9M_\odot$ and $6.1M_\odot$, if the standard Becker, Iben & Tuggle (1977) M - L relation is assumed for the calibrating models. These masses are in good agreement with both the Baade-Wesselink masses and with the evolutionary masses derived with the same M - L relation. The long standing conflict between the pulsation theory and the evolution theory, known as the "beat mass discrepancy", has been finally resolved.

The occurrences of the lightcurve bumps and the Hertzsprung progression have their origin in the 2:1 resonance between the fundamental mode and the second overtone (Simon & Schmidt 1976; Buchler, Moskalik & Kovacs 1990). This implies that the bump masses, like the beat masses, are in fact based on the period ratios. Therefore, they can be also studied within the linear pulsation theory. The observational constraint of placing the center of the bump progression at $P = 10.0 \text{ d} \pm 0.5 \text{ d}$ is equivalent to the requirement that the resonance center is located at this period.

With the new opacities and for an assumed metallicity of Z = 0.02, the new opacities yield bump masses at P = 10 d ranging from $5.90M_{\odot}$ to $5.68\pm0.9M_{\odot}$, depending on the adopted Cepheid luminosity scale. This is in a very good agreement with the Baade-Wesselink masses at the same period. Indeed, the two most recent Cepheid radii calibrations (Gieren, Barnes & Moffett 1989; Laney & Stobie 1995) lead to Baade-Wesselink masses of $6.55\pm0.9M_{\odot}$ or $5.68\pm0.9M_{\odot}$, respectively. New bump masses fall comfortably between these values.

The new bump masses are still somewhat low in respect to the standard evolutionary masses of Becker, Iben & Tuggle (1977), which are between $7.03M_{\odot}$ and $7.46M_{\odot}$ (again depending on the luminosity scale). However, the deficit is greatly reduced and is now only 16%. This remaing discrepancy can be entirely removed by adopting the evolutionary tracks with mild convective core overshooting of 0.5—0.7 H_p.

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Becker, S.A., Iben, I. & Tuggle, R.S. 1977, *Astrophys. J.*, **218**, 633
Buchler, J.-R., Moskalik, P. & Kovacs, G. 1990, *Astrophys. J.*, **351**, 617
Christy, R.F. 1968, *Quart. J. R. Astron. Soc.*, **9**, 13
Cox, A.N. 1980, *Ann. Rev. Astron. Astrophys.*, **18**, 15
Gieren, W.P. 1989, *Astron. Astrophys.*, **225**, 381
Gieren, W.P., Barnes, T.G. & Moffett, T.J. 1989, *Astrophys. J.*, **342**, 467
Iglesias, C.A., Rogers, F.J. & Wilson, B.G. 1992, *Astrophys. J.*, **397**, 717
Kanbur, S.M. & Simon, N.R. 1994, *Astrophys. J.*, **420**, 880
Laney, C.D. & Stobie, R.S. 1995, *MNRAS* (in press)
Moskalik, P., Buchler, J.-R. & Marom, A. 1992, *Astrophys. J.*, **385**, 685
Moskalik, P., Buchler, J.-R. 1993 in *New Perspectives on Stellar Pulsation and Pulsating Variable Stars*, IAU Coll. 139, Eds. J.M. Nemec & J.M. Matthews (Cambridge: University Press), p. 237
Petersen, J.O. 1973, *Astron. Astrophys.*, **27**, 89
Seaton, M.J., Yu Yan, Mihalas, D. & Pradhan, A.K. 1994, *MNRAS*, **266**, 805
Simon, N.R. & Schmidt, E.G. 1976, *Astrophys. J.*, **205**, 162
Stobie, R.S. 1969a, *MNRAS*, **144**, 485
Stobie, R.S. 1969b, *MNRAS*, **144**, 511
Szabados, L. 1988, in *Multimode Stellar Pulsation*, Eds. G. Kovacs, L. Szabados & B. Szeidl (Budapest: Konkoly Observatory), p.1