Blitz, L. 1988, in "Structure of Galaxies", Proc. 10[th] European Regional Meeting of the IAU, ed. J. Palous (Czech Academy of Sciences, Prague), p. 204.
Danks, A.C., Federman, S.R. and Lambert, D.L. 1984, *Astron. Astrophys.* **130,** 62.
Désert, F.X., Bazell, D., and Boulanger, F. 1988, preprint.
de Vries, C.P. and Le Poole, R. 1985, *Astron. Astrophys.,* **145,** L7.
de Vries, C.P. and van Dishoeck, E.F. 1988, *Astron. Astrophys.,* in press; and in preparation.
Hobbs, L.M., Blitz, L., and Magnani, L. 1986, *Astrophys. J. (Letters),* **306,** L109.
Knapp, G.R., Drdla, K., and van Dishoeck, E.F. 1988, in preparation.
Magnani, L., Blitz, L., and Mundy, L. 1985, *Astrophys. J.,* **295,** 402.
Magnani, L., Blitz, L., and Wouterloot, J.G.A. 1988, *Astrophys. J.,* **326,** 909.
Mattila, K. 1986, *Astron. Astrophys.,* **160,** 157.
van Dishoeck, E.F. and Black, J.H. 1988*a, Astrophys. J.,* submitted.
van Dishoeck, E.F. and Black, J.H. 1988*b,* in *Rate Coefficients in Astrochemistry,* eds. T.J. Millar and D.A. Williams (Kluwer, Dordrecht), in press.

Evolutionary Features in Distant Clusters of Galaxies

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1. Introduction

The study of distant clusters of galaxies is fascinating and fundamental for a variety of astrophysical problems ranging from the understanding of the evolution of the galaxies as a function of the cosmic time to the comprehension of the large scale structure of the Universe. Relevant contributions on this topic occurred in the recent years, following the pioneering work of Gunn and collaborators (Gunn, Hoessel and Oke, 1986) in the detection of clusters at high redshift, of Butcher and Oemler (1984) in emphasizing possible evolutionary effects present in distant galaxies and of Tinsley (1977) with her theoretical work.

No matter what our goals are, in observational cosmology we are always faced with the problem of using galaxies as tracers of the geometry of space, measuring their position in the sky and estimating their luminosity and distance. This is a relatively simple task if we refer to the nearby region of space, say, at cosmological distances smaller than z = 0.2. Here galaxies are still relatively bright and extended objects and they can be recognized and easily separated from stars. However, as soon as we look deeper in space, attempting to study galaxies located farther away, we start dealing with almost unresolved faint objects and it becomes difficult both to measure redshifts and estimate uncontaminated counts as a function of the magnitude (Fig. 1).

A way around the problem may be to use a combined approach by means of a multicolour photometry (Loh and Spillar, 1986, Rakos, Fiala and Schombert, 1988) properly matched with a set of evolutionary photometric models of galaxies. With this in mind, we started some time ago with a long term project on distant clusters. In this paper we present some of the preliminary results we have obtained; the observations have been carried out at La Silla and the analysis in Milano where, with the help of the ESO staff, we have installed the needed software for the data reduction.

2. Observations

We observed two high redshift clusters taken from the survey published by Gunn, Hoessel and Oke (1986): 2158 + 0351 at a nominal redshift of z = 0.445 and 0020 + 0407 at z = 0.689. The redshifts were taken at their face value and should eventually be confirmed.

A set of CCD frames were collected during two observational runs at the Cassegrain focus of the ESO 3.6-m telescope in November 1986 and November 1987. We used the three-colour Gunn photometric system (Thuan and Gunn, 1976, Wade et al. 1979) and the EFOSC focal reducer.

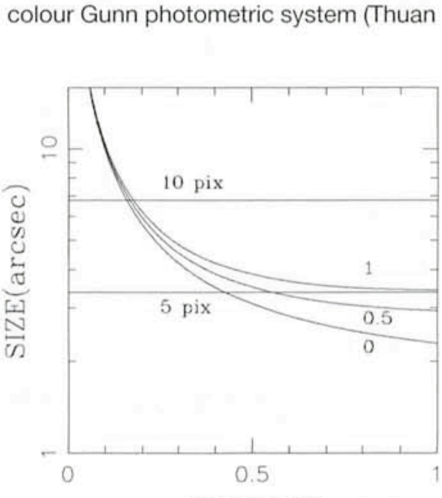

Figure 1: *The apparent size of the galaxies versus redshift. A galaxy size of 25 Kpc and a Hubble constant H_o = 50 are assumed. Each curve is labelled with the value of the deceleration parameter q_o. As a reference also the linear dimensions on our CCD frames are reported (the scale is 0.675 arcsec/pixel).*

The images were reduced using the MIDAS package (see Users Guide, Image Processing Group ESO V 4.3) installed in the reduction facilities of the Observatory of Brera while the detection of the objects in each frame and their photometric measurements have been carried out using the INVENTORY software (West and Kruszewski, 1981) implemented in MIDAS. We are confident that our completeness is down to the magnitude r = 23.5 as it is apparent from a direct inspection of the features detected automatically in the CCD images. The uncertainty in the photometry of the faintest objects detected should be less than ± 0.3 magnitudes (for details see Molinari, 1988).

The two clusters are shown in Figures 2 and 3. These images have been obtained by adding the CCD frames at our disposal in the r band and are equivalent to an integration time of 50 minutes for 2158 + 0351 and 85 minutes for 0020 + 0407. In Figure 4 we have marked all the objects photometered in 2158 + 0351 just as an example of the completeness attained. No serious attempt has been pursued to discriminate between stars and galaxies using the analysis of the photometric gradient of the single features. This is because at such redshifts the galaxies are expected to be essentially seeing limited images and cover only a few pixels on the CCD frame. As shown also in Figure 5, the brightest members of 2158 + 0351 are 8 × 8 pixels wide and obviously the situation gets worse for the more distant cluster. It is because of this and the difficulty to always have subarcsec seeing that we decided to use a statistical approach to the photometric information available (magnitudes and colours).

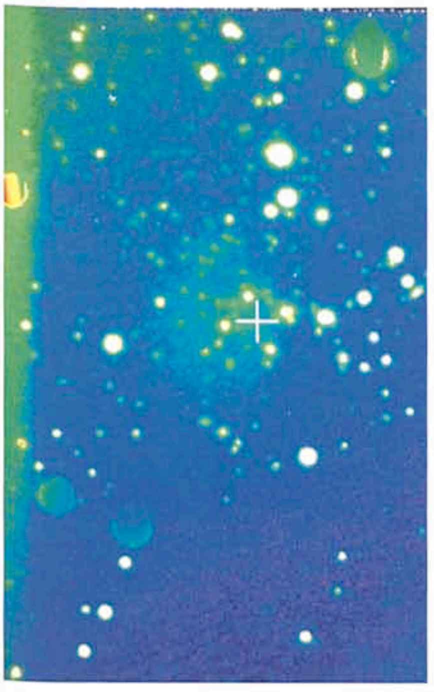

Figure 2: *Composed CCD frame in the r band of the central region (3.5 × 5.7 arcmin) of the cluster 2158 + 0351 at redshift z = 0.445. Cross marks the assumed centre of the cluster (see text for details). North is up, east to the left. (ESO 3.6-m + EFOSC; equivalent exposure time: 50 min.)*

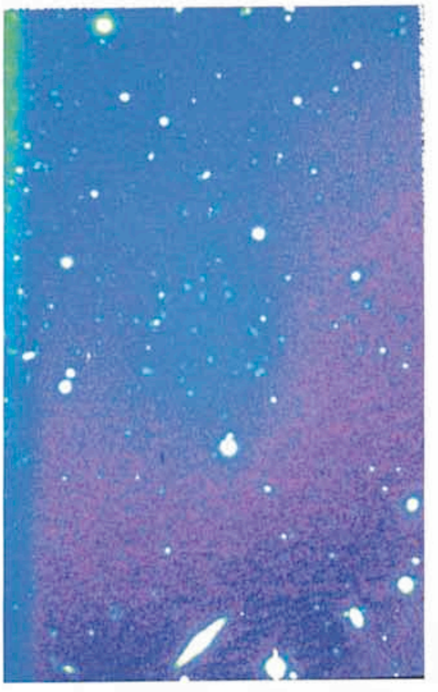

Figure 3: *The same as Figure 2 for the cluster 0020 + 0407 at z = 0.689. The magnitude limit is at least r = 24. (ESO 3.6-m + EFOSC; equivalent exposure time: 85 min.)*

Of course, when possible and at the cost of a large integration time, the analysis must be complemented by spectrophotometric observations.

3. Results

Assuming a (H_o, q_o) = (50,0) cosmology we derive a scale of 0.455 Mpc/arcmin and of 0.561 Mpc/arcmin respectively for the clusters at z = 0.445 and z = 0.689. A cluster core of about 0.5 Mpc would then cover about 98 and 79 pixels in our frames. That is the outermost region of each frame of 512 × 330 pixels is much more contaminated by fore-/background (stars and field galaxies) than the innermost one. We may attempt therefore a cleaning action (effects by non-members) by removing statistically the field as it is defined by the outermost region. We find 245 objects photometered on the whole r-frames of 2158 + 0351, whose 73 are placed in the region inside a circle centred as displayed in Figure 2 and of radius 92 pixels (a value very close to the expected core radius of the cluster). For 0020 + 0407 we divided horizontally the r-frames into three zones of equal area, assuming the cluster to be mainly in the central one. We find 196 objects in total, whose 88 are in the innermost region. Note however that due to the scarcity of objects the method suffers of some intrinsic uncertainties in carrying out a proper analysis of the cluster density profile. In any case the procedure overcomes the need of the individual identification of the galaxies and ensures the determination of the photometric information that is related to the cluster population.

The luminosity functions in the r band for the two clusters are plotted in Figure 6. They have been drawn in the integral form (i.e. cumulative counts) and have been normalized to their maximum value in order to ease their comparison. Such a normalization should be consistent, since the longer exposure time provided the completeness in the photometry of 0020 + 0407 at least at the same level of 2158 + 0351. The cluster 0020 + 0407 seems to be dominated by a larger amount of faint objects, when compared to 2158 + 0351. Moreover the overall morphology of the two clusters, as seen in Figures 2 and 3, is quite different. The cluster 2158 + 0351 is much more compact, symmetric and dominated by some bright elliptical galaxies while 0020 + 0407 shows a more spread (almost filamentary) structure with no evidence of dominating members; indeed even the fact that it is a real cluster may need spectroscopic confirmation.

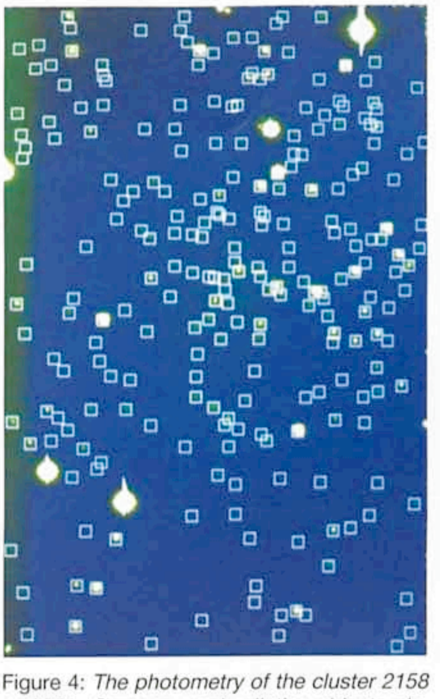

Figure 4: *The photometry of the cluster 2158 + 0351. Squares mark all the objects detected by the INVENTORY package and photometered in at least the r band (245 in total).*

4. Discussion

In the series of Figure 7 we have displayed the (g-r) vs. (g-i) colour diagrams for three subsamples of the objects photometered on our frames of 2158 + 0351. Panel (a) shows all the objects detected on the whole frame, panel (b) displays only the innermost region of the cluster (inside the 92 pixels radius) while in panel (c) come into view only the features of the outermost region (5 times wider in respect to the area of the innermost one). As a reference, contour levels are also reported on the panels. These refer to a smoothed representation of the overdensity due to the cluster galaxies after the field was removed statistically by properly combining panel (b) and (c). The smoothing has been obtained by filtering panel (b) and (c) with a beam of radius 0.15 magnitudes (displayed at the bottom of the figures). Four other curves are reported in the

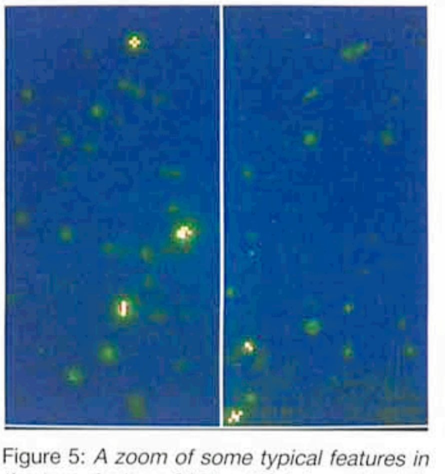

Figure 5: *A zoom of some typical features in the two clusters: 2158 + 0351 is on the left, 0020 + 0407 on the right. One sees that galaxies at these redshifts are essentially seeing limited objects.*

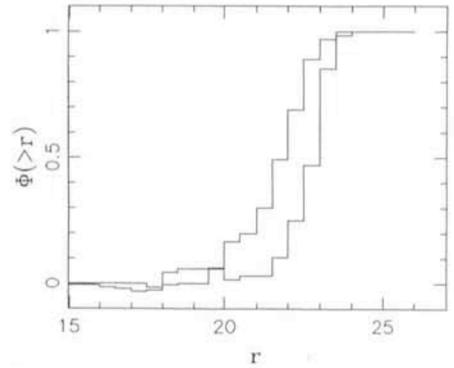

Figure 6: *The luminosity functions of the two clusters. The faintest curve refers to 0020 + 0407. Cumulative counts have been normalized to their maximum. A similar completeness in the photometry of the two clusters is assumed.*

figures: they show the expected changes in the apparent colours of the different morphological types of galaxies with varying redshift. In particular, the two "hooked" curves refer to the spirals and they have been calculated by passively redshifting mean spectral energy distributions of the present-day galaxies as they result from the work by Coleman, Wu and Weedman (1980).

The two other S-shaped curves refer to the models for elliptical galaxies (Buzzoni, 1987, 1988) and evidence the differences in the colours after evolution is taken into account. In the figure, the curve labelled with "nev" refers to a passive redshifted present-day model (closely representing mean local ellipticals) while the curve "ev" accounts for the rejuvenescence of the galaxies at higher redshifts. Crosses also mark the expected positions in the diagram for the different morphological types at the stated redshift z = 0.445. It is clearly seen that a marginal evidence of evolution in colour of the ellipticals seems to be present, within the photometric uncertainties, in the sense that the observed population is intrinsically bluer than the present-day descendants accounted for by the curve "nev". This fact is interpreted as due to the presence of a younger stellar component active in the past. One can also see in the figure that the splitting between evolved and non-evolved colours starts to be detectable around z = 0.4, increasing with increasing redshift. Note also from Figure 7 that an appreciable population of Sbc spirals seems to be present, since a bump in the colour counts peaks very close to the position expected for these galaxies around [(g-r), (g-i)] = [1,1].

This so fair accordance leads us to confirm that even at high redshift we do not expect a strong evolution in the intrinsic colours of the spirals: due to their continuous star formation rate they seem to be always dominated by young blue bright stars.

To completely exploit cosmological information coming from the photometry of the distant clusters we need to link observed magnitudes and colours with the two primary parameters that enable us to infer on the model of the universe: the absolute distance and the redshift. To do it we need a reliable calibration in order to take into account changes in the intrinsic properties possibly occurring in distant (young) galaxies. In this sense the direct comparison with the new grid of theoretical models of stellar populations (Buzzoni, 1987, 1988) seems to provide an effective tool to match the observed colours of the elliptical galaxies with redshift.

Indeed, one of the most encouraging results stemming from the work performed is that comparison of the observed mean colours of the ellipticals in the clusters with evolutionary models can provide a powerful method to determine redshift by only photometric information. As shown in Figure 8, if we plot the merit function in order to minimize the "distance" of the observed ellipticals from the theoretical locus in the colour-colour diagram, we are able to estimate z with an uncertainty of the order of ± 0.05: in fact for 2158 + 0351 we derive a formal value of z = 0.41, very close to the spectroscopic determination given by Gunn, Hoessel and Oke (1986). Our result confirms also the conclusions by Koo (1981), Couch et al. (1983, 1984), Ellis et al. (1985) and MacLaren et al. (1988) concerning the effectiveness of the photometric approach to recognize morphological types of distant galaxies and to estimate their redshift. However, since evolutionary effects become almost dominant at large distances they must be taken into account: otherwise photometric measurements of colours and redshift would be strongly biased in the sense that galaxies would be recognized to belong to later types and have systematically lower values of z.

As a further complementary evidence of the intrinsic evolution in luminosity of the galaxies, we note here that the observed difference of the distance moduli of the two clusters, as it appears from Figure 6, is less than the value expected for non-evolving galaxies, that turns to be around 2.0 magnitudes in the r band. This means in other words that the galaxies of the farthest (youngest) cluster 0020 + 0407 are intrinsically brighter than those of 2158 + 0351.

5. Conclusions

Work on high-redshift clusters of galaxies seems to contribute a quantity of meaningful constraints on the evolutionary status of the different hierarchical structures that populate the universe in the present and in the past. In particular we have shown here that the statistical analysis of the colour-col-

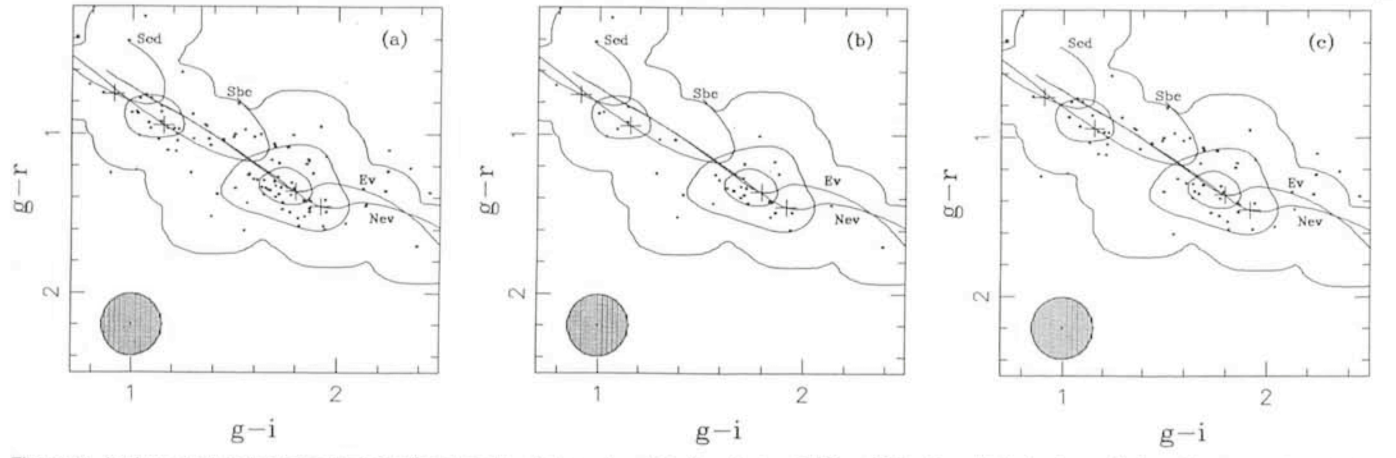

Figure 7: *(g-r) vs. (g-i) colour diagram for the objects photometered in the cluster 2158 + 0351. Panel (a) displays all the objects on the whole frame having measured g, r and i magnitudes (136 in total) and merges the points of panel (b) (45 objects inside a circle of radius 92 pixels centred in the core of the cluster) and of panel (c) (91 objects in the outermost region of the frame). See text for other details.*

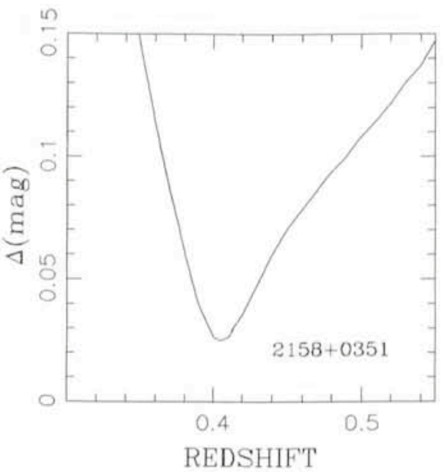

Figure 8: *The photometric determination of the redshift of the cluster 2158 + 0351. Displayed is the merit function which minimizes the difference between the colours (g-r) and (g-i) of the elliptical galaxies detected and those predicted by the evolutionary model of Figure 7.*

our diagram and of the luminosity function of the clusters obtained via an accurate multicolour photometry may provide an effective method (a) to discriminate galaxy morphology, (b) to evaluate their intrinsic evolution and (c) to estimate redshift with an accuracy of ± 0.05. We emphasize that two main requirements have to be fulfilled in order to reach such a fair resolution in exploring the universe at large distances:

(i) we need to observe clusters instead of field galaxies to be able to recognize them with high statistical confidence;

(ii) we need a combined comparison with evolutionary models, in order to properly account for the intrinsic photometric properties as we use galaxies as standard candles in the cosmological framework.

Such an approach is also preparatory to more detailed studies using the new generation telescopes (VLT) and will be complemented by deep surveys on selected fields possibly supported by spectrophotometric work.

References

Buzzoni, A.: 1987, in *Towards understanding Galaxies at Large Redshifts*, eds. R.G. Kron and A. Renzini, (Dordrecht: Reidel), p. 61.
Buzzoni, A.: 1988, in preparation.
Butcher, H. and Oemler, A.: 1984, *Ap. J.*, **285,** 426.
Coleman, G.D., Wu, C.C. and Weedman, D.W.: 1980, *Ap. J. Supp.*, **43,** 393.
Couch, W.J. and Newell, E.B.: 1984, *Ap. J.*, **56,** 143.
Couch, W.J., Ellis, R.S., Godwin, J. and Carter, D.: 1983, *M.N.R.A.S.*, **205,** 1287.
Ellis, R.S., Couch, W.J., MacLaren, I. and Koo, D.C.: 1985, *M.N.R.A.S.*, **217,** 239.
Gunn, J.E., Hoessel, I.G. and Oke, J.B.: 1986, *Ap. J.*, **306,** 30.
Koo, D.C.: 1981, *Ap. J.* (Lett), **251,** L 75.
Loh, E.D. and Spillar, E.J.: 1986, *Ap. J.*, **303,** 154.
MacLaren, I., Ellis, R.S. and Couch, W.J.: 1988, *M.N.R.A.S.*, **230,** 249.
Molinari, E.: 1988, Thesis dissertation, University of Milan.
Rakos, K.D., Fiala, N., Schombert, J.M.: 1988, *Ap. J.* **328,** 463.
Thuan, T.X. and Gunn, J.E.: 1976, *P.A.S.P.*, **88,** 543.
Tinsley, B.M.: 1977, *Ap. J.* **211,** 621.
Wade, R.A., Hoessel, I.G., Elisas, J.M. and Huchra, J.P.: 1979, *P.A.S.P.*, **91,** 35.
West, R.M., Kruszewski, A.: 1981, *Irish Astron. J.*, **15,** 25.

Trojan Search at ESO

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Doing minor planet research is sometimes considered a proof of bad taste among astronomers. It is a fact that asteroids, these rocky pieces between the orbits of Mars and Jupiter, have lost much of their interest, now that most of the larger ones have been catalogued: their orbits are well known, their chemical structure has been studied and their rotation properties investigated. Hence, chasing the smaller kilometer-sized members does not seem a useful occupation. Indeed, why should they be different from the larger ones?

I got engaged in asteroidal work in May 1986 (first GPO mission at ESO). Since that time my interest in asteroids has grown rapidly. In March 1988 I attended the "Asteroids II" conference in Tucson, Arizona. There I was really impressed by the wealth of possibilities in the field of minor planet research.

My primary interest are the Trojan asteroids, these objects that are describing their orbits at a mean distance of 5.2 A.U. from the Sun, i.e. at the 1 : 1 commensurability with Jupiter.

It is known from celestial mechanics that the problem of three bodies does not, in general, admit a finite solution in terms of known functions. Joseph Louis Lagrange (1736–1813), however, has shown that there is a solution in the special case that the three bodies (Sun, larger planet, asteroid) are moving in a fixed plane at equal distances from each other (triangular configuration). It is assumed that the mass of the third body (the asteroid) is negligible (Fig. 1).

The first object of this kind was found in 1906 at the Observatory of Heidelberg. The discoverer was the famous Max Wolf, and for some reason, he called his newly discovered asteroid "Achilles", after the hero from the Trojan war.

With the discovery of Achilles, a theoretical problem found an observational confirmation. Since then, more minor planets have been found at the so-called libration point L_4 and L_5 and all have been called after the heroes of Homer's Ilias.

It is interesting to note that we find only "real" Trojans (Priamus, Aeneas, Anchises . . .) at the libration point L_5 (preceding point) and Greeks (Achilles, Nestor, Agamemnon . . .) at L_4 (following point). This is of course a consequence of the appropriate naming convention.

However, one Trojan (Hector) is at L_4 and one Greek (Patroclus) at L_5. The motion of a Trojan is very complex, it will not remain constantly at L_4 or L_5; small changes from the triangular configuration will result in oscillations around these points. The theory of predicting

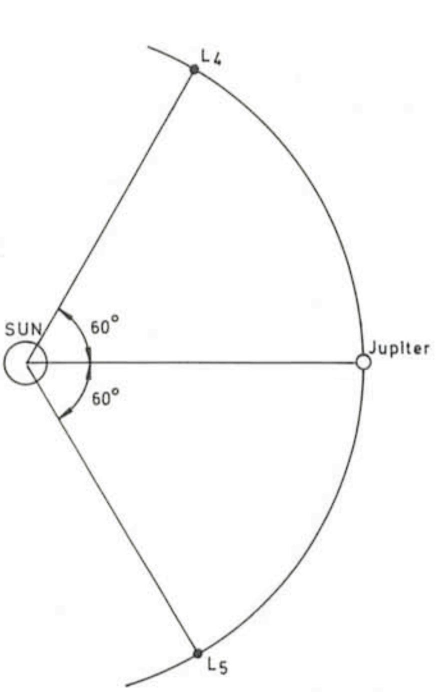

Figure 1: *Triangular configuration.*