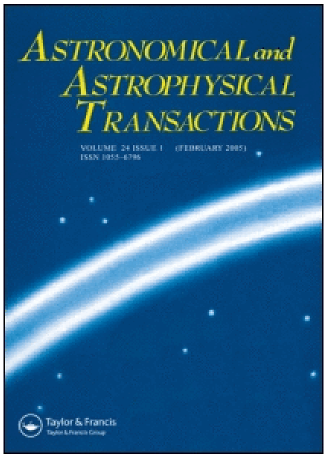

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

The signatures of the shock wave in the spiral ARM S4 of the andromeda galaxy

Yu. N. Efremov [a]
[a] Sternberg Astronomical Institute, Moscow, Russia

Online Publication Date: 01 June 2001
To cite this Article: Efremov, Yu. N. (2001) 'The signatures of the shock wave in the spiral ARM S4 of the andromeda galaxy', Astronomical & Astrophysical Transactions, 20:1, 115 - 118
To link to this article: DOI: 10.1080/10556790108208196
URL: http://dx.doi.org/10.1080/10556790108208196

Astronomical and Astrophysical Transactions, 2001,
Vol. 20, pp. 115–118
Reprints available directly from the publisher
Photocopying permitted by license only

THE SIGNATURES OF THE SHOCK WAVE IN THE SPIRAL ARM S4 OF THE ANDROMEDA GALAXY

Yu. N. EFREMOV
Sternberg Astronomical Institute,
13, Universitetskij pr., Moscow 119899, Russia,
E-mail efremov@sai.msu.ru

(Received December 15, 2000)

Straight segments are found along the SW segment of the spiral arm S4 of M31. According Chernin's theory, this is explained by the spiral shock wave along the segment of the arm. This is compatible with other evidence for the shock wave along this segment, which includes the high value of the orthogonal component of the velocity difference between the gas of the galaxy and the spiral pattern, and the concentration of OB stars along the inner edge of the spiral arm.

KEY WORDS Galaxies: individual (M31) – galaxies: spiral – galaxies

1 INTRODUCTION

The investigation of the structure of the spiral arms is the best way to understand their nature. The grand design pattern of the arms, delineated by the long and symmetric arms has been explained by the density wave theory (Lin and Shu, 1964). This theory of spiral arms predicts a gradient of stellar ages across the arm. Inside the radius of co-rotation the rotational velocity of stars and gas is higher than that of the spiral wave pattern; gas entering an arm along its inner side was compressed there and therefore new stars were born. Thus, the younger stars must be observed along the inner edge of the arm; outside the co-rotation radius the younger stars must lie along the outer edge. Therefore, observations of the distribution of stars of different ages across the arm provide a check of the theory and the value of its free parameter, the co-rotation radius.

2 DISCUSSION

Most investigations of this kind have dealt with the integral colors of stars which are connected with ages, yet suffer from light absorption; also, the resolution is

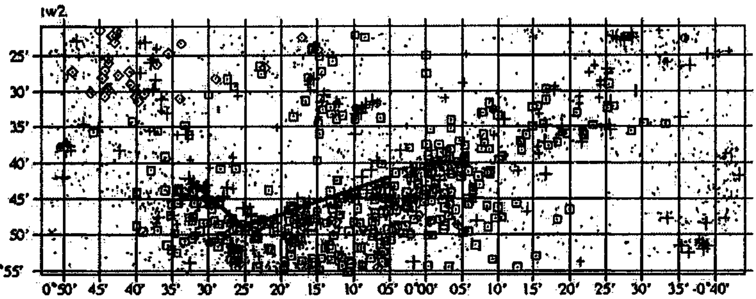

Figure 1 Deprojected map of the SW part of M31. The major axis of the galaxy is at $X = 0$, the axes measure arc minutes. The crosses are HII regions, squares are Cepheids, the points are stars with $B - V \leq 0.4$, i.e. members of the Andromeda galaxy.

mostly too low to get certain results. The nearest spiral galaxy, Andromeda, has a complicated structure, a high inclination to the plane of the sky and large angular dimensions, yet investigations of segments of its arms have given the best data on the distribution of objects of dafferent ages across the arm. The Cepheids, which have been studied in number of fields there, are especially useful because their periods are connected with txe ages (Efremov, 1979; Efremov and Elmegreen, 1998) and surely do not suffer from light absorption.

There is a segment of the arm S4 at the SW of this galaxy where the existence of the age gradient was noted long ago from the data on stellar associations (van den Bergh 1964). The distribution of Cepheids in this arm segment was studied and it was found that the youngest (those with the longest periods) Cepheids lie only along the inner edge of the arm; the rough data on the brightest stars also pointed in this direction, though only indirect evaluation of the light absorption, through the column density of HI, was available (Efremov, 1980, 1985; Efremov and Ivanov, 1982).

An interesting feature of the 'period–distance' diagram from the inner edge was the occurrence of the shorter period Cepheids at every distance from the edge, whereas the longer period Cepheids lie exclusively along the inner edge (Efremov, 1989, Figures 41 and 47). This might be explained by the suggestion that the stars born at the inner edge returned later (at scale of a few dozen Myrs) to this edge, and this implied certain conclusions about whether the stars were formed along the inner edge of the arm from the preexisting clouds or from the clouds formed within the density wave (Efremov 1985, 1989). In the latter case one could speak of triggered star formation. Thus, the features of the age – distance diagram are able to answer the most important and yet unsettled issue of star formation within the spiral density waves – whether star formation is active there just because the gas density is higher there, or because the new clouds are formed there and collapsed fast under the pressure of the density wave.

Whereas an age gradient does exist in this segment of the S4 arm, this is not the case in other parts of the spiral arms in the Andromeda galaxy (Efremov, 1989;

Efremov *et al.*, 1993), and this was explained by the observation that this segment of the S4 arm has a very large pitch angle, about 30° compared with some 7° over other arms of the galaxy. Thus, the component of the velocity difference between the spiral pattern and galaxy, which is orthogonal to the arm, is unusually high here. It is this component which determines the strength of an arm according the density wave theory (Roberts *et al.*, 1975). Its value in the arm in question is far above the velocity of the sound in the ISM and therefore a spiral shock wave arises, which leads to a high rate of star formation at the front of the shock; the HII regions in this segment of the S arm were found to lie just along the line where the HI clouds entered the stellar arm and hot O-stars formed (Efremov, 1985, 1989 (pp. 164–171).

These conclusions on the age gradient and the presence of the shock wave in this arm have neither been confirmed nor disproved. There is however indirect evidence for the presence of the shock wave here. According to a recent theoretical result (Chernin, 1999, 2000), a spiral shock wave in the ISM has a tendency to transform into straight segments, the angle between which being 120°, and there is a clear indication that this is really observed in the S4 arm. In the figure, which was constructed using a program elaborated by P. Bogdanovsky, the deprojected view of the SW part of S4 arm in M31 is presented, and the inner edge of two segments of the arm is outlined. One can see that this edge is well represented by two straight lines, the angle between them being some 120°. These point to the presence of a shock wave, according the Chernin theory (Chernin, 1999, 2000). The crosses in Figure are HII regions and squares are Cepheids.

The UBV data for stars within this small segment of the S4 arm are now becoming available. These data were obtained by S. Larsen *et al.* (in preparation) with the 2.5m Nordick telescope and it is now possible to determine the individual values of reddening for each star. The brightest OB stars are much younger than the youngest Cepheids and our preliminary de-reddened data demonstrate that they do concentrate along the inner edge of the arm and there are practically no such stars further to the center of the galaxy – they have not formed there yet. Until now there has been suspicion that such stars are simply unseen in the inner regions owing to the very high light absorption, and we are now able to disprove this suggestion. The determined values of reddening are really high there and are in accordance with the highest density of HI and CO along the inner side of the stellar arm (Efremov, 1985; Loinard *et al.*, 2000).

Thus, the detailed investigation of this crucial region of the Andromeda galaxy would give the most valuable data to test the theory of the spiral arms. The complicated structure, the large angular extent and the high inclination of the plane of this galaxy to the sky plane are not insurmountable obstacles to studying its spiral arms.

Acknowledgement

I am grateful to P. Bogdanovsky who elaborated the useful program, to A. Chernin who insisted this paper be prepared, and to A. Melnik for the careful editing of this text. This work was supported by the Program of the Support of leading Scientific Schools (grant 00-15-96627).

References

Chernin, A. D. (1999) *Month. Not. R. Astron. Soc.* **308**, 321.
Chernin, A. D. (2000) *Month. Not. R. Astron. Soc.* **318** L7.
Efremov, Yu. N.1978 *Astron. Zh.* **55**, 272.
Efremov, Yu. N.(1980) *Pis'ma v Astron. Zh.* **11**, 69.
Efremov, Yu. N. (1989) *Origins of Stars in Galaxies*, Moscow, Nauka (in Russian).
Efremov, Yu. N. and Ivanov, G. R. (1982) *Astrophys. Space Science* **86**, 117.
Efremov, Yu. N., Ivanov, G. R., and Nedialkov, P. L 1993 *Astron. Astrophys. Trans.* **3**, 237.
Lin, C. C. and Shu, F. H. (1964) *Astrophys. J.* **140**, 646.
Loinard, L. *et al.* (1999) *Astron. Astrophys.* **351**, 1087.
Roberts, W. W., Roberts, M. S., and Shu, F. H.(1975) *Astrophys. J.* **196**, 381.
van den Berrgh, S. (1964) *Astrophys. J. Suppl. Ser.* **9**, 65.