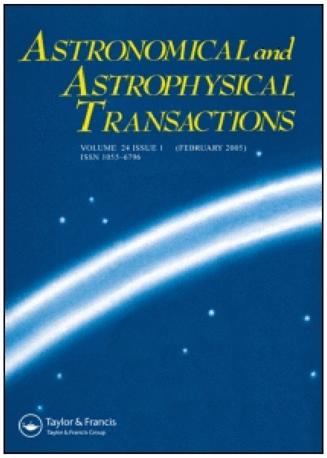

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

ON SYSTEMATICS IN OB/H II COMPLEXES IN THE SPIRAL ARMS OF M 51

Arthur Chernin

Online Publication Date: 01 January 2002
To cite this Article: Chernin, Arthur (2002) 'ON SYSTEMATICS IN OB/H II COMPLEXES IN THE SPIRAL ARMS OF M 51', Astronomical & Astrophysical Transactions, 21:1, 105 - 110
To link to this article: DOI: 10.1080/10556790215582
URL: http://dx.doi.org/10.1080/10556790215582

Astronomical and Astrophysical Transactions, 2002, Vol. 21(1–3), pp. 105–110

ON SYSTEMATICS IN OB/H II COMPLEXES IN THE SPIRAL ARMS OF M 51

ARTHUR D. CHERNIN[a,b,c]

[a]*Sternberg Astronomical Institute, Moscow University, Moscow, 119899, Russia;* [b]*Astronomy Division, Oulu University, Oulu, 90014, Finland;* [c]*Tuorla Observatory, Turku University, Piikkiö, 21500, Finland*

(Received 25 July 2001)

Systematics in the location of brightest OB/H II complexes in the major spiral arms of M 51 is discussed with the use of recently published far-UV and H_α data. It is demonstrated that the objects occupy predominantly the areas around the corners of the polygonal arm pattern of this galaxy. This is treated as evidence that the physical conditions in these specific areas can enhance massive star formation. A possible gas dynamical explanation is suggested for the phenomenon.

Keywords: Galaxies: individual (M 51); Galaxies: spiral; Stars: formation

1 INTRODUCTION

The nearly face-on giant Sbc spiral Messier 51 (NGC 5194), one of the most photogenic of galaxies, constitutes a textbook example of grand design spiral structure; it is also one of the most intensively studied of all spirals. In a previous paper (Chernin 1999), evidence has been reported that the global spiral pattern of M 51 contains multiple straight arm segments and can be schematically represented by two polygons almost entirely. The polygons are almost identical, and the pattern has approximate two-fold symmetry. The length of the straight segments increases with the distance from the center of the disc nearly linearly, and the segments intersect one another at an angle which is on average $\simeq 2\pi/3$.

Similar global patterns with straight arm segments were also recognized in M 101 (Waller *et al.*, 1997; Chernin, 1998) and a dozen other grand design giant spirals (Chernin *et al.*, 2000).

In this note, I discuss the systematics of star formation in M 51 in relation to the geometry of the global spiral pattern of the galaxy. It may be expected that physical conditions are not the same along an arm of polygonal geometry: the corners of the polygon present obviously specific loci. Can corners influence star formation in the arm? And if so, do physical conditions at corners enhance or suppress massive star formation?

In searching for an answer to these questions, I use a recently published far-UV image (Hill *et al.*, 1997) and an H_α image (Greenawalt *et al.*, 1998) of M 51, which make it possible

ISSN 1055-6796 print; ISSN 1476-3540 online
DOI: 10.1080/10556790290018872

to follow the distribution of bright regions of massive star formation along the arms of the galaxy.

Below I give, first, the map of the distribution of OB/H II complexes superimposed on the schematic of the arm pattern of M 51 (Sec. 2) and then discuss conclusions that can be drawn from this (Sec. 3); the results are listed in Section 4.

2 28 BRIGHTEST OB/H II COMPLEXES OF M 51

Hill *et al.* (1997) have recently presented a far-UV image of M 51 obtained during the Astro-2 Spacelab mission of March 1995. The resolution of the 38 cm Ultraviolet Imaging Telescope ($\simeq 3''$) is significantly higher than in prior imaging, which is important for the identification of UV sources coincident with H_α sources. The sources are OB/H II complexes (Hill *et al.*, 1984, 1992; Bohlin *et al.*, 1990a,b) which are similar to star/gas complexes studied by Efremov (1995) in the Milky Way and the Andromeda Galaxy.

The 28 complexes discussed by Hill *et al.* (1997) are located along the entire length of the major spiral arms of M 51, from the inner disc to its outer parts. These objects can be clearly recognized as the brightest knots in the H_α image of the galaxy obtained by Greenwalt *et al.* (1998). The distribution of the brightest complexes is obviously not uniform along the arms; there are several areas which are much more densely populated by the complexes.

In Figure 1, the distribution of OB/H II complexes is presented against the background of the polygonal arm pattern as traced by the dust lanes in M 51 (Chernin, 1999). Do the complexes 'feel' the geometry of the arms?

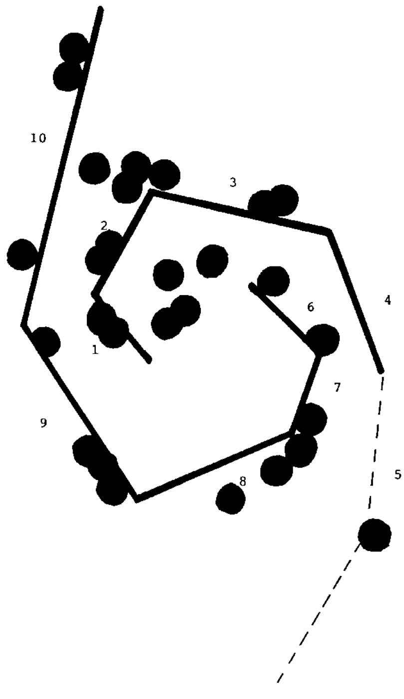

FIGURE 1 Bright complexes in the polygonal arm pattern of M 51. Dashed lines are the lines of maxima of synchrotron emission (after Mathewson *et al.*, 1972) which follow closely the dust lanes on inner edges of the arms.

One may see that two complexes in the longest segment #10 are not associated with any corner, but rather with the end of the segment. The arm pattern is not quite definitely traced in the area of segment #5, and so the position of a complex there cannot be identified with a corner reliably. Four complexes in the central area of the disc are seemingly not related to the polygon pattern at all.

Let us label each corner by two numbers (**i**,**j**) that are the numbers of the segments #i and #j which meet there. Corner (**2**,**3**), where segments #2 and #3 meet, hosts four complexes; another four complexes are located around the corner (**1**,**2**); three complexes are near the corner (**7**,**8**), *etc*.

Simple analysis shows that 36% of the complexes prove to be within 1.5 kpc of the nearest corner, and 53% are within 3 kpc of it (note that the size of complexes is 0.3 to 0.7 kpc).

It may be also seen that, if 28 objects would be randomly placed along the arms, only 25% will be within 1.5 kpc of a corner, and 43% will be within 3 kpc of it.

Four complexes located in the center of the disc (see above) seem to be isolated from the remaining complexes of Figure 1. If one does not take into account these 4 complexes and consider 24 complexes which are definitely related to the polygonal arms, contrast with random distribution will prove to be higher. In this case, 46% occur within 1.5 kpc of a nearest corner, against 23% in random distribution; and 62% occur within 3 kpc of a nearest corner, against 40% in random distribution.

Although the number of objects is not large enough for well reliable statistics, a trend seems to be apparent. The histogram and figures above indicate that the star formation process in the arms of M 51 is sensitive to the local geometry of the arms: the process is considerably enhanced around the corners of the arm polygons. This is the major conclusion that can be drawn from the data on the brightest complexes of the galaxy.

It may also be noted that the H_α image by Greenawalt *et al.* (1998) shows a rather smooth distribution of relatively fainter complexes along the arms of M 51.

3 DISCUSSION

3-1 As has long been known, star forming complexes are located in the major spiral arms of M 51 (see, for instance, Vogel *et al.*, 1988). It has also already been found that the star formation process is not uniform along the arms of the galaxy. Elmegreen *et al.* (1989) discussed star formation maxima and arm-intensity minima; they used them, as well as various optical spurs, in a search for the resonances of a spiral density wave.

Knapen *et al.* (1992) performed a detailed study of the distribution of ionized, molecular and atomic hydrogen in the disc of the galaxy and reported a strong dependence of star formation efficiency on position angle along each major arm with sharp, high peaks and deep troughs. It may not be surprising that these peaks are strongly correlated with the areas where OB/H II complexes of Section 2 gather. For instance, the peaks labeled as **D** and **d** in Knapen *et al.* (1992) are associated with the corners (**1**,**2**) and (**7**,**8**) in Figure 1, respectively. Knapen *et al.* (1992) recognized a symmetric pattern of peaks and dips in the star formation efficiency. They found that 6 peaks in one arm have 6 symmetric counterparts in the other arm. In two of these pairs the peaks have actually comparable amplitudes. The highest peaks are in the pair **D** and **d** mentioned above. The pair of the second highest peaks, **F** and **f**, are identified with corners (**3**,**7**) and (**8**,**9**) of Figure 1, respectively. The amplitudes of the peaks in four other pairs are rather low and their identification is not so obvious. In any case, the two-fold symmetry of the polygons of Figure 1 and the symmetry of the star formation efficiency are definitely correlated with each other.

Knapen *et al.* (1992) found also that the positions of the troughs agreed with the position of density wave resonances as identified by Elmegreen *et al.* (1989) and concluded that the peaks were due only to enhanced star formation in the arms between the density wave resonances. An explanation for specific positions between resonances may be found in Contopolos and Grosbol (1986): stellar orbit crowding is possible in these areas, and enhancement of star formation might be a secondary effect induced by the increased density of old stars of the disc.

3-2 Alongside with the stellar dynamical considerations (see above), a gas-dynamical approach to the pattern of enhanced star formation may also be interesting. It can be based on the fact that the dust lanes, which dominate the spiral pattern of M 51, delineate the fronts of spiral shocks seen edge-on. Roberts (1969) and Pikelner (1970) first argued that the fronts form when the gas of the galaxy disc passes through the gravitational potential of a density wave.

When we look at the pattern of dust lanes in M 51, we actually see the structure of the global shocks there. The shock fronts are flat in some arm segments, and as it was earlier assumed, local flattening of the spiral front may have the same physical nature as the universal stability of a flat shock against any weak perturbations that disturb its front surfaces (Chernin, 1999).

Arguing along this line, one may take into account that gas dynamical structures must be richer in the areas of the corners of the polygonal arms than between the corners. I will not try to develop here a complete theory and rather confine myself with a reference to Landau and Lifshitz (1979) and Courant and Friedrichs (1948). It is shown in these books that when two shock fronts meet (such as at the corners of Figure 1), there are usually other dynamical features in the same ares of the flow. These may include additional shock fronts, weak jumps, and tangential discontinuities; an example of such nonlinear configurations is given in Figure 2. Having this in mind, one may speculate that these complex features in the gas flows near corners can enhance massive star formation due to extra compression of gas in the additional shocks and/or turbulization of gas via decay of tangential discontinuities.

3-3 M 51 galaxy is not the only spiral with a polygonal arm pattern, but rather an archetypical example of a galaxy with this geometry (Chernin *et al.*, 2000). A detailed study of star formation systematics in other spirals of this type is now in progress.

Some instructive data can also be found in literature. For instance, an arm-only image of NGC 157 published recently by Rozas *et al.* (1998) reveals a fairly sharp straight geometry of

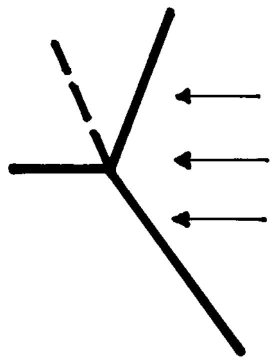

FIGURE 2 Gas dynamical 'corner' configuration with shock fronts (solid lines) and a tangential discontinuity (dash line); the arrows indicate the direction of the flow relative to the fronts.

the inner edges of two arms of this galaxy. This is similar to the geometry of the dust lanes on the inner edges of the arms in M 51 (see Fig. 1). Four or five corners may be seen in the image of the arms of NGC 157, and a tendency of the corners to host brightest complexes may be recognized there.

On the other hand, it may be important to study symmetries in star formation observed in galaxies with no obvious straight segments or corners (see Elmegreen and Elmegreen, 1989; Elmegreen *et al.*, 1992; Chen *et al.*, 1992, and especially Cepa and Beckman, 1990; Knapen *et al.*, 1996; Rozas *et al.*, 1998). The geometrical properties of the H II region distributions in a large number of spirals were studied by García Gomez and Athanasoula (1991, 1993) and Athanasoula *et al.* (1993).

An analysis of a wider range of observational data may give additional empirical indications on the physics of the phenomenon under consideration.

4 CONCLUSIONS

The galaxy M 51 with its large angular diameter and prominent spiral pattern has been a favorite target of astronomers for more than 150 years since first observations by Lord Rosse. The recent far-UV and H_α data I used in the study above enable to make new conclusions concerning the pattern of the galaxy and its relation to the star formation process.

1. Systematics in the location of brightest OB/H II complexes in the major spiral arms is found which is closely related to the geometry of the polygonal arm pattern of M 51.
2. It is demonstrated that objects occupy predominantly the areas around the corners of the polygonal arms of this galaxy.
3. An interpretation of the phenomenon is suggested which is based on gas dynamical approach; complex gas flow around the corners of the polygonal arms must include additional shock fronts and tangential discontinuities; these can enhance star formation because of extra compression of gas in the additional shocks and/or turbulization of gas via decay of the tangential discontinuities.
4. A complete theory of the process seems to require both stellar dynamics and gas dynamics of the spiral arms; this way, resonances of density waves and corners of polygonal arms (with gas dynamical configurations like in Fig. 2) may prove to be complementary elements of the same picture.

Acknowledgement

I thank Vera Arkhipova, Yuriy Efremov, Chris Flynn, Vitaliy Gorbatskiy, and Anatoliy Zasov for helpful discussions.

References

Athanasoula, E., García Gomez, C., Bosma, A. *A&A*, **102**, 229.
Bohlin, R. C., Cornett, R. H., Hill, J. K., O'Connel, R. W., Stecher, T. P. (1990a) *ApJ*, **352**, 55.
Bohlin, R. C., Cornett, R. H., Hill, J. K., Stecher, T. P. (1990b) *ApJ*, **363**, 154.
Cepa, J., Beckman, J. E. (1990) *ApJ*, **349**, 497.
Chen, P. C., *et al.* (1992) *ApJ*, **395**, L41.
Chernin, A. D. (1998) *Astrfizika*, **41**, 609.
Chernin, A. D., (1999) *MNRAS*, **308**, 321.
Chernin, A. D., Zasov, A. V., Archipova, V. P., Kravtsova, A. S. (2000) *Astron. Rep.*, **26**, 342.
Contopoulos, G., Grosbol, P. (1986) *Astron. Astrophys.*, **155**, 11.

Courant, R., Friedrichs, K. O. (1948) *Supersonic Flow and Shock Waves* (Interscience, NY).
Efermov, Yu. N. (1995) *Astron J.*, **110**, 2757.
Elmegreen, B. G., Elmegreen, D. M. (1989) In: Beckman, J. E. and Pagel, B. E. J. (eds.) *Evolutionary Phenomena in Galaxies* (Cambridge University Press, Cambridge), p. 83.
Elmegreen, B. G., Elmegreen, D. M., and Seiden, P. S. (1989) *ApJ*, **343**, 602.
Elmegreen, B. G., Elmegreen, D. M., and Montenegro, L. (1992) *ApJSS*, **79**, 37.
García Gomez, C., Athanasoula, E. (1991) *A&AS*, **89**, 159.
García Gomez, C., Athanasoula, E. (1993) *A&AS*, **100**, 453.
Greenawalt, B., Walterlos R. A. M., Thilker, D., Hoopes, C. G. (1998) *ApJ*, **506**, 135.
Hill, J. K., Bohlin, R. C., Stecher, T. P. (1984) *ApJ*, **277**, 542.
Hill, J. K., Waller, W. H., Cornett, R. H., *et al*. (1997) *ApJ*, **477**, 673.
Knapen, J. H., Beckman, J. E., Cepa, J., Nakai, N. (1996) *A&A*, **308**, 27.
Knapen, J. H., Beckman, J. E., Cepa, J., van der Hulst, T., Rand, R. J. (1992) *ApJ*, **385**, L37.
Landau, L. D., Lifshitz, E. M. (1979) *Fluid Mechanics* (Pergamon Press, Oxford).
Mathewson, D. S., van der Kruit, P. S., Brown, W. N. (1972) *A&A*, **17**, 468.
Pikel'ner, S. B. (1970) *Sov. Astron.*, **47**, 254.
Roberts, W. W. (1969) *ApJ*, **158**, 123.
Rozas, M., Knapen, J. H., Beckman, J. E. (1998) *MNRAS*, **301**, 631.
Vogel, S. N., Kulkarni, S. R., Scoville, N. Z. (1988) *Nature*, **334**, 402.
Waller, W. H., Bohlin, R. C., Cornett, R. H. *et al*. (1997) *ApJ*, **481**, 169.