ARE LYNDS DARK CLOUDS FRACTALS?

(Letter to the Editor)

MARTIN BEECH

Department of Astronomy, University of Western Ontario, London, Ontario, Canada

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Abstract. We have used the catalogue of dark nebulae compiled by Lynds (1962) to investigate the geometrical nature of the darkest, opacity class 5 to 6, clouds. There would appear to be some evidence that these objects are fractals of dimension $D = 1.4$.

1. Introduction

It has become increasingly clear over past years that the dust and molecular clouds are an integral part of our Galaxy and are important because of the role they play in star formation. These objects demonstrate complex internal dynamics, such that gravitational collapse is resisted by turbulent motions on the large scale (Fleck, 1981; Canuto *et al.*, 1985). Simply by observation, it is clear that the dust and molecular clouds are irregular in shape, we ask here, however, if there is an underlying geometry to these objects. This question takes us into the realm of fractal structures, as described by Mandelbrot (1983). In order to proceed with this study, we use the catalogue of dark nebulae compiled by Lynds (1962).

Lynds' (1962) catalogue gives the position, area and opacity class of dark clouds revealed by reductions in the local surface density of stars on the National Geographic Society–Palomar Observatory sky survey plates. Once a cloud has been identified, Lynds traced its outline directly from the plates and made a visual estimate of its opacity, on a scale of 1 to 6. The darkest clouds being classified as class 6. Lynds found that the angular size of the opacity class 5 to 6 clouds were much smaller than these of lower opacity class. The distance, however, to the majority of clouds is poorly known, but Lynds (1968) estimates that most lie in the range 0.1 to 1.0 kpc. This is to be expected, since as Rowan-Robinson (1979) points out, interstellar extinction makes the star count method ineffective at distances farther away than ~ 1 kp. At these distances the clouds have dimensions on the scale 0.1 to 10 pc (Rowan-Robinson, 1979; Drapatz and Zinnecker, 1984). Dickman (1975) has studied some of the opacity class 5 to 6 clouds in CO and finds a typical excitation temperature ~ 10 K.

2. The Area-Perimeter Relation

Fractal objects are those that exhibit a self-similar geometry (Mandelbrot, 1983). That is, the appearance of a fractal object is the same even when subject to arbitrary

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magnification. Mandelbrot (1983) proposed that a simple relation between the perimeter P and area A holds for a fractal object, such that

$$P \sim A^{D/2}, \tag{1}$$

where D is the fractal dimension of the perimeter and is an indicator of how complex and contorted the perimeter is. If an object has a regular, smooth appearance (e.g., squares and circles) then $D = 1$, the dimension of a line. If, on the other hand, the perimeter is greatly distorted then $1 < D \leq 2$, where $D = 2$ corresponds to a plane-filling, Peano curve.

If a set of objects describe a relation of the form (1), then they are fractal objects of the same dimension D. If, however, the area-perimeter relation is characterized by dimension D, up to area A_1 and D_2 for $A > A_1$, then this would indicate the existence of some prefered scale length $\lambda^2 \approx A_1$.

3. Method of Analysis

In our analysis, we concentrate on the opacity class 5 and 6 clouds of Lynds (1962). Of these we have selected 24 clouds that are well separated from background confusion.

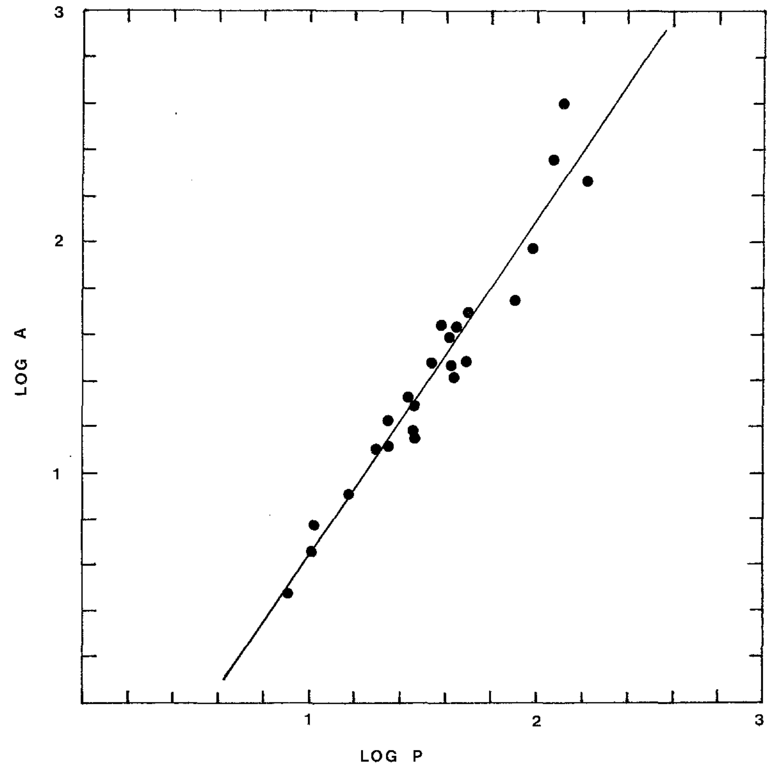

Fig. 1. A graph of log area versus log perimeter for the 24 selected dark clouds. The line is a least-squares fit to the data points.

Each cloud has been re-drawn in 'squared' form on graph paper, the area and perimeter thus being found by a simple adding process. This method is exactly that employed by Henderson-Sellars (1986) in his study of Martian cloud fractals, and as he points out, is the same process that a computer-driven processor would use. Lovejoy (1982), for instance, has used digitized pictures in his study of the fractal nature of terrestrial clouds.

We can see from Equation (1) that a logarithmic plot of area versus perimeter will give a straight line with slope $2/D$. Figure 1 shows such a plot for the 24 clouds selected. The data points indeed indicate a straight line relationship with a least square goodness of fit coefficient $r = 0.971$. The slope of this line implies $D = 1.4$.

4. Discussion and Conclusions

Any conclusions from the above analysis must be tentative. There is clear scatter about the line in Figure 1, but the graph would seem to indicate that the smaller ($r \lesssim 10$ pc) darker (opacity class 5 to 6) clouds described by Lynds are fractal objects of dimension $D = 1.4$. Clearly this analysis could be improved (invalidated?) with more data over many more cloud sizes and opacity classes. Similarly, the method by which the area and perimeters are obtained could probably be made more systematic. We have used linearized copies of copies, digitized images from the original plates would presumably offer a more refined analysis.

Even if our results had offered conclusive evidence for the fractal nature of dark molecular clouds, this would do little, at the present time, to advance our understanding of the physical processes operating in these objects. This is a general point concerning fractals that Kadanoff (1986) has alluded to. Mandelbrot (1983) has argued, however, that Kolmogorov isotropic, homogeneous turbulence should produce isotherms and isobars with fractal dimensions $D = \frac{5}{3}$ and $\frac{4}{3}$, respectively. There is hope then, that with an accurate analysis one might be able to study the turbulent nature of molecular clouds through their fractal appearance. This, however, will require much more data and a clear understanding of that elusive physical manifestation-turbulence.

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