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# mnassa

monthly notes of the astronomical society of southern africa

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recognition
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**Cover picture: Amateur Rocketry in South Africa**

Brian Page (left), Lance Roberts (obscured) and Les Page-Shipp of the University of Natal Rocket Society and Research Group busy hauling a launch tower, loaded with their RS60-1 rocket, into position on 11 September 1960 from a beach launch site just north of the Tongaat River, Kwa-Zulu Natal. See article starting on p.134.

Picture credit: Greg Roberts.

mnassa

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assa news

# Changes at *MNASSA*

The Editorial Board has agreed that *MNASSA* will go electronic and free of charge from the end of 2010. This is as part of a move to simplify the Society's business side.

Currently *MNASSA* is distributed to two categories: **members** and **subscribers**. The subscribers pay on a calendar year basis and the members pay their fee at mid-year. As it is too late to make changes in the arrangements for **members**, we will continue to send printed copies to them until at least June 2011 but we are thinking that they could be offered a reduced subscription in future years if they are willing to use the electronic edition. However, if the number who want the printed editions becomes too small, the costs will go up and we may have to stop it altogether (the printed version, that is). If the number becomes *very* small we could consider printing them ourselves on a laser printer.

It is proposed to notify all **subscribers** around the end of August of the changes and to have a demonstration web site in place by then.

The issues for **members** are delivered to the Hon Treasurer and the current address labels are given to him by the Hon Membership Secretary. The Treasurer organizes the postage costs and the distribution company then fetches the issues to go out and mails them.

The work in distributing *MNASSA* to **subscribers** is quite significant and has been handled over the years by voluntary Business Managers. There are 112 addresses on the list, receiving 121 copies in total. Many subscribers purchase through agents and get a 20% discount. Nearly all (91) are foreign, involving the Treasurer in negotiating foreign exchange and filling out a form for each. Many have to be individually invoiced. In addition, copies occasionally get lost in the post and have to be replaced. Then there are address changes etc. Six times per year the issues have to be sent out. Although the subscription business has been marginally profitable in principle, it is doubtful if it really has been in practice.

In addition to paid subscribers, mainly foreign, there are currently a number of free subscriptions and the new Council will have to decide if these will continue:

Each ASSA Centre (8)
Book review editor (2)
Chichester planetarium
David Dunham, USA
International Dark Sky Association, USA
RG Glass (Hon Auditor)
M Streicher (5)
Royal Astronomical Society, UK
SAAO (3)

Each of the (5) SA Copyright libraries receives a copy by law so long as we print 100 or more copies. This reduces to one if the print-run is less than 100.

The number of members is around 250 at maximum time of year. We are currently printing 450 copies. This is 79 too many and could be reduced by about 50 (to allow 29 spare copies). The spare copies are necessary to cover postal losses and occasional back orders.

We have changed printers with the June 2010 issue to Megadigital. The print method also changed from litho to digital. The cost per issue is about R4 500 typically and thus per copy it is around R10. If the print-run is smaller, the unit price will increase, but not as much as with traditional lithography. ☆

## New Members

The following new members were accepted during the last Council meeting. *MNASSA* would hereby want to welcome them all.

Mr Jonathan Balladon, Moreletta Park, Pretoria
Mr Derrick Caird, Kabega Park, Port Elizabeth
Mr PG Dormehl, Durban
Mr J Exelby, Howick, Kwazulu-Natal
Ms Karen Fischer, Strydenburg
Mrs Vivienne Gadd, Knysna
Mr Ernest Halberg, Welkom
Mr G Laubscher, Table View, Cape Town
Mr Ashleigh Maharaj, Esther Park, Kempton Park
Mr Michael Neale, Gezina
Mr AJ Nel, Bedfordview, Johannesburg
Mrs M Neumann, Northriding, Johannesburg
Mr Hannes Oelofse, Garsfontein, Pretoria
Miss Chantal Olivier, Bedfordview, Johannesburg

Mr Wessel Olivier, Rooihuiskraal, Pretoria
Miss Seshini Parther, Halfway House, Midrand
Mr Dick Plaistowe, Southbroom
Mr M Preston, Vaalpark, Vereeniging
Mr D Rampathi, Malanshof, Randburg
Mr Montagu Thorne, Morningside Manor, Sandton
Mr Dylan Van Rensburg, Meyersdal, Johannesburg
Mr R Walavalkar, Sandton, Johannesburg ☆

news notes

## Brief Update on Charles Affair

(see *MNASSA* April 2010, p.48)

This information is from a report by the NRF President, Dr van Jaarsveld, to SAAO staff on 14 July 2010.

Prof Bozzoli's report was presented to Minister Pandor. It has been decided not to release it in full.

**Recommendations:**

There should be conversations about the future of astronomy given the scale of the investment. These should include the Dept of Science and Technology.

An advisory board for SAAO will be appointed, independent of NRF and SAAO.

There should be broad consultation to establish a multi-wavelength community.

The NRF will establish an "astronomy desk", to be occupied by a senior astronomer or physicist. This person to lead discussions on formation of an SAAO board and other matters such as the location of the MeerKAT Operations Centre.

In the short term, the President of the NRF will control SAAO directly and will work closely with the Vice-president for Facilities (Dr Mazithulela).

**Answers to some questions at this session:**

Regarding successor to Prof Charles (he definitely will leave in September 2011): The "climate" for a search must be got right first, then a search will be made through the Astronomy Desk and the Advisory Board….If we are to have a new Institute of Astronomy this will affect things.

Regarding apology to Prof Charles and staff: NRF President has apologized personally to Charles. He is getting advice as CEO of NRF. Quote: "We were over-zealous in suspending Phil".

Regarding relationship between Prof Charles and Dr Mazithulela: They should not be pushed into a corner. It is essential to keep communication going. ☆

# Modified Newtonian dynamics at low accelerations as an alternative to dark matter

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**Abstract:** Newtonian dynamics applied to galactic conditions implies that there exists a large amount of matter in the Universe that we have hitherto been unable to detect directly. After nearly a century of extensive research, surprisingly little progress has been made regarding the nature of this dark matter. Some scientists believe that the missing mass is an illusion created by non-Newtonian dynamics that reign in certain astronomical environments. The most successful of these theories is MOND (MOdified Newtonian Dynamics). MOND has produced interesting results and has survived various observational tests despite certain shortcomings, particularly on the cosmological scale. None the less, MOND has proved to be a feasible solution to the missing mass problem based on our observations so far.

**Keywords: gravitation — dark matter — galaxies: kinematics and dynamics**

## 1 The missing mass problem

The missing mass problem is one of the conundrums of modern astrophysics. The mass of an astronomical object can be inferred in two different ways. (a) It can be calculated by studying its dynamical properties. For example, if the separation between two gravitationally bound objects is known, the time taken for them to orbit each other is dependent only on the sum of their individual masses. (b) Alternatively, because any body with a temperature above absolute zero emits radiation, one can deduce its mass by measuring its bolometric luminosity. A large discrepancy between the masses as determined by these two methods is found for several astronomical systems, with the dynamical mass being the larger of the two. This discrepancy has been termed the missing mass problem.

Zwicky (1933) was the first to recognize this problem. He estimated the mass of the Coma galaxy cluster by studying the motions of eight of its galaxies and found that it was considerably larger than that inferred from its luminosity. He proposed that there existed mass within the cluster that was somehow veiled from sight and called it dark matter (DM).

The DM hypothesis has become popular in the scientific community and a great deal of research has been dedicated to the subject. In spite of this, the nature of DM remains a mystery at the present time. The idea of DM has proven useful in other theories. Notably, an inflationary universe requires the density parameter $\Omega_0 \approx 1$. But Big Bang nucleosynthesis shows that baryonic matter can only account for a very small amount of the needed energy density to meet this requirement. Large amounts of non-baryonic DM would alleviate this problem.

There have been no observations that refute the DM hypothesis, but it has various shortcomings that suggest that the investigation of an alternative theory is not unreasonable. The DM hypothesis has been criticized for being arbitrary in that it can be assumed to be distributed in just the right amount and with just the right spatial distribution to fit empirical data (Milgrom 2004). Furthermore, the mix of dark and luminous matter seems to be different for different phenomena, resulting in separate assumptions for distinct cases. It is noteworthy that no DM has been detected directly, and this is not due solely to the definition of DM. Even though DM can resolve the question of the missing mass, it has not led to a better understanding of galaxy dynamics or offered relations between different observed phenomena (Milgrom 2004).

All dynamic mass determinations on galactic scale are based on a single relation, namely

$$v^2 = \frac{\alpha M G}{r} \tag{1}$$

where $v$ is the angular speed of a test particle about a body of mass $M$, $G$ is the gravitational constant and $r$ is the distance between the test particle and the massive body. $\alpha$ is a coefficient of the order of unity that depends on the exact definitions of $v$ and $r$, as well as the geometry of the system. This relation is derived from Newton's second law of motion and Newton's law of universal gravitation. Should either of these laws be found to break down, DM's position would be seriously threatened.

This is exactly what Milgrom proposed when he introduced MOdified Newtonian Dynamics (MOND) in a series of papers in 1983 (Milgrom 1983c,a,b). Milgrom suggested that Newtonian dynamics breaks down at low accelerations and showed how this can account for the mass discrepancy in the Universe. This is not such an outlandish idea when one considers that it has already been proved that Newtonian dynamics fails at certain other extremes. For example, general relativity is needed to describe physics at extremely high velocities, and quantum mechanics is necessary when dealing with small-scale phenomena.

Initially, Milgrom's theory received little attention from the scientific community. But MOND's phenomenological success has made it difficult to ignore. There is still only a handful of astronomers that support MOND in favour of DM, but the number is growing. DM advocates are also starting to take MOND seriously as indicated by many recent attempts to disprove MOND.

## 2 Theoretical aspects

MOND claims that Newtonian dynamical laws are not obeyed at low accelerations. In this section the theoretical aspects of MOND in the non-relativistic regime are reviewed. The three basic postulates on which MOND is based are listed and their two different interpretations discussed. Various formulations can be constructed from the basic postulates, and in the current work only one is discussed in detail. The effects of the ambient acceleration field are considered in the context of MOND and a common misconception of the nature of MOND is clarified.

### 2.1 Basic postulates

The basic assumptions of MOND are (Milgrom 1983c)

i. Newtonian dynamics breaks down when the accelerations involved are small.

ii. The acceleration $a$ of a test particle a distance $r$ from a point mass $M$ is given by

$$\frac{a}{a_0}\mathbf{a} \approx \frac{-GM}{r^2}\hat{\mathbf{r}} \equiv \mathbf{a}_\mathrm{N} \qquad (2)$$

where $\mathbf{a}_\mathrm{N}$ is the Newtonian gravitational acceleration, $\hat{\mathbf{r}}$ is the radial unit vector and $a_0$ is a constant with dimensions of acceleration. ($a_0 = 1.2 \times 10^{-8}$ cm s$^{-2}$ empirically (Begeman, Broeils, & Sanders 1991).)

iii. $a_0$ also plays the role of the transition acceleration from the Newtonian to the low acceleration regime. For $a \gg a_0$ Newtonian dynamics is a good approximation, whereas for $a \ll a_0$ the asymptotic relation (2) holds.

### 2.2 Interpretation

It is important to note that the basic postulates of MOND can be interpreted in two different ways, namely as a modification of the law of inertia or as a modification of Newtonian gravity.

#### 2.2.1 Modification of the law of inertia

In this scheme, MOND is interpreted as modifying Newton's second law to

$$\mu\left(\frac{a}{a_0}\right) m\mathbf{a} = \mathbf{F} \qquad (3)$$

where $m$ is the mass of the accelerated particle, $\mathbf{F}$ is an arbitrary force field and $\mu = \mu(x)$ is a monotonic function which is discussed below. For gravity, $\mathbf{a} = \mathbf{a_N}$ where $\mathbf{a_N} = -\nabla\varphi_\mathrm{N}$ and $\varphi_\mathrm{N}$ is the Newtonian gravitational potential derivable from the Newtonian Poisson equation.

As explained in Milgrom (1983c), (3) does not constitute a theory, but only a useful phenomenological scheme. An underlying theory is needed. This equation alone presents problems with conservation of momentum if its use is not restricted to light objects in the static mean field of a massive object. This has often been used as an argument against MOND (see for example Felten (1984)).

#### 2.2.2 Modification of Newtonian gravity

Alternatively, Newtonian gravity can be assumed to break down at low accelerations while the law of inertia is left intact. In this scheme, the Newtonian gravitational potential $\varphi_{\mathrm{N}}$, and thus the Newtonian gravitational acceleration $\mathbf{a_N}$, is modified in such a way that for gravity $\mathbf{F} = m\mathbf{a}$, where $(a/a_0)\mathbf{a} = \mathbf{a_N}$ for the deep-MOND (accelerations much less than $a_0$) case.

#### 2.2.3 Comparison of the interpretations

When gravity is the only force present, the two interpretations are equivalent. The only situations where MOND has been tested are in galaxy systems where gravity is the only significant force. We therefore do not know at this stage which interpretation to favour. Almost all MOND theories to date are based on the modified gravity approach. Some experiments for which the two interpretations predict different results are discussed in Milgrom (2006).
A more rigorous treatment of the difference between these interpretations, based on the action principle, can be found in Milgrom (2002b).

### 2.3 Formulation

Various theories can be constructed that incorporate the basic assumptions of MOND. A Lagrangian formulation as given by Bekenstein & Milgrom (1984) based on the modification of gravity is presented here.
In Newtonian theory, the gravitational acceleration field of a test particle that moves in a gravitational field of a mass density $\rho$ is given by $\mathbf{a_N} = -\nabla\varphi_{\mathrm{N}}$. Here $\varphi_{\mathrm{N}}$ s the Newtonian gravitational potential that is described by Poisson's equation $\nabla^2\varphi_{\mathrm{N}} = 4\pi G\rho$. Poisson's equation is derivable from the Lagrangian

$$L_{\mathrm{N}} = -\int d^3r \left[\rho\varphi_{\mathrm{N}} + \frac{1}{8\pi G}(\nabla\varphi_{\mathrm{N}})^2\right] \tag{4}$$

When modifying this theory, it is desirable that the new gravitational acceleration is derivable from a single potential $\varphi$, where $\varphi$ is arbitrary up to an additive constant. The most general modification of $L_{\mathrm{N}}$ that has these characteristics is

$$L = -\int d^3r \left[\rho\varphi + \frac{a_0^2}{8\pi G}F\!\left(\frac{(\nabla\varphi)^2}{a_0^2}\right)\right] \tag{5}$$

where $F(x^2)$ is an arbitrary function.

Varying $L$ with respect to $\varphi$ and having the variation of $\varphi$ vanish on the boundary yields the generalization of the Poisson equation:

$$\nabla \cdot \left[\mu\left(\frac{|\nabla\varphi|}{a_0}\right)\nabla\varphi\right] = 4\pi G\rho \quad (6)$$

with $\mu(x) = \frac{dF}{d(x^2)}$ and boundary conditions $|\nabla\varphi| \rightarrow 0$ as $r \rightarrow \infty$. A test particle is assumed to have gravitational acceleration $\mathbf{a} = -\nabla\varphi$. $F(x^2)$ is chosen so that

$$\mu\left(x\right) \approx \begin{cases} x & \text{if } x \ll 1 \\ 1 & \text{if } x \gg 1 \end{cases} \quad (7)$$

The exact form of $\mu(x)$ remains unspecified, but it is assumed to be monotonic. Fortunately, most relevant observations are made in the deep-MOND regime where $\mu(x) \approx x$. Methods for determining $\mu(x)$ observationally are discussed in Milgrom (1983a).

This Lagrangian theory can be shown to satisfy the postulates of MOND by eliminating $\rho$ from (6) and the Newtonian Poisson equation. This gives

$$\nabla \cdot \left[\mu\left(\frac{|\nabla\varphi|}{a_0}\right)\nabla\varphi - \nabla\varphi_{\mathrm{N}}\right] = 0 \quad (8)$$

which can be written as

$$\nabla \cdot \left[\mu\left(\frac{a}{a_0}\right)\mathbf{a} - \mathbf{a_N}\right] = 0 \quad (9)$$

Clearly, the expression in square brackets is a pure curl field.

In cases of high symmetry such as spherical-, cylindrical- or planar symmetric systems such a curl will vanish identically and we have the relation

$$\mu\left(\frac{a}{a_0}\right)\mathbf{a} = \mathbf{a_N} \quad (10)$$

In the MOND regime when $a \ll a_0$, $\mu(a/a_0) \approx a/a_0$ and we recover the relation for acceleration as given by postulate ii, i.e.

$$\left(\frac{a}{a_0}\right)\mathbf{a} \approx \mathbf{a_N} \quad (11)$$

It can be shown that this relation also holds at large distances from a bound mass (Bekenstein & Milgrom 1984) and can be used safely in some systems that do not have high symmetry, such as galaxy rotation curves.

Since the Lagrangian is symmetric under spacetime translations and space rotations, energy, total momentum and angular momentum are conserved in an isolated system. These conservation laws are derived explicitly in Bekenstein & Milgrom (1984).

An important feature of the above theory is that a particle moving in the gravitational field of a large mass can still be treated as a test particle even if the particle consists of many subparticles with high internal accelerations. For example, a star cluster's centre of mass motion at low accelerations in a galaxy will be MONDian, even though the accelerations of the stars in the cluster are high enough that their individual motions relative to the cluster's centre of mass are Newtonian. This is a requirement that all MOND theories should satisfy.

### 2.4 Effects of the ambient field

Consider a subsystem in free fall in the external acceleration field of a larger system. Let the field be varying slowly across the dimensions of the subsystem so that tidal effects on the subsystem can be neglected.

In a theory where the strong equivalence principle holds, like the Newtonian theory, the internal dynamics of the subsystem will be unaffected by the ambient acceleration field. The strong equivalence principle does not hold in MOND, however, and the effects of the external field have to be taken into account (Milgrom 1983c).

Suppose $\mathbf{a}$ is found to be the solution of the field equation (9) within the subsystem with boundary condition $\mathbf{a} \rightarrow \mathbf{a_{ex}}$ as $r \rightarrow \infty$. Let $\mathbf{a_{ex}}$ be the centre of mass acceleration of the subsystem, equivalent to the external field. The internal dynamics of the subsystem is then described by $\mathbf{a_{in}} \equiv \mathbf{a} - \mathbf{a_{ex}}$. In general, $\mathbf{a_{in}}$ is very different from the solution to the field equation with boundary condition $\mathbf{a} \rightarrow \mathbf{0}$ as $r \rightarrow \infty$. The behaviour for isolated systems is therefore very different from systems in an external field.

It can be shown that the field will correspond to Newtonian mass larger than the actual mass by a fraction $1/\mu(a_{\rm ex}/a_0)$ (Milgrom 1986b). The internal field will not be asymptotically radial and the radial part will not be spherically symmetric. It will in fact be elongated along the direction of the external field (refer to section 3.5 for an example).

The nature of the internal dynamics depend on the relative magnitudes of $\mathbf{a_{in}}$, $\mathbf{a_{ex}}$ and $a_0$, as illustrated in Fig. 1. When either $a_{\rm in} \gg a_0$ or $a_{\rm ex} \gg a_0$, the internal dynamics will be Newtonian. If $a_0 \gg a_{\rm in} \gg a_{\rm ex}$, the subsystem can be considered isolated and the behaviour will be MONDian. If $a_0 \gg a_{\rm ex} \gg a_{\rm in}$, the dynamics will be quasi-Newtonian. This means that the gravitational constant is substituted by $G_{\rm eff} = G/\mu(a_{\rm ex}/a_0) \gg G$ (Milgrom 1986b).

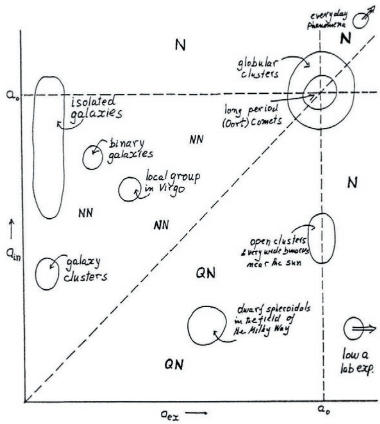


Figure 1: Classification of the dynamics of various astronomical systems according to their internal and ambient accelerations. See discussion below for explanation. Figure adapted from Milgrom (2004).

### 2.5 A common misconception

It is worth emphasizing that MOND is not a modification of gravity at large separations, but at small accelerations. When considering the cause for a problem with mass determination using Newtonian physics, the distance dependence is the most obvious case to consider. Some theories based on this have been suggested (e.g. Finzi (1963); Tohline (1983); Sanders (1984)). This approach is in clear conflict with observations. For example, such a theory would predict no mass discrepancy for small galaxies, but these mass discrepancies are observed.

## 3 Phenomenology

Various consequences of MOND and their comparison with observations are discussed below. Most of these follow directly from the basic postulates and therefore do not depend on the specific theory that is used, or even on the interpretation of MOND.

### 3.1 Phantom matter

One of the key consequences of MOND is that the Universe will appear to be filled with phantom matter if it is described with Newtonian dynamics. This phantom matter's only observable property will be that it has mass. The density distribution of the phantom matter can be predicted by solving (6) to obtain the actual matter density $\rho$, and subtracting this from the Newtonian matter density $\rho_{\mathrm{N}}$.
It can be shown that for various configurations $\rho_{\mathrm{N}} < \rho$. To explain this in the DM framework, one would have to invoke negative DM, which is very objectionable. Examples of such configurations are discussed in Milgrom (1986a), one of which is shown in Fig. 2.

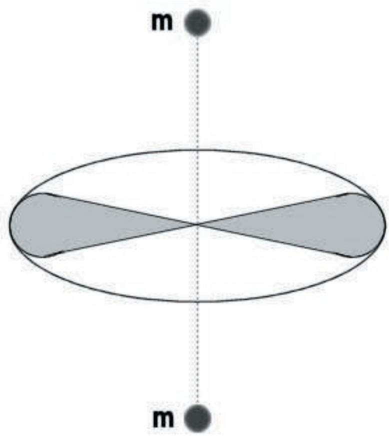


Figure 2: An example of a situation where MOND predicts negative phantom matter. The region for which the phantom matter is negative is indicated by the shaded region in the plane perpendicular to the line connecting two galaxies of equal mass $m$.

### 3.2 Disc galaxies

#### 3.2.1 Rotation curves

MOND's predictions regarding rotation curves are arguably its biggest observational success to date. It allows the rotation curves of galaxies to be described by only the observed baryonic matter of the galaxy. It is the prediction of MOND that can be studied in the most detail with our current capabilities and it presents a considerable problem to those trying to falsify MOND.

The main reason for suggesting MOND was the observed asymptotic flatness of rotation curves. (See the right panel of Fig. 4 for an example of such a rotation curve.) Let $v(r)$ be the angular speed of a test particle in the gravitational field of a mass $M$. For a test particle in a circular orbit ($a = v^2/r$), (2) gives

$$\left(\frac{v^2}{r}\right)^2 \approx \frac{GMa_0}{r^2} \tag{12}$$

or

$$v^4 \approx GMa_0 \equiv v_\infty^4(M) \tag{13}$$

at small accelerations, or in this case, at large enough $r$. Therefore the angular speed of an isolated galaxy tends to a constant value $v_\infty$ that depends only on the mass of the galaxy.

The observed Tully-Fisher relation (Tully & Fisher 1977) shows that for spiral galaxies $v_\infty^\delta \propto L$, where $L$ is the luminosity of the galaxy and $\delta$ is some constant. This can easily be explained with MOND, since the mass-luminosity ratio can be taken as constant:

$$v^4 \approx GMa_0 \propto M \propto \frac{L}{M}M = L \tag{14}$$

Fig. 3 shows a comparison of observations and predictions of MOND regarding the Tully-Fisher relation.

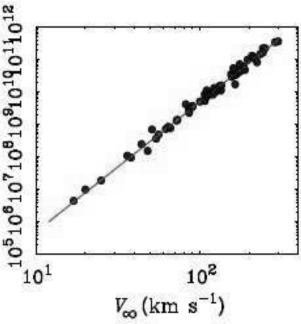


Figure 3: A plot analogous to the original Tully-Fisher relation. Here the mass of gas has been incorporated into the mass of the galaxy, unlike the original relation that only accounted for the mass of stars. The solid line has slope 4 as predicted by MOND, and is not a fit. (Adapted from Milgrom (2008b).)

Galaxies can be separated into two classes, namely high surface brightness (HSB) and low surface brightness (LSB) galaxies. Newtonian dynamics predicts different Tully-Fisher relations for these two classes, but they are observed to follow identical relations. The Tully-Fisher relation is universal in the framework of MOND, consistent with observations. There were no dynamical data for LSB galaxies at the time when MOND was suggested, so this was a prediction of MOND (Scarpa 2006).

It has been argued that the fact that MOND predicts rotation curves cannot be considered a success of MOND, since asymptotic flatness is implicitly built into the assumptions of MOND. This is a gross oversimplification. Asymptotic flatness of rotation curves was not as well established in 1983, when MOND was suggested, as it is today. Also, the exact form of rotation curves is not built into the assumptions of MOND and MOND not only predicts general trends, but also details in individual curves. Likewise, MOND fits curves that are not asymptotically flat (see Fig. 4).

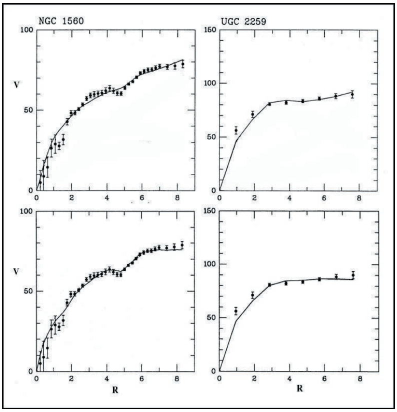


Figure 4: Rotation curves for NGC 1560 and UGC 2259. The graphs at the top show the fits using thee-parameter DM halo fits. Below these are the MOND fits for the same galaxies where the only free parameter is M/L. (Adapted from Scarpa (2006))

The excellent agreement between predictions and observed rotation curves contributes to the validation of MOND, while any systematic disagreement will easily disprove it. Sanders & McGaugh (2002) claim that only 10% of about 100 rotation curves that had been studied using MOND by 2002 show significant deviation from MONDian predictions. In these cases, a probable cause for the discrepancy is usually easily identifiable; for example, strongly barred systems or evidence of a faint interacting companion galaxy. A certain amount of error is also introduced by uncertainties inherent in methods of observation and interpretation.

Lake (1989) claimed to have found a systematic error in MONDian predictions. According to him, the value of $a_0$ had to be systematically smaller for galaxies with a lower maximum rotation velocity. He supported this claim with results from six dwarf galaxies with small internal accelerations. Milgrom (1991) responded to this, pointing out the large uncertainties of the data used by Lake.

Rotation curves of galaxies are explained by MOND in a very natural way, with the mass-luminosity ratio as the only free parameter. The DM hypothesis needs three free parameters to model rotation curves (mass-luminosity ratio of the disc, the halo's core radius, and the asymptotic velocity of the halo). This allows the DM model to be very arbitrary, and difficult to disprove. This is illustrated very clearly in Fig. 5, where DM was able to produce a good fit for an unphysical galaxy, whereas MOND could not.

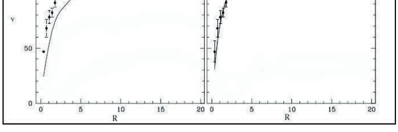

Figure 5: A fit was sought for a contrived galaxy. Velocity information of NGC 2403 was used and the mass was determined using photometry of another galaxy, UGC 128. The left panel shows the best MOND fit. Clearly, MOND is unable to fit this unphysical hybrid galaxy. Dark matter, however, is able to produce a good fit for the fake galaxy, due to the freedom that it allows. (Adapted from Scarpa (2006).)

It is difficult for DM to mimic the MONDian behaviour of rotation curves in a natural way. Even if MOND is someday disproved, its phenemological success regarding rotation curves will still need to be explained.

#### 3.2.2 Surface densities

The constant $a_0$ defines a surface density $\Sigma_0 = a_0 G^{-1}$. The rotation curves for disc galaxies with average surface density much greater than $\Sigma_0$ would show a considerable decrease from their maximum values to the asymptotic value. This is not observed, which suggests that $\Sigma_0$ is the upper bound for the surface density. Such a cut-off has been observed and is known as Freeman's Law (Freeman 1970).

In HSB galaxies the surface density $\Sigma \approx \Sigma_0$ and the internal accelerations are much larger than $a_0$. Therefore MOND predicts very little discrepancy between the Newtonian mass and the observed mass. For LSB galaxies, $\Sigma \ll \Sigma_0$, the internal accelerations are small and a large mass discrepancy is expected. Only a very small number of LSB galaxies were known to exist at the time MOND was proposed. This prediction has since been verified (McGaugh & de Blok 1998).

### 3.3 Elliptical galaxies

Elliptical galaxies are not rotationally supported, but are kept from collapse by the random motions of their constituents. If the velocity dispersion of these pressure supported systems does not vary much with position, they can be modelled with isothermal spheres (ISs). A detailed analysis of ISs using MOND for pressure supported systems (e.g. ellipticals, globular clusters, galaxy clusters) is presented in Milgrom (1984). The main results are discussed here.

In MOND, all ISs have finite mass, unlike in Newtonian dynamics where their mass is necessarily infinite (Milgrom 2004). The constant $\Sigma_0$, that was introduced earlier, is the upper limit for the surface density that an IS can have. The total mass $M$ of an IS is approximately proportional to the fourth power of the velocity dispersion $\sigma$ (Milgrom 2004):

$$(a_0 G)^{-1} \leq M/\sigma^4 \leq \frac{4}{9}(a_0 G)^{-1} \quad (15)$$

This is consistent with the observed Faber-Jackson relation (luminosity-velocity dispersion relation) for elliptical galaxies (Faber & Jackson 1976). Because of the high central velocities of ellipticals, a large portion of these galaxies falls into the Newtonian regime. Therefore many ellipticals can be described conventionally without the use of DM. This does indeed seem to be the case (Romanowsky et al. 2003; Milgrom & Sanders 2003).

The importance of MONDian effects differs for HSB and LSB galaxies and depends on the average surface brightness of the galaxy. HSB galaxies become less dense as their size (luminosity) increases. Therefore it is to be expected that MONDian effects will become more pronounced (and the Newtonian mass discrepancy more significant) for these galaxies as their size increases. On the other hand, LSB galaxies become denser as their size and luminosity increase, thus one expects the MONDian effect to be less prominent with increasing size. This is observed to be the case (Scarpa 2006).

Dwarf and ultra-compact dwarf (UCD) galaxies present interesting problems when studied using DM, whereas their dynamics are easily explained within the MOND framework. Dwarf galaxies are found to show a considerable mass discrepancy (Kleyna et al. 2001). This is expected in MOND, since they have low surface densities which imply low accelerations. Milgrom (1995) has shown that observations of seven dwarf galaxies are consistent with MOND, with no need for DM.

UCD galaxies were discovered fairly recently in a survey of the Fornax cluster (Drinkwater et al. 2000). UCDs have very high central densities, but are significantly more luminous than globular clusters. These galaxies show almost no mass discrepancy. The most widely accepted explanation for this under the DM hypothesis is that UCDs are nuclei of dwarf galaxies that have been stripped of their DM halo through interaction with other galaxies (Gregg et al. 2003). With MOND it is easily shown that, because of the high mass density, the acceleration at the outer edge of a UCD is much greater than $a_0$. Therefore it is appropriate to describe UCD using only Newtonian dynamics.

### 3.4 Galaxy clusters

MOND's predictions for small galaxy clusters and galaxy groups correlate reasonably well with observatons (Milgrom 1998). However, rich galaxy clusters prove to be problematic for MOND. Even when MOND is used to describe these clusters, there is still a systematic mass discrepancy.

The large mass discrepancies associated with rich galaxy clusters were greatly alleviated, but not fully explained, by the discovery of hot, x-ray emitting gas in these clusters. The dynamical mass is larger by a factor of 4 to 5 when using Newtonian dynamics, and is reduced to a factor of 2 for MOND (Sanders 1999). Fig. 6 illustrates the mass discrepancy for galaxy clusters for both the Newtonian and MONDian cases.

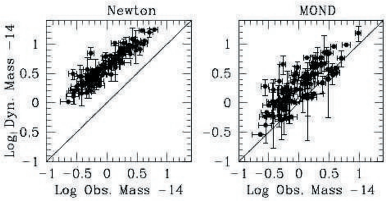


Figure 6: The dynamical mass of a sample of galaxy clusters plotted against their observed mass. The Newtonian case is shown on the left, and results in MOND on the right. The solid line represents zero mass discrepancy. (Adapted from Sanders (1999).)

Fortunately for MOND, the MONDian dynamical mass is larger than the observed mass. Had the situation been reversed, this would have invalidated MOND. It is possible that this mass discrepancy is due merely to the several simplifying assumptions that have to be made when dealing with galaxy clusters (Scarpa 2006).

On the other hand, it is certainly possible that the mass discrepancy is real. In this case, MOND's failure to explain the mass discrepancy in galaxy clusters may indicate the ruin of MOND (Aguirre, Schaye, & Quataert 2001). In the context of MOND, the mass discrepancy means that there is undetected matter in the core of the cluster. This matter and its relation to the cooling-flow puzzle are discussed in detail in Milgrom (2008a). The detection of this baryonic matter will tend to lend strong support to MOND as opposed to DM theories.

It is appropriate to mention recent observations regarding the Bullet Cluster (1E0657-56). Bradač et al. (2006) used gravitational lensing to map the mass distribution of this cluster and found that there are large concentrations of matter that are spatially separated from the luminous matter. They claim that this is in direct conflict with MOND, since the spatial distribution of MOND's phantom matter must necessarily be closely related to the distribution of luminous matter. But, it has been argued (see for example Angus & McGaugh (2008) and Milgrom (2008a)) that the Bullet Cluster proves to be far from devastating to MOND, and that recent observations pose as many problems to DM theory as it does to MOND (see Farrar & Rosen (2006)).

## 3.5 Breakdown of the strong equivalence principle

MOND does not obey the strong equivalence principle. Any violation of this principle will be firm evidence in favour of MOND. Examples of observations that would signify such a violation are discussed in Milgrom (1986a). For instance, in MOND a gas cloud with isotropic pressure in a constant external acceleration field $a_{\rm ex}$ with $a_{\rm in} \ll a_{\rm ex} \ll a_0$, will not be spherical, but elongated along the direction of the field.

## 4 MOND and cosmology

It may be premature to discuss cosmology in terms of MOND, since it is an incomplete theory that lacks a proper extension into the relativistic regime. Some consequences of MOND for cosmology are discussed in Sivaram (1994) and a recent review of the subject is given in Bekenstein (2006). All cosmological MONDian analyses are preliminary, but nothing has been found that categorically disproves MOND.

### 4.1 A relativistic theory of MOND

A proper relativistic extension of MOND is a very important next step for MOND. This is not only crucial for the conceptual completion of the hypothesis, but will also broaden the domain in which MOND can be tested. Relativistic phenomena that show a mass discrepancy have been observed, for instance gravitational light deflection and gravitational lensing. A relativistic extension is essential for the construction of a MOND cosmology, which will respond to an all important question of structure formation. It is generally believed that DM is required for structure to form in the early Universe. MOND supporters challenge this idea and believe that MONDian effects in the early Universe could have caused galaxies to form (Sanders 2008; Dodelson & Liguori 2006; Skordis et al. 2006). There have been a few proposals for a relativistic formulation of MOND (for example Bekenstein & Milgrom (1984); Sanders (1997)). By far the most successful proposal so far is the tensor-vector-scalar (TeVeS) formulation proposed by Bekenstein (2004). TeVeS has been receiving a good deal of attention from MOND advocates and some reformulations and generalizations of the theory can be found in Sanders (2005) and Zlosnik, Ferreira, & Starkman (2006). The theory seems promising, but requires further development. A review of TeVeS can be found in Sanders (2007). A more general review of relativistic theories of MOND is given in Bekenstein (2006).

### 4.2 MOND as an effective theory

Is has been noted that $a_0$ is very nearly equal to $cH_0/2\pi$ or to $c(\Lambda/3)^{1/2}$, where $\Lambda$ is the cosmological constant (Milgrom 2002b). This may be a coincidence, or hint at the fact that MOND is merely an effective theory which is at the surface of a deeper theory. To illustrate this, consider $g$, the gravitational acceleration of Earth. To observers fixed on Earth, $g$ might appear to be a constant of nature, whereas it is actually derivable from a more general gravitational theory. In the same way, $a_0$ might be derivable from a more fundamental theory.

If the above mentioned relations between $a_0$, $H_0$ and $\Lambda$ are lasting, then $a_0$ changes with cosmological time.

This would imply that galaxy dynamics and evolution are affected not only by nearby systems, but also by the general state of the Universe. The relations might also connect MOND and dark energy effects, showing that one is a result of the other, or that both are caused by some other mechanism (Milgrom 2008b).

Possible underlying theories for MOND are still very speculative and are discussed in Milgrom (2008b). This may prove to be the most fundamental result of MOND, or it may turn out to be pure coincidence.

## 4.3 Gravitational lensing

Mass discrepancy in the Universe is not only deduced from the motion of massive objects, but can also be measured by studying the way mass affects the path of light. Gravitational lensing has proved to be a powerful method of mass determination. Using this method, the mass of a object can be inferred from the degree of curvature in the path of light passing near it.

Zhao et al. (2006) used strong lensing data from the CASTLES catalogue and found TeVeS provides an acceptable description for strong lensing data generally. Most of the systems they studied could be explained with TeVeS, but a number of systems show significant deviation from the theory. Chen (2008) also studied strong lensing within the framework of TeVeS, and found that results were sensitive to the exact form of $\mu(x)$. He was able to fit lensing data from CLASS/JVAS with a $\mu(x)$ that is consistent with one that was constrained from galactic rotation curve data (Sanders 2007). He also concluded that MOND can account sufficiently for strong lensing observations.

Ferreras, Sakellariadou, & Yusaf (2008) claimed that MOND still needs DM to explain elliptical lenses. Bekenstein (2010) criticized their calculations, on the grounds that they used a mixture of MOND and general relativity, instead of TeVeS. Chiu, Tian, & Ko (2008) redid the calculations of Ferreras et al. (2008) in TeVeS, and found no need to invoke DM in order to account for observations.

Mavromatos, Sakellariadou, & Yusaf (2009) also used CASTLES data and found that TeVeS still require DM to explain observations. They found one form of $\mu(x)$ for which very little DM was required, but this form was found to be unrealistic, when rotation curve data was taken into account. The matter was explored futher in Ferreras et al. (2009) where the analysis of Chiu et al. (2008) is also criticized for not being truly relativistic.

Weak gravitational lensing proves to be particularly challenging for MOND. Takahashi & Chiba (2007) studied weak lensing of galaxy clusters and found their results inconsistent with MOND alone, and DM is still required. Natarajan & Zhao (2008) and Tian, Hoekstra, & Zhao (2009) came to similar conclusions by studying combined strong and weak lensing data from galaxy clusters and weak galaxy-galaxy lensing, respectively. It has been noted (Angus et al. 2007) that a halo of hot ordinary neutrinos with mass $\sim 2$ eV will reconcile weak lensing observations with MOND. But this solution is unlikely, since 2 eV has been determined to be the upper limit for neutrino mass from beta decay experiments (Amsler et al. 2008). The KATRIN experiment will be able to test this idea by measuring the neutrino mass with unprecedented accuracy. Measurements are expected to start in 2012 (Wolf 2008).

Gravitational lensing has proved problematic for MOND. MOND seems to be able to explain strong lensing reasonably well, but fails consistently with regard to weak lensing. It should be noted that most of the above results are based on predictions specific to TeVeS, and not a general relativistic theory of MOND. This may show that a relativistic theory based on modified inertia, not modified gravity like TeVeS, should be considered.

### 4.4 Cosmic background radiation

For a long time it has been believed that DM is necessary to explain the power spectrum of the temperature anisotropies of the cosmic background radiation (CBR). DM's ability to fitu CBR data consistently and accurately is arguably DM's greatest success. Skordis et al. (2006) used equations derived by Skordis (2006) for cosmological perturbations in TeVeS and found that TeVeS can be made consistent with the observed power spectrum without the need for DM, if one allows for massive neutrinos and a cosmological constant. Angus (2009) showed that a sterile neutrino with mass $\sim 11$ eV would reconcile the CBR observations with MOND. Such a neutrino would also obviate the need for DM in galaxy clusters when using MOND.

## 5 Discussion

The phenemological success of MOND is undeniable. This has been the main focus of the current work and it has also been the central reason for the promotion of the theory. Many of these successes were predictions that were verified at a later stage. MOND also unifies the observed laws of galaxy dynamics and provides relations between galactic observables.

However, MOND has various shortcomings. It is an empirically based theory that lacks a proper physical basis. There have been suggestions to this end, the most promising of which to date is that MOND is a vacuum effect (Milgrom 1999). A serious deficiency of MOND at present is the lack of a proper relativistic theory. This puts MOND at a disadvantage and restricts the environments where the theory can be tested.

The virtues and vices of DM and MOND are very different. MOND seems to work better on galactic scales, but DM is more successful to explain cosmological phenomena. How one weighs the different successes would affect ones opinion of which is the better theory. Current evidence does not clearly favour one theory over the other.

It has been suggested that MONDian effects can be explained in terms of DM (Kaplinghat & Turner 2002). This claim was strongly challenged by Milgrom (2002a) who pointed out various flaws in their argument. The idea was brought up again by Dunkel (2004)) who suggested that MOND is a limiting case of DM. McGaugh (2004) pointed out that Dunkel's analysis presents severe fine-tuning problems. The suggestion that MOND is a result of DM has been denounced by MOND supporters. They judge that the natures of the two theories are too dissimilar, and emphasize the fact that observational tests can be constructed where the predictions of the two theories are disjoint. Some suggestions regarding such tests are discussed in Sellwood (2004).

It is important to remark that the DM hypothesis has been far from unsuccessful. It has its triumphs and puzzles, just like MOND. The details of this are beyond the scope of the current work, but recent reviews can be found in Fornengo (2008), Caldwell (2003) and Dolgov (2000). DM has enjoyed considerable attention and resources over the past few decades. This has not been unfounded and by far the largest part of the astronomical community endorses the DM hypothesis. The intent of this work is not to try to falsify this theory, but to consider the current observational evidence and suggest that it is not the only feasible solution to the missing mass problem.

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# Amateur Rocketry in South Africa – 1952-63

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In the April 2010 issue of *MNASSA* (Vol 69, Nos 3 & 4, p.67) Dr Peter Martinez reviewed the book *Cracking the Sky: A History of rocket science in South Africa*. This book details the activities of Desmond Prout-Jones which deals solely with his activities. As Martinez pointed out, the book does not really live up to its title as it completely ignores the activities of other amateur rocketry groups that were active in South Africa at the time. Consequently, some of the claims made in the book are not completely valid.

During the period covered by the Prout-Jones book, there were three amateur rocketry groups in South Africa, working independently with very little mutual contact. These groups were: Desmond Prout-Jones' in Johannesburg, the Astronautical Research and Experimental Group of the Port Elizabeth branch of the South African Interplanetary Society and the University of Natal Rocket Society and Research Group (UNRS) in Durban.

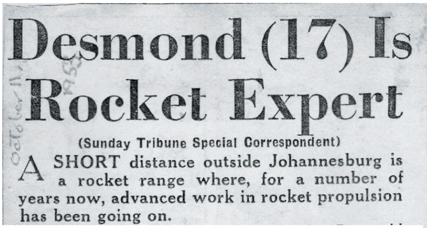
This article is an attempt to try to give a fuller, although still a **very** incomplete picture. Unfortunately there is very little information available on the Port Elizabeth (PE) group – only from occasional newspaper cuttings of this period. I was very actively engaged in the UNRS group (hence its dominance in this article). It is hoped that this brief summary might bring to life some of the other people involved so that ultimately as complete a history as possible can be assembled.

Perhaps the best way to cover the history will be a chronology of events that I had found over that period. It is certainly not complete but is all that is currently available. In compiling this I have had to rely on my memory as well as various newspaper articles, publications, photographs and correspondence with some of the members I have been able to locate after 50 years.

**Early beginnings**

The first indication of interest in rocketry and space travel in South Africa appears to have been the establishment of the South African Interplanetary Society in Johannesburg. Very little information is available about it and it does not appear to have been

**As the oldest reference in my possession (dated 11 October 1953), this newspaper clipping suggests Desmond Prout-Jones to be the "father" of amateur rocketry in South Africa.**



Desmond (17) Is Rocket Expert

(Sunday Tribune Special Correspondent)

A SHORT distance outside Johannesburg is a rocket range where, for a number of years now, advanced work in rocket propulsion has been going on.

DESMOND PROUT - JONES making an adjustment to his liquid fuel rocket.

very active or in existence for more than a few years. I did however attend their exhibition in the Johannesburg Public Library in December 1954, but do not recall much else about it. This society does pop up from time to time in the activities of two of the three amateur rocketry groups.

**1953**

11 Oct: A newspaper clipping about a 17-year-old radio apprentice, Desmond Prout-Jones, showing a 1 m long, 75 mm diameter, liquid fuelled rocket, still to be launched. Prout-Jones claims it took him exactly 5 years to get to this stage.

In 1999 Brian Evans (of the PE group) claimed to be the "father of S.A. rocketry". However, in the light of Prout-Jones's 1953 press article, this claim is contradicted. So, barring any further evidence, Prout-Jones can indeed be regarded as the father of amateur rocketry in South Africa.

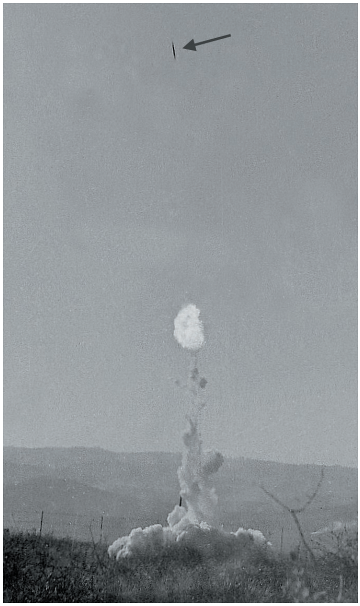
**1956**

10 June: *Youths Build S.A.'s First Rocket Motor* (S.A. Press Association): "South Africa's first supersonic rocket motor, built by two teenagers, Alan Bowman and John Deschamps, was tested in Port Elizabeth today, and was reported a 'complete success'. Dr. P.K. van Gent, a Government analyst who assisted the young rocket engineers, was enthusiastic about the test, which was watched by about 20 people." … no further details were given.

The author started doing backyard experiments in his home town, Glencoe (Northern Kwa-Zulu Natal), with home-made gunpowder rockets. Only static motor tests were carried out with no actual launches.

**1958**

The author and Brian Page, two 1st year Engineering students at the then University of Natal (Durban), formed a friendship and started some amateur rocket experiments using a tennis court near the university residence, Ansell May Hall, where Brian and the author resided during their university academic year. Due to the author's difficulties in walking as a result of polio in 1957, Brian became the Launch Officer (he could move faster than Greg!) and remained so for the entire duration of the Society's existence. Besides being the Launch Officer, Brian was also the person responsible for preparing and mixing the rocket propellants and was ably assisted by



**During the period 1958-1959 some 50 rockets were launched from behind the University of Natal, Durban. (left) Brian Page busy placing a small two-stage rocket on its launch rail. (right) A two-stage launch on 7 May 1959. The second stage firing is obvious (the lighter puff of smoke) with the rocket a black streak near the top of the picture (arrowed).**

Lance Roberts (no relation to the author) at the Society's launches. As they grew more adventurous, the tennis court soon proved too small and close to habitation. Launches were moved to a hill slope at the back of the University which faced in the direction of the relatively unpopulated area (later to become the suburb of Manor Gardens).

August 1958: The University of Natal Rocket Society and Research Group (UNRS) was formed. The leading members were (in no particular order): Brian Page, Greg Roberts, Arthur H.J. Sale and Allan J. Mash**.**

"The idea of organising a rocket research group at University occurred to Greg Roberts and Brian Page when they happened to see a Russian film exhibited in South Africa called *Blazing A Trail to the Stars* which showed some scenes of amateur rockets being launched – presumably in Russia. The pair decided to conduct some rocket experiments on their own and started first with static tests of small rocket engines powered with gunpowder. Roberts had had some previous experience with such engines when he was much younger, but discovered that his backyard test firings made him extremely unpopular in his hometown neighbourhood because all the dogs and chickens in the area would howl and cackle for about half an hour after each firing." *

* Source: Capt. Bertrand R. Brinley (U.S. Army) article on the UNRS that appeared in *American Model*, May 1960. Brinley was appointed by the U.S. Army to assist amateur rocketry groups in the United States. I do not recall how he came into contact with the Society but I corresponded with him. His article was based mostly on this correspondence.

**1959**

March: The UNRS applied to the Students Representative Council (SRC) of the University of Natal to be approved of as an official University Society. This enabled the Society to get a small annual grant to carry out activities. Membership of the UNRS averaged around 50 members each year but only about half a dozen students were actively engaged in the running of the Society.

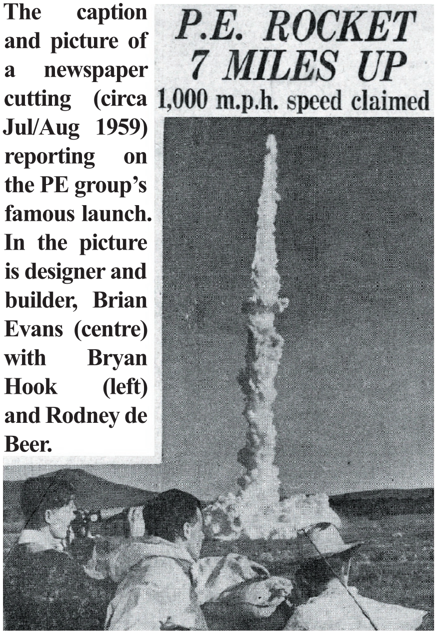
Several members, e.g. Allan Mash, Arthur Sale and the author, experimented with various rocket propellants – some of which resulted in spectacular and loud explosions! Whilst most of them proved more powerful than the so-called "micro-grain" propellant (zinc dust and sulphur) used by most amateur groups, this was not pursued being considered too dangerous.

Since May 1959 the UNRS launched several small two-stage rockets. This is believed to have taken place before Prout-Jones's first flight of a multistage rocket. In all approximately 50 rockets were launched from the UNRS's site at the back of the University and the highest altitude attained was about 1 000 metres. One launch resulted in a large grass fire with the students rapidly vacating the area and the Group realised that they had to find a larger test "range". At about this time it was discovered that the UNRS activities were breaking the law as permission had to be obtained from the Chief Inspector of Explosives (CIE) in South Africa to launch anything – red tape had struck!

In an undated press report (circa July/August 1959), the PE group claimed that one of their rockets soared to a record height of about 11 000 m, reaching a speed of 1 600 km/h. The designer and builder was Brian Evans. The rocket is believed to have been a 4,2 m long, solid fuel, three-stage, weighing 50 kg and launched from a 6 m high tower. There was some uncertainty whether the third stage fired, so the claim of a South African record cannot be substantiated.

**1960**

The UNRS started producing its own quarterly free publication, *BLAST-OFF*, which covered space matters including Astronomy for University members. Interested members of the public could subscribe to it for a




**The caption and picture of a newspaper cutting (circa Jul/Aug 1959) reporting on the PE group's famous launch. In the picture is designer and builder, Brian Evans (centre) with Bryan Hook (left) and Rodney de Beer.**

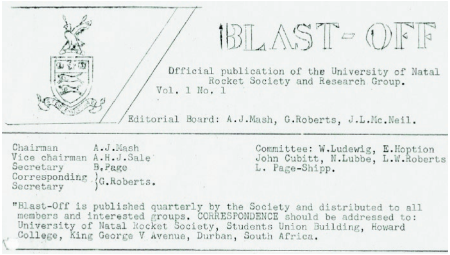
**(left) A reasonably small solid fuel rocket launch by the Port Elizabeth group.**

**(right) This is probably the 4,2 m long, solid fuel, three-stage rocket of the PE group, claimed to have reached 11 000 m, here being prepared for launch.**

nominal fee. The first issue contained an article on *Project Adamastor* which was a planned 3 m long liquid fuel rocket, developing 450 kg thrust for six seconds and capable of carrying a 9 kg instrumentation package to an altitude of 15 km. The propellants proposed were red fuming nitric acid (7,3 kg) and aniline (2,6 kg), stored in concentric tanks. A smaller static test motor, weighing about 6,3 kg and producing 115 kg thrust, was already under construction by Gilbert Hamer Engineering Works (a large marine ship construction/engineering concern in Durban). Arthur Sale also reviewed the choice of propellants for this rocket. It would appear that this project was subsequently abandoned as the proposed propellants were too toxic and dangerous to handle safely.

During the June/July vacation the University held a large exhibition called "From our World" at the Woolbrokers Federation Building in Umbilo, Durban. The UNRS was asked to put on an exhibition and the Department of Physics provided funding. Two rockets were designed by the author, one called RS60-1 which was a single stage solid fuel rocket. The other one (RS60-2) was a large two-stage solid fuel rocket, capable of reaching an altitude of about 11 km. These rockets were constructed in the Department of Mechanical Engineering workshops by a Society member, Frank Bullock, who had served an apprenticeship in "fitting and turning".

After the usual red-tape with the CIE, permission was finally obtained to launch RS60-1 which was achieved on 11 September from a beach launch site just north of the Tongaat River. The 45 kg, 1,8 metre long rocket with a diameter of 88 mm carried a radio beacon transmitter, parachute and di-chloro-fluorescein dye which produces



BLAST-OFF

Official publication of the University of Natal Rocket Society and Research Group.
Vol. 1 No. 1

Editorial Board: A.J.Mash, G.Roberts, J.L.Mc.Neil.

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"Blast-Off is published quarterly by the Society and distributed to all members and interested groups. CORRESPONDENCE should be addressed to: University of Natal Rocket Society, Students Union Building, Howard College, King George V Avenue, Durban, South Africa.

**(above) Cover page of the first issue of *BLAST-OFF*. (right) Lance Roberts and Brian Page, in protective clothing, busy fuelling RS60-1, here perched upside down in the hole prepared for the launch tower (see cover picture). (bottom-right) RS60-1 shortly after ignition, launched from Tongaat beach. The rocket can be seen near the top of the photograph whilst the object below-left of it is the nose-cone which separated prematurely.**

a bright green stain in water. The rocket achieved an altitude of nearly 4 km before splashing down in the sea. The thrust was about 1 525 kg and the rocket was estimated to have reached a top speed of about 1 280 km/h. The launch was attended by members of the press and also featured on *African Mirror* – a weekly report of news events in South Africa, screened in cinemas. This amount of publicity did not gain the Society any favourable points with the CIE!

*Blast-off*, September 1960, gave a comprehensive report on the launch with articles by the author on the technical aspects and by Les Page-Shipp who was the Range Safety Officer. In the same issue it was proposed that the various aspects of the Society be sub-divided into design, public relations,

propellants, instrumentation, electrical, equipment and transport, radio communications, photography, rocket tracking (radio and visual), first-aid, camp and food, range safety, etc. Members could volunteer for the areas that interested them.

**1961**

One of the founding members of the UNRS, Allan Mash, former chairman and editor, changed his choice of career and had moved to Grahamstown to study theology and eventually became a church minister.

The author wins an award by the Engineering Society for best student paper presented at the annual Engineering Society Student Papers contest, where he described the activities and ambitions of the UNRS. The judges were several University staff in the Engineering Department.

A sub-branch of the UNRS was formed at the University of Natal, Pietermaritzburg, by two ex-members of the Durban group, 'Jock' McNeil and Grey de Villiers, who changed universities. Not much is on record about their activities and how long it lasted but indications are that it never really took off. Grey's mother produced a beautiful red and white parachute which was used at the Red Desert launch for the RS60-2 first stage (more later).

*Blast-off* Vol 2, No 1, contained an article by Kenneth Wynn on the construction of a fibre-glass rocket which he and Len Dicks were investigating. R.F.N. Reynolds ('Robbie') reported on a 3-stage, solid fuel rocket that he was planning to make out of high tensile-temperature steel (diameter about 90 mm and 2,75 m long). In addition, a list of university and public members was published where the name Prout-Jones appears. However the author does not recall any correspondence or input from him.

**Len Dicks holding RS62-2 which was originally designed as the second stage of a larger two-stage rocket, dubbed RS60-2.**

*Blast-off* Vol 2, No 2: The fibre-glass rocket project was dropped as expert opinion was that the rocket would blow up like a balloon. Basil J. Gardner reported that he was working on a high altitude camera, whilst Lance Roberts had been conducting static tests on various propellants, best summarized as "Fizzzzzz----BANG!". A promising combination had been found and was being investigated further.

The CIE raised no objections to the rockets proposed to be launched, provided that the

UNRS obtain a site with a "radius equal to the rockets altitude which is clear of life". One of his worries was how the UNRS was going to ensure that rocket stages fire in the correct sequence. Since one of the rockets proposed for launch had a possible altitude of 70-80 km, it meant that its launch was unlikely as the UNRS could not find such a site. This is the main reason why all subsequent UNRS rockets were confined to relatively low altitudes.

An article by Basil Gardner on the possible use of an area 170 km south of Durban (known locally as the "Red Desert") as a launch site was proposed, following an examination by himself and Robbie Reynolds. (This site was used for the 1962 launchings – see later.)

*Blast-off* Vol 2, No 3, reported that Dr P.A. O'Brien, a lecturer in the Physics Department at University of Natal, Durban, had been appointed the UNRS President. O'Brien's hobby was radio astronomy which is believed what he eventually made his profession.

Kenneth Wynn gave a progress report on the fibre-glass rocket project as the previous test firing resulted in a "horrible mess" A comment made by the editor was that "the new rocket looks complicated and we would not be surprised if they leave something out by mistake"!

The UNRS was now a member of the British Interplanetary Society and mention was made of the Natal Group in one of their publications.

Two articles by the author dealt with liquid fuel propellants. Part 1 contained details on the proposed high altitude liquid fuel research rocket, then on the drawing board. This would be a multi-stage rocket using a solid fuel booster weighing about 225 kg, diameter 20-25cm and 1.5 metres long. The second stage was a liquid fuelled rocket (liquid oxygen and ethyl alcohol) having a planned diameter of 30 cm and 3,7 m long, weighing about 320 kg. The expected final velocity was in the region of 1 220 - 1 830 m/sec, reaching an altitude of over 160 km. The rocket was to be constructed in the University of Natal Mechanical Engineering workshops.

Fred Heyl presented a report by himself and Roy Spring on using the de Brug Army Gunnery Range at Tempe (near Bloemfontein) as a possible launch site. The commandant in charge of the range was very interested and suggested the UNRS approach the Commandant-General in Pretoria, Colonel Pienaar, who was the Army's Director of Explosives. This meant that the UNRS now by-passed the CIE as the whole project would then fall under the supervision of the Army. However, one of the complications was that this range was directly under the Kimberley to Cape Town air-route, which meant that dates and times would have to be published in the *Provincial Gazette* beforehand. Another complication was that radar tracking by the Army was out of the question as only a few units were available and moving them to de Brug would be a major task.

In *BLAST-OFF* Vol 2, No 4 (August 1961), the following from Jock of the Pietermaritzburg group: "A valuable source of ideas has left for the U.S.A. and his presence will definitely be missed. There was a suggestion that Tim Harwarden* should try and contact Capt. B.R. Brinley and give him some hints."

Part 2 of the article by the author was on Liquid Fuelled Propellants as well as an article dealing with the mathematics involved in designing a solid propellant rocket. A report by Trevor Dunstan on the use of naphthalene as a solid rocket fuel (mixed with other chemicals) which concluded that it was not a practical proposition.

Kenneth Wynn reported further on his fibre-glass rocket, now with a ceramic-lined nozzle. Grey de Villiers reported working on some instrumentation that was to fit in the 75 cm long fibre-glass nose cone, produced by Basil Gardner. Jock McNeil reported working on a concise history of the UNRS (unfortunately never completed or made available). It was also reported that the launching tower length had been increased to 7,5 m.

August 1961: The UNRS received a setback when permission was refused by the CIE to launch the 5 m high two-stage rocket, RS60-2. The reason given was that "the rocket could go off-course and since it has a range of about 35 km, it could possibly sink a ship in the Indian Ocean".

*BLAST-OFF* Vol 2, No 5 where the editor (Greg Roberts) wrote: "Unless more members take an active interest, the Society will soon fade out, and in this Age of Space, we think it would be deplorable if this occurred. One member made the statement that the Society is 'run by a gang'. This is very true but membership of the so called 'gang' is open to all members. This 'gang' contains the workers and brains of the Society. We encourage members to take an active part, but the vast majority state that since they know nothing, they cannot do anything - JUNK! How much rocketry did the founders and present active members know? NOTHING, but because they took the trouble to discuss or read about rocketry they now have a keen interest. I have been critical but something has to be done if the Society is to continue to function."

Basil Garner reported he was working on a very slow, though vigorously burning propellant and there was a further brief report by Kenneth Wynn on his fibre-glass rocket.

Part 3 (final) contained "Liquid Rocket Propellants" by Greg Roberts and "Radio Tracking of the Explorer VII satellite" by Basil Gardner and Greg Roberts.

No launches were held during 1961 as the Society tried to find a suitable launch site while battling with the restrictions of the CIE.

* Tim's father was Professor at the University of Natal, Pietermaritzburg, where Tim did his B.Sc. Tim later became a wellknown professional astronomer and was one of the shortlisted candidates for the directorship of the South African Astronomical Observatory many years later.

The society publication now became monthly during the academic year.

At one of its Council meetings the Durban SRC passed the following resolution regarding the UNRS: "Resolution 159: That this council once again warmly congratulates the Rocket Society on its energetic programme over the past year".

**1962**

*Blast-off* Vol 3, No 1 had an article by the author on "Tracking the Mercury Capsules" but not much else of interest.

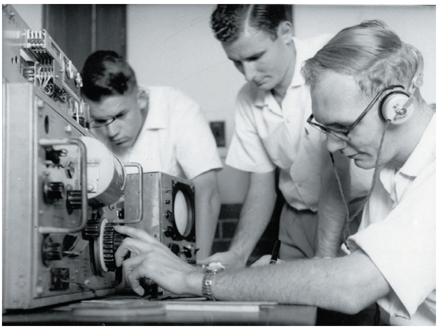
Following a trip by three members to see the CIE face-to-face in Johannesburg, permission was finally granted to launch RS60-2, but only as two separate single stage rockets with the altitude limited. (On the way back to Durban there was a car accident in which the car involved was written off and the three members landed up in the Pietermaritzburg hospital - fortunately with no serious injuries.)

The author was offered employment by the CIE when he completed his degree. This was not followed up.

A (circa 1962) newspaper cutting on the PE group stated: "Scrap of skin to be blasted 50 miles up into P.E. sky to be launched 'next year'. Brian Evans (24 years old) assisted by Brian Hook (23 years old)." Described as a two-stage rocket of which the first stage was liquid fuelled. Evans further stated "first liquid powered rocket to be launched in Africa".

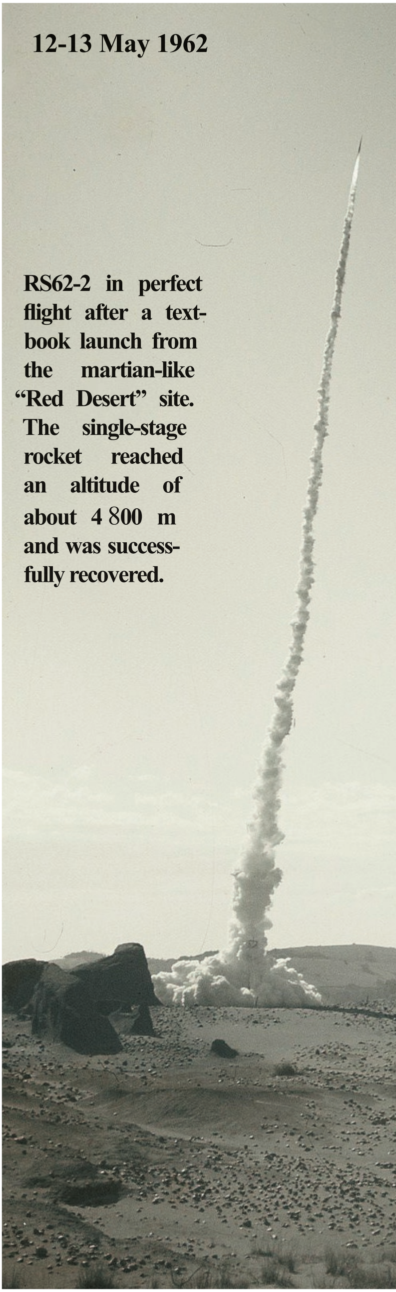
*Blast-off* Vol 3, No 2 was the pre-launch issue for launches planned for May 1962. It listed the allocation of duties for members at the launch, technical details of the rockets to be launched and the proposed count-down schedule. A rather arid region known locally as "Red Desert" between Port Edward and the then Umtamvuna River pont was approved as a launch site and during the weekend of 12-13 May 1962 the UNRS launched several rockets. There was no press coverage due to restrictions by the CIE and the remoteness of the launch site from Durban, but was well attended by about 60 people, including several University staff members who had assisted the Society in one way or another.

Three major rockets were launched. A fibreglass rocket, constructed by Len Dicks (not to be confused by the one Kenneth Wynn had been working on) which exploded shortly after launch



**Tracking one of the early Project Mercury missions (American man-in-space program which was followed by the Gemini and subsequent Apollo missions). Left to right - Len Dicks, Derek Woodburn and Greg Roberts.**

## 12-13 May 1962



RS62-2 in perfect flight after a text-book launch from the martian-like "Red Desert" site. The single-stage rocket reached an altitude of about 4 800 m and was successfully recovered.

(above) Brian Page and Lance Roberts loading RS62-2 into the launch tower after which the rocket was fuelled and the nose cone fitted.

(below-left) Roy Spring and Derek Woodburn holding the nose cone for RS62-1.
(below-right) Len Dicks with RS62-1 which got buried in rock on landing and could not be removed.

(not unexpected). The second stage of RS60-2 (now called RS62-2) did a perfect flight to about 4 800 metres and was successfully recovered. However, the larger first stage (called RS62-1) had insufficient velocity as it cleared the launch tower (the tower turned out to be too short). As it left the tower it did a slight tilt and possibly fouled one of the guide rails which imparted a rotational motion to the rocket, causing it to fly off in the wrong direction which severely limited its altitude. It was "recovered" where it was embedded in rocky soil, and abandoned. Its altitude was not determined as everyone was taking cover! There was an accelerometer in one of the rockets, emitting a continuous radio tone, related to the acceleration during flight. It gave one brief squeak on lift-off and then died – the acceleration was far greater than anticipated!

In the second half of 1962 the UNRS held a space conference at the University in Durban (open to the public as well) at which several of the leading members presented papers on various aspects of amateur rocketry. This was very well attended and was a great success but unfortunately no records exist as to papers presented or by whom. The author was approached by a member from the audience who was recruiting staff for an undisclosed organisation that was starting to develop rockets in South Africa – this turned out to be the future South African secret rocket program that eventually produced the Overberg missile range. However, they were only interested in "engineers".

*Blast-off* ceased to exist after the May launchings, probably because academics finally took precedence as all the main members were in their final year of study.

A moonwatch satellite tracking station was established in the last half of 1962 but never really became operational as part of the UNRS. It was only in subsequent years that this became operational (but nothing to do with the University) … which is another story.

The UNRS was involved in negotiations with a group in the United States (Aerospace Research Associates, Rochester, New York) with the intention of developing a launch site in South Africa as well as a large high altitude multi-staged rocket. As part of this project they tried to get the other South African rocketry groups involved. This all fell through after the Society ceased to exist.

With all the experience gained, several members used Space as topic in their end-of-year papers, required by various University departments, e.g. Brian Page did his B.Sc (Civil Engineering) paper on the design of a rocket launch site for large rockets, whilst the author did his B.Sc Chemistry paper on "Rocket propellants". In addition the UNRS presented various talks to several organisations and submitted papers to different technical publications, e.g. Derek Woodburn (Director of the Electronics and Instrumentation Group of the University Society) presented a paper to the South African Institute of Electrical Engineers on "Some Problems involved in Amateur Rocketry Telemetry and Recovery Systems".

**1963**

All the leading lights in the Society graduated at the end of 1962 and went onto their respective careers or further study. The author still lived in Durban and made an attempt to keep the UNRS going but the University regulations required that only registered students could hold office in a University society. The UNRS therefore shut down as there was insufficient interest and motivation to keep it going.

**A picture assumed to be the large two-stage rocket of the PE group that was probably never launched.**

There is no record of what happened to the high altitude Port Elizabeth rocket – it was probably never launched.

**Conclusions**

In his book, Prout-Jones had a lot to say about the role of the CIE. The UNRS also had its full share of difficulties from this office. The author personally recalls writing reams of material regarding rocket design, safety procedures, etc. for the CIE (and was certainly one of the factors that contributed to the author's less than brilliant academic record!) However it was felt that the CIE's restrictions were justified. One cannot simply launch a heavy rocket and not be concerned what it did or where it landed. Whilst a difficult customer, the CIE did not block the UNRS's activities, provided requirements were met. Besides protecting the public, it also protected Society members with its rigid safety precautions and procedures.

The UNRS was doomed to failure once the leading lights left. Whilst the Society had some support from individuals in departments such as Electrical, Mechanical, Physics, etc., it was strictly a student society, run and controlled by students. ☆

# *The Ancient Starry Ship*

by Magda Streicher
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Image source: Stellarium.org

Vela was part of Jason and the Argonauts' vessel, originally named *Argo Navis*, used, amongst others, in the hunt for the Golden Fleece. Until 1750 this ship was one large and sprawling constellation when the French celestial cartographer, Nicolas-Louis de Lacaille was producing charts of the southern hemisphere skies and dismembered it into four pieces. Puppis the poop deck, Vela representing the sails of the mighty ship, firmly attached to Carina the keel and Pyxis the ship's compass.

Vela is rich in a variety of deep-sky objects. It would take me a considerable amount of time and space to describe all these delights to you. This large constellation is not at all shy to show off its wonderful clusters and nebulae, beside other objects – far too many to deal with in one article. Such is the beauty of a constellation having the Milky Way as a close partner. There is no need to search out any objects – they are freely available.

The False Cross is found in the sails and consists of the magnitude 2 stars, kappa & delta Velorum, and the two borrowed stars, iota & epsilon Carinae. Due to the subdivision of Argo, Vela has no alpha or beta stars, but contains a few dozen stars brighter than magnitude 5. Delta Velorum was found to be a double-star in 1894, when the pair was much wider apart in their 142-year orbit. When John Herschel undertook his southern sky-survey in 1830s, it was too close for discovery. In 1997 delta Velorum was found by the Galileo spacecraft to be the brightest example of an eclipsing binary. It has a 45-day period. The system is about 80 light years away from us.

The far western part of Vela is marked by gamma Velorum, which is also the brightest star in the constellation. It is a double-star with a magnitude 7.1 primary and magnitude 9.2 companion. The primary is the brightest Wolf-Rayet star in the sky and one of the hottest known. Since it has a separation of only 0.1 arc second, it is virtually impossible to split with ordinary telescopes. Interesting, this double-star is actually part of a five-star system.

The lovely, rich, open cluster, **NGC 2547** is situated 1.8 degrees south of gamma Velorum and comprises an uneven scattering of brighter stars that mingle well with a mist of fainter members. The white coloured magnitude 6.4 star (HD 68478) dominates the middle part, with two strings of fainter stars running across the group from north

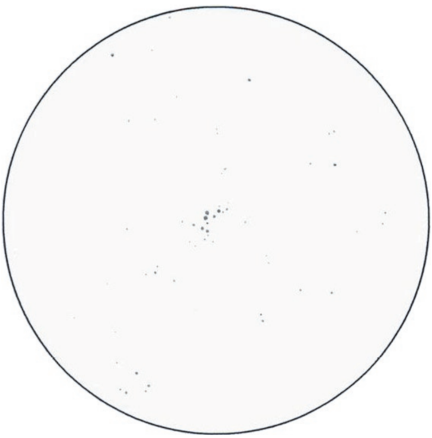

to south. The brighter string continues for almost 10 arc minutes to the north. A shorter branch is situated to the west inside the group, also going out north, but just half as far. The bulk of this swarm is situated inside the north-western part of the cluster. The cluster, which contains about 100 members, is easily seen in binoculars. The cluster was discovered by Nicolas-Louis de Lacaille in 1751-1752 during his stay at the Cape of Good Hope.

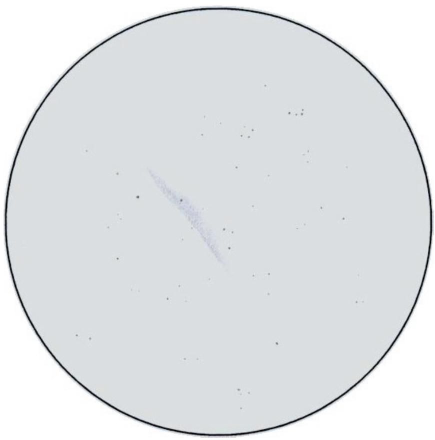
If we draw an imaginary line from gamma to lambda, we find, halfway along it, the cluster **NGC 2645,** which gives the impression of being suspended from the ropes of the sails. Also known as Pismis 6, this very tight group of about a dozen stars brings a close and warm feeling to the observer. This lovely compact group displays a slightly elongated shape in a north-west to south-east direction, with varied magnitude stars. Its shape could also be described as a zigzag that extends southwards, accompanied by fainter members (see sketch).

The small group, **Pismis 8**, is situated only 28 arc minutes east of NGC 2645. It is a special cluster with stars displaying colours of white and yellow, and is slightly curved in a north-south direction. Allowing my mind free rein, I imagined I could see a MacDonald's "M" sign in the positioning of the stars, with the open ends of the M towards the western side. Perhaps I was just a little hungry at the time!

Vela is the proud possessor of the great Gum Nebula, higher up against the slopes of the sail, appearing to be caught up in the various nebulae and star groups. Its fine filaments form streams and loops of nebulosity indicated as Gum 12, 15 and 17. Towards the south-eastern edge of this ancient supernova remnant, **NGC 2736** displays a small flimsy streak of light. This emission nebula displays a fairly straight north-northeast to south-southwest line. The north-eastern side is much more defined, with a softer bulge out on the south-western side. Various filters brought out this object to its full (see sketch). This southern nebula, also known as the famous Pencil Nebula is counterpart to the well-known Veil Nebula, which is located in the northern constellation Cygnus. Although the name Pencil Nebula is appropriate, I just love the designation "Herschel's Ray". A memorable object that should linger in one's mind for a long time. This object was discovered by Sir John Herschel during his stay at the Cape of Good Hope in the years 1834-1838. Named after the Australian astronomer Colin Stanley Gum, who published his finding in 1955, this complex is thought to be one of the closest supernova remnants, of over a million years old.

Magnitude 2.1 lambda Velorum points the way 3 degrees north-west to another beautiful open cluster, **NGC 2671**. It is situated in the northern extreme of the constellation. Also known as Bennett 40a, the cluster which is not very bright, displays a large group with a relatively dense core. The shape can also be described as roughly triangular and merges well with faint nebulosity. The stars are well strung together with a denser combination towards the north-east, gradually thinning out towards the south-west, giving it a comet-like appearance. Two sets of double-stars share the field of view towards the eastern edge of the cluster. Another discovery by Sir John Herschel during his Cape years.



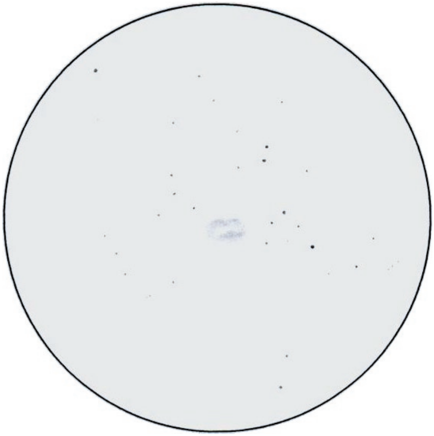


**Sketches of NGC 2645 (left) and NGC 2736 (right).**

On the south-western border, between the constellations Carina and Vela, 1.7 degrees north of delta Velorum, the character-filled **NGC 2669** cluster takes up its seat. It is a very rich cluster, relatively compact, with a sort of V-shape pointing towards the south. What actually held my eye was the knot of faint stars in the eastern part displaying an eye-catching trapezium. The group Van den Bergh-Hagen 52 probably forms the northern part which extends away from the southern group.

Between the northern border of Carina and kappa Velorum, a beautifully bright planetary nebula claims its place amongst the busy star-field. The soft glow of **NGC 2899** is easily visible in moderate-sized telescopes. However, high power is needed to truly observe detail and get a hint of its shape. Add to this an $0^{III}$ filter to reveal the nebula's kidney shape in an elongated west-northwest to east-southeast direction. With averted vision the nebula can be broken down along its centre into a long thin opening and a dent just visible towards the northern edge. The western- and southern sides are (sort of) washed out, fading into a lovely field of view (see sketch). John Herschel discovered this planetary nebula in 1835 from the Cape.

Just 3 degrees east of NGC 2899, a different kind of cluster can be seen in its decoration of stars. **NGC 3033** displays about fifteen very faint stars, gathered around a prominent yellow-coloured magnitude 6 star (HD 85250). This star is the focus of the group, creating a homely picture of a



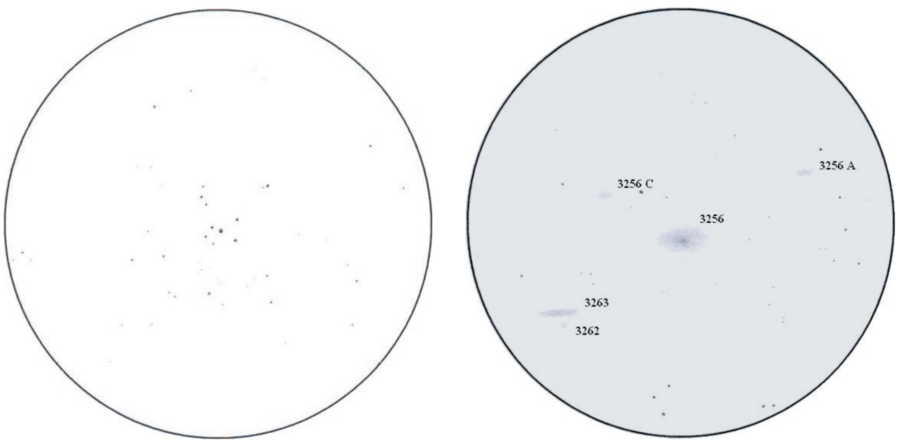
**NGC 2899 (above) and NGC 3033 (below).**

mother hen with her chicks following her in a north-east direction (see sketch). Quite amazing!

I said earlier that the constellation Vela contains many star clusters, so please indulge me as I share another one with you – the outstanding group, **NGC 3228**, which is situated halfway between the magnitude 3.5 phi and magnitude 2.7 mu Velorum. An impressive small group of bright stars with a notable form that strongly reminds of a daisy, complete with stem attached. The stars are unattached and strongly defined against the background stars (see sketch). Towards the south of this little flower impression, more stars can be seen that could be part of this group, giving it a north-south elongated shape in another context. Bright and outstanding, just like a summer daisy in bloom, despite its estimated age of about 42 million years! Another discovery by Nicolas-Louis de Lacaille from the Cape.

Despite the scarcity of globular clusters in Vela, we find an exceptional example only 5.8 degrees north-west of the magnitude 2.7 mu Velorum. **NGC 3201**, also known as Bennett 44, can be easily spotted using binoculars. The globular displays a mass of delicate star-strings radiating away from the somewhat loosely concentrated core and spherical halo. Faint stars are widely dispersed towards the fringy edges, extending into the rich star-field. A few knots of faint members and dark patches can be detected inside the northern area. My attention was held by the dark lane towards the western extreme of the globular, creating the impression of a piece that was cut off. The globular cluster was discovered by Sir John Herschel with an 18-inch f/13 speculum telescope during his Cape years (1834-38). James Dunlop however laid eyes on this cluster on the 28 May 1835.

It is unusual to find galaxies so close to the Milky Way, yet Vela offers a dozen or more NGC galaxies in the eastern extreme of the constellation, spilling over into Antlia. The **NGC 3256** group contains five galaxies, situated 3 degrees north-east of the globular cluster NGC 3201 and covering an area of only 46 arc minutes. However, NGC 3256, the largest and brightest, displays a soft oval in an east-west direction. Higher power reveals the galaxy's small stellar




**Sketches of NGC 3228 (left) and of the NGC 3256 group (right).**

**NGC 3446.**

core, surrounded by a slightly brighter halo. The haziness around the northern section of the oval extends slightly further north. NGC 3256C is the closest member but very faint, situated 18 arc minutes to the north-east of the main galaxy. In the same field of view, NGC 3256A displays a slightly brighter oval in an east-west direction, 23 arc minutes to the north-west of NGC 3256 (see sketch). Two other galaxies, (NGC 3263 and NGC 3262), divide NGC 3256 and member NGC 3256B, which is situated 32 arc minutes further south.

It is just appropriate to end off this article with yet another open cluster. **NGC 3446** is a special cluster with a dainty appearance, 4 degrees east of the above mentioned galaxy group. Around two dozen stars clearly concentrated into two groups. The eastern part seems brighter with a pair of stars at the southern tip whereas the north-western area includes a gathering of fainter stars (see sketch).

Cruise along the starry wind. The bow of the ship appears filled with jewels. To those who choose to feast their eyes onto them, the constellation Vela is more than willing to engage in a generous sharing of its deep-sky treasures. ☆

| Object | Type | RA (J2000.0) | Dec | Mag | Size |
|---|---|---|---|---|---|
| NGC 2547 | Open Cluster | $08^h10.2$ | -49º15′ | 4.7 | 25' |
| NGC 2645 | Open Cluster | 08 38.9 | -46 14 | 9 | 3' |
| PISMIS 8 | Open Cluster | 08 41.6 | -46 16 | 9.5 | 3' |
| NGC 2671 | Open Cluster | 08 46.2 | -41 53 | 11.6 | 5' |
| NGC 2669 | Open Cluster | 08 46.3 | -52 56 | 6 | 14' |
| NGC 2736 | Emission Neb | 09 00.4 | -45 54 | 10 | 20'x3' |
| NGC 2899 | Planetary | 09 27.1 | -56 06 | 11.8 | 117" |
| NGC 3033 | Open Cluster | 09 48.8 | -56 25 | 8.8 | 5' |
| NGC 3201 | Globular Cluster | 10 17.6 | -46 25 | 6.8 | 18' |
| NGC 3228 | Open Cluster | 10 21.8 | -51 43 | 6 | 18' |
| NGC 3256A/B/C | Galaxy | 10 27.8 | -43 54 | 11.3 | 7.4'x3.1' |
| NGC 3446 | Open Cluster | 10 52.3 | -45 10 | 9.6 | 6.5' |

## astronomical society of southern africa

The **Astronomical Society of Southern Africa** (ASSA) was formed in 1922 by the amalgamation of the Cape Astronomical Association (founded 1912) and the Johannesburg Astronomical Association (founded 1918). It is a body consisting of both amateur and professional astronomers.

**Publications:** The Society publishes its own journal, the *Monthly Notes of the Astronomical Society of Southern Africa (MNASSA)* (bimonthly) and an annual astronomical handbook, *Sky Guide Africa South*.

**Membership:** Membership of the Society is open to all. Enquiries should be addressed to the Membership Secretary, ASSA, PO Box 9, Observatory, 7935, South Africa or to the e-mail address below. Entrance fees are R25. Full members paying R100 per annum receive *MNASSA* and the *Sky Guide*. The subscription year runs from 1 July to 30 June. Persons joining during January to June need to pay only half the annual subscription, plus the entrance fee.

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