Some short comments about the paper :

An alternative model, explaining the VLS, created by the gravitational interaction of two matter populations, one composed of positive mass and the other of negative mass.

The allowed number of pages (four) of the paper, to be published in the proceedings, was quite short. Hereafter some additional information for the referee.

Our paper follows a series of papers published in peer reviewed Journals, since 1977, the first being issues in the French Compte Rendus de l'Académie des Sciences de Paris[1]. Main papiers issued in Nuevo Cimento, 1994[2] and Astrophysics and Space Science (1995).

1) Why the scientific community was not interested in negative matter since decades.

They are several reasons. The first is related to the energy. If a particle owns a negative mass

$$m < 0$$

If its energy can be written :

$$E = m c^2$$

then this corresponding energy would be negative :

$$E < 0$$

Immediately, a physicist would ask :

- If two particles meet, with opposite energies, the result of such collision would be … perfectly nothing !

As everybody knows, matter and antimatter have positive masses. When such particles collide, a so-called "annihilation" occurs, which is not really a true annihilation, because the energy is conserved. This couple is transformed into positive energy photons (just notice that " nihil " means " nothing " in latin).

If the universe would be a mixture fifty-fifty of positive energy particles and negative energy particles, all that content would be annihilated.

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[1] Jean-Pierre Petit : Enantiomorphic Universes with opposite time arrows. CRAS t. 263 May 1977 pages 1315-1318
[2] Jean-Pierre Petit : The missing mass effect. Il Nuovo Cimento, B , vol. 109, july 1994, pp. 697-710

If these amounts would be different a certain amount of positive or negative matter would survive. The behaviour of an universe filled by negative matter was investigated by H.Bondi in 1957[3]. Then by W.Bonnor in 1998[4].

In the papers, with common title "Negative mass and general relativity" they showed that :

- *Positive mass attracts both other positive masses and negative masses*

- *Negative mass attracts both other negative masses and positive masses.*

As a conclusion, if a positive mass encounters a negative mass, the first, repelled by the other, escapes, while the negative mass runs after it. *This couple accelerates without limit* (except relativistic one) *and the energy is conserved* because the sum

$$E = \frac{1}{2}(m_1 > 0)(V_1)^2 + \frac{1}{2}(m_2 < 0)(V_2)^2 = Cst \ !!!$$

negative mass

positive mass
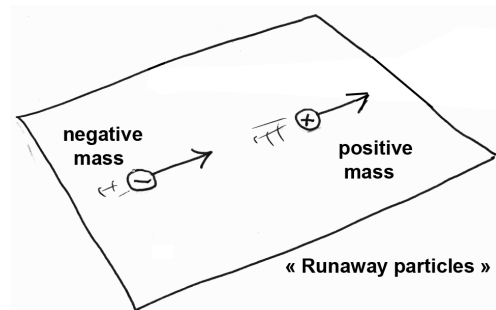
« Runaway particles »

Bonnor calls such particles « runaway ». This puzzling phenomenon made impossible to think about the possible presence of negative mass in the universe during decades.

In 1998 W.Bonnor studied a univers only filled by negative mass, quoting that it had nothing to do with our real universe because such masses, repelling each other, could not form any structures like stars, galaxies, by gravitational instability. He just found that such universe was expanding and accelerating (R″ >0).

Anyway, the analysis of H.Bondi and W. Bonnor were perfectly right and based of the Einstein equation :

$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} + \Lambda g_{\mu\nu} = \chi T_{\mu\nu}$$

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[3] H.bondi : Review of Modern Physics, Vol 29, Number 3, july 1957, entitled "Negative mass in General Relativity".
[4] W.B.Bonnor Negative mass and General Relativity. General Relativity and Gravitation, Vol. 21, n° 11, 1989

2) **1967 : The Andrei Sakharov's model**

In 1967 Andrei Sakharov introduced the concept of « twin universes »[5]. In this model he figured the universe as a couple of geometrical structures with opposite arrows of time, connected by a singularity, the so-called big bang.

3) **1970. J.M.Souriau sets the link between time and energy (and mass) inversions[6]**

This idea of opposite arrows of time was quite puzzling but was cleared up in 1970 by the french mathematician Jean-Marie Souriau, using his Dynamic Group Theory[7]. In this theory, based on dynamic groups, a particules is « a peculiar movement of a mass-point object », inscribed in a Minkowski space-time. Each element of the group (Poincaré's groupe) transforms a movement into another element.

The dynamic group of the Minkowski space is its isometry group, the Poincaré group :

$$\begin{pmatrix} L & C \\ 0 & 1 \end{pmatrix}$$

where C is the 4-vector space-time translation and L the Lorentz group.

If we consider the group with $C = 0$ space-time translation :

$$\begin{pmatrix} L & 0 \\ 0 & 1 \end{pmatrix}$$

or simply the (4,4) matrix L . It is well known that the complete Lorentz group contains matrixes which reverse time (forming its antichron subset). The Poincaré group inherits this property, so that it contains elements which reverse time. In other terms, given a movement oriented from past to future, inscribed in the Minkowski space-time, it can be transformed, using an anitchron element of the Poincaré's group into a « antichron » movement, oriented from future to past, with reversed arrow of time.

By the way, Souriau showed in 1970 this goes with the inversion energy, and mass :

$$t \rightarrow -t \quad \Rightarrow \quad E \rightarrow -E \quad and \quad m \rightarrow -m$$

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[5] A.Sakharov : CP violation and baryonic asymety of the Universe. ZhETF Pis'ma 5, 32- (JETP Letters 5, 24-27) And 1980 Cosmological model of the Universe with time vector inversion. JETP 52, 349-351
[6] J.P.Petit and G.D'Agostini have been students of J.M.souriau, died in 2013
[7] Jean-Marie Souriau : Structure des Systèmes Dynamiques, Ed. Dunod, 1970, France
  Jean-Marie Souriau : Structure of Dynamic Systems, Ed. Birkhauser

This includes the action of the group on the movement of photons, which follow null geodesics. So that, referring to the complete Poincaré group, negative energy and negative masses should exist, as well as negative energy photons.

4) **Towards a bimetric description of the universe**

Our paper in Nuovo Cimento (1994) was the first to suggest a bimetric description of the universe. The geometric framework is simple :

- We take a M_4 manifold
- We associate to this manifold two metrics g^+ and g^-.

Such metrics generates their own distinct geodesic system. One assumes that positive energy particles follow the geodesics of the first family, and negative energy particles the geodesics of the second family.

The two family being distinct, the encounter of opposite energies particles is impossible, on geometrical grounds. In addition positive mass structure cannot receive negative energy photons, so that, if they exist, such negative energy structures should be invisible to us (and vice versa).

- One assume that both contribute to the field and assume that the positive energy particles correspond to the tensor field :

$$
T^{(+)\mu}_{\nu} = \begin{pmatrix} \rho^+ & 0 & 0 & 0 \\ 0 & -\dfrac{p^+}{c^2} & 0 & 0 \\ 0 & 0 & -\dfrac{p^+}{c^2} & 0 \\ 0 & 0 & 0 & -\dfrac{p^+}{c^2} \end{pmatrix}
$$

The negative energy particles correspond to the tensor field :

$$
T^{(-)\mu}_{\nu} = \begin{pmatrix} \rho^- & 0 & 0 & 0 \\ 0 & -\dfrac{p^-}{c^2} & 0 & 0 \\ 0 & 0 & -\dfrac{p^-}{c^2} & 0 \\ 0 & 0 & 0 & -\dfrac{p^-}{c^2} \end{pmatrix}
$$

As presented in 1994 in Nuovo Cimento, one assumes that the two metrics are linked through the following field equations system

$$R_{\mu\nu}^{(+)} - \frac{1}{2} R^+ g_{\mu\nu}^{(+)} = \chi \left[T_{\mu\nu}^{(+)} + T_{\mu\nu}^{(-)} \right]$$

$$R_{\mu\nu}^{(-)} - \frac{1}{2} R^+ g_{\mu\nu}^{(-)} = -\chi \left[T_{\mu\nu}^{(+)} + T_{\mu\nu}^{(-)} \right]$$

The Newtonian approximation provides following interaction laws (different from Bondi's ans Bonnor') :

- *Two positive matter particles attract each other through Newton's law*

- *Two negative matter particles attract each other through Newton's law*

- *A particle of positive matter and a particle of negative matter repel each other through "anti-Newton's law".*

This suggested to perform numerical simulations, that was done since 1995 (Astrophysics and Space Science's paper) and provided good looking VLS (see the figures of the paper). This was presented later in an international scientific meeting[8].

The results are the following :

- The model explains VLS
- And confinement of galaxies (surrounded by repellent negative mass)
- In our galaxy, negative mass is very rarefied, so that the field equation system becomes :

$$R_{\mu\nu}^{(+)} - \frac{1}{2} R^+ g_{\mu\nu}^{(+)} \cong \chi T_{\mu\nu}^{(+)}$$

$$R_{\mu\nu}^{(-)} - \frac{1}{2} R^+ g_{\mu\nu}^{(-)} \cong -\chi T_{\mu\nu}^{(+)}$$

The first equation identifies with Einstein's equation, so that the model fits with local relativistic and non relativistic observations.

In 1957 and 1998 H.Bondi and W.B Bonner noticed that the Einstein's equation admitted external and internal solutions for negative mass. Our bimetric completely description clears up this question.

Negative gravitation lensing (Astrophysics an Space Science 1995) explains the observational facts, classically explained by the presence of some hypothetic positive mass "dark matter". In our model the observed gravitational effects are due to the surrounding negative mass.

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[8] International Meeting on astrophysics and Cosmology, Marseille, 2000