IC/84/80

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

MIRROR FERMIONS AND COSMOLOGY

Goran Senjanović

INTERNATIONAL ATOMIC ENERGY AGENCY

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

1984 MIRAMARE-TRIESTE

IC/84/80

International Atomic Energy Agency
and
United Nations Educational Scientific and Cultural Organization
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

MIRROR FERMIONS AND COSMOLOGY *

Goran Senjanović **
International Centre for Theoretical Physics, Trieste, Italy,
and
Physics Department, Virginia Polytechnic Institute and State University,
Blacksburg, Virginia 24061, USA ***

ABSTRACT

Extended supersymmetry, Kaluza-Klein theory and family unification all suggest the existence of mirror fermions, with same quantum numbers but opposite helicities from ordinary fermions. The laboratory and especially cosmological implications of such particles are reviewed and summarized.

MIRAMARE - TRIESTE
July 1984

* Talk given at the Inner Space/Outer Space Conference, Fermilab, May 1984.

** On leave from Brookhaven National Laboratory, Upton, NY 11973, USA.

*** Present address.

I. INTRODUCTION

One of the most striking features of the standard electroweak model is its left-right asymmetry in the fermionic spectrum f. Equally important is the repetitive family structure; both facts being just simply postulated ad hoc. Could it be that these phenomena have one and the same origin? This is the possibility I would like to discuss in my talk. Most of what will be presented here is based on the recent work in collaboration with Wilczek and Zee [1]; similar work has been simultaneously carried out by Bagger and Dimopoulos [2].

The problem of family repetition persists in single grand unified theories, such as SU(5) and SO(10). In these theories families are xeroxed at free will, without any handle on their number. Furthermore, the fact that fermions have only left-handed weak interactions is taken for granted. It should be mentioned that SO(10) is the minimal one family unification theory, since all the fermions in one family form an irreducible 16 dimensional spinorial representation.

This immediately suggests larger orthogonal groups SO(10 + 2n) as ideal candidates for family unification [3]. Even more important, spinorial representations possess a unique property: their decomposition on smaller subgroups contains only spinorial representations and nothing else. For example, 2^{n+4} dimensional irreducible spinorial representation of SO(10 + 2n) contains 2^{n-1} 16 dimensional representations of SO(10) and 2^{n-1} $\overline{16}$'s of SO(10). This leads to the vector-like low energy world: for every ordinary family f there is an opposite helicity "mirror" family F! [4-6]

Remarkably enough, completely independent theoretical ideas, such as extended supersymmetry (N>1) and Kaluza-Klein higher dimensional theories of gravity [7] require the existence of mirror fermions, too. Why have we not seen such particles yet? Why are they so weakly mixed with ordinary fermions? Are mirror fermions cosmologically stable or not? What about the increase in neutrino species that their existence leads to? These and similar questions must be answered before one has a consistent theory of mirror fermions.

To appreciate the problem, notice that the very existence of ordinary fermions in such theories appears to be a miracle. Namely, the mixing mass term $m_{fF} = M\bar{f}F$ is an $SU(2) \times U(1) \times SU(3)_C$ singlet and, according to the commonly accepted survival principle [8], M should escape to the Planck mass or at least the unification scale. This means that ordinary and mirror fermions should pair off to disappear from the low energy world, so why do they not? Now, the survival principle sounds a lot like social Darwinism and I, for one, believe that the world may be much milder than such ideas suggest. The purpose of my talk is to demonstrate not only that fermions have natural ways to survive down to low energies, but also

to try to convince you that the existence of mirror fermions has rather interesting, soon to be tested, laboratory and cosmological implications. In view of the nature of this conference, I will devote a substantial portion of my time to the cosmological issues.

As far as I know, the only natural way to forbid the bare mixing mass term requires larger orthogonal groups SO(10 + 2n). I start then, in the next section, by reviewing the basic properties of such theories and by presenting a realistic candidate for family unification based on SO(18). In section III, we shall study the general low energy properties of mirror fermions, especially those of cosmological relevance. The paper ends with a brief summary in section IV.

II. FAMILY UNIFICATION AND MIRROR FERMIONS

As I stressed in the Introduction, SO(10) is a perfect one family unified theory. Each family forms an irreducible 16 dimensional spinorial representation; anomalies are automatically cancelled.

Imagine a Clifford algebra

$$\{\gamma_i, \gamma_j\} = 2\delta_{ij} \qquad i,j = 1, \dots, 2N \tag{2.1}$$

You can easily convince yourself that

$$T_{ij} \equiv \frac{1}{4i}[\gamma_i, \gamma_j] \tag{2.2}$$

satisfy the usual commutation relations of SO(2N). Furthermore, $\gamma_{FIVE} = \gamma_1 \dots \gamma_{2N}$ commutes with all the generators and the 2^{N-1} dimensional representation of (2.2) is characterized by a helicity: LEFT(RIGHT) = 1/2 $(1 \pm \gamma_{FIVE})$. It is useful to use a basis in which $\hat{\varepsilon}_i \equiv 2T_{i-1,i}$ are diagonal operators; with eigenvalues $\varepsilon_i = \pm 1$. Therefore, each physical state can be characterized by the eigenvalues of $\hat{\varepsilon}_i$

$$|\varepsilon_1 \cdots \varepsilon_N\rangle \tag{2.3}$$

with $\varepsilon_i = +1$ or $\varepsilon_i = -1$. In this notation $\gamma_{FIVE} = \prod_{i=1}^{N} \varepsilon_i$.

As I mentioned before, the 16 dimensional representation of SO(10) with $\prod_{i=1}^{5} \varepsilon_i = 1$ contains a usual left-handed family.

SO(10 + 2n)

The irreducible representation is $2^{4+n} = 16 \times 2^n$ dimensional. Choose $\prod_{i=1}^{5+n} \varepsilon_i = 1$. Then, either $\prod_{k=1}^{5} \varepsilon_k = 1$ and $\prod_{k=6}^{5+n} \varepsilon_k = 1$ or $\prod_{k=1}^{5} \varepsilon_k = -1$ and $\prod_{k=6}^{5+n} \varepsilon_k = -1$.

In the first case we are dealing with ordinary families, i.e. 16's of SO(10), whereas in the latter case the helicities are switched - we get mirror families ($\overline{16}$'s). In short, the theory contains 2^{n-1} standard families and 2^{n-1} mirror families.

The characteristics of the theory depend dramatically on whether n is even or odd. Namely, for $n = 2k+1$ the representation is vectorlike (allows bare mixing mass term); for $n = 2k$ the theory is chiral (no mixing mass terms). For $n = 2k$, gauge symmetry

$$U_M = e^{i\frac{\pi}{2}(\epsilon_6 + \cdots + \epsilon_{2k})} = i^{2k}\epsilon_6 \cdots \epsilon_{2k} \qquad (2.4)$$

becomes a discrete symmetry on families and mirror families

$$f \to i^{2k} f, \qquad F \to -i^{2k} F \qquad (2.5)$$

Chirality of the theory is reflected in <u>mirror symmetry being a gauge symmetry</u>. Although we could make $n = 2k+1$ theories work by adding extra symmetries, we stick here to physically more natural $n = 2k$ theories.

<u>SO(14)</u>

Here $n = 2$; leading to $2f + 2F$. This group is too small.

<u>SO(18)</u>

Here $n = 4$, so that we would get $8f + 8F$. This is the minimal natural unified theory of families. As opposed to SO(14), it appears too big. If all fermions are light, it is not an asymptotically free theory. Actually, asymptotic freedom allows at most 4 families and 4 mirror families. We must "kill" some families and mirror families, by pairing them off and decoupling them from low energies. Obviously, this requires breaking U_M at high energies, with the remnant of it staying unbroken down to M_W. If we stay in SO(18), it turns out that we always end up with either $4f + 4F$ or $6f + 6F$.

It turns out, however, that with the inclusion of Peccei-Quinn symmetry we can end up with precisely <u>three families</u> and <u>three mirror families</u>. I do not have time to discuss our work here [1], so let me just summarize the main results [1]

(i) three are <u>five</u> light neutrinos

(ii) the mirror symmetry gets broken at M_W, with the lowest dimension breaking term being $d = 5$

$$H_{eff} = \frac{1}{M_X} \bar{f} F \phi_1^+ \phi_2 \qquad (2.6)$$

where ϕ_1 and ϕ_2 are SU(2) doublets.

III. PHENOMENOLOGY AND COSMOLOGY OF MIRROR FERMIONS

The main message from the previous section, if for whatever reason you did not go through it, is that we can naturally keep both ordinary and mirror fermions light. This was absolutely necessary in order to live in the world with observed fermions. We still must answer the questions posed in the Introduction.

(1) <u>Mixings and masses</u>

(a) Since F's get their mass at the SU(2) x U(1) level, we expect $m_F < 1$ TeV. If you further believe in unification, we must have $m_F \lesssim 250$ GeV to prevent Yukawa couplings from blowing up. We <u>must</u> see mirror fermions at the supercollider !

(b) Why is $m_F < m_f$? Could it be that separate Higgs doublets give them their masses, with $\langle\phi_F\rangle \neq \langle\phi_f\rangle$? But then, why is $\langle\phi_F\rangle > \langle\phi_f\rangle$? Bagger and Dimopoulos suggest that ordinary fermions get their masses radiatively, hence $m_f \ll m_F$.

(c) On the other hand, mirror fermions are naturally weakly coupled to ordinary fermions. Namely, there is <u>no</u> $d = 4$ renormalizable interaction of the type $fF\phi$, where ϕ is a SU(2) x U(1) Higgs doublet. To generate mixings, one needs $d = 5$ effective interaction in (2.6) (two doublets are needed to construct SU(2) x U(1) singlet), implying a mixing

$$\theta_{fF} \simeq \frac{M_W}{M_X} \simeq 10^{-13} \qquad (3.1)$$

The way to produce mirror fermions is to get them in pairs $(F\bar{F})$ in say e^+e^- or $p\bar{p}$.

(2) <u>Cosmological stability</u>

Although practically stable for laboratory purposes, mirror fermions are cosmologically unstable. Actually, charged mirror leptons should be expected to decay very fast [2]: $E \to e\, N_R\, \bar{\nu}_L$. Expected lifetime

$$\tau_E \simeq G_F^{-2}\, m_E^{-5} \simeq 10^{-21}\,\text{sec} \quad \text{for } m_E \simeq 100\,\text{GeV} \qquad (3.2)$$

Neutral mirror leptons and mirror baryons are, on the other hand, long lived. From (2.6) one gets possible $Q \to qqq$ decay through the small mixing in (3.1). We estimate

$$\tau_Q \simeq \frac{M_x^2}{m_Q^3} \simeq 1 \text{ sec}$$

$$\text{for} \quad M_x \simeq 10^{15}\text{ GeV}$$
$$m_Q \simeq 100 \text{ GeV} \tag{3.3}$$

This explains why we see no mirror baryons; they have all decayed long ago.

(3) Neutrinos

Adding mirror neutrinos increases the number of light neutrino species. In our SO(18) model we predict $n_\nu = 5$. What about the usually quoted cosmological limit from observed helium abundance $n_\nu \le 4$?

We could try to say that some of them, say N_R's, are heavy enough ($m \simeq 1$-10 MeV), as to decay fast enough: $N_R \to e^+e^- \nu_L$. However, in our case the scale of superheavy singlet neutrinos is $M_{PQ} \simeq 10^9$-10^{12} GeV, implying $m_{N_R} \le 10$ KeV (without fine tuning the parameters of the theory). To be honest, the natural prediction of our theory is five, effectively stable light neutrinos.

One possibility, as suggested by Bagger and Dimopoulos is to imagine a light SU(2) x U(1) Higgs triplet which gives mass to N_R's. This leads to various interesting phenomenological consequences, all to be tested. I do not find this alternative very appealing, since it violates the extended survival principle in the Higgs sector, in my opinion necessary to make predictive sense out of GUTs.

I would rather suggest that we ignore cosmological limits on n_ν at the moment. In due time, the precise measurements of the decay width of the Z boson will determine precisely n_ν. I suggest you have some patience before you reject the picture we suggested.

IV. SUMMARY

As I mentioned in the Introduction, various theoretical ideas that you may like (at least some of them) require the existence of mirror fermions. My aim in this talk was to try to convince you that you should not worry about this; but rather, take it as a blessing. If, however, I have failed in my task, I hope, at least, that our arguments which claim the consistency of the mirror fermion physics, appear convincing. If you find a mechanism which naturally forbids the large mixed mass terms for ordinary and mirror fermions (or accept what we suggested here), the rest follows naturally:

(a) f-F mixing is naturally small ($\sim M_W/M_X$)

(b) lightest Q is cosmologically unstable ($\tau_Q \sim 1$ sec)

(c) $m_F \le 250$ GeV (in unified theories)

(d) there are more than three neutrinos (5?)

I hope you can live (if uneasily) with the last prediction and wait for the supercollider to pass the final verdict on the ideas presented here.

Let us look into mirrors!

ACKNOWLEDGMENTS

The work described here has been done in collaboration with Frank Wilczek and Tony Zee. I wish to thank Palash Pal for numerous discussions and a careful reading of the manuscript. Furthermore, thanks are due to the ITP, Santa Barbara, and International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste, during various stages of this work. This work is supported in part by the U.S. Department of Energy under contract DE-AS05-80ER10713.

REFERENCES AND FOOTNOTES

1) G. Senjanović, F. Wilczek and A. Zee, ITP preprint NSF-ITP-84-28 (1984) - to appear in Phys. Lett. B.

2) J. Bagger and S. Dimopoulos SLAC preprint SLAC-PUB-3287 (1984). See also, H.M. Asatryan, Yerevan preprint (1982).

3) M. Gell-Mann, P. Ramond and R. Slansky, in Supergravity, Eds. P. van Nieuwenhuizen and D.Z. Freedman, (North-Holland, Amsterdam, 1979); F. Wilczek and A. Zee, Princeton report (1979) and Phys. Rev. D25, 553 (1982); R.N. Mohapatra and B. Sakita, Phys. Rev. D21, 1062 (1980).

4) Mirror fermions have been suggested by J.C. Pati and A. Salam, Phys. Lett. 58B, 333 (1975) and e.g. J.C. Pati, Proc. ICOBAN Conf., Bombay (1981) in order to achieve anomaly cancellation in their theory.

5) For the physics and phenomenology of mirror fermions see also P. Ramond, University of Florida preprint IT-83-21 (1983). Mirror fermions have been studied extensively by the Helsinki group; see e.g. K. Enquist, K. Mursula and M. Roos, Nucl. Phys. B226, 121 (1983); J. Maalampi, Nucl. Phys. B198, 519 (1982); J. Maalampi, K. Mursula and M. Roos, Nucl. Phys. B207, 233 (1982); K. Enquist and J. Maalampi, Z. Phys. C21 345 (1984). See also, K. Yamamoto, Phys. Lett. 120B, 157 (1983); ibid. 117B, 217 (1982) and references therein. For further references see Ref. 1 and Wilczek and Zee, Ref. 3.

6) Mirror fermions have been discussed also in the context of composite models. See e.g. P. Senjanović, Fizika 15, 126 (1979).

7) See e.g. E. Witten, Nucl. Phys. B186, 412 (1981) and references therein.

8) H. Georgi, Nucl. Phys. B156, 126 (1979).