Mirror fermions
and the hierarchy problem

G. Triantaphyllou
Institute for Theoretical Physics, Technical University Munich
James-Franck-Str., D-85748 Garching, Germany
E-mail: georg@ph.tum.de

Abstract
The introduction of strongly-interacting mirror fermions with masses between the
weak scale and 1 TeV could offer a viable alternative to the Higgs mechanism.
The framework provided solves the hierarchy problem naturally and predicts a rich
phenomenology for present and future experiments.

Even though present electroweak precision
measurements are more or less consistent with the
standard-model, the source of the masses of the
known fermions and the weak vector bosons, as
well as the unitarizing sector of the theory, remain
unknown. A fundamental scalar field acquiring a
non-zero vacuum expectation value could provide a
solution. However, not only such a field has not
been observed yet, but it is also hard to understand
why its mass is so much smaller than the Planck
scale.

Efforts to introduce new strongly-interacting
fermions as an alternative to the Higgs mechanism,
in the context of technicolor theories for instance,
are difficult to reconcile with precision measure-
ments and unification schemes. This recently led
[1] to the introduction of new heavy fermions with mirror
weak-charge assignments, which can overcome
these problems easier. Previous efforts to introduce
mirror fermions can be found in a review [2]; such
extensions have also been proposed as a solution to
the strong CP problem [3]. Our interest will be fo-
cused here on a particular version of these fermions
which we name “katoptrons”. These are differen-
tiated from usual mirror fermions by the fact that
they interact according to an additional gauge sym-
metry whose coupling becomes strong at around
1 TeV, and which gives to all of them dynamical
masses of that order of magnitude.

In particular, we consider the gauge structure
$SU(4)_{PS} \times SU(2)_L \times SU(2)_R \times SU(3)_{2G}$, under
which the standard-model fermions transform like
three copies of $(4, 2, 1, 1)$ and $(\bar{4}, 1, 2, 1)$ and the
katoptrons like $(4, 1, 2, 3)$ and $(\bar{4}, 2, 1, 3)$. At the
Pati-Salam scale $\Lambda_{PS}$, the gauge symmetry
is reduced according to $SU(4)_{PS} \times SU(2)_R \rightarrow
SU(3)_C \times U(1)_Y$. As is clearly shown in Fig. 1,
this easily leads to a unification of all gauge
couplings, including the $SU(3)_{2G}$ coupling, at a
scale $\Lambda_{GUT}$ consistent with proton life-time bounds
[4]. Moreover, the $SU(3)_{2G}$ coupling becomes
naturally strong at a scale $\Lambda_M \approx 1$ TeV. It
allows the formation of katoptron condensates at
that scale, which break the electroweak symmetry
dynamically. This provides us with the first
dynamical-symmetry-breaking scenario that post-
dicts correctly the weak scale with natural
assumptions (compare with Ref. [5] for instance),
and thus constitutes a reasonable solution to the
hierarchy problem.

![Figure 1](image-url)
The need to generate masses for the ordinary fermions leads us to consider scenarios in which the group $SU(3)_{2G}$ breaks after it becomes strong. Standard-model fermions can then mix with their mirror partners via gauge-invariant terms in the mass matrix. This can happen in a way that reproduces correctly not only the mass hierarchies but also the mixings of the charged fermions and neutrinos with each other. The mechanism responsible for the breaking of $SU(3)_{2G}$ remains however an important open problem.

This breaking is expected to reduce the contribution of the katoptrons to the $S$ parameter by roughly a factor of 2. This fact, together with the existence of light Majorana mirror neutrinos and negative vertex corrections allow the $S$ parameter to be in agreement with experimental constraints. Vertex corrections are sufficiently large if the right-handed top-quark anomalous weak coupling $\delta g^t_R$ is at least as large as $\delta g^b_R$. The latter is extracted from the deviation of the bottom-quark asymmetry $A_b$ from its standard-model prediction, which being a 2.5 $\sigma$ effect could be the first experimental indication at hand for the existence of katoptrons. Moreover, problems with the $\Delta \rho$ parameter can be circumvented since the top-bottom quark mass hierarchy can be reproduced by gauge-invariant terms in the mass matrix.

If one regards the $A_b$ anomaly as a first indication for the existence of a heavy mirror sector, one should investigate what signals should be expected next in the planned colliders. At the NLC and the Tevatron III, the katoptron model forces $V_{tb}$ to deviate from its standard-model value, predicting a value around 0.95. The measurement of an anomalous top-quark coupling $\delta g^t_R$, which could potentially be even larger than $\delta g^b_R$, would also support the katoptron scenario. The LHC could produce mirror fermions and their associated scalar resonances directly, giving however signals that would hardly be distinguished from corresponding fourth-generation or technicolor signals respectively. Note that, since the strong group $SU(3)_{2G}$ is eventually broken, it is likely that no vector resonances are formed and that no WW hard scattering can be observed.

The ultimate proof for the existence of katoptrons would come from a lepton collider with c.o.m. energies on the order of 4 TeV or higher, like the muon collider. Such a collider would be able to probe the weak charges of the new fermions directly and thus check their mirror-charge assignments. The forward-backward asymmetry of the katoptrons as a function of collider energy is shown in Fig. 2.

![Figure 2](image-url)

**Figure 2.** The forward-backward asymmetry $A_{FB}$ as a function of lepton-collider c.o.m. energy. The dotted line corresponds to $A_{FB}$ after $SU(3)_{2G}$ corrections have been taken into account.

It becomes evident from this figure how the strong $SU(3)_{2G}$ coupling smears out the directional information of the out-going katoptrons at low energies, underlining therefore the need for very powerful lepton colliders.

To conclude with a unifying perspective, it is useful to remember that some representations of gauge groups that arise in superstring theories include the standard-model fermions not only with their supersymmetric, but also with their mirror partners. Contrary to what is usually done nowadays, the present program is based on avoiding light scalar fields by keeping the supersymmetric partners decoupled at unification scales and bringing the mirror partners close to the weak scale, whose magnitude is, as shown above, an output of the model.

**References**

[1] G. Triantaphyllou, Technical University Munich Preprint No. TUM-HEP-326/98, September 1998, [hep-ph/9811250](http://arxiv.org/abs/hep-ph/9811250).

[2] J. Maalampi and M. Roos, Phys. Rep. 186, 53 (1990).

[3] S.M. Barr, D. Chang and G. Senjanovic, Phys. Rev. Lett. 67, 2765 (1991).

[4] G. Triantaphyllou, to appear in Eur. Phys. Jour. C, [hep-ph/9901344](http://arxiv.org/abs/hep-ph/9901344).

[5] F. Wilczek and A. Zee, Phys. Rev. D 25, 553 (1982).

[6] G. Triantaphyllou, Technical University Munich Preprint No. TUM-HEP-348/99, June 1999, [hep-ph/9906283](http://arxiv.org/abs/hep-ph/9906283).