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PHOTINOS FROM COSMIC SOURCES

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In supersymmetric theories[1] the photino is the fermion partner of the photon and is expected to be the lightest stable particle. There is a considerable literature on the possible production of photinos, and other supersymmetric particles, at existing and proposed accelerators.[2] So far, experiments have only set limits.[3] In this letter the production of photinos by sources of ultra high energy cosmic rays is considered. Specifically, an estimate is made for the photino flux from Cygnus X-3, which is known to be a powerful source of nuetral particles, assumed to be γ-rays, up to 10^{16} eV.[4] These γ-rays most likely result from the decay of π^0's produced by protons, accelerated at the source and striking a considerable thickness of matter (~50 gcm^{-2}) surrounding the source.[5] It is shown here that a photino flux approaching or exceeding the γ-ray flux above 10^{14} eV is possible, under certain conditions, and that this flux may be detectable in underground and undersea experiments.

There are several factors which make this proposal more than science fiction. First, the cross section for the production of pairs of gluinos in proton-proton interactions is strong and rises rapidly with energy.[6] The gluino decays into a photino plus a quark pair before having a chance to interact. The photino interacts with matter semi-weakly and can escape the matter surrounding the source, but possibly be more readily detected than neutrinos.

The observed γ-ray flux from Cygnus X-3 in the energy range from 10^{12} eV to 10^{16} eV can be fit by $F_\gamma(>E) = 30E^{-1}$ cm^{-2} s^{-1}, with E in eV, up to about 10^{16} eV where it seems to cut off.[4] This flux has been used to estimate the photino flux from the same source as follows. Protons from the source passing through matter will produce γ-rays through π^0 decay with the same spectrum. The efficiency for this process under the most optimum conditions for γ-ray production, viz., a column density of ~50 gcm^{-2}, is estimated to be 2.5%.[5] Other calculations give as much as 10%,[7] but lower efficiencies will result when the column density is not optimum or other photon absorption processes are present. The photino flux at an energy E then is taken to be $F(E) = 40F_\gamma(E)\sigma(E,M)\sigma_{pp}^{-1}$, where σ_{pp} = 50 mb is the pp cross section (assumed constant), $\sigma(E,M)$ is the cross section for gluino production in pp interactions[8] and M is the gluino mass.

The resulting photino flux from Cygnus X-3 is shown in Fig. 1. We see that it approaches the observed γ-ray flux above 10^{14} eV when the gluino mass is 2-3 GeV, about at the current experimental limit.[3] The total flux integrated over energy is 2×10^{-13} cm^{-2} s^{-1} for M = 2 GeV. Because the Cygnus X-3 flux cuts off above 10^{16} eV, fluxes at these levels are not ruled out by recent limits on deeply penetrating particles from the Fly's Eye.[9] If there is significant γ-ray attenuation, then the source luminosity is higher than determined from the γ-ray flux and an even greater photino flux than what is shown in Fig.1, perhaps up to 100 times higher, is possible.

The detectability of photinos at the level of Fig. 1 is feasible because of the semi-weak nature of the photino interaction with matter.[6] While photinos are very penetrating, they can interact in the earth and secondary particles might be detected by experiments underground[10] or in the sea.[11] It is even possible that the cross section is high enough for the photino to initiate a hadronic cascade in the atmosphere.

The photino interacts with a quark in the nucleus via squark exchange, producing a gluino which quickly decays into a photino and a quark pair. At 10^{15} eV the cross section can be of the order of 1 mb if the squark mass is low. In this case interaction in the atmosphere is probable. If the squark mass is above 10 GeV atmospheric interactions are unlikely, but the photino can penetrate into and interact in the earth.

A one-dimensional cascade calculation has been performed to estimate the flux of photinos which would penetrate to a detector underground or undersea. The result is shown in Fig. 2 as a function of zenith angle. For a low squark mass the photino flux is strongly cut off below the horizon, as the path length through the earth becomes many photino interaction lengths. For a high squark mass the photinos can penetrate further.

It is unlikely that any known secondary particles from a photino interactions other than muons can reach the detector in great numbers because of the large average distance between photino interactions in the earth. Whether photino interactions can generate a significant flux of muons is difficult to predict, but a crude guess can be made. For interactions in the earth, pions or kaons will not contribute since they will mostly interact before decaying. What is needed in this case is prompt muon production via heavy quark leptonic decay. This occurs at about the 10^{-3} level in ordinary cosmic ray interactions at the top of the atmosphere,[12] but there are reasons for expecting more in this case. First, there are strong indications from the CERN $p\bar{p}$ collider, where the equivalent lab energy is in the range involved here, that charm production is considerably larger than predicted.[13] Second, the squarks are expected to be approximately mass degenerate,[14] so perhaps half the squark-quark pairs produced will have heavy flavor (c,b,t) at very high energy. Third, if the gluino is fairly light it can be a nucleon constituent and produce heavy quarks by interaction with the exchanged squark. Of the heavy quarks which decay, approximately 10% will give muons by semi-leptonic decay.

Until calculations of these processes can be made we will suppose that 5% of the photino interactions in the earth give a muon. The results can be scaled down (or up) accordingly for different values. A cascade calculation for muons has been performed, with the results presented in Fig. 3, for a detector at a depth of 1600 mwe. We see that the largest flux occurs above the horizon for a quark mass of 10 GeV, cutting off below the horizon as the photino flux is absorbed. For an 80 GeV squark mass a lower flux is obtained above the horizon, where there are few photino interactions, but more muons occur below the horizon.

Ordinary cosmic ray muons flood underground detectors out to zenith angles of 70°–80°, depending on depth. Beyond that, muons from neutrinos are found out to 180°. Thus a distinctive signature for photinos would be a signal on the horizon beyond the cosmic ray cutoff, or in directions where the column density is not too large, cutting off below the horizon.

A flux of 10^{-15} photinos $cm^{-2}\ s^{-1}$ would not be detectable in the $400 m^2$ IMB detector.[10] For the DUMAND detector,[11] with an average cross sectional area of $10^5\ m^2$, a marginally measurable event rate of 30 per year would result for the same flux. However, our estimates are still at a very crude first stage and significantly higher fluxes cannot be ruled out. Preliminary results from the underground detectors IMB[15], Soudan[16] and NUSEX[17] show possible signals from Cygnus X-3 which appear to be inconsistent with any conventional interpretation, including neutrinos. These results may be consistent with the photino interpretation given here, with an optimistic choice of parameters.

Other sources than Cygnus X-3 are also promising. For example, Her X-1 has now been confirmed as a strong source of γ-rays from 10^{12} eV[18] to 10^{15} eV,[19] at a peak flux level 20 times higher than observed from Cygnus X-3. Thus it is not inconceivable that photinos, if they exist, will someday be observed from astronomical bodies.

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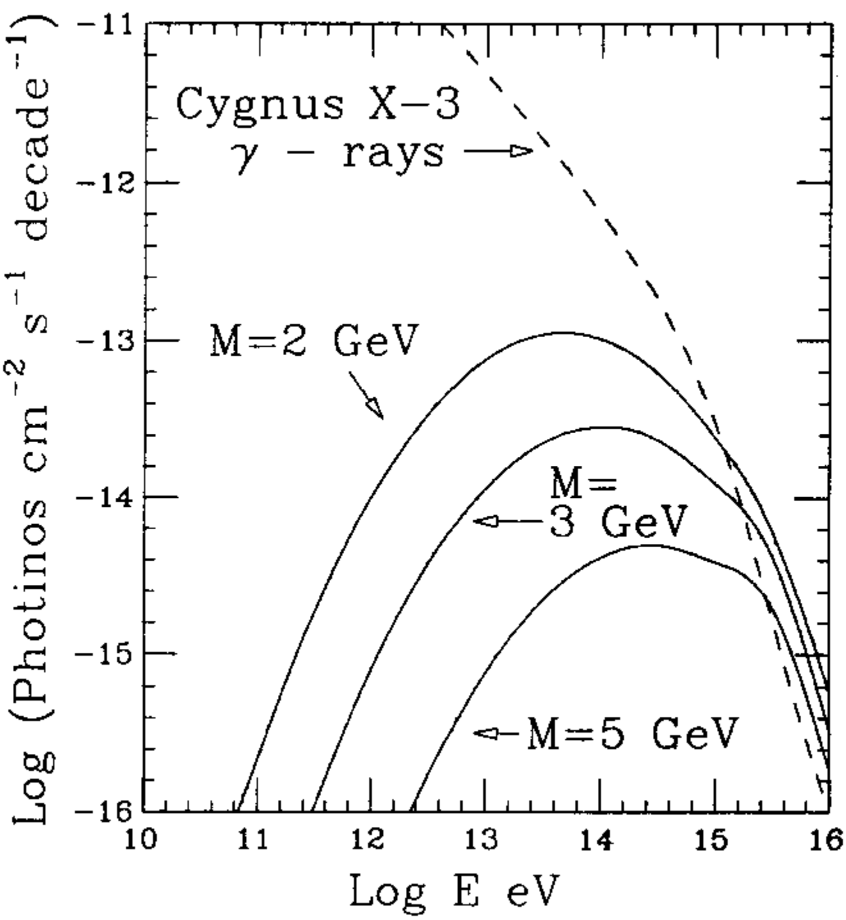
FIGURE CAPTIONS

1. The predicted flux spectrum of photinos from Cygnus X-3 if there is no attenuation of γ-rays at the source, for three gluino masses. The dashed line is the observed flux in γ-rays.[4] Larger fluxes are possible if there is significant γ-ray absorption.

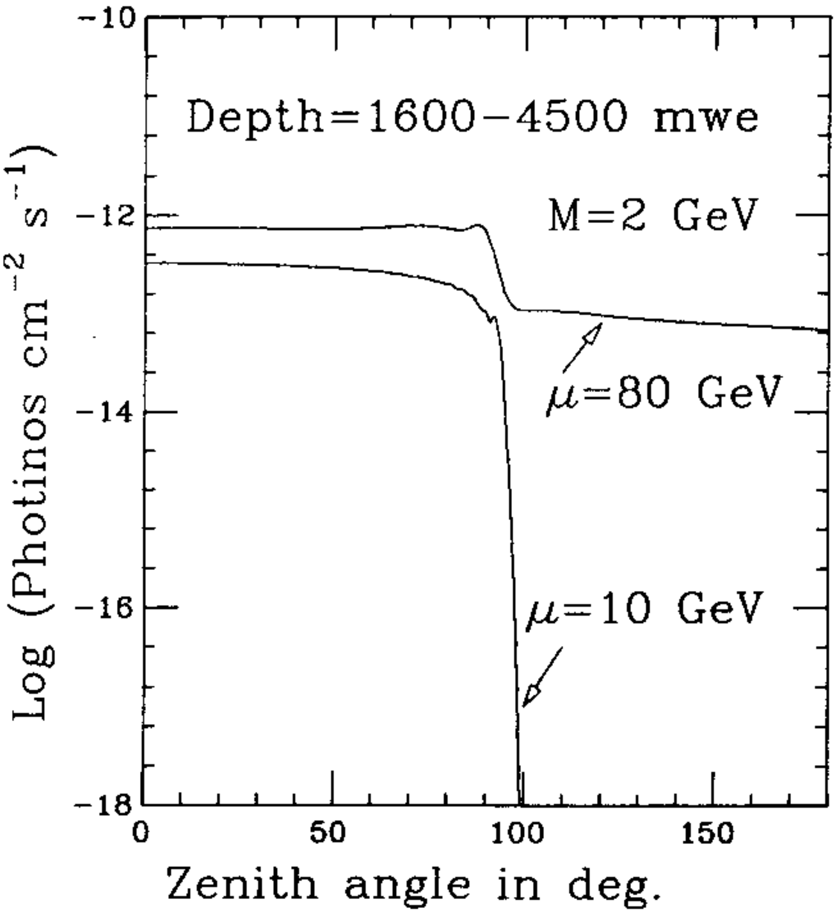
2. The predicted total photino flux from Cygnus X-3 which passes through a detector at a depth of 1600-4500 mwe, as a function of the zenith angle of the photino beam. A gluino mass of 2 GeV is assumed. The results for two values of squark mass are shown.

3. The predicted total flux of muons produced by photinos from Cygnus X-3 which passes through a detector at a depth of 1600 mwe, as a function of the zenith angle of the photino beam. A gluino mass of 2 GeV is assumed. The results for two values of squark mass are shown. The vertical dashed line indicated the zenith angle below which the flux of cosmic ray muons through the detector will be very high. Fluxes at greater depths are somewhat lower.



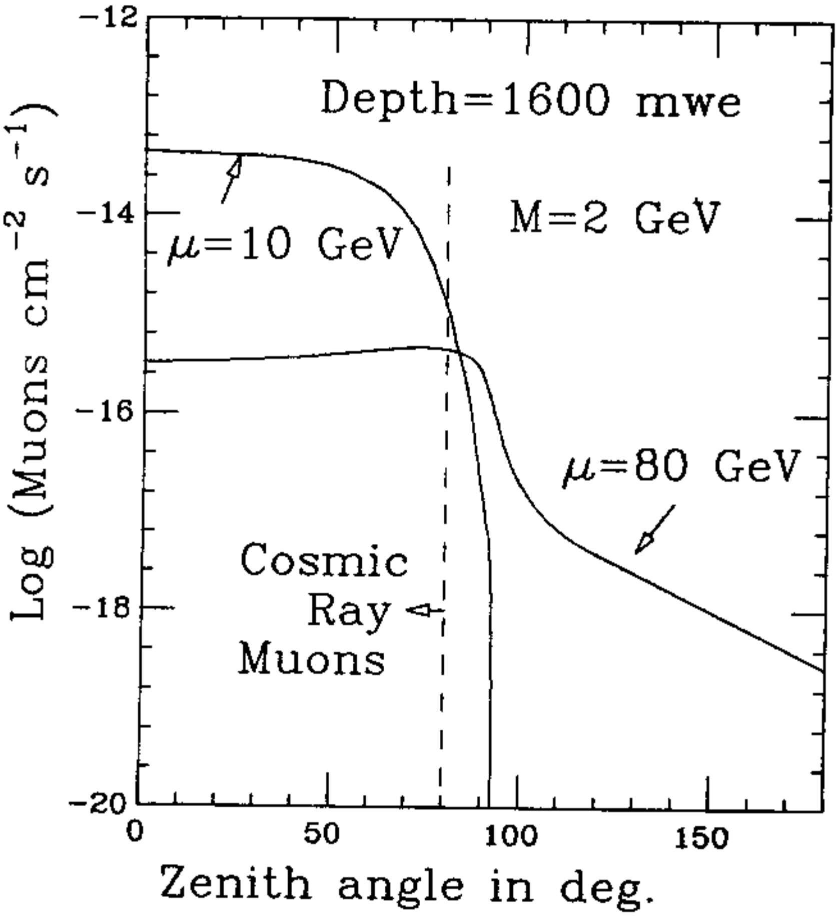
Cygnus X-3
γ - rays
M=2 GeV
M=
3 GeV
M=5 GeV
-11
-12
-13
-14
-15
-16
10
11
12
13
14
15
16
Log (Photinos cm^{-2} s^{-1} decade^{-1})
Log E eV

Figure 1



Depth=1600−4500 mwe
M=2 GeV
μ=80 GeV
μ=10 GeV
Log (Photinos cm^{-2} s^{-1})
−10
−12
−14
−16
−18
0
50
100
150
Zenith angle in deg.

Figure 2



Depth=1600 mwe
M=2 GeV
μ=10 GeV
μ=80 GeV
Cosmic
Ray
Muons
-12
-14
-16
-18
-20
0
50
100
150
Log (Muons cm^-2 s^-1)
Zenith angle in deg.

Figure 3