A Search for the Signature of Microquasars in the Cosmic-Ray Iron Spectrum measured by TIGER

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Abstract

In a recent paper Heinz and Sunyaev suggest that relativistic jets observed in microquasars might result in narrow features in the energy spectra of heavy cosmic rays with ≈ 1 to ≈ 10 GeV/nuc. They further argue that such features might be observable if there has been one or more micro-quasars nearby within the last few million years. We report preliminary results of a search for evidence of such features using data from a 32-day balloon flight of the Trans-Iron Galactic Element recorder (TIGER). Although this flight took place near solar maximum, calculations of the broadening effects of solar modulation indicate that a narrow feature of sufficient intensity should still be observable. An energy spectrum for iron with high statistical significance has been derived from $\approx 100,000$ Fe events in the energy range from about 2.5 to 10 GeV/nuc. Although our preliminary results do not reveal any obvious features, we will discuss the possibility of observing such features with TIGER and other instruments.

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1 Introduction

An astronomical phenomenon that has received widespread recent attention is the group of Galactic superluminal radio sources, commonly referred to as microquasars. Exemplified by the prototypical sources GRS1915+105 and GRO J1655-40, these constitute essentially a scaled-down version of normal quasars, consisting of black holes and neutron stars which eject plasma from accreted materials at bulk velocities in the relativistic regime. See, e.g [7].

Recently, Heinz and Sunyaev suggested [4] that the relativistic jets from these microquasars should be able to produce a distinct, heavy, possibly narrow component in the galactic cosmic radiation (GCR) that might be observable in the energy region between ~ 1 and ~ 10GeV/nuc if any such source has been within about a galactic disc height of the Sun in the last $\sim 10^7$ years. Their toy model for such a possible contribution of a single microquasar to the GCR spectrum is shown in figure 1.

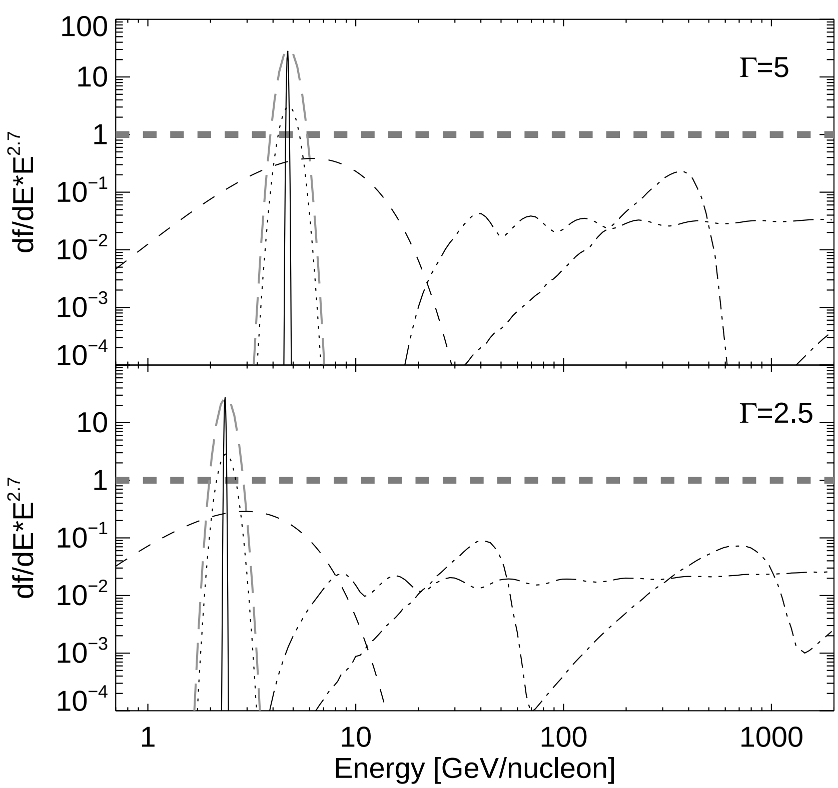

Fig. 1. This is figure 7 in [4] showing how a narrow cosmic-ray component of microquasar origin might extend measurably over the diffuse GCR background (thick dashed grey line). The components below the GCR background are for different scenarios, but only the narrow features, shown for two different upstream temperatures (dotted and solid curves), are considered here.

Note that the actual intensity of such a peak could exceed the GCR background by an order of magnitude or more. In order to compare such a narrow predicted component in space to the observed flux of GCR particles at the top of the atmosphere, the effects of cosmic ray transport through the heliosphere (solar modulation) must be taken into account.

We have estimated the effects of solar modulation using a spherically symmetric approach after Fisk [3], which includes diffusion, convection, and adiabatic deceleration. See, for example, [5].

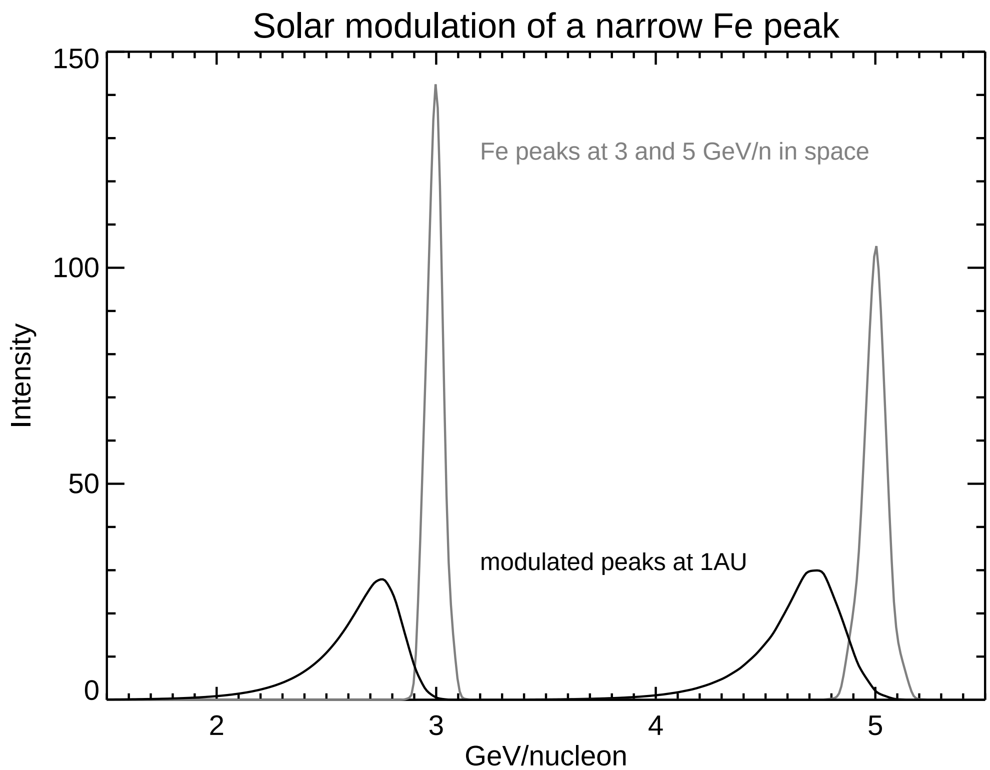

Fig. 2. Effect of solar modulation on the shape of a narrow GCR component in space for two energies. Black curves are modulated to 1AU.

Figure 2 shows how such a narrow component would be affected by solar modulation for two different energies in interstellar space, 3 and 5 GeV per nucleon. Note that the Fe ions lose on average $\Delta E \sim Ze\Phi/A \sim 500 MeV/nuc$ in penetrating to 1AU. In this presentation we examine the possibility of detecting such a suitably modulated distribution in the TIGER-01 dataset.

2 The Instrument

The Trans-Iron Galactic Element Recorder (TIGER) was launched on December 21, 2001 and flew for about 32 days on a long-duration balloon flight from McMurdo Base in Antarctica. The data from this flight was used in this study.

During a second flight in December/January 2003, an additional 19 days of data was obtained which are not included in this dataset.

The objective of the Trans-Iron Galactic Element Recorder (TIGER) experiment is the measurement of the elemental abundances of galactic cosmic ray nuclei with charge $26 \leq Z \leq 40$. These elements can help distinguish between a warm stellar atmospheric (FIP enhancement; e.g. [6]) and cold interstellar dust and gas (refractory enhancement; [2]) GCR source.

TIGER consists of four plastic scintillation detectors, two Čerenkov detectors and a scintillating fiber hodoscope. The top two scintillation counters provide the primary $\mathrm{d}E/\mathrm{d}x$ measurement while the bottom scintillation counters are used to identify nuclei that interacted in the instrument. The top Čerenkov detector, C0, has a 3 cm thick aerogel radiator with index of refraction $n = 1.042$, the bottom Čerenkov detector, C1, has an acrylic radiator made of BC-480 with thickness 1.2 cm and n=1.5. This design allows not only elemental separation, but also provides an energy determination for the individual detected particles. A more complete description of the instrument can be found in [8]

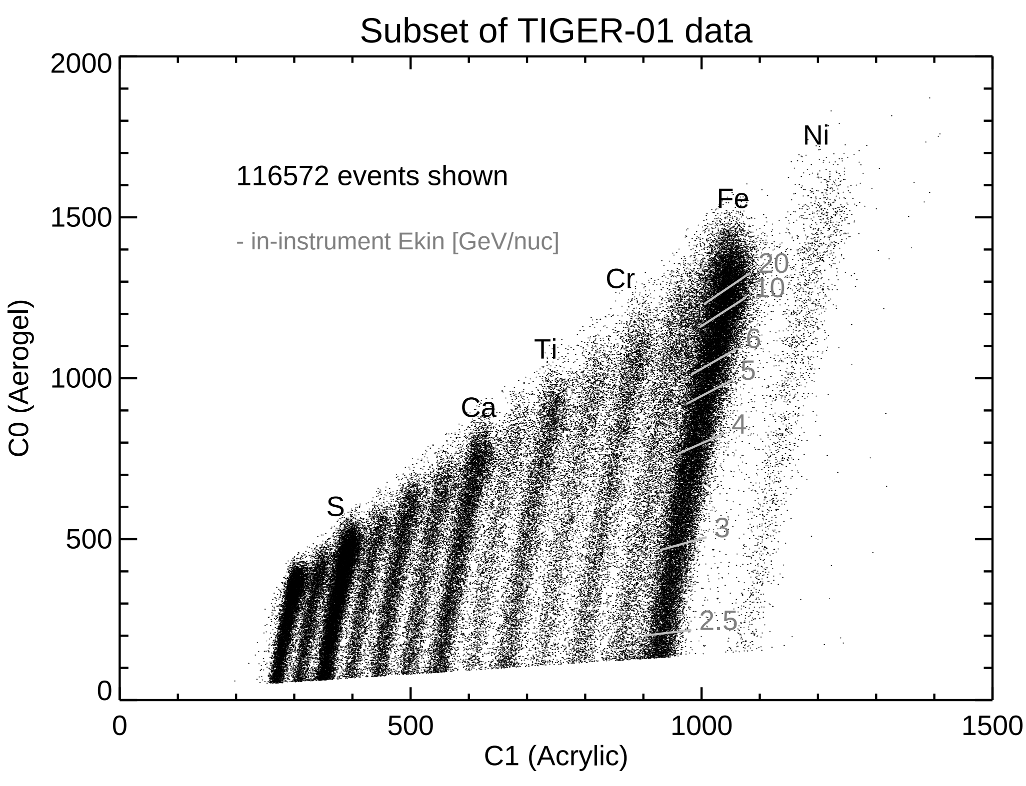

Fig. 3. A plot of C0/C1 illustrating element and energy determination. Approximate in-instrument measured energies, before any backpropagation through instrumental or atmospheric material are indicated on the Fe track. $E_{kin,TOA}$ is on average about 250MeV/nuc higher.

3 Data

A sample of the high energy data that illustrates particle and energy identification in TIGER is shown in Figure 3. This plot already contains the corrections for zenith angle, instrumental mapping, and small corrections for diurnal (mostly temperature related) variations in the gains of the photomultiplier tubes. In the energy region above the C0 cutoff, an average 1σ charge resolution of $\approx 0.26e$ was observed.

In total, during the first TIGER flight, approximately 360,000 iron nuclei were detected. Selecting the low-energy cutoff for C0 based on the known $n = 1.042$ and the high-energy peak at $\beta = 1$ sets an energy scale that can be used to compute the in-instrument energies for each particle above the C0 threshold.

Utilizing the measured zenith angle for each particle, the individual particles are then backpropagated both through the instrumental grammage (of about $4.2g/cm^2$ at normal incidence) and the atmospheric overburden which averaged somewhat under $5g/cm^2$ but was continuously monitored and taken at the value of the given event. Thus, a Top-of-the-Atmosphere (TOA) energy for each particle was derived.

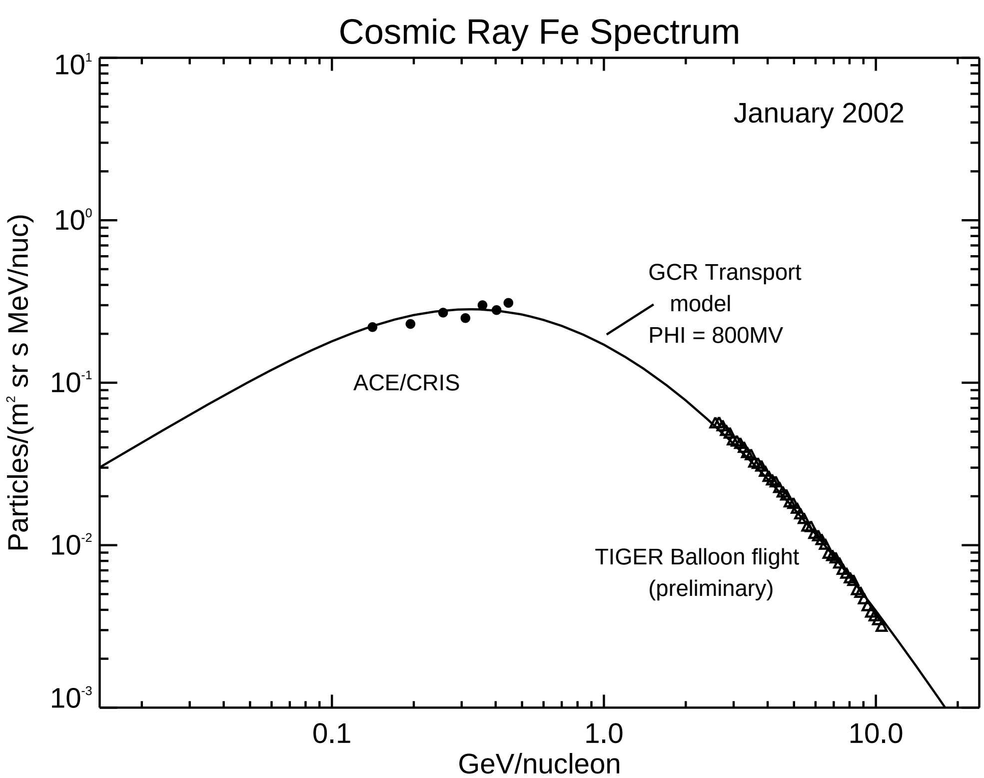

Fig. 4. Normalization of TIGER data to ACE/CRIS GCR measurements. Statistical uncertainties are smaller than data points.

During atmospheric propagation, only energy losses were taken into account, not the loss of particles to fractionation. This will have a small differential effect on particles of differing energies but should not change the shape of the spectrum as the interaction cross sections are only weakly dependent on energy.

No attempt was made to calibrate the absolute fluxes from first principles. Instead, the ACE CRIS fluxes were used to model the GCR transport through the heliosphere at the given epoch (see [1]), yielding a solar modulation level of about 800MV. Then the TIGER spectrum was scaled such that the overall intensity agreed with the model. Figure 4 shows the resulting spectra.

In order to gauge the possibility of detecting a narrow component in the resulting Fe spectrum, the modulated peaks as shown in figure 2 are scaled to a given percentage of the overall flux in the measured data and then added to yield a "hypothetical total spectrum". There were 96728 particles detected by TIGER for which the TOA energy was determined to be in the range between 2.5 and 10GeV/n. In order to assess how difficult it would be to spot the presence of a narrow component in the observed flux, figure 5 shows how the observations at 1AU would change if a solar-modulated peak was broadened

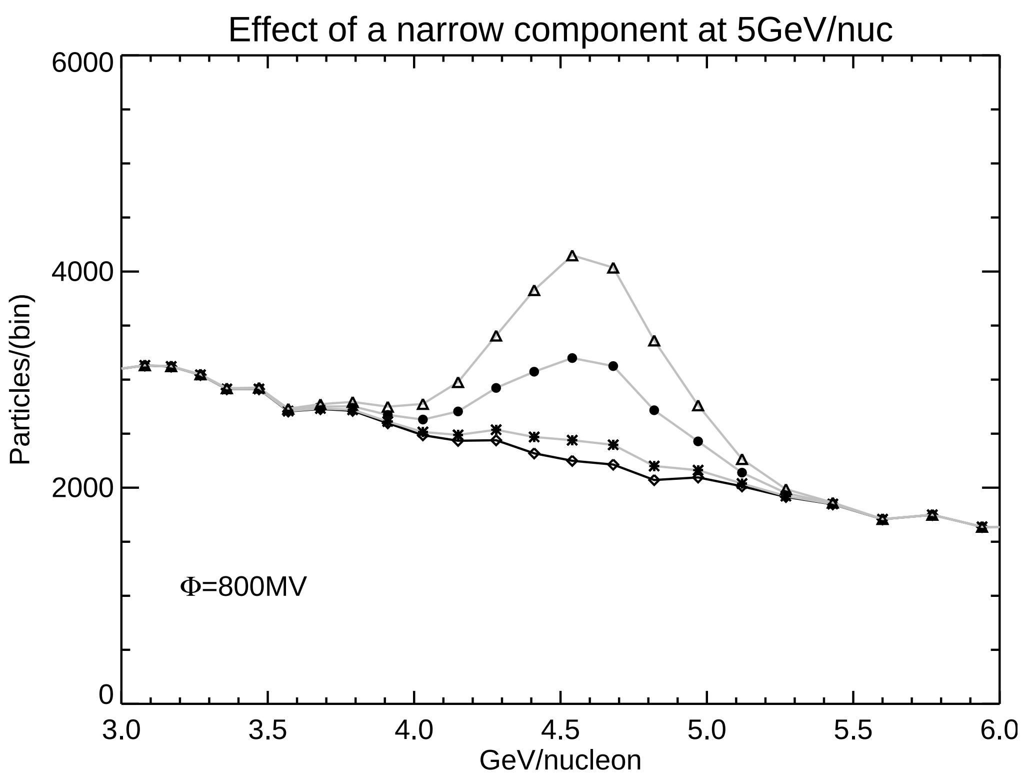

Fig. 5. Effect of modulated peak broadened by the TIGER energy resolution at 4.5GeV/nuc added to the measured distribution. The total flux of the original narrow component is assumed here to be 1% (asterisks), 5% (filled circles), or 10% (triangles) of the measured flux in the given energy range 2.5 to 10 GeV/nucleon.

by the energy resolution of the instrument and added to the observed data that contributes 1%, 5% or 10% of the number of observed particles. The energy resolution of the TIGER-01 instrument varies from $\sim 1.8\%$ at 3GeV/nuc to $\sim 24\%$ 8GeV/nuc. At 4.5GeV/nuc it is $\sim 6.1\%$

4 Conclusions

In the energy range between 2.5 and 10GeV/n there is no evidence for a spike or narrow feature contributing more than a few percent to the total number of detected particles.

This does not preclude the microquasar model since no consideration has been given here to the possible smearing of any spike by interstellar propagation or adiabatic losses within the source region as described in section 4 of [4]. Nor can we preclude the possibility of a large number of narrow features blending into each other. However, this data does show one thing: if there is a microquasar contribution to the GCR spectrum, it is not dominated by a single, recent, nearby event. The limits that can be placed on any deviation of the spectrum from a smooth power-law will be further improved in future, more thorough analysis of the data already obtained. In particular, examination of the relative abundant lighter elements Ca, Ti or Cr will yield additional independent pieces of information. We can also extend the energy spectra down to < 1GeV/nuc using the C1 Čherenkov counter data.

5 Outlook

It should be noted that this is a report on work in progress and that there are a number of corrections, like the energy dependence of iron fragmentation in the atmosphere, that have yet to be applied.

This analysis does not include the data from the TIGER-03 flight. Since one of the banks of photomultiplier tubes was turned off during the TIGER-01 flight due to a problem with the high voltage, the energy resolution is only about $\approx 6.1\%$ at 4.5GeV/nuc. This finite resolution leads to an additional smearing of any narrow feature and was included in figure 5. In comparison, the TIGER-03 data with its additional set of PMTs should have about $\approx 4.4\%$ resolution at the same energy. At $\sim$ 3GeV/nuc we expect the TIGER-03 resolution to be $\sim 1.3\%$. On the other hand, the TIGER-03 data set spans a little less than 20 days, while the TIGER-01 data set exceeds 30 days of flight time.

A future flight of TIGER or a successor instrument during solar minimum, would place more stringent limits on any features in the energy spectra.

6 Acknowledgements

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