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Gamma Rays from the Galactic Centre

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Abstract: Recent results from the HESS gamma ray telescope have shown the presence of both a diffuse, extended flux of gamma rays above ∼0.4 TeV and discrete sources in and near the Galactic Centre. Here, we put forward a possible explanation in terms of the diffusion of protons from a succession of supernova remnants (SNR) in the SgrA* region plus a probable contribution from SNR in the rest of the Galactic Centre Region. Protons are favoured over electrons and 'anomalous' diffusion over normal diffusion. A prominent feature is the need for a low efficiency for SNR acceleration in the high density regions.

The Galactic Centre seen in gamma rays

The HESS group has given contours of the TeV gamma ray emission from the Galactic Centre Region (GCR), specifically, that bounded by $-2^o < l < +2^o, -1.2^o < b < 1^o$ (http://www.mpi-hd.mpg.de/hfm/HESS, [1]). The 'map' is characterized by 'point source' emission from the SNR $G0.9+0.1$ and from SgrA*, very close to the nominal GC (GC). This region has many remarkable features: the very high density ($> 10^4 cm^{-3}$) of the molecular hydrogen with the mean trmperature $70°K$, surrounding very hot plasma with the temperature of 10-15 KeV, a value which is so high as to need the presence in the past of very energetic activity such as a giant Galactic explosion and/or the explosion of many SN within the central parsec over the past $10^4 - 10^5$ years [2].

Many measurements have been made of the distribution of gas in the GC region, most notably using CO [3;4] and CS [5]. The HESS group used the CS data to give the consequent column density of H_2 and we have done the same, although we have applied a correction for the loss of lower density molecular gas from the work of Dame [6] for the region $|l| < -1°$.

Adopting the local value of the CR intensity and our emissivity of the yield of gamma rays per hydrogen atom for the local CR spectrum [7] we have derived the ratio of the observed/expected gamma ray intensity which in fact is the excess of CR intensity over the local value at tens of TeV energy. The result is shown in Figure 1. The mean value of R(l) is 2.44±0.41 for the total flux including the central source. Without the central source it is $\langle R(l) \rangle$ = 1.83±0.15. It means that the CR density in the GC is probably higher than locally.

However, the likelihood of systematic errors in the inferred column density of molecular hydrogen means that the absolute values of the enhancement in CR intensity ratio are uncertain. However, the shape of the longitude-dependence should be reasonable. We notice also the trend of diminishing R(l) with increasing $|l|$. Interestingly there is a correlation of the shape with an integral radio intensity over $|b| < 0.3°$ measured at 5GHz [8]. These radio waves are emitted by low energy, GeV CR. The slope of the regression line is 0.96±0.11, the correlation coefficient is 0.85. This correlation indicates that there are SNR responsible both for TeV and GeV CR not only in the central SgrA* region but also in the wings to be called Galactic Centre Ridge (GCR).

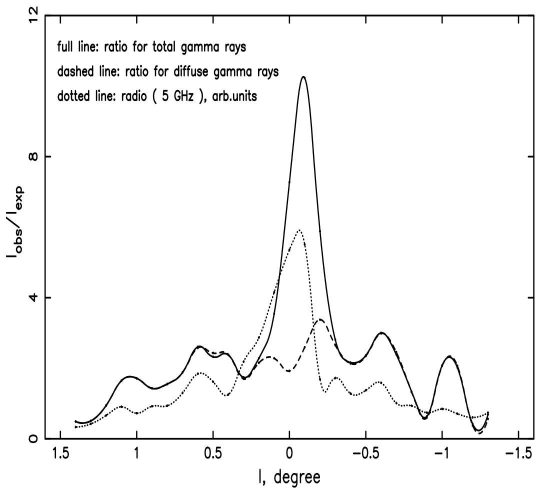

Figure 1: Ratio of observed to expected gamma ray intensity for $E_\gamma > 0.38$ TeV, the expectation being that the CR intensity is the same as that locally; the ratio is thus that of the proton intensity to that locally: $R(l)$. The full line shows the ratio for the total gamma-ray intensity, the dashed line - the same, but with the central source subtracted, the dotted line - the profile of the radio intensity in arbitrary units. The contribution from CR electrons is ignored. Most of the peaks appear are significant at 2-3 standard deviation level.

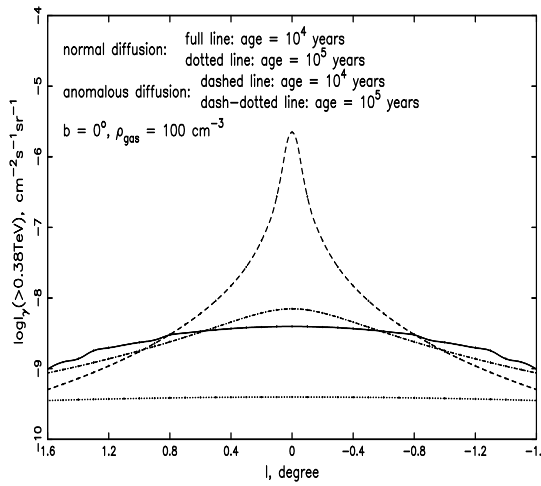

Figure 2: Longitude dependence of the gamma ray intensity from a single source at longitude l, in a medium of density $100cm^{-3}$ at $b = 0°$. Two ages are considered, 10^4 and 10^5 years and two modes of diffusion: normal and anomalous.

The shape of the gamma-ray intensity profile

Now we assume that gamma rays from GC originate from the explosion of just one SN in the SgrA* region. In Figure 2 we show the profiles of the gamma-ray intensity expected from our standard SN explosion occured 10^4 or 10^5 years ago. Two modes of diffusion were adopted - the normal gaussian and an anomalous diffusion. The effective average density of the gas is 100cm^{-3} (lower than 10^4 cm^{-3} because of the presence of a large volume of low density material and the 'filling factor', which is the fraction of space occupied by the high density molecular gas). It is seen that there is no sharp peak in the centre even for the youngest SN with an age of 10^4 years. The fall of the intensity with longitude in the wings is too strong to be compatible with the experiment. Flatter distribution in the wings could be obtained for normal diffusion but in this case there is no indication for any peak in the centre. Therefore to get agreement with experiment both in the central peak and in the wings we cannot use just a single SN and need the succession of SN explosions distributed in time.

In Figure 3 we show the results of the calculation for a succession of SN in SgrA*. Two sets of SN rates are taken: 10^2 SN in 10^4 years and 10^3 SN in 10^5 years. The actual column density of gas (rather than gas of constant density) was taken. The results were averaged over the galactic latitude interval of $|b| \leq 0.3°$ and smoothed by the finite angular resolution of the HESS telescope of $0.1°$. The central peak, which results mainly from SNR younger than about 10^4 years, from which the CR do not diffuse very far, is a consequence of anomalous diffusion. Normal diffusion gives a much weaker spike. The other, later SN will have given particles which have diffused out to permeate more of the molecular material in the GCR. The manner in which the particles diffuse is debatable both by way of the diffusion

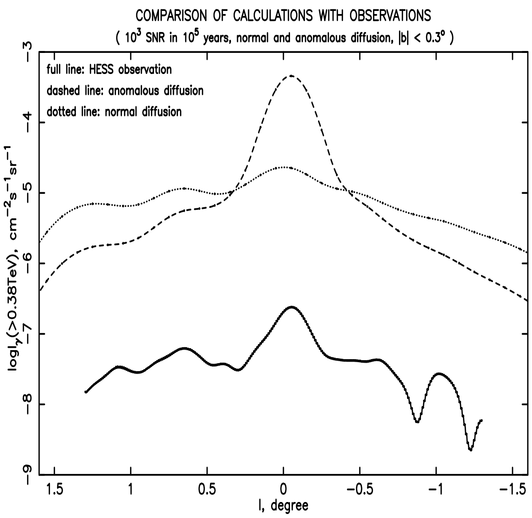

Figure 3: The angular profile of the gamma ray intensity in the GCR predicted for our model with 10^3 SN in 10^5 years at the position of SgrA*, placed at the longitude $l = -0.05°$, and for the actual molecular gas distribution. Results are averaged over the galactic latitudes $|b| \leq 0.3°$ and smoothed taking into account the finite angular resolution of the HESS telescope of $0.1°$. Normal and anomalous diffusion are shown by dotted and dashed lines respectively. The results of HESS observations are also shown by the full line for comparison.

coefficient to adopt and the manner of diffusion, viz 'normal' or 'anomalous'. We consider that, in view of the disturbed conditions in the region and highly non-uniform distribution of gas, the mode of diffusion in the very central region at least will be 'anomalous' [9]. Concerning the diffusion coefficient, in the absence of clear information we adopt the 'local' value (pertaining to the Galaxy as a whole). The preferred scenario is for 10^3 SN in 10^5 years with the anomalous diffusion which gives the higher central peak and reasonably flat longitudinal dependence of the gamma-ray intensity in the wings.

The efficiency of CR production

We introduce the efficiency f as the ratio of the observed to the expected gamma-ray intensity. The latter is calculated under our assumption of SN explosions. For the succession of 10^3 SN in 10^5 years in the SgrA* (Fig.3) we predict the flux of $4 \cdot 10^{-9} cm^{-2}s^{-1}$. The total flux from the GC observed by HESS in $|l| < 0.2°$ region including the point source in SgrA* is $F_\gamma(> 1TeV) = 7 \cdot 10^{-12} cm^{-2}s^{-1}$, therefore the efficiency is $f \approx 1.7 \cdot 10^{-3}$.

Undoubtedly there should be SNR in the GCR material too. The likely number can be estimated as follows. For the Galaxy as a whole with molecular mass $M(H_2) \sim 10^9 M_\odot$ [ ] and the SN rate of $10^{-2} y^{-1}$ we have the SN density rate of $10^{-11} M_\odot^{-1} y^{-1}$. It is likely that this value is also appropriate to the Ridge so that in 10^5 years with a mass of the molecular cloud of $4.4 \cdot 10^7 M_\odot$ we expect 44 SNR. Assuming that these SN give the same contribution to the flux in the wings as the central 10^3 SN which is equal to $8.6 \cdot 10^{-9} cm^{-2}s^{-1}$ and using the observed flux of $7 \cdot 10^{-12} cm^{-2}s^{-1}$ the derived f value is ~ 0.1. We obtained that the efficiency decreases with the increasing molecular gas density. This may help to understand the well-known problem of the small radial CR gradient which is less than the radial gradient of SN rate. In Figure 4 we present the efficiency vs. the relative surface density of the molecular gas taken for GeV CR from the gradient and TeV CR from HESS measurements. There are many phenomena which could contribute to f being less then unity for the unusual conditions in the GCR. These are, mainly,

1. The possibility that the majority of SN there are not of Type II - the main sources of SNR which accelerate CR to very high energies.

2. The high gas density causes the Sedov radius (which is proportional to $n^{-\frac{2}{5}}$, [10]) to be small; specifically it falls to only a few pc. The time taken to reach this radius, after which CR acceleration is reduced, is probably too short for efficient acceleration, despite the increased magnetic field in the GCR.

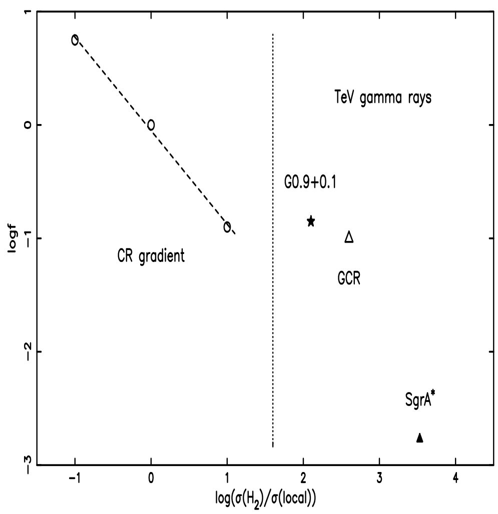

Figure 4: Efficiency of SNR for accelerating CR of energy and intensity sufficient to give gamma rays of GeV energy (CR gradient results) and above 0.38 TeV as a function of the surface density of molecular hydrogen. The local values of efficiency and surface density of gas are taken as datum in each case. For the TeV gamma rays we adopt a nominal mean density of 100 cm^{-3}.

3. The high gas density probably causes the injection efficiency to be low (Drury et al. [11] and private communication), the point being that ionization losses will be considerable during injection for the sub-relativistic particles.

4. The tube-like magnetic fields, referred to in §1, which will convey particles out of the Galaxy.

5. A very likely effect relates to the Galactic Wind. This is currently very strong in the GCR (eg [12;13;14]) - with a velocity of a few thousand $km\ s^{-1}$.

Concerning item 1, it seems unlikely that there is a shortage of the necessary massive pre-SN stars. Indeed, in parts (eg SgrB2), there are unusually massive stars being produced 'furiously'. Presumably the high rate of SN production overall in the GCR, and particularly in SgrA*, gives rise to many Type II SN.

The other factors are, therefore, considered to be the relevant ones.

Conclusion

There are two possibilities to explain the HESS observation. Firstly, there were 10^3 SN in 10^5 years in SgrA*, CR diffusing through the Ridge causing the Ridge emission and the recent SNR giving CR very close to SgrA*, which caused the point source. The problem is that the needed gas density to get the observed ratio of Ridge flux to SgrA* point source is very low.

Secondly perhaps the SNR in the Ridge itself are responsible for CR flux. The number of SN in SgrA* could be then smaller with higher density gas allowed.

References

[1] Aharonian, F.A. et al., Nature, **439**, 695, 2006
[2] Morris, M. and Serabyn, E., Ann. Rev. Astron. Astrophys., **34**, 645, 1996
[3] Bania, T.M., Astrophys. J., **216**, 381, 1977
[4] Oka, T. et al., astro-ph/9810434, 1998
[5] Tsuboi, M., Handa, T. and Ukita, N., Astrophys. J., **120**, 1, 1999
[6] Dame, T.M., Hartmann Dap and Thaddeus, P., Astrophys. J., **547**, 792, 2001
[7] Erlykin, A.D. and Wolfendale, A.W., J.Phys.G: Nucl. Part. Phys., **29**, 641, 2003
[8] Altenhoff, W.J. et al., Astron. Astrophys. Suppl. Ser., **35**, 23, 1979
[9] Erlykin, A.D., Lagutin, A.A. and Wolfendale, A.W., Astropart. Phys., **19**, 351, 2003
[10] Axford W.I. et al.,Proc. 17th Int. Cosm. Ray Conf. (Paris), **12** 155, 1981
[11] Drury l.O'C. et al., Astron. Astrophys. **309** 1002, 1996
[12] Breitschwerdt D. et al., Astron. Astrophys., **385**, 216, 2002
[13] Völk H.J. and Zirakashvili V.N., Astron. Astrophys., **417**, 807, 2004
[14] Sunyaev, R., Markevitch, M. and Pavlinsky, M., Astrophys. J., **407**, 606, 1993