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π^0 - DECAY γ-RAYS FROM THE GALAXY AND THE INTERSTELLAR GAS CONTENT

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Abstract: Knowledge of the total γ-ray production rate per H atom from the decay of π^0 mesons produced in interstellar cosmic-ray interactions is essential for determining the possible amount of interstellar H_2. This production rate is recalculated here using the latest accelerator data on π^0 production in pp-interactions up to $\sim$300 GeV. A simple but accurate approximation used here resolves the past disagreement over the magnitude of this rate. An upper limit is obtained of $(1.51 \pm 0.23) \times 10^{-25} s^{-1}$ consistent with the observed upper limit of $1.6 \times 10^{-25} s^{-1}$.

Knowledge of the total γ-ray production rate per hydrogen atom from interstellar π^0-decay is essential for determining whether molecular hydrogen may exist in significant quantities in interstellar space. Recently, Kraushaar, et al. (1972) have obtained an observed galactic γ-ray flux measurement corresponding to a production rate of 1.6×10^{-25} photons/s above 100MeV for each interstellar hydrogen atom observed in 21cm radio emission. At the same time, recent theoretical calculations have given diverse results on the γ-ray production rate per H atom. These values of $1.3\times10^{-25}s^{-1}$ (Stecker 1970), $1.8\times10^{-25}s^{-1}$(Cavallo and Gould 1971) and $3.2\times10^{-25}s^{-1}$(Levy and Goldsmith 1972) are enough in disagreement with each other to influence qualitative conclusions on the interstellar medium. If we compare the value given by Stecker (1970) with the observations we conclude that there may be some contribution to the observed γ-ray intensity from "cool" H and H_2 not observed in 21cm radio emission. (Stecker 1969, Stecher and Stecker 1970). The rate given by Cavallo and Gould (1971) would appear to allow for no significant contribution of cool atomic and molecular hydrogen to the galactic γ-ray production rate and, even so, would appear to be a bit high. The rate given by Levy and Goldsmith (1972) is so high as to throw the observation of Kraushaar, et al. (1972) into question.

The three calculations referred to above involved elaborate numerical integrations to determine first the differential γ-ray spectrum and cannot be easily checked by the reader. Fortunately however, if the calculation is limited to the total γ-ray intensity, a simple treatment can be given which the reader may check for himself. In this manner, a reliable figure for the γ-ray production rate may be arrived at.

Figure 1 shows an up-to-date summary of the accelerator data on the total cross section (σ) times multiplicity (ζ) for neutral pion production in p-p interactions for energies up to $\sim$300GeV shown as a function of kinetic energy (T) as given in the references. These data are well approximated by the broken power-law

$$\sigma_{\pi^0}(T)\zeta_{\pi^0}(T) \lesssim \begin{cases} 10^{-25}T^{7.64}\text{cm}^2 & 0.4\leqslant T\leqslant 0.7\text{GeV} \\ 8.4 \times 10^{-27}T^{0.53}\text{cm}^2 & T\geqslant 0.7\text{GeV} \end{cases}$$

as the reader can verify from the figure. Taking the cosmic-ray spectrum $I(T) = 0.15\ T^{-2.2}\text{cm}^{-2}\text{s}^{-1}\text{Sr}^{-1}\text{GeV}^{-1}$ used by Levy and Goldsmith (1972), the total γ-ray production rate from p-p interactions is given by

$$q_{\gamma H} = 8\pi \int dT\ I(T)\sigma_{\pi^0}(T)\zeta_{\pi^0}(T)$$

$$= 3.77\text{x}10^{-25} \int_{0.4}^{0.7} T^{5.44}dT + 3.17 \times 10^{-26} \int_{0.7}^{\infty} T^{-1.67}dT$$

$$= 0.66 \times 10^{-25}\text{s}^{-1}$$

Adding in the contribution from p-α, α-p and α-α interactions in the galaxy brings the total production rate per hydrogen atom up to $\sim 10^{-25}\text{s}^{-1}$, a value in good agreement with Stecker(1970) (which used a somewhat higher cosmic-ray intensity) and with previous work summarized by Stecker(1971). There is, of course, some uncertainty in the assumption of the true "demodulated" galactic cosmic-ray spectrum as distinguised from that observed at the earth. However, using the upper-limit to the demodulated cosmic-ray spectrum given by Comstock, et al.(1972), an upper limit on the γ-ray production rate is obtained of $(1.51\pm0.23)\text{x}10^{-25}\text{s}^{-1}$ with the error bracket reflecting the experimental error in the accelerator data on $\sigma\zeta$. The above value is consistent with the value of $1.6\text{x}10^{-25}\text{s}^{-1}$ given by Kraushaar, et al.(1972), which also represents an upper limit since it does not take account of the additional contribution from cool H and H_2 which may be adding to the observed flux.

It is hoped that the straightforward calculation presented here will at last resolve the discrepancy existing between various theoretical calculations and finally result in a consistent picture of γ-ray production in interstellar cosmic-ray interactions. It should, of course, be noted that whatever the shape of the differential γ-ray production spectrum (and here there is more uncertainty because it depends on the dynamics of pion production), the normalization to the total production rate has to be consistent with data on the total cross section and multiplicity.

References

Barnes, V. E., Bugg, D. V., Dodd, W. P., Kinson, J. B., and Riddiford, L., 1961, Phys. Rev. Lett. 7, 288.

Batson, A. P., and Riddiford, L. 1956, Proc. Roy. Soc. A 237, 175.

Batson, A. P., Culwick, B. B., Hill, J. G., and Riddiford, L., 1959, Proc. Roy. Soc. A 251, 232.

Bøggild, H., Dahl-Jensen, E., Hansen, K. H., Johnstad, J., Lohse, E., Suk, M., Veje, L., Karimäki, V. J., Laurikainen, K. V., Riipinen, E., Jacobsen, T., Sørensen, S. O., Allan, J., Blomquist, G., Danielson, E., Ekspong, G., Granstrøm, L., Holmgren, S. O., Nilsson, S., Ronne, B. E., Svedin, U., and Yamdagni, N. K., 1971, Nuc. Phys. B27, 285.

Cavallo, G., and Gould, J. R., 1971, Nuovo Cimento B2, 77.

Cence, R. J., Lind, D. L., Mead, G. D., and Moyer, B. J., 1963, Phys. Rev. 131, 2713.

Charlton, G., Cho, Y., Derrick, M., Engelmann, R., Fields, T., Hyman, L., Jaeger, K., Mehtani, U., Musgrave, B., Oren, Y., Rhines, D., Schreiner, P., Yuta, H., Voyvodic, L., Walker, R., Whitmore, J., Crawley, H. B., Ming Ma, Z., and Glasser, R. G., 1972, Phys. Rev. Lett. 29, 1759.

Comstock, G. M., Hsieh, K. C., and Simpson, J. A., 1972, Astrophys. J. 173, 691.

Dao, F. T., Gordon, D., Lach, J., Malamud, E., Meyer, T., Poster, R., and Slater, W., 1972, Phys. Rev. Lett. 29, 1627.

Dodd, P., Jokes, M., Kinson, J., Tallini, B., French, B. R., Sherman, H. J., Skillikorn, I. O., Davies, W. T., Derrick, M., and Radjojicic, D., 1961, Aix-en-Provence Conf. on High Energy Phys. (Centre d'Etudes Nuclearies de Saclay, Seine et Oise, Vol. 1, 433.

Eisner, A. M., Hart, E. L., Louttit, R. I., and Morris, T. W., 1965, Phys, Rev. 138, B 670.

Fields, T. H., Fox, J. G., Kane, J. A., Stallwood, R. A., and Sutton, R. B., 1956 CERN Symposium Proceedings (CERN, Geneva)Vol.2., 339.

Hughes, I. S., March, P. V., Muirhead, H., and Lock, W. O., 1956, CERN Symp. Proc. (CERN, Geneva) Vol. 2, 344.

Kraushaar, W. L., Clark, G. W., Garmire, G. P., Borken, R., Higbie, P., Leong, C., Thorsos, T., 1972, Astrophys. J. 177, 341.

Levy, D. J., and Goldsmith, D. W. 1972, Astrophys. J. 177, 643.

Melissinos, A. C., Yamanouchi, T., Fazio, G. G., Lindenbaum, S. J., and Yuan, L. C. L., 1962, Phys. Rev. 128, 2373.

Meshcheriakov, M. G., Znelov, V. P., Neganov, B. S., Vzorov, I. K., and Shabudin, A. F. 1956, CERN Symp. Proc. (CERN, Geneva) Vol. 2, 347.

Pickup, E., Robinson, D. K., and Salant, E. O., 1962, Phys, Rev. 125,2091.

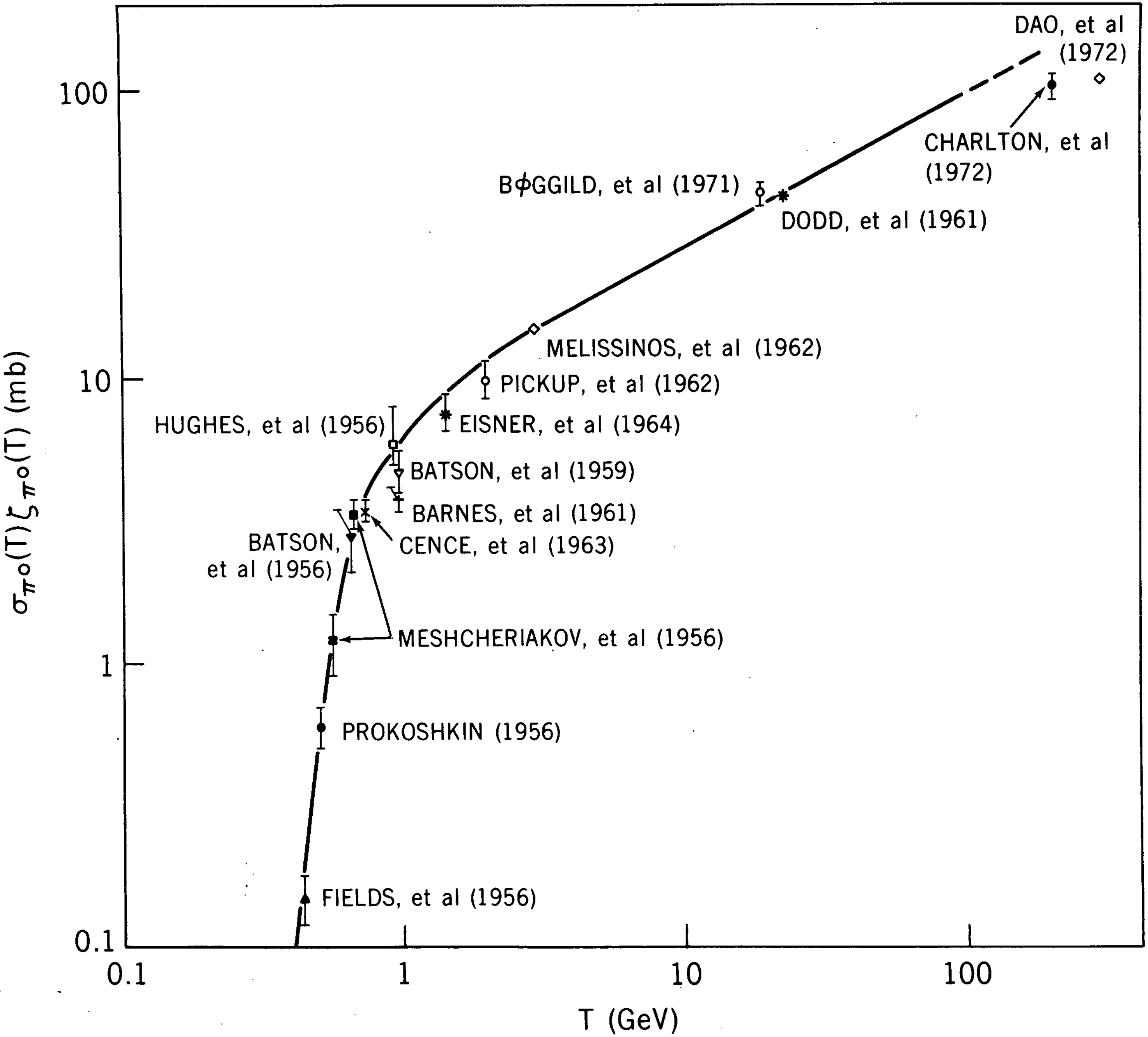
Prokoshkin, Iu. D., 1956, CERN Symp. Proc. (CERN, Geneva) Vol. 2, 385.

Stecher, T. P., and Stecker, F. W. 1970, Nature 226, 1234.

Stecker, F. W. 1969, Nature 222, 865.

Stecker, F. W. 1970, Astrophys. and Space Sci. 6, 377.

Stecker, F. W.,1971, Lettera al Nuovo Cimento Ser. 2,2,734.


DAO, et al (1972)
CHARLTON, et al (1972)
BΦGGILD, et al (1971)
DODD, et al (1961)
MELISSINOS, et al (1962)
PICKUP, et al (1962)
EISNER, et al (1964)
HUGHES, et al (1956)
BATSON, et al (1959)
BARNES, et al (1961)
CENCE, et al (1963)
BATSON, et al (1956)
MESHCHERIAKOV, et al (1956)
PROKOSHKIN (1956)
FIELDS, et al (1956)
100
10
1
0.1
0.1
1
10
100
$\sigma_{\pi^o}(T)\zeta_{\pi^o}(T)$ (mb)
T (GeV)

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