NUCLEAR PHOTO-DISINTEGRATION AT HIGH REDSHIFTS BY GAMMA-RAY BLAZARS

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ABSTRACT: We analyse the photodisintegration of nuclei near the center of blazars, in particular PKS 0528+134. We show that this process could explain the recent observation of a high Al/Si ratio in a cloud on the line of sight of a distant quasar and we calculate the effect of this gamma irradiation on the abundance of deuterium, an isotope of the highest cosmological interest since it is sensitive to the baryon density of the universe. The process has interesting consequences and deserves to be inserted in a consistent scenario of the early evolution of the universe.

KEYWORDS: nucleosynthesis; photodisintegration; gamma-rays; blazars.

1. INTRODUCTION

Blazars are extremely intense sources of gamma-rays and in their close vicinity, the abundance of certain nuclei could be distorted by photodisintegration. This process has been applied to AGN (e.g. Boyd, Ferland and Schramm 1989) but never explicitly to blazars. The aim of this work is to stress the interest of this mechanism and to make a link between gamma-ray astronomy, nucleosynthesis and cosmology following a line of reasoning close to that of Gnedin and Ostriker (1992, 1995), but more observationally oriented (von Montigny et al. 1995, McNaron-Brown et al. 1995). The Big Bang connexion is deuterium whose abundance could be modified by photodisintegration in high redshift clouds where it is observed by the most powerful instruments as the HST and the KECK telescope (Wampler et al. 1996, Webb et al. 1997, Tytler et al. 1996, Vidal–Madjar et al. 1997). Contrary to Sigl et al. (1995) we don’t care of 3He since it is unobservable in cosmological clouds. Indeed the measurements of the abundances in high redshift absorbers deliver a wealth of data (Petitjean and Charlot 1998). Among them, one is particularly intriguing: two clouds on the line of sight of a quasar at $z = 1.94$ show very different Al/Si ratios (Ganguly et al. 1998). Cloud A has a normal pop II abundance for its age (Al/Si $\approx 10^{-2}$). However Cloud B show a strong Al overabundance with respect to solar (Al/Si $\approx 1$). No stellar source can explain this ratio. For instance the production ratio in core collapse supernova is about 0.1, close to the solar one. The high Al/Si ratio observed, reminiscent of the one observed in galactic cosmic rays is certainly of non-thermal origin. We surmise that it is due to the removal of one nucleon from $^{28}$Si by protons or other particles. Here we favor high energy photons since blazars are very copious sources of gamma-rays. The spallation case will be described elsewhere. Accordingly, the production mechanism should be $^{28}$Si($\gamma,n$)$^{27}$Si $\rightarrow$ $^{27}$Al and $^{28}$Si($\gamma,p$)$^{27}$Al. The ($\gamma,n$) cross section are well measured. The ($\gamma,p$) one is only estimated.

On the other hand, the D/H ratio measured in high $z$ clouds is very dispersed (ranging from $3 \times 10^{-5}$ to $2 \times 10^{-4}$, Vidal–Madjar et al. 1998), and we are inclined, provided this dispersion is real, to explore the idea that it is due to photodisintegration of He and D in the vicinity of blazars. Apart the cross sections of the various reactions of interest, the main parameters of the problem
are the flux at the source above the energy threshold of the relevant reactions, the duration of the emission and the average spectrum of the photons.

2. Al AND D PRODUCTION/DESTRUCTION

2.1 Cross sections

As far as Al and D are concerned, the main production and destruction cross sections, with their associated energy threshold are the following:

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\begin{align*}
\gamma + ^4\text{He} &\rightarrow \text{D} \ (E > 20 \text{ MeV}) \\
\gamma + ^{28}\text{Si} &\rightarrow \text{n} + ^{27}\text{Si} \rightarrow ^{27}\text{Al} \\
\gamma + ^{28}\text{Si} &\rightarrow \text{p} + ^{27}\text{Al} \ (E > 17 - 10 \text{ MeV}) \\
\gamma + \text{D} &\rightarrow \text{p} + \text{n} \ (E > 2 \text{ MeV}) \\
\gamma + ^{27}\text{Al} &\rightarrow \text{X} \ (E > 10\text{MeV}) \\
\gamma + ^{28}\text{Si} &\rightarrow \text{X} \ (E > 17\text{MeV})
\end{align*}
\]

The reaction $^4\text{He}(\gamma,\text{D})\text{D}$ is unsignificant. The production of D by $^3\text{He}$ will be considered in future work. D/He is very sensitive to the photon flux between 2 and 30 MeV and Si/H to the flux between 20 and 30 MeV.

2.2 Spectra and fluxes

Recent observations by the three CGRO instruments, EGRET, OSSE and COMPTEL, have revealed a new class of extragalactic gamma ray sources associated to blazars AGN (von Montigny et al. 1995, McNaron–Brown et al. 1995, see Dermer, this meeting, for a review). Blazars are flat spectrum radio sources with jets closely aligned with our line of sight. In short and violent flaring phase the accelerated particles are injected in the form of plasma blobs along a preferential axis, forming a jet. We are not concerned by the detailed physics of these fascinating objects but by the long term (or statistical average) of their properties. Blazar spectra above 30 MeV, can be approximated by a power law ($E^{-1.4}$ to $E^{-2.7}$). EGRET, COMPTEL and OSSE observations combined show a flattening of the spectrum in the MeV range, above 1 to 50 MeV. The change in slope is between 0.5 and 1. We have shifted the observed spectra back to the sources, taking into account the cosmological effects through a model of the universe implying reasonable parameters (expansion rate, matter density and cosmological constant), which will be described in a forthcoming paper (Lehoucq et al. 1999).

With all these parameters at hand, we can calculate the effect of gamma-ray irradiation on a cloud located at a distance $R$ of the central engine of a blazar during a time $t$, then select a $(R, t)$ couple and finally estimate the corresponding alteration of D at a fixed Al/Si enhancement, here the one observed by Ganguly et al. (1998), say by a factor about of 100.

3. RESULTS

As a reference model we have taken PKS 0528+134 associated to a cosmological model with $h_{100} = 0.7$, $\Omega_m = 0.3$ and $\Lambda = 0$. It is a very strong gamma ray source located at a redshift of $z = 2.06$, with a rather flat power law spectrum ($\Phi \propto E^{-1.5}$) which steepens above 17 MeV.
Note that at the source, the break is shifted to about 60 MeV due to multiplication by the factor $(1 + z)$. As shown in figure 1, to get an Al/Si ratio of 1 as observed in cloud B, starting from a ratio of $10^{-2}$ (cloud A) we need an irradiation time $t$ of $6.7 \times 10^3$ year at a distance of 1 parsec. This result can be scaled to any other distance considering $t$ is inversely proportional to the square of $R$. It is worth noting that short times scales, by astronomical standards, are involved. The sensitivity of the results to the parameters are shown in Tables 1 and 2, other spectra (for the same number of photons) ($E^{-1.4}$ and $E^{-2}$), two different primordial D/H ratios ($10^{-4}$ and $4 \times 10^{-5}$) and a rather extreme cosmology ($\Omega_m = 0.1$ and $\Lambda = 0.9$) have been considered for comparison with the standard case. It appears that the most influential parameter is the spectral index. Flat spectra are more efficient than steep ones to produce the required effect. Note that D can be both produced or destroyed depending on the shape of the spectrum, this by modest amounts (less than 4). Cosmological effects introduce at most a factor of about 2 at $z = 2$. We think that we have demonstrated the interest of photodisintegration for the understanding of the abundances of nuclei in high redshift clouds (Cassé and Vangioni–Flam 1998). This mechanism remains to be integrated in a consistent scenario of cosmic nuclear evolution of the kind developed by Gnedin and Ostriker (1992, 1995). The elaboration of this great perspective should start, most modestly, from the study of irradiation of falling matter on the central black hole feeding blazars, its ejection in relativistic blobs, and its subsequent condensation in the form small intergalactic clouds.

![PKS0528+134 spectrum](image)

**FIGURE 1.** Evolution of Al/Si and D/H for the standard case (PKS 0528+134 associated to a cosmological model with $\text{h}_{100} = 70$, $\Omega_m = 0.3$ and $\Lambda = 0$.)
4. CONCLUSIONS

The recent observation of a large Al/Si ratio in a cloud on the line of sight of a distant quasar seem to justify the photodisintegration mechanism. The high Al/Si observed could be explained by gamma irradiation near a blazar core during $10^4 / R_{pc}^2$ years. The final Al/Si ratio depends weakly on the cosmology adopted (at least up to $z = 4$). A flat spectrum ($E^{-1.4}$) is favoured. The final abundance of D is sensitive to the source spectrum between 2 and 20 MeV and depends on the initial D/H ratio adopted. D can be circuitously destroyed or produced by quite moderate factors however ($< 4$). These variations could explain the scattering of the observed D/H on line of sight of remote quasars, if real. As a conclusion, photodisintegration is worth integrating in a consistent cosmological/astrophysical scenario.

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