Indications for $\gamma$-ray Bursts Originating Within an Extended Galactic Halo?

Eyal Maoz

Harvard-Smithsonian Center for Astrophysics, MS 51, 60 Garden Street, Cambridge, MA 02138

E-mail: maoz@cfa.harvard.edu

Submitted to the Astrophysical Journal Letters

ABSTRACT

If a substantial fraction of the observed $\gamma$-ray bursts originates within an extended Galactic halo then their spatial distribution should deviate slightly from spherical symmetry in a very particular way which involves features both in the bursts’ angular and radial distributions. This conclusion is based on various reasons which are all related to the presence and motion of the satellite galaxies around the Galaxy, and is independent of the nature and origin of the sources.

We analyze the spatial distribution of the bursts, according to the BATSE catalog until March 1992, and argue that the expected signature of an extended Galactic halo model is indicated by the data. The distance to the faintest bursts in the halo is either $\sim 130$ Kpc or $\sim 270$ Kpc.

Although a signature of a nearby-extragalactic distance scale in the data is very suggestive, we argue that a comparison with specific models is necessary before regarding our findings as a conclusive evidence. If the increasing data supports our results then $\gamma$-ray bursts may be the first detected manifestations of nearby intergalactic objects, either primordial or which have escaped predominantly from our satellite galaxies.

Subject headings: Gamma Ray: bursts
1. INTRODUCTION

Two decades after the discovery of \( \gamma \)-ray bursts (Klebesadel, Strong, and Olson 1973) the origin of these events is still an enigma. There are some indications that \( \gamma \)-ray bursts may originate on or near neutron stars (Mazets 1988; Murakami \textit{et al.} 1988; Fenimore \textit{et al.} 1988) but there is no consensus on a distance scale, not even to within orders of magnitude (Paczyński 1992). According to the observations made with the BATSE experiment on the \textit{Compton Gamma-Ray Observatory (GRO)}, \( \gamma \)-ray bursts are distributed isotropically over the sky (Fishman \textit{et al.} 1991; Meegan \textit{et al.} 1992) and do not show any association with known astronomical populations such as a concentration towards the Galactic plane, a correlation with the Galactic center, the Magellanic Clouds, or with prominent extragalactic regions such as the Virgo cluster. A single Galactic disk distribution seems to be ruled out from the angular distribution of weak \( \gamma \)-ray bursts (Mao and Paczyński 1992a), and the Oort cloud of comets is also an unlikely source of the bursts (Maoz 1993). The observed bursts’ distribution is consistent with a cosmological distance scale (e.g. Fenimore \textit{et al.} 1992; Paczyński 1992; Mao and Paczyński 1992b; Piran 1992; Dermer 1992; Paczyński 1991; Kouveliotou \textit{et al.} 1992; Paciesas \textit{et al.} 1992; Norris \textit{et al.} 1992), or with an extended Galactic halo distribution (see detailed discussion and references in §2.2).

We argue that if the observed \( \gamma \)-ray bursts, or at least a substantial fraction of them, originate within an extended Galactic halo then their spatial distribution should slightly deviate from spherical symmetry in a very particular way, regardless of the nature and origin of the bursting objects. This is based on a variety of reasons which are all related to the presence and motion of the satellite galaxies around our galaxy (§2). In §3 we show that a detection of the signature for a nearby-extragalactic distance scale is very suggestive. We then discuss the possibly emerging picture (§4) and make predictions (§5).

2. IMPRINTS IN A HALO DISTRIBUTION

2.1. The Magellanic Planes

First, let us discuss the existence of two special planes which will turn out to be relevant to \( \gamma \)-ray bursts in §2.2.

The Magellanic Stream, a narrow band of neutral hydrogen gas (e.g. Mihalas and Binney 1981) defines a great circle on the sky. Various analyses (Murai and Fujimoto 1980; Lin and Lynden-Bell 1981 and references therein) have led to the following, generally accepted, picture: The Stream consists of material torn out from the Magellanic Clouds by
the Galaxy’s tidal field during the previous close passage, and lies in their orbital plane. The Magellanic Clouds have been orbiting together in this plane as a binary system for a long time, their orbit is eccentric and runs roughly between 50-120 Kpc from the galactic center at the present epoch. The normal to this plane (hereafter, the *Magellanic Stream plane*, or the *MS-plane*) points to the direction \((l, b) = (185^\circ, 3^\circ)\) (Lin and Lynden-Bell 1981), where \(l\) and \(b\) are the Galactic longitude and latitude, respectively. Thus, the MS-plane is almost perpendicular to the Galactic plane and is orthogonal to the line joining the Sun to the Galactic center.

Our galaxy has several other companions which could in principle be orbiting each in a different plane. However, Kunkel and Demers (1976) noticed that most of these dwarf spheroidal galaxies and distant globular clusters appear to lie very close to a great circle on the sky (see also Lynden-Bell 1976a,b,1982a; Fich and Tremaine 1991). This includes Leo I, Leo II, Draco, Ursa Minor, NGC 7006, Pal 3,4, and 12 (hereafter, the *Magellanic Group*). This plane is likely to be the common orbital plane of these satellites since, on one hand, the probability that such a planar distribution might arise by chance is less than 0.002 (Kunkel and Demers 1976), and on the other hand, there are a few coincidences which indicate some physical association between these satellites such as structural elongation along the circle (e.g., Lynden-Bell 1982a), and longitudinal distribution in this plane which matches the expected from dynamical considerations (e.g., Hunter and Tremaine 1977). This roughly planar distribution may be explained by a breakup of a larger satellite during a past tidal interaction with the Galaxy which led to the strewn distribution of smaller systems over its orbital plane (Toomre 1974; Lynden-Bell 1982b). The normal to this plane (hereafter the *Magellanic Group plane* or the *MG-plane*) points to the direction \((l, b) = (169^\circ, -23^\circ)\) (Kunkel and Demers 1976). It differs from the normal to the MS-plane by 40°, but the Magellanic Clouds lie only 7° from it (Figure 1).

### 2.2. The Expected Imprints

There are suggestions for γ-ray bursts originating in an extended Galactic halo of neutron stars (e.g., Fishman *et al.* 1978; Jennings and White 1980; Shklovski and Mitrofanov 1985; Atteia and Hurley 1986; Jennings 1984; Yamagami and Nishimura 1986). These neutron stars could be born in the Galactic disk and ejected at high velocities, either due to asymmetric explosions or due to the unbinding of a binary system during a supernova explosion, and in this way populate a large spherical region (Lyne, Anderson, and Salter 1982; Cordes 1986; Hartmann, Epstein, and Woosley 1990), but there are some difficulties with this idea (Mao and Paczyński 1992a; Paczyński 1991). In general, if the conceivable bursting objects have migrated away from the Galactic disk forming an extended halo we may expect also similar objects escaping from the Magellanic Clouds
and from the other satellite galaxies. These satellites may contribute to the hypothesized extended halo more than the expected from their masses (relative to the disk’s mass) since their escape velocities are lower. Fabian and Podsiadlowski (1993) have even suggested that most of the bursting objects originate in the Magellanic Clouds. The important point is that the spatial distribution of these objects will not be spherically symmetric, but should show some concentration towards the orbital plane of the satellite they have escaped from. We do not expect this enhancement to look like a narrow disk but it should have some oblate shape with the principle plane coinciding with the satellite’s orbital plane.

This general idea does not necessarily require having an efficient ejection mechanism for the objects. Tidal fields from the Galaxy during a satellite’s close passage (Lynden-Bell 1976a; Fujimoto and Sofue 1976; Murai and Fujimoto 1980), or interactions between the satellites themselves would lead to a strewn distribution of matter (and also of potentially bursting objects) over the orbital planes in a similar way to the recent formation of the Magellanic Stream. Again, the detached material need not necessarily form a very narrow ring since, for example, the spin axis of the LMC lies close to the orbital plane, so angular momentum of the LMC can carry detached material some distance out of the MS-plane.

It is also possible that γ-ray bursts are associated with an extended Galactic halo of primordial objects (e.g. Eichler and Silk 1992) which could be isotropically distributed. However, regardless of their origin, the spatial distribution of any conceivable objects must be gravitationally distorted due to their interaction with the satellite galaxies which are traveling through this halo. Each satellite induces a density perturbation in the halo which can be viewed as the combination of tidal forces (dynamical tides) and a wake of density enhancement trailing behind the moving satellite (which generates dynamical friction). The response of the halo distribution to the gravitational perturbation of an orbiting satellite has a complex pattern but it always involves some concentration of halo particles towards the satellite’s orbit (e.g., Weinberg 1989).

All the above arguments essentially predict some concentration of bursting objects towards the satellites’ orbits. This implies an enhancement in their angular distribution towards the MS-plane and the MG-plane, but also some overdensity in their radial distribution at the distances at which the satellites are orbiting. We shall now define the signature that should identify an extended Galactic halo model.

2.3. The Signature of an Extended Halo

Testing an extended Galactic halo model for the distribution of γ-ray bursts is not straightforward as, for example, the $\langle \sin^2 b \rangle$ statistics applied for testing a Galactic disk model, or the dipole test, $\langle \cos \theta \rangle$, for a (non-extended) Galactic halo model. In our case,
the expected magnitude and pattern of the deviations from spherical symmetry should be computed for specific models (either analytically or using simulations) and confronted with observations. Such model-dependent tests would probably involve some free parameters and require more data than currently available. However, all the various reasons for expecting deviations from spherical symmetry (§2.2) predict very similar patterns of distortion in the bursts’ distribution, and these common features define the first-order signature of an extended Galactic halo model.

The expected signature in the bursts’ distribution is thus the following: a) There should be some concentration of bursts towards the two planes (§2.1), but since the Magellanic Group satellites seem to orbit at larger distances than the Magellanic Clouds (e.g. Binney and Tremaine 1987) the imprints of the MG-plane should be dominant at higher distances, and that of the MS-plane at smaller distances. Therefore, if the observed $\gamma$-ray bursts originate within $\lesssim 80$ Kpc then we expect to detect some concentration in their angular distribution mainly towards the MS-plane, but if their spatial distribution extends further out then a concentration should show up towards the MS-plane only within small relative distances, but also towards the MG-plane over larger relative distances. b) Regarding the radial distribution, we expect some concentration of bursts within the range of distances inside which the dominant satellites are orbiting (§2.2). This does not mean an increase in the burst number density at the corresponding radii, but that the density profile should become less steep at those distances.

3. COMPARISON WITH OBSERVATIONS

We use the recently published BATSE catalog at the GRO Science Support Center which includes the locations and count rates of 241 bursts observed until March 1992 (Fig. 1). Assuming ”standard candles” (see discussion in §5) we construct a data set of the 3-D bursts’ locations sorted by relative distance, $D_i \propto (C_{\text{max}}/C_{\text{min}})^{-1/2}$, where $0 < D_i \leq 1$, $i = 1, \ldots, 241$.

Figure 2 shows the concentration towards both planes of $\gamma$-ray bursts which originated within an increasing relative distance. Apparently, there is a concentration of bursts towards the MS-plane, but only of close (strong) ones (Fig.2-a). However, the same plot with respect to the MG-plane (Fig.2-b) shows that the entire curve rises considerably above the expectation value, indicating a concentration of bursts towards the MG-plane essentially at all radii. This is precisely the signature of a very extended Galactic halo distribution (i.e. a nearby-extragalactic origin) of $\gamma$-ray bursts (§2.3), namely, a concentration only of relatively close bursts towards the MS-plane, along with a concentration towards the MG-plane over larger radial distances.
Although these plots are cumulative ones, their shapes still reflect variations in the degree of concentration towards the planes due to the rapidly increasing density of data points on the curves with distance. In order to demonstrate that the cumulative nature of these plots does not introduce a severe artifact, we grouped the bursts into five independent bins according to their radial distance and show that the results nicely agree with the expected signature in the angular distribution (Table 1).

Regarding the radial distribution, Figure 3 shows the $\langle V/V_{\text{max}} \rangle$ parameter as a function of sample depth (see also Atteia and Dezalay 1993) and thus gives an estimate for how fast the bursts spatial density falls with distance. For example, a value of 0.5 indicates a constant density, 0.4 corresponds to $\sim r^{-1}$ falloff, and 1/3 to $\sim r^{-3/2}$. Apparently, the bursts’ density profile varies from roughly constant at small distances to roughly $\sim r^{-3/2}$ at large distances, but the logarithmic slope does not seem to change monotonically. We notice that there are interesting coincidences between the distances at which $\langle V/V_{\text{max}} \rangle$ increases and the distances at which the concentration towards the two planes is relatively high: both curves (Fig. 2 and 3) rise between $0.4 \leq D \leq 0.45$, both of them (Fig. 2-a and 3) show concentration higher than the expected from a monotonic decline between $0.4 \leq D \leq 0.6$, and similarly at $0.15 \leq D \leq 0.22$ in which the density profile even increases with distance ($\langle V/V_{\text{max}} \rangle > 0.5$). These coincidences could arise by chance, but the fact is that they are expected on theoretical grounds in any extended Galactic halo scenario (§2.3).

We have qualitatively identified in the data the first order signature (§2.3) of an extended Galactic halo model, but a rigorous evaluation of the statistical significance of this signature requires confronting our results with quantitative predictions of specific models. Since detailed models are out of the scope of this paper, we shall just draw the attention to the following points: a) the curve in Figure 2-b is consistently above the expectation value (see also Table 1) which implies a concentration of bursts towards the MG-plane over a wide range of distances, as indeed expected. The statistical significance for such concentration depends on the sample depth and varies roughly between 1-2$\sigma$ (Fig. 2-b). b) The distribution of 160 bursts of pre-BATSE data obtained from the KONUS experiment (Mazets, et al. 1981) also show a concentration (1.4$\sigma$) towards the MG-plane (Table 1), but it is unclear whether the sky exposure for this data is uniform enough for taking this seriously. c) There is a concentration of bursts also towards the MS-plane, but only of relatively close ones, exactly as expected. d) There seem to be correlations between features in the radial and the angular distributions, as indeed expected if they are due to the presence and motion of the satellite galaxies.

These findings cannot be taken as a conclusive evidence at this stage, but a detection of the signature for a nearby-extragalactic distance scale in the bursts’ distribution is definitely suggestive.
4. THE SUGGESTED PICTURE

Assuming that the increasing data supports our findings, we may identify the distance to the Magellanic Clouds (∼ 60 Kpc) either with the peak (Fig.2) at $D \sim 0.45$ or with the one at $D \sim 0.22$ (the Magellanic Clouds are the major satellite, they lie very close to both planes, and we are not aware of any other closer substantial structures). Normalizing the distance scale accordingly we find that the current maximum sampling depth ($D=1$) is either $\sim 130 Kpc$ or $\sim 270 Kpc$, respectively, but this is only a crude estimate since the clouds’ orbit is eccentric (Lin and Lynden-Bell 1981). b) Assuming that most bursts originate in this extended halo we find that their rate is $\sim 10^{-5} yr^{-1}(Kpc)^{-3}$ in our near vicinity, so we do not expect an enhancement of bursts from the LMC itself, neither from any visible part of other galaxies (see discussion in §5).

Our findings support the picture that a fraction of the bursting objects have escaped (or have been detached) from our satellite galaxies, but it is also consistent with the idea of a primordial population of bursting objects. We find the latter possibility especially interesting for the following reason: if the observed roughly planar distribution of our satellite galaxies (the MG-plane) is due to some primordial conditions in the surrounding mass density field, then it is reasonable to expect also some concentration of the hypothesized primordial objects towards this plane. Furthermore, simulations of halo formations (Dubinski and Carlberg 1991) show strong tendency towards triaxial shapes, with the minor axis in the direction of the angular momentum vector (Dubinski 1992). This nicely coincides with the observed indication for a slightly nonspherical distribution with a minor axis normal to the MG-plane, i.e., parallel to the angular momentum vector of the satellites’ orbit. It is also interesting to notice that M31’s initial direction, i.e., the direction ($l=101^\circ, b=−27^\circ$) from which M31 had emerged during its formation epoch (Lynden-Bell and Roychaudhury 1989) is very close to the MG-plane. This strengthens our suggestion that this plane is of special physical importance throughout the entire Local Group, and thus should also show up in the bursting objects’ distribution if they are primordial or left over from the formation epoch of the Local Group of galaxies. Thus, $\gamma$-ray bursts may well be associated with intergalactic objects such as primordial black holes or old dense stellar systems (e.g., Eichler and Silk 1992).

5. DISCUSSION AND PREDICTIONS

The expected signature (§2.3) for an extended halo of sources implies that applying statistical tests only for the entire distribution of the observed bursts as a whole is inadequate. Furthermore, if some of the observed bursts originate at distances which are
beyond the scale over which the MG-plane is expected to make an imprint, this would smear out the expected anisotropic features. Therefore, we had to examine the degree of burst concentration towards both planes as a function of increasing sample depth.

The assumption of “standard candles” need not necessarily be adequate, but if the peaks in Figure 2-b will not get much broader with the increasing data then it would indicate that the luminosity function is probably quite peaked for the following reason: wide-range luminosity functions (e.g., shallow power-laws) would smear out any real structure in the radial distribution. Afterall, the variable $D \equiv \left( \frac{C_{\text{max}}}{C_{\text{min}}} \right)^{-1/2}$ is actually a convolution of the real distance to the sources with the luminosity function, and a convolution with a slowly changing function erases high frequency features.

We might be on the edge of observing the halo of bursting objects around M31, but this strongly depends on how peaked is the bursts’ luminosity function. We predict that a concentration of bursts will rapidly grow in that direction if the bursts’ detection limit is reduced by $\sim 1.5$ orders of magnitude (at the expanse of lowering the statistical significance of identifying a real burst). We also predict that the conventionally applied $\langle \sin^2 b \rangle$ test in Galactic coordinates will keep indicating a weak concentration of all bursts towards the Galactic disk with low significance level due to a simple reason: we see in Figure 1 that the MG-plane runs only between the Galactic latitudes $\sim \pm 70^\circ$. Thus, if bursts are concentrated towards the MG-plane they must be, on the average, also slightly closer to the Galactic disk than the expected from an isotropic distribution.

Finally, we should bear in mind that the data is also statistically consistent with a featureless isotropic distribution. However, the fact is that the (small) anisotropies in the angular distribution and the variations in the radial distribution agree very well with what is theoretically expected if $\gamma$-ray bursts (or at least a substantial fraction of them) originate in an extended Galactic halo. If the detected signature ($\S$2.3) will not disappear with the increasing data then it would strongly support our suggested distance scale. The possibility that the distribution of bursting objects is similar to that of the dark matter, and thus might be related to it in some way, is especially exciting.

I wish to thank William Press, George Field, and John Dubinski for discussions and comments, and Alar Toomre for an enlightening discussion. This work was supported by the U.S. National Science Foundation, grant PHY-91-06678.
Fig. 1 - An equal-area (Aitoff) projection of the 241 bursts' locations from the BATSE catalog on the entire celestial sphere in galactic coordinates. The orbit of the Magellanic Clouds (empty triangles) runs very close to the 90° and 270° longitude lines (the MS-plane). The clouds and the other members of the Magellanic Group (small empty circles) define the MG-plane (the dotted curve). The location of the Andromeda galaxy (M31) is also shown as a larger circle near the lower left corner.

Fig. 2 (a) Each point on the curve indicates the degree of concentration towards the MS-plane for bursts which originated within a relative distance $D_n$, where $\langle \cos^2 b' \rangle_n \equiv n^{-1} \sum_{i=1}^{n} \cos^2(b'_i)$, $n=3, \ldots, 241$, and $b'$ is the angular distance to the plane. The higher this value is above $2/3$, the stronger is the concentration. The error bars reflect one standard deviation from the expectation value for an isotropic distribution, and are given by $(45n/4)^{-1/2}$. (b) - A similar plot relative to the MG-plane. There is some concentration of bursts towards the MG-plane over large relative distances, and towards the MS-plane only at small distance, exactly as expected (§3). Surprisingly, taking the non-uniform sky coverage into account (a function of declination) results only in marginal changes in both plots: the curves exactly maintain their shapes but are lowered by $\sim 0.1\sigma$ on the average, and nowhere change by more than $0.24\sigma$.

Fig. 3 The $\langle V/V_{\text{max}} \rangle$ parameter as a function of sample depth. There is some correlation between the distances at which $\langle V/V_{\text{max}} \rangle$ increases and the distances at which the concentration towards both planes is higher than the average, as indeed expected in an extended halo model (see §3).
Table 1 - The BATSE data binned into five independent sets according to ranges of distance, and the sample of 160 bursts obtained from the KONUS (Mazets et al. 1981) experiment aboard the Soviet satellites Venera 11-14. All the sets show various degrees of concentration towards the MG-plane ($\langle \cos^2 b'_MG \rangle$ higher than $2/3$) but only the close ones show some concentration towards the MS-plane, exactly as expected (see §2.3).
REFERENCES

Atteia, J.L., and Hurley, K. 1986, Adv.Space.Res., 6(4), 39
Atteia, J.L., and Dezalay, J.P. 1993, Submitted to A&A.Lett.
Binney, J., and Tremaine, S. 1987, In Galactic Dynamics, Princeton University Press, Princeton, New Jersey.
Cordes, J.M. 1986, ApJ, 311, 183
Dermer, C.D. 1992, Phys.Rev.Lett, 68, 1799
Dubinski, J. 1992, ApJ, 401, 441
Dubinski, J., and Carlberg, R.G. 1991, ApJ, 378, 496
Eichler, D., and Silk, J. 1992, Science 257, 937
Fabian, A.C., and Podsiadlowski, P. 1993, to appear in MNRAS.
Fenimore, E.E., et al. 1988, ApJ.Lett, 335, L71
Fenimore, E.E., et al. 1992, Nature, 357, 242
Fich, M. and Tremaine, S. 1991, Ann.Rev.Astron.Astrophys, 29, 409
Fishman, G. et al. 1978, ApJ.Lett, 223, L13
Fishman, G. et al. 1991, presentation for BATSE at GRO workshop in Annapolis
Fujimoto, M., and Sofue, Y. 1976, A&A, 47, 263
Hartmann, D., Epstein, R.I., and Woosley, S.E. 1990, ApJ, 348, 625
Hunter, C., and Tremaine, S. 1977, AJ, 82, 262
Jennings, M.C., and White, R.S. 1980, ApJ, 238, 110
Jennings, M.C. 1984 in AIP Conf. Proc. 115, High Energy Transients in Astrophysics, ed. S. Woosley (New York:AIP), p. 412
Klebesadel, R.W., Strong, I.B., and Olson, R.A. 1973, ApJ, 182, L85
Kouveliotou, C. et al. 1992, in The Compton Obs. Sci. Workshop, p. 61, Shrader, C.R., Gehrels, N., and Dennis, B. Eds., NASA
Kunkel, W.E., and Demers, S. 1976, R. Greenwich Obs.Bull., 182, 241
Lin, D.N.V., and Lynden-Bell, D. 1981, MNRAS, 198, 707
Lynden-Bell, D. 1976a, MNRAS, 174, 695
Lynden-Bell, D. 1976b, R. Greenwich Obs.Bull., 182, 235
Lynden-Bell, D. 1982a, Observatory, 102, 202
Lynden-Bell, D. 1982b, Observatory, 102, 7
Lynden-Bell, D., and Roychaudhury S. 1989, MNRAS, 240, 195
Lyne, A.G., Anderson, B., and Salter, M.J. 1982, MNRAS, 213, 613
Mao, S. and Paczyński, B. 1992a, ApJ, 388, L45
Mao, S. and Paczyński, B. 1992b, ApJ, 389, L13
Maoz, E. 1993, to appear in ApJ.
Mazets, E.P., et al. 1981, Ap.Space Sci., 80,3
Mazets, E.P. 1988, Adv.Space.Res., 8(2), 669
Meegan C.A. et al. 1992, Nature, 355, 143
Mihalas, D., and Binney, J.J. 1981, Galactic Astronomy, 2nd ed., San Francisco: Freeman.
Murakami, T., et al. 1988, Nature, 335, 234
Murai, T., and Fujimoto, M. 1980, Publ.Astron.Soc.Japan, 32, 581
Norris, J.P. et al. 1992, Bull.A.A.S., 24, 1259
Paciesas, W.S. et al. 1992, in Proc. Huntsville GRO Meeting, p.190, Paciesas, w.S., and Fishman, G.J. Eds.
Paczyński, B.1991, Acta Astronomica, 41, 257
Paczyński, B. 1992, Nature, 355,521
Piran, T. 1992, ApJ,389, L45
Schklovski, I.S., and mitrofanov, I.G. 1985, MNRAS, 212, 545
Toomre, A., 1974, I.A.U Symposium No. 58. Formation and Dynamics of Galaxies, Ed. J.R. Shakshaft, Reidel: Dordrecht, P.347
Weinberg, M.D. 1989, MNRAS, 239, 549
Yamagami, T., and Nishimura, J. 1986, Ap.Space.Sci., 121, 241

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