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Diffuse γ-ray background from Seyfert galaxies

AT least 20% of all Type I Seyfert galaxies are detectable[1,2] (at the comparable Ariel 5 and Uhuru sensitivities) as X-ray sources in the ~2–10 keV band. Both the Ariel 5 and Uhuru results indicate the X-ray luminosity function is quite steep ($\mathrm{d}N/\mathrm{d}L \sim L^{-2}$) so that more sensitive HEAO X-ray detectors may reveal that nearly all Type I Seyfert galaxies are X-ray sources. It is suggested here that the diffuse background spectrum observed at hard X-ray and γ-ray energies can be accounted for by Seyferts, given their individual (hard) spectra.

As 4U1410−03 has been precisely located[3] as coincident with NGC5506, which may be a Type 2 Seyfert but morphologically resembles Cen A, the integrated X-ray emission from all emission line galaxies and active galaxies may exceed the ~15% contribution previously estimated[1,2] for the diffuse X-ray background at ~2–10 keV. If these sources typically have photon spectra flatter than $\mathrm{d}N/\mathrm{d}E \sim E^{-2.4}$, which is[4] the approximate diffuse background above ~20 keV, their contribution to the diffuse background spectrum at energies $E > \bar{E}_c$ will become ~100%. The critical energy

$$\bar{E}_c \simeq [31.9 \int_2^{10} E^{-\alpha+1}\,\mathrm{d}E]^{1/(2.4-\alpha)} \text{ keV}$$

is the energy at which the average Seyfert spectrum, $\mathrm{d}N/\mathrm{d}E = AE^{-\alpha}$, crosses the diffuse background spectrum. Thus to account for all of the high energy diffuse background flux, individual Seyferts and active galaxies must typically have high energy cutoffs with $E_c \gtrsim \bar{E}_c \simeq 300$ keV–10 MeV for $\alpha \sim 1.5$–2.

Some recent observations suggest this may usually be true. The hard X-ray flux from the archetypical Type 1 X-ray Seyfert, NGC4151, has now been detected (with $\alpha \sim 1.5$) through at least ~200 keV and possibly several MeV (refs 5, 6). As NGC 4151 is relatively close and among the brightest X-ray Seyferts, its detection is reminiscent of the detection[7] of the nearby active galaxy Cen A with $\alpha \simeq 1.9$ at several MeV. Increased sensitivity would confirm whether these spectra are typical for more distant members of each class of object. In fact, the Type I Seyfert 3C120 (with $z = 0.032$) has also been positively identified[8] as an X-ray source and is fit by a spectral index $\alpha \simeq 1.2$–2.0. At least one much more distant ($z \simeq 0.047$) Seyfert has now also been identified[9] with 4U0241+61, which has[10] a very hard spectrum ($\alpha \simeq 1.0$) through ~1 MeV and then steepens (with $\alpha \simeq 3$) at energies through ~100 MeV, if its identification with the COS-B γ-ray source[10] CG135+1 is correct.

Thus in all cases where spectra have been measured for individual Seyferts and active galaxies, their spectra are both hard ($\alpha \sim 1$–2) and extend to cutoff energies ($E_c \gtrsim 100$ keV—1 MeV) large enough for their summed spectra to account for the diffuse background at energies $\gtrsim \bar{E}_c \sim 100$ keV. Where γ-ray spectra at $E \sim 1$–100 MeV are measured[10,11] or at least limited[12] (as for Cen A; C. Fichtel, personal communication) there is direct evidence for a high energy cutoff ($E_c \sim 1$–10 MeV) or steepening with $\alpha \sim 3$. This spectral shape can be explained by Compton–synchroton models[12] where the typically flat spectrum of a selfabsorbed synchrotron source in the galaxy nucleus is scattered into a self-similar spectrum in the X ray–γ ray range. The cut off is then due to the primary spectrum cut off in the infrared range where synchrotron lifetime effects are usually important, and variations (time scales $\gtrsim$ h–d) in the hard X-ray flux correlated with changes in the radio–infrared spectrum are expected[12].

The diffuse background spectrum might then be expected to show a flattening at $E \sim \bar{E}_c$, where the Seyfert contribution is ~100%, and a steepening at higher energies. The most recent summary[13] of low energy ($\lesssim 1$ MeV) γ-ray data and high energy ($\gtrsim 35$–100 MeV) diffuse flux in fact show this shape, with a marginal flattening ($\alpha < 2.4$) at ~1–10 MeV and $\alpha \simeq 2.85^{+0.5}_{-0.3}$ at $E \gtrsim 35$ MeV. As the contribution (~15%) of Seyferts in the 2–10 keV range satisfies the limits for granularity of the background[2], so also must their dominant contribution at high energies. Finally, if all galaxies have recurrent active phases or evolve through a Seyfert-like stage, then perhaps their typically hard spectra with a range of apparent cutoffs $E_c > E_{c,\mathrm{min}} \simeq 20$ keV could account for the entire diffuse flux with $\alpha \simeq 1.4$ ($E \leqslant E_{c,\mathrm{min}}$) and $\alpha \simeq 2.4$ ($E > E_{c,\mathrm{min}}$). However, whereas this is questionable due to uncertain evolutionary effects, the contribution now observed for (primarily) Type 1 Seyferts at least strongly suggests that Seyferts can account for all of the diffuse background at hard X-ray through γ-ray energies.

Note added in proof: Strong observational support for the Seyfert origin of the diffuse background is given by the recent announcement by Schonfelder at the Symposium on γ-ray Spectroscopy in Astrophysics (Goddard Space Flight Center, 28 April 1978) that γ rays have been detected from NGC4151. The spectrum seems to extend the power law from the hard X-ray range to a break at about 3 MeV, and is thus consistent with our prediction for the individual sources comprising the diffuse spectrum.

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Coherently overturned flaps surrounding craters

MANY large impact and explosion craters exhibit coherently overturned flaps in the form of ejecta blankets[1–7] in which the pre-existing stratigraphy of the cratered ground is preserved in detail, but inverted. Sequential ejection of material into ballistic trajectories could produce a coarsely graded inversion of the material, but would not retain detailed stratigraphic coherence. The field evidence from fully excavated craters[3–7] shows that even totally incompetent strata composed of free flowing sand may be traced continuously through a hinge region below the crater rim outwards to at least three times the crater rim radius. The strata retain their integrity and relative position despite being reduced by stretching from an original thickness of some tens of centimetres to less than a centimetre at the extreme limit of coherent overturning. Figures 1 and 2, a photograph and a stratigraphic plot[3] of the hinge region of the Prairie Flat crater at the Defence Research Establishment, Suffield, illustrate the phenomenon. Similar examples are given in the reports of the excavation[3–4]. The effect was

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present in all the Suffield trials, and was inconsistent with a free flight mechanism in which discrete elements of sand and clay would follow independent trajectories. However, in very small scale experiments in sand[8], which would be most likely to exhibit a free flight phenomenon, the coherence in the overturned flap increased markedly when the sand was saturated with water, as compared to the case with dry sand. In this note I suggest that such coherent overturning may be produced by a wave of hydrodynamic type, which becomes a 'plunging breaker' of the type described by Longuet–Higgins and Cokelet[9]. Evidence to support this suggestion is given below, and consequences of the mode of formation are predicted and compared with the field data.

Seismic surface-wave motion, which exhibits prograde displacement orbits of hydrodynamic type, first detected in the vicinity of nuclear explosions, was described and called H-waves by Leet[10]. The suggestion that these waves were unique to explosive events is not now accepted, but it is certain that they are quite commonly produced by explosive sources. I[11,12] confirmed the presence of tilted prograde elliptic orbits in the surface waves near Suffield explosions which produced craters, but also detected orthogonally tilted retrograde elliptic orbits and classified the motion in terms of discrete branches of the Rayleigh-wave solution. In the case of surface explosions, it was demonstrated[12] that a modified type of Press–Ewing[13] coupling occurred between the ground and atmosphere, resulting in large amplitude surface waves of constant frequency. A more detailed computation of the dispersion curves for the test site was used by Hasegawa[14] to demonstrate the theoretical possibility of prograde motion consistent with the experimental data.

It has also been shown[7] by combining data on permanent displacement of marked elements of the ground[15] with velocity gauge data[16] and the stratigraphy[3] of the Prairie Flat test site that a prograde elliptic motion was large enough to produce permanent displacement in the ground below the ejecta blanket. It is not certain that this interpreted displacement of material through three-quarters of a tilted prograde elliptic orbit[7] needs to be correlated with the elastic surface seismic waves detected beyond the plastic displacement zone, but it is probable.

Fig. 1 Rim section of prairie flat crater.

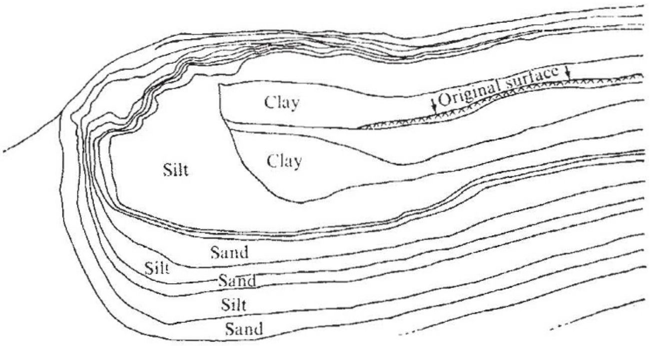

Fig. 2 Stratigraphy of prairie flat crater rim.

According to Longuet–Higgins and Cokelet[9] the essential criterion for a breaking wave is that a wave of large amplitude suffers a rapid retardation of its forward motion, so that the front profile tends to steepen and overturn. These authors discuss the difference between a spilling breaker and a plunging breaker, and show that in the latter case a smooth jet of material is ejected from the top front face of the wave, and the flow in this jet may remain laminar even to the point where the jet impacts upon the 'undisturbed' surface ahead of the breaking wave. The calculations are detailed in ref. 9 together with computer generated cross-sections demonstrating the internal flow for the early part of the process. A more generalised account by Cokelet[17] describes the main features of breaking waves in water.

The experimental craters at Suffield were all formed in lacustrine deposits with large void ratios, saturated at depth but with much connate water even above the water table. Such a material is essentially thixotropic and behaves under stress more like a fluid than a solid. The geological significance of connate water has been described in ref. 18 and some of the consequences for crater mechanics in ref. 4. In naturally occurring impact craters where coherent overturning has been detected, the rigidity of the rock may resemble, on a scale basis, the much weaker material at the experimental site.

The potential for a wave of hydrodynamic type is thus demonstrated by the experimental data. It can also be shown that if such a wave is generated by the explosion, it will be retarded very rapidly. At the onset, the material will be displaced at a velocity close to that of the detonation wave in the explosive (say 7 km s^{-1}). The shock wave induced in the ground by this motion attenuates rapidly and converts to a variety of seismic waves, the main surface manifestation being the surface seismic wave whose characteristics have already been described. At the Suffield test site the velocity of propagation of these elastic surface waves is in the region of 1 km s^{-1}, though due to the stratigraphy of the site, the medium is highly dispersive. An initially short pulse develops into long trains of surface waves which couple progressively[12] to the airblast. Thus a ground motion, originally of large amplitude and high velocity, decays into a small amplitude train of low velocity seismic waves in a distance comparable with the extreme limit of ejecta deposition. It is not yet possible to describe this decay in detail, but refs 7, 11, 12 give limited aspects of the process. For an impacting meteorite, the initial velocity will be related to that of the meteorite and may be far higher than that of the explosive detonation front.

The foregoing indicates that a wave of hydrodynamic type may be formed, and may break in either the spilling or plunging mode. It remains to consider the probable consequences of such a mechanism and compare these with the experimental data.

First, consider the nature of the laminar jet ejected from the front face of a plunging breaker. As shown by the computed cross sections, such a jet will be in the form of a nappe (or recumbent anticlinal fold), so that when the jet impacts upon the surface it will superimpose the mobile strata in a folded form upon the undisturbed strata.

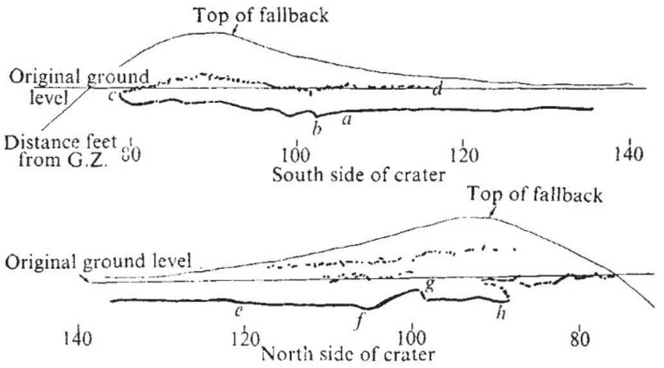

Fig. 3 Displacement of horizontal marker chain in 1961 Suffield 100-ton trial.

The field data cited so far only indicates two sets of strata, one the undisturbed bedding and the other the 'inverted' bedding perfectly preserved in the ejecta blanket. However, the upper elements of the ejecta blanket are subjected to late stage erosion and may become too turbulent for easy recognition of the original layering, especially when such an effect is not suspected. (Even the coherent overturning which is now easily detected in the field was not recognised in the majority of craters studied before the excavation of the Suffield craters.) Also, where any part of the upper layers of the ejecta blanket retain clear stratification with beds in the 'normal' attitude, the effect would probably be described as 'thrust faulting'. Thrust faulting is frequently reported from the relevant regions of large craters[1-4], but usually from the rim and hinge regions where the stratification is most commonly exposed. One of the Suffield experiments, however, in which a 100-ton TNT charge was detonated on the surface (in 1961) incorporated a set of markers in a horizontal chain just below the original precratering surface. Excavation of the crater revealed the markers disposed in the pattern shown in Fig. 3 (using the data of D. J. James). These data have been interpreted[3,4] as demonstrating coherent overturning and thrust faulting within the ejecta blanket. However, these data may also be interpreted as supporting the present hypothesis of emplacement of the ejecta blanket. The evidence of small recumbent folds is clear, and the triple layering evident in the north section may represent the preservation of a large recumbent fold rather than a thrust sheet.

Second, striations, caused by sliding contact of blocks in the ejecta blanket of the Ries crater, may be explained[19] by a form of roll-glide transport, suggesting a turbulent flow region of the ejecta blanket. Overturning and sliding of discrete surface blocks was also documented from the Suffield trials[3]. Such a mechanism is inherent in the second form of breaking wave—a spilling breaker[8,16]. In this form, the wave breaks by spilling forward from its crest a highly turbulent layer of material (visible as a froth in water waves) quite different from the laminar projection of a jet in the plunging type of breaker. Both types of breaking may occur in the cratering process, even at the same crater.

Attention is also drawn to the so-called 'wet craters' on Mars[20]. In these craters there is clear evidence that the ejecta blanket has flowed around pre-existing obstacles. This is consistent with the behaviour to be expected of a jet from a breaking wave but may also, of course, be explained by any other form of fluidised transportation of the material in the blanket. It seems inconsistent with ballistic emplacement unless all the material, including the last to impact, travelled in a relatively high velocity, low angle sheaf of trajectories.

Finally, if the breaking wave hypothesis is valid, one can anticipate that the ground will be depressed by the incipient trough ahead of the breaking wave. In the region of plastic deformation (or thixotropic behaviour) this downwarping may be preserved. The phenomenon is certainly present at all the craters excavated at Suffield, with the downwarping coinciding roughly with the region covered by the coherently overturned blanket. Various attempts have been made to correlate this downwarping with the inward movement of underlying material[6], which is demonstrable in some cases[4] but there is insufficient resolution of the field data at present to indicate whether the downwarping was a consequence of, or the cause of, the flow. Certainly, downwarping implies either the removal or the compaction of underlying material.

Thus, the suggestion made here that the mechanism of deposition of coherently overturned ejecta blankets may be related to the formation of a hydrodynamic type of wave motion, which breaks in the plunging pattern, is consistent with the field data and is worthy of further investigation.

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The extensional flow capillary as a new method for extensional viscosity measurement

THE behaviour of non-newtonian fluids in extensional flow is of both theoretical and practical importance. However, because of the difficulty of imposing a purely extensional deformation on a fluid material, very few experimental measurements of extensional viscosity have been obtained in well defined kinematic conditions. All of the experimental techniques currently available which utilise constant extension rate kinematics involve the application of a tensile stress to a cylindrical sample, and thus require the assumption of uniform deformation of

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