POSSIBLE CONTRIBUTION OF A SOLAR TRANSIENT TO ENHANCED SCINTILLATION OF A QUASAR

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Abstract. Observations of the quasar 2314 + 038 were carried out during 16–21 December, 1985 at a solar elongation (ϵ) around 85°, when the plasma tail of comet Halley swept in front of it. These observations have shown a two-fold increase in scintillation index (m) as compared to the expected levels of scintillation for the source, computed using the well-known RKH model. Spacecraft data and the geomagnetic indices available during the period show that a shock-front had reached the earth on the 18 December, the day when maximum increase in scintillation was recorded. The possible contribution of such a shock-front to the enhancement has been shown to be not greater than 15 percent. Hence, the major contribution to the enhancement came from the plasma tail of a comet.

1. Introduction

Several recent observations of enhanced interplanetary scintillation (IPS) at large solar elongations (ϵ) have been attributed to cometary plasma, contained in the ion-tail of a comet, sweeping across the line of sight to the source during the period of observation. The most recent observation is that of comet Austin (Janardhan *et al.*, 1991). However, it is known (Houminer and Hewish, 1972; Houminer, 1973, 1976) that large day-to-day variations in scintillation index at solar elongations greater than 60° are strongly correlated with plasma density fluctuations contained in corotating streams. Since the first reported enhancements in scintillation due to comet Halley (Alurkar *et al.*, 1986) it has been felt (Ananthakrishnan *et al.*, 1987; Kojima, M., 1986 – private communication) that a possible cause of the observed scintillation might have been either a corotating interaction region (CIR) or a shock-front which swept across the line of sight. Recent spacecraft and solar geophysical data have provided an opportunity to estimate the possible contribution of such interplanetary disturbances to the observed enhancements.

2. Observations and Analysis

The observations (Alurkar *et al.*, 1986) were carried out with a 10,000 m^2 dipole antenna array at Thaltej, near Ahmedabad operating at 103 MHz. This antenna is a filled-aperture phased array, made up of 2048 fullwave dipoles. The array is divided into two halves in the North and South directions. Each half comprises 32 transmission lines each loaded with 32 dipoles, polarized horizontally in the N–S direction to form a correlation type interferometer observing sources at meridian transit. Thirty two beams are formed by each half of the array using a

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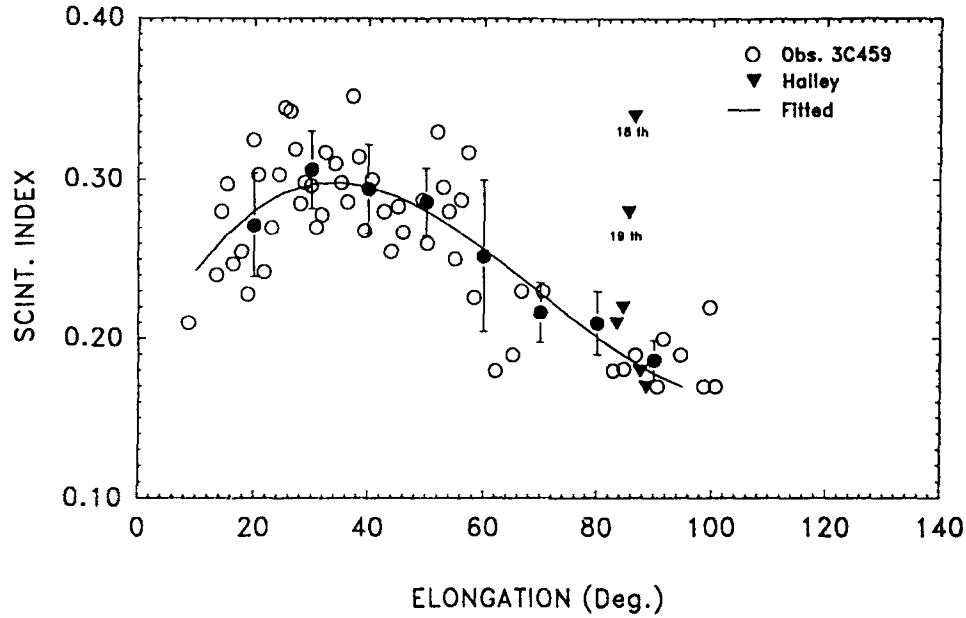

Fig. 1. Variation of scintillation index (m) as a function of solar elongation (ϵ) for the occulted source 3C459 shown by open circles. The filled triangles represent the scintillation index measured between 16 and 21 December. The solid line is a third order polynomial fit to the data.

beam-forming network called the Butler Matrix, which is essentially an analogue equivalent of a Fast Fourier Transform. These beams are deployed in declination and are each 1.8° N–S × 3.6° E–W and cover ±30° of declination centered on the zenith. A pair of identical beams is connected, during each observation, to a correlation type receiver which yields Sine and Cosine quadrature outputs. The rapidly changing intensity fluctuations are picked up by a device called the scintillometer whose output is proportional to the square of the scintillating flux of the source. A full description of the system can be found in the paper (Alurkar *et al.*, 1989).

The occulted source was regularly observed between mid-1984 and end of 1987 and Figure 1 shows a plot of the variation of scintillation index (r.m.s. flux/mean source flux) with solar elongation (ϵ) for all the data obtained in this period. The open circles represent the scintillation indices which have been averaged into one degree bins and then fitted by a third order polynomial – here marked by a continuous curve. This matches well with the values expected from the RKH model (Readhead *et al.*, 1978). The filled triangles represent the scintillation indices obtained during 16–21 December, 1985, when the ion-tail of comet Halley occulted the source. These values have not been considered when making the fit. A standard error bar is shown for each 10 deg bin, with the filled circles showing the mean value in each bin. It can be seen that there is an enhancement by a factor of about two in the scintillation index (m) of 18th as compared to the expected level of about 0.19 from the third order fit and about 0.18 as calculated

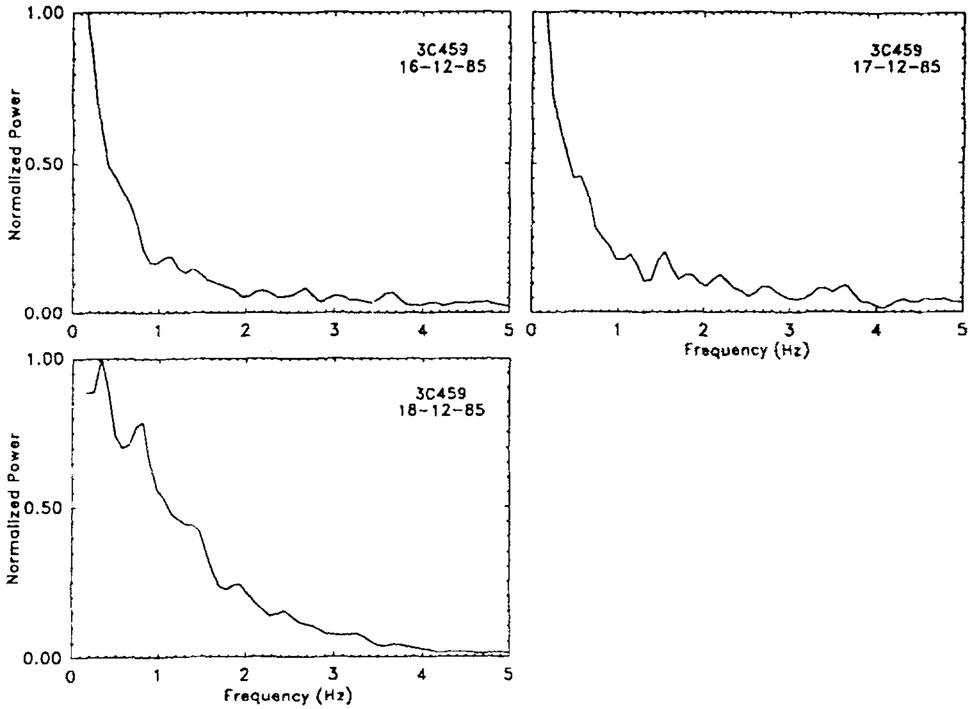

Fig. 2a-c. Shows the power spectra obtained on each day between 16 and 21 December. The spectra have been normalized to the highest spectral density and have a frequency resolution before Hanning of 0.0813 Hz. Note the clear shift in the peak of the spectrum to higher frequencies on the 18 and 19 December.

from the RKH model. All the scintillation indices (m) were obtained from the measured deflections, on a strip chart, of the sine, cosine and scintillometer outputs after correcting the deflections of the sine and cosine channels for the effects of the AGC.

Figure 2a–f shows the power spectra obtained for each day between 16 and 21 December. The power spectra were computed by subtracting a Hanned spectrum of 10 minutes of data off-source, from a Hanned spectrum of 10 minutes of data on-source. The on-source data was taken 5 min on either side of the transit time on each day from the observed on-source data of about 15 minutes, around meridian transit. The data was sampled at 20 Hz and digitized using a 12-bit, ± 5 V A/D converter (Alurkar *et al.*, 1989) and stored on a magnetic tape for analysis. The spectra are all typical IPS spectra and it is important to note the clear shift in the peak from 0.16 Hz on the 16th to 0.33 Hz on the 18th, when the source was closest to the tail axis and when maximum increase in scintillation was observed, and 0.24 Hz on the 19th. If the shift in the peak to higher frequencies were not present then it would have meant that other processes like ionospheric scintillation or gain changes were responsible for obscuring the true peak due to the plasma in the tail. Assuming that the thin screen theory (Salpeter, 1967) is

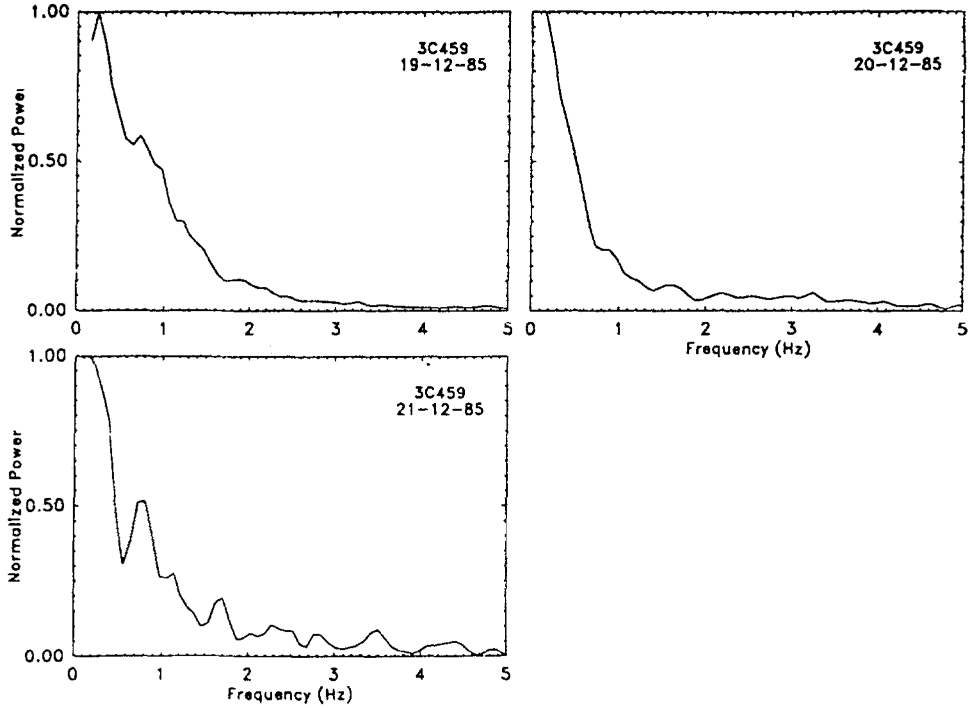

Fig. 2d–f.

TABLE I

Spectral widths & RMS phase deviations

Occulted source	: 23 14 + 038 (3C459)	
Solar elongation (ϵ)	: 86.5°	
Gaussian diameter (θ)	: 0.41″ arc	
Mean source flux	: 45 Jy	
Date (1985)	Spectral width – f_2 (Hz)	RMS phase – Φ (Rad)
16-12-85	0.23	0.12
17-12-85	0.31	0.13
18-12-85	0.87	0.24
19-12-85	0.56	0.20
20-12-85	0.34	0.16
21-12-85	0.49	0.15

valid for these observations one can calculate the rms phase deviation (ϕ) imposed on the emerging wavefront from a knowledge of the scintillation index (m) through the equation

$$m = \sqrt{2}\phi .$$

Table I gives the spectral widths measured on each day and the r.m.s. phase deviation imposed on the wave emerging from the screen.

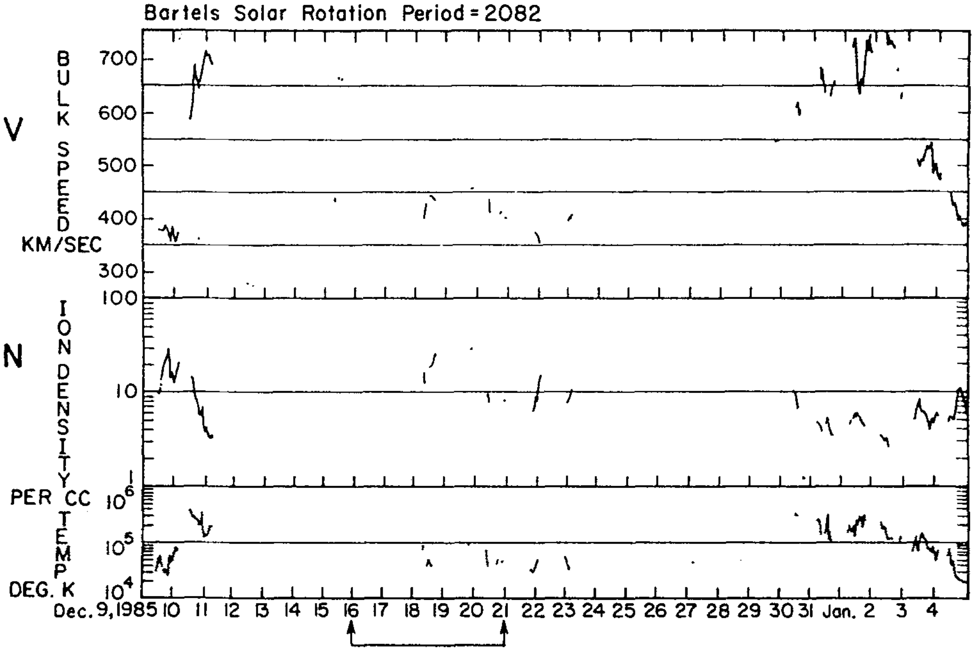

Fig. 3. Available spacecraft measurements of ion density N, bulk velocity V, and magnetic field strength during December 1985.

In the earlier work (Alurkar *et al.*, 1986; Janardhan *et al.*, 1992), a quantitative estimate of the electron content in the plasma tail of the comet was calculated by using the equations of the thin screen theory (Salpeter, 1967): i.e.,

$$a = \frac{V}{2\pi f_2},$$

where a is the scale size of the plasma irregularities in the plasma tail, V is the velocity of the diffraction pattern across the observer and f_2 is the width of the power spectrum at the exp(−0.5) points. For a circularly symmetric Gaussian electron density correlation function the r.m.s. phase deviation imposed across the wave emerging from the screen is given by Little (1976) as

$$\phi = (2\pi)^{1/4} \lambda r_e (aL)^{1/2} \Delta N,$$

where r_e is the classical electron radius and is equal to 2.82×10^{-13} cm, λ is the operating wavelength of 291 cm, ΔN is the rms electron density and L is the thickness of the screen. The thickness was assumed to be equal to the width measured on a photograph of the comet taken close to the date of observation. The value of the scale size (a) was obtained from the measured widths of the spectrum and an assumption of the velocity.

Figure 3 shows the spacecraft data available from the Interplanetary Medium Data Book – Supplement 4, 1985–1988, NASA Goddard. The data showed that

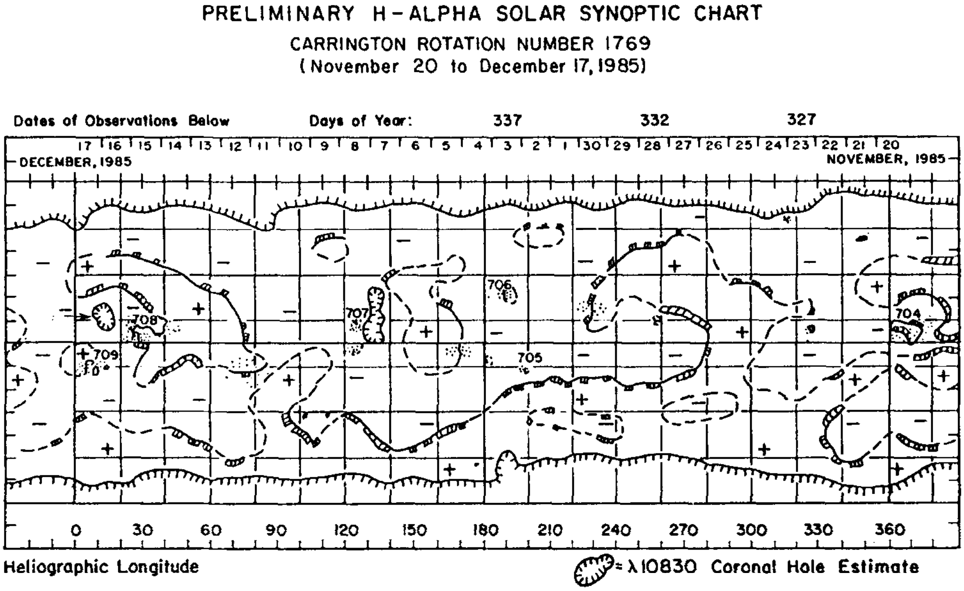

Fig. 4. H-Alpha – 10830 λ, Solar Synoptic chart showing the position of coronal holes.

a shock reached the earth around midday on 18 December. The bulk velocity V increased to 450 km sec^{-1}, the ion density increased to at least 20 cm^{-3} which is roughly twice the quiet value, and the interplanetary magnetic field rose to more than 12γ which is more than twice the average value. The magnetic K_p index showed a sudden commencement around 0600 on 18 December followed by a moderately strong magnetic storm (see Solar Geophysical Data Handbook – February 1986). The solar source of this disturbance was probably the coronal hole at central meridian on 16 December, adjacent to the active region 708 as seen from the H-Alpha Solar Synoptic Chart shown in Figure 4. The disturbance probably left the sun about four days earlier so that it would have been most pronounced to the East of the Sun–Earth line, thus affecting 3C459 more than sources to the West of the sun. Figure 3 also shows a high speed stream and its associated enhancement of N, which corotated past the earth between 9 and 14 December, 1985. This stream was due to the coronal hole at central meridian on 7th December and is clearly a CIR as N peaked one day before V increased.

3. Discussion

From this data it is apparent that the enhancement in scintillation observed on the 18 December was not due to a CIR. Recent work (Lindblad, 1990) has shown that the measured lifetime of a plasma stream at the earth orbit is about three days if the parent coronal hole has a latitudinal extension of around 45°. The parent coronal hole during the present observations was no more than 20° in latitudinal extent and could not have caused the observed effects over a period of

TABLE II

Estimated enhancements for different ΔN.

Observed scint. index	: 0.34 (18/12/85)	
Expected scint. index	: 0.19	
Thickness of shock	: 10^5 km (Pioneer 9)	
ΔN (cm^{-3})	Scint.index (calculated)	Enhancement in scintillation
0.4	0.21 ± 0.015	$\approx 11\%$
0.8	0.23 ± 0.015	$\approx 22\%$

6 days. Also since the IPS observations are limited to once every 24 h, it is most likely that streams less than two days in extent will be missed altogether. Moreover it is known from many observations (Niedner *et al.*, 1978; Jockers, 1981; Brandt *et al.*, 1980) that the interaction of a cometary plasma tail with a CIR will cause rapid changes of the ion-tail pointing direction. Observations of Halley's comet did not indicate any such deflections.

The same equations can now be used to calculate the rms phase deviation (ϕ) assuming that the enhancements were entirely caused by the shock-front which gave rise to the sudden commencement geomagnetic storm on the 18 December. Using the value of the width of the observed spectrum and the spacecraft velocity of 450 km sec^{-1} the scale size of the irregularities in the shock-front turns out to be about 82 km. A detailed study of interplanetary disturbances in the solar wind caused by the strong flare activity of August 2, 4 and 7, 1972 has been made using the data obtained by Pioneer 9, and upper limits on the thickness of these shock-fronts have been estimated (Dryer *et al.*, 1976) to be $\approx 10^5$ km. The rms electron density deviation ΔN in the solar wind is known to be about 0.1 cm^{-3} at 1 AU and 0.4 cm^{-3} at 0.1 AU representing respectively a 1% and 4% modulation (Hewish, 1971) of the mean ion density N. The spacecraft data showed an increase in N to 20 cm^{-3} and since the scintillation index m is $\propto \Delta N$ and m is correlated with N (Houminer and Hewish, 1974) the value of ΔN on the 18 December can be taken to be 2 percent of the observed value. Thus $\Delta N = 0.4\ cm^{-3}$ will be a reasonable estimate. Using these values the rms phase deviation imposed on the wavefront by the interplanetary shock will be $\phi \approx 0.015$ rad giving a scintillation index (m) equal to 0.021. The background scintillation index at a solar elongation of around 90°, as seen from Figure 1, is 0.19. Thus the expected scintillation index on the 18 December would be 0.21. This represents roughly a 10% enhancement in scintillation index. Table II shows the enhancements expected for various values of ΔN.

4. Conclusions

The above analysis shows that in the case of the comet Halley observations of December 1985 – the presence, on the day of maximum observed scintillation, of a shock-front that gave rise to the moderately strong sudden-commencement type geomagnetic storm, had around 10% contribution to the observed enhancements in scintillation. This is within the scatter at 90° as seen from Figure 1. The observed effects between the 16 and 21 December (Alurkar *et al.*, 1986; Janardhan *et al.*, 1992) were thus caused mainly due to the plasma tail of the comet sweeping across the line of sight in front of the source during the observations. Even if the value of ΔN was taken to be $0.8\,\mathrm{cm}^{-3}$, (representing a 4% modulation of the mean ion density which is the case in the quiet solar wind at 0.1 AU) the expected scintillation would turn out to be 0.23 corresponding to an enhancement of around 22% over the expected value. Thus it would be reasonable to say that in the worst case the contribution to the enhancements could not be more than 15% on the 18 December, 1985.

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References

Alurkar, S. K., Bhonsle, R. V., and Sharma, A. K.: 1986, *Nature* **322**, 439.

Alurkar, S. K., Bobra, A. D., Nirman, N. S., Venat, P., and Janardhan, P.: 1989, *Indian Journal of Pure and Applied Phys.* **27**, 322.

Ananthakrishnan, S., Manoharan, P. K., and Venugopal, V. R.: 1987, *Nature* **329**, 698.

Brandt, J. C., Hawley, J. D., and Niedner, M. B., Jr.: 1980, *Astrophys. J.* **241**, L51.

Dryer, M., Smith, Z. K., Steinolfson, R. S., Mihalov, J. D., and Wolfe, J. H.: 1976. *J. Geophys. Res.* **81**(25), 4651.

Hewish, A.: 1971, in C. P. Sonett, P. J. Coleman, Jr., and J. M. Wilcox (eds.), *Solar Wind*, p. 477.

Houminer, Z. and Hewish, A.: 1972, *Planet. Space Sci.* **20**, 1703.

Houminer, Z.: 1973, *Planet. Space Sci.* **21**, 1617.

Houminer, Z. and Hewish, A.: 1974, *Planet. Space Sci.* **22**, 1042.

Houminer, Z.: 1976, *Planet. Space Sci.* **24**, 951.

Janardhan, P., Alurkar, S. K., Bobra, A. D., and Slee, O. B.: 1991, *Austr. J. of Phys.* **44**, 565.

Janardhan, P., Alurkar, S. K., Bobra, A. D., Slee, O. B., and Waldron, D.: 1992, *Austr. J. of Phys.* **45**, (in press).

Jockers, K.: 1981, *Icarus* **47**, 397.

Little, L. T.: 1976, *Meth. Exp. Phys.* **12c**, 118.

Lindblad, B. A.: 1990, *Astrophys. Space Sci.* **170**, 55.

Niedner, M. B., Jr., Roth, E. D. and Brandt, J. C.: 1978, *Astrophys. J.* **221**, 1014.

Readhead, A. C. S., Kemp, M. C., and Hewish, A.: 1978, *Mon. Not. Roy. Astron. Soc.* **185**, 207.

Salpeter, E. E.: 1967, *Astrophys. J.* **147**, 433.