LIGHT CURVE FITTINGS OF ACTIVE GALACTIC NUCLEI USING SUPERNOVA EXPLOSIONS*

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Abstract. In the starburst-warmers scenario, we have used a supernova (SN) explosion model to construct theoretical light curves for active galactic nuclei (AGN). The ionizing flux, in this model, should show variability according to the SN rate in the galaxy.

1. Introduction

Galactic nuclei are usually divided into two main groups: 'normal' and 'active', according to nuclei whose properties can and cannot be explained in the framework of normal star formation and evolution. Traditionally the ionizing source of gaseous emission in AGNs is assumed to be non-thermal. In Seyfert 1 galaxies and QSOs, it is attributed to a hot accretion disk surrounding a massive black hole (Rees, 1984, and references given therein). This mechanism has been extrapolated to galaxies with a lower activity level as Seyfert 2s and LINERS (Heckman, 1987). However, Terlevich and Melnick (1985) have shown that, at least for these latter objects, the observed emission line spectra can be the result of the evolution of a starburst in a high metallicity and high density interstellar medium.

The variability in AGNs in the Violent Star Formation model is just a direct consequence of stellar evolution: supernova explosions and the evolution of the remnants (Terlevich, 1989). This phase begins 8 Myr after the birth of the starburst, when the first SN II explodes inside a small wind bubble (0.01 pc).

2. Theoretical AGN Light Curve Generation

According to Shull (1980) and Wheeler *et al.* (1980), a SN light curve of total energy $E \simeq 10^{51}$ erg and circumstellar density $n \simeq 3 \times 10^7\ \mathrm{cm}^{-3}$, typical of the conditions expected in AGNs, is characterized by

$$L = 0 \qquad \text{for } t < 0\,,$$

$$L = 3 \times 10^9\, L_\odot \qquad \text{for } t = 0\,,$$

* Paper presented at the 11th European Regional Astronomical Meetings of the IAU on 'New Windows to the Universe', held 3–8 July, 1989, Tenerife, Canary Islands, Spain.

Astrophysics and Space Science **171**: 61–64, 1990.

$$L = 0 \qquad \text{for } t = 60 \text{ days},$$

$$L = 3 \times 10^9 L_\odot \qquad \text{for } t = 250 \text{ days},$$

$$L = 3 \times 10^9 L_\odot \left(\frac{t}{250 \text{ days}}\right)^{-11/7} \qquad \text{for } t > 250 \text{ days}.$$

(*Note*: Linear interpolation is used between 0 and 60 days and 60 and 250 days.)

The first peak in the curve corresponds to the SN explosion itself, and the second one, to the time when the remnant reaches the interstellar medium outside the wind blown bubble.

We have used a simple method for AGN light curve construction: given this theoretical SN light curve and a certain SN explosion rate in the galactic nucleus, we superpose such light curves at random for a long period of time.

Theoretical light curves calculated in this way are shown in Figure 1 for three different SN rates: 1, 10, and 100 SN yr^{-1}. We have measured the r.m.s. of the theoretical light curves with explosion rates from 0.5 to 100 SN yr^{-1} and, as a rule, the r.m.s. decreases

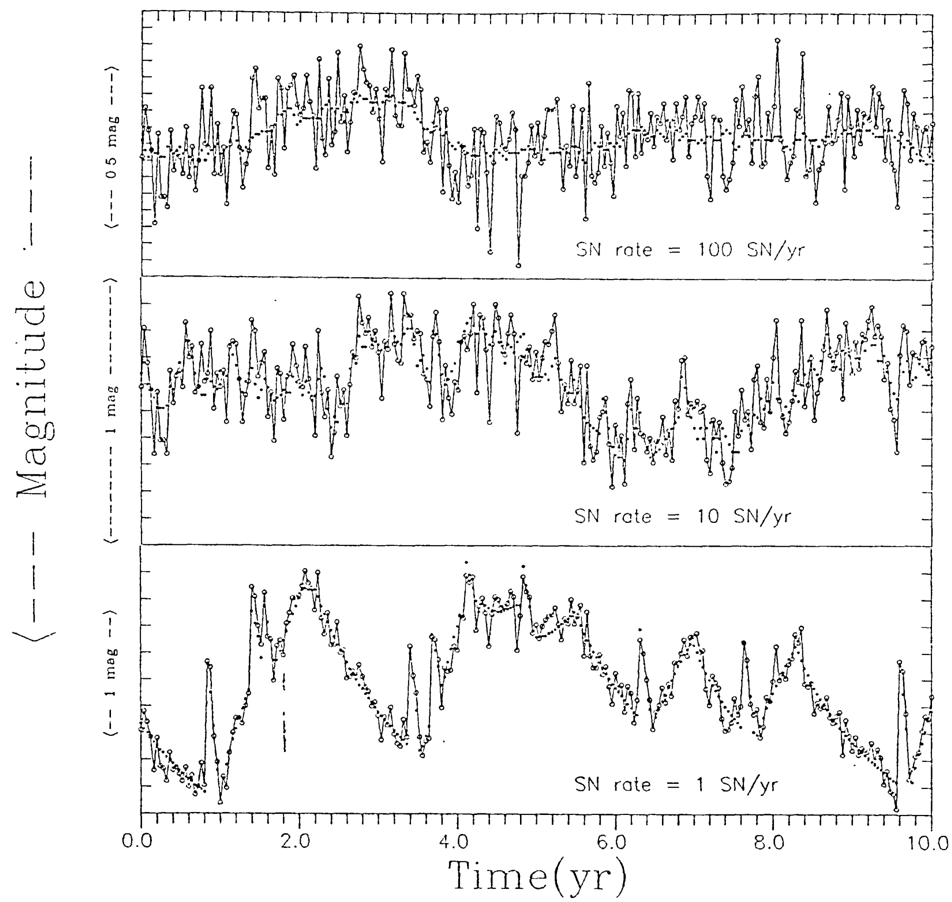

Fig. 1. Comparison between theoretical light curves (●) and simulated observed (i.e., theoretical curves with the inclusion of simulated errors) light curves (○). For small SN rates, they are almost identical, but as the rate increases, the scatter becomes greater (observational $\sigma_m^0 = 0.1$ mag).

while, naturally, the mean flux increases. Some of these values can be seen in Table I (columns 2 and 3).

TABLE I

Comparison of statistics of theoretical light curves and simulated observed ones (σ^0 denotes observational error)

SN rate (yr^{-1})	Theoretical L.C.		Simulated observed L.C. ($\sigma_m^0 = 0.1$ mag)	
	L ($L_\odot$)	σ_m (mag)	σ_m (mag)	Peak-to-peak Δm (mag)
0.5	2.4×10^9	0.55	0.55	1.05
0.8	3.0×10^9	0.49	0.50	0.85
1	4.2×10^9	0.42	0.43	0.89
2	8.9×10^9	0.31	0.32	0.85
4	1.8×10^{10}	0.15	0.19	0.56
6	2.6×10^{10}	0.15	0.18	0.55
8	3.5×10^{10}	0.13	0.17	0.50
10	4.4×10^{10}	0.13	0.16	0.46
100	4.5×10^{11}	0.05	0.12	0.38

3. Comparison with Observed Data

In order to make the comparison between theoretical light curves and observed ones more realistic, we have introduced, for a sample of points (interval = 15 days), gaussian errors which simulate the observational errors attached to the data. The corresponding r.m.s. values and peak-to-peak variations are given in columns 4 and 5 of Table I.

The light curves of the less luminous galaxies change slightly, but observational errors seem to be an important source of variation for the brighter ones.

From the comparison of the actually observed light curves of some Seyfert 1 galaxies and our calculations we obtain the SN rates listed in Table II. They range from 1 to 4 SN yr^{-1}. Some simulated light curves corresponding to these typical SN rates are shown in Figure 2.

TABLE II

Comparison between actual data and simulated observed light curves

Galaxy	Reference	M_{abs} (mag)	Observed r.m.s.	SN rate (yr^{-1})
NGC 4151	Lyutyi and Oknyanskii, 1987	−19.1	~0.25 mag	~3
NGC 3783	Barr *et al.*, 1983	−20.2	~0.1–0.4 mag	1–4
Fairall 9	Chapman *et al.*, 1985	−23.9	~$0.23\bar{F}$	~3
Mk 279		−21.8	~$0.33\bar{F}$	~1
NGC 7469		−22.0	~$0.28\bar{F}$	~3

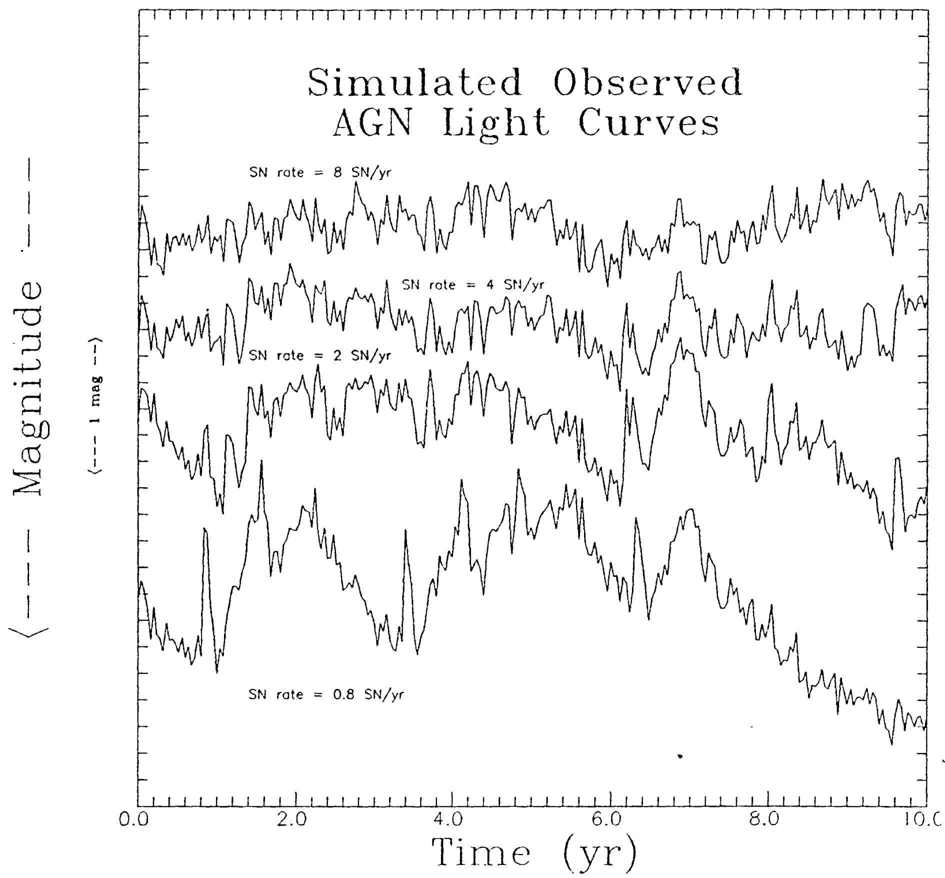

Fig. 2. Simulated observed light curves for some SN rates (observational $\sigma_m^0 = 0.1$ mag).

4. Conclusions

The observed light variations can be reproduced by the occurrence of SN explosions in the scenario of the starburst model for AGNs. The required SN rate for Seyfert 1 galaxies is about 1 SN yr^{-1}. The sharp peaks observed in the light curves of these galaxies would correspond to the actual SN explosions, and the long-term variation, to the superposition of their remnants.

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