1. INTRODUCTION

The advent of large panoramic photometric surveys of the sky offers the possibility of exploring the association of gamma-ray bursts (GRBs) with supernovae. To date, a few GRBs have been connected possibly with supernovae: GRB 980425–SN 1998bw, GRB 011121–SN 2001ke, GRB 970228, and GRB 980326. A combination of a large detection rate of GRBs and rapid coverage of a large portion of the sky to faint magnitude limits offers the possibility of detecting a supernova preceding an associated GRB or at least placing limits on the rate of association between these two phenomena and the time delay between them. This would provide important constraints on theoretical models for GRBs.

Subject heading: gamma rays: bursts

Long gamma-ray bursts are thought to be associated with the collapse of a massive star, a supernova. Specifically, in the collapsar model, the formation of a black hole in the center of the star results in relativistic jets that pierce the envelope of the star (MacFadyen & Woosley 1999). Along the axis of the jets, the collapsing star appears as a gamma-ray burst, and the supernova reaches its peak a few weeks after the GRB. Vietri & Stella (1998) proposed an alternative model in which the gamma-ray burst accompanies the delayed collapse of a quickly spinning neutron star that is more massive than the maximum mass of a nonrotating neutron star. The neutron star may take several months or years after the supernova to spin down to the critical frequency and collapse.

In this paper, I estimate the number of GRB events with photometry that overlap on the sky but shortly precede in epoch from SDSS and other surveys and compare the flux limits with the expected flux from a supernova that may precede the GRB.

2. GAMMA-RAY BURST OVERLAP WITH FUTURE SURVEYS

To calculate how often sufficiently deep photometry will precede the observation of a GRB on the sky, several ingredients are required: a model for the spectral energy distribution as a function of time of a supernova associated with a GRB, an estimate of the luminosity-rate function of GRBs as a function of redshift \([\phi(z, L)]\), a model for the field of view of the gamma-ray burst detector \((1_{\text{GRB}} = 2 \text{ for Swift})\) and its detection threshold \((P_1)\), and the rate of sky coverage of the photometric program \((\Phi_{\text{photo}})\) and its detection threshold \((R_{\lim})\). Porciani & Madau (2001) provide models for \(\phi(z, L) = \frac{1}{R_{\text{GRB}}(z)\psi(L)}\). The rate of GRBs, \(R_{\text{GRB}}(z)\), is taken to be proportional to the star formation rate, and the luminosity function of GRBs, \(\psi(L)\), is constrained by the BATSE GRB number counts. The rate of overlapping photometry is given by the product of the rate of sky coverage with an integral over the assumed cosmological distribution of GRBs,

\[
\frac{dN_{\text{overlap}}}{dt} (P > P_1, R < R_{\lim}) = \Phi_{\text{photo}} \Delta t \frac{dN_{\text{total}}}{dt} (P > P_1, R < R_{\lim}), \tag{1}
\]

\[dN_{\text{total}}/dt\] is the GRB rate, and \(\Phi_{\text{photo}}\) is the rate of sky coverage.
\[ \frac{dN_{\text{total}}}{dt} (P > P_1, R < R_{\text{lim}}) = \frac{\Omega_{\text{GRB}}}{4\pi} \int_0^\infty dz \int \frac{dL}{dL(z)} \frac{dV(z)}{dz} \phi(z, L). \] (2)

For lack of a better model for the evolution of a supernova associated with a GRB, I assume that SN 2001ke (Garnavich et al. 2003) is a prototype for this class, and furthermore that a supernova associated with a GRB maintains its peak brightness for a period \( \Delta t = 14(1 + z) \) days in the observer’s frame and otherwise is undetectable (see Reichart 1999 and Bloom et al. 1999 for other GRB-associated supernovae). It is reasonable to use the median value of \( z \) for GRBs whose associated supernovae are brighter than the magnitude limit of the particular photometric survey. However, to be highly conservative, I take \( \Delta t = 14 \) days to calculate the rate of overlap.

If a survey covers the same area of sky more often than once per interval \( \Delta t \), as does the SNAP supernovae search and Pan-STARRS, the rate of sky coverage \( \Phi_{\text{photo}} \) should only account for the first visit in each period \( \Delta t \); for example, \( \Phi_{\text{photo}} \) for Pan-STARRS is \( 2\pi \) per 14 days. The additional visits during each fortnight do not increase \( \Phi_{\text{photo}} \), but they do allow the survey to probe deeper by co-adding the successive images.

According to the original supernova model (Vietri & Stella 1998), the supernova may reach its peak at any time up to several years before the GRB, so this calculation implicitly assumes that both the GRB survey and the photometric survey will be operating at the appropriate times. Here \( L(P_{\text{1}}, z) \) is the luminosity of a GRB at a redshift \( z \) that is detected at a count rate of \( P_1 \), and \( R(z) \) is the \( R \)-band apparent magnitude of a GRB-associated supernova at a redshift \( z \). Both of these functions include the \( k \)-correction (Hogg 1999) and assume the cosmographic parameters \( \Omega_m = 0.3 \) and \( \Omega_{\Lambda} = 0.7 \). Figure 1 shows the number per year of GRBs detected by Swift whose associated supernova would be brighter at its peak than a particular \( R \)-band magnitude.

The results shown in Figure 1 assume the SF1 model of Porciani & Madau (2001). This model provides a conservative lower limit for the overlap. It predicts that Swift will localize about 110 bursts per year—the more generous estimates range up to 300 bursts per year (Myers 2002). Furthermore, this model predicts that the bursts detected will be at higher redshifts than other models, so the accompanying supernovae will be fainter and more difficult to detect.

Table 1 gives the overlap rate between various photometric surveys and the Swift GRB localization mission. What is striking is that the shallow but wide Pan-STARRS and LSST surveys will perform much better than any of the other surveys. Furthermore, if supernovae precede GRBs, Pan-STARRS and LSST each should detect nearly 10 GRB-associated supernovae per year. If they find none, it would place severe constraints on the supernova model for GRBs. It must be emphasized that this rate of overlap is extremely conservative. It assumes a low Swift burst localization rate and a distribution of GRBs skewed to high redshift (therefore, faint associated supernovae). The actual rate of overlap will probably be higher if both programs operate simultaneously. Furthermore, Swift will generate a catalog of burst positions and redshifts. One should be able to cross-correlate a posteriori this catalog with earlier Pan-STARRS or LSST observations and exclude the appearance of transients to \( R \approx 25 \) over a wide range of epochs preceding the burst yielding definitive constraints on GRB progenitors independent of assumptions about the GRB luminosity function and its evolution.

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\[^{3}\text{See http://swift.gsfc.nasa.gov.}\]

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**Fig. 1.**—Number of GRB-associated supernovae brighter than a given \( R \)-magnitude. The lines show the cumulative contribution of GRBs above given flux limits. The right panel shows the entire distribution, while the left panel focuses on the bright end. From bottom to top, only the supernovae associated with GRBs whose peak flux is above \( 10^{8.9}, 10^{10.6}, 10^{8.5}, 10^{9.4}, 10^{9.1}, 1, 10^{9.2}, 10^{-0.25}, 10^{-0.45}, 10^{-0.5}, 10^{-0.7}, \) and \( 10^{-0.75} \) photons \( \text{cm}^{-2} \text{s}^{-1} \). See Porciani & Madau (2001) for further details.
This calculation of the overlap rate assumes that either the GRB localization program or the photometric survey studies random portions of the sky. In fact, both the Swift mission and all of the photometric surveys avoid studying the region of the sky near the Sun. Although the average rate of overlap over a year in given by the formulae above and the values in the tables, the chance of detecting the supernova associated with GRB is somewhat higher than average if the supernova precedes the GRB by less than 3 months or between 9 and 15 months. If the supernova precedes the GRB by 6–9 months, the chance of detecting it is somewhat lower than average. However, this seasonal variation is smaller than the uncertainties in the GRB luminosity function.

3. DISCUSSION

The philosophy employed for finding GRB precursors is somewhat different than what is necessary for finding supernovae or microlensing events. Because the precursors will be sought after the GRB is detected and localized, it is not necessary to have more than one epoch of data from the particular region of sky before the burst. Even a single epoch would yield important constraints. Furthermore, unless the cadence of the observations is sufficiently low (no more than biweekly), the repeated observations of the same patch of sky do not improve the chances of catching a precursor (unless one co-adds the data to probe deeper), because supernovae typically evolve over the course of weeks. Consequently, although supernova and microlensing surveys have a large data rate of high-quality photometry, because of their relative lack of sky coverage and depth they do not contribute much to the detection rate of precursors. From another point of view, only a small fraction ($<10^{-4}$) of supernovae result in GRBs directed toward us, so one would typically have to find at least $10^4 (4\pi/\Omega_{\text{GRB}})$ supernovae in a blind search before finding a single GRB-associated supernova.

The best bets are the large, deep, wide surveys of the sky. SDSS is the prototype, and Pan-STARRS and LSST should deliver results. There is a small possibility that SDSS will catch a supernova before a GRB, providing important evidence for the supernova model for GRBs (it may have done so already). Pan-STARRS or LSST, if it overlaps with a high localization rate GRB mission such as Swift, will be able to provide important constraints on GRB models. Specifically, it should be able to exclude the possibility that GRBs follow supernovae within a year.

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**REFERENCES**

Mönch, P., et al. 2002, A&A, 396, L21

**TABLE 1**

| Survey              | $R_{\text{lim}}$ | $z_{\text{max}}$ | $z_{\text{med}}$ | $\#_{\text{phot}/\Delta t}$ | $dN_{\text{total}}/dt$ (yr$^{-1}$) | $dN_{\text{overlap}}/dt$ (yr$^{-1}$) |
|---------------------|------------------|-------------------|-------------------|-------------------------------|-------------------------------------|--------------------------------------|
| SDSS .................. | 23.2             | 0.56              | 0.48              | 0.035                         | 1.9                                 | 0.0052                               |
| Pan-STARSS (single) | 24.2             | 0.78              | 0.66              | 6.3                           | 7.1                                 | 3.6                                  |
| Pan-STARSS (co-added) | 25.0             | 1.00              | 0.83              | 6.3                           | 17.0                                | 8.8                                  |
| LSST (single)       | 24.5             | 0.86              | 0.72              | 6.3                           | 10.0                                | 5.1                                  |
| LSST (co-added)     | 25.1             | 1.04              | 0.85              | 6.3                           | 19.0                                | 9.8                                  |
| SNAP SN (single)    | 28.0             | 2.59              | 1.45              | 0.0046                        | 98.0                                | 0.036                                |
| SNAP SN (co-added)  | 28.8             | 3.35              | 1.50              | 0.0046                        | 110.0                               | 0.039                                |
| SNAP lensing        | 28.0             | 2.59              | 1.45              | 0.0091                        | 98.0                                | 0.071                                |

Myers, J. D. 2002, Swift: Catching Gamma-Ray Bursts on the Fly (NASA Tech. Rep.)

Porciani, C., & Madau, P. 2001, ApJ, 548, 522

Reichart, D. E. 1999, ApJ, 521, L111

Salamanca, L., Rol, E., Wijers, R., Ellison, S., Kaper, L., & Tanvir, N. 2002, GCN Circ. 1611 (http://gcn.gsfc.nasa.gov/gcn3/1611.gcn3)

SDSS Collaboration. 2001, Five-Year Baseline Plan for SDSS Operations (Sloan Digital Sky Survey Tech. Rep.)

Shirasaki, Y., et al. 2002, GCN Circ. 1565 (http://gcn.gsfc.nasa.gov/gcn3/1565.gcn3)

Vietri, M., & Stella, L. 1998, ApJ, 507, L45

Wood-Vasey, W. M., Aldering, G., Lee, B. C., Helin, E. F., Pravdo, S., Hicks, M., & Lawrence, K. 2002, GCN Circ. 1572 (http://gcn.gsfc.nasa.gov/gcn3/1572.gcn3)