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Gaia contribution to the low-redshift supernova population

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Abstract. The effectiveness of the ESA *Gaia* mission in obtaining a meaninful sample of supernovae (SNe) is based on three key points: detection rates, characterization capability and an extended validation phase. Focussing on the second, we present our investigations into the use of a range of classification techniques, whereby we demonstrate the ability to discriminate between various SN subtypes, based on the *Gaia* data (photometry and spectrophotometry) alone. In particular, we comment on the potential ability of *Gaia* to rapidly estimate SN redshifts and epochs. The methods presented here indicate that ground-based follow-up observations can then be more effectively targeted to the highest-priority SNe.

Keywords. supernovae: general, methods: statistical, surveys, catalogs

1. Introduction

Supernovae (SNe) play an important role in determining the cosmological distance scale, but there are still many uncertainties (Howell *et al.* 2009) and non-observationally confirmed predictions. A blind search, such as that performed by *Gaia* (to launch in late 2013), will be one of the main sources of SN detection in the forthcoming years. For the nominal five-year mission, *Gaia* is estimated to detect around 6500 SNe, mainly in the Hubble flow (up to $z = 0.14$). Approximately one third of those will be detected before the peak (Belokurov & Evans 2003) and confirmed by independent estimation by Altavilla *et al.* (2012). This large sample will have an important statistical impact and it will provide unbiased discovery of rare or completely new events, such as superluminous or Type Ia SNe.

The Photometric Science Alerts system is the *Gaia* DPAC (Data Processing Analysis Consortium) processing component (developed and running operationally at the Cambridge Data Processing Centre) which will perform the detection, classification and dissemination of these alerts to the scientific community. Low-dispersion spectrophotometry and historic information will allow for early and robust classification of transient events. The alert robustness will be tested during the first 3 to 6 months of the mission during the ground-based verification phase, which involves wide participation of a range of telescopes from around the world.

The aim of the Science Alerts system is to give access to the first science data from *Gaia*. The main *Gaia* catalogue and data products will only be published at a later stage during the mission (Mignard & Prusti 2012). The event photometry provided for each alert will be complemented with information on the probable nature of the transient: SN, nova, cataclysmic variable (CV) or active galactic nucleus, among others. For SNe,

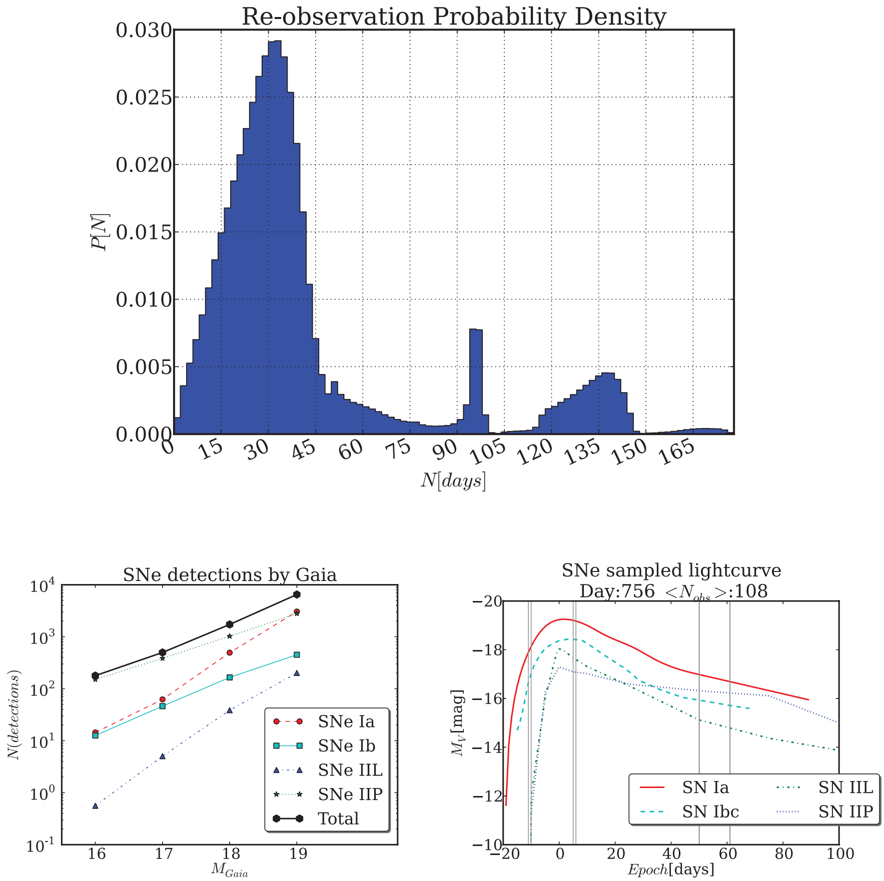

Figure 1. (top) Probability distribution of days needed to re-observe the same sky area (around 1 square degree) at 1 day resolution. (bottom left) Number of SNe of different types detected by *Gaia* for different apparent-magnitude thresholds. Updated rates from Belokurov & Evans (2003). (bottom right) Example of SN light-curve sampling in a high observation density area (around 108 transits per mission length) with a random SN appearing on day 756 of the mission.

expected to be a significant source of alerts, each alert will also include information on their subtype, estimated redshift and epoch compared to the date of maximum brightness.

2. SN detection rates

The SN detection rates by *Gaia* have been computed and consequently revised by Altavilla *et al.* (2012), taking into account the updated spacecraft scanning law. The results show that *Gaia* will detect around 6500 SNe, mainly in the Hubble flow ($z \leqslant 0.14$) down to a *Gaia* magnitude of $G = 19$ (see Fig. 1), which suggests an average rate of 3.5 per day.

The sky sampling of *Gaia* is determined by the predefined spacecraft scanning law, which gives a maximum number of observations in areas at 45° from the ecliptic plane. The most common revisiting period for a certain area is 30 days (see Fig. 1), which limits the ability of *Gaia* to effectively detect fast-rising transients. Around 40% of the sky will have more observations than this mean density coverage, which will make it possible to register a more complete set of epoch photometry points. These can later be combined

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with information from low-resolution spectroscopic information for light-curve typing, and redshift-stretch corrections can be applied.

3. Transient classification and preliminary results

Three independent classification schemes have been defined in the Science Alerts system, based on the different sets of input data: epoch photometry from *Gaia* broad band (G band), low-resolution spectrophotometry from the blue and red photometers (BP and RP) or either or both of them combined, with additional environmental data from external catalogues, e.g., 2MASS, SDSS, OGLE or ASAS.

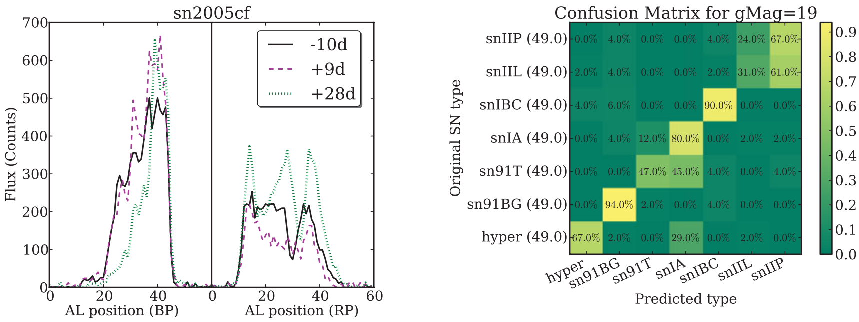

Figure 2. (left) Spectra of SN 2005cf at epochs $-10, +9, +28$ days, simulated at magnitude $G = 17$ to resemble the output of *Gaia*'s red and blue photometers. (right) Confusion matrix displaying the classification results for a well-defined set of the most common SN types.

Gaia broad-band photometry in the 350–1000 nm wavelength range will provide up to 0.5% precision for a single transit of a G2V star at 20 mag (de Bruijne 2012). This precision is often enough to detect fast variations in the light-curve characteristics for two subsequent transits from each field of view, temporarily separated by a 106 minute gap. Many of the transients have light curves with a characteristic signature in their slope and amplitude parameters. Consequently, probability density maps may be created to trace the distribution of these parameters and allow a statistical inference to estimate the transient type.

Light-curve classification was tested on light curves from SDSS Stripe 82, containing at least 40 photometric samples per object. Different sets of two consecutive points in the light curve were taken to emulate the *Gaia* sampling strategy. Around 50% of transients were properly classified into different major categories: SNe, novae, long-period variables. Some of the anticipated improvements will focus on expanding the light-curve training set with objects from other surveys or the inclusion of additional parameters, such as the source colour.

Raw low-resolution spectra come in two separate sets: one for the BP (330–680 nm), with a spectral resolution of 4 to 32 nm pixel^{-1}, and the other for the RP (640–1050 nm), with slightly finer 7 to 15 nm resolution pixel^{-1}. Because of the dominance of the faint end, we assume that the majority will consist of a one-dimensional window with 60 samples each.

The classification algorithm correlates each input spectrum with elements from a training set, basically composed of both transient synthetic libraries and spectra from large transient follow-up campaigns, such as the Center for Astrophysics (CfA) SN archive†,

† http://www.cfa.harvard.edu/supernova/SNarchive.html

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the Palomar Transient Factory (PTF; Rau *et al.* 2009) or PESSTO‡ (see Valenti *et al.* 2012). High-resolution spectra are then converted into different redshift displacements and interstellar extinction values and finally degraded to *Gaia*-like low-resolution spectra using the DPAC's internal simulation tools (XpSim; A. Brown, priv. commun.), so that also instrument characteristics are taken into account. The ground-based observational nature of the training set may present some difficulties, such as incomplete coverage in the *Gaia*-covered wavelength, low signal to noise, telluric absorption-line residuals or misscorrections in the quantum efficiency of the CCD. The direct implication is that not all spectra are compared for the same wavelength range. An interactive approach allows to make an initial pre-selection of the best candidates, and then choose among them by comparing the same absorption/emission features. The model spectrum with the best fit is chosen to estimate the transient characteristics.

Preliminary results of this module based on heterogeneous data (samples from PTF, CfA and PESSTO) showed that more than 60% of SN types are properly recognised, a number which increases up to 80% for Type Ia SNe, (for which more extensive training sets exists). Redshift parameters for these spectra were estimated up to an accuracy of $\sigma_z \leqslant 0.01$, which is the training set's resolution.

The final classification scheme is based on retrieval of environmental features from ancillary catalogues, e.g., 2MASS, SDSS, OGLE or ASAS, and the use of both combined *Gaia* and catalogue data to perform a final classification.

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‡ http://www.pessto.org

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