What can Gaia do for supernova science?

(What supernovae can do for Gaia)

Rubina Kotak (Queen’s Uni. Belfast)
• Current generation of transient discovery surveys
• Managing follow-up effort
• Examples of current science drivers: mixture of serendipity and targeted searches for specific goals
• Where does GAIA fit in?
Current generation of transient discovery surveys:

Pan-STARRS1
1.8m primary
1.4 Gigapixel detector
7 sq deg FoV
⇒ 6000 sq deg per 8-hr night

Wide-field: 4-10 sq. deg. FoV on 1-2m class telescopes

Transients only e.g. (i)PTF or all-purpose survey e.g. PS1

array of 60 chips (8x8 minus corners)
The PS1 experience

3π Survey (grizY, 56%)
Survey of entire visible sky (from Hawaii)

Medium Deep Survey (grizY, 25%)
10 GPC1 footprints: well-known extra-gal. fields
e.g. COSMOS, GOODS, DEEP2.. with 8 in SDSS footprint

3π Survey
(+90 to -30 decl)

5 epochs per lunation
Cadence: 6 +/- 4d
Per year, revisit ~4 in each of grizY

Cycle through 5 filters / 4d
~4 fields per night

Medium Deep Survey
(10 Designated Pointings)
### PS1 Transient Science Server @ QUB

<table>
<thead>
<tr>
<th>Stage</th>
<th>Remaining Detections</th>
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<tbody>
<tr>
<td>1. Raw Data</td>
<td>3,036,226</td>
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<td>2. Flag &amp; GP Check</td>
<td>1,364,961</td>
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<td>3. Detection Grouping</td>
<td>1,135,166</td>
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<td>6. Post Ingest Cuts</td>
<td>2,389</td>
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<td>7. Convolution Check</td>
<td>1,891</td>
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<tr>
<td>8. Bright Object Check</td>
<td>1,699</td>
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<tr>
<td>9. Chip Crosstalk Elimination</td>
<td>1,168</td>
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<tr>
<td>10. Movers</td>
<td>1,163</td>
</tr>
<tr>
<td>14. Eyeballing</td>
<td>184</td>
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</tbody>
</table>

GAIA transient alerts: similar logic

Next talk: Morgan

Courtesy K.W. Smith
$\sim 7 \times 10^3$ "good", $\sim > 500$ spectroscopically-confirmed SNe (QUB)
Finding static transients is easy! (1000s / yr)
Several competing and complementary “all-sky” surveys currently ongoing + planned (PTF, PS1, LSQ, SkyMapper, LSST, etc.)

Some designed to target particular areas of parameter space.

Follow-up strategy for each survey is generally clear

Where does GAIA fit in?

Kulkarni & Kasliwal ‘09; Zwicky ‘37
Parameter space

Populating new regions dependent on efficiently linking discoveries to follow-up strategy + resources

Kulkarni & Kasliwal ‘09; Zwicky ‘37
Public ESO Spectroscopic Survey of Transient Objects

- P.I.: Smartt (QUB)
- 90n / year on the NTT (9 months @10n/month)
- 4 yrs start: Apr. 2012
- Optical and NIR spectra of transients: EFOSC + SOFI
- Will classify ~2000 supernovae
- Classification target range : \( r < +20 \) mag
- Key Science P.I.s (~10)
- ~150 supernovae (or unusual optical transients) with full spectroscopic time series coverage (~10 epochs)
- Surveys partners are La Silla-Quest, SkyMapper, Pan-STARRS1, CHASE.
• Raw data publicly available immediately
• 24-hour turnaround for fast-reduction

Observing team 2-3

Data support team EU/CL

Phase III team

Final reduction (of all data) using best calibrations etc. done for annual data release
As of yesterday:
- 599 transients classified
- 104 follow-up status

Data Release 1

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<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th>Per Cent</th>
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<tr>
<td>Ia</td>
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<td>47</td>
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<tr>
<td>Ia-pec</td>
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<td>6</td>
</tr>
<tr>
<td>II</td>
<td>39</td>
<td>14</td>
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<tr>
<td>II(n)</td>
<td>21</td>
<td>8</td>
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<tr>
<td>II(b)</td>
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<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Ic</td>
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<td>4</td>
</tr>
<tr>
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<td>5</td>
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<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>274</strong></td>
<td><strong>100</strong></td>
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</table>

arXiv:1411.0299v1
From Feeder surveys to follow-up

One tool to manage all transients

MySQL, CSV, HTML, VODEvents/XML

PESSTO Marshall

GAIA transients Marshall

Courtesy: D. Young / QUB
Current SN science

• Very early time: few hrs to \( \sim 1-2 \text{d} \) from explosion
Pastorello al. '10

SNe Ia

Peak

Tail: $^{56}\text{Co} \rightarrow ^{56}\text{Fe}$

Explosion

Rise time to peak:

$\propto \text{Diffusion timescale}$

$\propto (\text{Explosion energy})^\alpha \times (\text{ejecta mass})^\beta \times (\text{opacity})^\gamma$ 

Pastorello al. '10
Example of an early type IIb SN discovery: 2011dh

Shock break-out cooling tail?

<15 hrs

e.g. Arcavi et al. 2011
Type II-L(inear) SN: 1 day after explosion

H envelope

IIP → IIL → IIb → Ib/c Progenitor mass

$z = 0.045$

Gall, RK+ PESSTO 2015 tbs
Current SN science

- Very early time (few hrs to \(~1-2\)d from explosion)
- Special and / or peculiar objects: progenitor detections;
The curious case of SN 2009ip

Fraser et al. 2013

$M_V \sim -9.8$

$\Rightarrow \log(L/L_{\text{sun}}) \sim 5.9$

$\Rightarrow M > \sim 40 M_{\text{sun}}$

Smith et al. 2009; Foley et al. 2010
SN 2009ip: historical lightcurves

Smith et al. 2009
Discovery +5yrs: now
Enormous follow-up effort by several groups

Pastorello et al. 2012  Fraser et al. 2013
Fraser, RK+ PESSTO (2015, TBS)
SN 2009ip: supernova or not?

Arguments for and against SN interpretation
- Energetics
- Nucleosynthesis
SN 2009ip: supernova or not?

- The unprecedented 2012 outburst of SN 2009ip: a luminous blue variable star becomes a true supernova (Mauerhan et al. 2013)
- Interacting Supernovae and Supernova Impostors: SN 2009ip, is this the end? (Pastorello et al. 2013)
- SN 2009ip à la PESSTO: no evidence for core collapse yet (Fraser et al. 2013)
- ...
- Clues to the Nature of SN 2009ip from Photometric and Spectroscopic Evolution to Late Times (Sand et al. 2014)
- SN 200ip at late times (Fraser, RK+PESSTO 2015)
SN progenitors with GAIA

Accurate SN positions to $\sim$mas within 25 Mpc

Alignment to other archival images reliable?

Legacy value

Smartt et al. '04
Current SN science

- Very early time (few hrs to ~1-2d from explosion)
- Special and / or peculiar objects: progenitor detections
- “super-luminous”, “super-under-luminous” etc.
New type of “ultra-bright” transients?

PS1 r’ (3π survey)

SDSS r’

z ~ 0.2
Supernova or AGN?

- Energy: $\sim 15x$ higher c.f. typical SN.
- Lightcurves atypical of AGN

Kankare+PS1 (2014, TBS)
Search for SN in nuclear regions: rates

Ground-based K-band + AO

Kankare et al. 2011
RESOLVING GALAXY-SUPERNova

- theta=0 deg (separation along the scanning angle)
- two stars at 15mag each
  min. separation: 0.24 arcsec

theta=90 deg
two stars at 15mag each
min. separation: 0.86 arcsec
Search for SN in nuclear regions:

- New experimental sub-science group within PESSTO to classify nuclear transients (IoA / QUB / Tuorla)
- Exceptional spatial resolution of GAIA
- Simulate detectability with GAIA: Nadia’s talk
Current SN science

- Very early time (few hrs to ~1-2d from explosion)
- Special and / or peculiar objects: progenitor detections
- “super-luminous”, “super-under-luminous”
- Supernova Rates
Predicted redshift distribution of GAIA SNe

Assume:
-- Limiting mag: G~19
-- Evenly distributed transits over 5 yrs

6300 SNe: 85%: Ia

Altavilla et al. 2013
GAIA & SN rates

- > 50% of the sky will be revisited 60-90 times over 5 years
- Survey parameters: well-constrained c.f. ground-based SN searches or c.f. rates from SNe discovered using combinations of surveys
- All-sky, untargeted

c.f. numbers from LOSS volume ltd sample:
13 yrs, N = 175
~ 75% are not SNe Ia (N = 106)

GAIA: 5 yrs, z ~ 0.01 => N ~ 100 (Altavilla et al. ‘13)

Li et al. 2011
GAIA & SN rates: challenges

- Is assuming a 5-yr baseline for rates realistic? reasonable?
- Detection thresholds of SN variable over mission lifetime? (Possible to revisit retrospectively, but for G~20 objects would rely on classification-by-”colour”, lightcurve (Ia, IIP, other), or independent discovery and spectroscopy from some other source)
- Spectroscopic classification for G > +19
- Completeness? Define volume-ltd sample from areas of the sky with >60 visits <-> epoch of SN discovery
- …
Concluding Remarks

- Basic questions for new and peculiar transients e.g. “SN or not SN?”
- GAIA: some very early detections and/or detections of peculiar objects => follow-up in place e.g. PESSTO
- Thresholds + alert release timescales
- GAIA niche: long-term + statistics + spatial resolution