Supernova search and rates with Gaia

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Talk layout

• Overview and motivations: unresolved issues in SN studies
  understanding the final stages of stellar evolution
  new SN sub-types
  understanding the SN diversity
  probing different explosion mechanisms
  estimating unbiased SN rates
  exploring transient phase-space

• Potential Gaia contribution to SN science:
  differences with traditional SN searches
  expected Gaia SN detections

• Gaia Science Alerts
• Our interest
• Conclusions
Overview and motivation: new SN sub-types

SNe are classified by their optical spectra

- No H
  - Type I
    - Si
    - He
    - Ia
      - Thermonuclear
    - Ib
    - Ic
      - Ib
      - Ibn
      - IIb
      - II-P, II-L, IIn
  - Core Collapse

- H lines
  - Type II
    - Photometry/spectra properties

Smooth transition
Hybrid classes
Need a more physical classification
Pastorello et al 2007
Overview and motivation: understanding the final stages of stellar evolution

the standard scenario of the death of the massive stars may not be complete and has to be revised

what is the minimum mass of CC SN progenitors in a single or binary system?
what is the mass range of progenitor stars of different CC SN types?
Overview and motivation: understanding the final stages of stellar evolution

• Red supergiants are progenitors of II-P Sne
• Lower limit for core-collapse: no more than 7-8M
• Lack of high mass progenitors – statistically significant?
• No detection of Ibc progenitors – the known massive WR population is not the progenitor population of Ibc SNe
• Massive stars collapse to black holes?
Overview and motivation: understanding the SN diversity

Wide range in energy and ejected masses

a wide range of explosion conditions and, potentially, of progenitors

Which are the physical parameters leading diversity?
What is the nature of bright and faint populations?
What is the physical origin of their luminosities?

Nomoto et al 2006
Benetti et al 2005, Maeda 2010
Overview and motivation: probing different and extreme explosion mechanisms

There are distinct sub-classes which differ significantly from the bulk of events

Faint and fast type Ia SNe: He detonation or deflagration on the surface of a WD?

Ultra bright CC SNe: Pulsational pair instability)?
Faintest CC SNe: electron capture SNe?
Overview and motivation: estimating unbiased SN rates

New wide-field surveys are discovering transients with no galaxy bias fainter limiting magnitude

- Complete SN sample within some distance
- Rates of different subtypes
- Rates as a function of host galaxy properties
- Rates in dwarf, sub-luminous galaxies
Overview and motivation: exploring the transient phase-space

Rapid growth in transient science
Our knowledge of explosions is still very incomplete

- Find new parameter space
- Fast transients
- Optical vs X ray/UV picture

Transients in the gap:
SNe, outbursts, mergers or exotica?

SN impostors are not only LBVs

Difference between explosive and eruptive transients
Gaia contribution: differences with traditional SN searches

Transients are not the founding scientific rationale of Gaia but are an important by-product

How does Gaia complement and compete in the low-z SN search landscape?

<table>
<thead>
<tr>
<th>SN searches</th>
<th>Rolling searches</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Old searches</strong></td>
<td>dedicated telescopes</td>
</tr>
<tr>
<td>large detector or big telescope</td>
<td>survey of the same large area of sky</td>
</tr>
<tr>
<td>large volume at low-z or at high-z</td>
<td>constant cadence</td>
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<tr>
<td>frequent sampling</td>
<td>detection on difference images</td>
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<tr>
<td>detection on difference images</td>
<td>photometric classification</td>
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<tr>
<td>spectroscopic classification</td>
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</table>

**Gaia**

a scanning mission (uniform coverage of the sky)
“quasi-regular” time sampling over 5 years but sky field revisited every ~70 days
detection in flux
3 data taking (astrometric, photometric and spectroscopic)
Gaia contribution: expected SN detections

Belokurov & Evans 2003 (G ~ 20)  
21400 SNe (67% Ia, 33% CC)  
8500 SNe pre-max (74% Ia)  
Half are daytime objects

Cappellaro (G ~ 19)  
6300 SNe (87% Ia, 13% CC)  
1800 SNe pre-max (95% Ia, 5% CC)  
500 SNe < -5 days pre-max (97% Ia, 3% Ib/c)  

CC SN shock break-out

Expected number from 0 to few  
Limit distance $z = 0.015$  
(M = -15 mag in G, Tominaga et al. 2008)

Assumptions:  
1- V band  
2 - Volumetric rate evolution (from Botticella et al 2008)  
3 - Observations of a given sky field are uniformly distributed
Gaia contribution: scientific possibilities

1) Transient discovery for free
2) Large number of transients, some rare transients
3) Unbiased SN sample

Gaia can help us to build a comprehensive understanding of the SN explosions of nearby SNe covering the full range of

- SN properties
- Host galaxy properties

systematic studies
statistical studies (SN rates)
The Gaia Science Alerts WG

- to produce reliable and robust alerts
- to prepare the community for the influx of alerts

Transient alerts will be public
will run in real time (24 - 48 h)
will use photometric and spectroscopic data

Operation scheme

Timeline for the data flow
Real-time classification is needed

From tens to hundreds of thousands of transients

Detection and classification methods need a validation process using ground based observations
Ground based follow-up is critical

Gaia is a survey with a relatively poor sampling.

Without a follow-up its alerts in most cases will be meaningless.

- International coordination
- Different dedicated telescopes

4m-class telescopes $\rightarrow$ spectroscopic classification
2m-class telescopes $\rightarrow$ photometric follow-up

Possible contribution from WF instrumentation and multi object spectrograph.
Our interest

• long term follow-up
  with immediate response in North and South hemisphere

• Systematic study for selected objects
  photometric and spectroscopic follow-up
  progenitor detection
  light curve and spectra modeling
  nucleosynthesis yield

• Rates of a sub-sample of SNe
  in dwarf, low metallicity host galaxies
  of rare transients
Our program is focused on
➢ determining the contribution to the chemical enrichment by different SN types
➢ the study of the extremes of the SN population
Network of telescopes

- **LBT**
- **ESO**
- **TNG**
- **NOT**
- **CAHA 3.5**
- **NTT+VLT**
- **WHT**
- **Gemini**
- **LT**
- **Faulkes**
- **REM**
- **Copernico**

**NTT large program**
120 nights (2009 - 2013)

**TNG large program**
50 nights (2009 - 2011)
### Supernovae 2010

<table>
<thead>
<tr>
<th>Chart</th>
<th>SN</th>
<th>Galaxy</th>
<th>Type</th>
<th>RA (J2000)</th>
<th>Dec (J2000)</th>
<th>Priority</th>
<th>Astronomer in charge</th>
<th>Collaborations</th>
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<tbody>
<tr>
<td>SN2010p</td>
<td>NGC2207</td>
<td>II/SNmp</td>
<td>06:16:30.63</td>
<td>-21:24:36.3</td>
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<td>Pastorello</td>
<td>ESO/TNG Large Programme Collaboration</td>
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<td>SN2010j</td>
<td>UGC5189A</td>
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<td>09:42:53.33</td>
<td>0:29:41.8</td>
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<td>SN2010g</td>
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<td>00:18:50.01</td>
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<td>54:33:18.3</td>
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<td>lla</td>
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<td>Anon</td>
<td>Icpec</td>
<td>07:10:31.80</td>
<td>-56:15:20.2</td>
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<td>F.Bulano</td>
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<td>SN group</td>
<td>ESO/TNG Large Programme Collaboration</td>
<td></td>
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</tbody>
</table>

**Synergies**

**Observational strategy**

All the data are reduced with the same pipeline.

**Data management**

- Alert Group + Observer Group
- (1 P.I. for each SN)

**Instrumental coverage**

- Swift and GALEX for UV coverage
- Spitzer for MIR coverage
- HST archive

**SN progenitor detection**
Large Program Future outlook

A public spectroscopic survey of the Transient Universe

PI: S.J. Smartt (Queen’s University Belfast). CoIs: S. Benetti, E. Cappellaro, L. Zampieri, M.T. Botticella (INAF- Padua Observatory); M. Sullivan, I. Hook, K. Maguire (University of Oxford); M. Turatto (INAF-Trieste Observatory); E. Bufano, C. Inserra (INAF-Catania Observatory); W. Hillebrandt, S. Taubenberger (MPA, Munich); P. Mazzali (INAF-Pisa), R. Kotak, A. Pastorello, S. Valenti, M. Fraser, M. McCrum, K. Smith (Queen’s University Belfast); S. Mattila, E. Kankare, (Univ. of Turku); J. Sollerman, C. Fransson, M. Ergon, A. Jerkstrand P. Lundqvist, A. Goobar, M. Stritzinger, R. Amanullah, J. Nordin (University of Stockholm); F. Patat (ESO); R. Pain, N. Regnault L. Le Guillou (LPNHE, Paris); M. Dennefeld, J.-B. Marquette (IAP); N. Elias-Rosa, J. Isern (Institut de Ciencies de L’Espai); V. Stanishev (CENTRA - Instituto Superior Tecnico); M. Kowalski, N. Langer (Bonn); J. J. Eldridge (Cambridge); A. Gal-Yam (Weizmann Institute); B. Schmidt, R. Scalzo, S. Sim, F. Yuan (ANU); C. Baltay (Yale); J. Danziger (INAF Trieste); L. Greggio, M.L. Pumo (INAF-Padua Observatory); M. Limongi (INAF Roma); J. R. Maund, (DARK, Copenhagen); A. Rest (STScI), M. Huber (JHU), C. Stubbs (Harvard, CfA); M. Della Valle, M. Dall’Ora (INAF - OACapodimonte); S. Blondin (CPPM, Marseille); M. Hammuy, G. Pignata (MCSS, Chile); A. Clocchiatti (PUC, Chile); L. Östman (IFAE, Barcelona) A. Harutyunyan (TNG, Italy)

High-quality time series optical+NIR spectroscopy of 150 transients

<table>
<thead>
<tr>
<th>Period</th>
<th>Instrument</th>
<th>Time</th>
<th>Mean RA</th>
<th>Moon</th>
<th>Seeing</th>
<th>Transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>P89-P96</td>
<td>NTT + EFOSC2</td>
<td>58 Nights/Period</td>
<td>all</td>
<td>grey</td>
<td>all</td>
<td>all</td>
</tr>
<tr>
<td>P89-P96</td>
<td>NTT + SOFI</td>
<td>14 Nights/Period</td>
<td>all</td>
<td>grey</td>
<td>all</td>
<td>all</td>
</tr>
</tbody>
</table>

all raw data will be non-proprietary
all the reduced data will be public in a timely fashion
a comprehensive datasets of standard SNe, exotic SNe and new class of optical transients
Conclusions

• Overview and motivations
  our group is dedicated to a systematic study of nearby SNe and SN rates

• Potential Gaia contribution to SN science
  excellent opportunities available to exploit SNe found with Gaia

• Gaia Science Alerts
  need ground based observations for transients follow-up

• Our interest
  Systematic studies and statistical analysis of nearby SNe
  Coordination of ground based follow-up campaign
    ( Network of telescope is being formed )