G7.7-3.7: a young supernova remnant probably associated with the guest star in 386 CE

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Collaboration
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(historians of astronomy) G. Li, S. Zhao
Historical supernovae in the 2nd millennium

SNR—SN connections using historical records

SN 1006  
Crab  
Tycho’s SNR  
Kepler’s SNR

CE records from

<table>
<thead>
<tr>
<th>CE</th>
<th>1006</th>
<th>1181 (3C58?)</th>
<th>1054</th>
<th>1572</th>
<th>1604</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>China</td>
<td>Japan</td>
<td>Arabia</td>
<td>Europe</td>
<td>China</td>
</tr>
</tbody>
</table>

Green & Stephenson 2003
Light curve of Kepler’s SN using ancient observations

black dots — European observations
red dots — Korean observations

Vink 2017
### Historical supernovae in the 1st millennium?

<table>
<thead>
<tr>
<th>Supernova</th>
<th>CE Records</th>
<th>Length of Visibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCW86</td>
<td>China</td>
<td>8 or 20 months</td>
</tr>
<tr>
<td></td>
<td>Europe</td>
<td></td>
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<tr>
<td></td>
<td>185</td>
<td></td>
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<tr>
<td></td>
<td>369?</td>
<td></td>
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<td></td>
<td>386?</td>
<td></td>
</tr>
<tr>
<td>RXJ1713.7-3946</td>
<td>China</td>
<td>8 months</td>
</tr>
<tr>
<td></td>
<td>393</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- **RCW86:**
  - Image credit: NASA/JPL-Caltech/UCLA - WISE
  - Credit: Vink et al. 2006
- **RXJ1713.7-3946:**
  - Image credit: H.E.S.S. (2016) RX J1713.7-3946, E > 250 GeV
  - Credit: Wang, Qu, Chen 1997, Acero + 2017

**China CE records:**
- 后汉中平二年 (185 CE)
- 晋太和四年 (369 CE)
- 晋太元十一年 (386 CE)
- 晋太元十八年 (393 CE)

**Europe CE records:**
- Xi 1955, Xi & Bo 1965
Types/Diversity of historical supernova remnants (SNRs)

Type Ia
(from white dwarfs)

- RCW 86
- SN 185
- SN 1006
- Tycho
- SN 1572
- Kepler
- SN 1604

SNR with a central compact object, progenitor mass ~15 Msun (Chen, Zhou & Chu 2013)

A pulsar wind nebula likely from a Type IIn-P SN, progenitor mass ~ 8—10 Msun (Smith 2013)

The number of historical core-collapse SNRs < sub-types of core-collapse SNe (Type IIP, IIL, IIb, Ib, Ic, ...)

core-collapse or non-Type-Ia
(from massive stars)

- RXJ 1713.7-3946
- SN 393
- Crab Nebula
- SN 1054
- 3C 58
- SN 1181?

We need to find more historical core-collapse SNRs. Guest stars 386 and 369
During the third month of the eleventh year of the Tai-Yuan reign-period of the Jin dynasty, there was a guest star at Nan-Dou (南斗) until the sixth month, when it was extinguished.

- **time:** 386 CE
- **position:** Nan-Dou
  - $l$$\sim$$6.9^\circ$$-10^\circ$, $b$$\sim$$-1.6^\circ$$-15.4^\circ$
- **duration of the visibility:** 2—4 months
Previous searches for the remnant of Guest star 386

G11.2-0.3

- position: a few degrees away
- distance: 5 kpc
- age: 1.4—2.4 kyr
- absorption: too large
  \((A_V \sim 16 \pm 2)\)

Borkowski+2016

X-ray: NASA/CXC/NCSU/K.Borkowski et al; Optical: DSS
Position of Nan-dou and SNRs

G11.2-0.3

Jian

Nan-Dou

Tian-Yue

Ji
G7.7-3.7

Distance: 3—6 kpc (Σ-D, Milne + 1996, Pavlovic+2014)

Archival XMM data:
2005 (ObsID: 0304220401, PI: E. Gotthelf, only MOS2)
2012 (ObsID: 0671170101, PI: M. Smith)
only 10 ks in total

We need the SNR age and extinction

red: VLA (radio)
cyan: XMM-Newton (X-ray)
Spectral analysis of the 10 ks X-ray data

- Temperature $kT = 0.4 - 0.8$ keV
- Abundance $<\text{solar}$ (ISM dominated)
- Density: $n_H \sim 0.5 \text{ cm}^{-3}$

**NEI plasma**

**SPEX code**

- $NH = 3 - 4 \times 10^{21} \text{ cm}^{-2} \rightarrow \text{low extinction } Av \sim 1.2$
- Ionization timescale: $1 - 4 \times 10^9 \text{ s cm}^{-3} \rightarrow \text{SNR age } t \sim 0.6 - 1.8 \text{ (d/4 kpc)}^{0.5} \text{ kyr}$

**Ionization timescale**

$$\tau = \int_{t_s}^{t_0} n_e \, dt$$
Info about G7.7

Probably SN 386:

Age: 600 — 1800 yr \([1- \sigma]\)
Position: very close to Nan-Dou [part of Sgr]
Distance: 3—6 kpc \([\Sigma-D, \text{Milne } + 1996, \text{Pavlovic+2014}]\)
Av: 1.2
Peak Brightness: brighter than -2 mag for normal SN with peak \(m_v=-17\)
Explosion energy: \(2e51 \times (d/4 \text{ kpc})^{4.5} \text{ erg}\)

Intriguing properties:
- faintest historical SNR in X-ray
- no evidence of SN ejecta
- no X-ray synchrotron emission
- Low density medium (0.1 cm\(^{-3}\) + special SN?)

Zhou+2018
A special SN according the historical record in 386 CE?

The guest star was only visible on the Earth within 2—4 months.

Record of SN 386: Apr 15/May 14 — Jul 13/Aug 10

Visibility of Nan-Dou asterism in 386 CE: Jan — Oct

low-luminosity SN explosion?

\[ m_V = M_V + 5 \log(d/10 \text{ pc}) + A_V \]

V-band light curve
Summary and outlook

• G7.7-3.7 is a probable remnant of the Guest star 386, which is likely a rare low-luminosity SN.

• To date, we have known ~8 historical SNRs. Our study increases the diversity of this small sample.

• The properties and SN (transient?) type of G7.7-3.7 are intriguing. We are conducting a multi-wavelength campaign to pin down the association between G7.7-3.7 and Guest star 386 and to unveil its SN properties.
Workshop at Lorentz Center
Leiden, the Netherlands

Historical Supernovae, Novae and Other Transient Events
from 14 Oct 2019 through 18 Oct 2019

Topics:
- historical supernovae
- historical novae
- properly understanding historical records and exploring (new) records from different cultures
- prehistorical transient phenomena (e.g. nearby supernovae measured with 60Fe, proton events measured with 14C, etc.)