Soft Gamma Repeaters (SGRs)

March 5, 1979

$L_T \sim 8 \times 10^{44}$ erg/s

$E_{	ext{tot}} = 2.5 \times 10^{41}$ erg

($50-150$ keV)

$L_C \sim 3.6 \times 10^{42}$ erg/s

$P = 8.0$ s

Mazets et al.
Giant Flares in Soft Gamma Repeaters
(Konus-Wind and Helicon - Coronas-F summary)

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St.Petersburg, Russia

NASA Goddard Space Flight Center,
Greenbelt, Maryland, USA
Konus-Wind Summary

Joint Russian-American experiment on US GGS-WIND spacecraft

Launch: November 1, 1994
Konus-Wind instrument switched on: November 11, 1994

Orbit: beyond the magnetosphere of the Earth

Observations:
November 11, 1994 –December 18, 2004 (3689 days)

Gamma ray bursts total >2500
• Burst mode >1450
• Background mode >1150
• Solar flares >750
• SGR bursts >300
Wind Instruments
Wind trajectory during extended mission

L1 excursion → L2 excursion → L1 Lissajous orbit (2002-2008+)

XY (ecliptic plane) projection
Two detectors S1 and S2: NaI(Tl) 13 cm diameter, 7.5 cm height, 12.5 cm Be window. Located on opposite faces of spacecraft, observing correspondingly the southern and northern celestial hemispheres.

Burst mode: Time history analyzer: resolution 2ms – 256 ms, total duration 230s
- 12 – 50 keV 4096 ch
- 50 – 200 keV 4096 ch
- 200 – 770 keV 4096 ch
Instrument description (ii)

• *Pulse Height analyzer*: accumulation time 64ms – 8.192 s, duration 79 – 492 s
  - PHA1  12 – 770 keV  63 ch quasilog scale
  - PHA2  0.2 – 10 MeV  63 ch quasilog scale

• *Background mode*: accumulation time 1.47 – 2.94 s
  - Count rate:
    - 12 – 50 keV
    - 50 – 200 keV
    - 200 – 770 keV
    - > 10 MeV
Coronas-F is a Russian solar observatory that was lunched on 2001 July 31 on near-Earth orbit (inclination 82°). S/c is stabilized by rotation with axis directed to Sun.

Helicon is a gamma-ray spectrometer (20keV-15MeV). Two detectors identical to Konus-Wind, observed solar and anti-solar hemispheres.
SGR history

- 5 March 1979 – giant flare from SGR 0526-66 detected by Konus experiment on Venera-11, 12
- End of March 1979 – 3 short, soft bursts were detected by Konus from SGR 1900+14
- SGR 1806-20 – 1983 (Prognoz 9, ICE, SMM)
- SGR 1801-23 – two bursts were detected on 1997 June 29 (BATSE, Konus-A, Konus-W, Ulysses)
SGR observational summary (i)

- **Active** and **Quiet** states
- Recurrent bursts:
  - duration ~0.1-1 s;
  - energy release ~ $10^{38}-10^{41}$ erg,
  - Spectra can be described by OTTB model
    \[ \frac{dN}{dE} \sim E^{-1}\exp(-E/kT) \] for $E>20$ keV;
  - $kT \sim 15\div30$ keV
SGR 0526-66

- Burst 790306 detected from SGR 0526-66 by Konus on Venera-11
Konus-Wind observations of SGR 1900+14

- Burst 790324 - the first burst detected from SGR 1900+14 by Konus on Venera-11

- Burst 980902b – a typical burst from SGR 1900+14 detected by Konus-Wind
• Burst 040828 – one of the most intense burst (both in peak flux and fluence) detected by Konus-Wind from this SGR.
SGR 1627-41

- An intense burst 980625 from SGR 1627-41 which demonstrates strong spectral evolution typical for this SGR.
New SGR 1801-23

Burst 970629b detected by Konus-Wind at $T_0=23493.221$ s UT
Soft Gamma Repeaters (SGRs)

Recurrent bursts statistics
(Gogus et al., 1999, 2001)

- RXTE, BATSE data
SGR observational summary (ii)

• Persistent X-ray emission (0.5-10 keV)
  – Flux \( \sim 10^{-11} \text{erg cm}^{-2} \text{s}^{-1} \) (\( L_X \sim 10^{35} \text{erg s}^{-1} \))
  – power law spectra with \( \gamma \sim 2.2 \)
  – Pulsation \( \sim 10\% \), \( P \sim 5-8 \text{ s} \), \( dP/dt \sim 10^{-11} \text{ s/s} \)
## Persistent emission

<table>
<thead>
<tr>
<th></th>
<th>SGR 0526-66</th>
<th>SGR 1627-41</th>
<th>SGR 1806-20</th>
<th>SGR 1900+14</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance, kpc</strong></td>
<td>~55</td>
<td>11±0.3</td>
<td>6-15</td>
<td>10-14</td>
</tr>
<tr>
<td><strong>$L_X$ (erg s$^{-1}$)</strong></td>
<td>$1 \times 10^{36}$</td>
<td>$&lt;3 \times 10^{34}$</td>
<td>$4 \times 10^{35}$</td>
<td>$2 \times 10^{35}$</td>
</tr>
<tr>
<td><strong>PL photon index</strong></td>
<td>3.1</td>
<td>2.5</td>
<td>2.0 - 2.2</td>
<td>1.0 - 2.2</td>
</tr>
<tr>
<td><strong>$kT_{BB}$, keV</strong></td>
<td>-</td>
<td>-</td>
<td>0.5-0.7</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Period (s)</strong></td>
<td>8.0</td>
<td>6.4(?)</td>
<td>7.5</td>
<td>5.2</td>
</tr>
<tr>
<td><strong>$dP/dt$ (10$^{-11}$ s s$^{-1}$)</strong></td>
<td>6.5</td>
<td>…</td>
<td>8 – 30 (55 in 2004 –XMM data)</td>
<td>6 - 35</td>
</tr>
</tbody>
</table>
Recent progress

• Discovery of hard component (up to ~150 keV) in persistent emission of SGR 1806-20 by Integral/IBIS (Molkov et al. 2005; Mereghetti et al. 2005)

• Discovery of likely IR-counterpart of SGR 1806-20 by Subaru and VLT (Kosugi et al. 2005; Israel et al. 2005)
Giant flare on 1979 March 5 (SGR 0526-66)

Time and energy characteristics of the March 5 event.

Top: Background subtracted light curve of the outburst. Horizontal sections with triangles specify count rates averaged over the period. The sloped dashed line is a plot of $\exp(-t/\tau)$ relation for $\tau=100$ s.

Bottom: Horizontal sections with squares specify $kT$ averaged over the period.
Giant flare on 1998 August 27 (SGR 1900+14)

Time and energy characteristics of the August 27 event.

Top: Background subtracted light curve of the outburst. Horizontal sections with triangles specify count rates averaged over the period. The sloped dashed line is a plot of $\exp(-t/\tau)$ for $\tau = 91.5$ s.

Bottom: Horizontal sections with squares specify $kT$ averaged over the period.
Soft Gamma Repeaters (SGRs)

Not-so-giant flare on June 18, 1998 (SGR 1627-41)

Time and energy characteristics of the June 18 event.

*Top:* Background subtracted light curve of the outburst.

*Bottom:* Spectral evolution during the burst.
SGR 1806-20 activity before giant flare on 27 December 2004

• In 2004 2-10 keV luminosity nearly doubled (XMM data; Mereghetti et al. 2004)

• Steep rise of activity in May 2004 (since January till May, only 2 trigger bursts from SGR 1806-20 had been detected by Konus-Wind)

• Since May, 74 triggers on K-W and Helicon were due to SGR 1806-20. Their total fluence $7.4\times10^{-4}$ erg cm$^{-2}$ (energy release $2\times10^{43}$ erg)
Burst series on 1998 May 30 (SGR 1900+14)

- 89 days before the giant flare on August 27
- Total fluence (>20keV) $S=5.6 \times 10^{-5}$ erg cm$^{-2}$ [Energy release $Q=1.1 \times 10^{42}$ erg]
Burst series on 5 October 2004 from SGR 1806-20

- 83 days before the giant flare
- The series was also detected by INTEGRAL (IBIS/ISGRI)
Burst series 040510 (i)

- Total Fluence (>20keV)
  \[ S = 7.6 \times 10^{-5} \text{ erg cm}^{-2} \]
  [Energy release \( Q = 2 \times 10^{42} \text{ erg} \)]

- Peak Flux (>20keV)
  \[ P_{\text{max}} = 5.6 \times 10^{-5} \text{ erg cm}^{-2}\text{s}^{-1} \]
  [\( L_{\text{max}} = 1.5 \times 10^{42} \text{ erg s}^{-1} \)] for \( d = 15 \text{ kpc} \)
Burst series 040510 (ii)

- The most intense peaks have lower rigidity ($G_2/G_1$) than remaining parts of the series.
Activity of SGR 1806-20 after the burst series of October 5, 2004

- Long burst series (~600 s) on December 21, More than 30 bursts.
- Another, weaker series on December 25
- Three bursts on December 27 just before giant flare
KONUS-WIND 041227 $T_0=77278.447$ s UT (21:27:58.447)

16.5-280 keV

$P=7.56$ s
Giant flare on 27 December 2004 from SGR 1806-20

- Detected by many s/c (INTEGRAL, RHESSI, HEND, Wind, Swift, Geotail)
- First GCN Circular – INTEGRAL (Borkowski et al., 2004)
Konus-Wind and Helicon-Coronas-F observations of giant flare on 27 Dec. 2004

- Precursor – the most intense recurrent burst ever detected: fluence $1.25 \times 10^{-4}$ erg cm$^2$ (energy release $Q=3.4 \times 10^{42}$ erg for $d=15$ kpc)
Initial pulse (saturation)
Soft Gamma Repeaters (SGRs)

Helicon-Coronas-F event

HELCION-CORONAS-F
041227 T₀ = 77429.303 s UT

Counts / 0.004 s

G1 (25 - 105 keV)

G2 (105 - 440 keV)

G3 (440 - 1700 keV)

G2/G1

T - T₀, s

10²

100

400

E, кэВ
Soft Gamma Repeaters (SGRs)

Schematic diagram of the flare detection by the Konus-Wind and Helicon-Coronas-F

- $T_E = T_W + 5.086$ s
- $T_{Cor} = T_W + 7.69$ s
- Front spreading: $2R_M/c = 11.6$ ms
- $(R_M –$ Moon radius)
Reconstruction of initial pulse

- Calculation of lunar response matrix with GEANT4
- Folding lunar matrix with Helicon detector response matrix
- Standard spectral fitting procedures with XSPEC
- Light curve reconstruction
Soft Gamma
Repeaters (SGRs)

Moon response

Lunar Soil Composition

- Oxygen: 42%
- Silicon: 21%
- Iron: 13%
- Calcium: 8%
- Aluminum: 7%
- Magnesium: 6%
- Other: 3%
Soft Gamma Repeaters (SGRs)

Moon response

- Scatter angle $\theta = 159^\circ \pm 2^\circ$
- Energy of incident $\gamma$-quanta $E_0 = 20 \text{ keV} \div 12 \text{ MeV}$
- Compton scattering:

$$E' = \frac{E_0}{1 + \frac{E_0}{mc^2} (1 - \cos \theta)}$$

$$E' \rightarrow \frac{mc^2}{(1 - \cos \theta)} \approx 264 \text{ keV} \quad E_0 \gg mc^2$$

![Diagram showing energy distribution and 511 keV peak]
Moon reflectance efficiency

- Albedo (photons) as function of energy of an incident photon
Fitting models (i)

- Power law with exp cutoff: $\alpha = 0.995 \pm 0.025$, $E_0 = 1150 \pm 330$ keV, $\chi^2 = 11.4/12$
- GRB (Band) model: the same, $\beta \leq 1.6$
- Power law: $\gamma = 1.41 \pm 0.07$, $\chi^2 = 18.4/13$
- Blackbody: $kT=116$ keV, $\chi^2 = 27.5/13$
Fitting models (ii)
Reconstructed time history of the initial pulse
Soft Gamma Repeaters (SGRs)

The giant flare on 2004 December 27

General view

KONUS-WIND 041227

$T_0 = 77278.447 \text{ s UT (21:27:58.447)}$

$P = 7.56 \text{ s}$

G1+G2 (16.5-280 keV)
Giant flare – general view (Konus-Wind)

- **G1 (16.5 - 65 keV)**
  - Counts/s
  - $10^5$ to $10^2$

- **G2 (65 - 280 keV)**
  - Counts/s
  - $10^5$ to $10^3$

- **G3 (280 - 1060 keV)**
  - Counts/s
  - $10^3$

- **G2/G1**
  - $0.0$ to $1.0$

- Time in $T - T_0$, s
  - Range: 140 to 220
Giant flare on 27 Dec. - beginning
Giant flare on 27 Dec. – pulsating tail
Tail spectra (i)

- **Average spectrum:** two components
- **OTTB** ($kT \approx 30$ keV)
- **+ Power Law**
  \[ \gamma = -1.8 \pm 0.2 \]
Soft Gamma Repeater (SGRs)

Tail spectra (ii)

![Graphs showing energy spectra for different intervals (sp 57-58, sp 59-60, sp 61-62, sp 63-64) with corresponding photon counts per second keV.](image)
Soft Gamma Repeaters (SGRs)

80 keV – 1 MeV afterglow (Konus-Wind)

- Reported by INTEGRAL SPI-ACS (Mereghetti et al. 2005)
- Detectable during ~7000 s
- Fluence ~$2 \times 10^{-4}$ erg cm$^{-2}$
- Power law index ~1.6
SGR 1806-20 after the giant flare

- Since Dec 27, 2004, Konus and Helicon detected ~20 bursts from SGR 1806-20
- Bursts are generally weaker (than the bursts detected before the giant flare)
- As with post-flare SGR 1900+14, some bursts are unusually long
Soft Gamma
Repeaters (SGRs)

SGR 1806-20 051203a event

- Duration ~8.7s
- $E_0 = 20.6 \pm 0.4$ keV
- $(5.17 \pm 0.03) \times 10^{-5}$ erg cm$^{-2}$
- $(1.19 \pm 0.06) \times 10^{-5}$ erg cm$^{-2}$ sec$^{-1}$
Soft Gamma Repeaters (SGRs)

Duration – Fluence

![Graph showing duration vs. fluence with logarithmic scale]
• Duration \( \sim 22.5 \text{ s} \) (!)
• \( E_0 = 19.9 \pm 0.5 \text{ keV} \)
• \((1.53 \pm 0.03) \times 10^{-4} \text{ erg cm}^{-2} \)
• \((3.5 \pm 0.2) \times 10^{-5} \text{ erg cm}^{-2} \text{ s}^{-1} \)
## Giant flares summary (initial pulse)

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<tr>
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<tbody>
<tr>
<td><strong>Distance, kpc</strong></td>
<td>55</td>
<td>10</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td><strong>Initial pulse</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Duration, s</strong></td>
<td>~0.25</td>
<td>~0.5</td>
<td>~0.35</td>
<td>~1</td>
</tr>
<tr>
<td><strong>Rise time, ms</strong></td>
<td>&lt;2</td>
<td>~8</td>
<td>~4</td>
<td>~6</td>
</tr>
<tr>
<td><strong>Fluence, erg cm(^{-2})</strong></td>
<td>~4.5(\times)10(^{-4})</td>
<td>~7(\times)10(^{-4})</td>
<td>&gt;5.5(\times)10(^{-3})</td>
<td>~0.6</td>
</tr>
<tr>
<td><strong>Q, erg</strong></td>
<td>~2(\times)10(^{44})</td>
<td>~1(\times)10(^{43})</td>
<td>&gt;1.1(\times)10(^{44})</td>
<td>~1.8(\times)10(^{46})</td>
</tr>
<tr>
<td><strong>Peak Flux, erg cm(^{-2}) s(^{-1})</strong></td>
<td>~1(\times)10(^{-3})</td>
<td>~2(\times)10(^{-2})</td>
<td>&gt;3(\times)10(^{-2})</td>
<td>~9</td>
</tr>
<tr>
<td><strong>L(_{\text{max}}), erg s(^{-1})</strong></td>
<td>~4(\times)10(^{44})</td>
<td>~3(\times)10(^{44})</td>
<td>&gt;6(\times)10(^{44})</td>
<td>~2.3(\times)10(^{47})</td>
</tr>
</tbody>
</table>
## Giant flares summary (tail)

<table>
<thead>
<tr>
<th></th>
<th>SGR 0526-66</th>
<th>SGR 1627-41</th>
<th>SGR 1900+14</th>
<th>SGR 1806-20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>5 March 1979</td>
<td>18 June 1998</td>
<td>27 August 1998</td>
<td>27 December 2004</td>
</tr>
<tr>
<td>Distance, kpc</td>
<td>55</td>
<td>10</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td><strong>Tail</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period, s</td>
<td>8.0</td>
<td>N/A</td>
<td>5.16</td>
<td>7.56</td>
</tr>
<tr>
<td>Duration, s</td>
<td>&gt;70</td>
<td></td>
<td>~300</td>
<td>~380</td>
</tr>
<tr>
<td>Fluence, erg cm⁻²</td>
<td>1.0×10⁻³</td>
<td></td>
<td>4.2×10⁻³</td>
<td>1.2×10⁻²</td>
</tr>
<tr>
<td>Q, erg</td>
<td>1.6×10⁴⁴</td>
<td></td>
<td>7.5×10⁴³</td>
<td>3.2×10⁴⁴</td>
</tr>
</tbody>
</table>
Conclusion

- Three Giant Flares from four SGR in 25 year observation history
- SGR 1627-41 – a peculiar SGR?
- Recurrence period?
Short Hard GRB – SGR GF connection

• Short
• Hard
• Rare identifications
• Cataloged events search
• Statistical studies (rapid afterglows?)
GRB 051103

IPN triangulation of GRB 051113

Wind-Swift
Wind-RHESSI
MO-Wind
GRB 051103 (contd)

- Observed by **Konus-Wind**, **Swift-BAT**, **HETE-Fregate**, **Mars-Odyssey (GRS and HEND)**, and **RHESSI**
- Duration ~0.17 sec
- \( E_{\text{peak}} = 1940 \pm 400 \text{ keV} \)
- Fluence (20keV–10 MeV): \( (2.34 \pm 0.3) \times 10^{-5} \text{ erg cm}^{-2} \)
- Peak flux (2ms scale): \( (1.89 \pm 0.3) \times 10^{-3} \text{ erg cm}^{-2} \text{ s}^{-1} \)
- \( Q_{\text{iso}} \sim 4.5 \times 10^{46} \text{ erg} \), assuming M81 distance (~4 Mpc)