A bright γ-ray flare interpreted as a giant magnetar flare in NGC 253

On 15 April 2020, the extremely bright, short γ-ray burst GRB 200415A occurred at 08:48:06 UTC at Earth, and was detected by five space-based missions of the Interplanetary Network of γ-ray detectors (IPN, Methods). Here we report the final localization of the burst by the IPN to a 20-square-arcmin region of the starburst galaxy NGC 253, located about 3.5 million parsecs away. The burst had a sharp, millisecond-scale hard spectrum in the initial pulse, which was followed by steady fading and softening over 0.2 seconds. The energy released (roughly $10^{46}$ erg) is similar to that of the superflare from the Galactic soft γ-ray repeater SGR 1806−20 (roughly $2.3 \times 10^{46}$ erg). We argue that GRB 200415A is a giant flare from a magnetar in NGC 253.

Soft γ-ray repeaters exhibit bursting emission in hard X-rays and soft γ-rays. During the active phase, they emit random short (milliseconds to several seconds long), hard-X-ray bursts, with peak luminosities of $10^{48}$ to $10^{45}$ erg per second. Occasionally, a giant flare with an energy of around $10^{44}$ to $10^{46}$ erg is emitted. These phenomena are thought to arise from neutron stars with extremely high magnetic fields ($10^{14}$ to $10^{15}$ gauss), called magnetars. A portion of the second-long initial pulse of a giant flare in some respects mimics short γ-ray bursts, which have recently been identified as resulting from the merger of two neutron stars accompanied by gravitational-wave emission. Two γ-ray bursts, GRB 051103 and GRB 070201, have been associated with giant flares. Here we report observations of the γ-ray burst GRB 200415A, which we localized to a 20-square-arcmin region of the starburst galaxy NGC 253, located about 3.5 million parsecs away. The burst had a sharp, millisecond-scale hard spectrum in the initial pulse, which was followed by steady fading and softening over 0.2 seconds. The energy released (roughly $10^{46}$ erg) is similar to that of the superflare from the Galactic soft γ-ray repeater SGR 1806−20 (roughly $2.3 \times 10^{46}$ erg). We argue that GRB 200415A is a giant flare from a magnetar in NGC 253.

On 15 April 2020, the extremely bright, short γ-ray burst GRB 200415A occurred at 08:48:06 UTC at Earth, and was detected by five space-based missions of the Interplanetary Network of γ-ray detectors (IPN, Methods). Here we report the final localization of the burst by the IPN to a roughly 20-square-arcmin region (Methods) that overlaps with the central part of the nearby galaxy NGC 253, at a distance of $D_{\text{NGC253}} = 3.5$ Mpc (ref. 14) (Fig. 1). The chance occurrence for GRB 200415A to be spatially consistent with a nearby galaxy likely to produce detectable giant flares is approximately 1 in 200,000 (ref. 15).

GRB 200415A triggered Konus–Wind at $T_0 = 08:48:01.403$ UTC. As observed by Konus–Wind, the lightcurve of the burst starts with the fast (around 2 ms) rise of a narrow (around 4 ms) initial spike, which is followed by an exponentially decaying phase with a count-rate e-folding time of $\tau_0 = 50$ ms (Fig. 2a). The total duration of the burst is 0.138 s, and $T_\alpha$ (the duration of the time interval that contains the central 90% of the total count fluence of the burst) is $0.100 \pm 0.014$ s (hereafter, all the quoted uncertainties are at the 68% confidence level).

The hardness of the burst (the ratio between the 390–1,600-keV and 90–390-keV count rates) increases rapidly during the initial spike, peaks and then decays gradually with the count rate of the burst. Our spectral analysis (Methods) shows that, starting from the rise of the spike and up to about $T_\alpha + 100$ ms, the energy spectrum of the burst is well described by a cutoff power-law function (proportional to $E^{-\alpha} \exp\left\{-E(T_\alpha + 2)/E_p\right\}$). The temporal evolution of the spectrum is illustrated in Fig. 2, which shows the behaviour of the cutoff power-law model parameters: the peak energy $E_p$, which corresponds to the maximum of the spectral energy distribution $\nu F_\nu$, where $F_\nu$ is the energy flux per unit frequency interval at frequency $\nu$ (Fig. 2b) and the photon power-law index $\alpha$ (Fig. 2d). The initial spike is characterized by $E_p = 1.2$ MeV, with $\alpha = -0.6$. This $E_p$ was the highest reached in the entire event. A non-thermal cutoff power-law model, with $E_p$ decaying nearly exponentially, adequately describes burst spectra up to about $T_\alpha + 100$ ms. Afterwards, the very hard photon index $\alpha$ becomes poorly constrained; and, simultaneously, the emission spectrum can be described by a blackbody function (with a temperature $kT$ = 70 keV), which is excluded by our analysis at the initial stage of the burst.

In Fig. 2c we show the temporal evolution of the 20 keV–10 MeV energy flux. It peaks in the initial spike with a 4-ms peak flux of $0.96^{+0.32}_{-0.16} \times 10^{-3}$ erg cm$^{-2}$ s$^{-1}$ and, starting from around $T_\alpha + 50$ ms, decays with $\tau_{\text{rms}} = 30$ ms. The time-integrated spectrum, measured...
from \(T_a\) to \(T_a + 0.192\ s\), is best described by a sum of non-thermal (cutoff power-law) and thermal (blackbody) components (see Extended Data Table 1 for the model parameters). The total burst fluence is \(8.5^{+1.2}_{-1.0} \times 10^{-6}\) erg cm\(^{-2}\) in the 20 keV–10 MeV band.

A preliminary analysis of the Konus–Wind detection\(^8\) of GRB 200415A revealed its remarkable similarity to GRB 051103, historically the first extragalactic giant-flare candidate outside the Local Group, associated with the M81/M82 group of galaxies\(^9\)–10 at a distance of \(D_{\text{M81/M82}} = 3.6\) Mpc (ref. \(^3\)). To explore this similarity further, we performed a detailed comparison between the temporal and spectral properties of GRB 200415A and GRB 051103. The bursts have similar lightcurve and spectral evolution patterns (Fig. 2; Extended Data Tables 1, 5, 6). Although the peak count rates, reached in the first 2 ms of the initial spikes, are very similar (about (1.5–1.7) \times 10^7\ s\(^{-1}\)), the photon flux over the entire extent of the decaying phase is about twice as high in GRB 051103 as in GRB 200415A. The initial pulses of both bursts are best described by the cutoff power-law model, with \(E_p = 1.2\) MeV, but GRB 051103 has a much harder \(\alpha = -0.1\). In contrast to GRB 200415A, the hardest emission in GRB 051103 (\(E_p = 3\) MeV, \(\alpha = 0.2\)) was observed during the roughly 30 ms immediately after the initial spike. In accordance with the similarities of the bursts in peak count rate and \(E_p\) measured in the initial spikes, their 4-ms peak flux estimates also agree with uncertainties. The blackbody components in the time-integrated spectra of GRB 200415A and GRB 051103 have similar temperatures (\(kT = 70–100\) keV), with blackbody contributions to the total fluence of about 14% and 9%, respectively. The contribution of the initial short spike to the total fluence is about 45% for GRB 200415A and 13% for GRB 051103.

Thus, the extremely bright, short GRB 200415A, which strong evidence suggests is associated with the NGC 253 galaxy, is remarkably similar to GRB 051103, which presumably originated from the M81/M82 group of galaxies at nearly the same distance, in terms of light curve morphology, spectral behaviour and observed peak energy flux. A lightcurve with a bright, millisecond-scale initial pulse followed by an exponentially decaying emission is unusual for short cosmological \(\gamma\)-ray bursts (GRBs); none of more than about 500 short bursts detected by Konus–Wind in more than 25 years of observations displays such a shape\(^1,13\). On the other hand, this pattern was observed in two Galactic giant flares, from SGR 1900+14\(^19,20\) and SGR 1806–20\(^20,21\).

Furthermore, higher-time-resolution lightcurves of GRB 200415A from Swift–Burst Alert Telescope (BAT) and Fermi–Gamma-ray Burst Monitor (GBM)\(^22\) have an initial short (less than 1 ms) subpeak, followed by a sharp decrease for approximately 1 ms, before the main part of the peak. This pattern is also seen in SGR 1806–20\(^23\) and may be a general property of giant flares that can be used to identify them within the short-GRB sample. Thus, the interpretation of GRB 200415A and GRB 051103 as magnetar giant flares is strongly suggested, with additional support provided by the non-detection of an accompanying gravitational-wave signal for GRB 051103\(^24\) (there is no sensitive coverage by a gravitational-wave detector for GRB 200415A).

At source distances of \(D_{\text{NGC253}} = 3.5\) Mpc and \(D_{\text{M81/M82}} = 3.6\) Mpc, the characteristic radius of the emission region, estimated from the blackbody spectral fits, is \(R = 20–40\) km, the same order of magnitude as the radius of a neutron star or its magnetosphere. The implied isotropic-equivalent energy release in \(\gamma\)-rays for GRB 200415A (GRB 051103) is \(E_{\text{iso}} = 1.3 \times 10^{46}\) erg (\(E_{\text{iso}} = 5.3 \times 10^{46}\) erg) and the isotropic-equivalent peak luminosity is \(L_{\text{iso}} = 1.4 \times 10^{46}\) erg s\(^{-1}\) (\(L_{\text{iso}} = 1.8 \times 10^{46}\) erg s\(^{-1}\)). Therefore, the total energies released in both flares are comparable with that estimated for the most energetic flare from a Galactic magnetar\(^22,23\). Taken together, these results make GRB 200415A and GRB 051103 the most...
substantial candidates for extragalactic magnetar giant flares: both are at least about five times more luminous than any Galactic magnetar flare observed previously. Such high luminosities may indicate that the magnetar sources of GRB 200415A and GRB 051103 are younger than a few hundred years, so their magnetic fields are strong enough to power such flares. Assuming the same spectra and energetics, similar events could be detected with Konus–Wind from distances up to around 16 Mpc.

Despite the strong evidence in favour of the giant-flare nature of GRB 200415A and GRB 051103, it cannot completely be ruled out that they might belong to an as-yet undiscovered branch of the cosmological short GRB population. For the observed energy fluence, and assuming a cosmological redshift of $z = 0.05 - 1$, GRB 200415A is consistent with the Konus–Wind sample of short GRBs with known redshifts, in terms of a hardness–intensity relation in the cosmological rest frame (Extended Data Fig. 1). In the case of GRB 051103, the implied short-GRB redshift is $z = 1$, with intrinsic $E_p = 5$ MeV.

The detection of extragalactic giant flares facilitates the study of emission processes on millisecond and sub-millisecond timescales, such study is not possible for galactic events because they saturate almost all γ-ray detectors. On the timescale relevant to Konus–Wind (more than about 2 ms), the single-peaked GRB 200425A and GRB 051103 are clearly different from the third known extragalactic giant-flare candidate, GRB 070201, which has highly variable emission during the first roughly 50 ms. This suggests that the physical processes behind the emission in the initial pulses of giant flares may develop on timescales that span more than an order of magnitude.

The IPN box of GRB 200415A is projected partially into the nuclear region, the bar, a ring-like structure enclosing the bar and a spiral arm of NGC 253, which contain many young star groups. This is consistent with the Galactic magnetars, which are associated with the young stellar population. The current sample of giant-flare host galaxies includes five massive galaxies (the Milky Way, M31, M81/M82 group and NGC 253) and the Large Magellanic Cloud, which resemble the host galaxies of non-repeating fast radio bursts. This provides evidence for a connection between soft γ-ray repeaters and fast radio bursts.

Online content
Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41586-020-03076-9.

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The observed event may be a magnetar giant flare in NGC 253 (the Sculptor galaxy) located at $D_{\text{NGC253}} = 3.5$ Mpc.

For this analysis, we use a standard Konus–Wind dead-time correction for the GBM, 360–1,000 keV, constructed from the time-tagged event data of triggered detectors (0, 1, 2, 3, 4, 5, 9 and a; only NaI data were used); 0.1-keV BAT, 25–350 keV, constructed from the time-tagged event data from the GUANO system; 250–ms HEND, 50–3,000 keV; and 7.8 ms INTEGRAL–PICsIT. 250–2,000 keV.

For the Konus–Wind detector, a cylinder 5 inches in diameter and 3 inches in height, placed into an aluminium container with a beryllium entrance window. The crystal scintillator is viewed by a photomultiplier tube through a 20-mm-thick lead glass, which provides effective detector shielding from the spacecraft's background in the soft spectral range. The detector effective area is about 80–160 cm², depending on the photon energy and incident angle. The energy range of γ-ray measurements covers the incident photon energy interval from 20 keV to 20 MeV.

The instrument has two operational modes: waiting and triggered. While in the waiting mode, the count rates (lightcurve) are recorded in three energy bands (G1, G2 and G3) covering roughly 20–1,500 keV (Extended Data Table 3), with 2.944 s time resolution. When the count rate in the roughly 80–350-keV band exceeds an approximately 9σ threshold above the background on one of two fixed timescales (1 s or 140 ms), the instrument switches into the triggered mode.

In the triggered mode, lightcurves are recorded in the same bands, starting from 0.312 s before the trigger time $T_0$, with time resolution varying from 2 ms to 256 ms. For the bursts of interest here, the whole time history is available with 2-ms resolution.

Multichannel spectral measurements are carried out, starting from $T_0$ (no multichannel spectra are available before $T_0$) in two overlapping energy intervals, PHA1 and PHA2 (Extended Data Table 4), with 64 spectra being recorded for each interval over a 63-channel pseudo-logarithmic energy scale. The first four spectra are measured with a fixed accumulation time of 64 ms to study short bursts.

For this analysis, we use a standard Konus–Wind dead-time correction procedure for lightcurves (with a dead time of a few microseconds) and multichannel spectra (with a dead time of about 42 μs).
Temporal analysis. For the temporal analysis, we used time histories from $T_0 = 0.512$ s to $T_0 + 0.512$ s in three energy bands (G1, G2 and G3), with a time resolution of 2 ms. The total burst duration $T_{90} +$ and the $T_{50}$ and $T_{90}$ durations (the time intervals that contain 5%–95% and 25%–75% of the total burst count fluence, respectively), were calculated using the lightcurve in the roughly 0.1-1000 keV energy band (G2 + G3). Burst start and end times in each band were calculated at the 5σ level using a method similar to BATSE17. The background count rates, estimated using the data from about $T_0 - 2500$ s to about $T_0 - 150$ s, are 958.7 s$^{-1}$ (G1), 349.5 s$^{-1}$ (G2) and 223.0 s$^{-1}$ (G3) for GRB 200415A, and 1,080.3 s$^{-1}$ (G1), 394.0 s$^{-1}$ (G2) and 135.5 s$^{-1}$ (G3) for GRB 051103.

Spectral analysis. For the bursts of interest, we analysed multichannel and three-channel Konus–Wind energy spectra. The multichannel spectra accumulation intervals are presented in Extended Data Tables 5 and 6. The background multichannel spectra were extracted in the intervals from $T_0 + 8.448$ s to $T_0 + 491.776$ s and from $T_0 + 98.560$ s to $T_0 + 491.776$ s for GRB 200415A and GRB 051103, respectively. The emission evolution at a finer timescale can be explored using three-channel spectra, constructed from the counts in the G1, G2 and G3 energy bands in the six intervals (Extended Data Tables 5, 6). Details on Konus–Wind three-channel spectral analysis can be found elsewhere18.

We performed the spectral analysis in XSPEC, version 12.10.158, using the following spectral models: a simple power law, a custom exponential cutoff power-law (CPL) parameterized by the peak of $\nu F_\nu$, spectrum and with the energy flux as the model normalization, the Band GRB function19, a single blackbody (BB) function with the normalization proportional to the surface area, and a sum of the CPL and BB functions (CPL + BB). The details of each model are as follows: the power law model is described by

$$f_{PL} = A \left( \frac{E}{E_p} \right)^{\alpha},$$

the custom exponential CPL model by

$$n(E) = \left( \frac{E}{E_p} \right)^{\alpha} \exp \left[ \frac{E(2 + \alpha)}{E_p} \right],$$

$$F_{CPL} = \int_{E_{min}}^{E_{max}} n(E) E \, dE = \int_{E_{min}}^{E_{max}} A \left( \frac{E}{E_p} \right)^{\alpha} \exp \left[ \frac{E(2 + \alpha)}{E_p} \right] E \, dE,$$

and the Band function by

$$f_{Band} = A \left[ \left( \frac{E}{E_n} \right)^{\alpha} \exp \left[ \frac{E(2 + \alpha)}{E_p} \right] - \left( \frac{E}{E_n} \right)^{\beta} \exp \left[ \frac{E_p(2 + \alpha)}{E(2 + \alpha)} \right] \right] \exp(\beta - \alpha), \quad E < \frac{(\alpha - \beta)E_p}{2 + \alpha},$$

where $f_{PL, CPL, Band}$ is the relevant photon spectrum (measured in photons cm$^{-2}$ s$^{-1}$ keV$^{-1}$), $A$ is the model normalization, $E_p = 100$ keV is the pivot energy, $E_n$ is the peak energy of the $\nu F_\nu$ spectrum and $F_n$ is the model energy flux in the $E_{min} - E_{max}$ energy band; $\alpha$ and $\beta$ are the low-energy and high-energy photon indices, respectively, and $n(E)$ is the unnormalized photon spectrum. The single BB function is the bodydom XSPEC model.

The Poisson data with Gaussian background statistic (PG-stat) was used in the model-fitting process as a figure of merit to be minimized. The spectral channels were grouped to have a minimum of one count per channel to ensure the validity of the fit statistic. Because the CPL fit to a three-channel spectrum has zero degrees of freedom (and, in the case of convergence, PG-stat = 0), we do not report the statistic for such fits. The 68% confidence intervals of the parameters were calculated using the command steppar in XSPEC.

A summary of constrained spectral fits with the CPL, BB and CPL + BB models is presented in Extended Data Tables 5 and 6. For GRB 200415A and GRB 051103, the power-law model failed to describe the spectra, with PG-stat/dof > 10 in all cases. Use of the Band GRB function does not constrain the high-energy photon index $\beta$ for GRB 200415A spectra, and only marginally improves the CPL fit to the time-integrated spectrum of GRB 051103, with similar (within errors) $E_p$ and $\alpha$ and $\beta = -3$.

Burst energetics. For both bursts, the total energy fluence S was derived using the 20 keV–10 MeV energy flux of the best-fitting (CPL + BB) spectral model. Because the time-integrated spectrum accumulation interval differs from the $T_{90} +$ interval, a correction that accounts for the emission outside the time-integrated spectrum was introduced when calculating $S$.

The peak flux $F_{peak}$ was calculated on the 4 ms scale using the energy flux of the best models with the CPL model to the three-channel spectrum at the peak count rate interval ($T_0 - 0.002$ s to $T_0 + 0.002$ s). The peak flux of GRB 051103 estimated here is a factor of about 2.5 lower than that reported from previous analyses of Konus–Wind and RHESSI data30, which used wider spectral intervals and did not separate the relatively soft spectrum in the huge 4 ms spike ($E_p = 1.2$ MeV) and the considerably harder emission observed immediately after its falling edge ($E_p = 3$ MeV).

Data availability

The Fermi (https://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/triggers/2020/bn200415367/current/), Swift (https://www.swift.psu.edu/guano/) and INTEGRAL (http://isdc.unige.ch/~savchenk/spiacs-online/spiacs.pl) data are freely available online. The HEND data used for the triangulation and Konus–Wind lightcurve and spectral data are available at http://www.ioffe.ru/LEA/papers/SvinkinNat2020/data/. Links to the Wind ephemeralis and clock accuracy data are provided in Methods. Source data are provided with this paper.

Code availability

XSPEC is freely available online (https://heasarc.gsfc.nasa.gov/xanadu/xspec/).

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Acknowledgements We thank E. Burns for discussions, O. Roberts for reading the manuscript and providing comments, and V. Pal’shin for contributing to the Konus–Wind and IPN data analysis tools. A.B., P.U. and J.C.R. acknowledge the continuous support from the Italian Space Agency ASI via different agreements including the latest one, 2019-35-HH.0. The Konus–Wind experiment is supported by the Russian State Space Corporation ROSCOSMOS. The HEND experiment is supported by ROSCOSMOS and implemented as part of Gamma-Ray Spectrometer suite on NASA Mars Odyssey. HEND data processing is funded by Ministry of Science and Higher Education of the Russian Federation, grant AAAA-A18-118012290370-6.

Author contributions D.S. and K.H. performed the IPN localization, with contributions from the Konus–Wind team (R.A., D.F., S.G., A.V.R. and T.L.C.), the Mars Odyssey (HEND and GRS) teams (I.M., D.G., A.K., M.S., W.B., C.W.F., K.P., H.E. and R.S.), the Fermi–GBM team (A.G., M.S.B. and C.W.-H.), the INTEGRAL (SPI-ACS and IBIS-PICsIT) teams (A.v.K., X.-L.Z., A.R., V.S., E.B., C.F., P.U., A.B. and J.C.R.), and the Swift–BAT team (S.B., J.C., H.K. and D.M.P.). D.F. and D.S. performed the Konus–Wind temporal and spectral data analysis, with contributions from A.L., A.V.K., A.T. and M.U. D.S. and D.F. wrote, and K.H. refined, the manuscript. All authors provided comments on the paper.

Competing interests The authors declare no competing interests.

Additional information Supplementary information is available for this paper at https://doi.org/10.1038/s41586-020-03076-9.

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Peer review information Nature thanks the anonymous reviewer(s) for their contribution to the peer review of this work. Peer reviewer reports are available.

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Extended Data Fig. 1 | GRB 051103 (red stars) and GRB 200415A (blue stars) as possible cosmological GRBs at various redshifts \((0.01 < z < 1)\). The Konus–Wind samples of short–hard GRBs and long GRBs with known redshifts\(^2\) are shown by green triangles and grey circles, respectively. The recent update\(^2\) for the hardness–intensity relation in the cosmological rest frame \((E_{p,z}, E_{iso})\), ‘Amati’ relation) is plotted as a solid line, together with its 68% and 90% prediction intervals (dashed black lines). Considering only its spectrum and energy fluence, GRB 200415A is consistent with the Konus–Wind sample of short GRBs if at redshift \(z = 0.05\)–1. In the case of GRB 051103, the implied short-GRB redshift is \(z = 1\), with intrinsic \(E_p \approx 5\) MeV.
## Extended Data Table 1 | Summary of GRB 200415A and GRB 051103 properties

| Parameter                             | GRB 200415A          | GRB 051103          |
|---------------------------------------|----------------------|---------------------|
| Host galaxy (distance)                | NGC 253 (3.5 Mpc)    | M81/M82 group (3.6 Mpc) |
| **Temporal properties**               |                      |                     |
| $T_{\text{rise}}$ (ms)                | $\lesssim 2$         | $\lesssim 4$        |
| $\tau_{\text{cr}}$ (ms)               | $\sim 50$            | $\sim 50$           |
| $\tau_{\text{ilux}}$ (ms)             | $\sim 30$            | $\sim 30$           |
| $T_{100}$ (s)                         | 0.138                | 0.324               |
| $T_{90}$ (s)                          | 0.100 ± 0.014        | 0.138 ± 0.020       |
| $T_{50}$ (s)                          | 0.048 ± 0.005        | 0.058 ± 0.004       |
| **Peak spectrum $T_0$ (-0.002 s, +0.002 s), CPL model** | | |
| CPL photon index $\alpha$             | $-0.59^{+0.17}_{-0.17}$ | $-0.13^{+0.18}_{-0.17}$ |
| CPL Peak energy $E_p$ (keV)           | $1190^{+460}_{-240}$  | $1250^{+590}_{-290}$  |
| **Time-integrated spectrum $T_0$ (0, +0.192 s), CPL+BB model** | | |
| CPL photon index $\alpha$             | $-0.02^{+0.38}_{-0.25}$ | $0.08^{+0.28}_{-0.19}$ |
| CPL Peak energy $E_p$ (keV)           | $1080^{+210}_{-150}$  | $2690^{+310}_{-180}$  |
| Blackbody temperature $kT$ (keV)      | $99^{+37}_{-33}$      | $107^{+11}_{-10}$    |
| Blackbody radius $R$ (km)             | $23^{+16}_{-9}$ (@3.5 Mpc) | $37^{+6}_{-6}$ (@3.6 Mpc) |
| Blackbody contribution to flux         | $\sim 14\%$          | $\sim 9\%$          |
| **Peak energy fluxes (erg cm$^{-2}$ s$^{-1}$), in the 20 keV–10 MeV band** | | |
| 4 ms scale, $T_0$ (-0.002 s, +0.002 s) | $9.6^{+3.2}_{-1.6} \times 10^{-4}$ | $11.5^{+5.2}_{-2.4} \times 10^{-4}$ |
| 16 ms scale, $T_0$ (-0.002 s, +0.014 s) | $1.1^{+0.21}_{-0.14} \times 10^{-4}$ | $8.98^{+5.79}_{-2.36} \times 10^{-4}$ |
| 64 ms scale, $T_0$ (-0.002 s, +0.062 s) | $0.43^{+0.07}_{-0.05} \times 10^{-4}$ | $4.38^{+1.61}_{-0.88} \times 10^{-4}$ |
| **Energy fluences (erg cm$^{-2}$), in the 20 keV–10 MeV band** | | |
| Initial spike                         | $3.86^{+1.27}_{-0.66} \times 10^{-6}$ | $4.61^{+2.09}_{-0.96} \times 10^{-6}$ |
| $T_0$ (-0.002 s, +0.002 s)            | $T_0$ (-0.002 s, +0.002 s) |
| Total                                 | $8.5^{+1.2}_{-1.0} \times 10^{-6}$ | $34.3^{+4.0}_{-2.0} \times 10^{-6}$ |
| $T_0$ (-0.004 s, +0.192 s)            | $T_0$ (-0.006 s, +0.192 s) |
| **Flare energetics, in the 20 keV–10 MeV band** | | |
| $L_{\text{iso}}$, 4 ms scale (erg s$^{-1}$) | $\sim 1.4 \times 10^{46}$ | $\sim 1.8 \times 10^{48}$ |
| $E_{\text{iso}}$ (erg)                | $\sim 1.3 \times 10^{46}$ | $\sim 5.3 \times 10^{46}$ |
| KW maximum detection distance (Mpc)   | $\sim 13.5$          | $\sim 15.8$         |

KW, Konus–Wind.
### Extended Data Table 2 | Triangulation annuli

| Instruments involved | R.A. (J2000) (deg) | Dec.(J2000) (deg) | R (deg) | δR (deg) |
|----------------------|--------------------|------------------|---------|----------|
| GBM(0.1 ms)–KW(2 ms) | 1.9406             | 2.0665           | 28.9781 | 0.0298   |
| BAT(0.1 ms)–KW(2 ms) | 2.0920             | 2.0554           | 28.9243 | 0.0262   |
| KW(2 ms)–HEND(250 ms)| 313.0127           | -18.9203         | 54.5051 | 0.0394   |
| GBM(1 ms)–HEND(250 ms)| 313.3351          | -18.8199         | 54.2444 | 0.0391   |
| KW(2 ms)–PICsIT(7.8 ms)| 4.1624            | -2.1891          | 24.2751 | 0.1681   |

First column, the instruments involved in triangulation and the lightcurve temporal resolution used; second and third columns, the right ascension (R.A.) and declination (Dec.), respectively, of the centre of the annulus in the equatorial J2000 system; fourth and fifth columns, the radius of the annulus $R$ and its half width $\delta R$, corresponding to $3\sigma$ statistical cross-correlation time delay uncertainty with systematics added in quadrature.
Extended Data Table 3 | The 3σ IPN box

| Box center/vertices | R.A. (J2000) (deg) | Dec. (J2000) (deg) |
|---------------------|--------------------|--------------------|
| Center              | 11.885 (00h 47m 32s) | -25.263 (-25d 15m 47s) |
| 1                   | 11.846 (00h 47m 23s) | -25.308 (-25d 18m 29s) |
| 2                   | 11.931 (00h 47m 43s) | -25.279 (-25d 16m 44s) |
| 3                   | 11.923 (00h 47m 42s) | -25.218 (-25d 13m 05s) |
| 4                   | 11.839 (00h 47m 21s) | -25.247 (-25d 14m 49s) |

The area of the error box is 17 arcmin$^2$ and its maximum (minimum) dimension is 7 arcmin (4 arcmin). The Sun distance was about 37°.
| Burst     | Det | Inc. angle (deg) | G1  (keV)   | G2  (keV)   | G3  (keV)   | PHA1 (keV) | PHA2 (keV) |
|-----------|-----|-----------------|--------------|--------------|--------------|------------|------------|
| GRB 200415A | S1  | 62.2            | 22–90        | 90–390       | 390–1600     | 28–1600    | 330–20000  |
| GRB 051103  | S2  | 70.8            | 17–70        | 70–300       | 300–1200     | 20–1170    | 240–14800  |
### Extended Data Table 5 | GRB 200415A spectral fits

| Time interval (s) | Model | $\alpha$ | $E_p$ (keV) | $kT$ (keV) | $R$ (km) | Flux (20 keV–10 MeV) $(10^{-6}$ erg cm$^{-2}$ s$^{-1}$) | PGstat/dof |
|------------------|-------|----------|------------|-----------|---------|--------------------------------|-------------|
| -0.004 – -0.002  | CPL   | $-0.28^{+0.58}_{-0.49}$ | $520^{+390}_{-140}$ | -         | -       | $81^{+35}_{-17}$                          | -           |
| -0.002 – 0.002   | CPL   | $-0.59^{+0.17}_{-0.17}$ | $1190^{+460}_{-240}$ | -         | -       | $960^{+250}_{-130}$                      | -           |
| 0.002 – 0.032    | CPL   | $0.30^{+0.29}_{-0.25}$  | $980^{+230}_{-150}$  | -         | -       | $111^{+21}_{-14}$                       | -           |
| 0.032 – 0.064    | CPL   | $0.16^{+0.29}_{-0.26}$  | $710^{+160}_{-100}$  | -         | -       | $43^{+7}_{-5}$                           | -           |
| 0.064 – 0.096    | CPL   | $0.44^{+0.60}_{-0.45}$  | $496^{+84}_{56}$     | -         | -       | $19.3^{+2.9}_{-2.2}$                     | -           |
| 0.096 – 0.128    | BB    | -        | -           | $73^{+8}_{-7}$ | $54^{+21}_{-14}$ | $6.8^{+1.1}_{-0.9}$                       | 0.5/1       |

### Multichannel spectra

| Time interval (s) | Model | $\alpha$ | $E_p$ (keV) | $kT$ (keV) | $R$ (km) | Flux (20 keV–10 MeV) $(10^{-6}$ erg cm$^{-2}$ s$^{-1}$) | PGstat/dof |
|------------------|-------|----------|------------|-----------|---------|--------------------------------|-------------|
| 0.000 – 0.064    | CPL   | $0.12^{+0.15}_{-0.14}$ | $1066^{+491}_{-79}$ | -         | -       | $85.4^{+6.9}_{-6.3}$                        | 55/64       |
| 0.064 – 0.128    | CPL   | $0.39^{+0.39}_{-0.33}$  | $458^{+78}_{-57}$   | -         | -       | $12.5^{+2.2}_{-1.8}$                       | 49/47       |
| 0.128 – 0.192    | BB    | -        | -           | $71^{+22}_{-15}$ | $26^{+12}_{-9.0}$ | $1.47^{+0.57}_{-0.42}$                   | 22/31       |
| 0.000 – 0.192    | CPL   | $0.01^{+0.12}_{-0.12}$  | $887^{+76}_{-67}$   | -         | -       | $32.3^{+2.4}_{-2.3}$                       | 67/75       |
| CPL+BB           | -0.02$^{+0.38}_{-0.25}$ | $1080^{+210}_{-150}$ | $99^{+31}_{-32}$ | $23^{+16}_{-9.0}$ | $33.3^{+5.1}_{-5.0}$ | 63/73 |
## Extended Data Table 6 | GRB 051103 spectral fits

| Time interval (s) | model | $\alpha$ | $E_p$ (keV) | $kT$ (keV) | $R$ (km) | Flux (20 keV–10 MeV) ($10^{-6}$ erg cm$^{-2}$ s$^{-1}$) | $\chi^2$/dof |
|------------------|-------|----------|-------------|-----------|---------|---------------------------------|-------------|
| **Three-channel spectra** |       |          |             |           |         |                                 |             |
| -0.004 – -0.002  | CPL   | -0.32$^{+0.43}_{-0.36}$ | 1380$^{+960}_{-640}$ | –         | –       | 207$^{+817}_{-94}$ | –           |
| -0.002 – 0.002   | CPL   | -0.13$^{+0.18}_{-0.17}$  | 1250$^{+590}_{-290}$ | –         | –       | 1150$^{+520}_{-240}$ | –           |
| 0.002 – 0.032    | CPL   | 0.20$^{+0.18}_{-0.16}$   | 3620$^{+790}_{-1540}$ | –         | –       | 940$^{+1370}_{-430}$ | –           |
| 0.032 – 0.064    | CPL   | 0.64$^{+0.73}_{-0.43}$   | 930$^{+350}_{-240}$  | –         | –       | 116$^{+41}_{-20}$  | –           |
| 0.064 – 0.096    | CPL   | 0.28$^{+0.40}_{-0.31}$   | 607$^{+153}_{-97}$  | –         | –       | 42$^{+7}_{-5}$  | –           |
| 0.096 – 0.128    | BB    | –        | –           | 93$^{+6}_{-7}$ | 47$^{+7}_{-7}$ | 13.1$^{+2.6}_{-1.5}$ | 0.8/1      |
| **Multichannel spectra** |       |          |             |           |         |                                 |             |
| 0.000 – 0.064    | CPL   | -0.02$^{+0.08}_{-0.08}$ | 2570$^{+160}_{-150}$ | –         | –       | 444$^{+27}_{-25}$ | 93/77       |
| CPL+BB           | 0.39$^{+0.34}_{-0.24}$ | 2790$^{+200}_{-130}$ | 129$^{+22}_{-18}$ | 35.5$^{+18.1}_{-8.9}$ | 444$^{+32}_{-31}$ | 83/75       |
| 0.064 – 0.128    | CPL   | 0.47$^{+0.25}_{-0.23}$  | 565$^{+153}_{-45}$ | –         | –       | 34.2$^{+3.1}_{-2.8}$ | 57/58       |
|                  | BB    | 0.66$^{+1.30}_{-0.87}$  | 320$^{+119}_{-67}$ | –         | –       | 5.5$^{+1.0}_{-0.9}$ | 29/43       |
|                  | –     | –        | 75$^{+9}_{-8}$  | 45$^{+9}_{-8}$ | –       | 5.1$^{+0.8}_{-0.7}$ | 30/44       |
| 0.128 – 0.192    | CPL   | -0.30$^{+0.06}_{-0.06}$ | 2300$^{+150}_{-140}$ | –         | –       | 162$^{+9}_{-9}$  | 127/85      |
|                  | CPL+BB| 0.08$^{+0.28}_{-0.19}$ | 2690$^{+1210}_{-180}$ | 107$^{+11}_{-10}$ | 36$^{+6}_{-7}$ | 162$^{+11}_{-10}$ | 98/83       |