High-Resolution and High-Sensitivity wanted: the impact of SKA on GRBs

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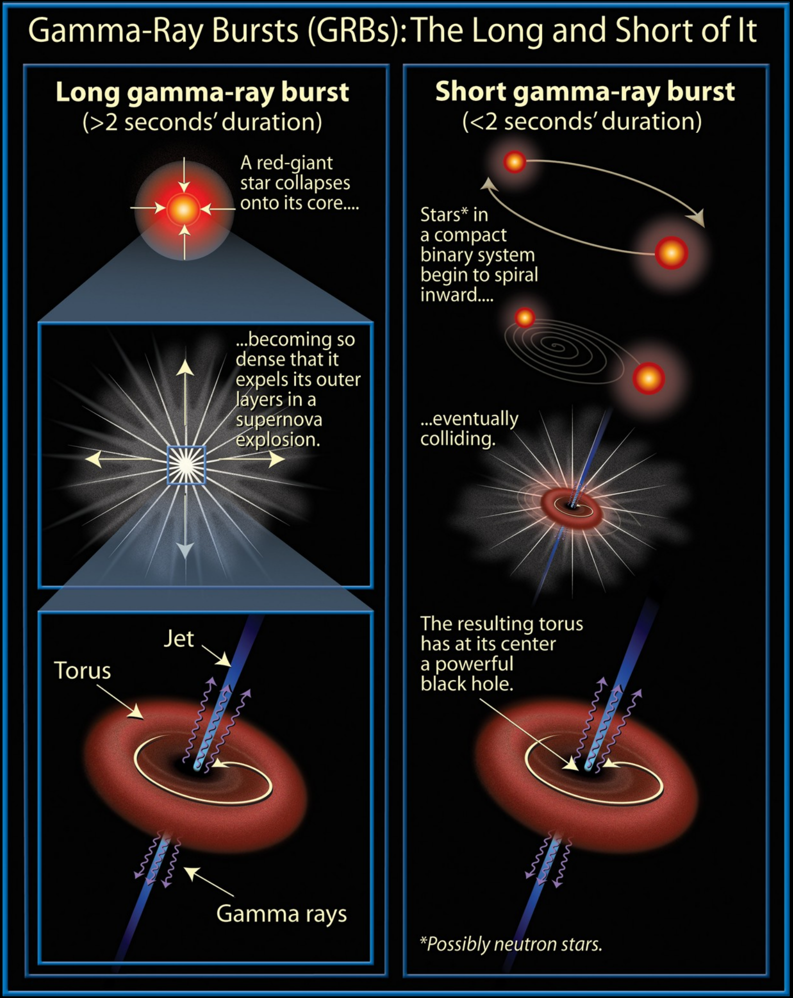
Contents

1. Introduction

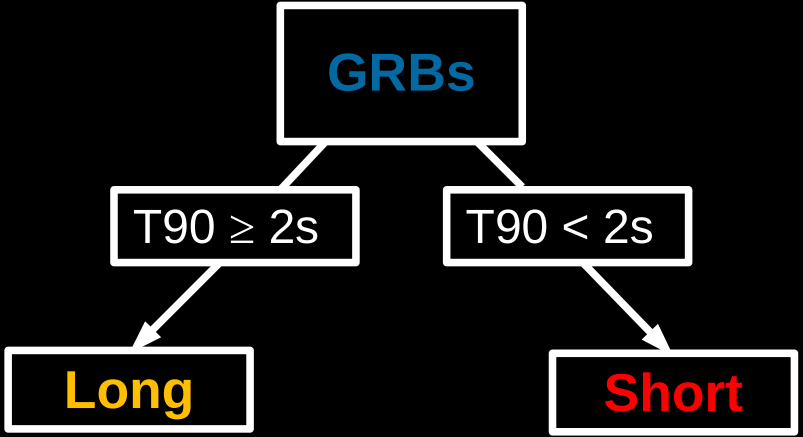
1.1 Intro: Short and Long GRBs



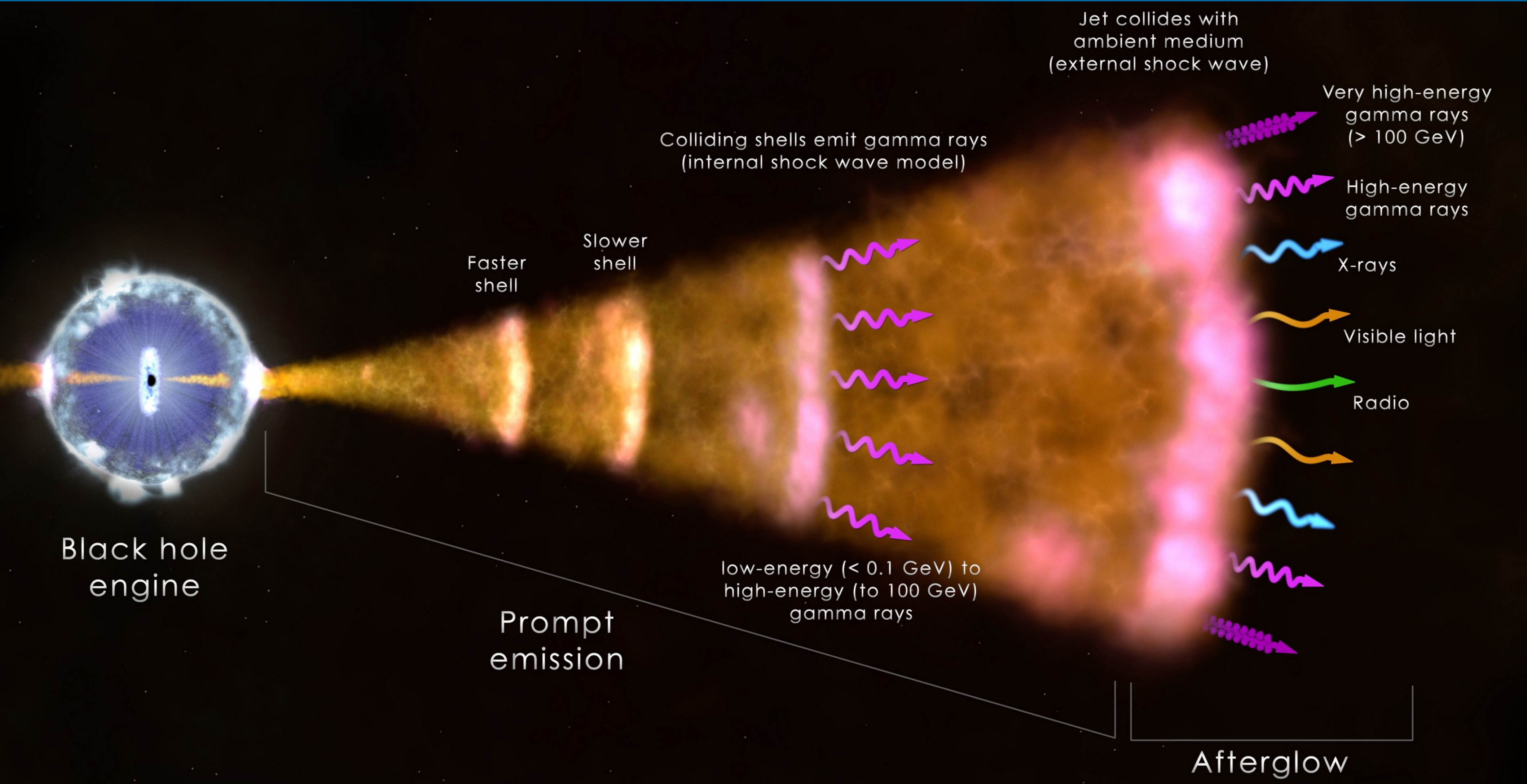
Credits: NASA and A. Feild (STScI)

GRBs are brief flashes observed in γ- and X-rays.

They are the *most powerful* explosions in the Universe



1.2 Intro: Prompt and Afterglow emission



2. GRBs in Radio

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Long Lasting
(≈ weeks up to years!)

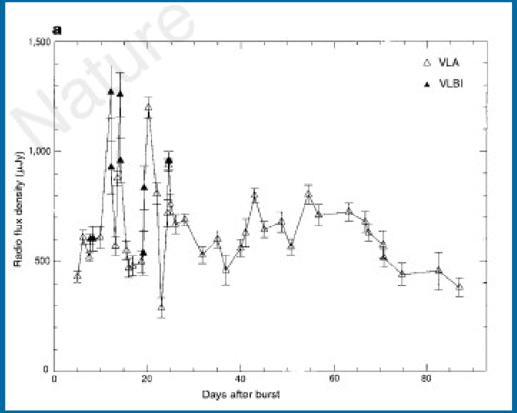
30% detection rate

Early Scintillation

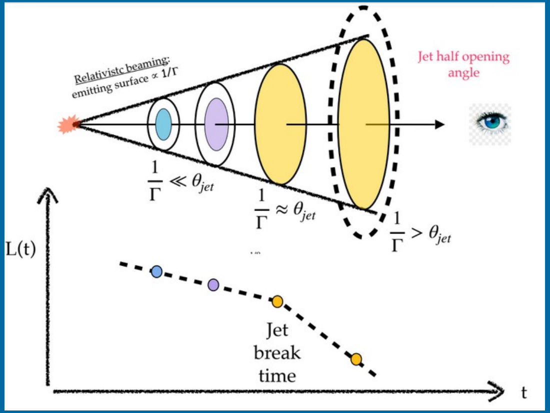
Jet break

Radio "Calorimetry"

Interferometry and VLBI

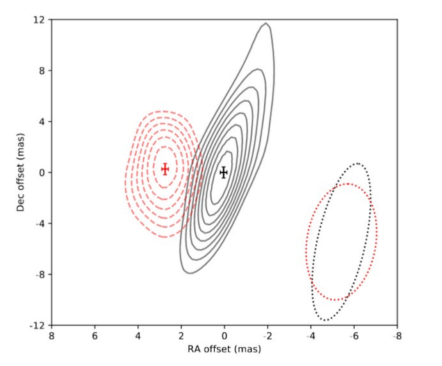


Scintillation of GRB 970508 at 8.46 GHz. From *Frail et al. 1997.*

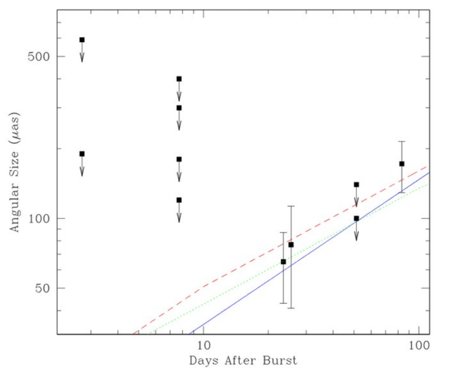


From a lecture by G. Ghirlanda

2.1 GRBs in Radio: VLBI studies



Superluminal motion of GRB 170817A (75d to 230d at 4.5 GHz). From *Mooley et al. 2018.*



Expansion of GRB 030329. From *Taylor et al. 2004.*

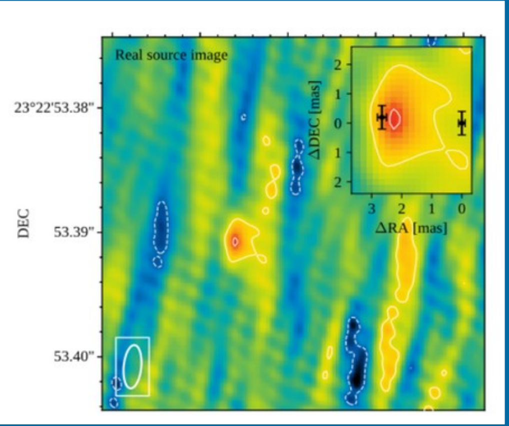
High angular resolution

Superluminal motion

Size of the outflow

Expansion of the jet

Galaxy *vs* Afterglow



Displacement and size of the outflow emission from GRB 170817A at 4.85 GHz (207d). From *Ghirlanda et al. 2019.*

3. Scientific cases

3.1 Scientific cases: GRB 201015A

//
TITLE: GCN CIRCULAR
NUMBER: 28632
SUBJECT: GRB 201015A: Swift detection of a burst
DATE: 20/10/15 22:58:36 GMT
FROM: David Palmer at LANL <palmer@lanl.gov>

V. D'Elia (SSDC), E. Ambrosi (INAF-IASFPA), S. D. Barthelmy (GSFC), A. D'Ai (INAF-IASFPA), J.D. Gropp (PSU), N. J. Klingler (PSU), A. Y. Lien (GSFC/UMBC), D. M. Palmer (LANL), B. Sbarufatti (PSU) and M. H. Siegel (PSU) report on behalf of the Neil Gehrels Swift Observatory Team:

At 22:50:13 UT, the Swift Burst Alert Telescope (BAT) triggered and located GRB 201015A (trigger=1000452). Swift did not slew immediately to the burst due to an observing constraint.
The BAT on-board calculated location is
RA, Dec 354.343, +53.393 which is
RA(J2000) = 23h 37m 22s
Dec(J2000) = +53d 23' 36"
with an uncertainty of 3 arcmin (radius, 90% containment, including systematic uncertainty). The BAT light curve showed a multi-peaked structure with a duration of about 10 sec. The peak count rate was ~700 counts/sec (15-350 keV), at ~0 sec after the trigger.

Due to an observing constraint, Swift will not slew until T0+51.6 minutes. There will be no XRT or UVOT data until this time.

Burst Advocate for this burst is V. D'Elia (delia AT ssdc.asi.it). Please contact the BA by email if you require additional information regarding Swift followup of this burst. In extremely urgent cases, after trying the Burst Advocate, you can contact the Swift PI by phone (see Swift TOO web site for information: http://www.swift.psu.edu/)

$z \approx 0.423$
E_iso ≈ 10^50 erg

3.1 Scientific cases: GRB 201015A

//

TITLE: GCN CIRCULAR
NUMBER: 28659
SUBJECT: MAGIC observations of GRB 201015A: hint of very high energy gamma-ray signal
DATE: 20/10/16 16:48:37 GMT
FROM: Oscar Blanch at MAGIC Collaboration <blanch@ifae.es>

O.Blanch (IFAE-BIST Barcelona), M. Gaug (UAB Barcelona), K. Noda (ICRR University of Tokyo),
A. Berti (INFN Torino), E. Moretti (IFAE-BIST Barcelona), D. Miceli (University of Udine and INFN Trieste),
P. Gliwny (University of Lodz) S. Ubach (UAB Barcelona), B. Schleicher (University of Wuerzburg),
M. Cerruti (University of Barcelona) and A. Stamerra (INAF Rome) on behalf of the MAGIC collaboration
report:

On October 15, 2020, the MAGIC telescopes observed GRB 201015A following the Swift-BAT trigger (D'Elia et al., GCN 28632). MAGIC started observations under good conditions about 40 seconds after the initial Swift trigger, revealing a hint of signal with significance >3 sigma in the very high energy band. Refined off-line analyses of the data are ongoing.

Further MAGIC observations on GRB 201015A are planned in the coming night. We strongly encourage follow-up observations by other instruments at all wavelengths.

The MAGIC point of contact for this burst is O. Blanch (blanch@ifae.es). Burst Advocate for this burst is M. Gaug (Markus.Gaug@uab.cat)

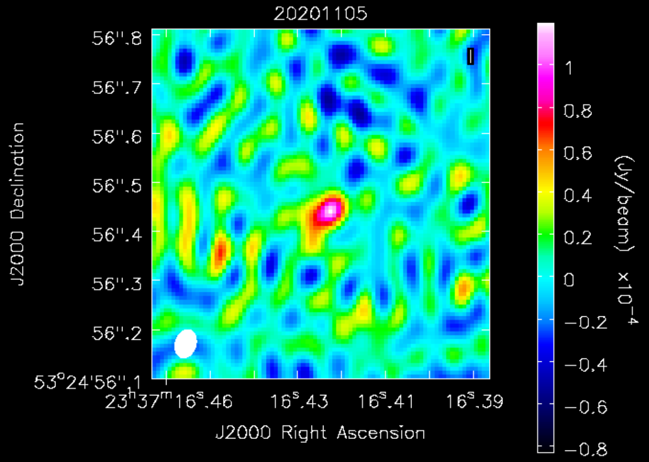
MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

Swift TOO web site for information: http://www.swift.psu.edu/)

3.1 Scientific cases: GRB 201015A

EVN

3 epochs
4.57 – 5.11 GHz
rms ≈ 10 μJy/beam
beam ≈ 3.4x2.8 mas

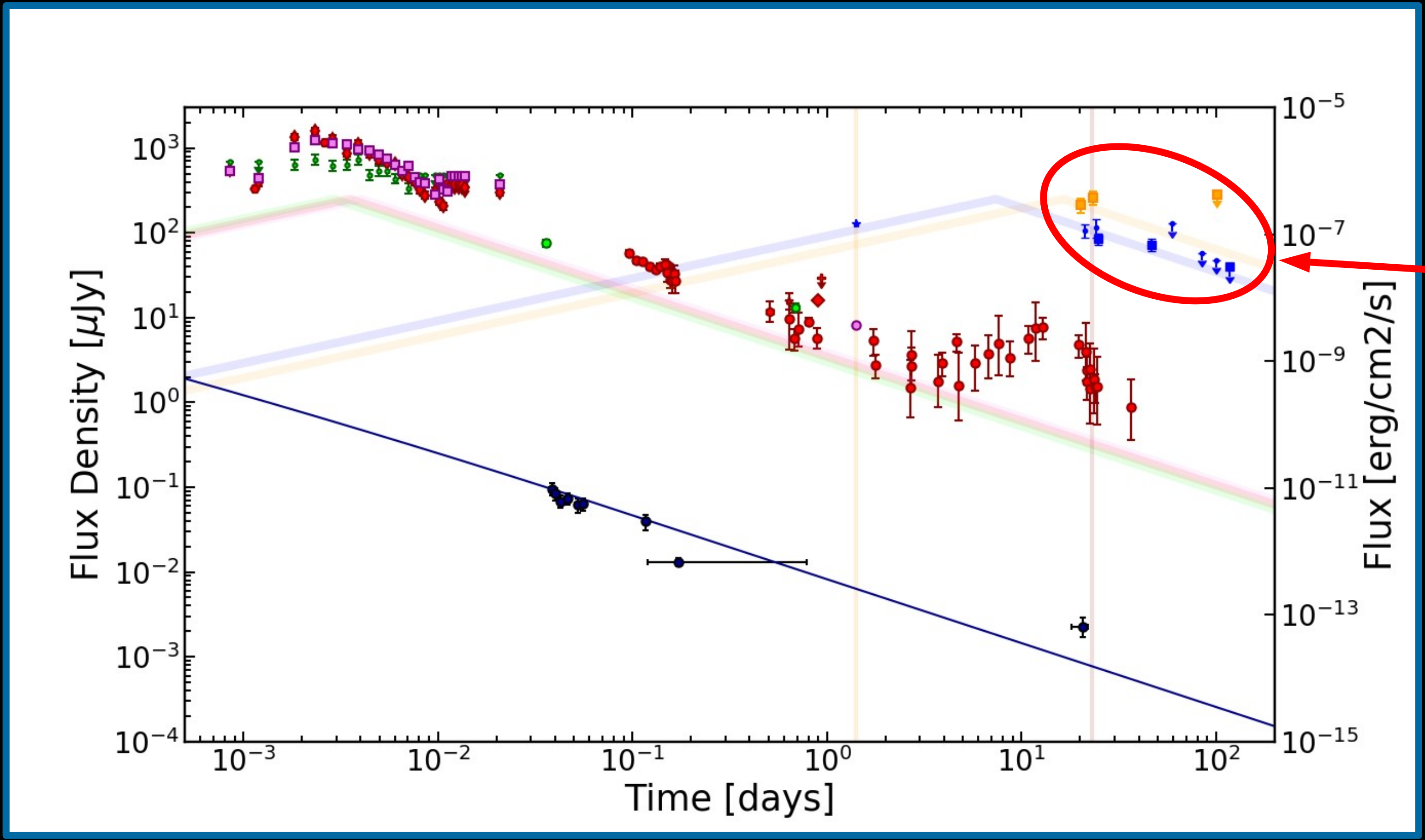


e-MERLIN

3 epochs
1.5 GHz
rms ≈ 44 μJy/beam
beam ≈ 0.18”x0.12”

5 epochs
4.50 – 5.01 GHz
rms ≈ 24 μJy/beam
beam ≈ 0.06”x0.04”

3.1 Scientific case: GRB 201015A



5 GHz:
four detections and 4 upper limits

1.5 GHz:
two detections and an upper limit.

GRB afterglow or ***host galaxy*** emission?

3.2 Scientific case: GRB 200716C

FIRST
Before Spring 2011 - 1.4 GHz

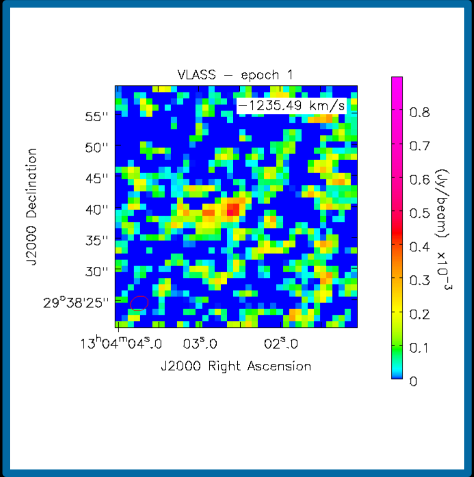
LOFAR (Hardcastle+16)
Before July 2014 - 0.13 to 0.17 GHz

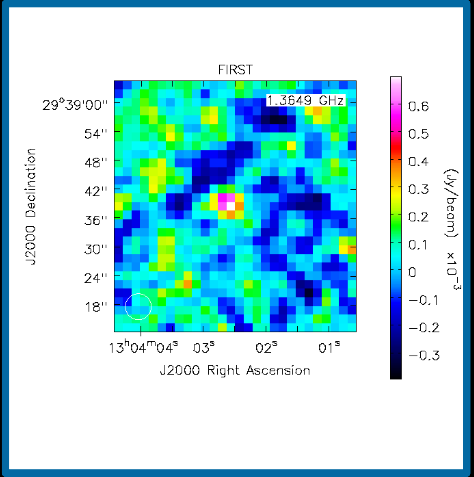
VLASS 1
25 Nov 2017 - 3 GHz

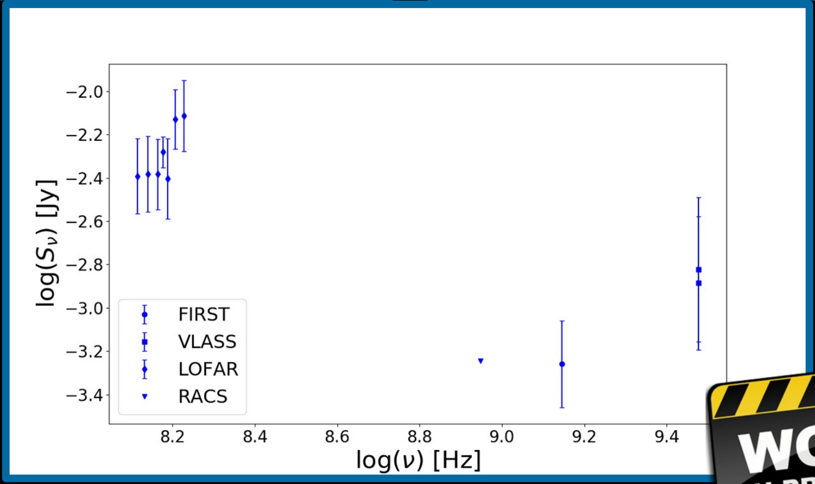
GRB

VLASS 2
9 Oct 2020 - 3 GHz

RACS
22 Sep 2020 - 0.89 GHz







4. SKA impact on GRBs

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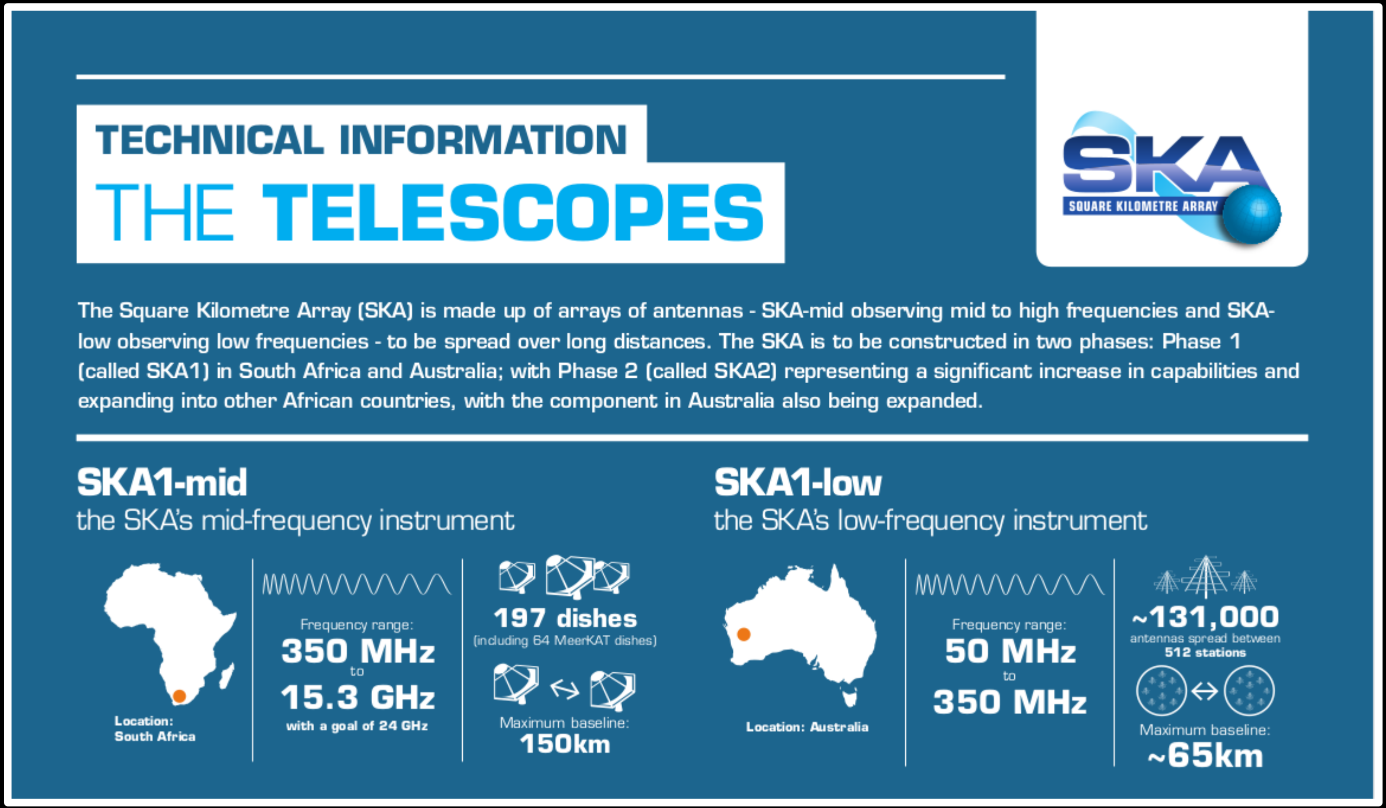
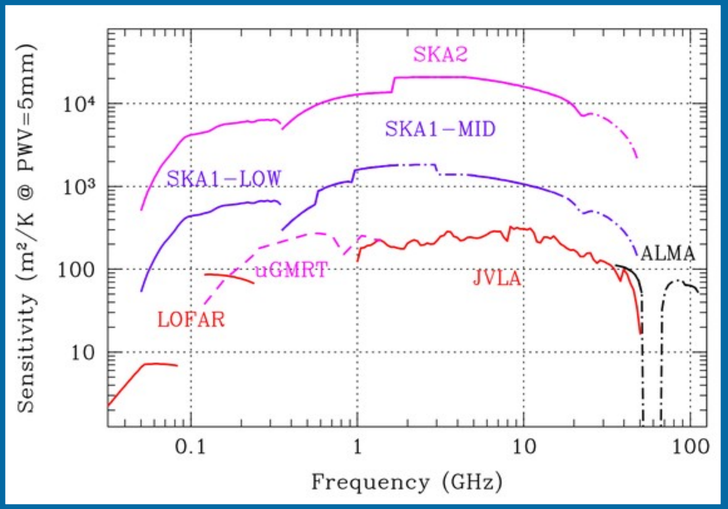
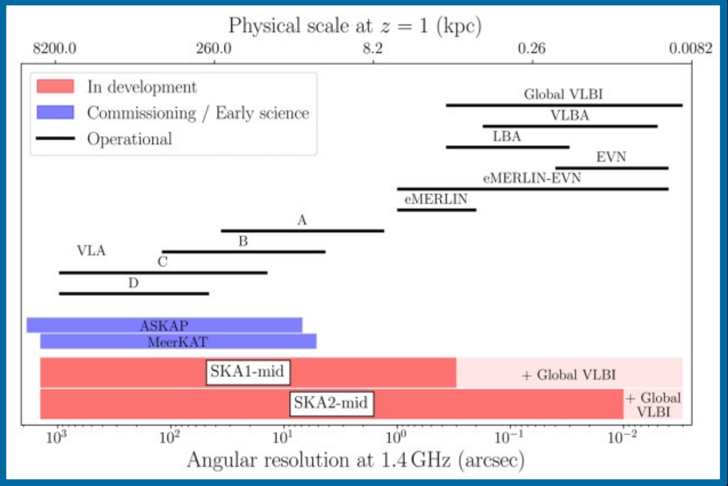


Info sheet from the SKAO Public Website: *https://www.skatelescope.org/technical/info-sheets/*

4. SKA impact on GRBs





10 μJy/beam

1 min at 1.4 GHz!

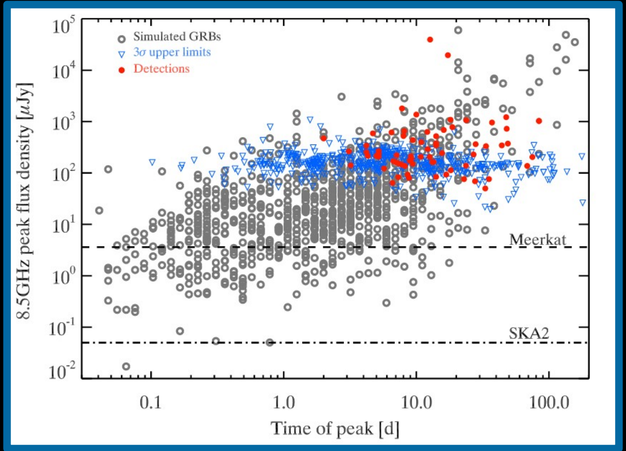
31 sec at 6.7 GHz!

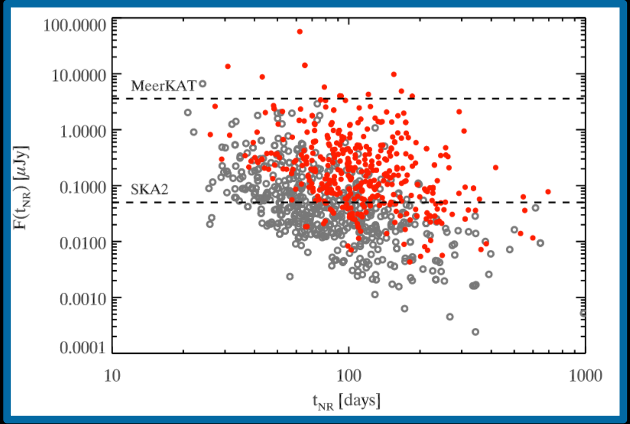
SKA2: 10x SKA1 sensitivity (350 MHz – 24 GHz)

At 1.4 GHz:
0.3 arcsec (SKA1-mid)
10 mas (SKA2-mid)

SKA2: 20x SKA1 angular resolution (50 MHz – 24 GHz)

4. SKA impact on GRBs





From Ghirlanda et al.(2013) - the Italian SKA White Book:
https://www.ira.inaf.it/SKA-Italy/SKA_IT_WP.v4%2Bcover.pdf

- From 30% to almost 100% of detection rate
- From <15% to 50% detections at the transition time
- Amati relation and cosmological parameters
- Orphan Afterglow
- PopIII stars?

… Unknown!

5. Conclusions

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- **Sensitivity**: detection of GRB afterglows
  Angular resolution: resolving out host galaxies
- SKA1 will improve the sensitivity, but **VLBI** will be still needed for the angular resolution
- SKA2, with both its sensitivity and resolution, will allow us to detect *almost 100%* of the radio afterglows

5. Conclusions

- **Sensitivity**: detection of GRB afterglows
  Angular resolution: resolving out host galaxies
- SKA1 will improve the sensitivity, but **VLBI** will be still needed for the angular resolution
- SKA2, with both its sensitivity and resolution, will allow us to detect *almost 100%* of the radio afterglows

THANKS!!!

Backup Slides

1.1 Intro: Short and Long GRBs

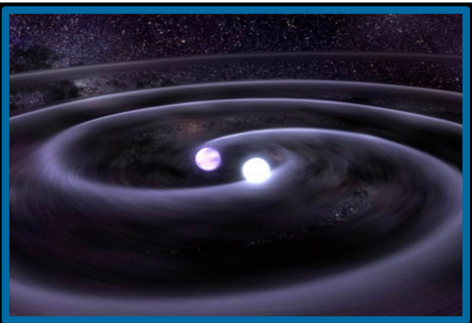
T90 < 2 s
(*Kouveliotou+93*)

Harder spectrum
(*Hurley+92, Kouveliotou+93, Ghirlanda+04*, ...)

< z > ≈ 0.5
(*Berger13*, ...)

All morphological types of galaxies
(*Berger09, Fong+13, Berger13*, ...)

[Recently] Associated with KNe
(*Tanvir+13*, …)



Credits: NASA/Goddard Space Flight Center

T90 ≥ 2 s
(*Kouveliotou+93*)

Softer spectrum
(*Hurley+92, Kouveliotou+93, Ghirlanda+04*, ...)

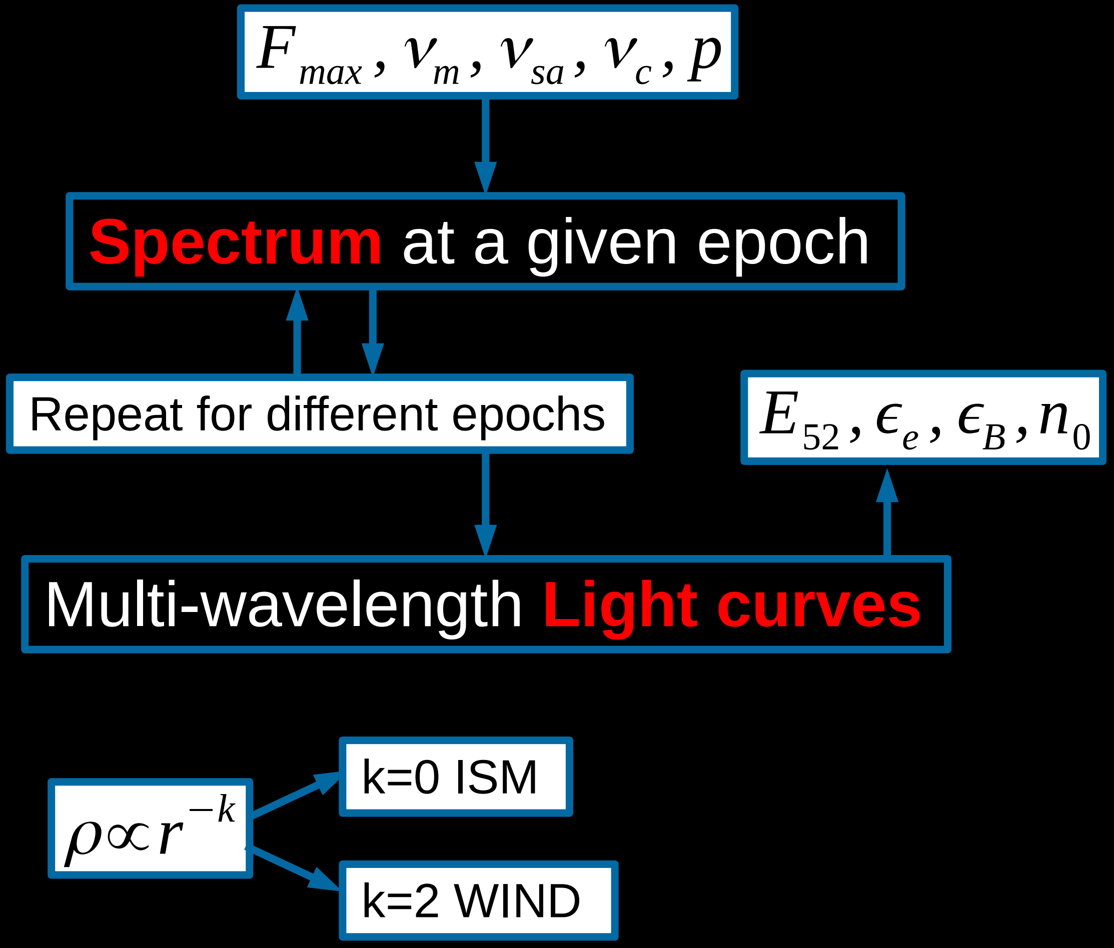
< z > ≈ 2.0
(*Berger13*, ...)

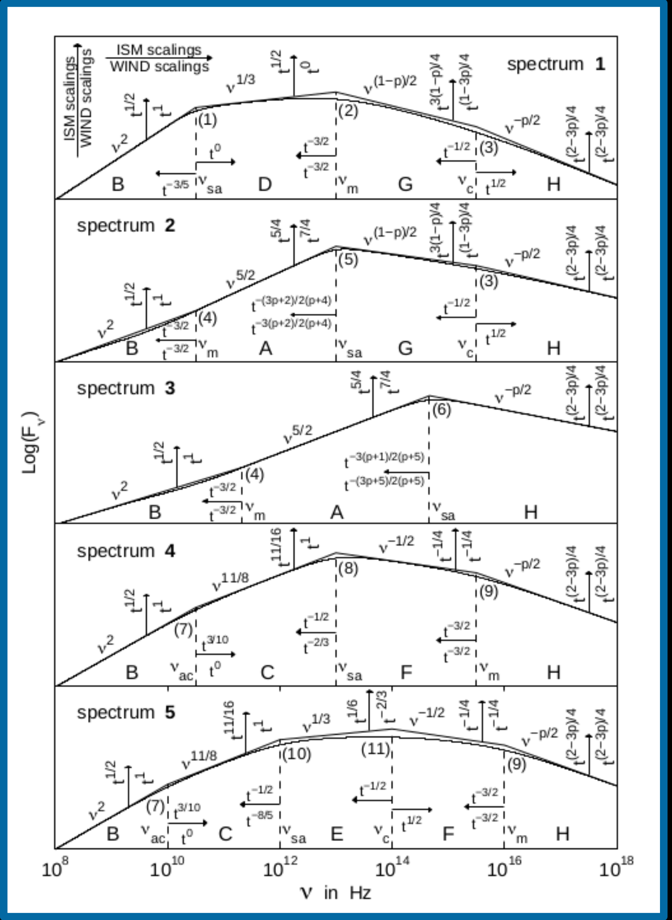
High star-forming regions
(*Berger09, Fong+13, Berger13*, ...)

[Almost always] Associated with SNe
(*Galama+98*, …)

Credits: Hubble Legacy Archive

Backup Slides: Afterglow Modeling





Models for the spectrum and the temporal evolution of the afterglow. From *Granot & Sari (2002).*

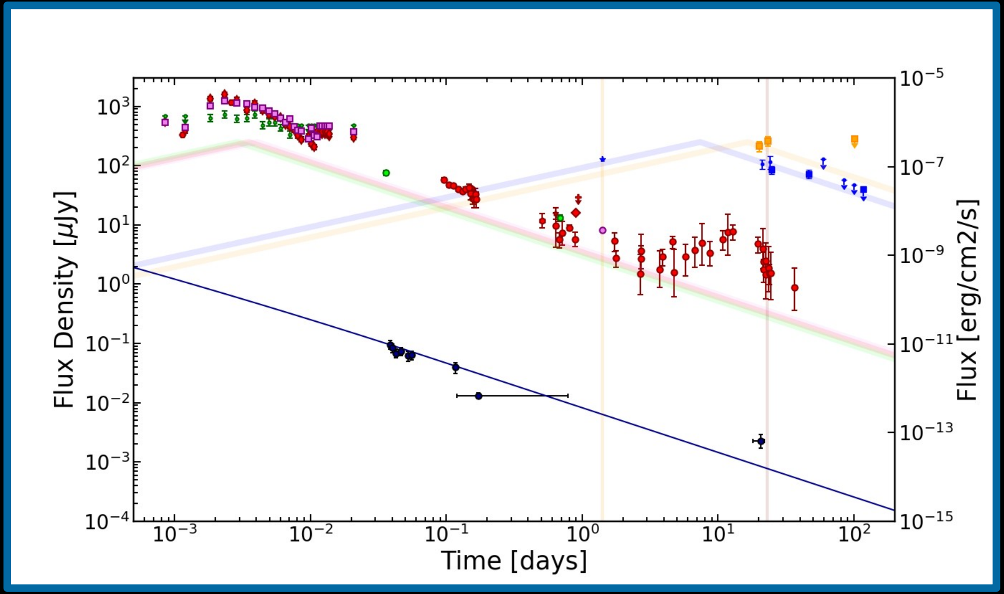
Backup Slides: GRB 201015A Observations

Array	Date	Freq [GHz]	Flux [μJy]	R.M.S [μJy/beam]
e-MERLIN	20/11/05	4.76	107	17
e-MERLIN	20/11/08	4.76	116	26
EVN	20/11/09	4.84	85	9
EVN	20/12/01	4.91	73	10
e-MERLIN	20/12/14	6.80	-	43
e-MERLIN	21/01/08	4.76	-	19
e-MERLIN	21/01/23	4.76	-	16
EVN	21/02/09	4.91	-	13
e-MERLIN	20/11/04	1.5	213	34
e-MERLIN	20/11/07	1.5	261	40
e-MERLIN	21/01/24	1.5	-	57

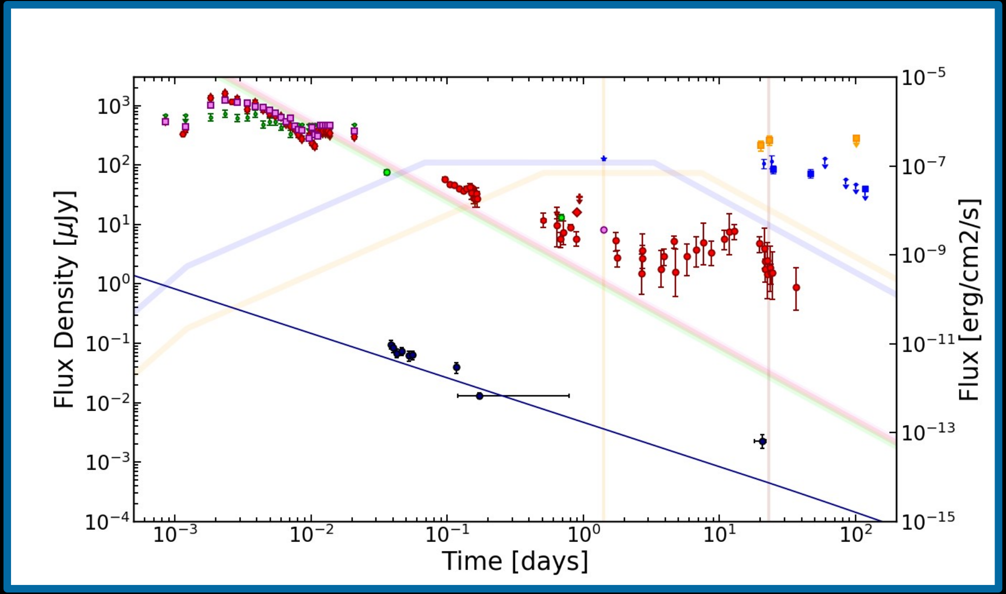
Backup Slides: GRB 201015A Calibration

	Epoch	Flux cal / Fringe Finder	Bandpass	Phase cal	Calibration
e-MERLIN (5 GHz)	20/11/05	1331+3030 (1), 0319+4130 (2)	1407+2827	2322+5057 (3), 2353+5518 (4)	1 → 3,4 → 2 2 → 3,4 → targ
e-MERLIN (5 GHz)	20/11/08	1331+3030 (1)	1407+2827	2322+5057 (2)	1 → 2 → targ
e-MERLIN (5 GHz)	20/12/14, 21/01/08, 21/01/23	1331+3030 (1)	1407+2827	2322+5057 (2), 2353+5518 (3)	1 → 2,3 → targ
EVN	20/11/09, 20/11/09, 21/02/09	0854+2006, 3C84, 0555+3948, 0102+5824	0854+2006, 3C84, 0555+3948, 0102+5824	2353+5518	A-priori amp → fringe fitting and phase cal → selfcal
e-MERLIN (1.5 GHz)	20/11/04, 20/11/07, 21/01/24	1331+3030 (1)	1407+2827	2353+5518 (2)	1 → 2 → targ

Backup Slides: ISM vs WIND

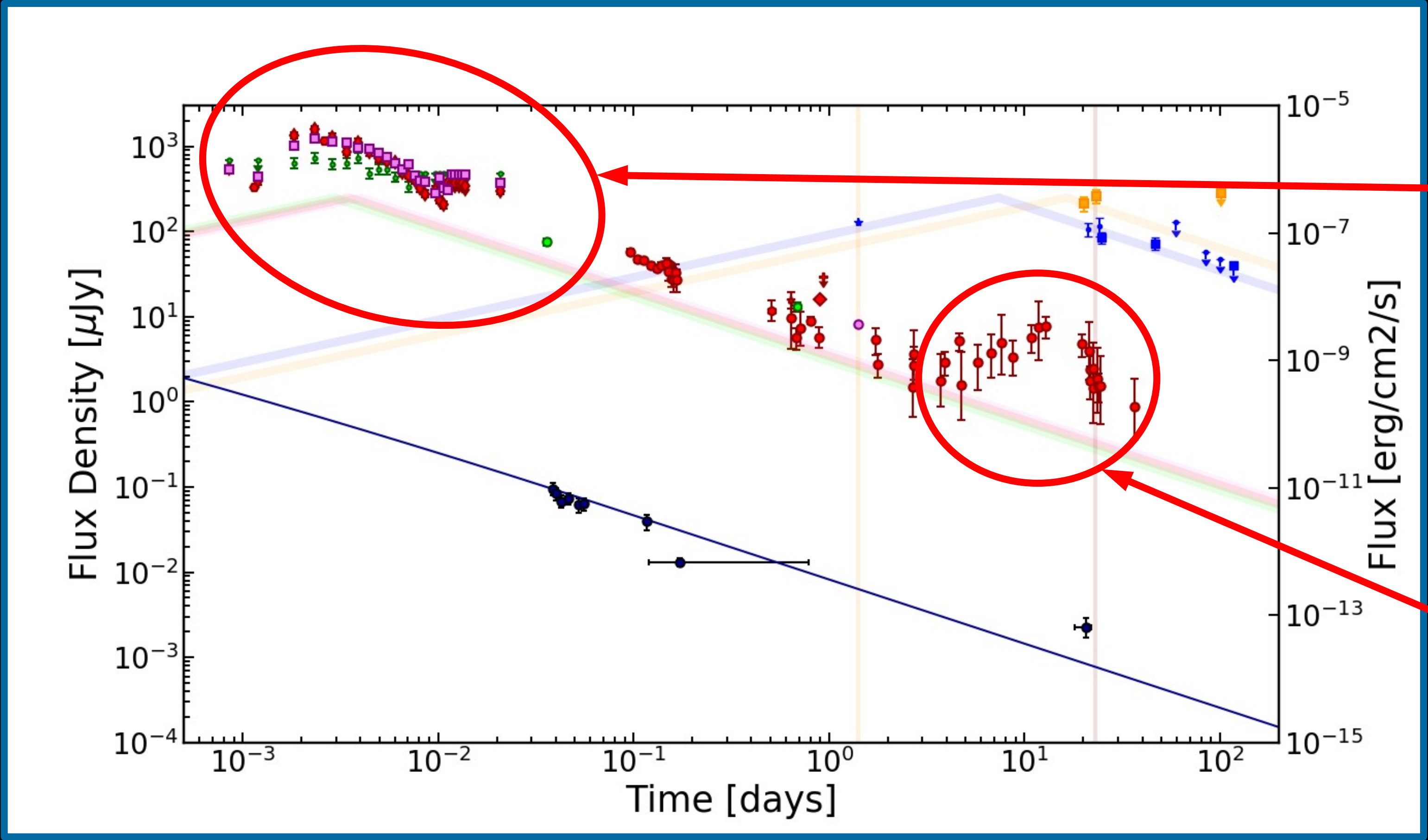


Homogeneous Interstellar medium (ISM)



Wind-like circum-burst medium (WIND)

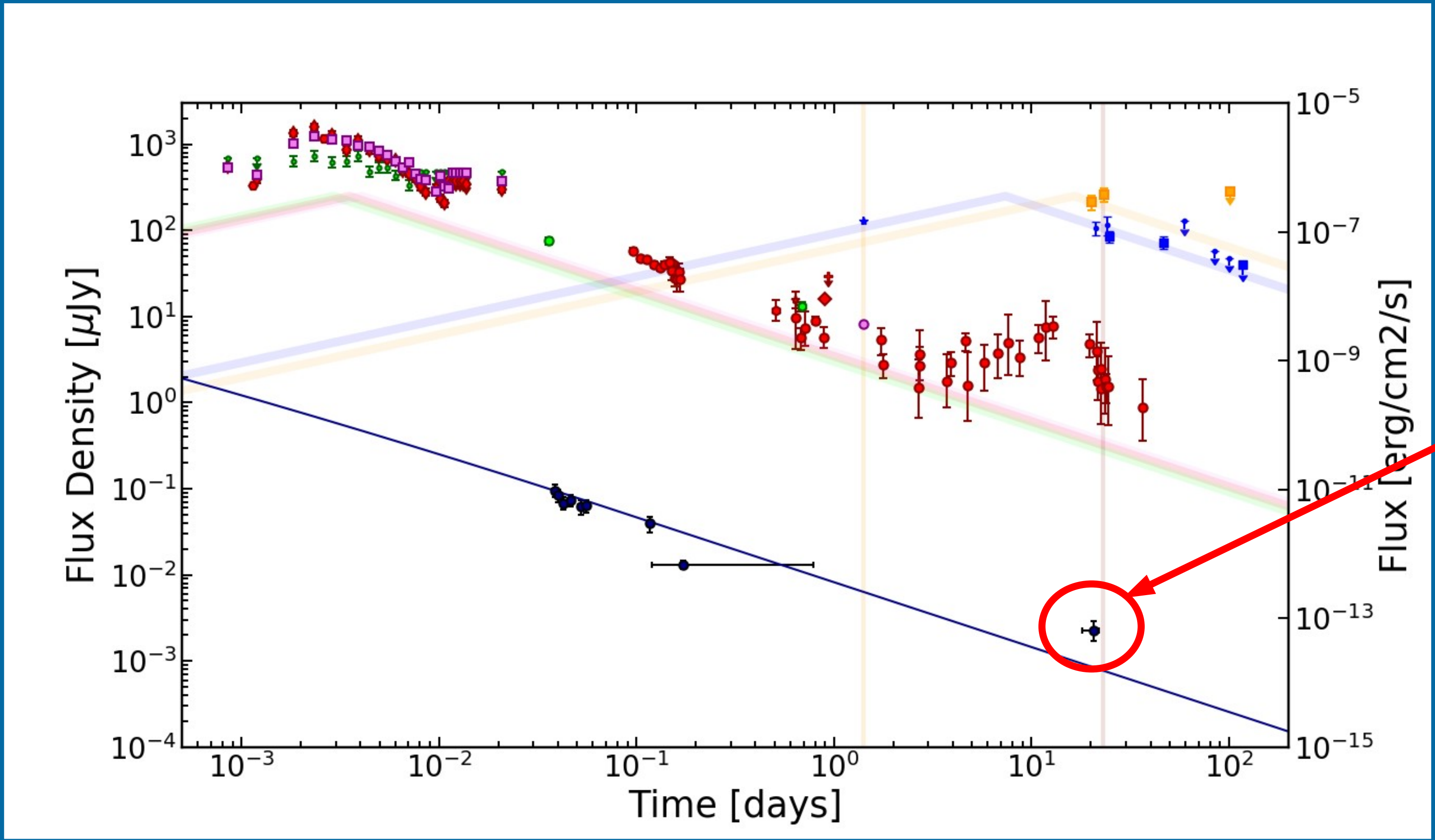
3.1 Scientific case: GRB 201015A



Reverse Shock Component?

SN Ic-BL bump! (*Pozanenko+20, Rossi+21*)

3.1 Scientific case: GRB 201015A

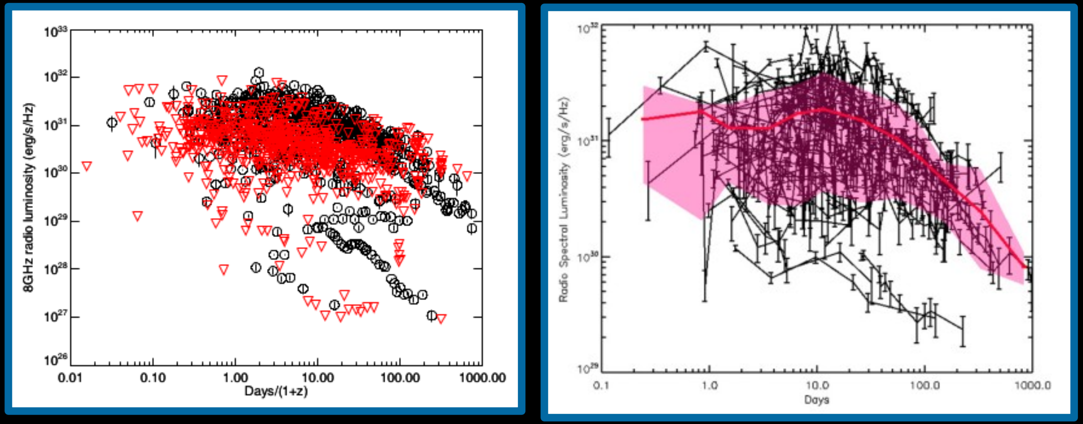


X-ray ***rebrightening*** or something else?

Backup Slides: Parameters @ 1 day

F(m)	ν(sa)	ν(m)	ν(c)	p	ε(B)	ε(e)
250 μJy	1 GHz	100 GHz	2e7 GHz	2.01	0.4	0.8

- z = 0.423
- E(iso) ≈ 10^50
- L ≈ 10^30 erg/s/Hz (*low luminosity*)
- p value hard
- ε(B) unusually high



k-corrected radio spectral luminosities (left) and radio light curves in the observer's frame (right) at 8.5 GHz. From *Chandra & Frail 2012*.

Backup Slides: SKA Performance Sheet

SKA1 Telescope Expected Performance – Imaging

Nominal Frequency	110 MHz	300 MHz	770 MHz	1.4 GHz	6.7 GHz	12.5 GHz
Range [GHz]	0.05-0.35	0.05-0.35	0.35-1.05	0.95-1.76	4.6-8.5	8.3-15.3
Telescope	Low	Low	Mid	Mid	Mid	Mid
FoV [arcmin]	327	120	109	60	12.5	6.7
Max. Resolution (arcsec)	11	4	0.7	0.4	0.08	0.04
Max. Bandwdith [GHz]	0.3	0.3	1	1	4	5
Cont. rms, 1 hr (μJy/beam)[a]	26	14	4.4	2	1.3	1.2
Line rms, 1 hr [μJy/beam][b]	1850	800	300	140	90	85
Resolution Range for Cont. and Line rms [arcsec][c]	12–600	6–300	1–145	0.6–78	0.13–17	0.07–9
Channel width (uniform resolution across max. bandwidth) [kHz]	5.4	5.4	15.2	15.2	61.0	79.3
Spectral zoom windows X narrowest bandwidth [MHz]	4 X 4.0	4 X 4.0	4 X 3.125	4 X 3.125	4 X 3.125	4 X 3.125
Finest zoom channel width [Hz]	244	244	190	190	190	190

Info sheet from the SKAO Public Website: *https://www.skatelescope.org/technical/info-sheets/*