Studying the dynamics and the structure of Gamma-Ray Bursts with the VLBI

Speaker
S.Giarratana

Supervisor
Dr. M. Giroletti

Collaborators
Prof G. Ghirlanda, Dr. O.S. Salafia, Dr. L. Rhodes, Dr. B. Marcote, Dr. M.E. Ravasio and many more...

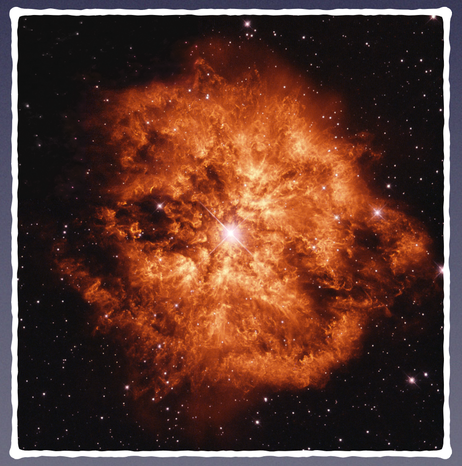
Long and Short

T90 ≥ 2s
(Kouveliotou+93)

< z > ≃ 2.0
(Berger13,...)

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

Associated with SNe
(Galama+98,...)



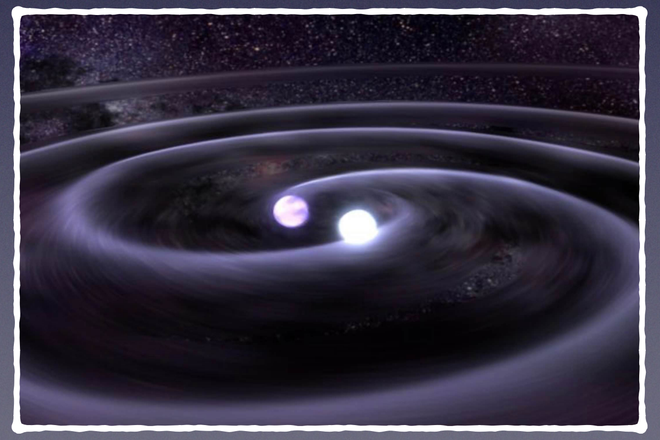
From the Hubble Legacy Archive.
Processing by Judy Schmidt.

T90 < 2s
(Kouveliotou+93)

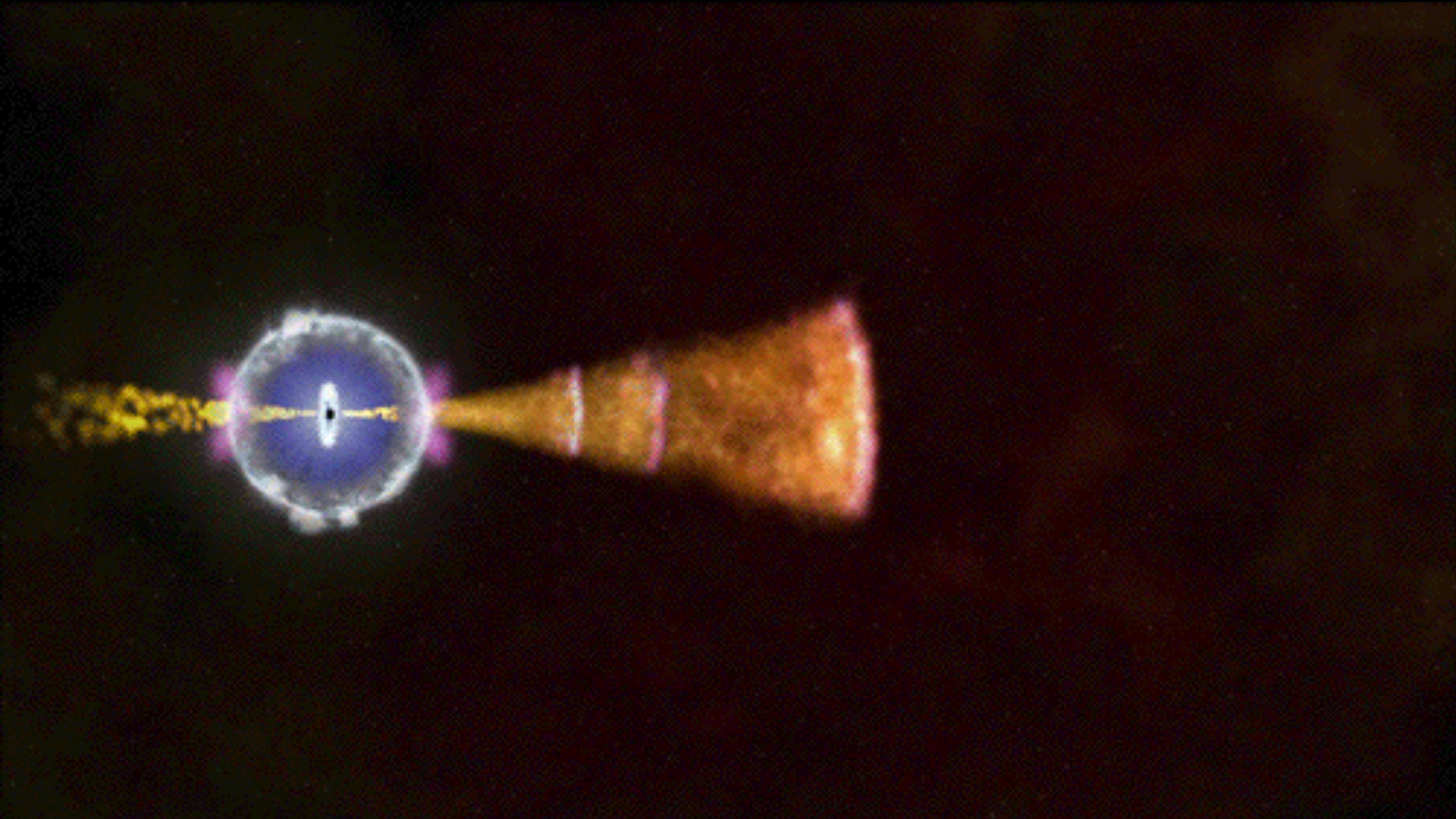
< z > ≃ 0.5
(Berger13,...)

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

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



Credits: NASA's Goddard Space Flight Center



GRBs in Radio

Emission mechanism

Forward vs Reverse shocks

See Om's talk

Geometry

Viewing angle

Collimation angle

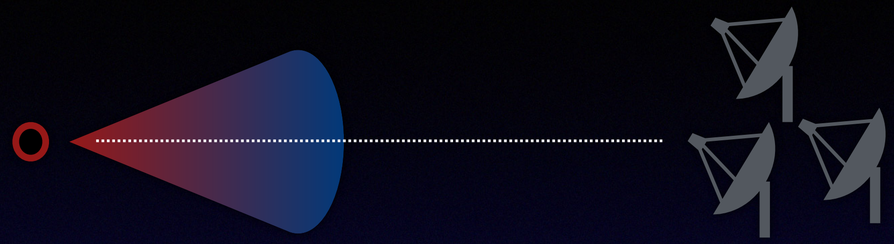
Size and structure

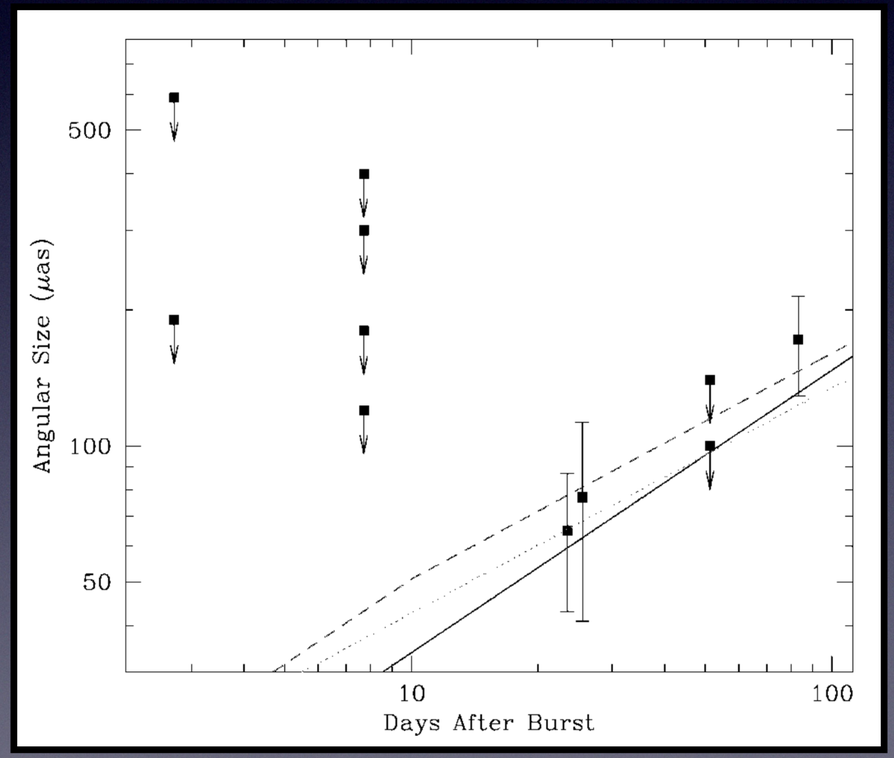
Progenitors

Circumburst density profile

Credits: Sergio Poppi (Inaf Cagliari)

High resolution studies of GRBs

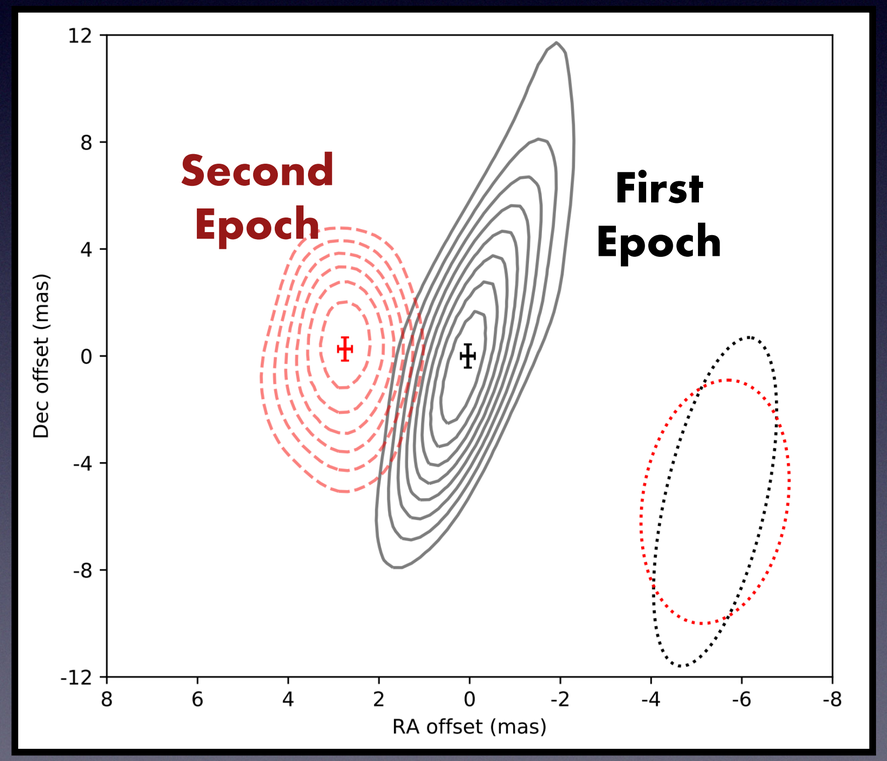




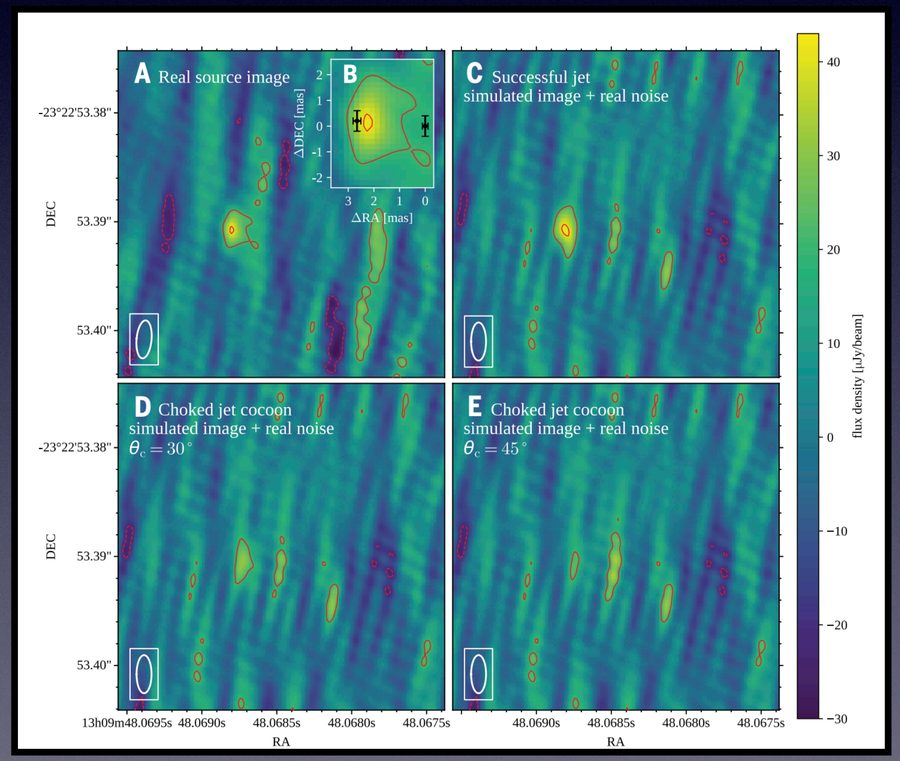
Angular diameter increase: GRB 030329
From *Taylor et al. (2003)*

High resolution studies of GRBs

See Om's talk



Centroid displacement: GRB 170817A
From *Mooley et al. (2018)*

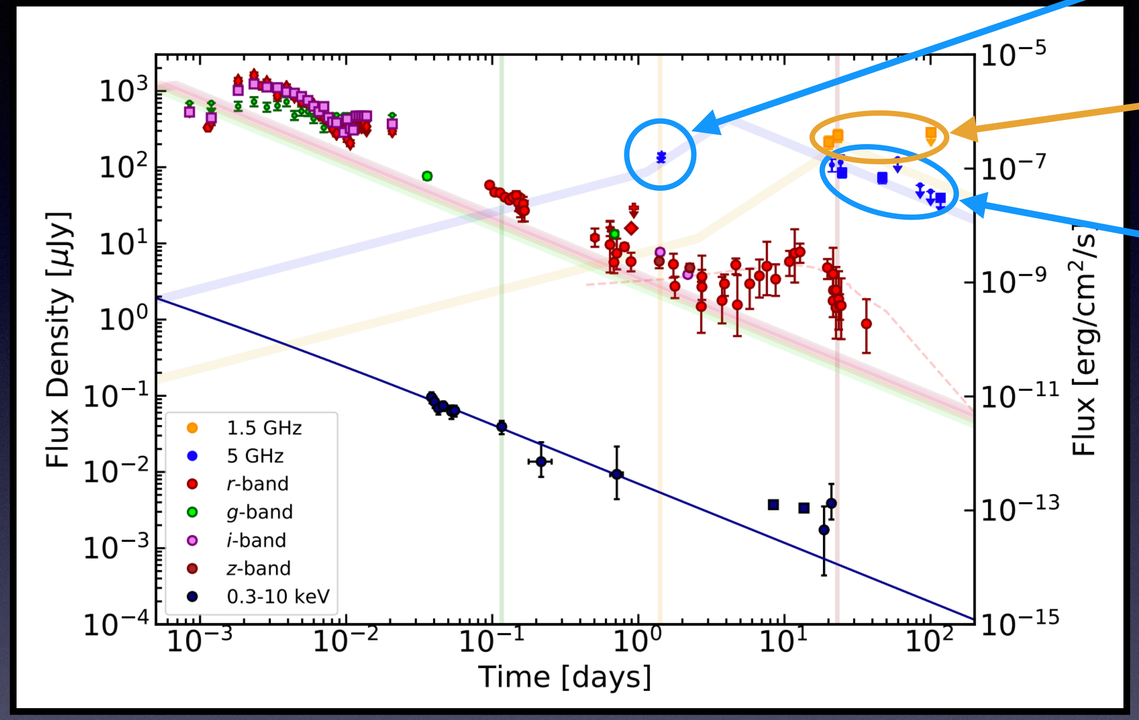


Real and simulated images: GRB 170818A
From *Ghirlanda et al. (2019)*

GRB 201015A

GRB 201015A

Hint of VHE emission!



VLA

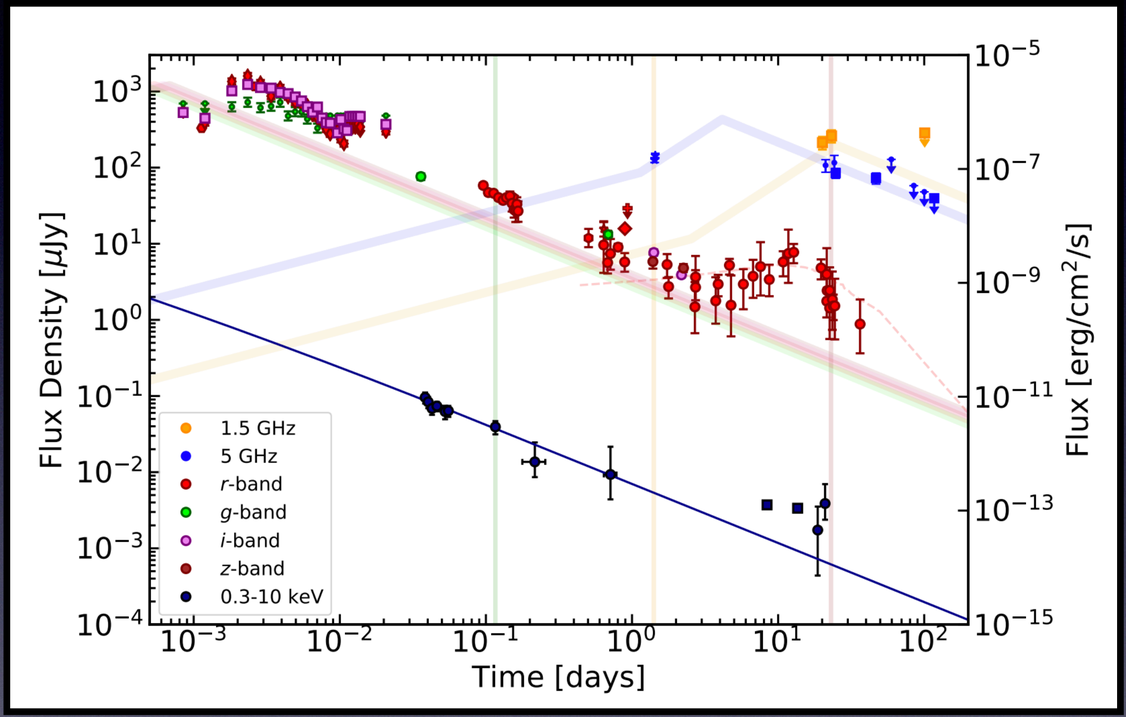
eMERLIN

EVN & eMERLIN

Multi-wavelength afterglow light curves of GRB 201015A
From *Giarratana et al. (2022)*

See also: *Suda et al. (2022), Komesh et al. (2023), Ror et al. (2023)*

GRB 201015A

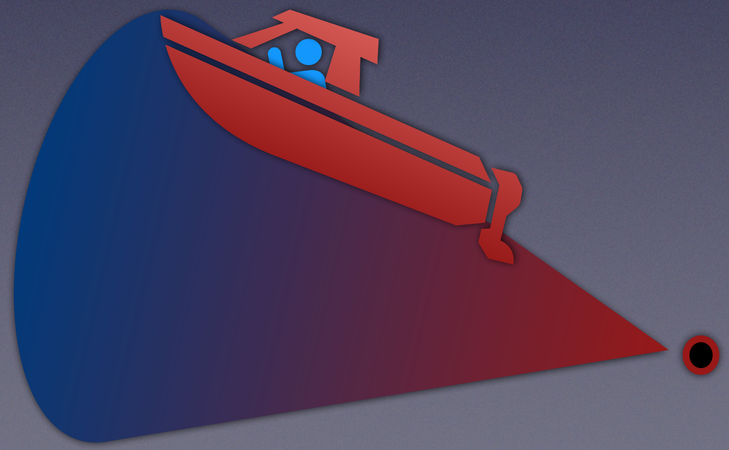


Multi-wavelength afterglow light curves of GRB 201015A
From *Giarratana et al. (2022)*

GRB	z	mas	pc	if z = 0.426
170817A	0.0093	2.44	0.46	0.08
030329A	0.1685	0.17	0.5	0.09

Displacement	**Size**
Gamma(Dec) < 61	< 5 pc at 25 d
Gamma(RA) < 40	< 16 pc at 47 d

GRB 221009A:
the Brightest Of All Time



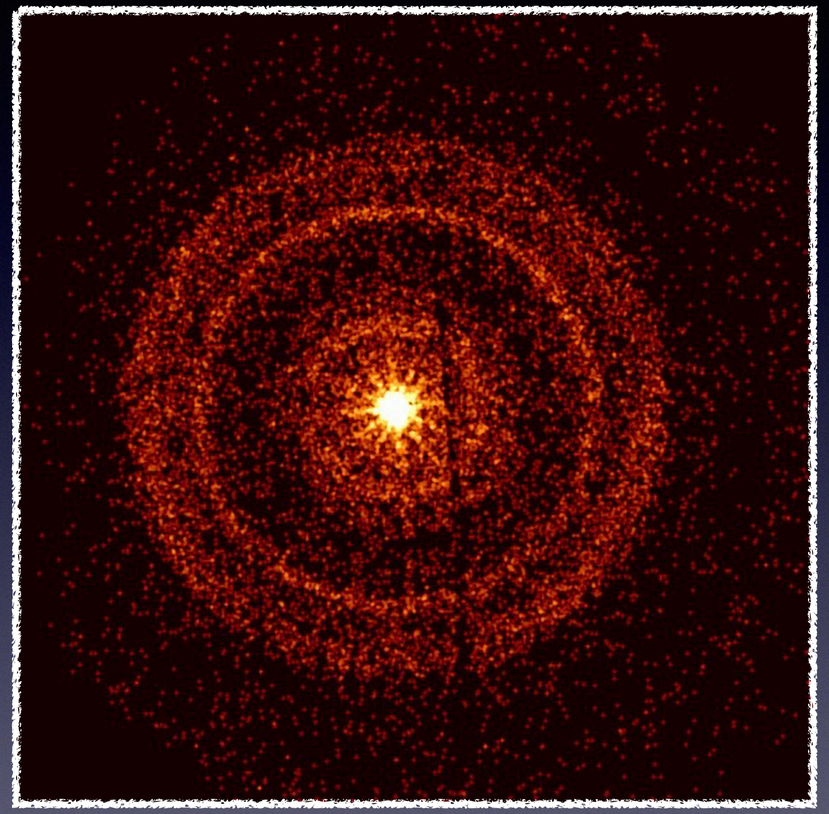
GRB 221009A

TeV emission!

- $T_{90} = 327$ s (10 - 1000 keV; GCN 32642)

- $E_{iso} \simeq 3 \times 10^{54}$ erg (GCN 32668)

- z = 0.151 (GCN 32648, 32686,...)



Credit: NASA/Swift/A. Beardmore (University of Leicester)

A Significant Sudden Ionospheric Disturbance associated with Gamma-Ray Burst GRB 221009A

Laura A. Hayes[1] and Peter T. Gallagher[2]

[1] *European Space Agency (ESA), European Space Research and Technology Centre (ESTEC), Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands*

[2] *Astronomy & Astrophysics Section, DIAS Dunsink Observatory, Dublin Institute for Advanced Studies, Dublin, Ireland*

ABSTRACT

We report a significant sudden ionospheric disturbance (SID) in the D–region of Earth's ionosphere (∼60–100 km), which was associated with the massive γ–ray burst GRB 221009A on 2022 October 9. We identified the SID over northern Europe–a result of ionisation by X– and γ–ray emission from the GRB–using very low frequency (VLF) radio waves as a probe of the D–region. These observations demonstrate that an extra–galactic GRB (z∼0.151) can have a significant impact on the terrestrial atmosphere and illustrates that the Earth's ionosphere can be used as a giant X– and γ–ray detector. Indeed, these observations may provide an insight into the impacts of GRBs on the ionospheres of planets in our Solar System and beyond.

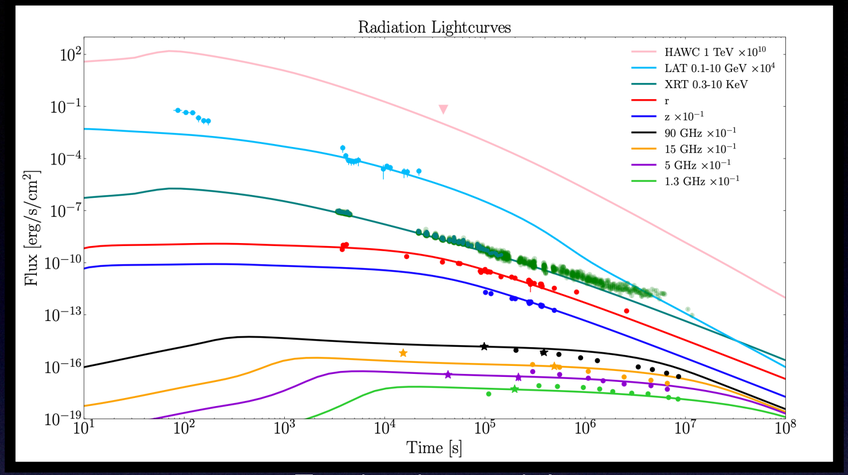
Afterglow Models

(1) *Ren et al. (2023)*: top-hat jet in a wind-like environment

(2) *Sato et al. (2023)*: two-component jet in a uniform environment

(3) *Laskar et al. (2023)*: FS from a jet in a low-density wind-like environment

(4) O'Connor *et al. (2023)*: structured jet in a medium with k < 4/3



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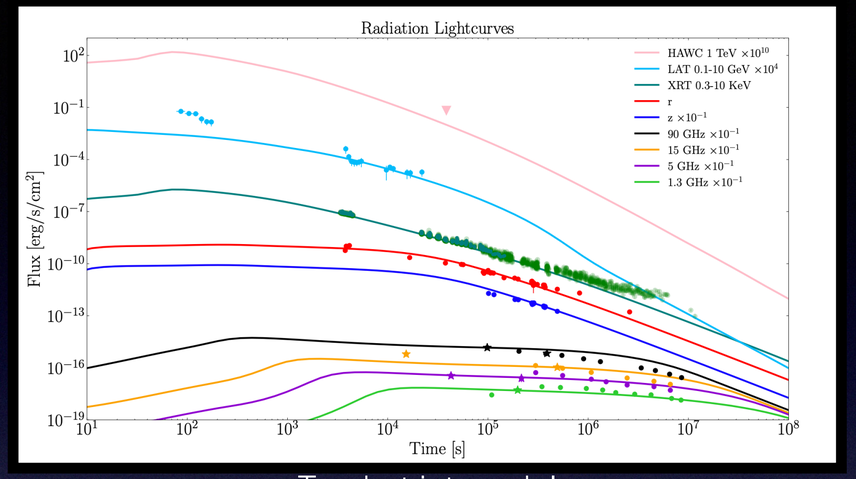

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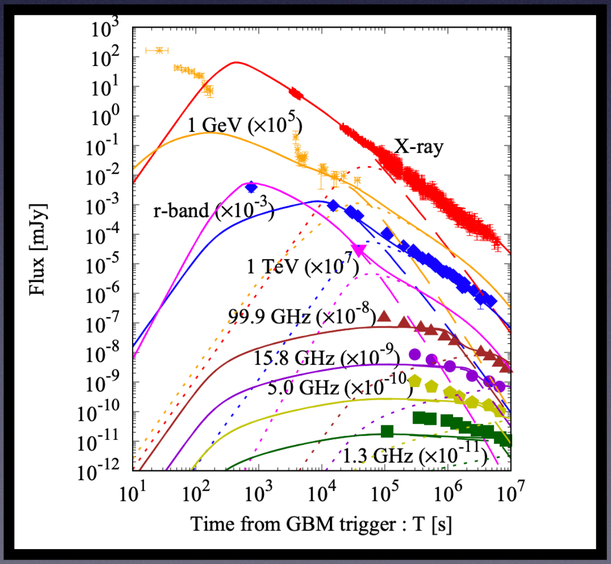

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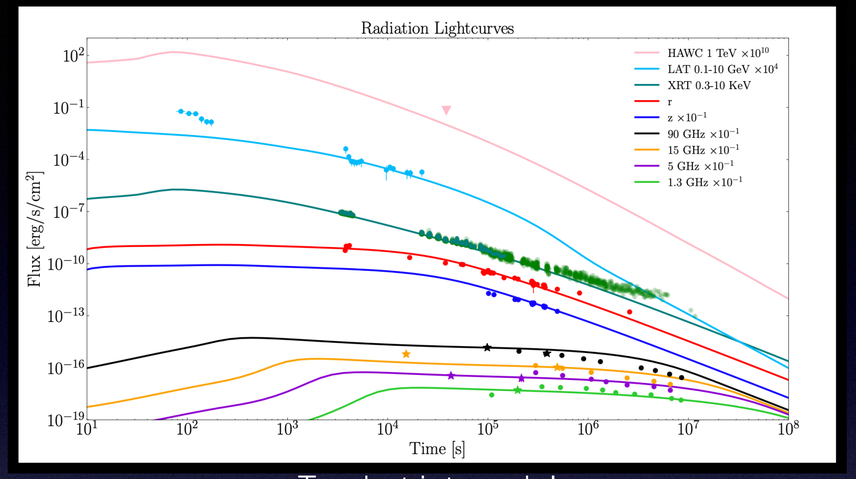

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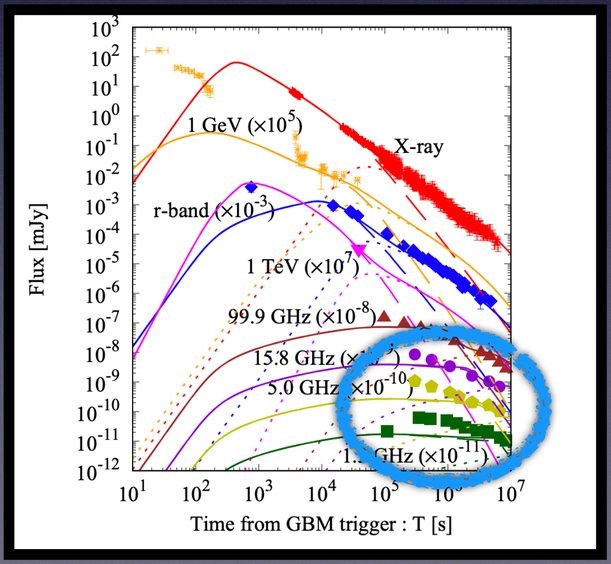

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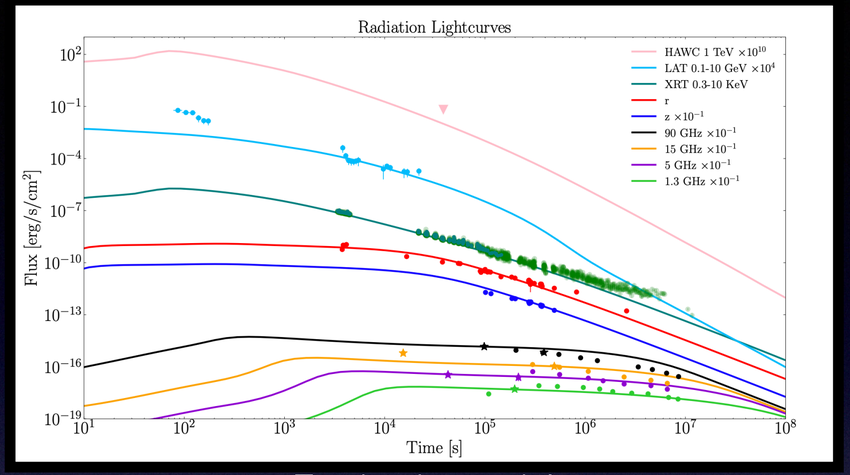

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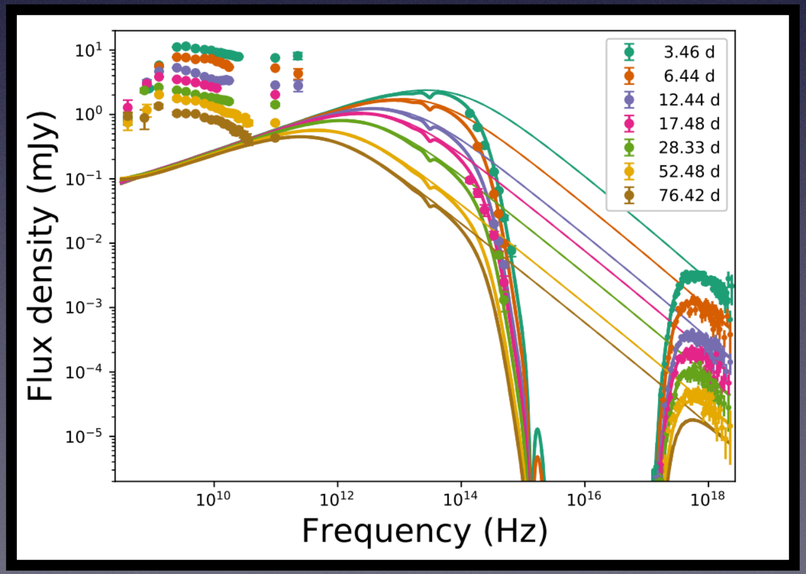
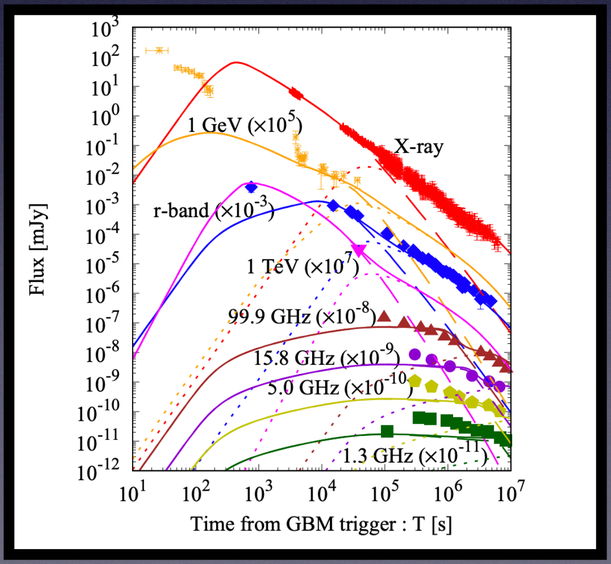


Single FS model
From *Laskar et al. (2023)*



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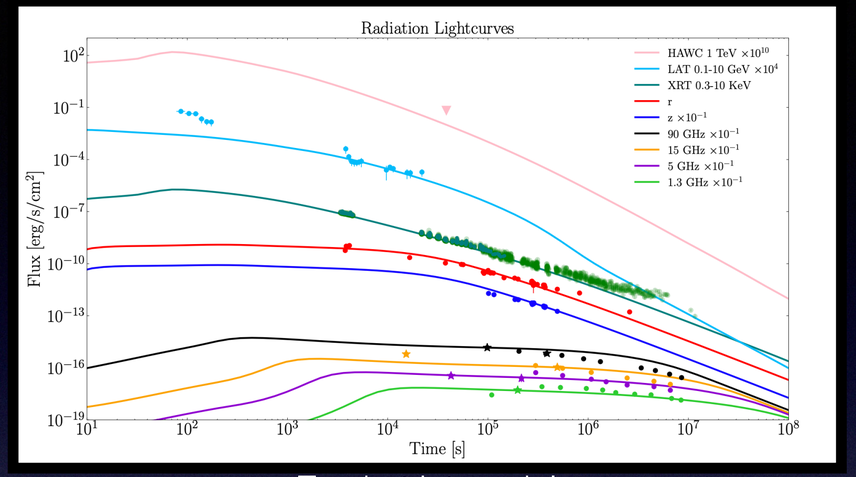

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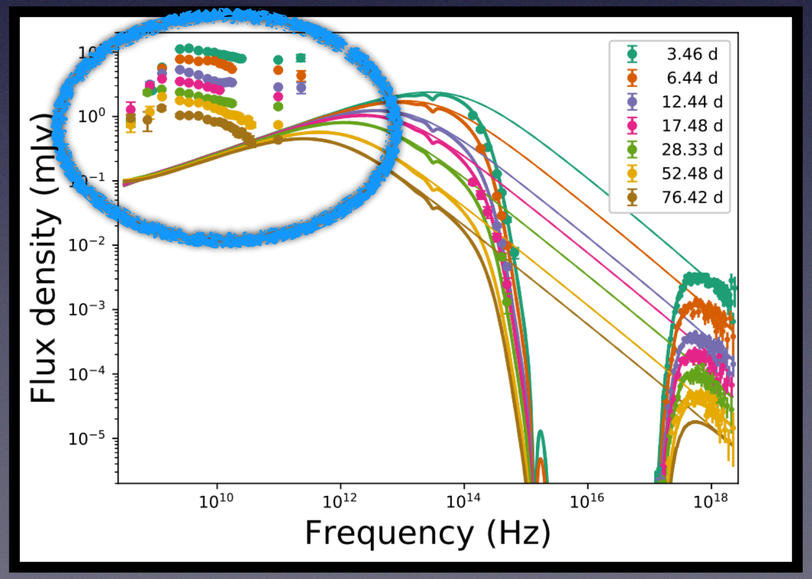

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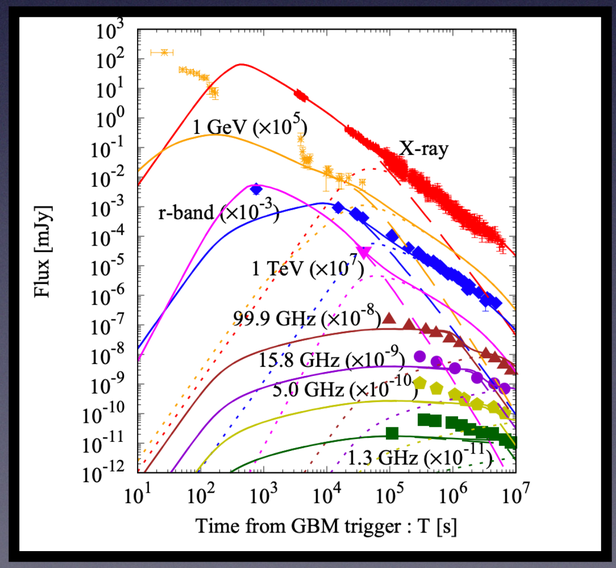

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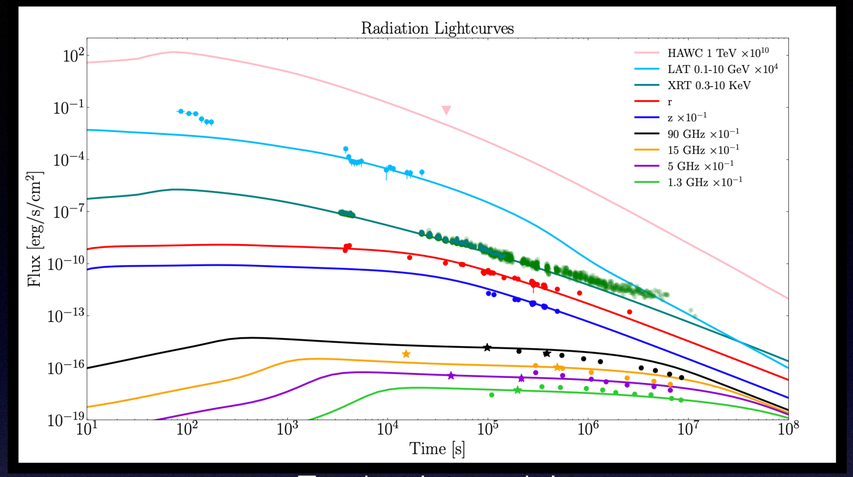

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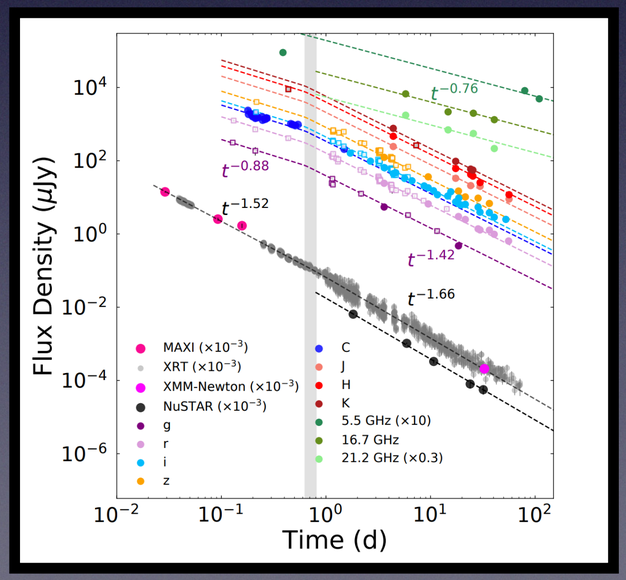
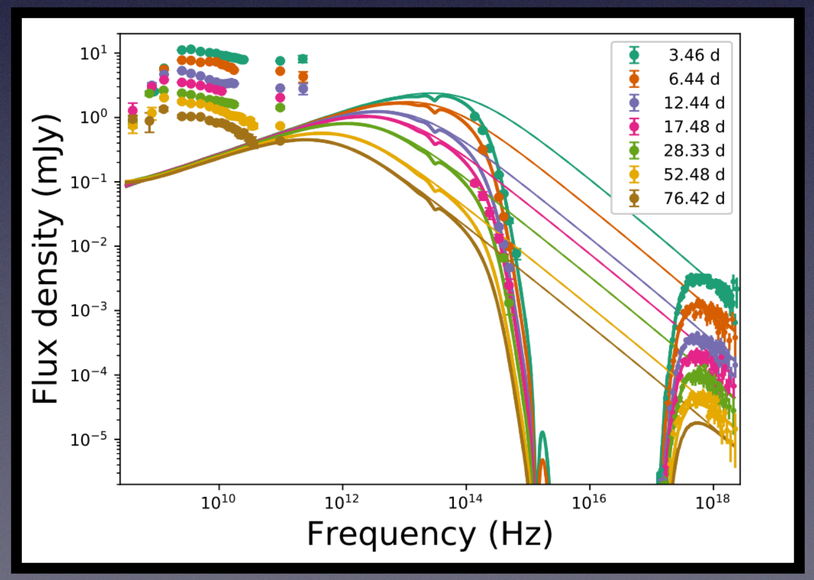


Structured jet model
From *O'Connor et al. (2023)*



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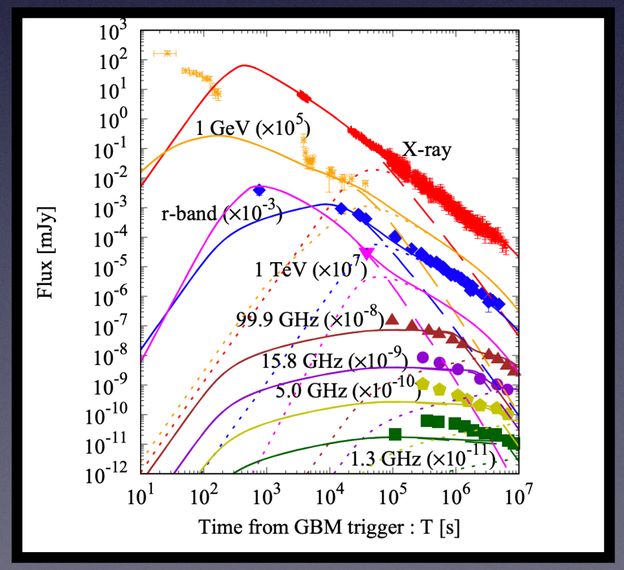

Two-component jet model
From *Sato et al. (2023)*

GRB 221009A

MWL Afterglow Models:

(1) *Ren et al. (2023)*: top-hat jet in a wind-like environment

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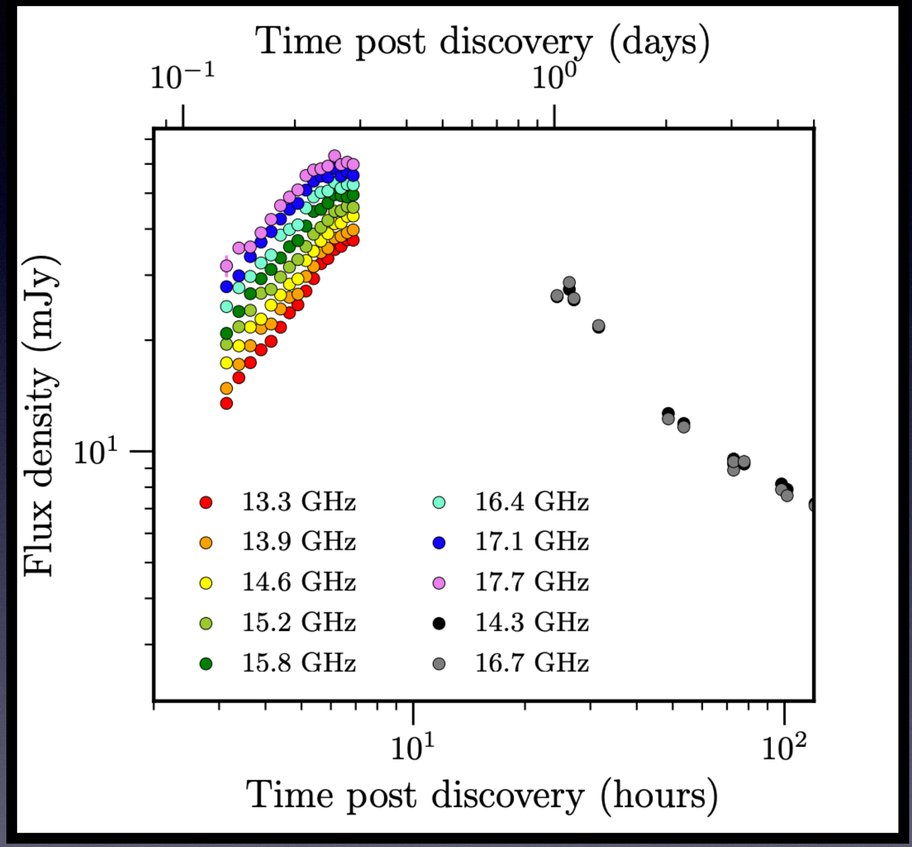
...[See also *Gill & Granot (2023)*]



AMI observations of GRB221009A
From *Bright, Rhodes et al. (2023)*


JIVE
Joint Institute for VLBI ERIC
EUROPEAN
vlbi
NETWORK
Metsähovi
Onsala
JIVE
WSRT
Torun
Svetloe
Jodrell Bank
Irbene
Zelenchukskaya
Badary
Yonsei
e-MERLIN
Effelsberg
Wettzell
Tamna
Medicina
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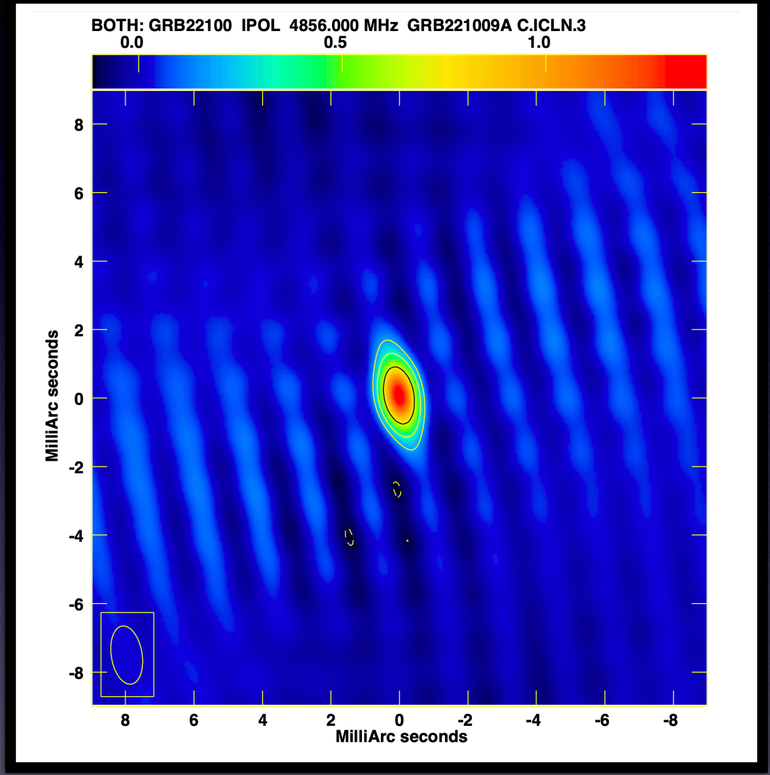
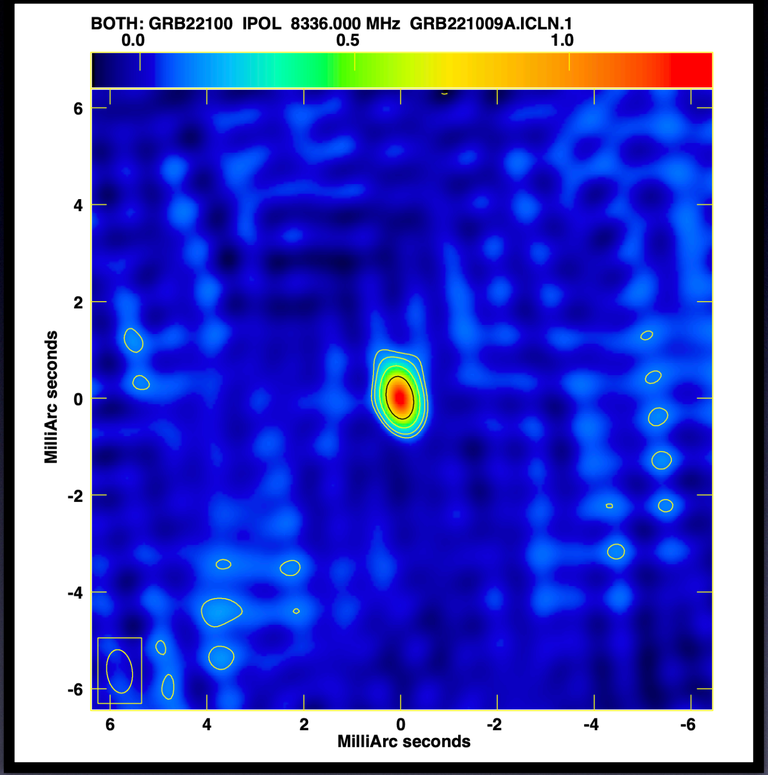
Urumqi
Sardinia
Noto
Ulsan
Arecibo
Kunming
Tianma
Hartebeesthoek

GRB 221009A



EVN map of GRB221009A at 4.9 GHz.
The surface brightness peak is ~1.4 mJy/b.
The synthesized beam is
1.7 x 0.9 mas (PA = 9.25°).



EVN map of GRB221009A at 8.3 GHz.
The surface brightness peak is ~1.3 mJy/b.
The synthesized beam is
0.9 x 0.5 mas (PA = 7.7°).

Global-VLBI observation planned for this week!

Outlook

The Square Kilometer Array

The Square Kilometer Array

Technical Information

The Telescopes

SKAO

The SKA telescopes are made up of arrays of antennas – SKA-mid observing mid to high frequencies and SKA-low observing low frequencies – to be spread over long distances. The SKA is to be constructed in phases: A first phase in South Africa and Australia, with a later expansion representing a significant increase in capabilities and expanding into other African countries, with the component in Australia also being expanded.

SKA1-Mid
the SKA's mid-frequency telescope

Location: South Africa

Frequency range:
350 MHz
to
15.4 GHz
with a goal of 24 GHz

197 dishes
(including 64 MeerKAT dishes)

Maximum baseline:
150km

SKA1-Low
the SKA's low-frequency telescope

Location: Australia

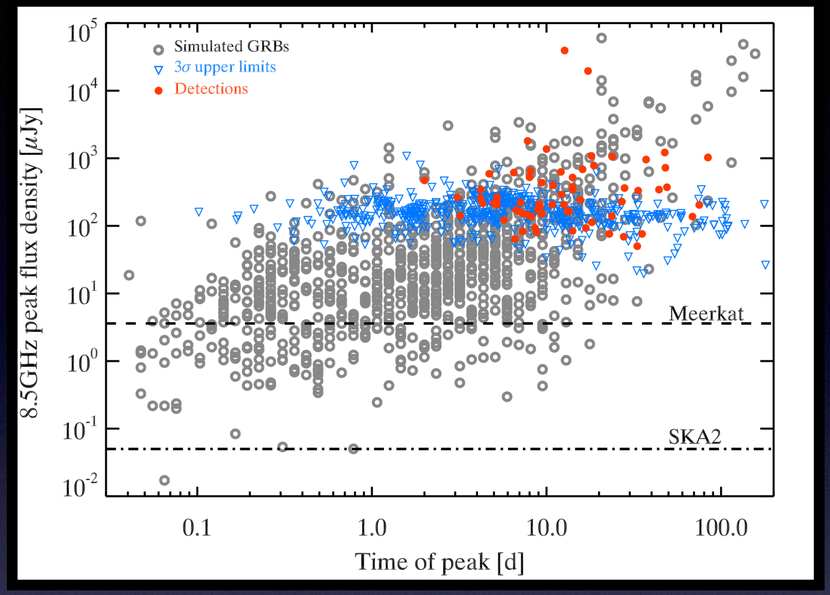
Frequency range:
50 MHz
to
350 MHz

131,072
antennas spread between
512 stations

Maximum baseline:
~74km

SKA info sheet from the public SKAO website

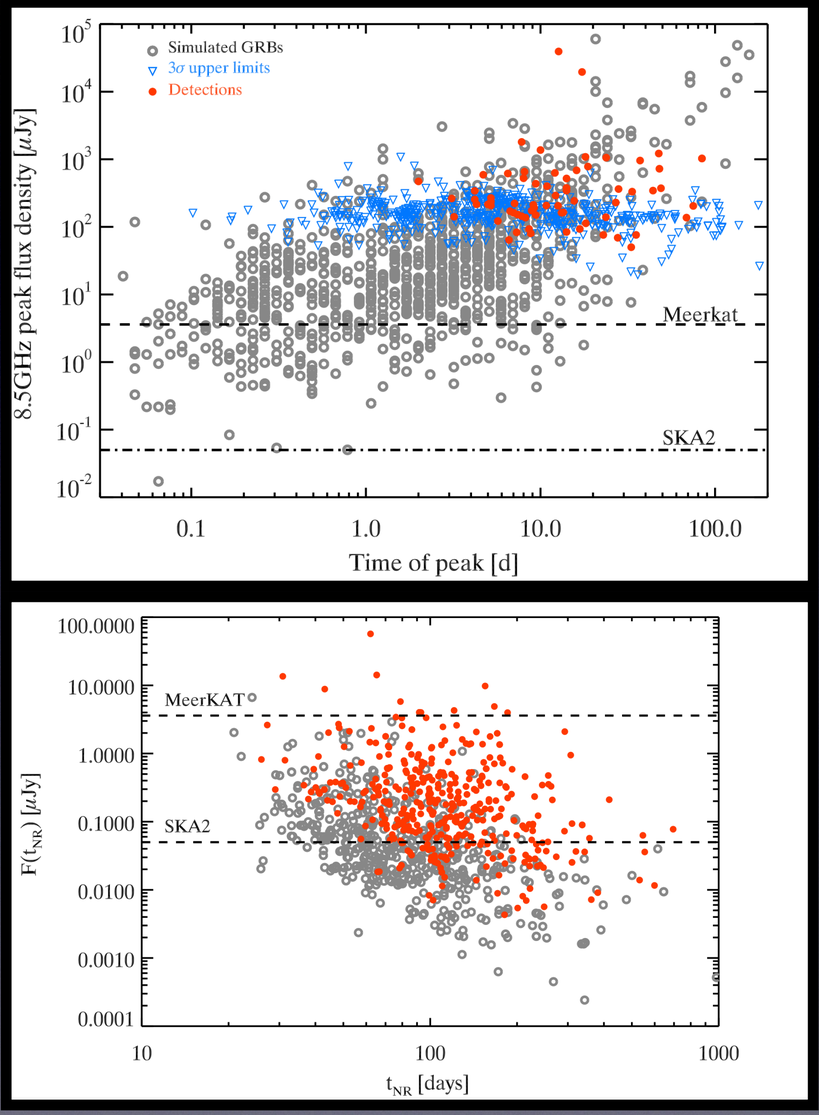
SKA and GRBs



From *Ghirlanda et al. (2013)*

From 30% to almost 100% of detection rate

SKA and GRBs

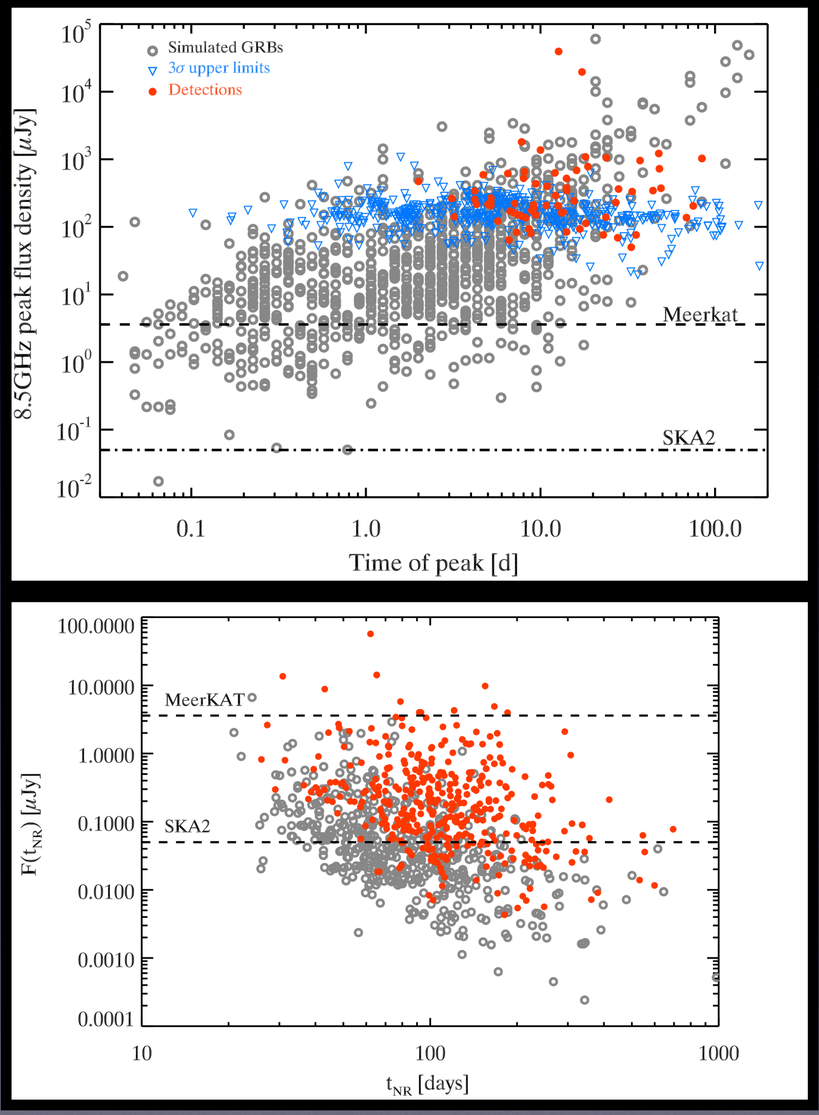


From 30% to almost 100% of detection rate

From <15% to almost 50% of detections at the transition time

From *Ghirlanda et al. (2013)*

SKA and GRBs



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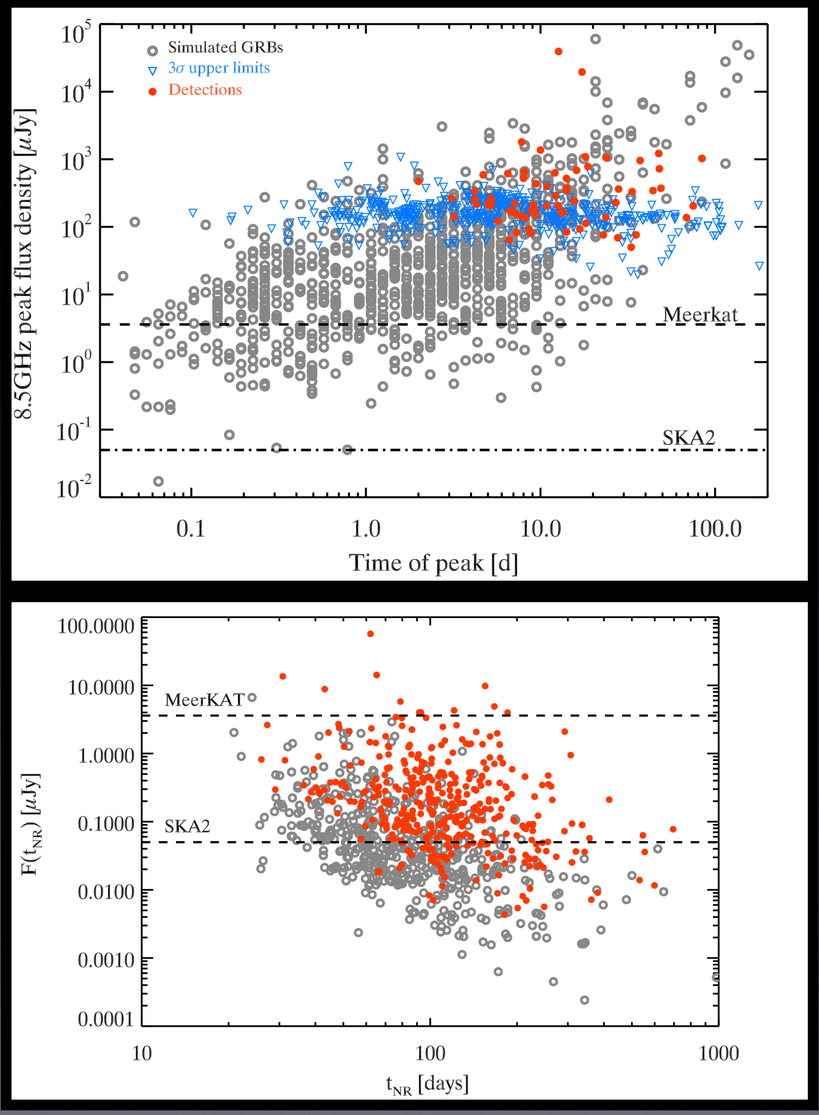
+**VLBI**: structure and geometry

From *Ghirlanda et al. (2013)*

SKA and GRBs



From 30% to almost 100% of detection rate

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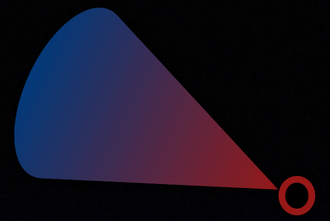
+**VLBI**: structure and geometry

...Unknown!

From *Ghirlanda et al. (2013)*

Conclusions



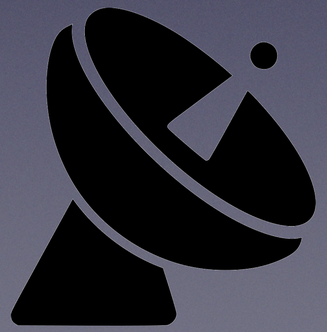
Radio observations can:

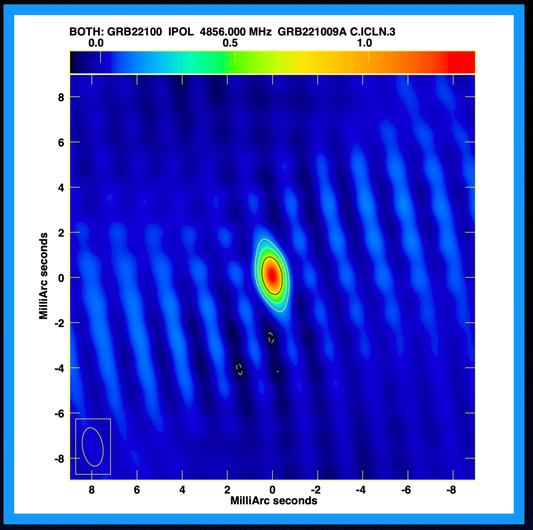
Break the **degeneracy** in the afterglow modeling

Reveal emitting **components** and/or mechanisms not accessible at other wavelengths

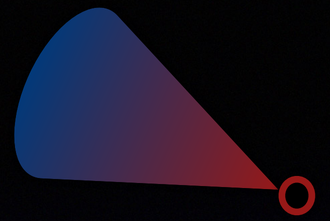
(with VLBI) provide a direct access on the **size** and the **geometry** of the afterglow

…SKA will enable this for the bulk of the GRB population!





Conclusions



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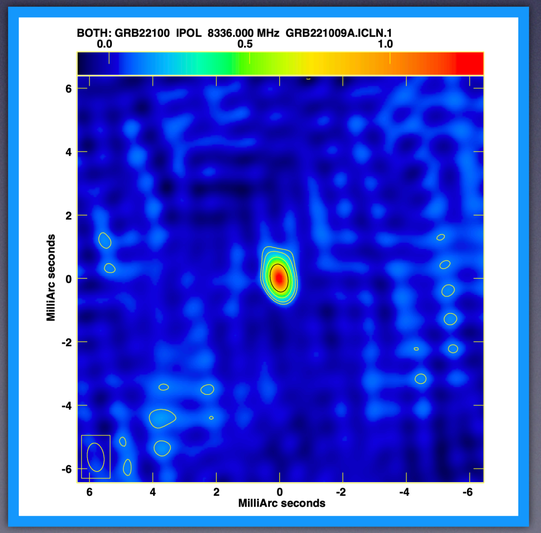
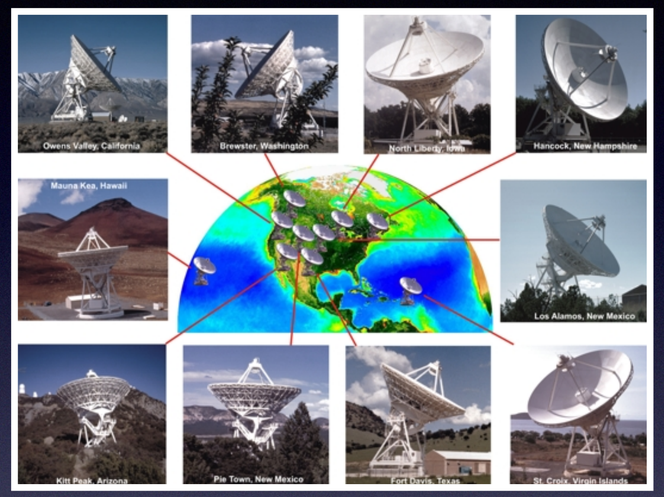
Take Home Message

Radio is the key to study GRBs...
and VLBI can provide a unique view on
their dynamics and structure!



Backup Slides

Very Long Baseline Interferometry



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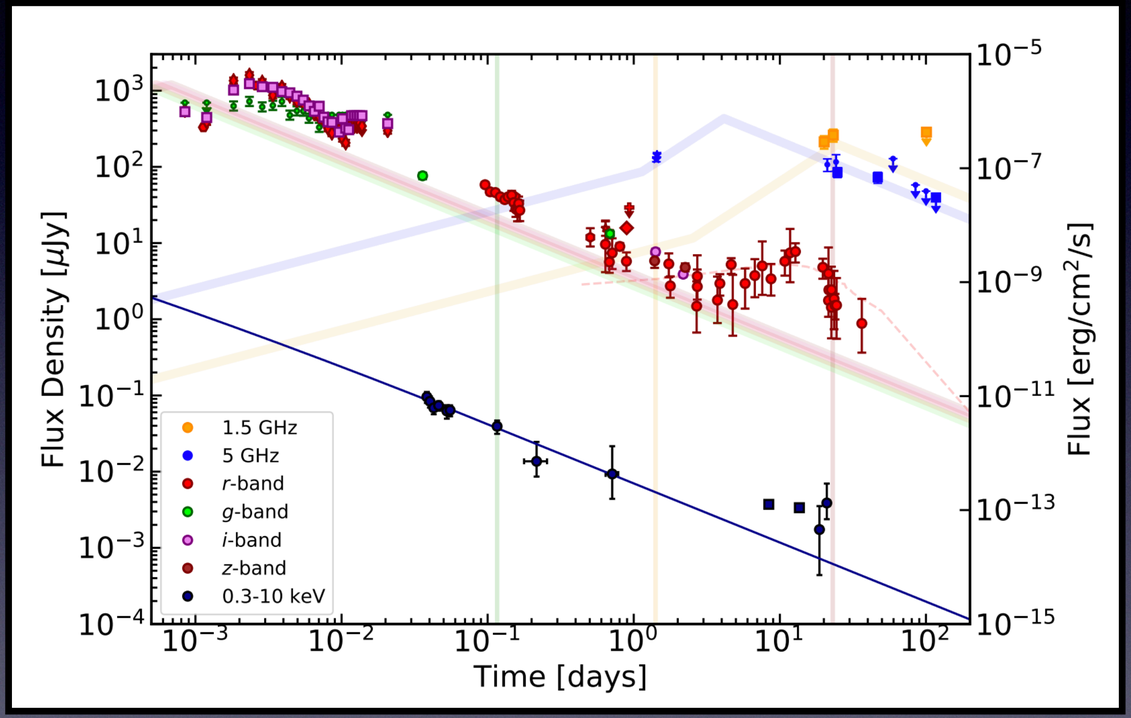
T - To [days]	Freq [GHz]	Peak [uJy/b]	RMS [uJy/b]	Array	Beam
1.4	4.23 - 7.10	132	5	VLA	1.70" x 1.14"
20	1.25 - 1.76	213	34	e-MERLIN	0.18" x 0.12
21	4.50 - 5.01	107	17	e-MERLIN	0.06" x 0.04"
23	1.25 - 1.76	261	40	e-MERLIN	0.19" x 0.12"
24	4.50 - 5.01	116	26	e-MERLIN	0.06" x 0.04"
25	4.57 - 5.11	85	9	EVN	1.8mas x 0.9mas
47	4.77 - 5.05	73	10	EVN	3.4mas x 2.8mas
60	6.55 - 7.06	-	43	e-MERLIN	0.12" x 0.07"
85	4.50 - 5.01	-	19	e-MERLIN	0.04" x 0.04"
100	4.50 - 5.01	-	16	e-MERLIN	0.07" x 0.03"
101	1.25 - 1.76	-	57	e-MERLIN	0.17" x 0.14"
117	4.77 - 5.05	-	13	EVN	3.1mas x 3.6mas



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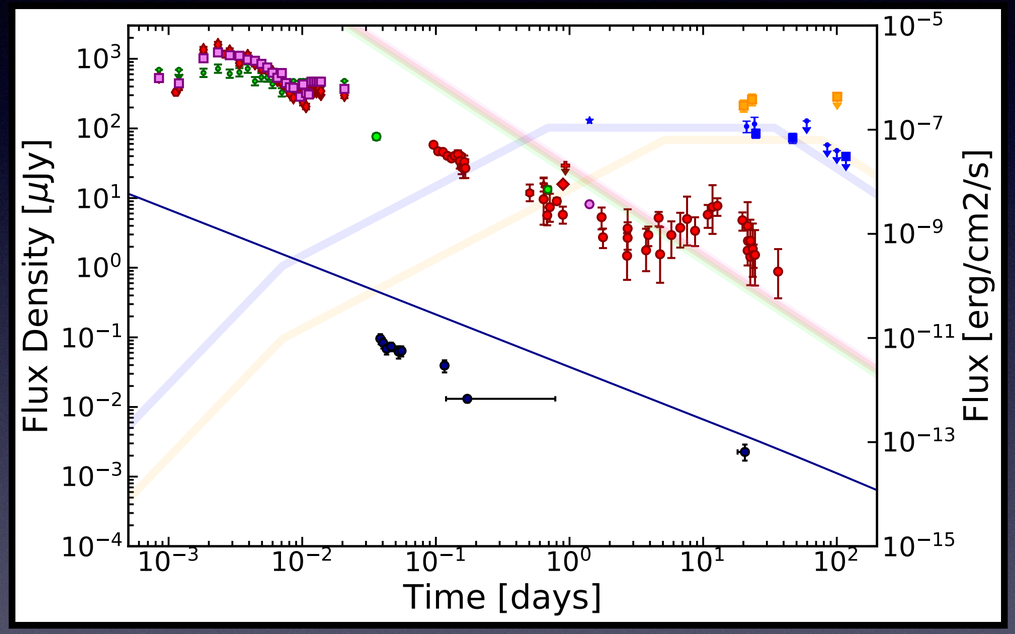
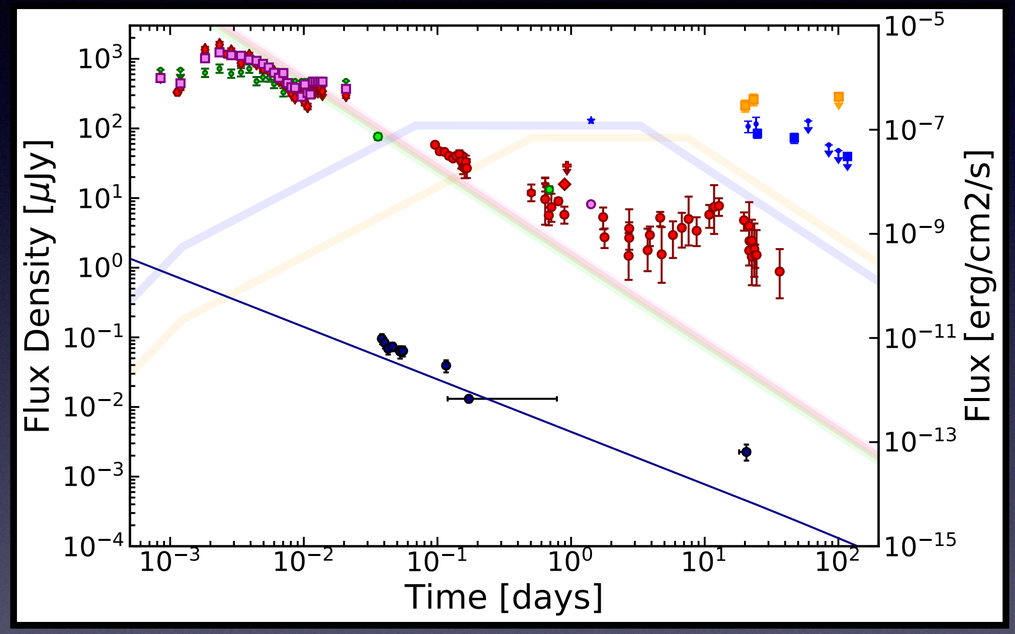

Flux Density [μJy]
Flux [erg/cm2/s]
Time [days]


Flux Density [μJy]
Flux [erg/cm2/s]
Time [days]

SKA and ngVLA

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	8.3-15.4
Telescope	Low	Low	Mid	Mid	Mid	Mid
FoV [arcmin]	327	120	109	60	12.5	6.7
Max. resolution [arcsec]	9.7	3.5	0.7	0.3	0.06	0.03
Max. bandwidth [MHz]	300	300	700	810	3900	2 x 2500
Cont. rms, 1hr [μJy/beam] [a]	26	14	4.4	2	1.3	1.2
Line rms, 1hr [μJy/beam] [b]	1850	800	300	140	90	85
Resolution range for cont. & 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	13.4	13.4	80.6	80.6
Narrowest bandwidth, zoom mode [MHz]	3.9	3.9	3.1	3.1	3.1	3.1
Finest zoom channel width [Hz]	226	226	210	210	210	210

a. Continuum sensitivity at nominal frequency, assuming fractional bandwidth of $\Delta\nu/\nu = 0.3$

b. Line sensitivity at nominal frequency, assuming fractional bandwidth per channel of $\Delta\nu/\nu = 10^{-4}$ ($>10^{-6}$ will be possible]

c. The sensitivity numbers apply to the range of beam sizes listed

For more details refer to the document "Anticipated SKA1 Science Performance" (SKA-TEL-SKO-0000818 available on astronomers. skatelescope.org and at arxiv.org/abs/1912.12699)

SKA info sheet from the public SKAO website.

ngVLA Key Performance Metrics

Parameter [units]	2.4 GHz	8 GHz	16 GHz	27 GHz	41 GHz	93 GHz
Band Lower Frequency, f_L [GHz]	1.2	3.4	12.3	20.5	30.5	70.0
Band Upper Frequency, f_H [GHz]	3.5	12.3	20.5	34.0	50.5	116.0
Field of View FWHM [arcmin]	24.852	7.440	3.561	2.143	1.442	0.628
Aperture Efficiency [%]	0.828	0.936	0.941	0.920	0.886	0.648
Effective Area, A_{eff} x 10^3 [m^2]	51.41	58.15	58.42	57.10	55.03	40.25
System Temp, T_{sys} [K]	17.07	22.00	24.40	32.42	47.41	65.37
Max Inst. Bandwidth [GHz]	2.3	8.8	8.2	13.5	20.0	20.0
Antenna SEFD [Jy]	232.3	264.8	292.2	397.3	602.8	1136.3
Resolution of Max. Baseline θ_{max} [mas]	2.97	0.89	0.43	0.26	0.17	0.08
Naturally Weighted Sensitivity						
Continuum rms, 1 hr [μJy/beam]	0.24	0.14	0.16	0.17	0.21	0.40

ngVLA expected performance. From the public ngVLA website.