INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

Measuring the expansion of GRB afterglows

Speaker
S.Giarratana

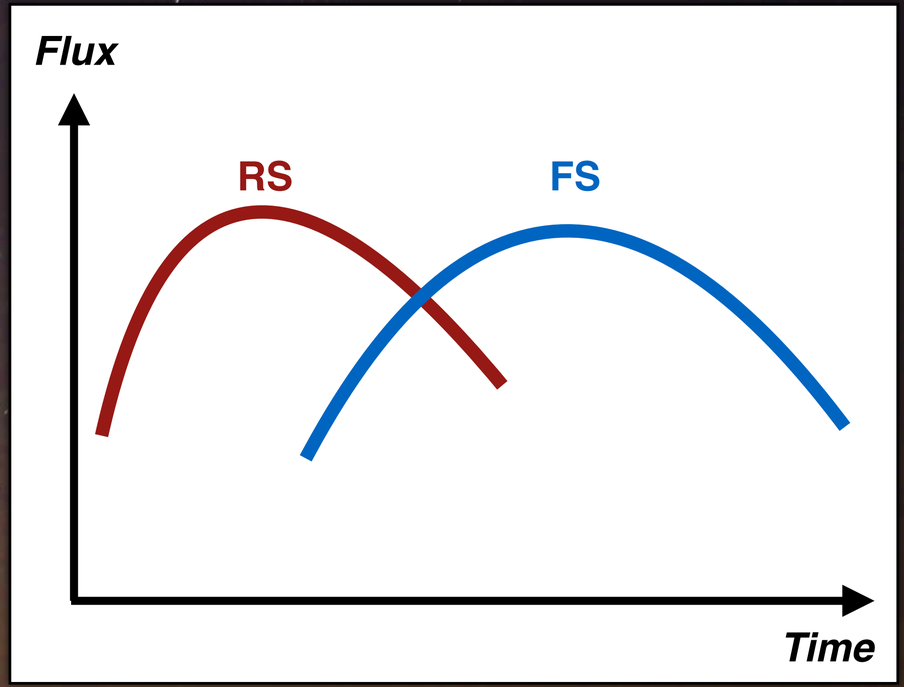
with the (fundamental) help of
G. Ghirlanda, M. Giroletti, O. S. Salafia, L. Nava, L. Rhodes, B. Marcote, J. K. Leung and many more...

Credits: Sergio Poppi (Inaf Cagliari)

GRBs in Radio

Emission mechanism

Forward vs Reverse shocks



Credits: Sergio Poppi (Inaf Cagliari)

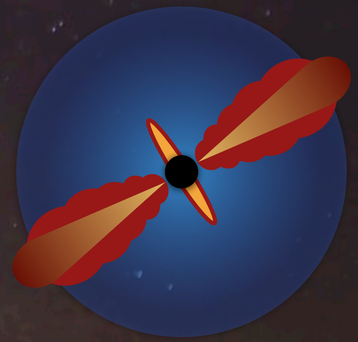
GRBs in Radio

Geometry

Viewing angle

Collimation angle

Size and structure

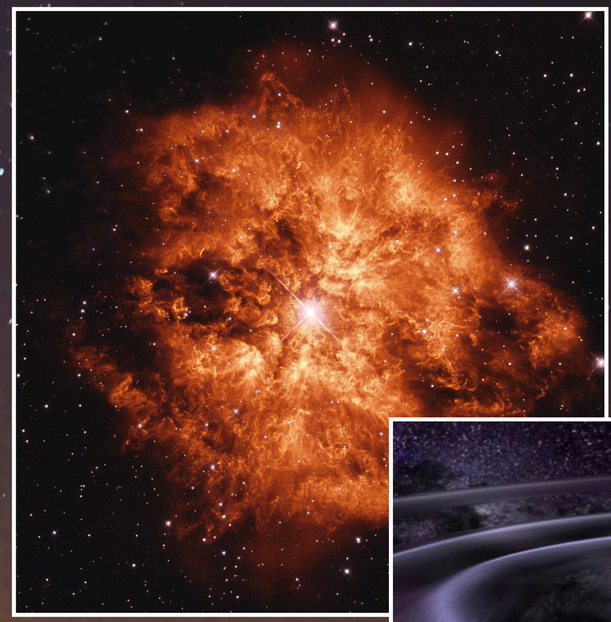


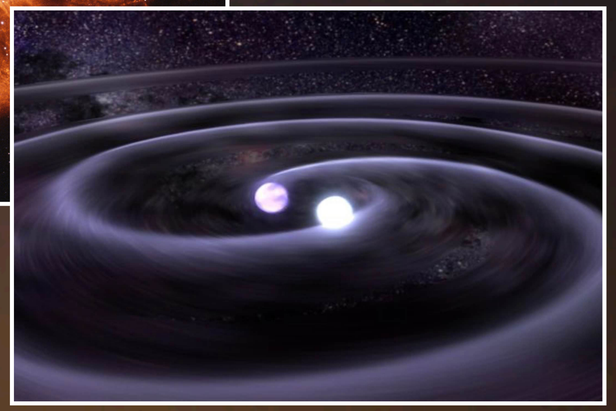
Credits: Sergio Poppi (Inaf Cagliari)

GRBs in Radio

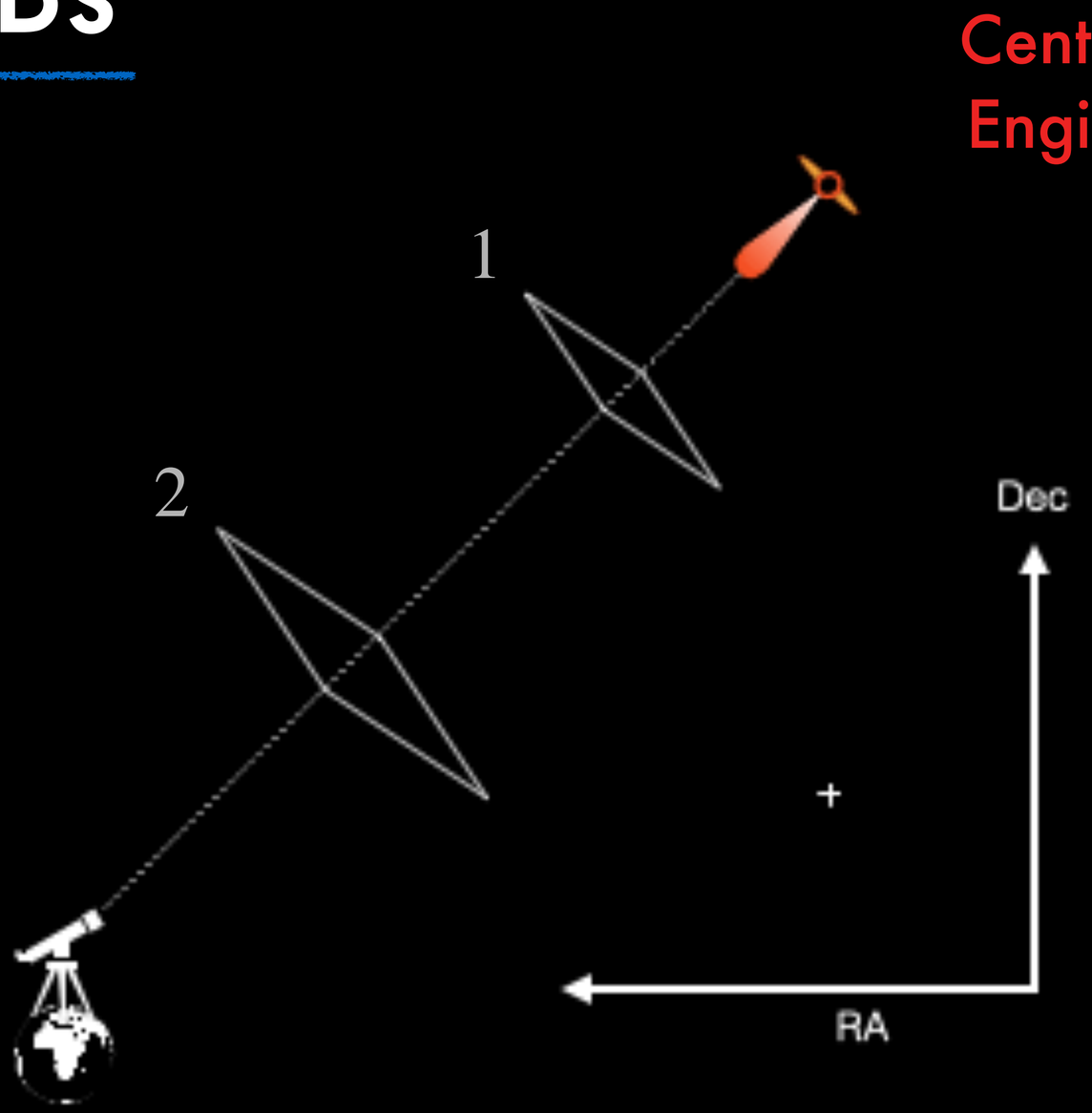
Progenitors

Circum-burst density profile

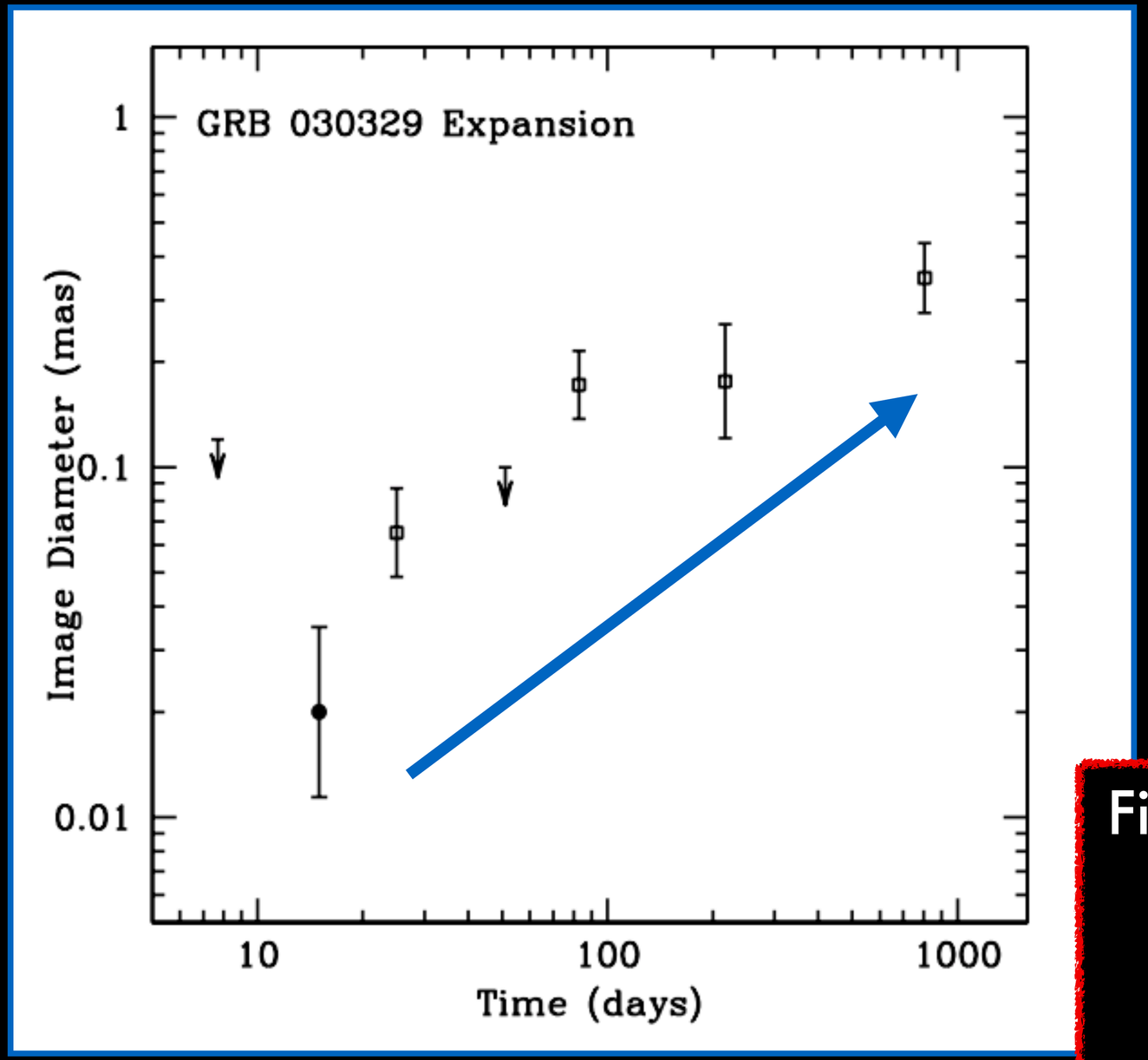




On-axis GRBs



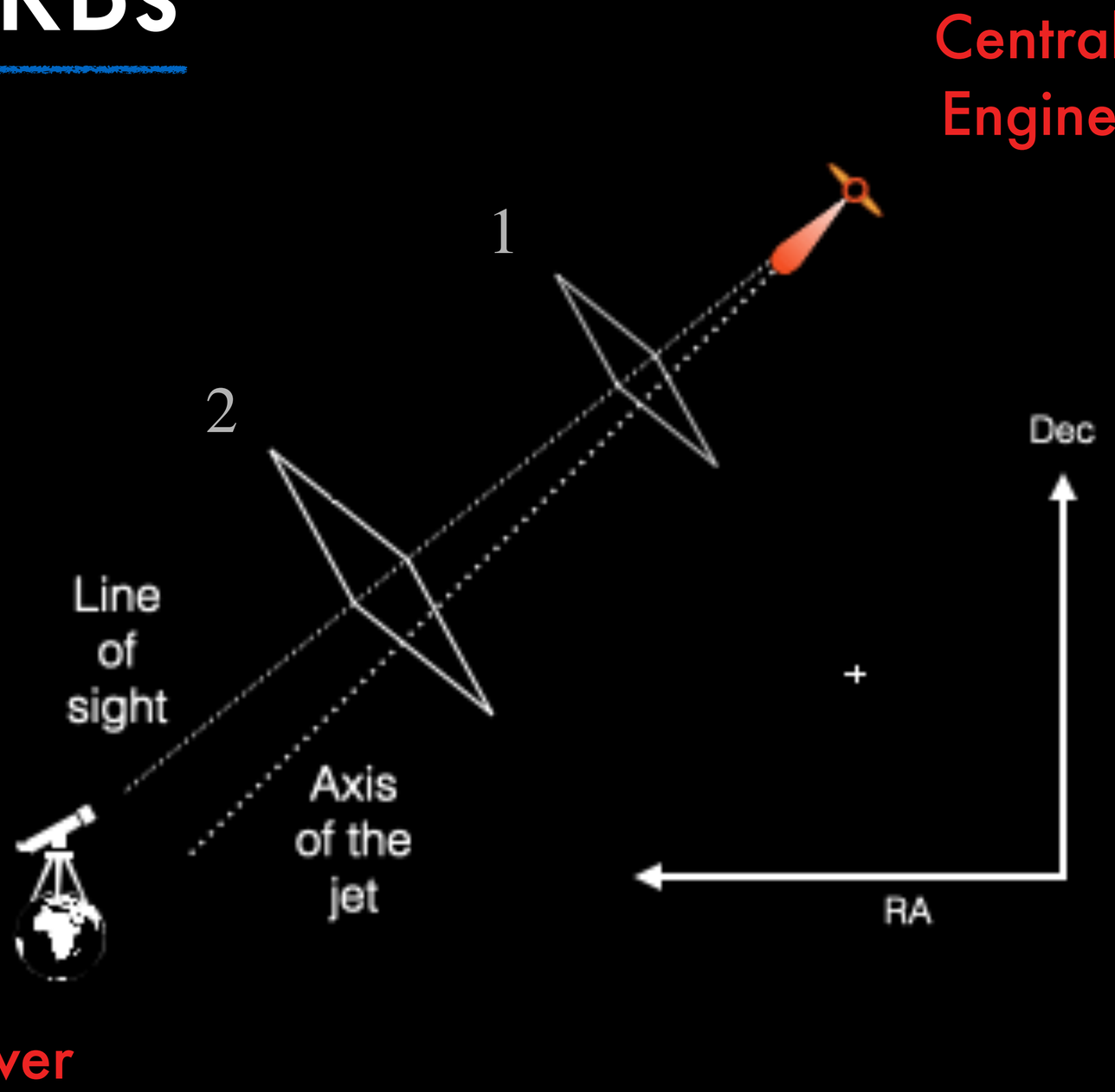
GRB 030329



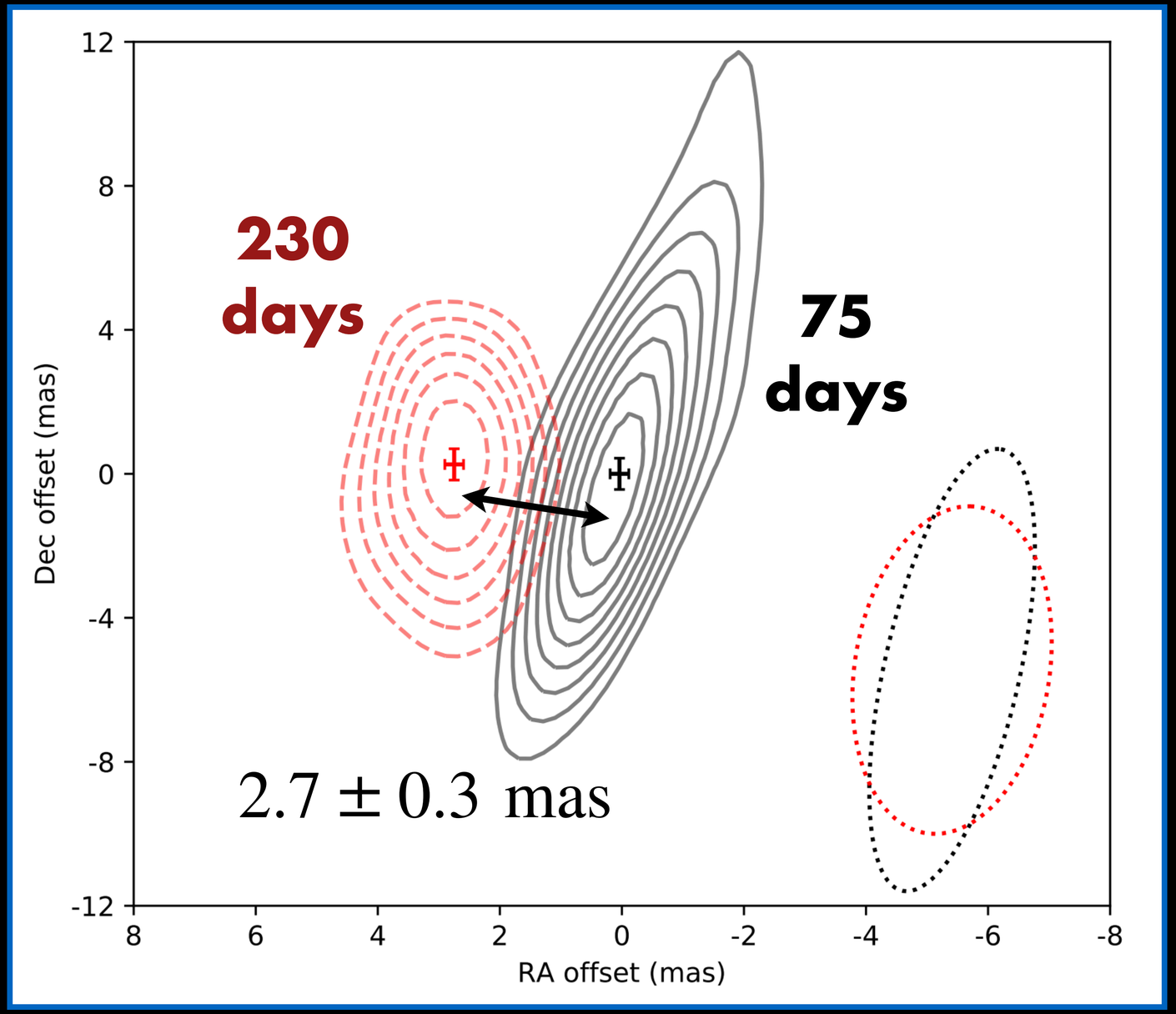
From *Pihlström et al. (2007)*

First direct proof of (apparent) superluminal expansion

Off-axis GRBs



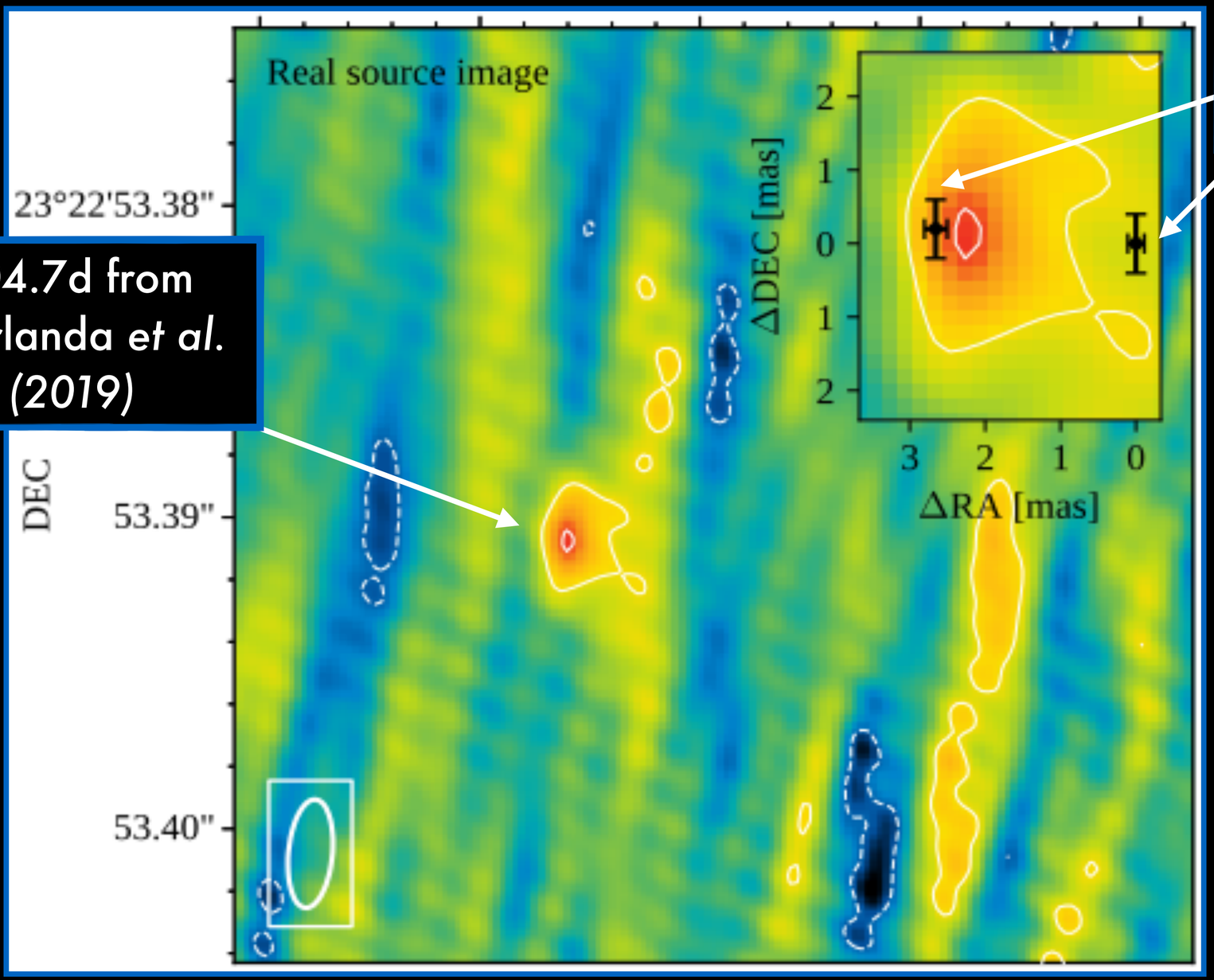
GRB 170817A



A (slightly) off-axis GRB

From *Mooley et al. (2018)*

GRB 170817A



204.7d from Ghirlanda *et al.* (2019)

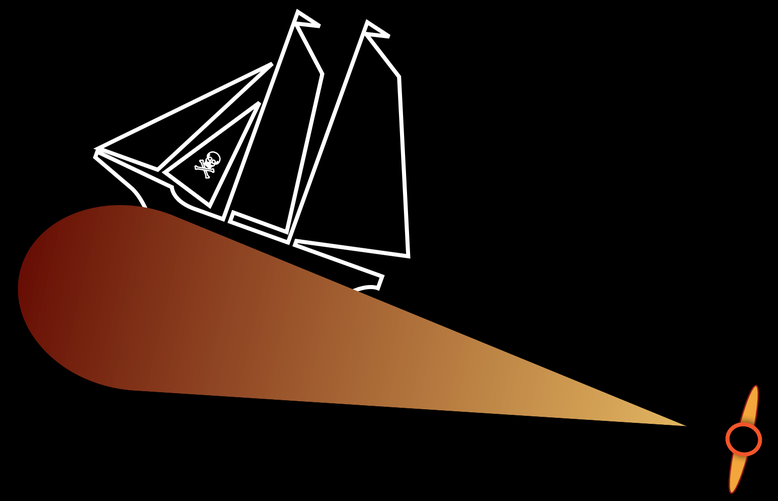
75d & 230d from Mooley *et al.* (2018)

First proof of successful jet from a BNS merger

From *Ghirlanda et al. (2019)*

GRB 221009A

the Brightest Of All Time



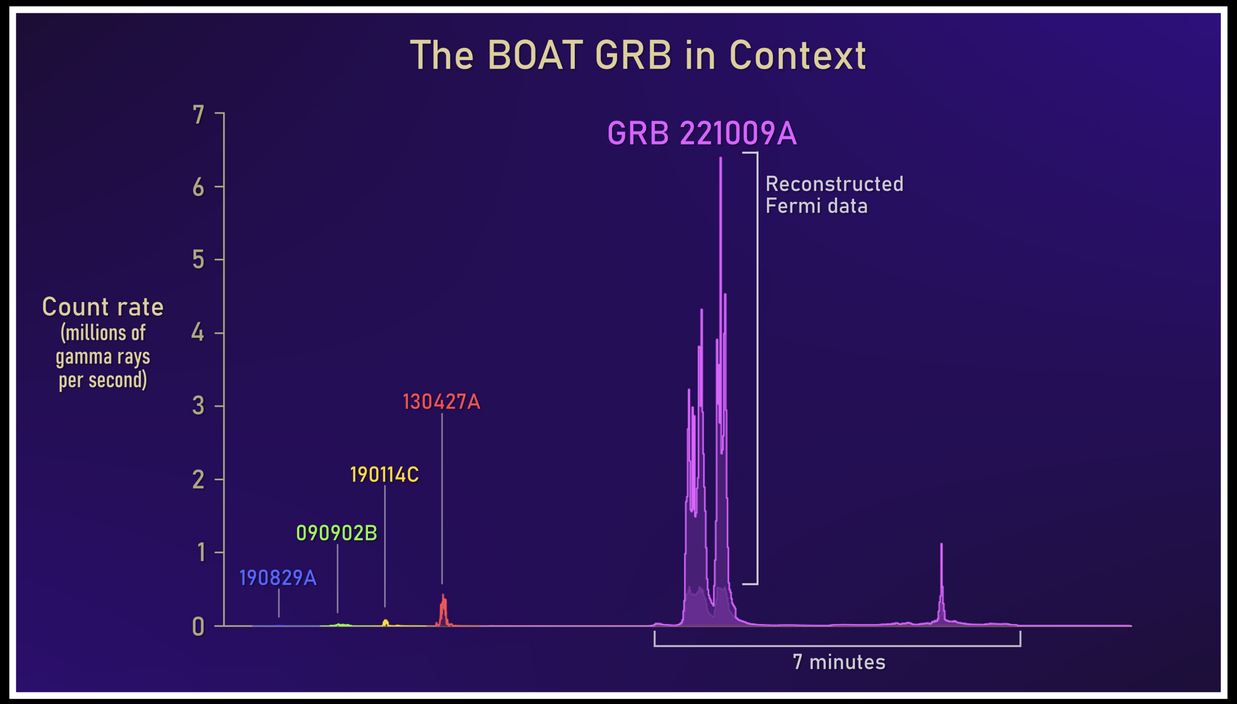
GRB 221009A

$E_{iso} \simeq 3 \times 10^{54}$ erg

$z = 0.151$

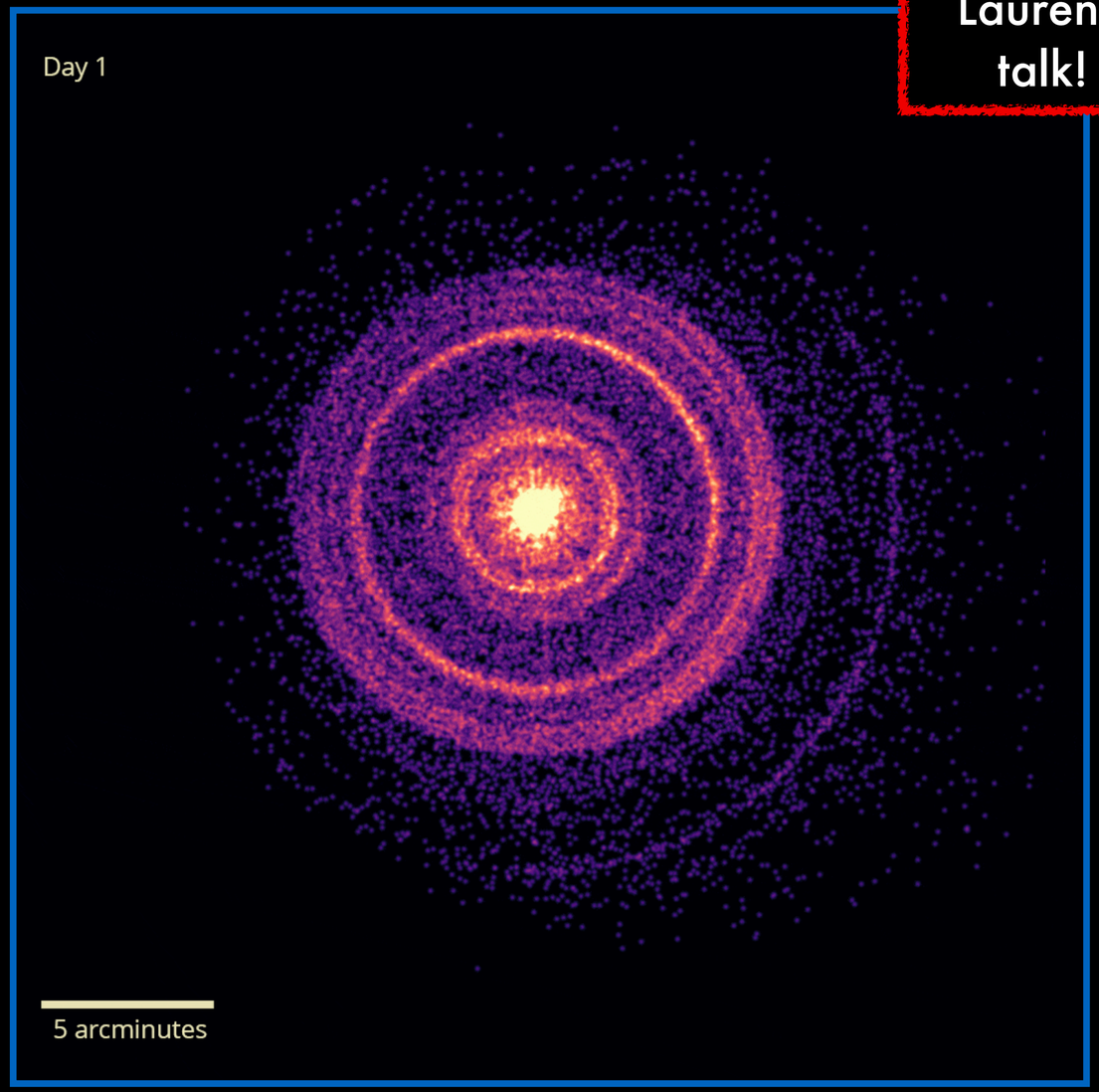
$R = 1/10000\, yr^{-1}$

See Om's talk!



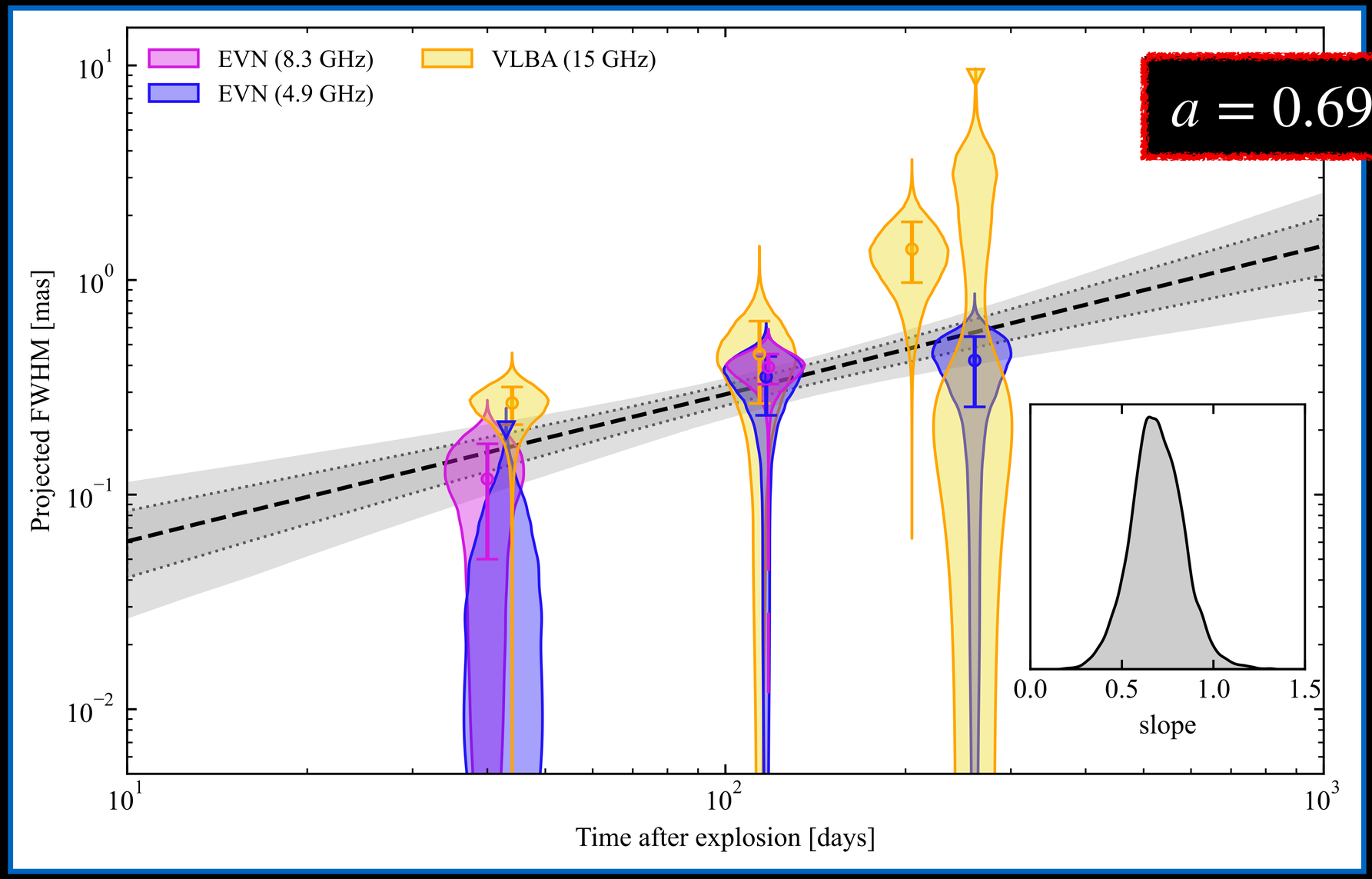
Credit: NASA's Goddard Space Flight Center and Adam Goldstein (USRA)

See Lauren's talk!



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

Measuring the expansion



Apparent size evolution.
From *Giarratana et al. (2024)*

ISM vs wind-like?*

ISM

Post jet-break:
$a = 1/4$

Lateral spreading:
$a \sim 0.7$

No jet break:
$a = 0.625$

Structured jet

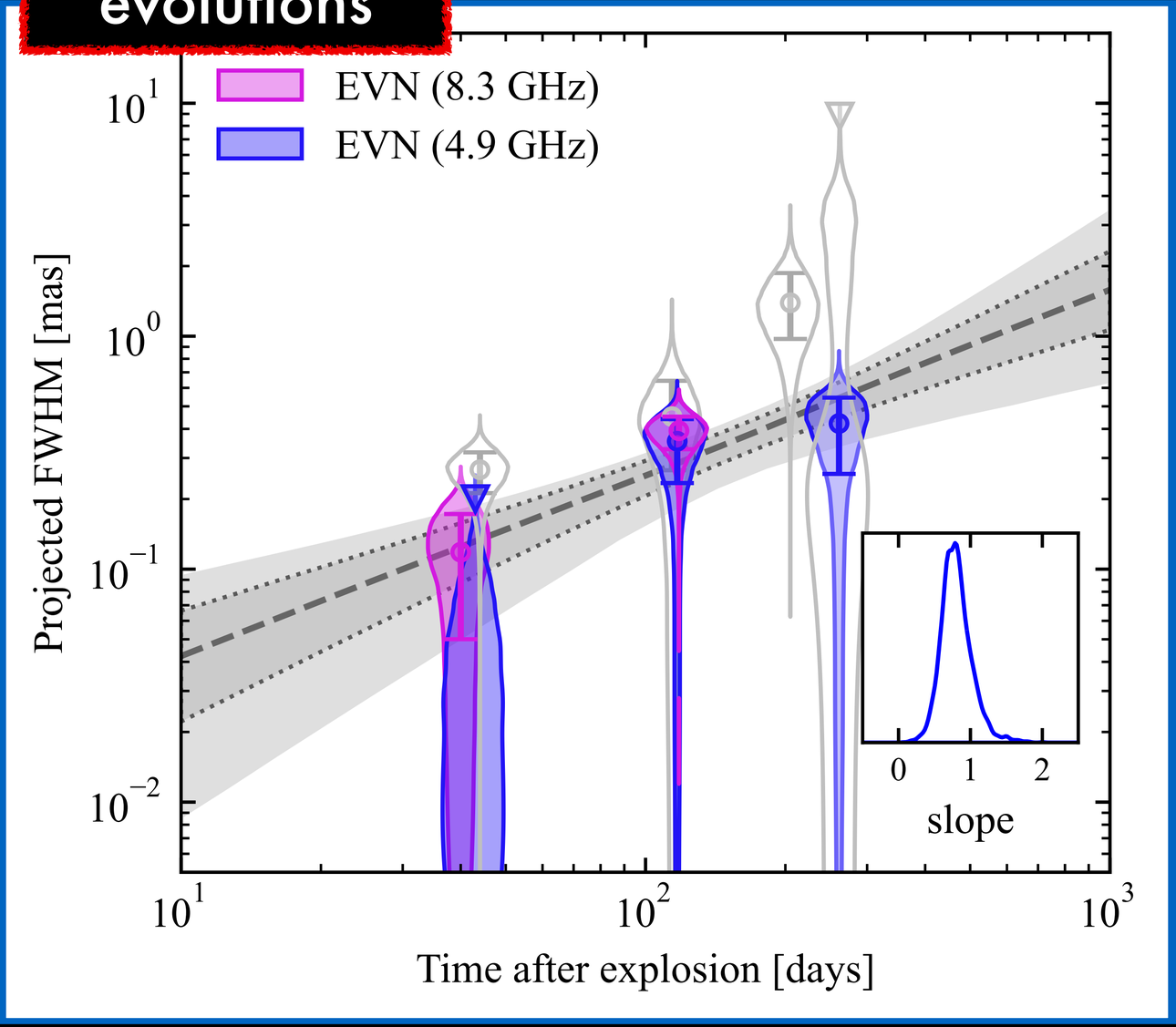
Wind

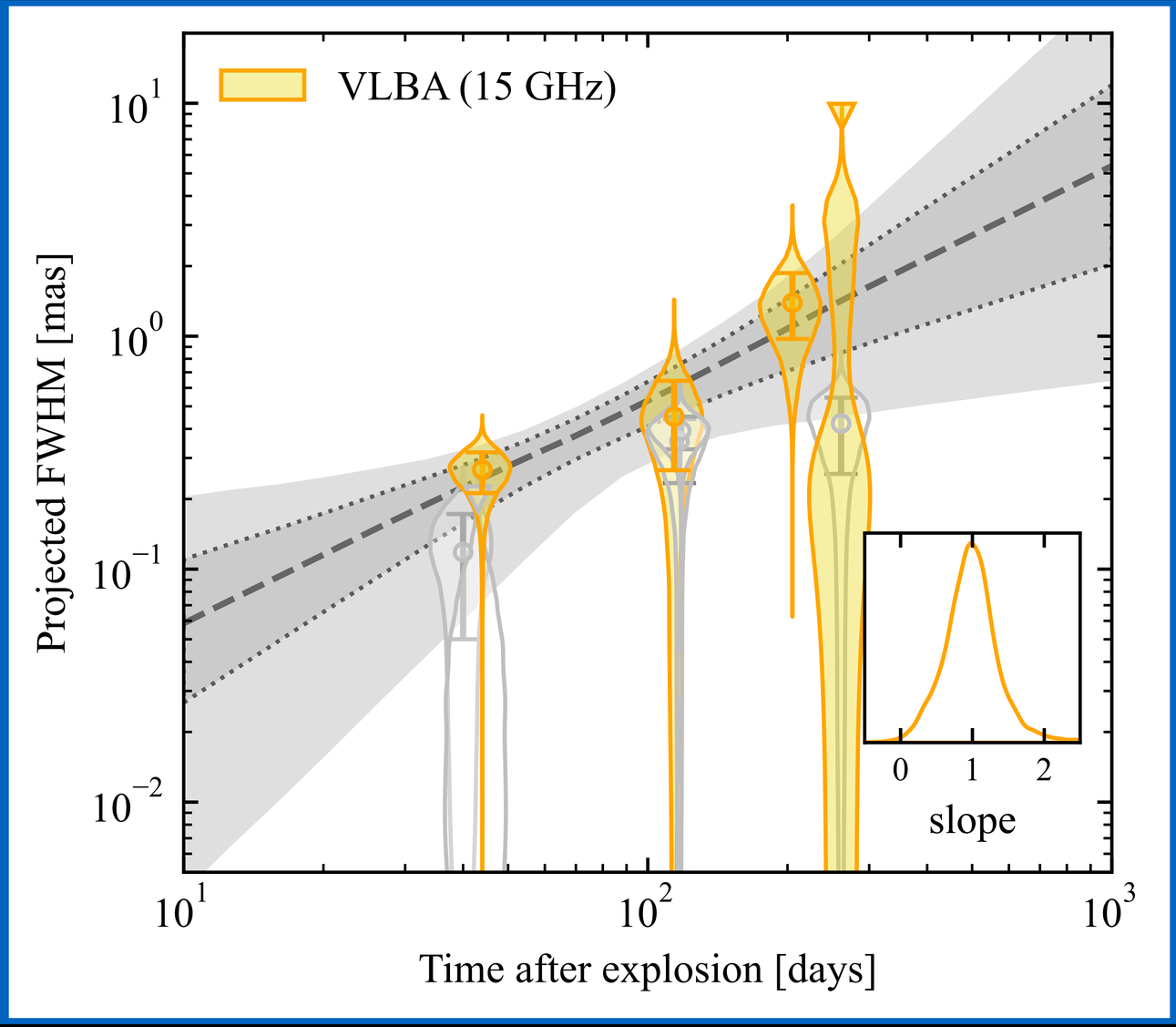
Post jet-break:
$a = 1/2$

* *Blandford & McKee (1976)* blastwave

Forward vs Reverse shocks?

Hint for different size evolutions

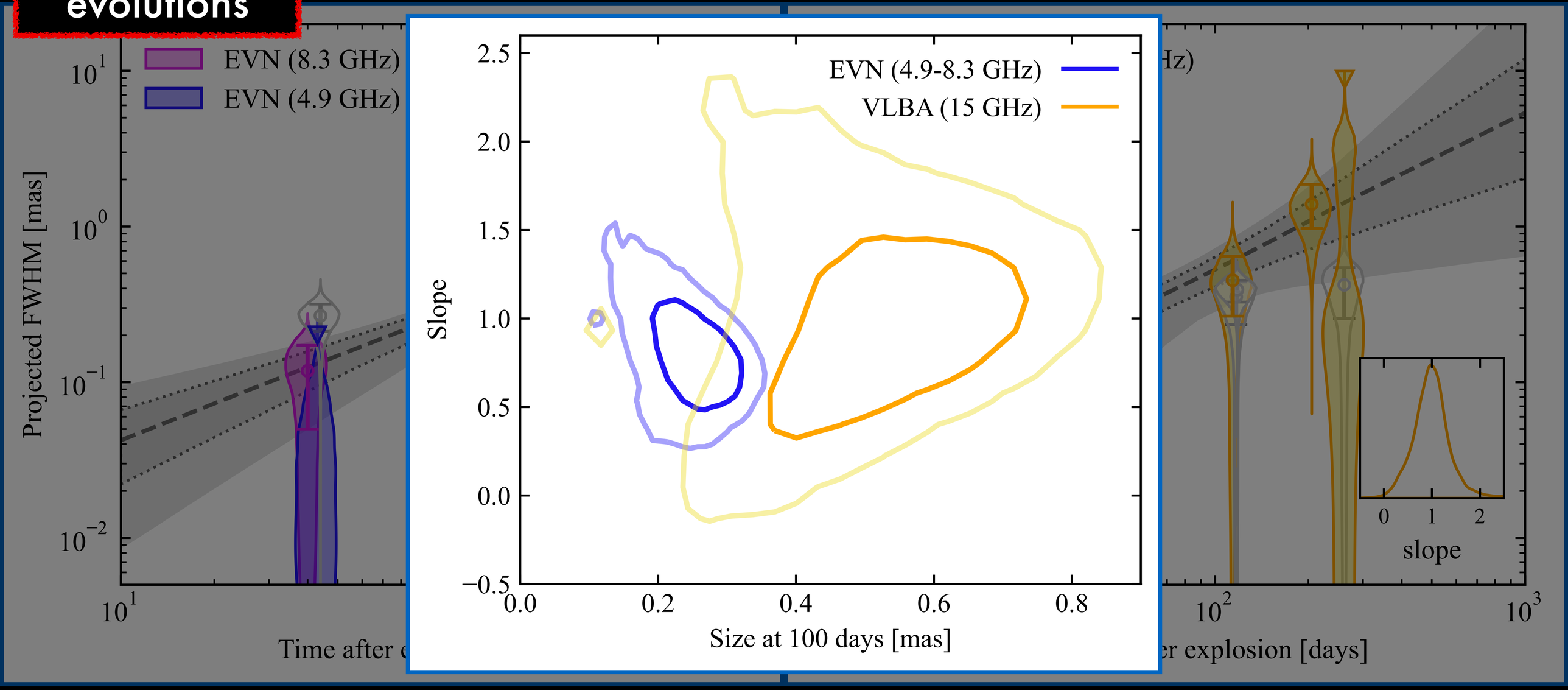




From *Giarratana et al. (2024)*

Forward vs Reverse shocks?

Hint for different size evolutions

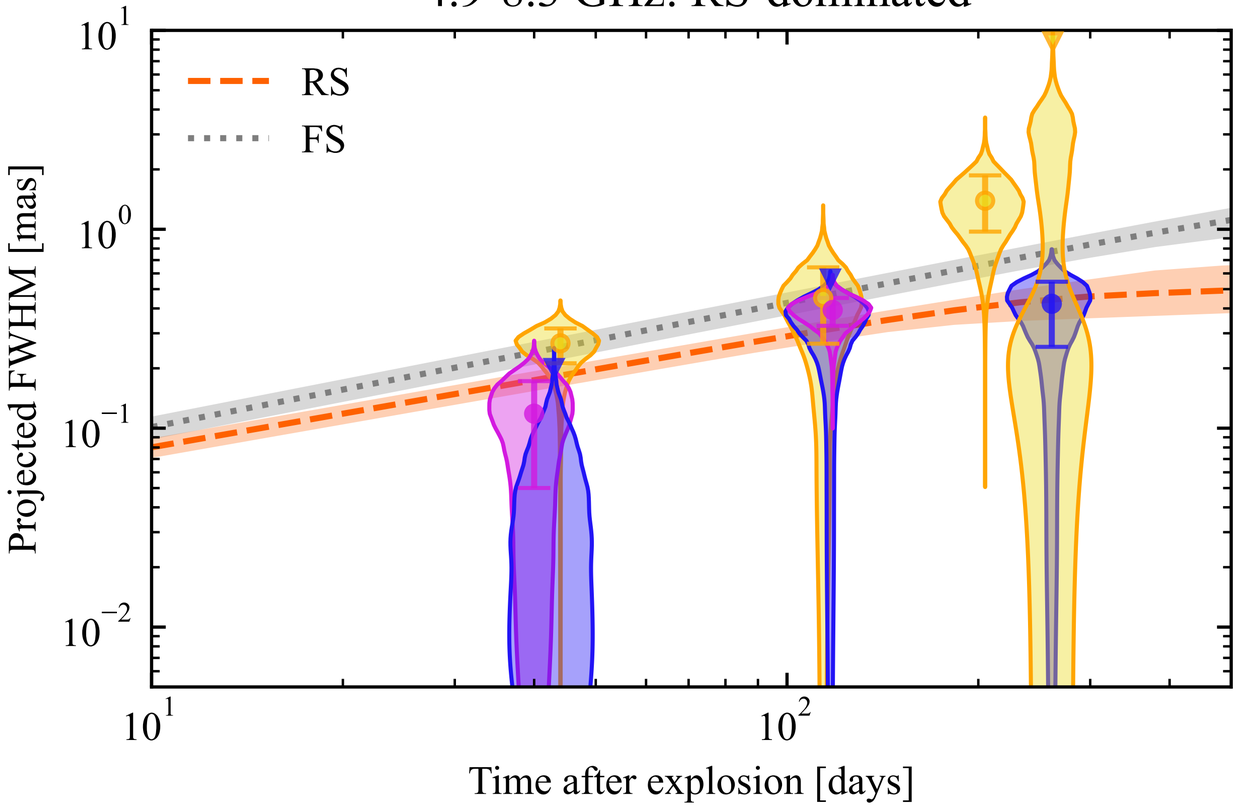


From *Giarratana et al. (2024)*

GRB 221009A

ISM

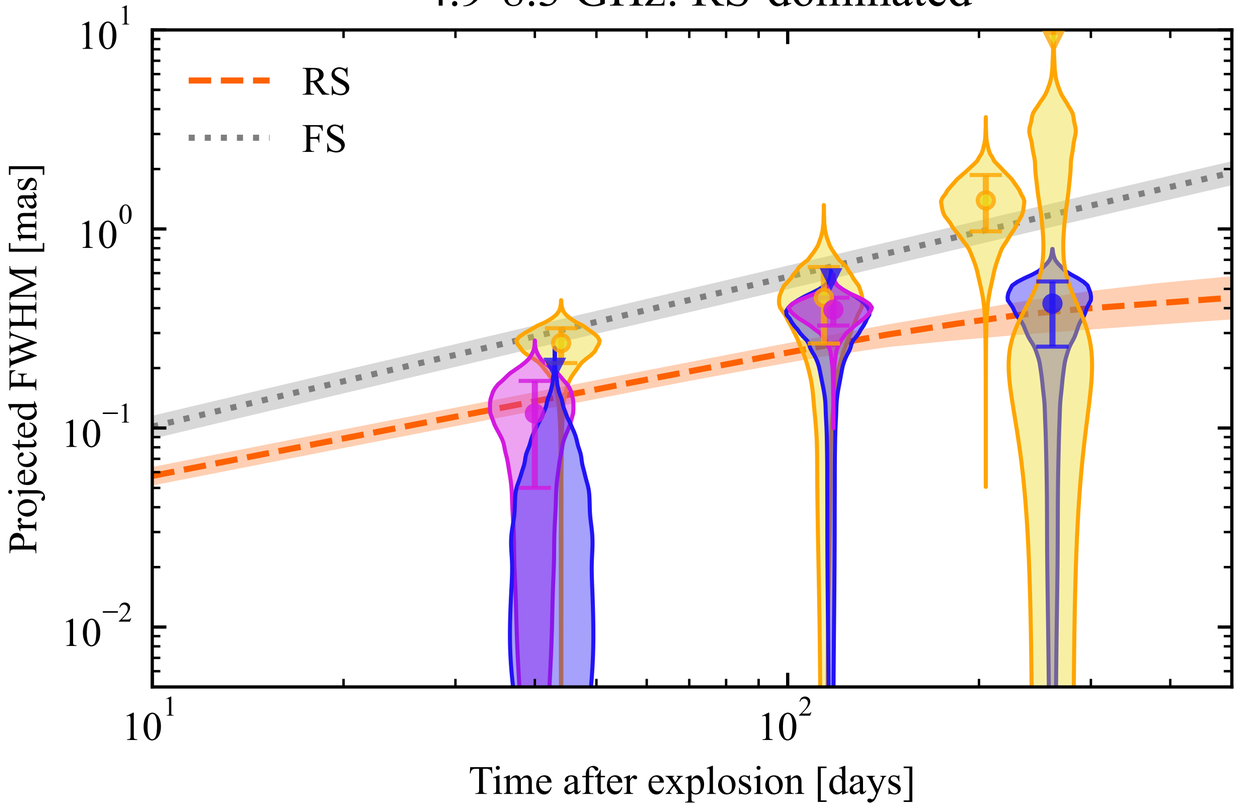
15 GHz: FS-dominated
4.9-8.3 GHz: RS-dominated



$E/A \simeq 10^{57}$ erg cm^3
$\theta_j \simeq 21^\circ$

Wind

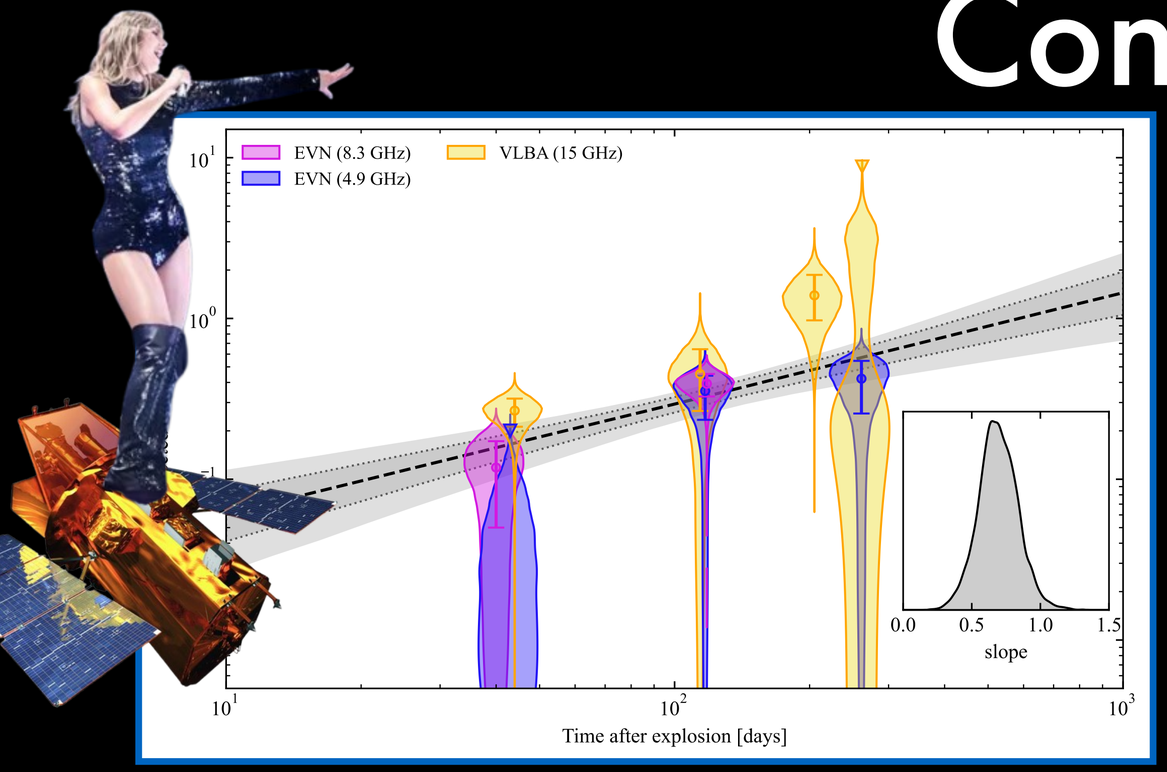
15 GHz: FS-dominated
4.9-8.3 GHz: RS-dominated



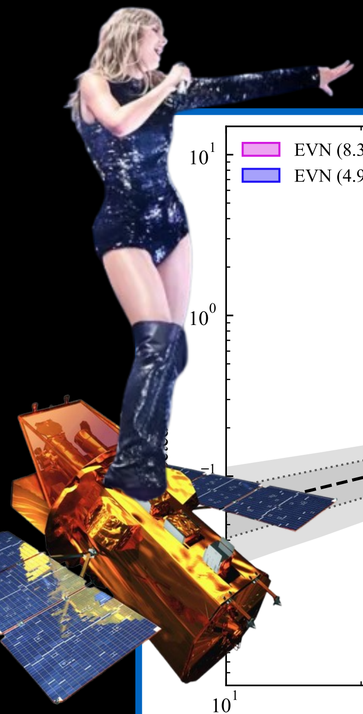
$E/A \simeq 10^{55}$ erg cm^3
$\theta_j \simeq 23^\circ$

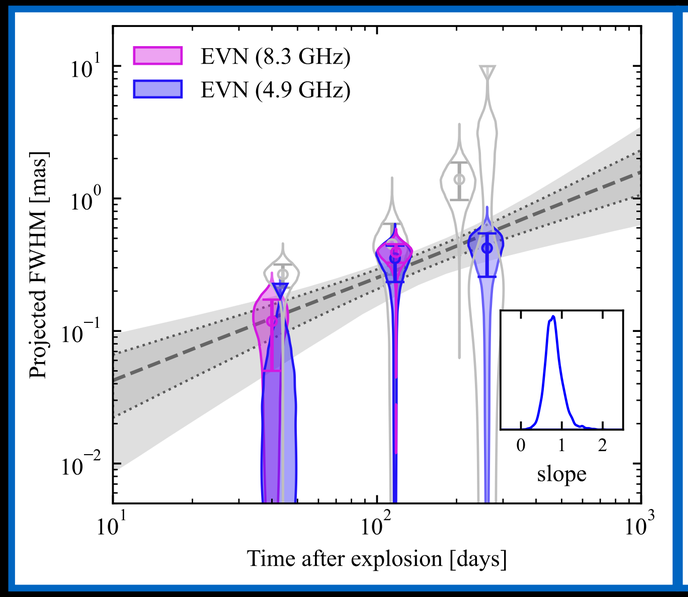
Model size evolution in a FS + RS scenario.
From *Giarratana et al. (2024)*

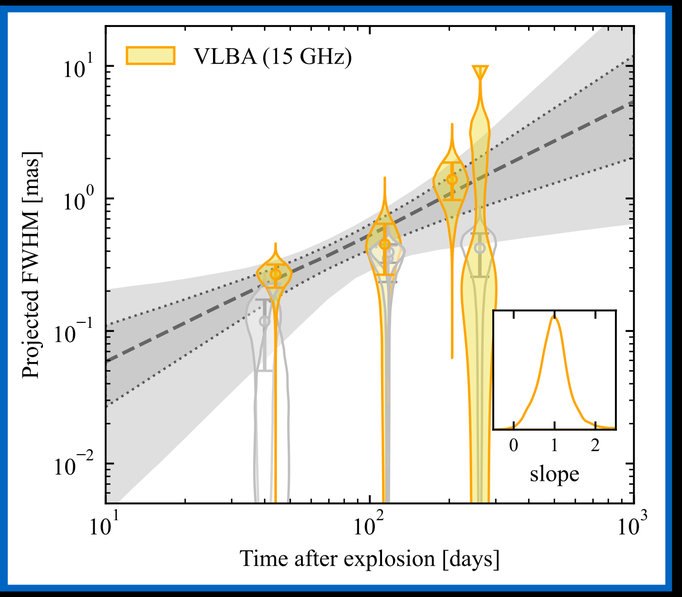
Conclusions



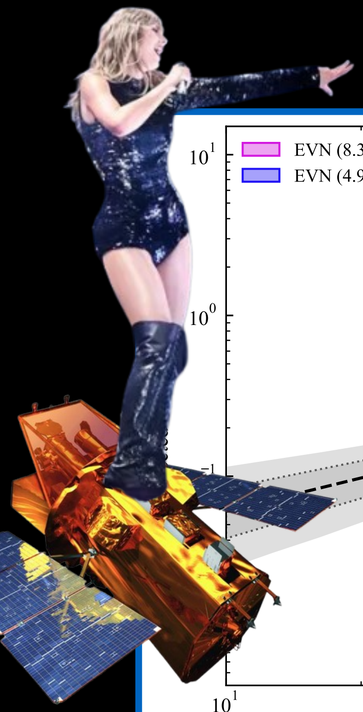
Conclusions

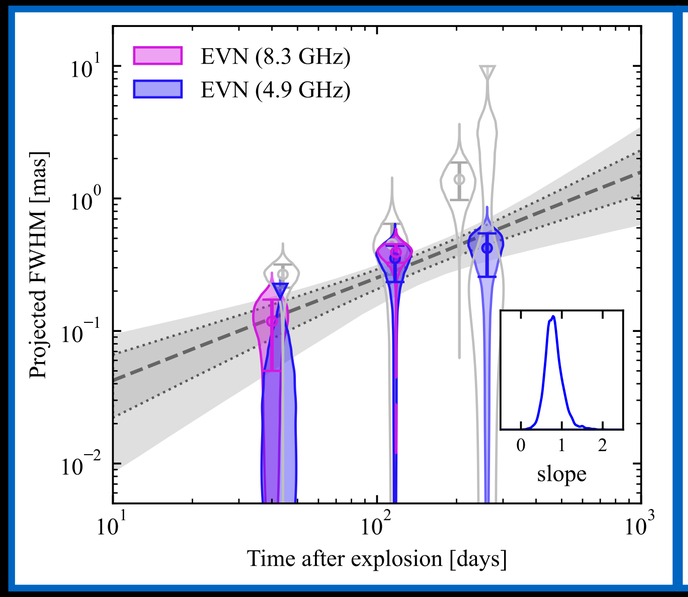


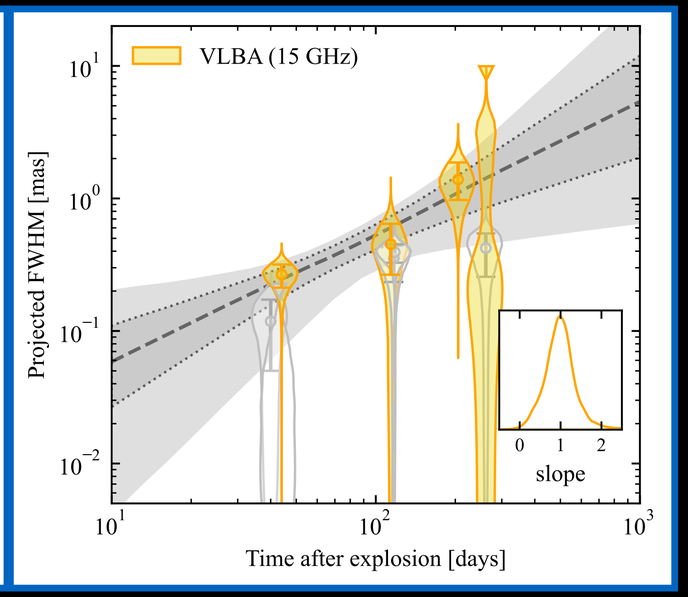




Conclusions

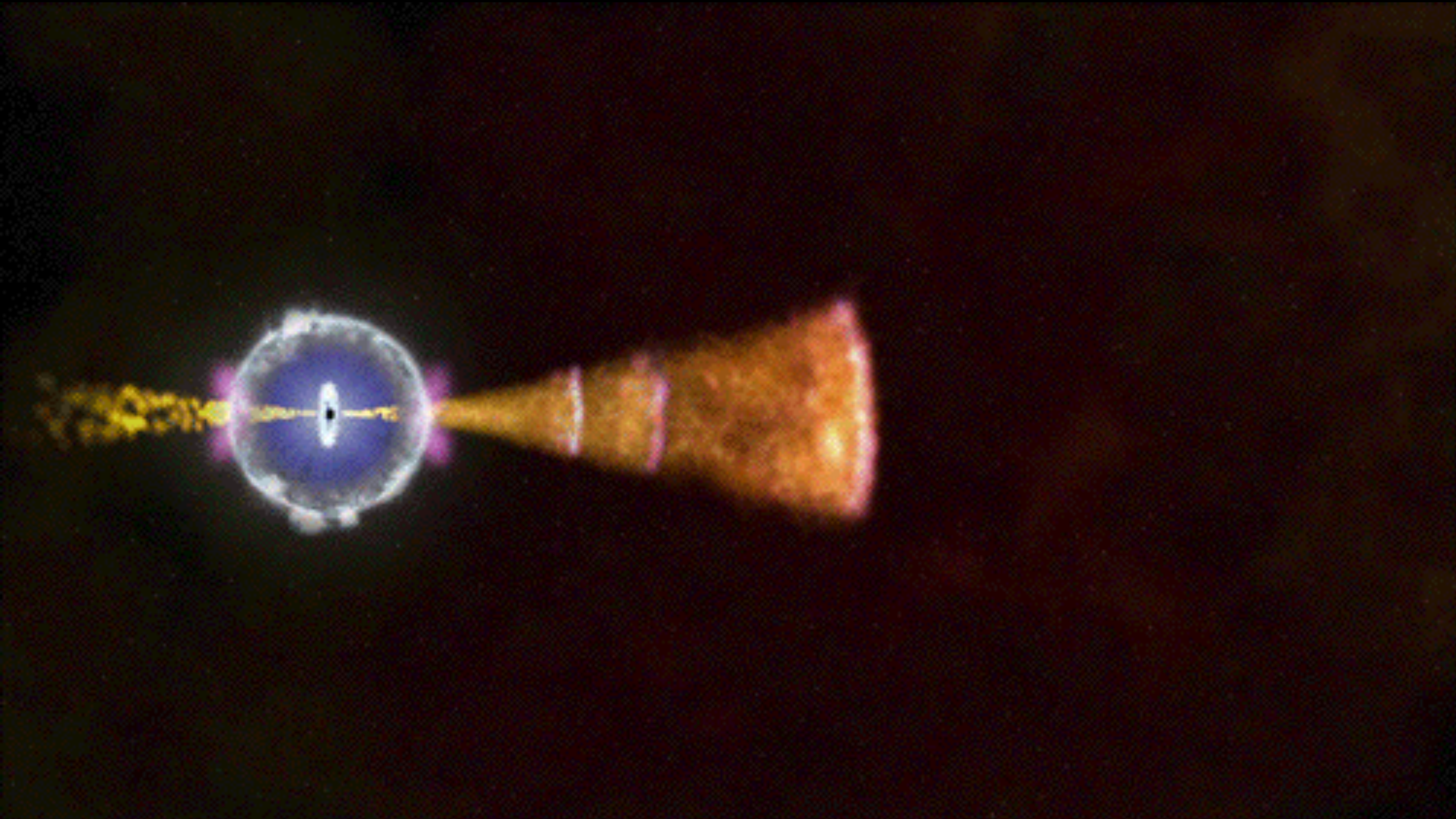




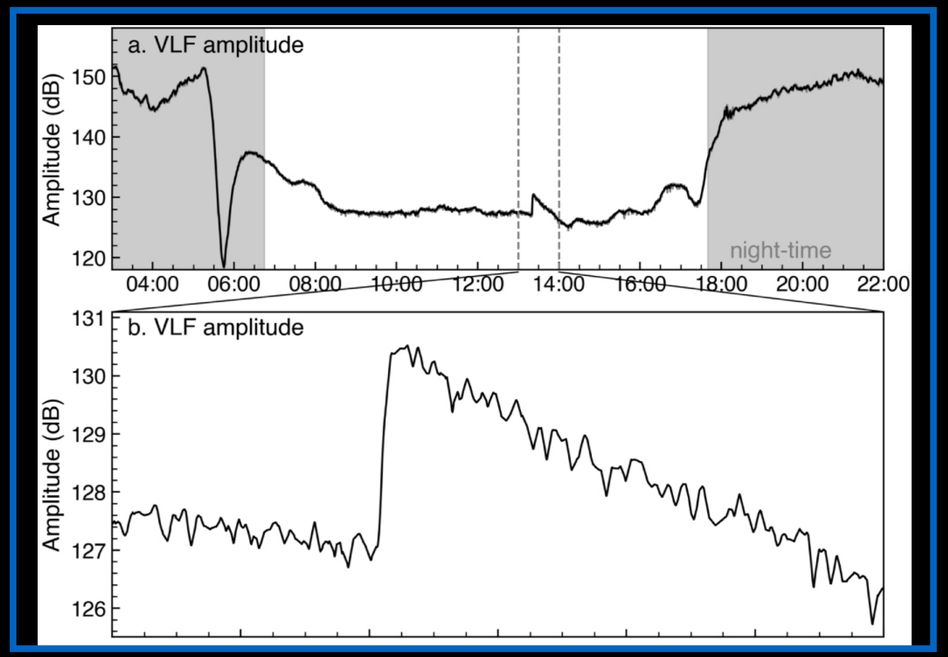


Thank you!

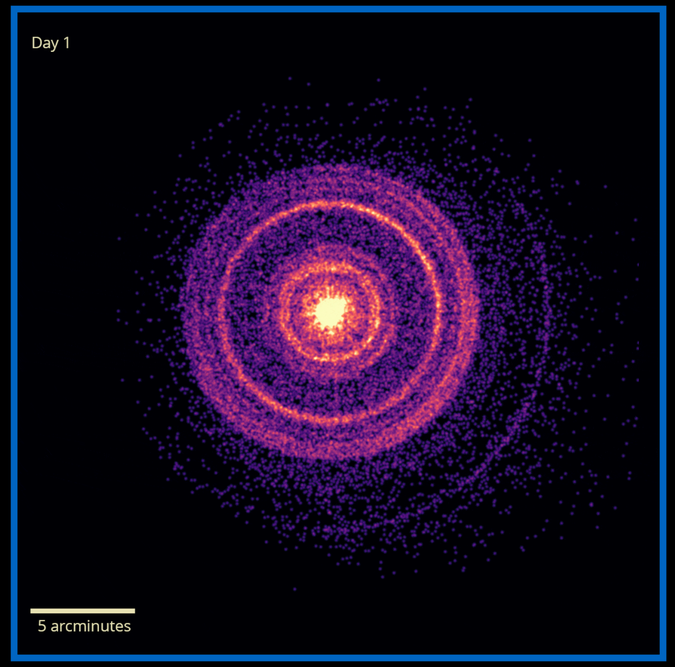
Backup Slides



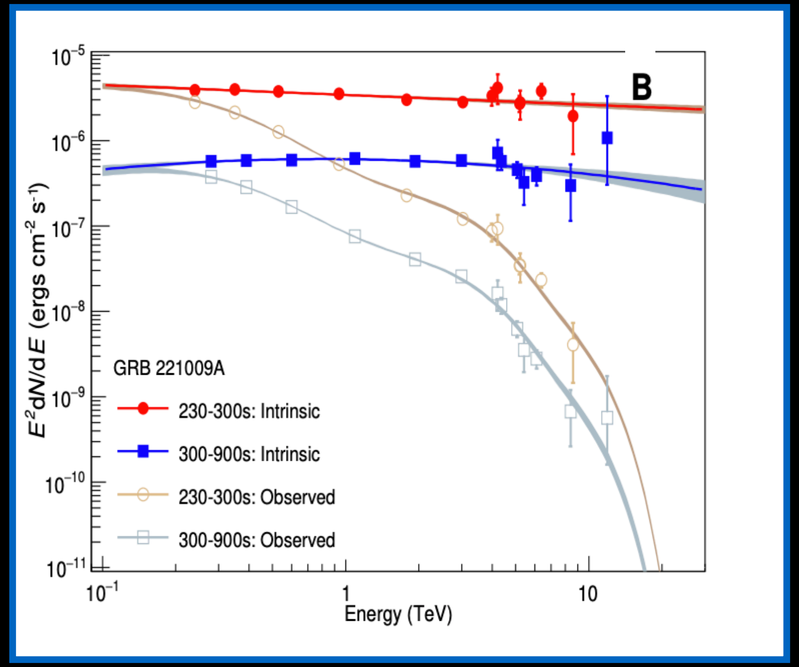
GRB 221009A



VLF amplitude on 2022 Oct 09.
From *Hayes & Gallagher (2022)*



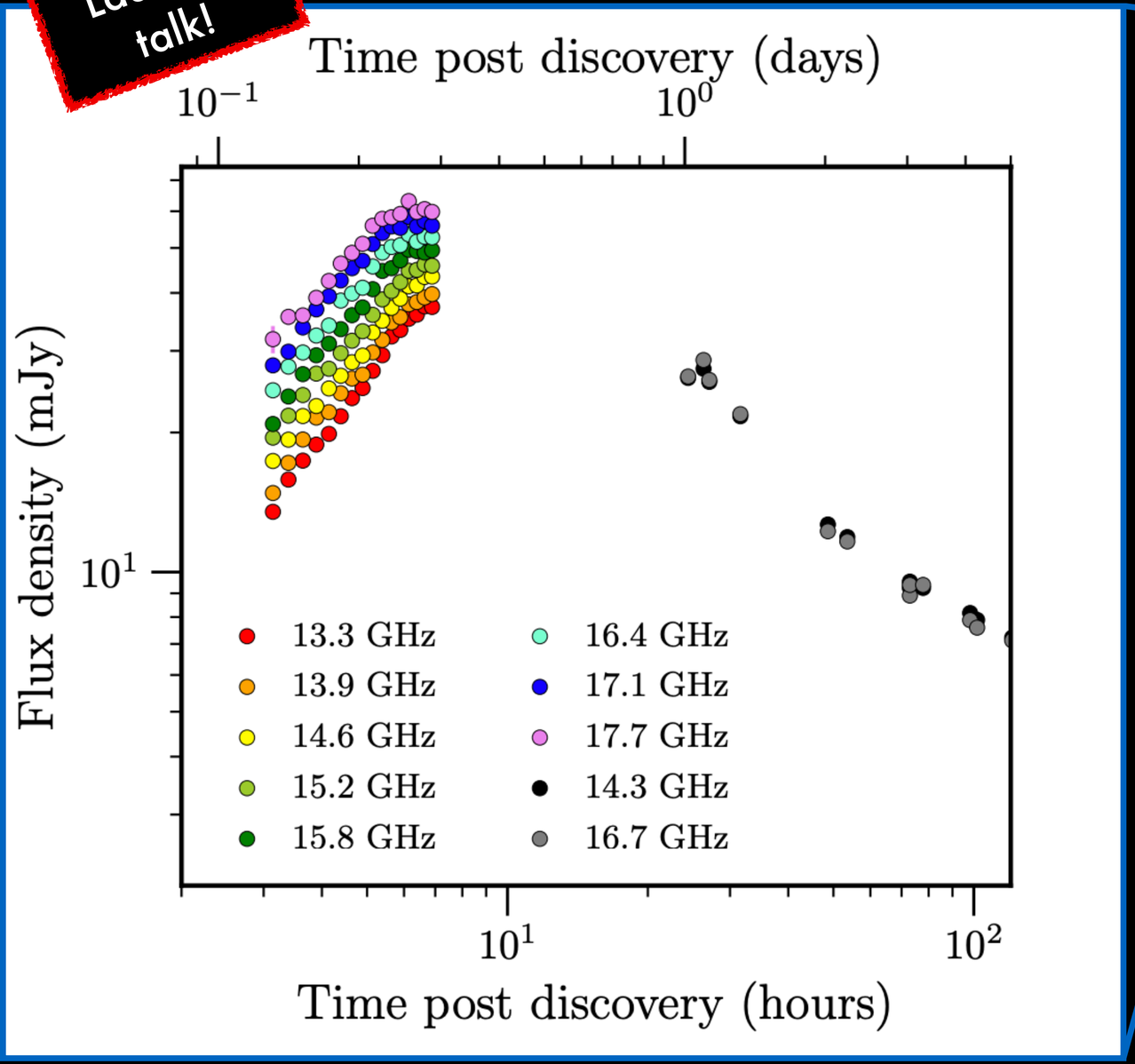
Credit: NASA/Swift/A. Beardmore (Univ of Leicester)



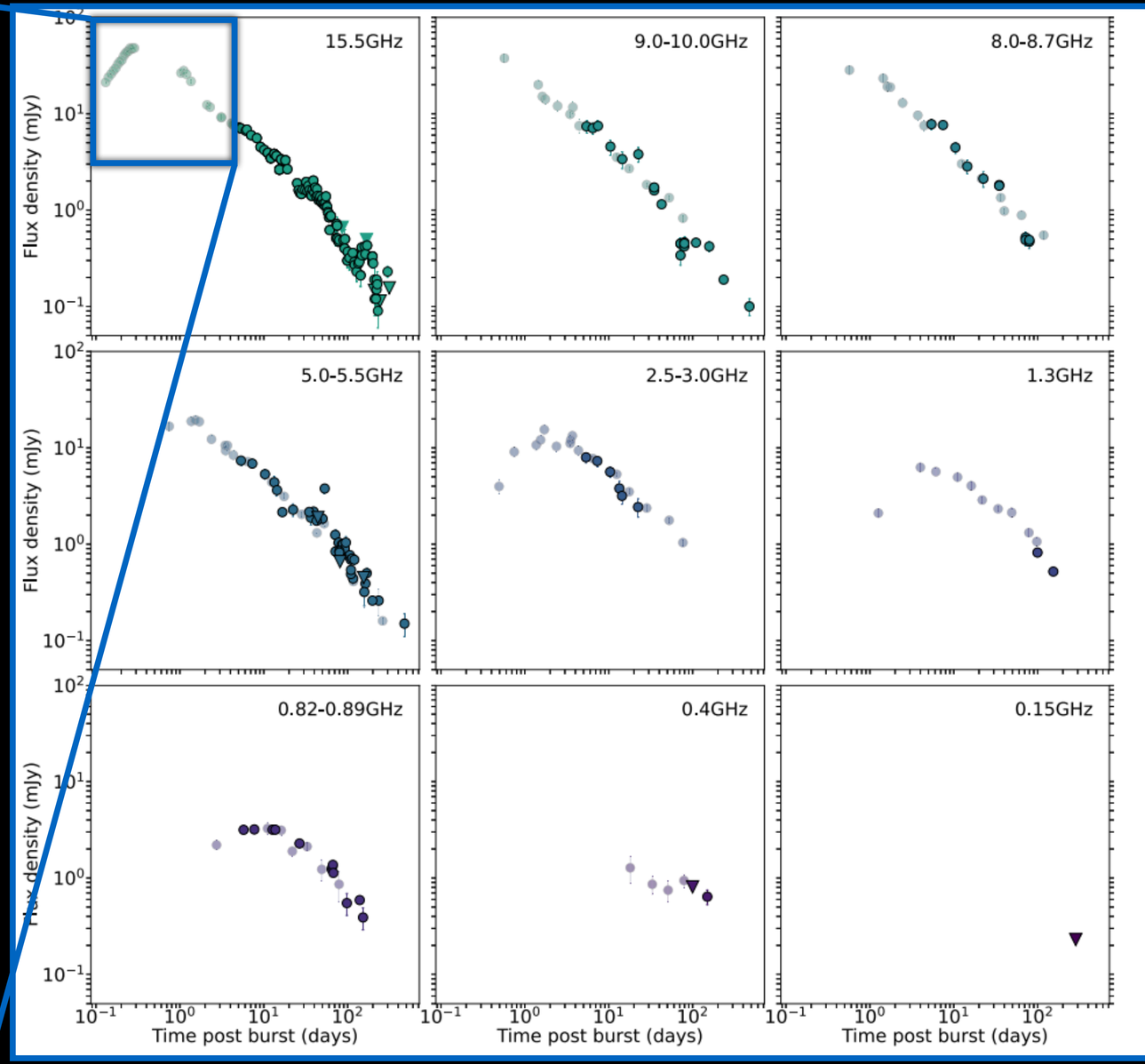
Intrinsic VHE spectra corrected for EBL.
From *LHAASO Collaborarion (2023)*

The radio emission of the BOAT

See Lauren's talk!

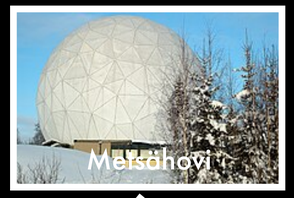


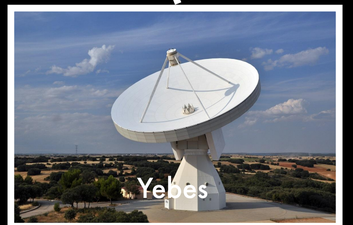
From *Bright, Rhodes, …, SG et al. (2023)*



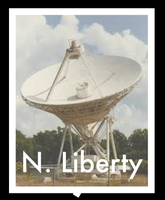
From *Rhodes, …, SG et al. (2024)*

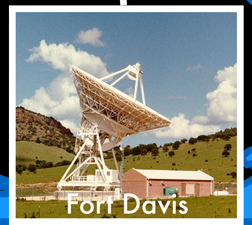
The European VLBI Network



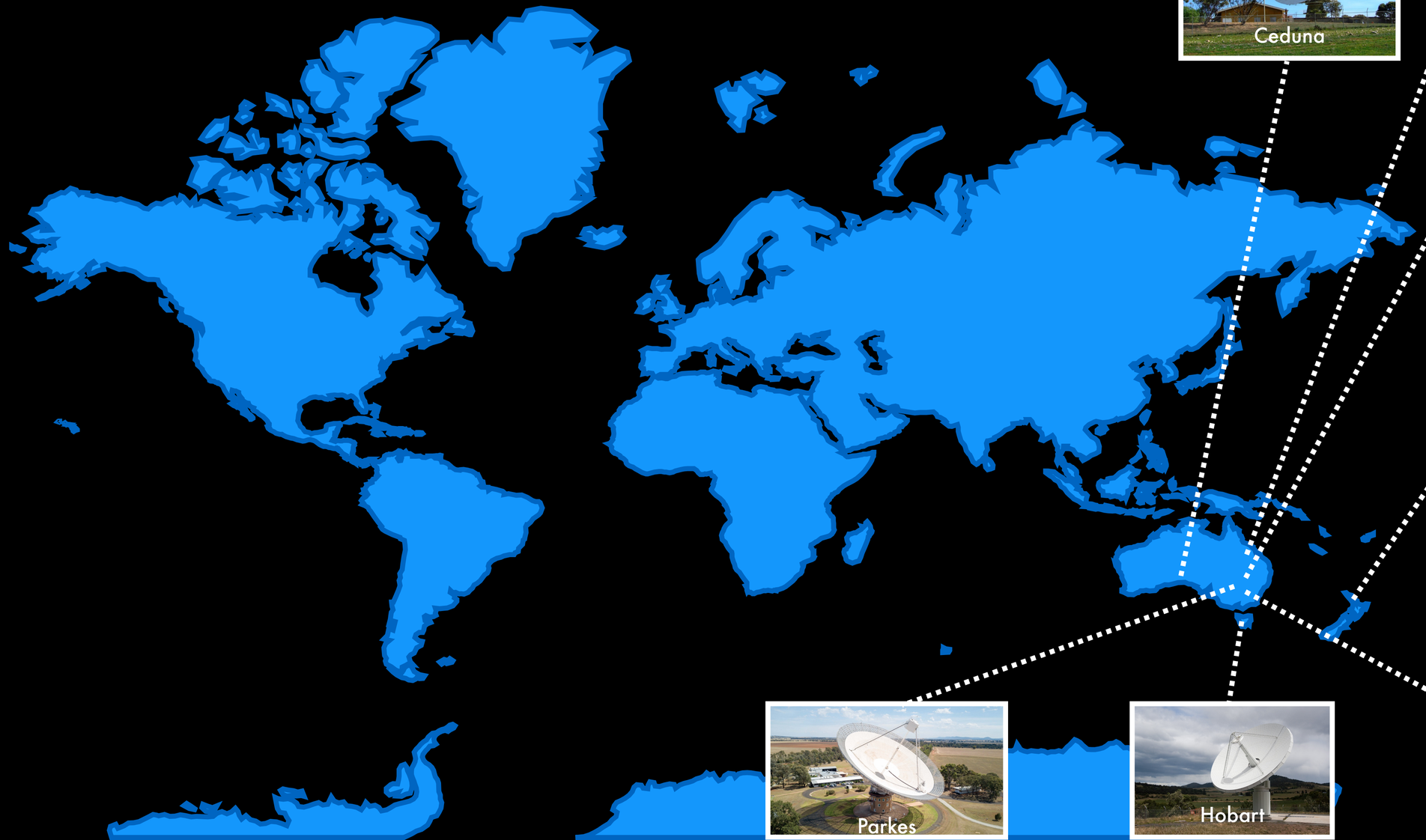


The Very Long Baseline Array





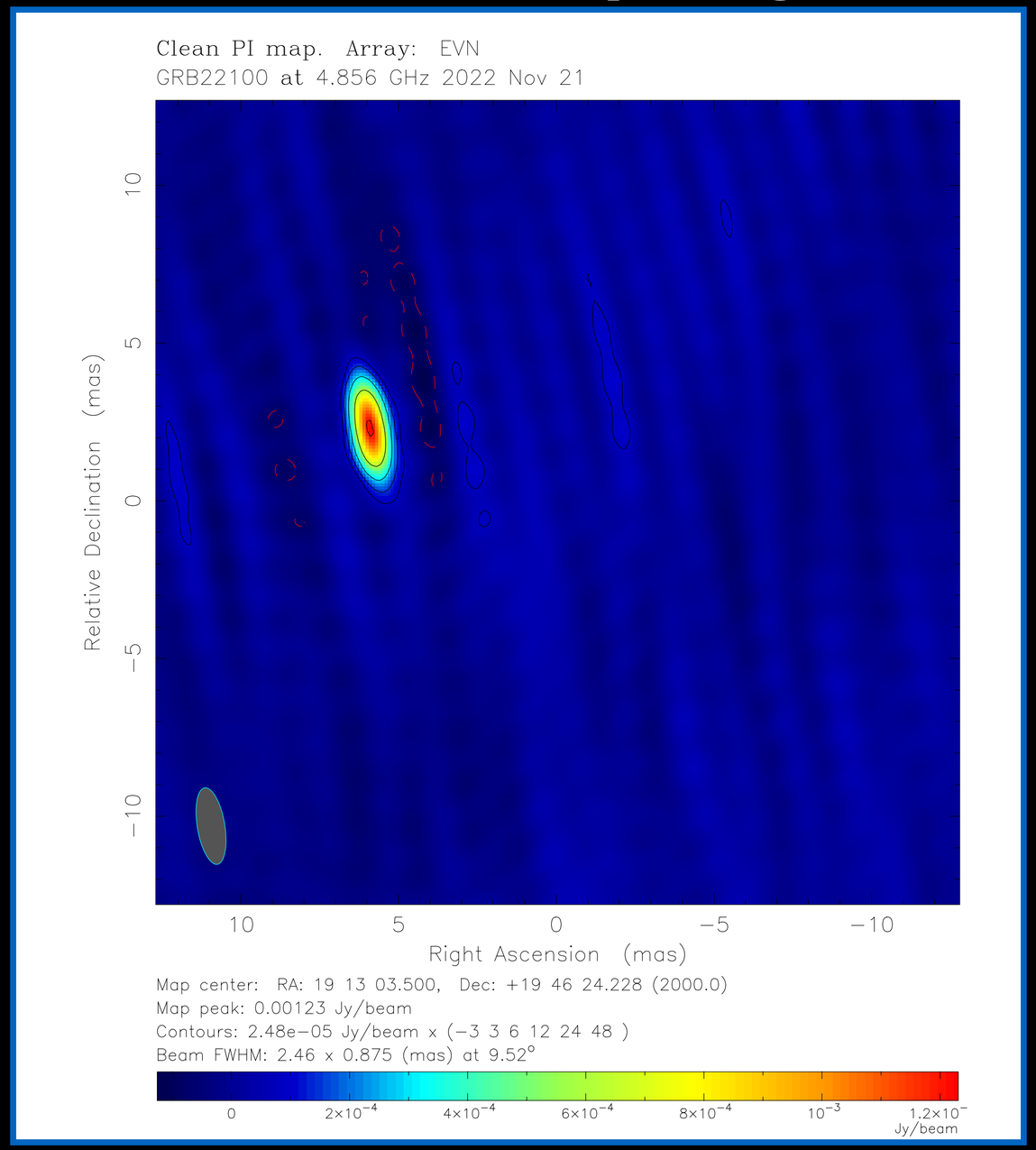
The Long Baseline Array



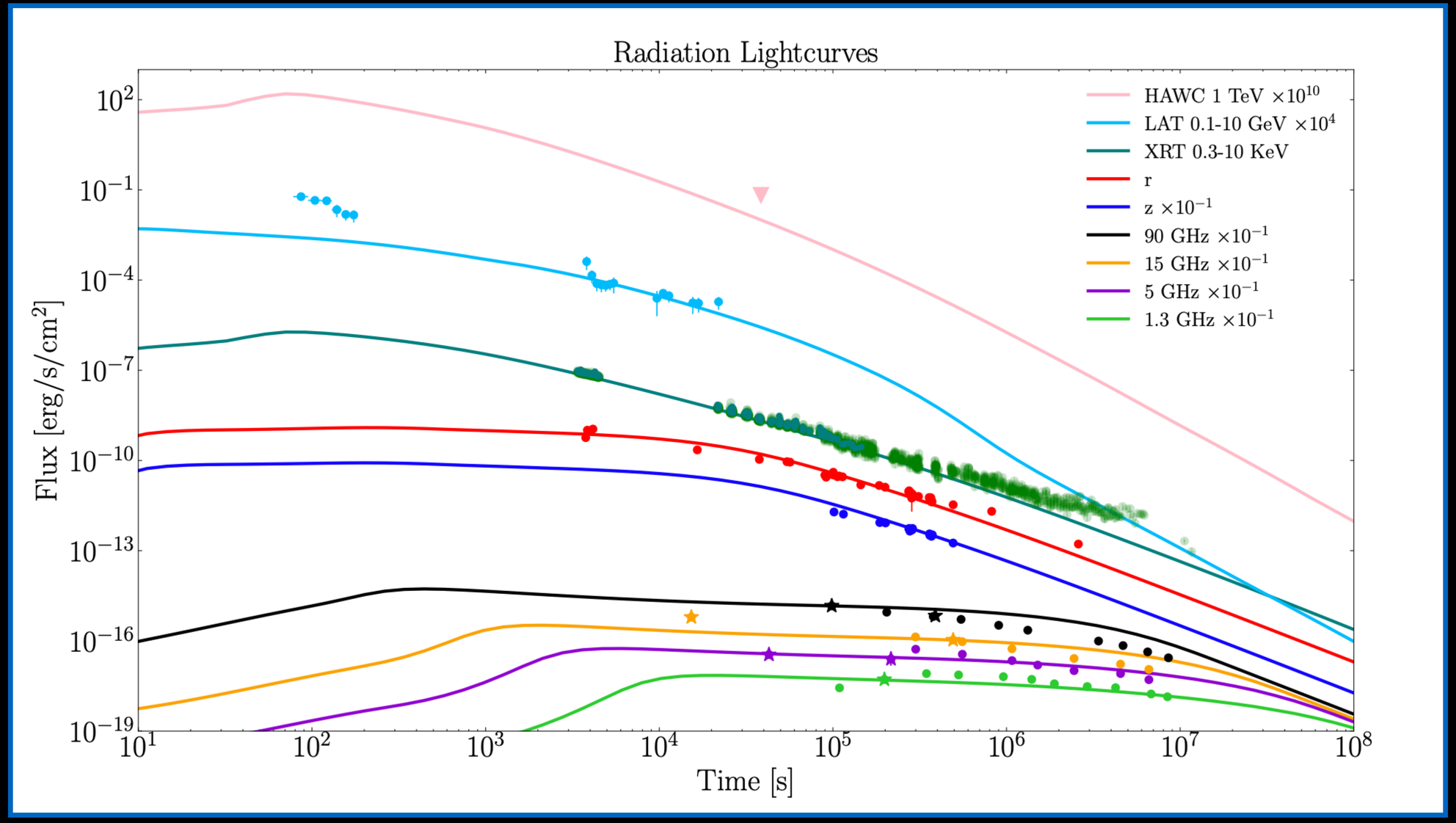
VLBI campaign

Frequencies
5, 8, 15 GHz

Time
40 to 262 days

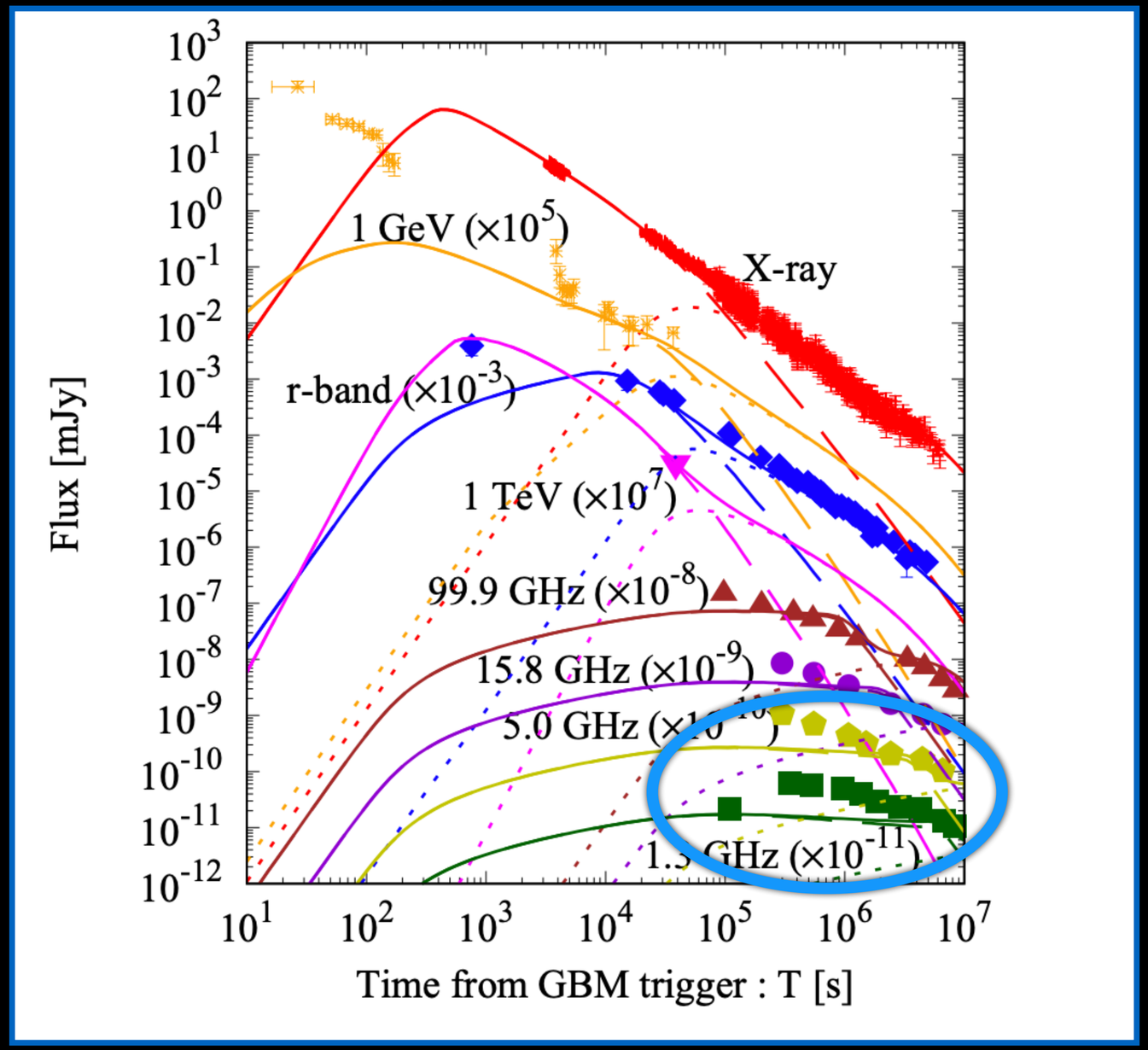


Afterglow Models



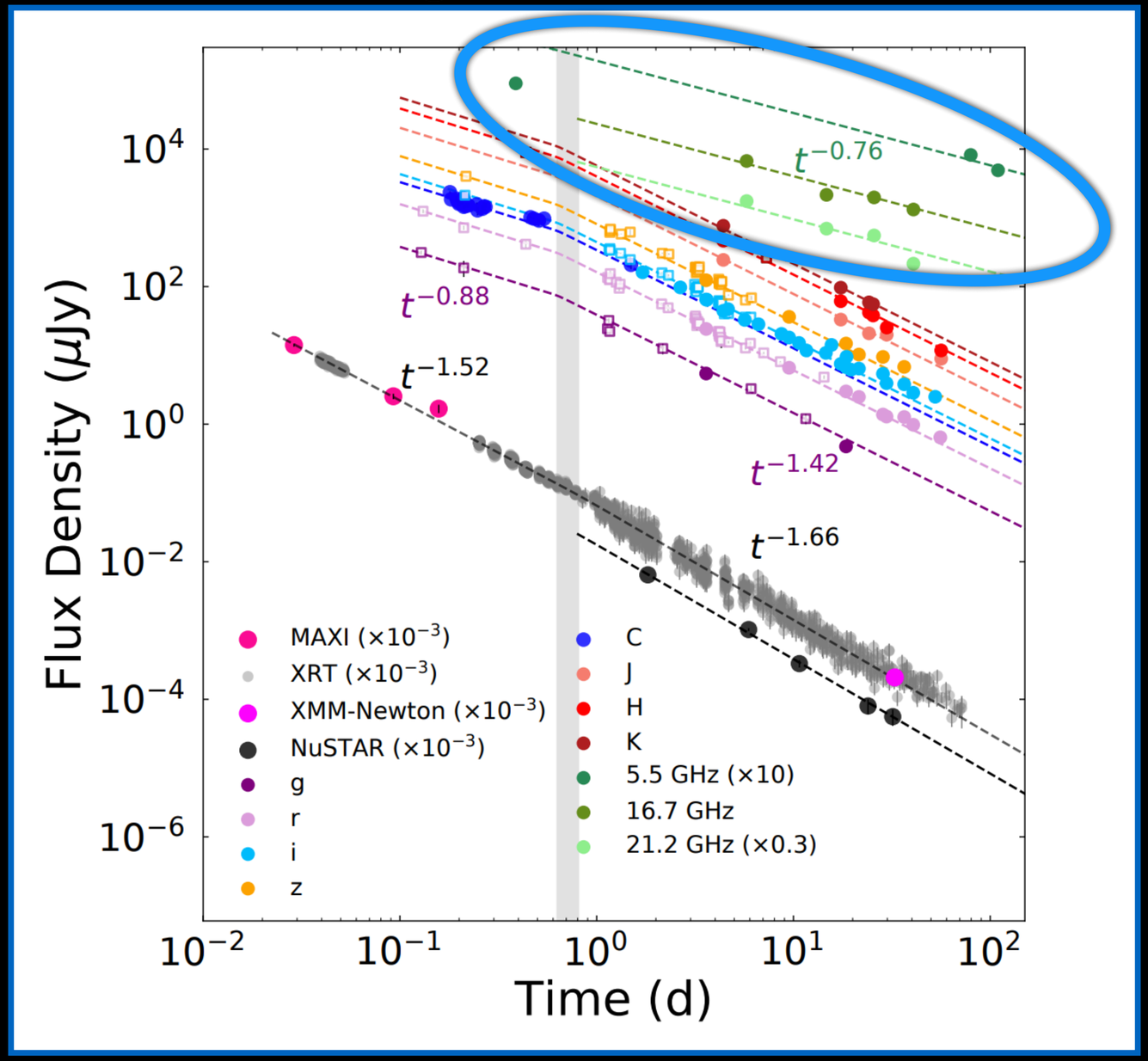
Top-hat jet model expanding in a wind-like environment. From *Ren et al. (2023)*

Afterglow Models



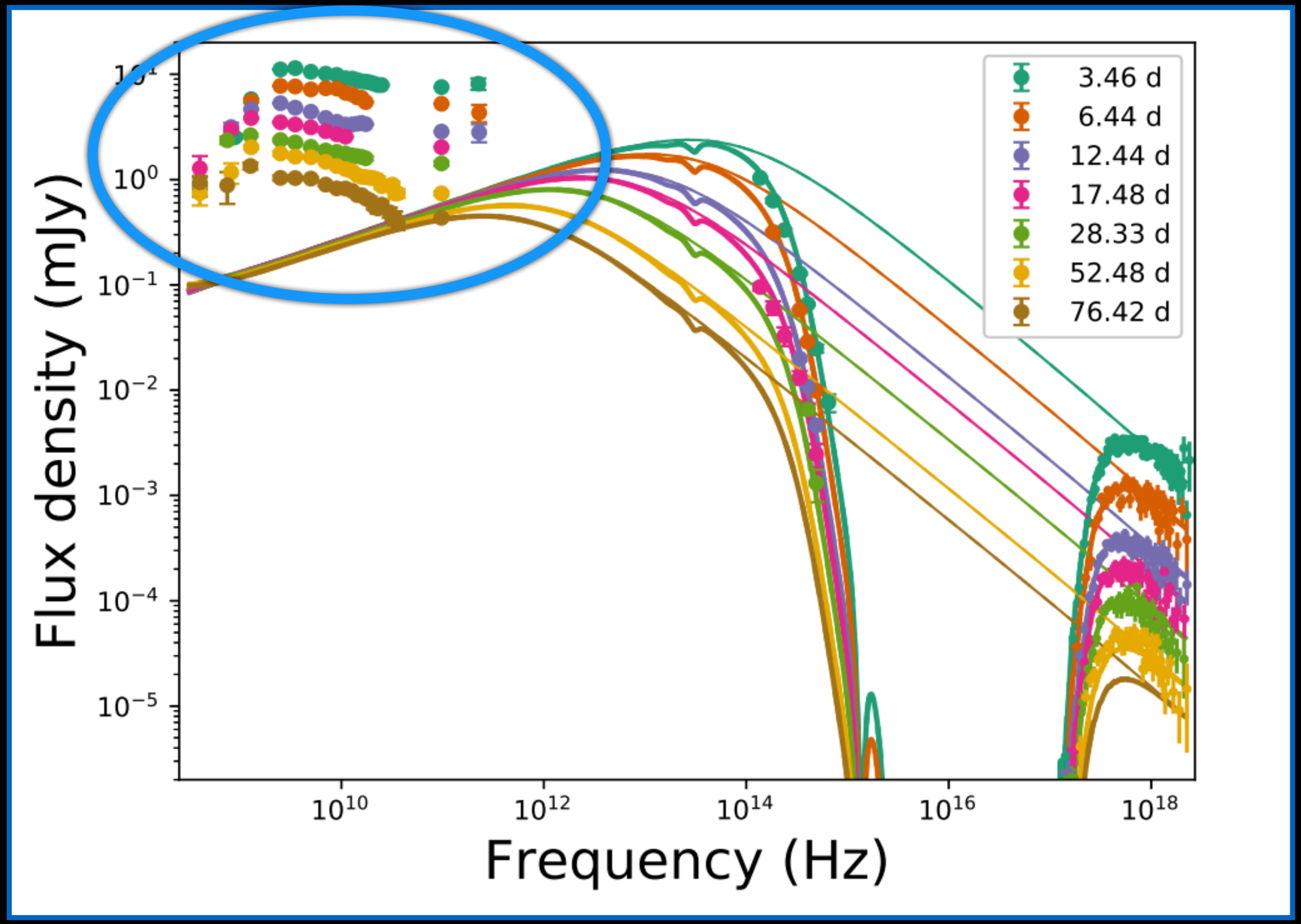
Two-component jet expanding in a uniform environment. From *Sato et al. (2023)*

Afterglow Models



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

Afterglow Models

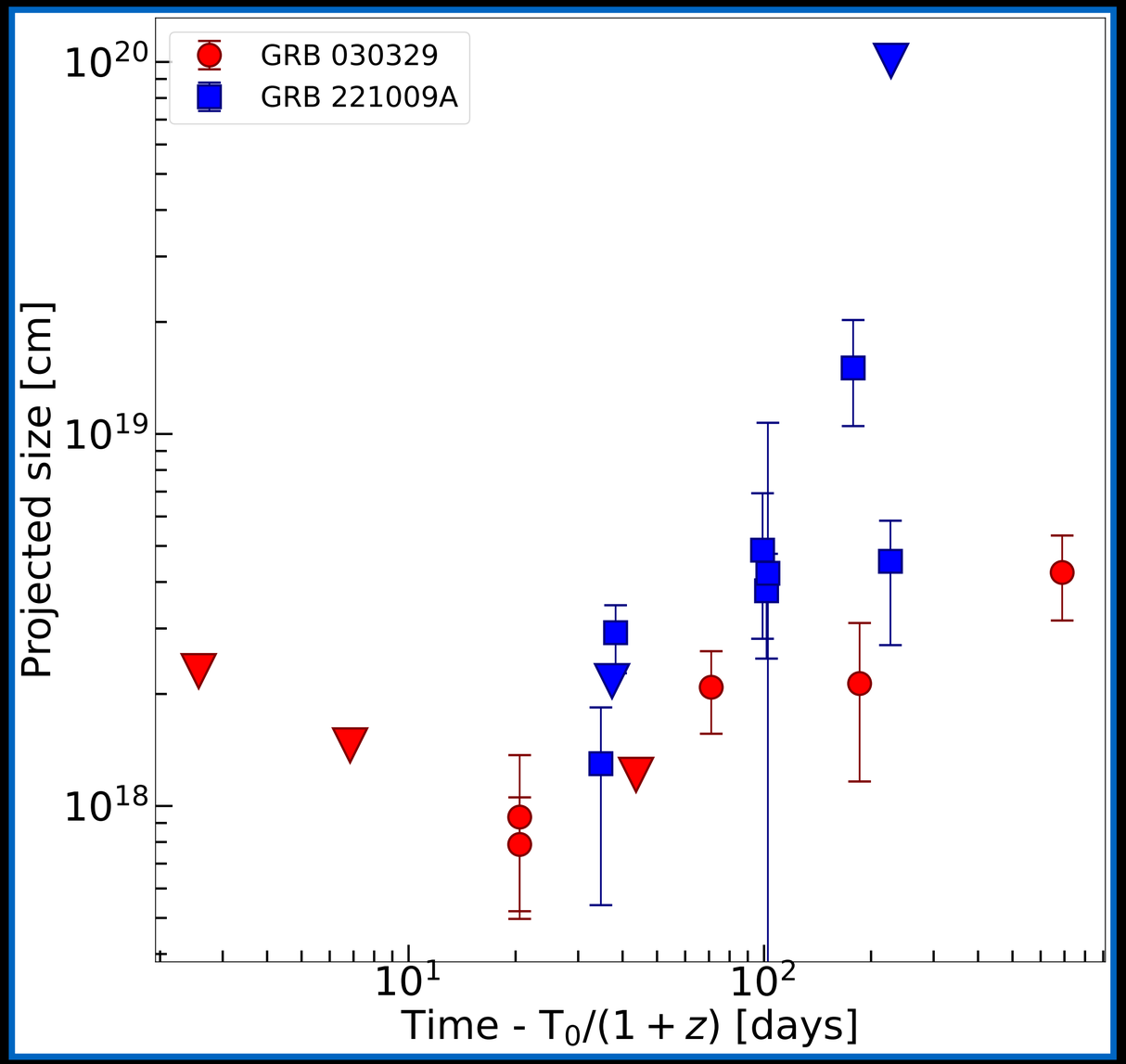


From *Laskar et al. (2023)*

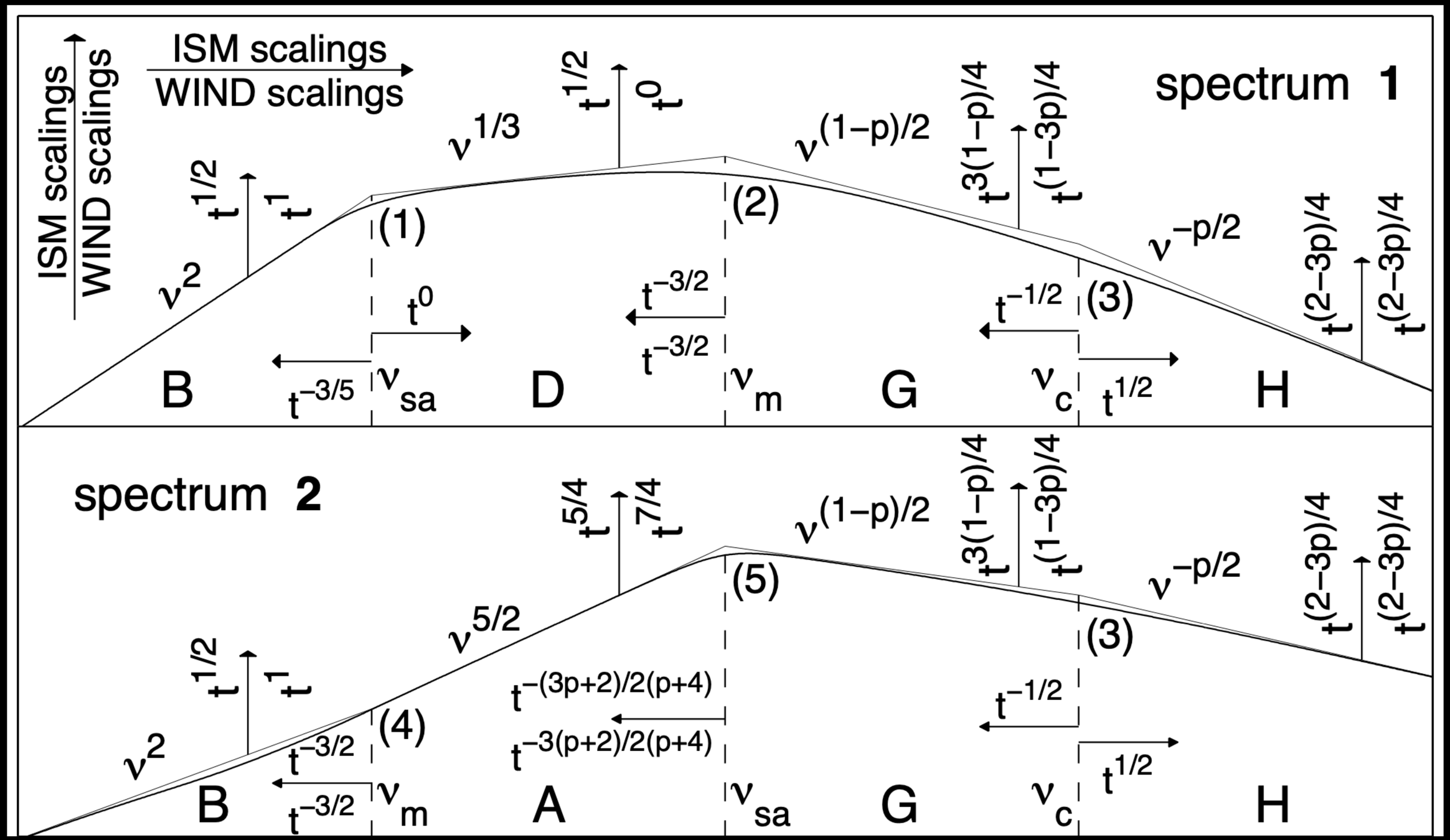
Our VLBI campaign

T - To	Freq	Array
40	8.3	EVN
43	4.8	EVN
44	15.1	VLBA
114	15.1	VLBA
117	4.8	EVN
118	8.3	EVN
205	15.1	VLBA
231	6	Global
261	4.8	EVN
262	15.1	VLBA
391	6	Global

GRB 221009A



Size evolution of GRB 221009A and GRB 030329.
From *Giarratana et al. (2024)*



Synchrotron spectrum for the afterglow model. From *Granot & Sari (2002)*

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.