



# Loud and Bright: challenges and needs of MM astronomy

Giancarlo Ghirlanda - INAF - Osservatorio Astronomico di Brera

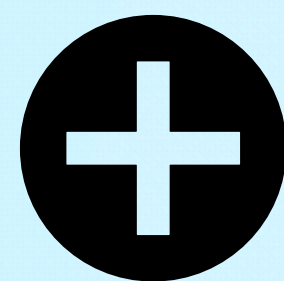


## EM counterparts of GW (what, how, lessons)

## What EM facilities we have, will have, wish to have

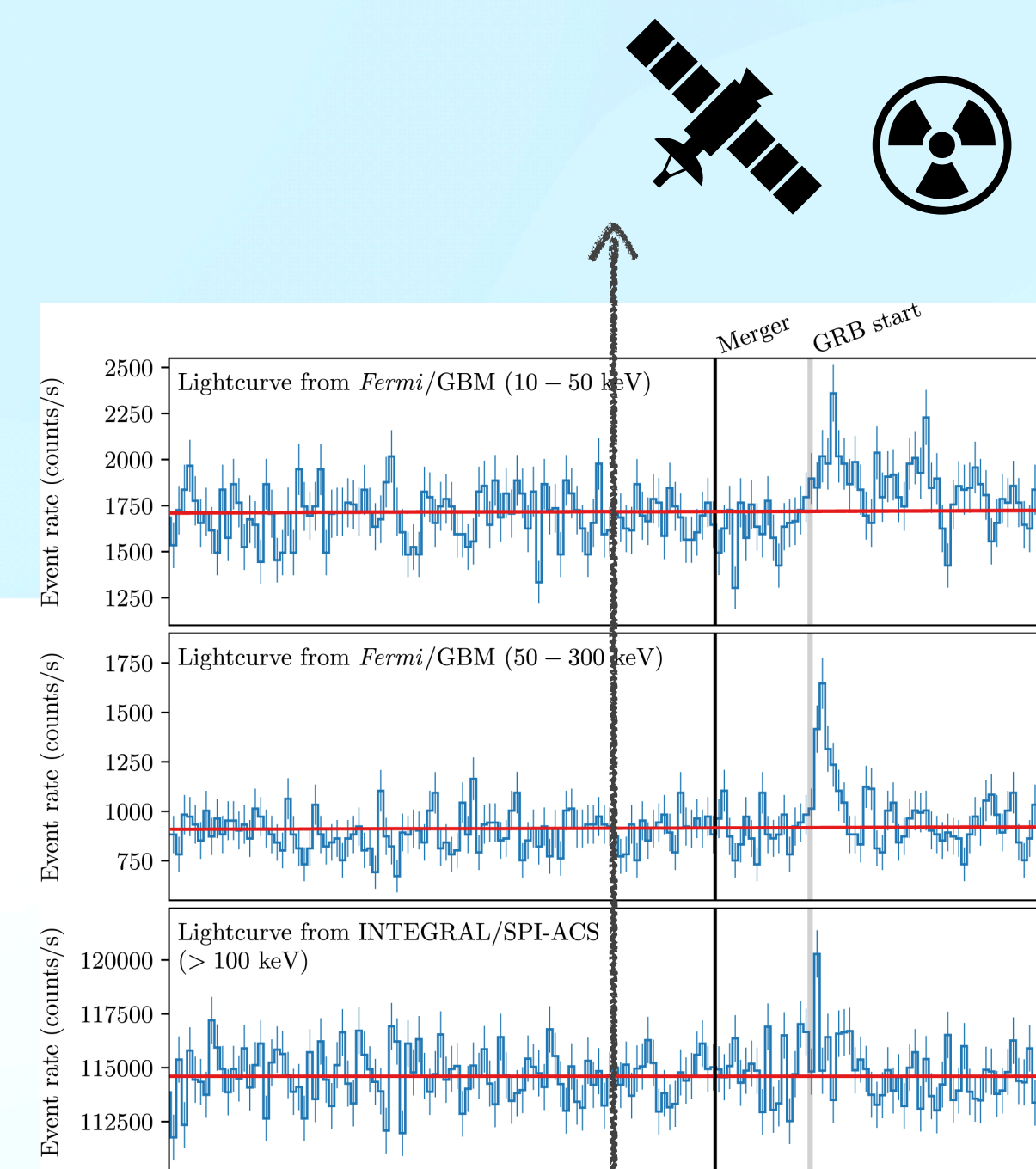
[Apologise for incompleteness]





# The rosetta stone: What & How

## GW/GRB/KN 170817



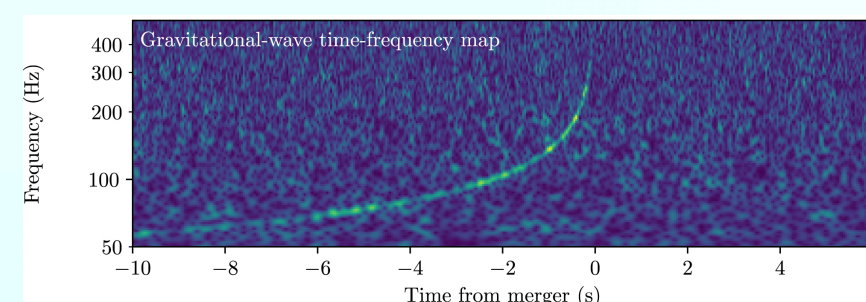
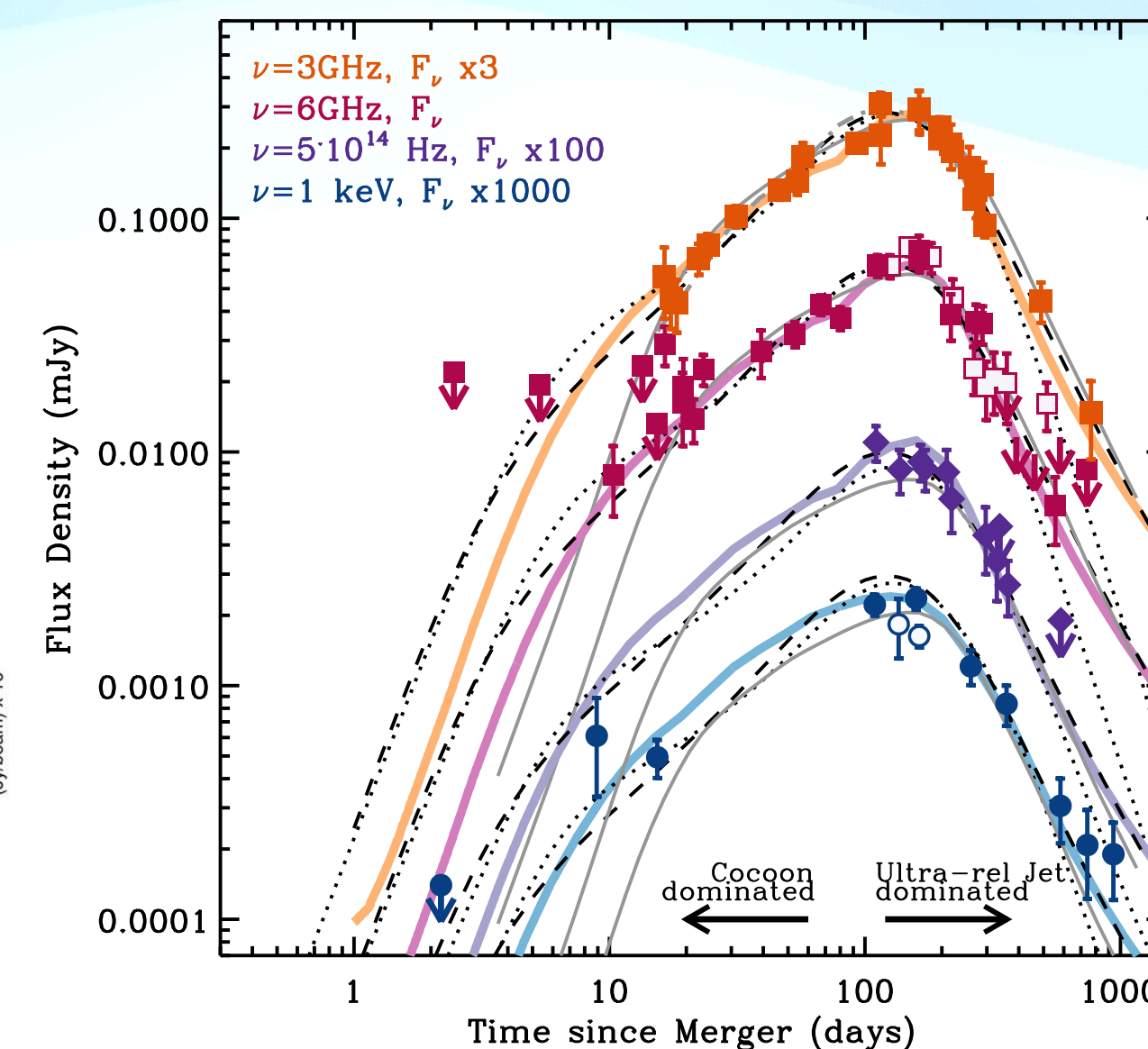
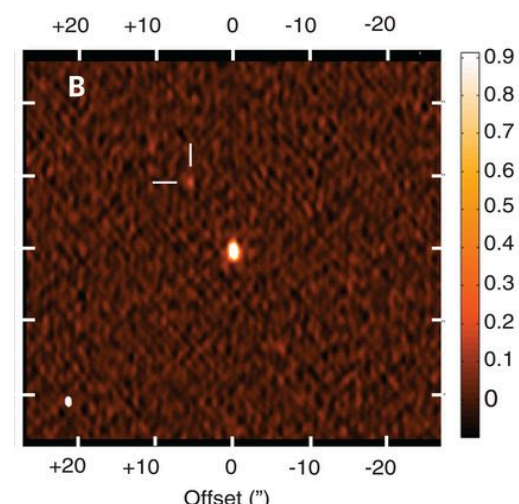
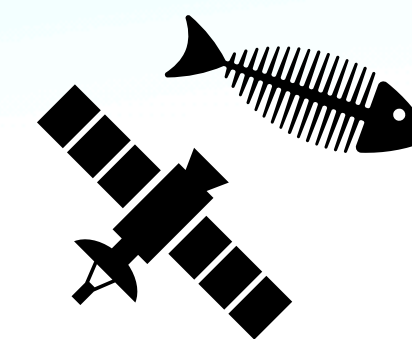
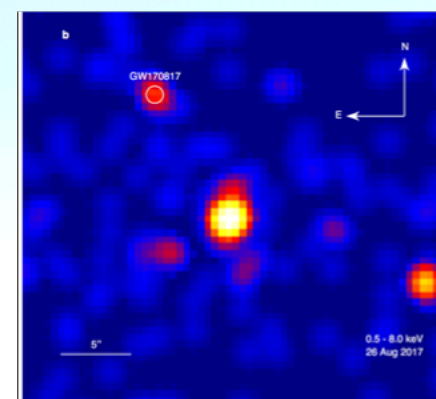
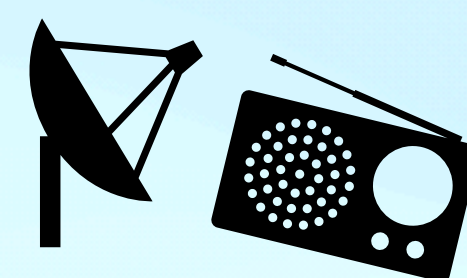
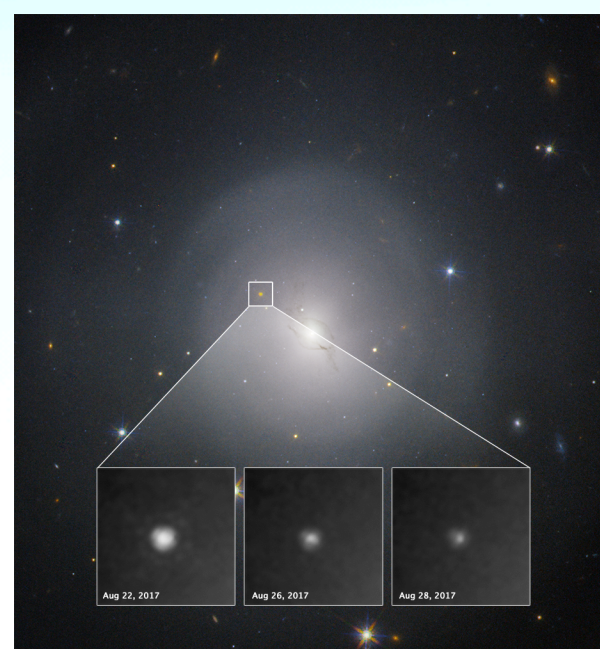
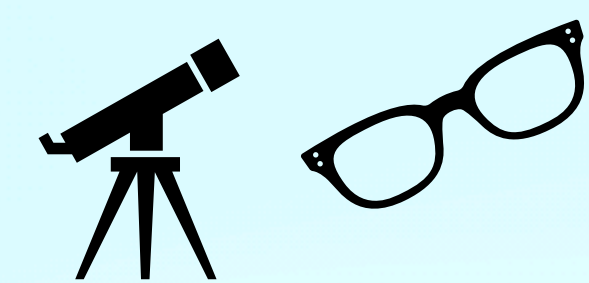
1.7 sec

10.5 hours

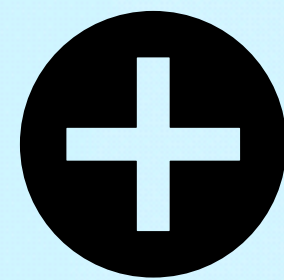
9 days

16 days

2.7 years

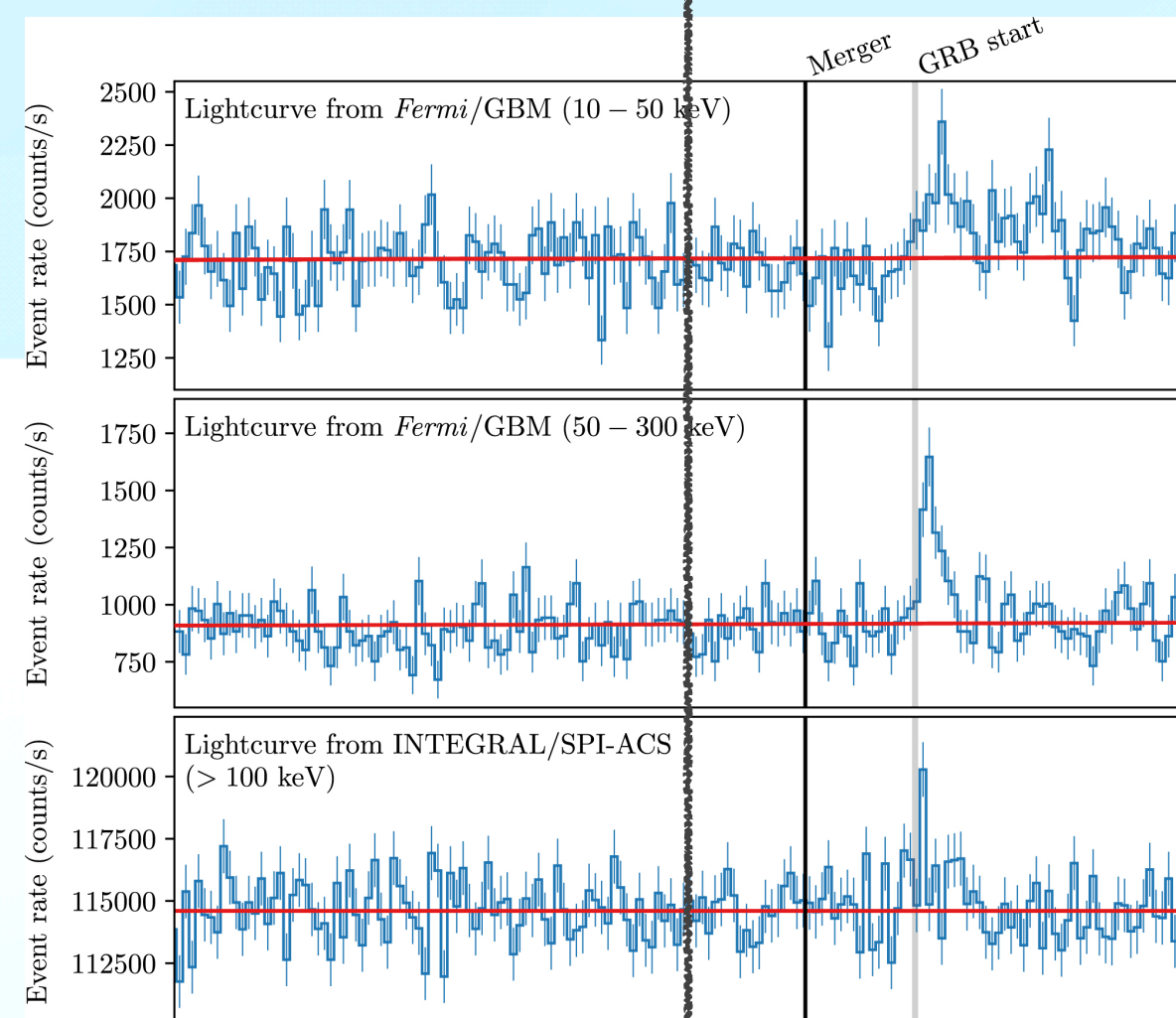




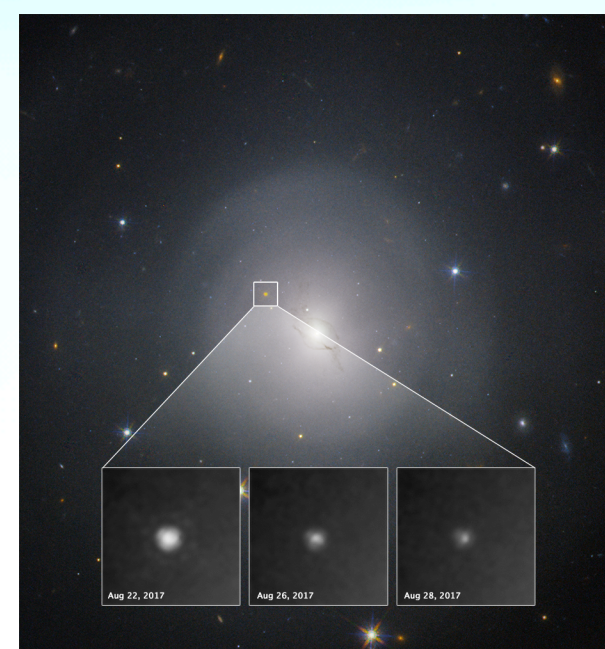
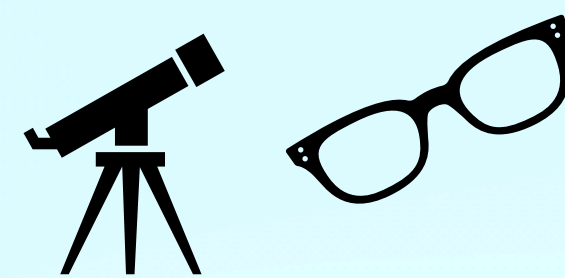


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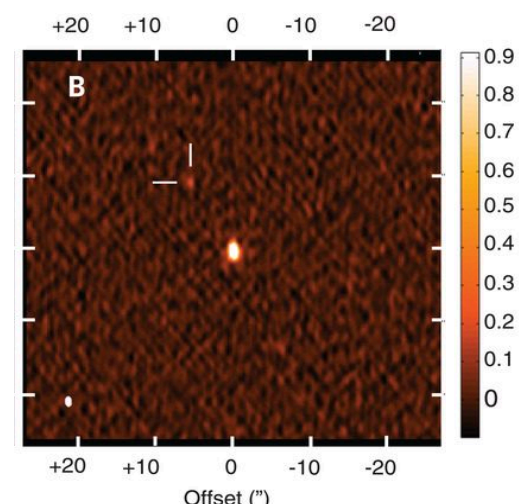
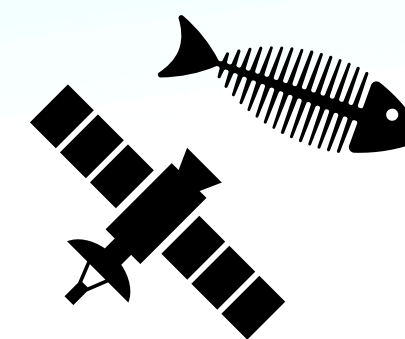
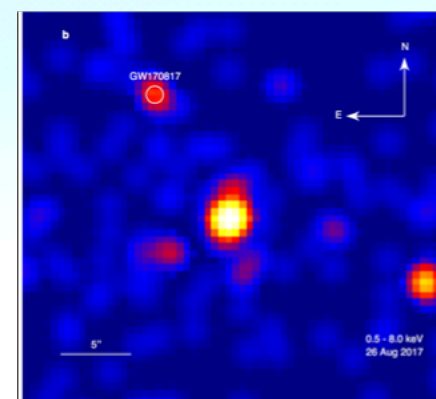
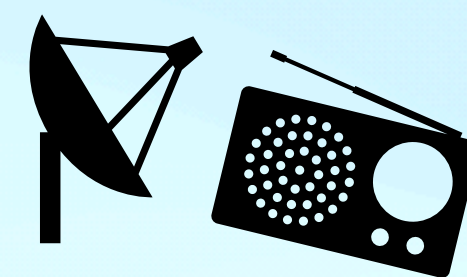
## GW/GRB/KN 170817



1.7 sec

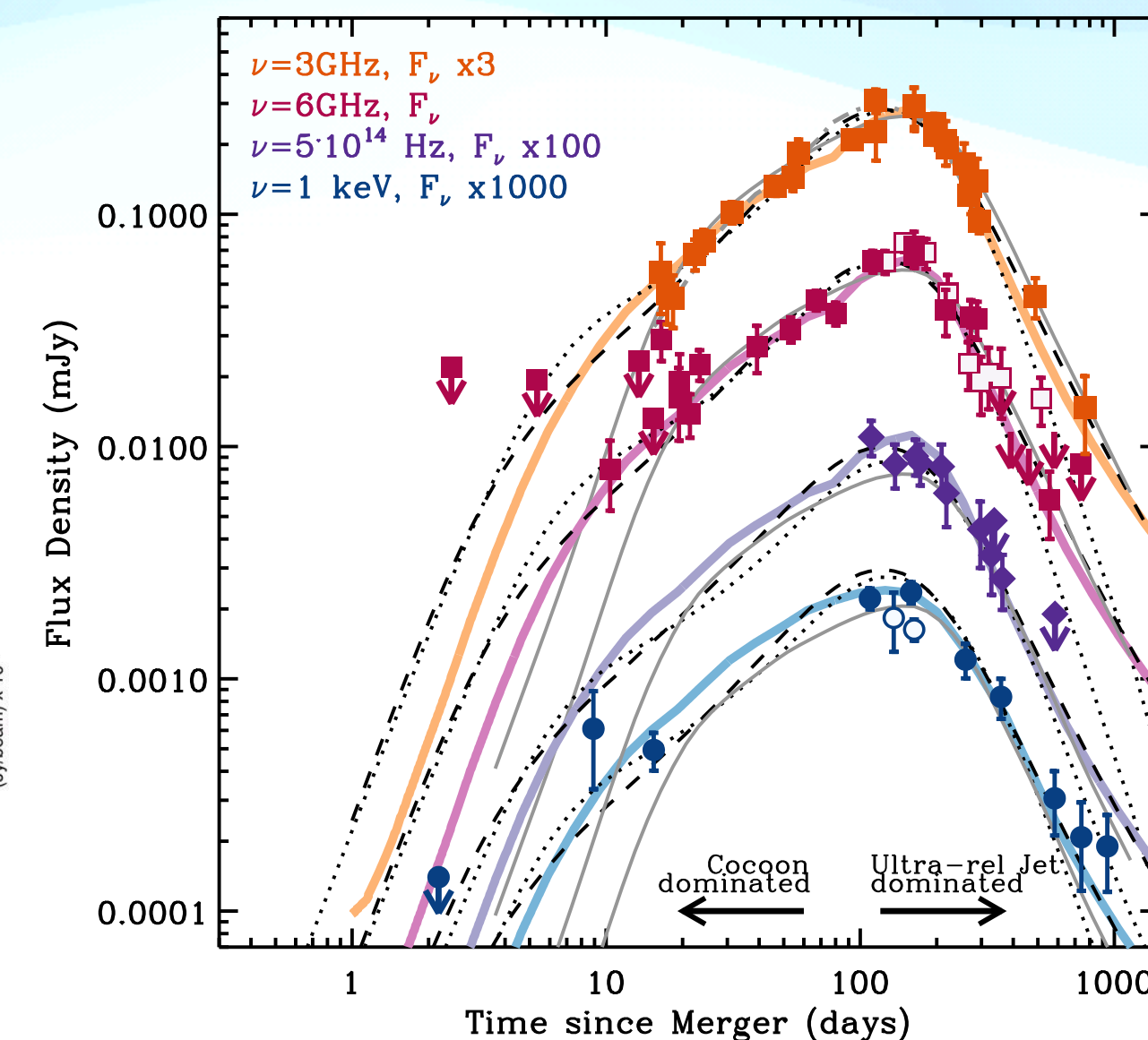


10.5 hours

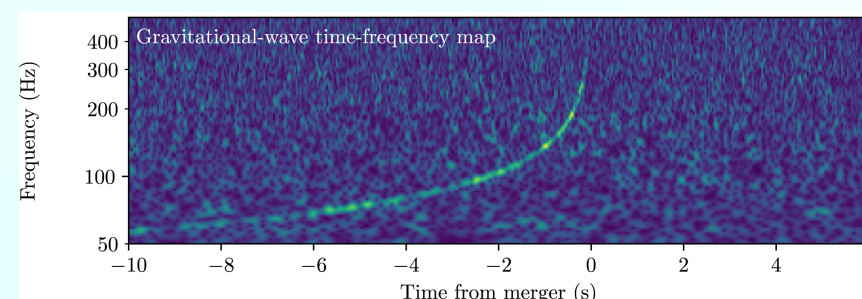


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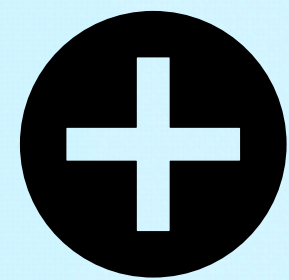
2.7 years



Discovery

Follow-up (characterisation)



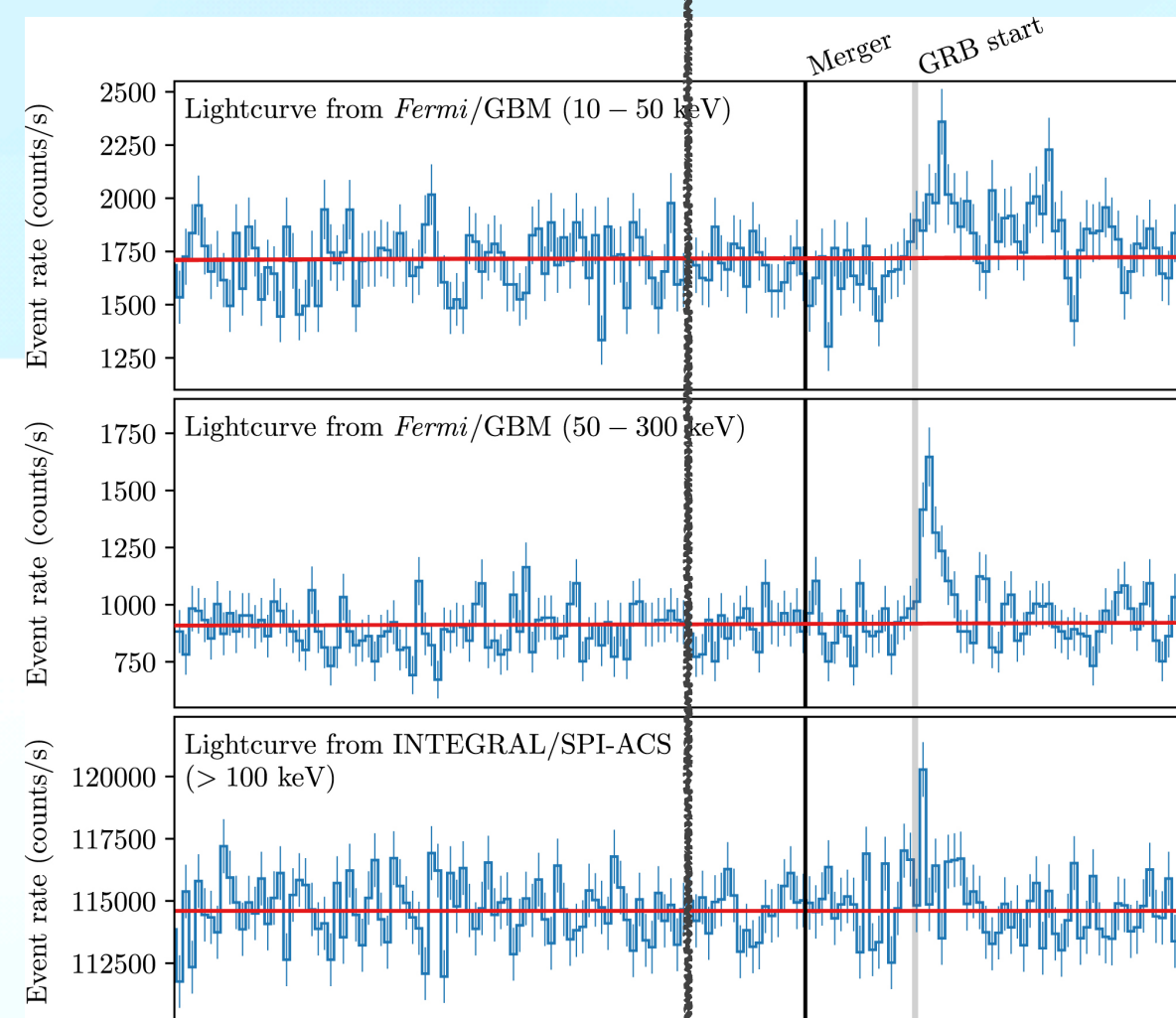


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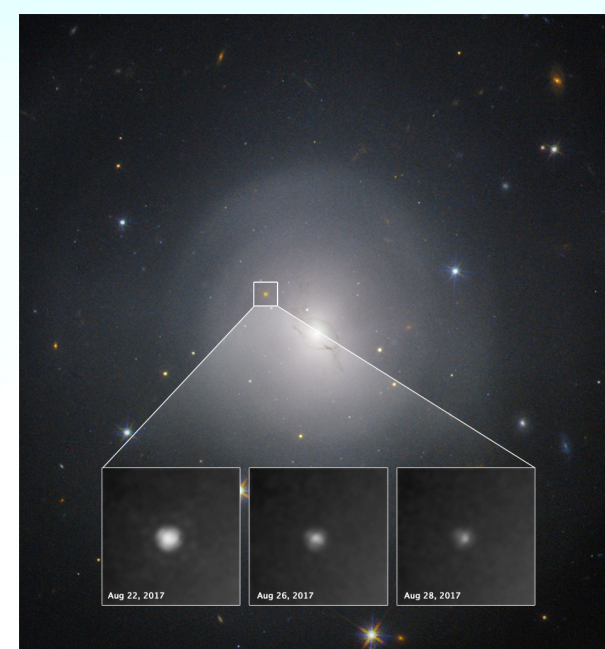
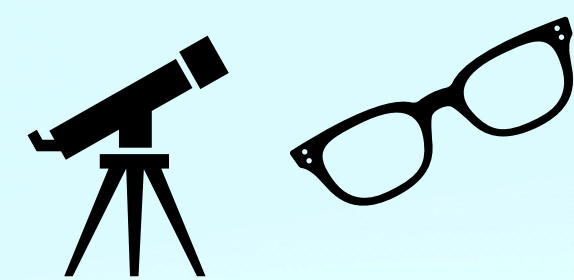
Large FoV

FoV  $\leftrightarrow$  Depth

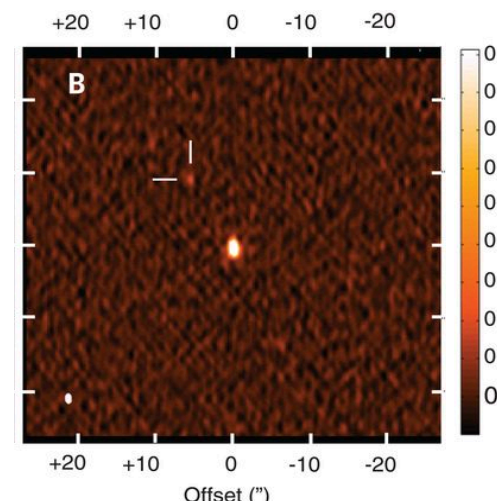
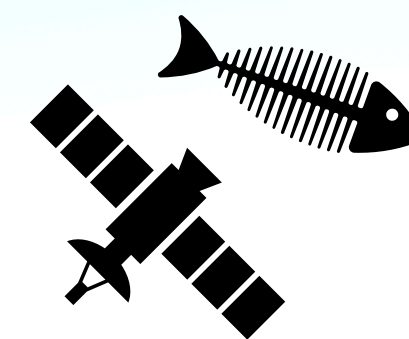
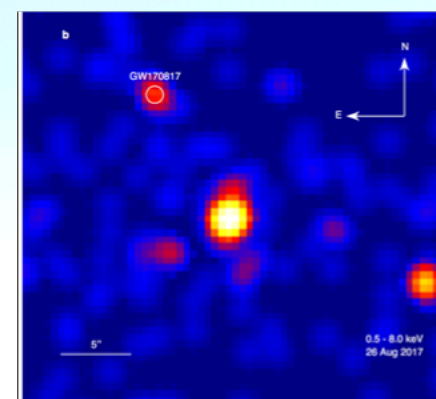
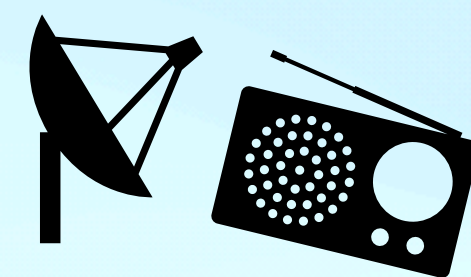
Depth + Imaging



1.7 sec

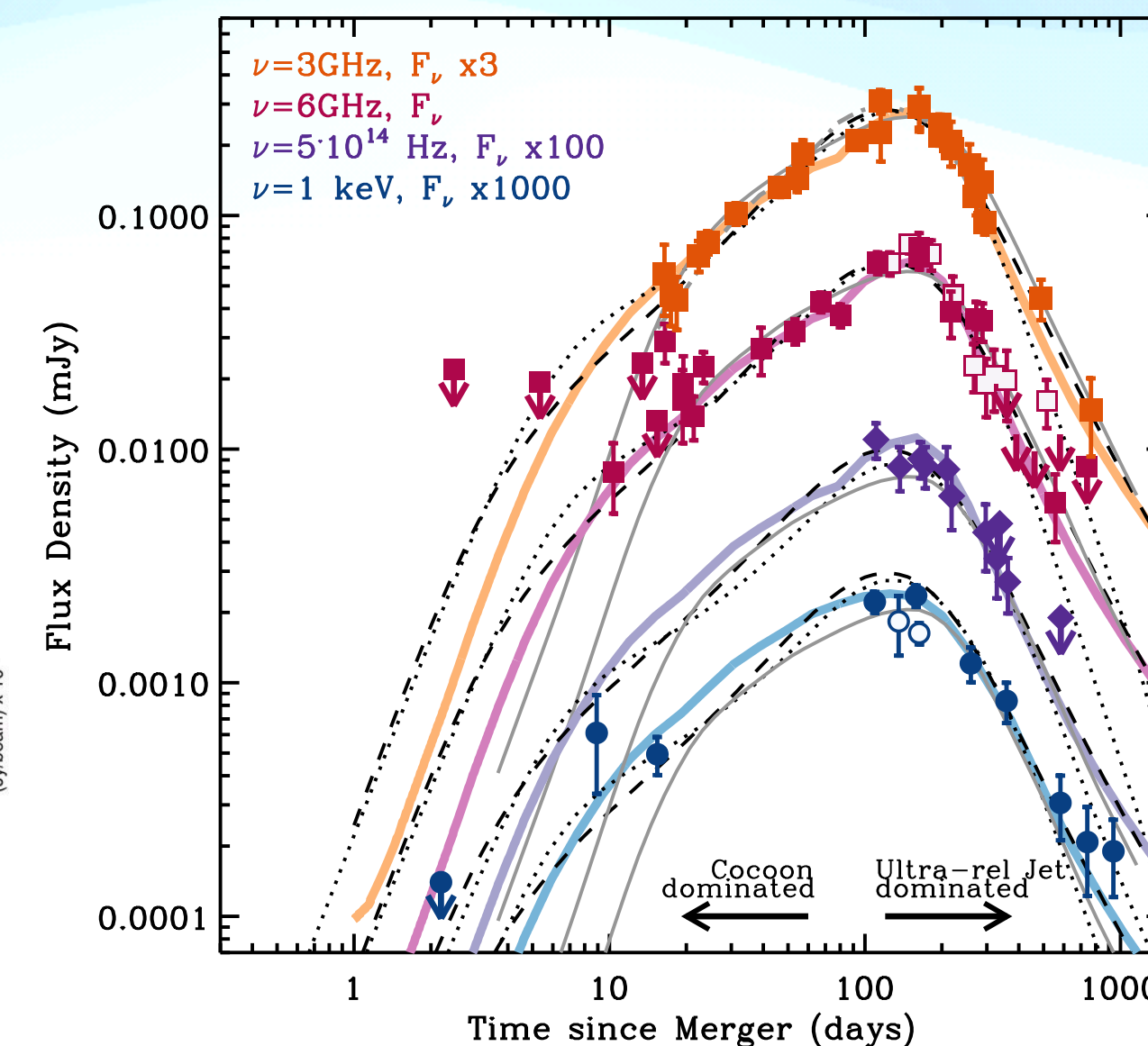


10.5 hours

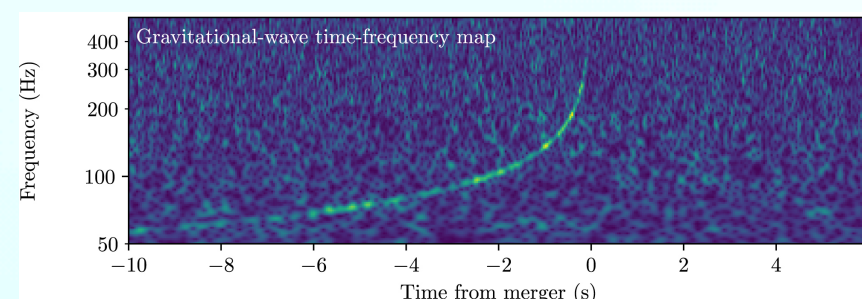


9 days

16 days



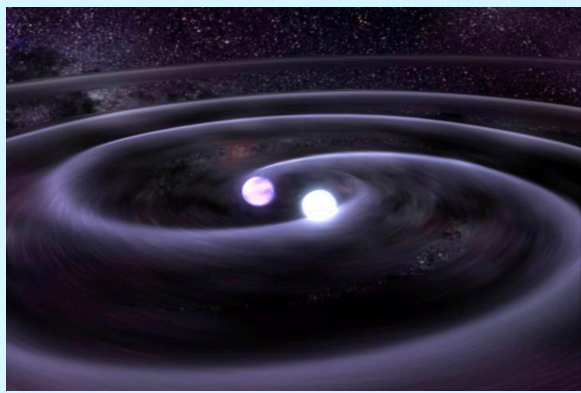
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Discovery

Follow-up (characterisation)





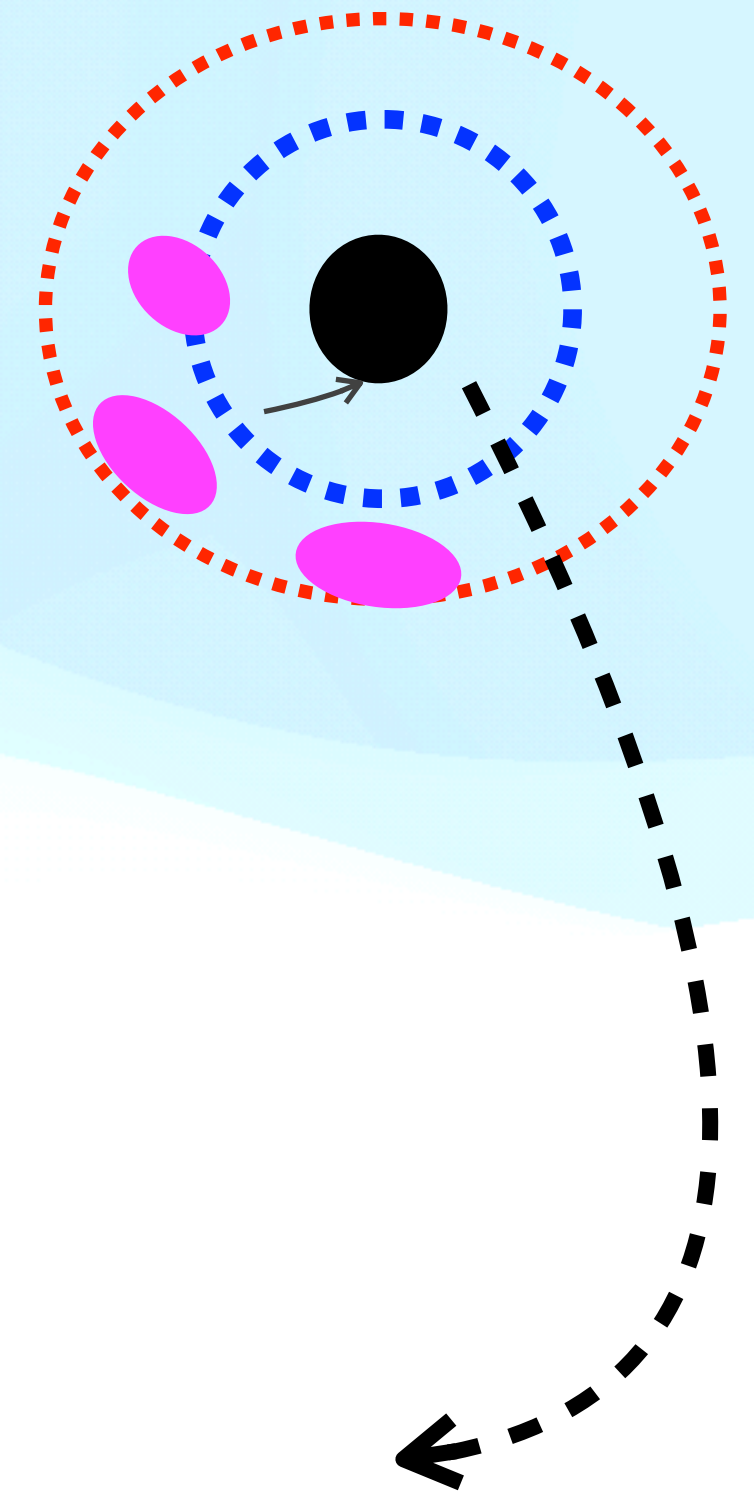
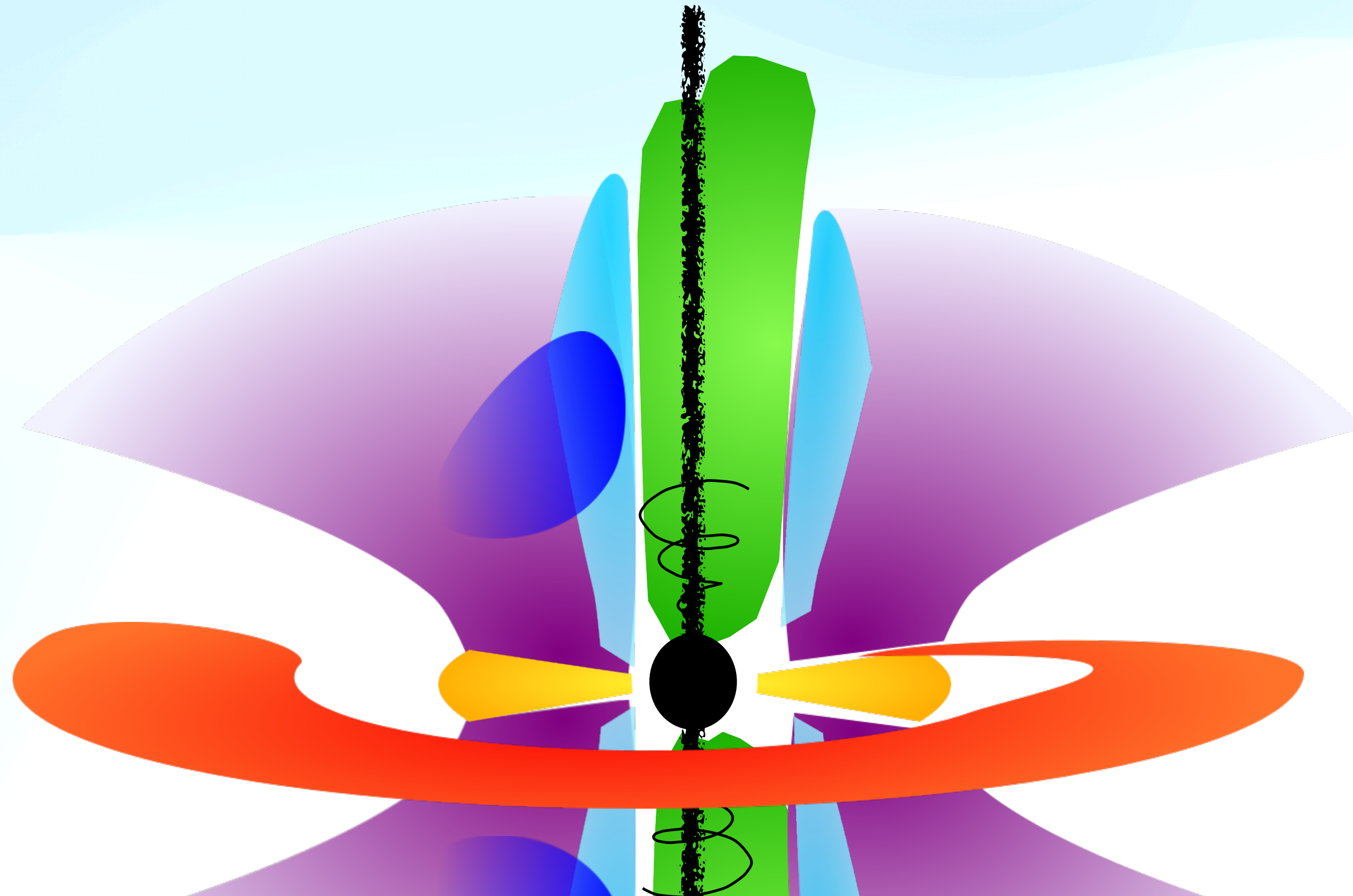
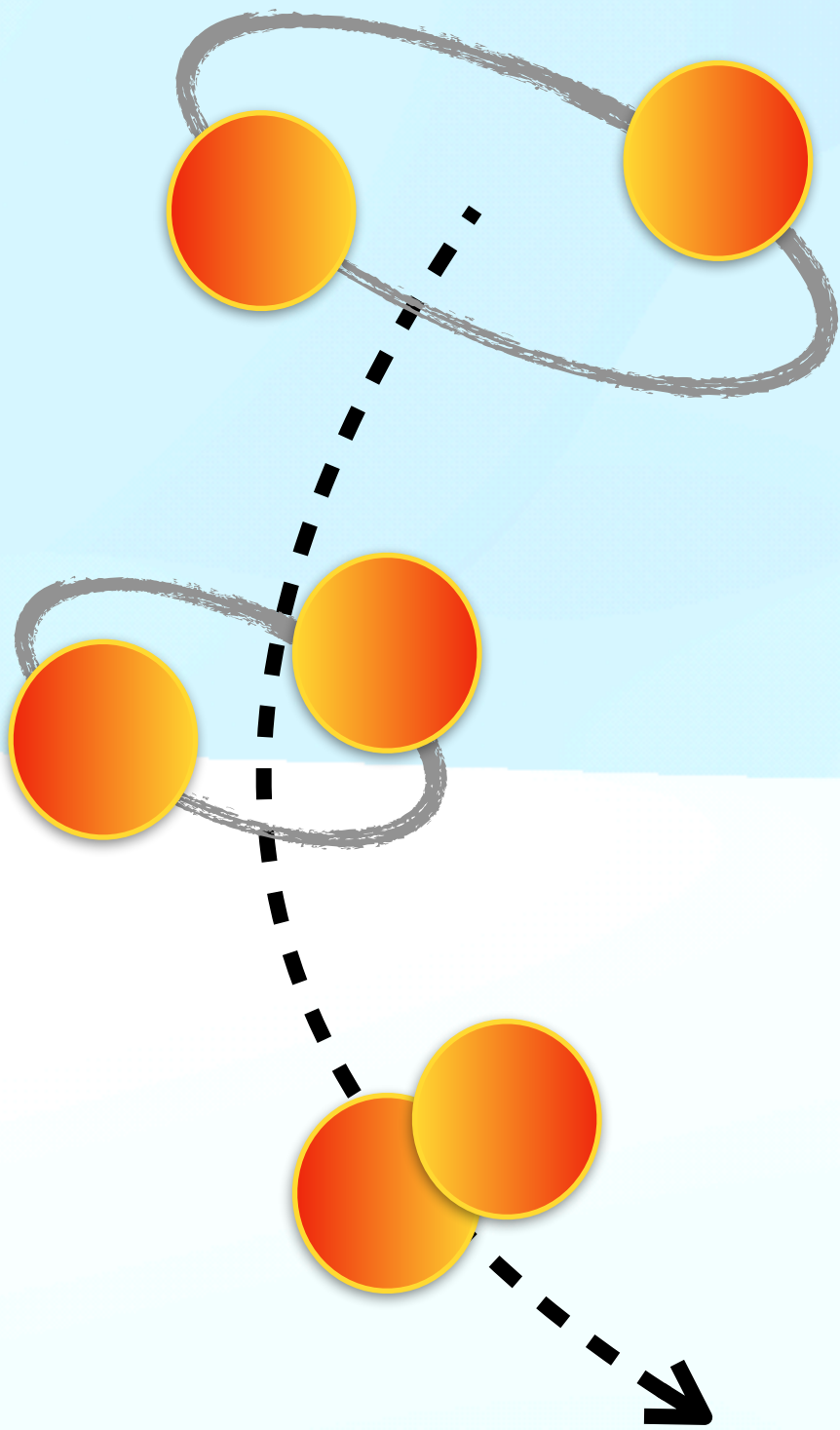
# BNS

# Scenarios

# BHNS



EM emission components  $\leftarrow$  Outflows  $(\theta, \beta, E)$

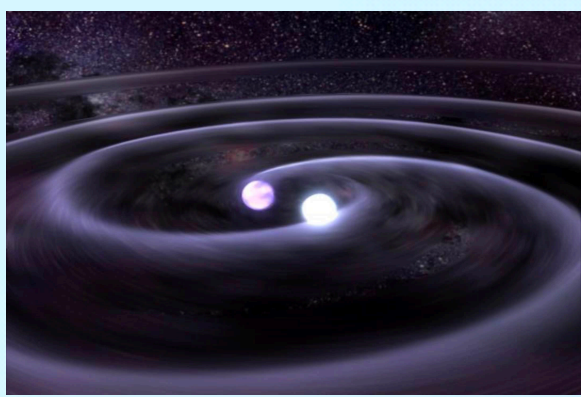


Tidal NS disruption

$$R_{\text{tidal}} > R_{\text{ISCO}}$$

$$M_{\text{out}} \neq 0$$





# BNS

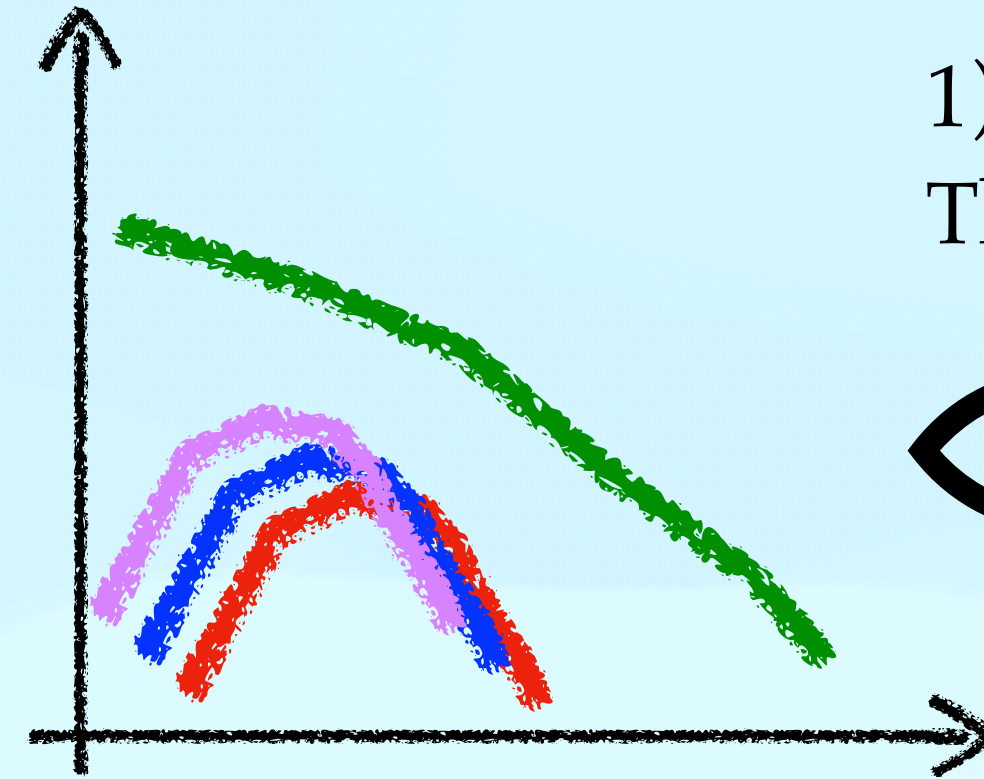
# Scenarios

# BHNS

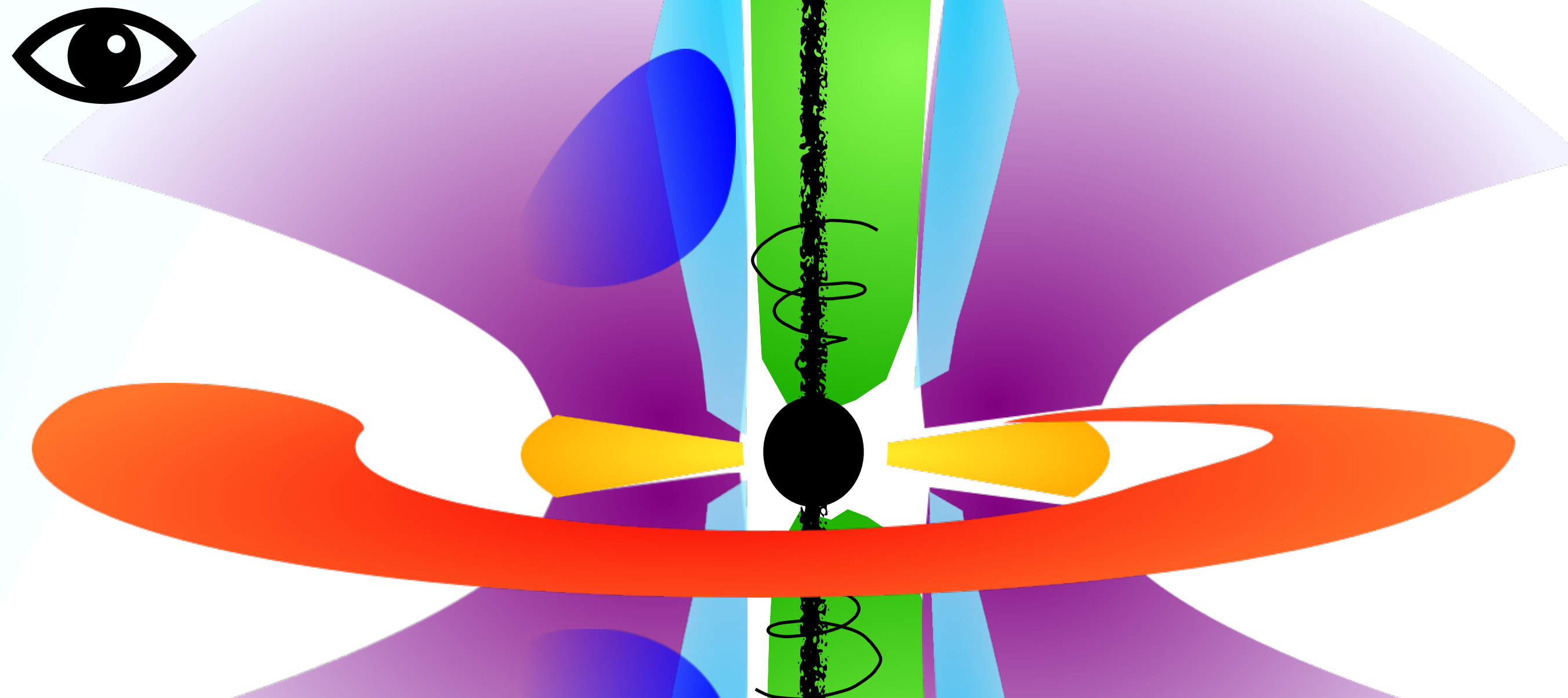
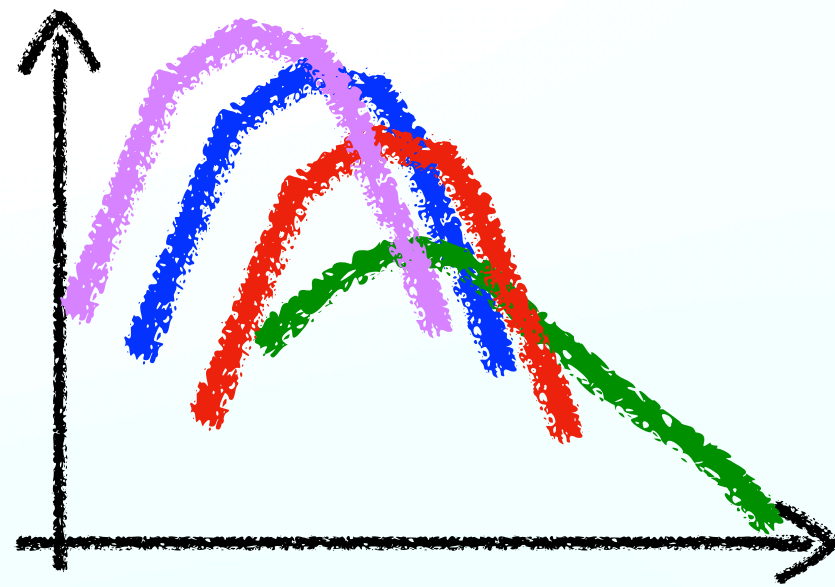


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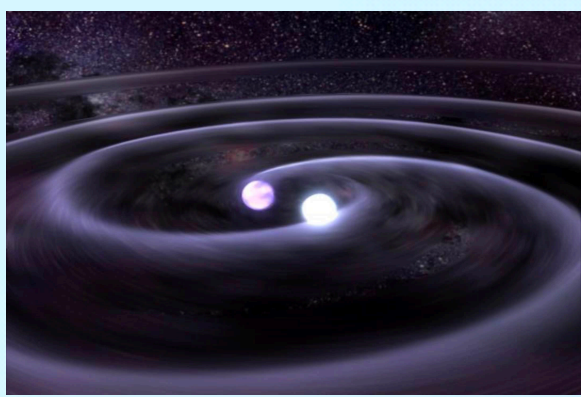
1) Ultra-relativistic jet ( $\Gamma \sim 100$ )  $\rightarrow$  Non Thermal emission (GRB + AFTERGLOW)



2) Neutron rich ejecta  $\rightarrow$  Thermal emission (Kilonova)







# BNS

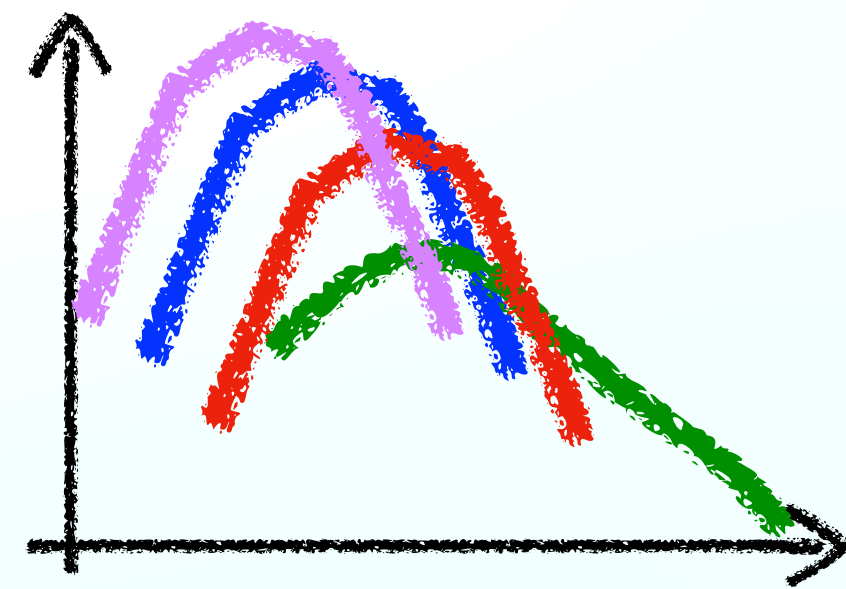
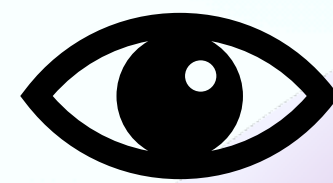
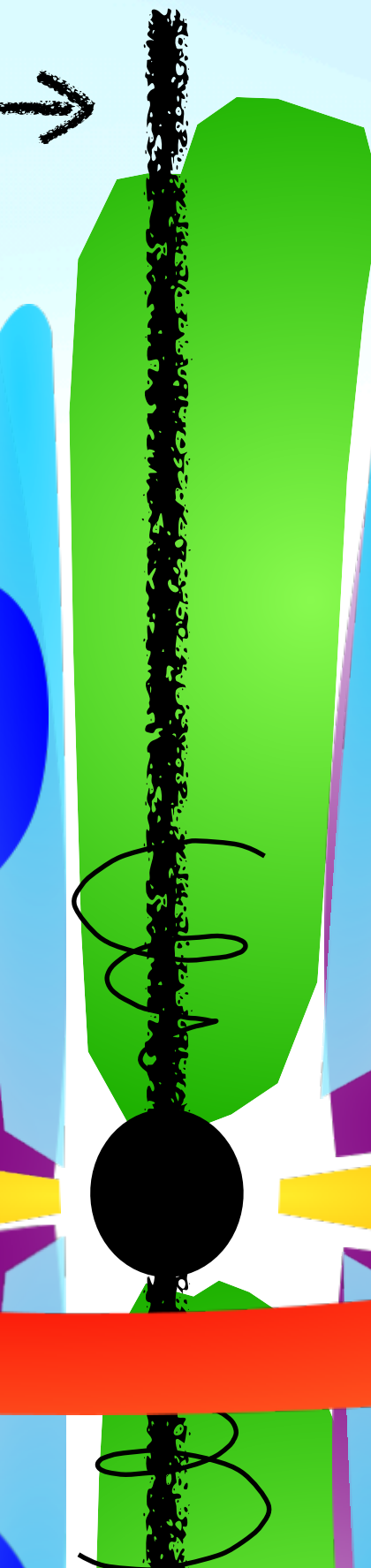
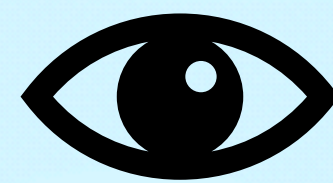
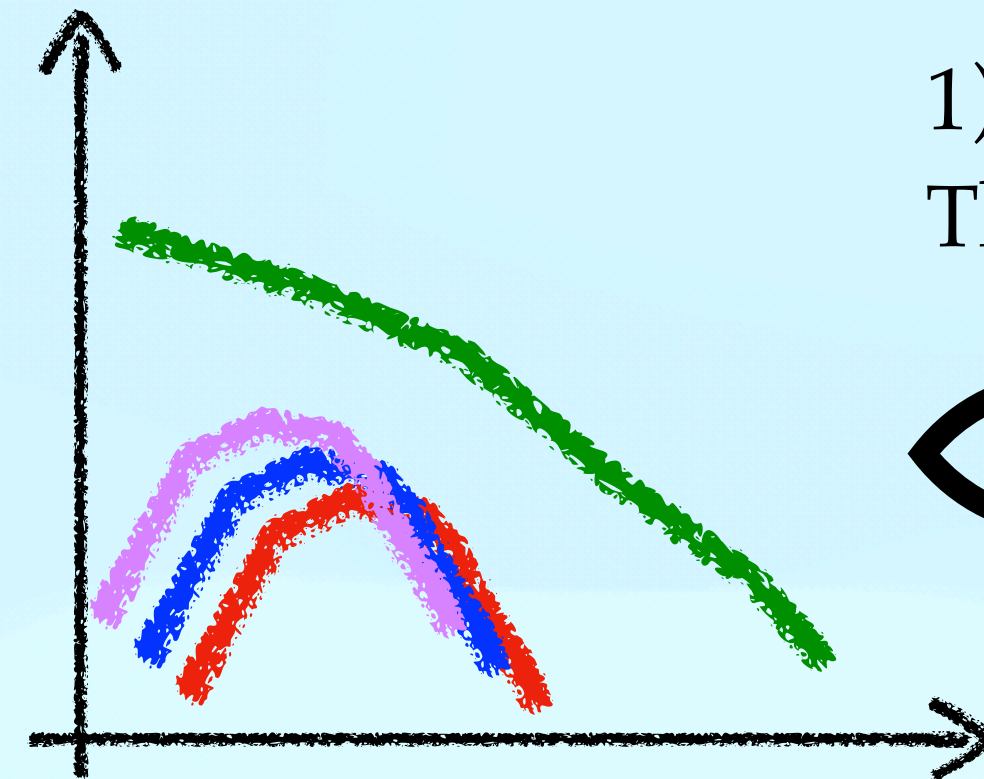
# Scenarios

# BHNS



EM emission components  $\leftarrow$  Outflows  $(\theta, \beta, E)$

1) Ultra-relativistic jet ( $\Gamma \sim 100$ )  $\rightarrow$  Non Thermal emission (GRB + AFTERGLOW)



Inclination (relative luminosity)  
Distance (detectable component)

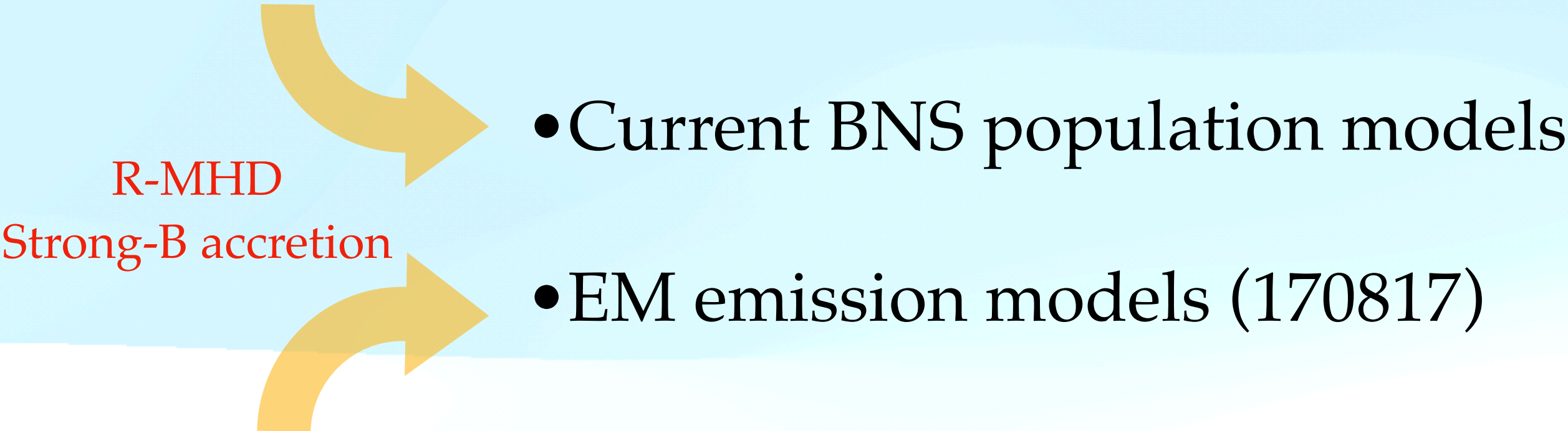
2) Neutron rich ejecta  $\rightarrow$   
Thermal emission (Kilonova)



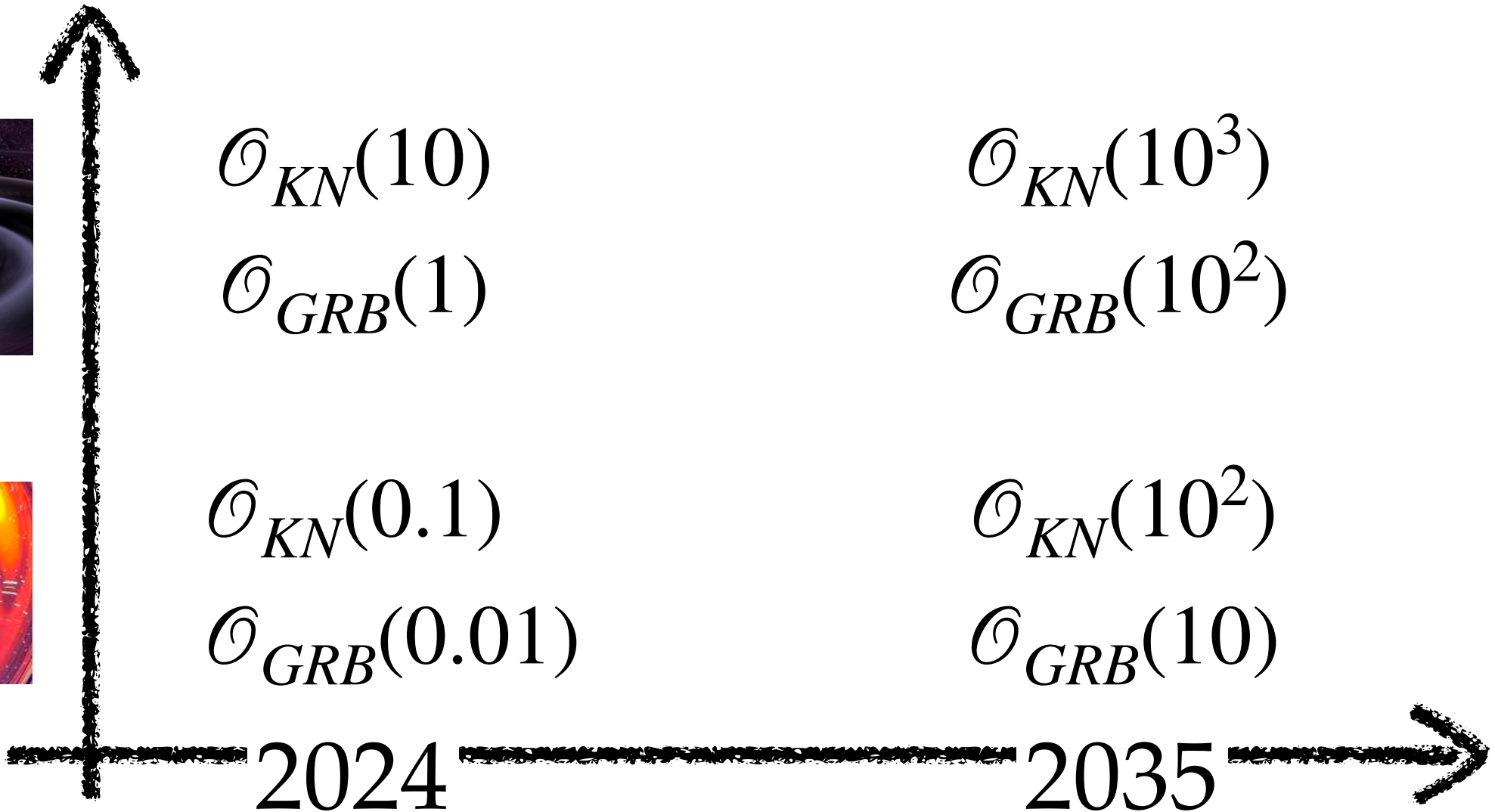
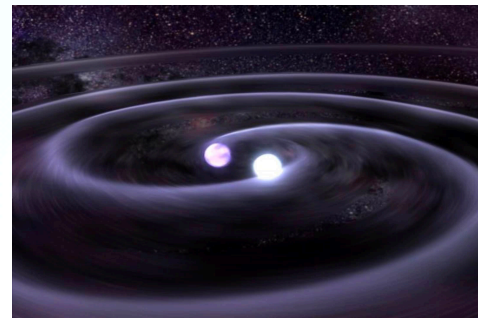
# MM expectations

Colombo et al., 2022; 2023 (in prep)  
Ronchini et al. 2022; Branchesi et al. 2023; ...

Binary formation + Stellar evolution codes



Nuclear physics (KN)  
+  
jet (dynamics+emission)  
physics (GRB)





# MM expectations

Colombo et al., 2022; 2023 (in prep)  
Ronchini et al. 2022; Branchesi et al. 2023; ...

Binary formation + Stellar evolution codes

R-MHD  
Strong-B accretion

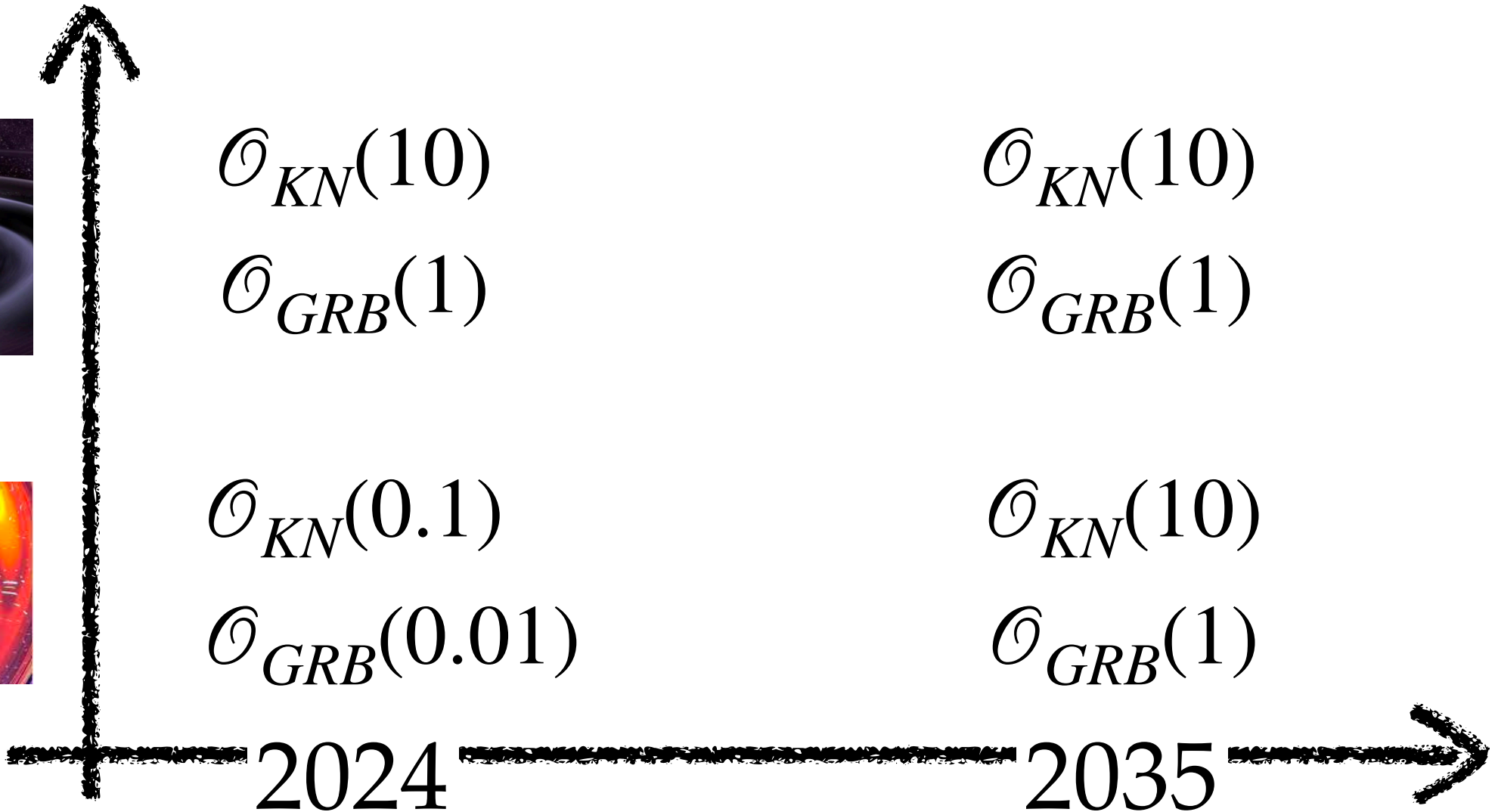
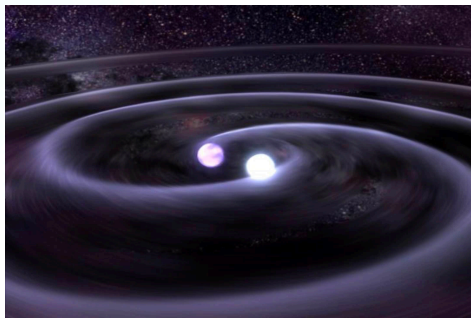
- Current BNS population models
- EM emission models (170817)

- Refinement and evolution through 3G
- Improvement / new EM facilities

Knowledge

Technology

Nuclear physics (KN)  
+  
jet (dynamics+emission)  
physics (GRB)







# Electromagnetic Facilities

- Search / detection
- Follow up (characterisation)

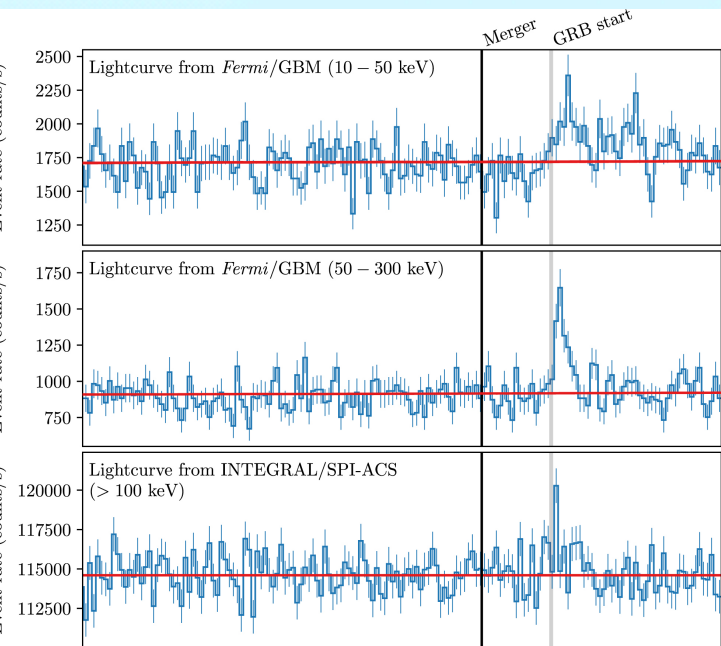
- Field of view
- Sensitivity
- Resolution

Photometry / Spectroscopy / HR Imaging

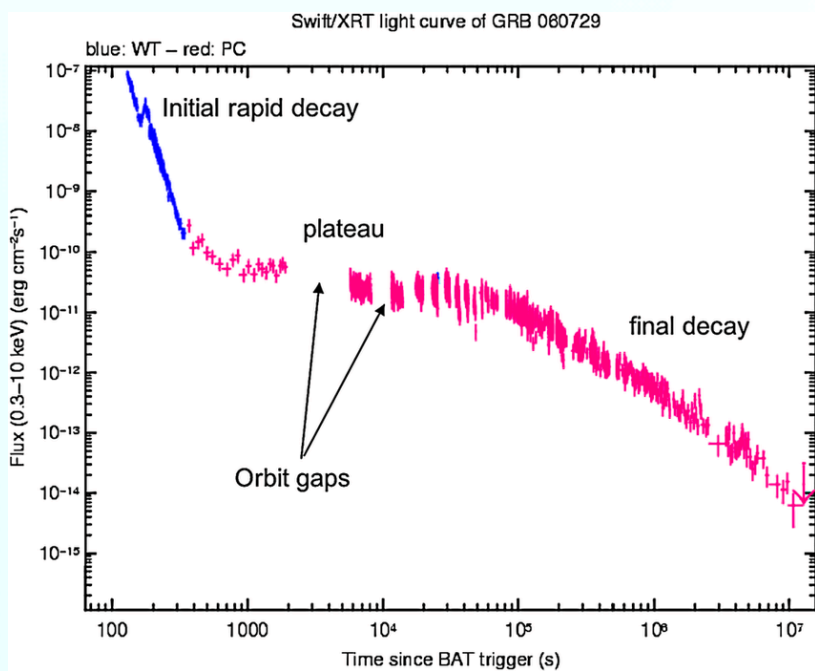


GRB prompt & HE afterglow

Prompt Jet Emission



Afterglow



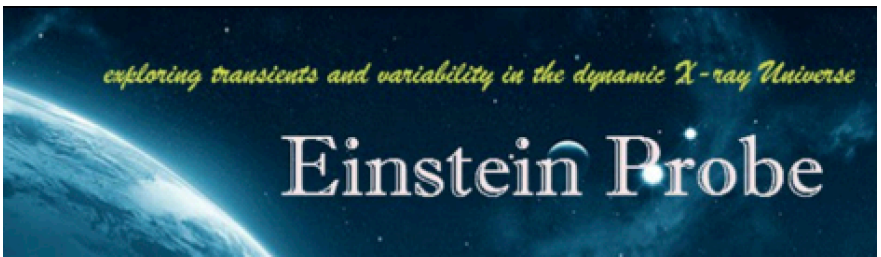
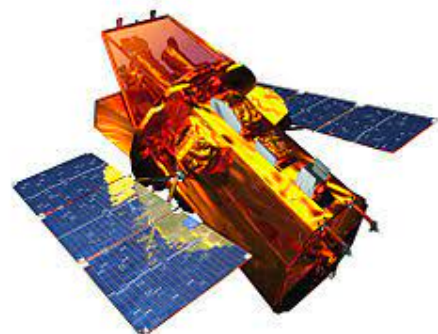
TeV

MeV

KeV



Swift



Now

2024

2035







# Electromagnetic Facilities



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Distributed architecture

Ronchini et al. 2022

INSTRUMENT	band MeV	$F_{lim}$ $\text{erg cm}^{-2} \text{s}^{-1}$	FOV/ $4\pi$	loc. acc.	Joint ET + $\gamma$ -ray	$N_{JD}/N_{\gamma}$	Joint (ET+CE) + $\gamma$ -ray	$N_{JD}/N_{\gamma}$
<i>Fermi</i> -GBM	0.01 - 25	0.5(*)	0.75	5 deg ( <sup>a</sup> )	$33^{+14}_{-11}$	$68^{+13}_{-18}\%$	$47^{+14}_{-14}$	$95^{+5}_{-7}\%$
<i>Swift</i> -BAT	0.015 - 0.15	$2 \times 10^{-8}$	0.11	1-3 arcmin	$10^{+3}_{-3}$	$62^{+11}_{-14}\%$	$13^{+5}_{-4}$	$94^{+6}_{-7}\%$
SVOM-ECLAIRs	0.004 - 0.250	1.792(*)	0.16	< 10 arcmin	$3^{+1}_{-1}$	$69^{+10}_{-9}\%$	$4^{+1}_{-1}$	$95^{+5}_{-4}\%$
SVOM-GRM	0.03 - 5	0.23(*)	0.16	~ 5 deg	$9^{+4}_{-3}$	$59^{+6}_{-6}\%$	$14^{+6}_{-4}$	$92^{+3}_{-3}\%$
THESEUS-XGIS	0.002 - 10	$3 \times 10^{-8}$	0.16	< 15 arcmin	$10^{+5}_{-4}$	$63^{+13}_{-13}\%$	$15^{+6}_{-4}$	$94^{+6}_{-7}\%$
HERMES	0.05 - 0.3	0.2(*)	1.0	1 deg	$84^{+42}_{-30}$	$61^{+10}_{-11}\%$	$139^{+54}_{-36}$	$94^{+6}_{-6}\%$
TAP-GTM	0.01 - 1	1(*)	1.0	20 deg	$60^{+24}_{-24}$	$67^{+13}_{-14}\%$	$84^{+30}_{-24}$	$95^{+5}_{-6}\%$



Monolithic



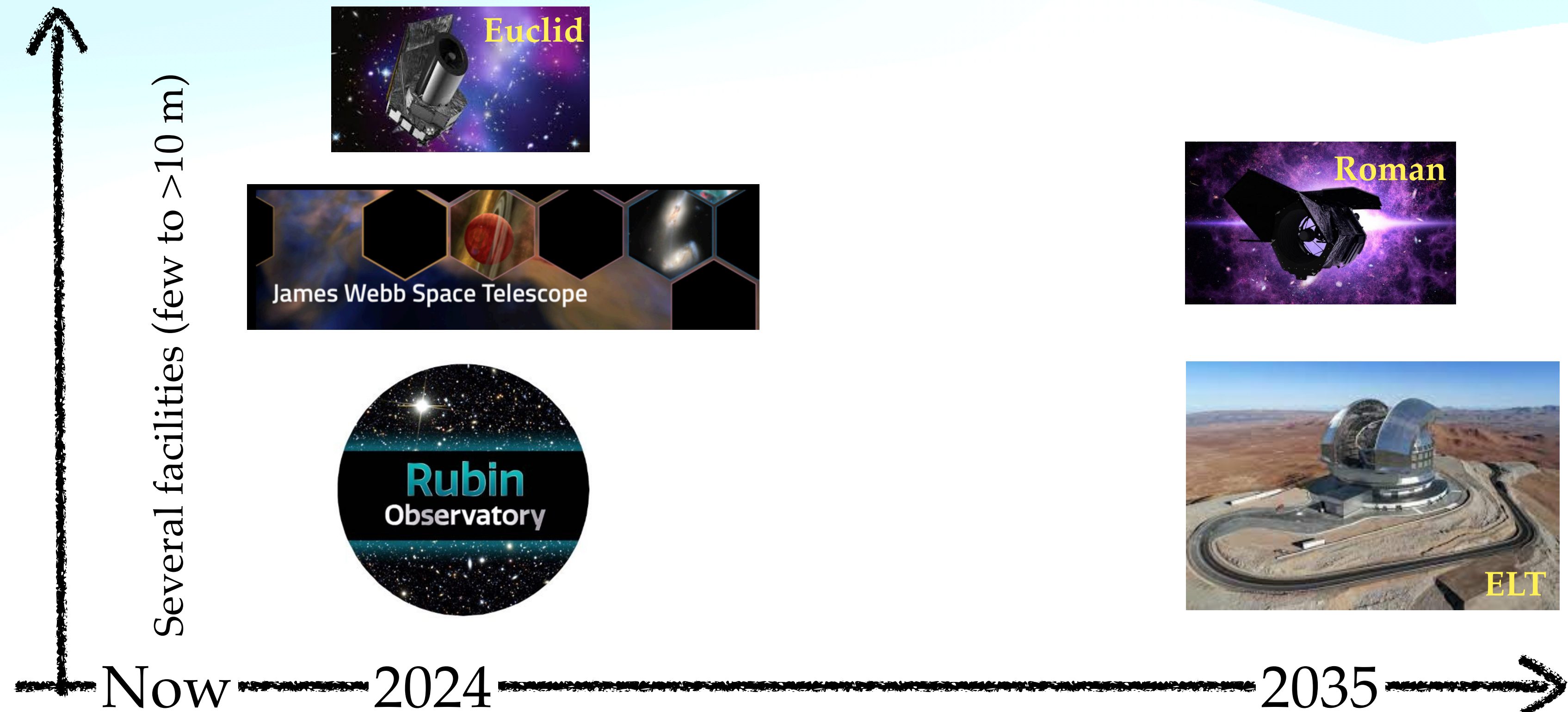


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- Field of view
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- Resolution

Photometry / Spectroscopy / HR Imaging







# Electromagnetic Facilities



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Vera Ruby Observatory (VRO)

>2024 for 10 yrs (O5 ... ET?)

$\varnothing=8\text{m}$

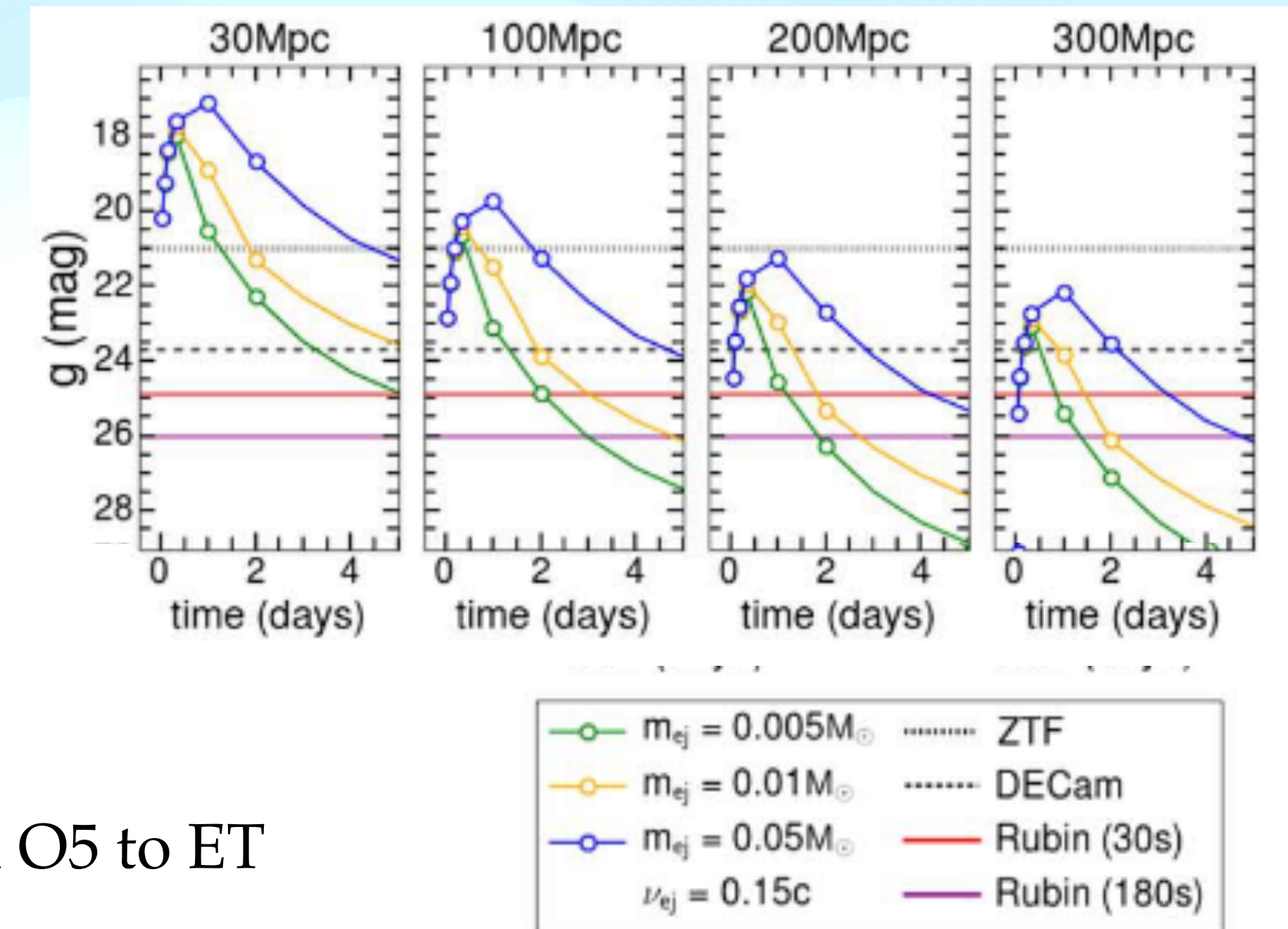
FoV=10 deg<sup>2</sup>

ugrizy,  $r \approx 24$  (27.5 stack)

1/2 sky 1000 visits

$2 \times 10^{10}$  🌌 & ✨

- Early (<10 hr) discovery —> Blue KN
- MM-KN enabled by ToO:
- ~10 - 40 KN with 2-5% of ToO time from O5 to ET  
(Andreoni et al., 2022; Branchesi et al. 2023)
- Catch BHNS KN (dimmer and more distant)



Andreoni et al. 2022





# Electromagnetic Facilities



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## Extremely Large Telescope (ELT)

- Full KN characterisation and spectroscopy
- GRB afterglow imaging / spectroscopy / photometry

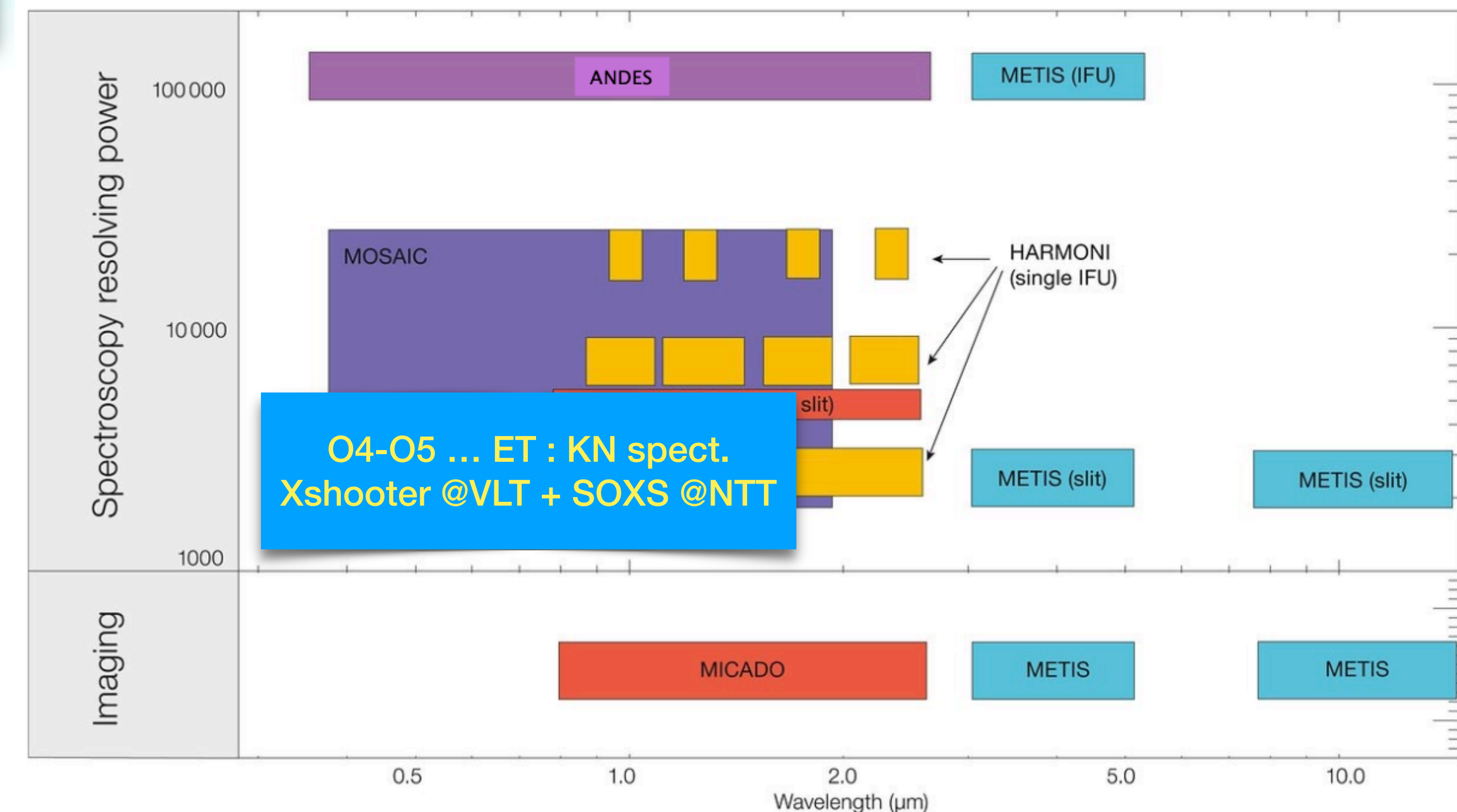
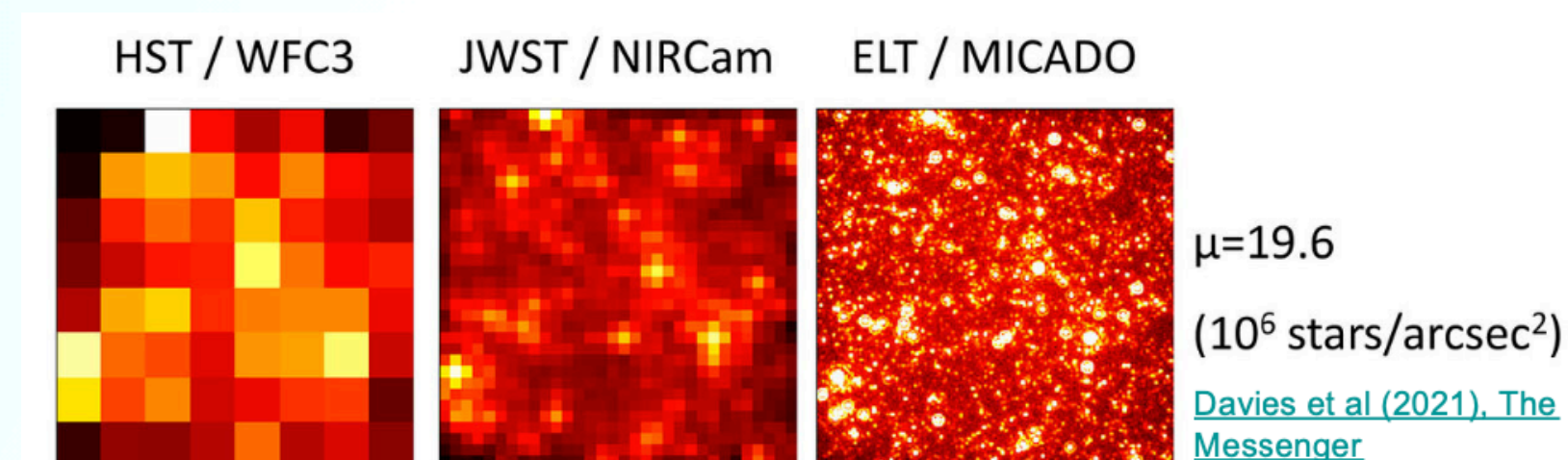
>2027 (ET)

$\varnothing=39\text{m}$

$\text{FoV}=0.01 \text{ deg}^2$

$0.3\text{-}20\mu\text{m}$ ;

$H\sim 24\text{-}29.5$





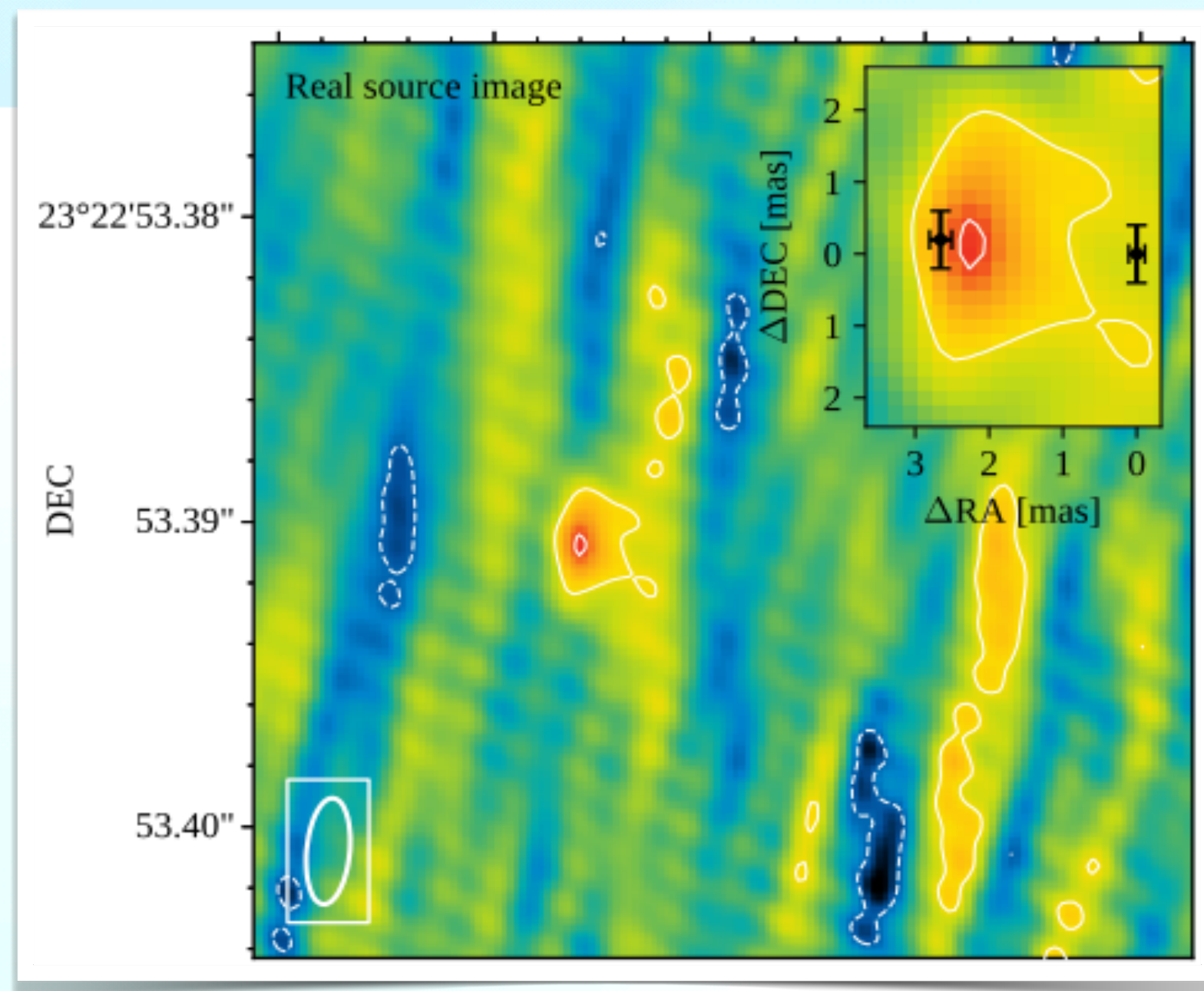


# Electromagnetic Facilities

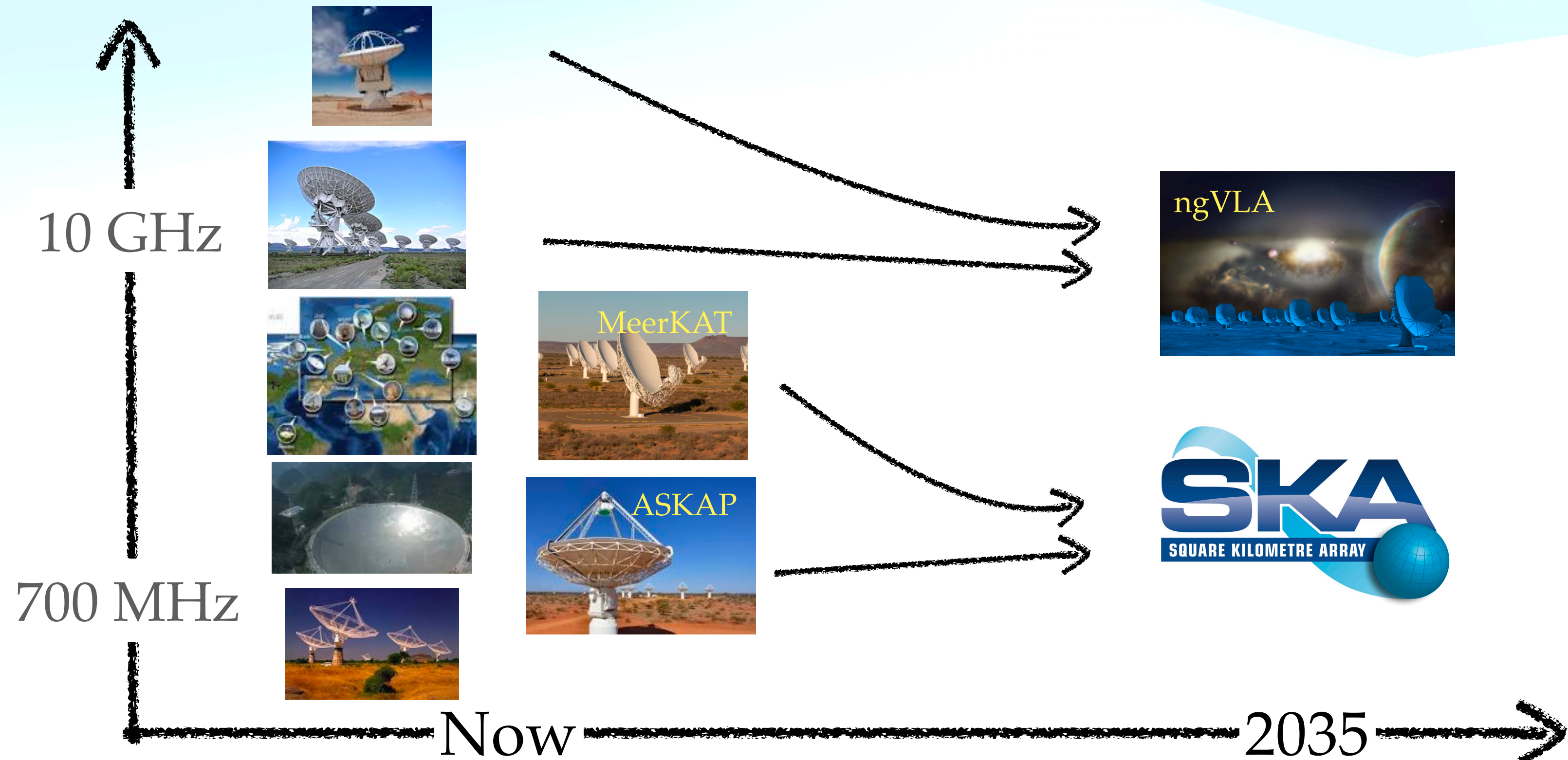


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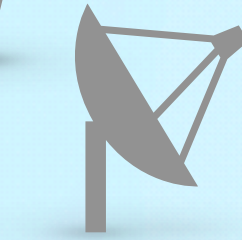
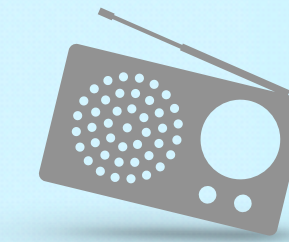
Ghirlanda et al., 2019







# Electromagnetic Facilities

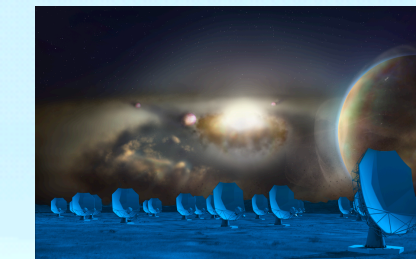


GRB (KN)  
afterglow

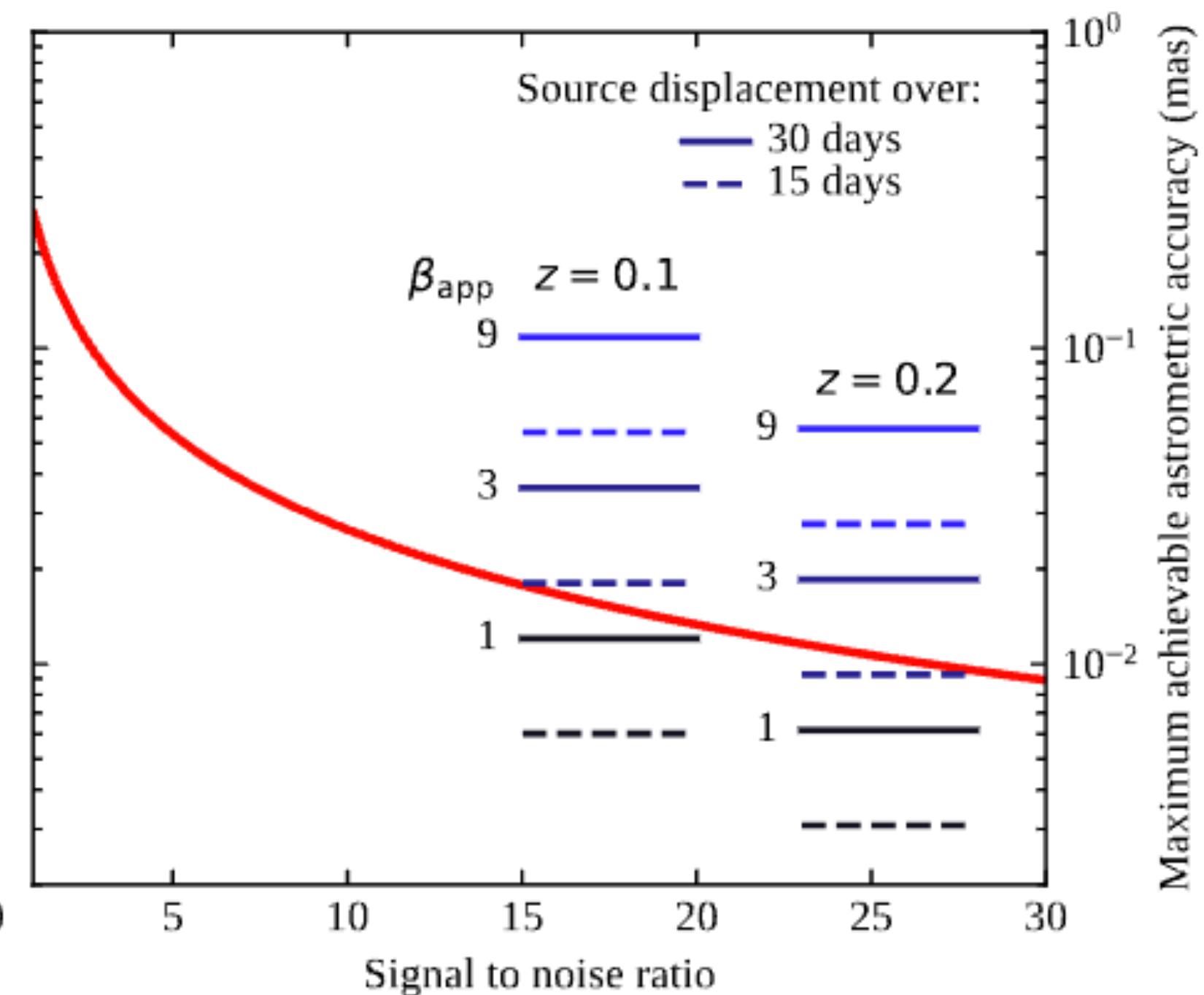
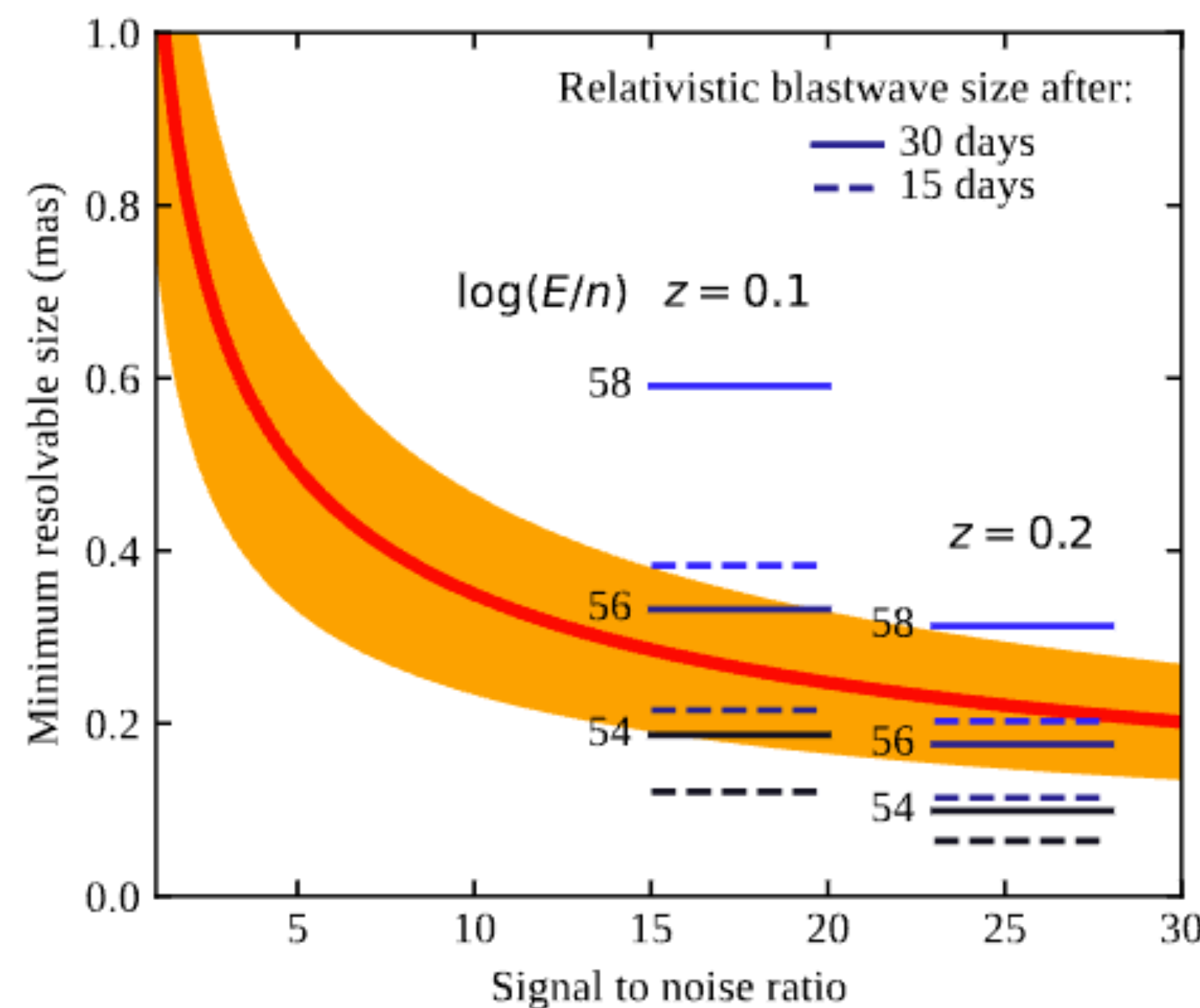
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Photometry / Spectroscopy / HR Imaging



Can probe the less dense environment (as those of CBC)



Can probe apparent superluminal motion (off axis jets of CBC in the local Universe)

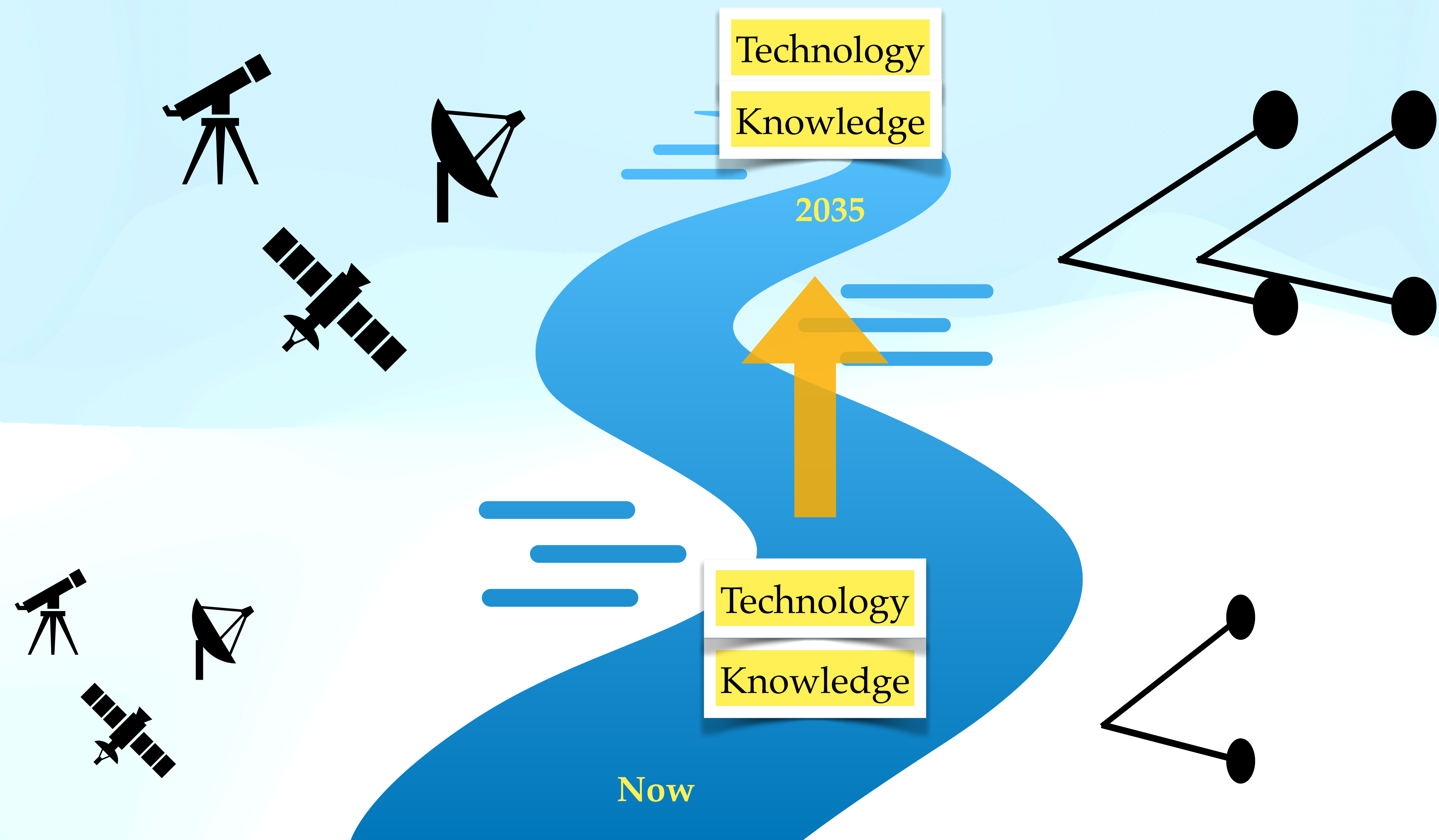


# Conclusions: pathways towards the future of MM (GW+EM) astronomy





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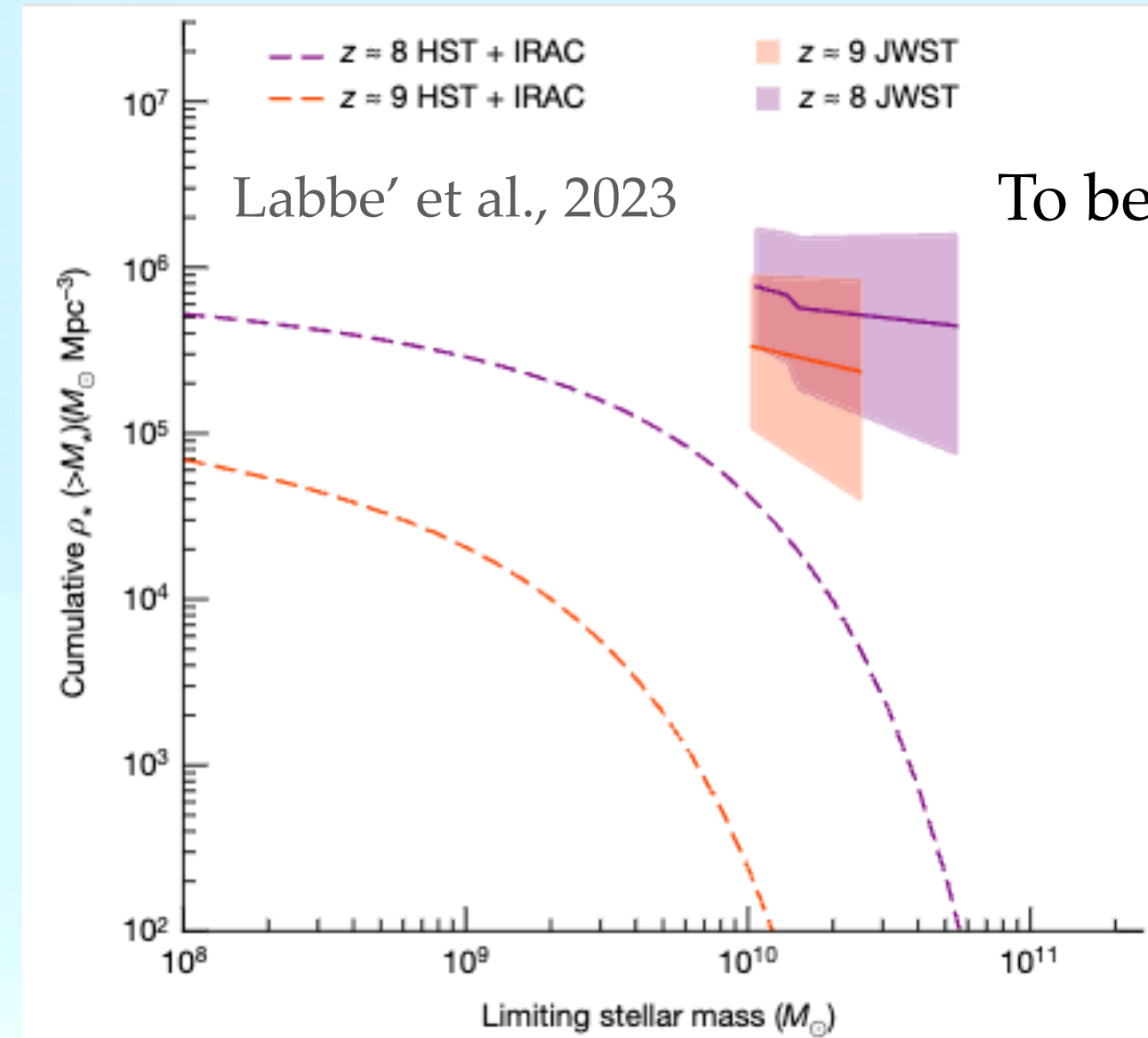
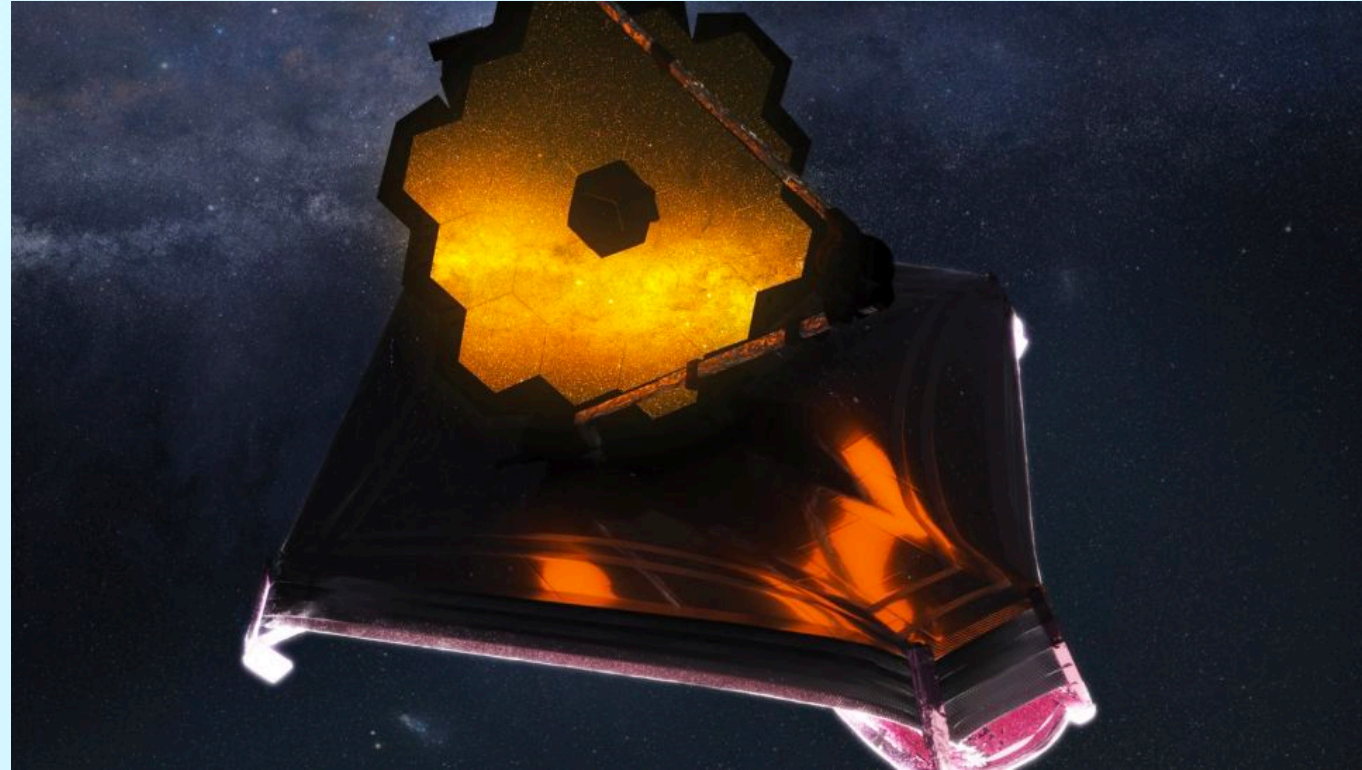




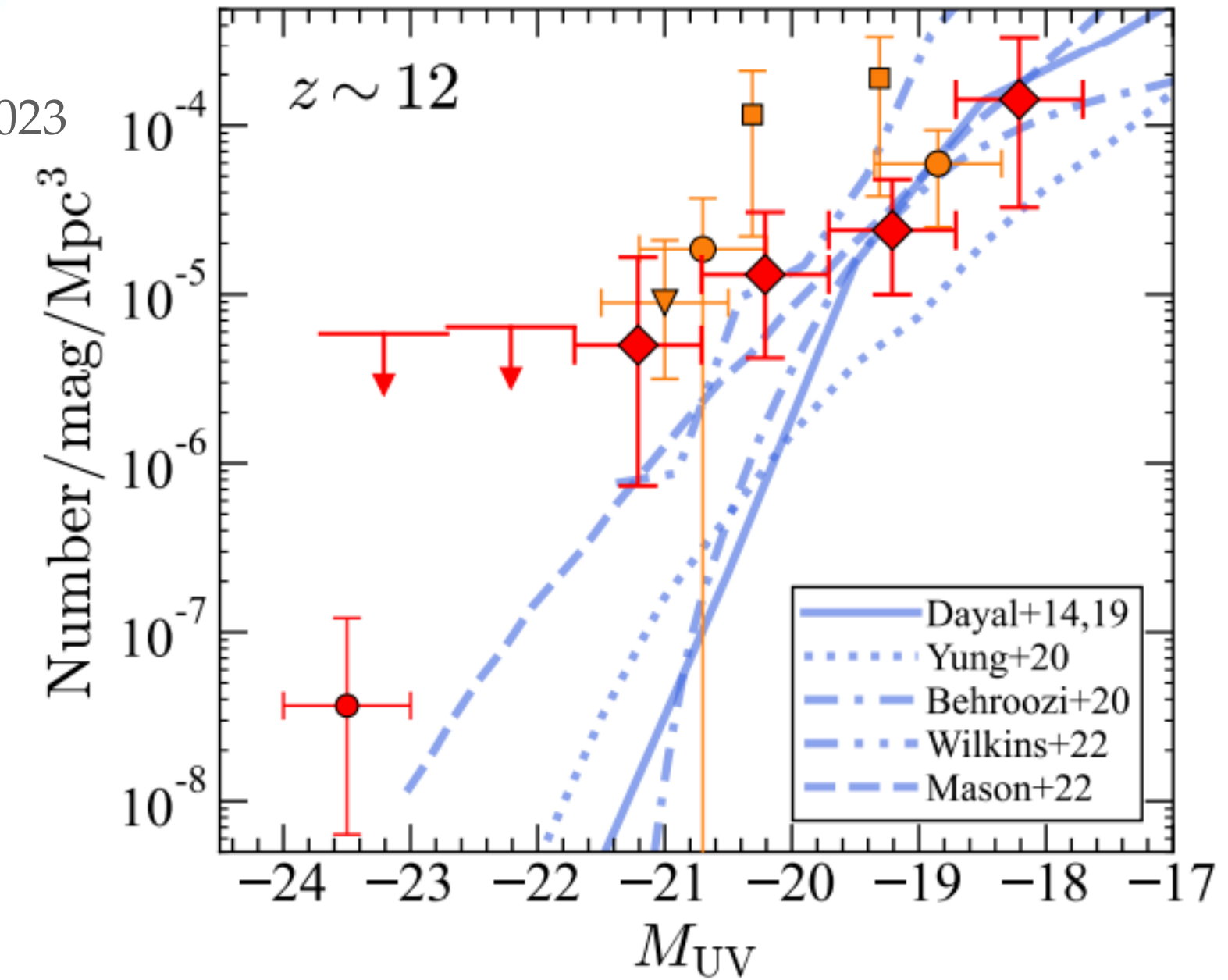
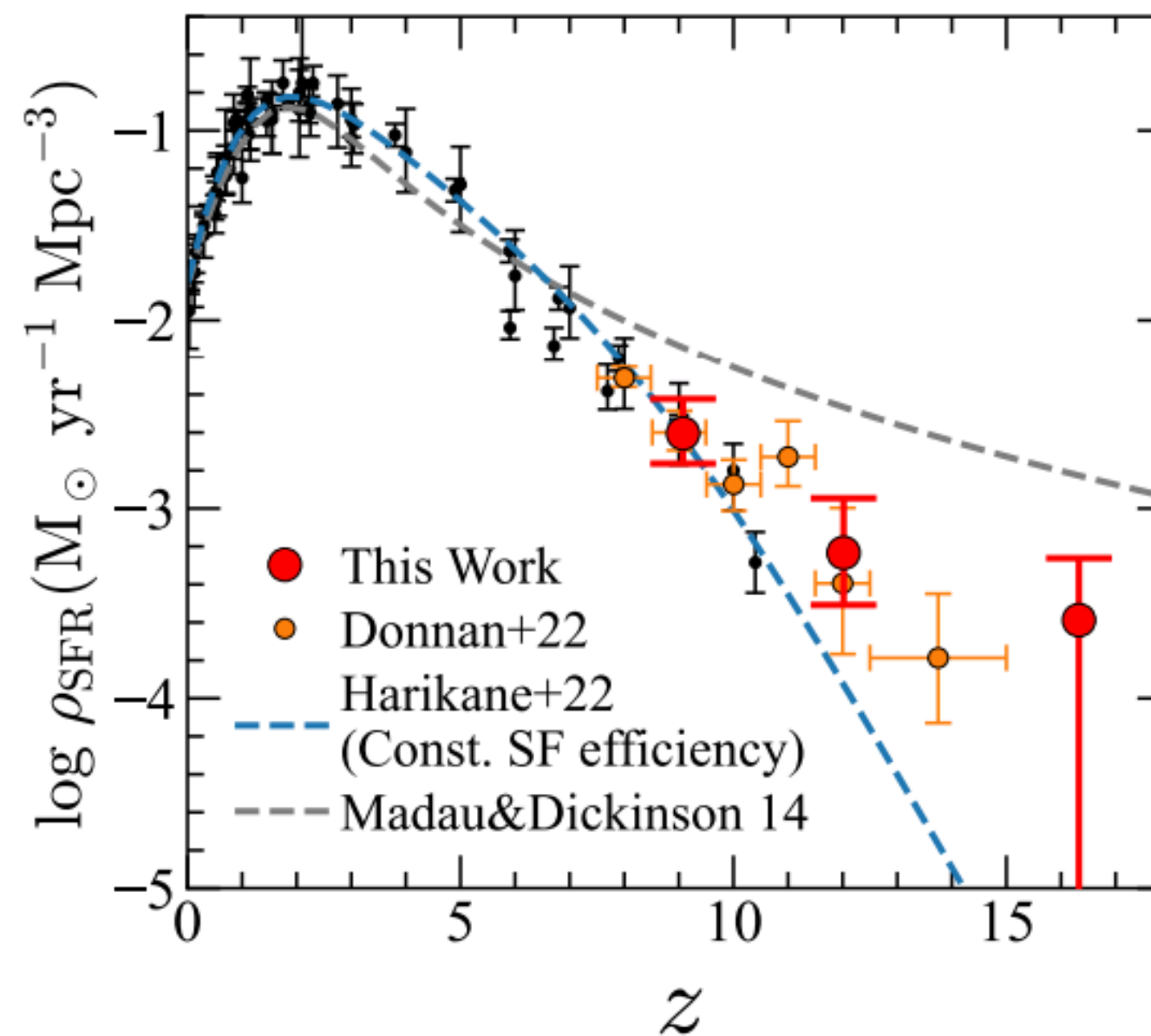


Knowledge

# Challenging discoveries



Harikane et al., 2023



- Discovery of massive galaxies at  $z > 10$
- High star formation (MW like) in high  $z$  small galaxy
- Galaxy counts challenge formation models



# BBH Possible EM emission

Takawa et al. 2026

