About Gamma-Ray Bursts and Boats

What we (don't) know about the most energetic explosions in the Universe

Sylvia Zhu, Annika Rudolph

CARLSBERG FOUNDATION

Forbes

FORBES > INNOVATION > SCIENCE

Today's Most Powerful Explosion Ever Recorded Was The 'Birth Cry Of A New Black Hole,' Say Scientists

Frankfurter Rundschau

Startseite › Wissen

Extrem heller Gammastrahlenblitz ...ft die Erde – „Bricht alle Rekorde"

VICE Video TV News Tech Rec R...

Scie... ...ely Un... ...pace

Bright, powerful burst... detected by multiple telescopes

By Ashley Strickland, CNN

3 minute read · Published 3:03 PM EDT, Mon October 17, 2022

The New York Times

A Supernova 'Destroyed' Some of Earth's Ozone for a Few Minutes in 2022

When it all started

[IM1]

[IM2, R1]

When it all started

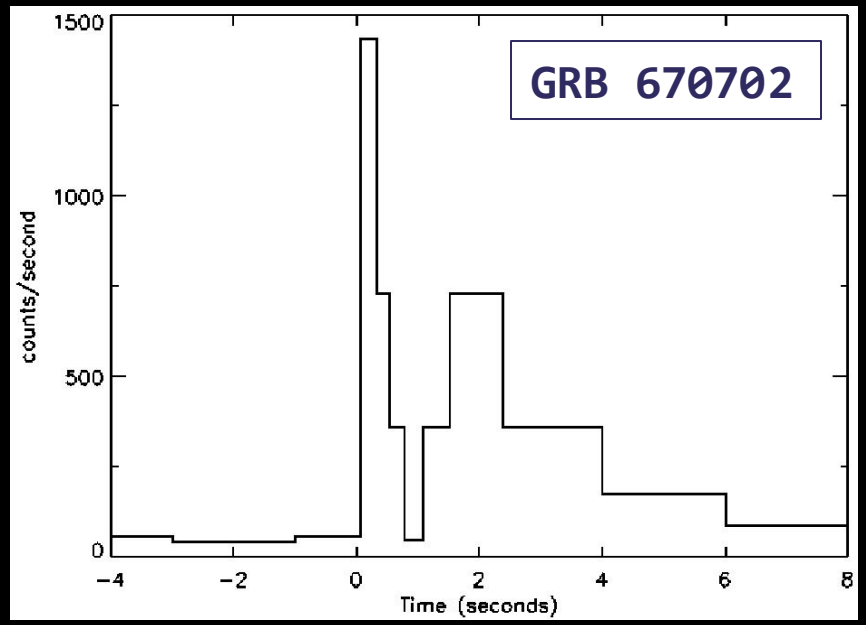
OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico

Received 1973 March 16; revised 1973 April 2

[R2]

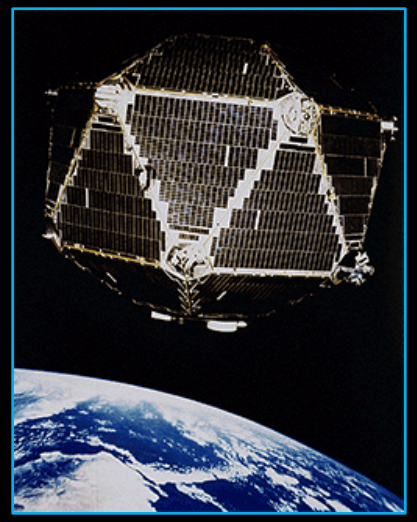


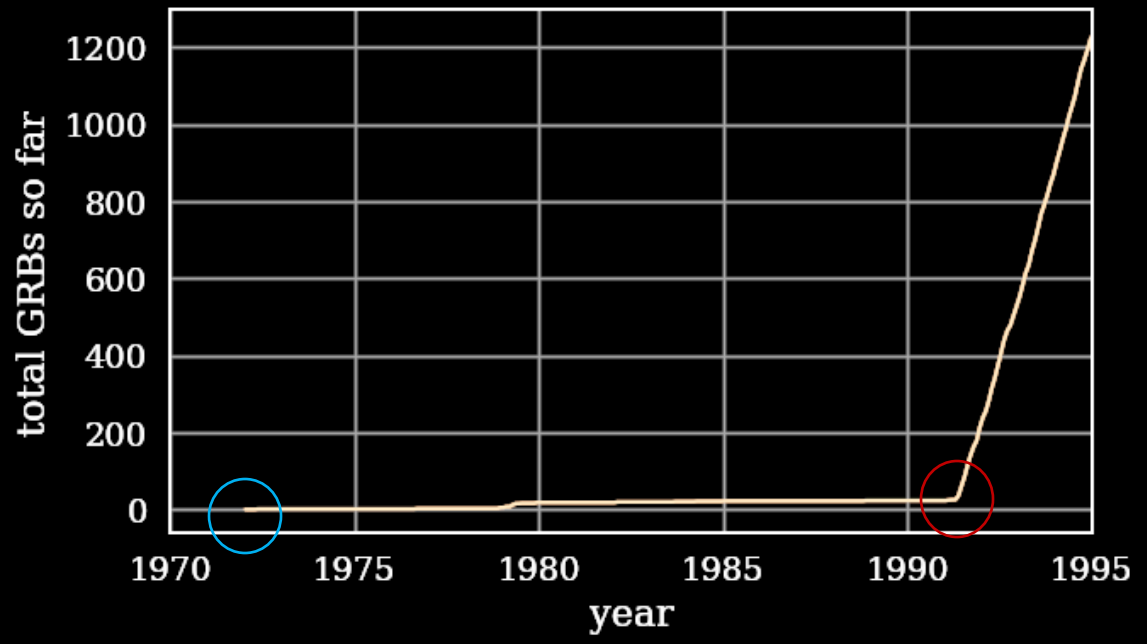
[IM3]

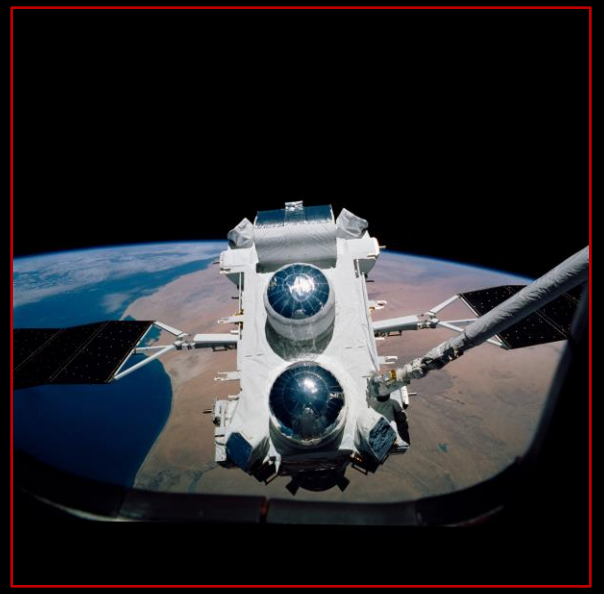
[IM2, R1]

Fast forward a few decades

[IM4]

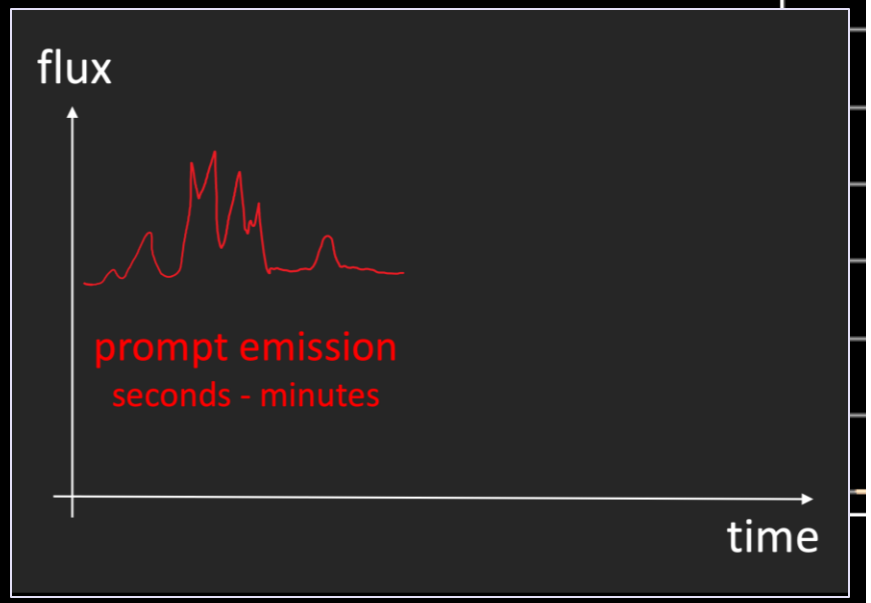


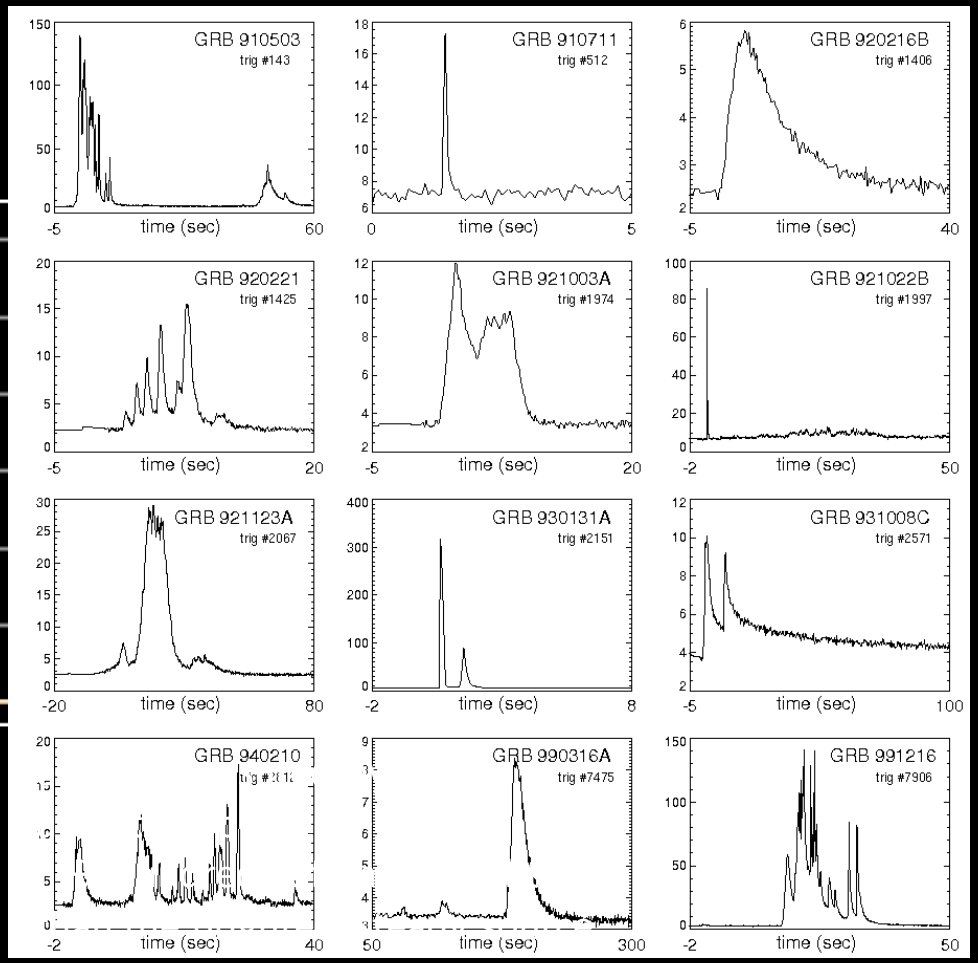




Compton Gamma-Ray Observatory

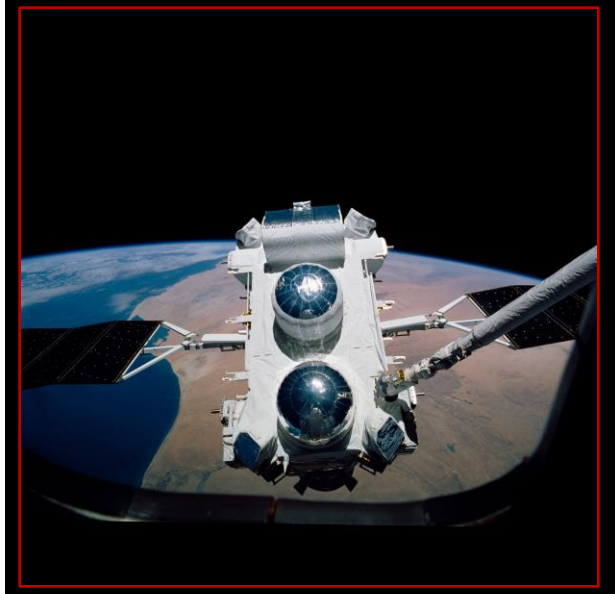
Fast forward a few decades





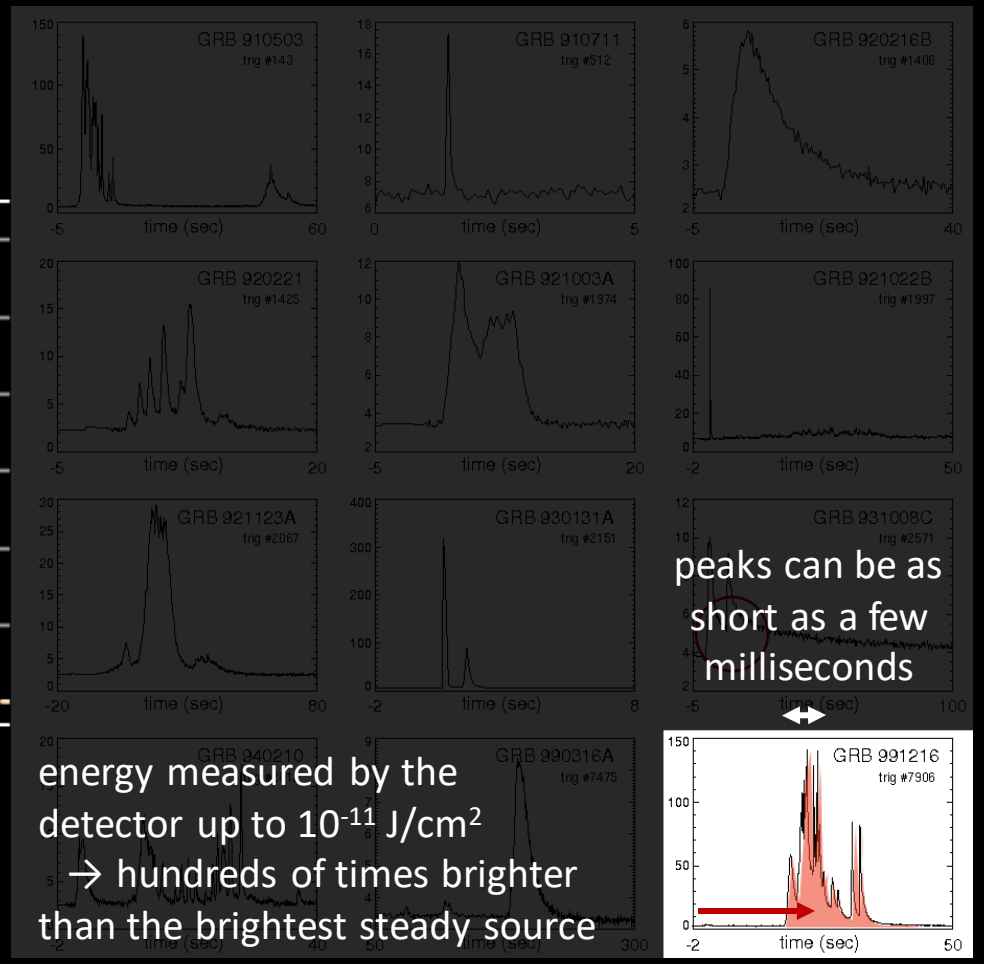
[IM5]

[IM4]



Compton Gamma-Ray Observatory

Fast forward a few decades

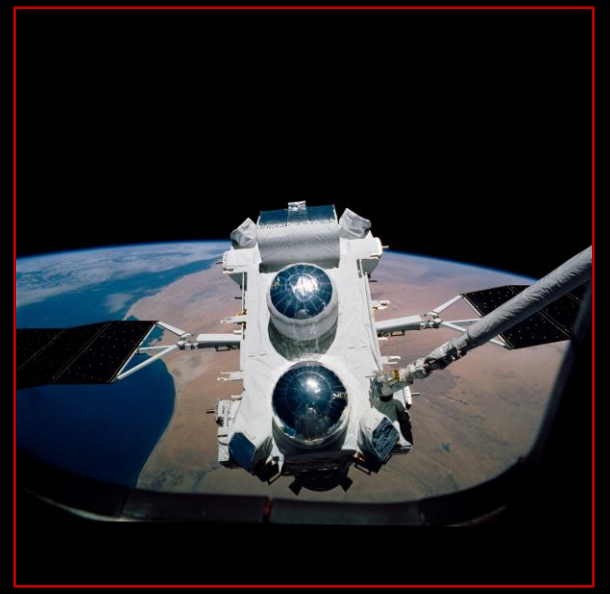


peaks can be as short as a few milliseconds

energy measured by the detector up to 10^{-11} J/cm^2
→ hundreds of times brighter than the brightest steady source

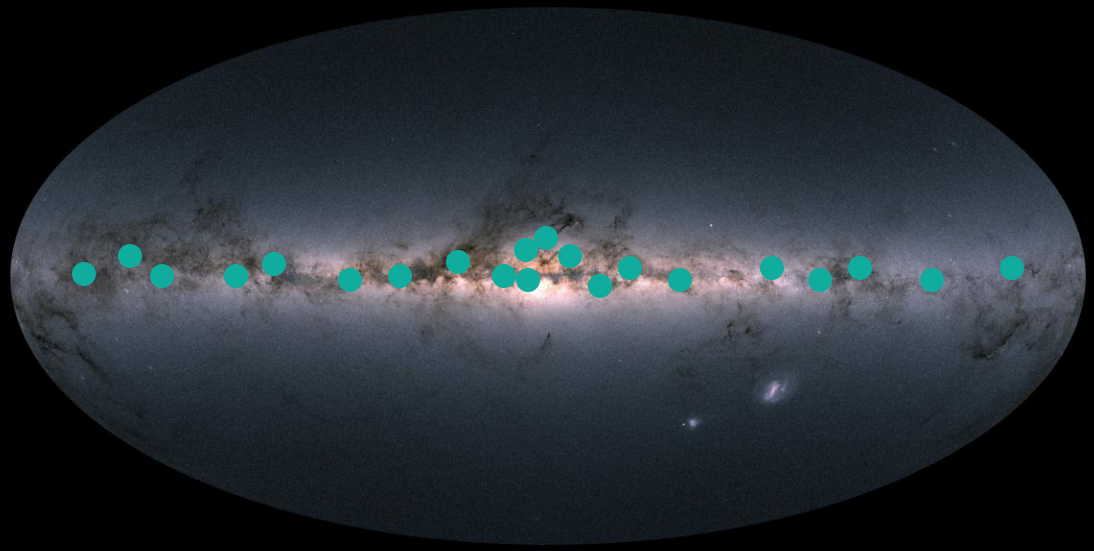
[IM5]

[IM4]

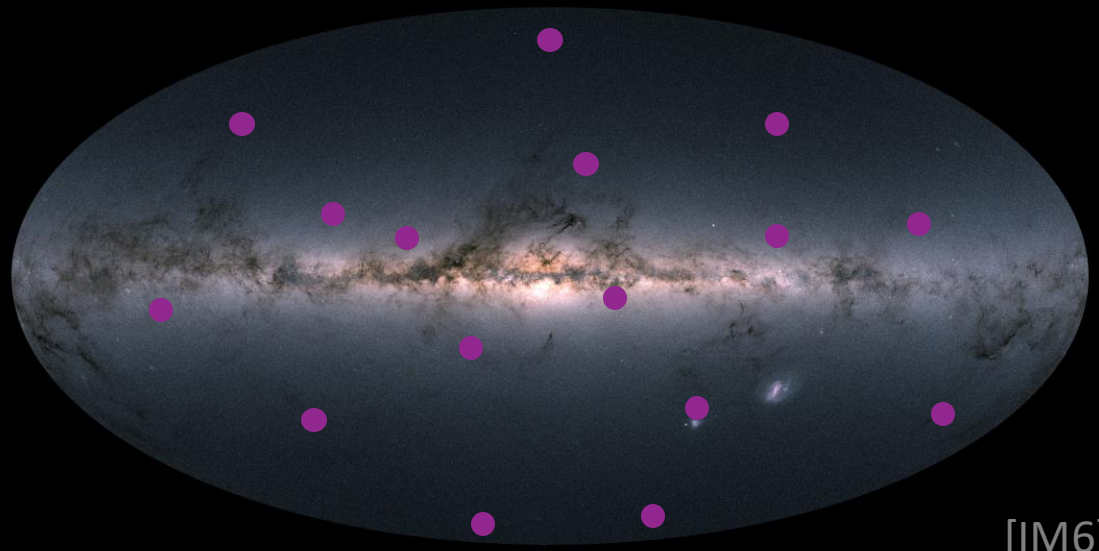


Compton Gamma-Ray Observatory

Where are the GRBs coming from?



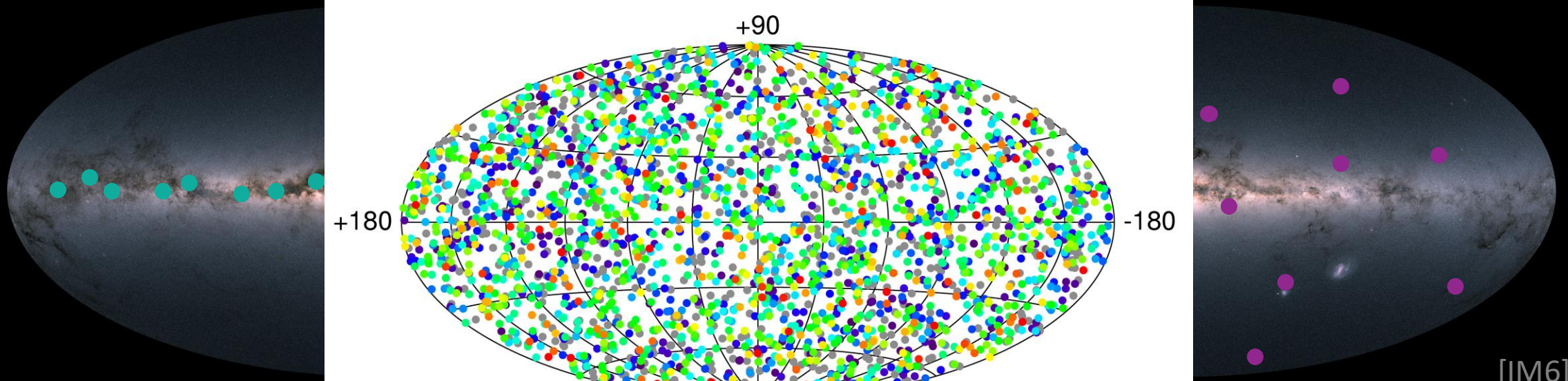
Within our Galaxy ...



… or outside of our Galaxy?

[IM6]

Where are the GRBs coming from?

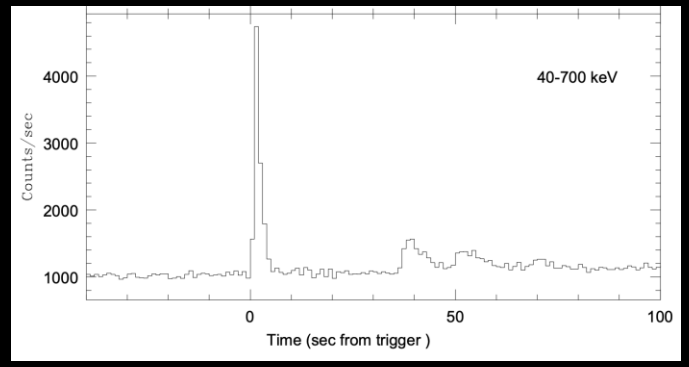


Within our Galaxy ...

... or outside of our Galaxy?

Beyond the prompt emission

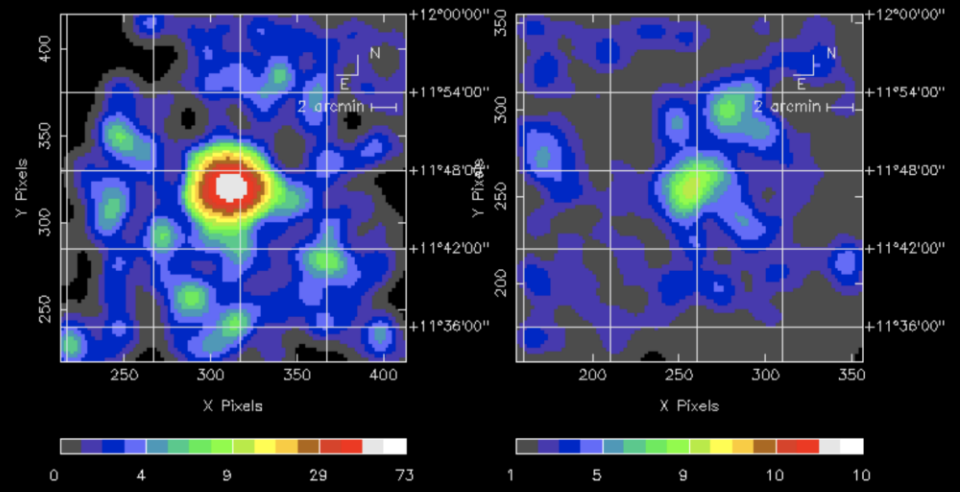
GRB prompt emission



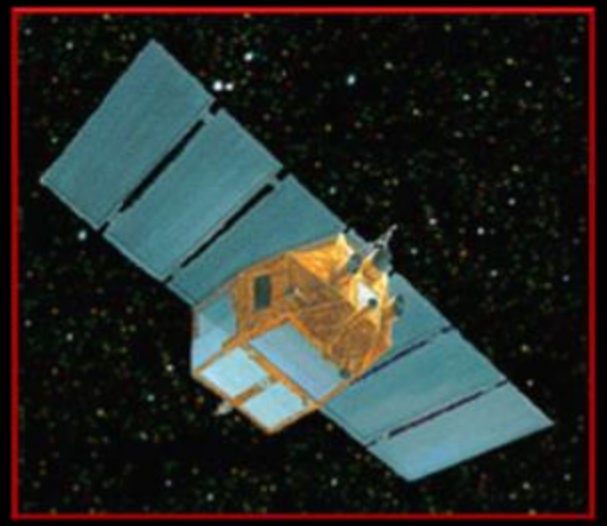
[IM8]

8 hours later

3 days later

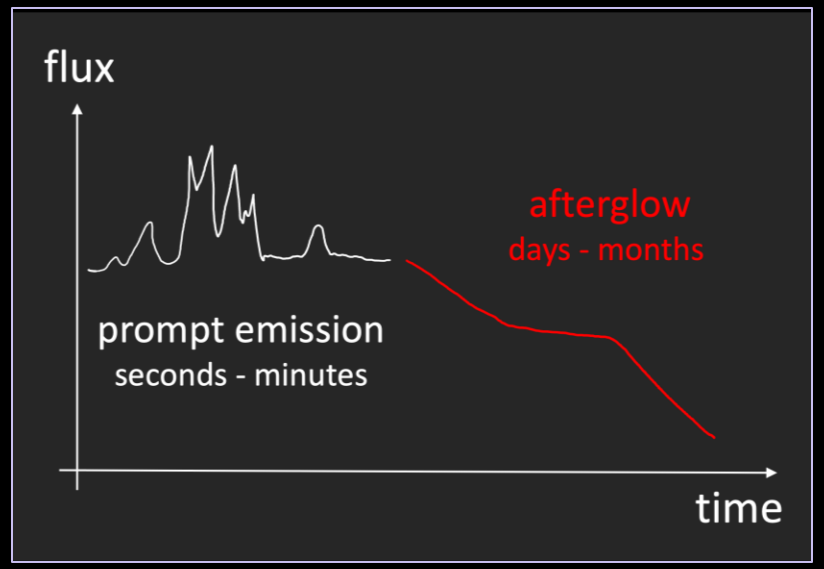


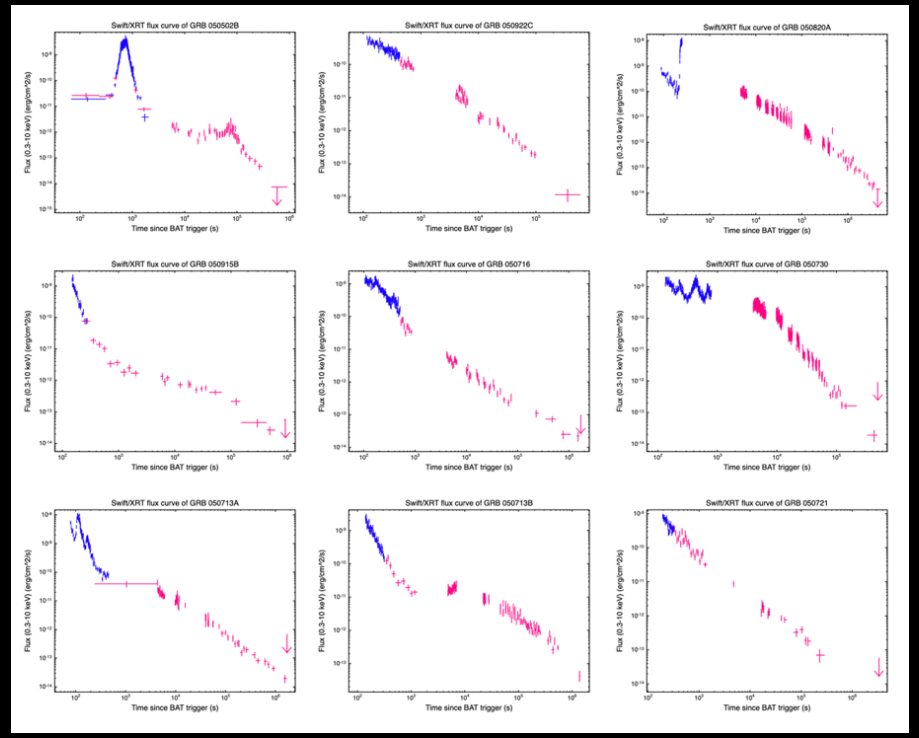
[IM8, R4]



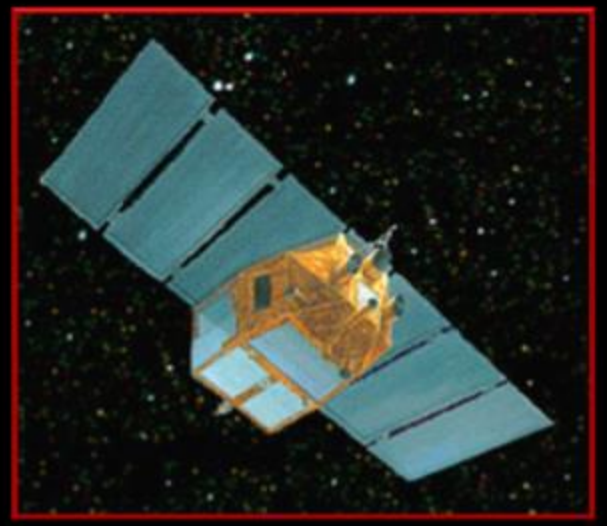
BeppoSAX [IM9]

Beyond the prompt emission





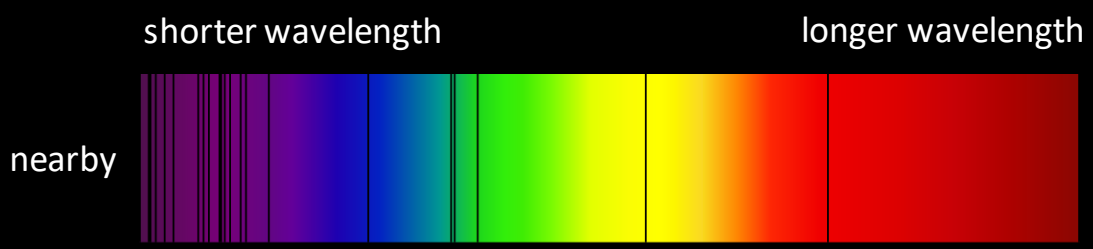
[IM10]

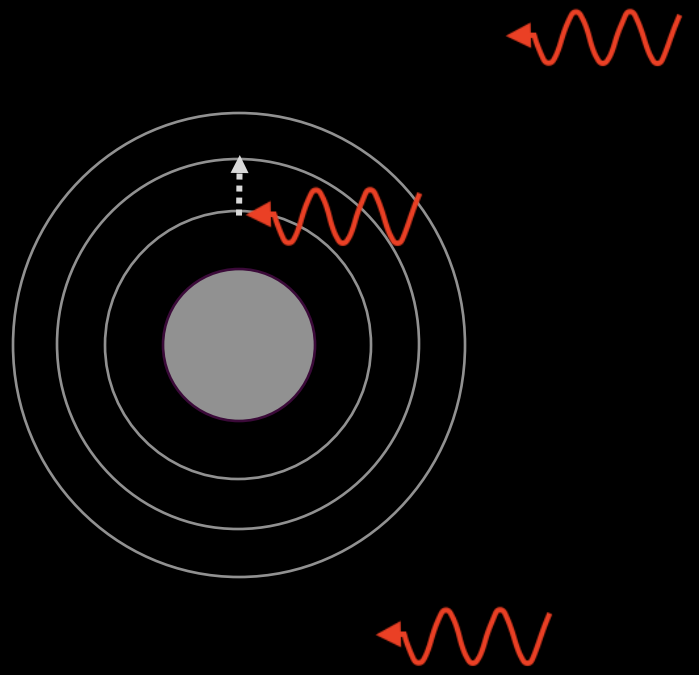


BeppoSAX

Measuring the distances to GRBs

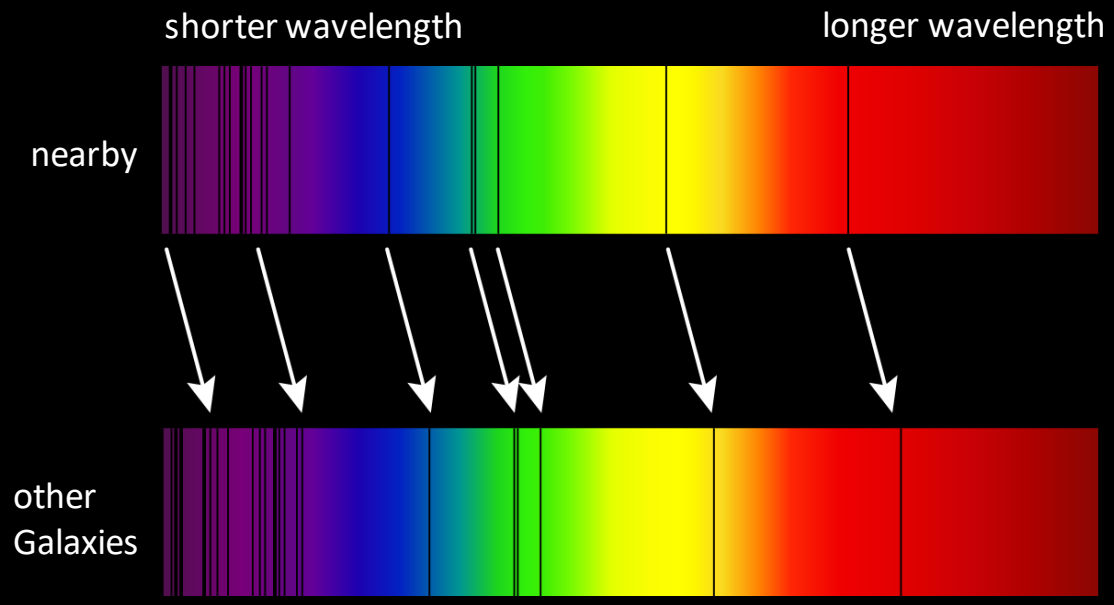
Spectrometry



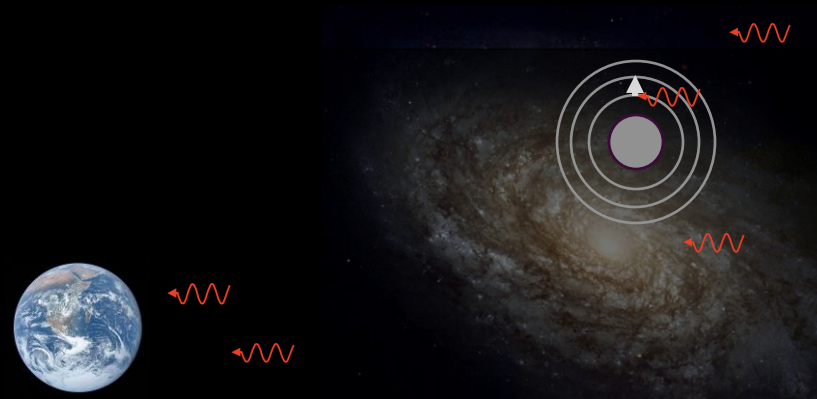


Measuring the distances to GRBs

Spectrometry can determine a GRB's **redshift**



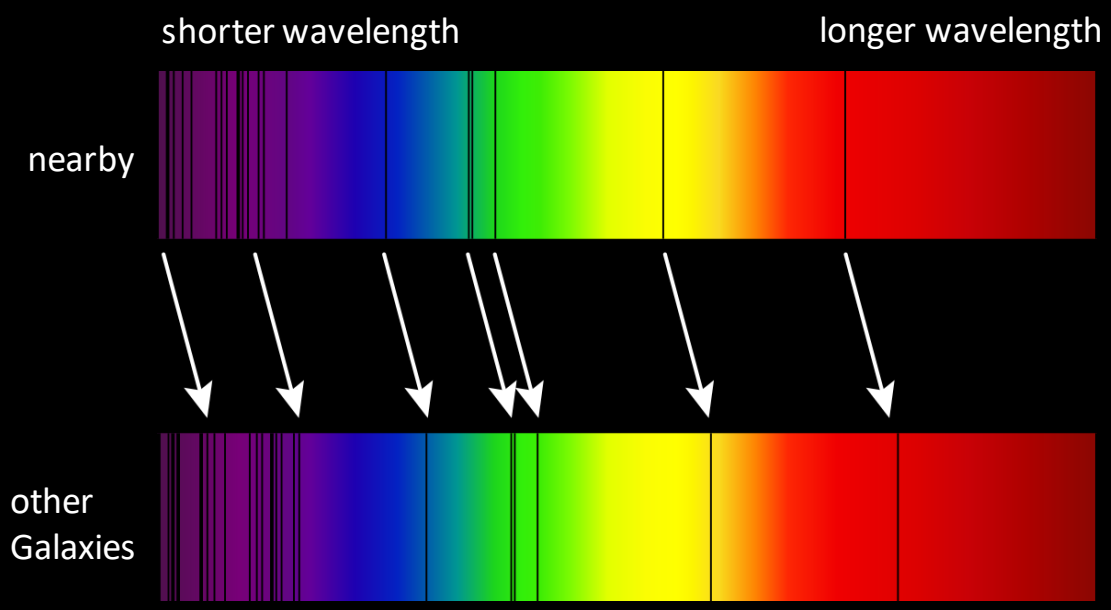
[IM11]



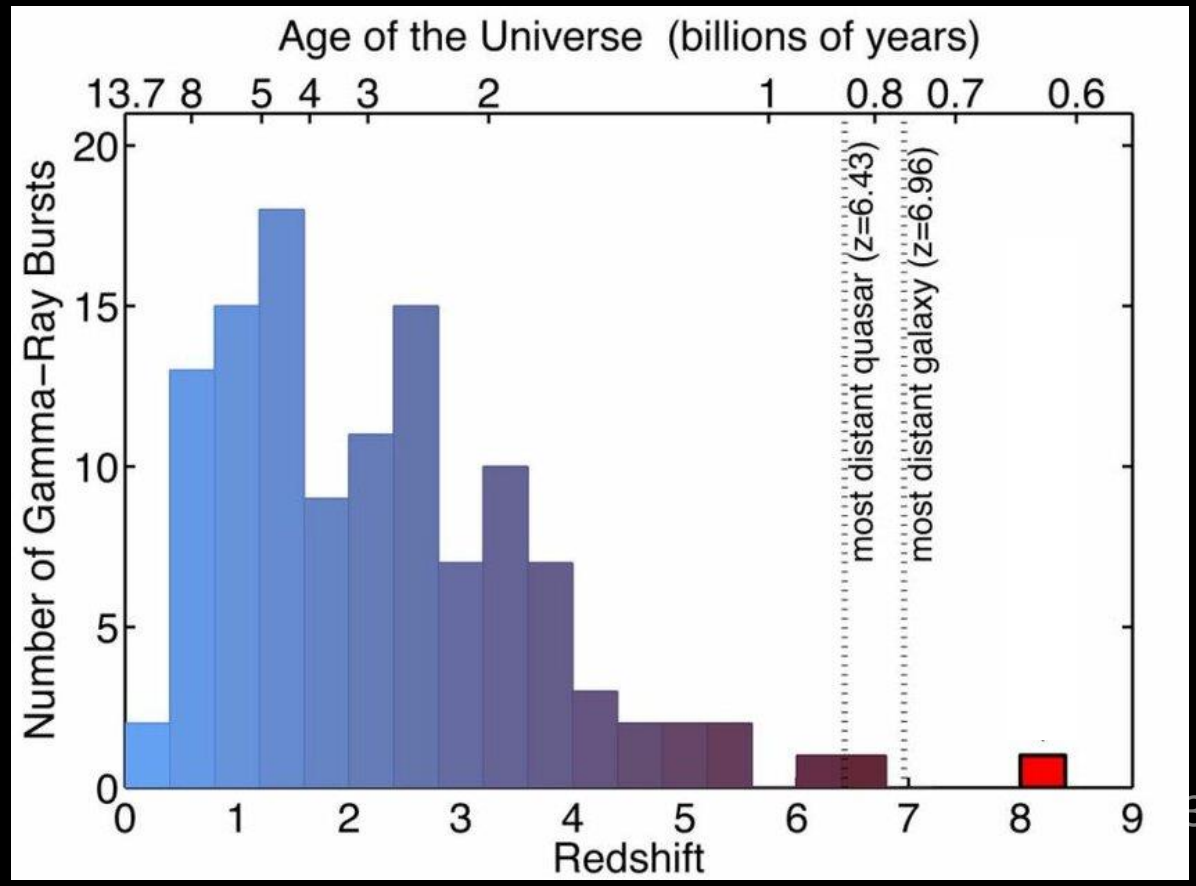
[IM12, IM13]

Measuring the distances to GRBs

Spectrometry can determine a GRB's **redshift**



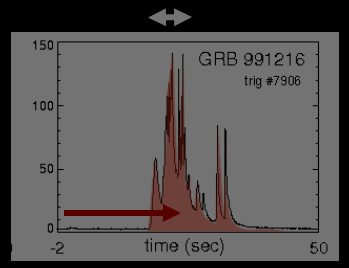
[IM11]



[IM14,R5]

Combining the clues

rapid variations, as fast as milliseconds



energy measured by the detector up to 10^{-11} J/cm^2

+

GRBs are billions of light years away (10^9)

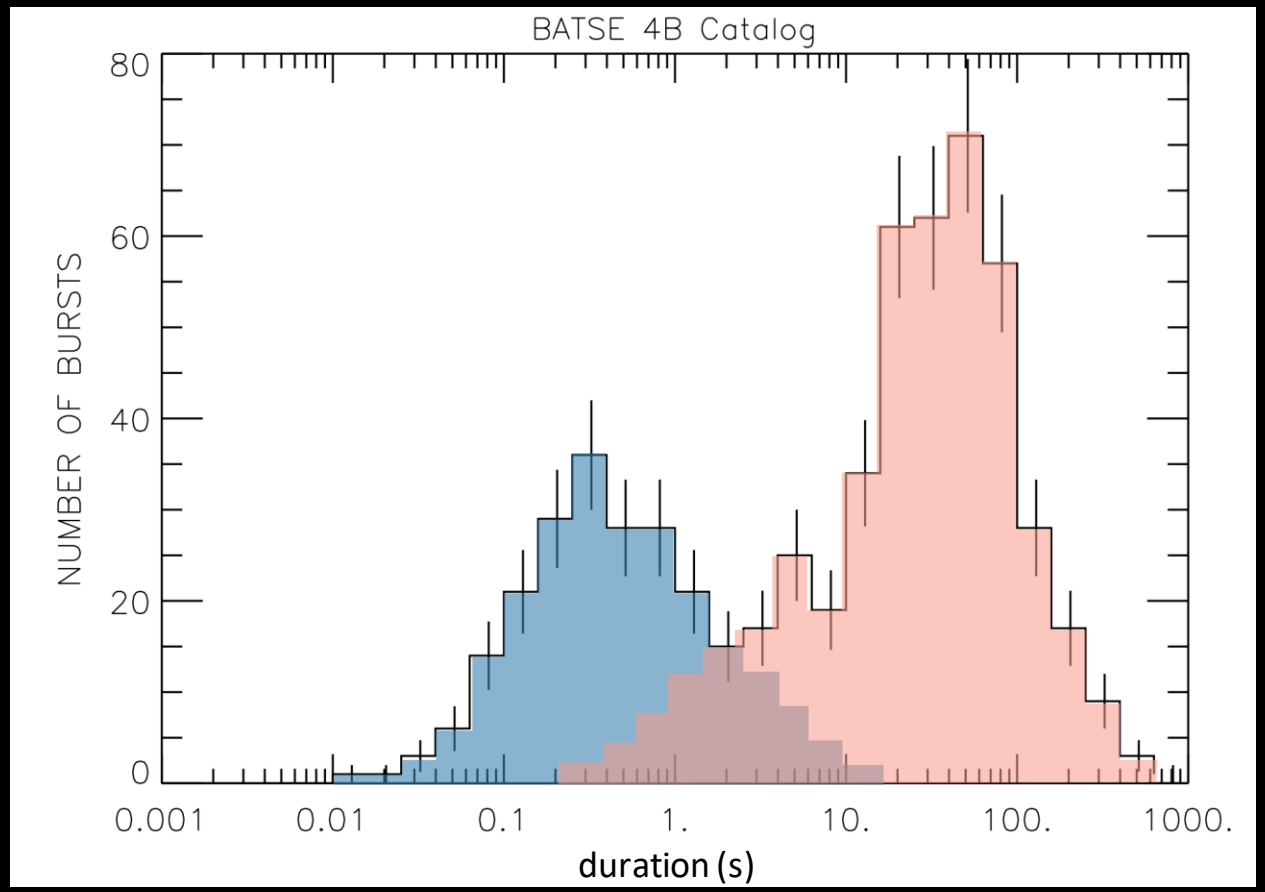
=

compact objects
(black holes, neutron stars)
must be involved
+
emission from relativistic jet

Two populations of gamma-ray bursts

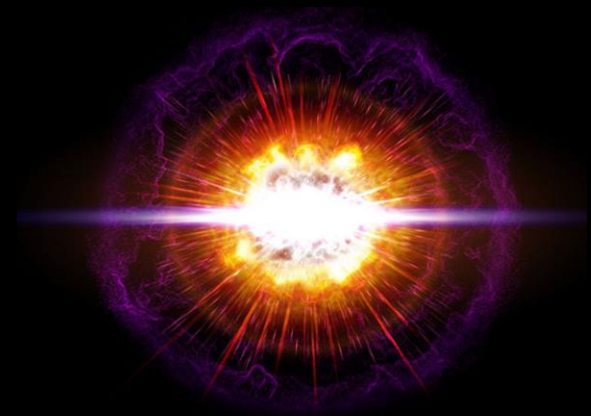
[IM15,R6]

two compact objects merge



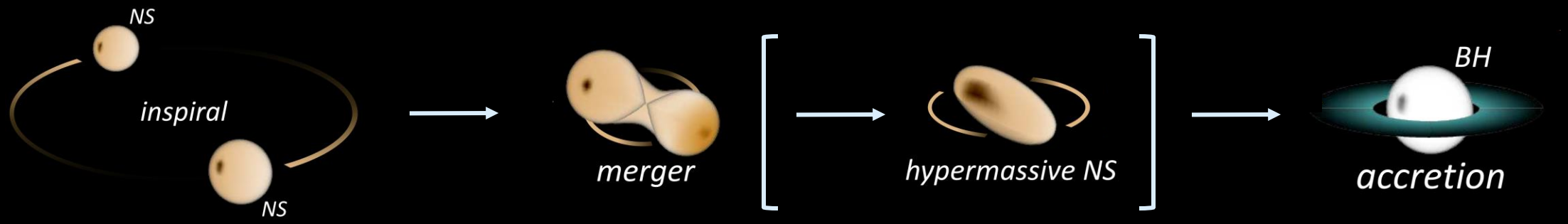
[IM16]

[IM17]



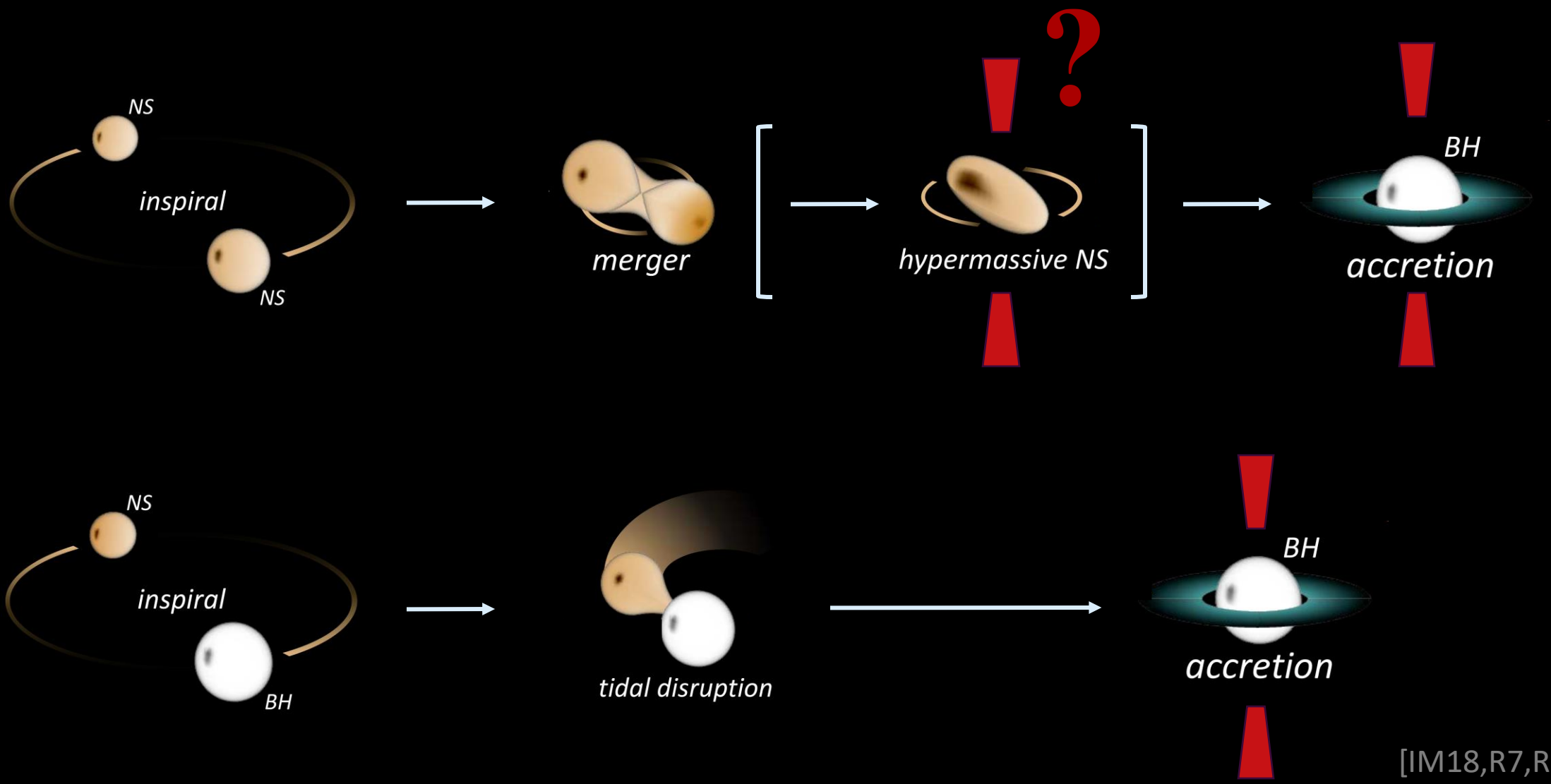
a massive star collapses

The evolution of a compact binary merger



[IM18,R7,R8]

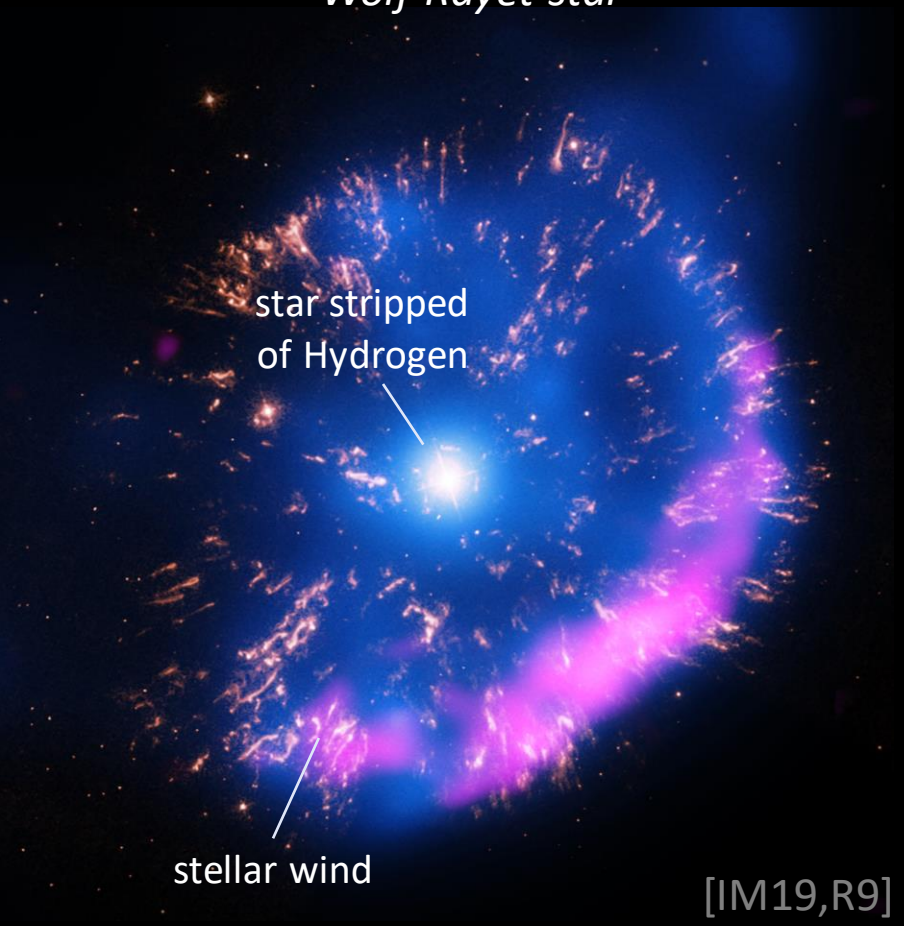
The evolution of a compact binary merger



[IM18,R7,R8]

The evolution of a massive star collapse

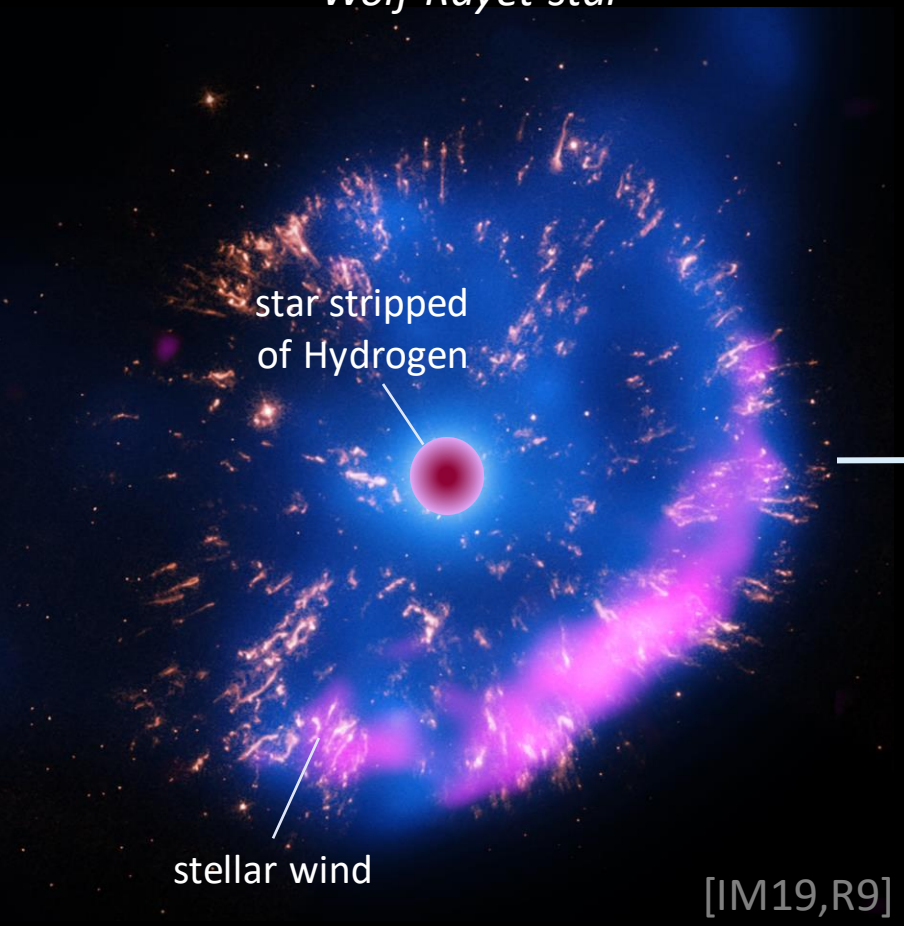
Wolf-Rayet star



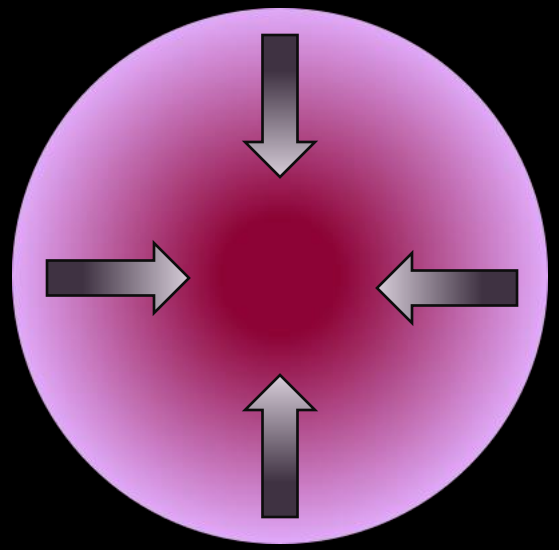
[IM19,R9]

The evolution of a massive star collapse

Wolf-Rayet star



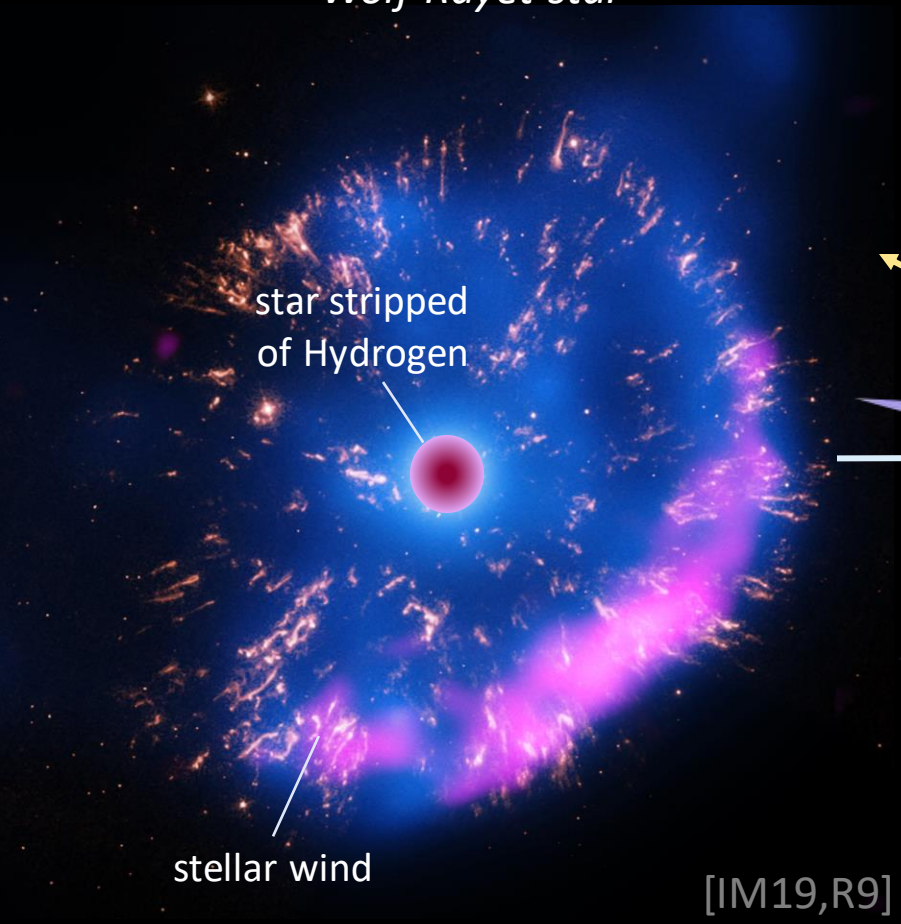
stellar collapse



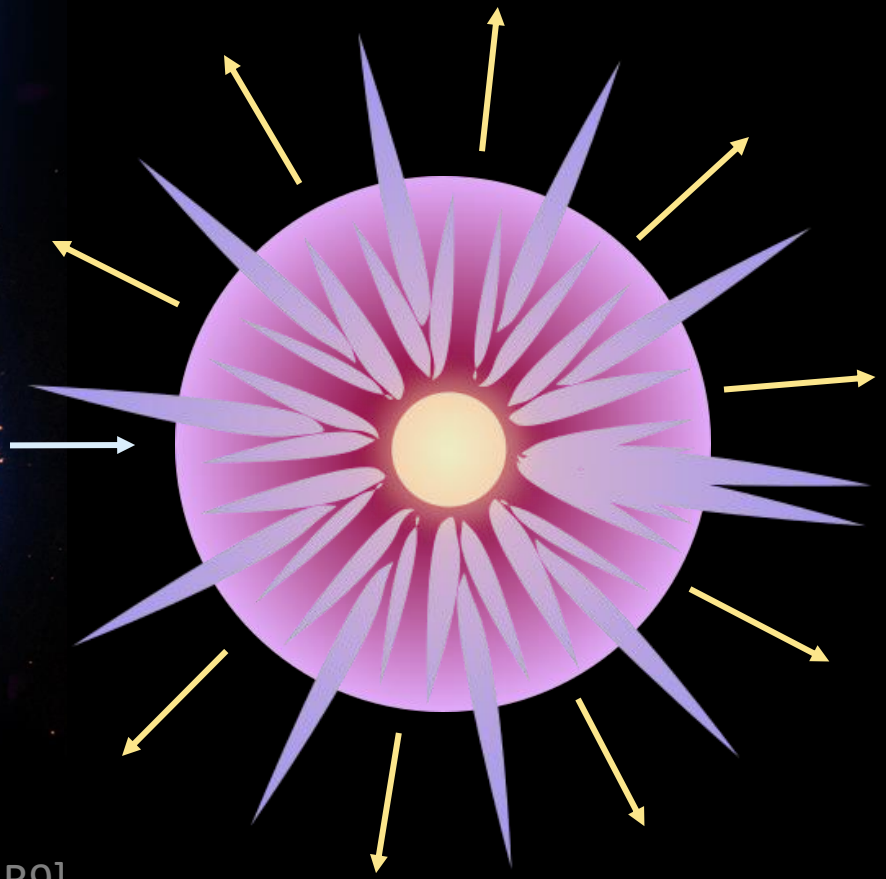
[IM19,R9]

The evolution of a massive star collapse

Wolf-Rayet star

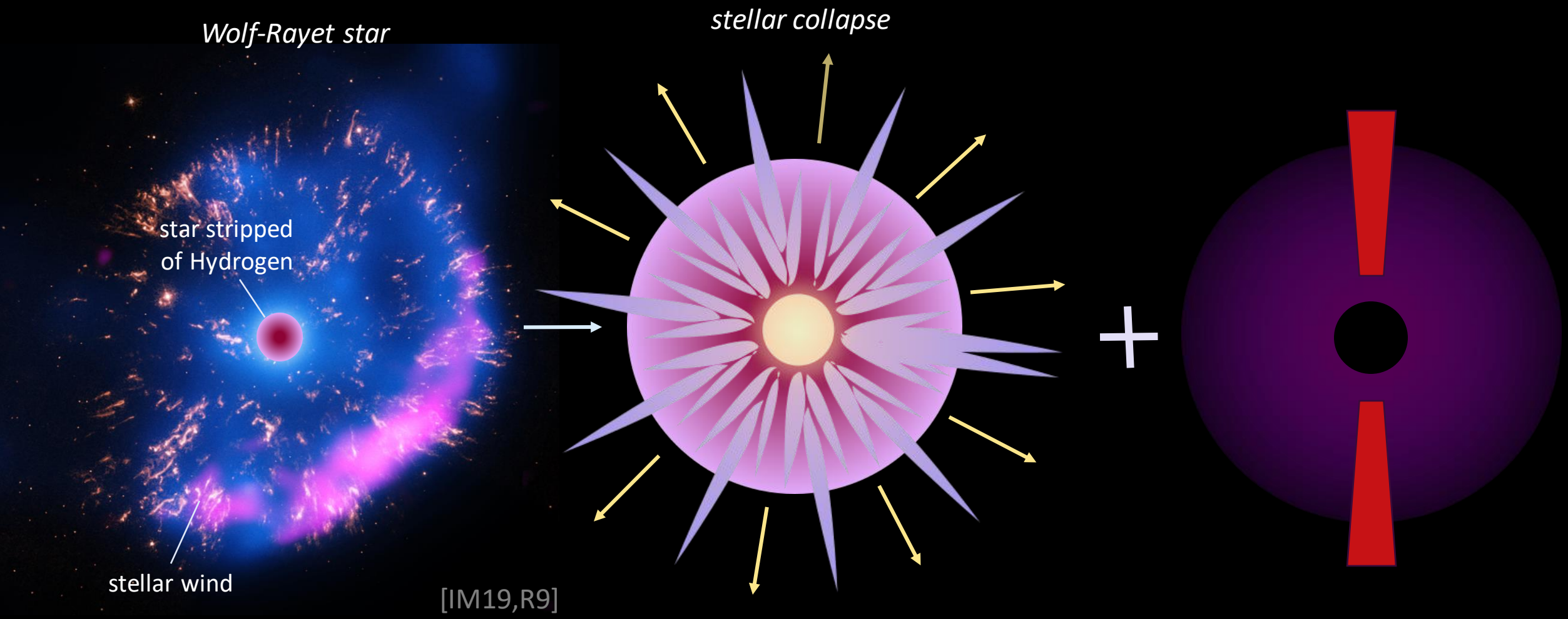


stellar collapse



[IM19,R9]

The evolution of a massive star collapse



[IM19,R9]

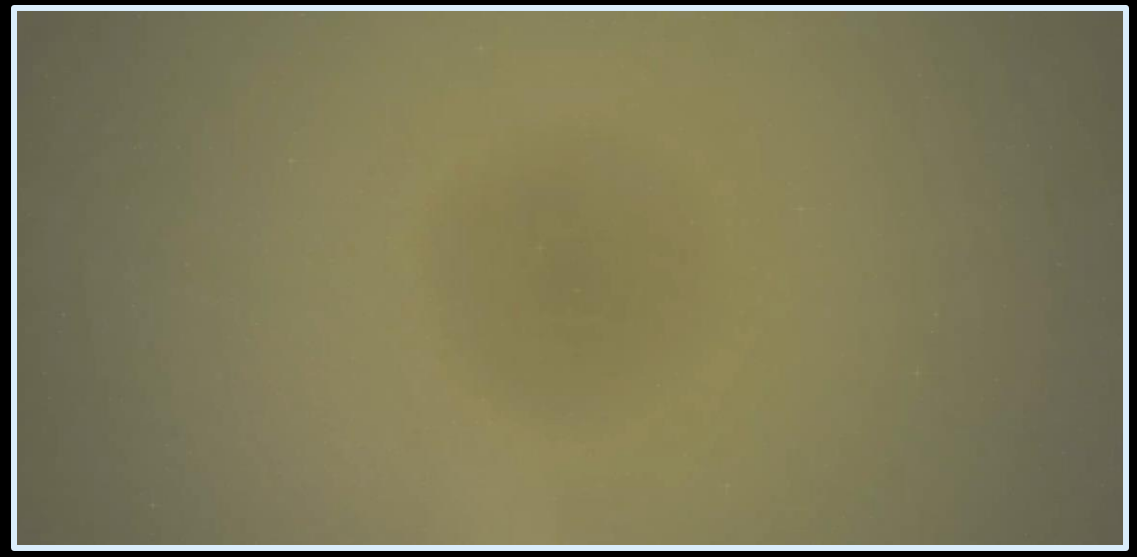
Simulating GRB jets produced by black holes

Neutron star merger

[IM20]

central BH is surrounded by dynamical ejecta created in the merger process

Collapsar



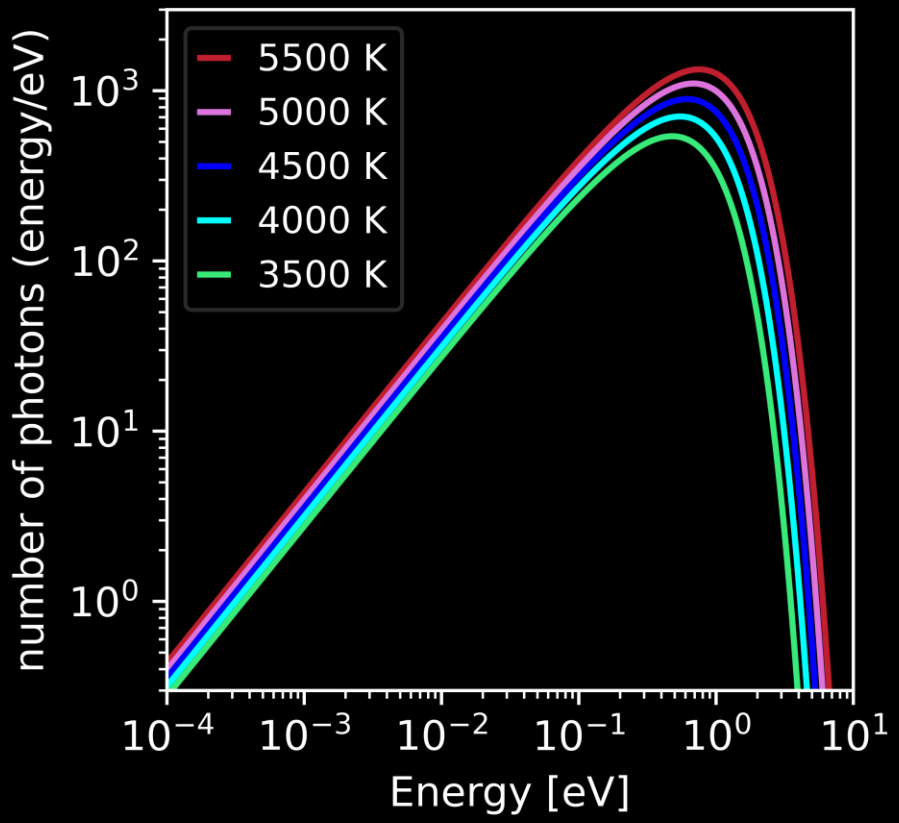
[IM21]

central BH is surrounded by stellar envelope from the progenitor

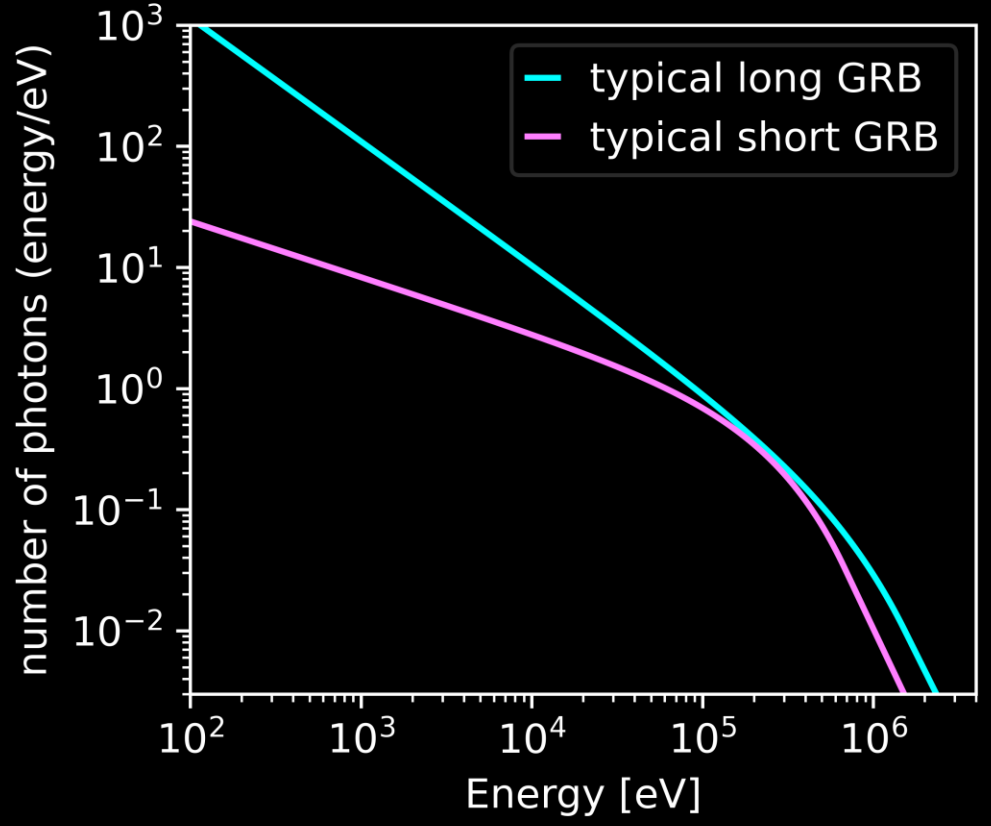
[R10, R11, R12]

Photon spectra hint at efficient particle acceleration

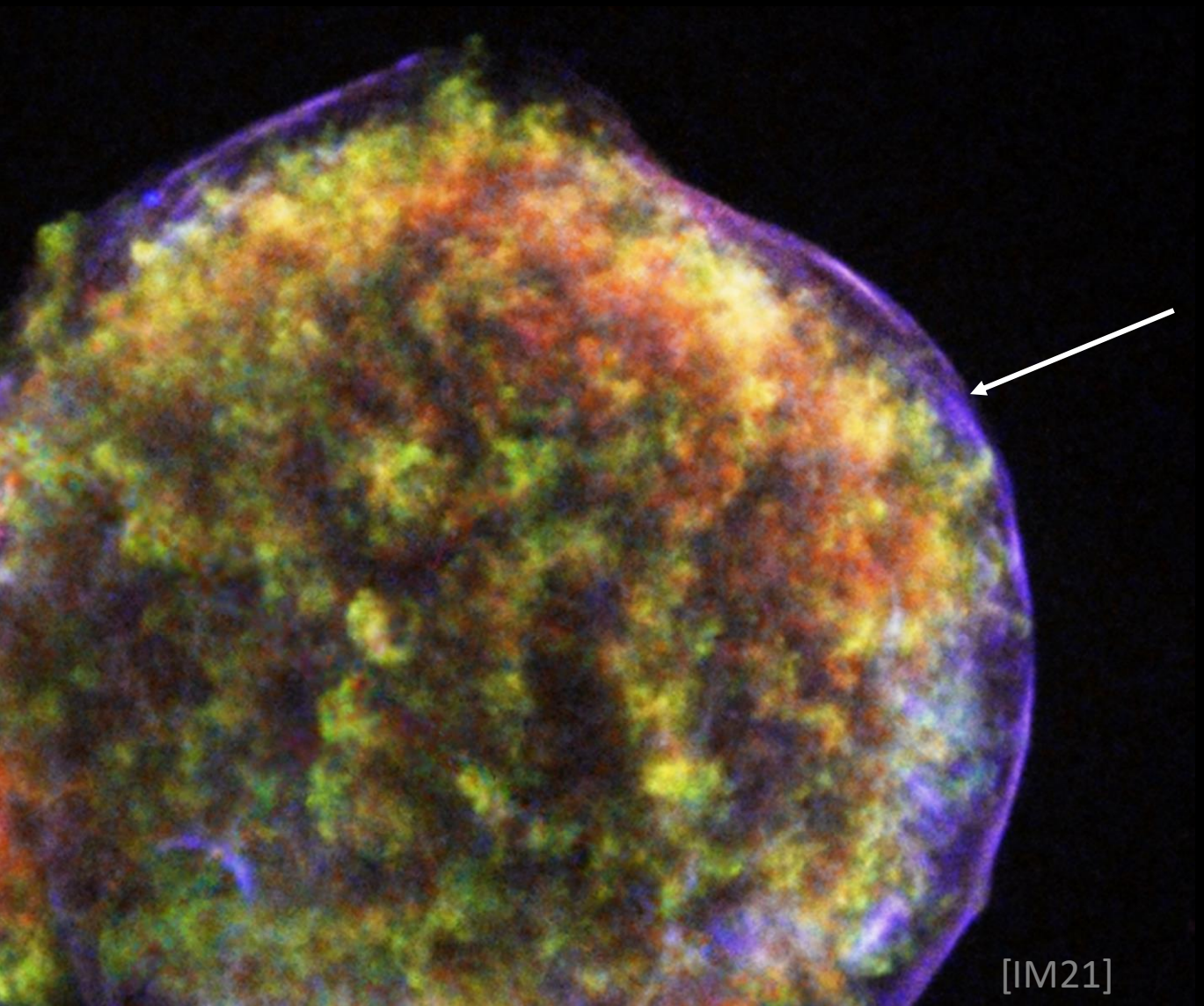
Spectra from thermal "hot" plasma



Non-thermal spectra in GRBs



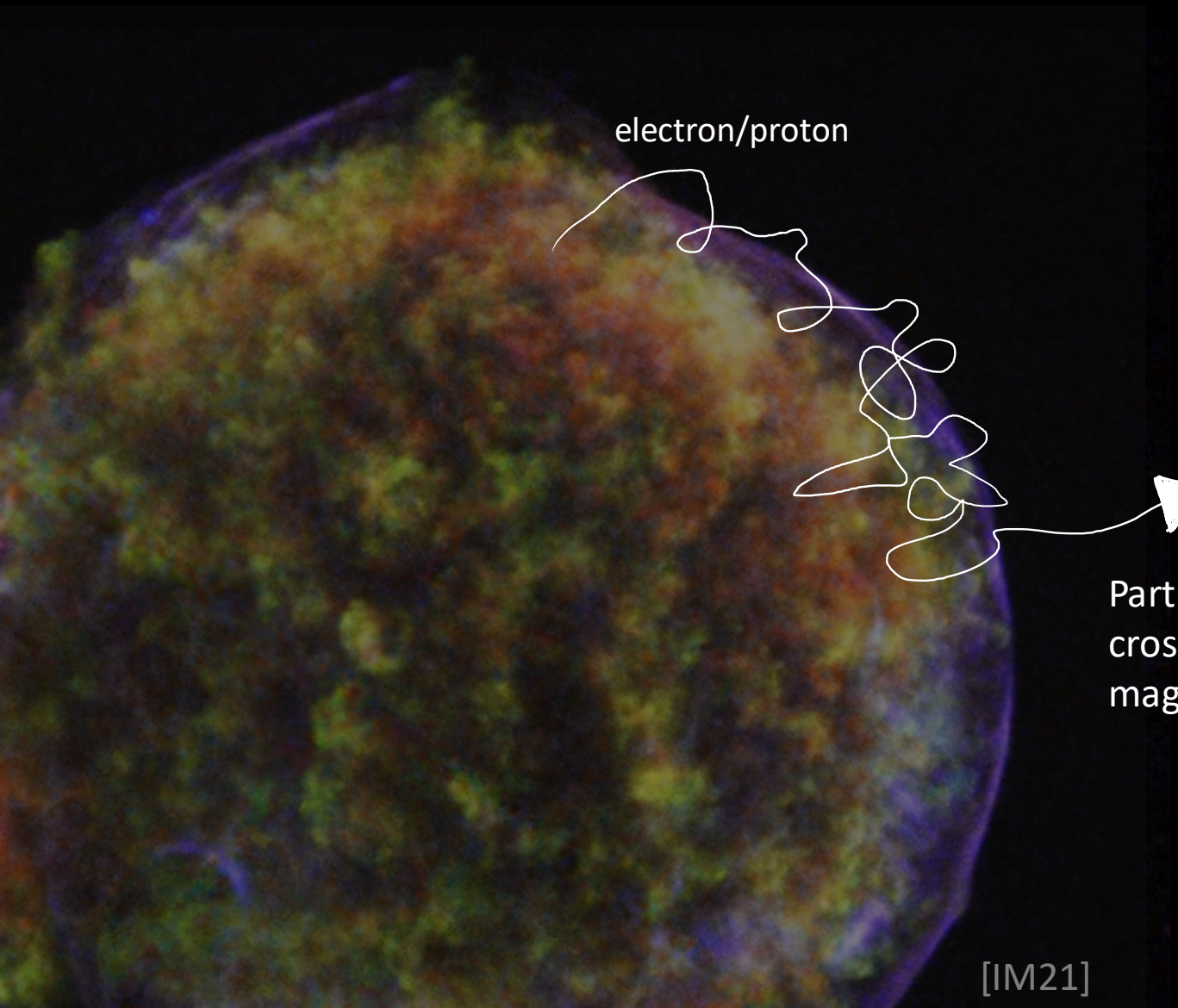
Accelerating particles in space



A fast plasma hits a slower one:
Creation of an astrophysical shock

[IM21]

Accelerating particles in space

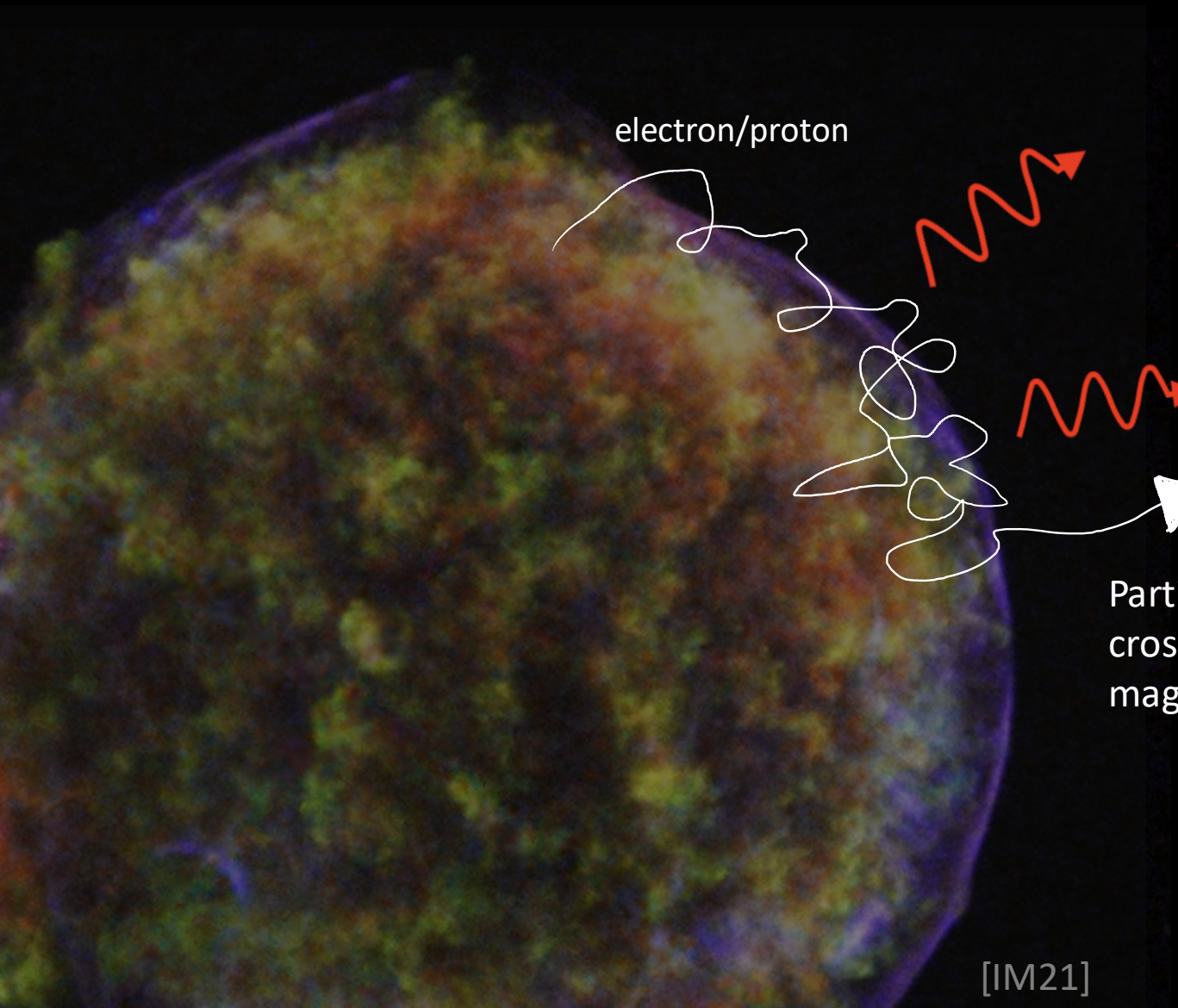


Particles are accelerated as they cross the shock and are scattered by magnetic fields

[R13]

[IM21]

Accelerating particles in space

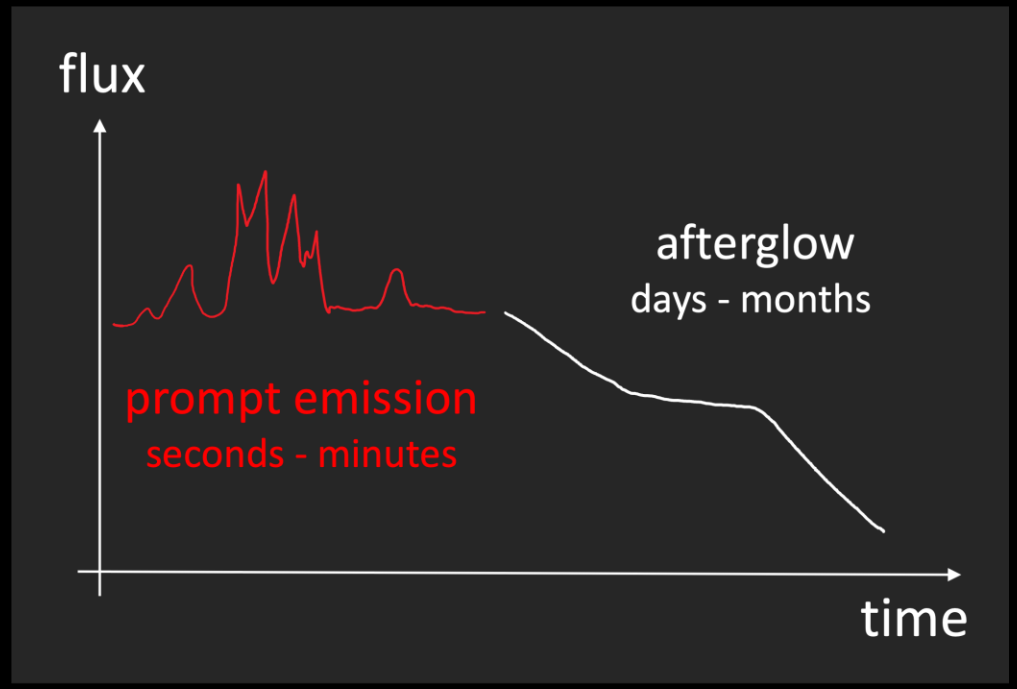


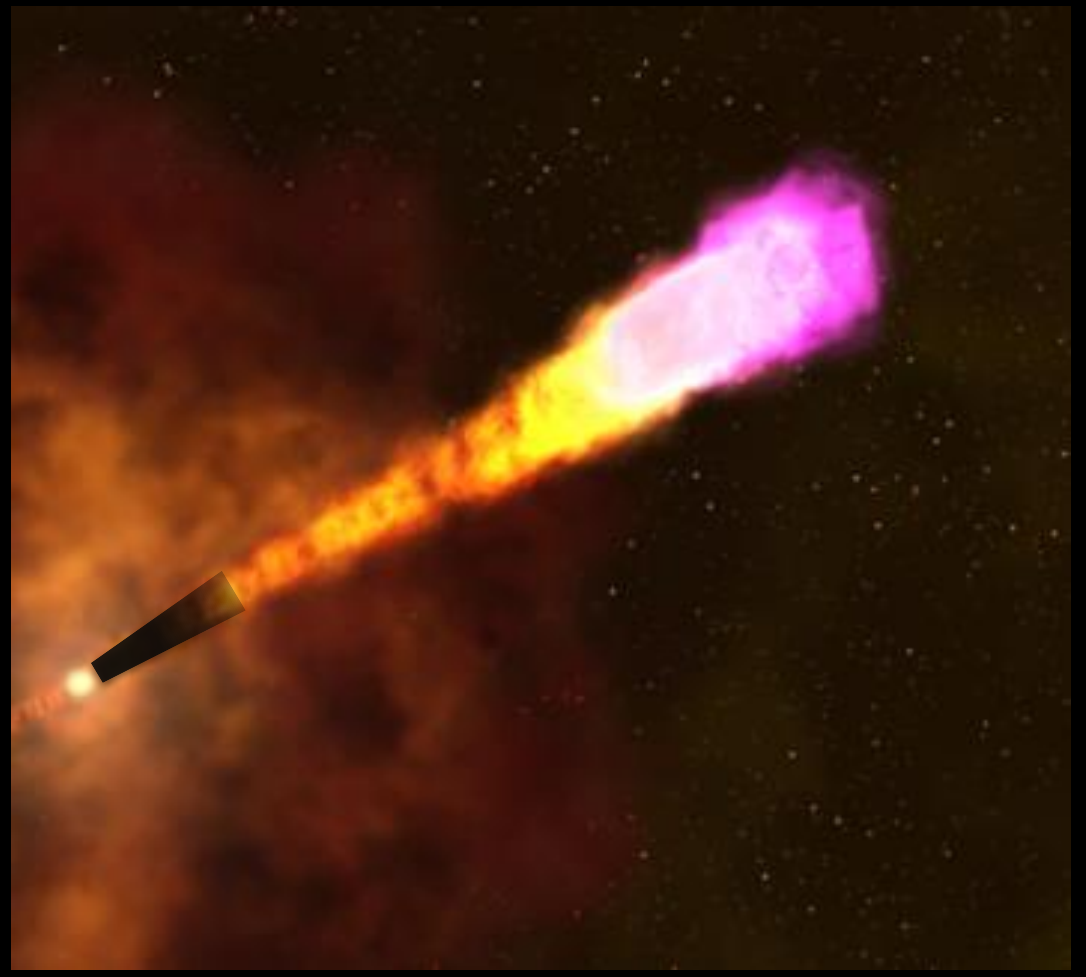
Particles are accelerated as they cross the shock and are scattered by magnetic fields

[R13]

[IM21]

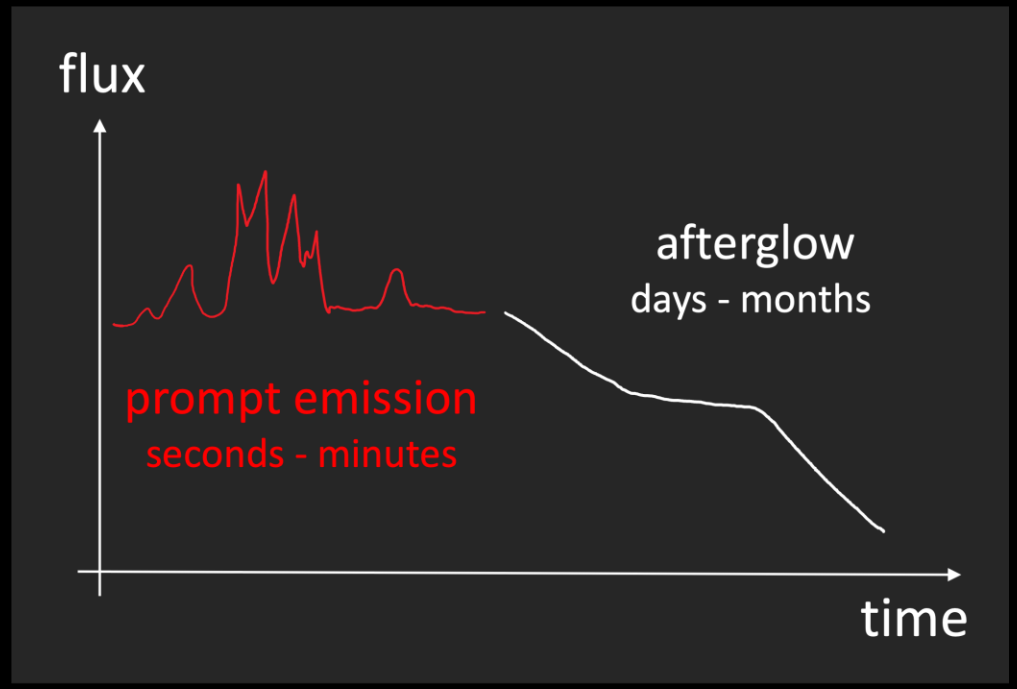
So we understand how GRBs shine?

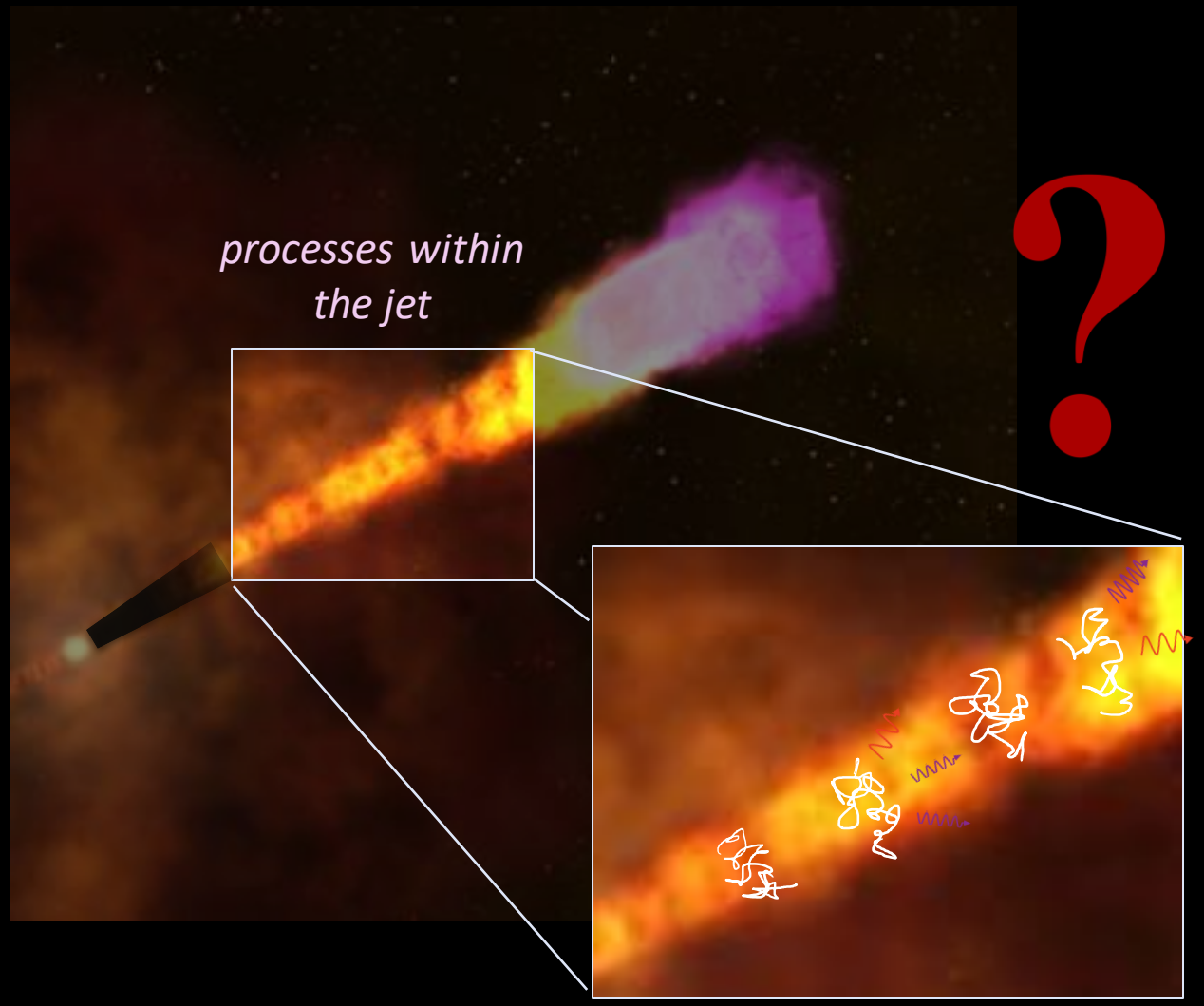




[IM22]

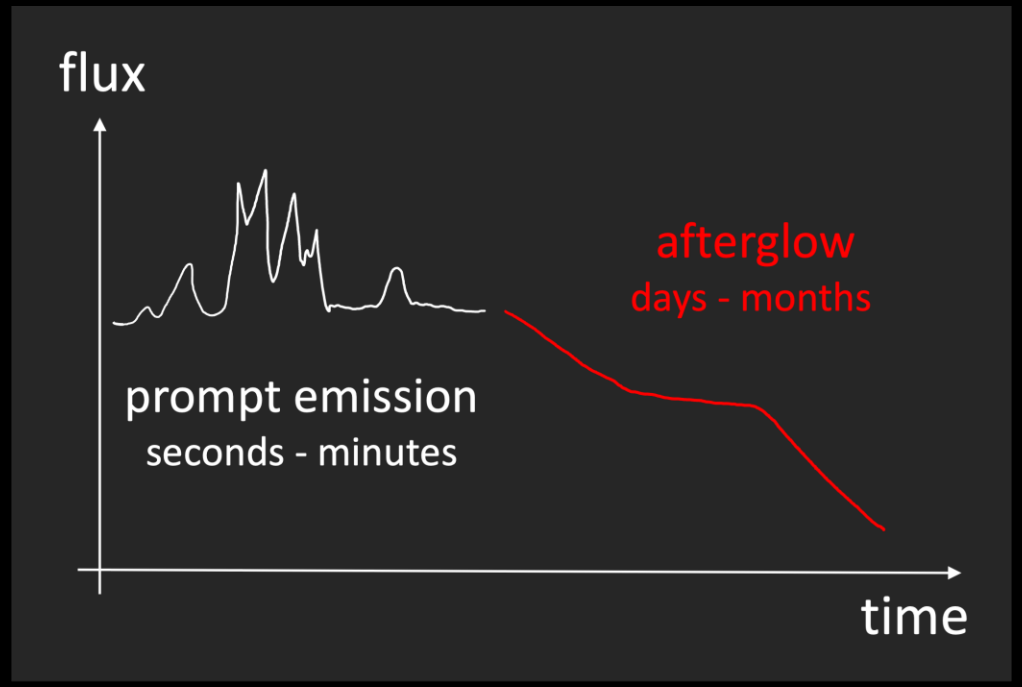
So we understand how GRBs shine?





[R14,R15]

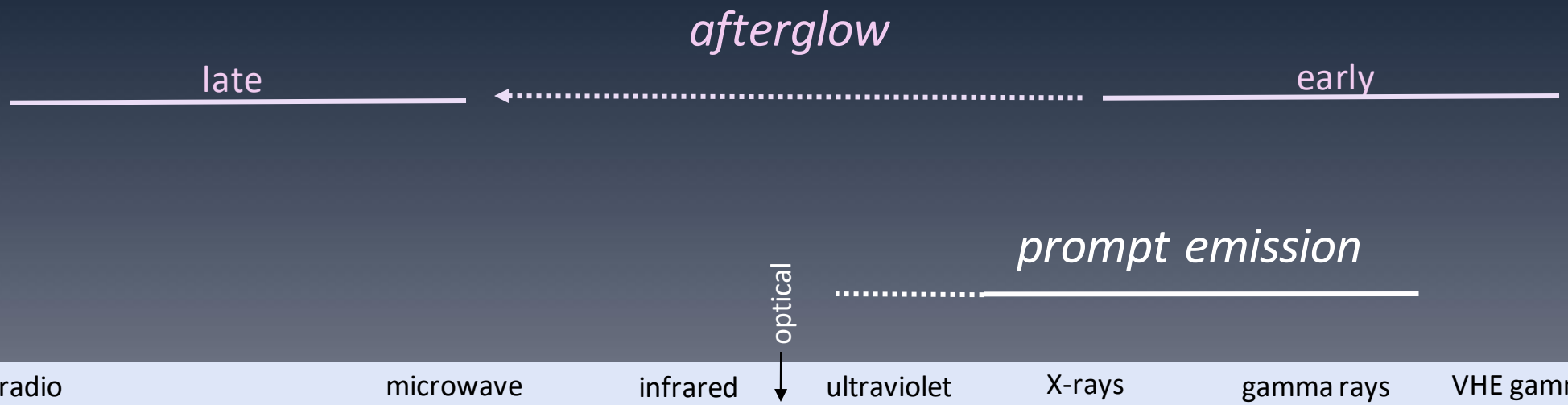
So we understand how GRBs shine?



Interaction with external medium

[R16]

[IM22]



	radio	microwave	infrared	optical	ultraviolet	X-rays	gamma rays	VHE gamma ray
Energy [eV]	10^{-12}	10^{-4}	10^{-1}	1		10^{2}	10^{3} - 10^{9}	10^{12}

[IM23

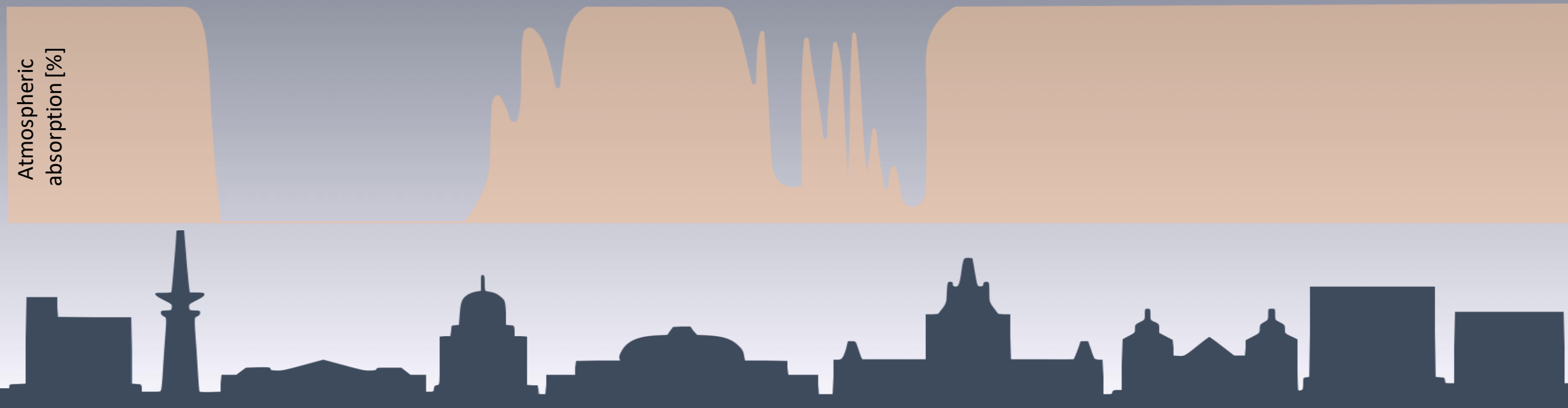
afterglow

late ← early

prompt emission

optical

	radio	microwave	infrared		ultraviolet	X-rays	gamma rays	VHE gamma ray
Energy [eV]	10^{-12}	10^{-4}	10^{-1}	1		10^{2}	10^{3} - 10^{9}	10^{12}



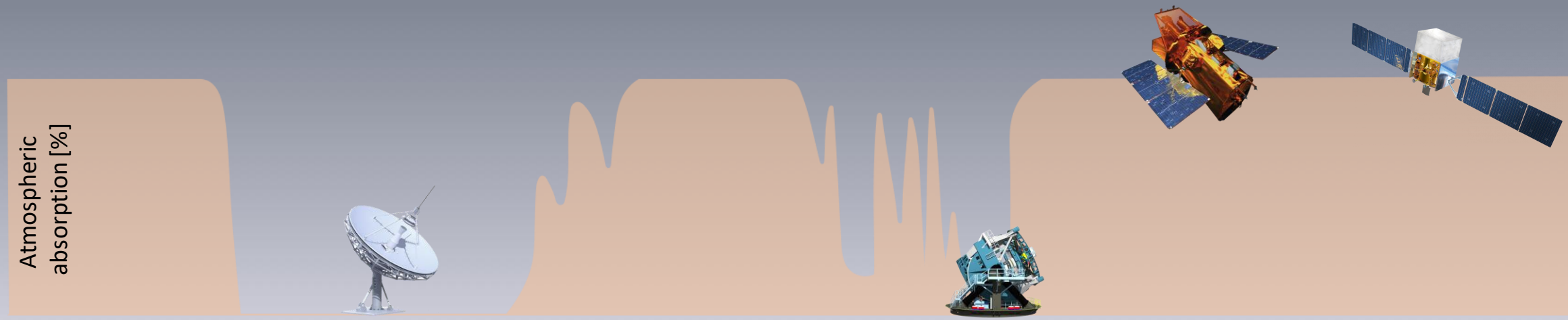
afterglow

late ← early

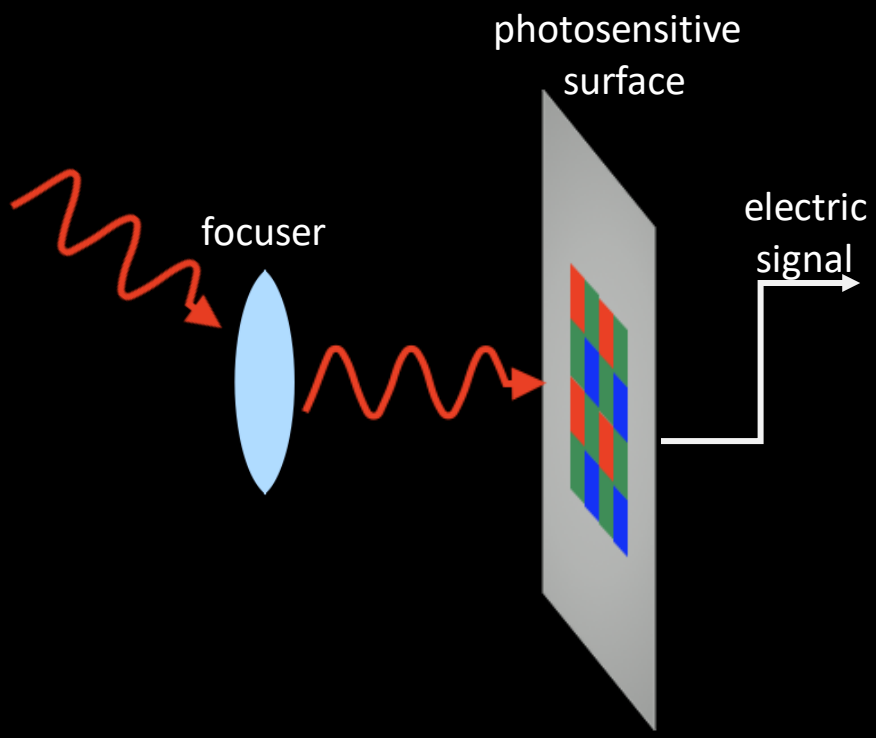
prompt emission

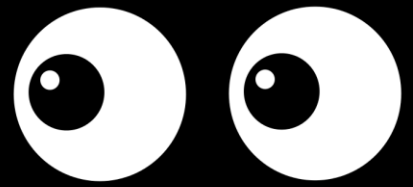
optical

	radio	microwave	infrared		ultraviolet	X-rays	gamma rays	VHE gamma ray
Energy [eV]	10^{-12}	10^{-4}	10^{-1}	1		10^{2}	10^{3} - 10^{9}	10^{12}



How do we detect photons?





optical photons

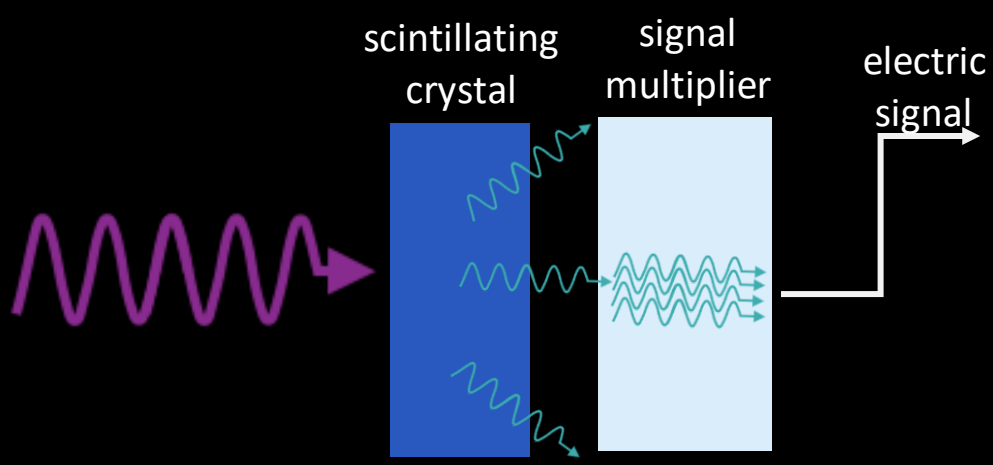
energy ~ 1 eV

[R17]

[IM24]

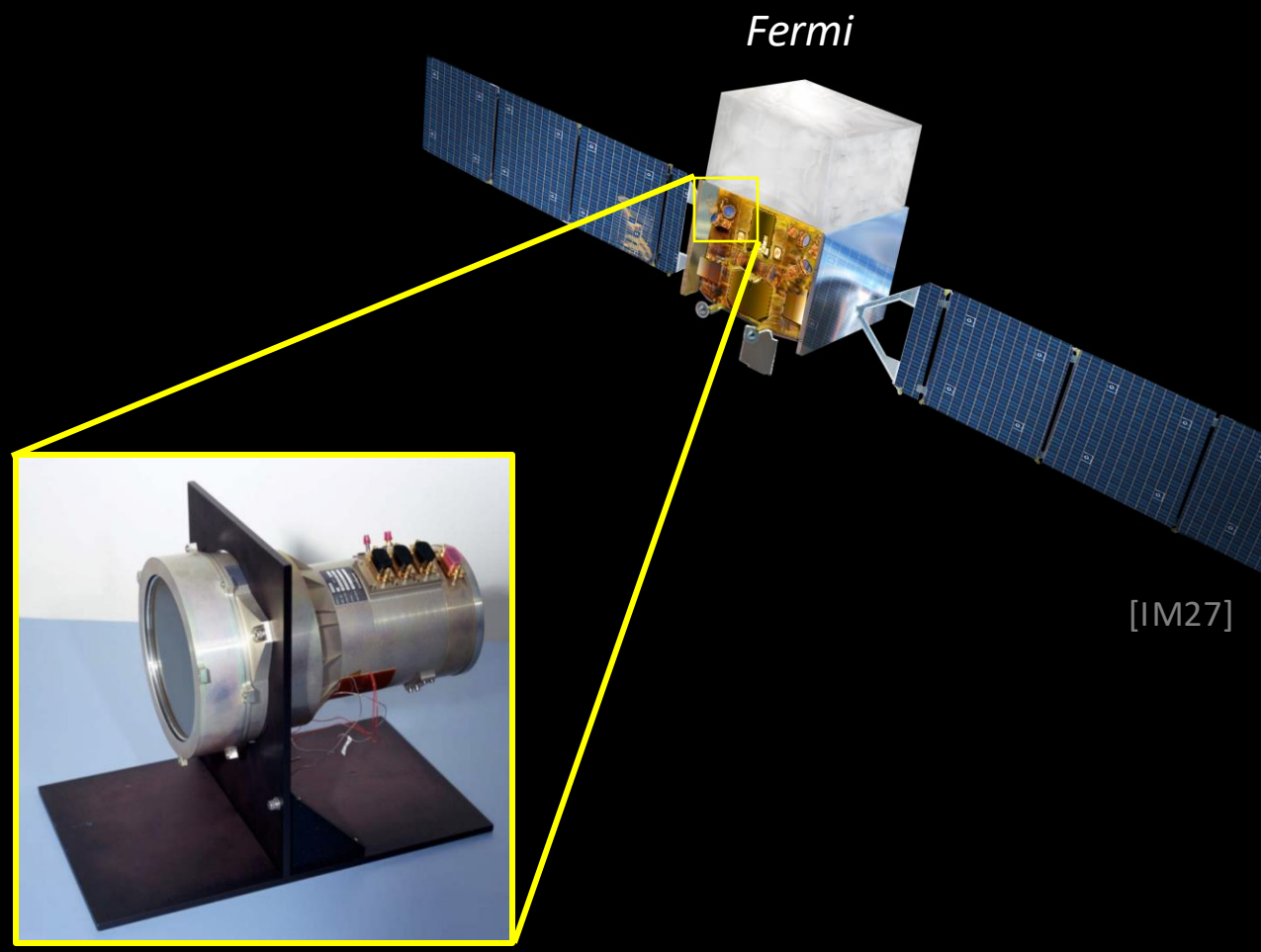
How do we detect photons?

[IM25]



gamma-ray photons
energy ~ 1 keV – 1 MeV

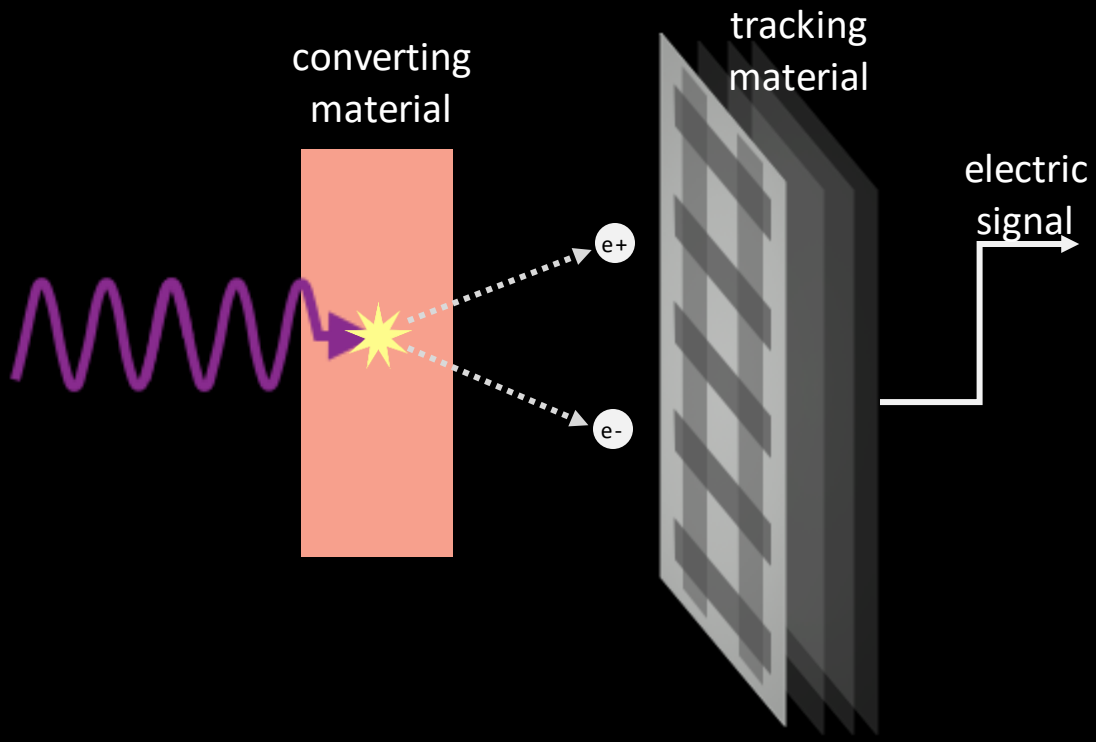
[R18]



[IM27]

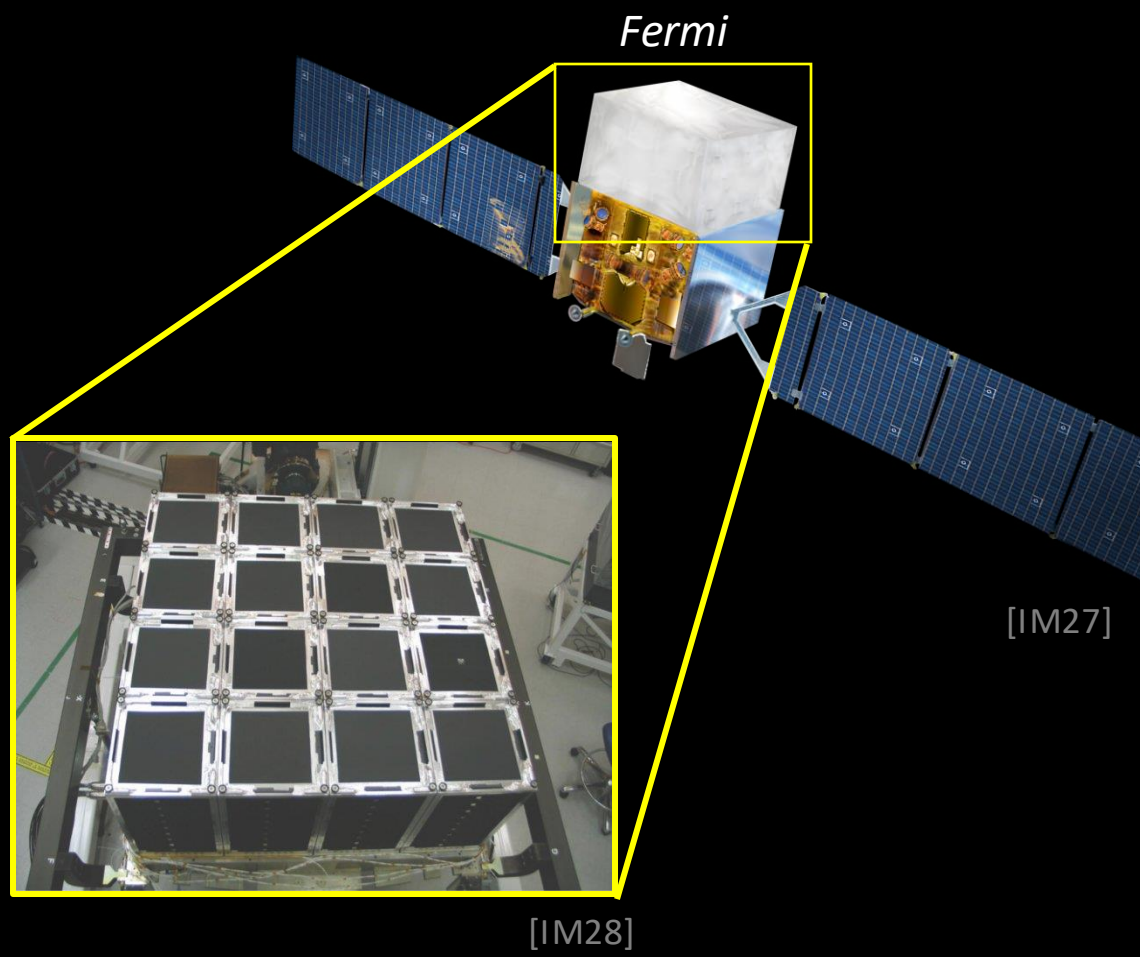
[IM26]

How do we detect photons?



gamma-ray photons
energy ~ 1 GeV

[R19]



[IM27]

[IM28]

How do we detect photons?

[IM29]

electric signal

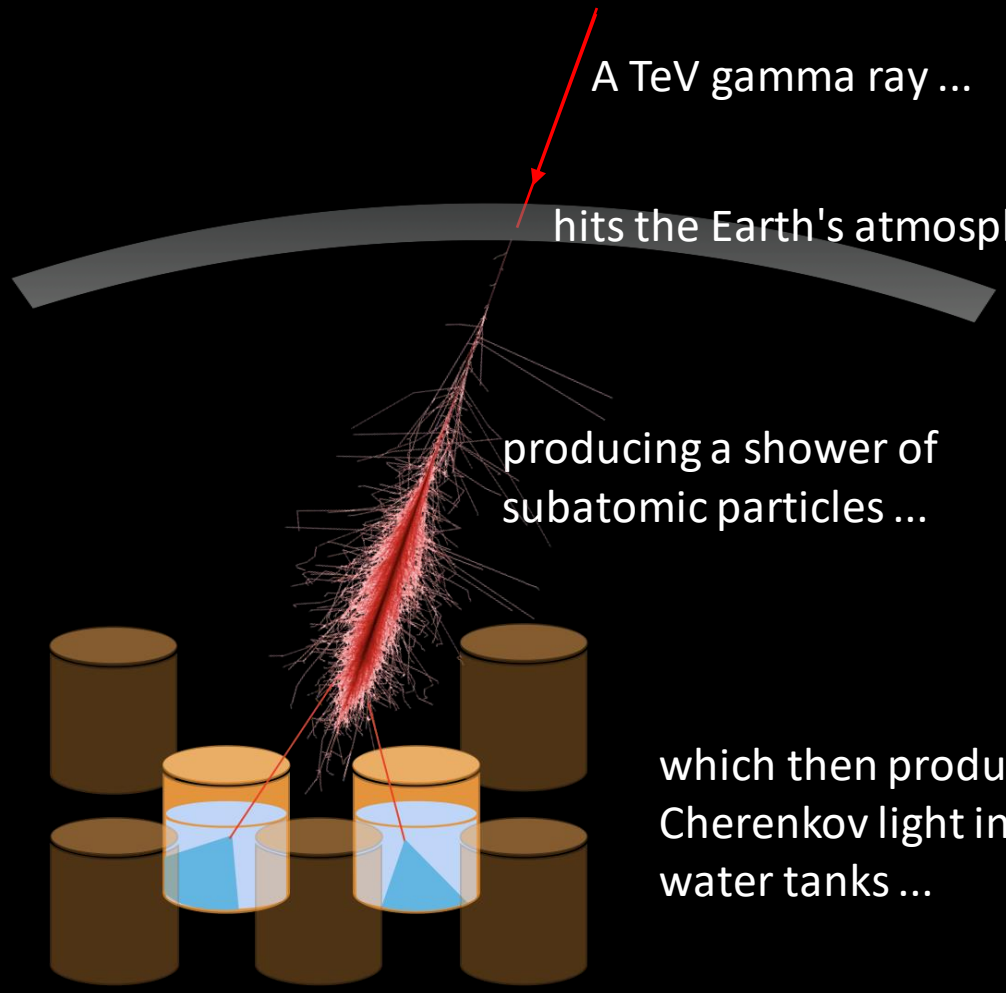
Fermi

[IM27]

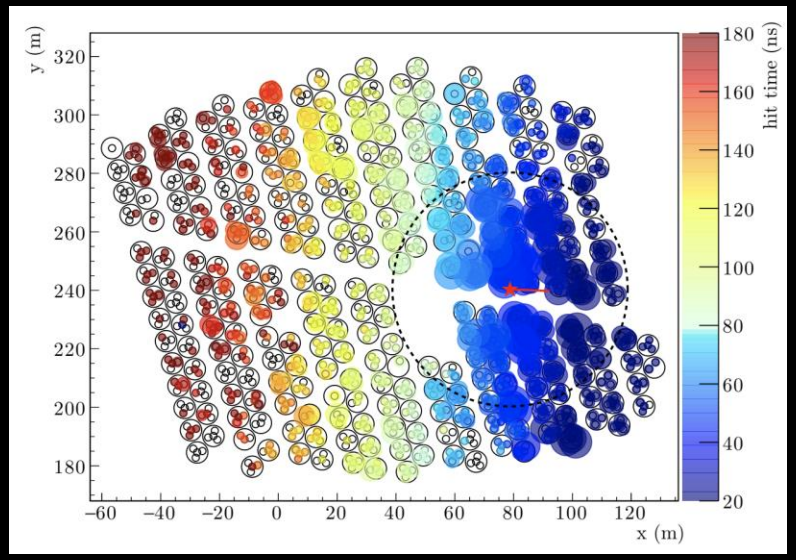
[IM30]

[R18,R19]

Detecting the highest energy gamma rays



[IM31]

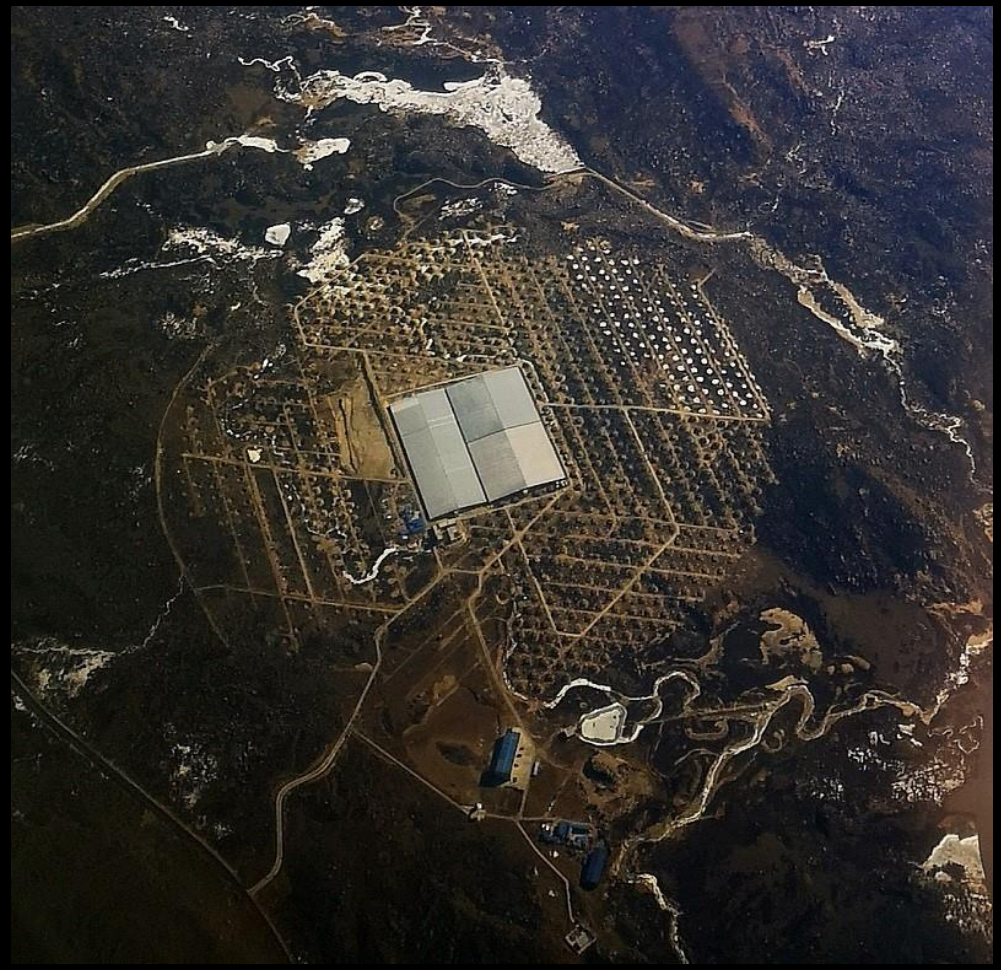


[IM32]

... which is analyzed to understand the properties of the original photon.

[R20]

Large **H**igh **A**ltitude **A**ir **S**hower **O**bservatory



[IM33]

[IM34]

[IM35]

[R20]

What the public saw

Forbes

FORBES > INNOVATION > SCIENCE

Today's Most Powerful Explosion Ever Recorded Was The 'Birth Cry Of A New Black Hole,' Say Scientists

FrankfurterRundschau

Startseite › Wissen

Extrem heller Gammastrahlenblitz trifft die Erde – „Bricht alle Rekorde“

VICE Video TV News Tech Rec Room Life Horoscopes

Scientists Have Detected a 'Completely Unprecedented' Burst of Energy in Space

Bright, powerful burst of gamma rays detected by multiple telescopes

By Ashley Strickland, CNN

3 minute read · Published 3:03 PM EDT, Mon October 17, 2022

The New York Times

A Supernova 'Destroyed' Some of Earth's Ozone for a Few Minutes in 2022

[R21]

What astronomers saw

09.10. 20:44
Swift

```
////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  32635
SUBJECT: GRB 221009A: Swift detected transient may be GRB
DATE:    22/10/09 20:44:25 GMT
FROM:    Jamie Kennea at Penn State U  <jak51@psu.edu>

J. A. Kennea and M. Williams (PSU) report on behalf of the Swift Team:

We provide an update on the BAT trigger 1126853, AKA Swift J1913.1+1946
(GCN #32632). Examination of XRT data from this trigger shows strong
fading. We also note that Fermi/LAT has triggered on the same location.
There is also a possible association with a Fermi/GBM trigger @
13:16:59UT. Given this, we believe that this source is now likely a
Gamma-Ray Burst and not a Galactic Transient. If the GBM trigger is the
same source, this would suggest a highly energetic outburst, and therefore
we strongly encourage follow-up of this usual event.
```

[R21]

What astronomers saw

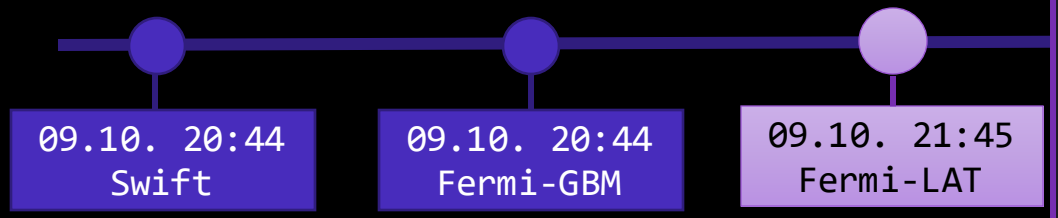
09.10. 20:44
Swift

09.10. 20:54
Fermi-GBM

```
////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  32636
SUBJECT: GRB 221009A: Fermi GBM detection of an extraordinarily bright GRB
DATE:    22/10/09 20:54:36 GMT
FROM:    Peter Veres at UAH  <veresp@gmail.com>

P. Veres (UAH),  E. Burns (LSU), E. Bissaldi (Politecnico and INFN
Bari), S. Lesage (UAH), O. Roberts (USRA)
report on behalf of the Fermi GBM Team:

"At 2022-10-09 13:16:59.000 UT on 9 October 2022, the Fermi Gamma-Ray
Burst Monitor (GBM) triggered and located GRB 221009A (trigger
687014224 / 221009553).

This event, if it is a GRB, it is the brightest among the GBM detected
GRBs. If it is not a GRB then it is a rare transient event. Follow-up
across all wavelengths is encouraged.

The on-ground calculated location, using the GBM trigger
data, is RA = 290.4, DEC = 22.3 (J2000 degrees,
equivalent to 19 h 22 m, 22 d 15 '), with a statistical uncertainty
of 1 degrees (radius, 1-sigma containment,
statistical only; there is additionally a systematic
error which we have characterized as a core-plus-tail model, with 90% of
GRBs having a 3.7 deg error and a small tail suffering a larger than 10 deg
systematic error. [Connaughton et al. 2015, ApJS, 216, 32] ).
```

[R21]

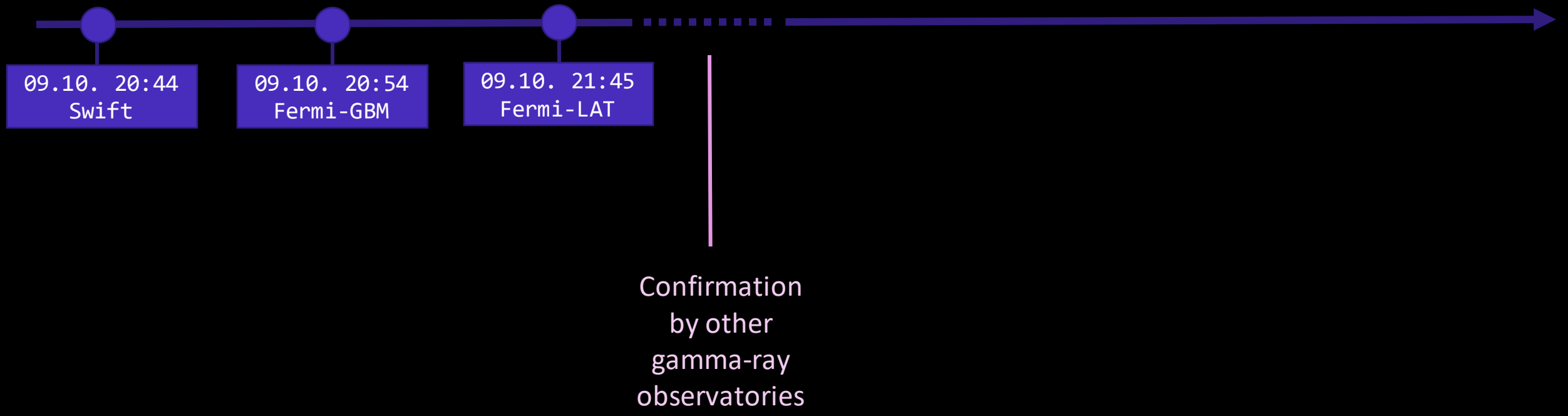
What astronomers saw




```
////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  32637
SUBJECT: GRB 221009A or Swift J1913.1+1946: Fermi-LAT detection
DATE:    22/10/09 21:45:05 GMT
FROM:    Elisabetta Bissaldi at INFN,Bari  <elisabetta.bissaldi@ba.infn.it>

E Bissaldi (Politecnico and INFN Bari), N. Omodei (Stanford Univ.),
M. Kerr (NRL), report on behalf of the Fermi-LAT team:


At 14:17:05.99 on October, 09, 2022 Fermi-LAT detected high-energy emission
from Swift J1913.1+1946 or GRB 221009A, which was reported by
Swift (Dichiara et al. GCN #32632) and by GBM (Veres et al. GCN #32636).
The best LAT on-ground location is found to be

RA, Dec = 288.21, 19.73 (J2000)

with an error radius of 0.09 deg (90 % containment, statistical error only).
This was 94 deg from the LAT boresight at the time of the trigger.

The data from the Fermi-LAT show a significant increase in the event rate
that is spatially and temporally correlated with the trigger with high significance.

The 100 MeV - 1 GeV photon flux in the time interval 500-3500 s after
the Swift trigger is (1.27 +/- 0.16)E-05 ph/cm2/s.
The estimated photon index above 100 MeV is -2.12 +/- 0.11.
The highest-energy photon is a 7.8 GeV
which is observed 766 seconds after the Swift trigger.
```

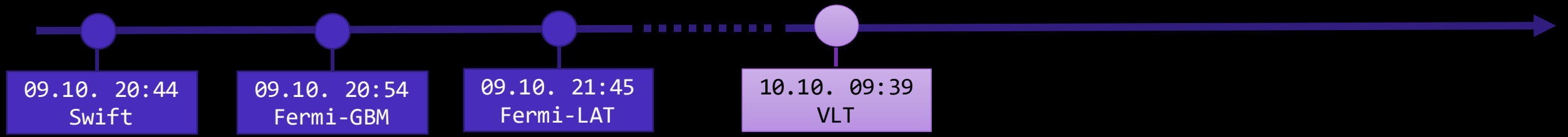
[R21]

What astronomers saw



[R21]

What astronomers saw

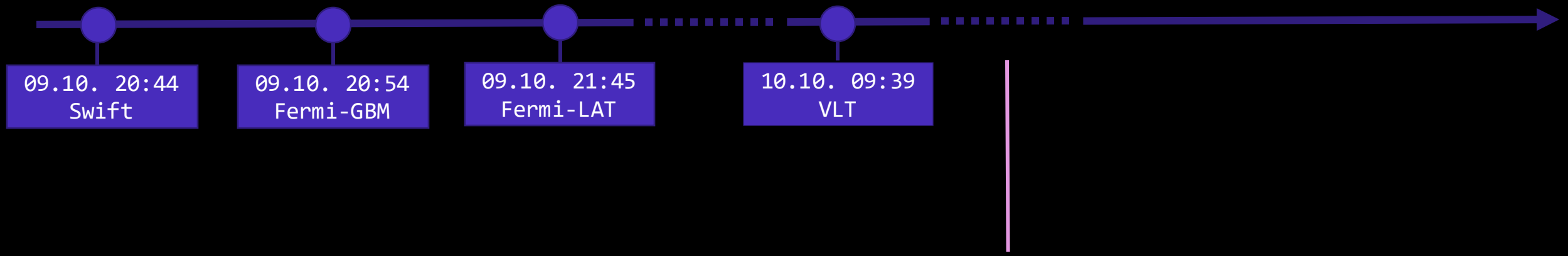


z = 0.151 : Light travel time of 2 10^9 years!

```
////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  32648
SUBJECT: GRB 221009A: Redshift from X-shooter/VLT
DATE:    22/10/10 09:39:41 GMT
FROM:    Antonio de Ugarte Postigo at OCA  <deugarte@oca.eu>

We detect a very red continuum with absorption features that
correspond to CaII, CaI and NaID at a redshift of z = 0.151. We
also detect multiple features due to the Milky Way's interstellar
medium, due to the large Galactic column density of material
along this line of sight. At this redshift the event has an isotropic
equivalent energy of Eiso=2x10^54 erg (using the GBM fluence
reported in GCN 32642), barring saturation effects in the
Fermi/GBM fluence. This is within the upper end of GRB
energetics. Further follow-up is strongly encouraged.
```

[R21]

What astronomers saw



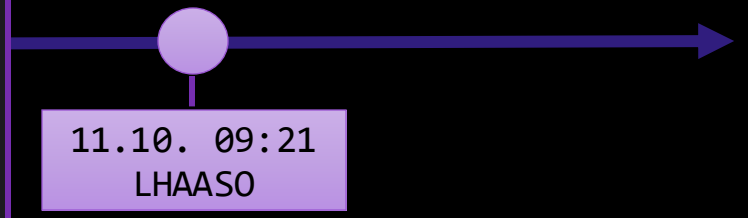
afterglow by other observatories

refined gamma-ray analysis

[R21]

What astronomers saw

```
////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  32677
SUBJECT: LHAASO observed GRB 221009A with more than 5000 VHE photons up to around 18 TeV
DATE:    22/10/11 09:21:54 GMT
FROM:    Judith Racusin at GSFC  <judith.racusin@nasa.gov>

Yong Huang, Shicong Hu, Songzhan Chen,  Min Zha, Cheng Liu, Zhiguo Yao and
Zhen Cao report on behalf of the LHAASO experiment

We report the observation of GRB 221009A, which was detected by Swift (Kennea
et al. GCN #32635), Fermi-GBM (Veres et al. GCN #32636, Lesage et al. GCN #32642),
Fermi-LAT (Bissaldi et al. GCN #32637), IPN (Svinkin et al. GCN #32641) and so on.

GRB 221009A is detected by LHAASO-WCDA at energy above 500 GeV, centered at
RA = 288.3, Dec = 19.7 within 2000 seconds after T0, with the significance above
100 s.d., and is observed as well by LHAASO-KM2A with the significance about 10 s.d.,
where the energy of the highest photon reaches 18 TeV.

This represents the first detection of photons above 10 TeV from GRBs.

The LHAASO is a multi-purpose experiment for gamma-ray astronomy (in the energy
band between 10^11 and 10^15 eV) and cosmic ray measurements.
```



[R21]

What astronomers saw

09.10. 20:44
Swift

09.10. 20:54
Fermi-GBM

09.10. 21:45
Fermi-LAT

10.10. 09:39
VLT

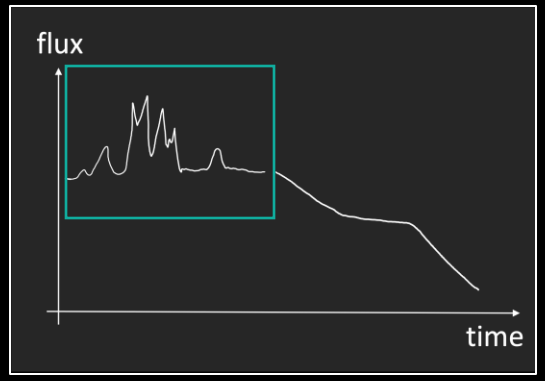
11.10. 09:21
LHAASO

Continued monitoring, refined analysis

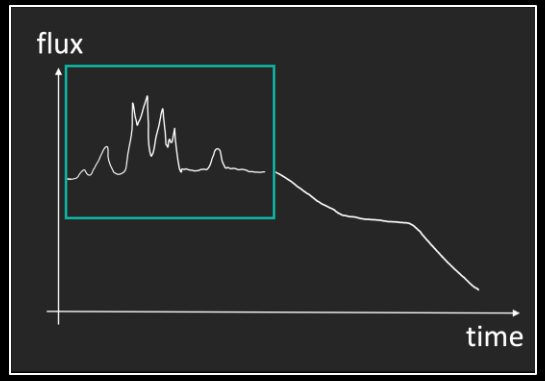
afterglow observations still ongoing

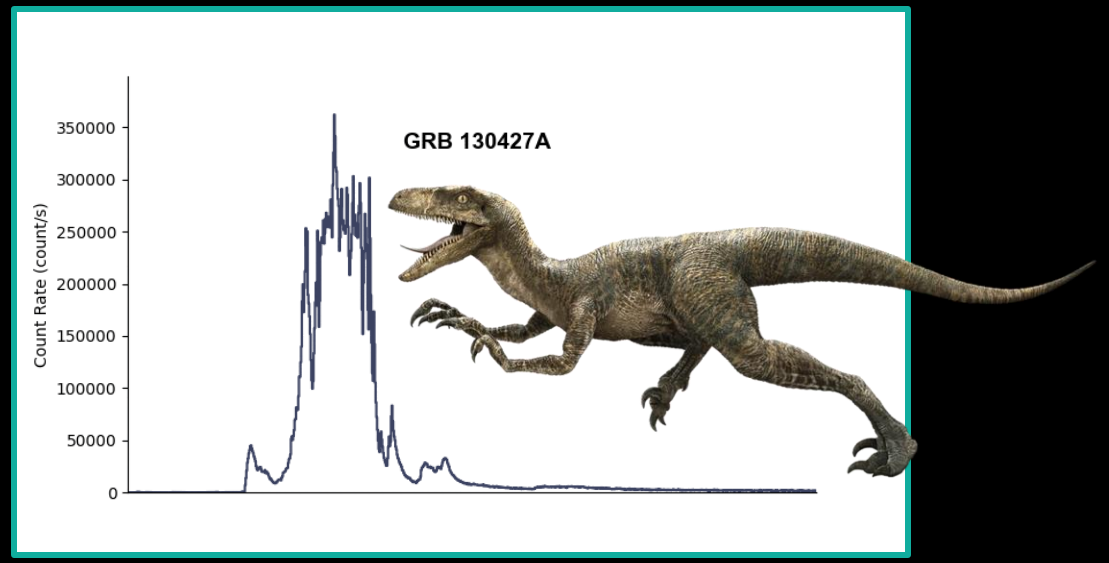
"Brightest Of All Time"

So how BOAT-y was it, really?



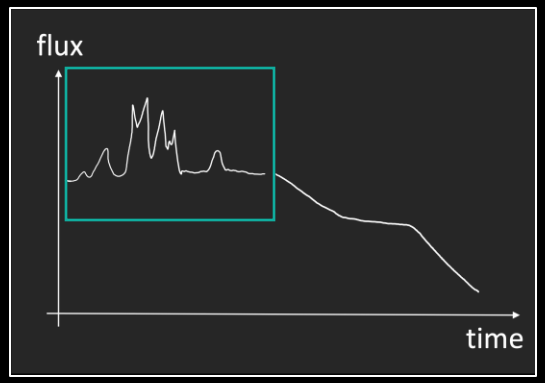
So how BOAT-y was it, really?

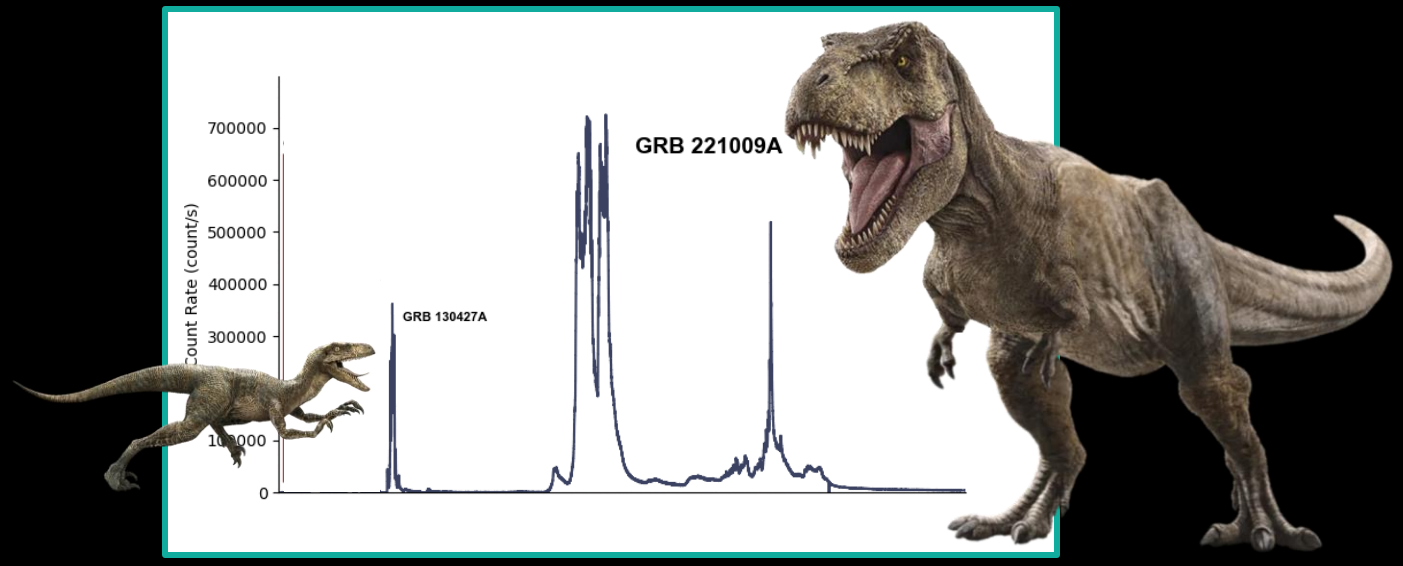




the previous record breaker [IM36]

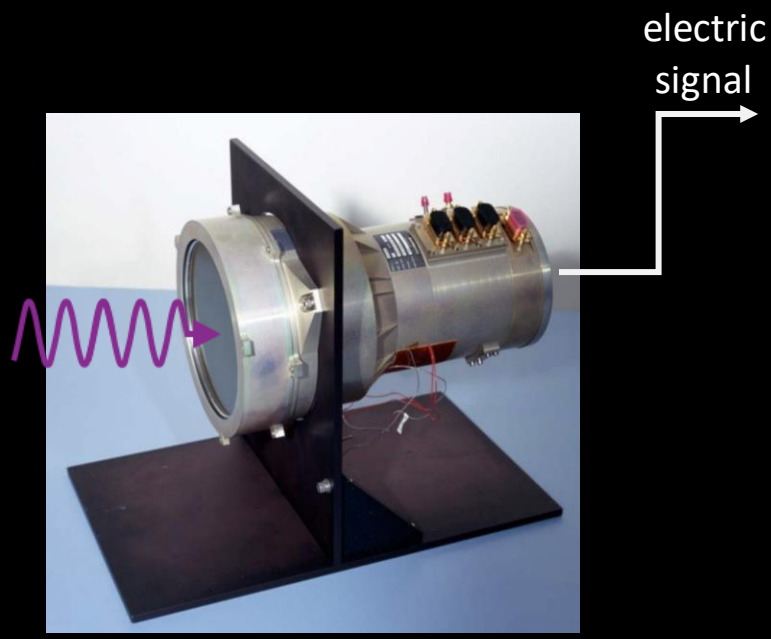
So how BOAT-y was it, really?



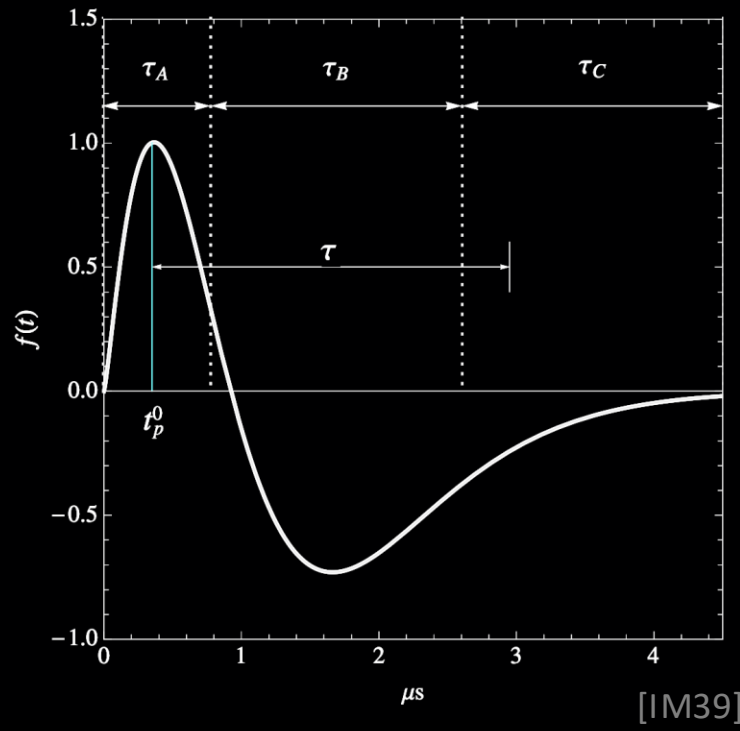


the BOAT [IM37]

A little *too* BOAT-y ...



[IM40]

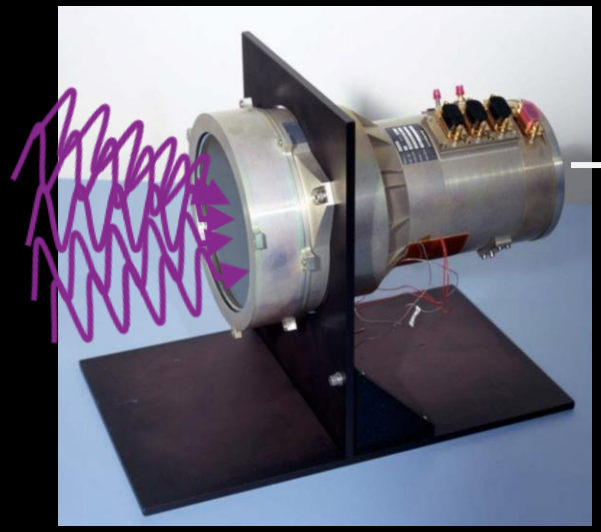


[IM39]

For a single gamma ray, the electric signal has a particular pulse shape depending on the photon's energy

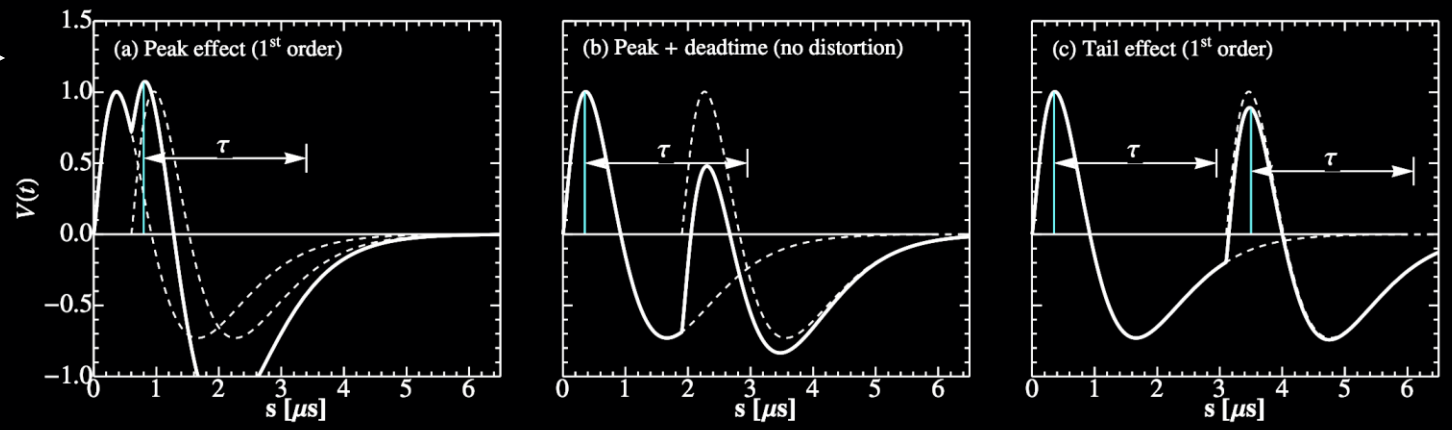
[R22]

A little *too* BOAT-y …



[IM40]

electric signal

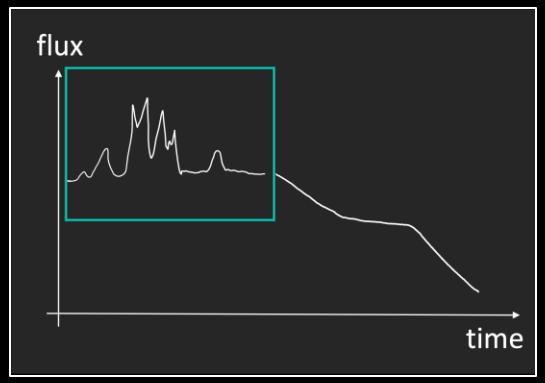


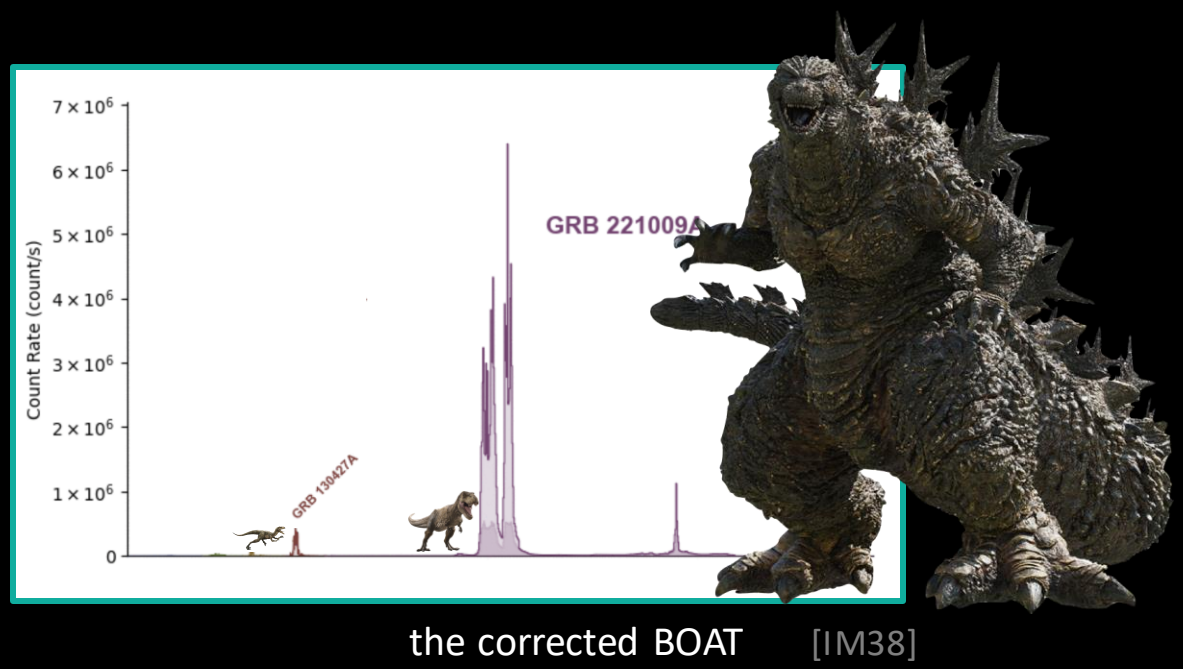
[IM39]

When the photon rate is too high, multiple photons hit before a single pulse can be read out

[R22]

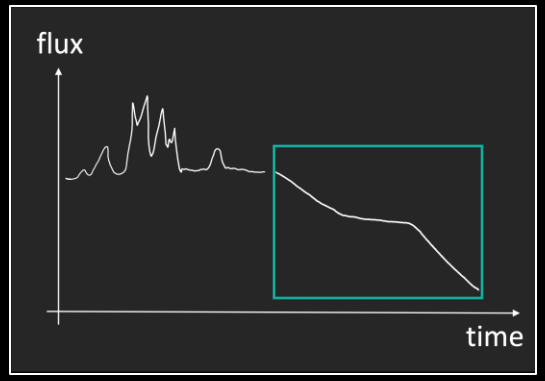
So how BOAT-y was it, really?

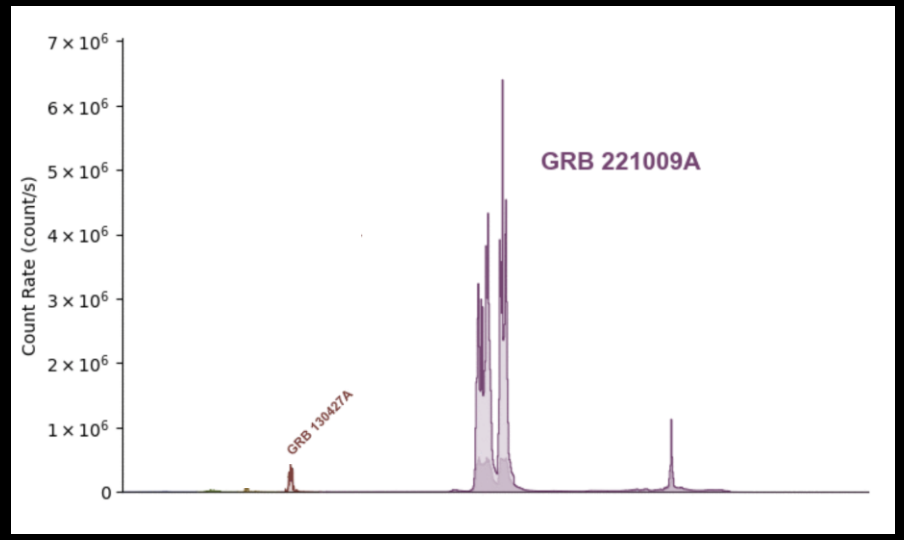




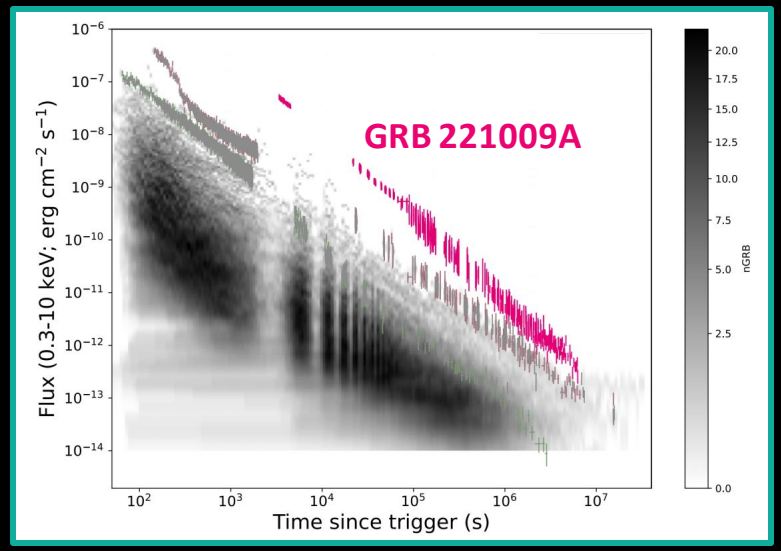
the corrected BOAT [IM38]

So how BOAT-y was it, really?





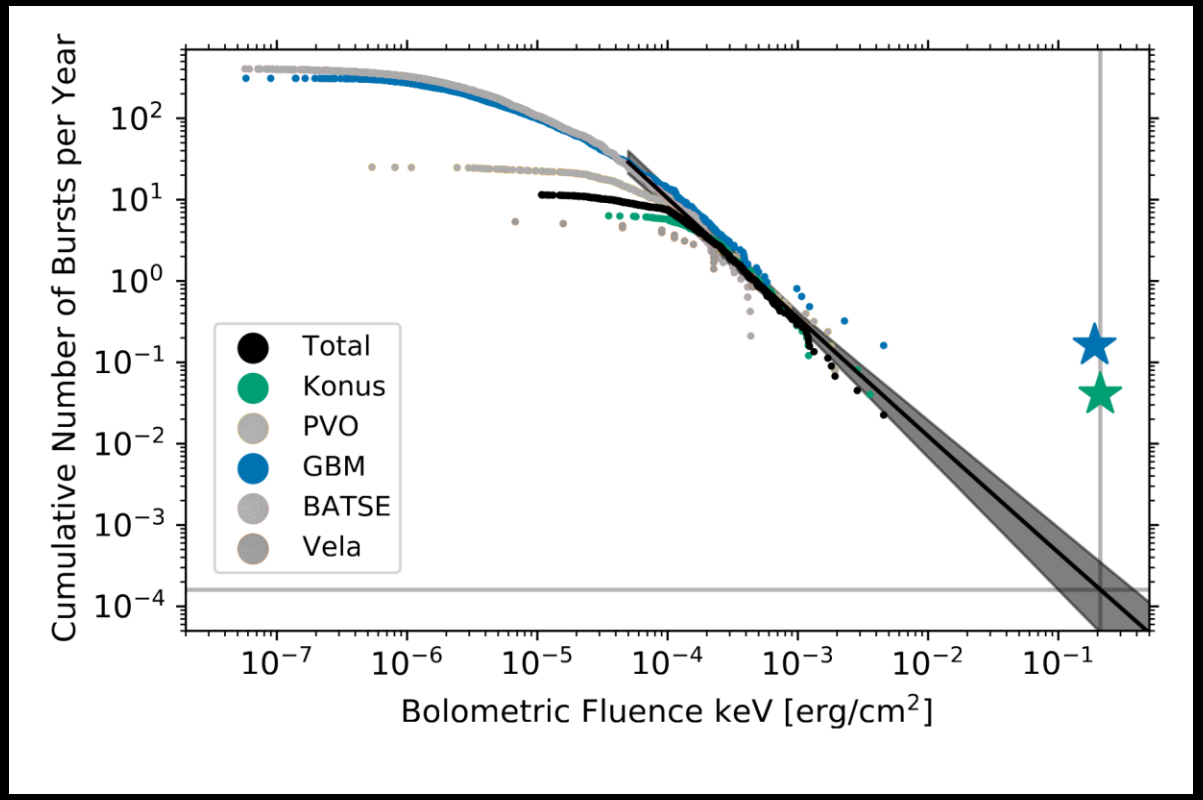
[IM38]



[IM41]

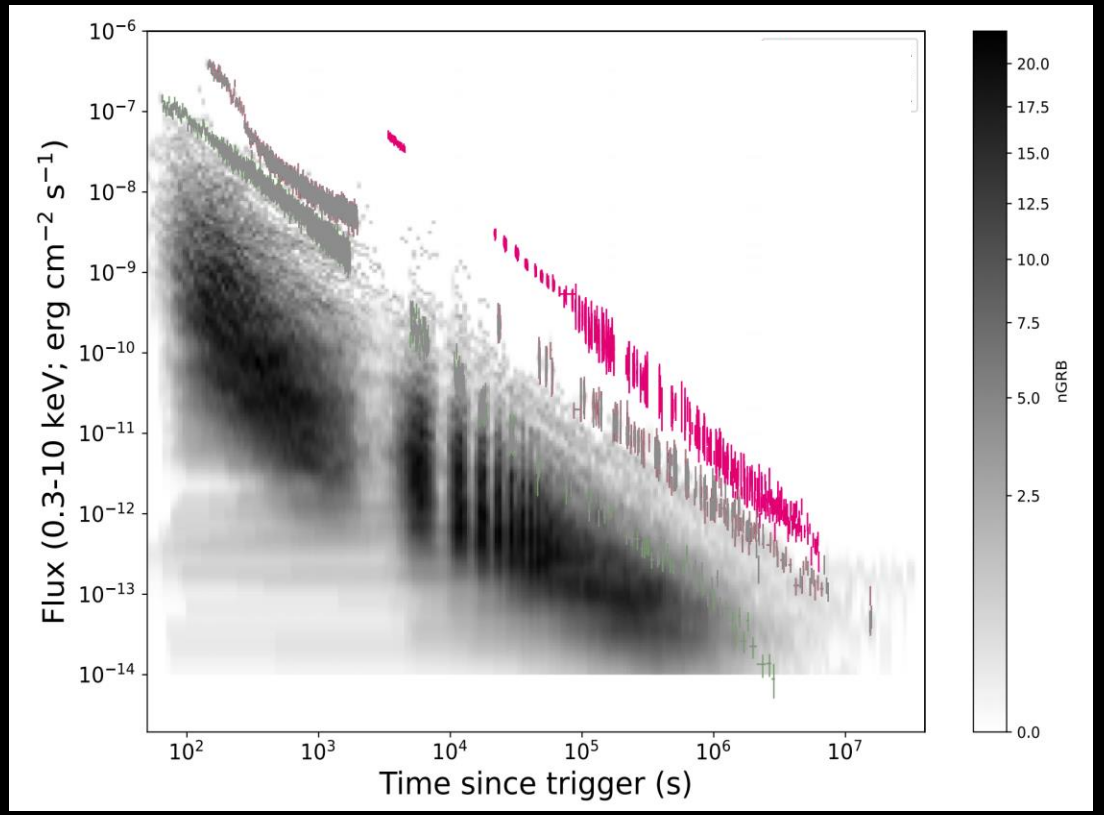
The BOAT in perspective

Prompt emission energy, at the detector



[IM42,R23]

Afterglow energy, at the detector

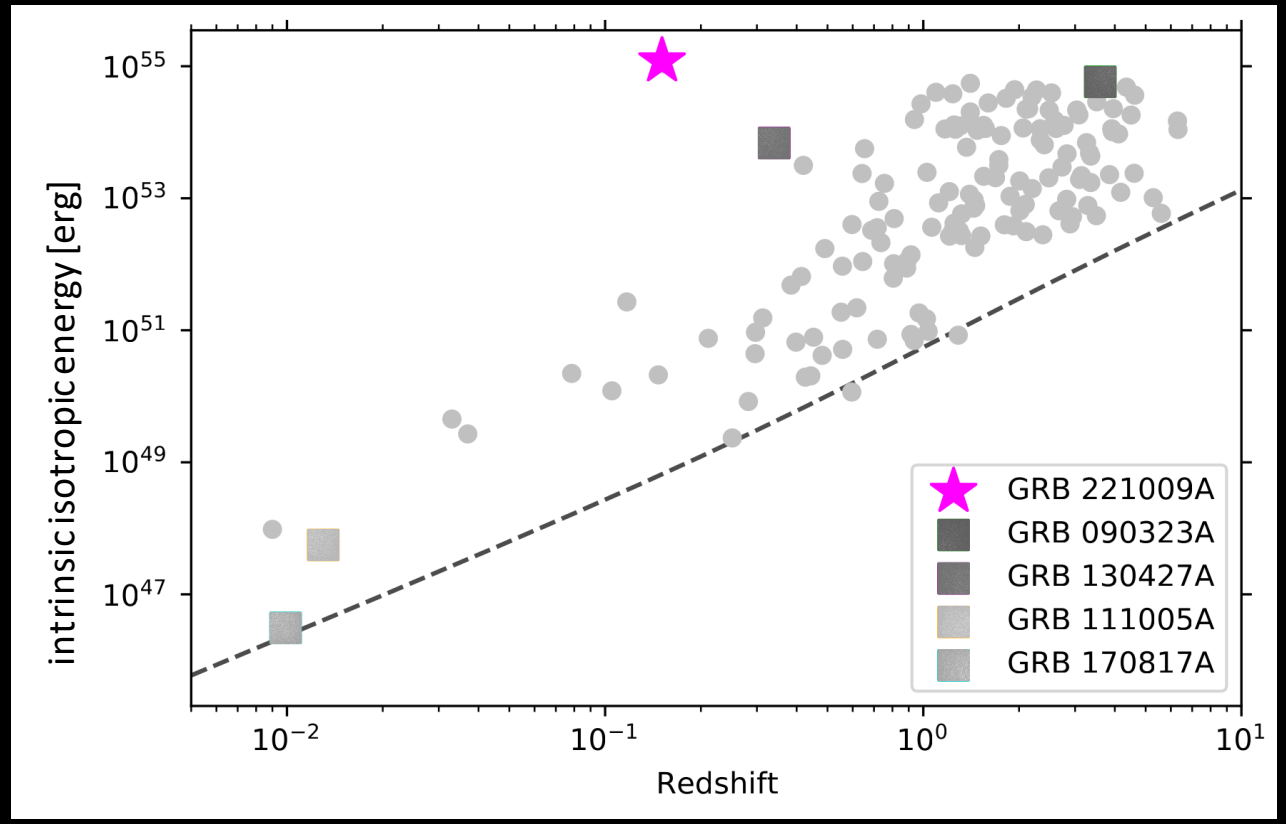


[IM41,R24]

"once in 10.000-year event"

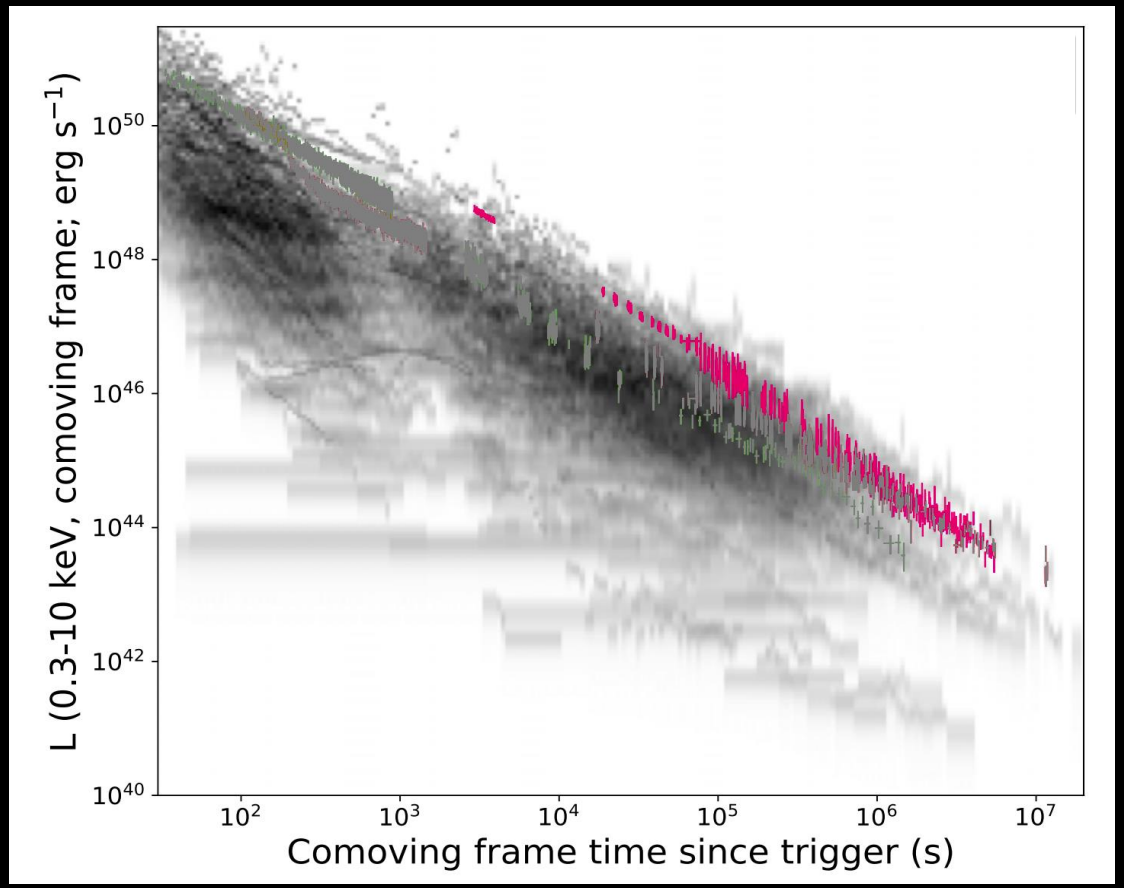
The BOAT in perspective

Prompt phase energy



[IM43,R23]

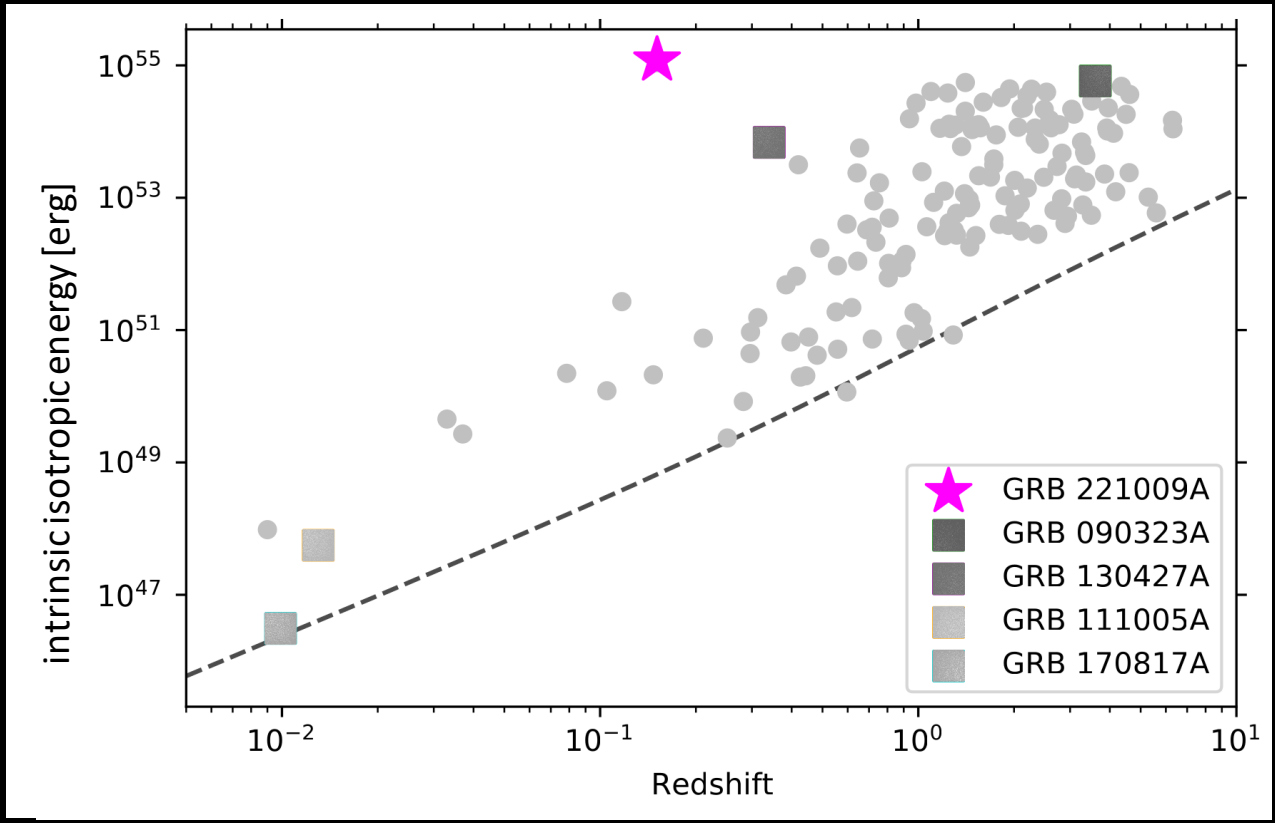
Afterglow



[IM44,R24]

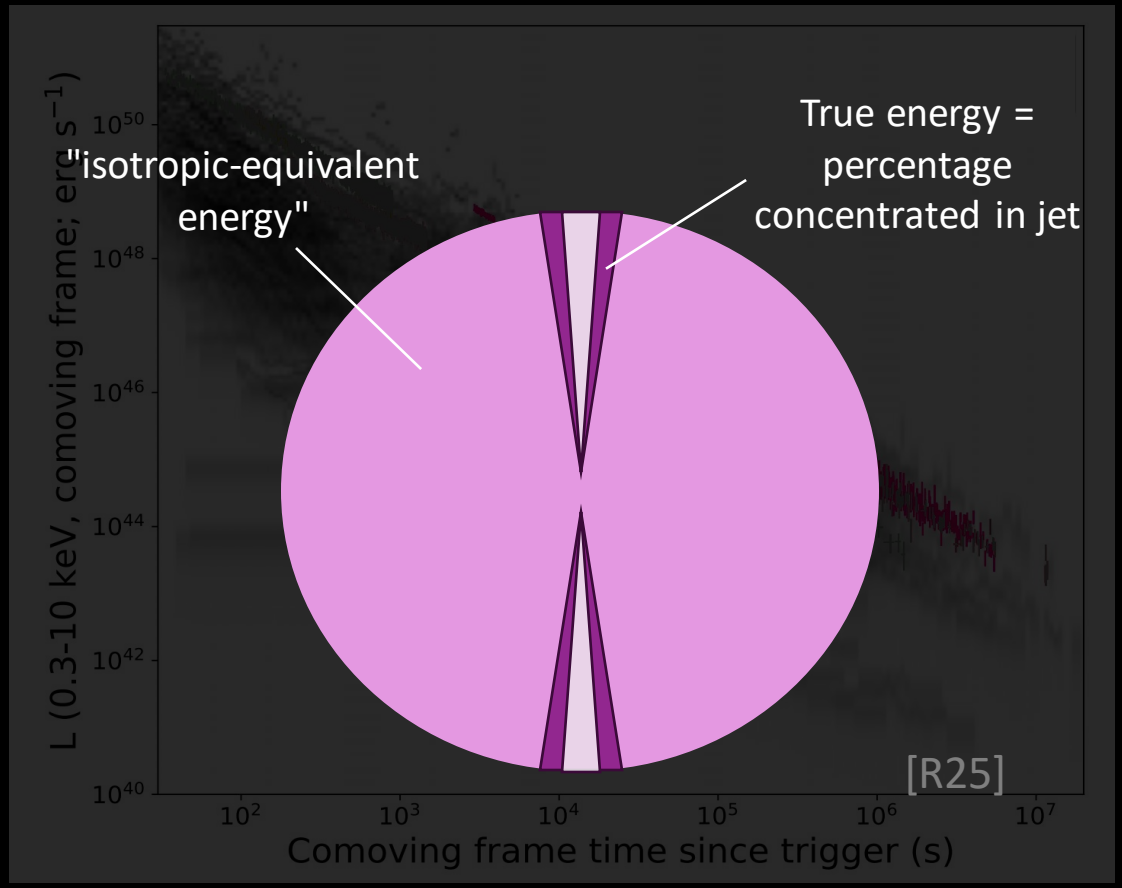
The BOAT in perspective

Prompt phase energy



[IM43,R23]

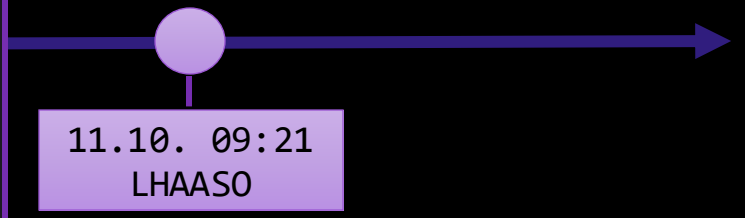
Afterglow



[R21]

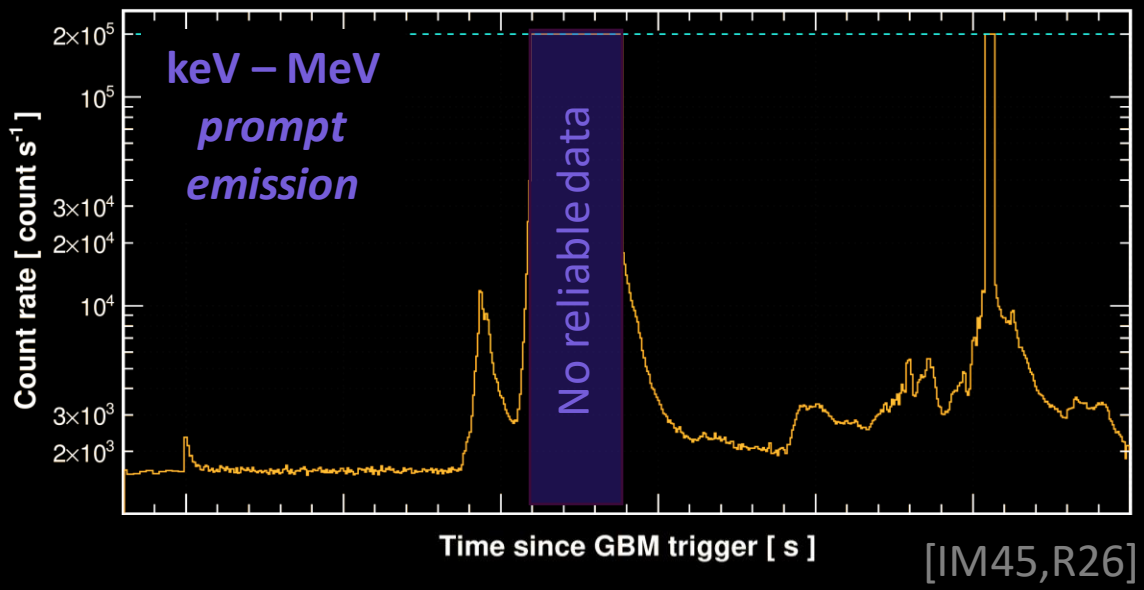
The most surprising announcement

```
////////////////////////////////////////////////////////////////////////
TITLE:   GCN CIRCULAR
NUMBER:  32677
SUBJECT: LHAASO observed GRB 221009A with more than 5000 VHE photons up to around 18 TeV
DATE:    22/10/11 09:21:54 GMT
FROM:    Judith Racusin at GSFC  <judith.racusin@nasa.gov>

Yong Huang, Shicong Hu, Songzhan Chen,  Min Zha, Cheng Liu, Zhiguo Yao and
Zhen Cao report on behalf of the LHAASO experiment

We report the observation of GRB 221009A, which was detected by Swift (Kennea
et al. GCN #32635), Fermi-GBM (Veres et al. GCN #32636, Lesage et al. GCN #32642),
Fermi-LAT (Bissaldi et al. GCN #32637), IPN (Svinkin et al. GCN #32641) and so on.

GRB 221009A is detected by LHAASO-WCDA at energy above 500 GeV, centered at
RA = 288.3, Dec = 19.7 within 2000 seconds after T0, with the significance above
100 s.d., and is observed as well by LHAASO-KM2A with the significance about 10 s.d.,
where the energy of the highest photon reaches 18 TeV.

This represents the first detection of photons above 10 TeV from GRBs.

The LHAASO is a multi-purpose experiment for gamma-ray astronomy (in the energy
band between 10^11 and 10^15 eV) and cosmic ray measurements.
```



[R26]

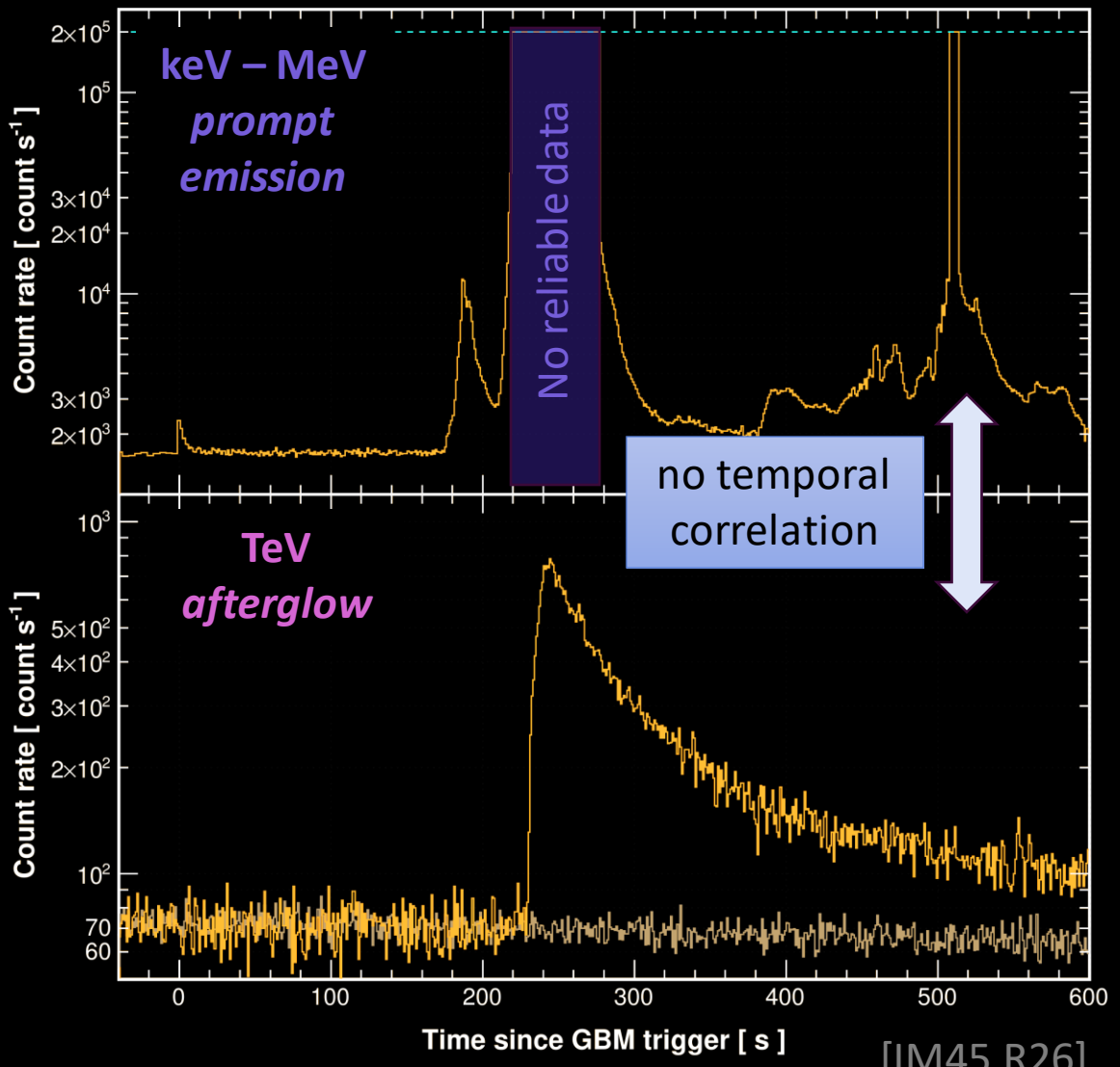
A clear TeV afterglow



[IM45,R26]

A "normal" GRB from a massive star collapse...
… with not the best data.

A clear TeV afterglow

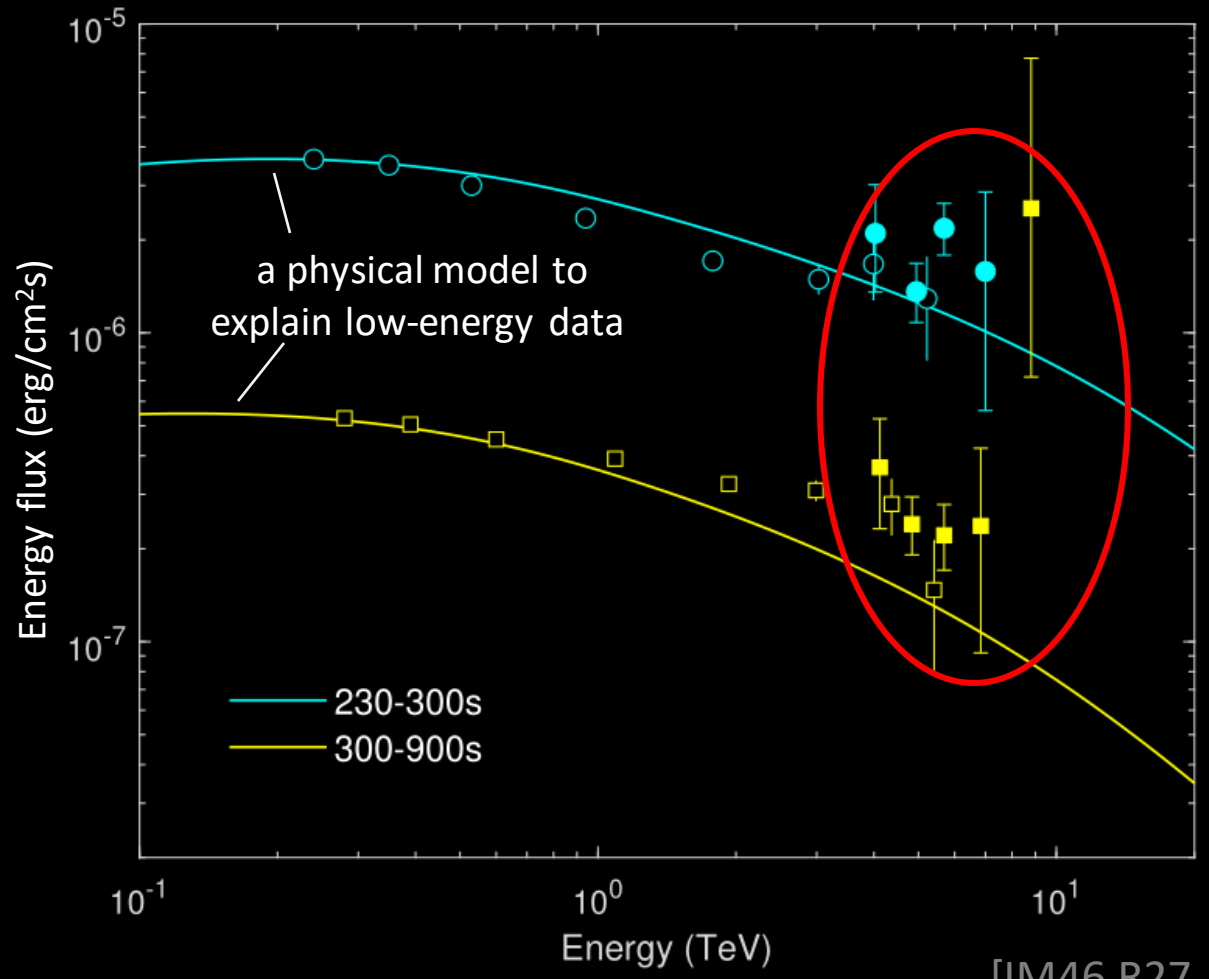


[IM45,R26]

A "normal" GRB from a massive star collapse...
... with not the best data.

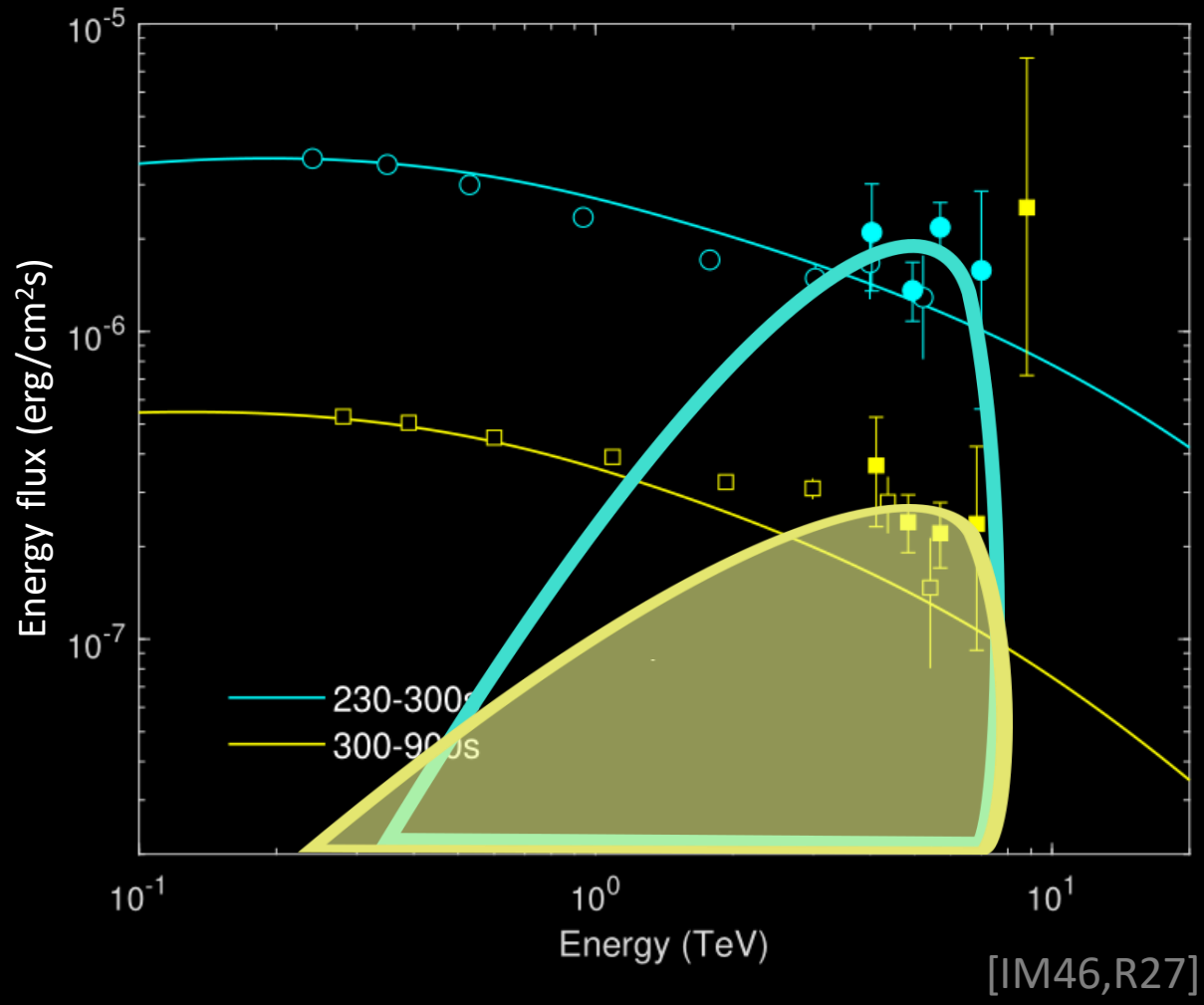
... but what about this pretty TeV afterglow?

Finding a model to explain the high-energy data



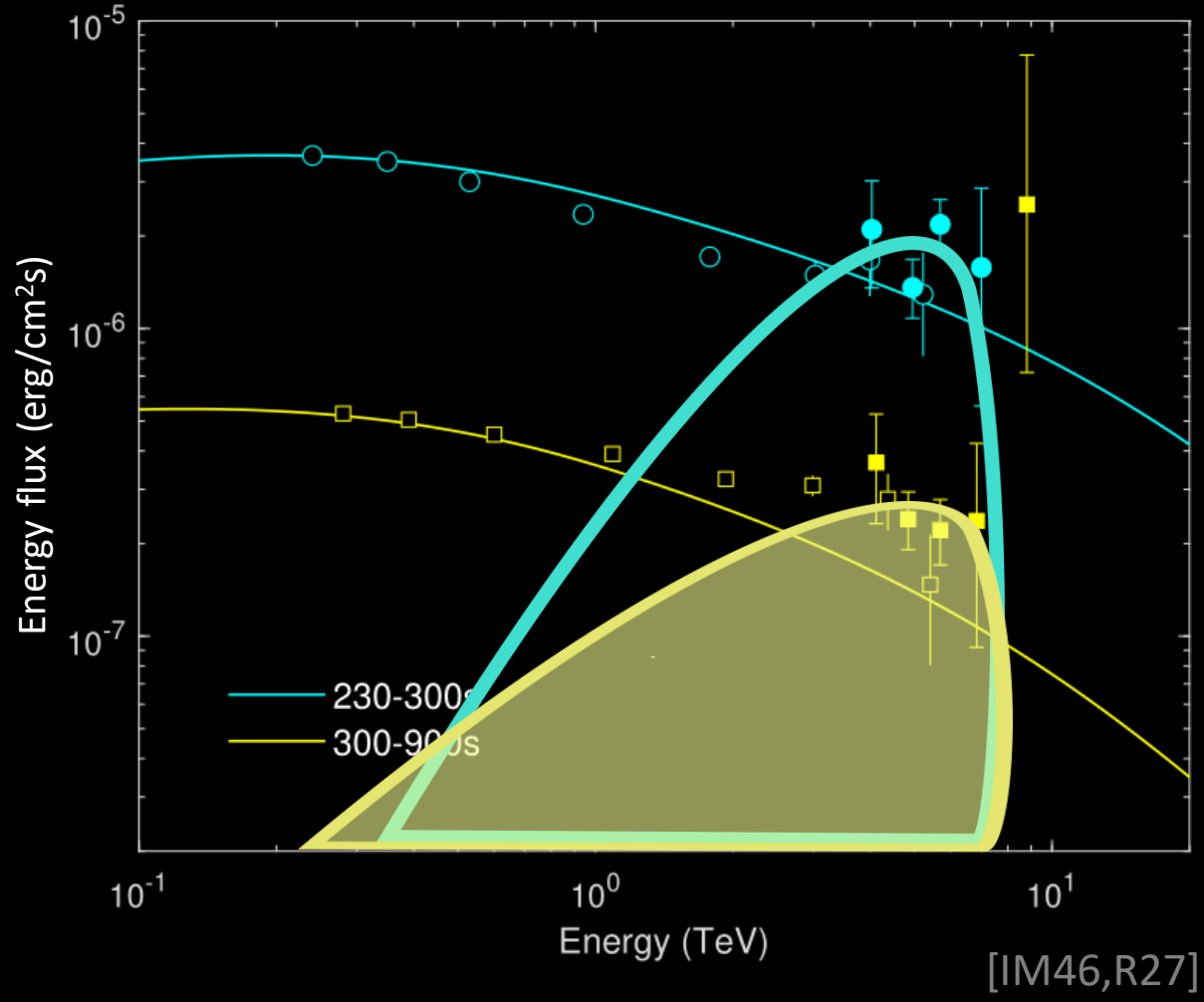
[IM46,R27
]

Finding a model to explain the high-energy data



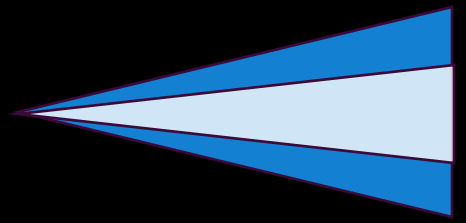
[IM46,R27]

Finding a model to explain the high-energy data



[IM46,R27]

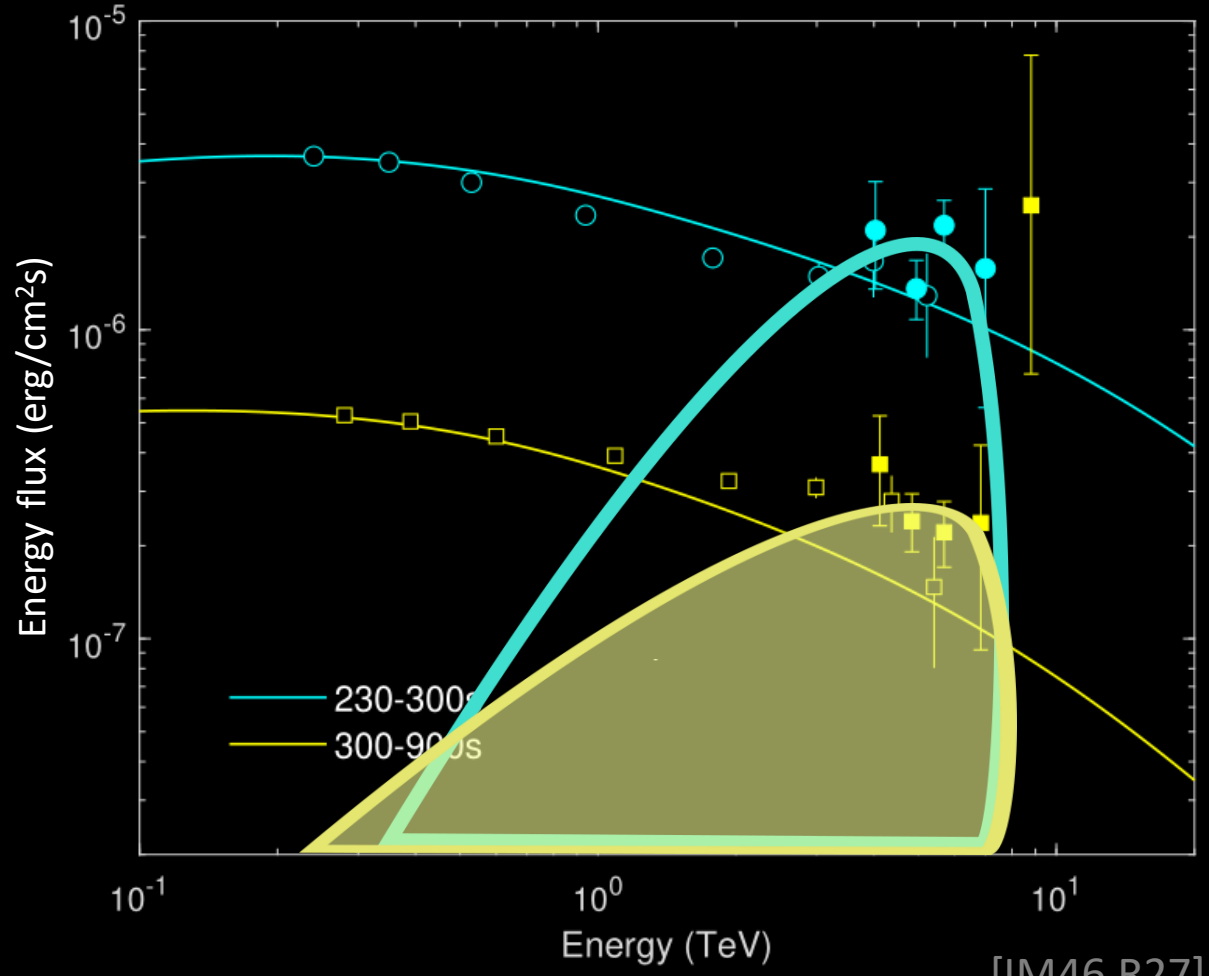
(A)



Increase model complexity

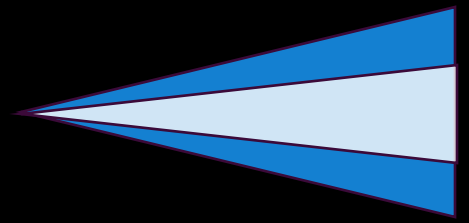
[R25]

Finding a model to explain the high-energy data



[IM46,R27]

(A)



Increase model complexity

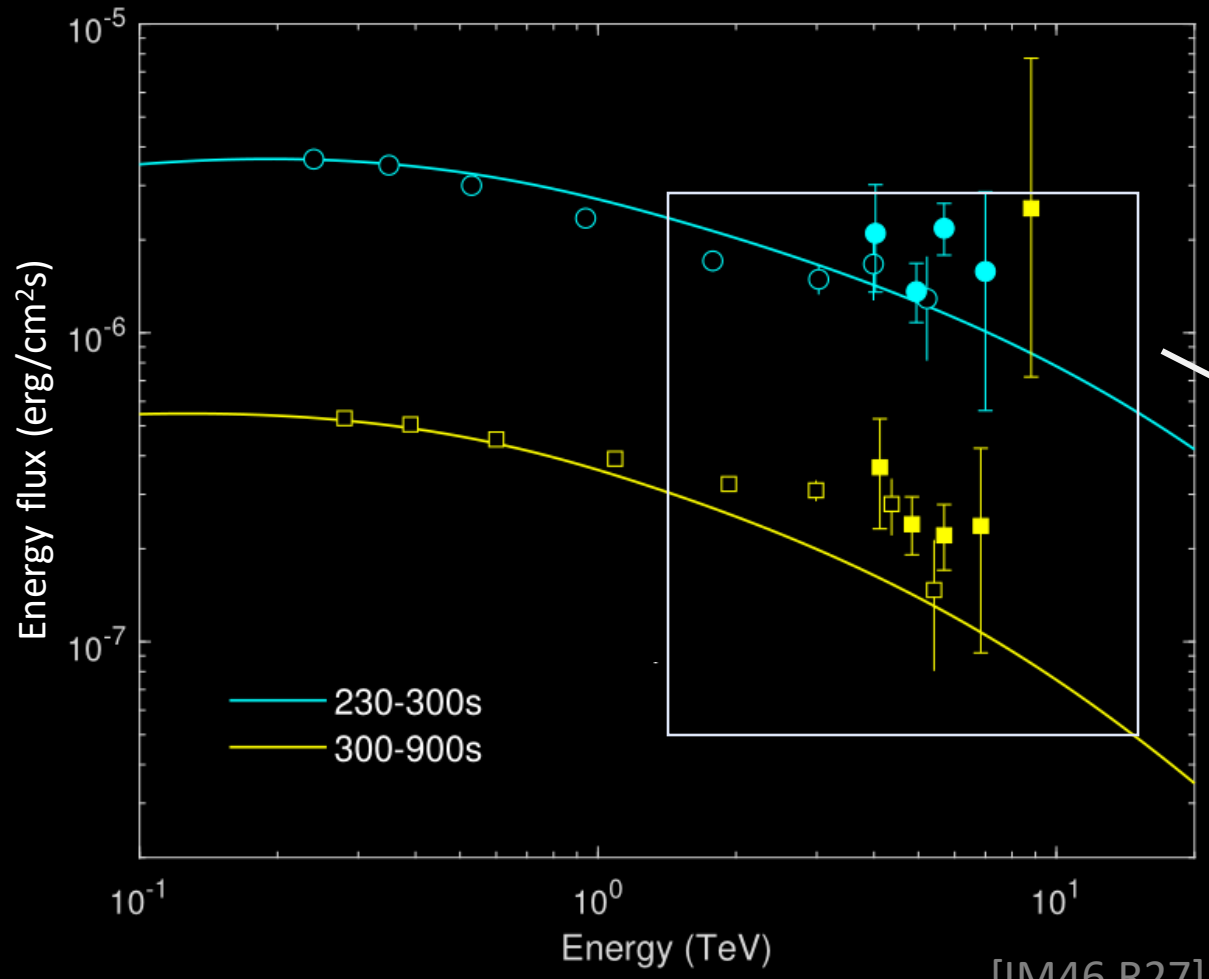
[R25]

(B)

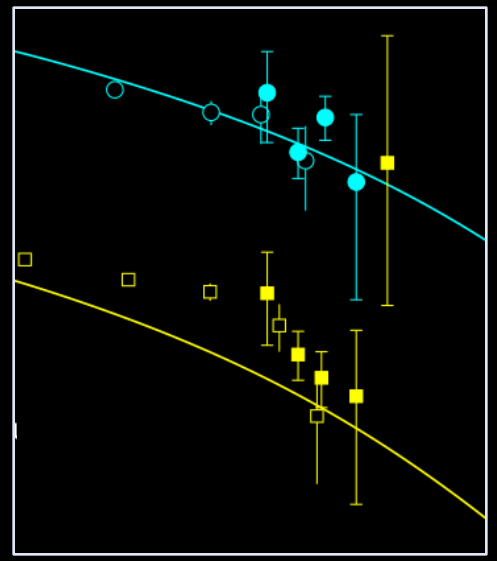
Exotic Physics

[R28]

Finding a model to explain the high-energy data



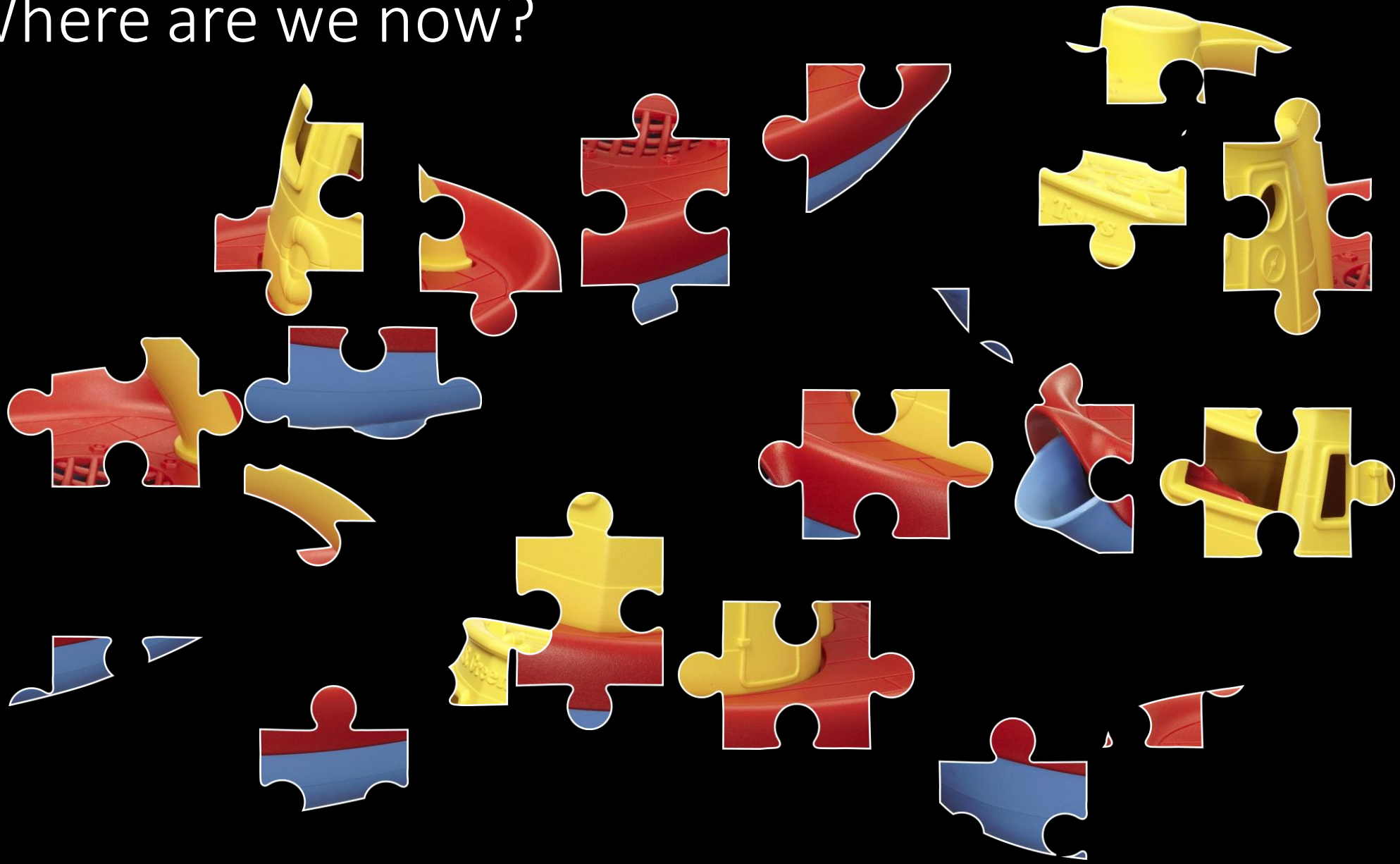
(C) Effects during propagation



[IM46,R27]

Where are we now?

Where are we now?



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