The electromagnetic afterglow of GW170817 a.k.a. GRB170817A

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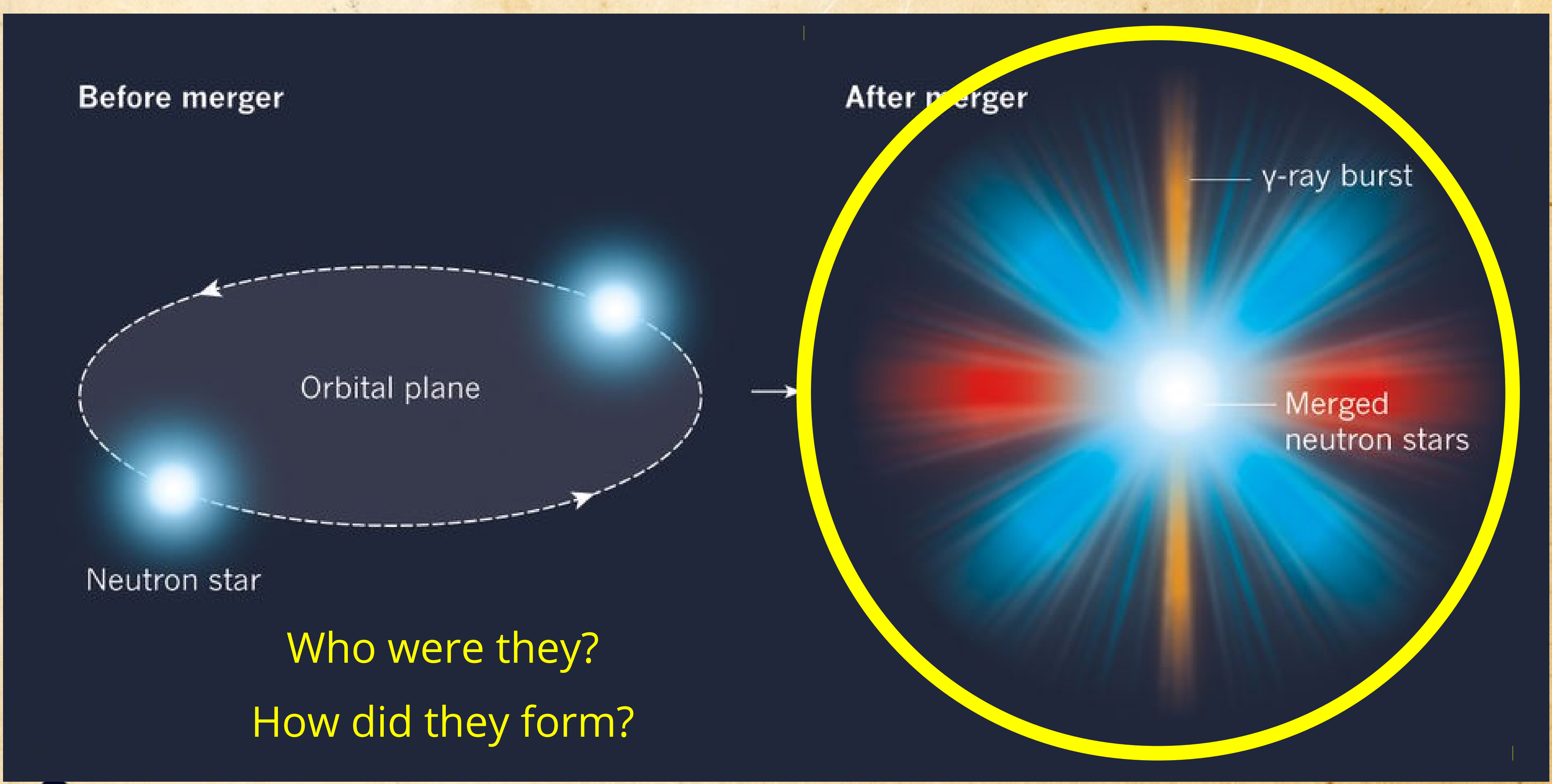
- EX LABORE FRUCTUS -

light from/over the...

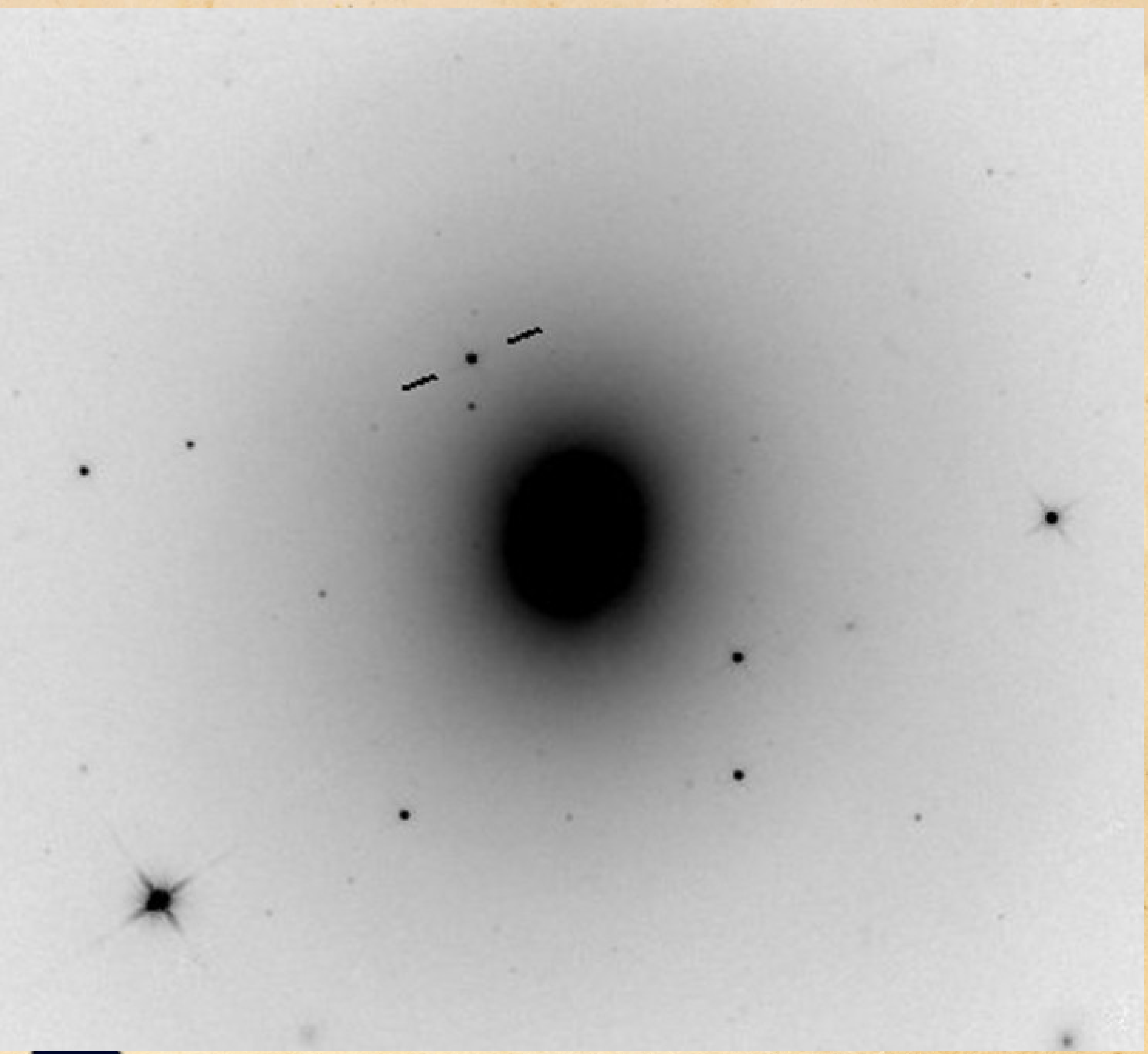
Binary Neutron Star Merger GW170817



Who were they?

How did they form?

In NGC 4993, some 130 million light-years (~40 Mpc) away from us



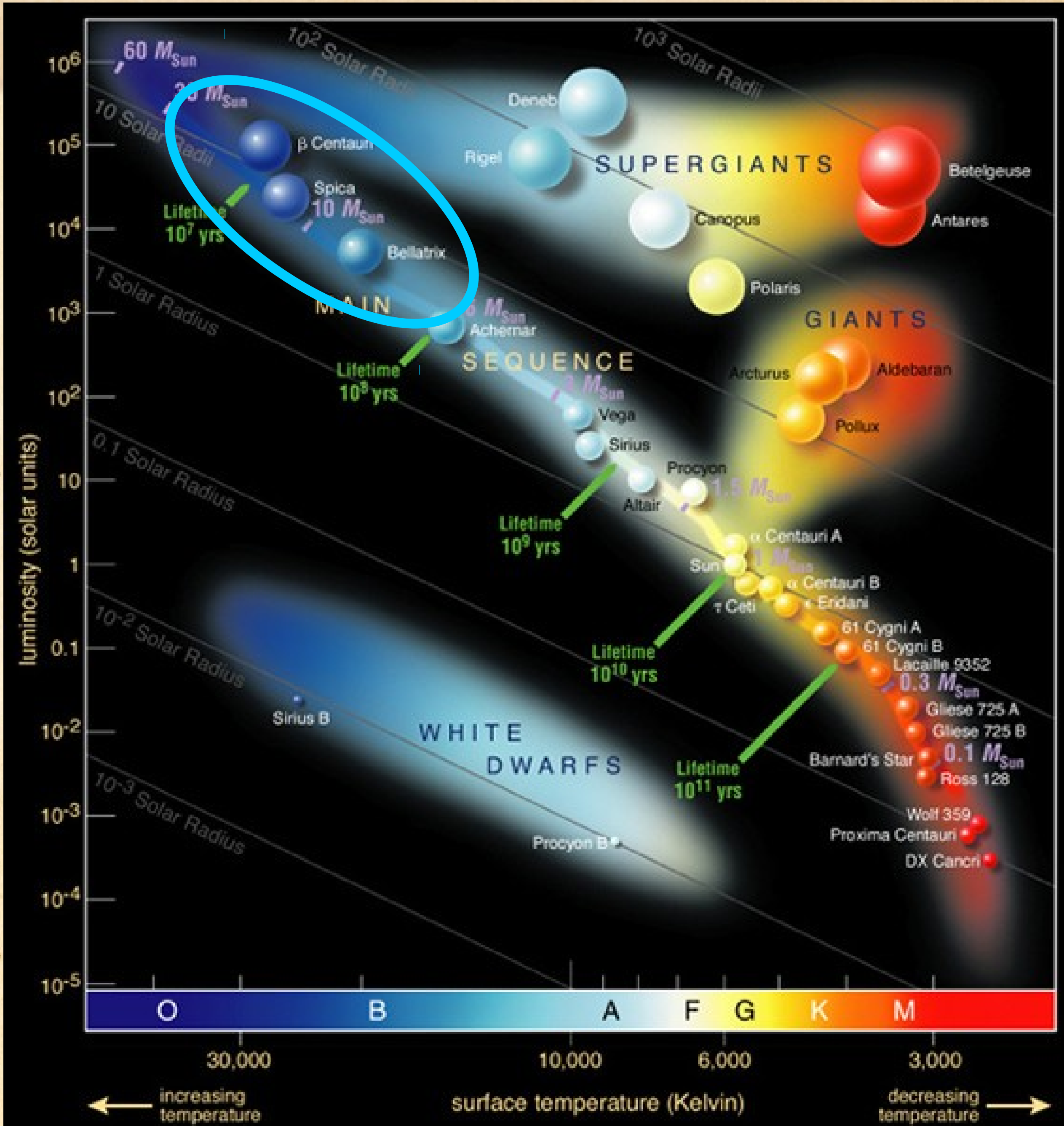
Low SFR= 0.01 $M_{sol}\,yr^{-1}$

$M_* = 10^{10.65}\ M_{sol}$

r_e=3.3 kpc

d=2.1 kpc

Once Upon a Time (~10^{10} y before…)

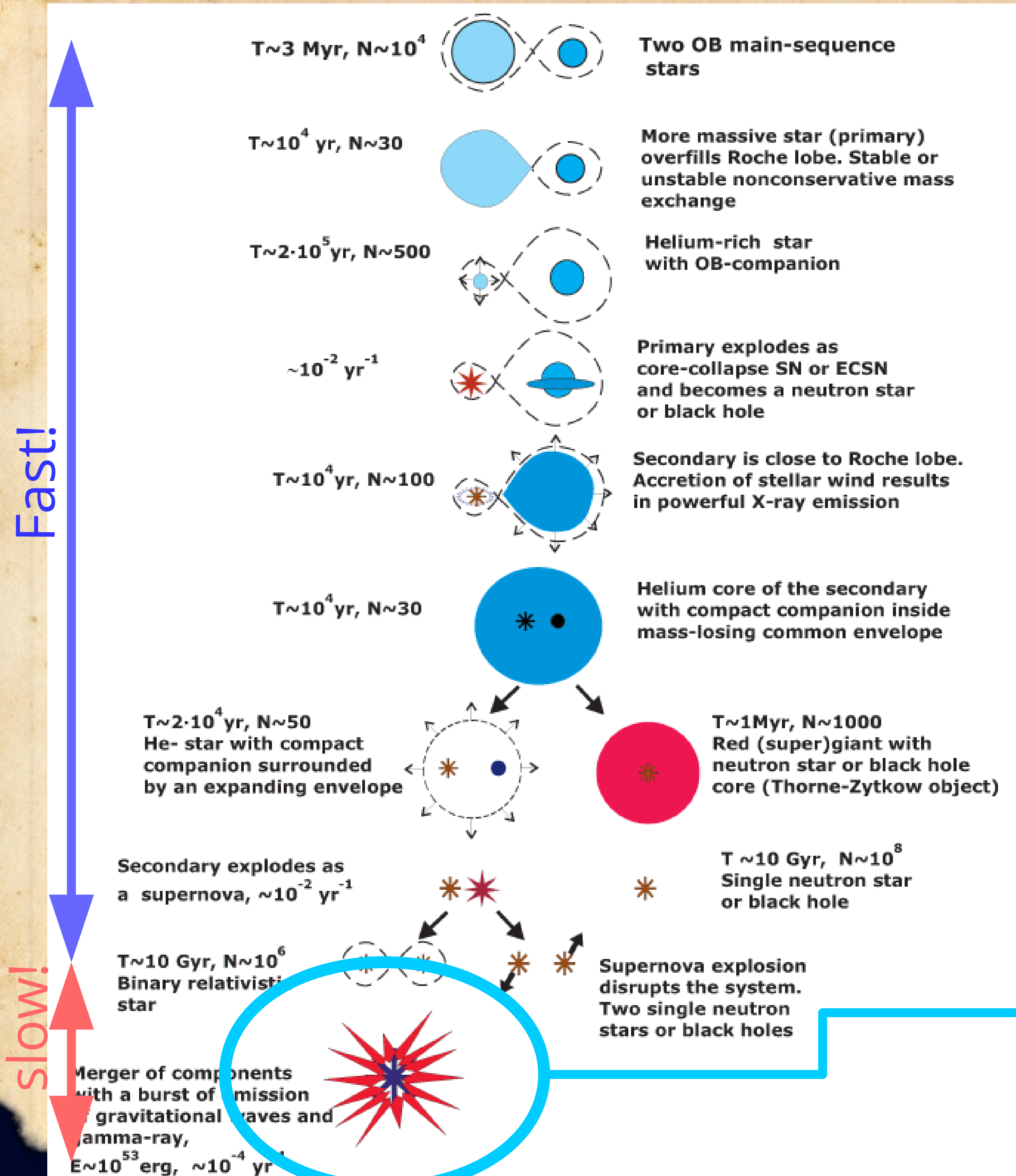


Born as massive stars

(between 8 and ~25 solar masses)

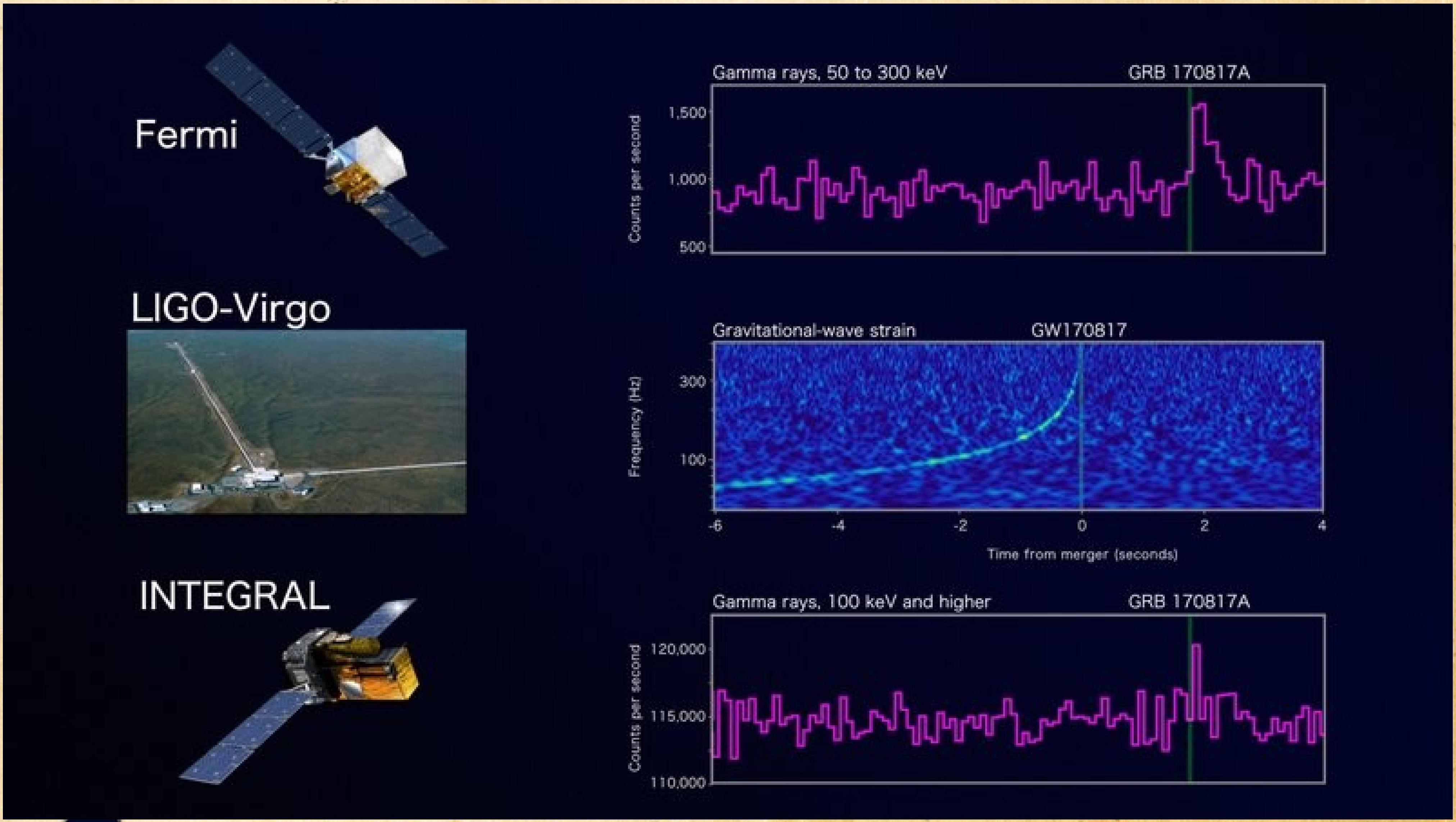
Binary NS formation

(Postnov+14)



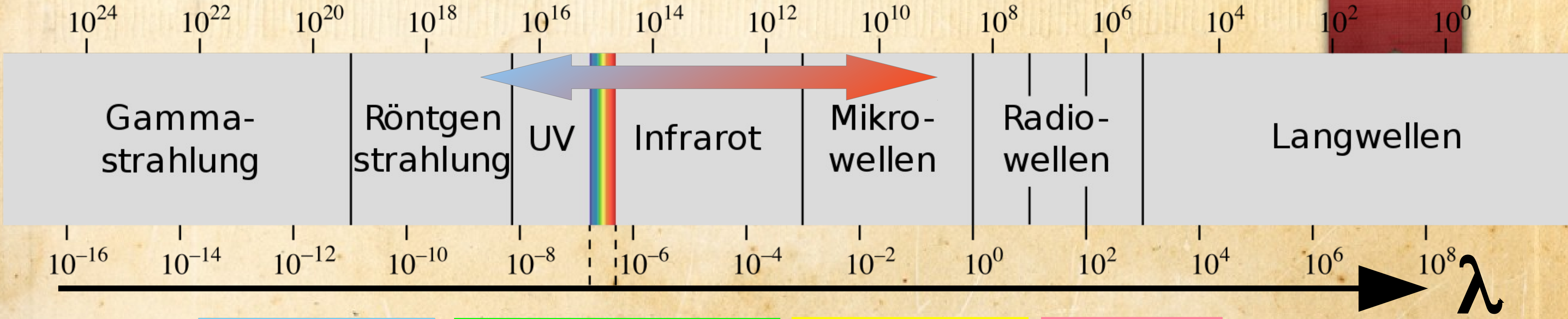
Our story begins here

A short gamma-ray burst at +1.7 s



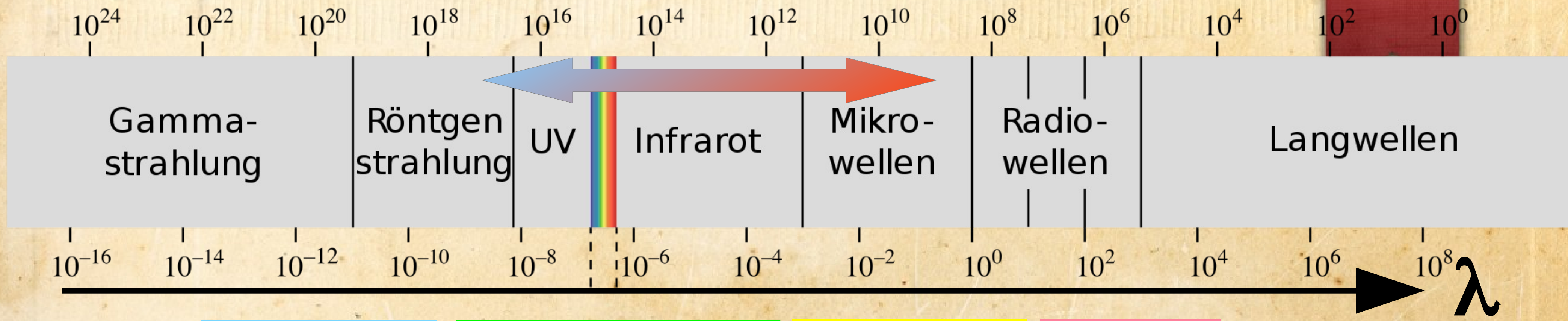
(LIGO+Virgo+gamma+17,ApJ)

e.m. follow-up: 9 decades across



X-ray **UV/Optical** **Near-IR** **Radio**

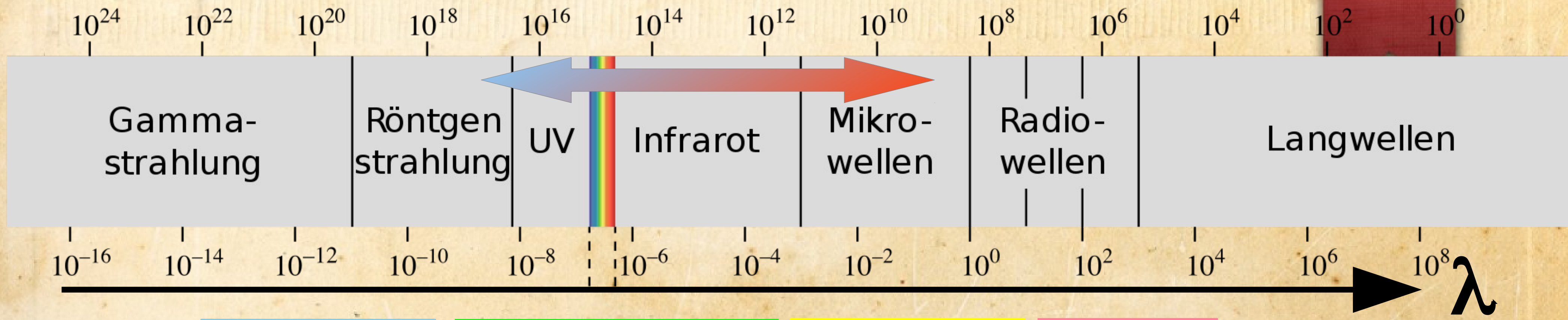
e.m. follow-up: 9 decades across



X-ray **UV/Optical** **Near-IR** **Radio**

Heavy element production
Host galaxy

e.m. follow-up: 9 decades across

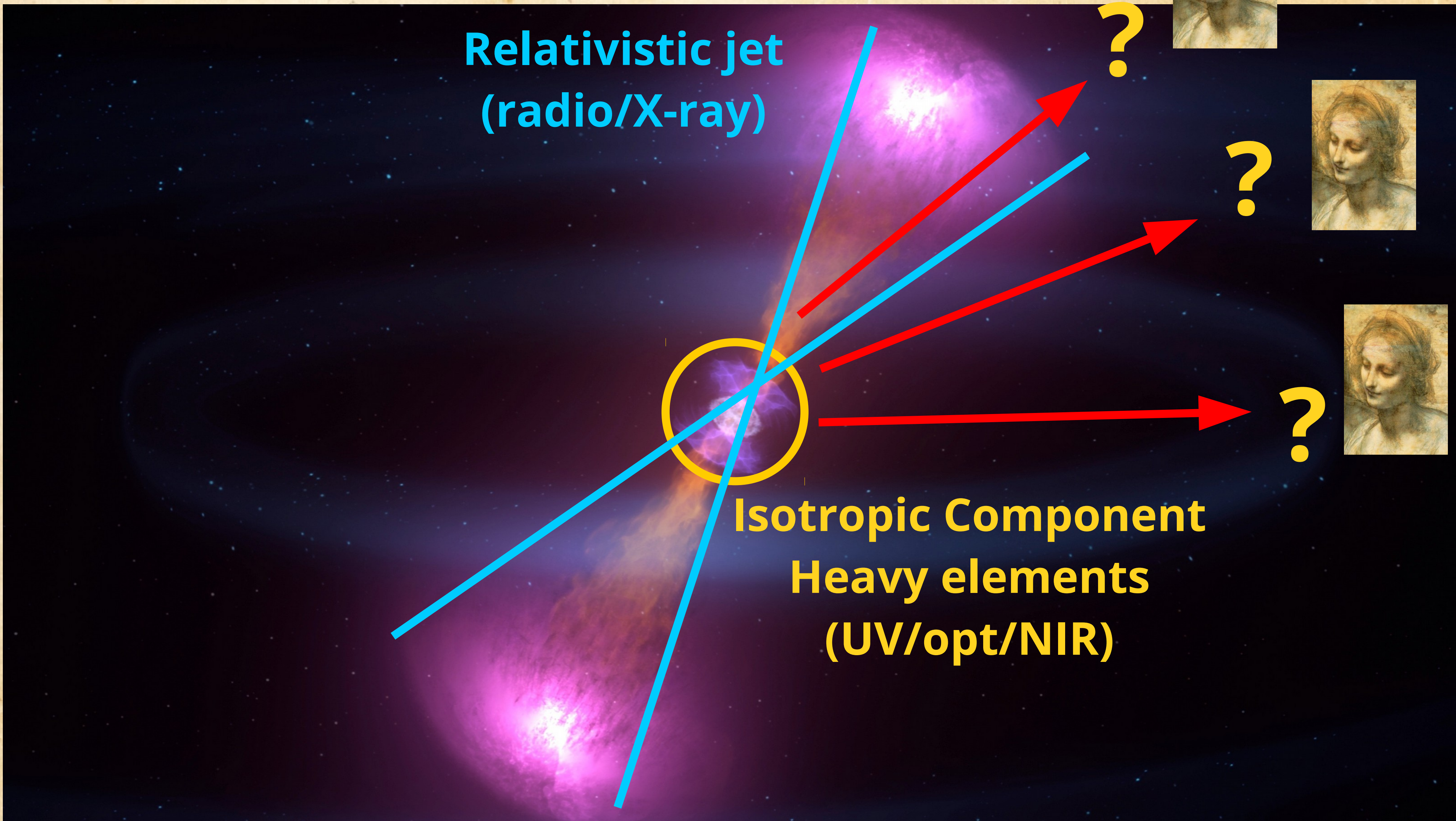


X-ray | **UV/Optical** | **Near-IR** | **Radio**

Heavy element production
Host galaxy

Relativistic outflow (collimation, geometry, kinetic energy, particle density)

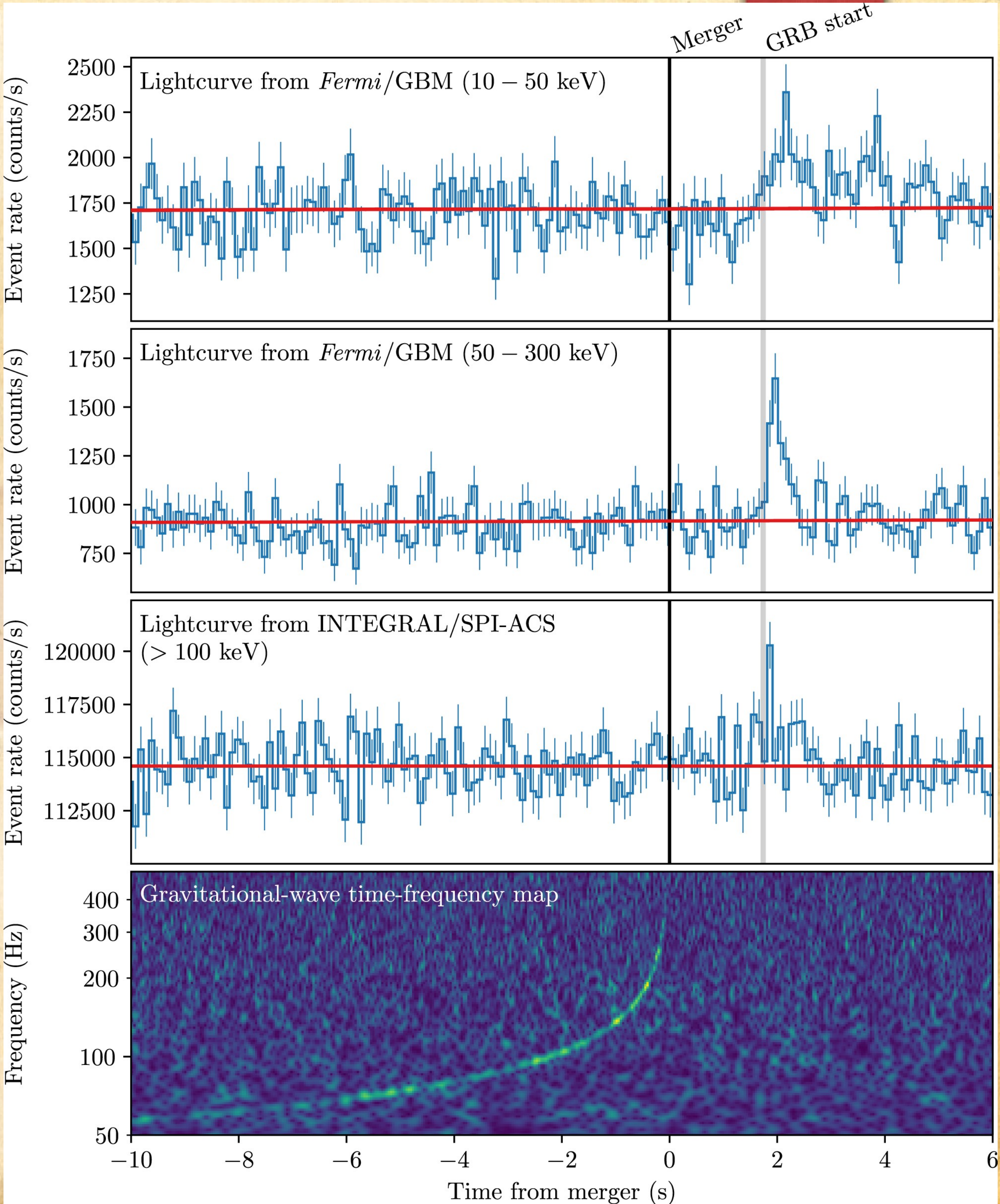
Picture to keep in mind



Witnessing the birth of multi-messenger astrophysics:

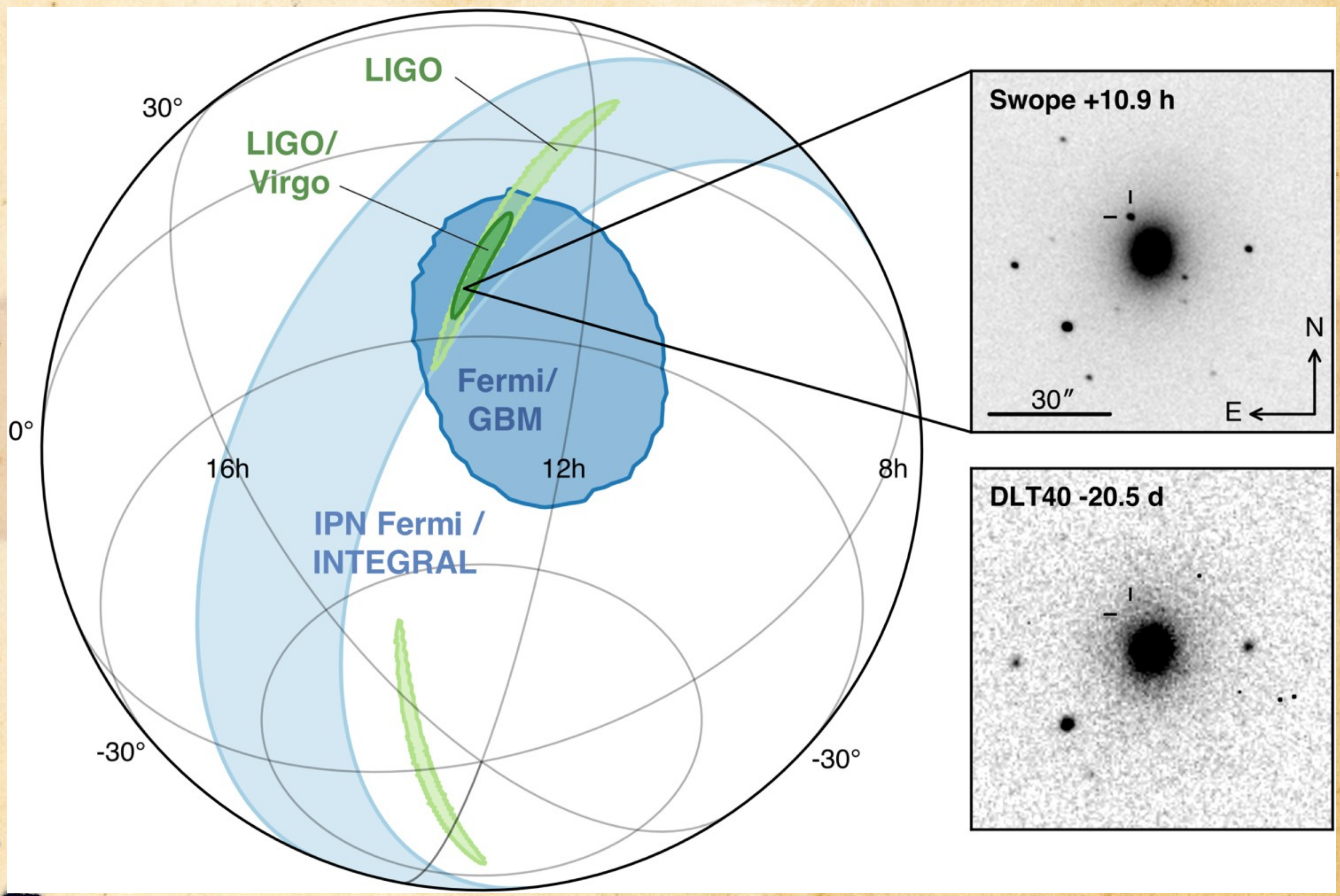
time-lapse of the e.m. counterpart discovery

A short GRB at +1.7 s



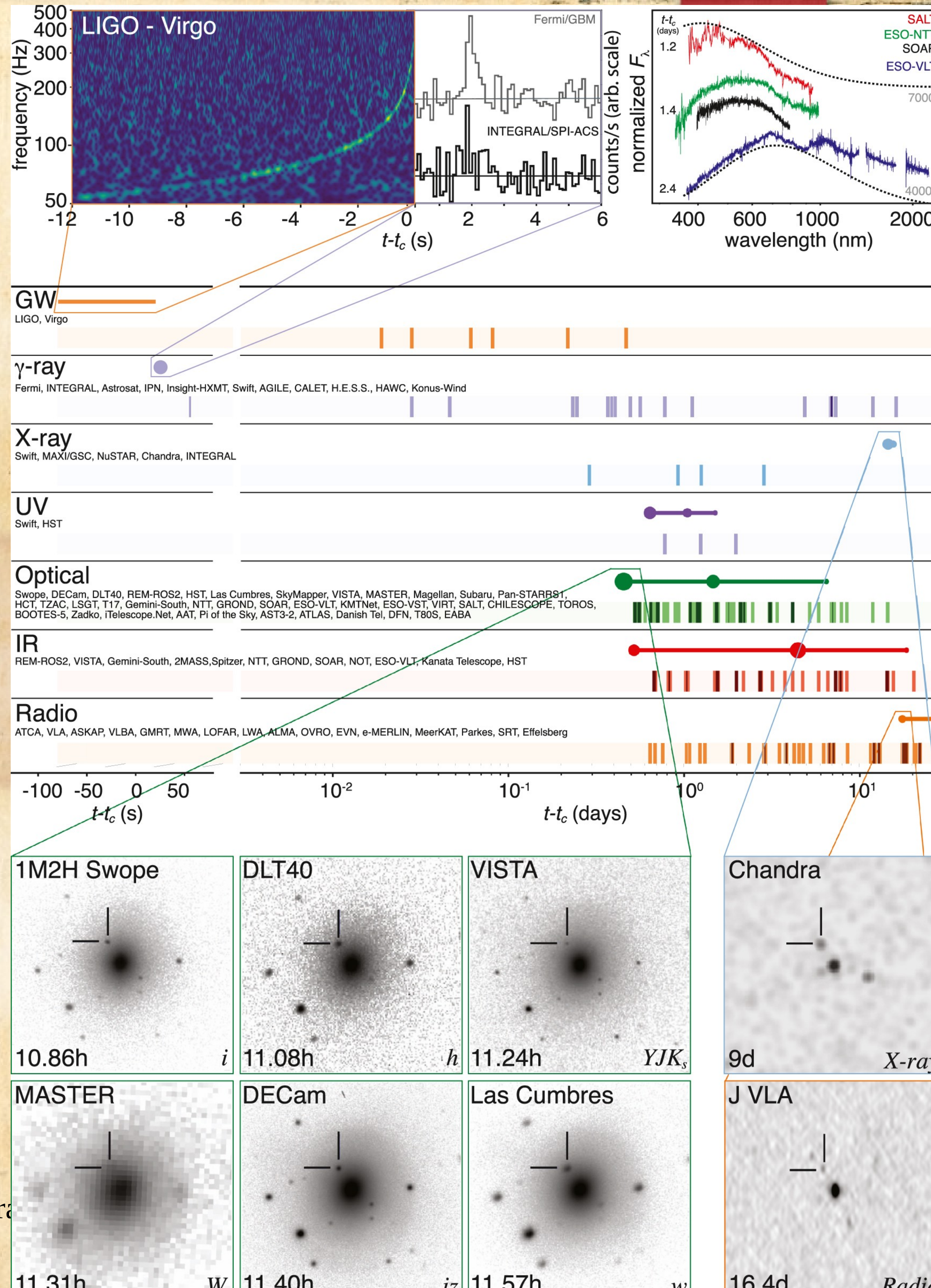
Nov 23, 2017
(LIGO+Virgo+gamma+17,ApJ)

e.m. counterpart discovery



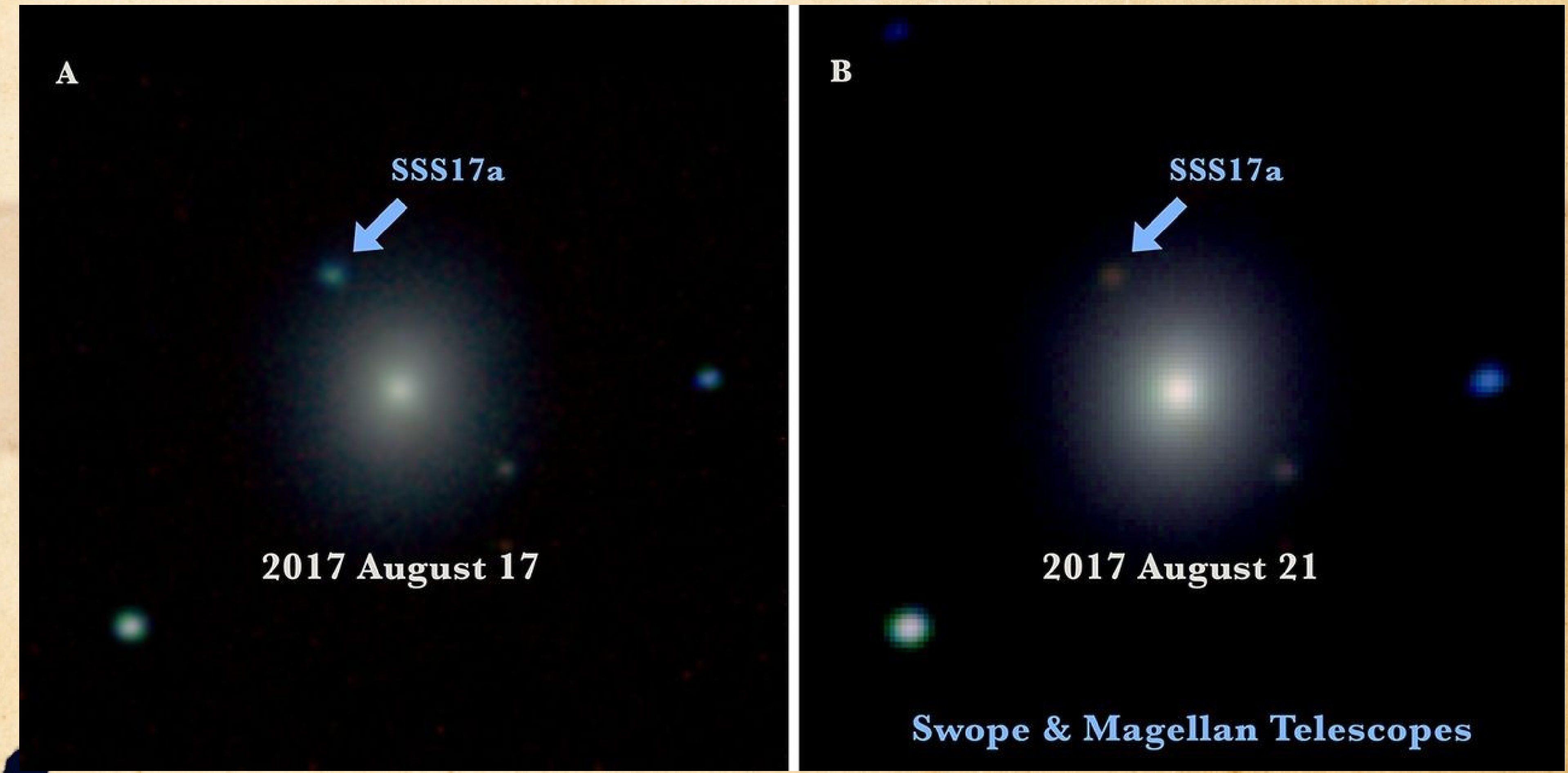
(LIGO+Virgo+em+17, ApJ)

e.m. counterpart: a time-lapse of snowballing discoveries



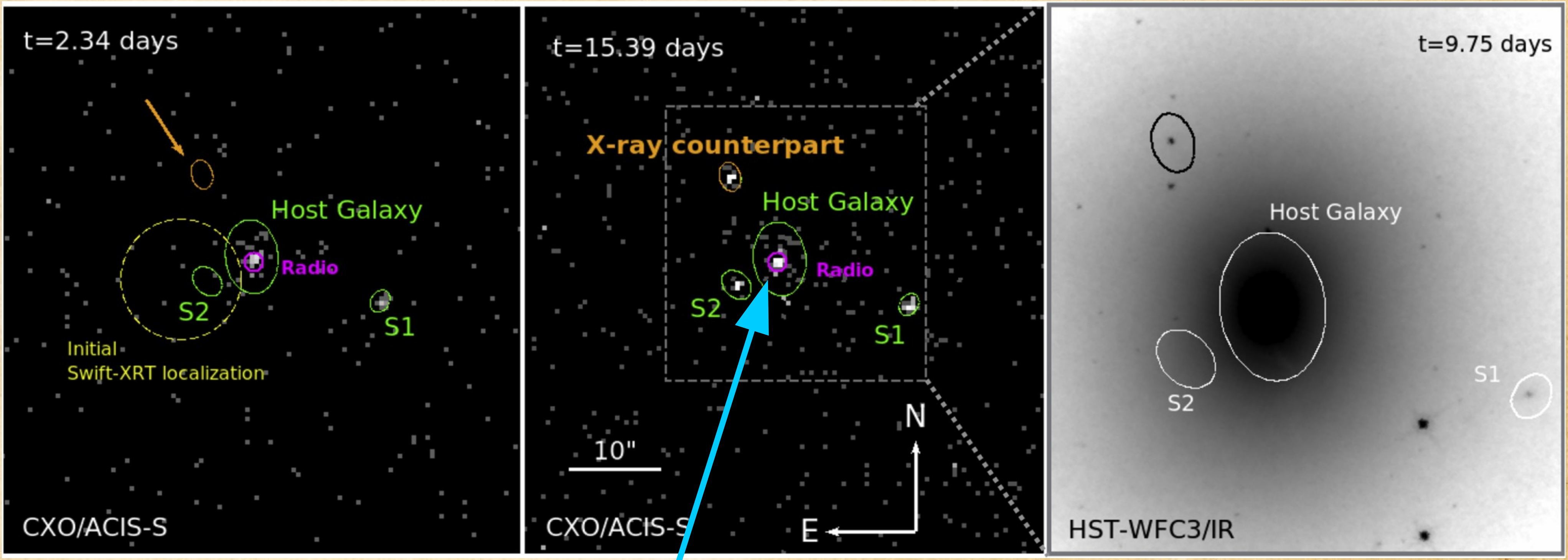
(LIGO+Virgo+em+17, ApJ)

Swope Telescope: the very first in the optical at 10 hours



(Coulter+17, Science)

X-ray and radio join in days later

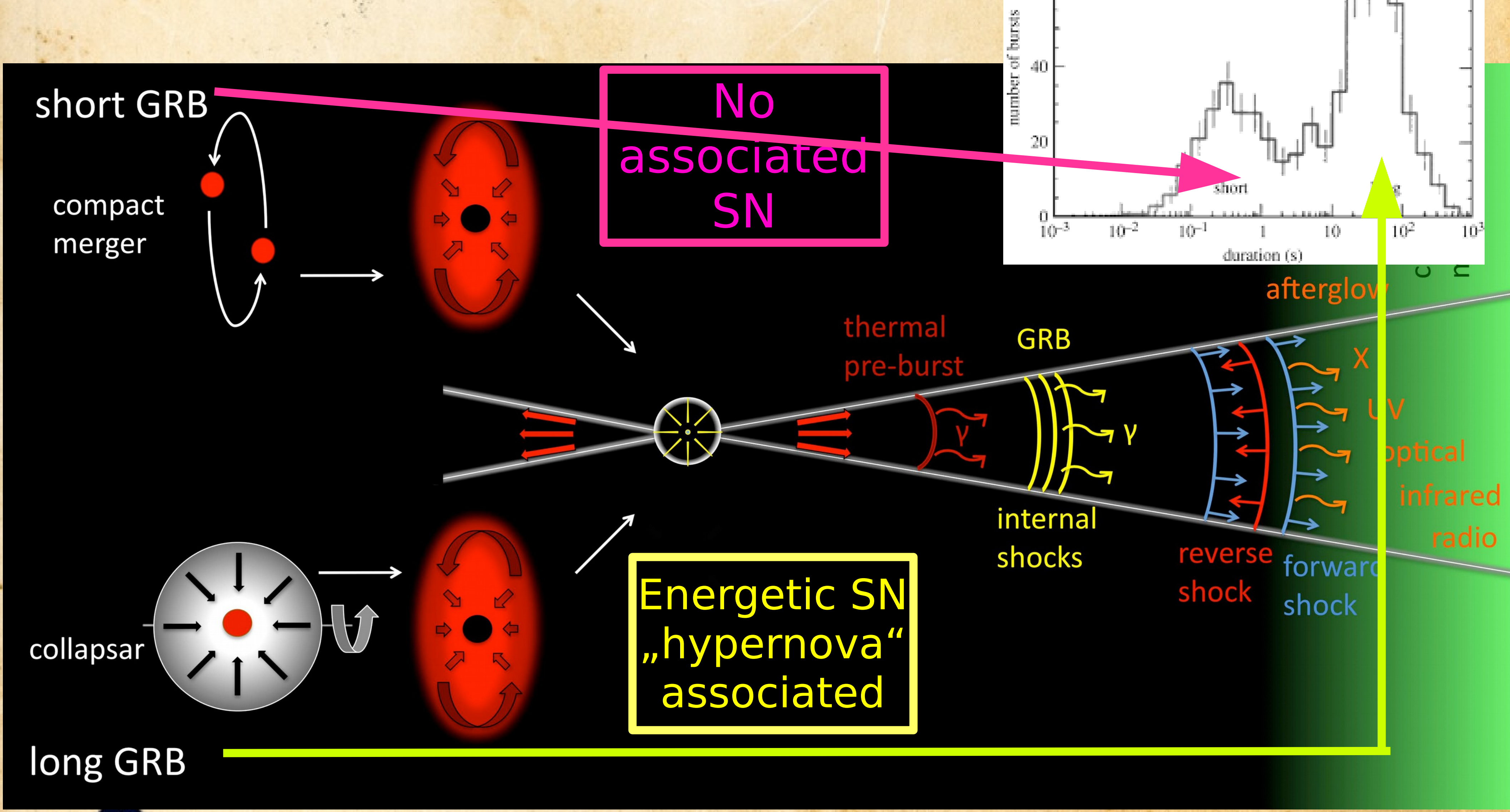


Host: weak AGN (Blanchard+17, ApJ)

(Margutti+17,ApJ)

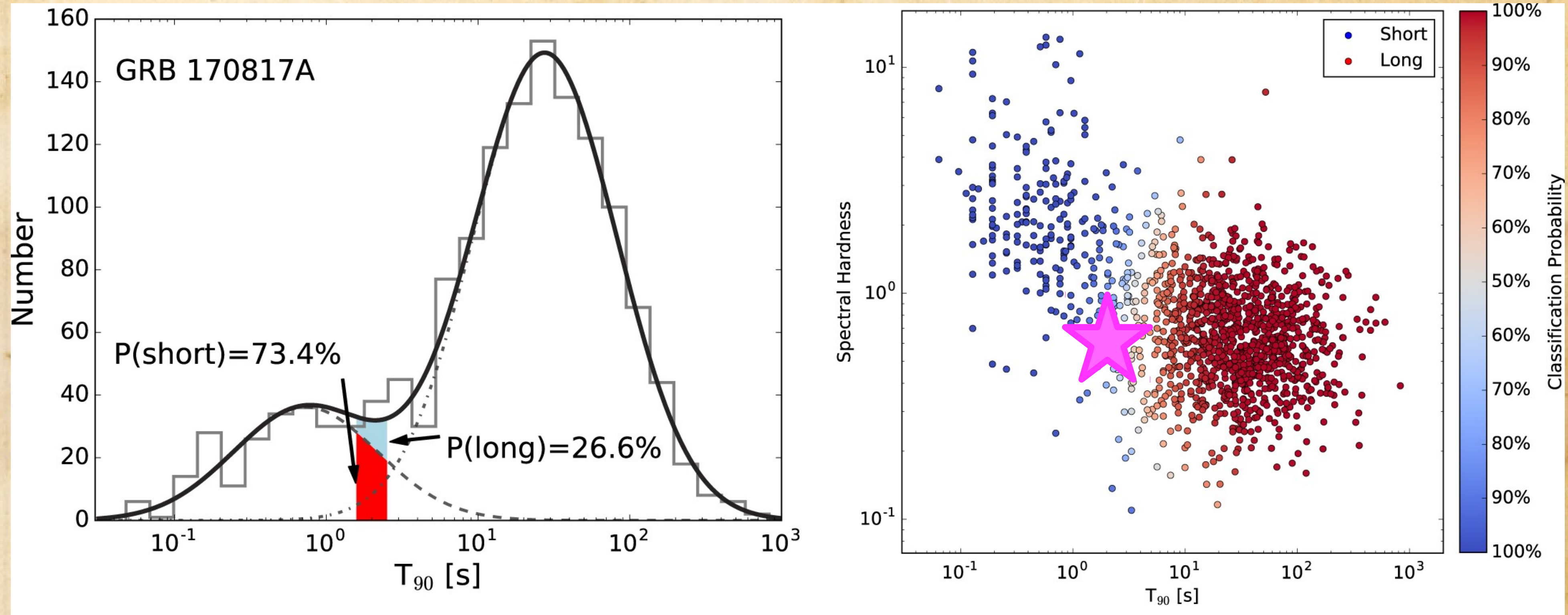
The γ-ray burst itself compared with other SGRBs

Short and Long GRBs: two families (at least)



GRB170817A: put in context

a borderline short-ish soft-ish GRB

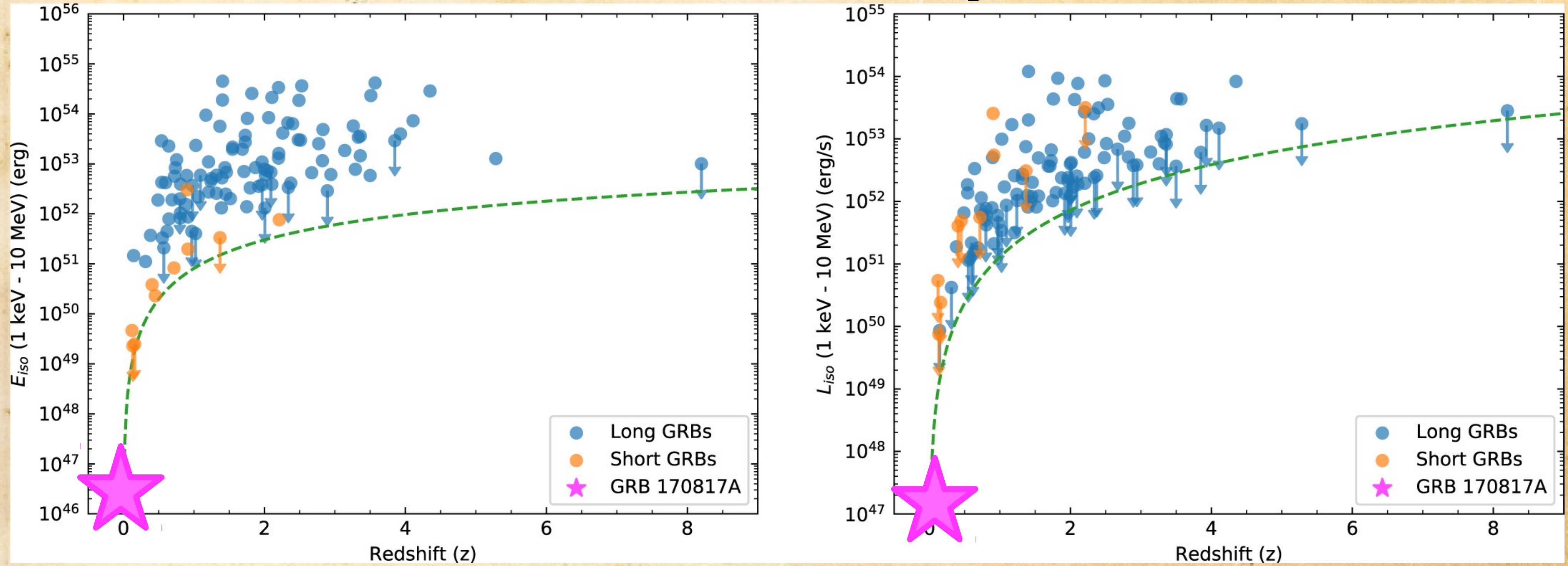


(a) (b)

$T_{90} = 2.0 \pm 0.5$ s

 (FermiGBM team,2017,ApJ)

GRB170817A: very low (isotropic-equivalent) luminosity GRB!



$E_{iso} = (5.3 \pm 1.0) \times 10^{46}$ erg

$L_{iso} = (1.2 \pm 0.6) \times 10^{47}$ erg/s

Detectable out to d<80 Mpc (=twice as far)

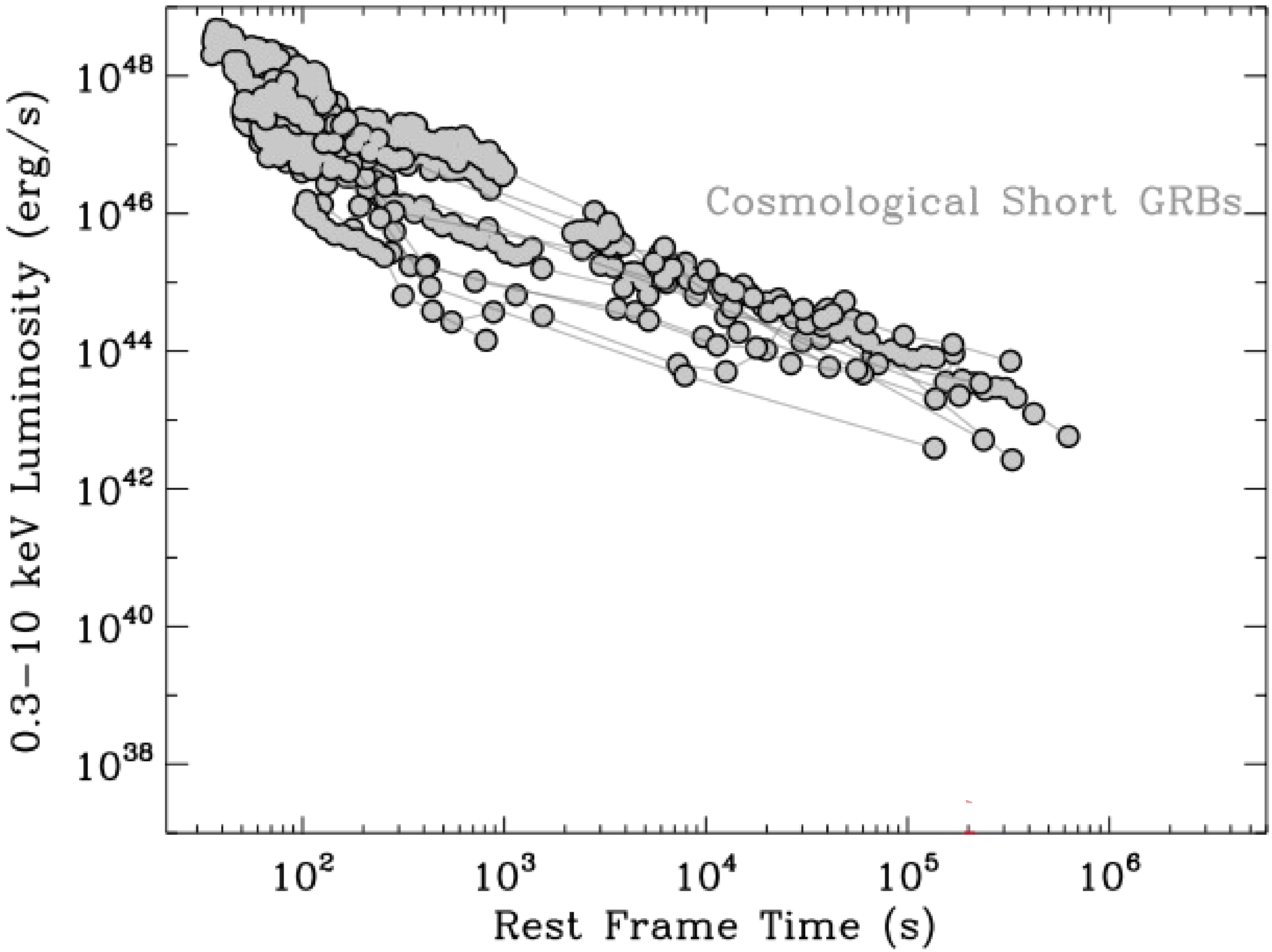
(our cosmological courtyard)

 (LV+Fermi+INTEGRAL teams,2017,ApJ)

X + radio afterglow

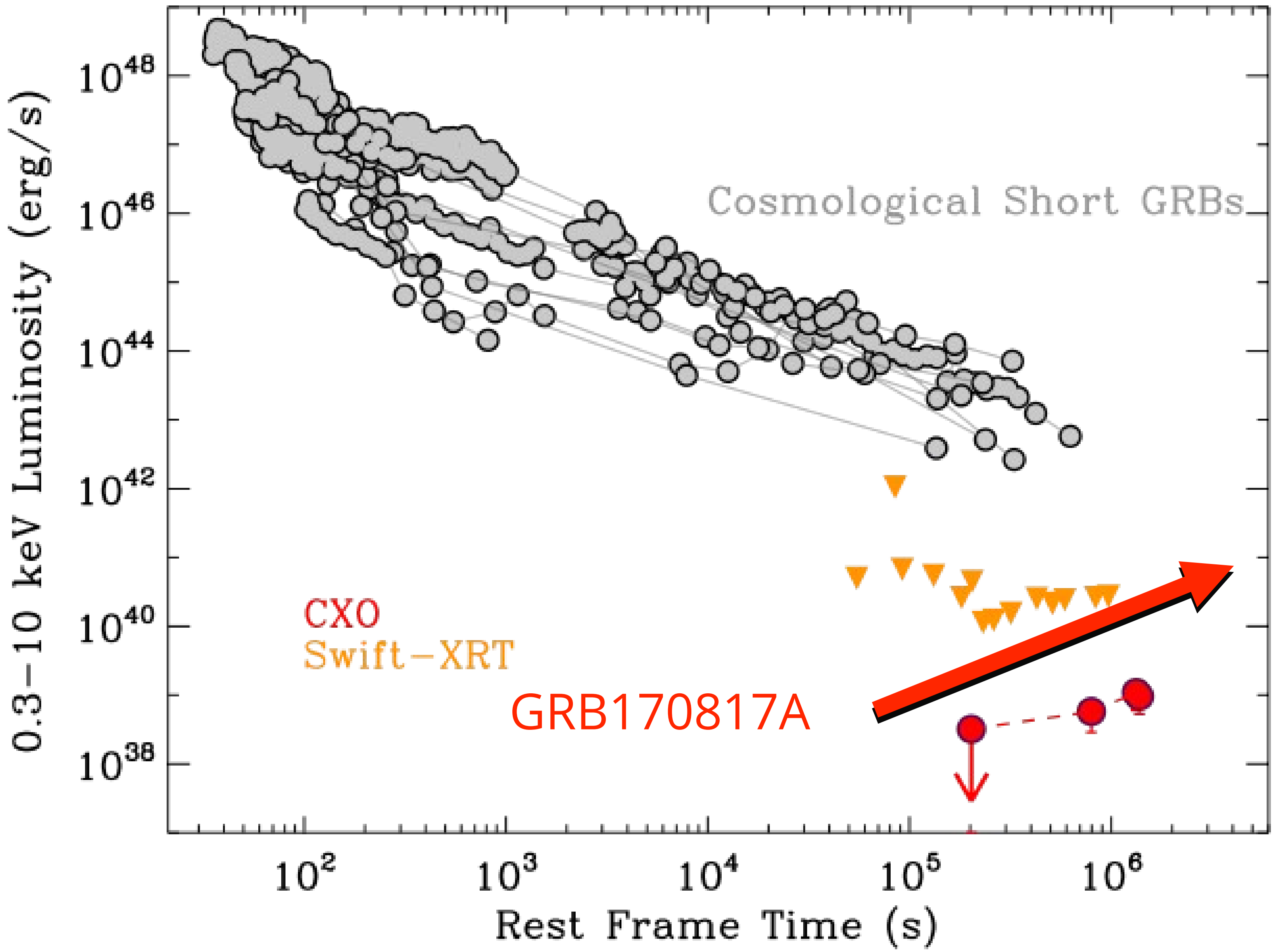
an off axis jet sweeping up the interstellar medium

X-ray



(Fong+17, Margutti+17, ApJ)

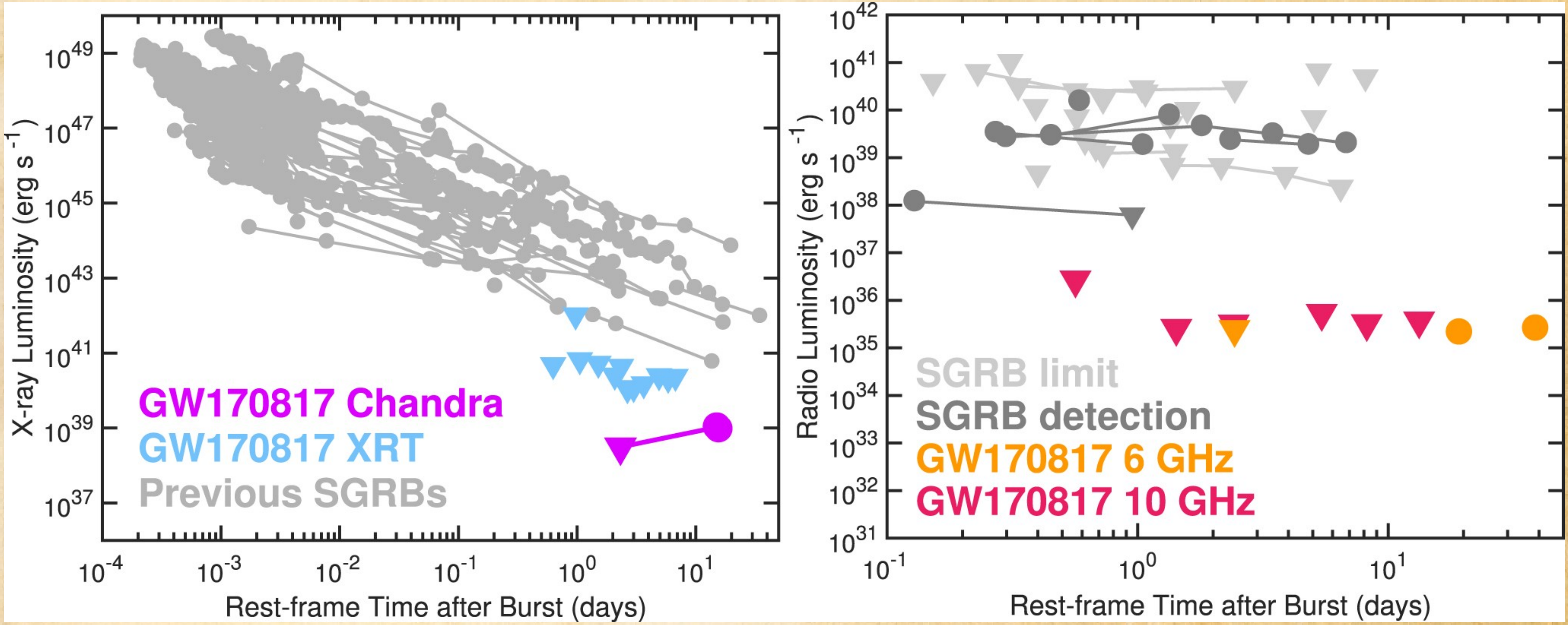
X-ray



 (Fong+17, Margutti+17, ApJ)

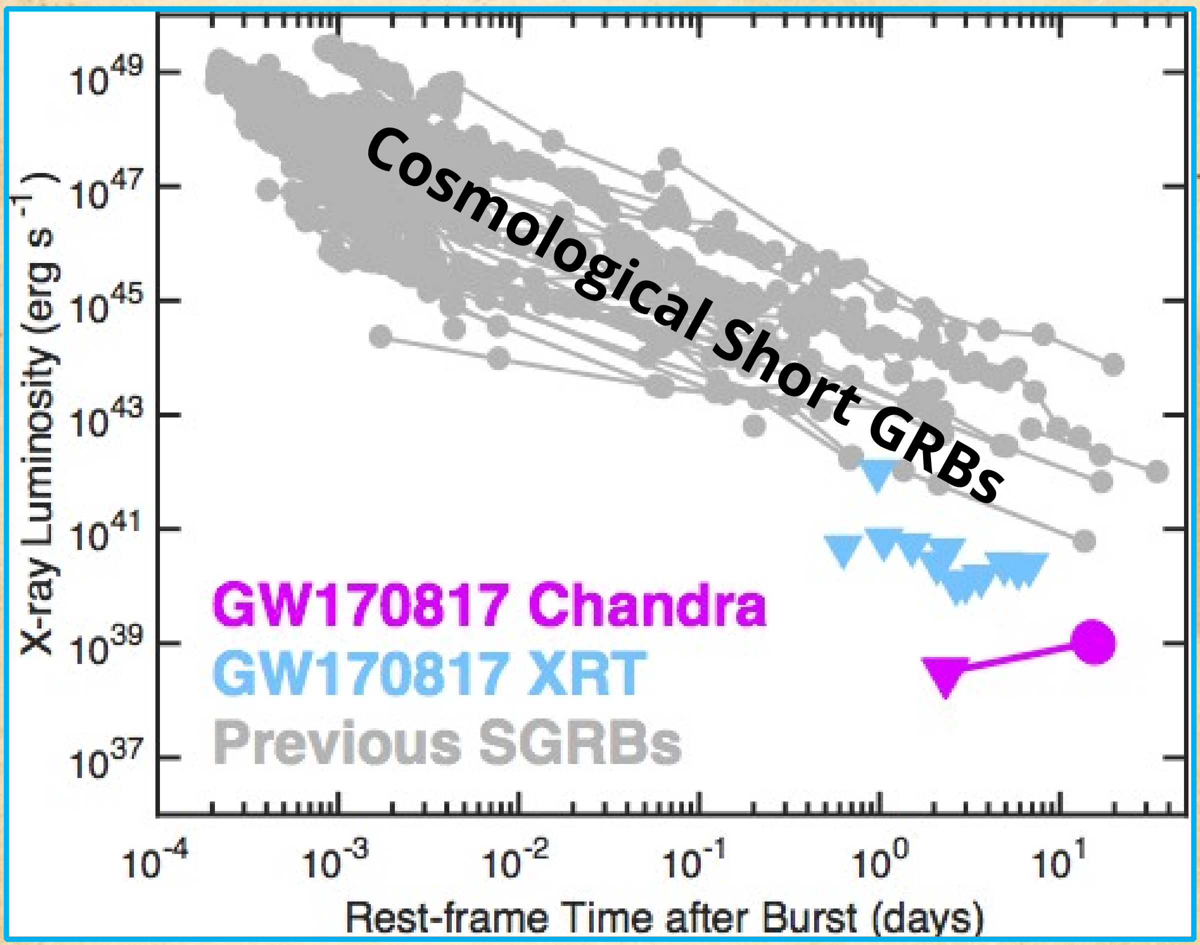
X-ray+radio afterglow: how does it compare with other SGRBs?

X-ray/radio afterglow comparably underluminous



(Fong+17,ApJ)

One must explain



★ **Rising X-ray emission**

★ **Mild rise, peak ~20 days**

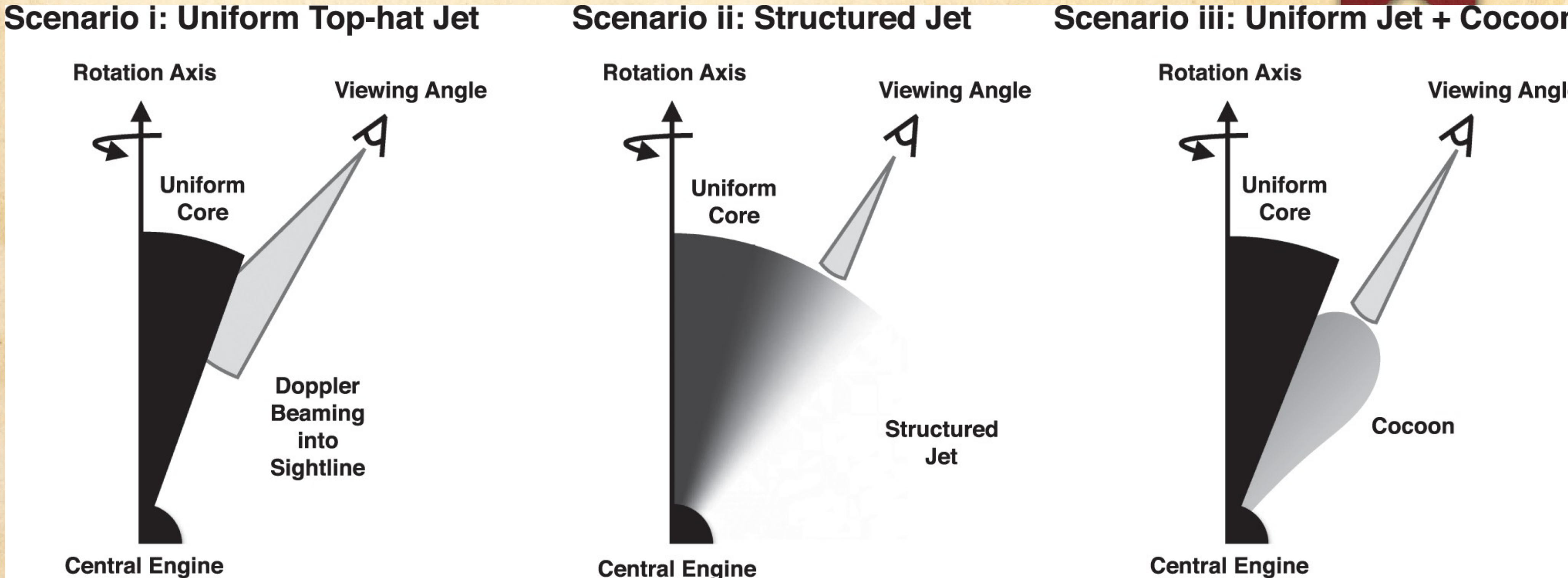
★ **Lx~10^{39} erg/s**

★ **Hard spectrum with Γ~1.5 (β~0.5)**

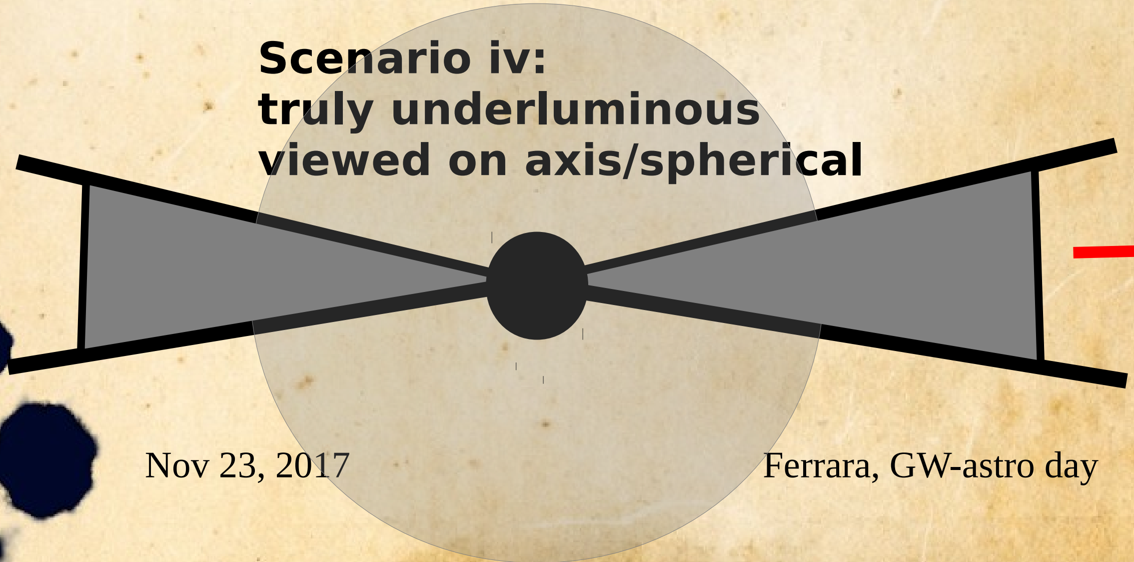
★ **Radio-to-Xray SED also demands β(radio-X)~0.5**

 (Credits: R. Margutti)

Interpretations

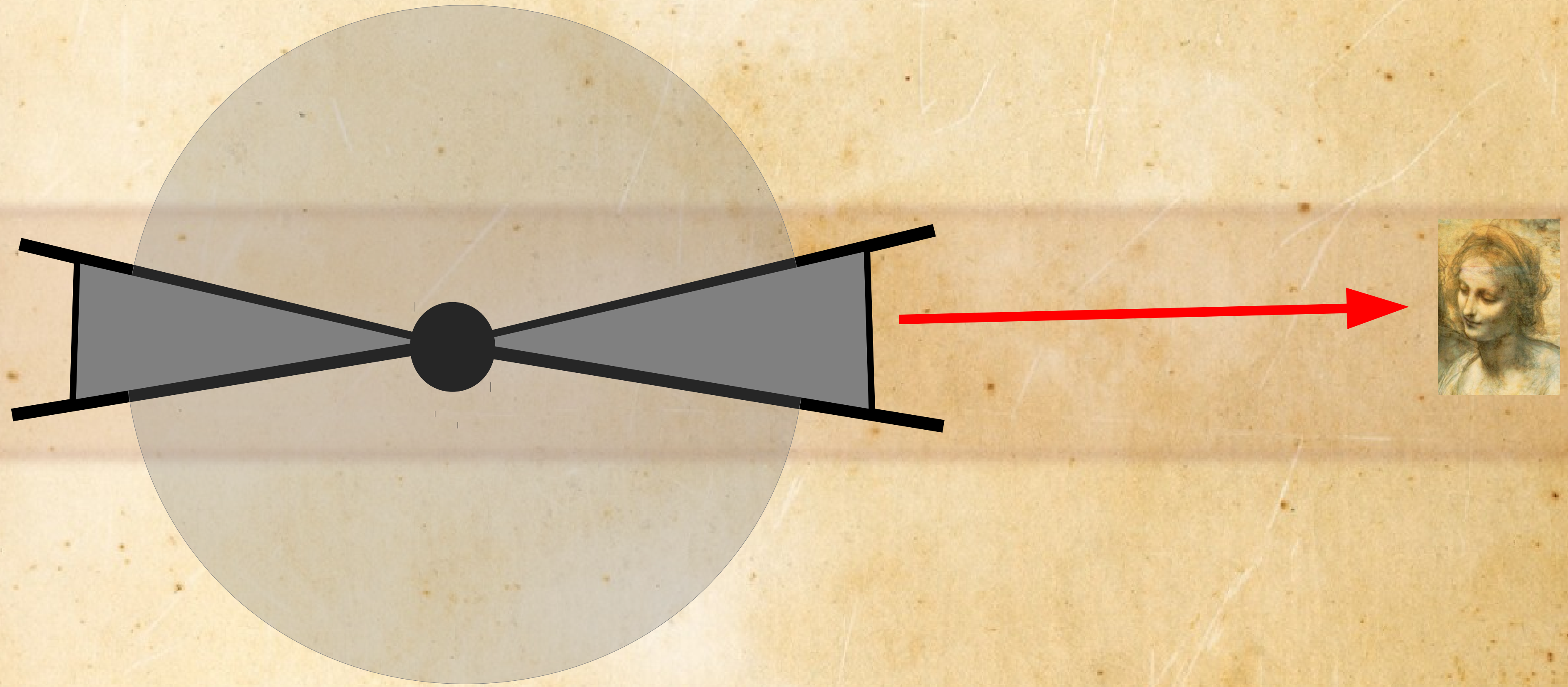


Scenario iv:
truly underluminous
viewed on axis/spherical



(LV+Fermi+INTEGRAL teams,2017,ApJ)

Scenario iv: truly underluminous viewed on axis/spherical



Rise: fireball deceleration and afterglow onset ?

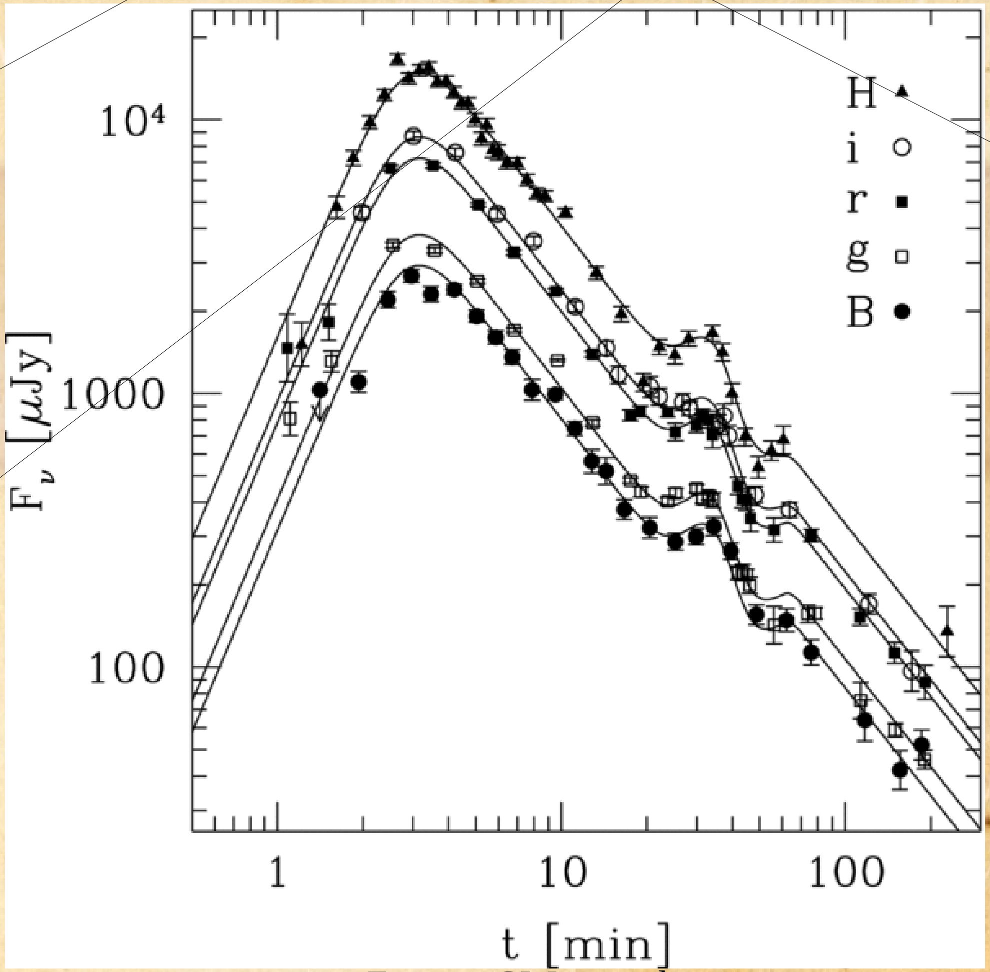
$$t_{pk} = \left(\frac{3 E_{k,iso}}{32 \pi c^5 n m_p \Gamma_0^8} \right)^{1/3}$$

(Sari&Piran99)

GRB energy

Environment density

Ejecta initial bulk Lorentz f.



(Nysewander+09)

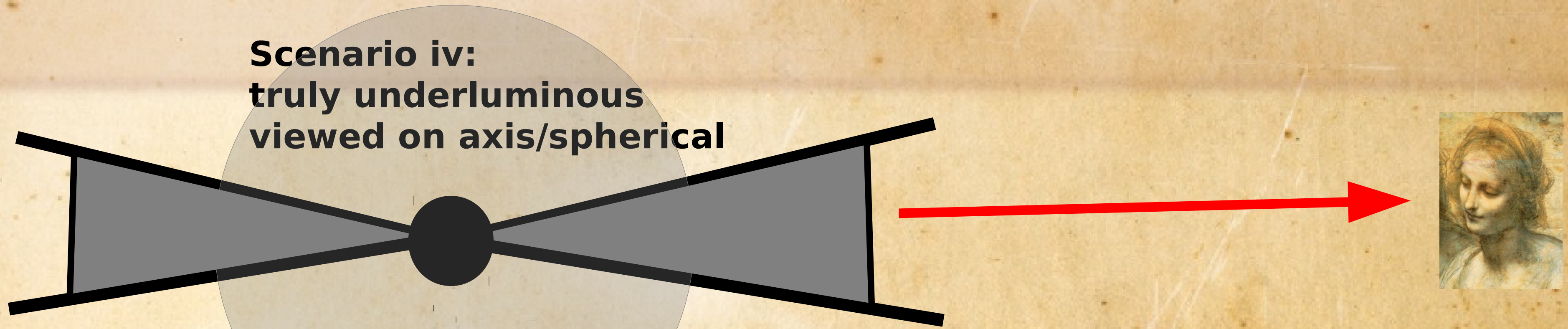
On-axis: afterglow onset?

$$\Gamma_0 \sim 8.0 \left(\frac{E_{k,iso,52}}{n_0}\right)^{1/8} t_{pk,day}^{-3/8} \sim 2$$

$E_{k,iso} \sim 10\ E_{\gamma,iso} = (5.3 \pm 1.0)\mathrm{x}10^{47}$ erg

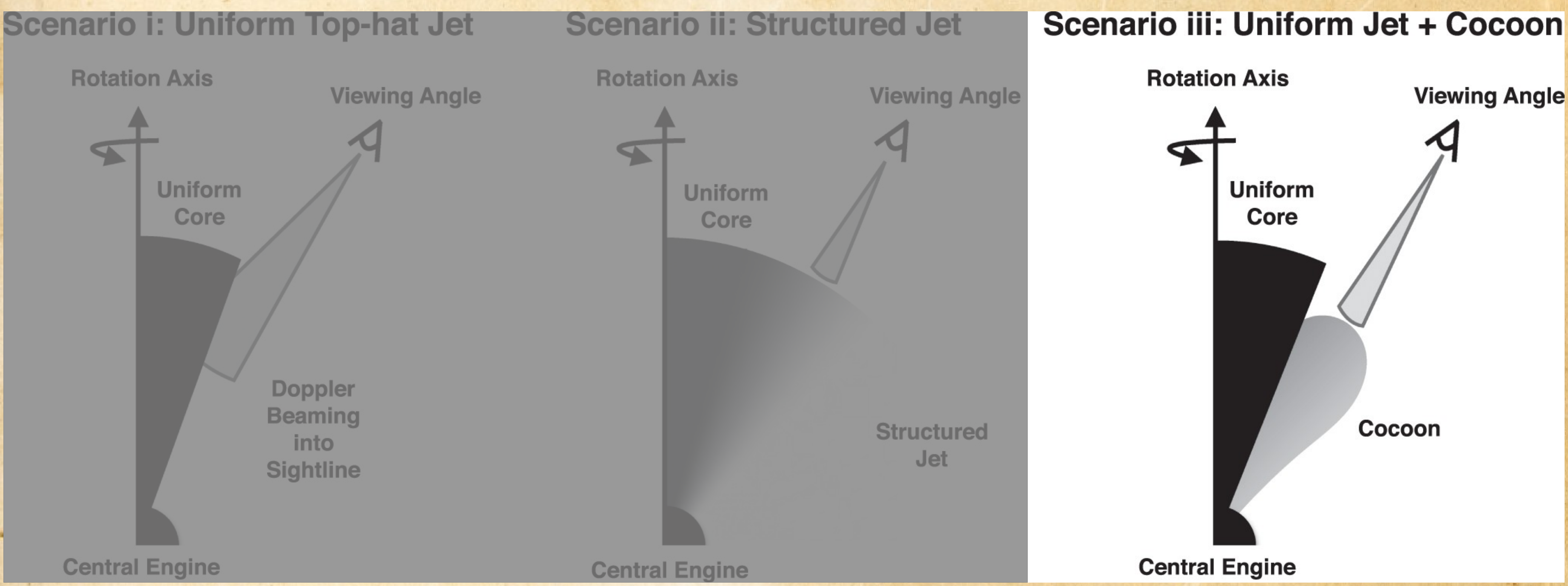
$t_{pk} \sim$ 15-30 days

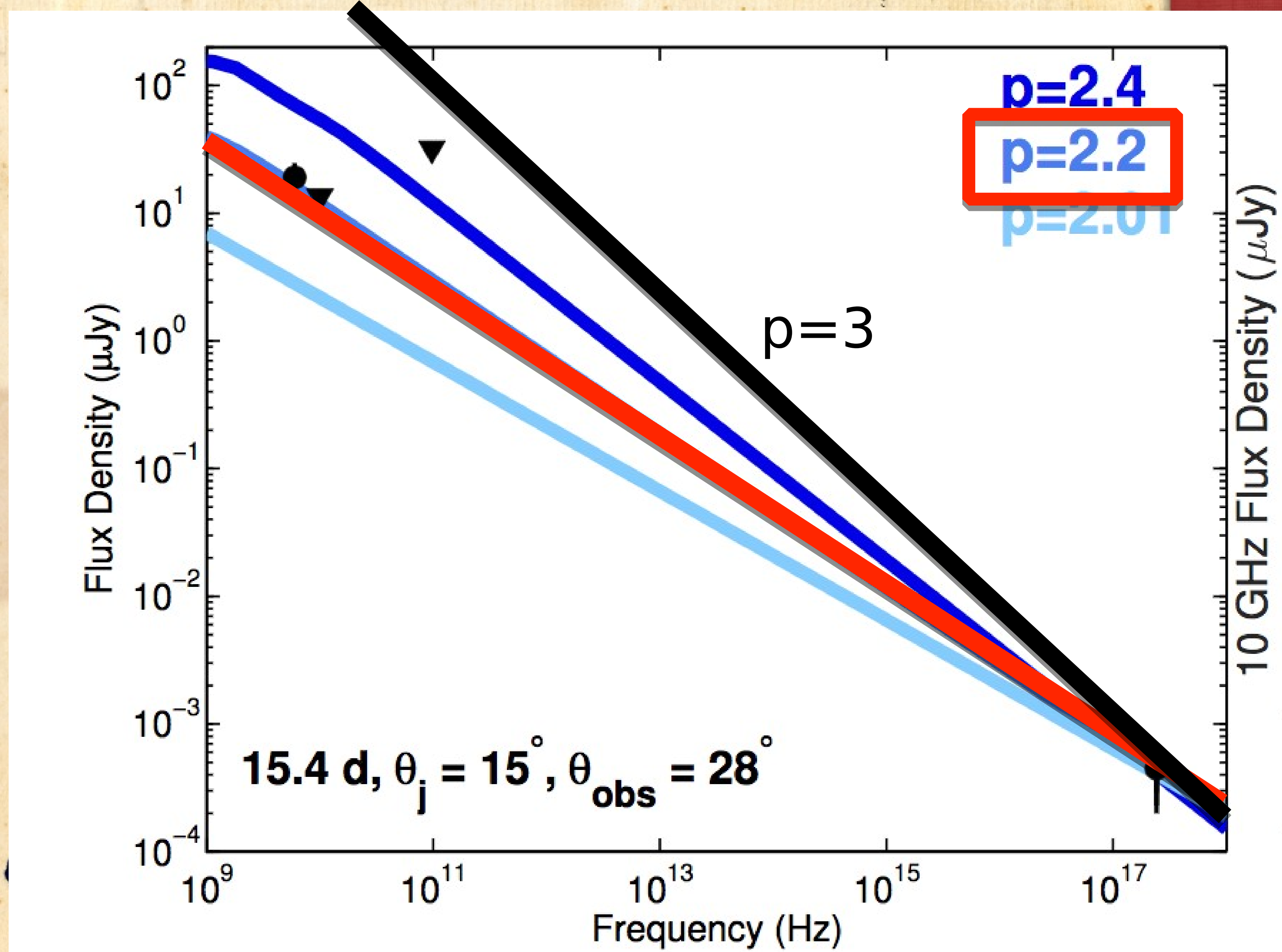
$n = (3 - 15)\mathrm{x}10^{-3}\ \mathrm{cm}^{-3}$



Mildly Relativistic shock ➡ Cocoon emission?

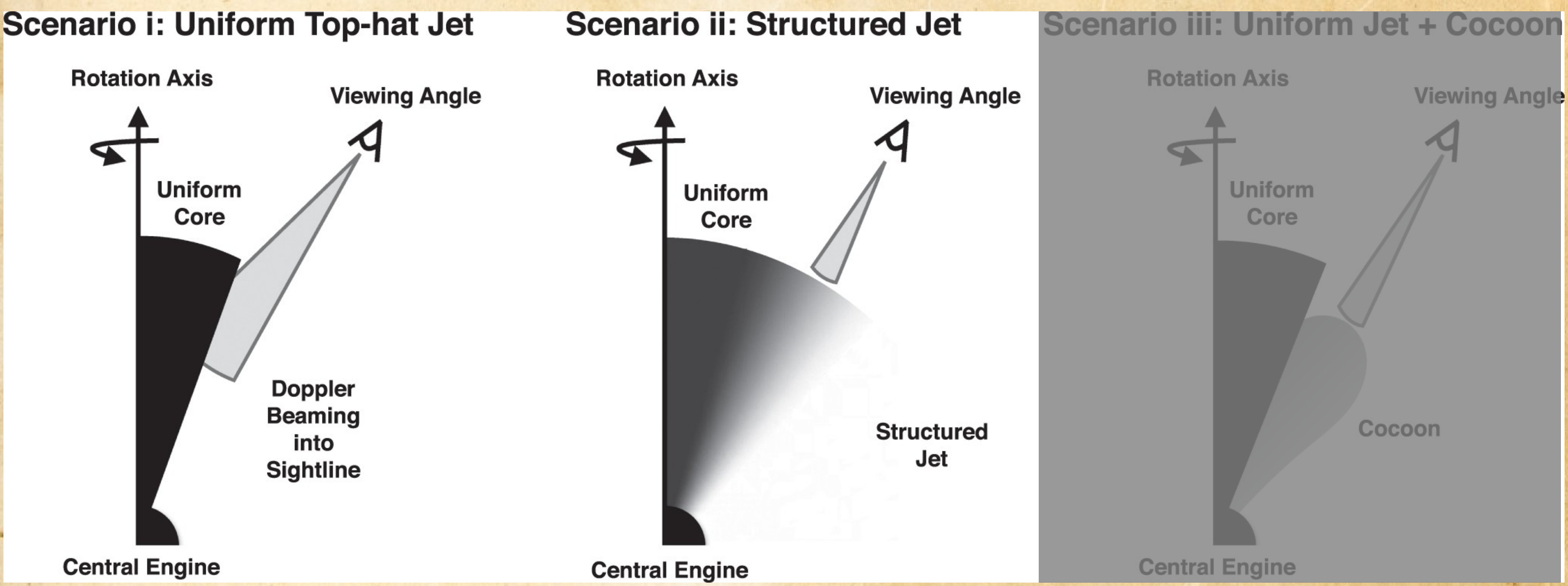
Scenario iii: Cocoon



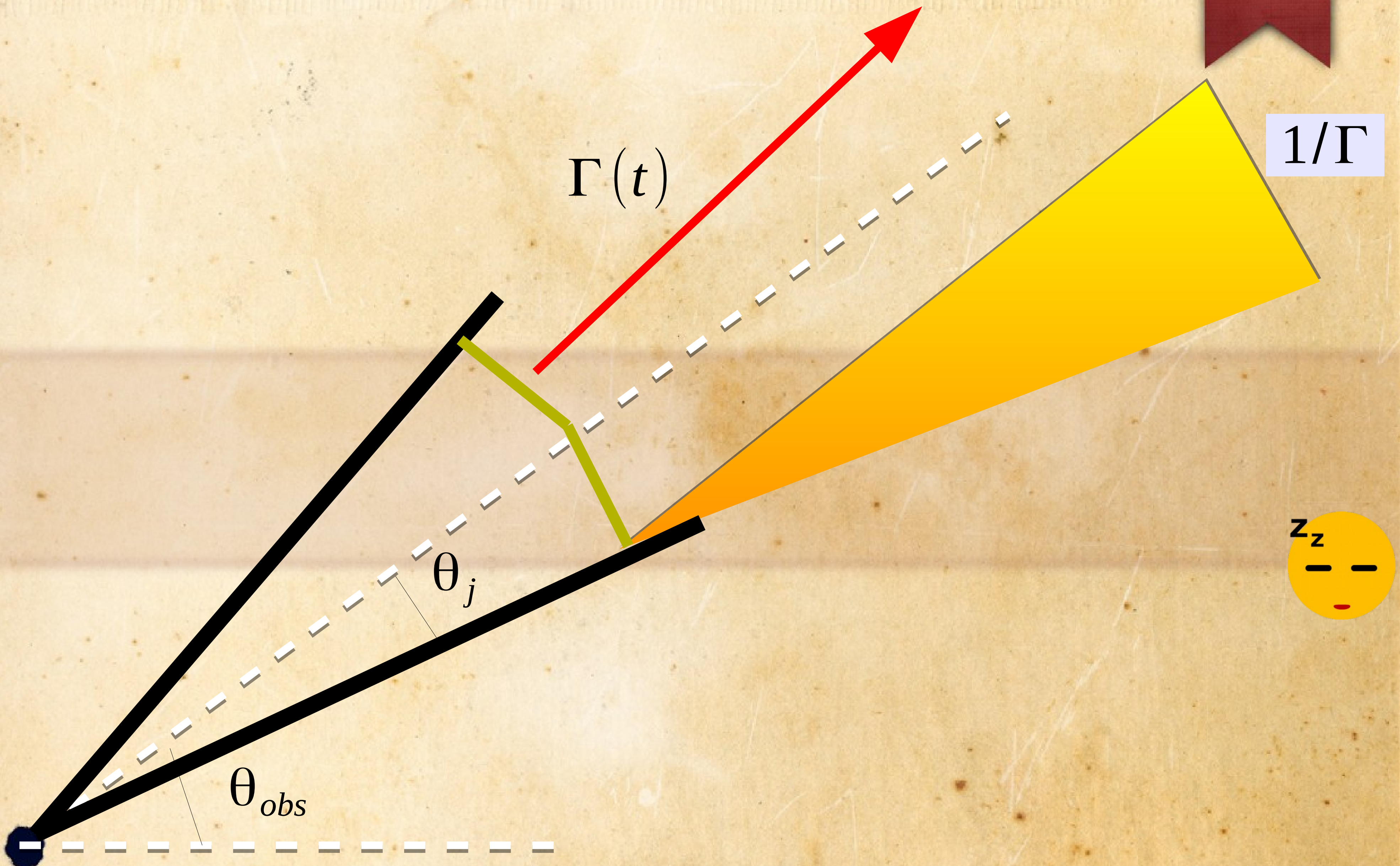


(Alexander+17)

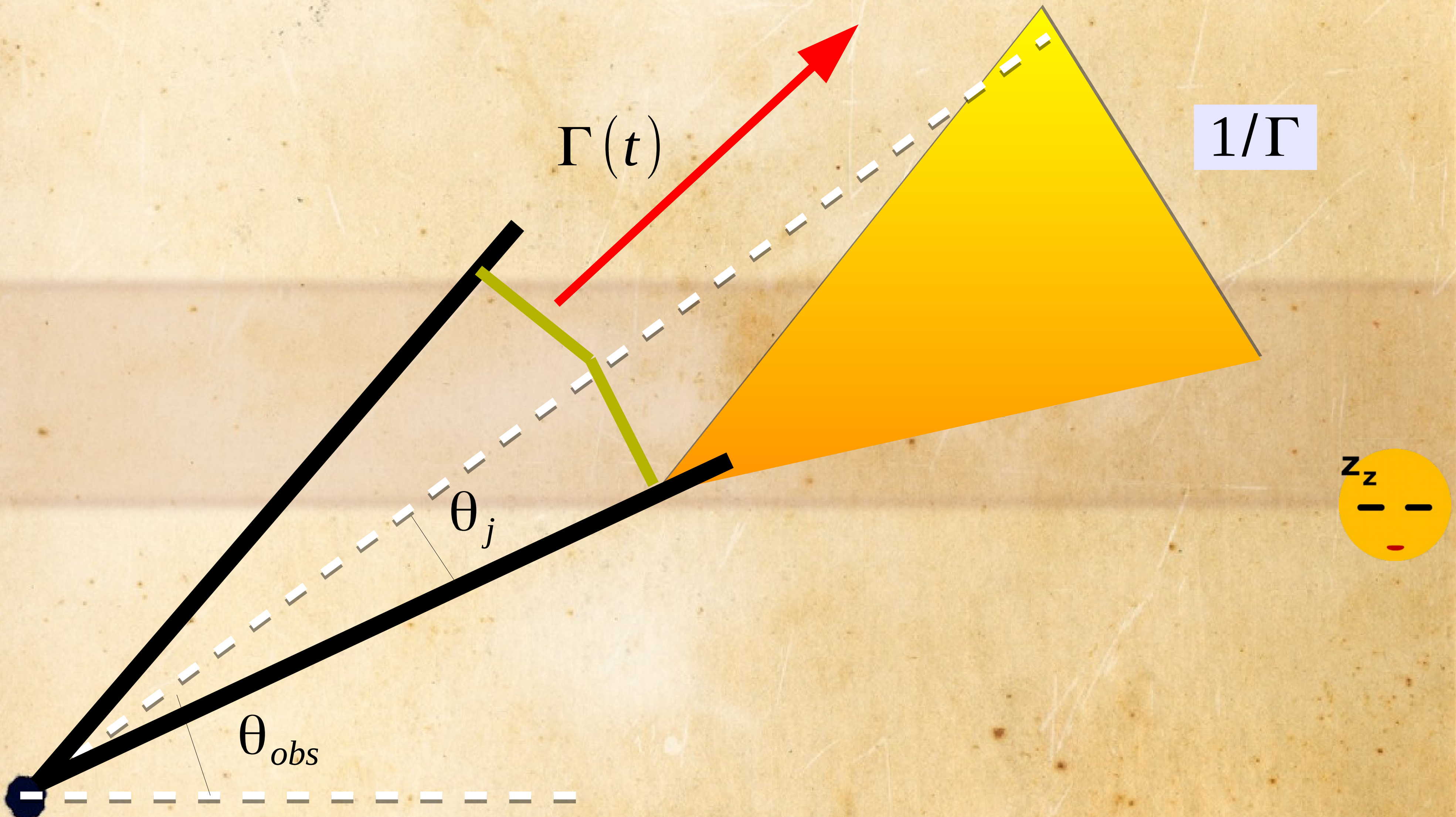
Scenari i-ii: off axis jet



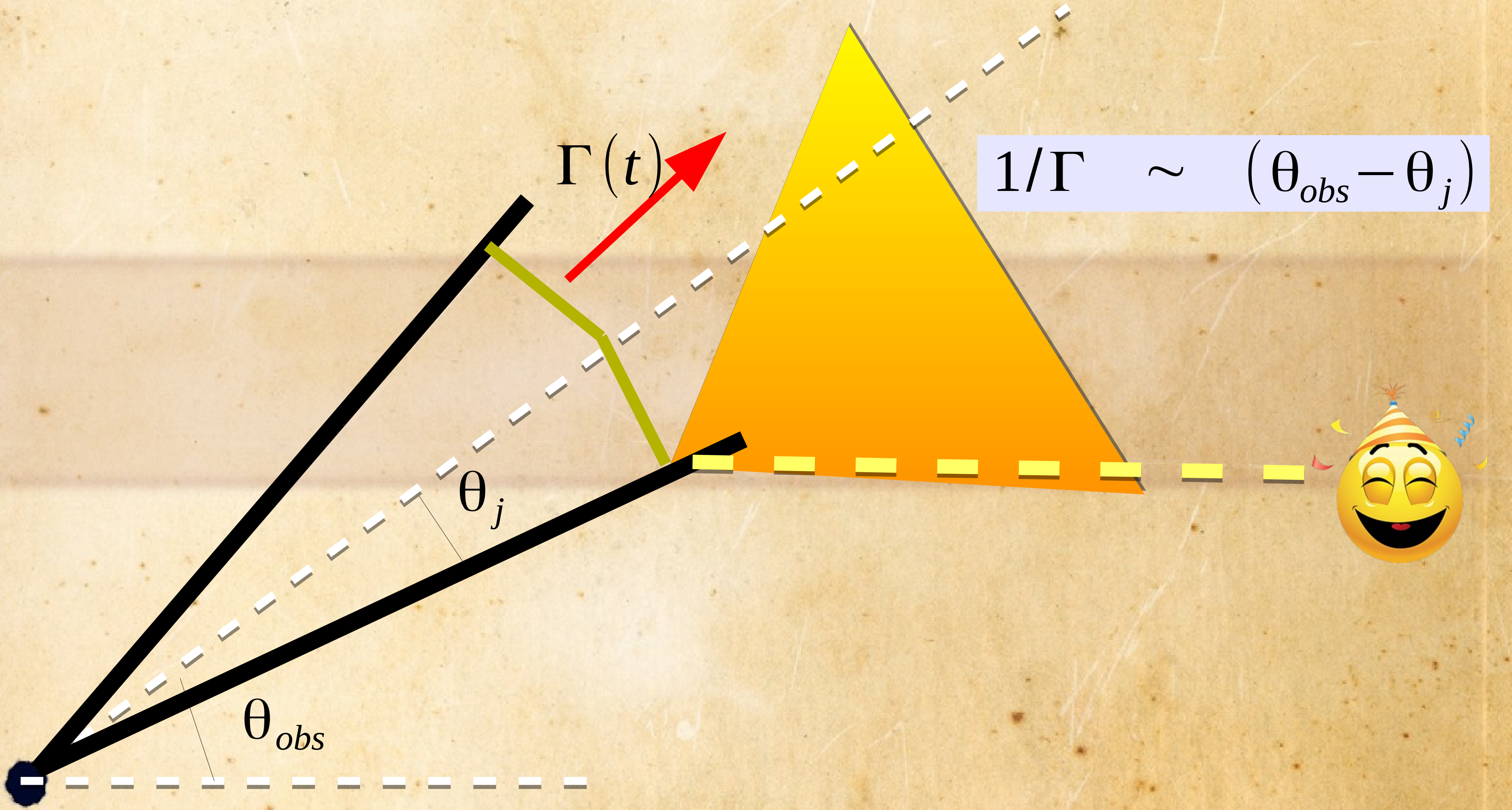
Relativistic beaming and deceleration



Relativistic beaming and deceleration



Relativistic beaming and deceleration



off axis jet: clues

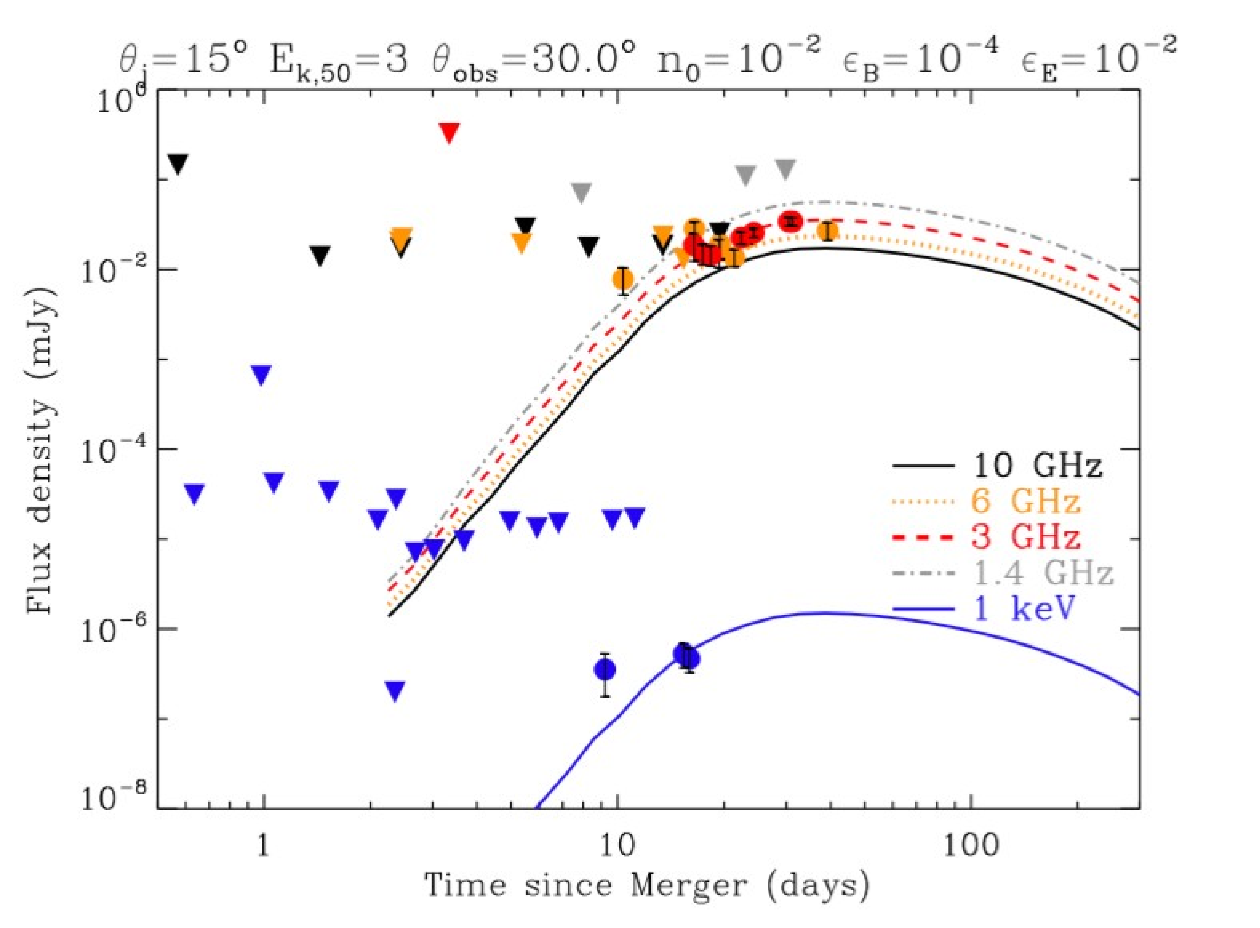
$$t_{pk} \approx 2.1 \left(\frac{E_{k,iso,52}}{n} \right)^{1/3} \left(\frac{\theta_{obs} - \theta_j}{10^\circ} \right)^{8/3} d$$

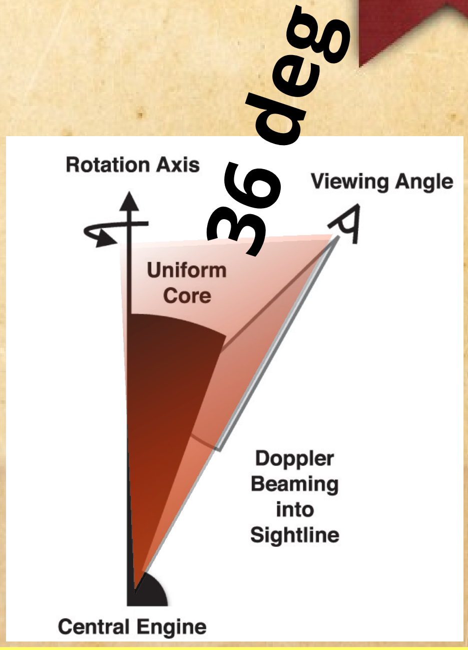
For t_{pk} ~ 15-70 d

For typical parameters inferred from SGRBs (θ_j ~5-15 deg):

θ_{obs} ~20-40 deg

X-ray+radio: entire data set at t<40 d





Margutti+17; Guidorzi+17; Alexander+17

n~10^{-2} - 10^{-4} cm^{-3}

$E_k=10^{48}$ – $3x10^{50}$ erg

θ_{obs}=25 – 50 deg

Simulations on 4 clusters

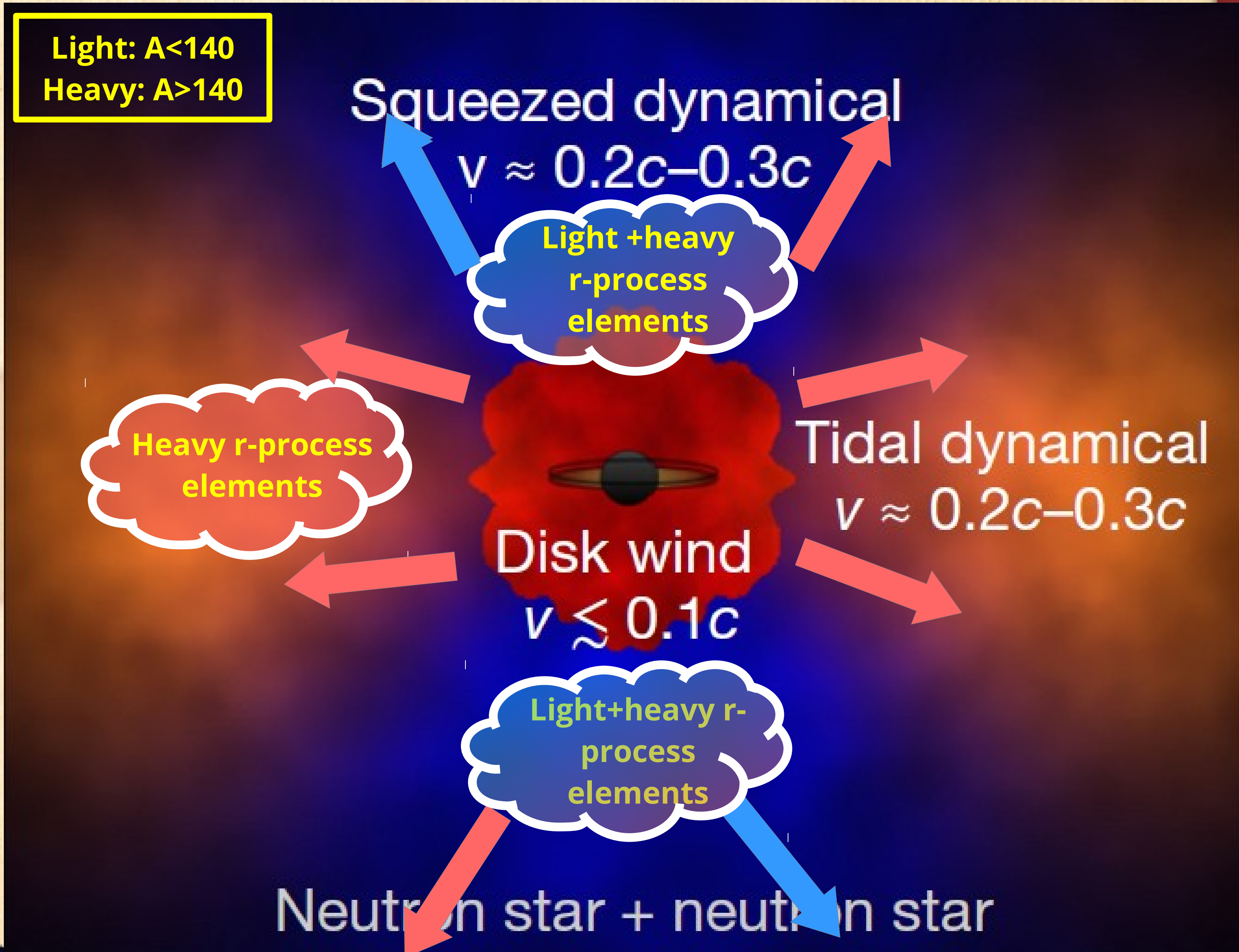
Many thanks to:

- Fermi cluster (**UNIFE**, PI Zanghirati)
- Piero Rosati's team (**UNIFE**)
- Northwestern U.
- COKA GPU cluster (**UNIFE & INFN-FE**)

UV/Optical/NIR emission

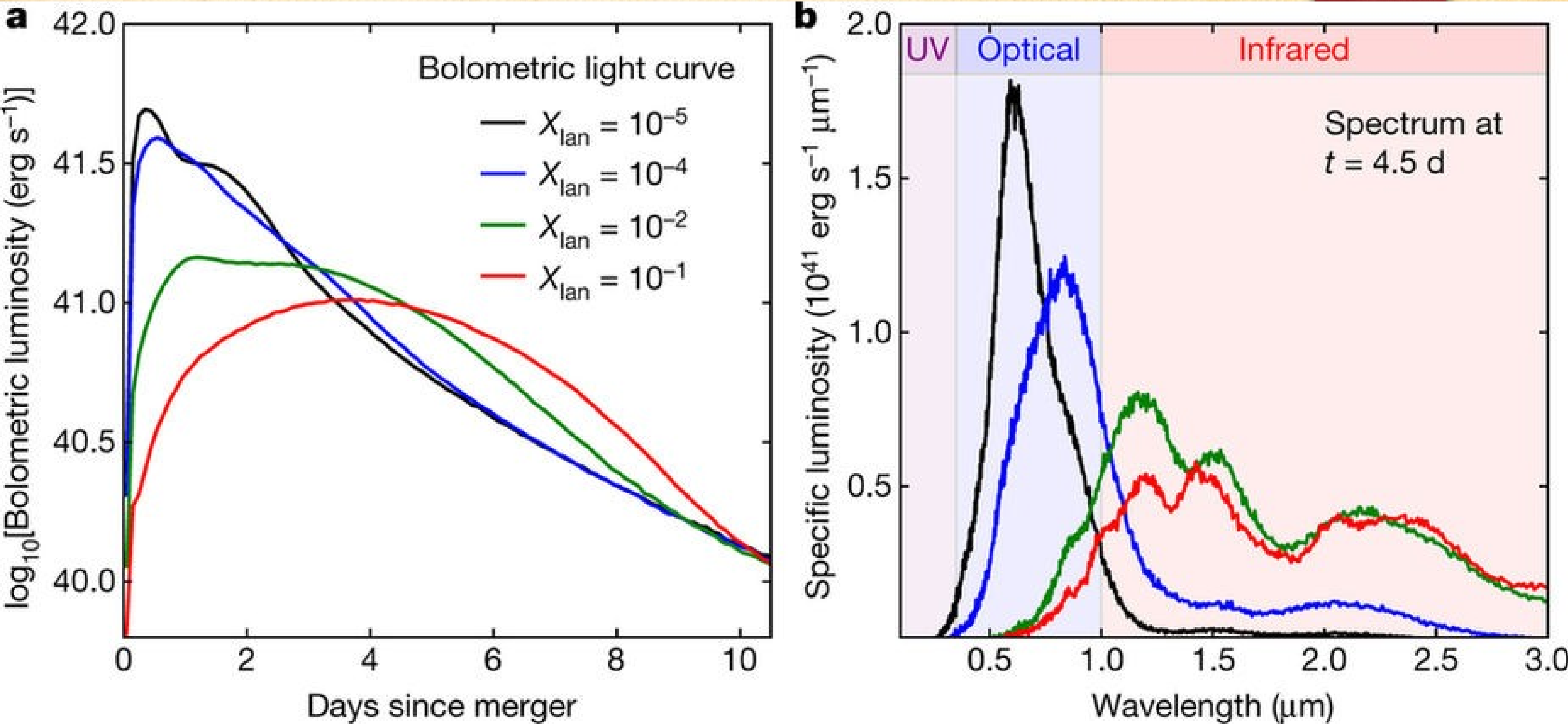
kilonova and heavy elements nucleosynthesis

Macronova/Kilonova



(Kasen+17)

Kilonova: theoretical evolution



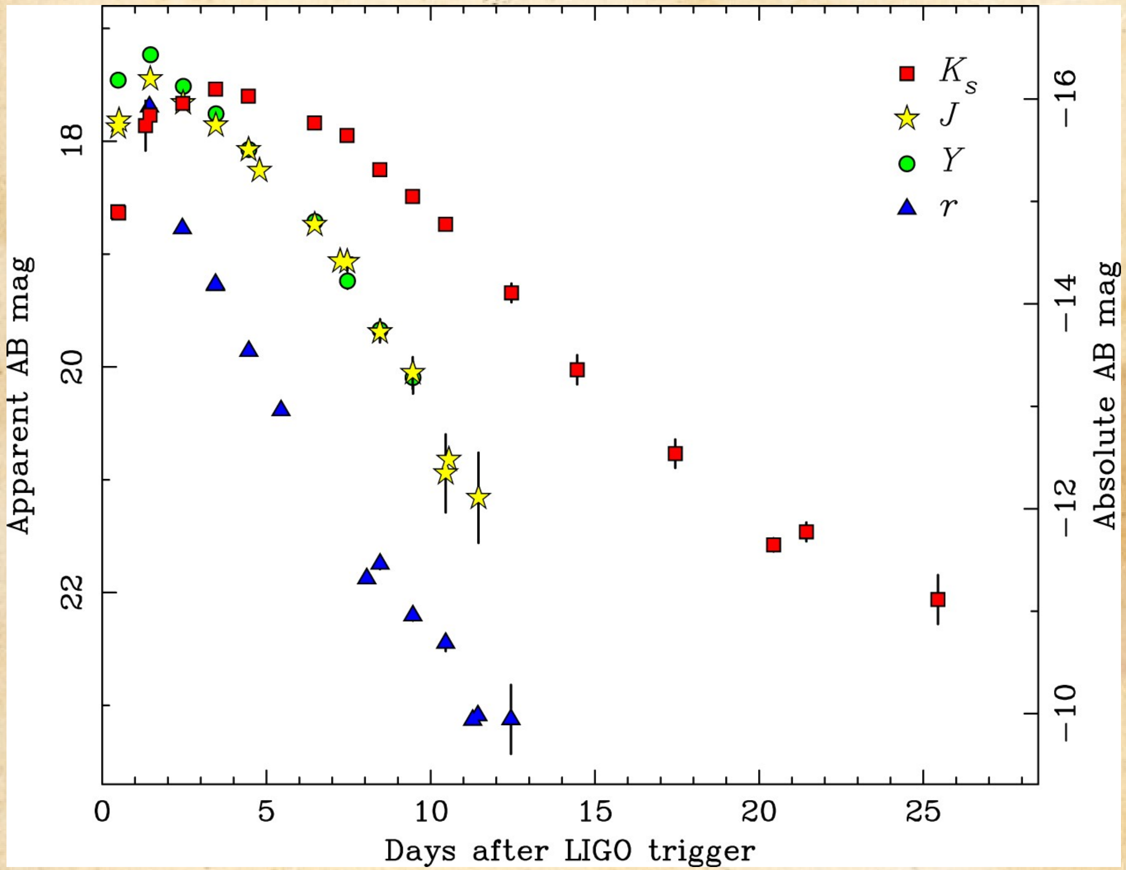
$$t_{lc} \approx \left(\frac{3\kappa M}{4\pi c v}\right)^{\frac{1}{2}} \approx 2.7\,\text{days} \times \left(\frac{M}{0.01 M_\odot}\right)^{\frac{1}{2}} \left(\frac{v}{0.1c}\right)^{-\frac{1}{2}} \left(\frac{\kappa}{1\,\text{cm}^2\,\text{g}^{-1}}\right)^{\frac{1}{2}}$$

$$L_{lc} \approx M\dot{\varepsilon}_{nuc}(t_{lc})$$
$$\approx 5 \times 10^{40}\,\text{erg s}^{-1} \times \left(\frac{M}{0.01 M_\odot}\right)^{1-\frac{\alpha}{2}} \left(\frac{v}{0.1c}\right)^{\frac{\alpha}{2}} \left(\frac{\kappa}{1\,\text{cm}^2\,\text{g}^{-1}}\right)^{-\frac{\alpha}{2}}$$

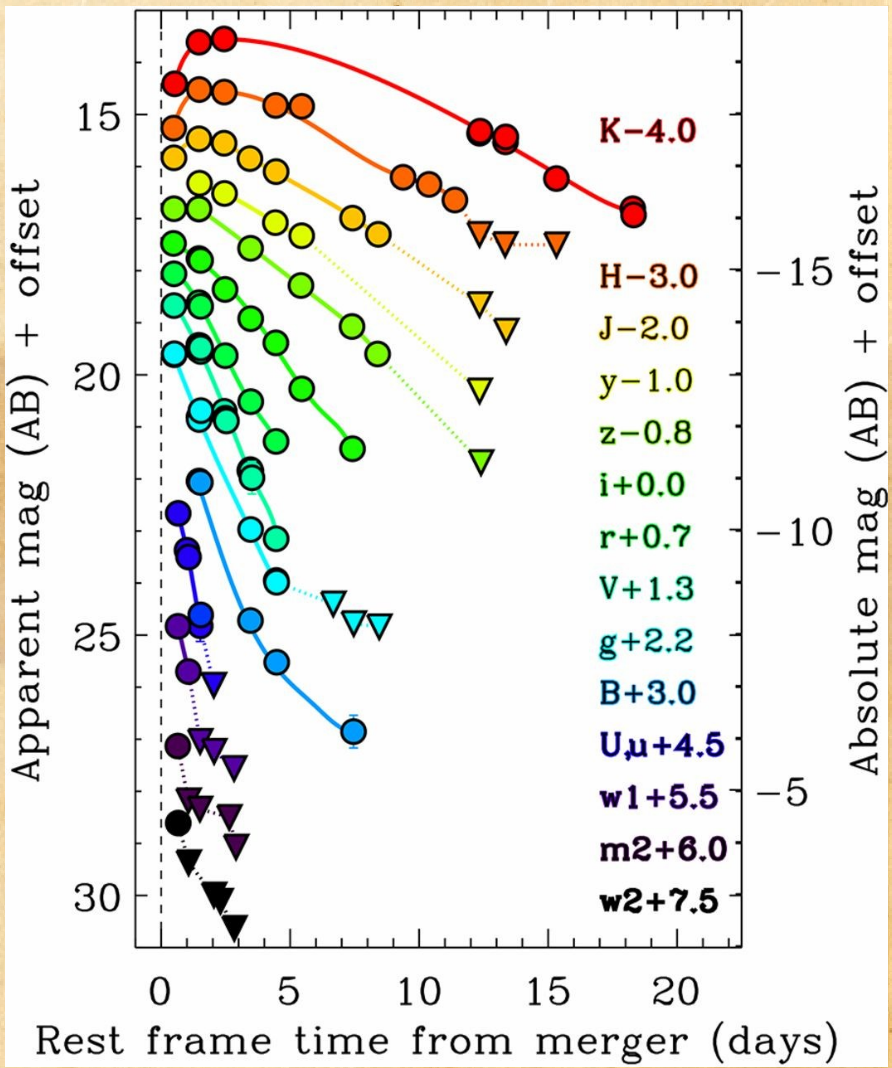
α~1.3

(Kasen+17)

170817: KN decays faster in blue than in red

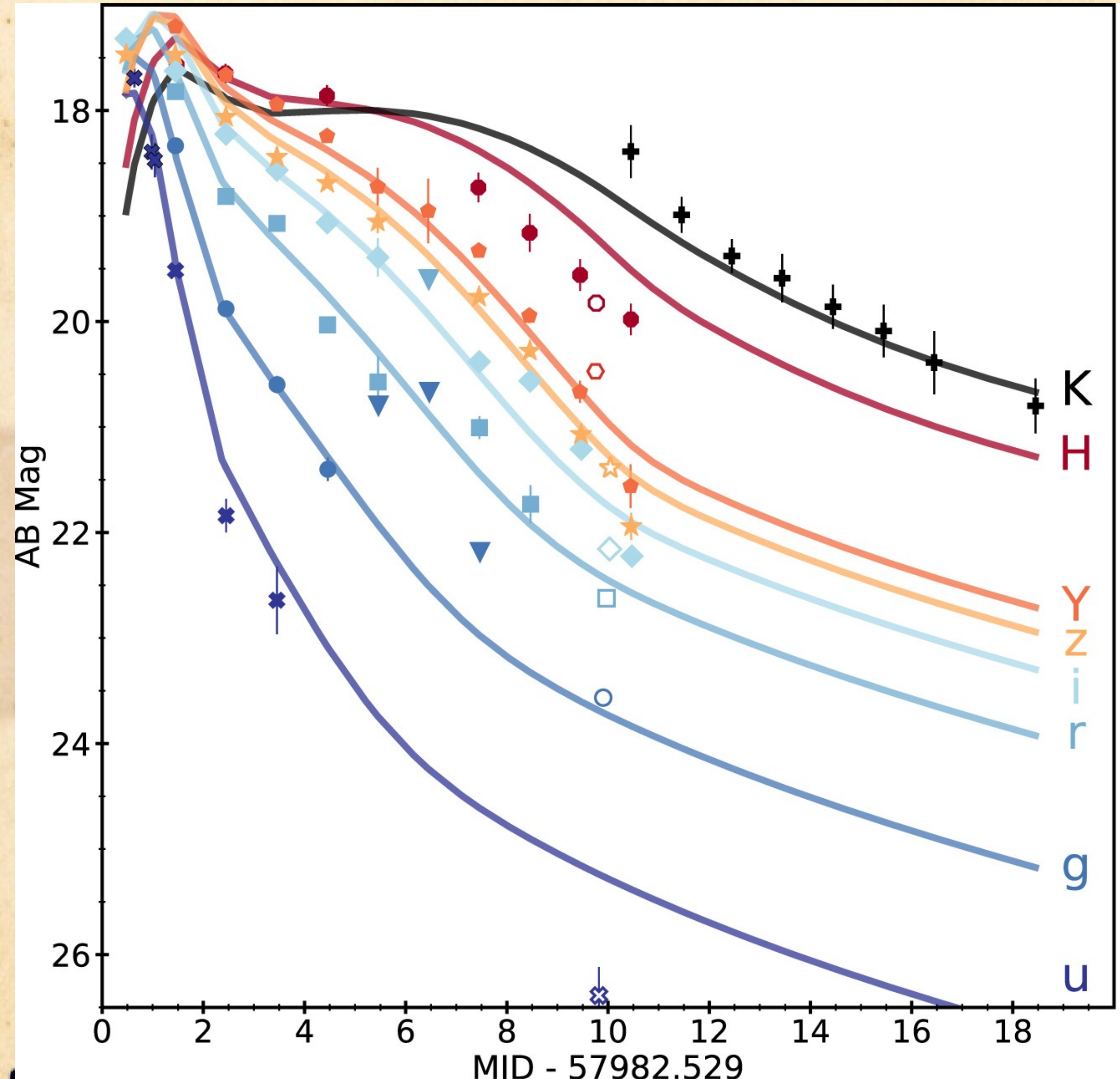


(Tanvir+17,ApJ)



(Drout+17,Science)

2-comp model (blue+red KN) ~ works

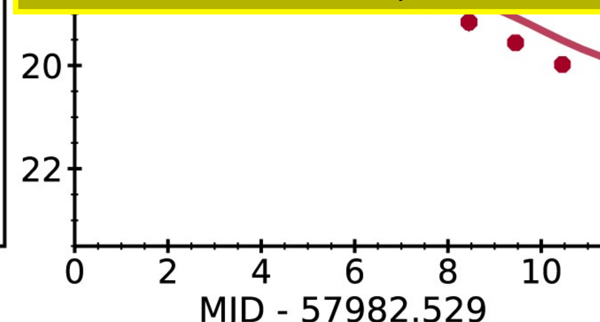


Near-infrared observations, together with information from visible light, the observations require two components!

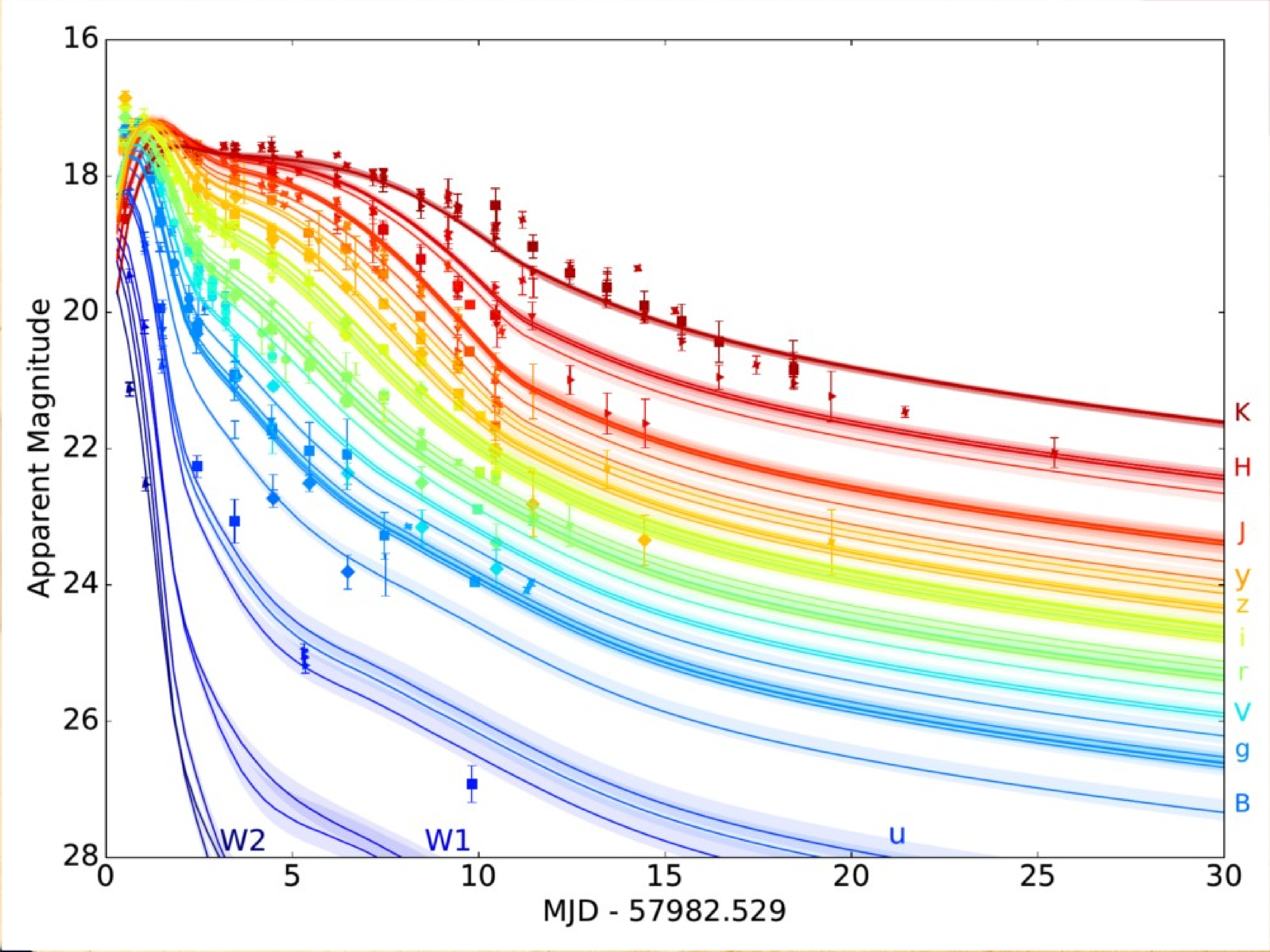
i) **Blue, fast:** $M_{ej} = 0.01\ M_{sol}$
$v_{ej} = 0.3c$

ii) **Red, slow**: $M_{ej} = 0.04\ M_{sol}$
$v_{ej} = 0.1c$

(Cowperthwaite+17; Nicholl+17, Smartt+17, Kasliwal+17 and etc...)

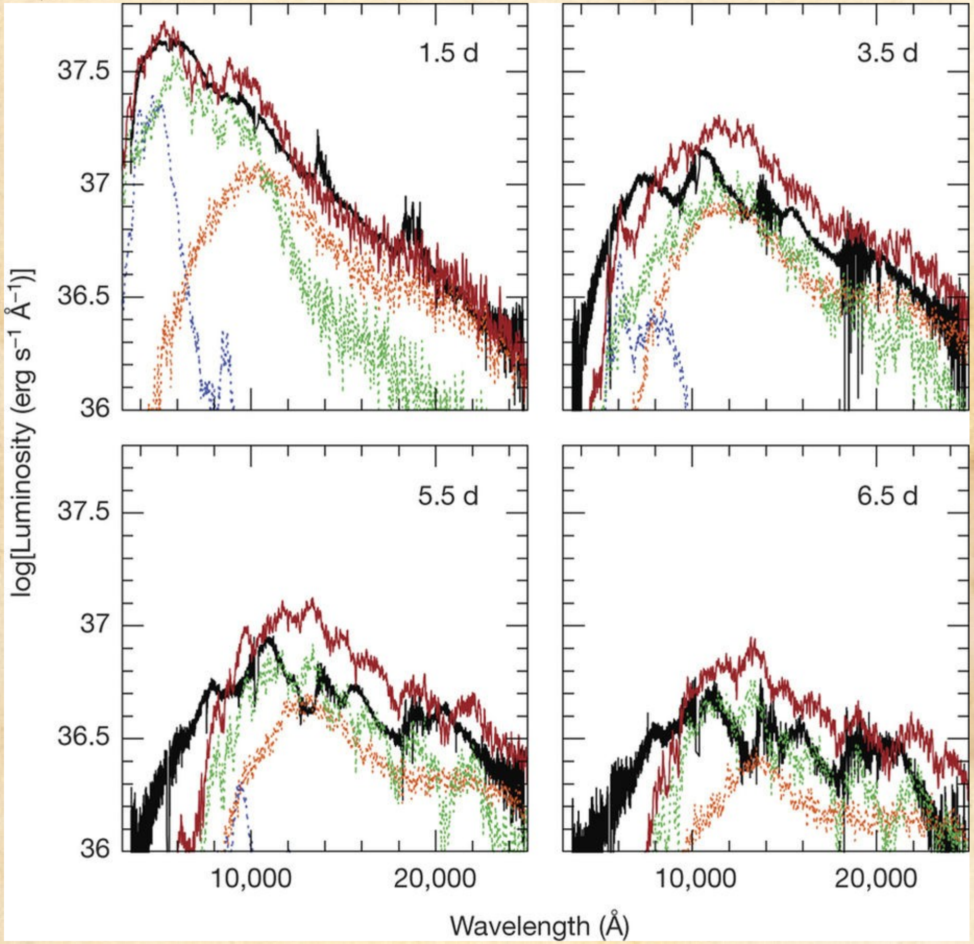


(Cowperthwaite+17,ApJ)

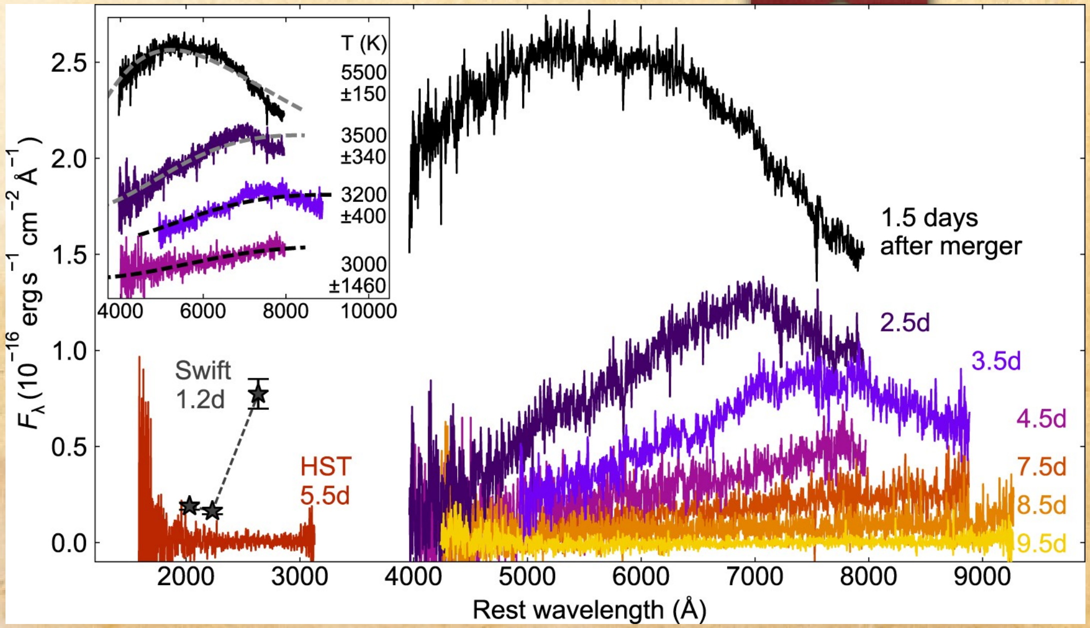


(Villar+17)

NIR/opt spectrum: unprecedented



(Pian+17)

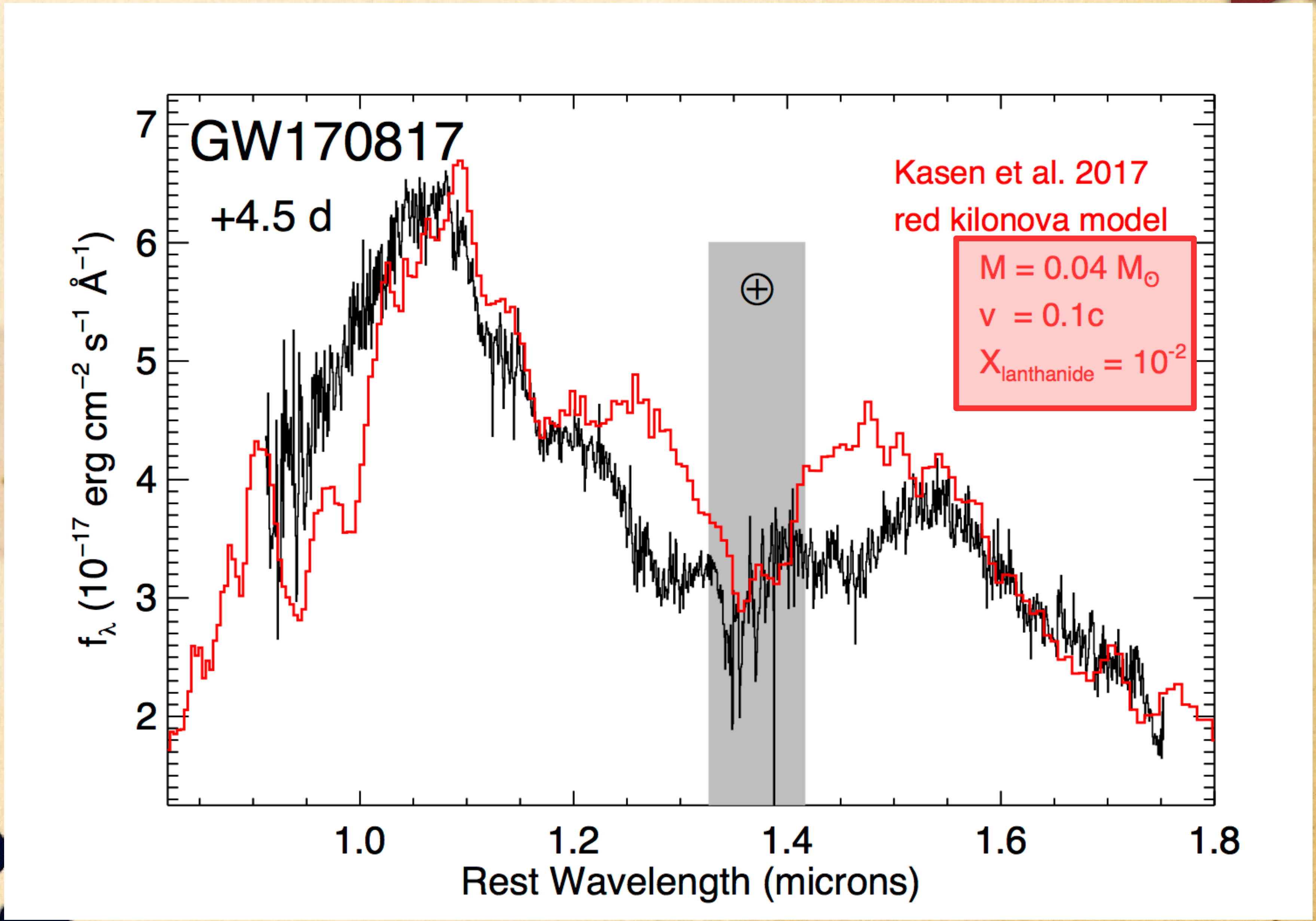


(Nicholl+17)

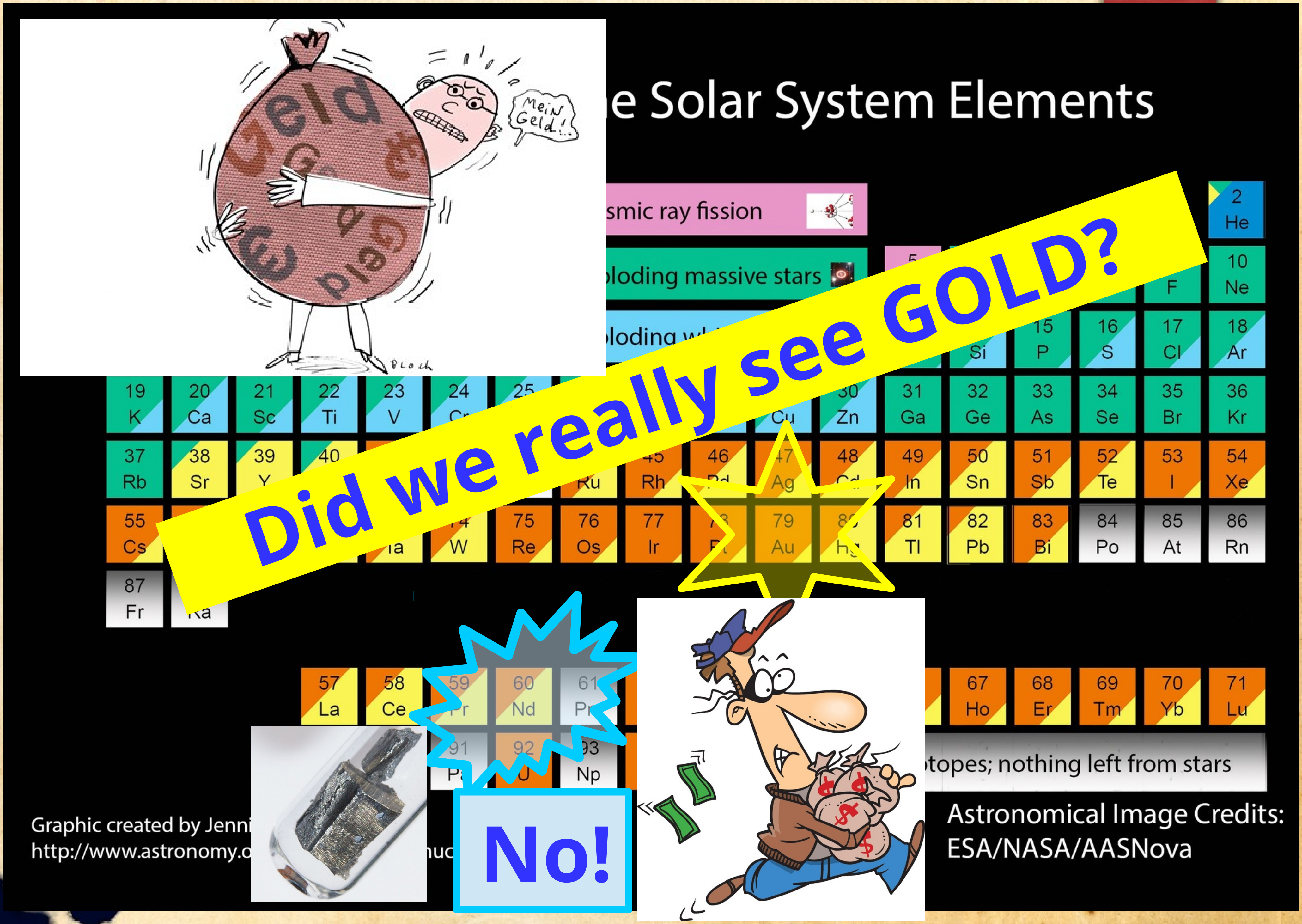
First clear support for heavy element production in a neutron star merger

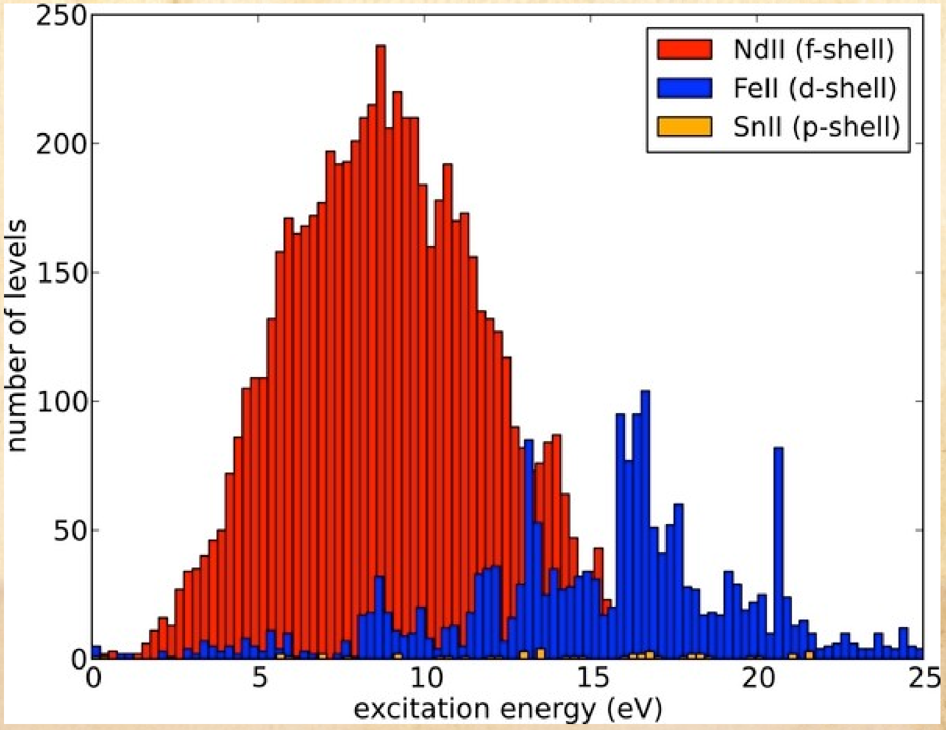
See also Chornock+17; Smartt+17; Kasliwal+17; Troja+17

NIR: Impressive agreement with theory!



(Chornock+17,ApJ)


e Solar System Elements
Did we really see GOLD?
Mein Geld!
smic ray fission
loding massive stars
No!
topes; nothing left from stars
Graphic created by Jenni
http://www.astronomy.o
Astronomical Image Credits:
ESA/NASA/AASNova



(Kasen+13)

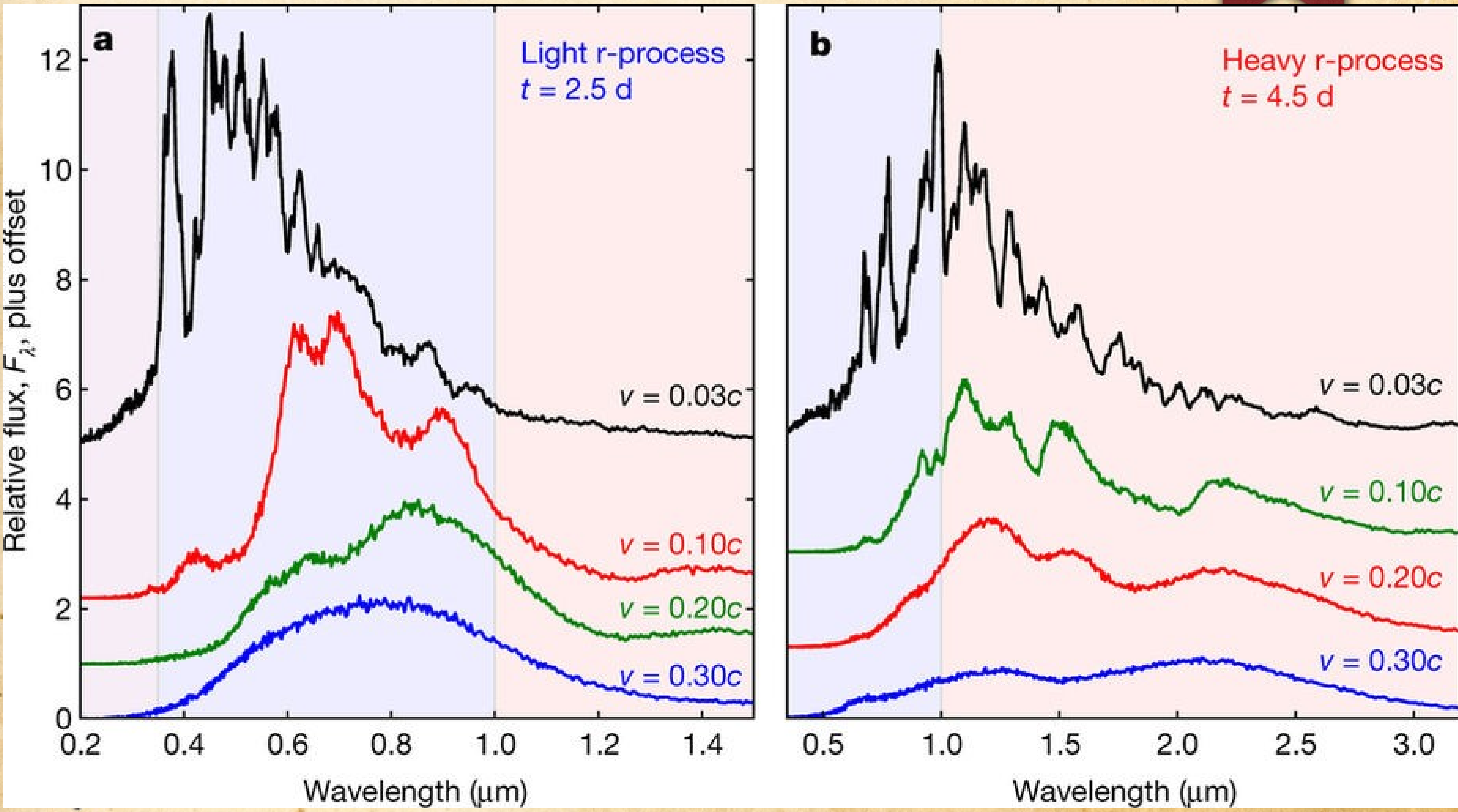
- Atoms/ions with open *f*-shells have many more available states compared to iron-peak elements

Ion	Configurations	Number of levels	Number of lines
Nd I	$\mathbf{4f^4 6s^2}$, $\mathbf{4f^4 6s(5d, 6p, 7s)}$, $\mathbf{4f^4 5d^2}$, $\mathbf{4f^4 5d6p}$, $4f^3 5d6s^2$, $4f^3 5d^2(6s, 6p)$, $4f^3 5d6s6p$	31,358	70,366,259

(Tanaka+07)

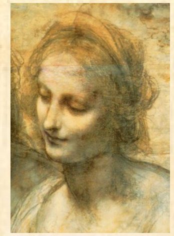
Huge opacity! Flux shifts towards NIR

Broadenend and blended lines: high ejecta vel!



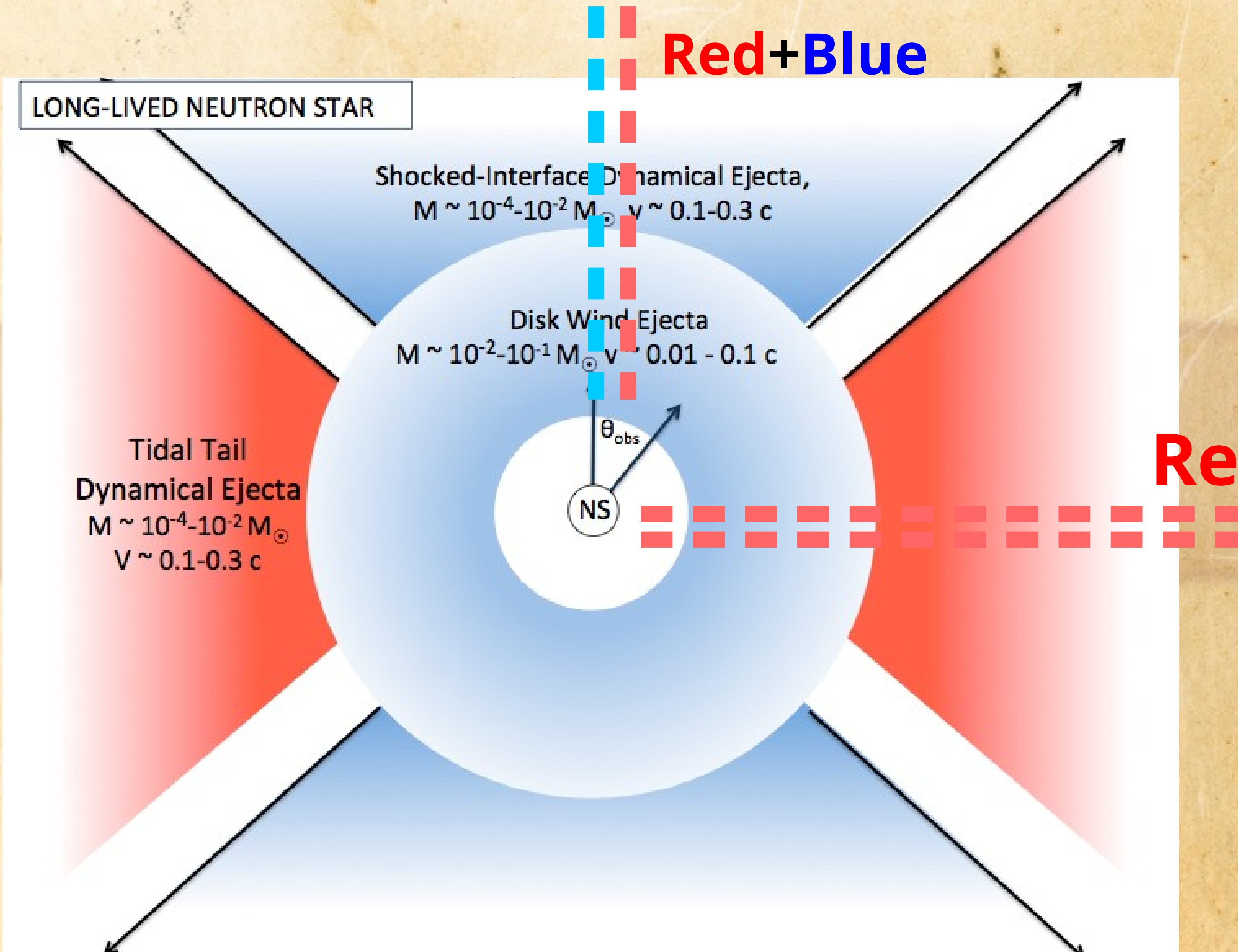
(Kasen+17)

$M_{ej} \sim 0.01\text{-}0.02\ M_{sol}$
$v_{ej} \sim 0.3c$
$X_{lan} \sim< 10^{-4}$



$M_{ej} \sim 0.04\ M_{sol}$
$v_{ej} \sim 0.1c$
$X_{lan} \sim 10^{-2}$

Red+Blue

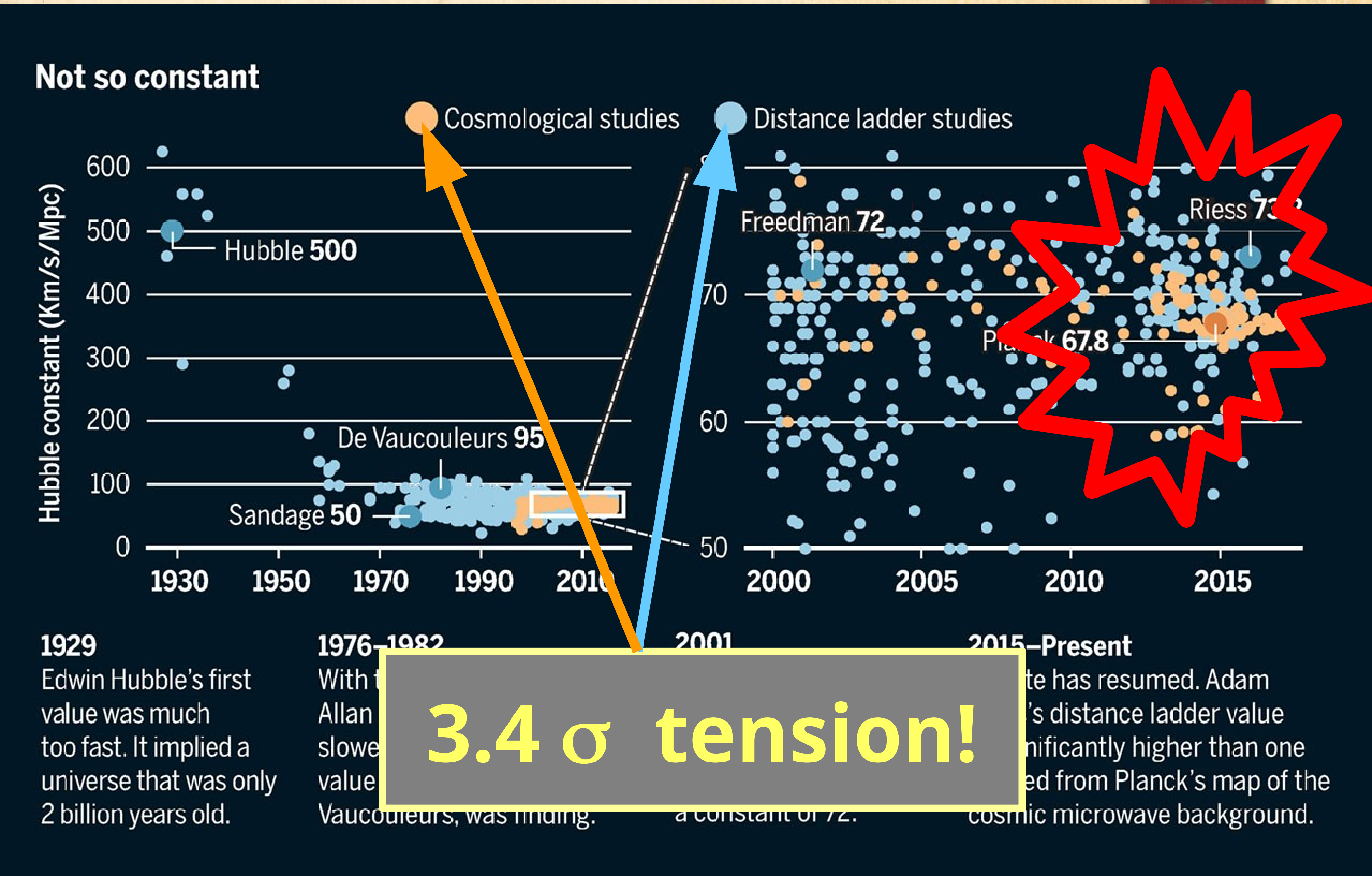


Red

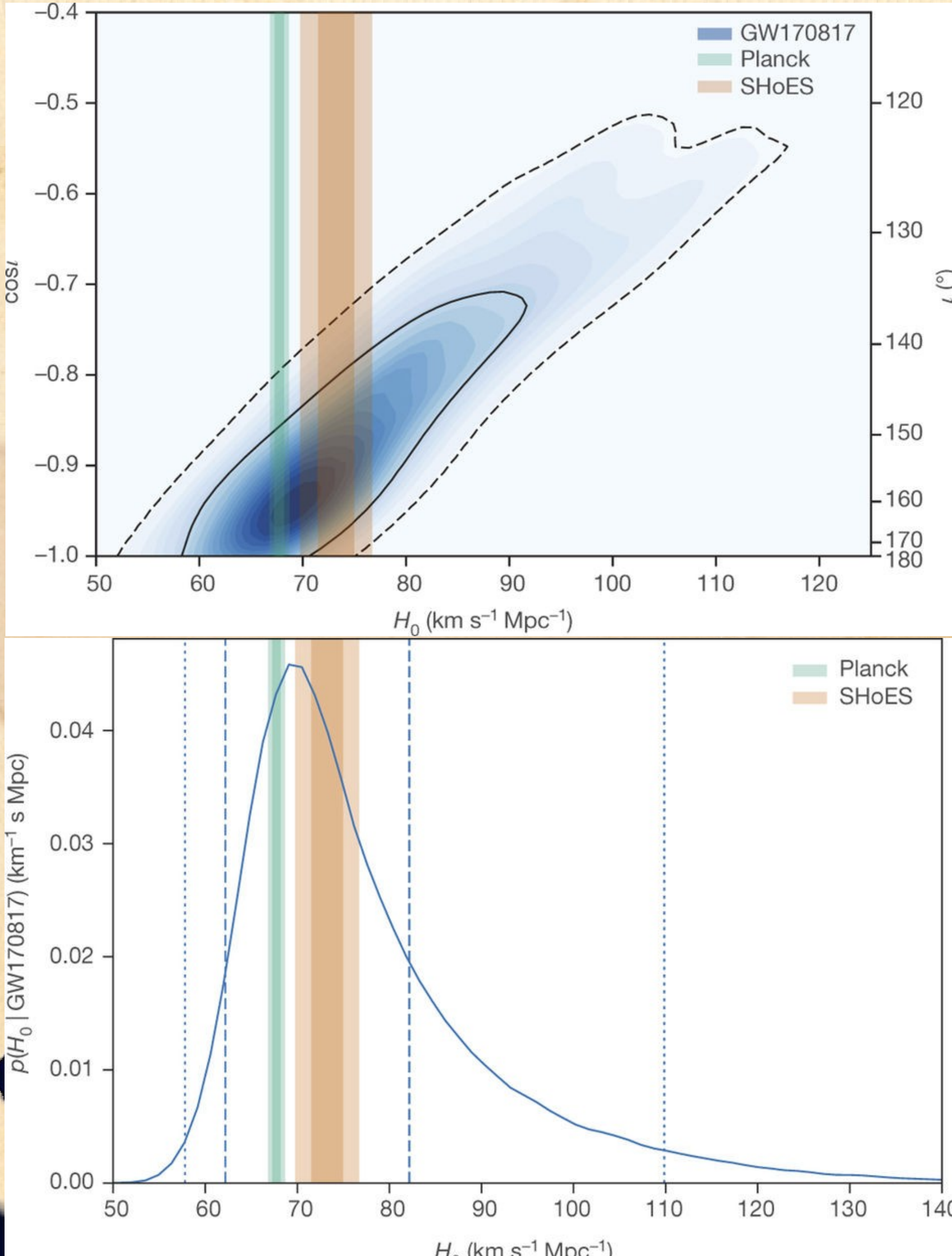
(Metzger17)

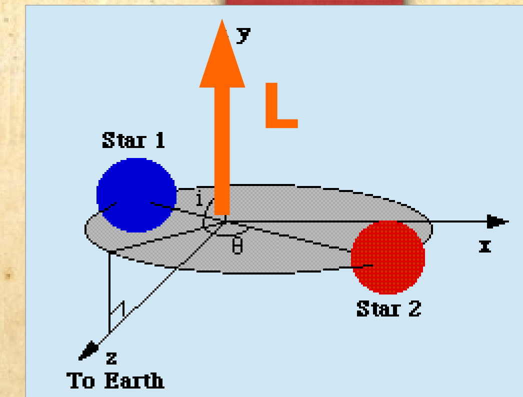
Combining GW+e.m. information to constrain the Hubble Constant H0

The Hubble (not so) Constant H0



GW170817: measuring H0!





GW signal:

amplitude=f(cos(i), d)

$v_H = H_0\, d$ (Hubble, small z)

$\mathbf{v}_H = \mathbf{v}_r - \mathbf{v}_p$

Recessional velocity (z)

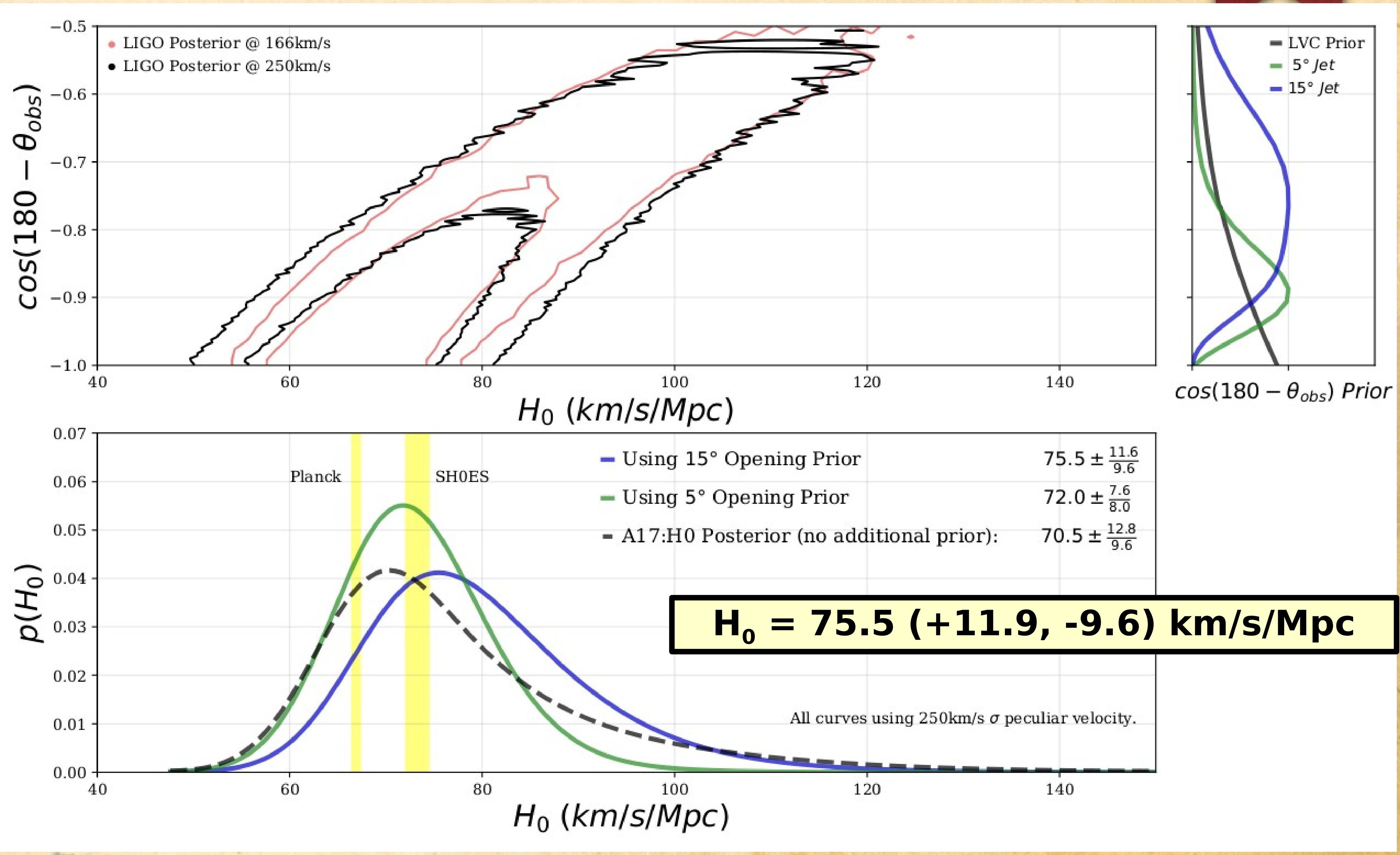
Peculiar motions

At d~40 Mpc: $|\mathbf{v}_p| \sim |\mathbf{v}_H|/10$

H_0 = 70 (+12, -8) km/s/Mpc

(LV+em 17,Nature)

GW170817: combining afterglow info on inclination ➡ measuring H0!



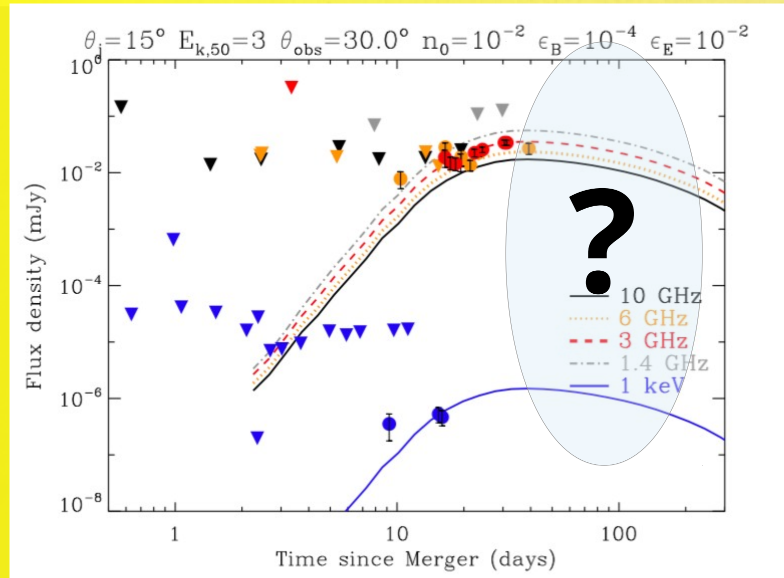
H_0 = 75.5 (+11.9, -9.6) km/s/Mpc

(Guidorzi+17)

(credits: LIGO+Virgo+gamma+17,ApJ)

What's coming up next? Are we already done with GW170817?

The FUTURE of our EM follow-up:



GW trigger

9 days

15 days

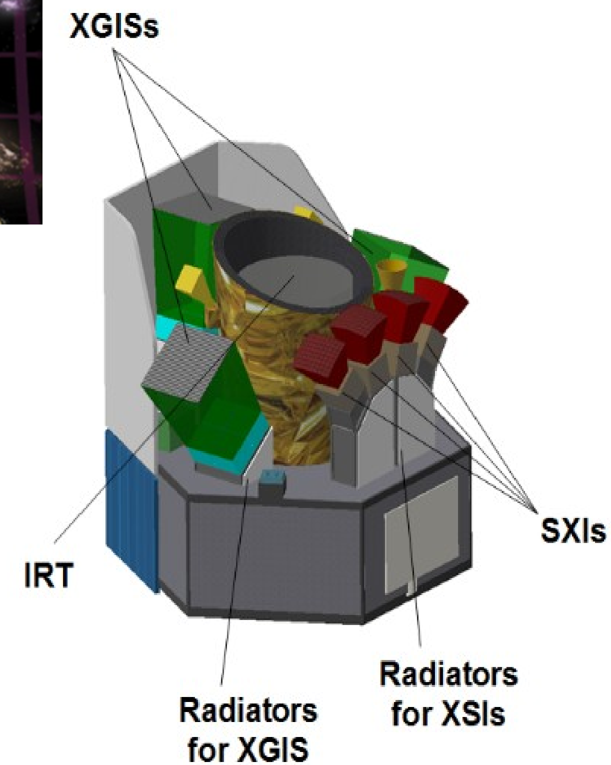
SUN block!

100days

GW170817 is still ON in X-rays and radio!

theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR



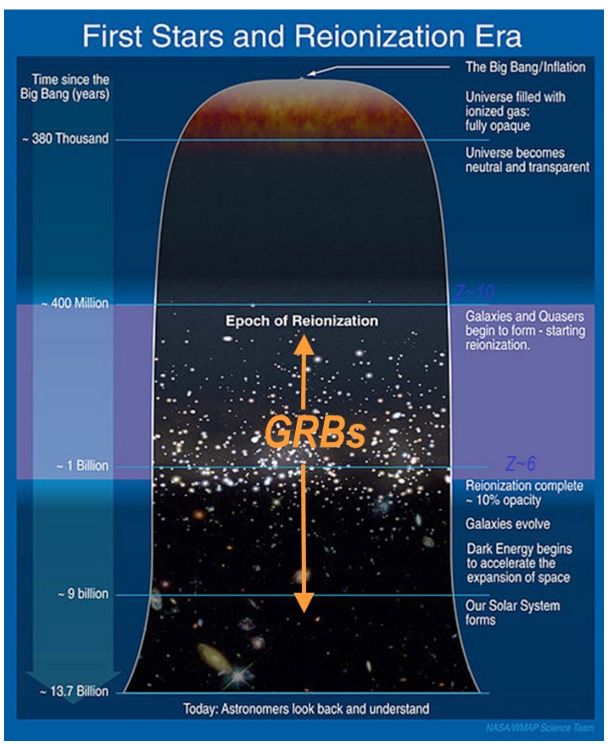
THESEUS mission design and science objectives

Probing the Early Universe with GRBs

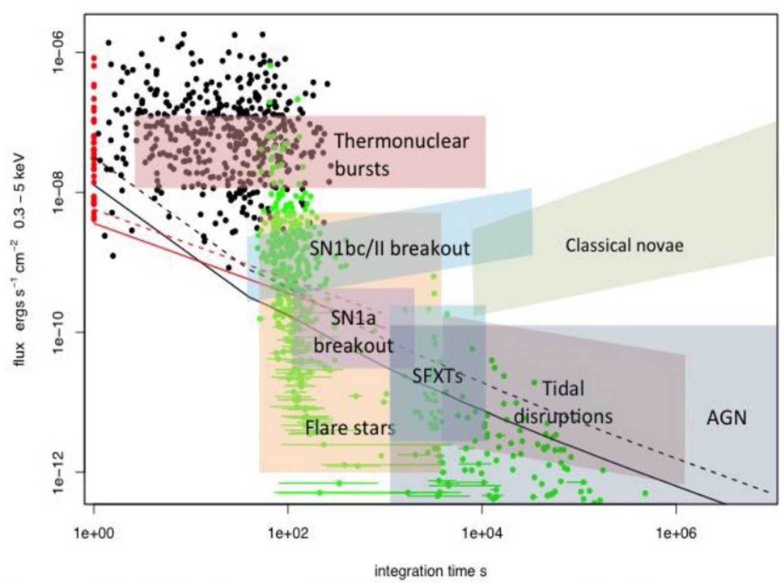
Multi-messenger and time domain Astrophysics

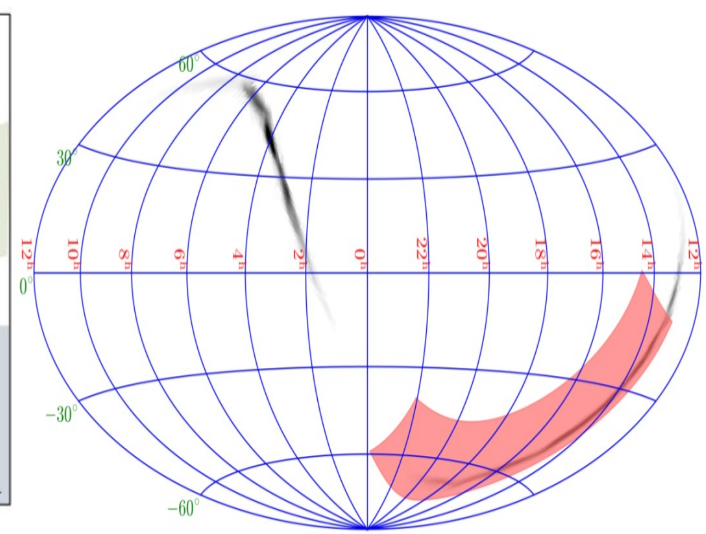
The transient high energy sky

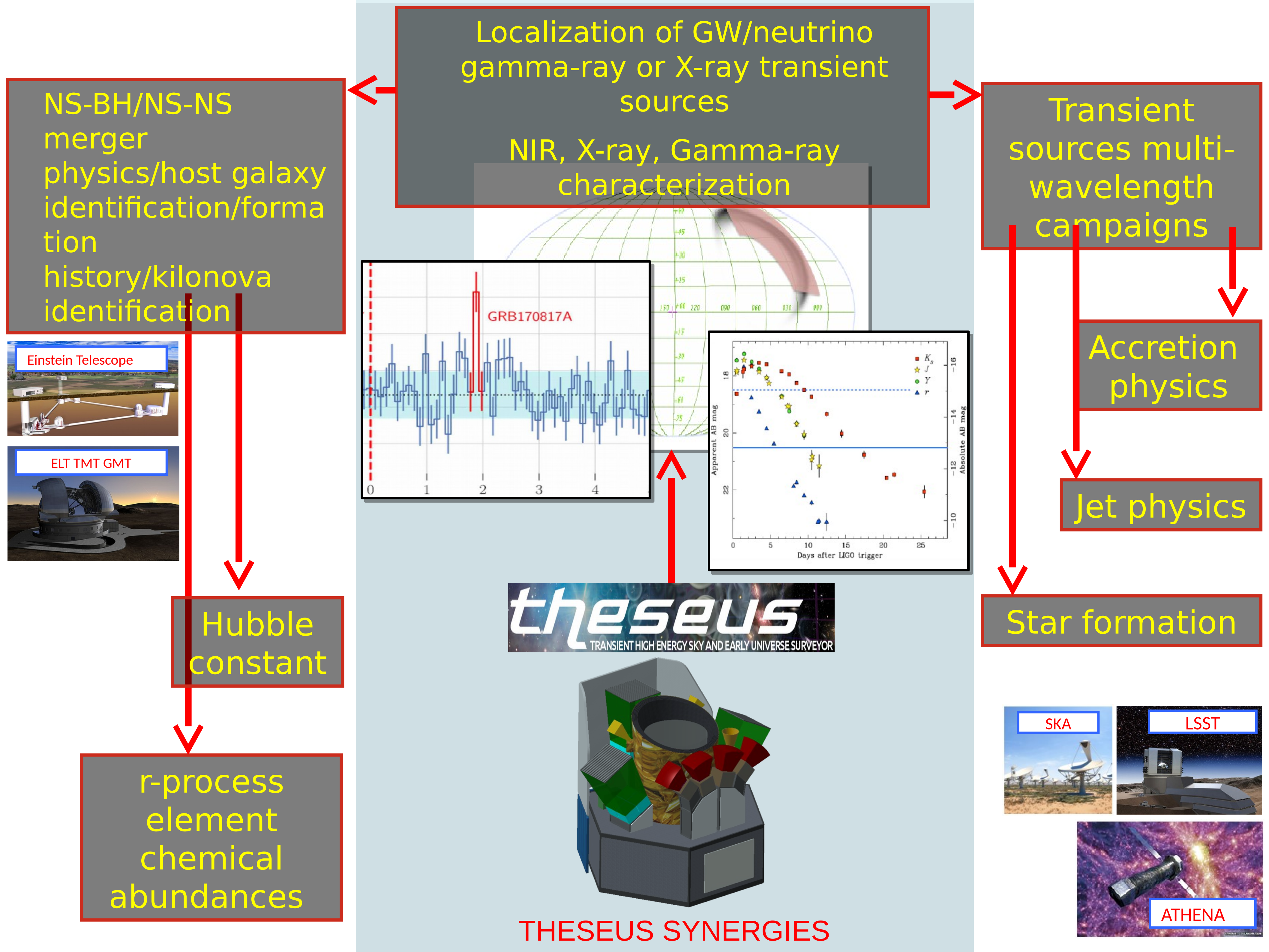
Synergy with next generation large facilities (E-ELT, SKA, CTA, ATHENA, GW and neutrino detectors)



Time-domain multi-messenger astrophysics







Localization of GW/neutrino gamma-ray or X-ray transient sources
NIR, X-ray, Gamma-ray characterization
NS-BH/NS-NS merger physics/host galaxy identification/formation history/kilonova identification
Transient sources multi-wavelength campaigns
Accretion physics
Jet physics
Star formation
Einstein Telescope
ELT TMT GMT
Hubble constant
r-process element chemical abundances
GRB170817A
Apparent AB mag
Absolute AB mag
Days after LIGO trigger
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TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR
SKA
LSST
ATHENA
THESEUS SYNERGIES

The End

Näherungsweise Integration der Feldgleichungen der Gravitation.

Von A. Einstein.

§ 2. Ebene Gravitationswellen.

Aus den Gleichungen (6) und (9) folgt, daß sich Gravitationsfelder stets mit der Geschwindigkeit 1, d. h. mit Lichtgeschwindigkeit, fortpflanzen. Ebene, nach der positiven x-Achse fortschreitende Gra-