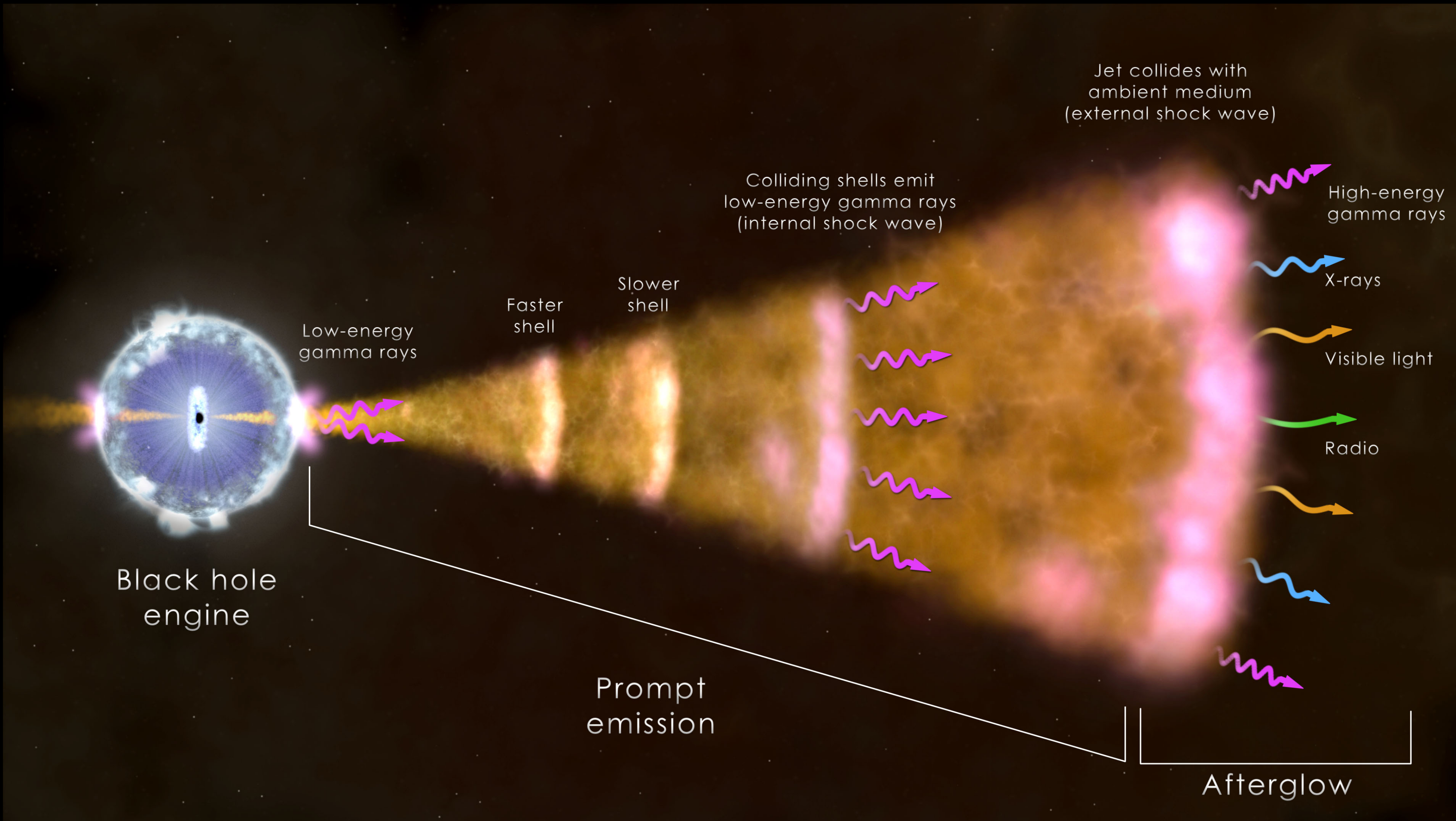
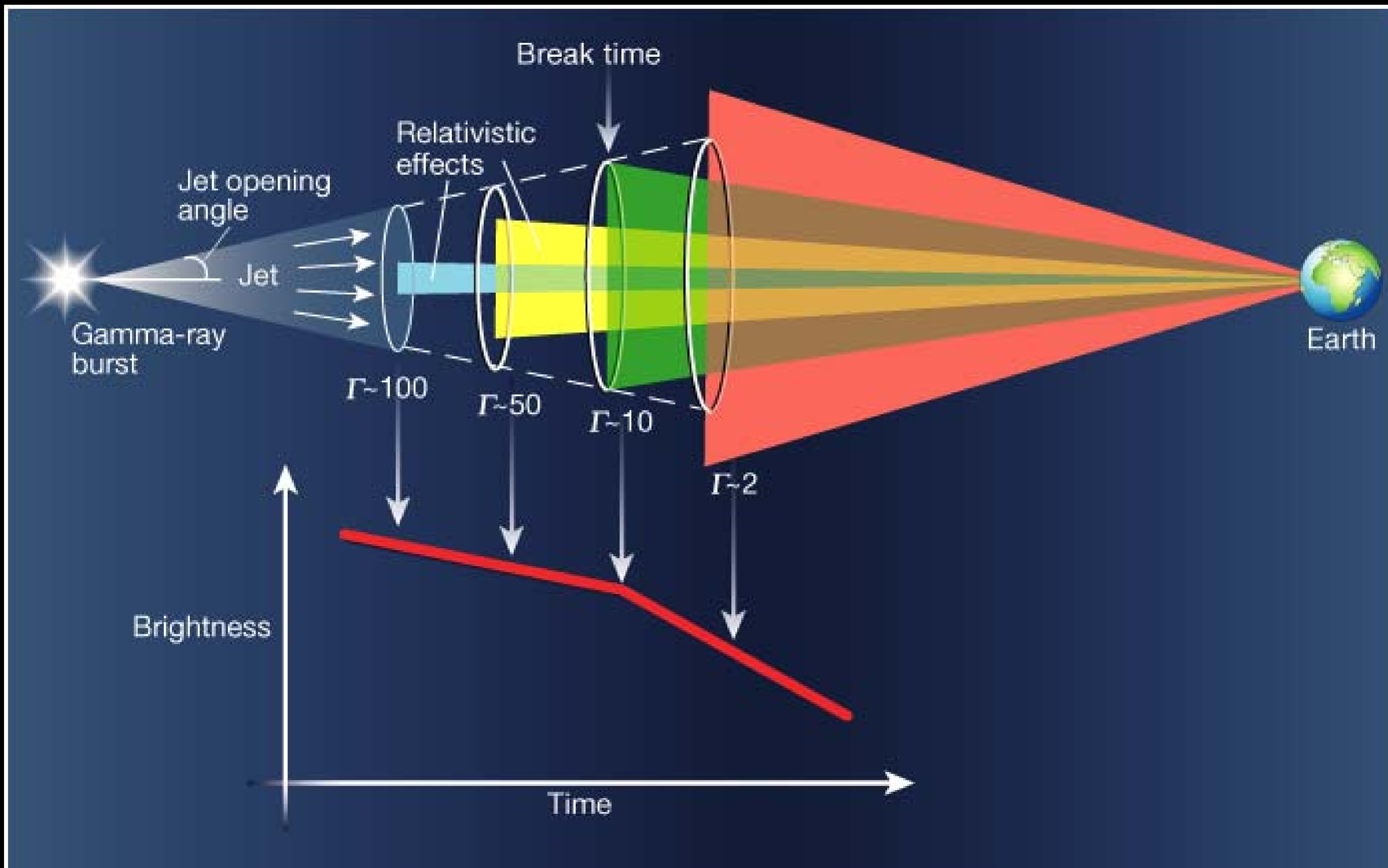
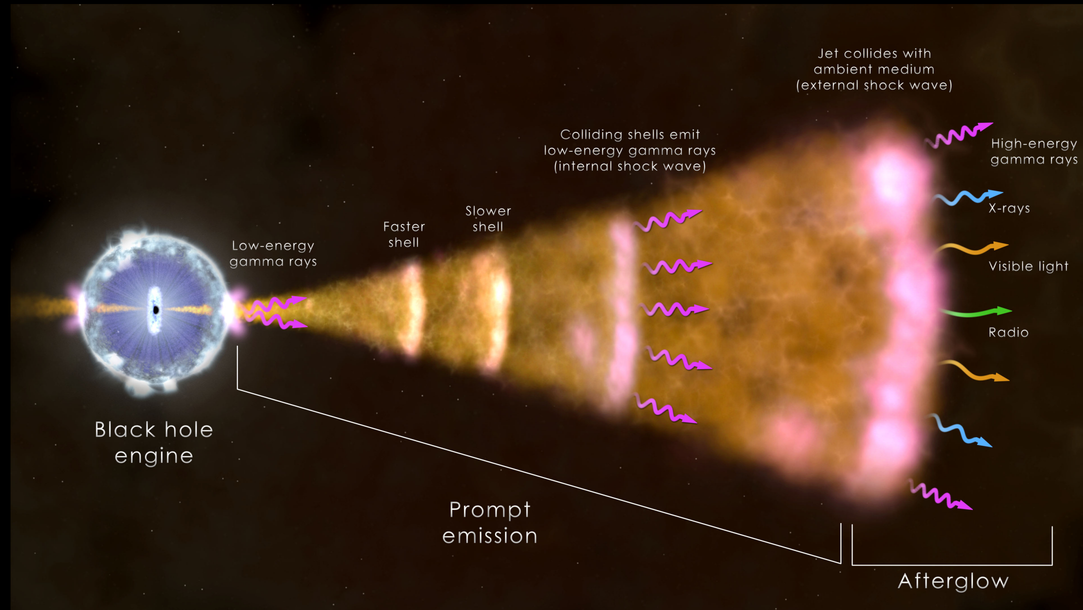
Afterglow emission from GRBs

Fabio De Colle
Instituto de Ciencias Nucleares, UNAM


Jet collides with
ambient medium
(external shock wave)
Colliding shells emit
low-energy gamma rays
(internal shock wave)
High-energy
gamma rays
X-rays
Visible light
Radio
Slower
shell
Faster
shell
Low-energy
gamma rays
Black hole
engine
Prompt
emission
Afterglow

Jet structure

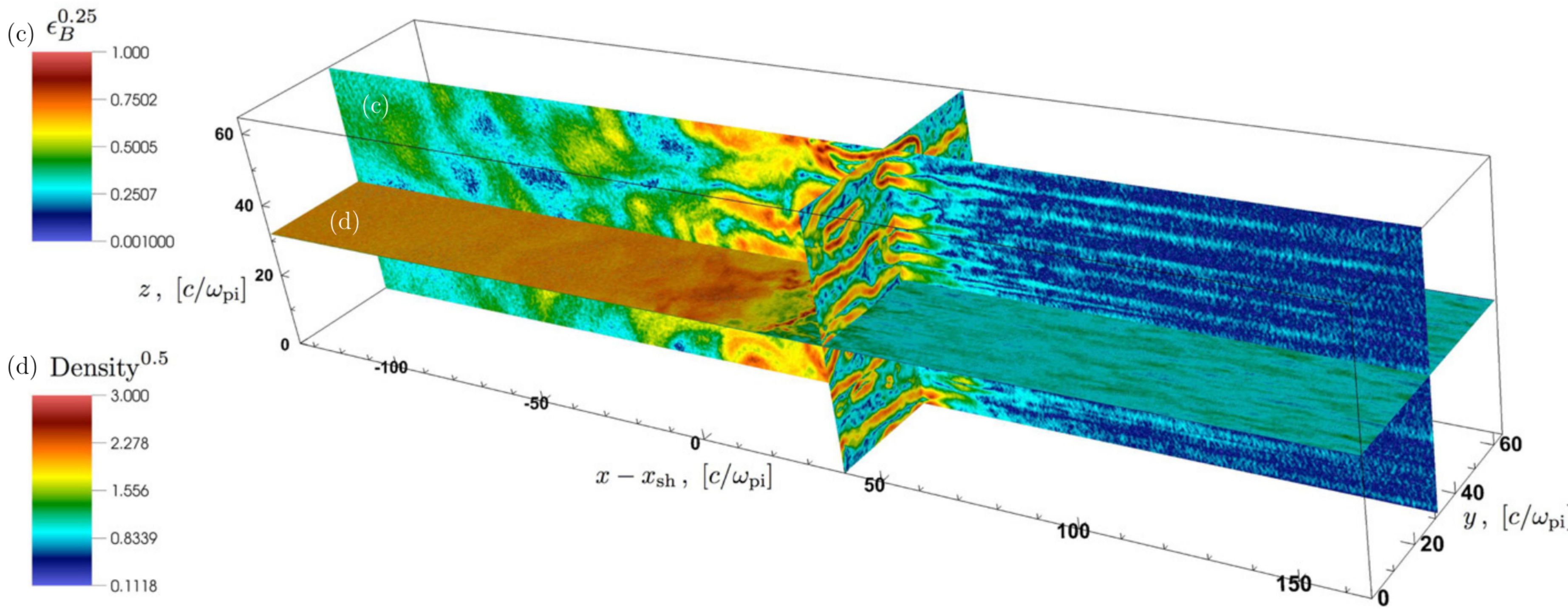




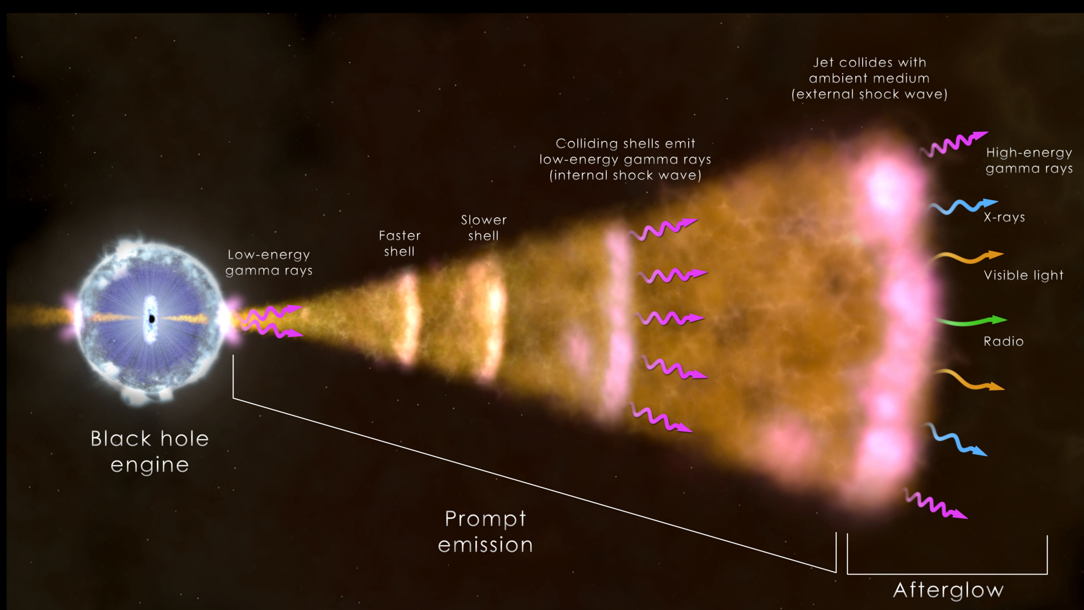
$$\frac{\partial \gamma\rho}{\partial t} + \nabla \cdot \left(\gamma\rho\vec{v} \right) = 0$$

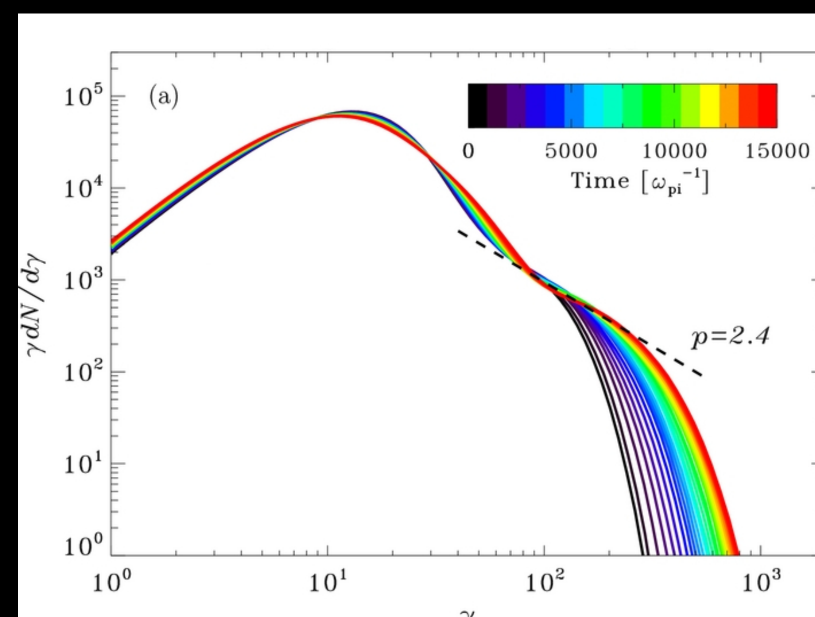
$$\frac{\partial \rho\vec{v}\vec{v}\gamma^2 h}{\partial t} + \nabla \cdot \left(\rho\vec{v}\vec{v}\gamma^2 h + p\mathcal{I} \right) = 0$$

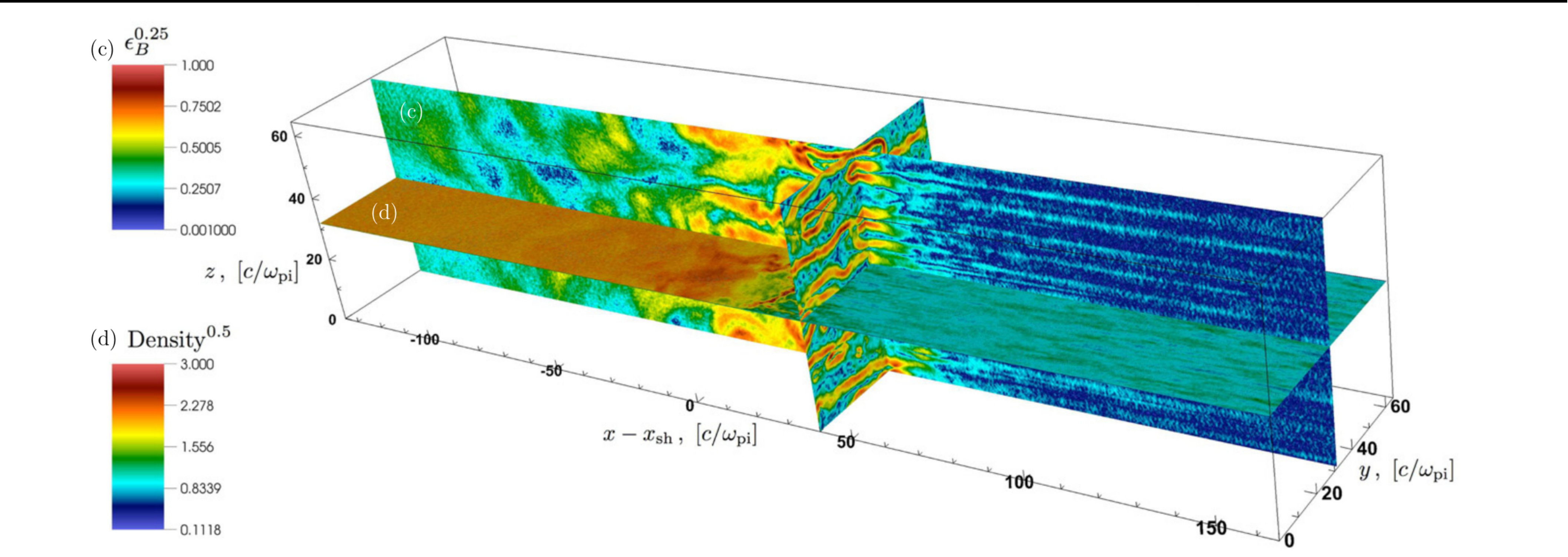
$$\frac{\partial e}{\partial t} + \nabla \cdot \left((e + p)\vec{v} \right) = 0$$



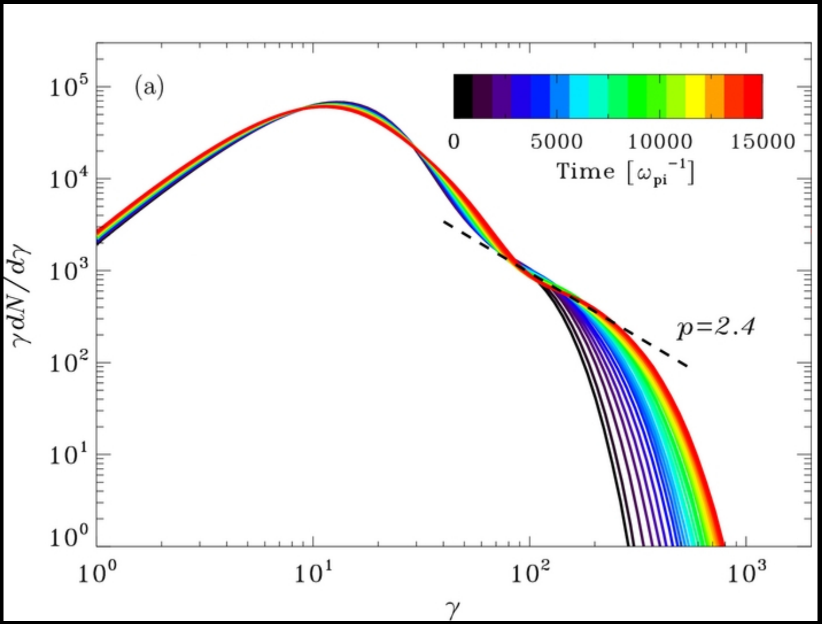
Sironi et al. (2013)







Sironi et al. (2013)

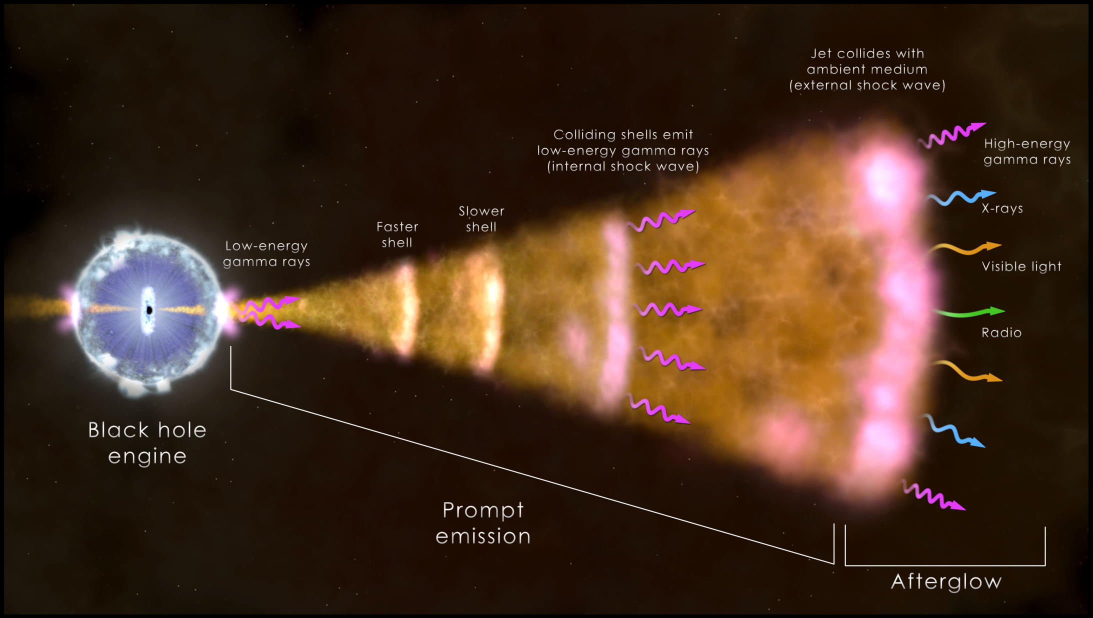


Parametrization of our "ignorance"…

Magnetic field is amplified by the shock: ε_B

Electrons are accelerated by the shock: ε_e

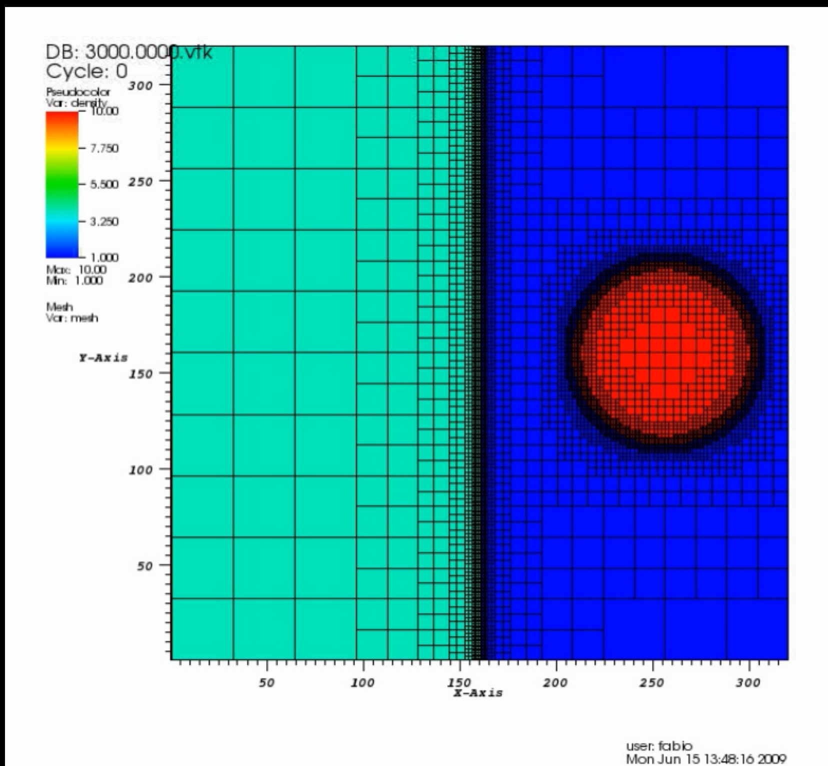
Electron number density is a power-law: $n \propto \gamma^{-p}$

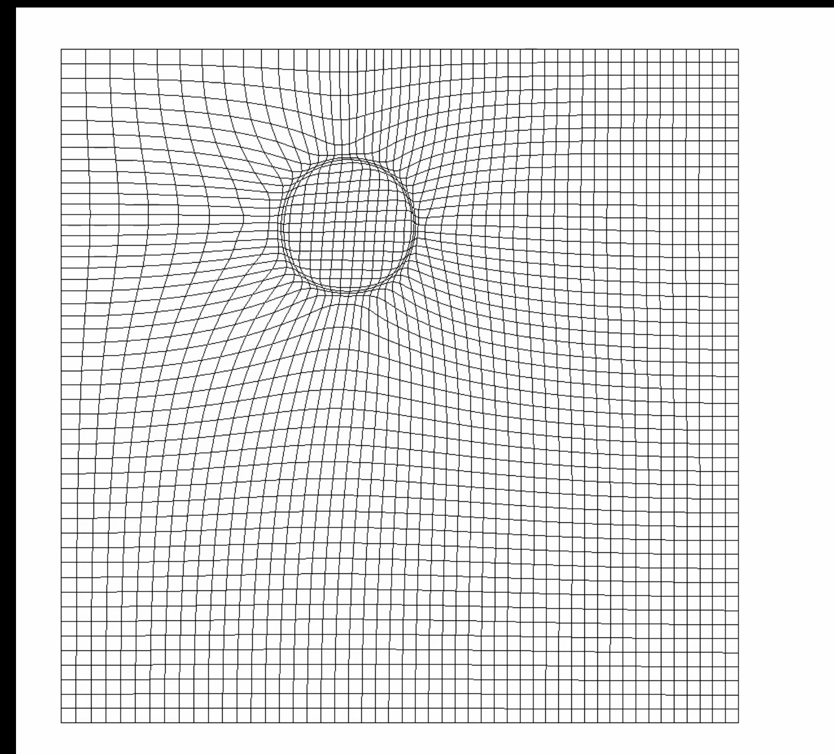


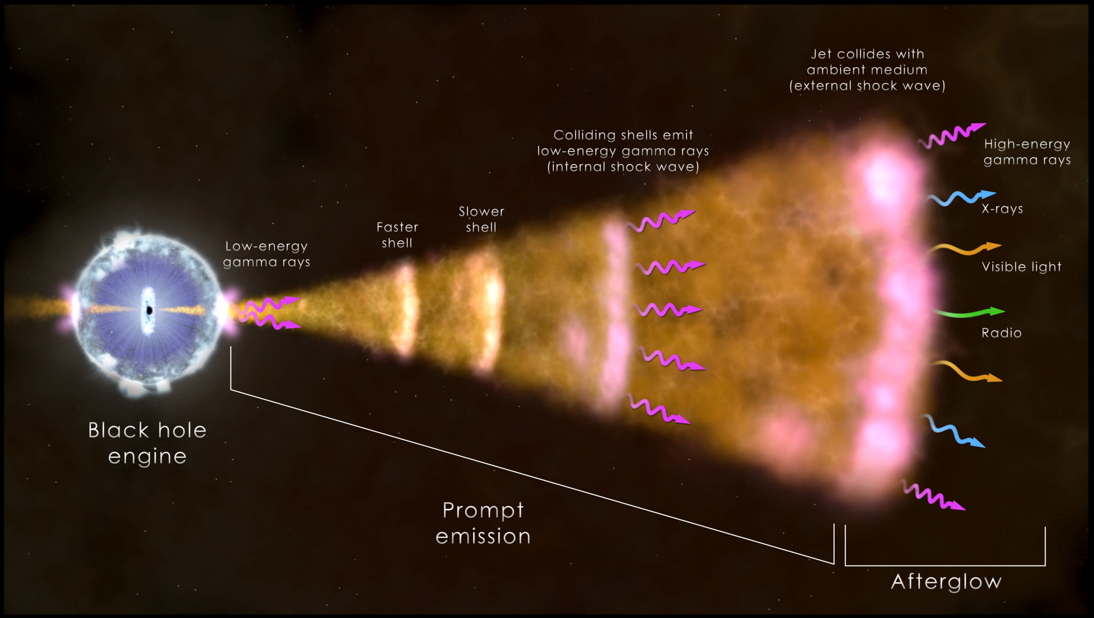
Main problem

...

Huge spatial range (10^8-10^{18} cm)


DB: 3000.0000.vtk
Cycle: 0
Pseudocolor
Var: density
10.00
7.750
5.500
3.250
1.000
Max: 10.00
Min: 1.000
Mesh
Var: mesh
Y-Axis
300
250
200
150
100
50
50
100
150
200
250
300
X-Axis
user: fabio
Mon Jun 15 13:48:16 2009

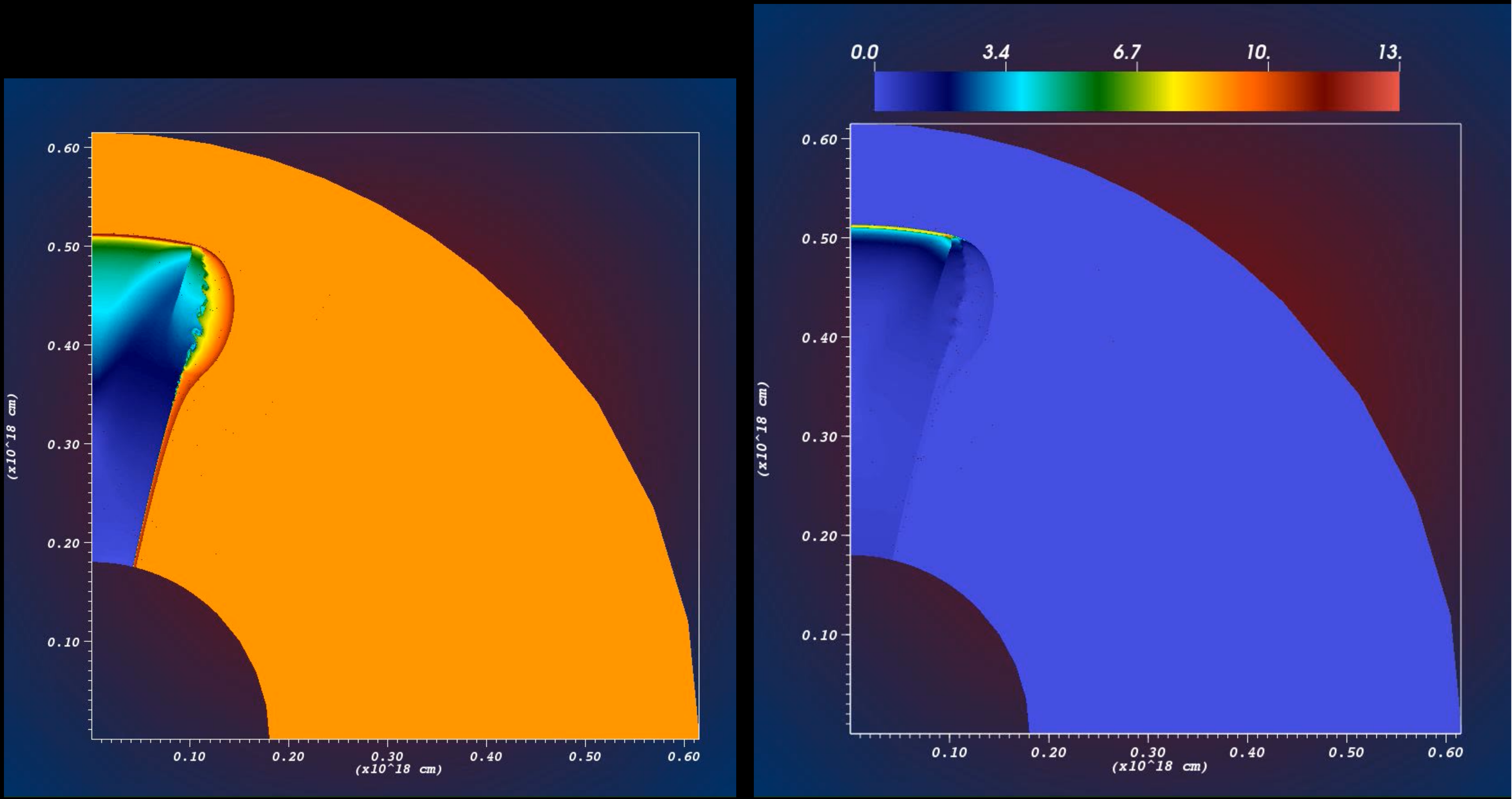




Main problem

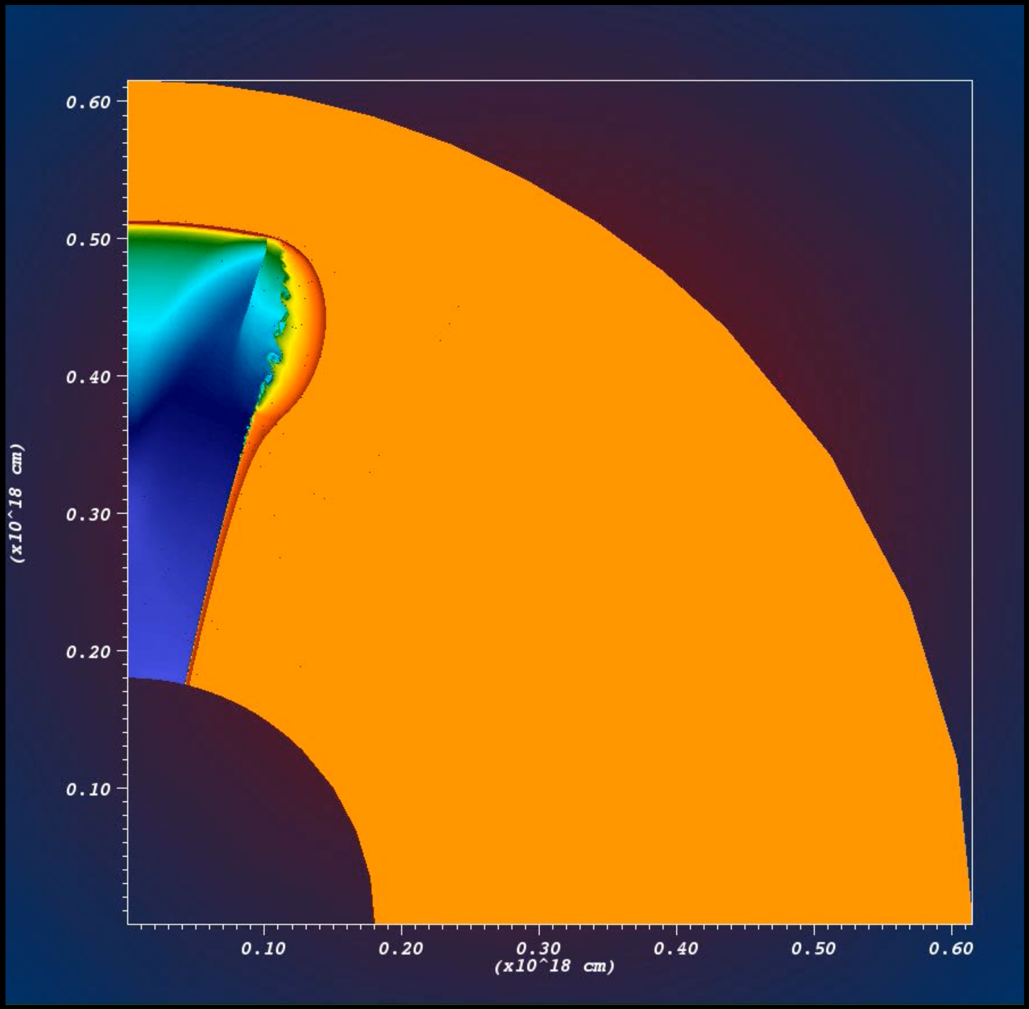
…

Huge spatial range (10^8-10^{18} cm)



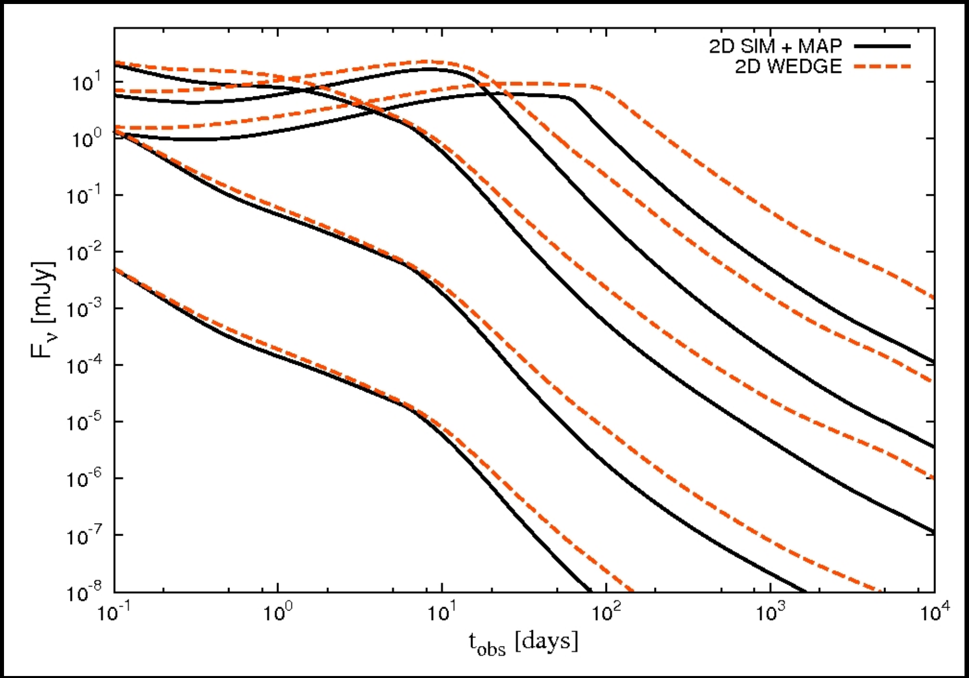
De Colle et al. (2012)

The dynamics can be rescaled...



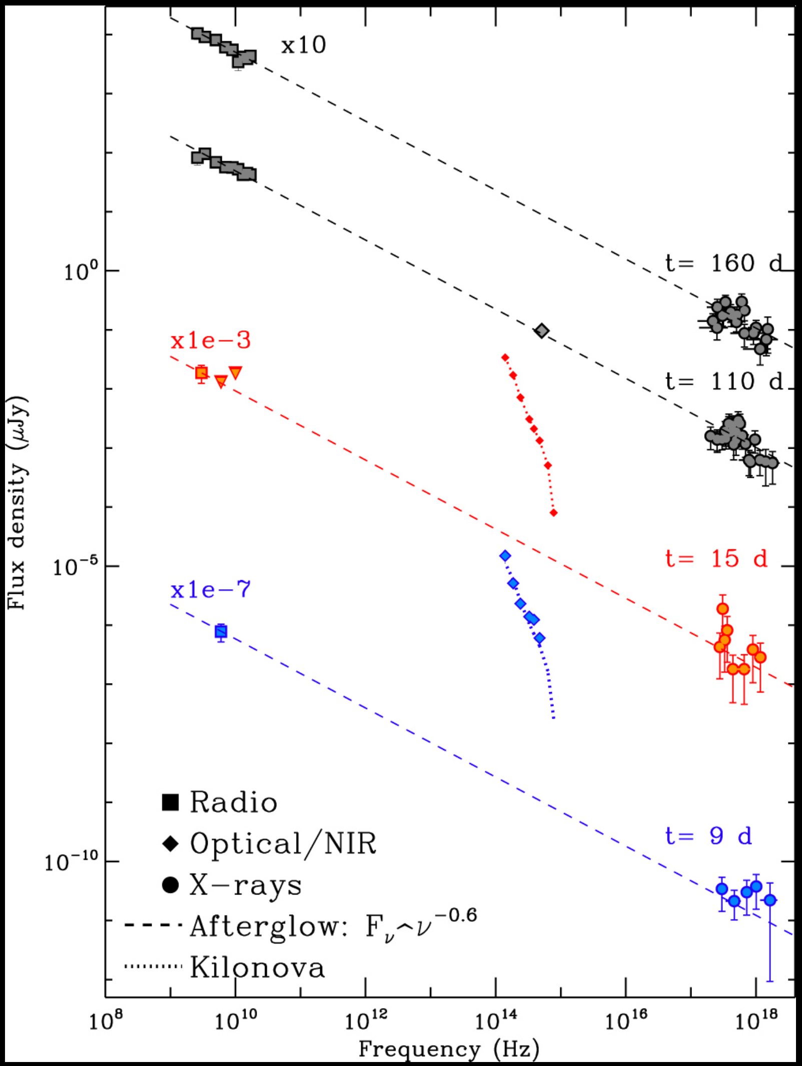
$$
\begin{aligned}
E &= \int_0^\infty e dV = \int_0^\infty 4\pi r^2 e dr \\
E' &= kE \\
n' &= \lambda n \\
\Rightarrow \frac{r'}{r} &= \frac{t'}{t} = \left(\frac{k}{\lambda}\right)^{1/3}
\end{aligned}
$$

And the radiation too… (see VanEerten 2012, Granot 2012)

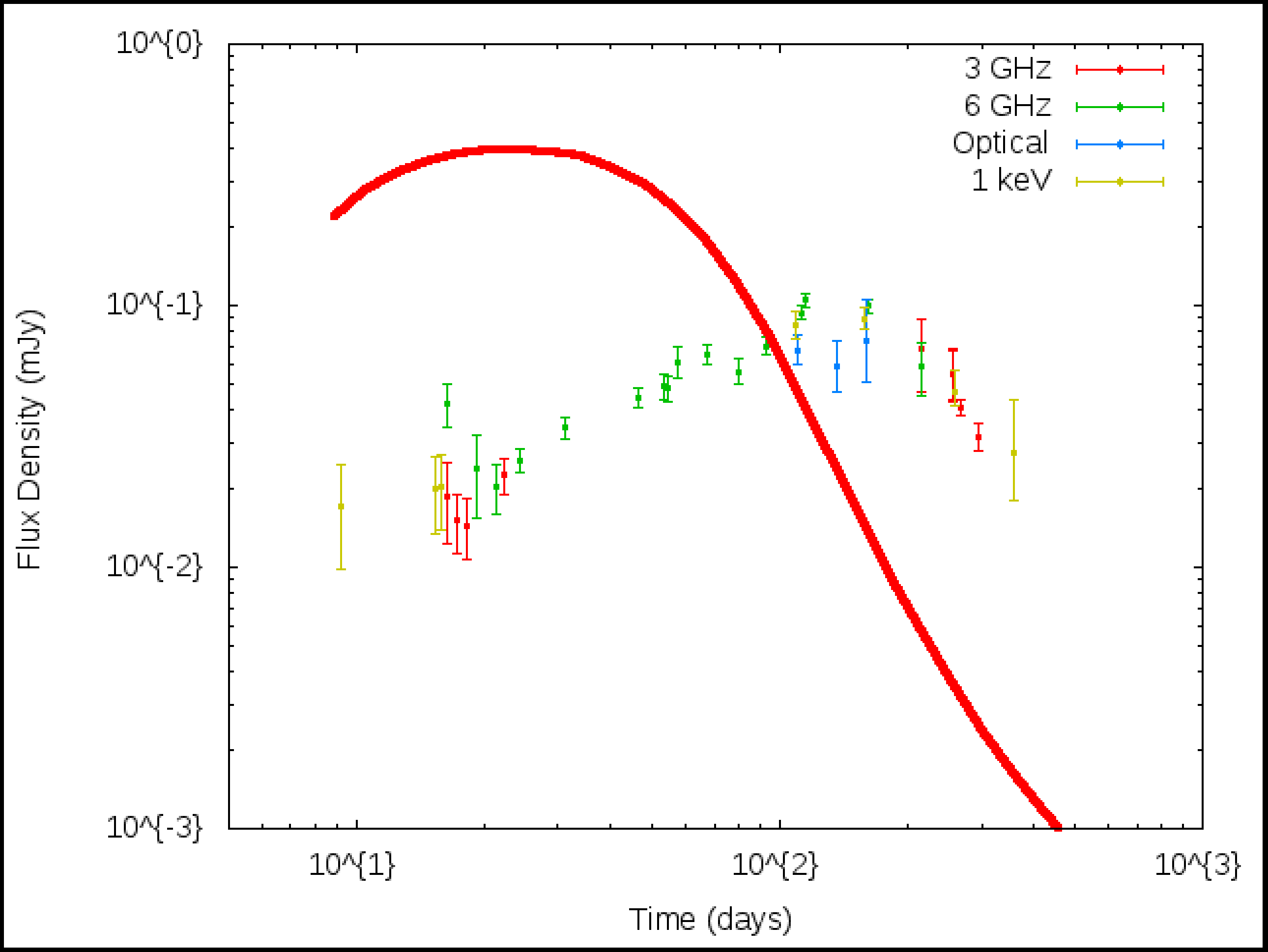


$$\frac{F'}{F} = k\lambda^{(1+p)/4}\left(\frac{\epsilon_e'}{\epsilon_e}\right)^{p-1}\left(\frac{\epsilon_B'}{\epsilon_B}\right)^{(1+p)/4}$$

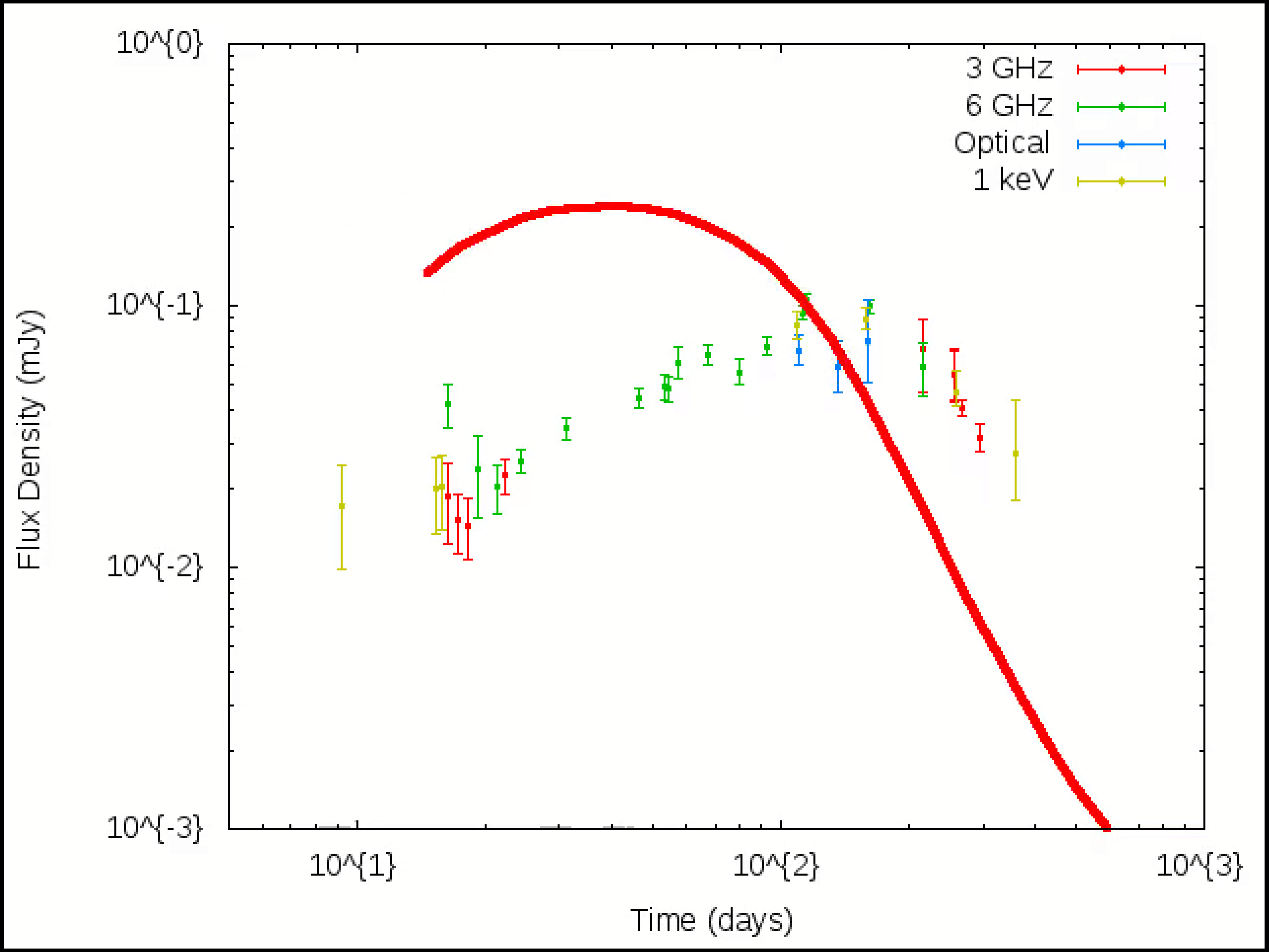
GRB 170817A



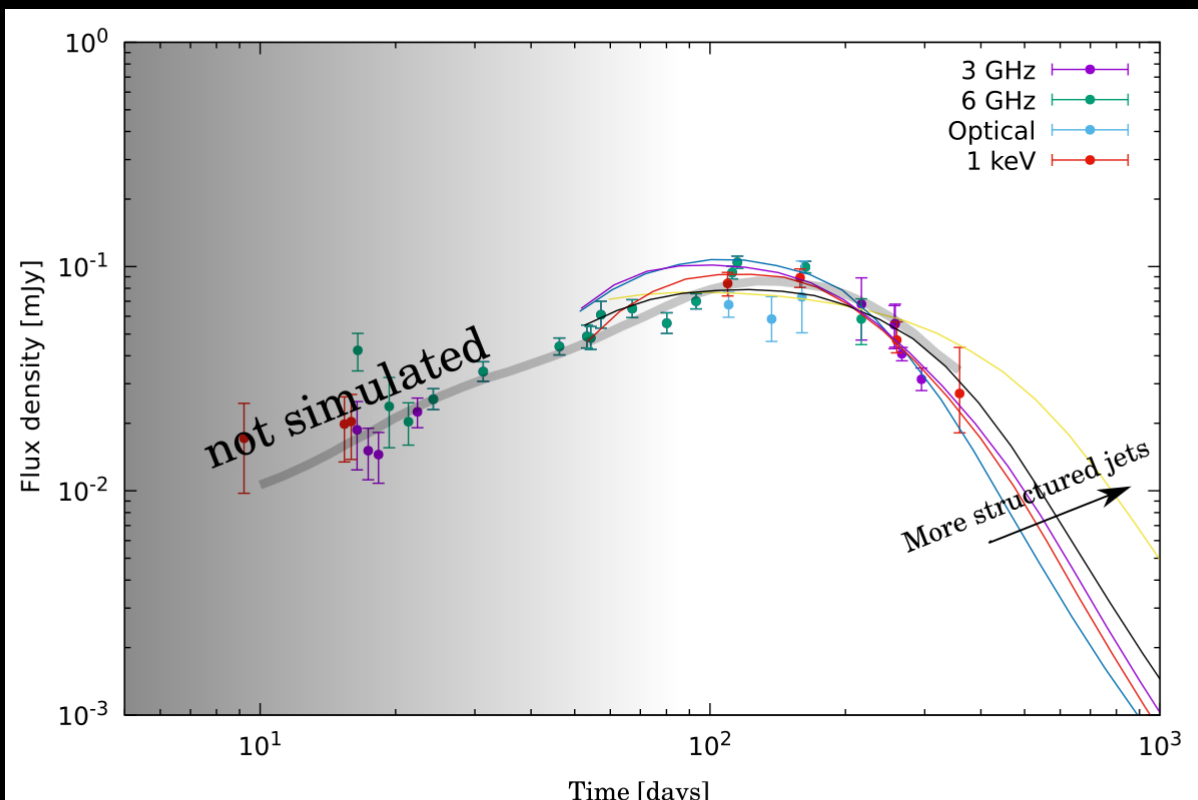
Margutti et al. (2018)



10^{0}
10^{-1}
10^{-2}
10^{-3}
Flux Density (mJy)
10^{1}
10^{2}
10^{3}
Time (days)
3 GHz
6 GHz
Optical
1 keV



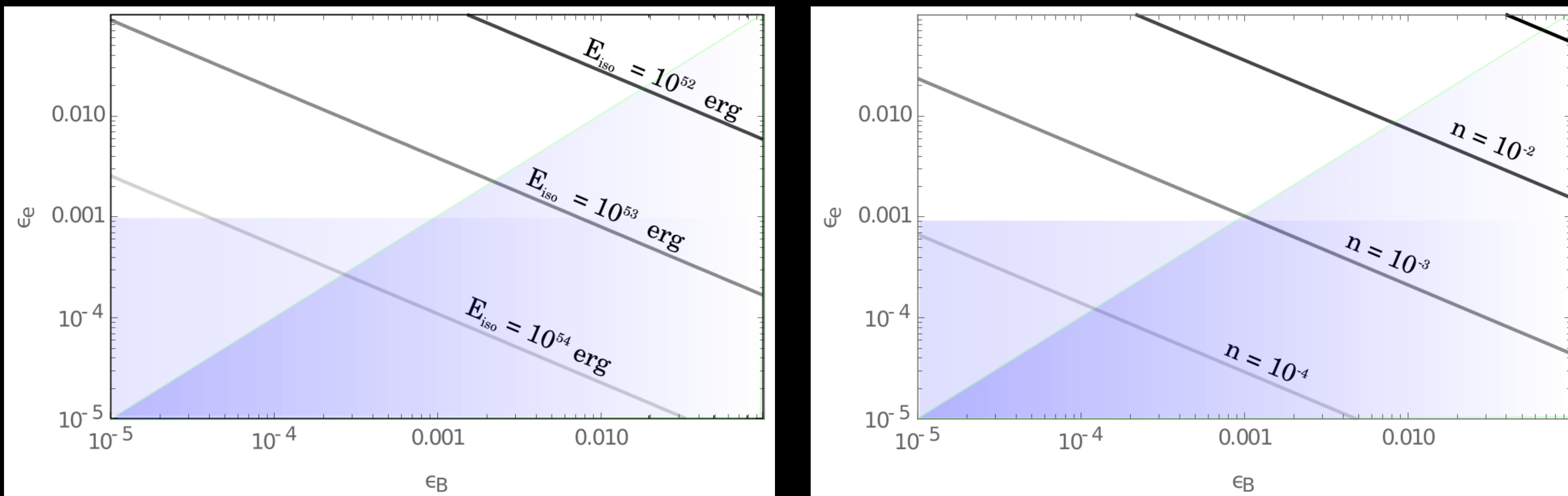
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{1}
10^{2}
10^{3}
Flux Density (mJy)
Time (days)
3 GHz
6 GHz
Optical
1 keV



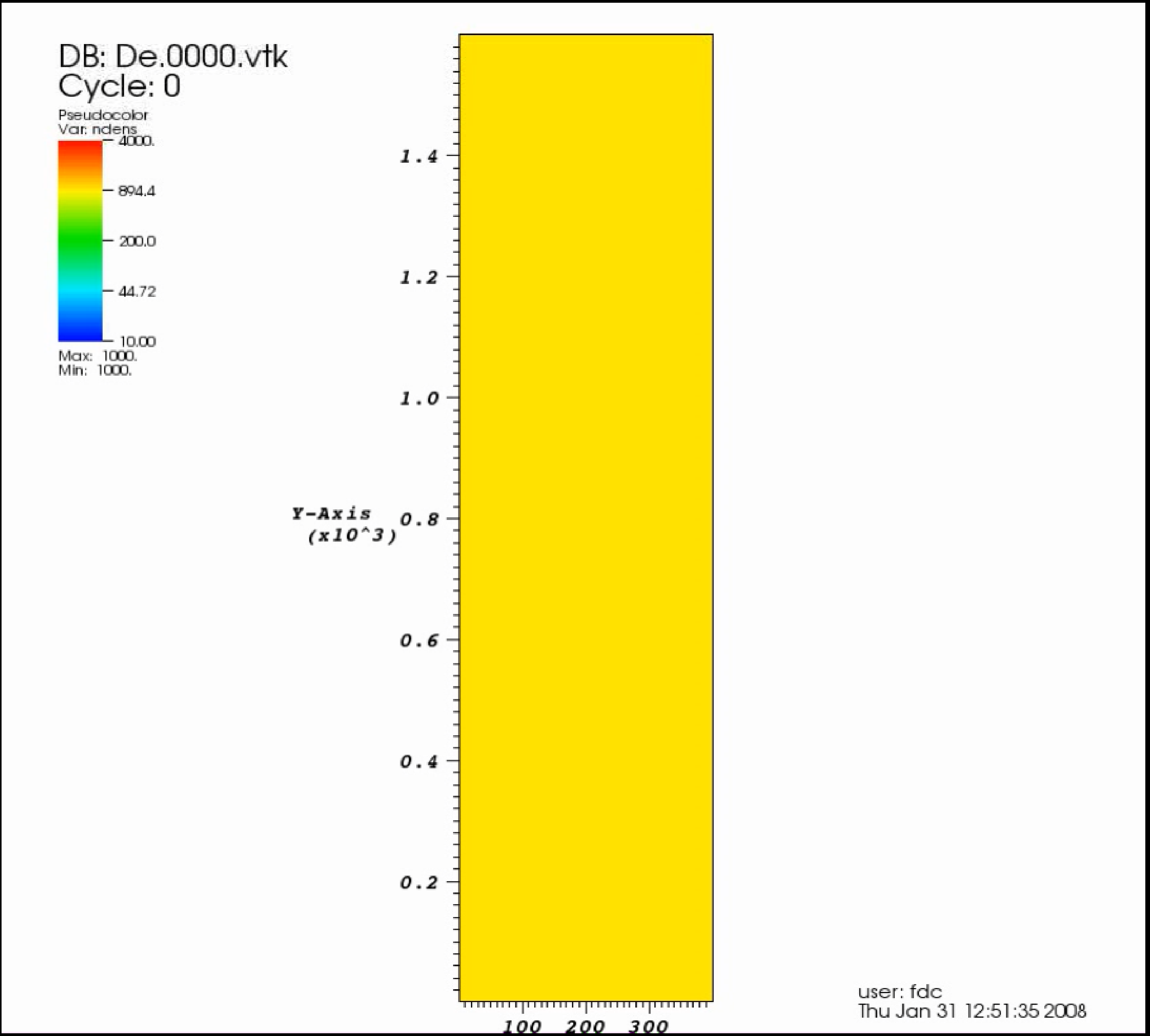
$$\frac{F'}{F} = k\lambda^{(1+p)/4}\left(\frac{\epsilon'_e}{\epsilon_e}\right)^{p-1}\left(\frac{\epsilon'_B}{\epsilon_B}\right)^{(1+p)/4}$$

$$\frac{t'}{t} = \left(\frac{k}{\lambda}\right)^{1/3}$$

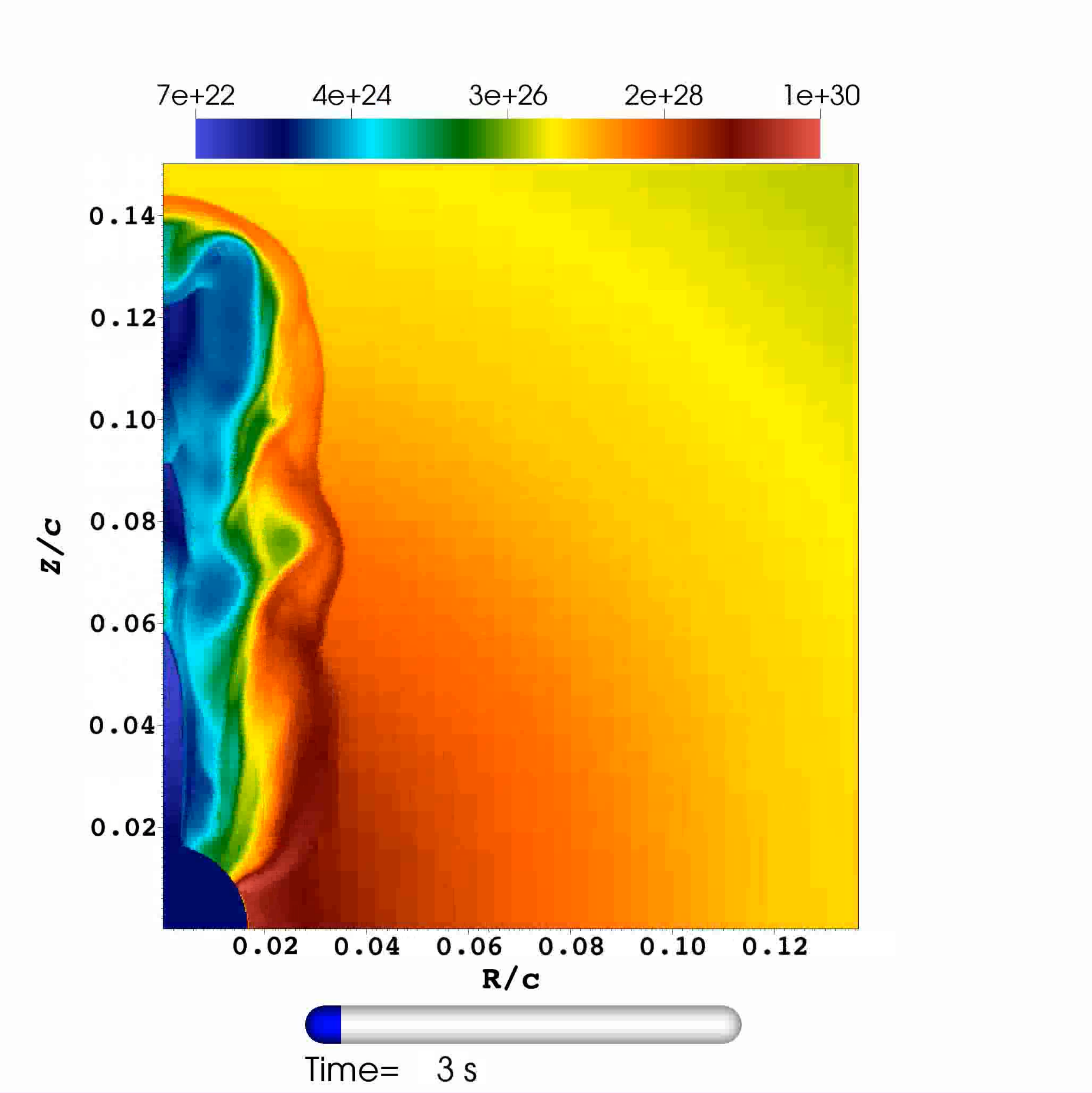
Urrutia, FDC et al. (in preparation)



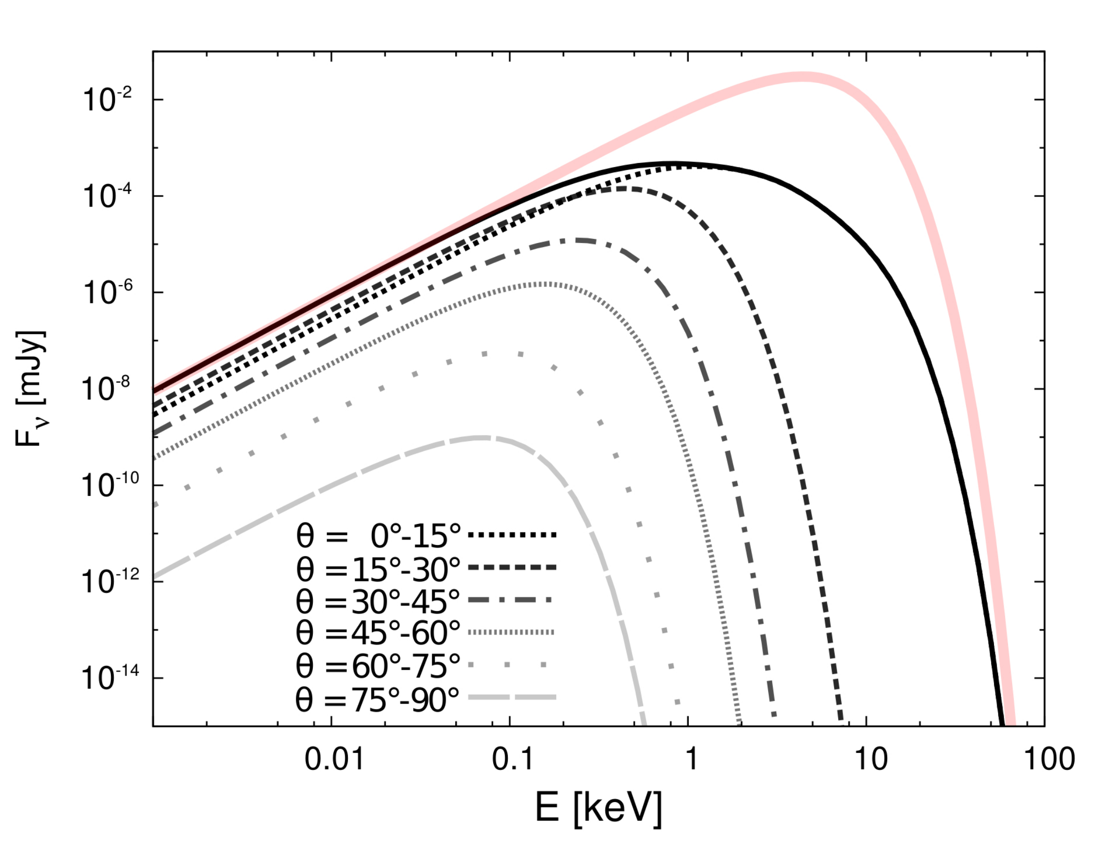
Urrutia, FDC et al. (in preparation)

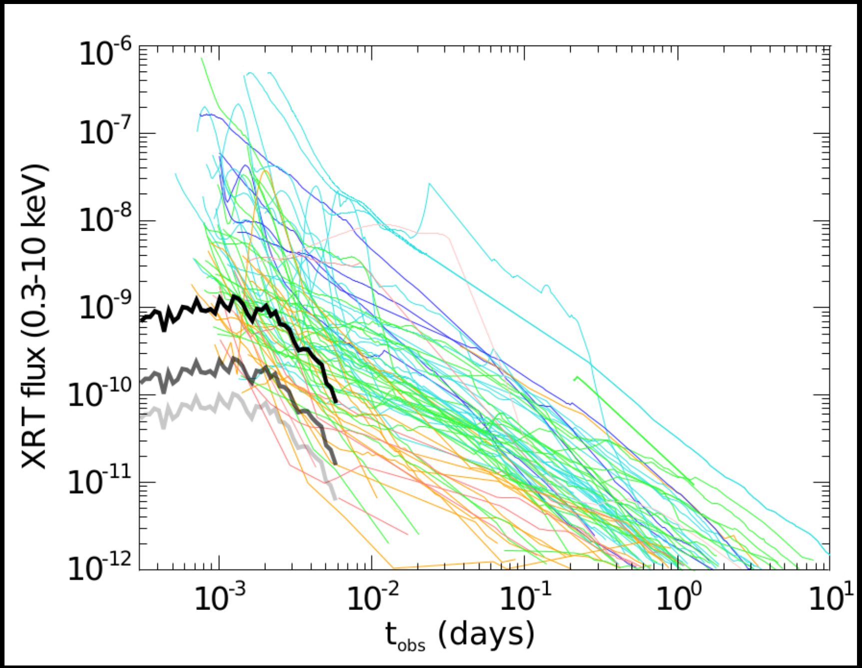


DB: De.0000.vtk
Cycle: 0
Pseudocolor
Var: ndens
4000.
894.4
200.0
44.72
10.00
Max: 1000.
Min: 1000.
Y-Axis
(x10^3)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
100
200
300
user: fdc
Thu Jan 31 12:51:35 2008



De Colle et al. (2018a, 2018b)





De Colle et al. (2018a)

LETTER

https://doi.org/10.1038/s41586-018-0826-3

Signatures of a jet cocoon in early spectra of a supernova associated with a γ-ray burst

L. Izzo[1]*, A. de Ugarte Postigo[1,2], K. Maeda[3], C. C. Thöne[1], D. A. Kann[1], M. Della Valle[1,4,5,6], A. Sagues Carracedo[7], M. J. Michałowski[8], P. Schady[9,10], S. Schmidl[11], J. Selsing[2,12,13], R. L. C. Starling[14], A. Suzuki[15], K. Bensch[1], J. Bolmer[9,16], S. Campana[17], Z. Cano[1], S. Covino[17], J. P. U. Fynbo[12,13], D. H. Hartmann[18], K. E. Heintz[12,13,19], J. Hjorth[2], J. Japelj[20], K. Kamiński[8], L. Kaper[20], C. Kouveliotou[21,22], M. Krużyński[8], T. Kwiatkowski[8], G. Leloudas[2,23], A. J. Levan[24], D. B. Malesani[2,12,13], T. Michałowski[8], S. Piranomonte[25], G. Pugliese[20], A. Rossi[26], R. Sánchez-Ramírez[27], S. Schulze[28], D. Steeghs[24], N. R. Tanvir[14], K. Ulaczyk[24], S. D. Vergani[29] & K. Wiersema[14,24]

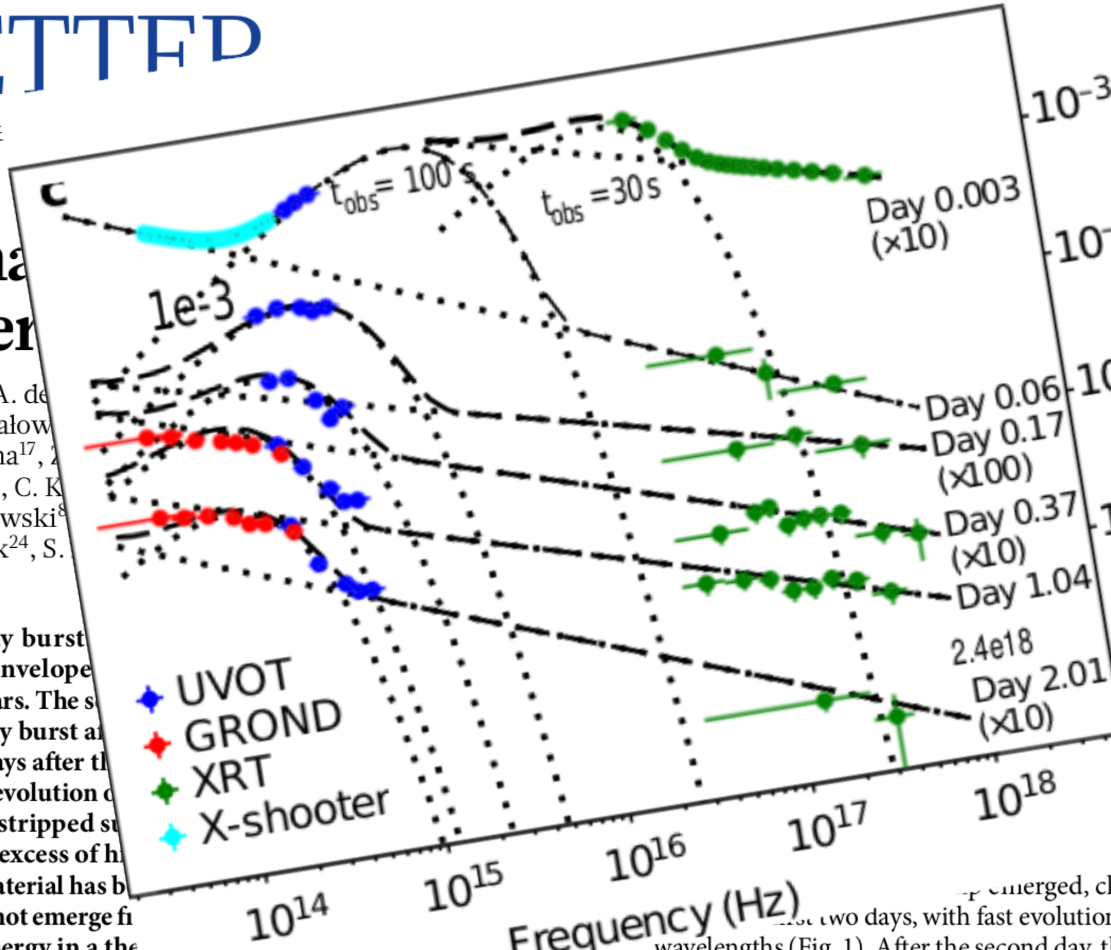
Long γ-ray bursts are associated with energetic, broad-lined, stripped-envelope supernovae[1,2] and as such mark the death of massive stars. The scarcity of such events nearby and the brightness of the γ-ray burst afterglow, which dominates the emission in the first few days after the burst, have so far prevented the study of the very early evolution of supernovae associated with γ-ray bursts[3]. In hydrogen-stripped supernovae that are not associated with γ-ray bursts, an excess of high-velocity (roughly 30,000 kilometres per second) material has been interpreted as a signature of a choked jet, which did not emerge from the progenitor star and instead deposited all of its energy in a thermal cocoon[4]. Here we report multi-epoch spectroscopic observations of the supernova SN 2017iuk, which is associated with the γ-ray burst GRB 171205A. Our spectra display

metallicity ($12 + \log(O/H) = 8.41$; Methods). It is much more massive than typical GRB hosts, which are normally metal-poor, star-forming dwarf galaxies, particularly at low redshift[12].

The proximity of GRB 171205A motivated us to undertake multi-wavelength photometric and spectroscopic follow-up observations. The light curve exhibits unusual behaviour, with colour evolution of the optical and ultraviolet emission at very early phases, in contrast to the rapid decay observed in X-ray emission. A few minutes after the burst, a first light-curve bump emerged, characterizing the emission during the first two days, with fast evolution from ultraviolet to redder wavelengths (Fig. 1). After the second day, the luminosity of the underlying supernova (SN 2017iuk) started to increase, reaching its maximum *B*-band magnitude on 2017 December 16.4 UT, roughly 11.0 days

/s41586-018-0826-3

Signa... super...



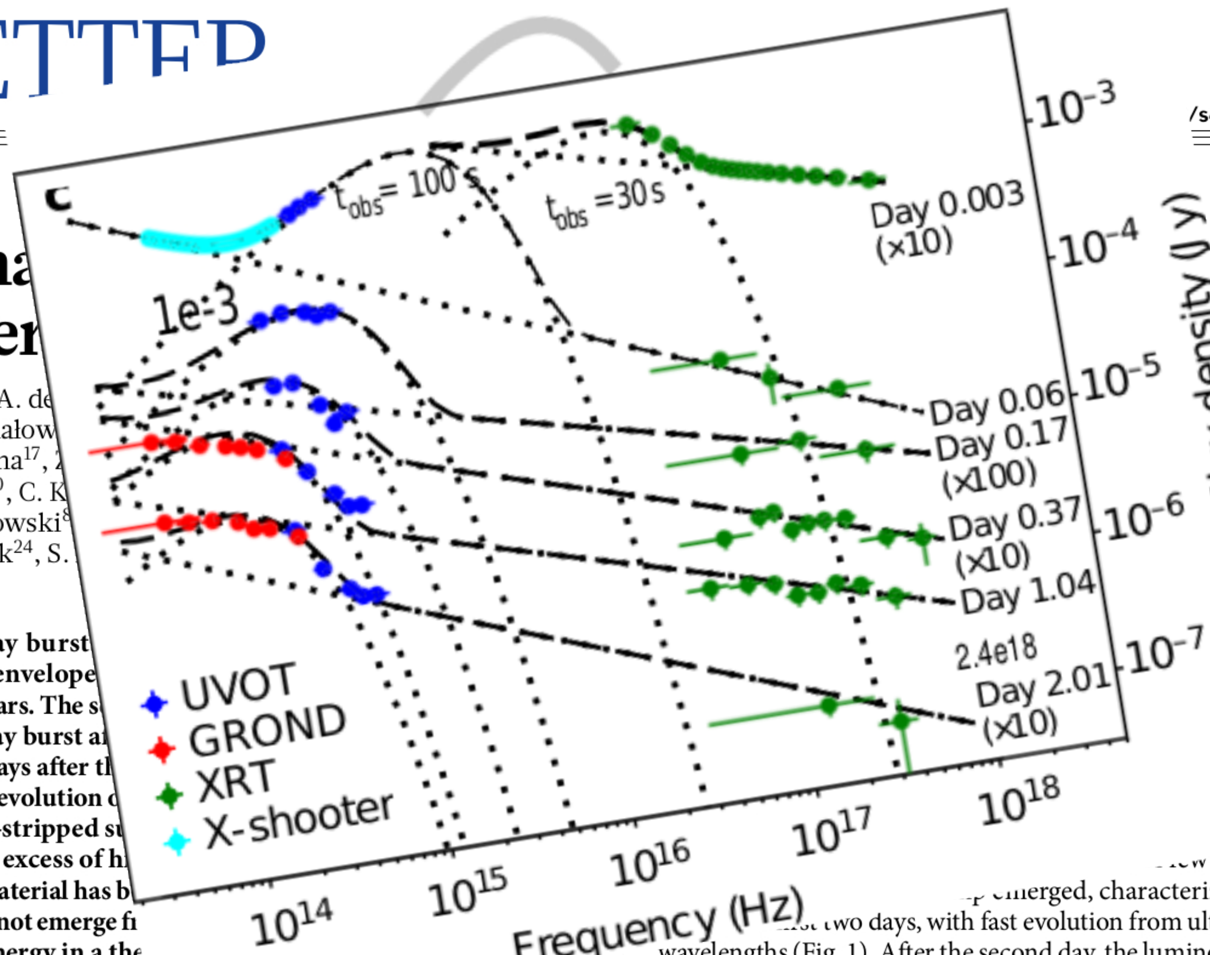
L. Izzo[1]*, A. de ... [16],
M. J. Michałow... Kamiński[8],
S. Campana[17], ...
L. Kaper[20], C. K...
T. Michałowski[8] ... Tanvir[14],
K. Ulaczyk[24], S. ...

Long γ-ray burst... ore massive stripped-envelope... ar-forming massive stars. The s... of the γ-ray burst a... ake multi- first few days after th... ervations. very early evolution o... olution of hydrogen-stripped su... ntrast to bursts, an excess of hi... few minutes after the second) material has b... emerged, characterizing the emission which did not emerge fr... first two days, with fast evolution from ultraviolet to redder all of its energy in a the... spectroscopic observati... 2017iuk, which is associated with the γ-ra... GRB 171205A. Our spectra display

... wavelengths (Fig. 1). After the second day, the luminosity of the underlying supernova (SN 2017iuk) started to increase, reaching its maximum *B*-band magnitude on 2017 December 16.4 UT, roughly 11.0 days

LETTER

/s41586-018-0826-3

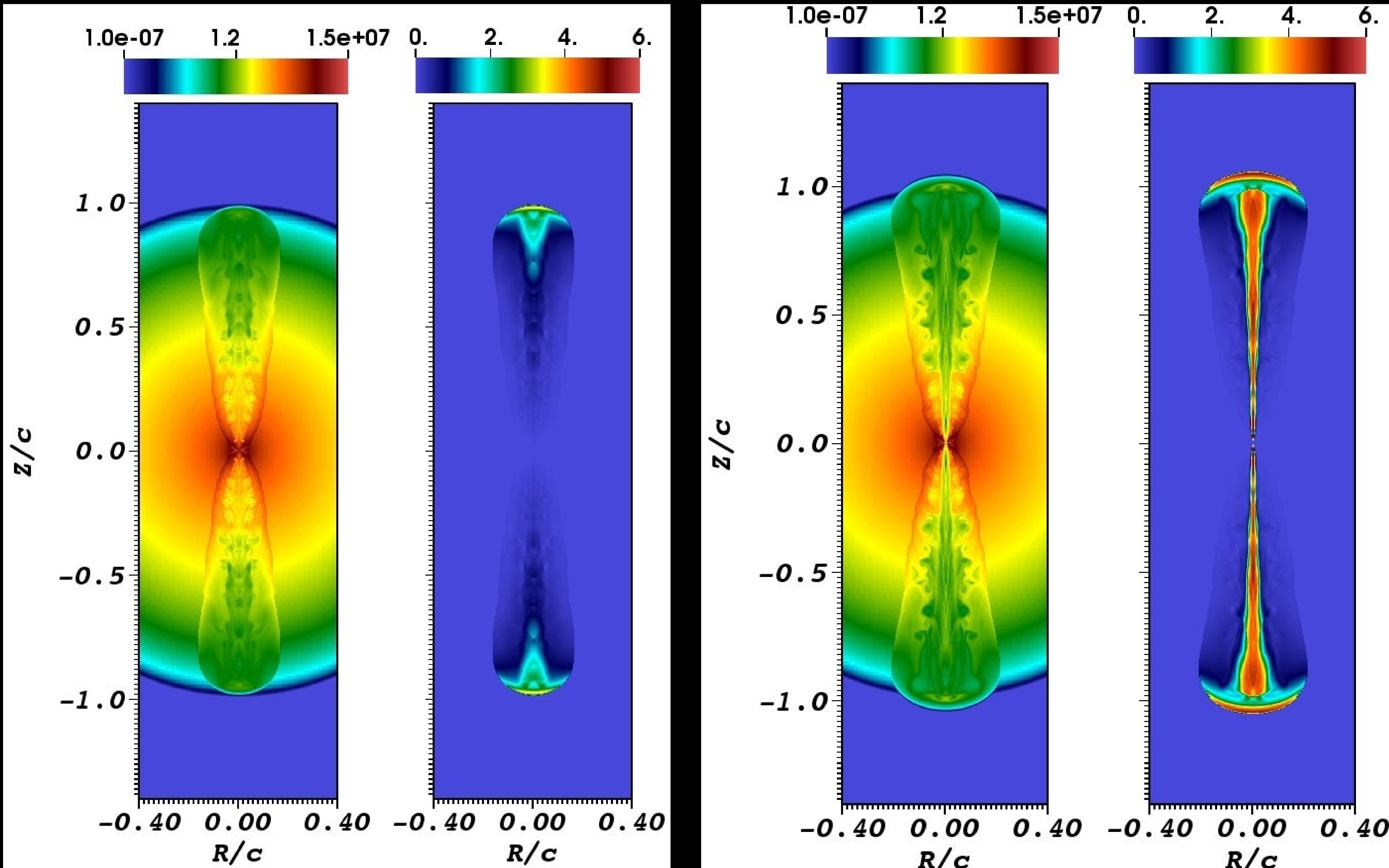


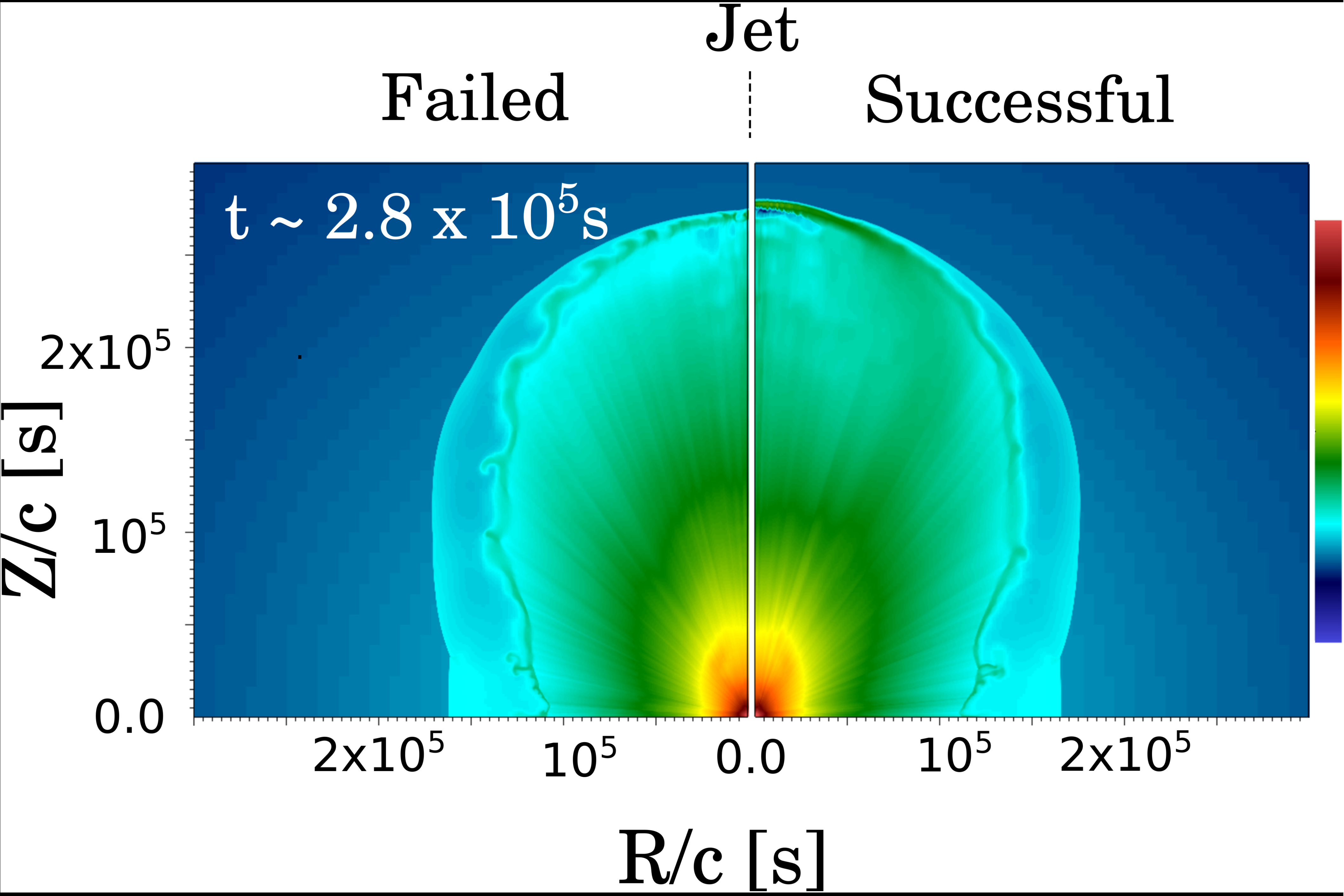
Signa… super…

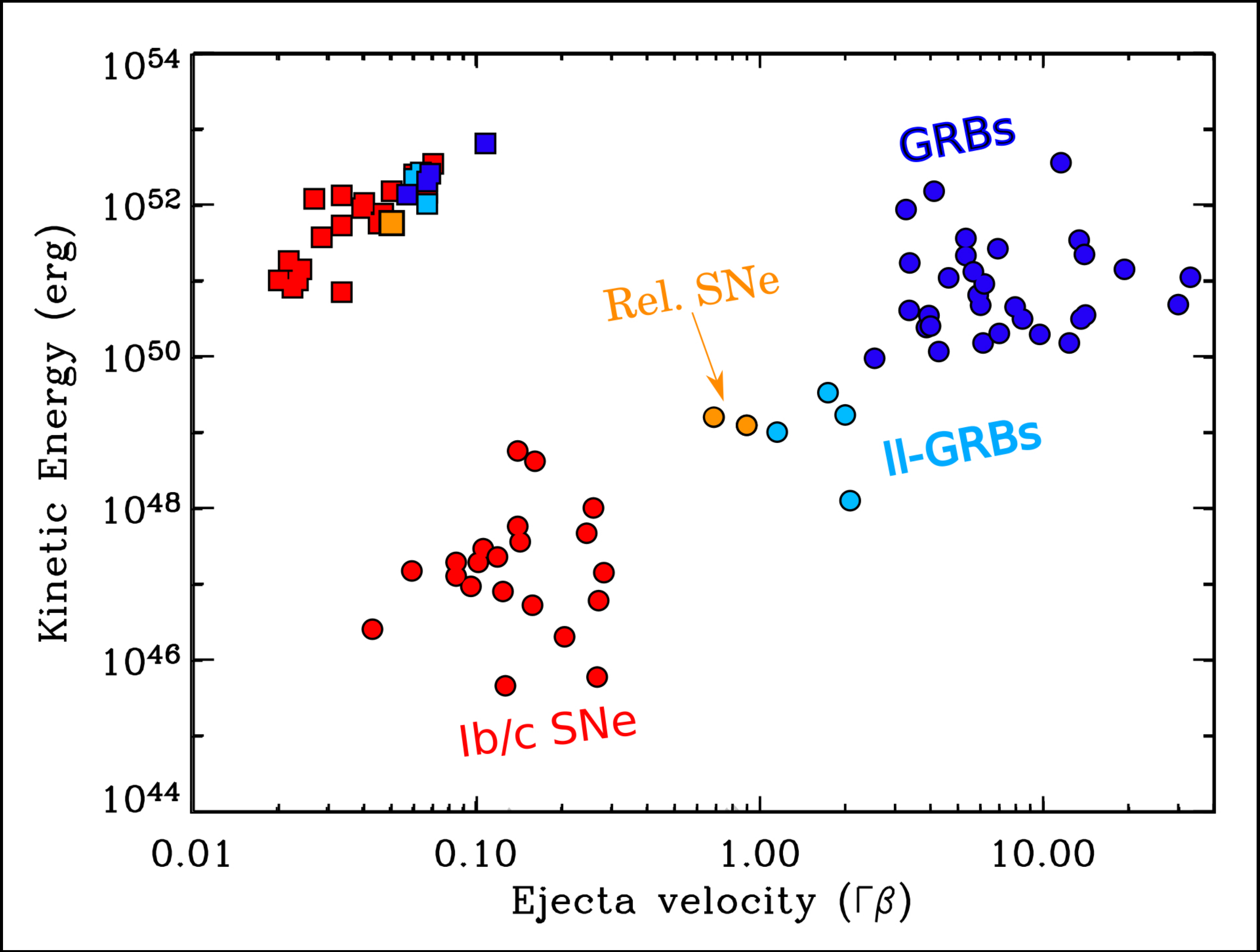
L. Izzo[1]*, A. de … [16],
M. J. Michałow … Kamiński[8],
S. Campana[17], …
L. Kaper[20], C. K …
T. Michałowski[8] … Tanvir[14],
K. Ulaczyk[24], S. …

**Long γ-ray burst … ore massive
stripped-envelope … ar-forming
massive stars. The s…
of the γ-ray burst a…
first few days after th…
very early evolution o…
hydrogen-stripped su…
bursts, an excess of hi…
second) material has b…
which did not emerge fr…
all of its energy in a the…
spectroscopic observati… 2017iuk, which is
associated with the γ-ray… GRB 171205A. Our spectra display**

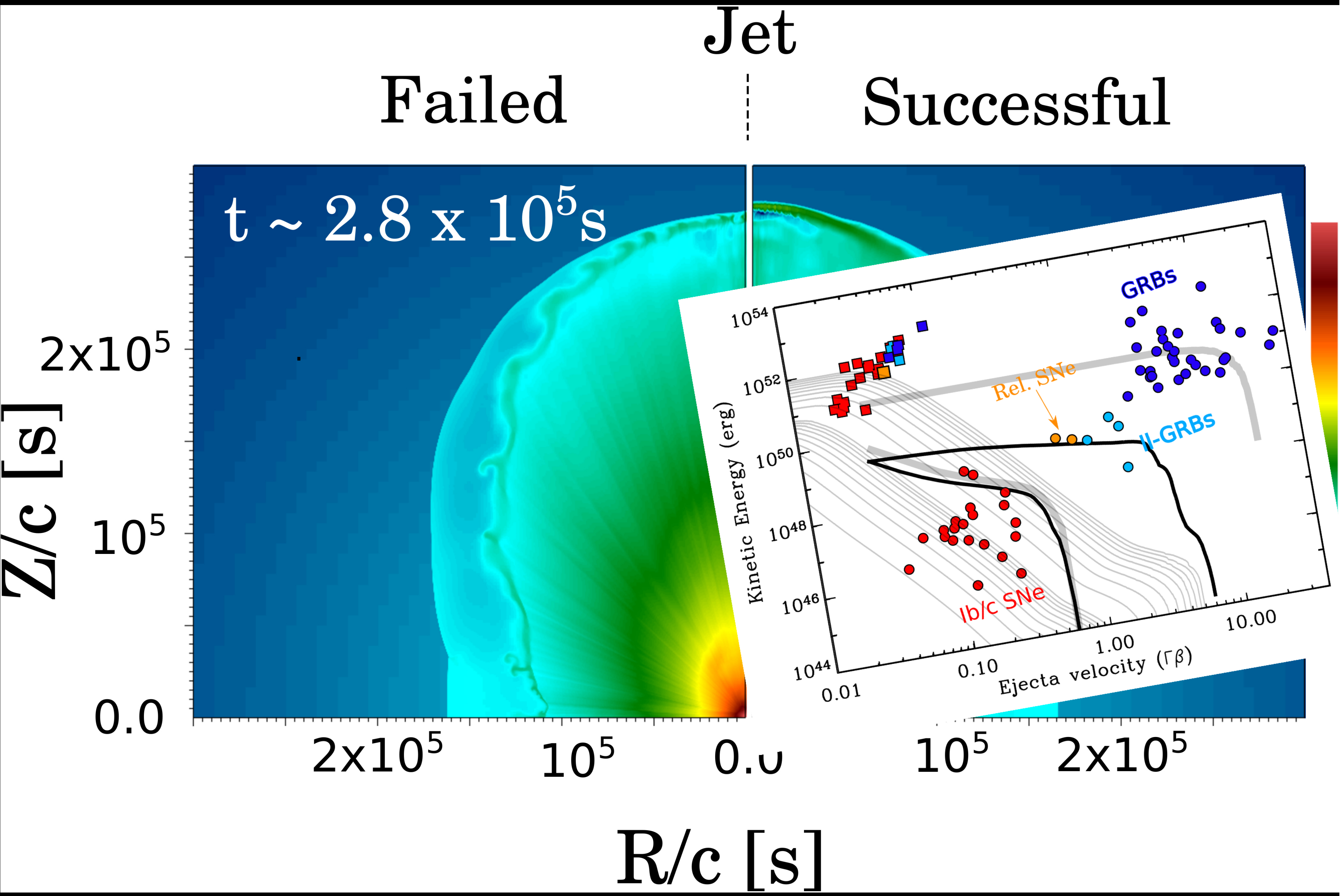
…ake multi-
…ervations.
…olution of
…ntrast to
… few minutes after the
… emerged, characterizing the emission
… two days, with fast evolution from ultraviolet to redder wavelengths (Fig. 1). After the second day, the luminosity of the underlying supernova (SN 2017iuk) started to increase, reaching its maximum *B*-band magnitude on 2017 December 16.4 UT, roughly 11.0 days


1.0e-07
1.2
1.5e+07
0.
2.
4.
6.
1.0
0.5
0.0
-0.5
-1.0
z/c
-0.40
0.00
0.40
R/c

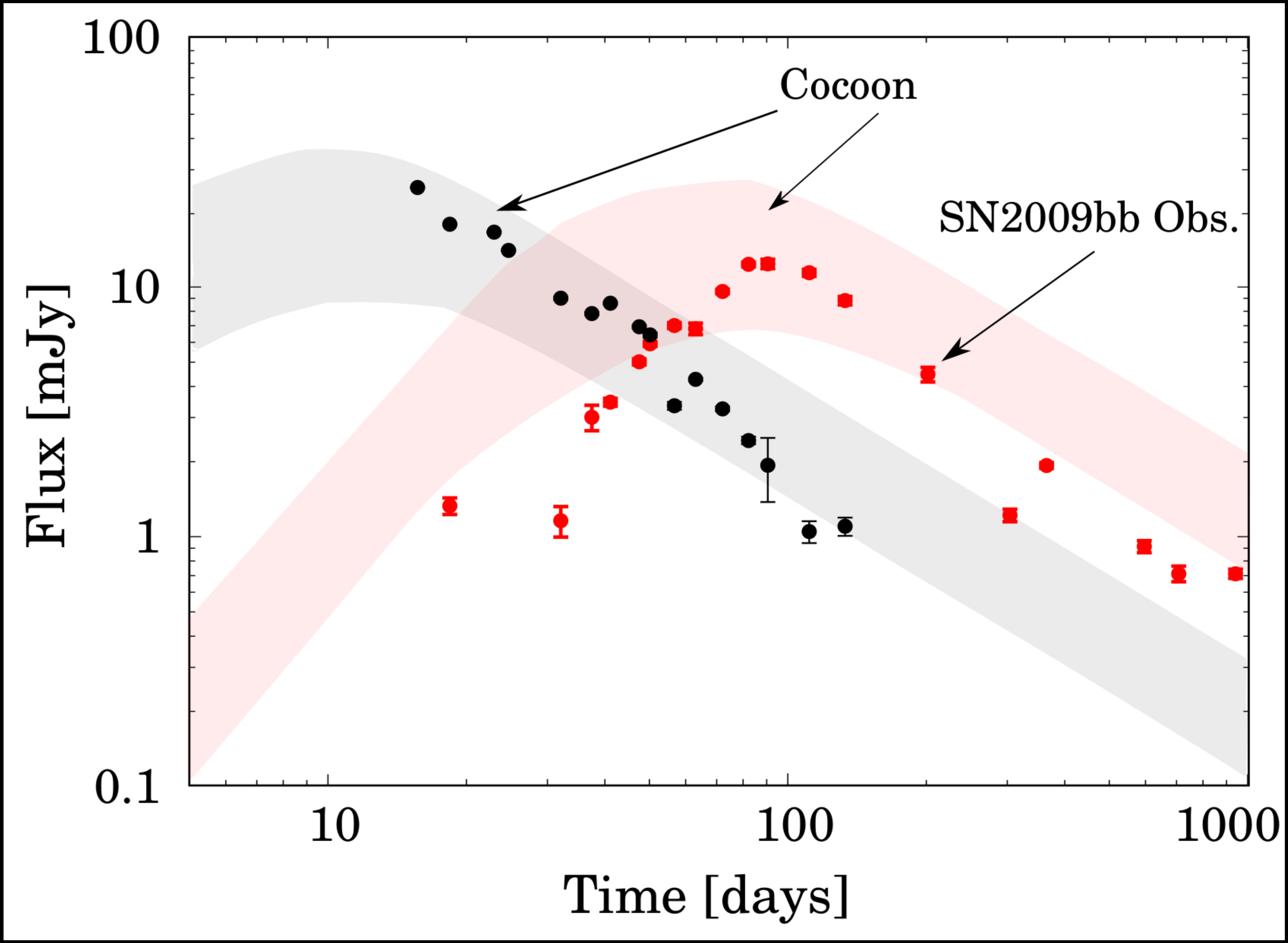

Jet
Failed
Successful
t ~ 2.8 x 10^5s
2x10^5
10^5
0.0
Z/c [s]
2x10^5
10^5
0.0
10^5
2x10^5
R/c [s]



Soderberg et al. (2010), Margutti et al. (2014)



Jet
Failed
Successful
t ~ 2.8 x 10^5s
2x10^5
10^5
0.0
Z/c [s]
R/c [s]
GRBs
Rel. SNe
ll-GRBs
Ib/c SNe
Kinetic Energy (erg)
Ejecta velocity (Γβ)
0.01
0.10
1.00
10.00



De Colle et al. (2018b)

Conclusions

- Determination of the physical parameters from the observations is complicated

- Cocoon emission is important!
  - Thermal emission can help us to understand the progenitor structure
  - Non-thermal emission contributes and in some cases dominates the emission…