

Gamma-ray burst prompt and afterglow emission theory and models

A brief overview

Om Sharan Salafia

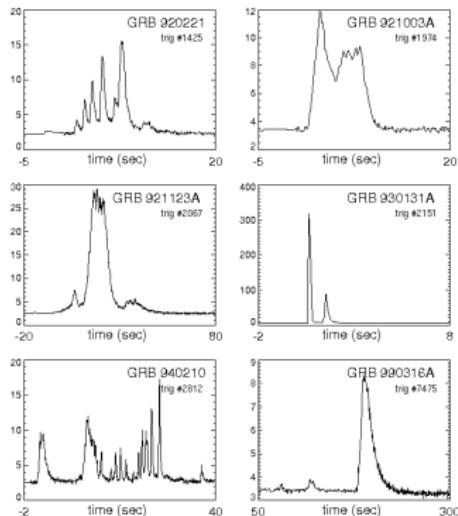
INAF – Osservatorio Astronomico di Brera - Merate
INFN – Sezione di Milano-Bicocca
Italy

2018-06-06 GEMMA Workshop

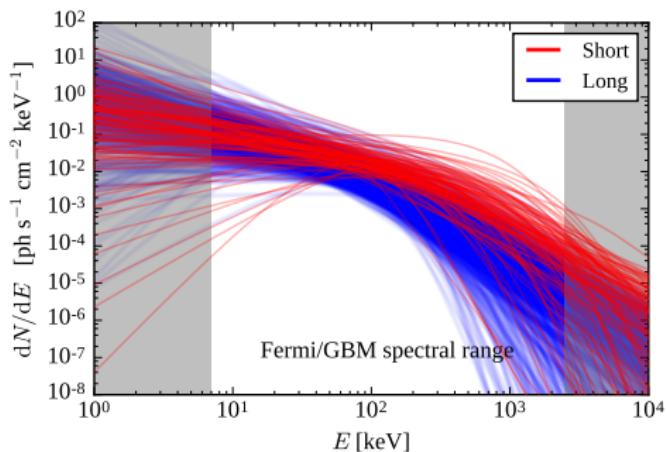


Prompt emission - observational features

Light curves



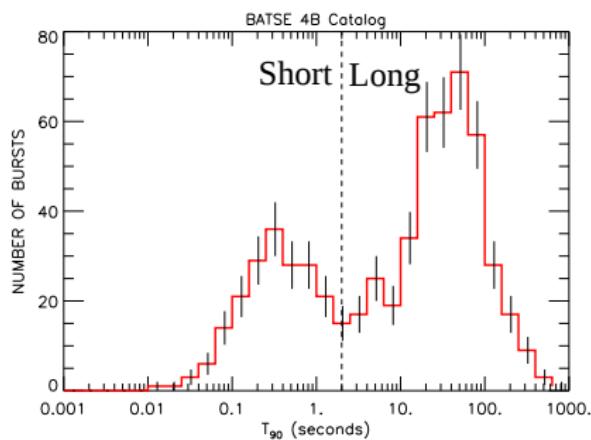
Spectra



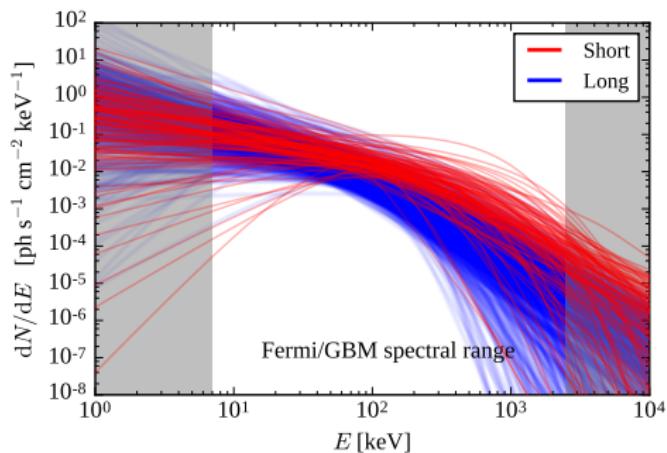
(see J. McEnery's talk)

Prompt emission - observational features

Duration

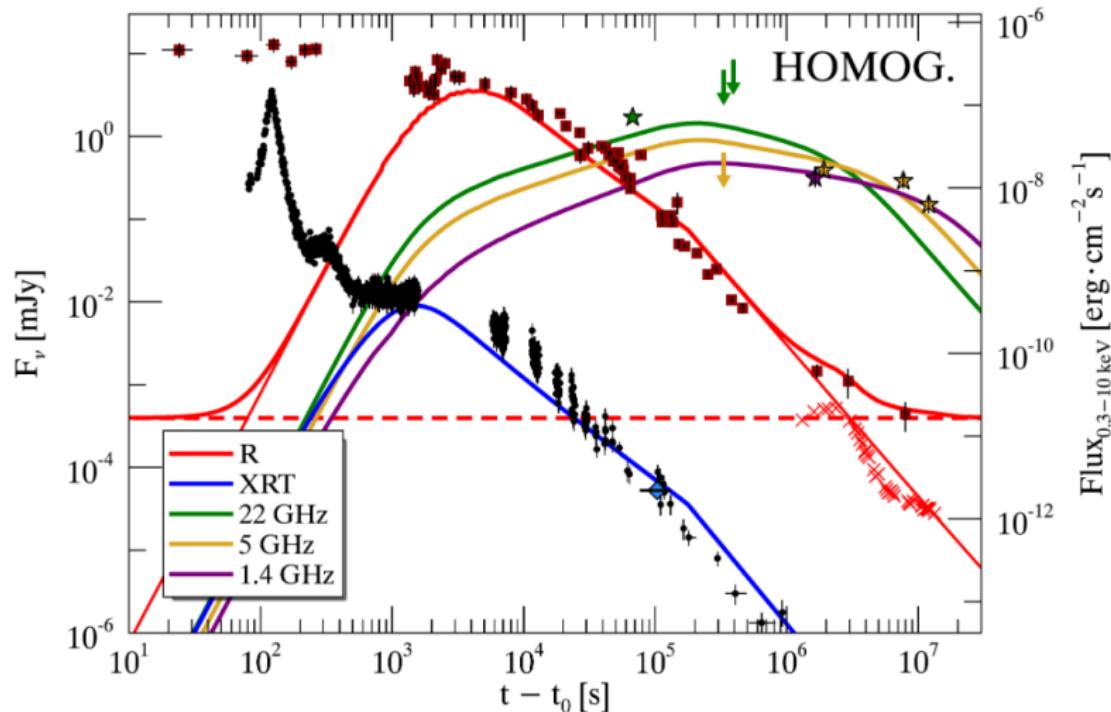


Spectra



(see J. McEnery's talk)

Afterglow - observational features



(GRB151027A – Nappo et al. 2017)

Prompt emission - theory: relativistic bulk motion

Fast variability

$$t_{\text{var}} \sim 1 \text{ ms}$$

High luminosity

$$L \gtrsim 10^{50} \text{ erg/s}$$

High photon energy

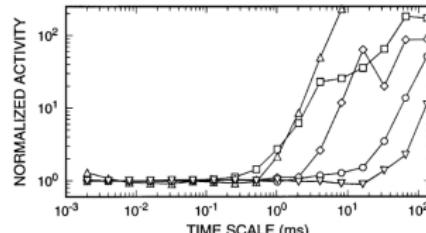
$$E_p \sim 0.5 \text{ MeV}$$

Non-thermal spectrum

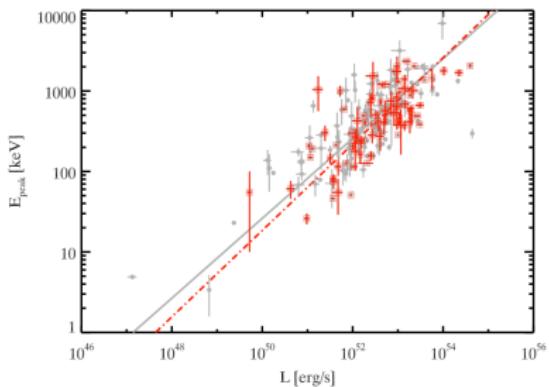
Compactness arguments



relativistic bulk motion

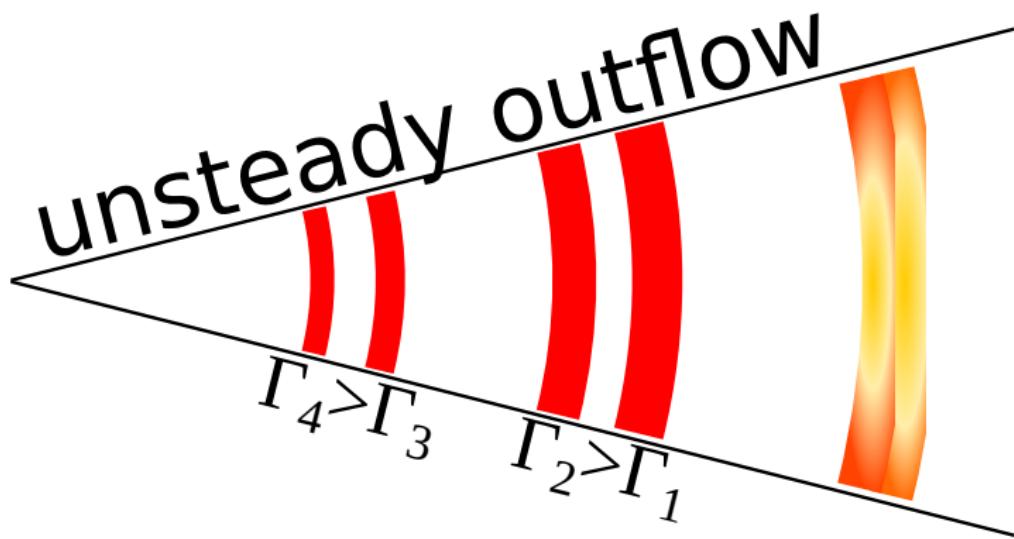


[Walker+00]



[Pescalli+16]

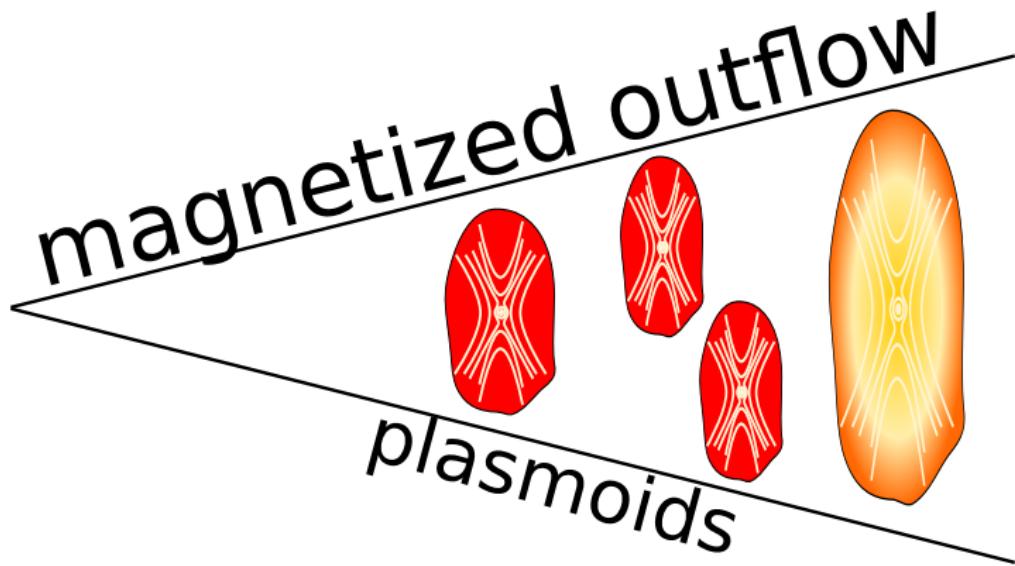
Prompt emission - theory: energy dissipation



Internal shocks

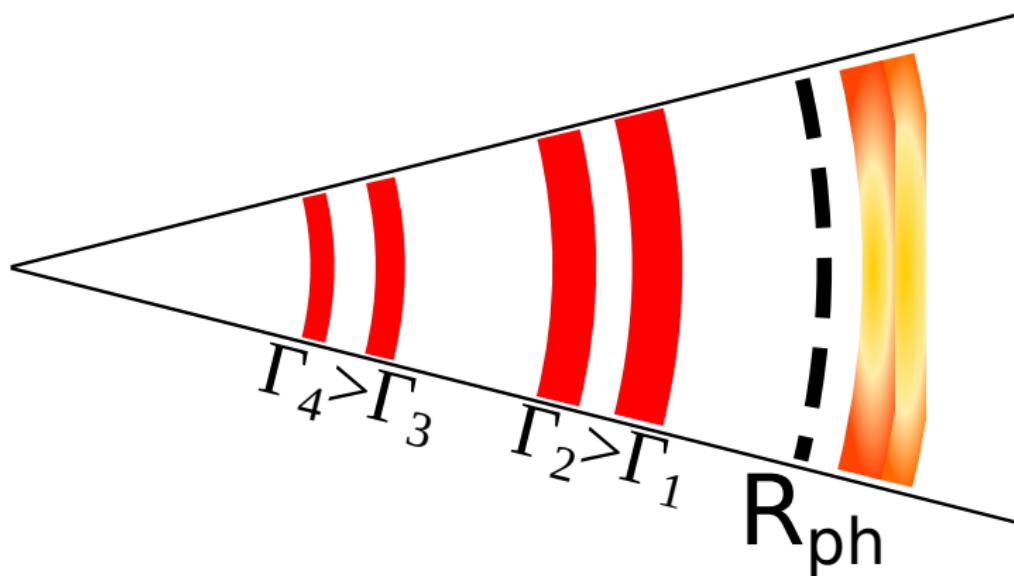
(Rees '78 , Rees & Meszaros '94)

Prompt emission - theory: energy dissipation



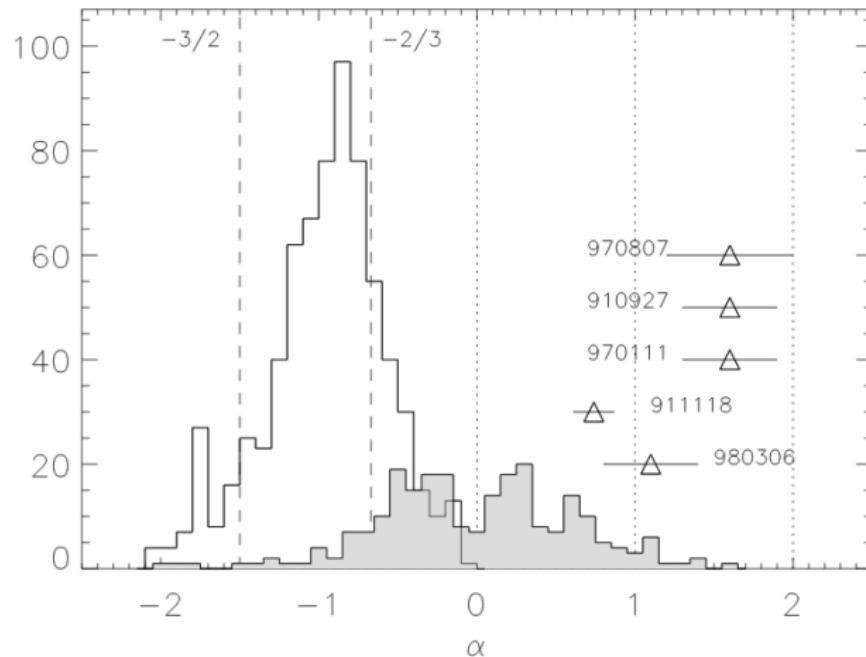
Magnetic reconnection
(e.g. Zhang et al. '11)

Prompt emission - theory: energy dissipation



Optically thin dissipation

Prompt emission - theory: synchrotron emission?



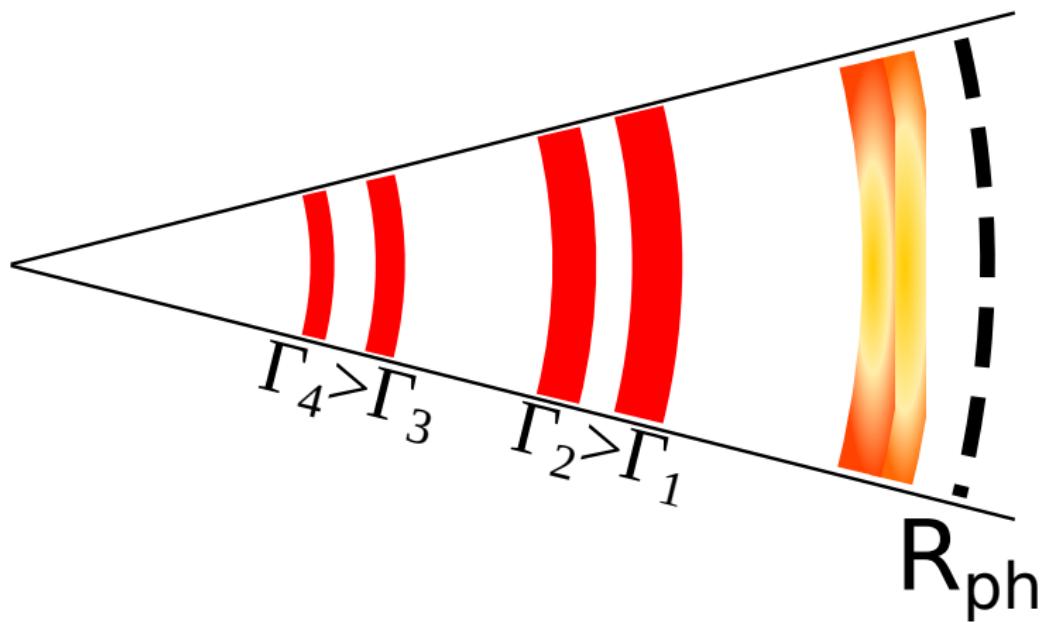
$(\alpha \equiv \text{low-energy spectral index})$
(Ghirlanda et al. 2003)

Prompt emission - theory: synchrotron emission?

Possible ways out, e.g.:

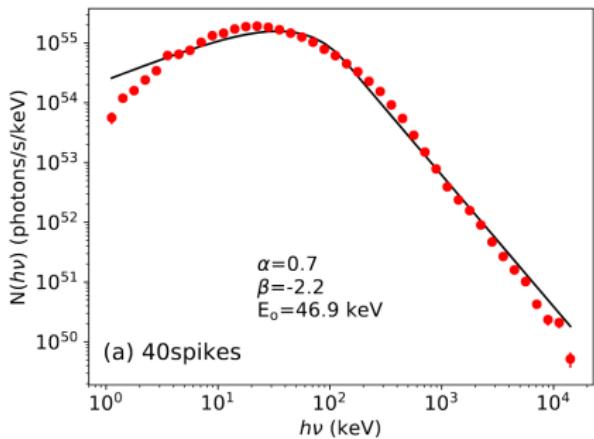
- marginally fast cooling (e.g. Daigne et al. 2010, Ravasio et al. 2017, Beniamini et al. 2018)
- inverse compton losses in Klein-Nishina regime (e.g. Daigne et al. 2010)
- geometrical effects?

Prompt emission - theory: energy dissipation

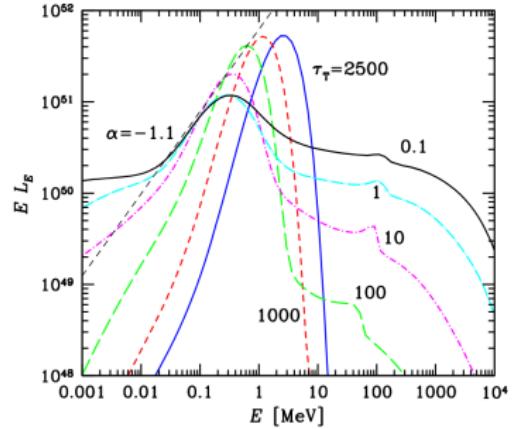


Subphotospheric dissipation
(Rees & Meszaros '05)

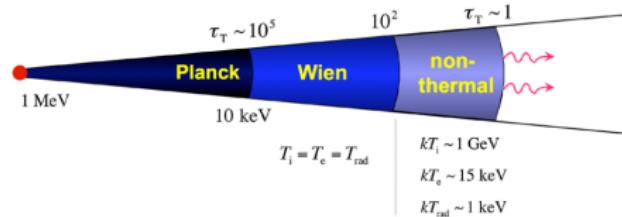
Prompt emission: subphotospheric dissipation?



(Parsotan et al. 2018)

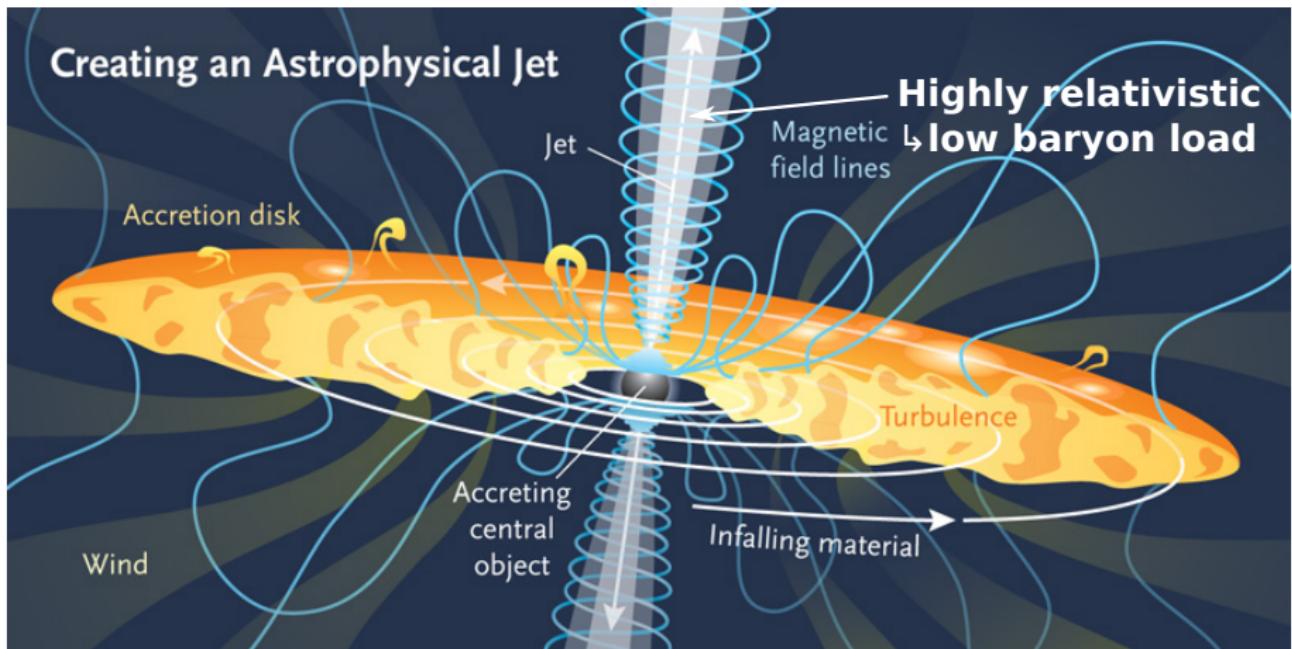


(Vurm & Beloborodov 2016)



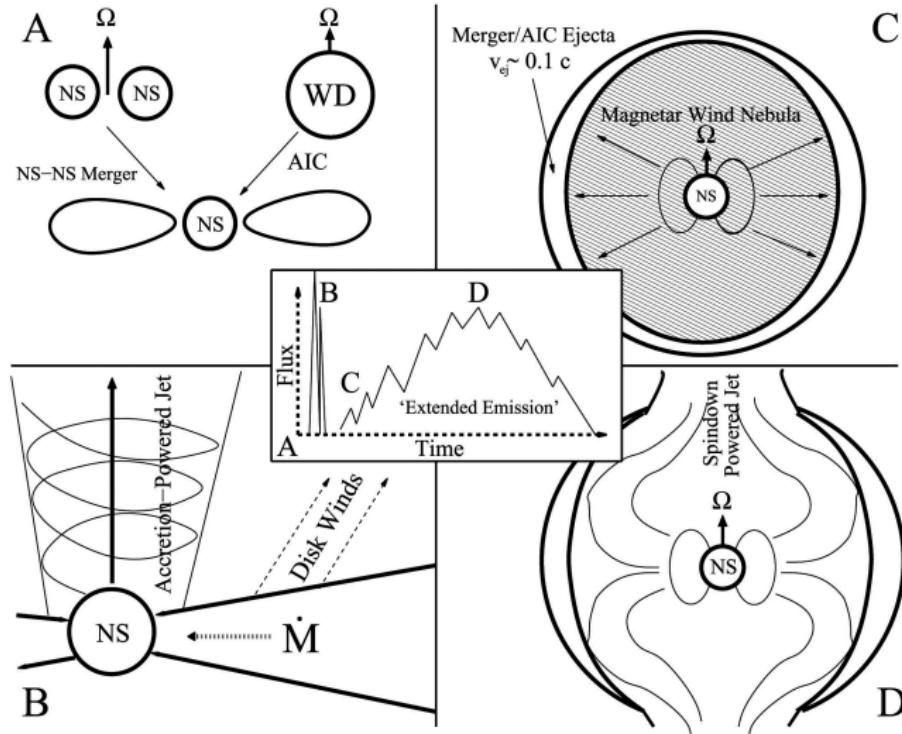
(Beloborodov & Meszaros 2017)

Central engine: BH + BZ-type mechanism



(McKinney et al. 2012)

Central engine: proto-magnetar + spin-down



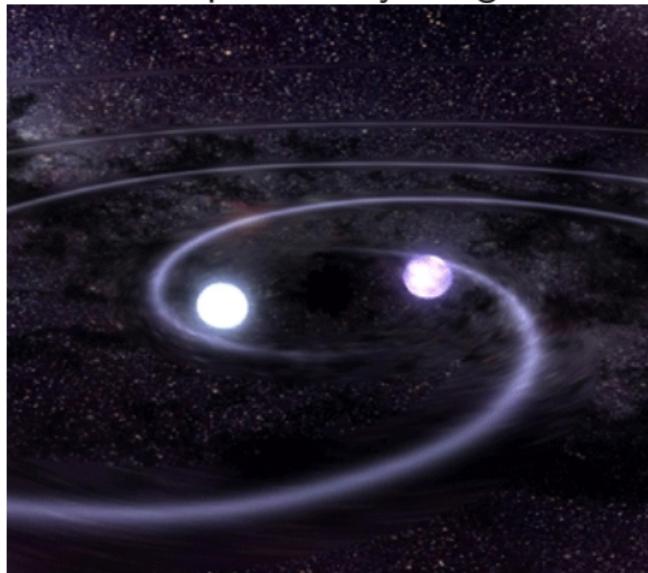
(Bucciantini et al. 2012)

Thus progenitors are GW emitters

Massive star collapse



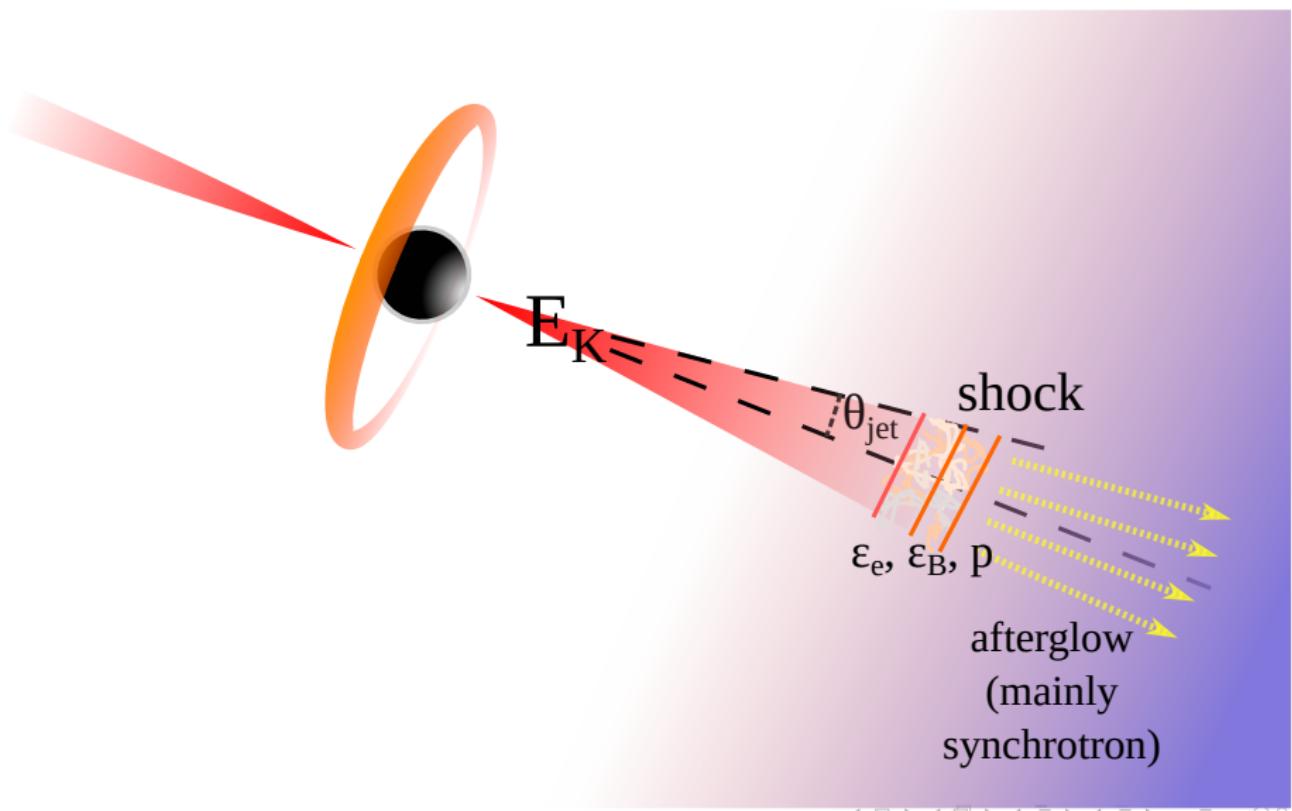
Compact binary merger



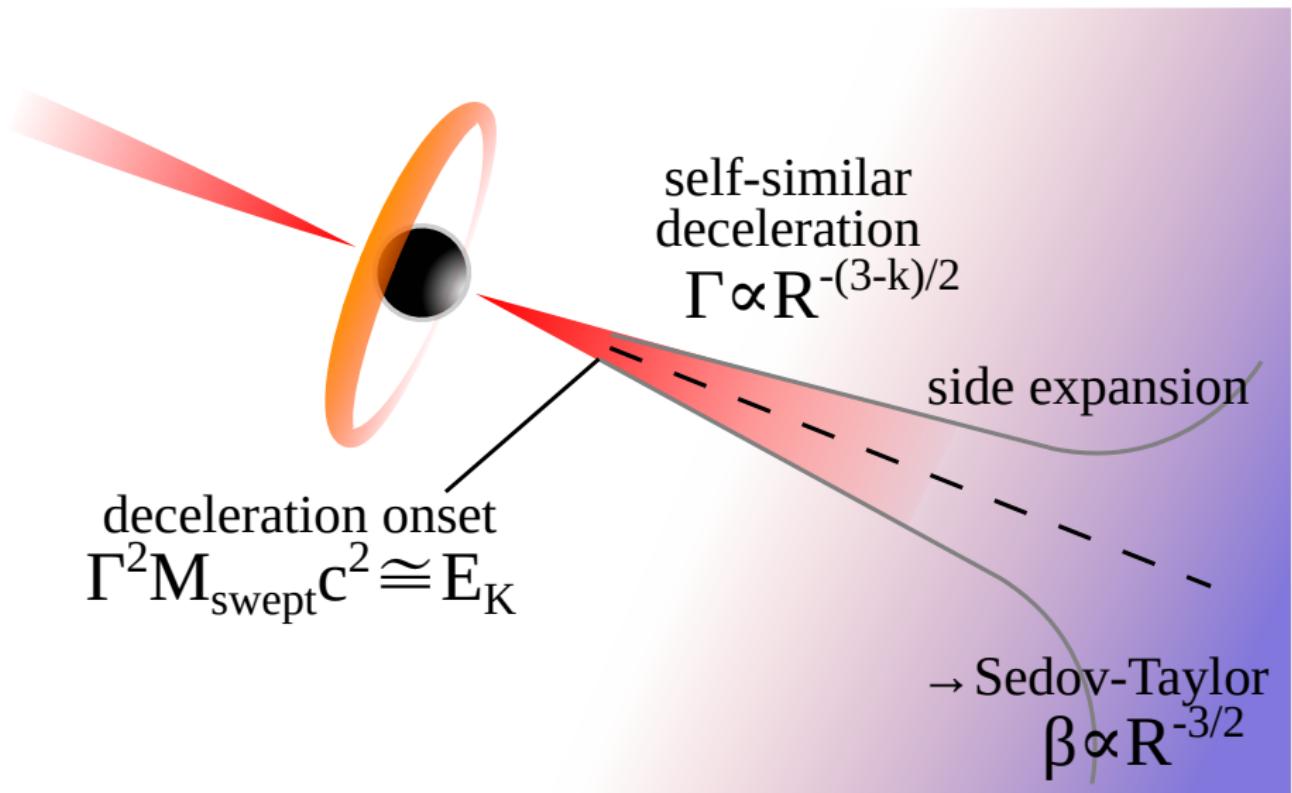
Long GRBs
(established through supernova association!)

Short GRBs
(still not established!)

Afterglow - theory: the external shock paradigm



Afterglow - theory: the jet dynamics

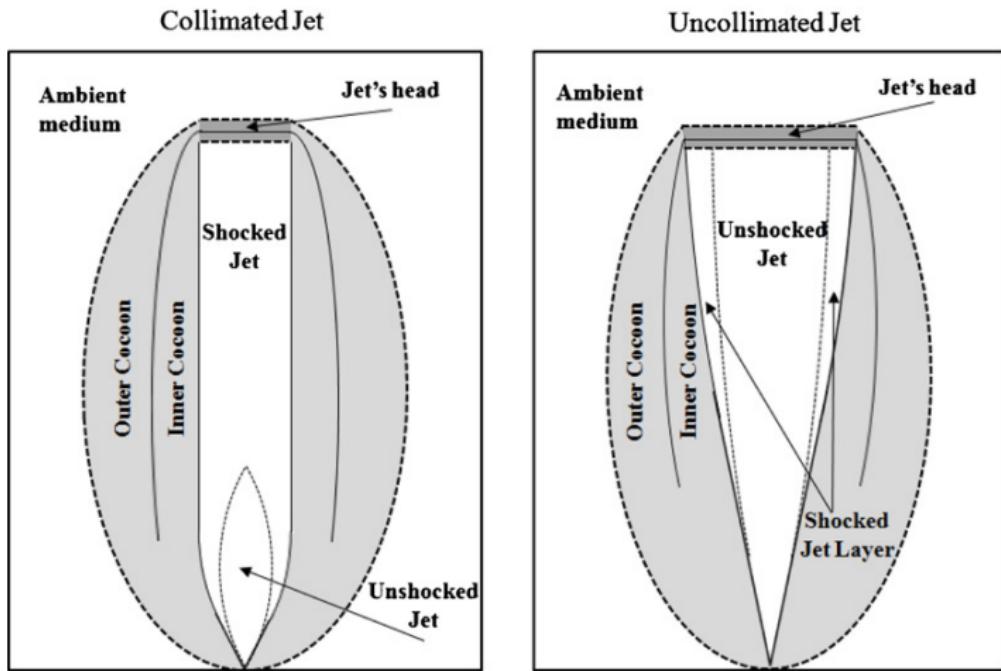


Afterglow - theory: the jet dynamics

~ 50% of GRB afterglows (Wang et al. 2015) agree with the standard external shock predictions.

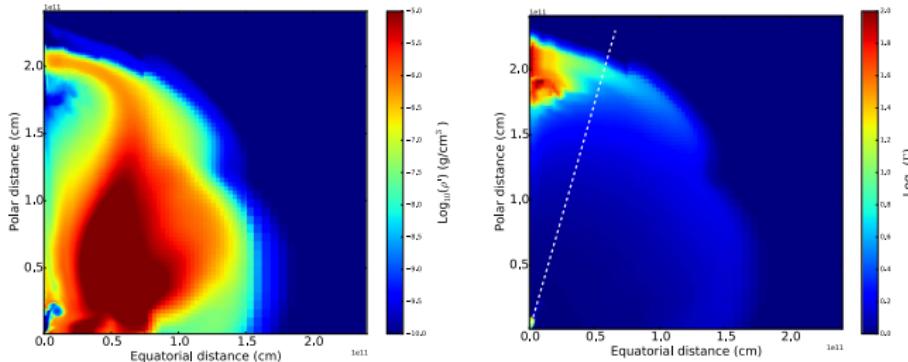
What about the other half? Missing ingredients?

Jet interaction with the ambient material

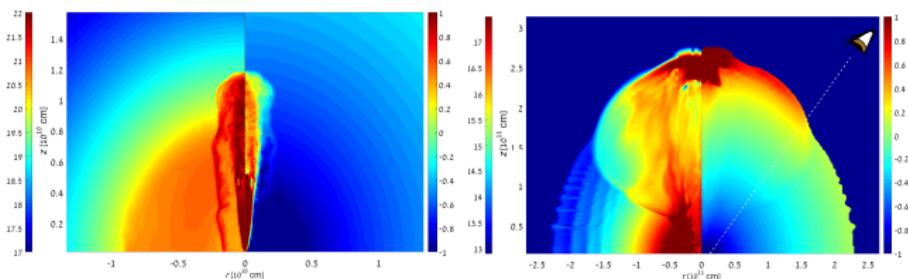


(e.g. Begelman et al. '89, Martì et al. '94, Matzner '03, Bromberg et al. '11,
Murguia-Berthier et al. '14)

Jet interaction with the ambient material



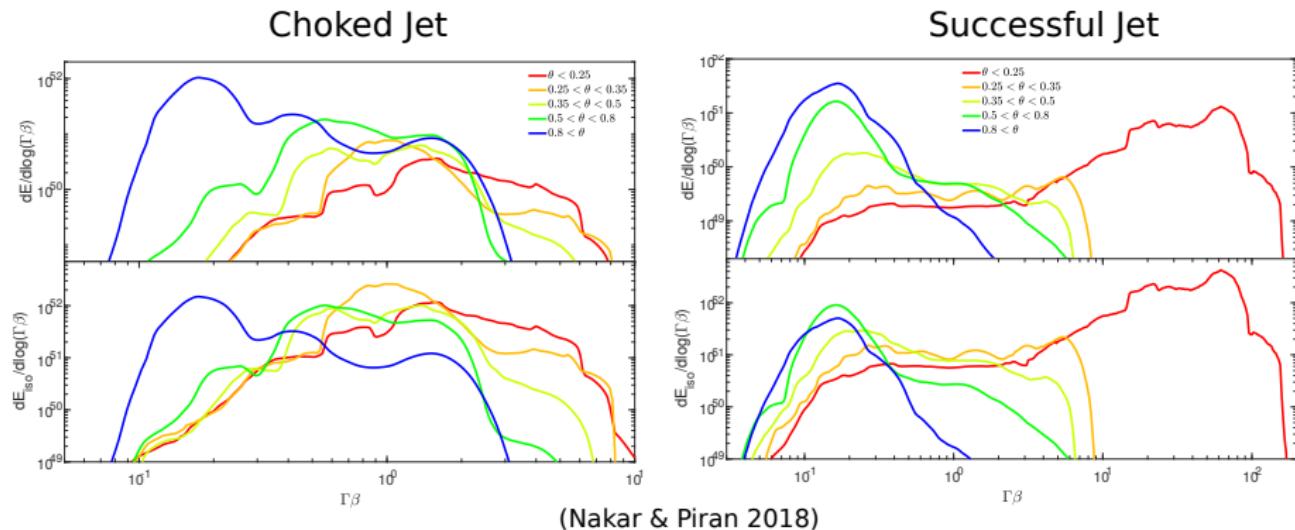
Lazzati+17



Kathirgamaraju+17

Gottlieb+17

Outflow structure: core, cocoon, velocity profile

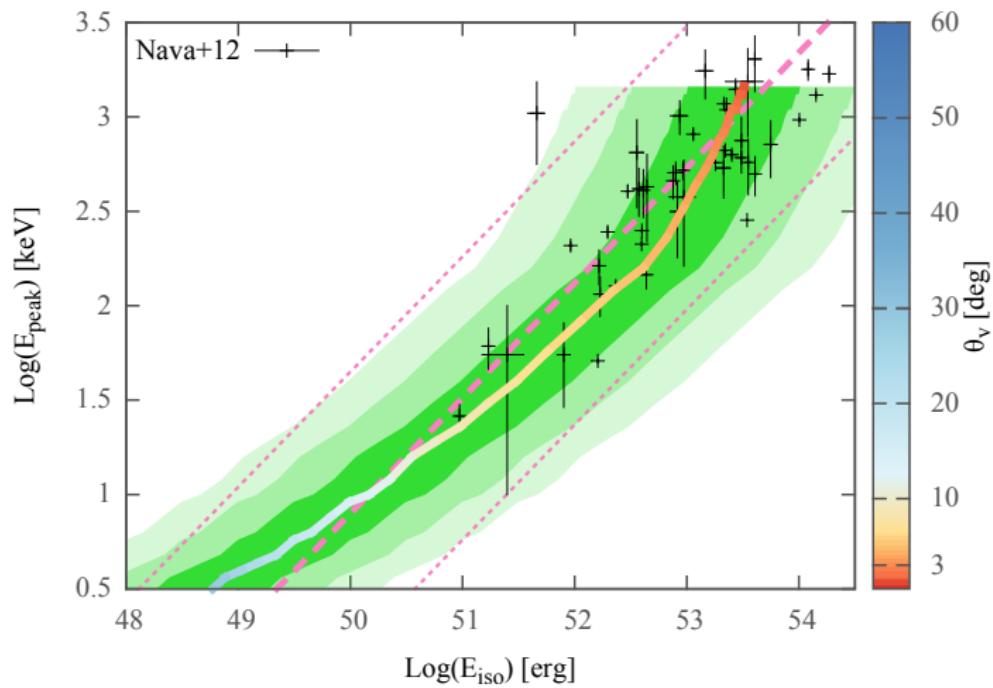


Outflow structure: impact on prompt emission

Angular energy and velocity structure + beaming

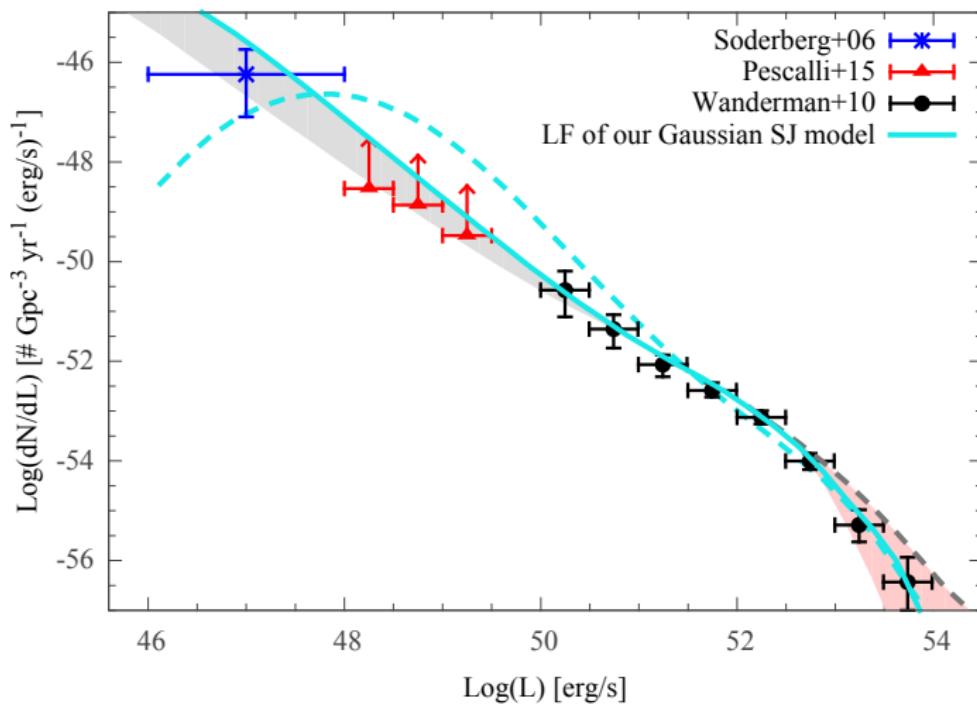
Non-trivial dependence of luminosity, energy, duration and spectrum on
the viewing angle

Jet structure: spectral energy correlations



(Salafia et al. 2015)

Jet structure: GRB luminosity function



(Salafia et al. 2015, Pescalli et al. 2015)

Outflow structure: impact on afterglow emission

Angular energy and velocity structure

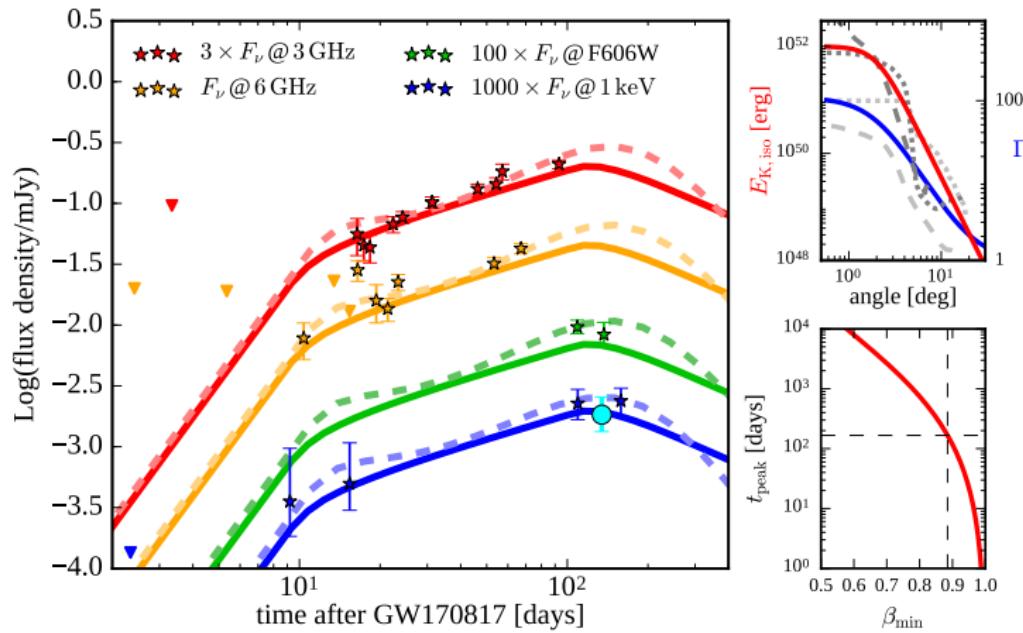
Modified afterglow light curves (see e.g. Rossi+02,04)

Non-trivial jet dynamics, especially during side-expansion phase (see
e.g. Kumar & Granot 2003)

Radial velocity structure

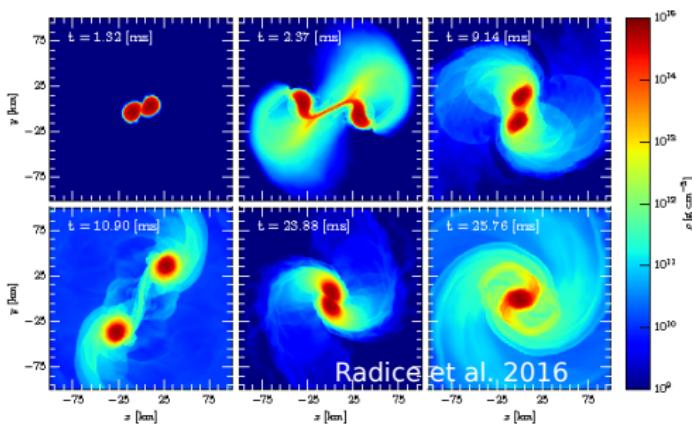
Effective energy injection in the external shock → non-standard dynamics
(see e.g. Gill & Granot 2018)

GRB 170817A outflow structure: afterglow light curves



(D'Avanzo et al. 2018; see also Gottlieb+17; Margutti+17; Lyman+18; Troja+18)
(see L. Piro's talk)

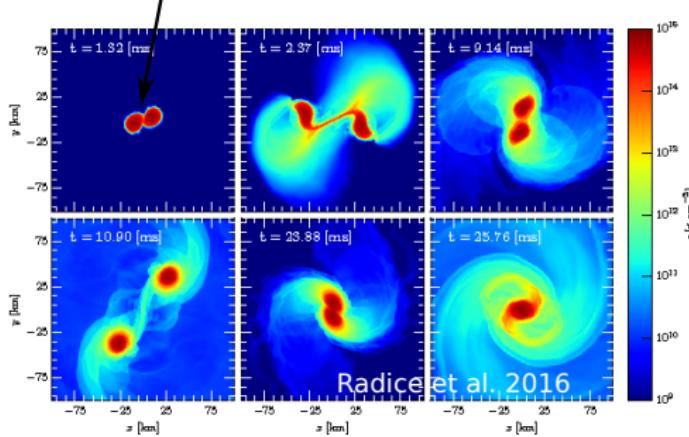
Gravitational Waves & GRB Open Questions



Gravitational Waves & GRB Open Questions

masses, spins
& rate

(Abbott et al. 2017a)



Gravitational Waves & GRB Open Questions

[see M. Arca Sedda's talk]

progenitor

formation
channels

constraints

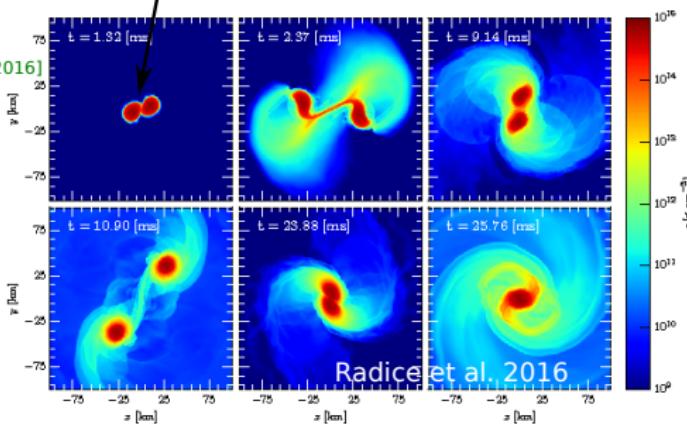
on SGRB rate and
jet geometry

[see Ghirlanda, Salafia et al. 2016]

masses, spins

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Gravitational Waves & GRB Open Questions

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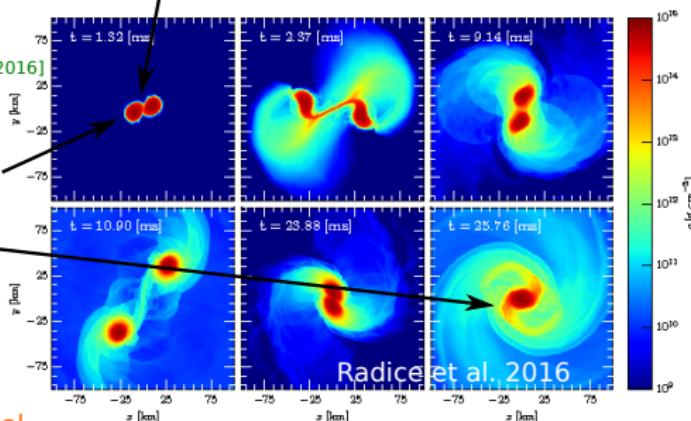
constraints
on SGRB rate and
jet geometry

[see Ghirlanda, Salafia et al. 2016]

delay between
merger and jet
emission

constraints
on jet interaction
with ambient material,
viewing angle and
Lorentz factor

[see Salafia et al. 2017]



Gravitational Waves & GRB Open Questions

[see M. Arca Sedda's talk]

progenitor formation channels

constraints
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[see Ghirlanda, Salafia et al. 2016]

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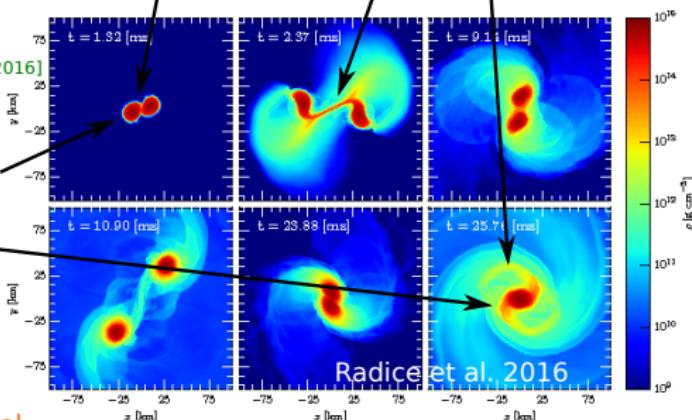
constraints on jet interaction with ambient material, viewing angle and

[see Salafia et al. 2017]

→ masses, spins & rate (Abbott et al. 2017a) mass ejection in merger and post-merger [see also A. Perego's talk]

(e.g. Foucart et al. 2012 (BH-NS disk), Kawaguchi et al. 2016 (BH-NS ejecta), Dietrich et al. 2017 (NS-NS dyn ejecta), Fujibayashi et al. 2018 (post-merger))

[see also A. Perego's talk]



Gravitational Waves & GRB Open Questions

[see M. Arca Sedda's talk]

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[see Ghirlanda, Salafia et al. 2016]

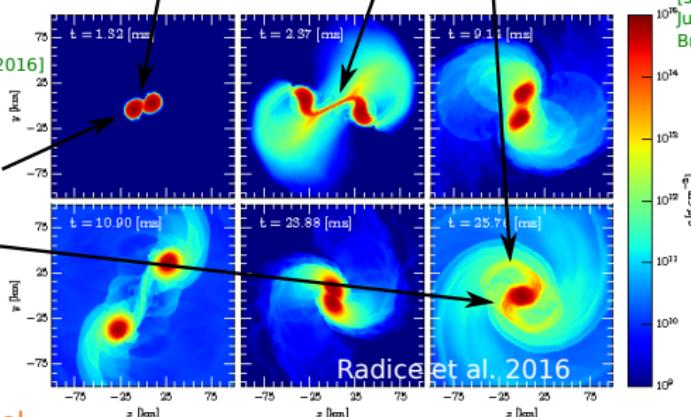
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[see Salafia et al. 2017]

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mass ejection in
merger and post-merger
[see also A. Perego's talk]



set the stage for
the jet interaction
with ambient material,
eventually
on jet structure

[see Murgia-Berthier et al. 2014, 2016,
Just et al. 2016, Gottlieb et al. 2017,
Bromberg et al. 2017]

Gravitational Waves & GRB Open Questions

[see M. Arca Sedda's talk]

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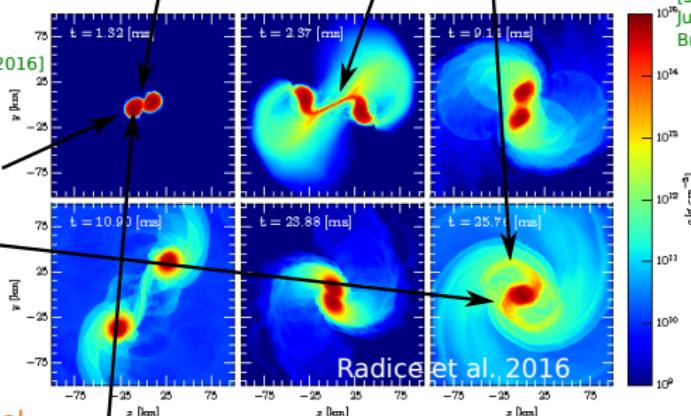
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NS matter

EoS constraints

(e.g. Abbott et al. 2017a (GW only),
Radice et al. 2017 (GW + EM))

Gravitational Waves & GRB Open Questions

[see M. Arca Sedda's talk]

progenitor
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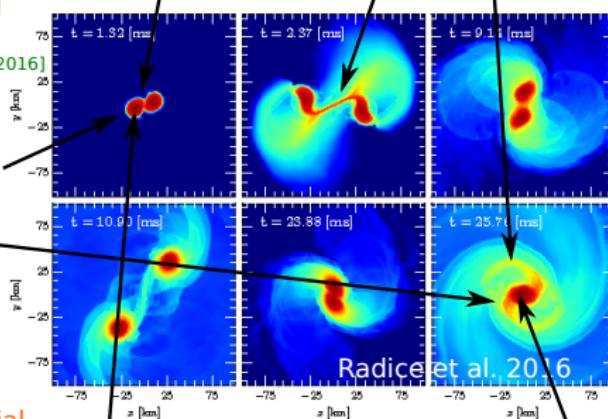
[see Ghirlanda, Salafia et al. 2016]

delay between
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mass ejection in
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[see also A. Perego's talk]

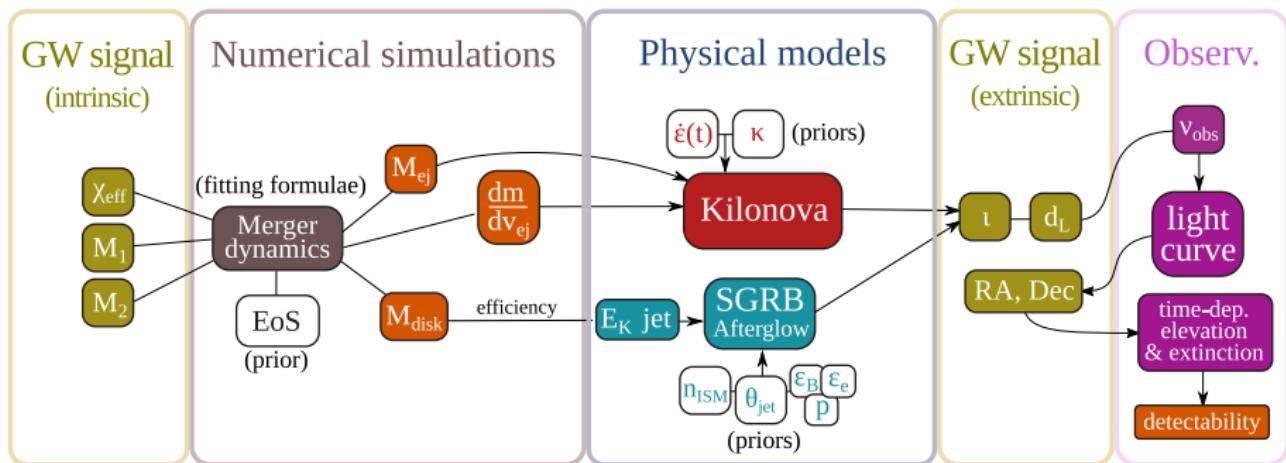
set the stage for
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[see Murguia-Berthier et al. 2014, 2016,
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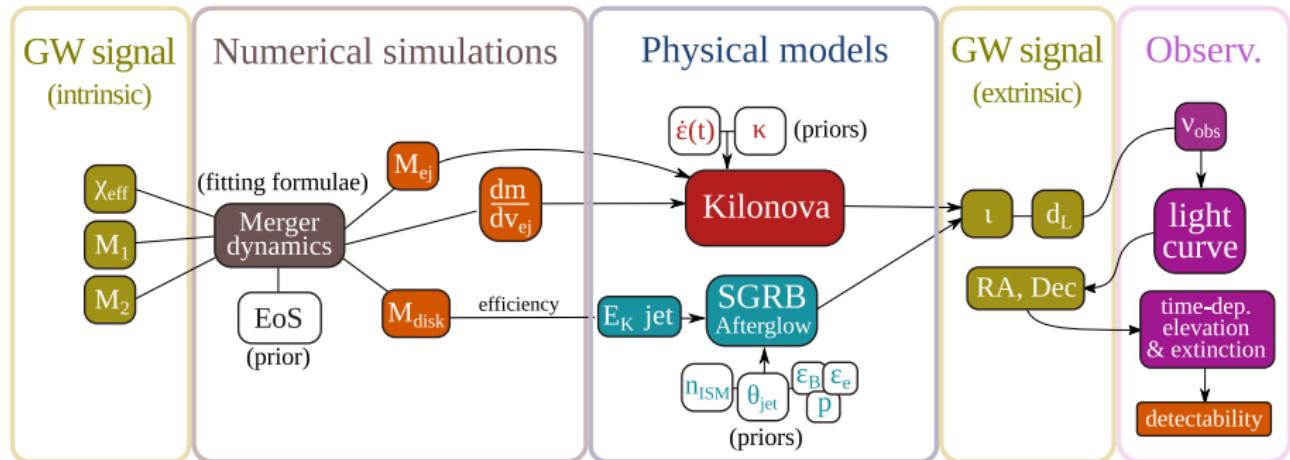
post-merger
remnant
(e.g. Piro et al. 2017,
Radice et al. 2018)

set the stage for
the central engine

“Coherent” GW + EM approach



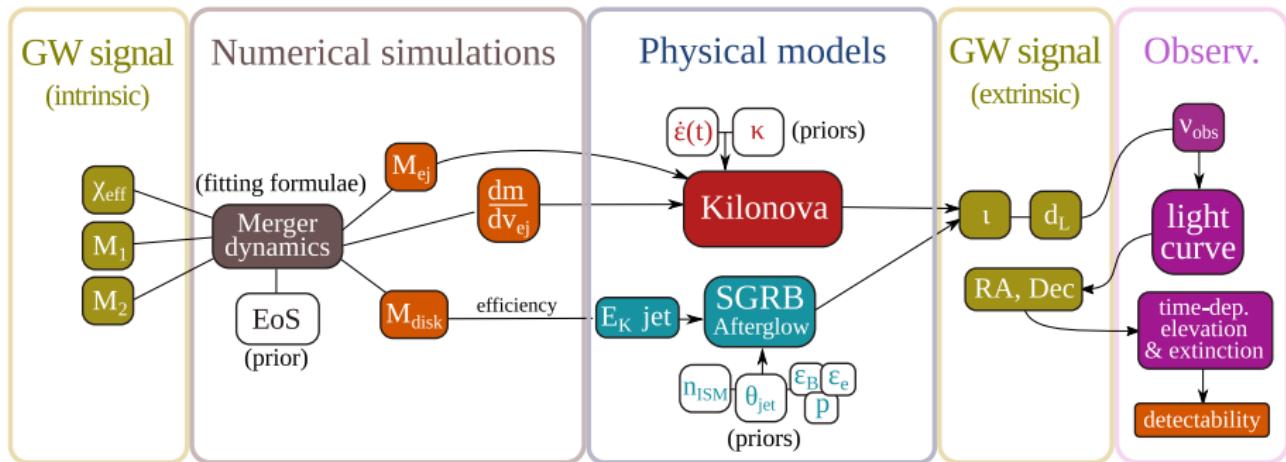
“Coherent” GW + EM approach



(Salafia et al. 2017b)



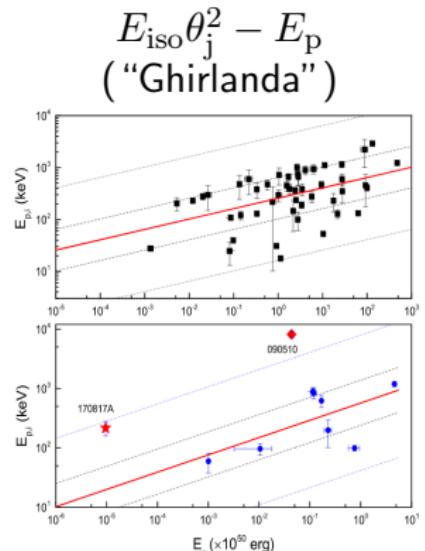
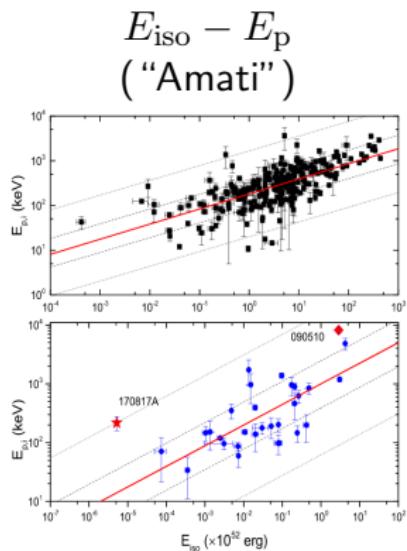
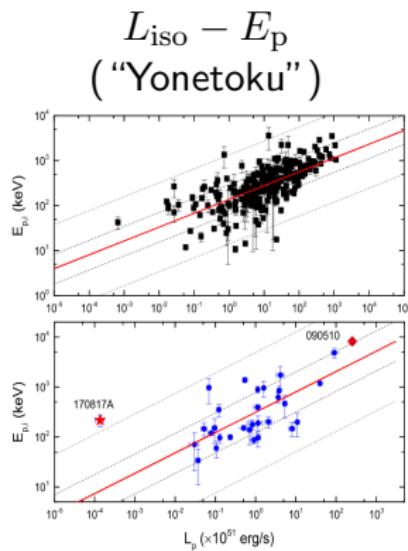
“Coherent” GW + EM approach



Thank you!

Backup slides – hic sunt leones

Prompt emission - “spectral – energy” correlations



(Zhang et al. 2018)