Guetter les sursauts gamma dans leur diversité

Bruce Gendre

Roadmap of the talk

I. Introduction : the gamma ray bursts and their afterglows
   historical approach

II. The fireball model
   Theoretical view
   Observational view: GRB 110205A

III. Different views of progenitors
   Stars
   Binaries

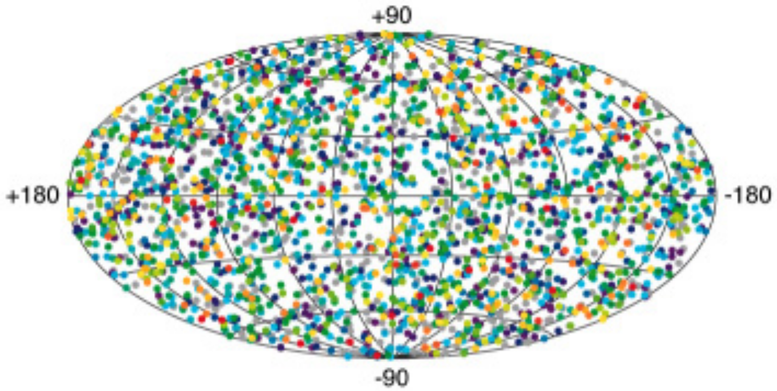
IV. Other hints for the multiplication of progenitors

Description of a GRB

Gamma-ray Burst : burst of high energy photons, with an extragalactic origin, very energetic

Isotropic distribution on the sky

- extragalactic events
- quite common (~2/day)



Energy

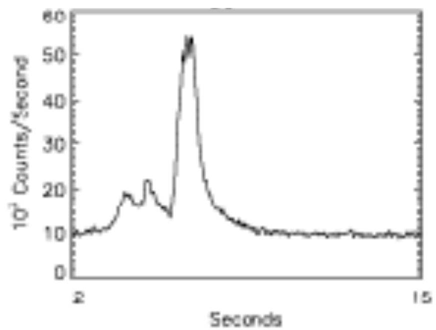
10^{11} erg	10^{34} erg	10^{43} erg	10^{52} erg
simple toaster	Sun	Galaxy	GRB
(~1 min)	(1 s)	(1 s)	(~100 s)

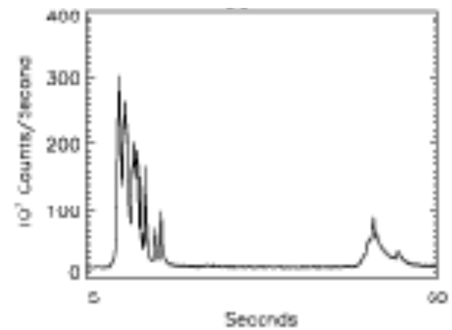
Description of a GRB

Gamma-ray Burst : burst of high energy photons, with an extragalactic origin, very energetic, brief and intense, followed by an afterglow

Prompt phase

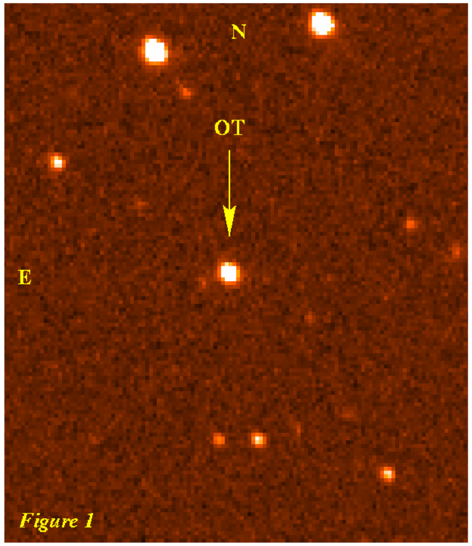
- temporal profile very variable from burst to burst
- typical duration is ~ 20 seconds
- longest GRBs last 7 hours
- shortest GRBs last a few milliseconds

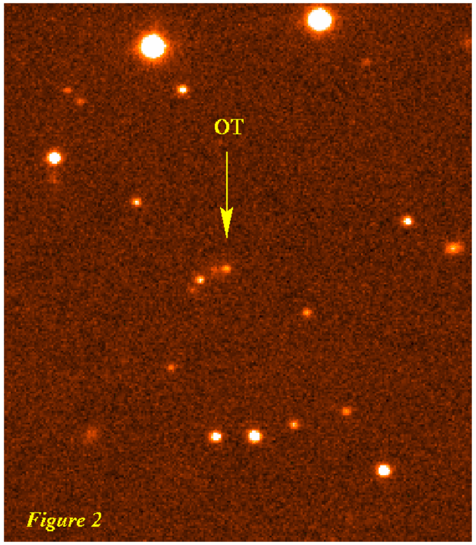




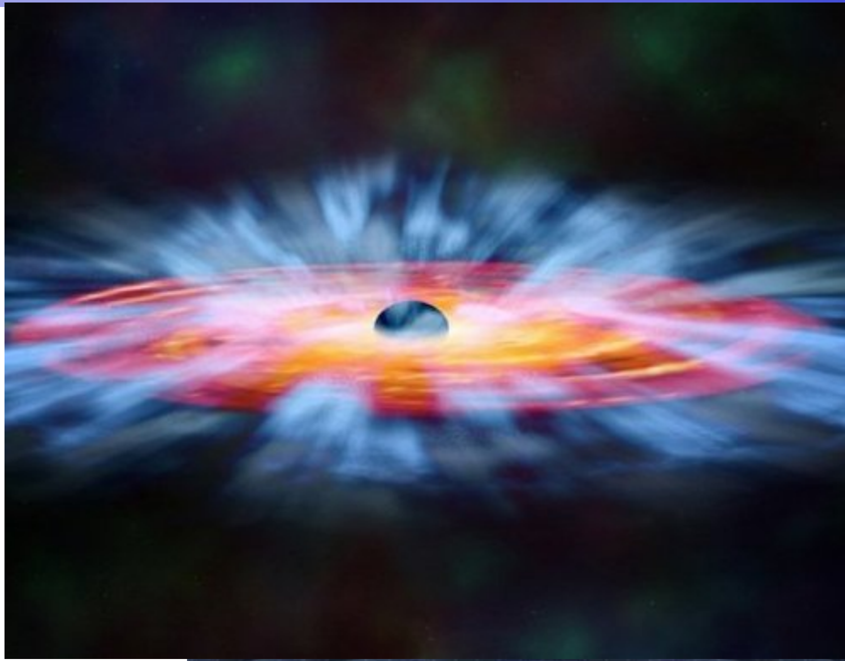
Afterglow phase

- Observed at all wavelengths (X to radio)
- Transient event (typical observation time : 1 week)





Progenitors of GRBs



There are two kinds of possible progenitors

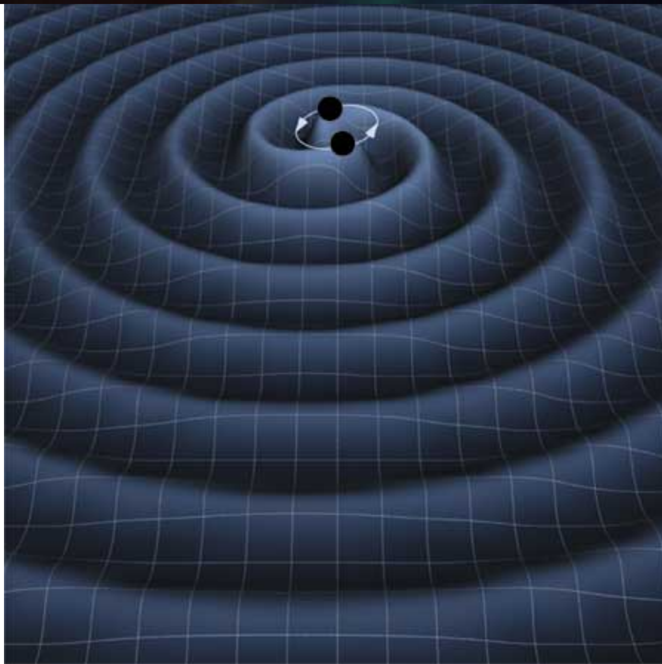
- Super massive stars
- Binary of compact objects

Super massive stars

- Expected to be WR stars
- Neutrino emitters

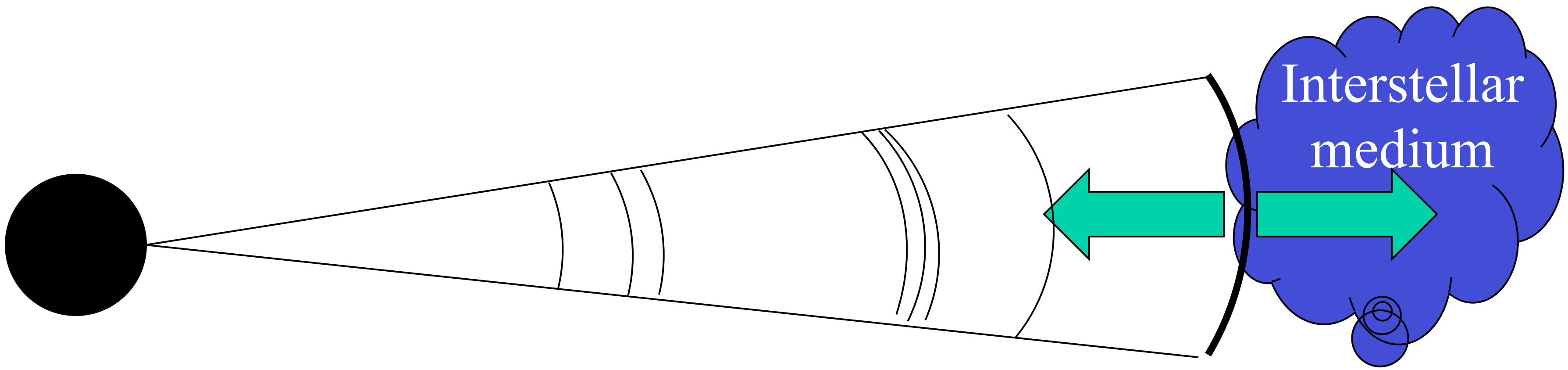
Binary of compact objects

- End-point of stellar evolution
- Radiation of gravitational waves before and during merging



Both of them lead to a stellar mass black hole accreting the remains of the progenitor

The standard model : the fireball model



A progenitor eject shells of matter

- each shell has it own speed, slightly different from the others
- ejection beamed toward the Earth

A fast shell encounter a slower one : internal shocks

- produce the prompt emission

The shells interact with the external medium : external shock

- produce the afterglow

A reverse shock interact with remaining and late shells

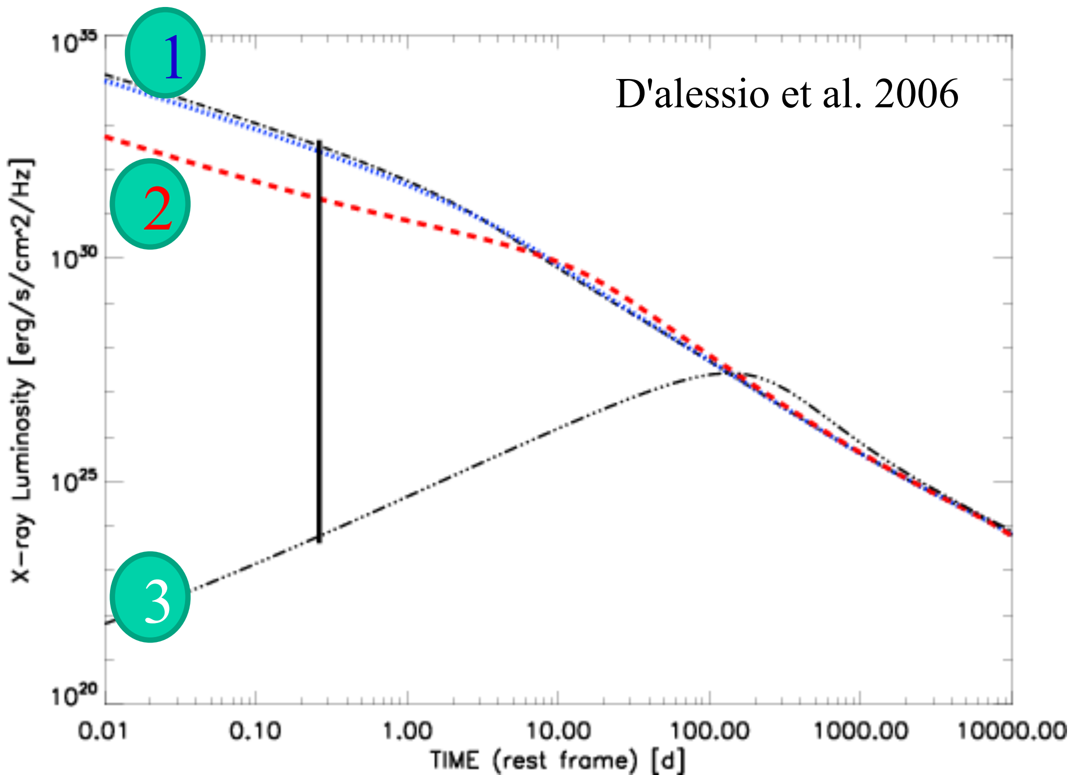
Relativistic beaming

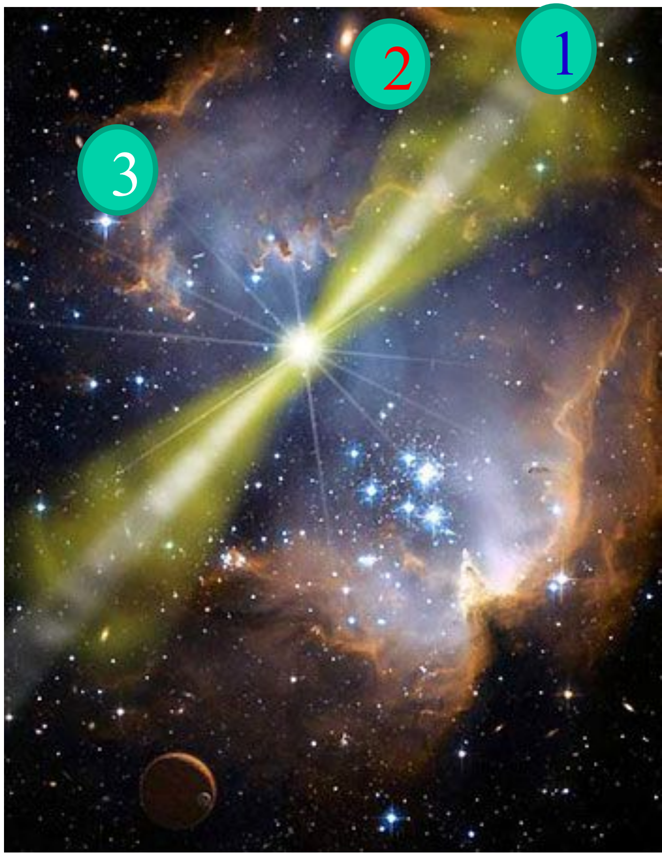
The relativistic beaming, forbid to observe off-axis

However, the jet slows down

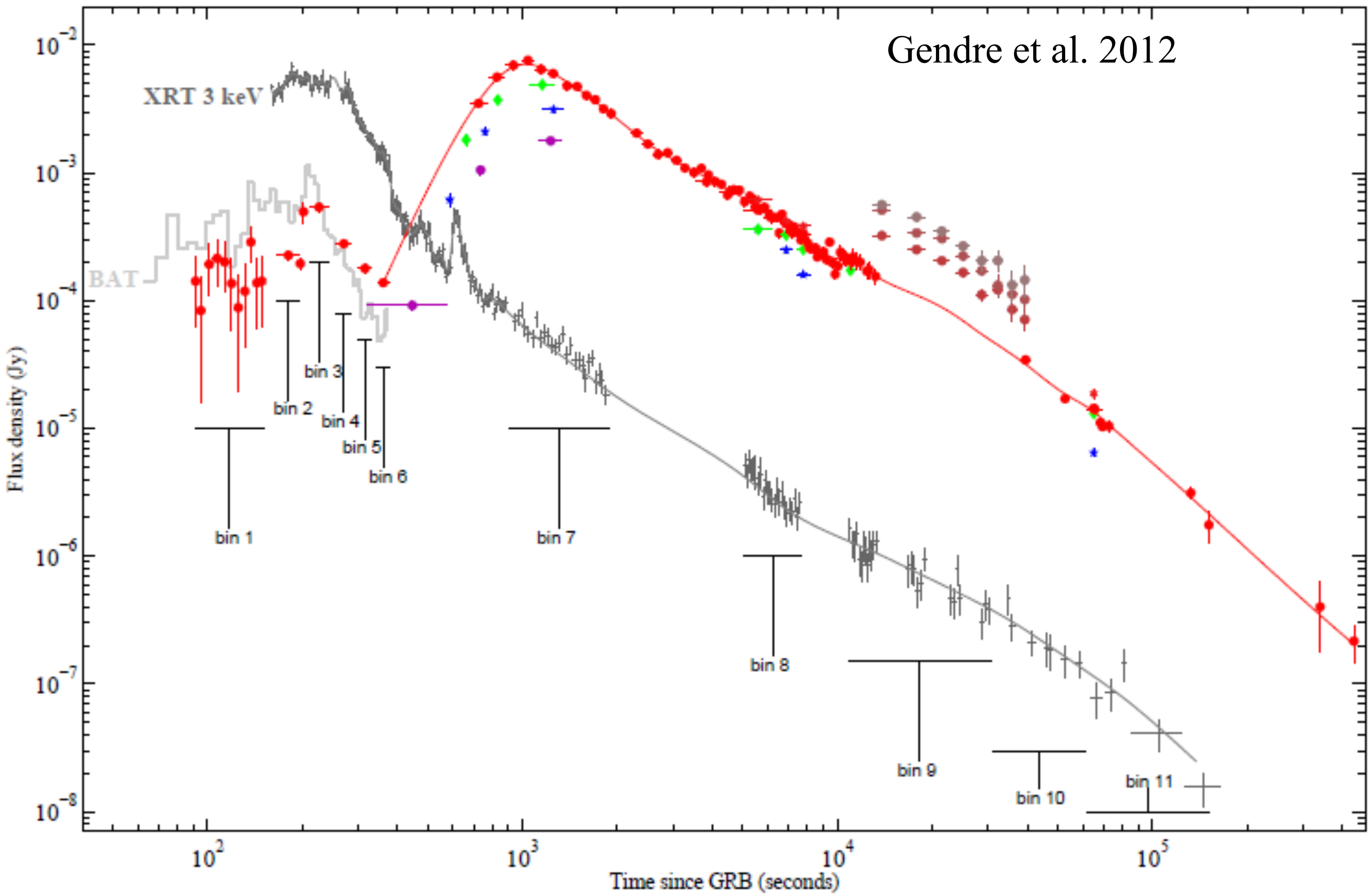
At one point, the relativistic beaming disappear

- This is the so called jet-effect in face-on light curve
- But this has also an effect when seen off-axis





The model in image: GRB 110205A



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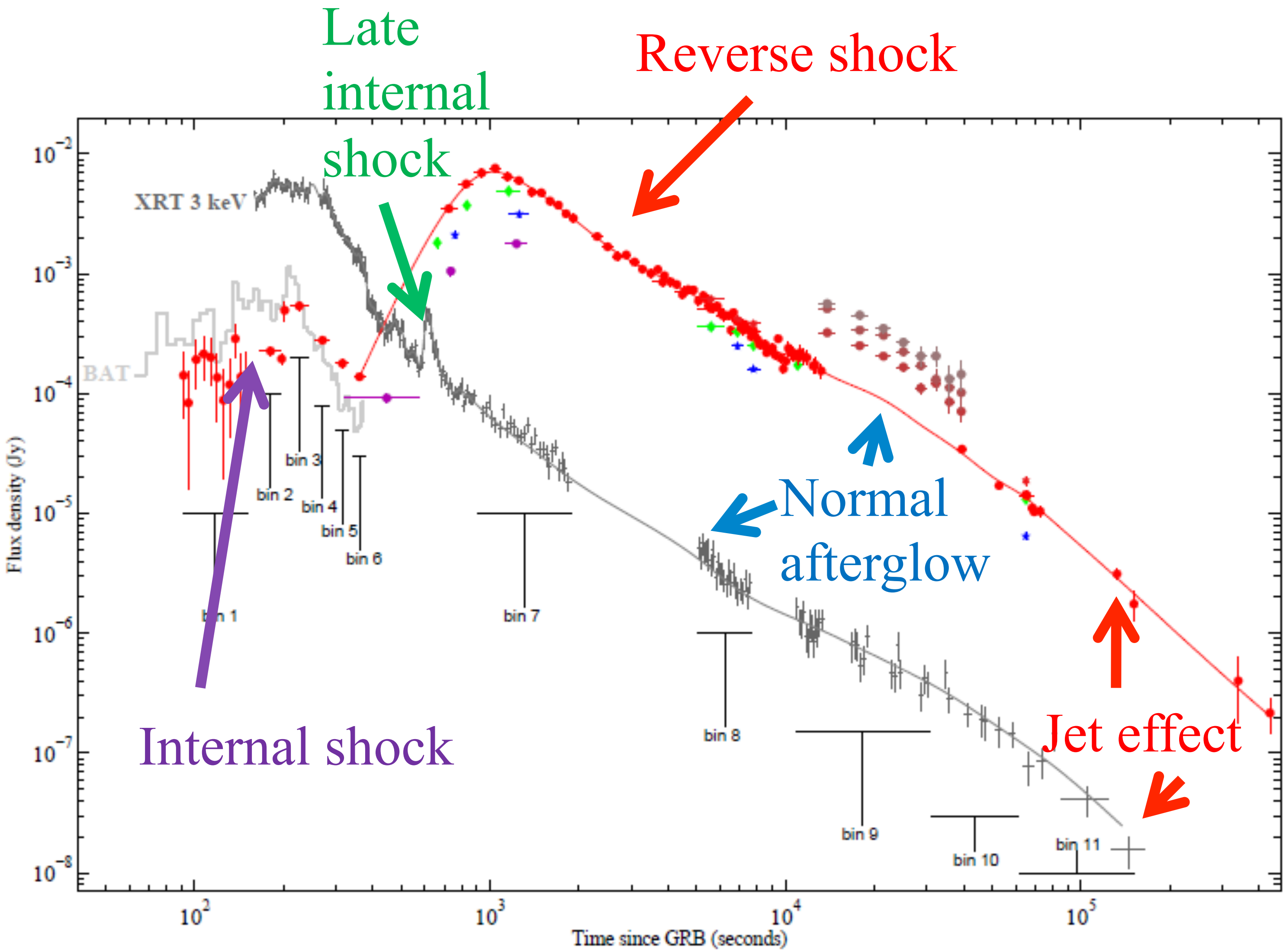
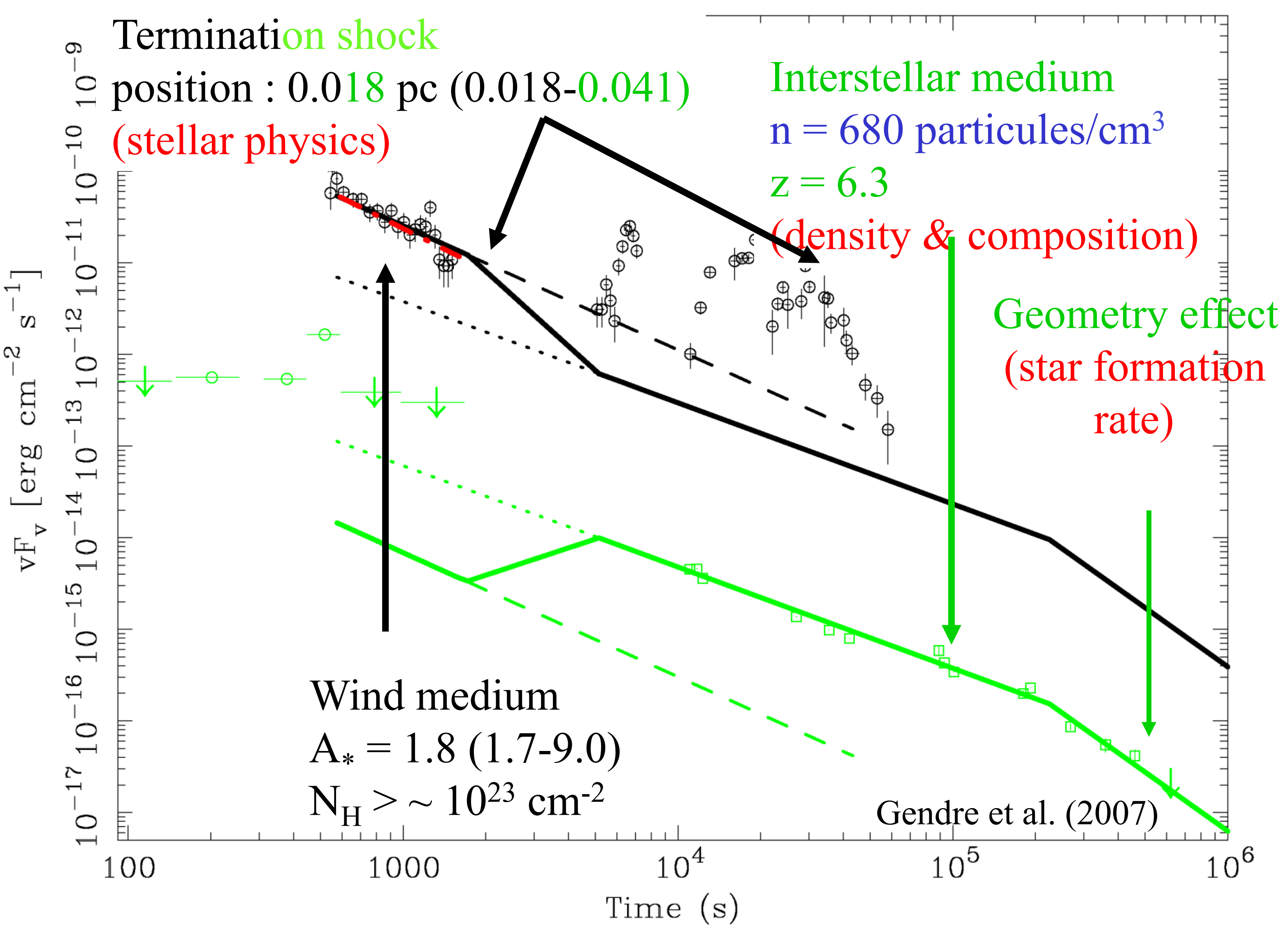
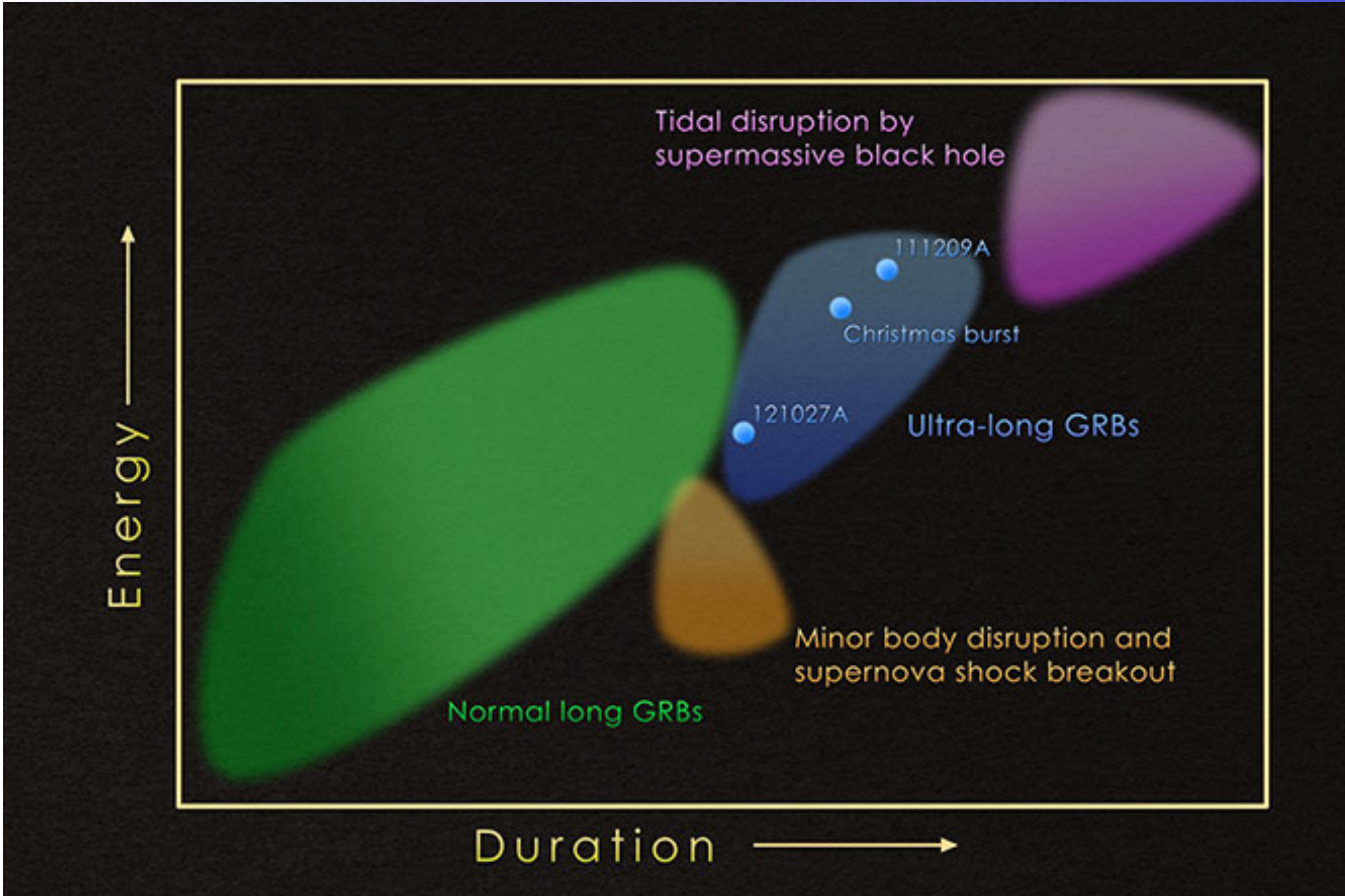


Imprints the progenitor can leave on observations

GRB 050904, located at z = 6.3 (Boër et al. 2005, Gendre et al. 2007)



Another imprint: ultra-long bursts



Gendre et al. 2013, NASA press release illustration

A gallery of progenitors

If dying stars were people:

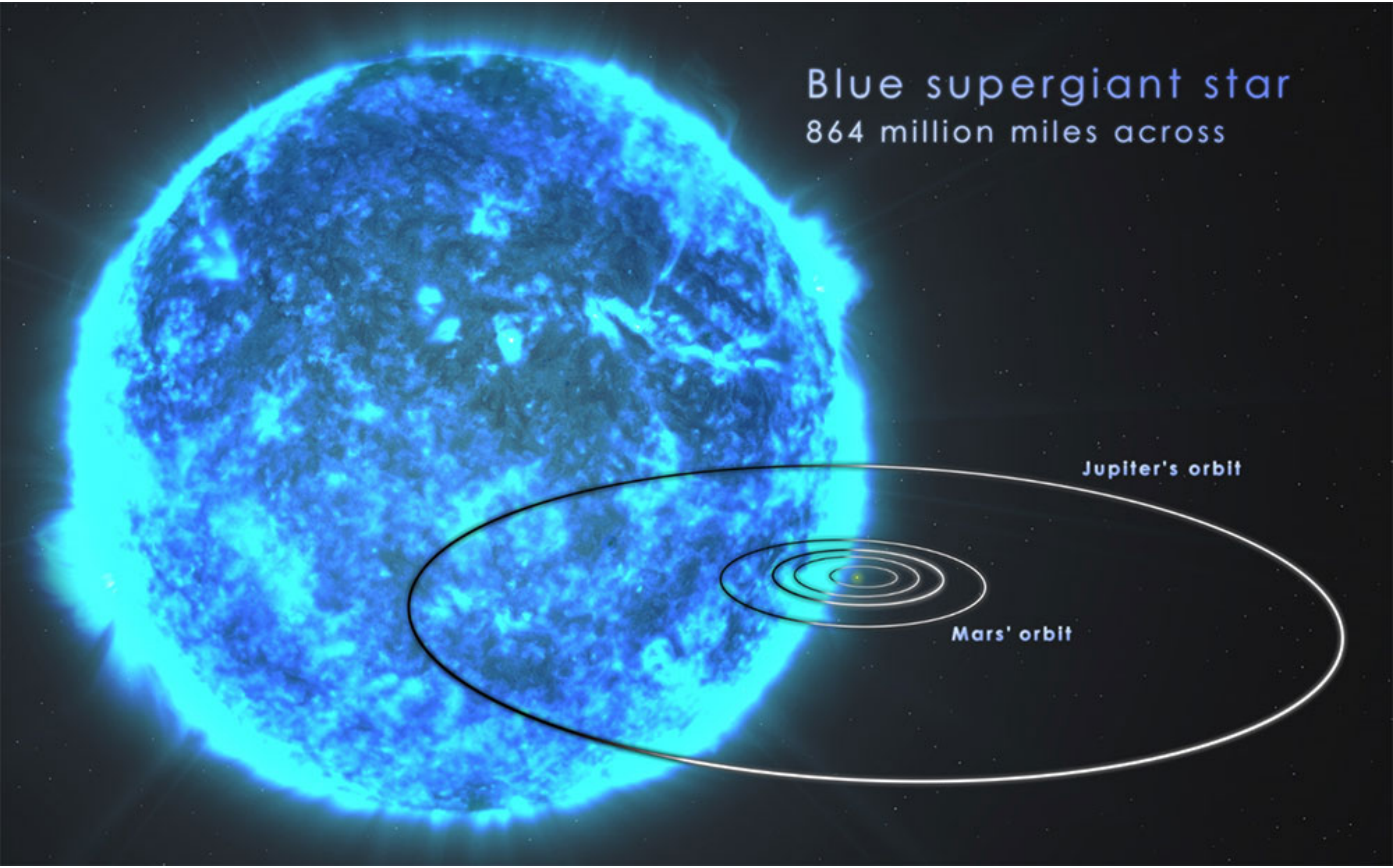
Massive star | Very massive star | ?

Energy

Supernovae | Gamma-ray burst | Ultra-long gamma ray burst

?

An extreme progenitor



An extreme progenitor

Why this is so important?

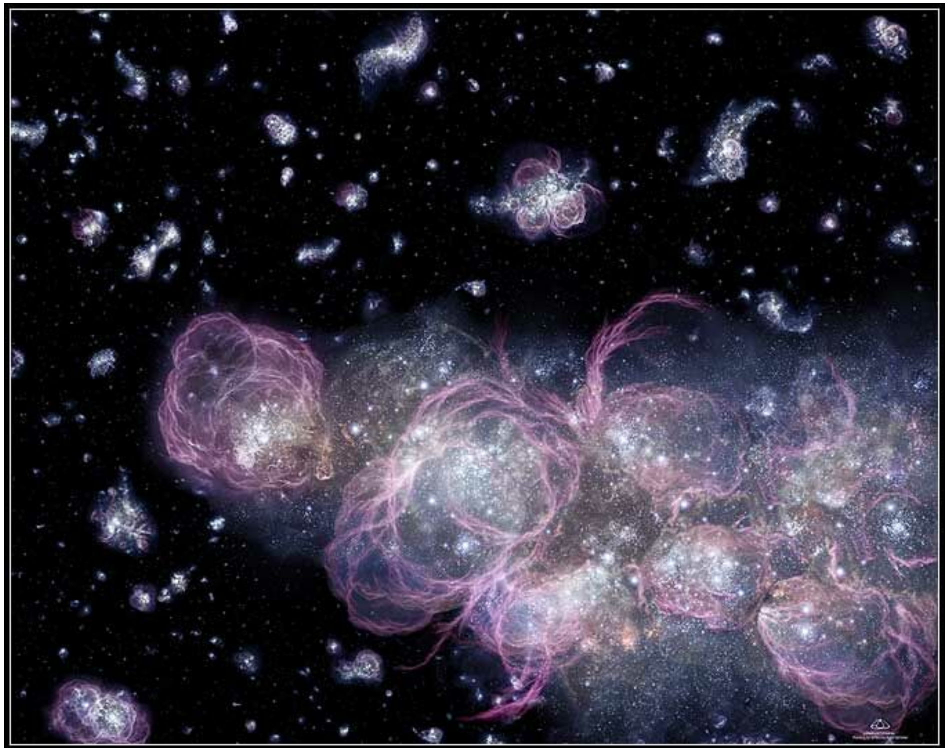
Blue supergiants evolve as WR stars

Not here

- Need to reduce the mass loss
- Best solution is to reduce metalicity

Giant stars are a challenge for jet travel

A very fast rotation may help



Artist's View of Star Formation in the Early Universe
Painting by Adolf Schaller • STScI-PRC02-02

A (very) brief history of the Universe

14 billion years ago: Big Bang

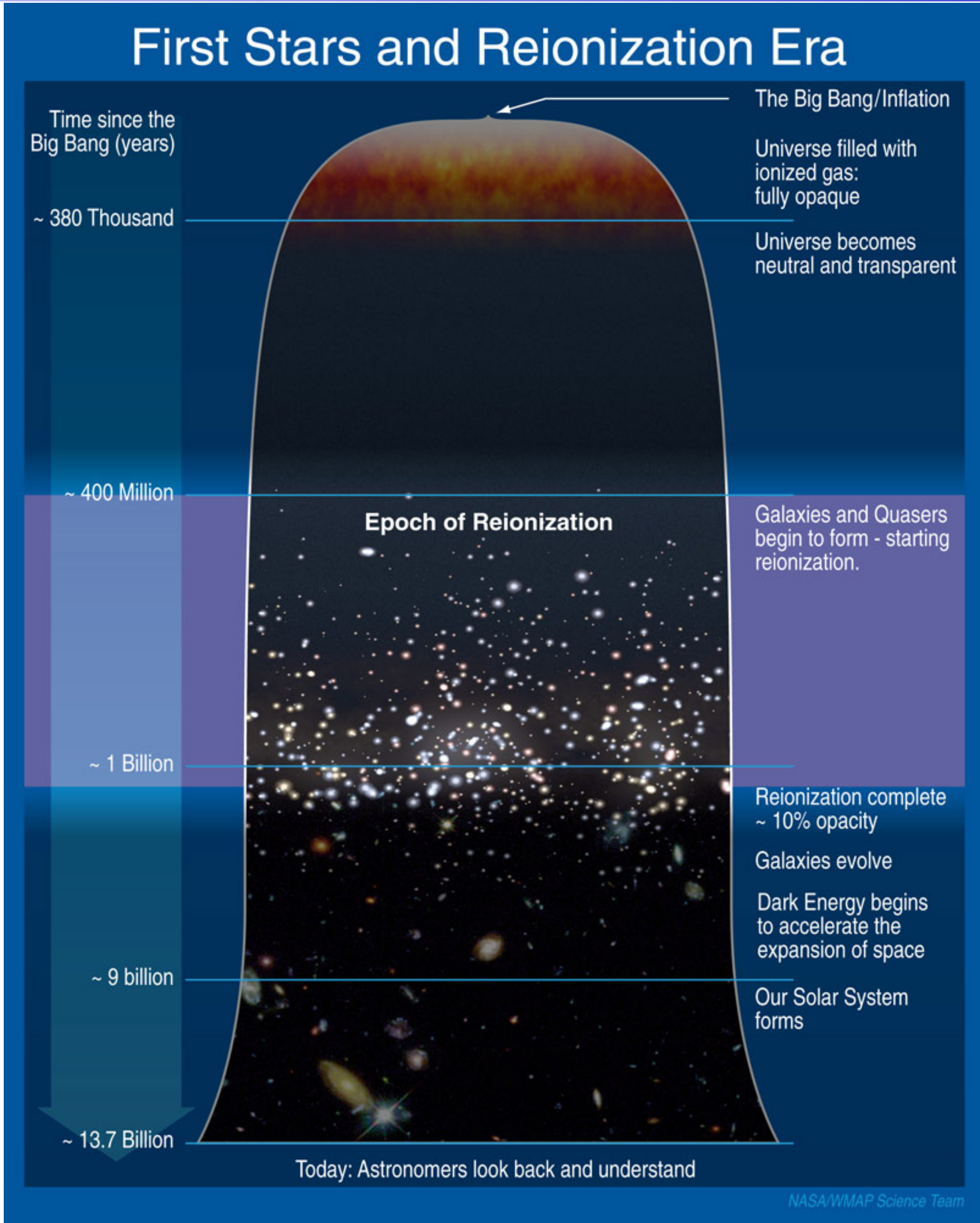
The matter is ionized

Start of cooling

- The matter become transparent
- Echo of the Big Bang @ 3K

Now

- The matter is ionized
- Need of something
- The Re-ionization



An extreme progenitor

The re-ionization was complete at about 1 billion years after BB

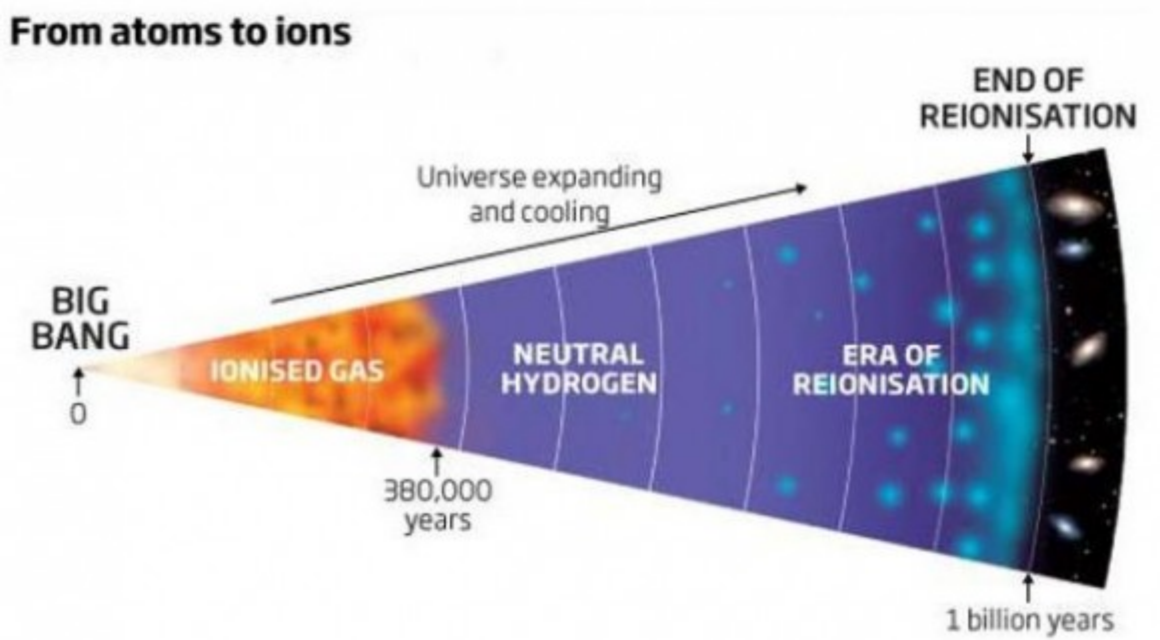
But started when ?

The cause of it… Stars of population III

No metals

But ejected some material

Population II are only "low metallicity"

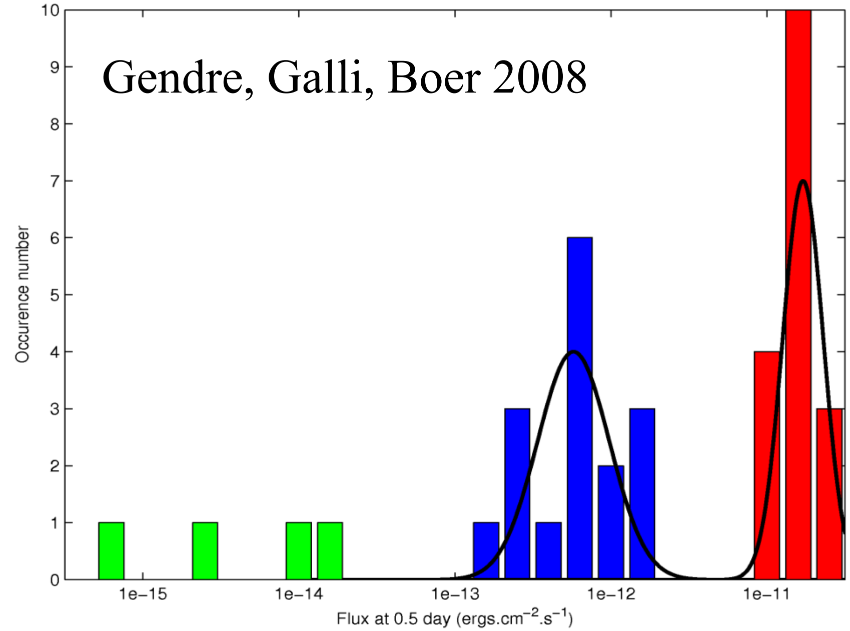


GRB 111209A may be the closest object to Pop III stars ever seen

Strange facts not explained yet

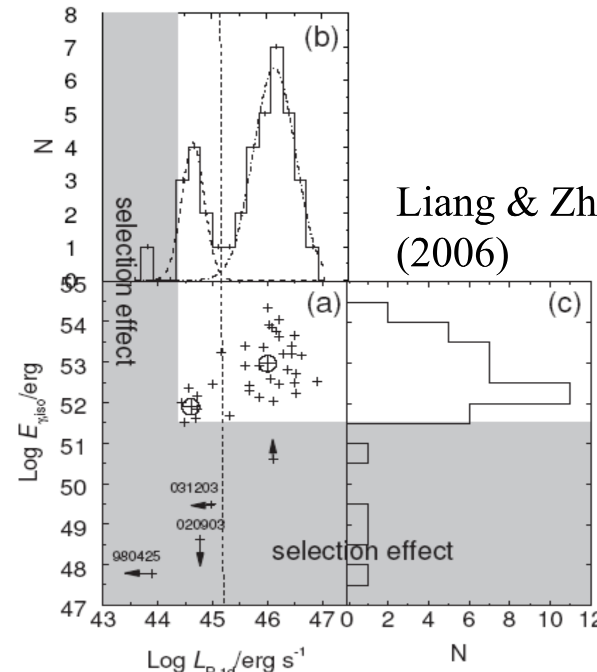
Several works done so far

- Boër & Gendre 2000
- Gendre & Boër 2005
- Gendre & Boër 2006
- Nardini et al. 2006
- Liang & Zhang 2006
- Gendre et al. 2008



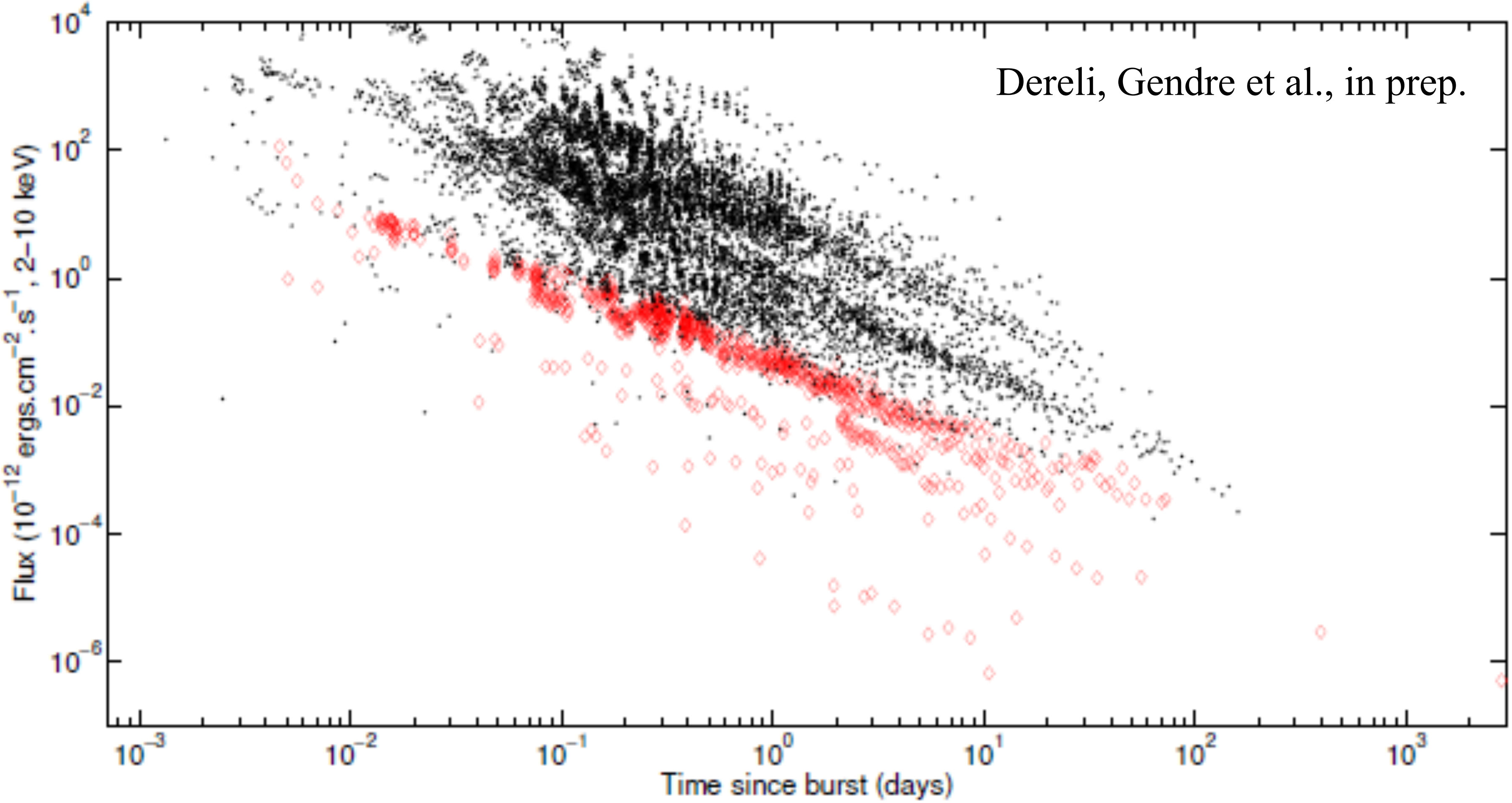
Main conclusions:

- Presence of several groups of events
- Presence of several outliers (10% of sample), all nearby events (z < 0.5)
- Only in the afterglow



Liang & Zhang (2006)

A closer view in X-ray



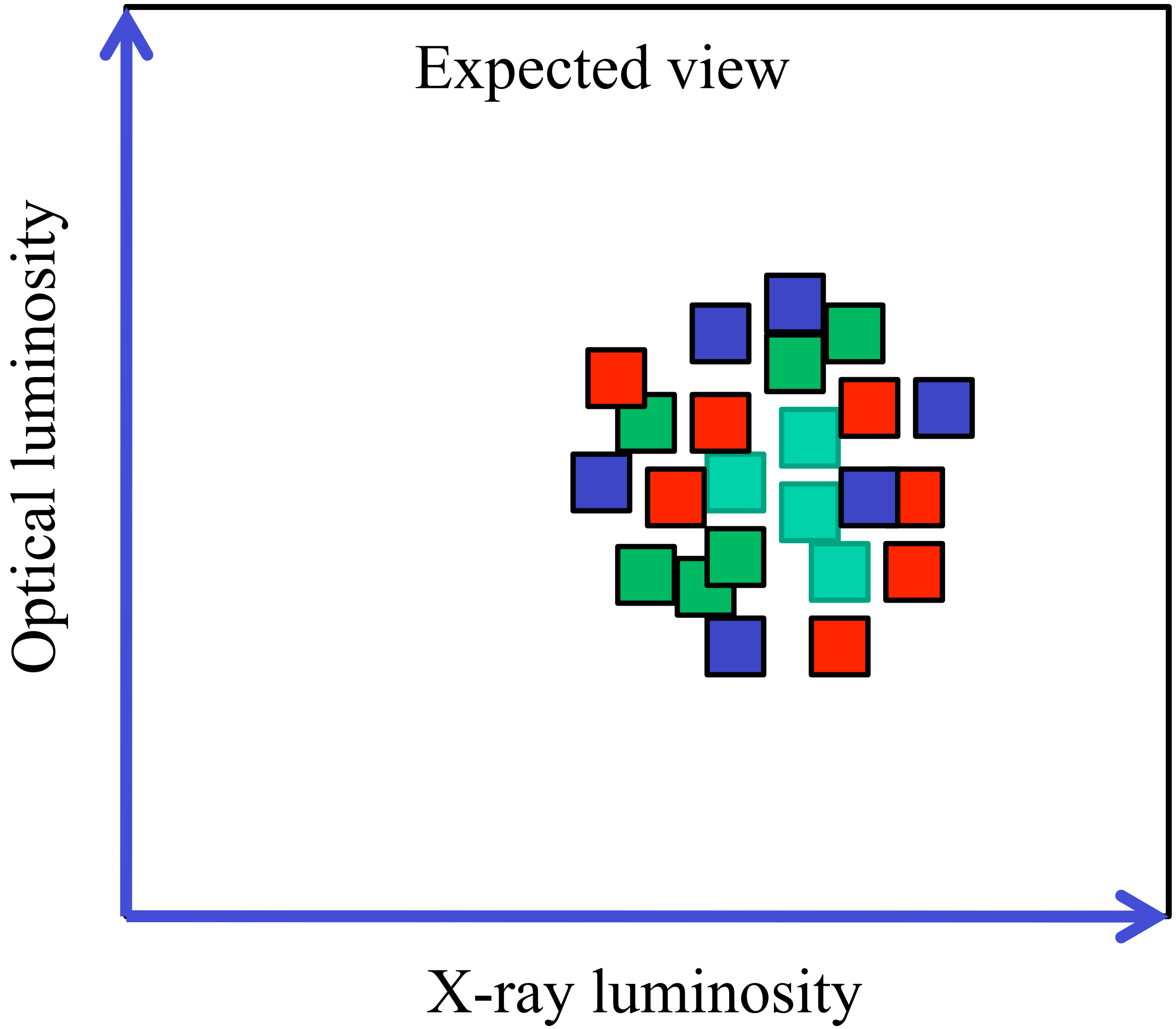
Strange facts not explained yet

The model does not predict any clustering or standard candle property

- This is not what is observed in the prompt phase : the Amati relation (Amati 2002)

How about the afterglow ?

- See a luminosity at a given time

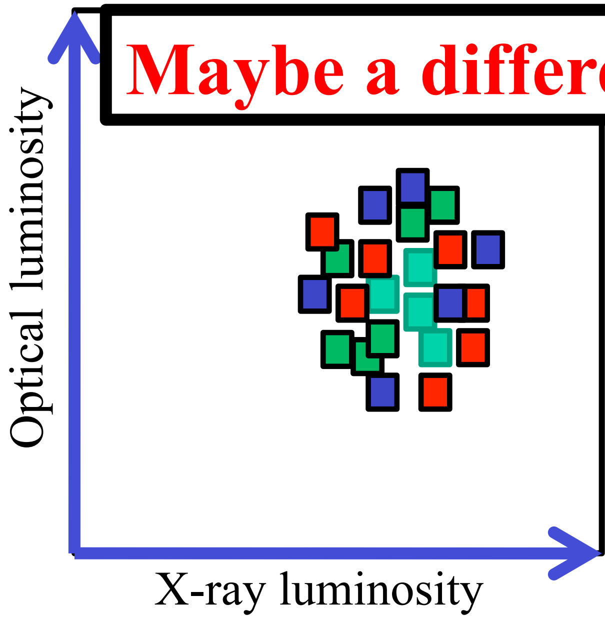


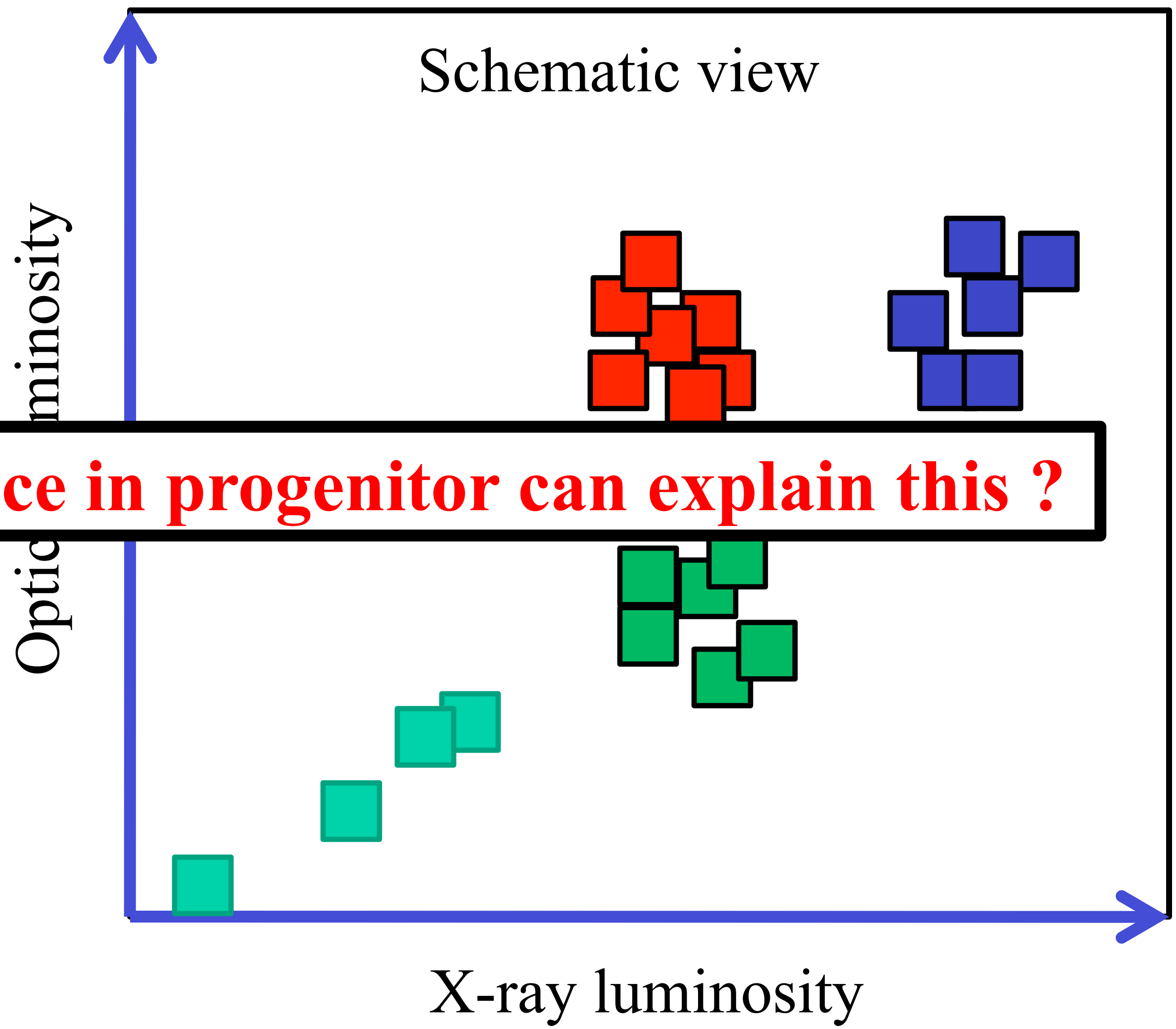
Strange facts not explained yet

Combining the results from X-ray, optical and near infrared

Results

- 3 groups of equal weight
- 10% outliers
- Franc group separation
- Small dispersion within each group





Maybe a difference in progenitor can explain this ?

Strange facts not explained yet

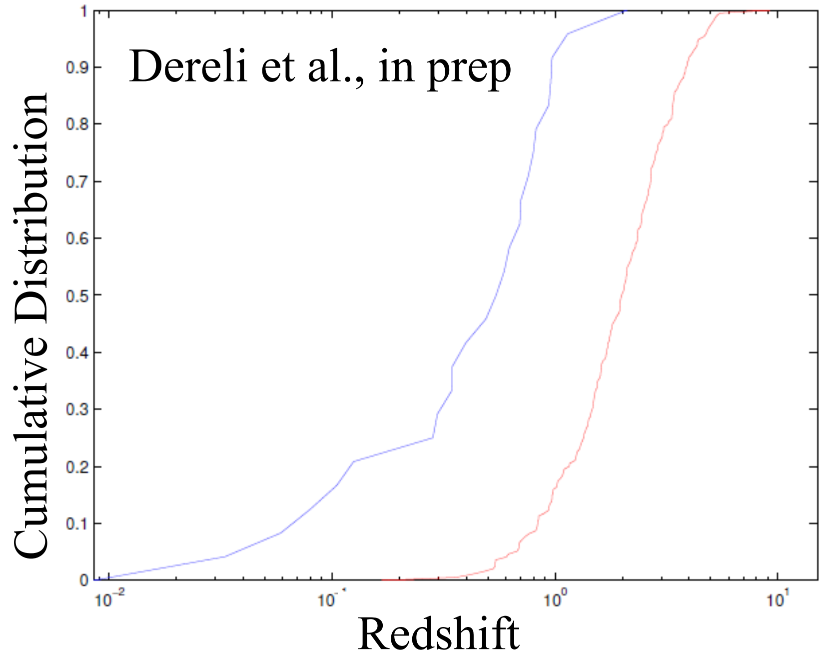
Even more evident when looking at under-luminous events

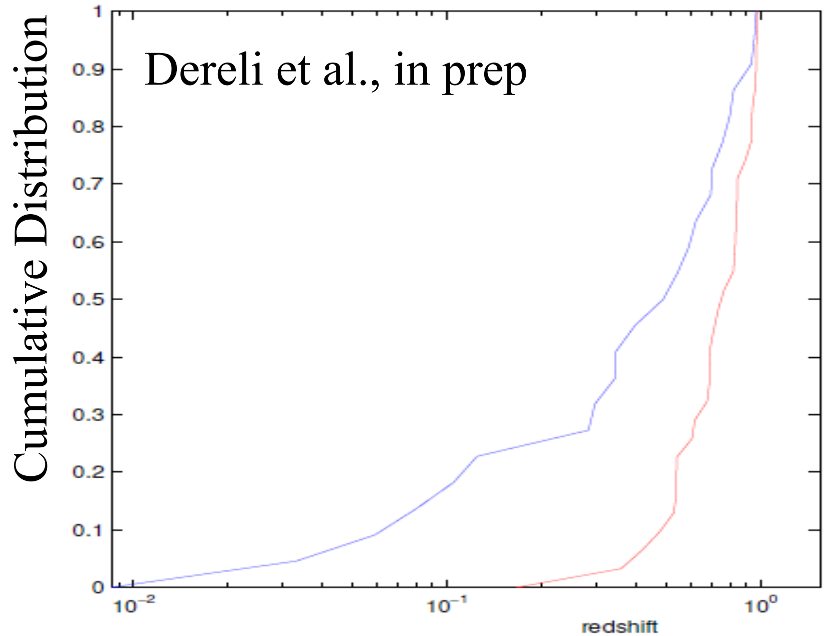
Clearly nearby events

But even when looking to local events, more common than groups I and II events

Possible sign of difference in physics or progenitor

The difference between groups I and II can be explained by different fireballs (see Gendre et al. 2008)





Possible new population of progenitor for short bursts ?

Short bursts are supposed to be produced by merging of neutron stars

Several facts are consistent with this (see Berger et al. 2005)

However the fireball model cannot explain well the plateau phase in case of short event

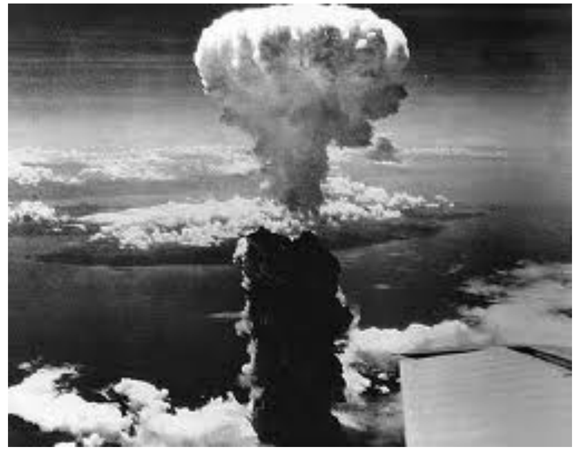
- We can discard this (Siellez, Boër, Gendre 2014)
- Or try to explain it

A solution : the magnetar model (Usov 1994, Troja et al. 2007)

- Magnetic extraction of rotational energy of the magnetar
- Occurs after or during the prompt
- But cannot explain a plateau AND a prompt
- Also has a limit in energy: possible only for nearby events

Knowing better the physics at play

What we can understand by EM studies

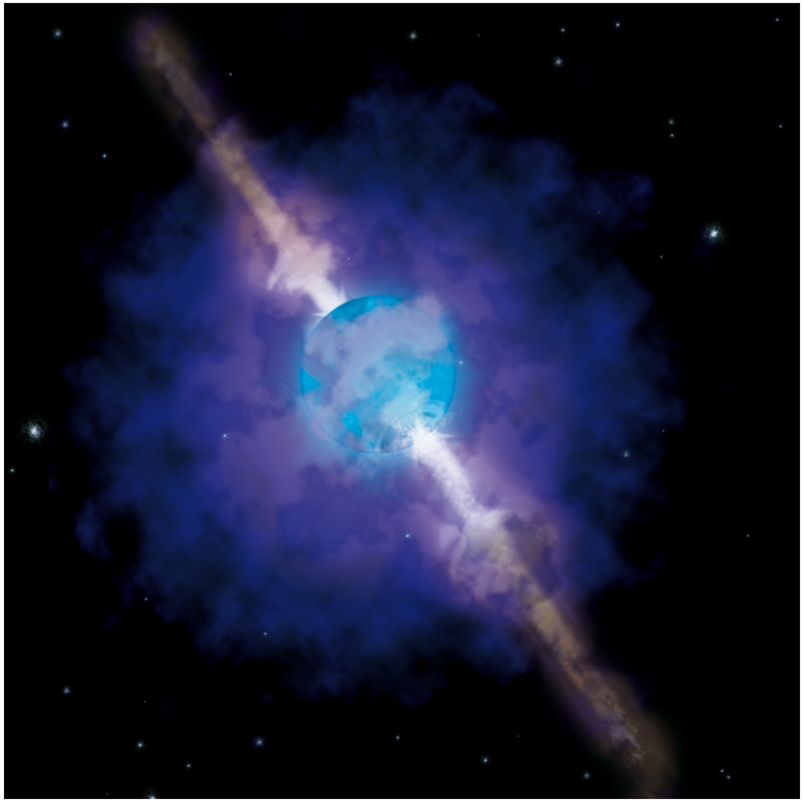


What the GW studies can tell us in addition

Missing parameters that can be inferred by GW studies

Progenitor type

- Binary or single object
- Binary component nature (black hole or neutron star)



Progenitor parameters

- Mass
- Asymmetry degree (case of single object)
- Rotation plane and jet orientation

In fact, all that is needed to characterize the physical properties of the progenitor

Just to be sure that Earth neighborhood is safe…

How to estimate the rate of trigger?

Theory (population synthesis)

- Lead to strong uncertainties
- Model always under debate
- Difficult (if possible) to correct for a change in the knowledge of the model, or to insert a new observational fact

Theoretician way of life

Observations (and some hypotheses)

- Define a sample of known source of GW
- Correct for selection effects
- Correct for volume repartition
- Results are more precise
- Hypotheses changes can be done easily

Siellez, Gendre & Boër way of life

Estimation of the detection rate

Source of GW

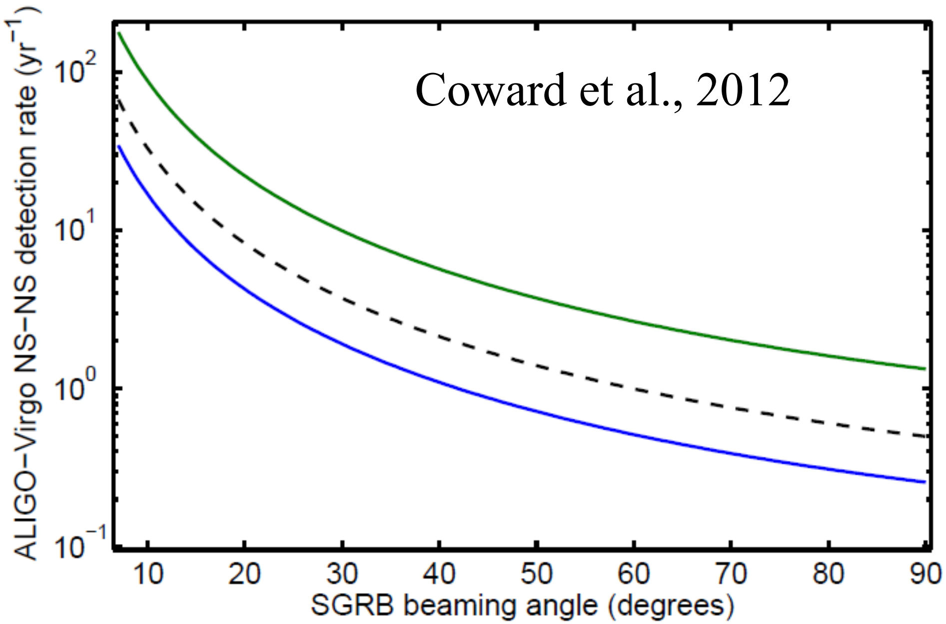
- NS-NS binary merging
- Short GRBs : 14 objects

Working hypotheses

- Low density of the medium
- Beaming angle taken as a free parameter
- Completeness of the sample : pessimistic/complete view or optimistic view

Results:

- Assuming a mean opening angle, at least 8 event/year
- Worst case, 0.25 event/year
- My guess, about 1 event during the instrument life



Pessimistic

Optimistic

Combined Adv Virgo/ aLIGO

Similar (pessimistic?) results in Siellez et al. 2014

Conclusions

Gamma-Ray Bursts are fascinating objects

Most violent explosion in the Universe

Can help in a lot of studies

- First stars
- Faint galaxies
- Ultra-relativistic shocks
- and many more

Can lead to puzzling fact

GRB 111209A is nearby, but with very few metals, for instance

Conclusions

The electromagnetic band is not enough to gather all information

- Gravitational waves

- And also neutrinos

With the help of gravitational waves we can:

- Obtain physical properties of the progenitors

- Study the first seconds of the event in the electromagnetic domain

- Trigger new advances in instrumentation dedicated for these studies (and ask for funds)