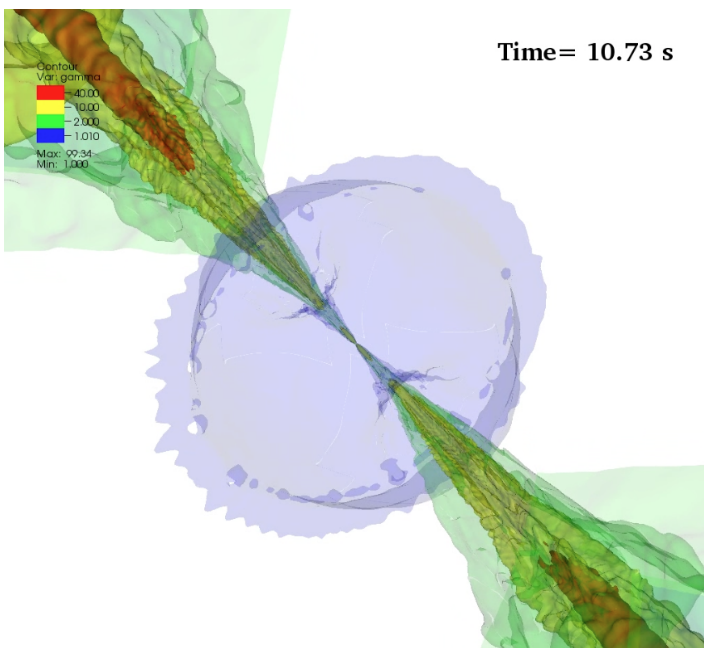
Massive Stars as the Progenitors of (long) Gamma-Ray Bursts



Davide Lazzati (NCSU)

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Outline

- Prehistory
- History
- Modern Age
- Future

Prehistory

- Woosley 1993 “Gamma-Ray Bursts from stellar mass accretion disks around black holes”

- Paczynski 1998 “Are Gamma-Ray Bursts in star forming regions?”

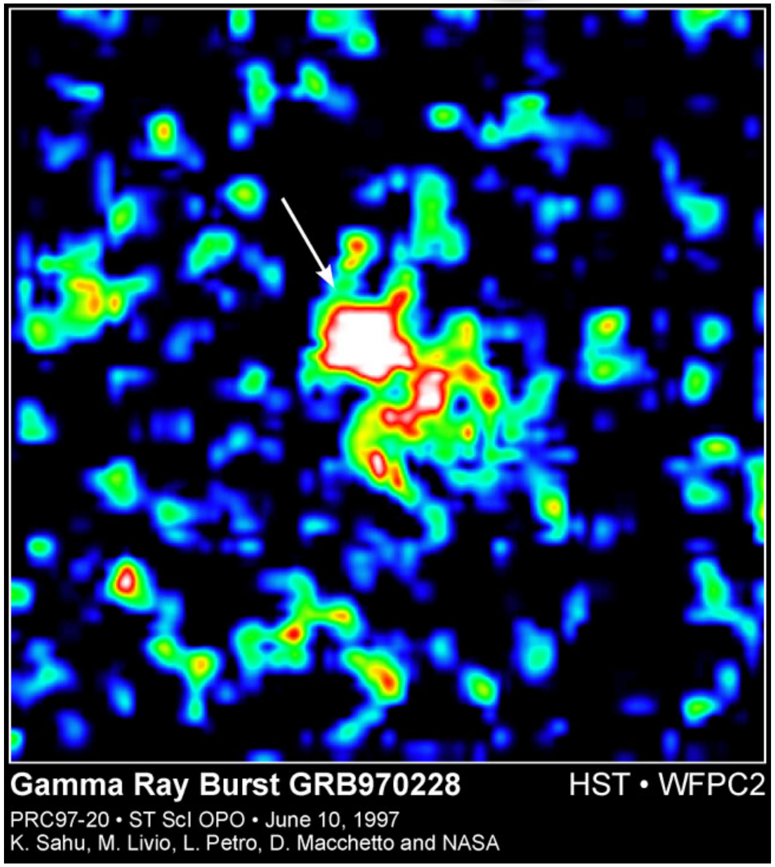
History: Middle Ages

Era of indirect evidence

- Host Galaxies
- Star forming environments
- Location of explosion
- Environment density & density profile
- Iron lines
- GRB980425 - SN1998bw

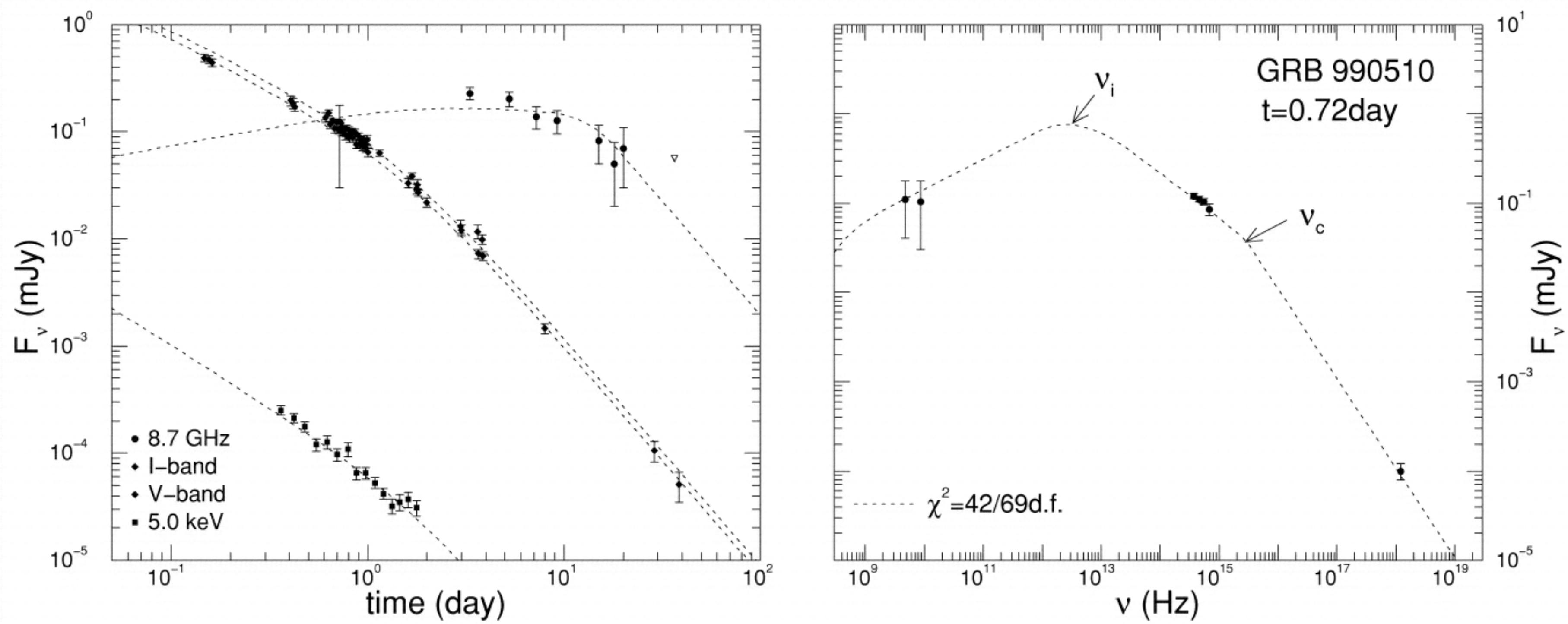
History: Middle Ages

- Host Galaxies



History: Middle Ages

- Environment density & density profile



Panaitescu & Kumar 2001

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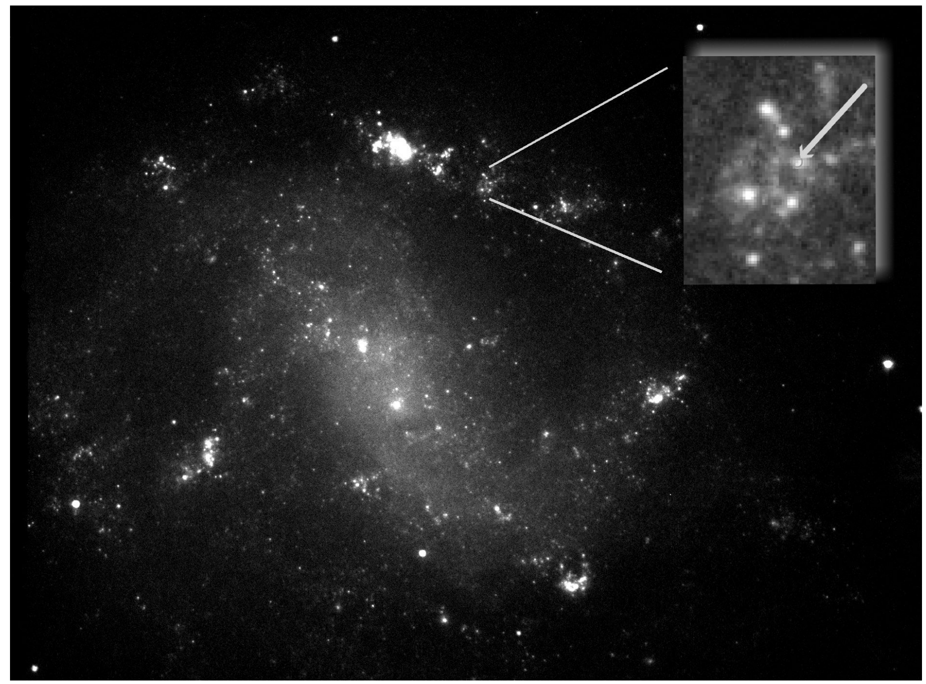
History: Middle Ages

- GRB98045 - SN1998bw

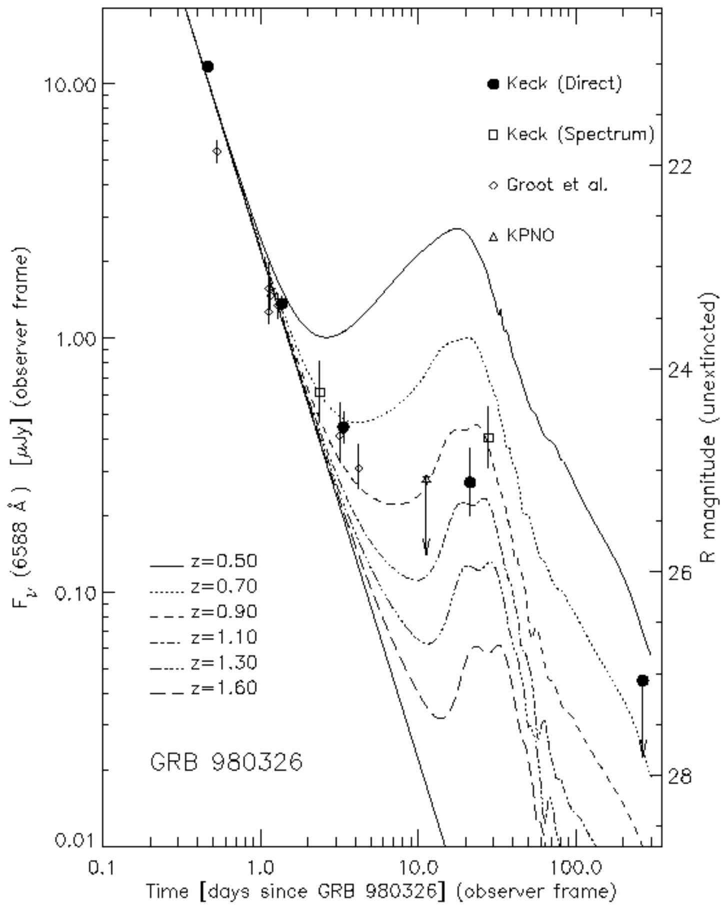
Holland et al. 2002



History: Renaissance

History: Renaissance

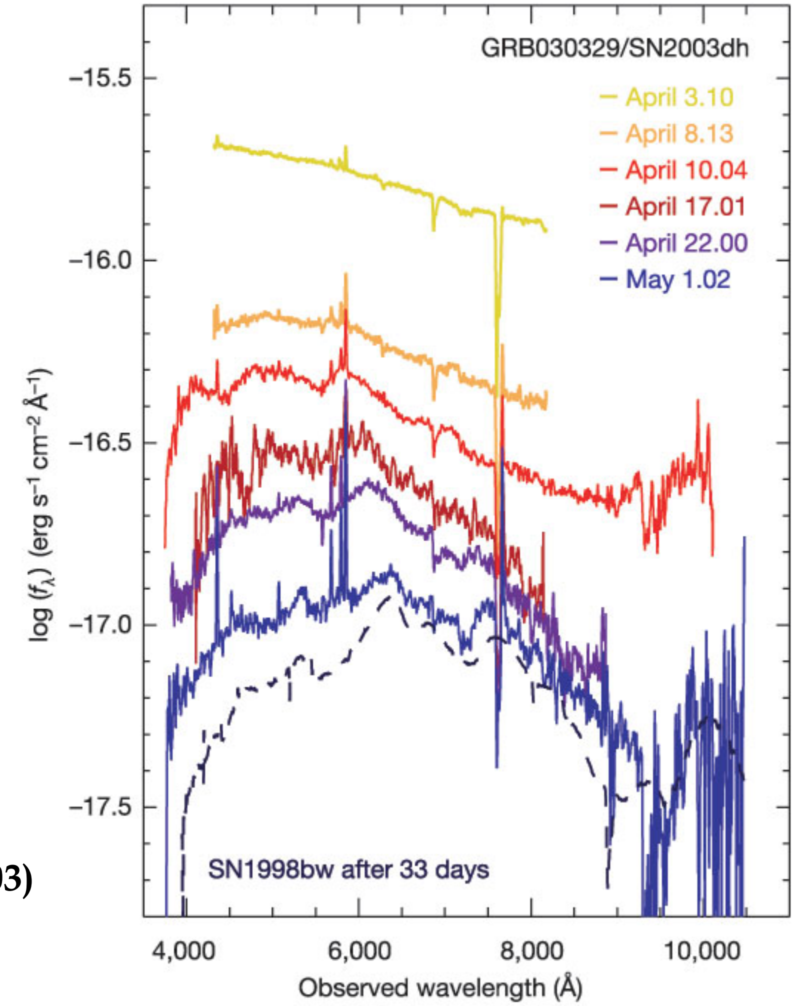
- **SN Bumps**



Bloom et al. 1999

History: Renaissance

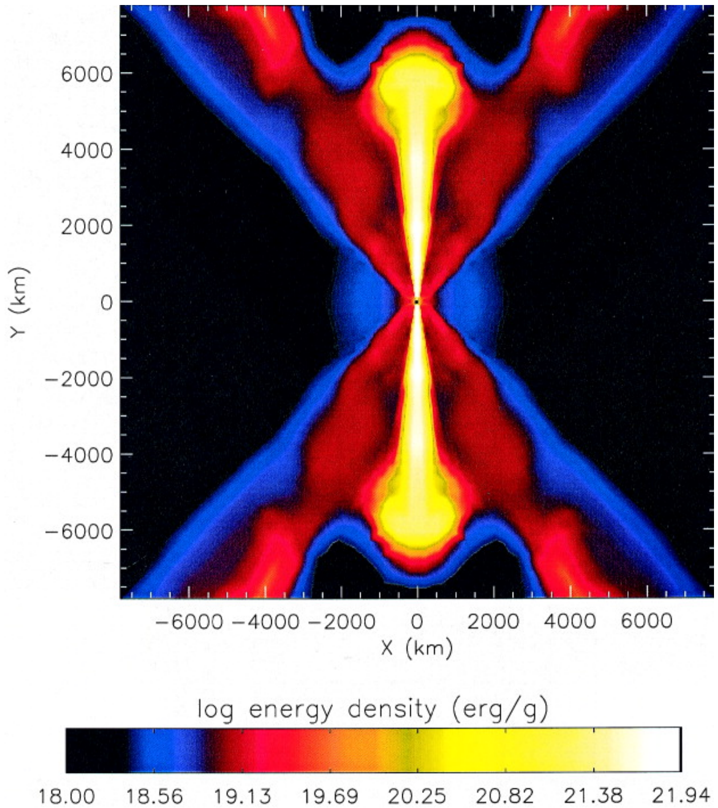
- **GRB030329-SN2003dh**

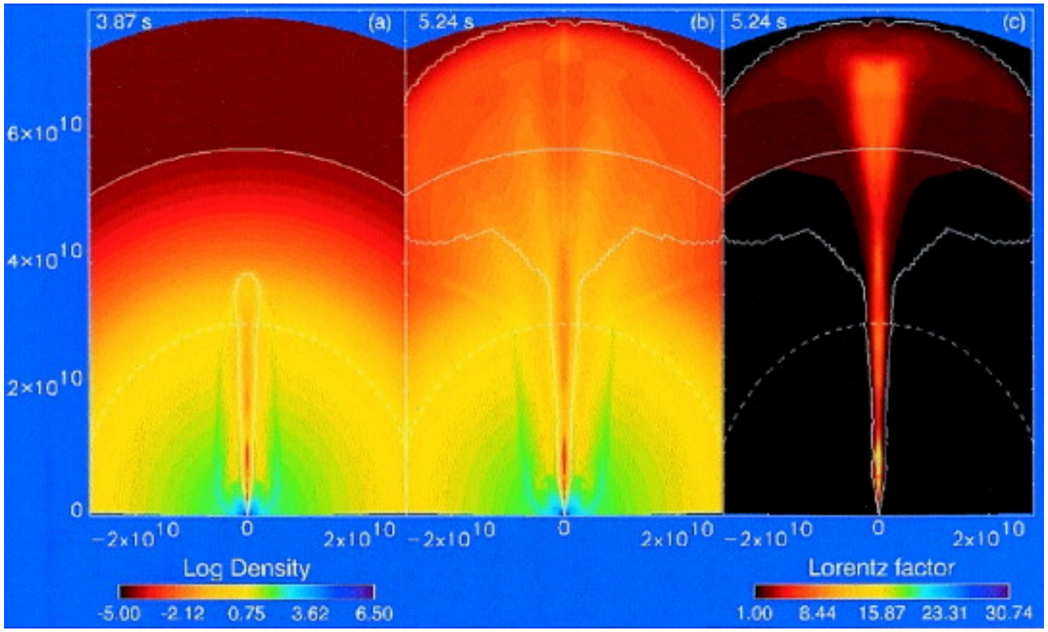


Hjorth et al. 2003
(also Stanek et al. 2003)

History: Renaissance

- MacFadyen & Woosley (1999) and Aloy et al. (2000)





Modern Era

Modern Era: setting the stage

- At least some long-duration GRBs are associated to the explosion of massive compact stars.
- The two events are coeval to within less than 1 day.
- If we release relativistic energy in the core of a massive compact star, we can get a relativistic jet outside of it.

Do all long GRBs have SNe?

- Every time we can see one we do see it
- But we cannot see SNe at $z>1$, where most GRBs are observed
- At least two long durations GRBs with no SN, but probably misclassification or evidence that the long-short classification is not physical
- "No SN" does not necessarily implies "no stellar progenitor" (^{56}Ni production issue, see next talk by S. Nagataki)

Nature of the central engine

- Two main candidates: Black Hole Accretion Disk system, Magnetar.
- All require rotation
- How to tell?

Evidence of BH-Sne
e.g. SN1979C, SN2009kf

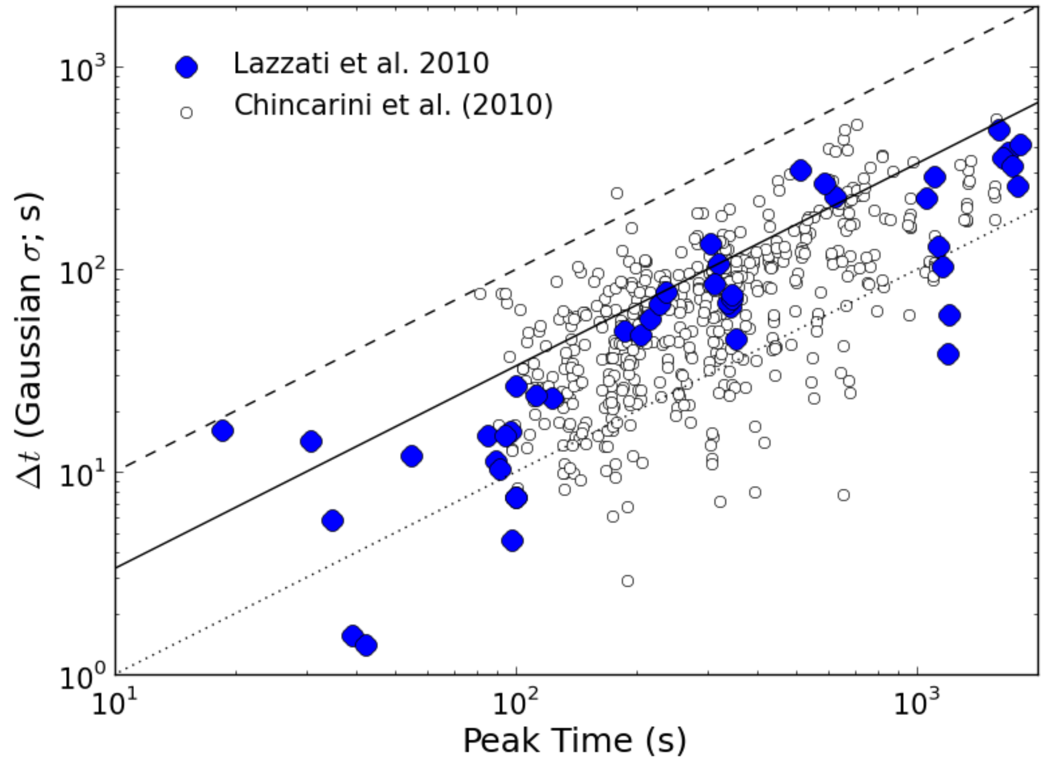
Associated NRO (Non-Relativistic Outflow) and implications on nucleosynthesis (better seen in No-GRB SNe)

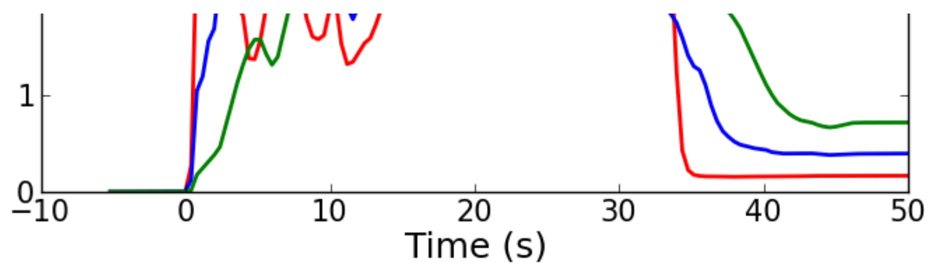
Very energetic events

Pre-explosion progenitor properties and/or or late-time engine emission

Consequences on the GRB

- Some 10^{51} e
  drilling the
- Opening an
- Variability
- Increased p
- X-ray flares





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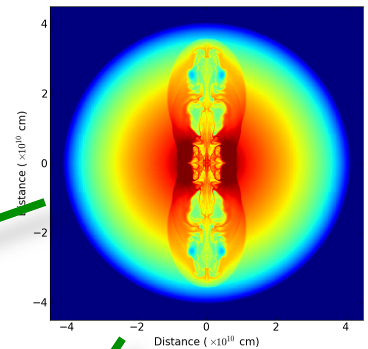
How many WR stars/type Ibc SNe produce GRBs? Why some do and some don't?

- GRBs rate ~1% of type Ibc SNe, 0.2% of all CCSNe
  (Podsiadlowski et al. 2004, Soderberg et al. 2010)
- Special ingredient 1: rotation (for formation of BH)
- Special ingredient 2: low metallicity (to keep angular momentum)
- [illegible]

Best constraints from observations, still too many uncertainties on the theoretical side. Most models predict only a few per cent of SNe to be associated to a GRB

Massive stars & BROs

BROs = Bipolar Relativistic Outflows



Successful GRB

When engine lasts long enough (t>5 s)
~1% of Ibc

980425-like Faint GRB

When the engine barely makes it to breakout (4.5<t<5 s)
~1% of Ibc

Radio-Bright SN

When the engine barely fails to break out (4<t<4.5s)
~1% of Ibc

Apparently Normal SN

Any time
$E<=10^{51}$ erg
t<4 s
10% of Ibc???

Rates from Podsiadlowski et al. 2004; Guetta & Della Valle 2007; Soderberg et al. 2010

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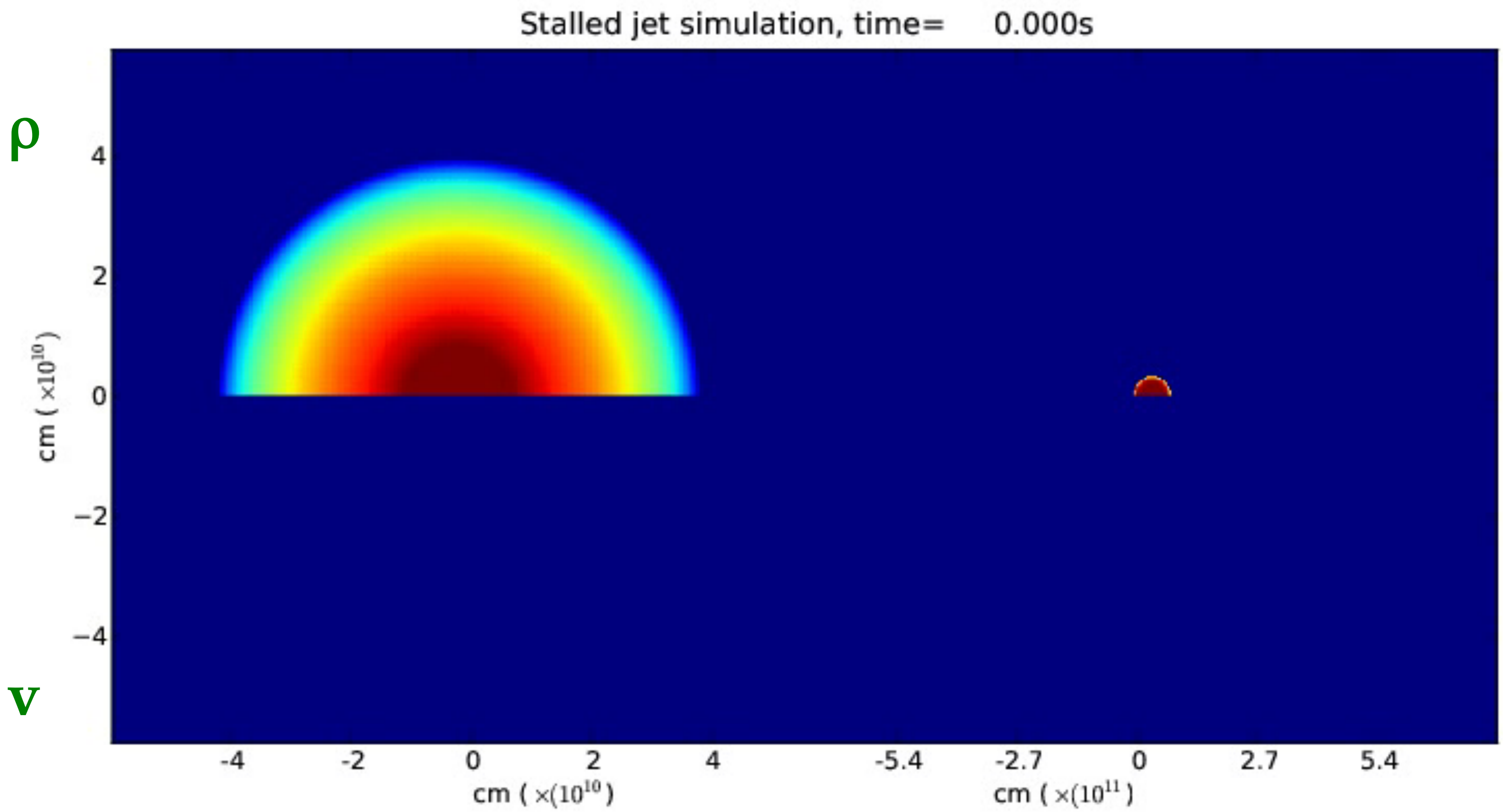
BROs-induced SNe



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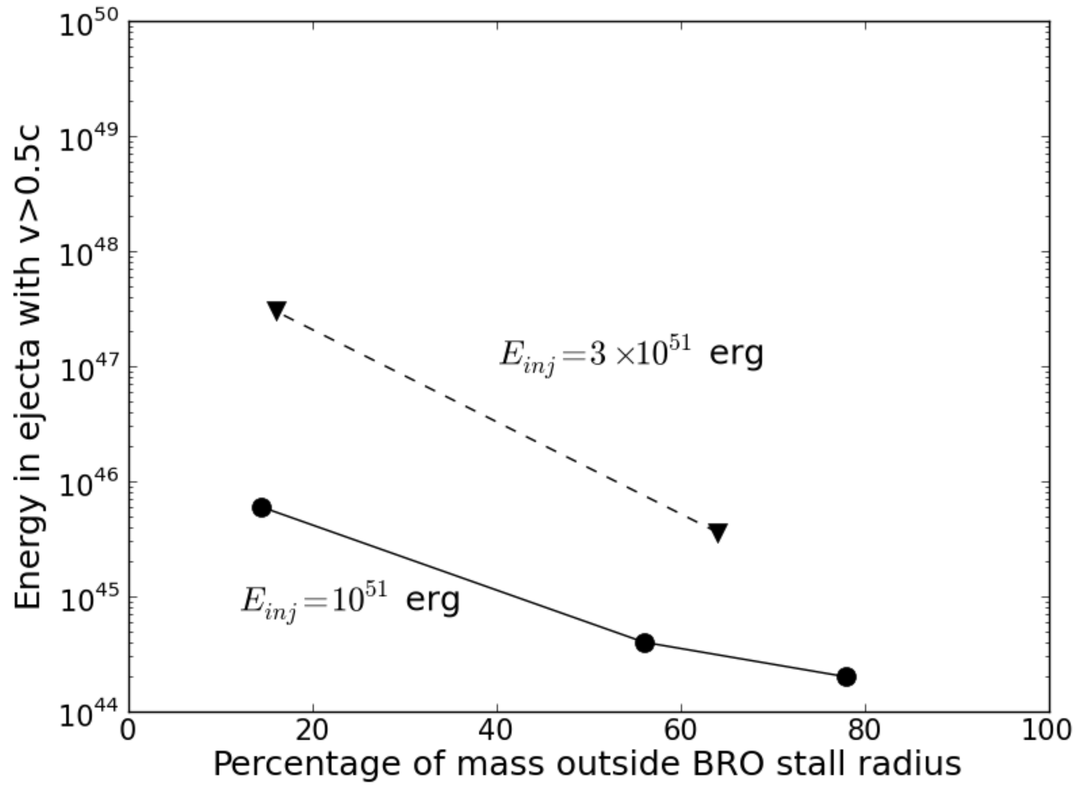
BROs-induced SNe

None of 5 simulations succeeded in reproducing SN2009bb

$E_{inj}=10^{51}$ erg
t=1, 3, 6 s

$E_{inj}=3x10^{51}$ erg
t=1, 3 s



Lazzati et al. in prep.

BROs-induced SNe

Producing a 2009bb-like SN requires fine tuning

All SNe with detectable BRO effects amount to ~3% of Ibc SNe

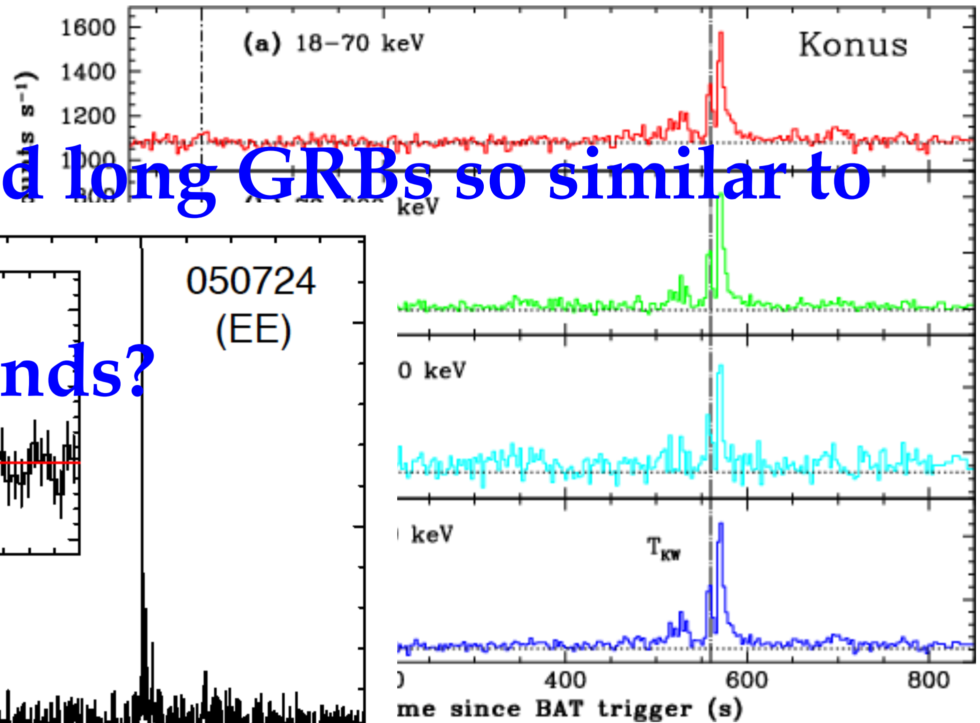
Models for the origin of BROs predict only a few per cent (<1%) Ibc with BROs

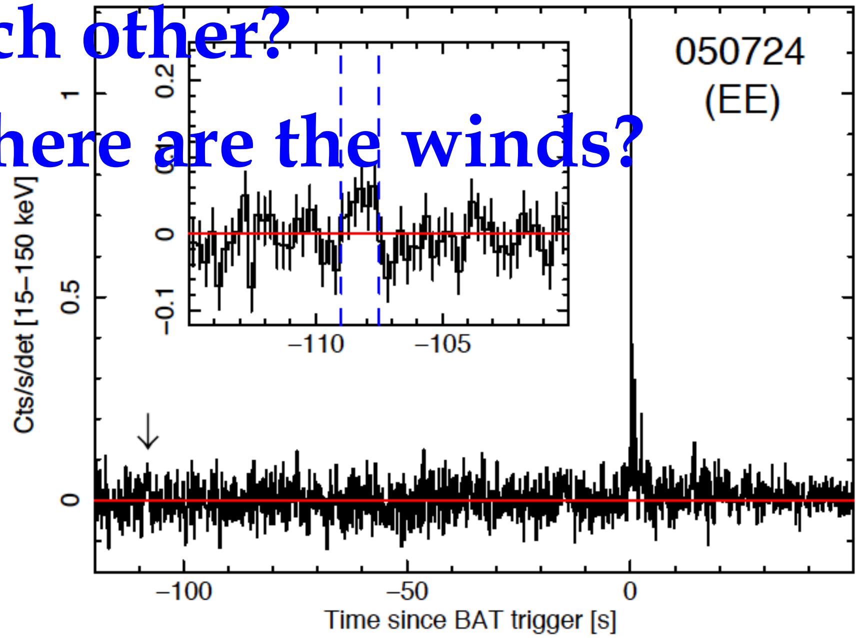
Are BROs SNe relevant cosmologically (e.g. for heavy elements inventory?)

Riddles

- Precursors
- Why are short and long GRBs so similar to each other?
- Where are the winds?

GRB 060124





Conclusions

What are the BROs engines, how they come about, how many of them?

Better stellar evolution models to explain high incidence of engines in stripped massive stars

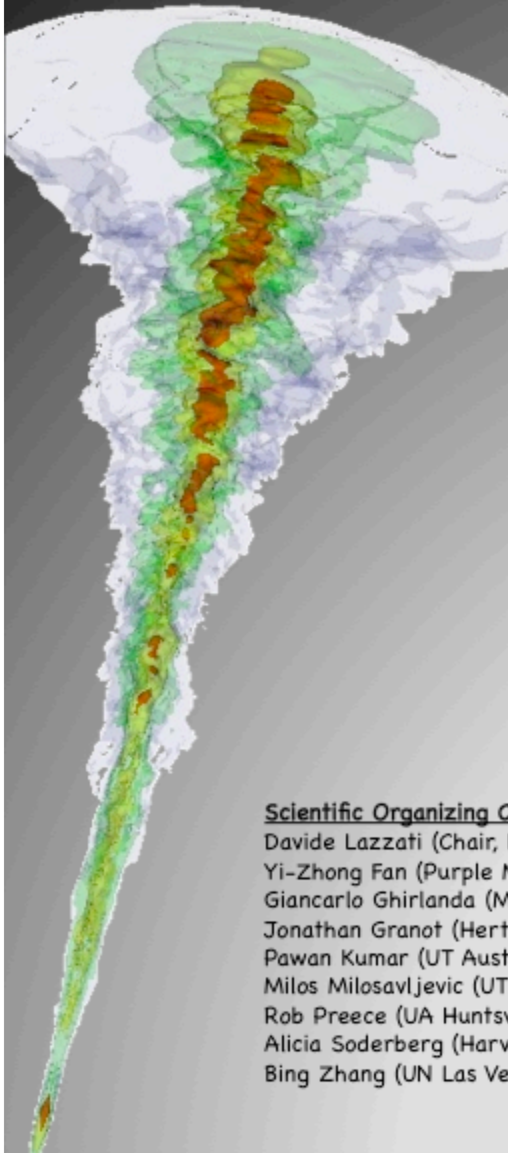
Better observational features to select BROs SNe

Better engine models (especially for the BH-AD case)

The Prompt Activity of Gamma-Ray Bursts

Their Progenitors, Engines, and Radiation Mechanisms

NC State University
Department of Physics
5-7 March, 2011
Raleigh, NC



Invited Speakers:
Andrei Beloborodov (Columbia)
Edo Berger (Harvard)
Niccolò Bucciantini (Stockolm)
Giancarlo Ghirlanda (Mialn)
Gabriele Ghisellini (Milan)
Dimitrios Giannios (Princeton)
Serguei Komissarov (TBC, Leeds)
William Lee (UNAM, Mexico City)
Paolo Mazzali (MPA)
Ramesh Narayan (Harvard)
Paul O'Brian (Leicester)
Nicola Omodei (Stanford)
Rosalba Perna (UC Boulder)
Tsvi Piran (Jerusalem)
Rob Preece (UA Huntsville)
Stephan Rosswog (TBC, Bremen)
Alicia Soderberg (Harvard)
Anatoly Spitkovski (Princeton)
Binbin Zhang (UN Las Vegas)

Scientific Organizing Committee:
Davide Lazzati (Chair, NCSU)
Yi-Zhong Fan (Purple Mountain Obs.)
Giancarlo Ghirlanda (Milan)
Jonathan Granot (Hertfordshire)
Pawan Kumar (UT Austin)
Milos Milosavljevic (UT Austin)
Rob Preece (UA Huntsville)
Alicia Soderberg (Harvard)
Bing Zhang (UN Las Vegas)

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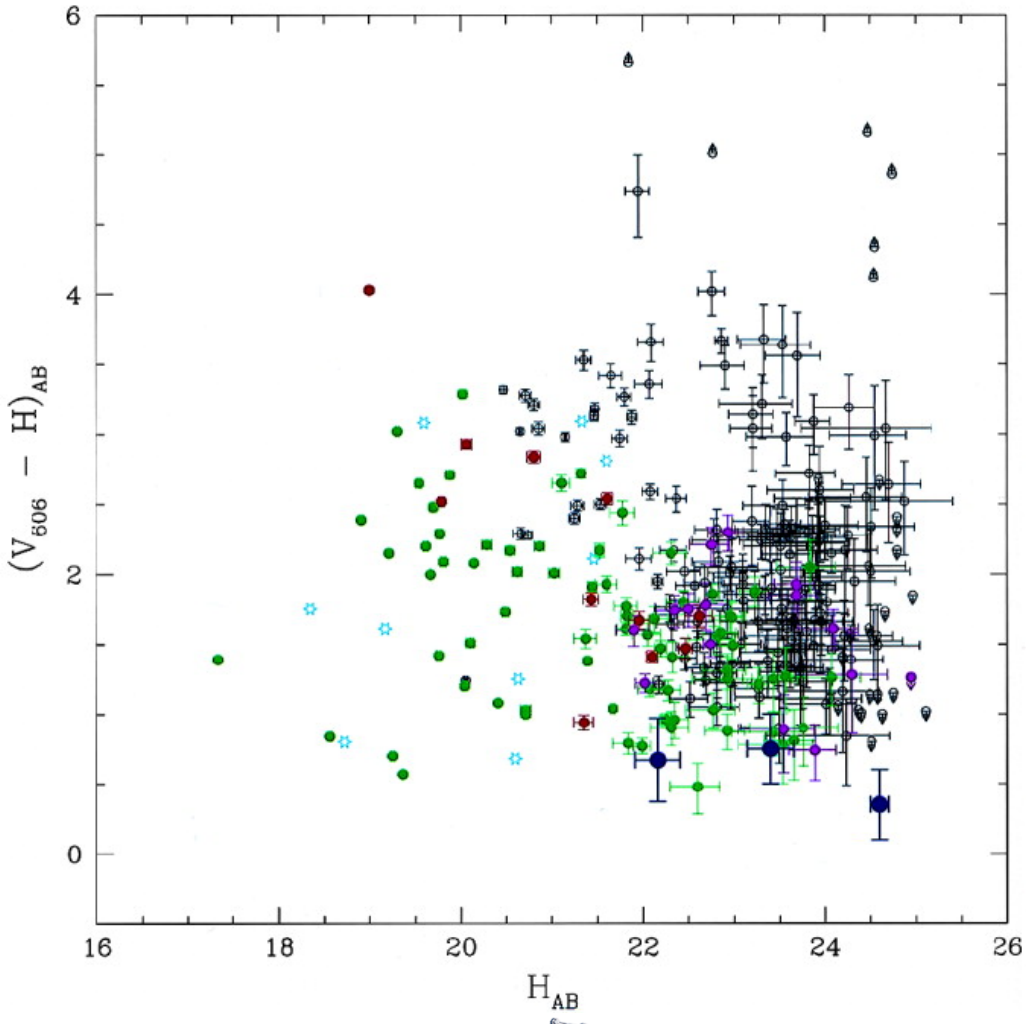
History: Middle Ages

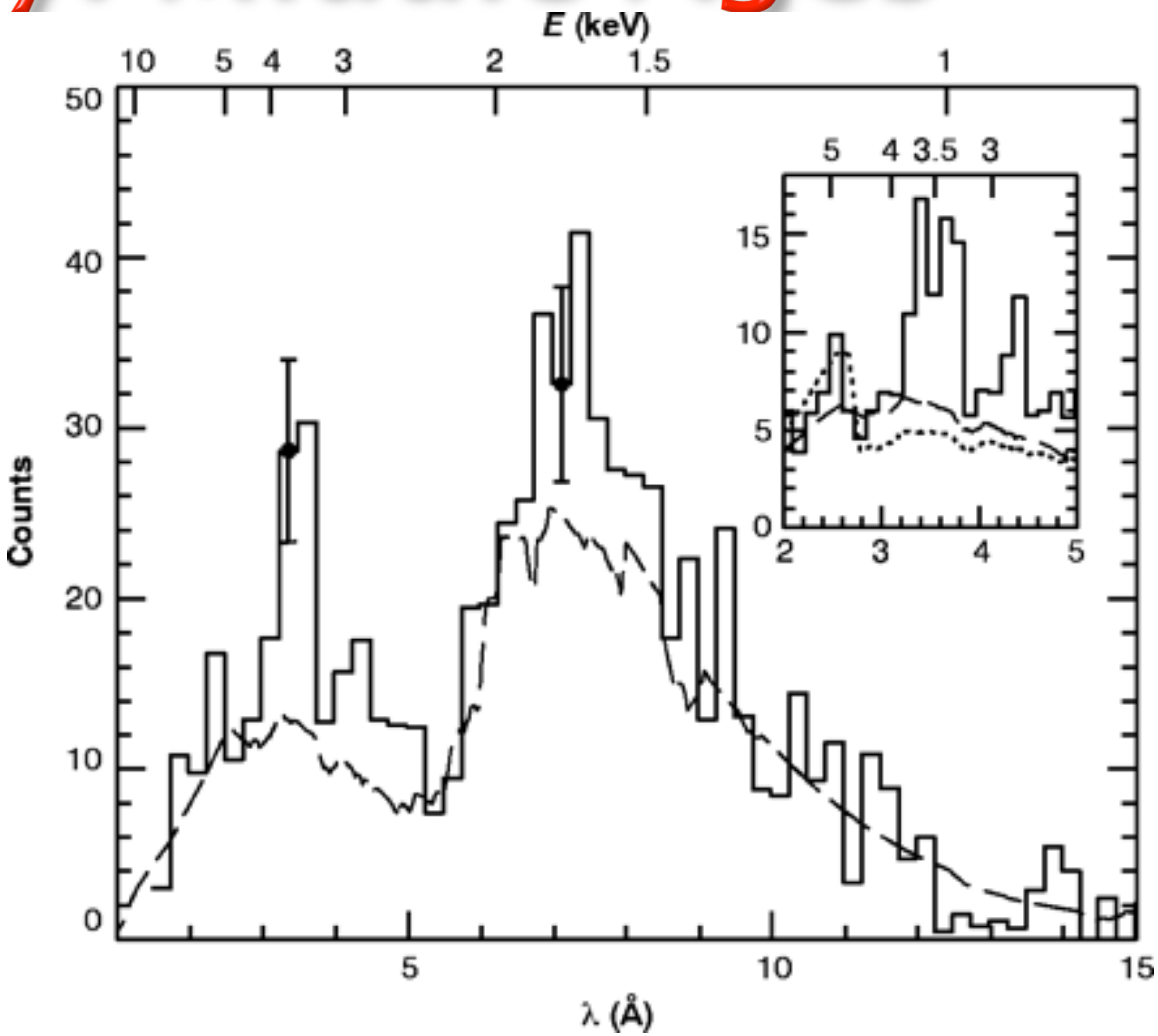
- Star forming environments



Hogg & Fruchter 1999

History: Middle Ages

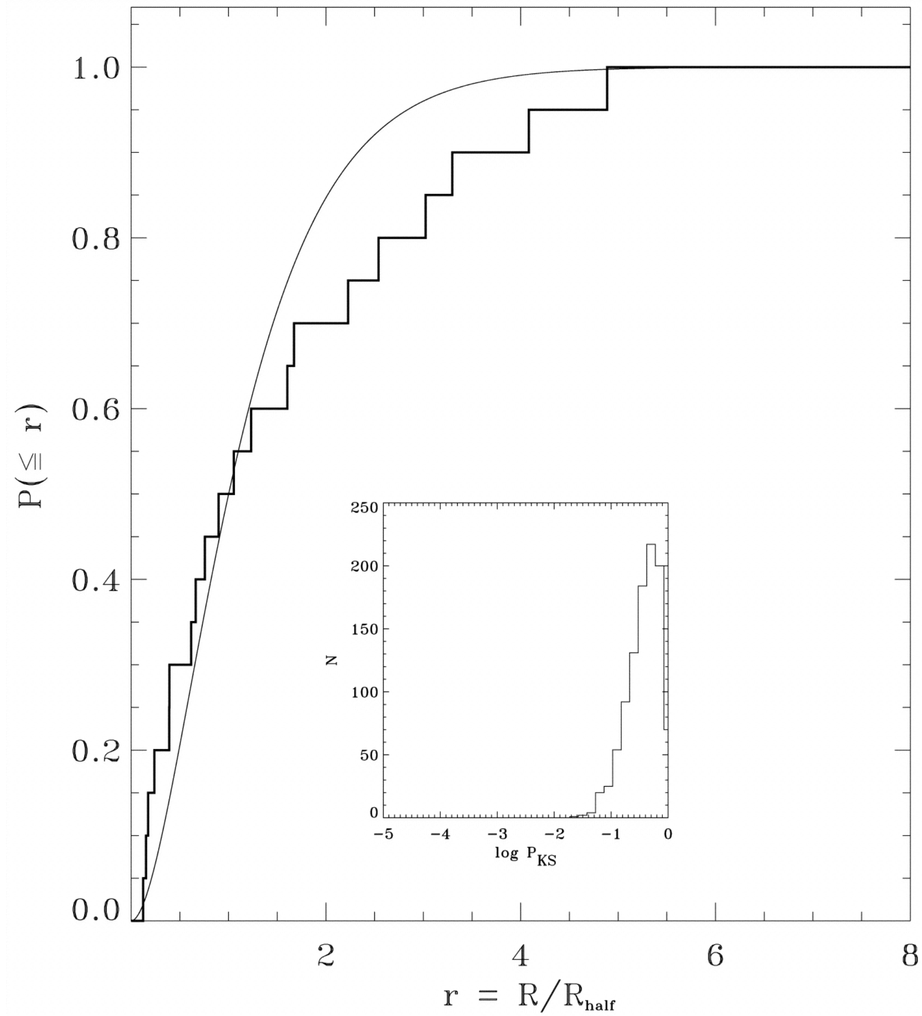
- Iron lines



Piro et al. 2000

History: Middle Ages

- Location of explosion



Bloom et al. 2002