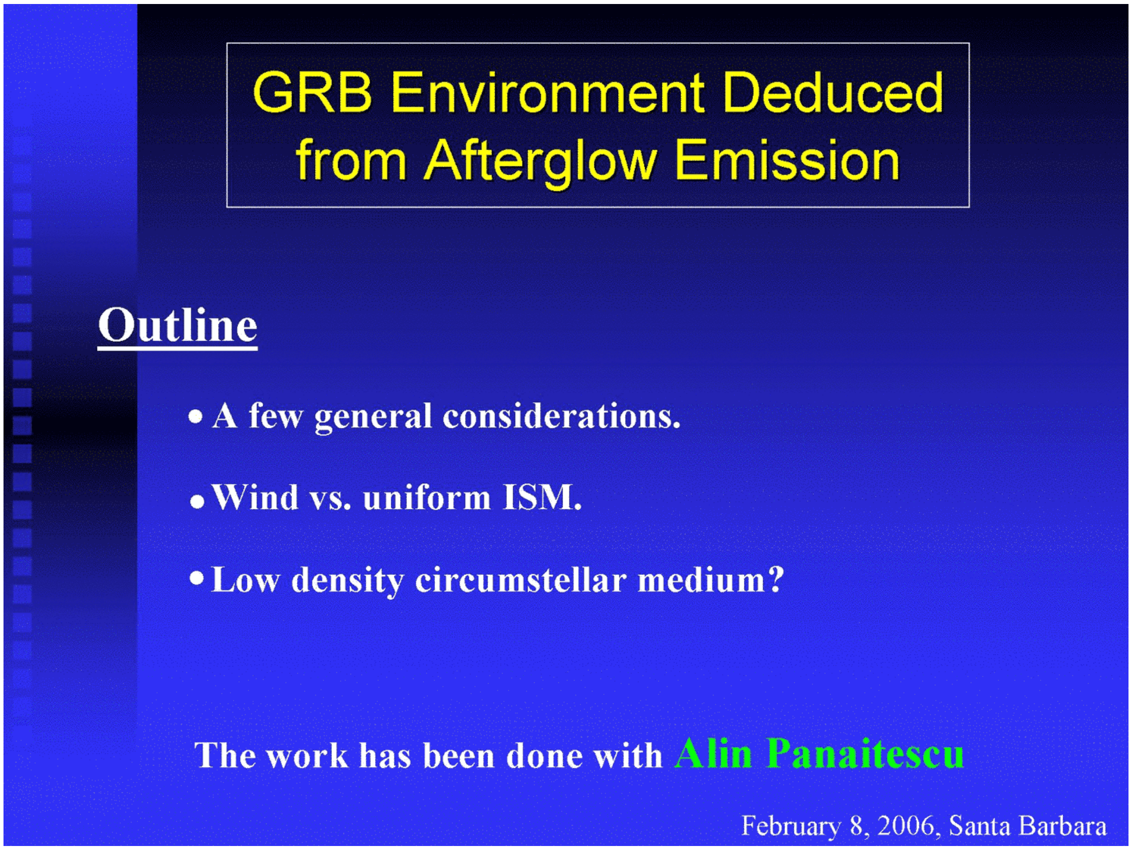


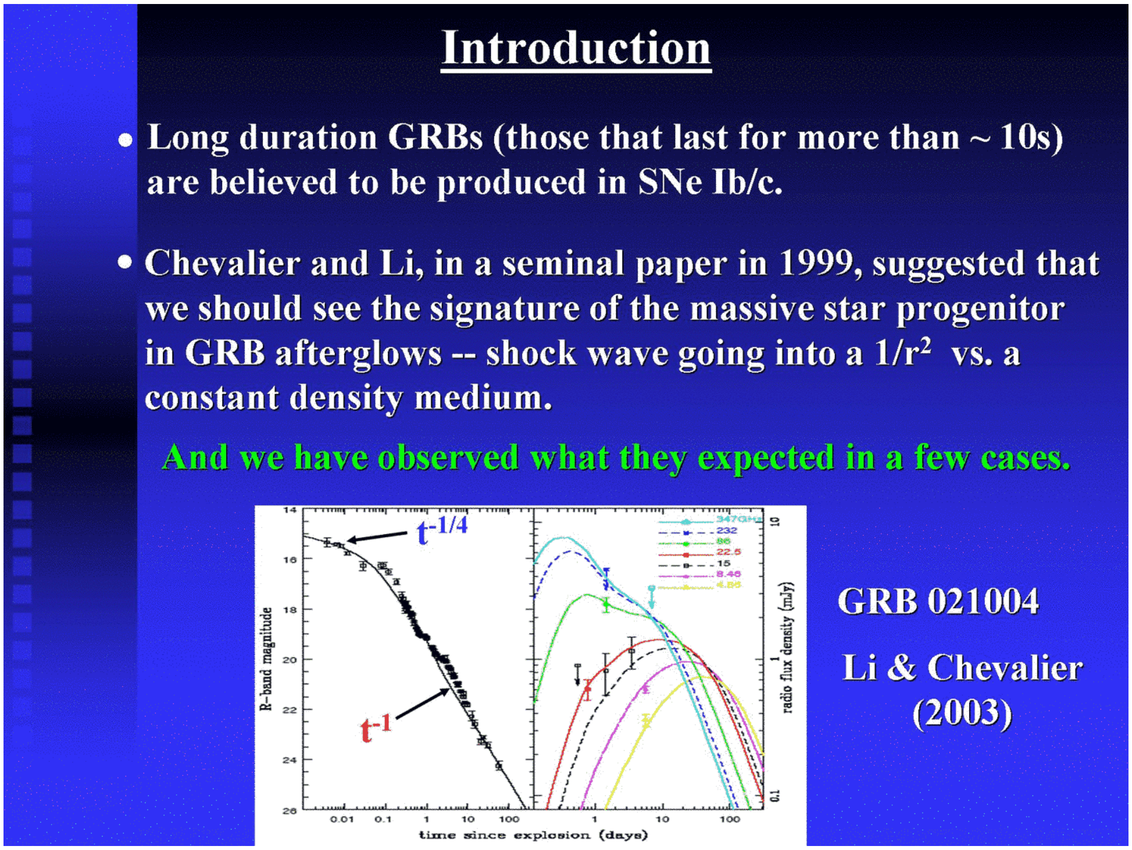
GRB Environment Deduced from Afterglow Emission

Outline

- A few general considerations.
- Wind vs. uniform ISM.
- Low density circumstellar medium?

The work has been done with **Alin Panaitescu**

February 8, 2006, Santa Barbara



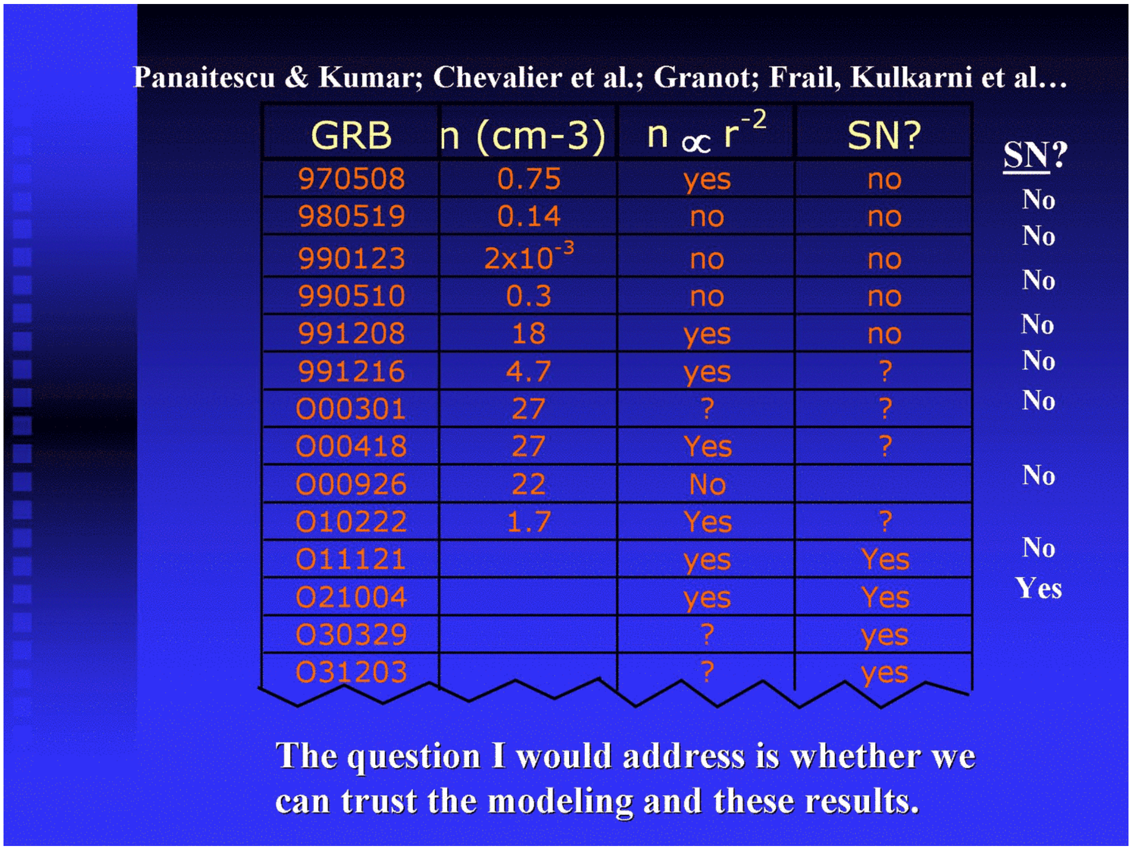
Introduction

- Long duration GRBs (those that last for more than ~ 10s) are believed to be produced in SNe Ib/c.
- Chevalier and Li, in a seminal paper in 1999, suggested that we should see the signature of the massive star progenitor in GRB afterglows -- shock wave going into a $1/r^2$ vs. a constant density medium.

And we have observed what they expected in a few cases.

GRB 021004

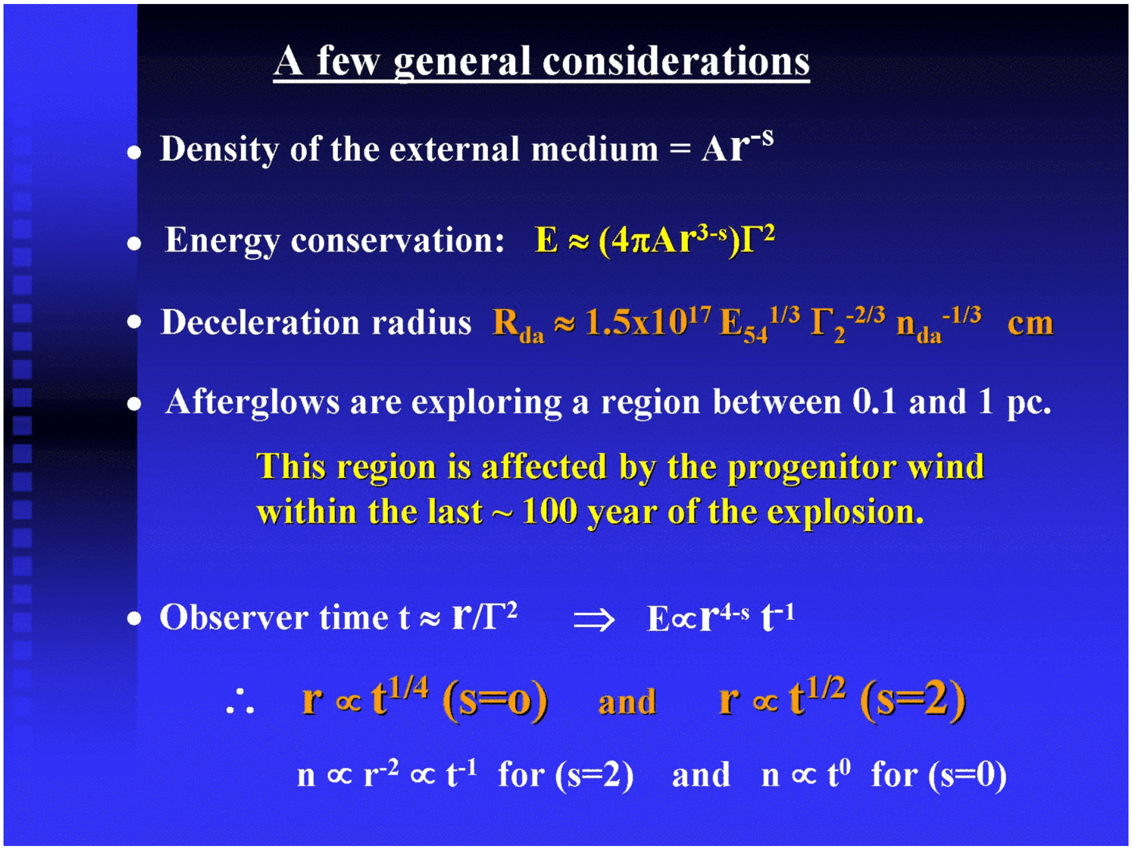
Li & Chevalier (2003)



Panaitescu & Kumar; Chevalier et al.; Granot; Frail, Kulkarni et al…

GRB	n (cm-3)	$n \propto r^{-2}$	SN?	SN?
970508	0.75	yes	no	No
980519	0.14	no	no	No
990123	2×10^{-3}	no	no	No
990510	0.3	no	no	No
991208	18	yes	no	No
991216	4.7	yes	?	No
000301	27	?	?	
000418	27	Yes	?	No
000926	22	No		
010222	1.7	Yes	?	No
011121		yes	Yes	Yes
021004		yes	Yes	
030329		?	yes	
031203		?	yes	

The question I would address is whether we can trust the modeling and these results.



A few general considerations

- Density of the external medium = Ar^{-s}
- Energy conservation: $E \approx (4\pi A r^{3-s})\Gamma^2$
- Deceleration radius $R_{da} \approx 1.5\times10^{17} E_{54}^{1/3} \Gamma_2^{-2/3} n_{da}^{-1/3}$ cm
- Afterglows are exploring a region between 0.1 and 1 pc.

  This region is affected by the progenitor wind within the last ~ 100 year of the explosion.

- Observer time $t \approx r/\Gamma^2 \quad \Rightarrow \quad E \propto r^{4-s}\, t^{-1}$

$$\therefore \quad r \propto t^{1/4}\ (s=0) \quad \text{and} \quad r \propto t^{1/2}\ (s=2)$$

$$n \propto r^{-2} \propto t^{-1} \text{ for } (s=2) \quad \text{and} \quad n \propto t^{0} \text{ for } (s=0)$$

- The flux is $\propto n^{1/2}$ (as $B \propto n^{1/2}$).

  Therefore, the flux ratio for s=2 and s=0 decreases with time as $t^{-1/2}$.

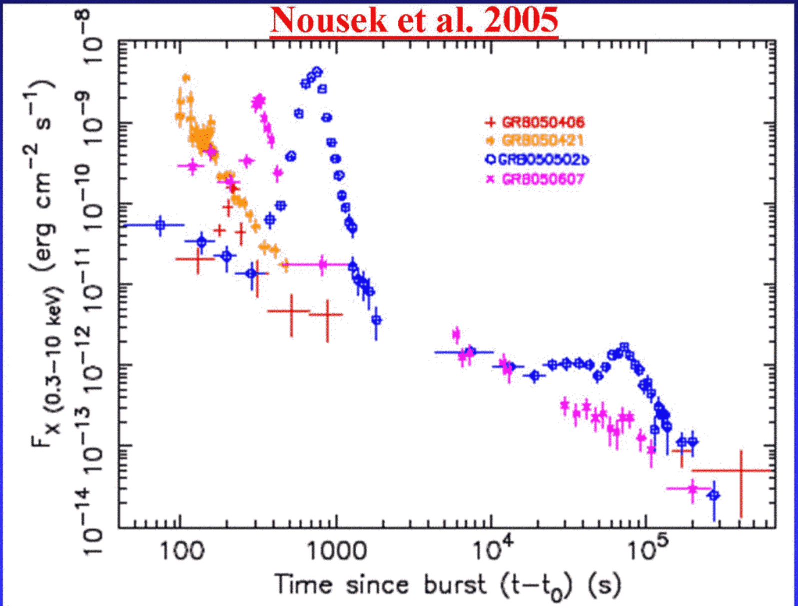
- If we have observations spanning a factor 10 in time (say ~ 1 to 10 days) then the flux (below the cooling frequency) for s=2 is smaller by a factor ~ 3 compared with a uniform density medium.

- The factor of 3 difference in flux does not lend itself to a unique interpretation for s=2 medium -- uncertainty in ε_e , ε_B & p and their time dependence (if any) can easily mask this factor of 3 or so in flux;

  $f \propto \varepsilon_e^{p-1}\varepsilon_B^{(p+1)/4}$ -- an increase in ε_B or ε_e can hide the faster decrease in flux due to s=2.

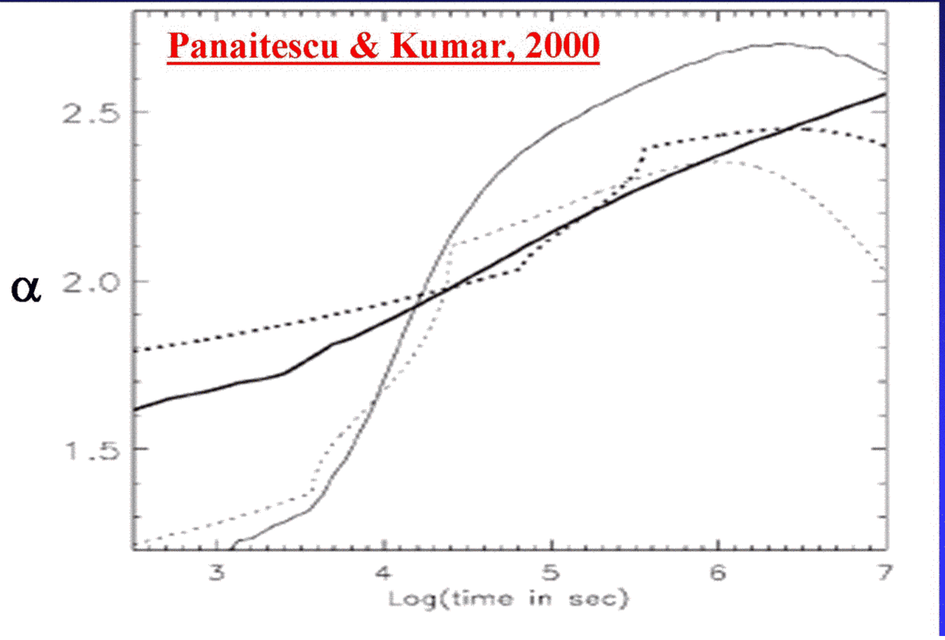
- The hope was that Swift will increase the time coverage by a factor 10^3 -- 100s to 10 days -- which would have made it quite easy to differentiate between s=2 & s=0 media.

0.3-10 kev lightcurve for some Swift bursts

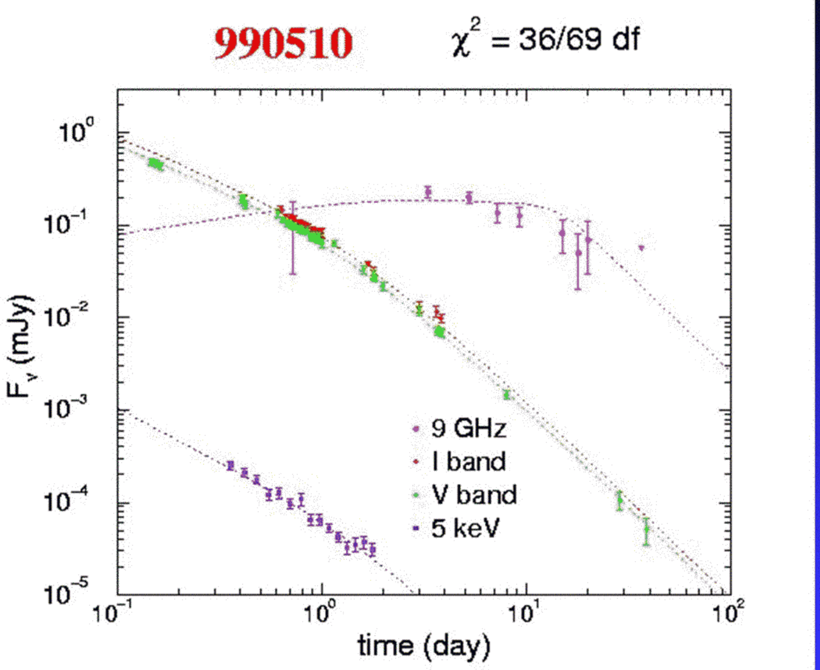


The best ways to tell wind and ISM apart

1. **Early optical observation showing $\nu < \nu_m \rightarrow \nu > \nu_m$ transition.**
2. **Jet break: for s=2 the steepening is smaller and very smooth**

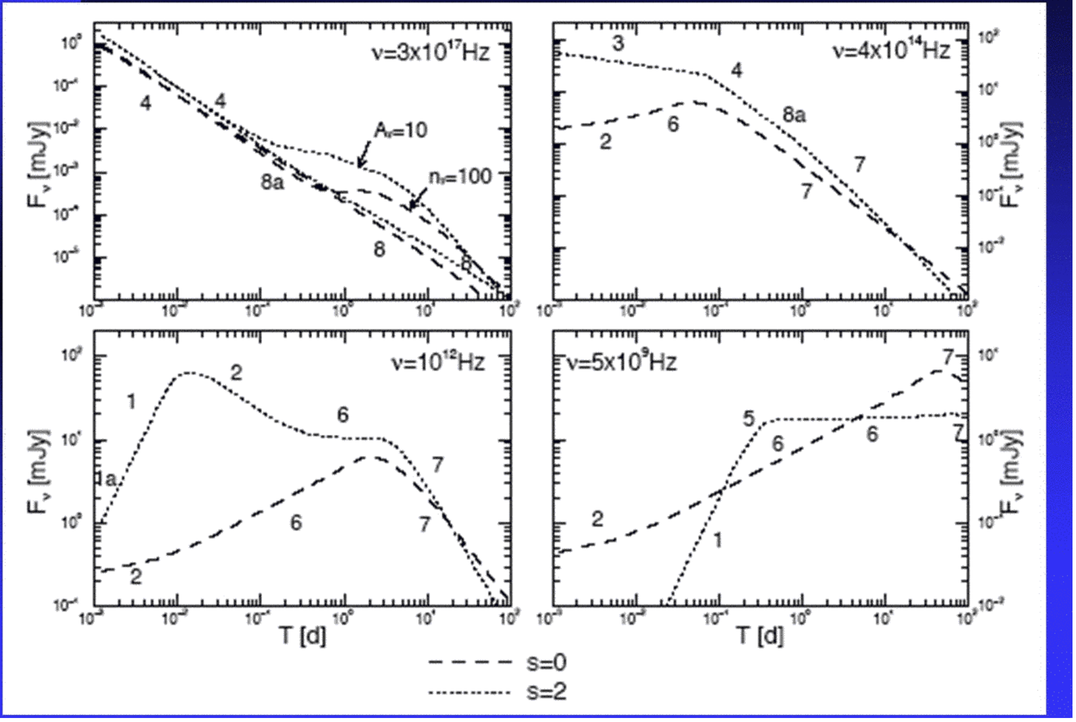


Panaitescu & Kumar (2000)



Unfortunately we have very few Swift bursts with jet break -- due to lack of late time (1 to 10 days) coverage in optical.

3. Sub-millimeter observations at less than 1 day.
(The flux is small, and these observations are not easy)



Summary

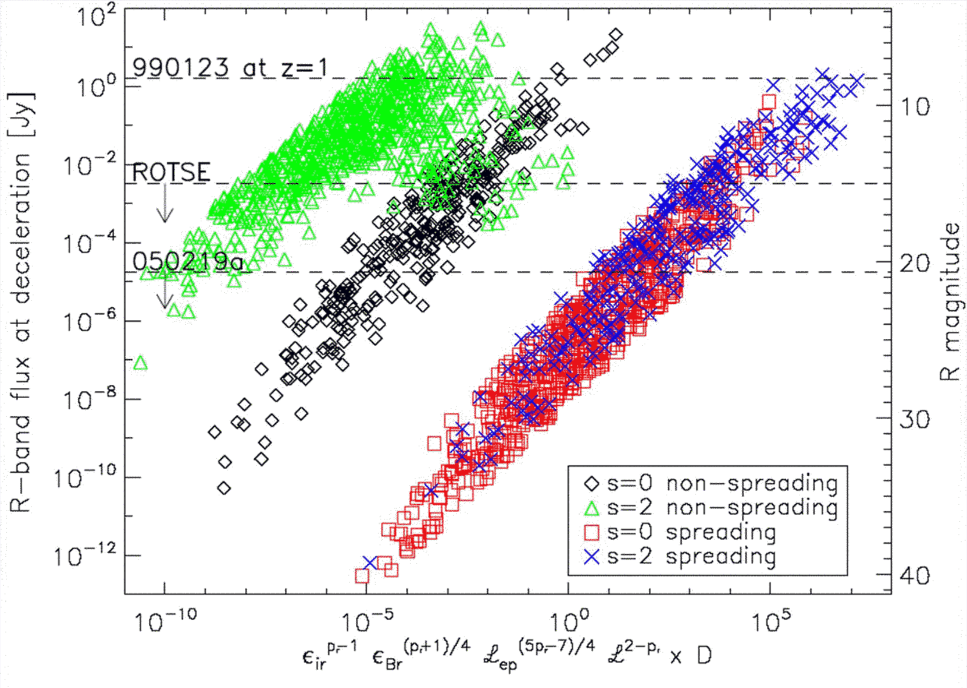
- The evidence for wind is seen for a few cases.

  But for many others -- such as 990123, 990510 etc. -- we are confident of a uniform density medium ~ 0.1 to 1 pc.

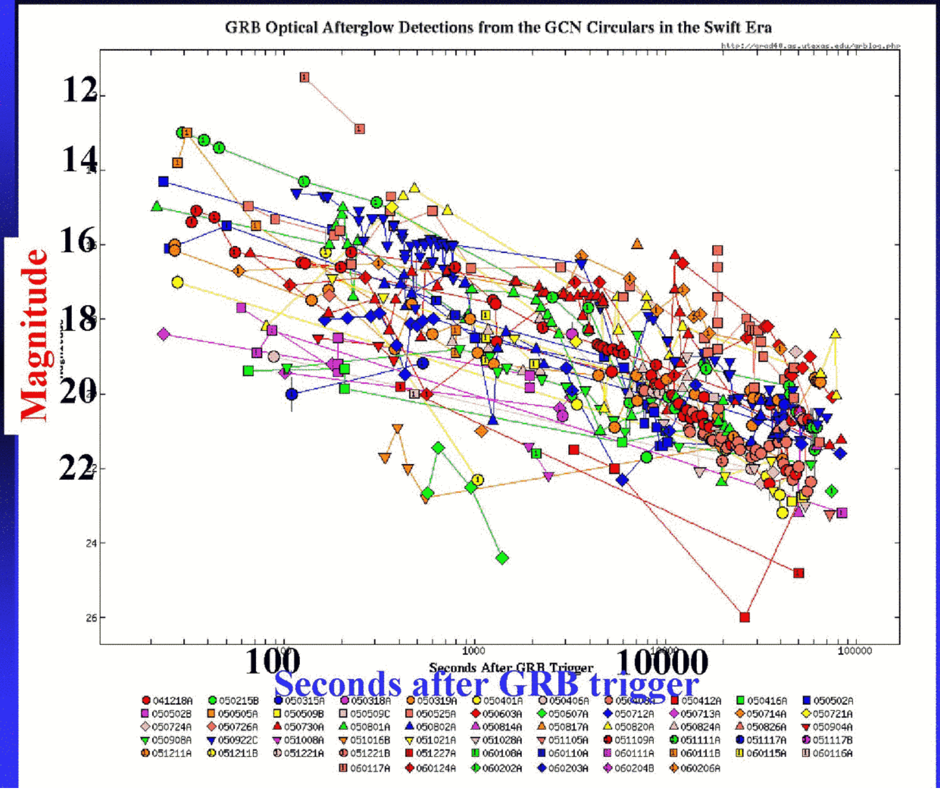
- Wind like medium is unlikely for a good fraction of bursts because of lack of bright reverse-shock emission.

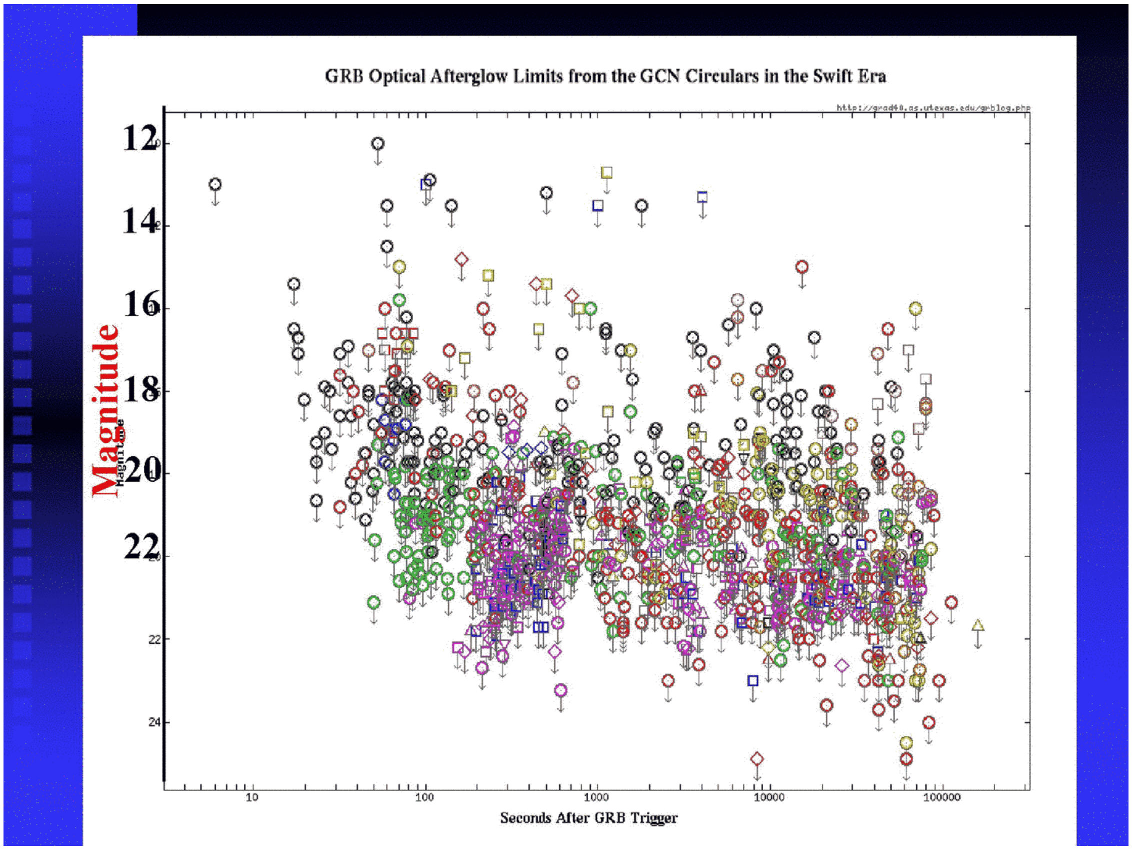
Reverse-shock Emission for s=0 & 2

McMahon, Kumar and Piran, 2006



Optical Afterglow flux for Swift detected Bursts



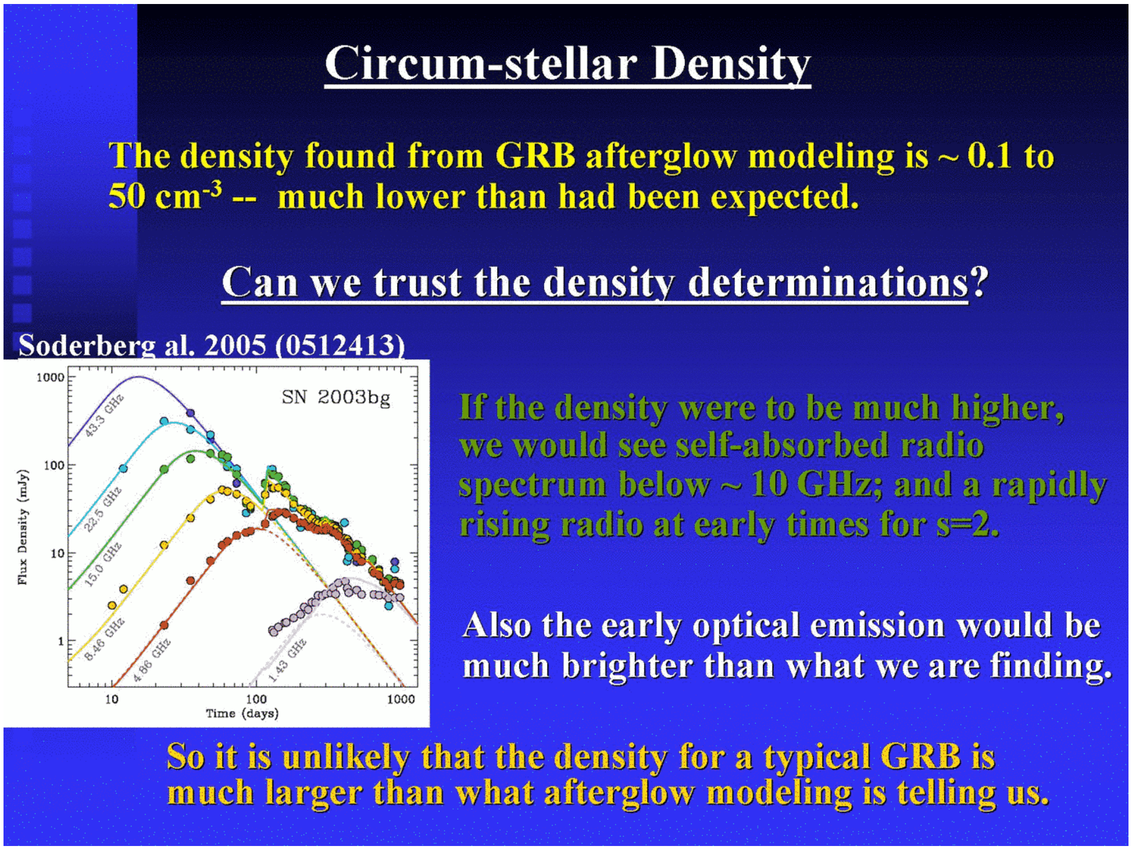


- It might be that the GRB afterglow is produced in shocked and homogenized stellar wind as suggested by Wijers et al., Ramirez-Ruiz et al., Chevalier et al…

This requires quite high pressure for the ISM.

- Or it might be that the progenitors of GRBs were rotating close to the breakup speed and their wind was highly suppressed along the polar axis.

(Goldreich conjecture)



Circum-stellar Density

The density found from GRB afterglow modeling is ~ 0.1 to 50 cm^{-3} -- much lower than had been expected.

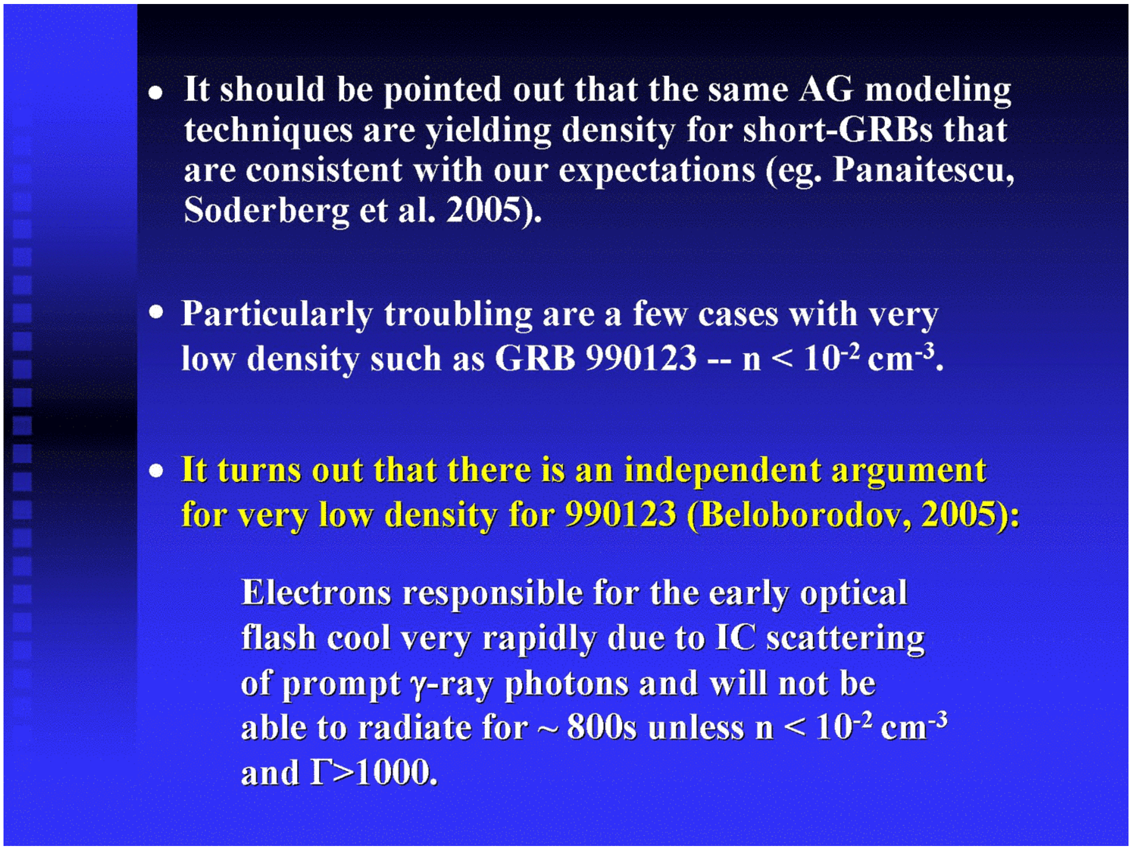
Can we trust the density determinations?

Soderberg al. 2005 (0512413)

If the density were to be much higher, we would see self-absorbed radio spectrum below ~ 10 GHz; and a rapidly rising radio at early times for s=2.

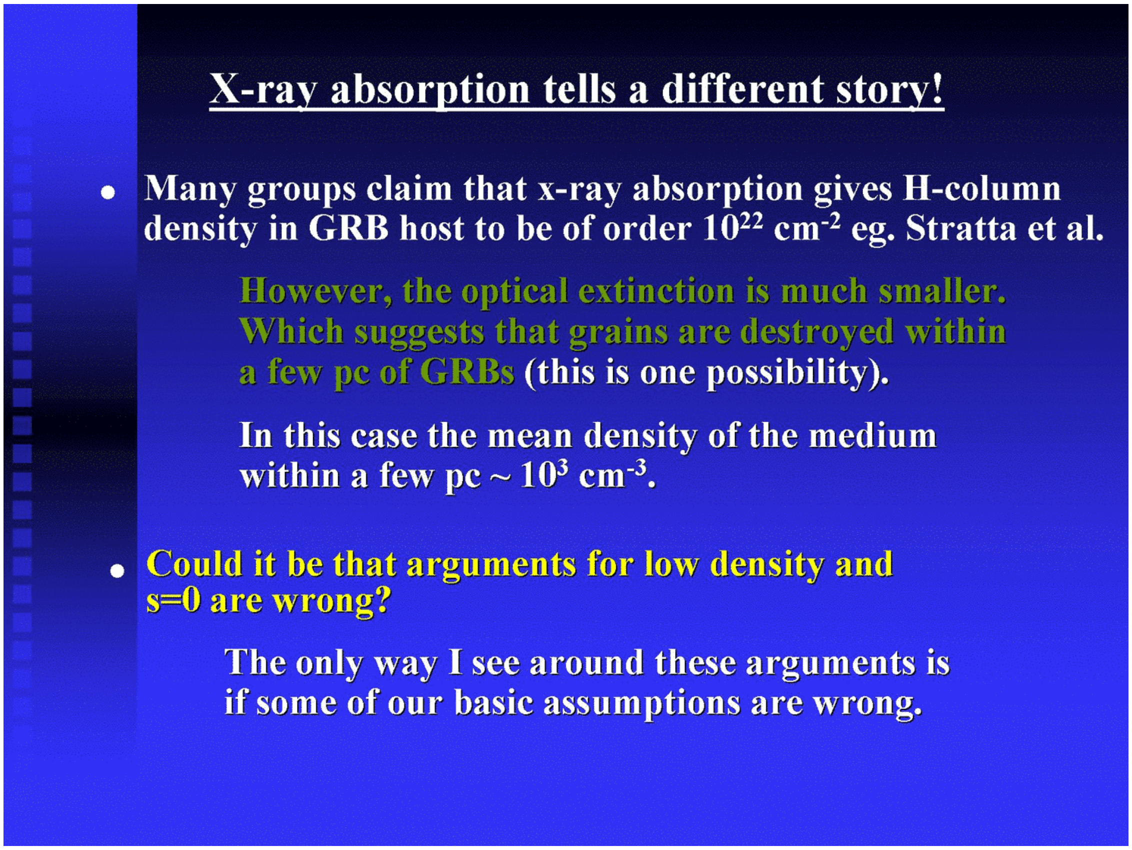
Also the early optical emission would be much brighter than what we are finding.

So it is unlikely that the density for a typical GRB is much larger than what afterglow modeling is telling us.



- It should be pointed out that the same AG modeling techniques are yielding density for short-GRBs that are consistent with our expectations (eg. Panaitescu, Soderberg et al. 2005).
- Particularly troubling are a few cases with very low density such as GRB 990123 -- $n < 10^{-2}$ cm^{-3}.
- It turns out that there is an independent argument for very low density for 990123 (Beloborodov, 2005):

  Electrons responsible for the early optical flash cool very rapidly due to IC scattering of prompt γ-ray photons and will not be able to radiate for ~ 800s unless $n < 10^{-2}$ cm^{-3} and $\Gamma>1000$.



X-ray absorption tells a different story!

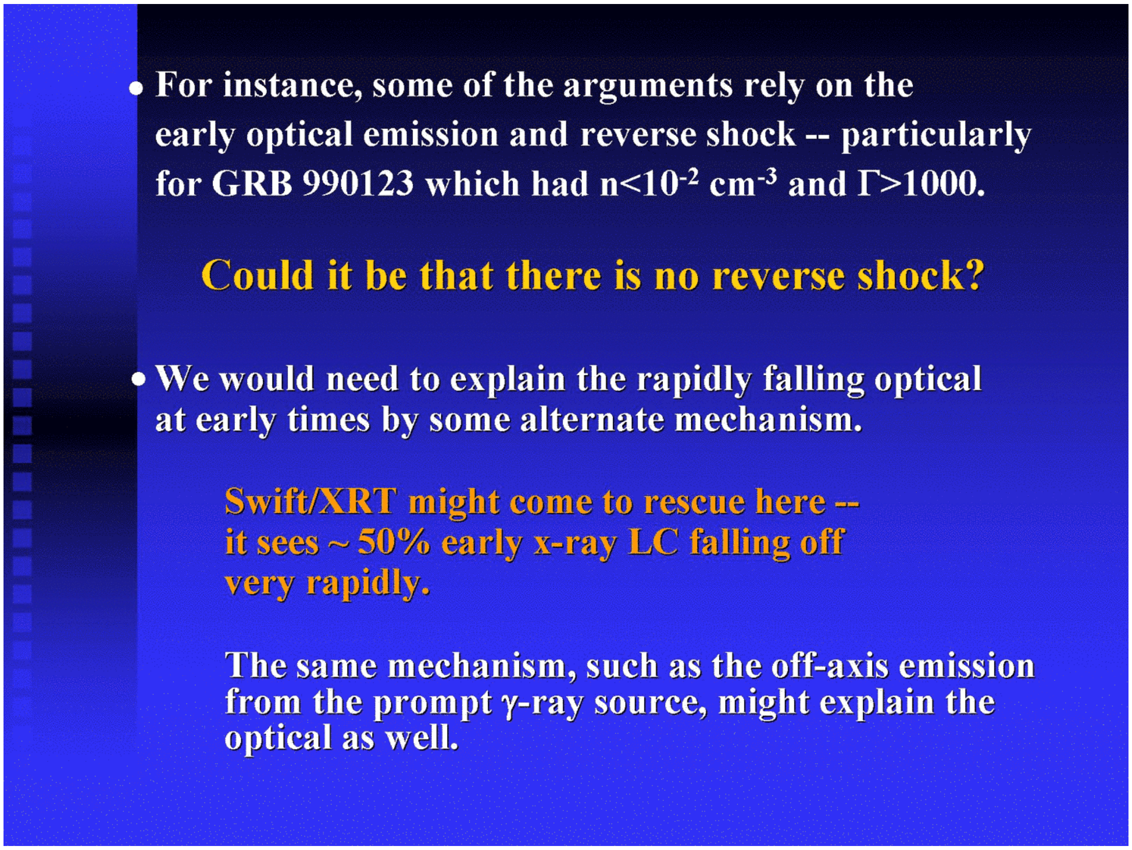
- Many groups claim that x-ray absorption gives H-column density in GRB host to be of order 10^{22} cm^{-2} eg. Stratta et al.

  However, the optical extinction is much smaller. Which suggests that grains are destroyed within a few pc of GRBs (this is one possibility).

  In this case the mean density of the medium within a few pc ~ 10^3 cm^{-3}.

- Could it be that arguments for low density and s=0 are wrong?

  The only way I see around these arguments is if some of our basic assumptions are wrong.



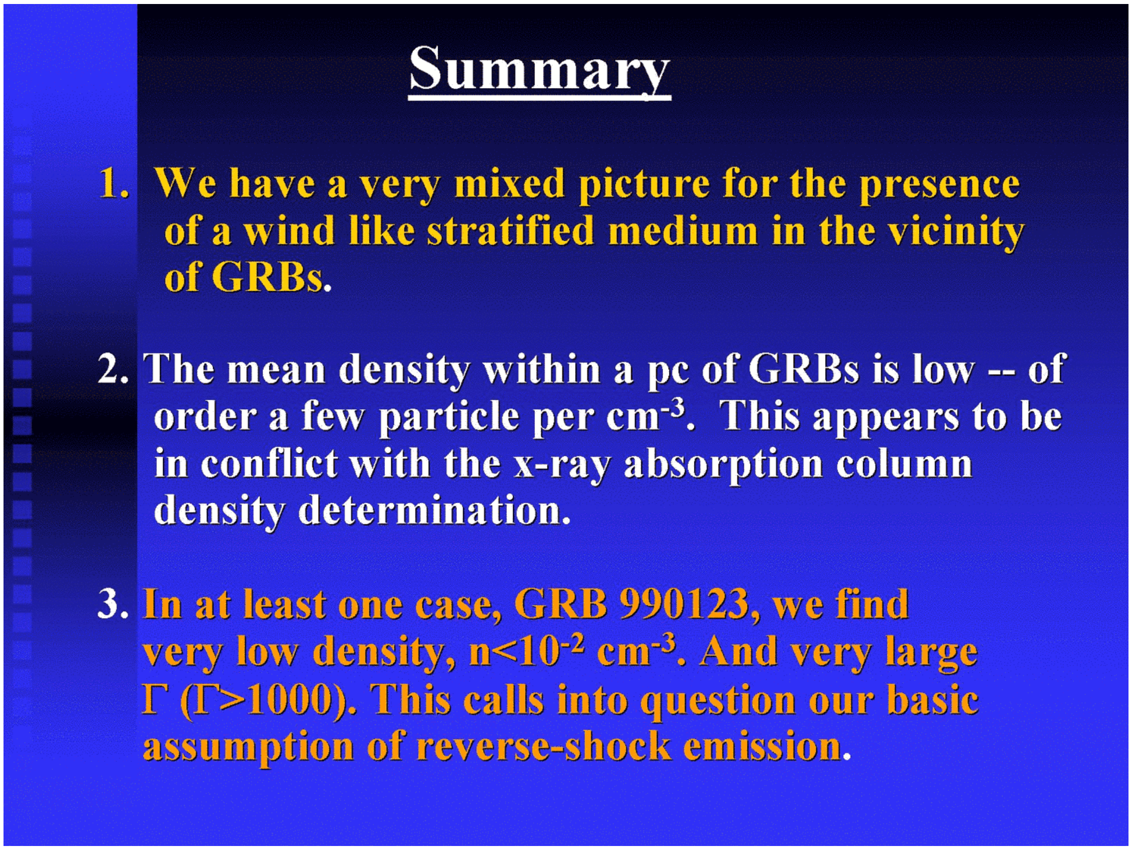
- For instance, some of the arguments rely on the early optical emission and reverse shock -- particularly for GRB 990123 which had $n<10^{-2}$ cm^{-3} and $\Gamma>1000$.

Could it be that there is no reverse shock?

- We would need to explain the rapidly falling optical at early times by some alternate mechanism.

  Swift/XRT might come to rescue here -- it sees ~ 50% early x-ray LC falling off very rapidly.

  The same mechanism, such as the off-axis emission from the prompt γ-ray source, might explain the optical as well.



Summary

1. We have a very mixed picture for the presence of a wind like stratified medium in the vicinity of GRBs.
2. The mean density within a pc of GRBs is low -- of order a few particle per cm^{-3}. This appears to be in conflict with the x-ray absorption column density determination.
3. In at least one case, GRB 990123, we find very low density, $n<10^{-2}\ cm^{-3}$. And very large Γ ($\Gamma>1000$). This calls into question our basic assumption of reverse-shock emission.