Frontier Research Institute for Interdisciplinary Sciences
Tohoku University

Theoretical Astrophysics
Tohoku University

Radio Polarimetric Study of Gamma-Ray Bursts

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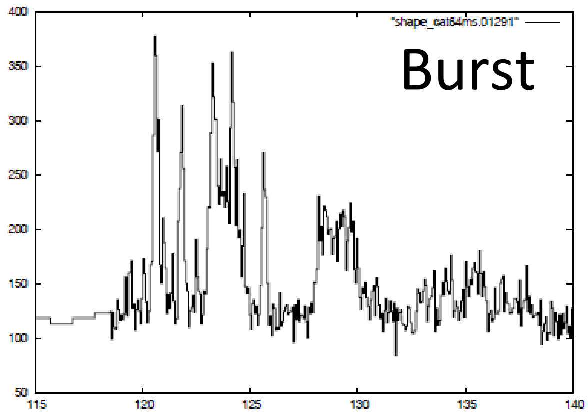
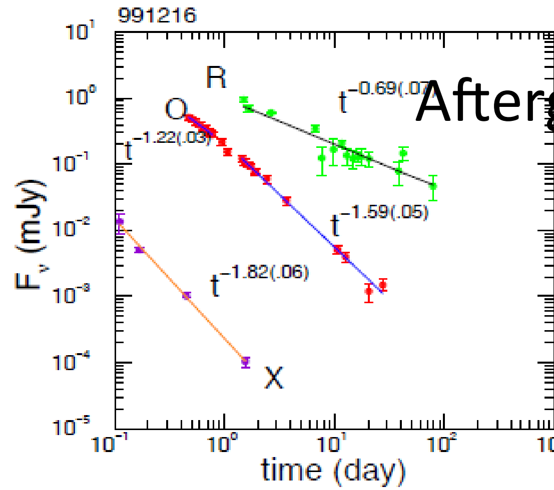
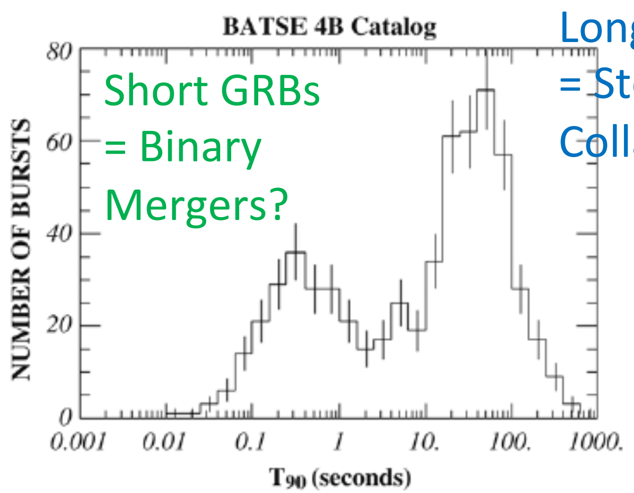
SMA Science in the Next Decade, Oct 27-28, 2016 @ ASIAA

Gamma-Ray Bursts

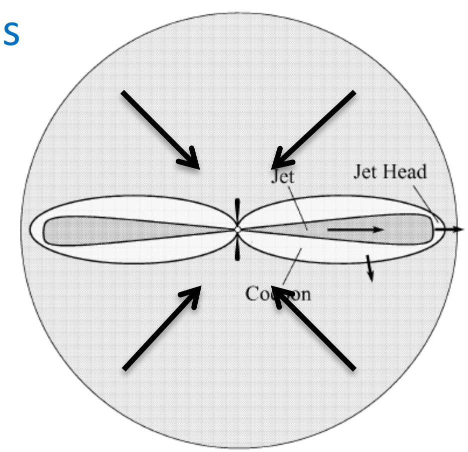
The most luminous objects in the universe, which are at cosmological distances





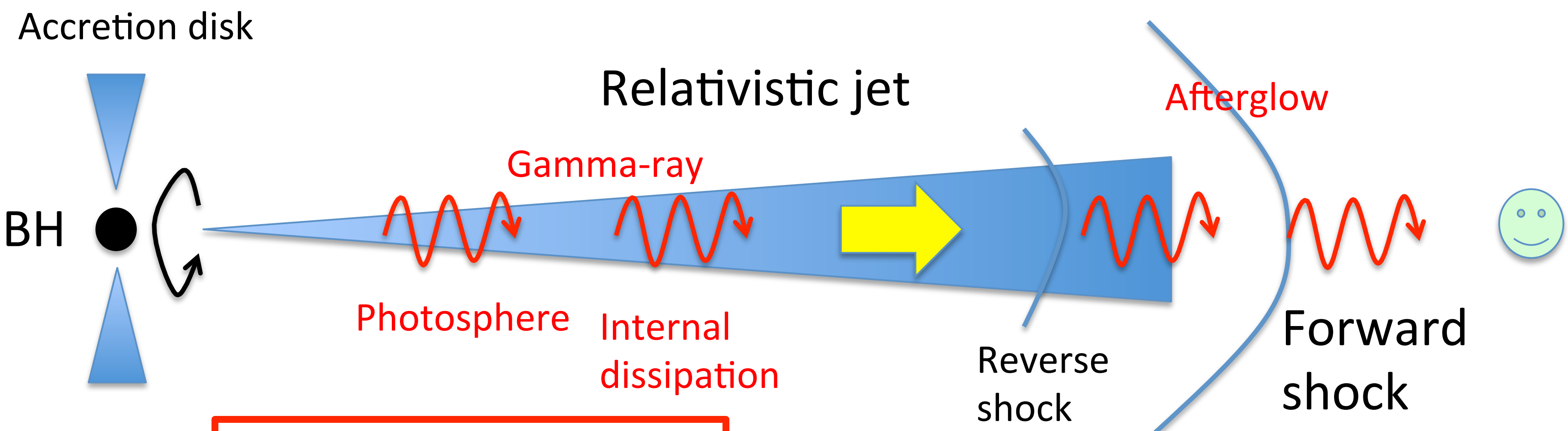


Long GRBs
= Stellar
Collapses

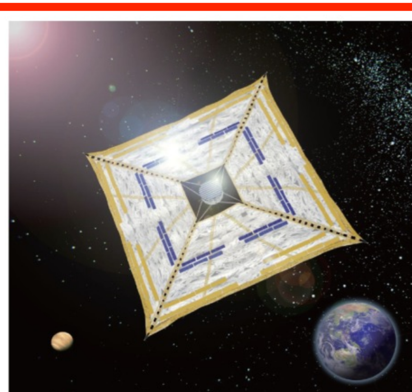


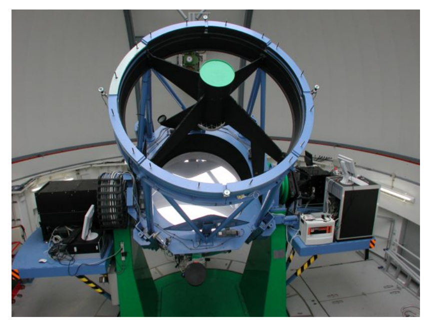
- Gravitational waves
- Cosmological structure formation

GRB Polarization: another frontier



Recent reports of detections Π_L > 30% at 2σ (Yonetoku+ 11;12; KT 13)





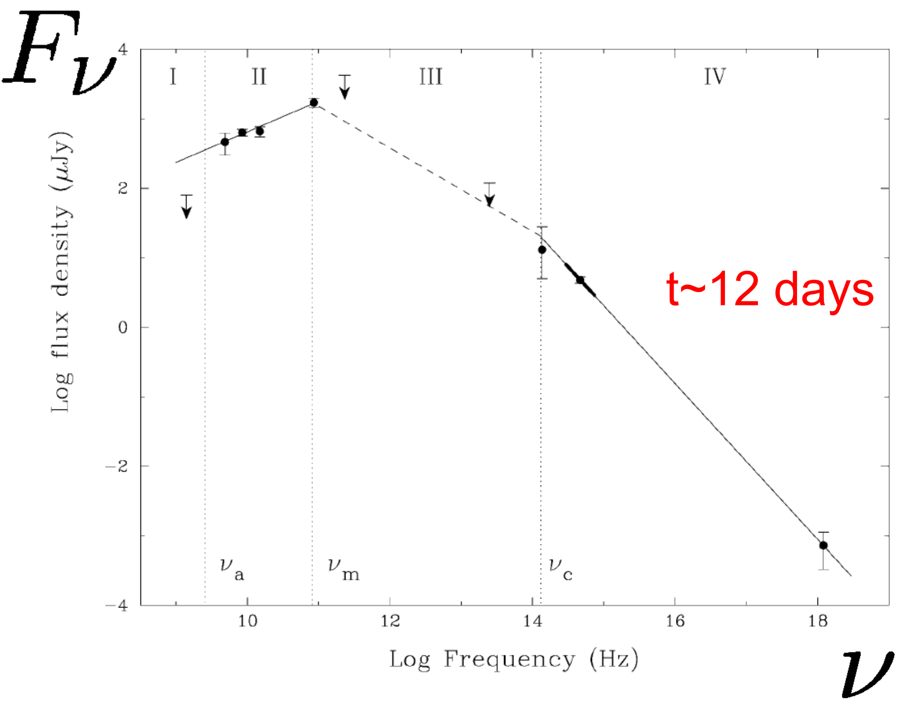
Late-time optical afterglow Π_L ~ 1-3% (Covino+03), Π_C ~ 0.6 % !!(Wiersema, Covino, KT+14)

Early-time afterglow (t < 1000 sec)
Π_L ~ 30% !! (Mundell+13), Π_L ~ 10% (Steele+09),
Π_L ~ 10% (Uehara, KT, Kawabata+12)
Π_L < 8% (Mundell+07)

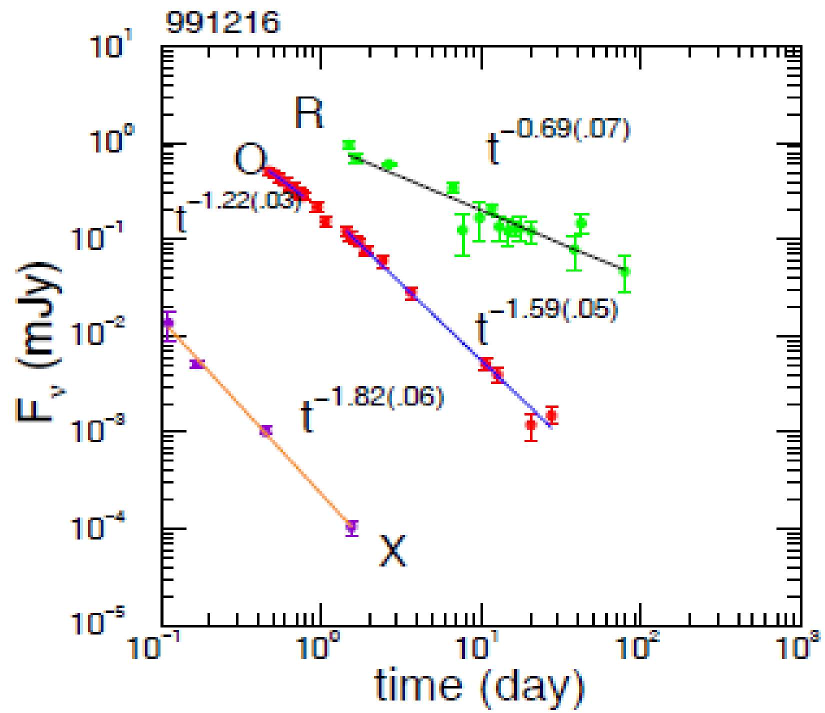
No radio detection yet !!

Late-time Afterglows

(Galama et al. 98)

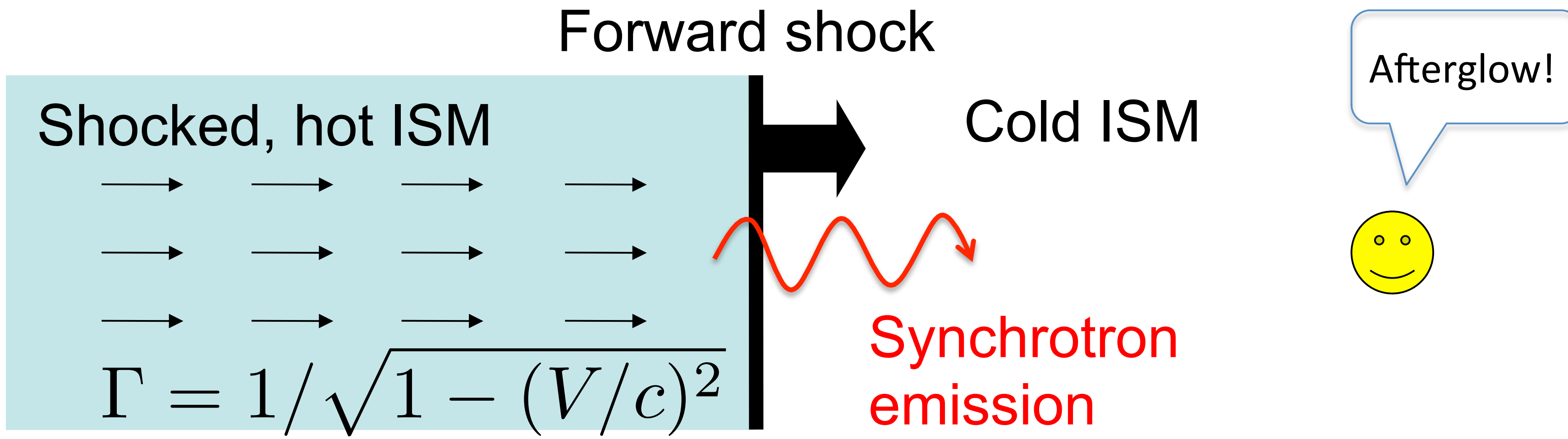


(Panaitescu & Kumar 02)



Relativistic shock - synchrotron emission model can explain the late-time afterglows

Relativistic Shocks



Lorentz factor

$$\boxed{E_{\rm k,iso} \simeq \frac{16\pi}{17} R^3 \Gamma^2 n m_{\rm p} c^2} \Rightarrow \Gamma \propto R^{-3/2}$$

$$E_{\rm tot} - E_{\gamma-{\rm ray}}$$

(Blandford & McKee 1976)

As seen in the rest frame of the shock…

Large internal energy + Non-relativistic bulk velocity

$$n' \simeq 4\Gamma n$$

$$\frac{e'_p}{n'} \simeq \Gamma m_p c^2$$

$$\frac{e'_e}{n'} \simeq \Gamma m_e c^2$$

(If no e-p interactions)

Relativistic bulk velocity

Γn Density

$\Gamma m_p c^2$ Energy per proton

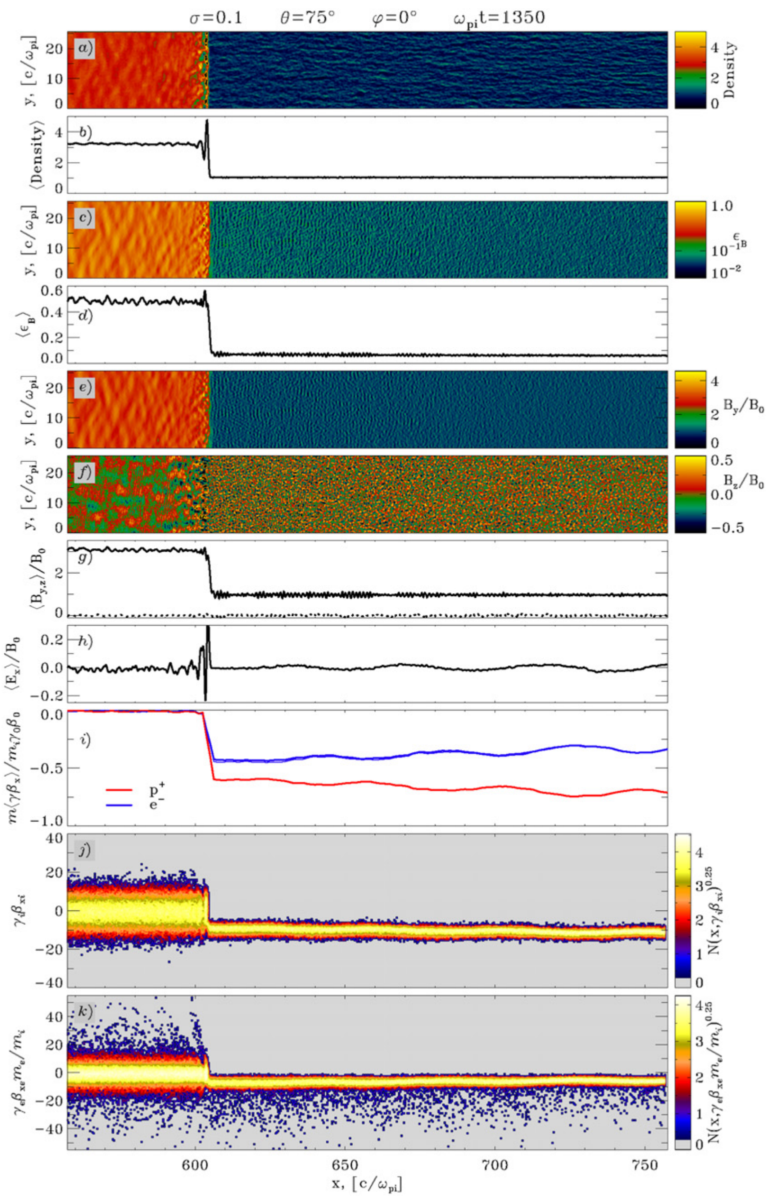
$\Gamma m_e c^2$ Energy per electron

- Most of the energy is carried by protons
- e & p may not be fully thermalized

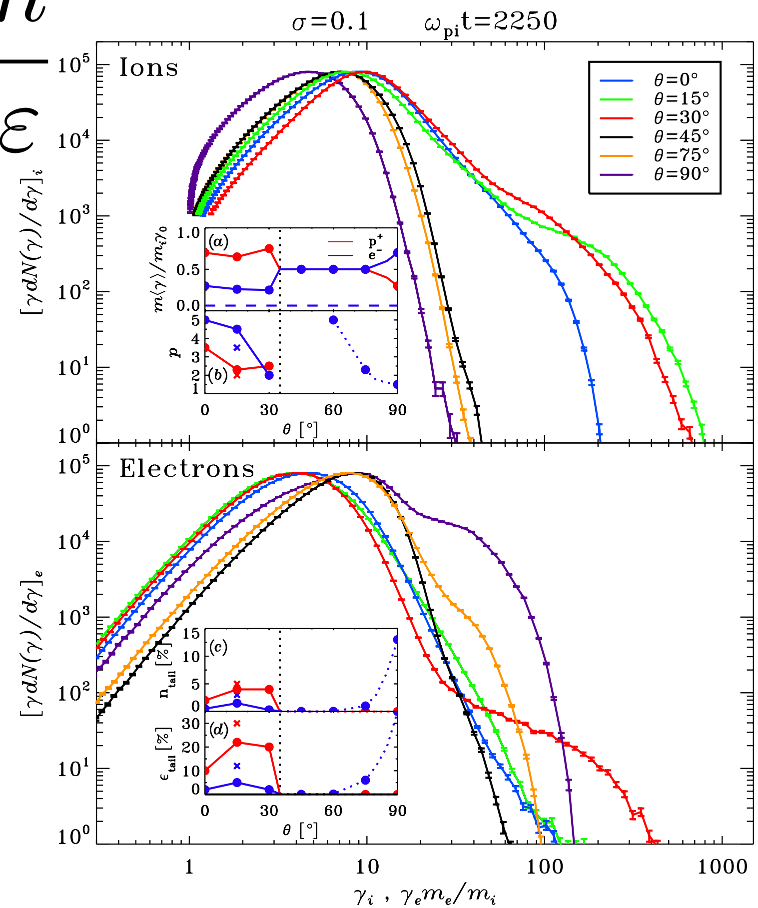
They are collisionless, interacting via electromagnetic fields

Physics of Collisionless Shocks

(Sironi & Spitkovsky 2011)



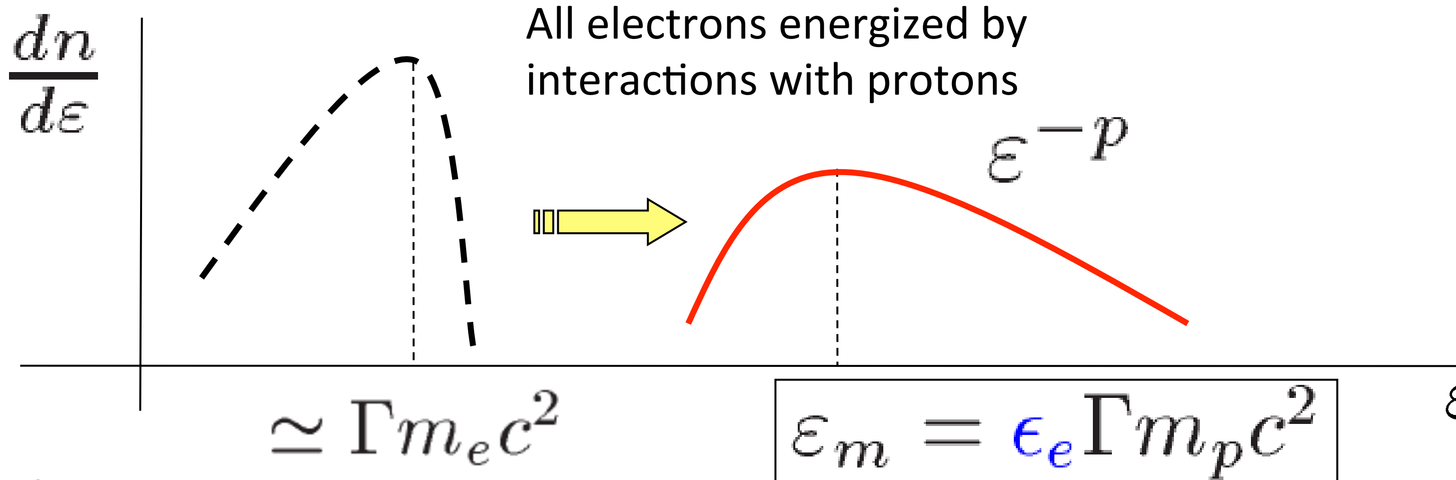
$\varepsilon \frac{dn}{d\varepsilon}$



ε

e-p interaction efficiency and B field amplification are still matter of debate

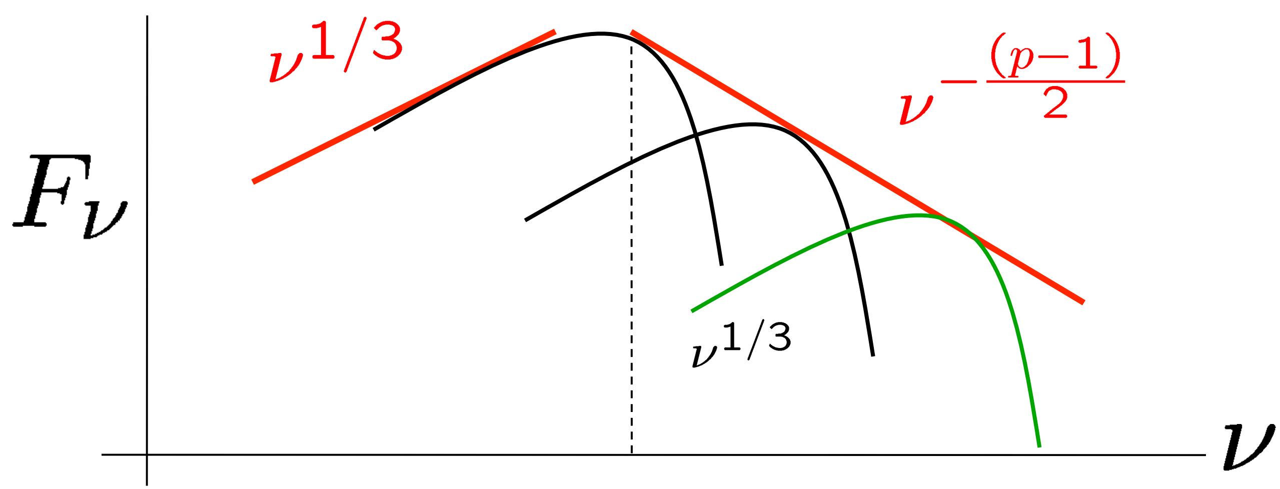
e-p interaction & B field amplification



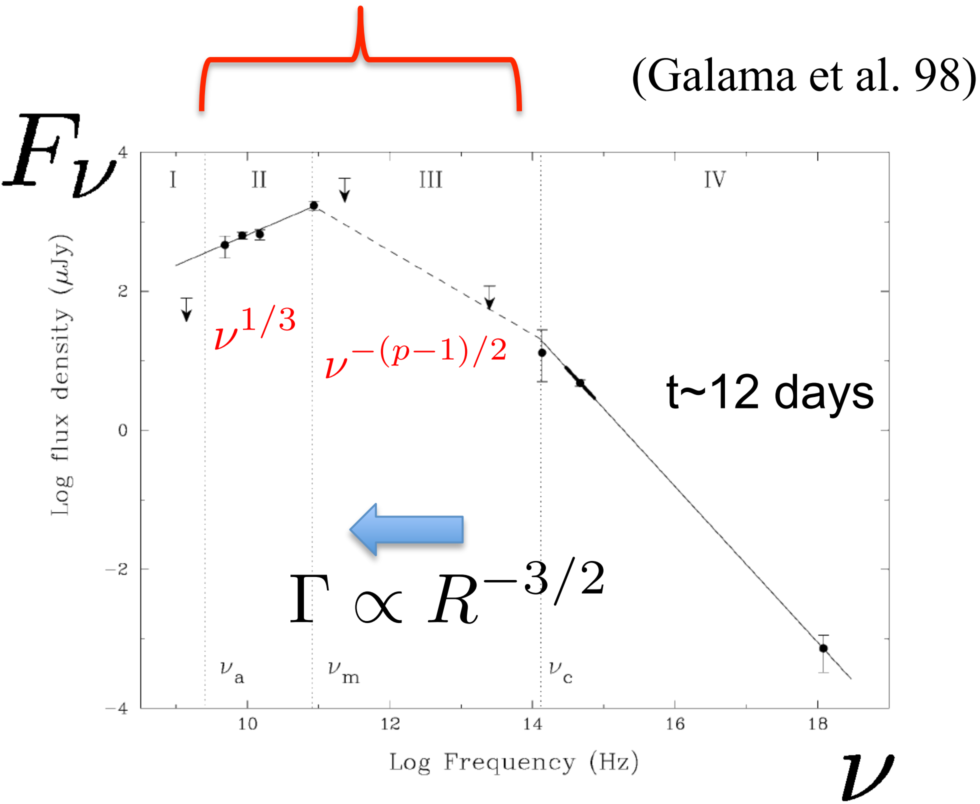
B field amplification

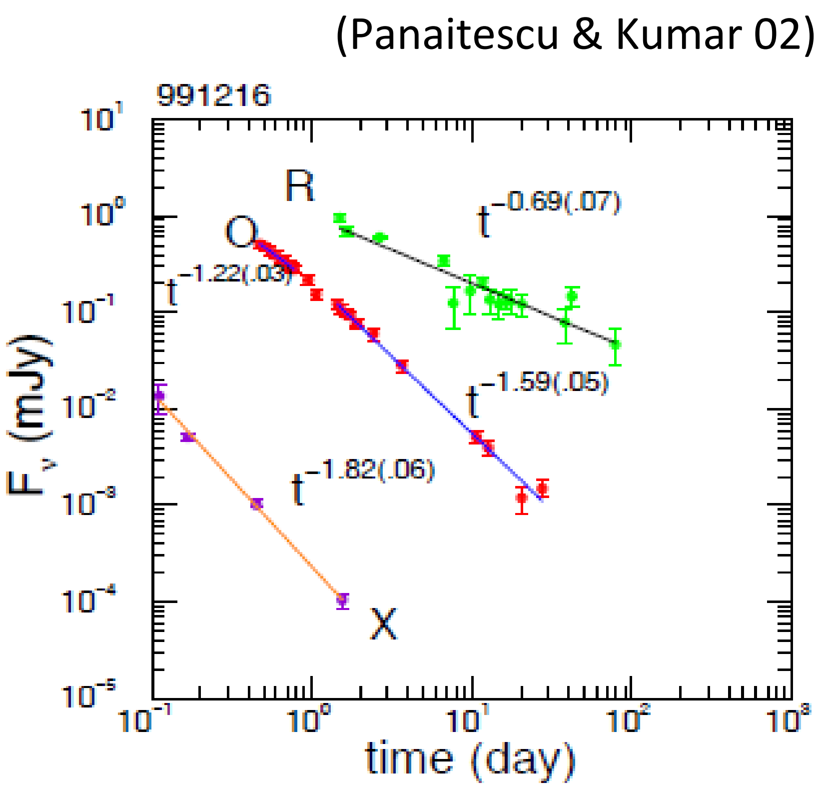
$$\frac{B^2}{8\pi} = \epsilon_B 4\Gamma^2 n m_p c^2$$

Synchrotron emission spectrum



Late-time Afterglows

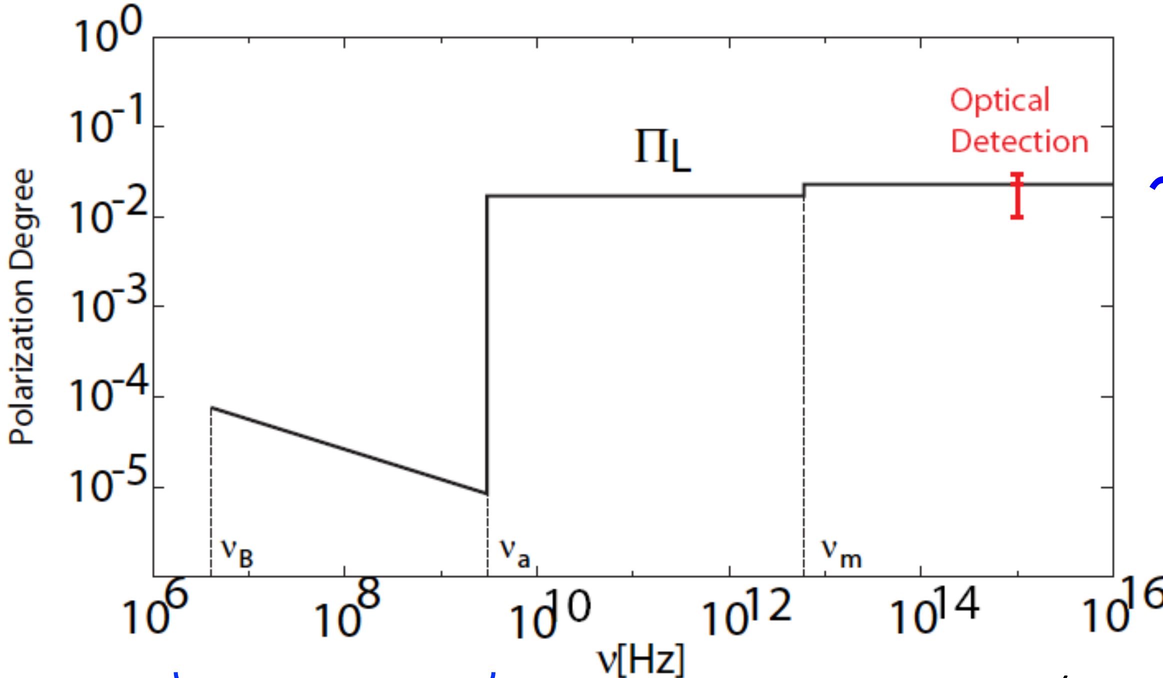




Relativistic shock - synchrotron emission model can explain the late-time afterglows

Linear Polarization

Synchrotron emission has linear polarization as high as 70% in the case of ordered magnetic field



~1−3%

Could be for magnetic field turbulence

(KT, Ioka & Nakamura 2008)

Synchrotron self-absorption

↓

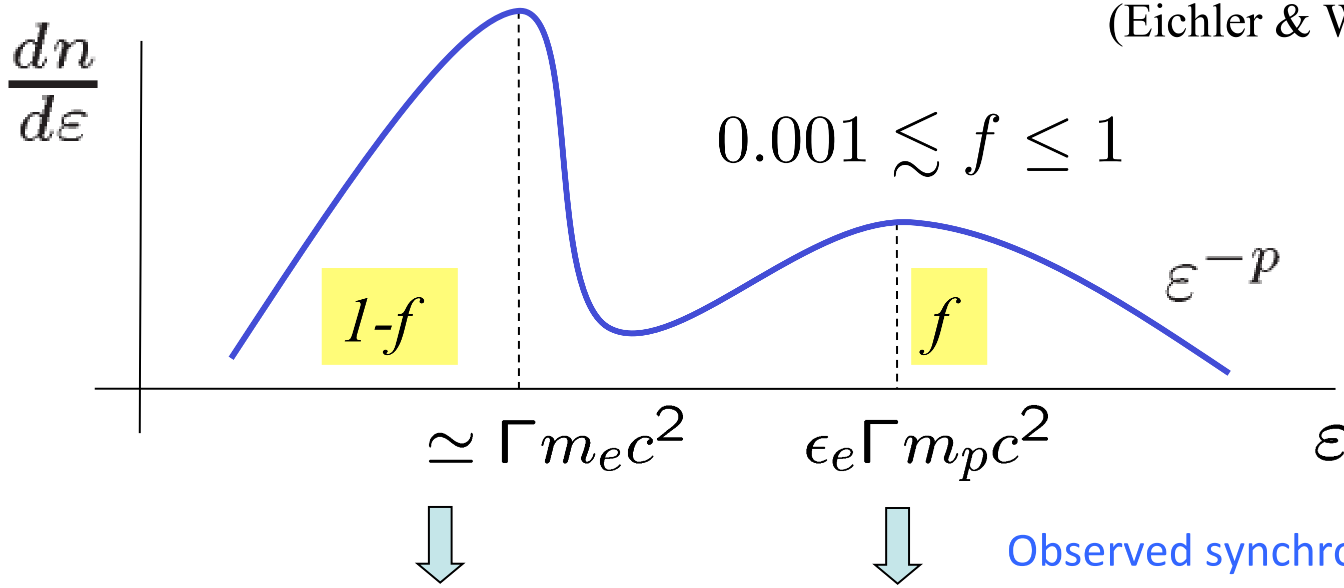
Blackbody

Consistent with no radio polarization detection so far

Efficiency of e-p interaction

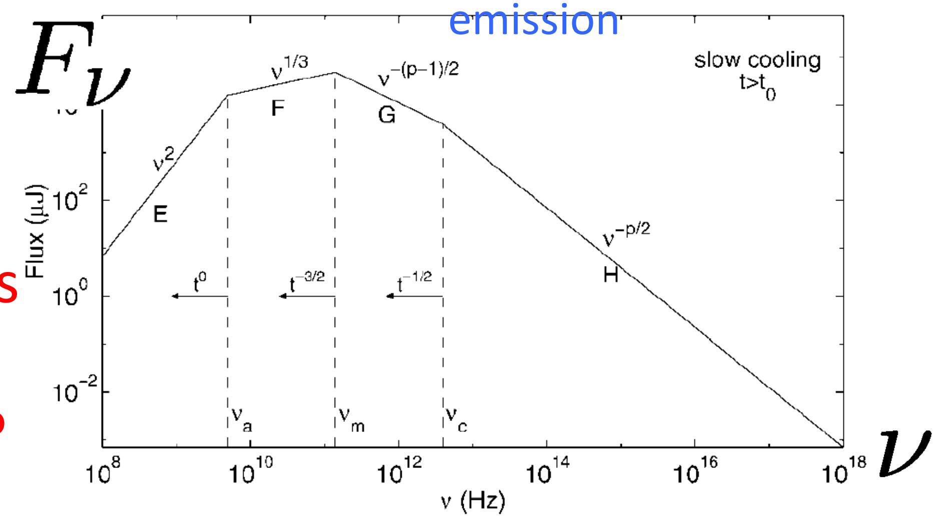
Not all the electrons are required to be accelerated

(Eichler & Waxman 05)



Observed synchrotron emission

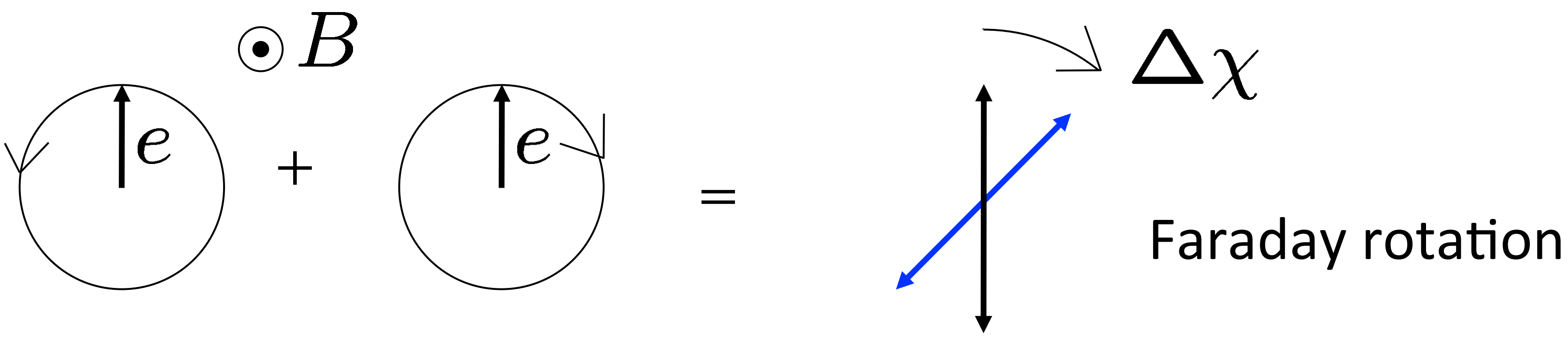
Synchrotron self-absorbed at late times



In this case, GRB total energy is *1/f* times larger !!

More massive progenitor star?

Faraday effects within emitting region

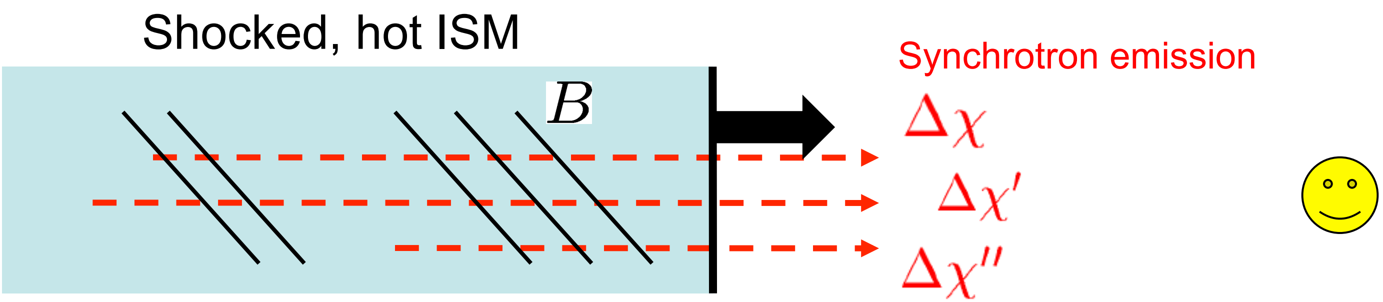


$$\Delta\chi \simeq \frac{e^3}{\pi m_e^2 c^2} n (B\cos\theta) \frac{\ln\gamma_e}{\gamma_e^2} \nu^{-2}\ \Delta s$$

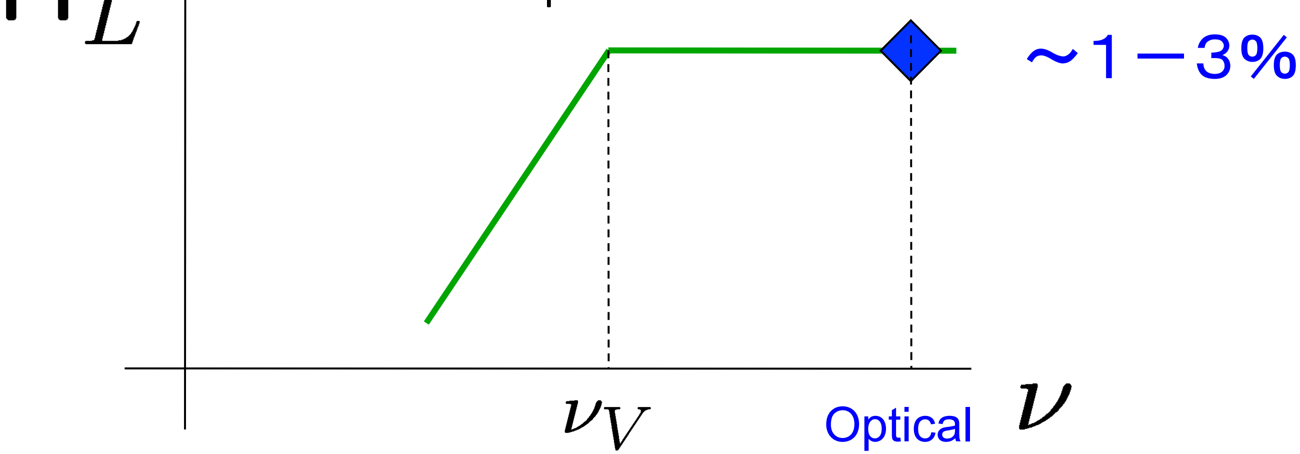
- Lower-energy electrons cause larger Faraday rotation
- Faraday rotation is stronger in lower frequencies

Faraday depolarization

$$\boxed{\Delta\chi(\nu) \gg 1}$$



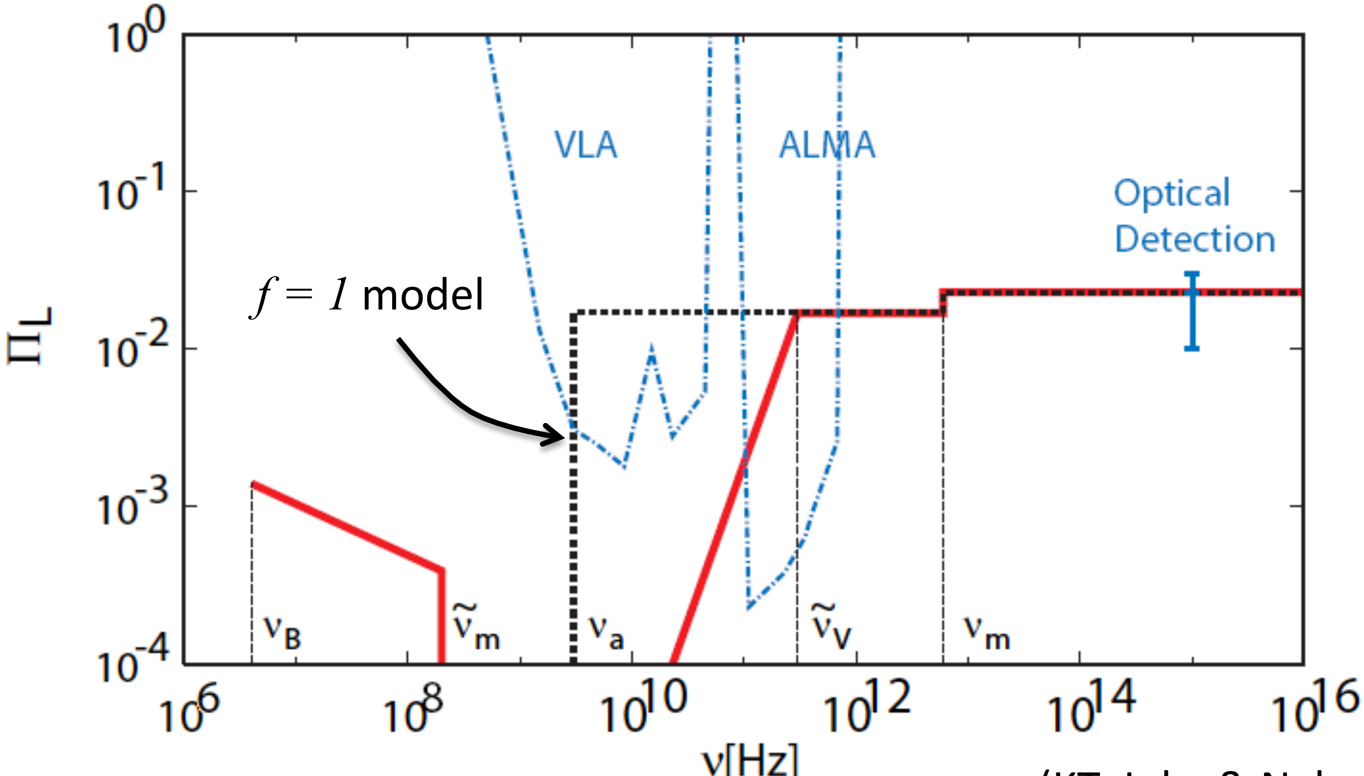
In lower frequencies, the emissions with different polarization directions are superposed, which lead to low net polarization



$$\Delta\chi(\nu_V) = 1$$

Polarimetric Probe of low-energy e

Result of polarization transfer calculation for typical afterglows at D = 1 Gpc, t = 1day

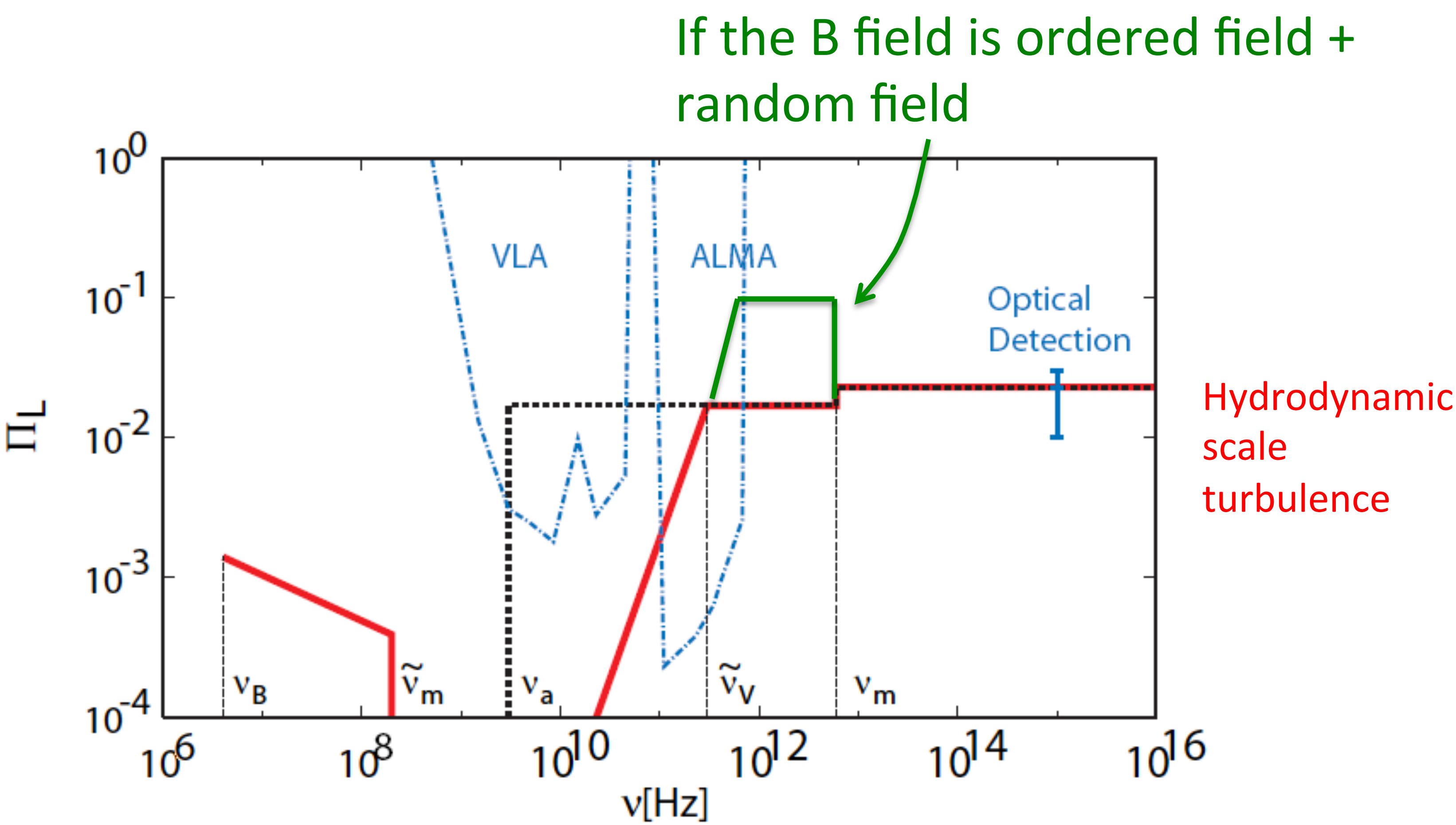


(KT, Ioka & Nakamura 2008)

This test can be done for bright afterglows by SMA.

$$\tilde{\nu}_V \simeq 3 \times 10^{11} \left[\frac{(1-f)/f}{10} \right]^{1/2} E_{52}^{3/16} n_0^{9/16} \epsilon_{B,-2}^{1/4} t_d^{-1/16} \text{ Hz},$$

B field configuration

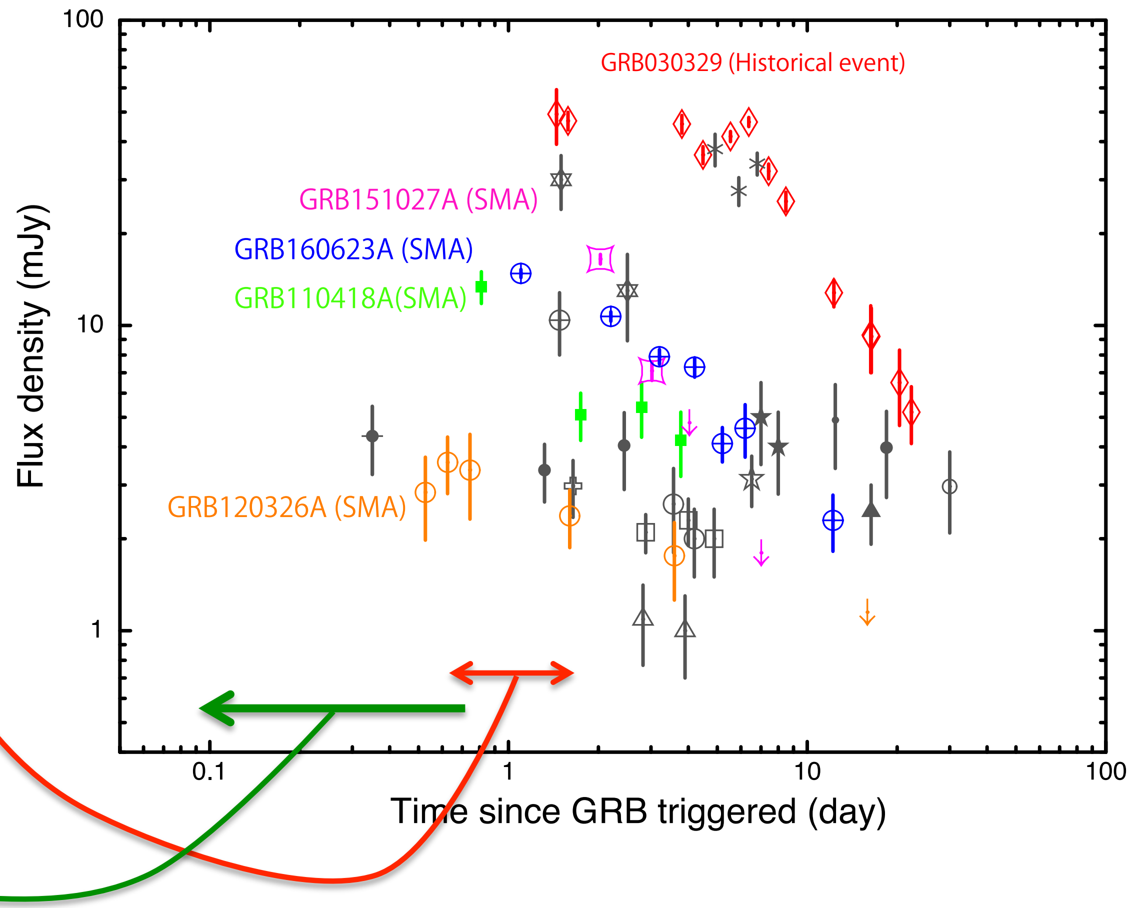


The difference of optical and radio polari degrees depend on B field configuration, which constrain the mechanism of B field amplification.

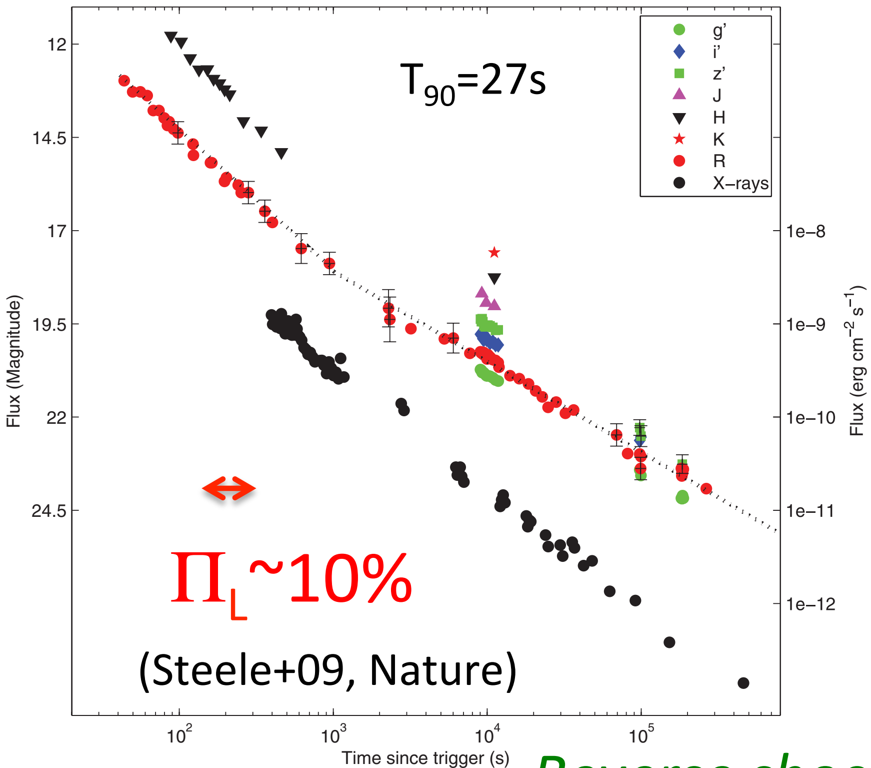
Summary & Proposition

- No radio pol detection yet
- Radio polarimetry has a potential for solving some big problems in collisionless shock physics and GRB total energy scale
- Faraday depolarization tests can be done for bright ones by SMA
- Earlier observations may catch brighter, higher-pol(?) reverse shock emission

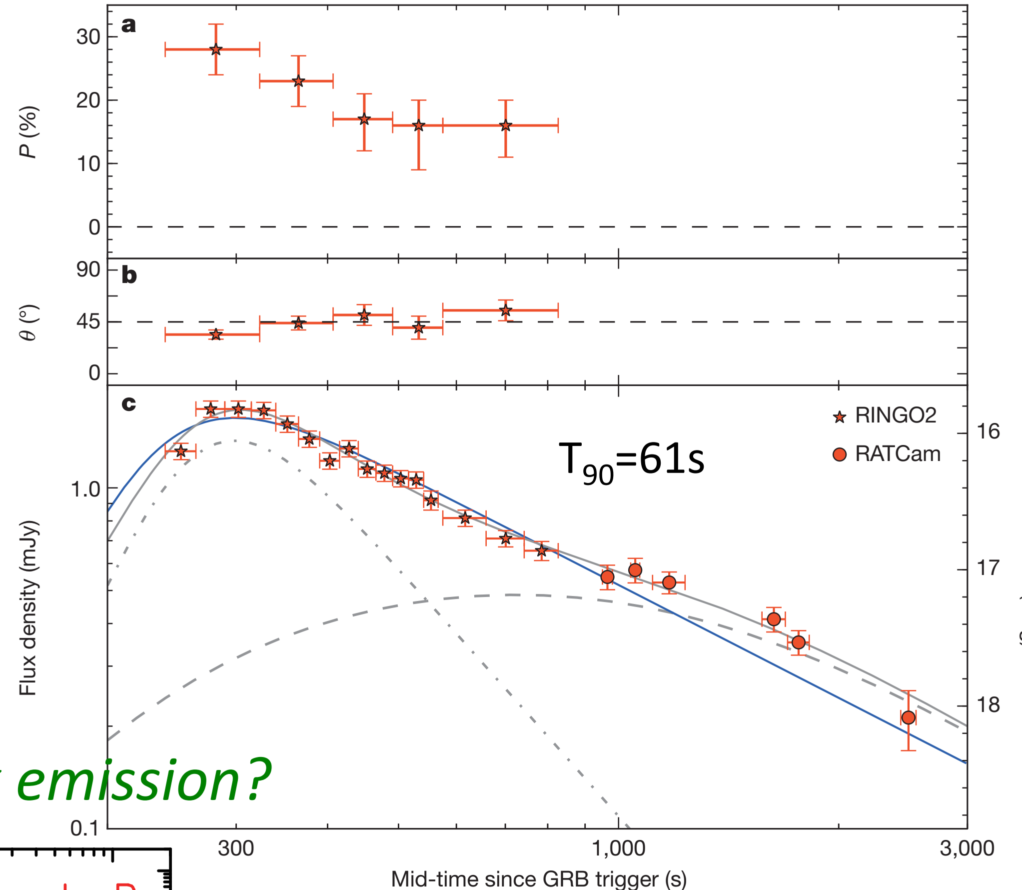
(Poster by Y. URATA)



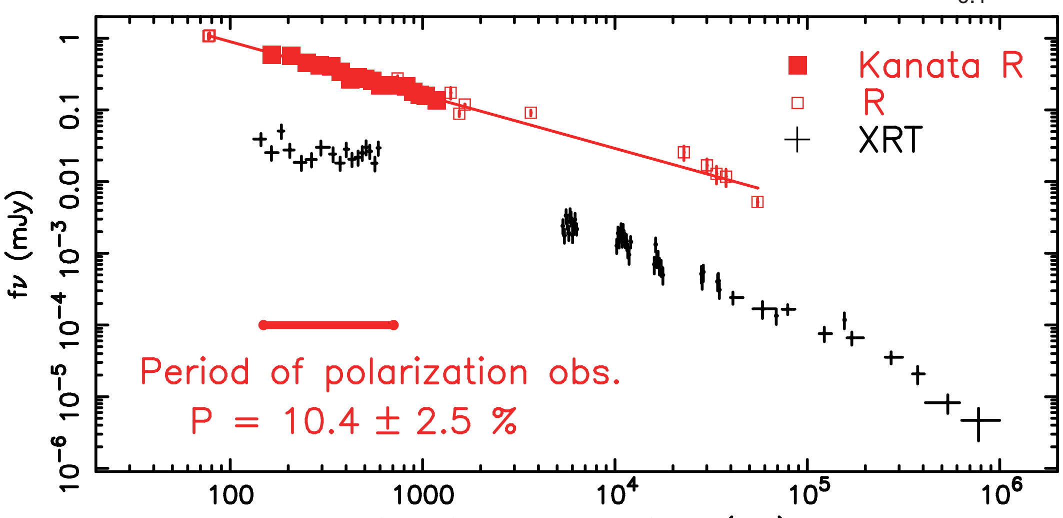
GRB 090102 (Gendre+10)



GRB 120308A (Mundell+13, Nature)



Reverse shock emission?



Forward shock emission?