超新星及びガンマ線バーストと将来大型観測機器

京大基研	長滝重博 (40+10)
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東大	前田啓一 (5)
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理論懇星、コンパクト班（メーリングリスト）

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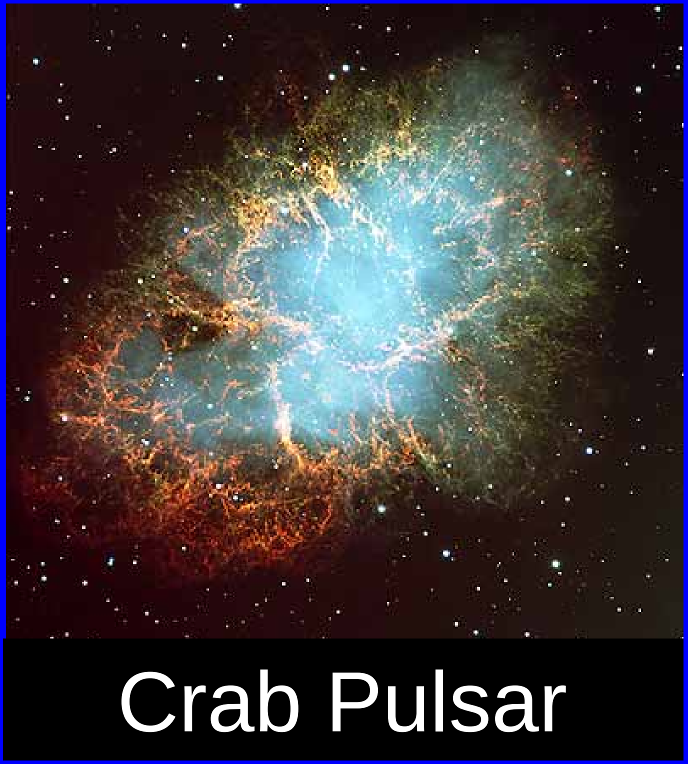
村上敏夫さん（金沢大）森正樹さん（東大）
山岡均さん（九大）山崎了さん（阪大）山田章一さん（早大）
吉田滋さん（千葉大）吉田龍生さん（茨城大）米徳大輔さん（金沢大）

Plan of This Talk

- 超新星及びガンマ線バーストの爆発メカニズムと将来大型観測機器
- 宇宙線源としての超新星及びガンマ線バーストと将来大型観測機器
- 宇宙論としてのガンマ線バーストと将来大型観測機器

§超新星及びガンマ線バーストの爆発メカニズムと将来大型観測機器

Examples of Collapse-driven Supernovae

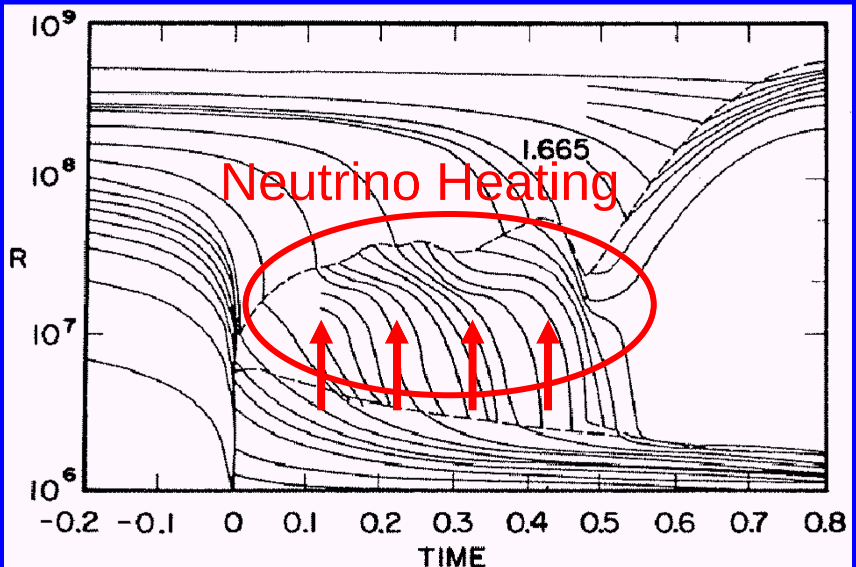


Explosion energy amounts to 1E+51 ergs.

Required Physics to Understand Collapse-driven Supernovae

There are many physics involved in Collapse-Driven Supernovae such as…

Hydrodynamics, Neutrino Physics, Nuclear Physics, General Relativity, Magnetic Fields ..etc.



Standard Scenario (Delayed Explosion Model) has been established by Wilson (1985).

But, some physics are treated simply (neutrino transport, Equation of state(EOS)..).

Required Physics to Understand Collapse-driven Supernovae

There are many physics involved in

5. *The super-nova process*

We have tentatively suggested that the super-nova process represents the transition of an ordinary star into a neutron star. If neutrons are produced on the surface of an ordinary star they will "rain" down towards the center if we assume that the light pressure on neutrons is practically zero. This view explains the speed of the star's transformation into a neutron star. We are fully aware that our suggestion carries with it grave implications regarding the ordinary views about the constitution of stars and therefore will require further careful studies.

W. Baade
F. Zwicky

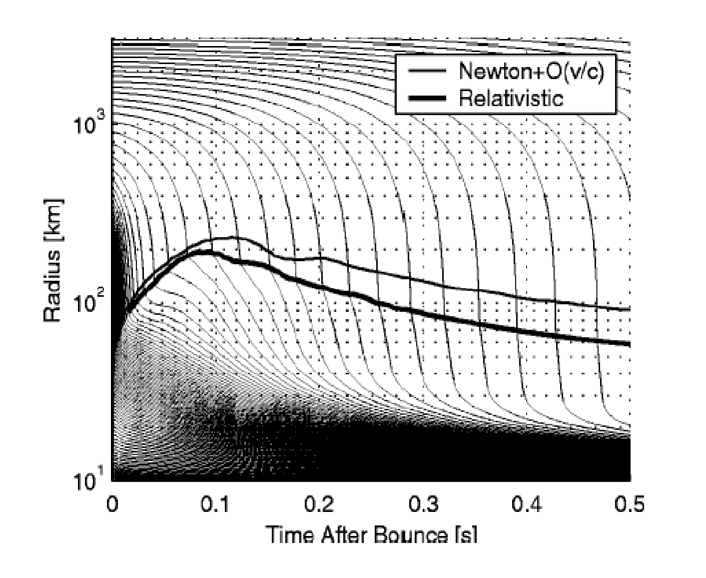
1934

First report was seen in second century by Chinese astronomers.

ed
n
35).
ted
nply (neutrino transport,
Equation of state(EOS)..).

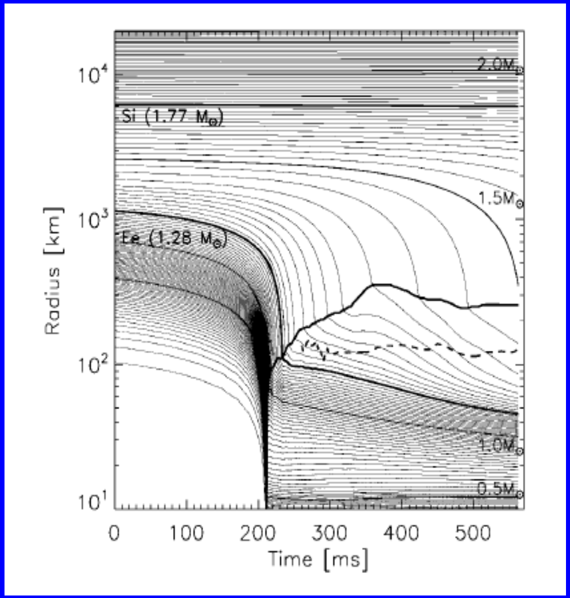
Latest Results of 1D Simulations

Method of Simulation has been refined. No Explosion is found. But small correction will lead to a successful explosion!



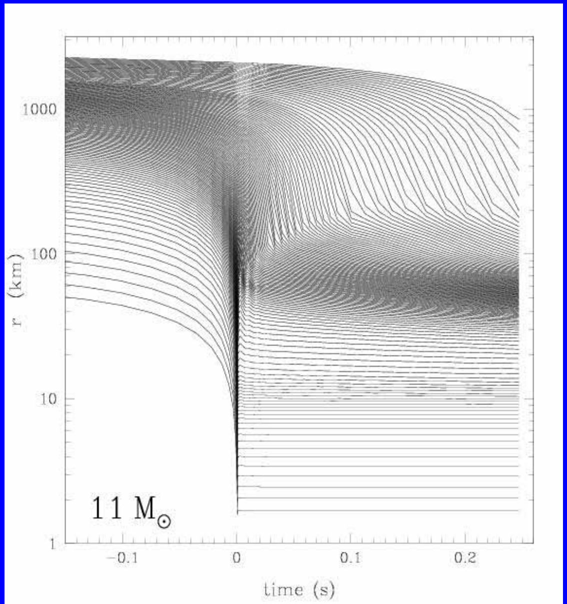
Liebendoerfer et al. 01

Boltzmann Solver
EOS of Lattimer Swesty
Many Weak Interactions
General Relativity



Rampp et al. 00

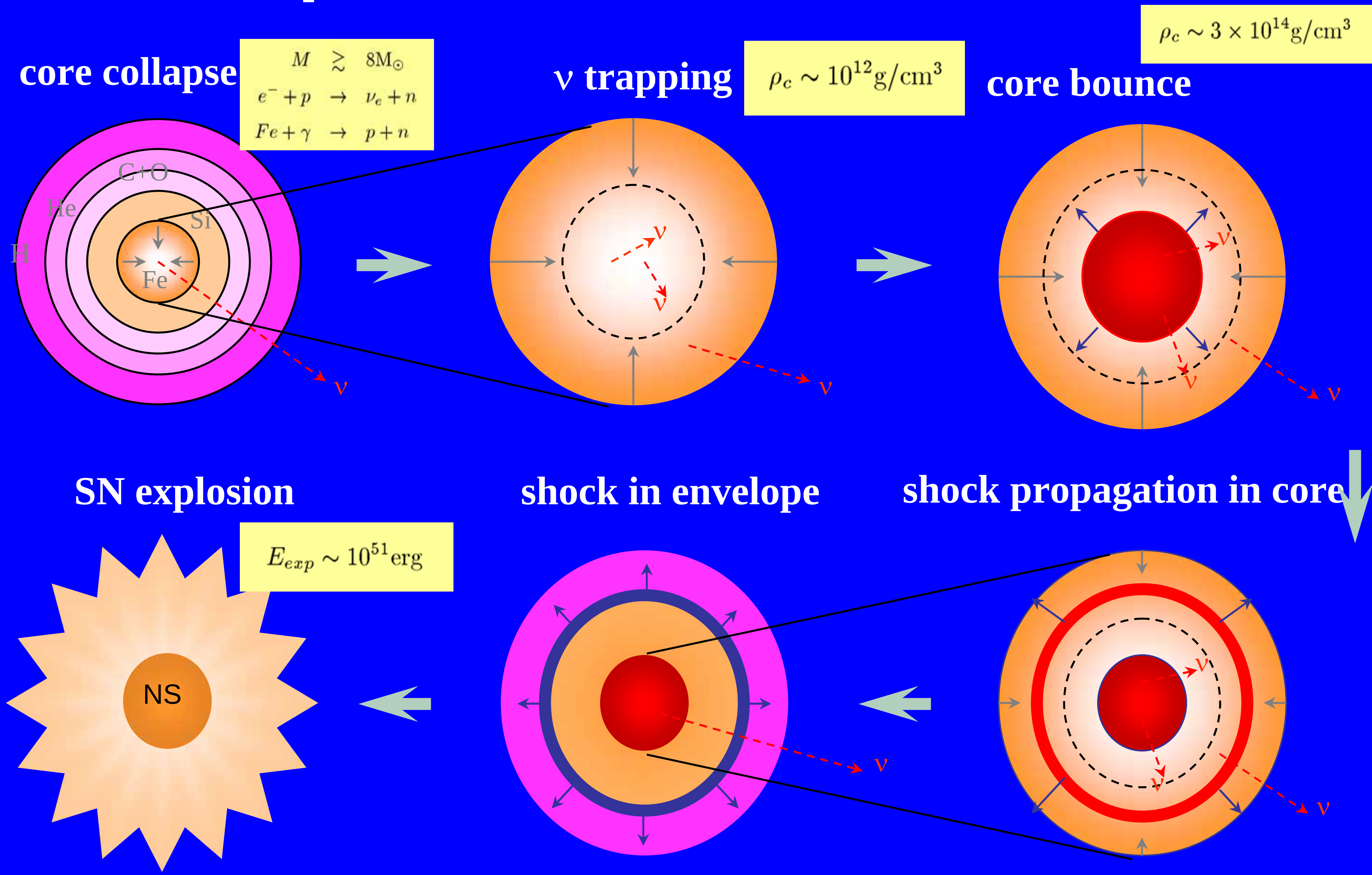
Boltzmann Solver (Tangent Ray-Method),
EOS of Lattimer Swesty
Many Weak Interactions
Newtonian Gravity



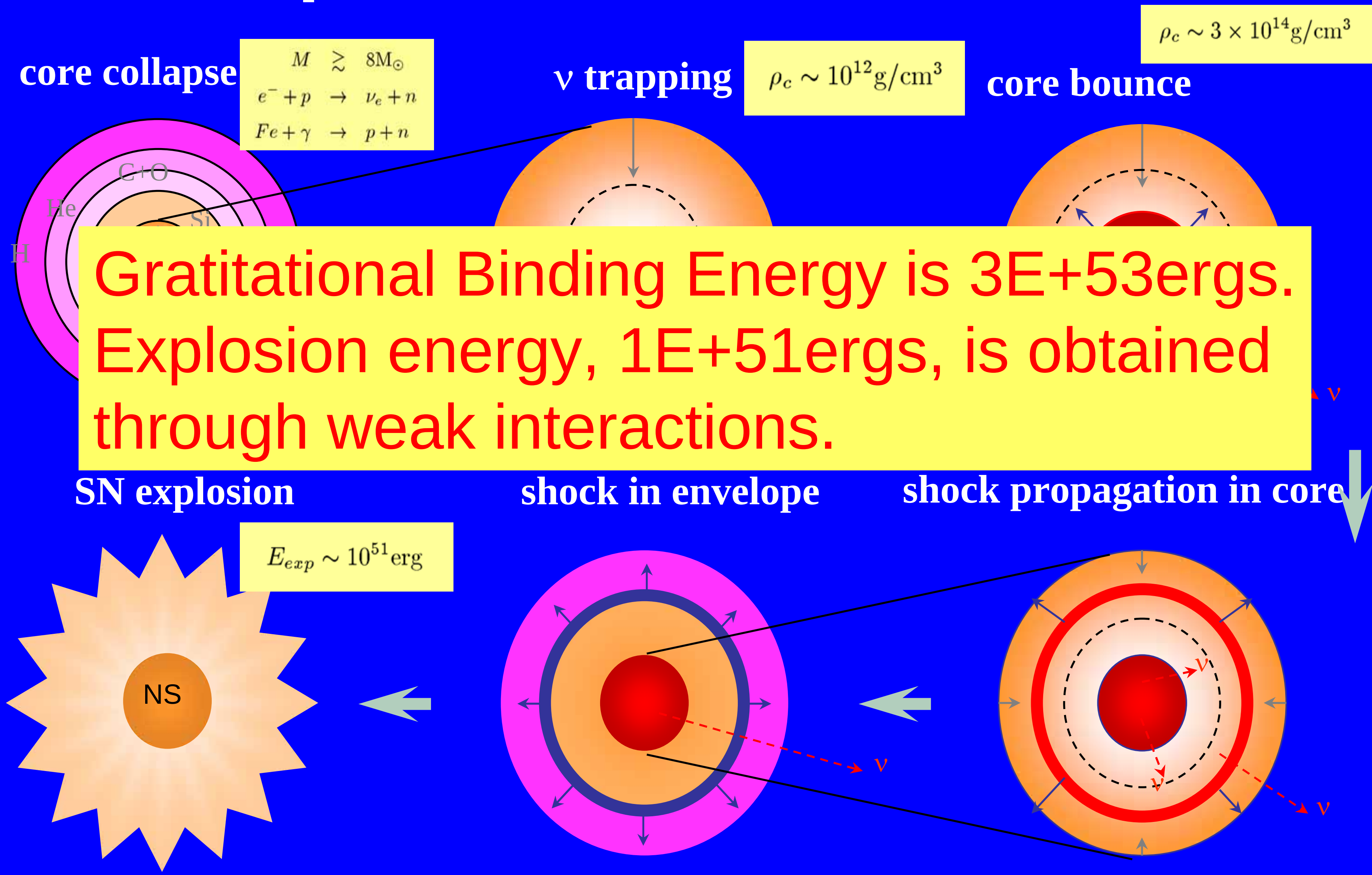
Thompson et al. 03

Boltzmann Solver (Tangent Ray-Method),
EOS of Lattimer Swesty
Many Weak Interactions
Newtonian Gravity

Scenario of Collapse-driven Supernovae 山田章一さんより



Scenario of Collapse-driven Supernovae　山田章一さんより



Gratitational Binding Energy is 3E+53ergs.
Explosion energy, 1E+51ergs, is obtained through weak interactions.

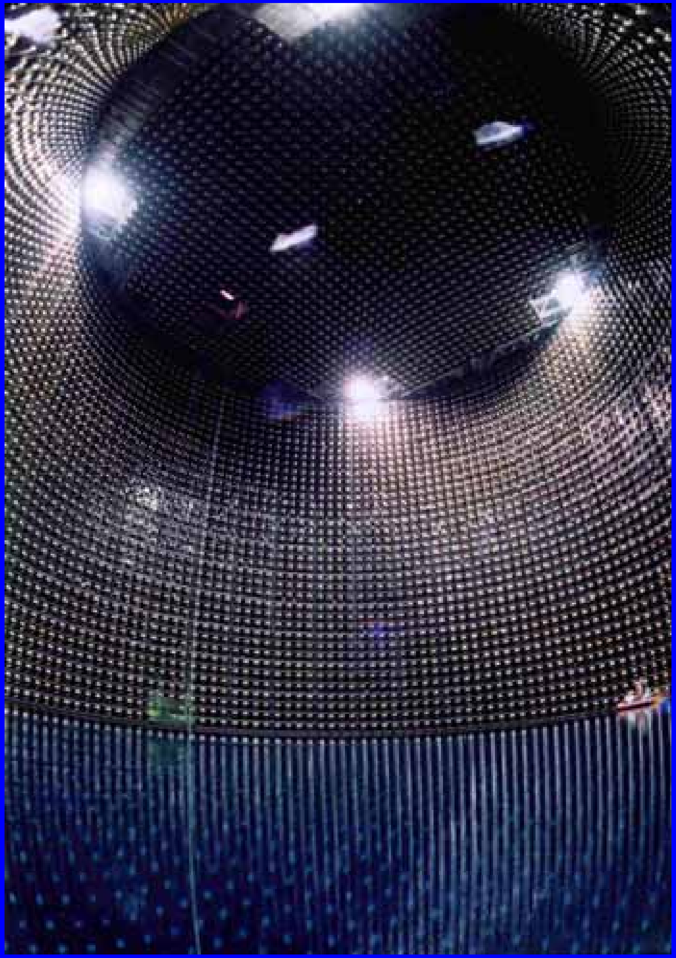
What carries information of explosion mechanism?

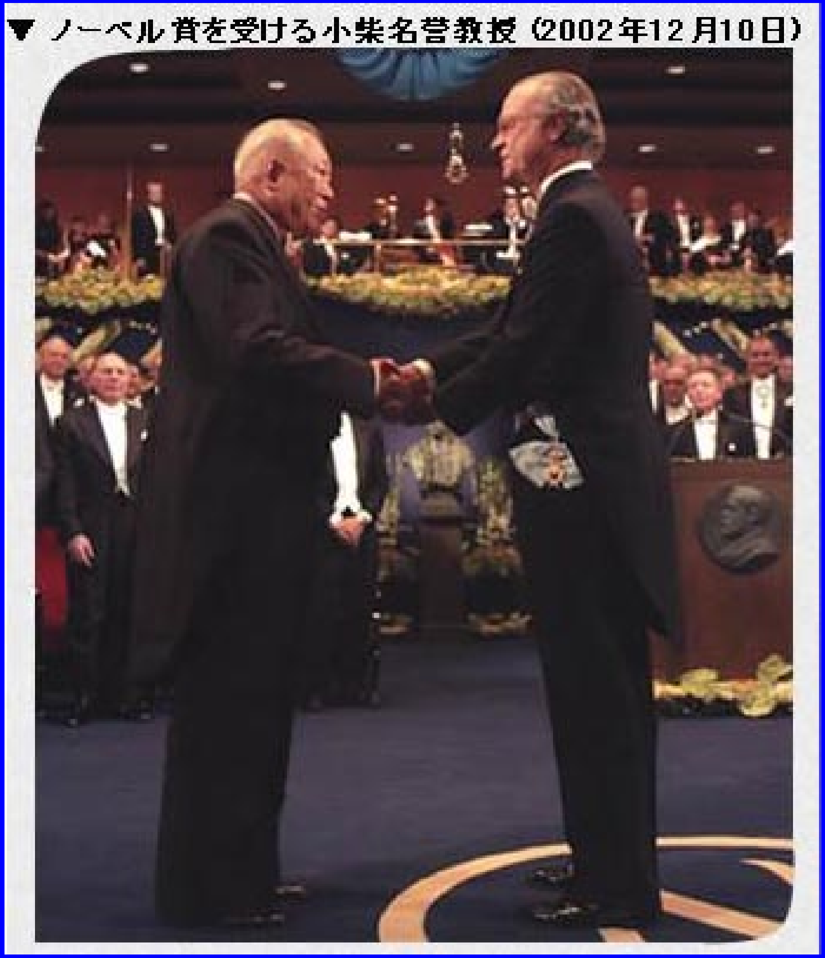
Central core of a progenitor is opitcally thick.

↓

- Neutrino
- Gravitational Wave

Neutrino Signals from Collapse-Driven Supernovae





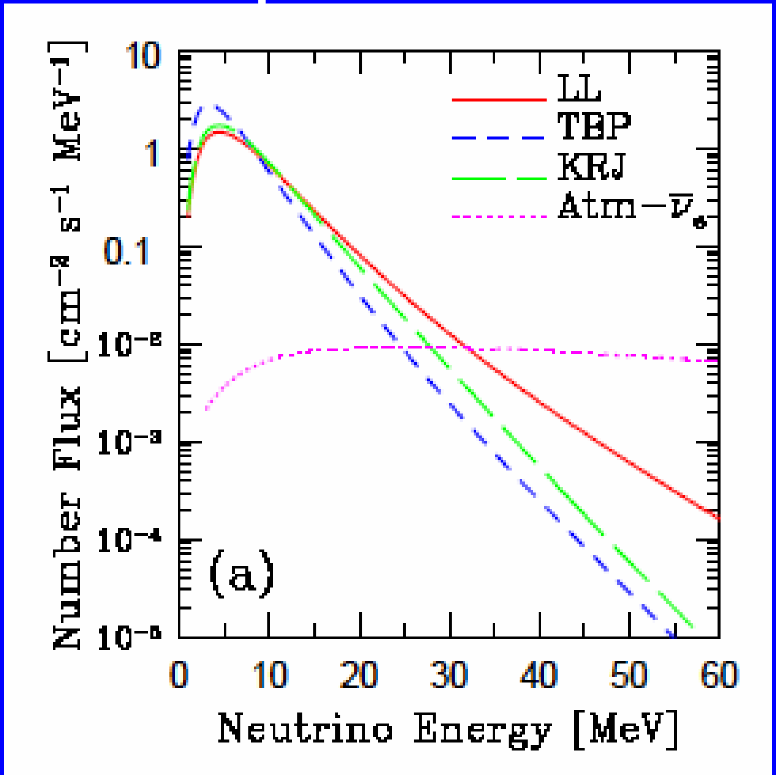
Super-Kamiokande

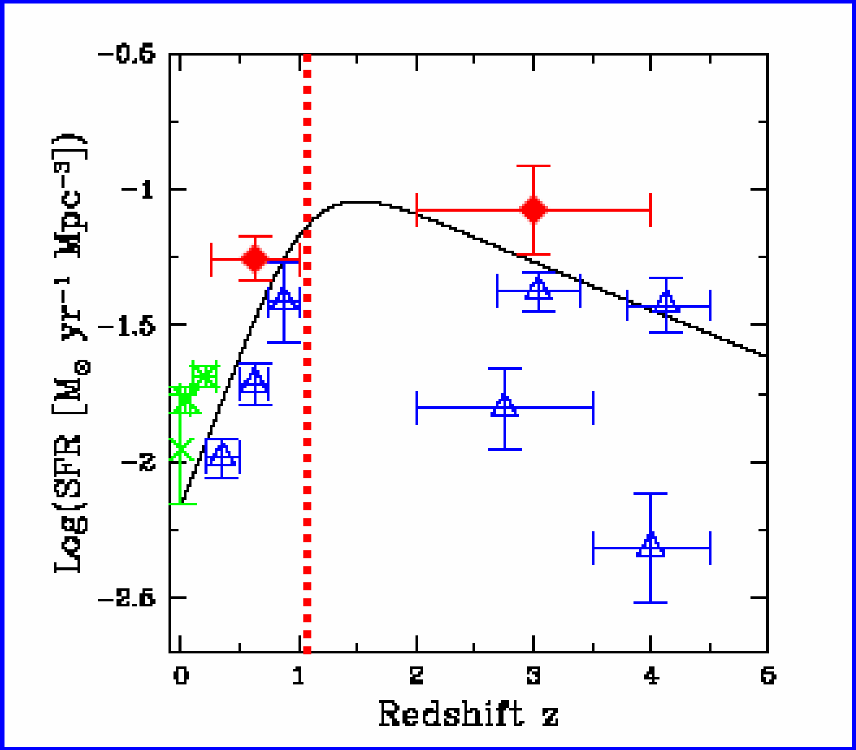
Prof. M. Koshiba

Supernova Relic Neutrino (anti-electron type neutrino)

$\bar{\nu}_e + p \longrightarrow n + e^+$

Ando and Sato, astro-ph/ 0410061





Star formation rate and Madau plot (2001)
Note that contribution of supernovae with z < 1 dominates over that of the other supernovae with z>1.

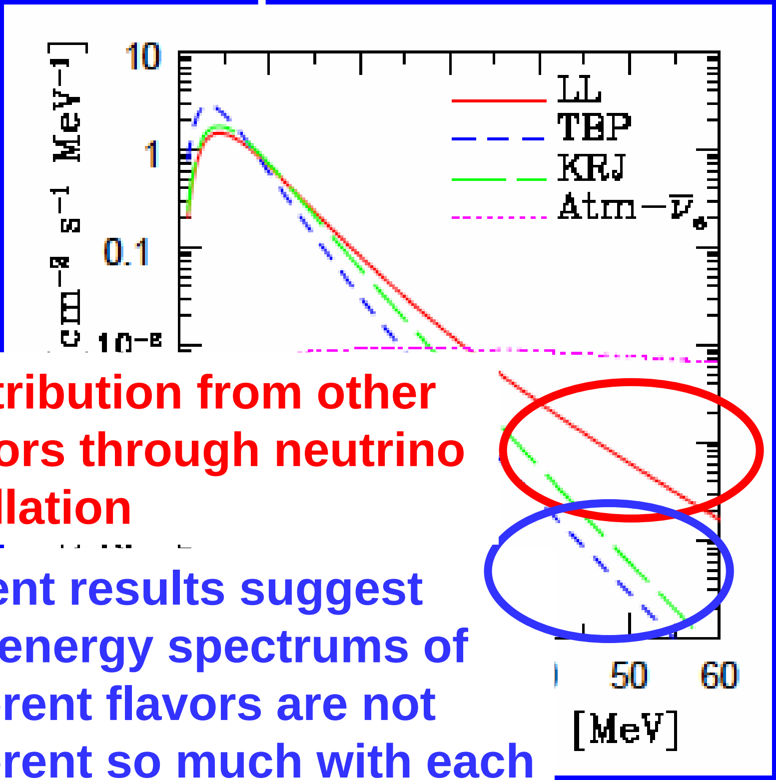
Supernova data:
Lawrence Livermore group (1998)
Thompson, Burrows, Pinto (2003)
Keil, Raffelt, Janka (2003)

$$\psi_*(z) = 0.32 f_* h_{70} \frac{\exp(3.4z)}{\exp(3.8z)+45} \frac{\sqrt{\Omega_m(1+z)^3+\Omega_\Lambda}}{(1+z)^{3/2}} M_\odot \text{ yr}^{-1} \text{ Mpc}^{-3}$$

Supernova Relic Neutrino (anti-electron type neutrino)

$\bar{\nu}_e + p \longrightarrow n + e^+$

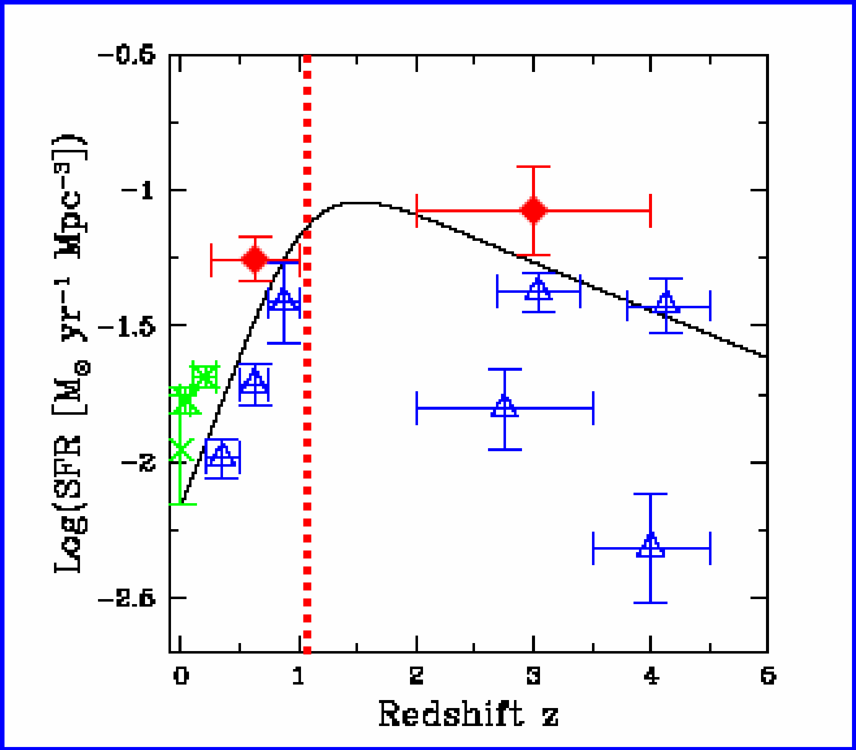
Ando and Sato, astro-ph/ 0410061



Contribution from other Flavors through neutrino oscillation

Recent results suggest that energy spectrums of Different flavors are not Different so much with each Other.

Supernova data:
Lawrence Livermore group (1998)
Thompson, Burrows, Pinto (2003)
Keil, Raffelt, Janka (2003)



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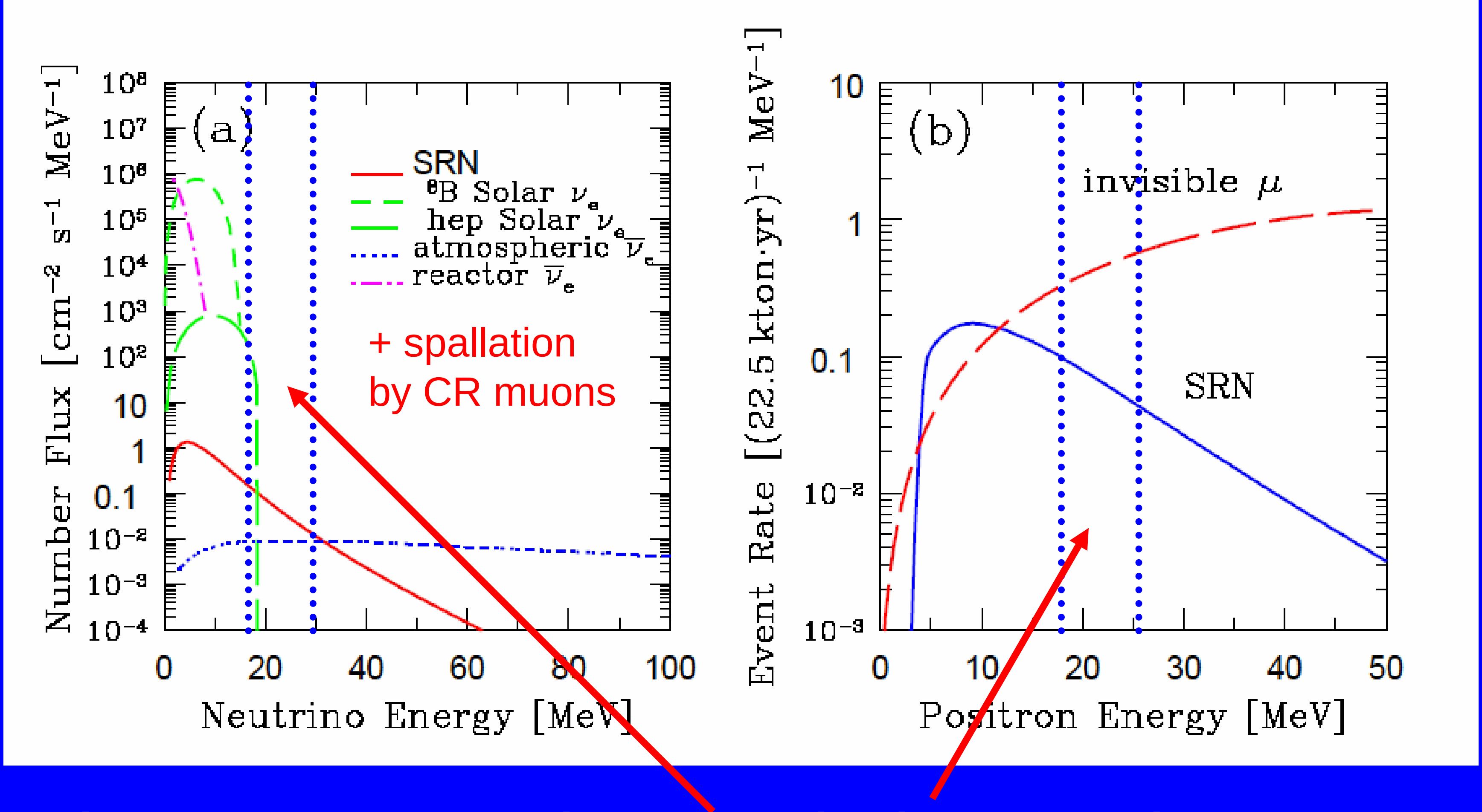
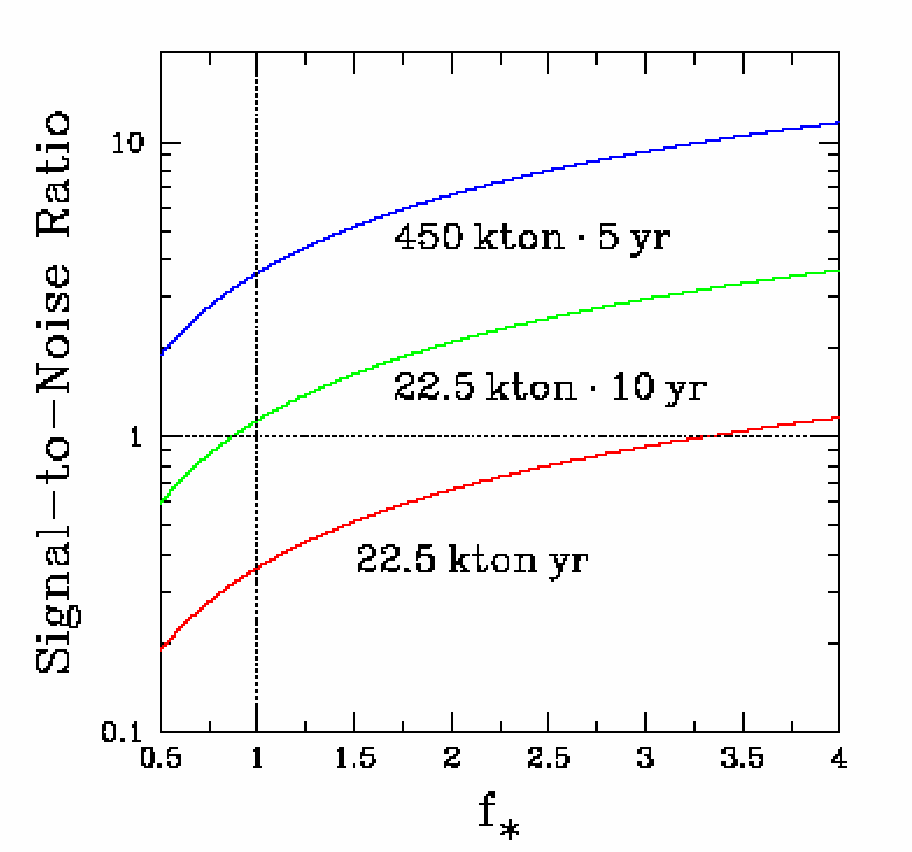
Supernova Relic Neutrino (2)



There seems to be no window for the SRN detection at Super-Kamiokande.

Signals from SRN at Water Cerenkov detector



$$S/N \equiv \frac{N_{\rm SRN}}{\sqrt{N_{\rm SRN}+N_{\rm bg}}} = \frac{0.73 f_*}{\sqrt{0.73 f_* + 3.4}} \left(\frac{V_{\rm eff}}{22.5\ {\rm kton\ yr}}\right)^{1/2}$$

Statistical significance for the detection of the SRN may be Obtained by Super-Kamiokande.

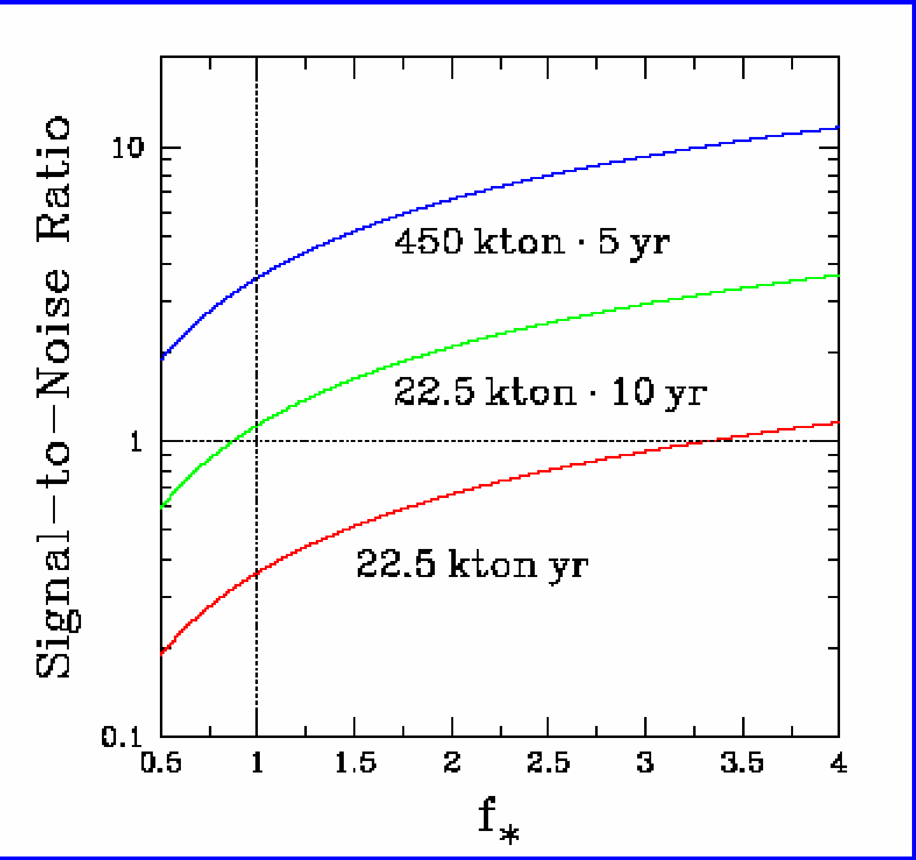
If GdCl3 is included (0.2%), neutron Is captured and cascades should be Detected from the excited Gd, which Can be used to distinguish signals From invisible muon events.

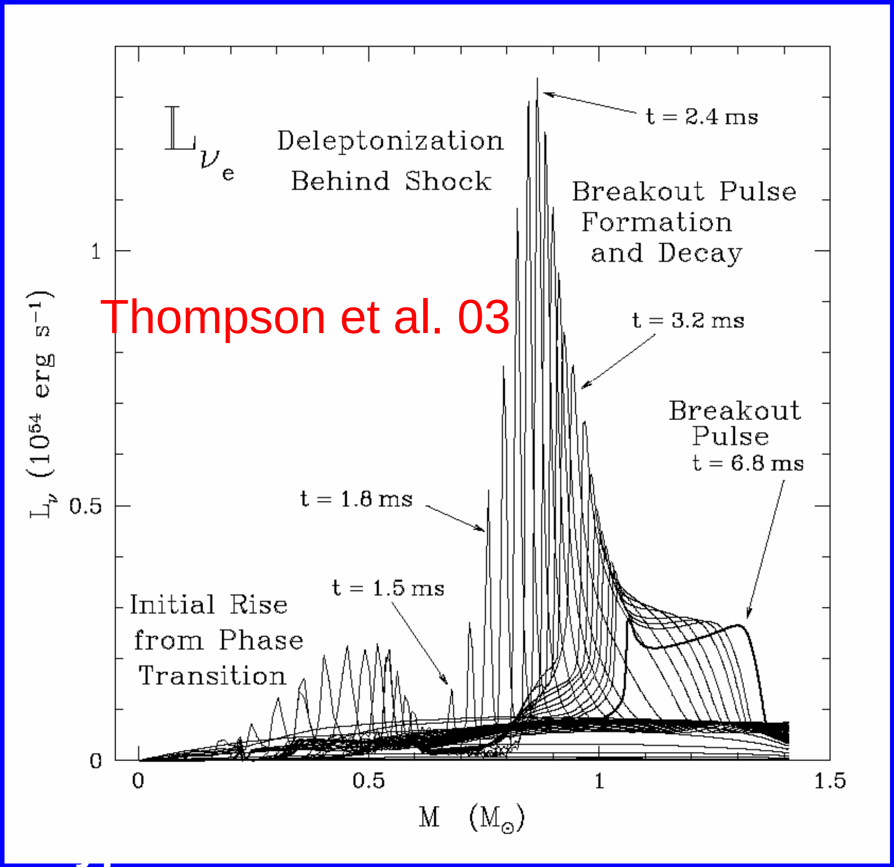
Event rate at other detectors:
KamLAND 0.4 events/yr.
SNO 0.03 events/yr.

Future mega-ton detectors such as Hyper-Kamiokande and UNO will give us a considerable number of detection of the SRN.

If a collapse-driven supernova occurs in our galaxy, about 10000 events will be detected by SK.

Signals from SRN at Water Cerenkov detector





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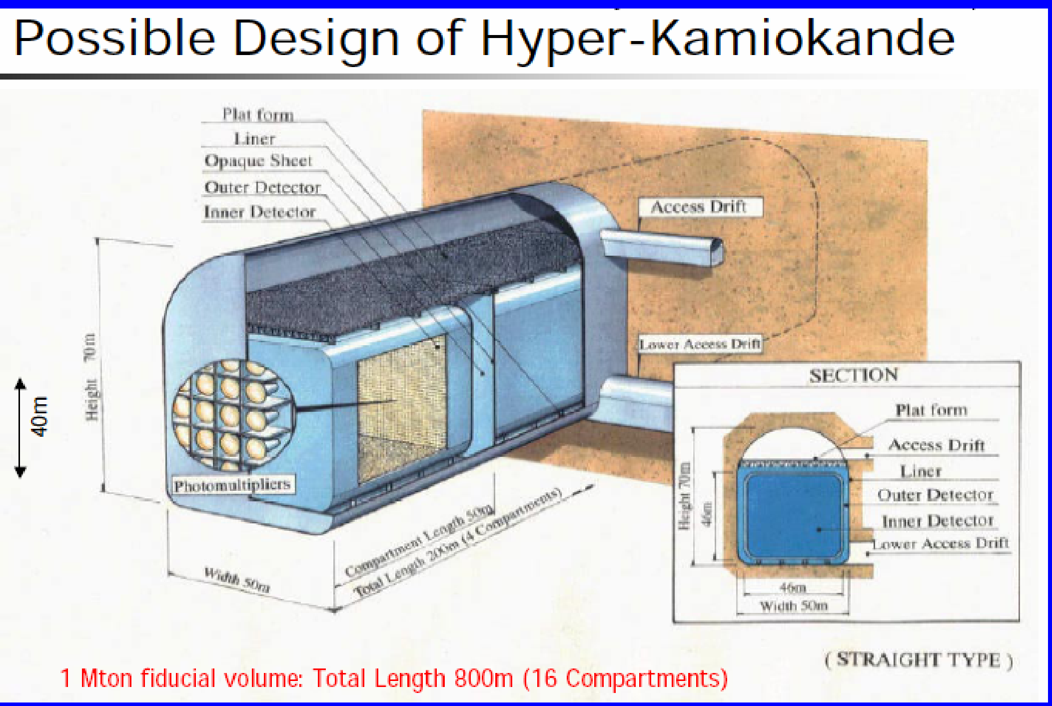
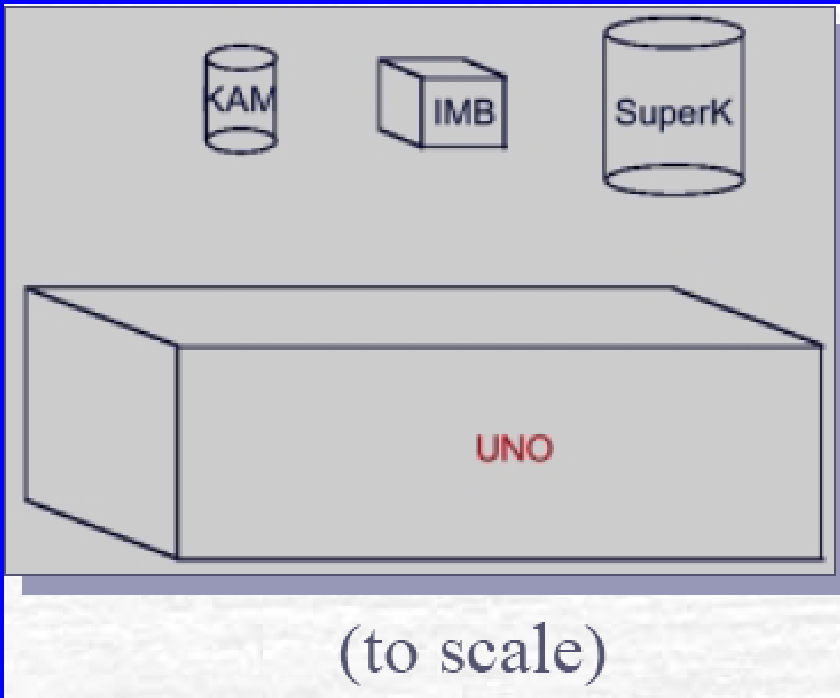
Hyper-Kamiokande and Underground Nucleon decay and neutrino Observatory

Water Cherenkov Detectors





Total 1.5Mton
Fiducial 1.1Mton
Kamioka
Shiozawa et al. 01

Total 650kt
Fiducial for SN 580kt
New Mexico
Casper, ppt file

Gravitational Waves from Collapse-Driven Supernovae

LIGO
(Washington and
Louisiana)

TAMA 2003.4.6

Total observation
time of 1000hours
was achieved.

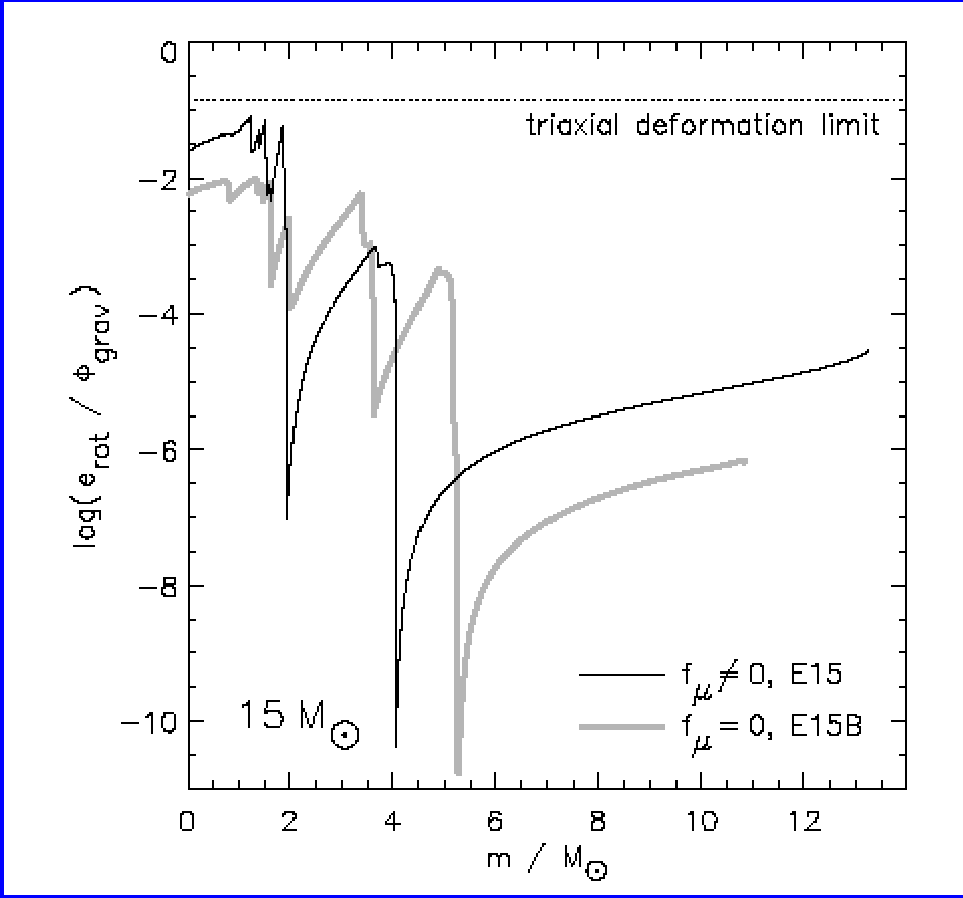
Gravitational Waves from Collapse-driven supernovae (1)

Our group considers that globally asymmetric explosion is caused by effects of rotation, which can be one possibility that helps a successful explosion.

Observationally, most massive stars are rapid rotators (Tassol 78).

Recent theoretical studies suggest a (fast) rotating core prior to collapse (Heger et al.00; Heger et al. 04) .

But, it is reported that angular Momentum transfer due to magnetic field is Effective (Heger et al. 04).



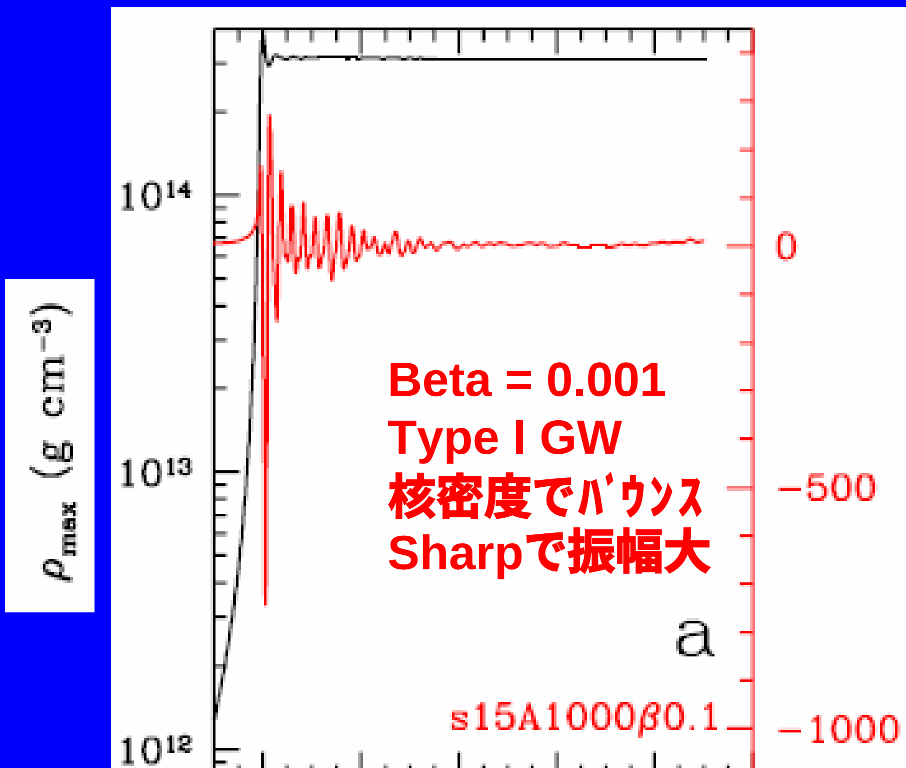
Heger et al. 00

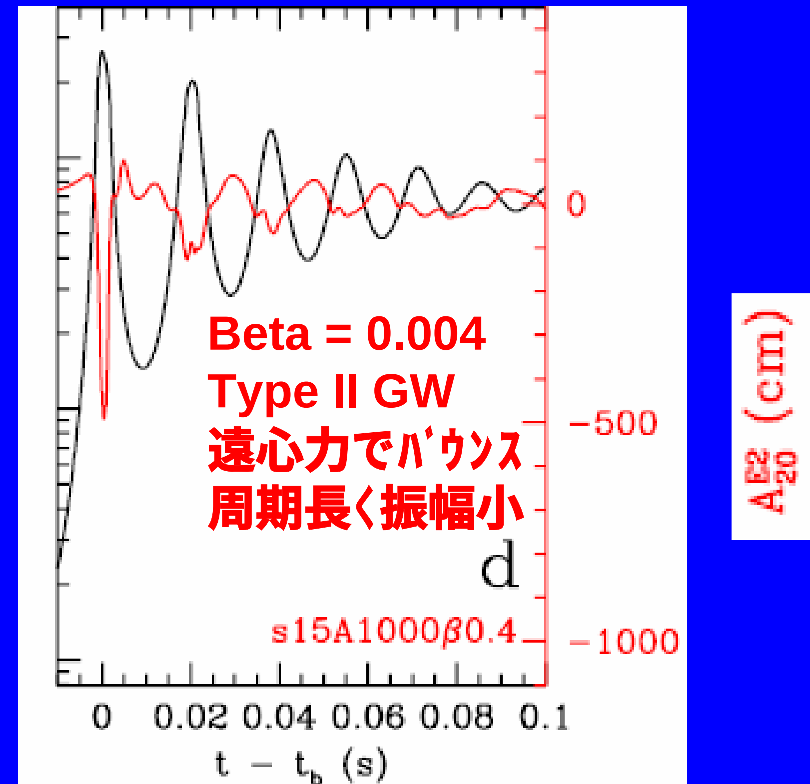
Note that Fe core of 20 and 25Msolar Rotates at a period of 7.0ms and 6.3ms after collapse even in Heger et al. 04.

Examples of Gravitational Waves from Collapse-driven Supernovae

Ott, Burrows, Livne, Walder astro-ph/0307472

See also Kotake et al. (2004) and Shibata and Sekiguchi (2004)





2-D axial-symmetric Hydrodynamics
EOS of Lattimer Swesty
Newtonian Gravity
No neutrino transfer
Quadrupole formulation to estimate the amplitude of GW
Parametric study of GW emission, using 72 models.

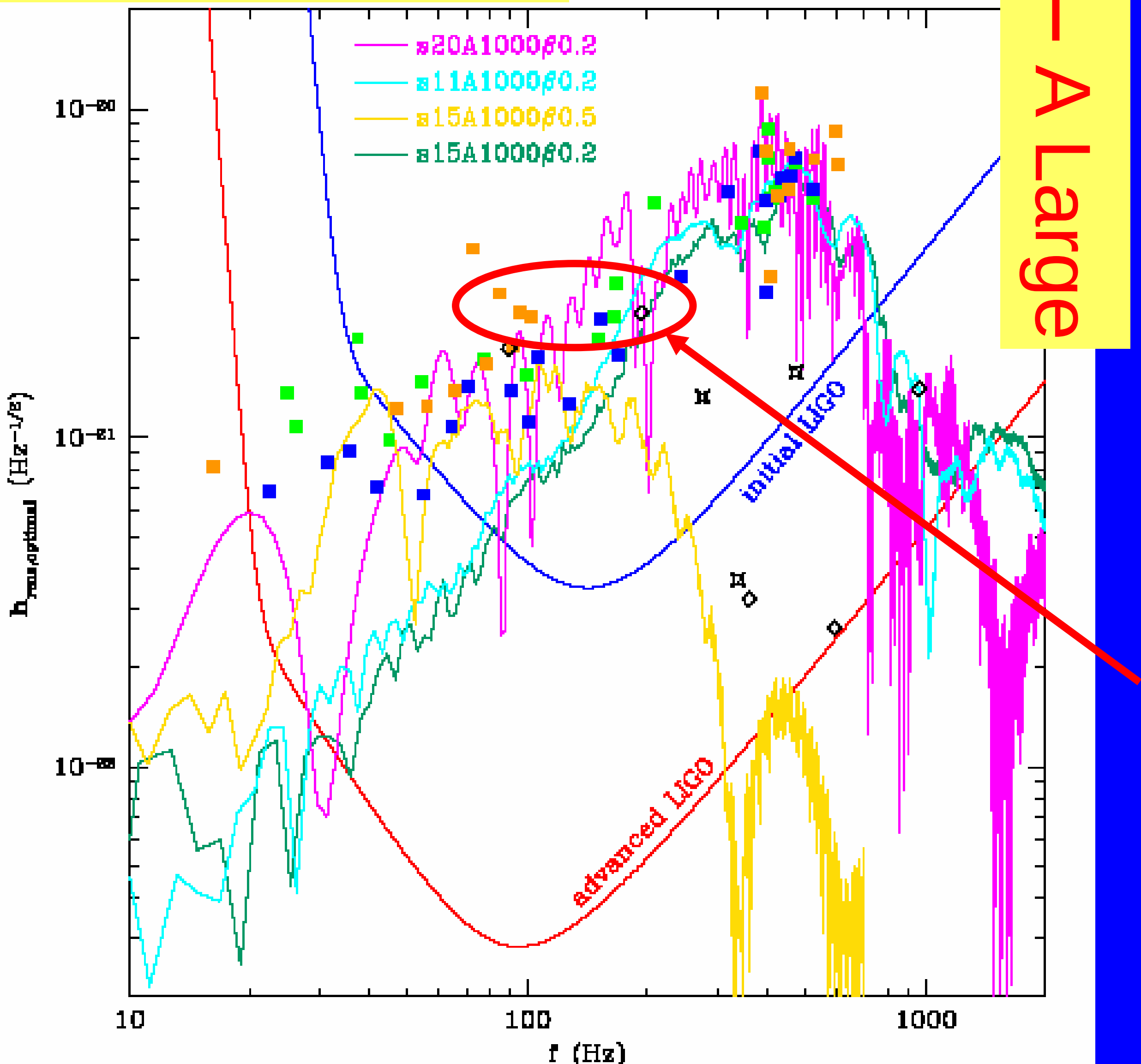
$$\beta = \frac{E_{rot}}{|E_{grav}|},$$

$$\Omega(r) = \Omega_0 \left[1 + \left(\frac{r}{A}\right)^2\right]^{-1}$$

Peak Amplitude of GW at 10kpc and Sensitivities of LIGO

← Beta Large

↑ A Large



GW reflects the Dynamics of central engine of collapse-driven supernova. LIGO (and TAMA,LCGT) will detect the GW signals.

Evolution of the Models by Heger et al. (2000) without Magnetic field.

Peak Amplitude of GW at 10kpc and Sensitivities of LIGO

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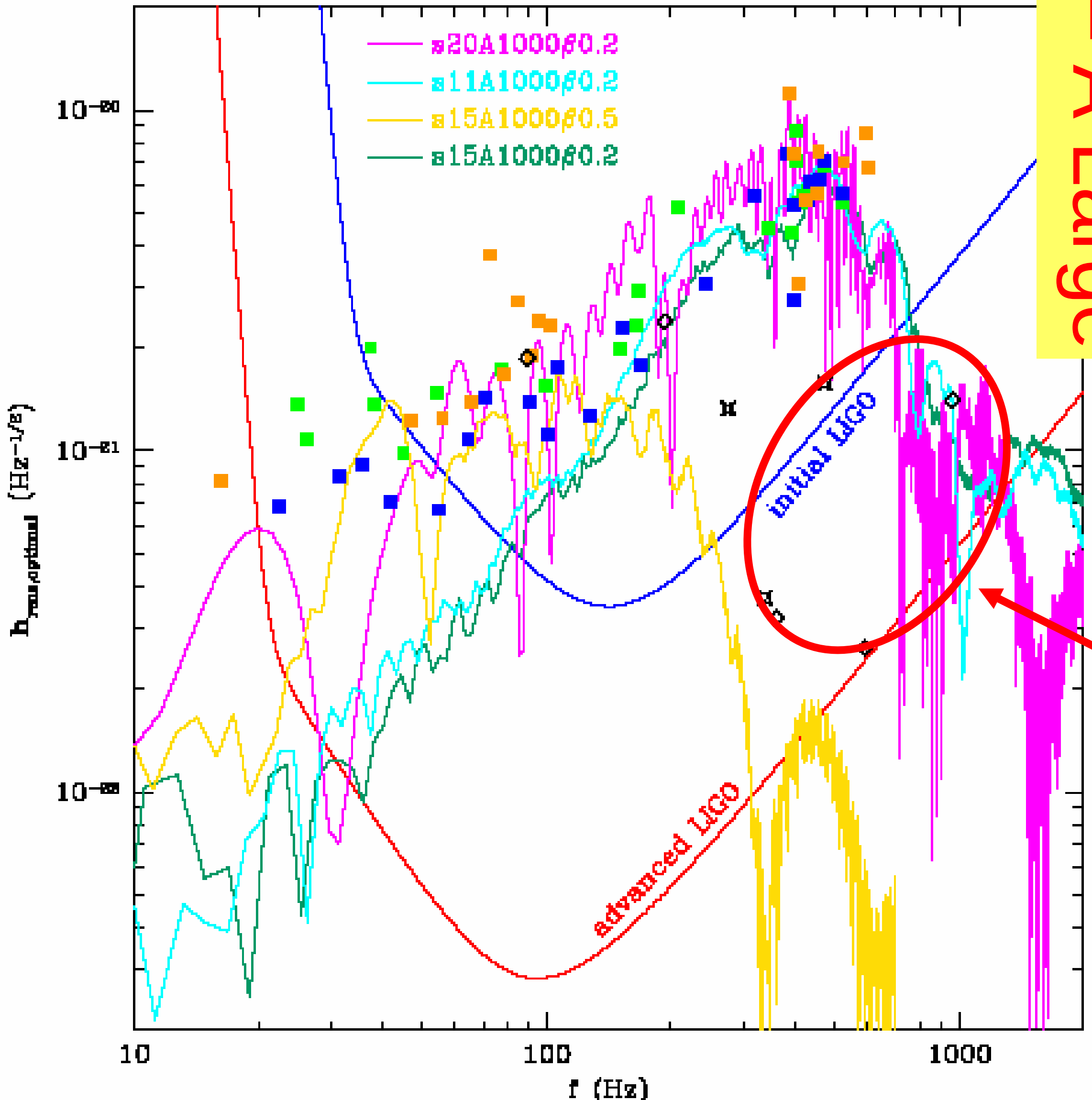

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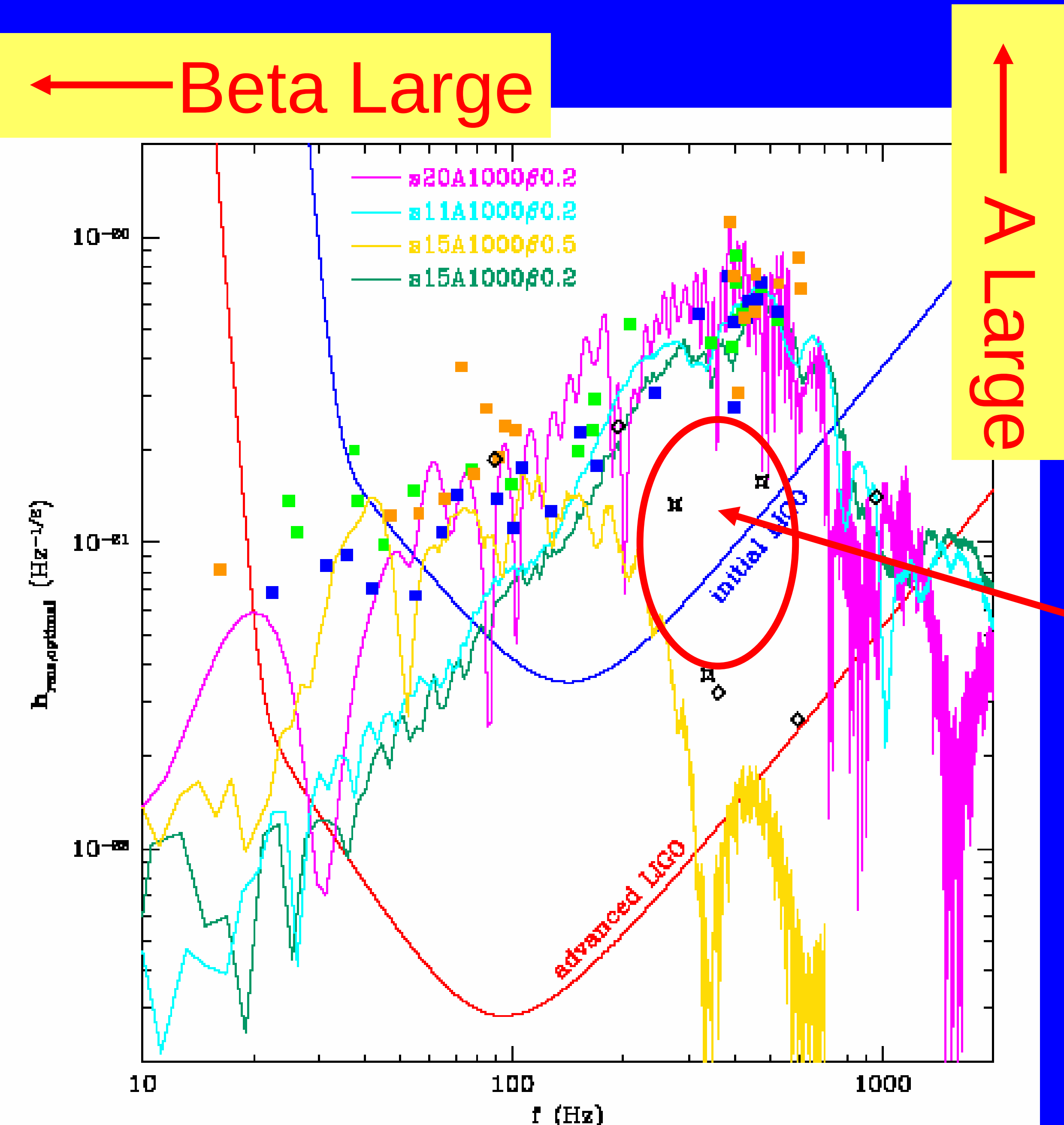
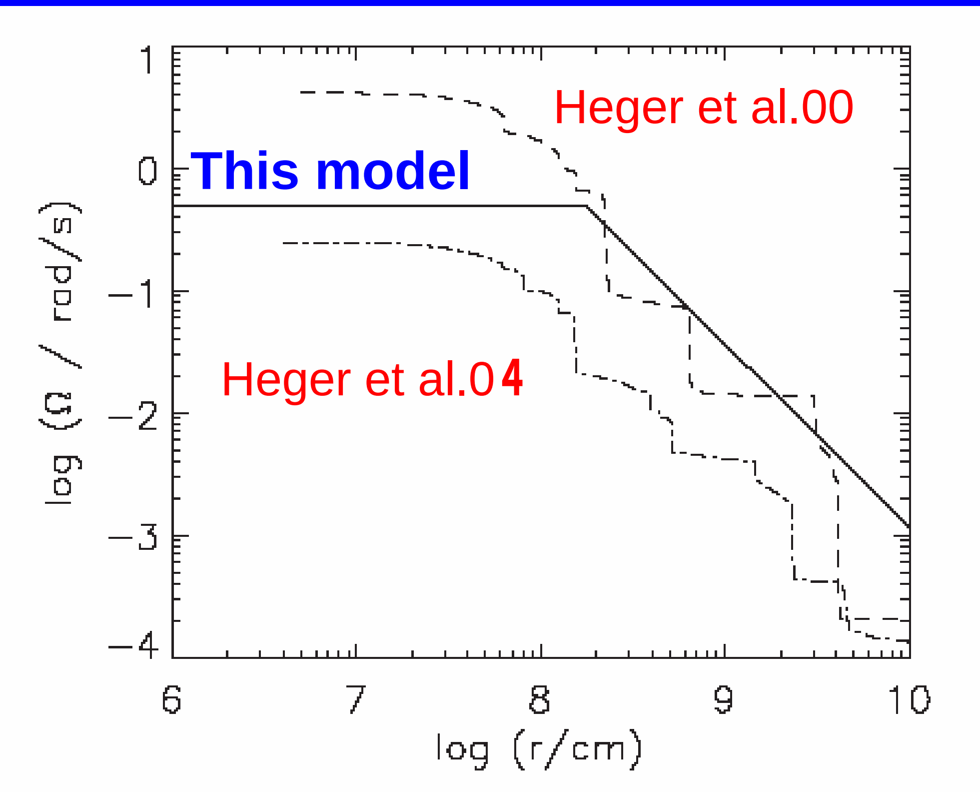


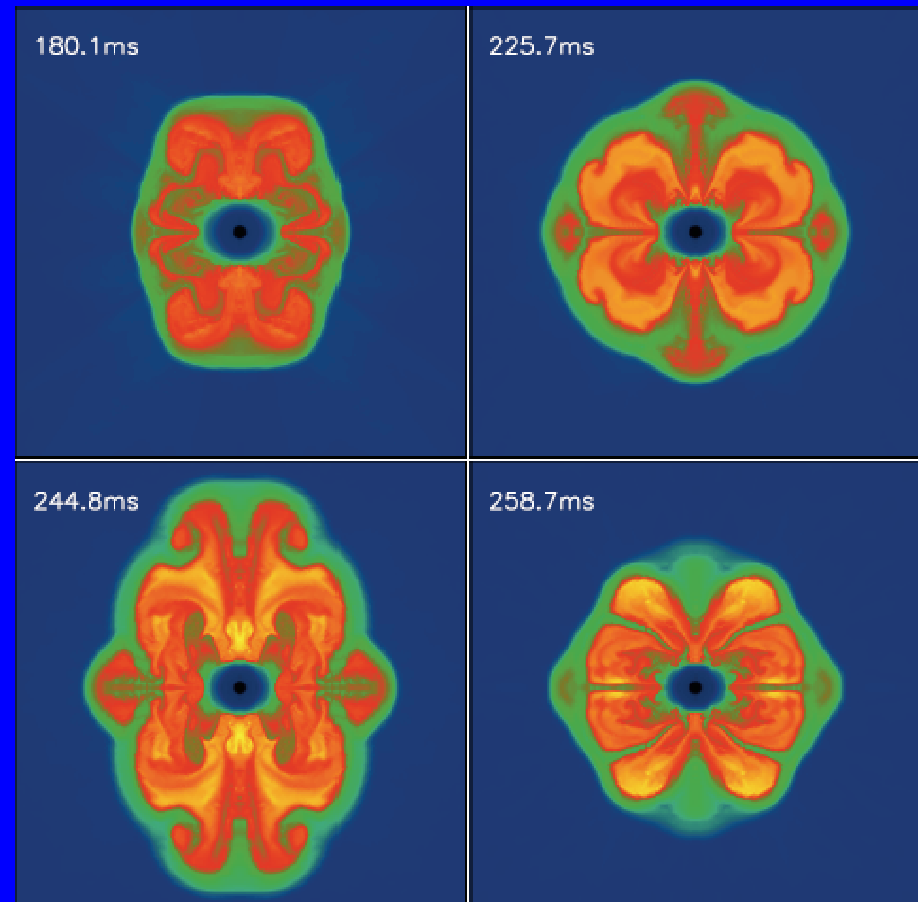
GW reflects the Dynamics of central engine of collapse-driven supernova. LIGO (and TAMA,LCGT) will detect the GW signals.

Non-rotating models. GW is emmitted due to small perturbation Introduced by the numerical scheme and mapping of the 1-D progenitor model onto 2-D computational grid.

GW signals from convective modtion after core bounce

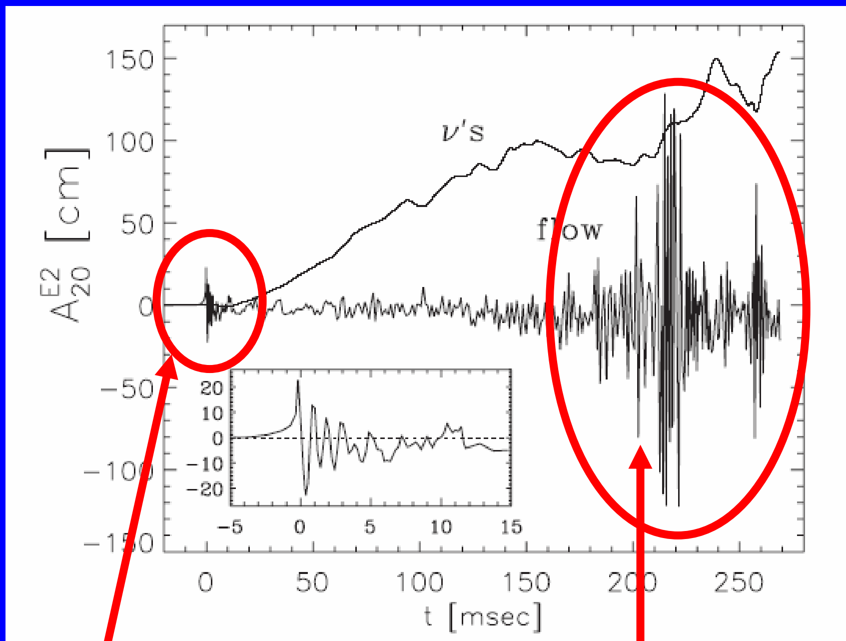
Muller et al. ApJ 603 221 (2004)



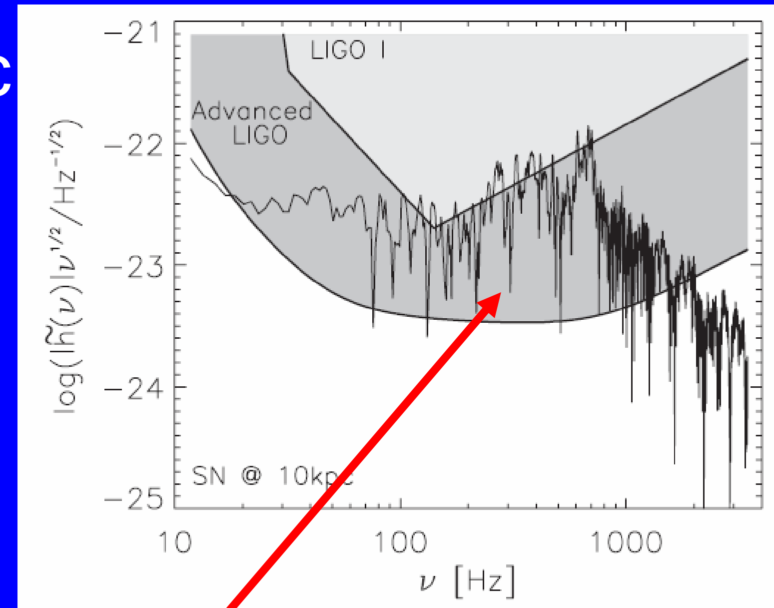


2-D axial-symmetric Hydrodynamics
EOS of Lattimer Swesty
Newtonian Gravity
Ray by ray method for neutrino transfer (Boltzman solver)
Quadrupole formulation to estimate the amplitude of GW.

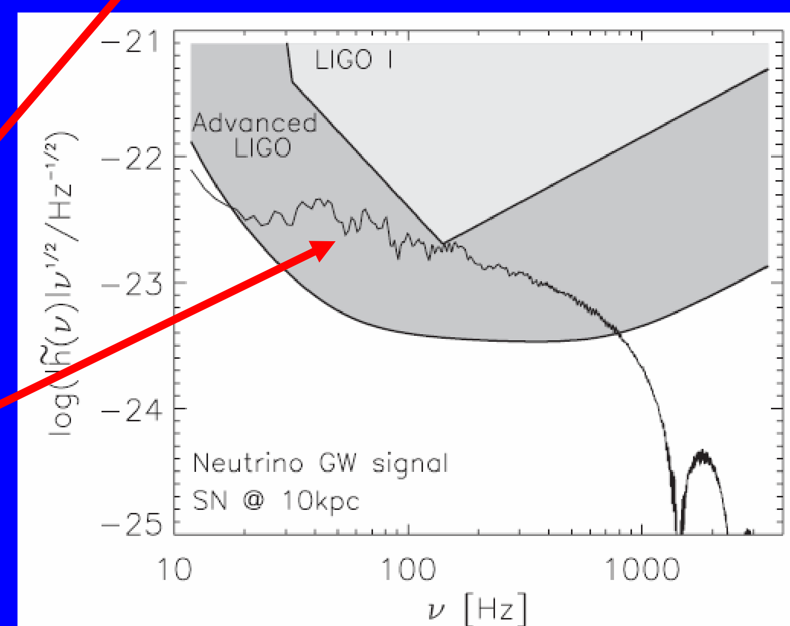
Examples of GW signals at 10kpc



$$h = \frac{1}{8}\sqrt{\frac{15}{\pi}}\sin^2\theta\,\frac{A_{20}^{E2}}{R},$$



Upper: Total
Lower: Contribution of neutrinos



Amplitude of GW
Due to convection
Flow (large)

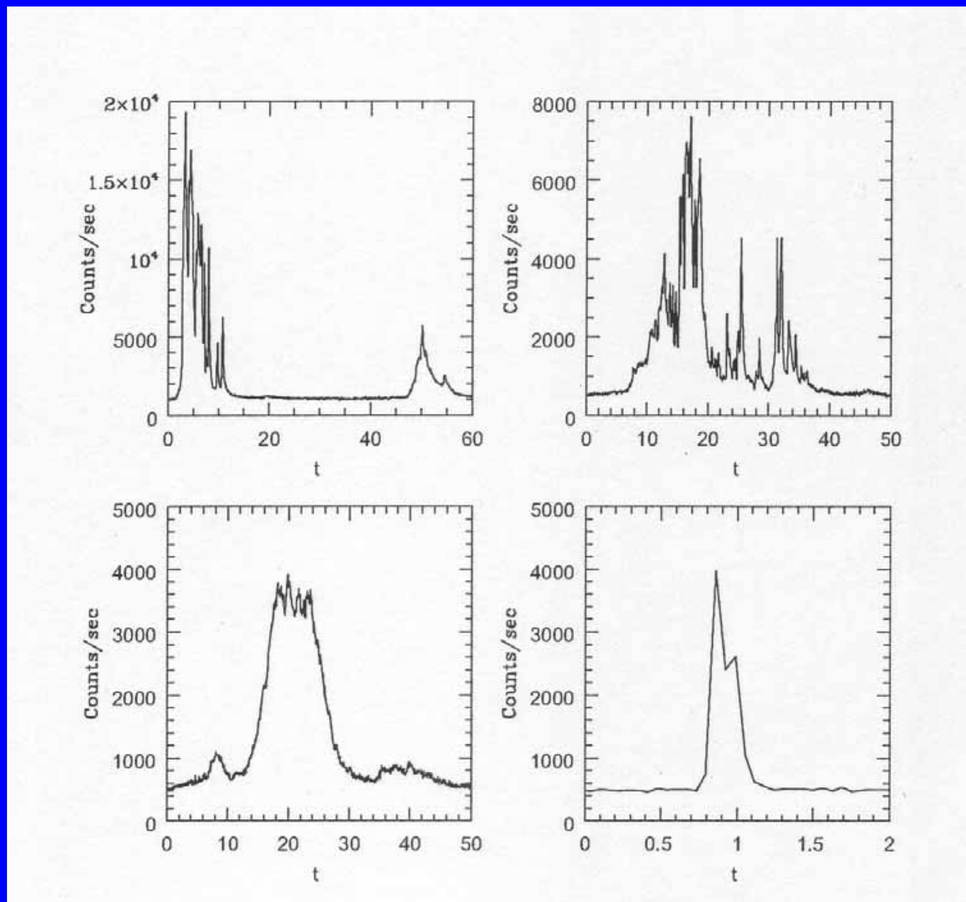
High frequency

Low frequency

Amplitude of GW
At the core bounce
(small)

Gamma-Ray Bursts

Counts/s



Time (sec)

Non-thermal
Rapid time variation (~ms)
Long bursts (>2sec)
Short bursts (<2sec)

Only gamma-rays had been Detected for 30years.

Origin had/has been unknown.

Gamma-Ray Bursts

THE ASTROPHYSICAL JOURNAL, 182:L85–L88, 1973 June 1

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1973 March 16; revised 1973 April 2

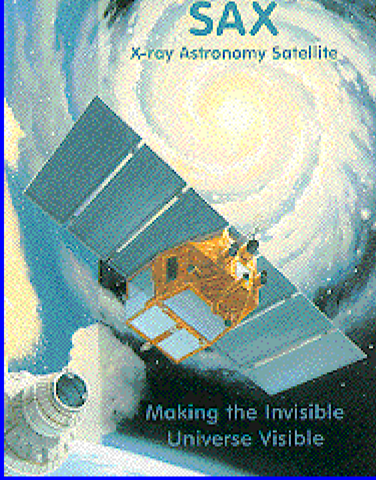
ABSTRACT

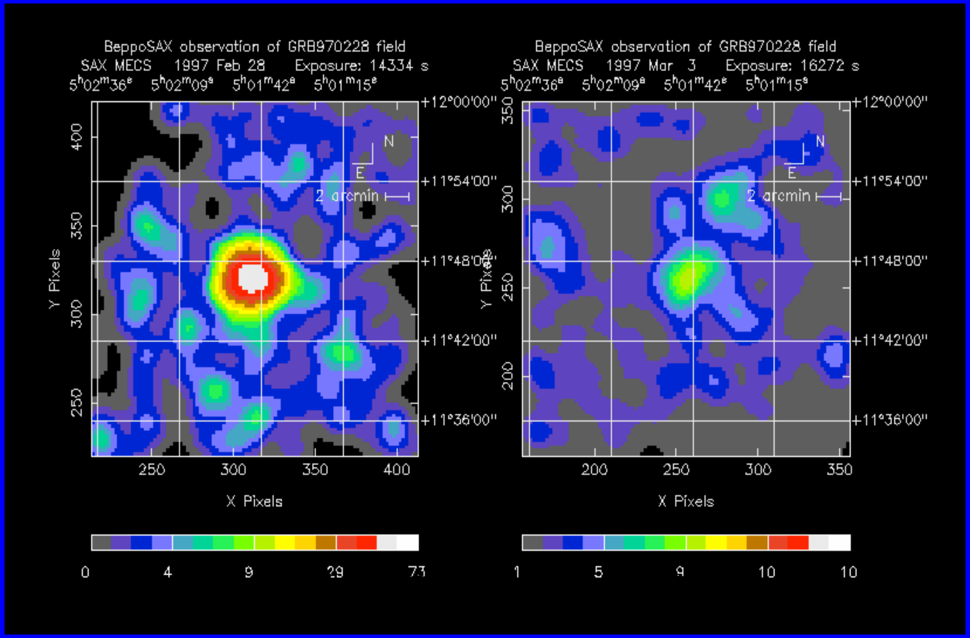
Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from $\sim 10^{-5}$ ergs cm^{-2} to $\sim 2 \times 10^{-4}$ ergs cm^{-2} in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

Subject headings: gamma rays — X-rays — variable stars

Time (sec)

Discovery of Afterglow





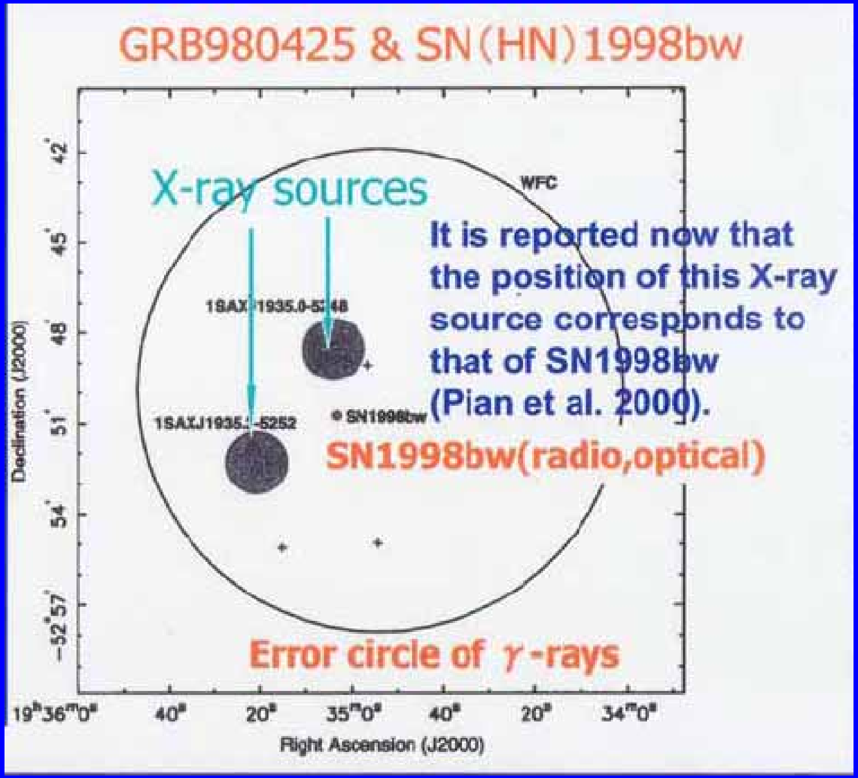
8時間後 3日後

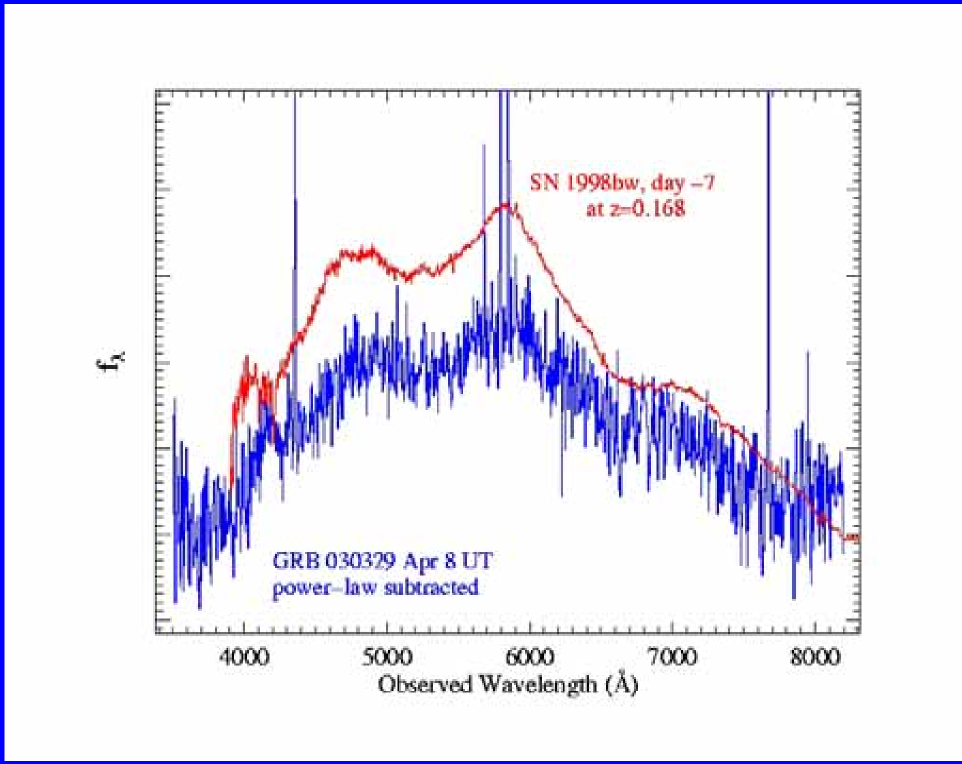
Redshifts of GRBs can be determined By Emission lines from host galaxies.

Phenomena of afterglows have been Confirmed in multi-band observations (X-rays, optical, IR,radio), which shed lights on the understanding of GRBs.

GRB970228 (z=0.695)

Origin of Long GRBs is Hypernova





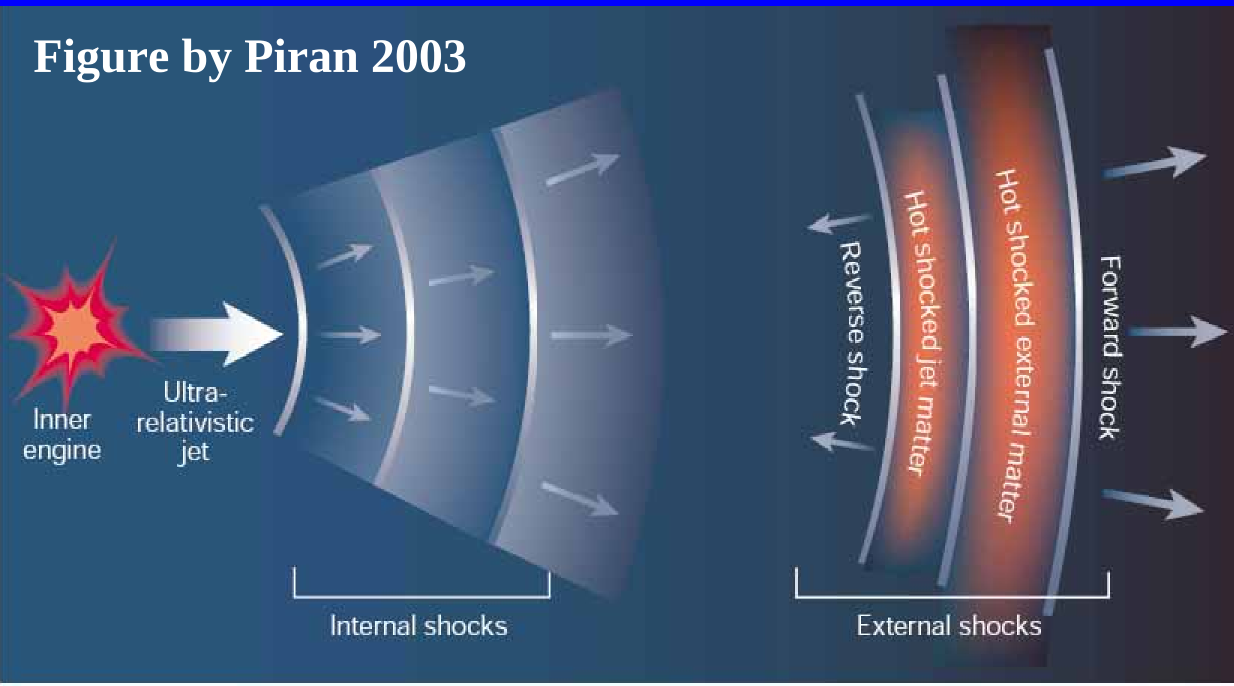
GRB980425/SN1998bw

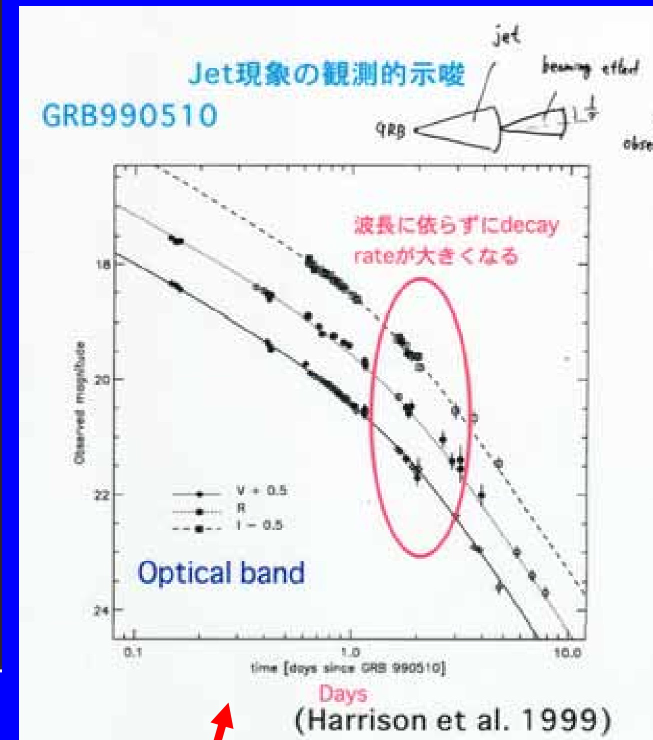
GRB030329/SN2003dh

HETE II

Explosion energy is estimated to be ～1E+52ergs, Which cannot be explained by the standard scenario Of collapse-driven supernova.

Fireball model and Jets





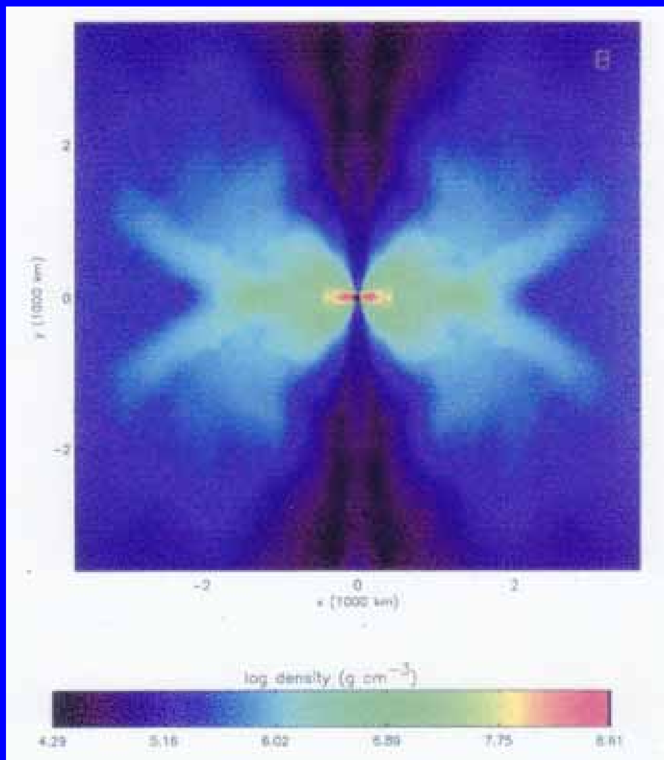
To explain the features of GRBs, relativistic flow with Lorentz factor > 100 is required. This corresponds to explosion energy of 1E+51 ergs with 1E-6 solar mass.

To realize such an environment, a jet from a hypernova is Required, which is confirmed by observations of afterglow.

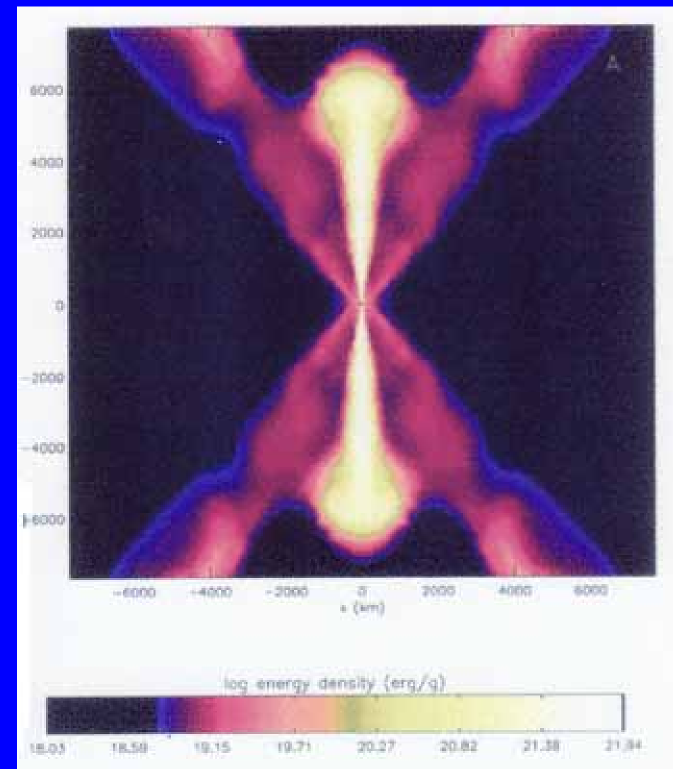
Toward understanding of central engine of GRBs

MacFadyen and Woosley (1998)

Jet off

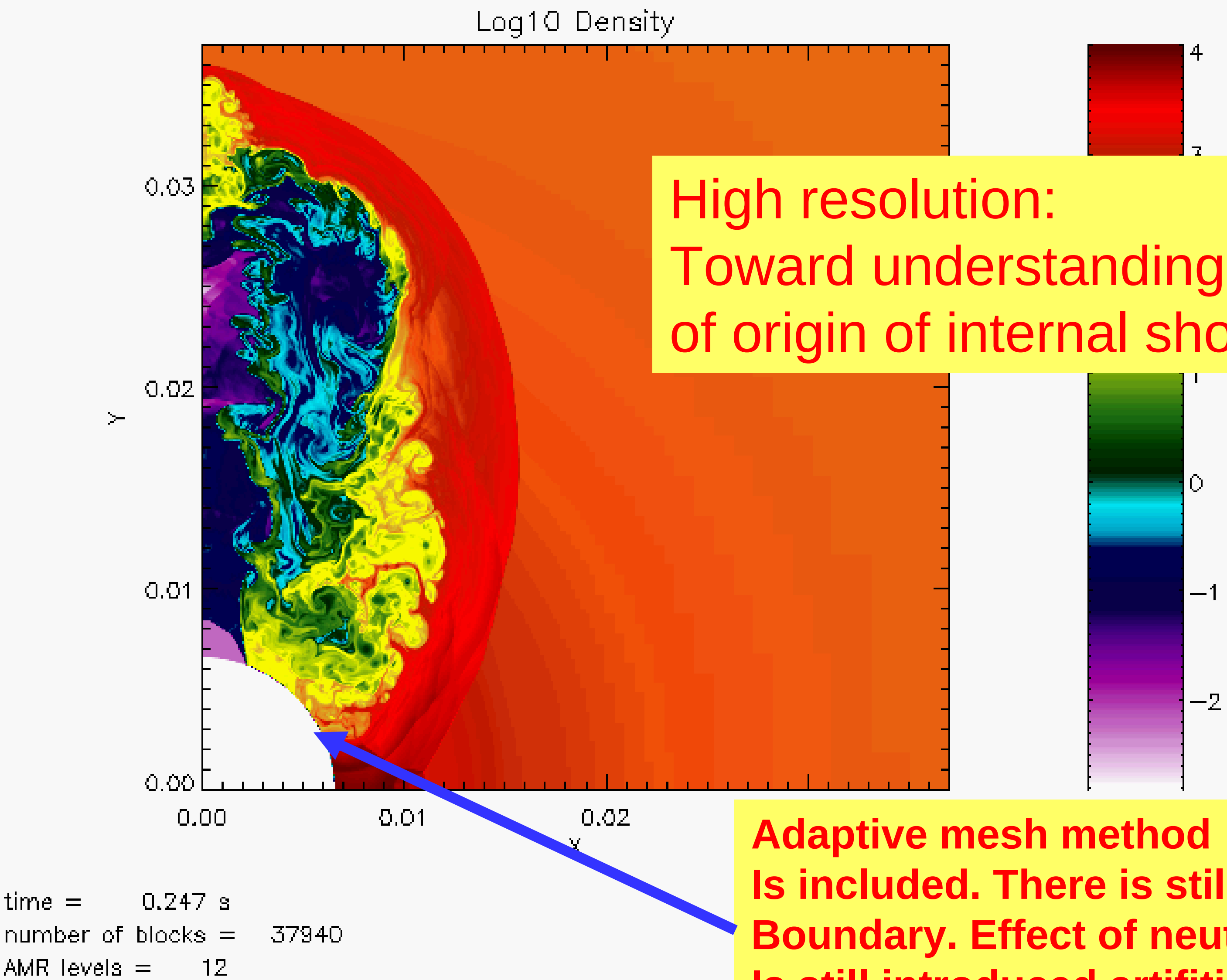


Jet on



BH with 3solar mass is put at the center as an initial condition.
Rotation is introduced so that the model mimics Heger et al. (00).
Thermal energy is deposited at the inner most region, which might be realized when effect of neutrino annihilation is included.
Newtonian gravity.

Latest Calculation by MacFadyen and Zhang (2005)

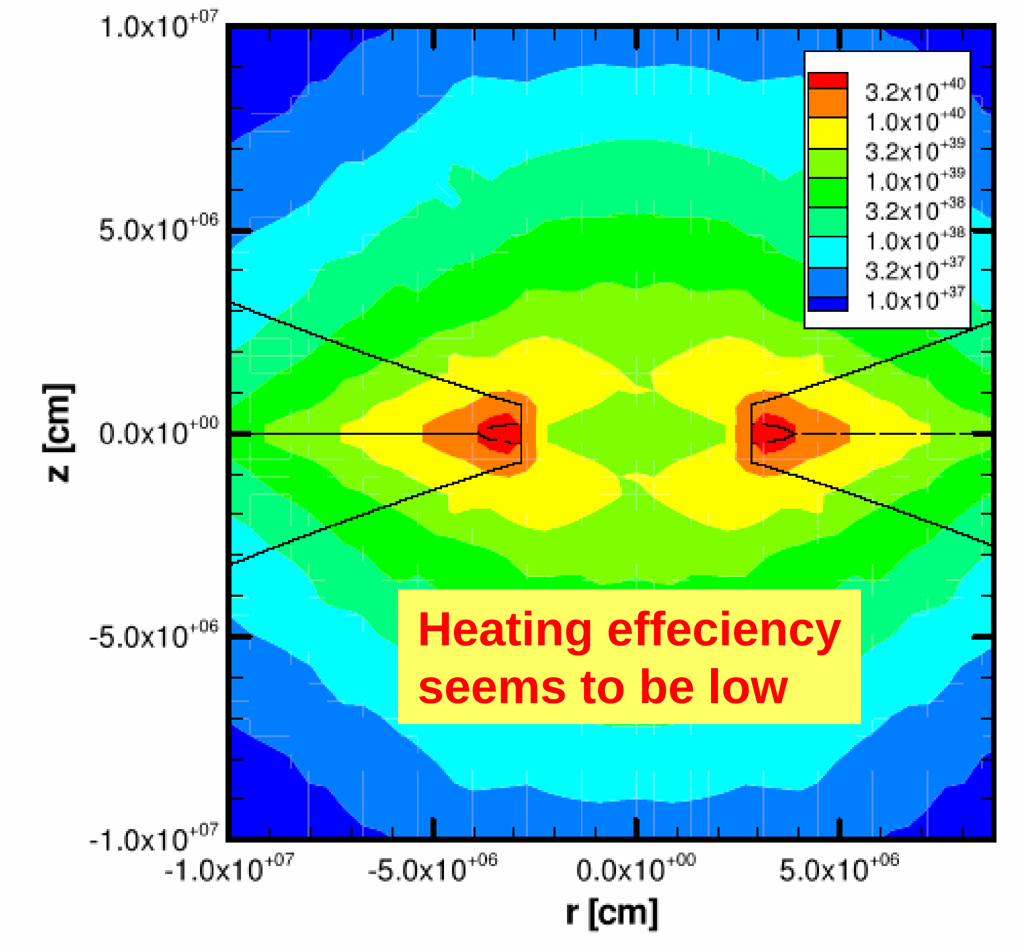


High resolution:
Toward understanding
of origin of internal shocks

Adaptive mesh method
Is included. There is still an inner
Boundary. Effect of neutrino heating
Is still introduced artifitially.

Evaluation of the Effect of Neutrino Heating

Kneller et al. astro-ph/0410397 see also Yokosawa et al. astro-ph/0412558



Analytical models (DiMatteo et al.02 and Popham et al. 99) are used to estimate the heating rate.

Emmisivity of neutrinos depends on (rho,Temp), which in turn strongly depend on Mbh, viscosity, kerr parameter, and mass accretion rate.

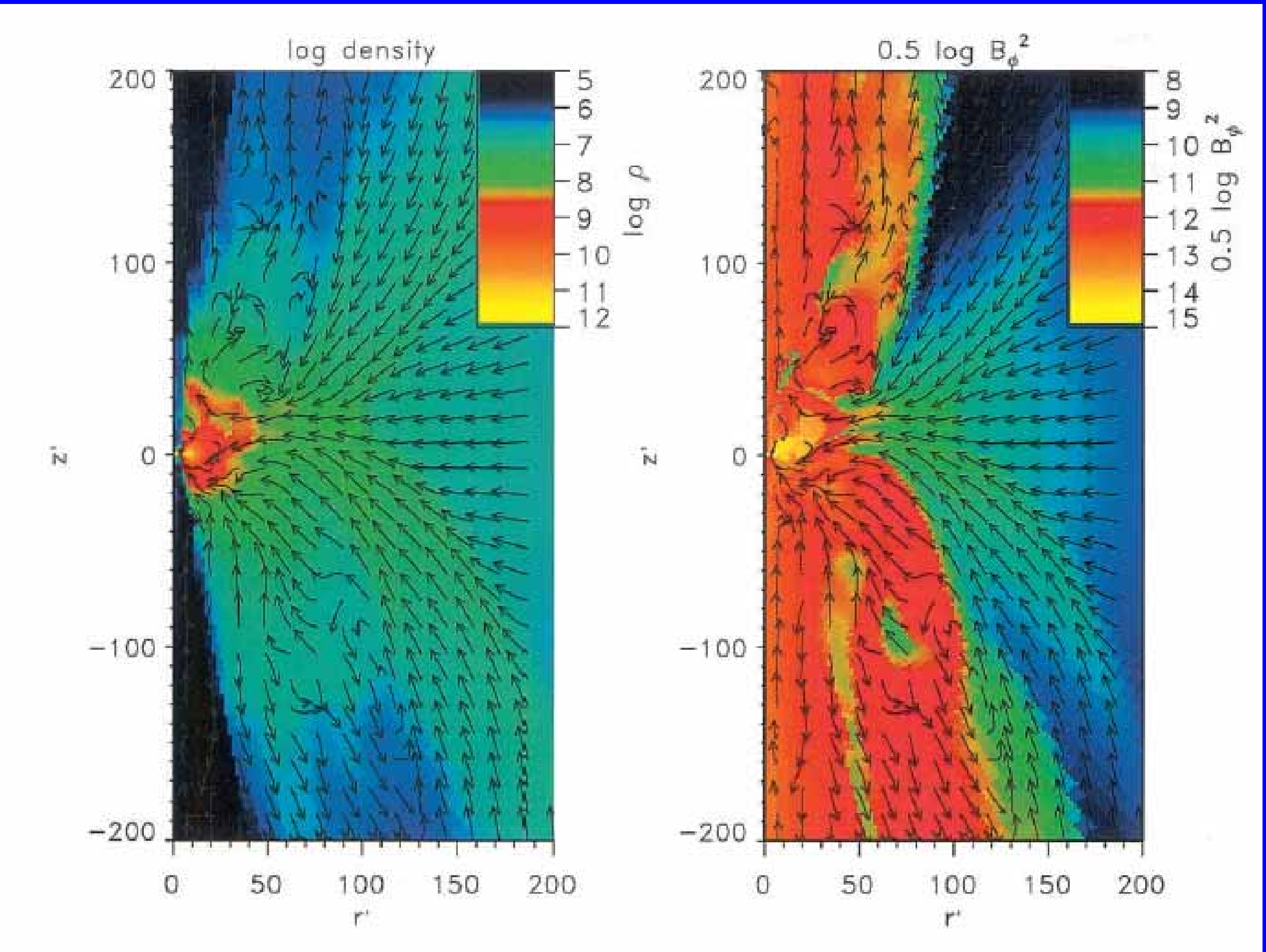
When Mdot > 0.1 msolar/s, accretion Disk becomes to be optically thick Against neutrinos.

Lnunubar ~ 1E+48erg/s (Mdot =0.1)
1E+50ergs/s (Mdot=1)
1E+51ergs/s (Mdot=10)

Heating rate is shown
In units of eV/cm^3/s.
Mdot = 1Msolar/s, Mbh=3Msolar, a=0, alpha=0.1

MHD Calculation of a Collapsar

Proga et al. ApJ 599 L5 (2003)



Initial magnetic field is Radial and weak (beta>>1 everywhere).

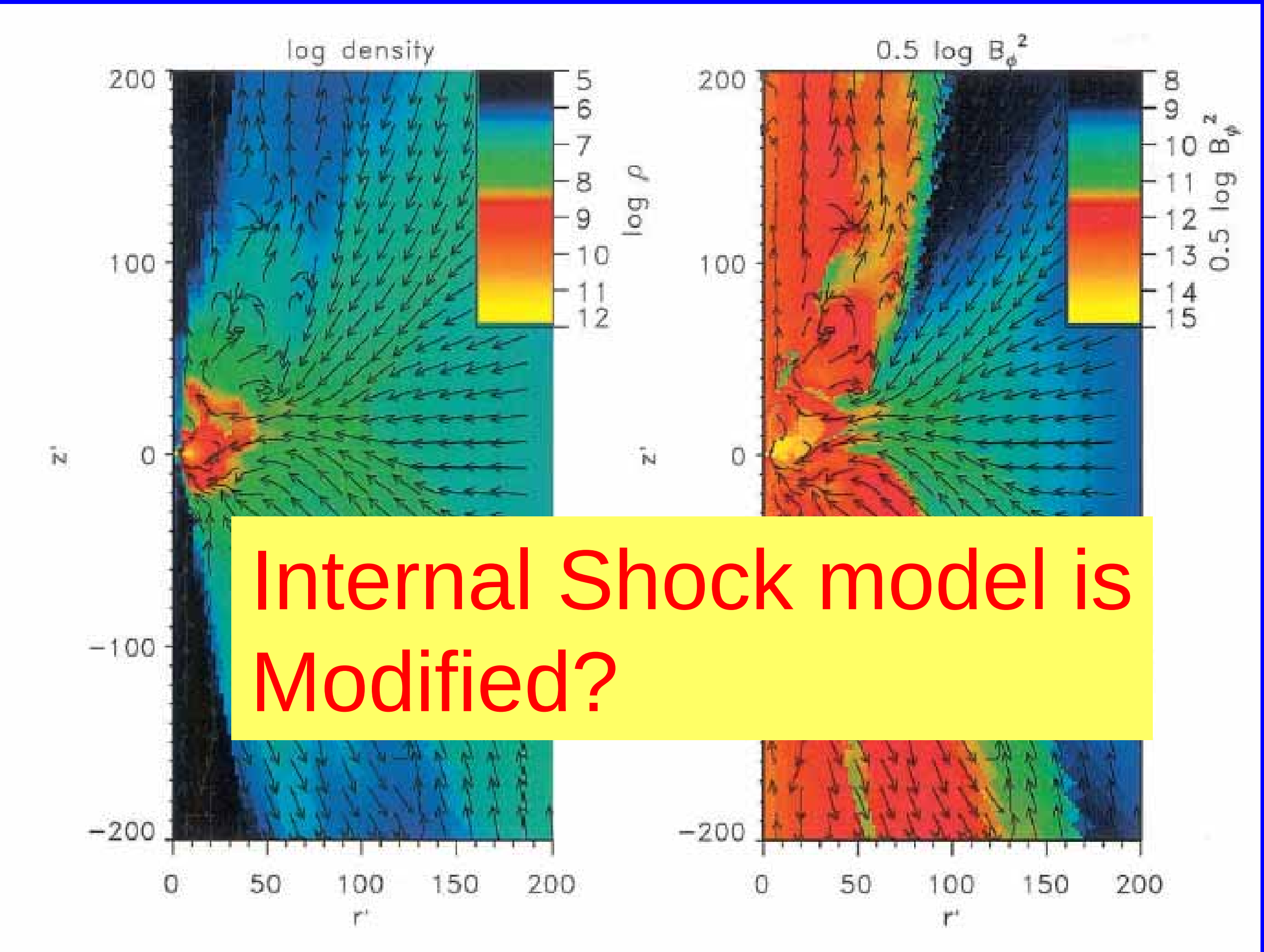
Magnetic field is amplified By MRI and shear.

At t=0.2735s,
Outflow can be seen, which is Poynting flux Dominated.
Poynting flux/Kinetic flux> 10.

2-D, 3Mbh, MHD, realistic EOS, Neutrino cooling, photo-disintegration,
Angular momentum which mimics Heger et al. (00) .
Reconnection is realized by Anomalous resitivity.

MHD Calculation of a Collapsar

Proga et al. ApJ 599 L5 (2003)



Internal Shock model is Modified?

Initial magnetic field is Radial and weak (beta>>1 everywhere).

Magnetic field is amplified By MRI and shear.

At t=0.2735s,
Outflow can be seen, which is Poynting flux Dominated.
Poynting flux/Kinetic flux> 10.

But, newtonian.
GW and neutrinos should give us valuable information on the dynamics of collapsar.

2-D, 3Mbh, MHD, realistic EOS, Neutrino cooling, photo-disintegration,
Angular momentum which mimics Heger et al. (00) .
Reconnection is realized by Anomalous resitivity.

Explosion Mechanisms

Collapse-driven Supernovae:

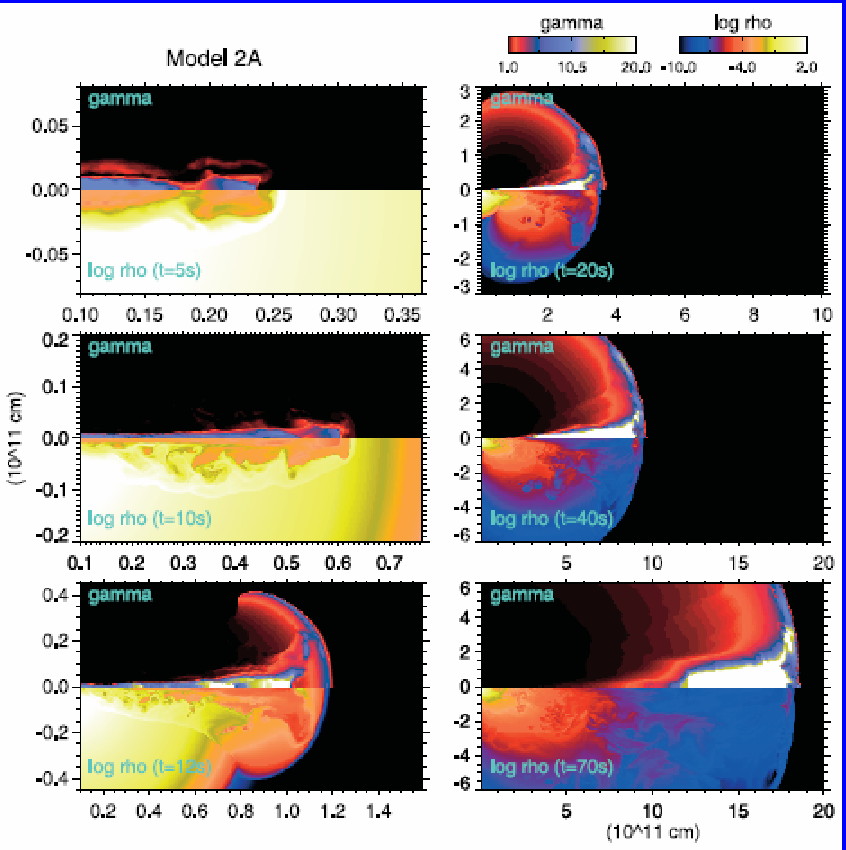
Outline of scenario has been established.

GRBs (Collapsar):

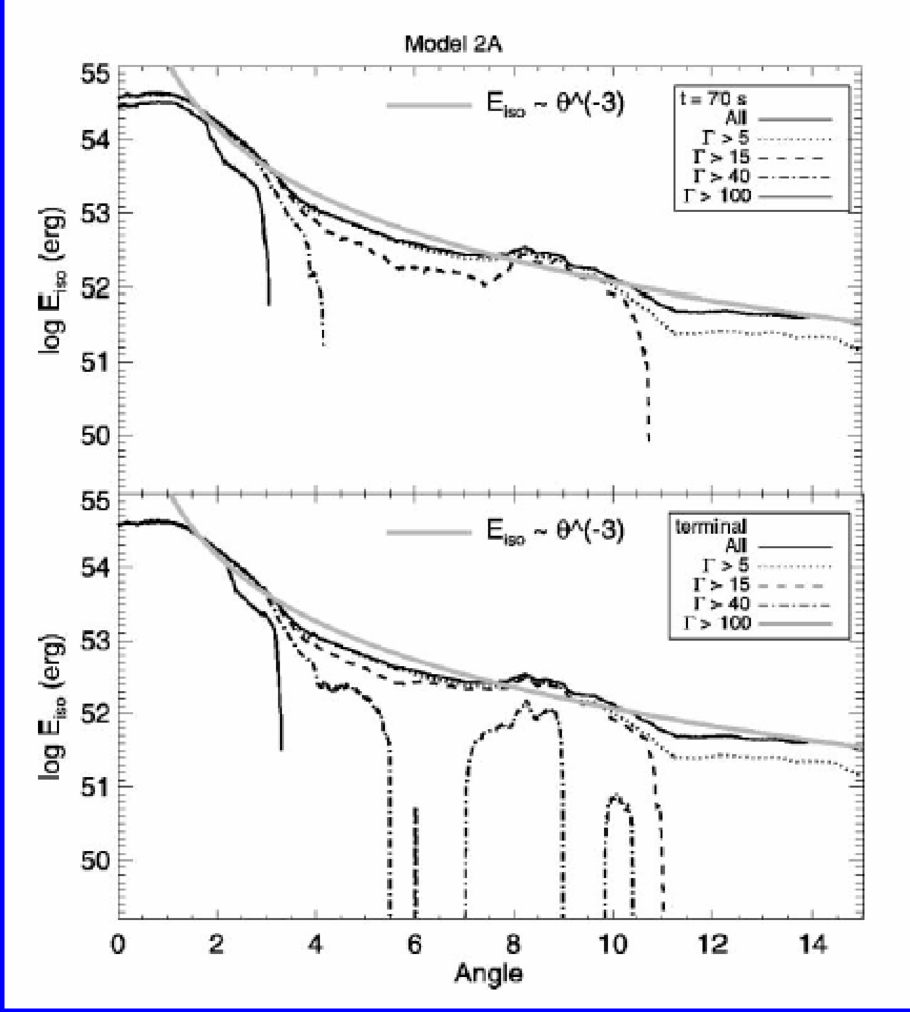
Outline of scenario is not established.

Propagation of Relativistic Jet

Zhang and Woosley ApJ, 608,365,(2004)



Eiso (erg)

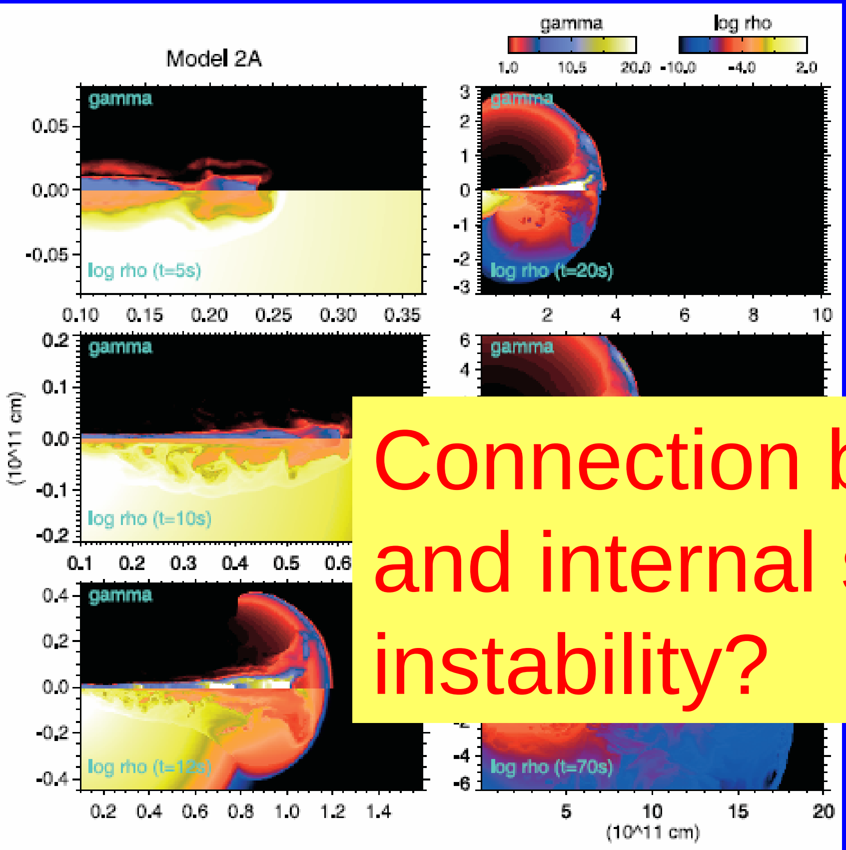


Viewing Angle (deg)

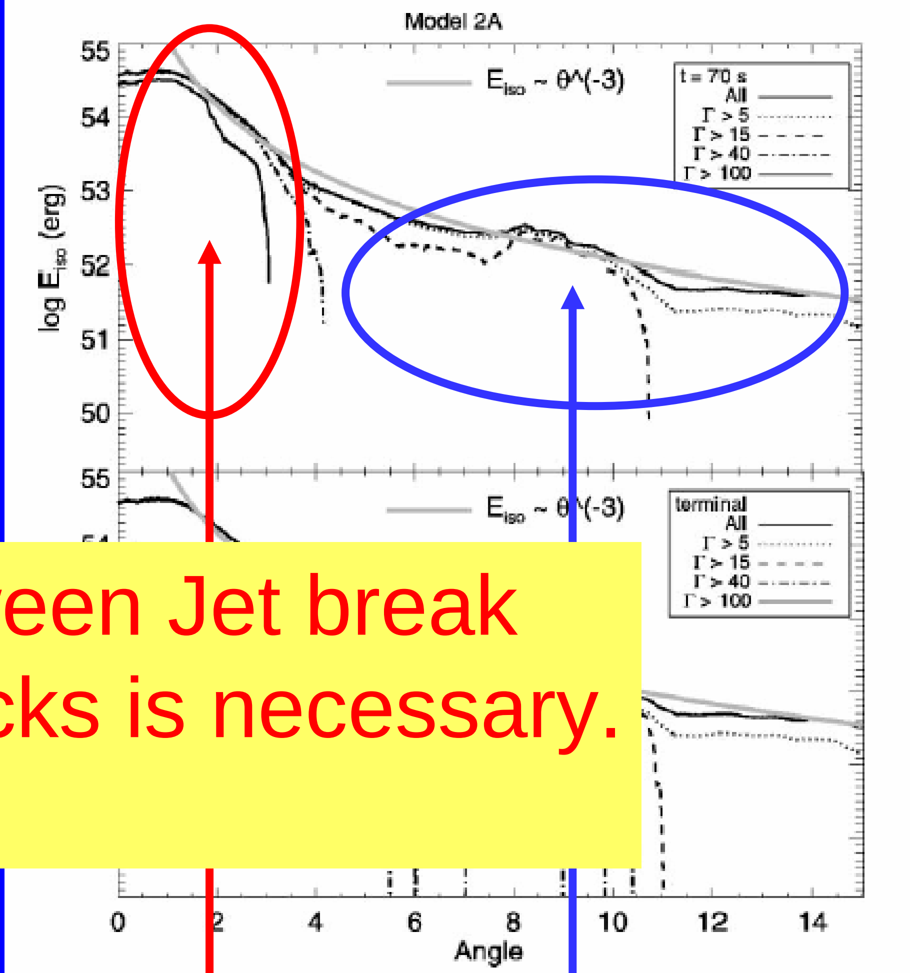
2-D, 3-D relativistic calculations
No magnetic field
15Msolar He star (Heger and Woosley 03)
Thermal energy dominated flow is injected from
Z = 10^10cm with half-opening angle, 5 degree.

Propagation of Relativistic Jet

Zhang and Woosley ApJ, 608,365,(2004)



Eiso (e



Connection between Jet break and internal shocks is necessary. instability?

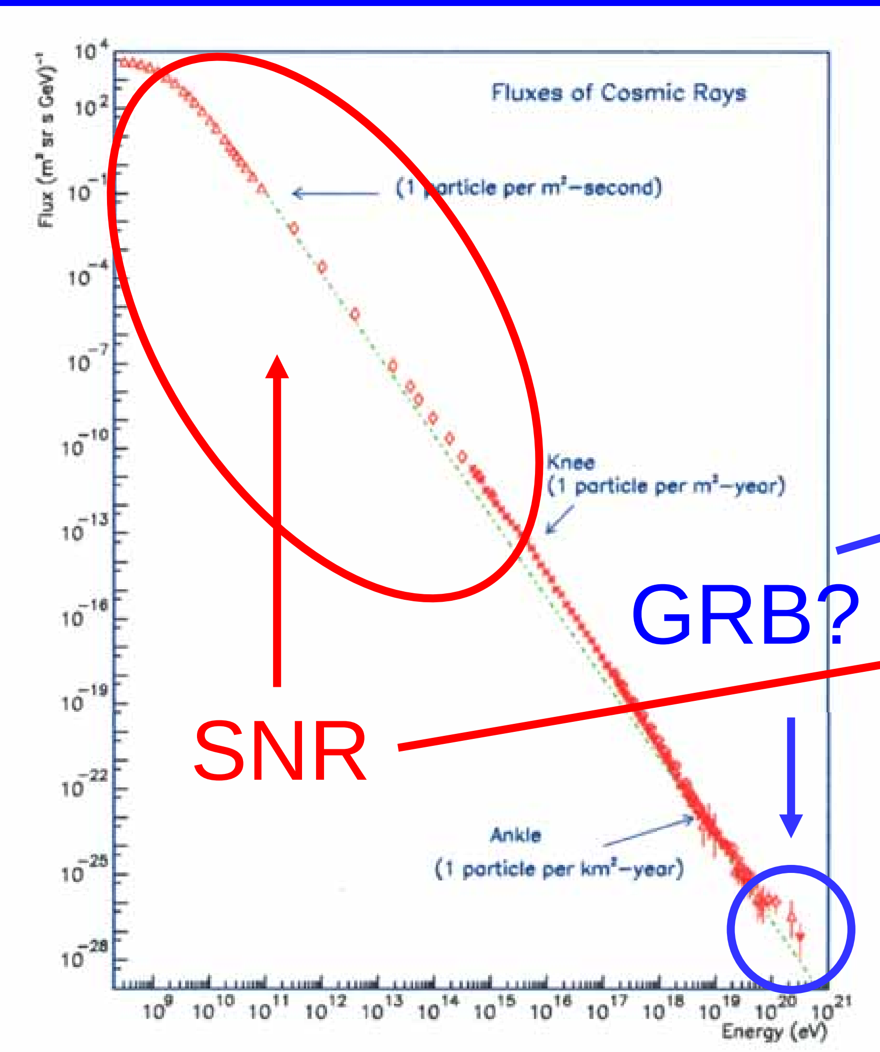
Viewing Angle (deg)

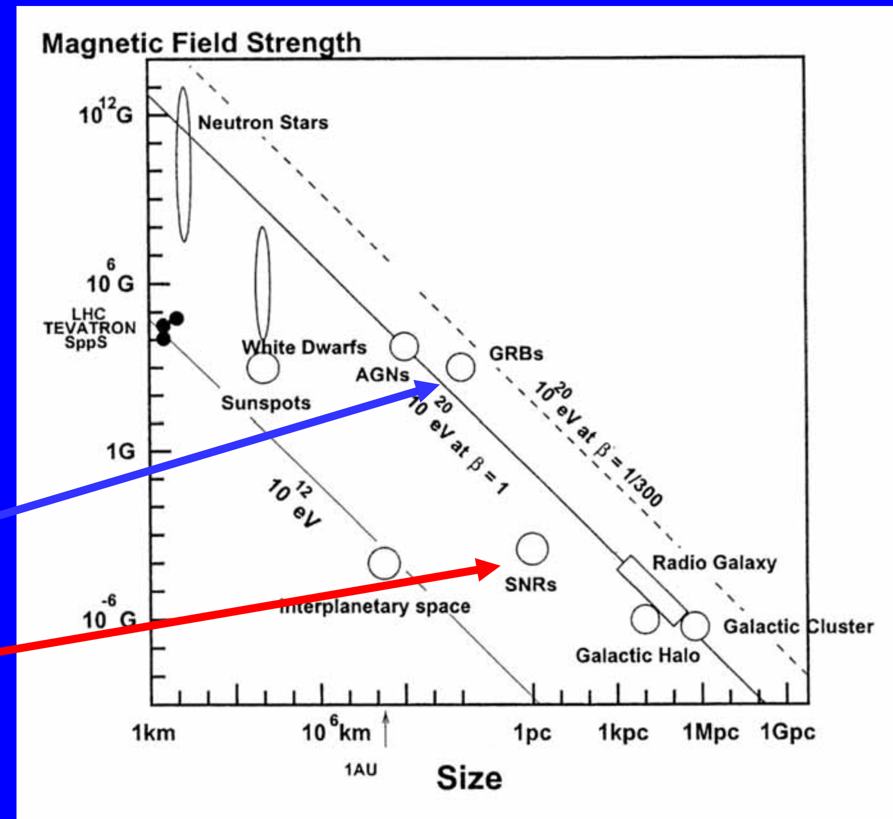
2-D, 3-D relativistic calculations
No magnetic field
15Msolar He star (Heger and Woosley 03)
Thermal energy dominated flow is injected from Z = 10^10cm with half-opening angle, 5 degree.

Highly relativistic flow Is realized along the Jet axis. This flow is surrounded By Mildly relativistic flow.

§宇宙線源としての超新星及びガンマ線バーストと将来大型観測機器

CR spectrum and CR sources

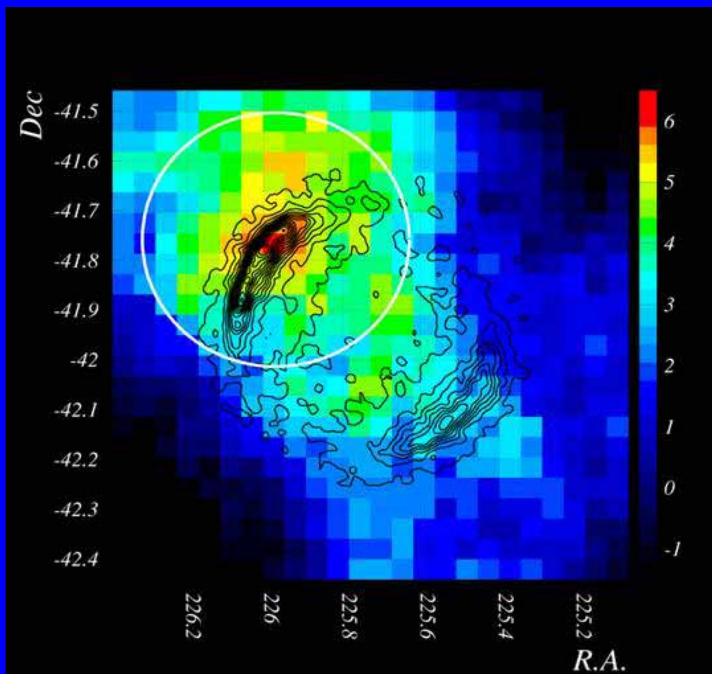




Hillas Diagram

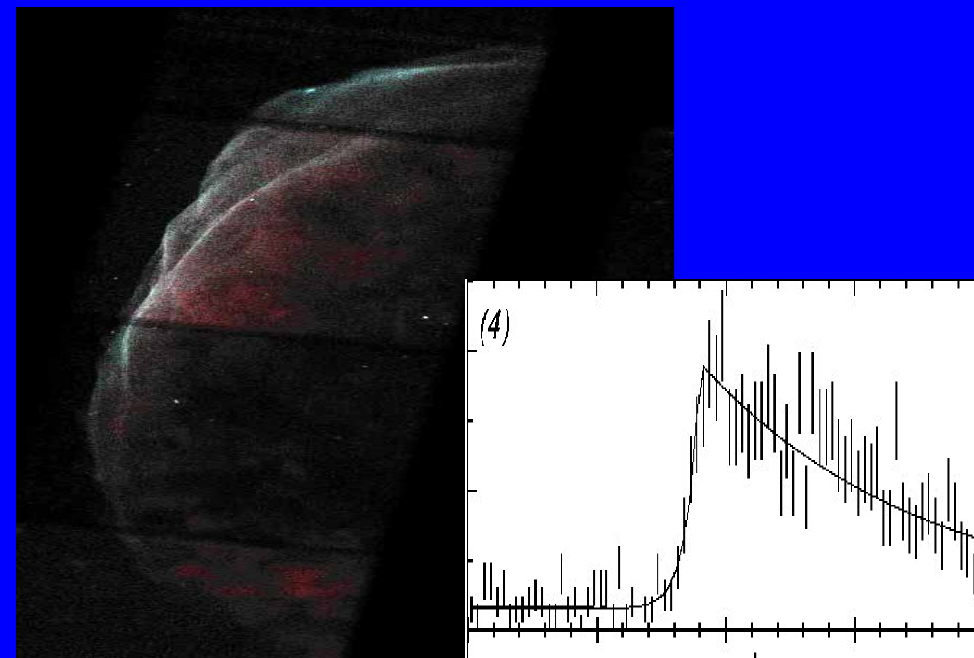
Gyroradius < System Size

X-rays and Gamma-rays from SN1006



ASCA and CANGAROO

ICRR Home Page But see also HESS's report



Chandra

0.01-0.1pc

Bamba et al. 2003

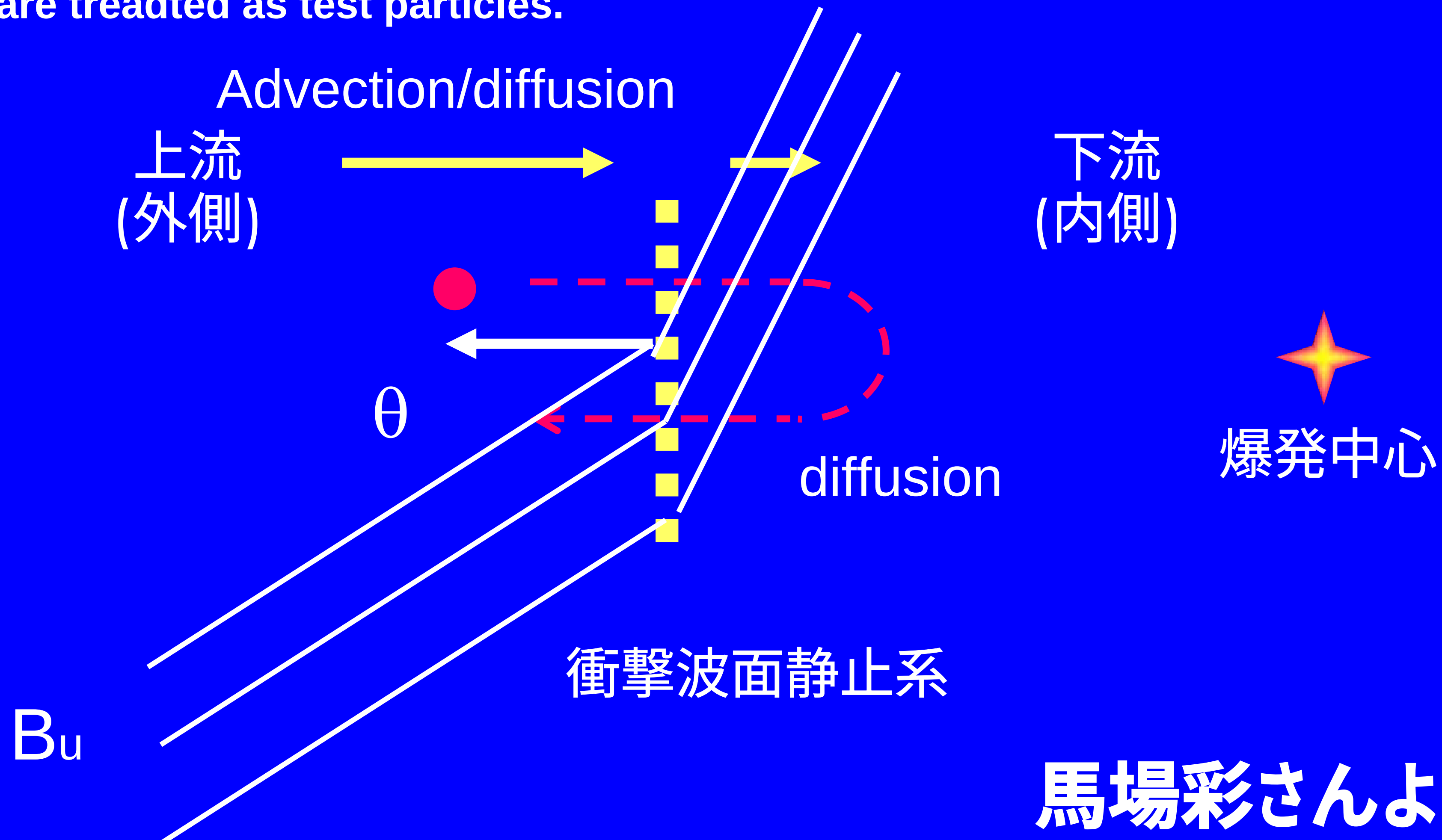
Direct evidence that CRs are generated has been obtained. Acceleration region is bi-polar. Note that this SN is a Type Ia SN. Shock acceleration theory can be compared with observations.

Which emit X/Gamma-rays, electrons or protons?

Electron : X-ray Synchrotron **Bamba et al. astro-ph/030822**

: X and Gamma-rays Synchrotron and IC Tanimori et al. ApJ 497, L25 (98)

Diffusive Shock acceleration mechanism is adopted.
CRs are treadted as test particles.



馬場彩さんより

Assumptions: Theta = 0 (parallel shock)

$t_{adv} = t_{diff}$

$$t_{adv} = w/u$$

$$t_{dif} = w^2/K$$

W is the shock scale length (observable).Ks are determined in both of up/down-streams.

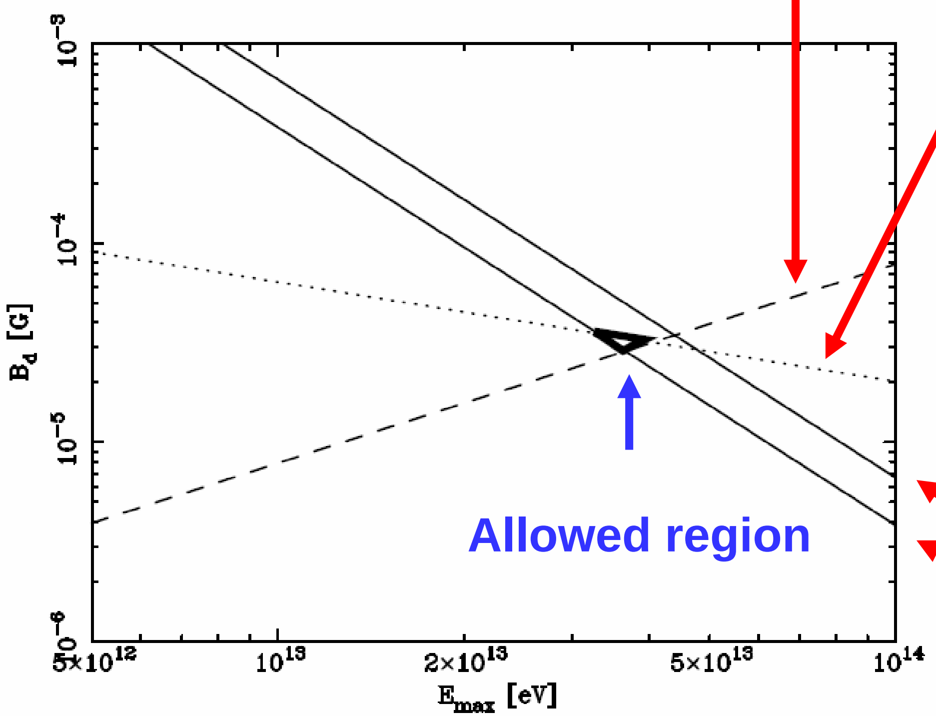
Constraint by Borm limit

$$K_d = \frac{1}{3}\xi_d \frac{E_{max}}{eB_d} c,$$

$t_{acc} < t_{loss}$

$$t_{acc} = \frac{3}{u_u - u_d}\left(\frac{K_u}{u_u} + \frac{K_d}{u_d}\right)$$

$$t_{loss} = \frac{6\pi m_e^2 c^3}{\sigma_T E B^2} = 1.25 \times 10^3 \text{ yrs} \left(\frac{E_{max}}{100\text{TeV}}\right)^{-1} \left(\frac{B}{10\mu\text{G}}\right)^{-2}$$



Direct comparison between Fermi I acceleration model and observations. Allowed region seems to be too small? Perpendicular shock?

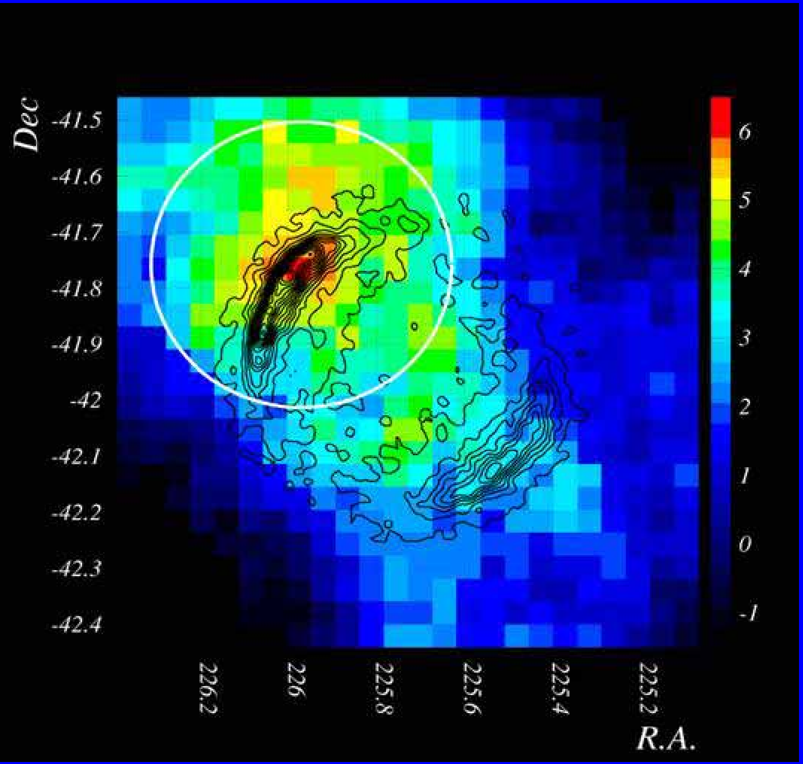
$$\nu_{rolloff} = 5 \times 10^{17} \text{ Hz} \left(\frac{B}{10\mu\text{G}}\right)\left(\frac{E_{max}}{100\text{TeV}}\right)^2$$

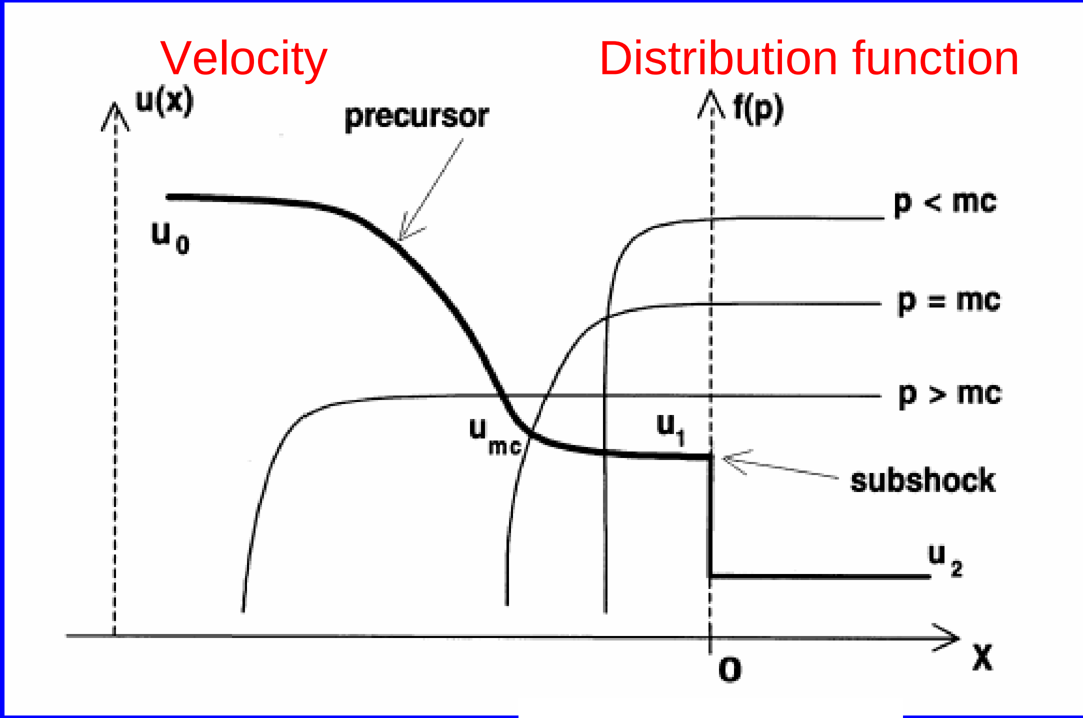
observable

Berezhko et al. 2002

X-rays: synchrotron of electron

Gamma-rays: Pion decays produced by p-p interactions





Shock wave

It is usually considered that Injection efficiency is higher in Parallel shock regions.

Nonlinear shock acceleration Is considered. Shock wave is modified by non-thrmal protons, which makes the spectrum of accelerated particles harder.

Berezhko et al. 2002

X-rays: synchrotron of electron

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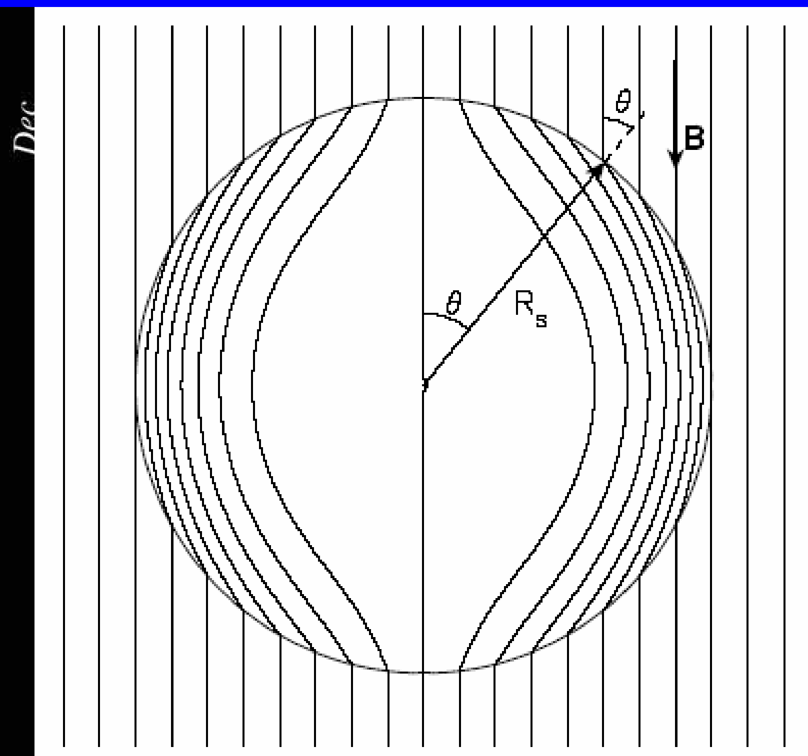

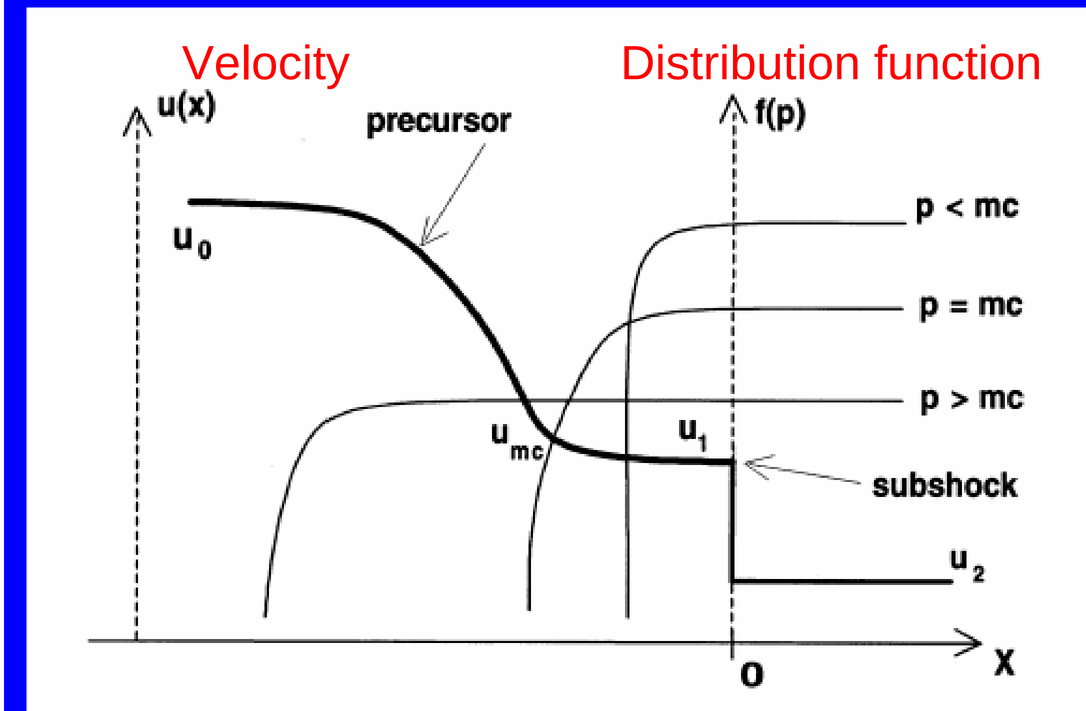

Shock wave

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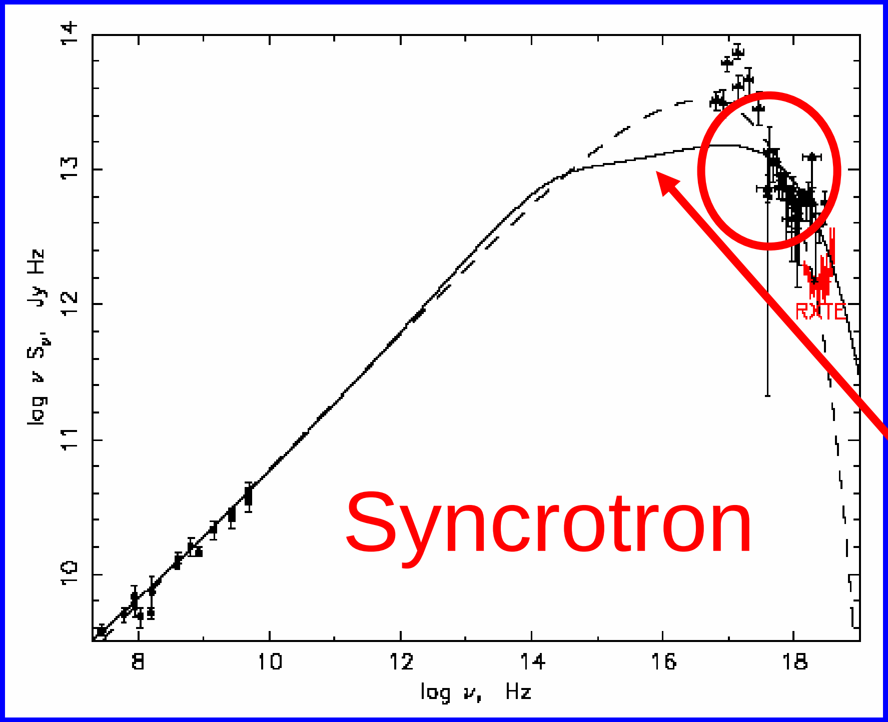
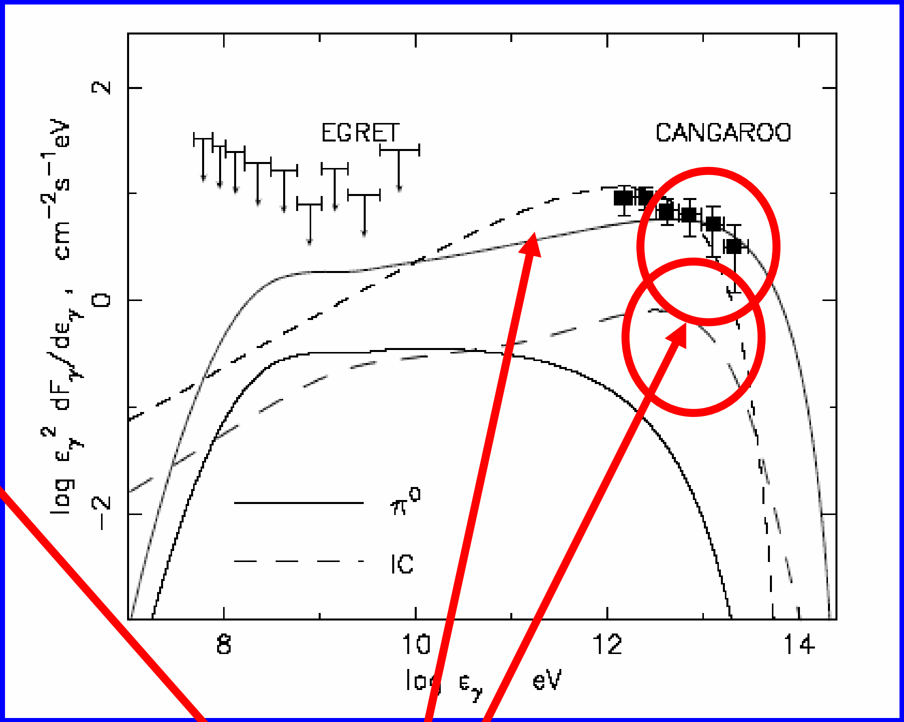
Reproduced spectrum of X-rays and Gamma-rays

Radio and X-rays



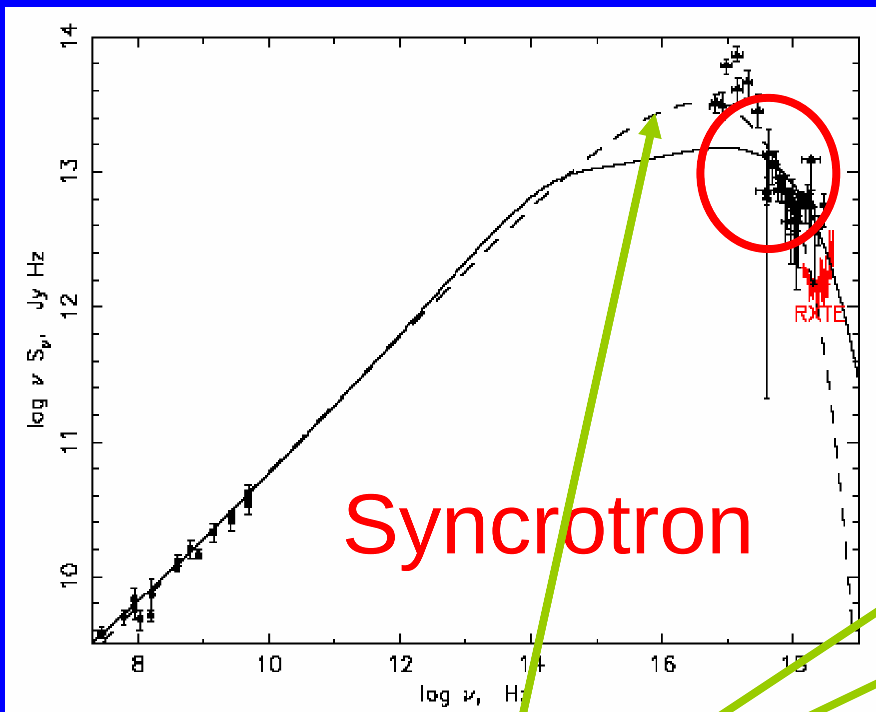
Gamma-rays



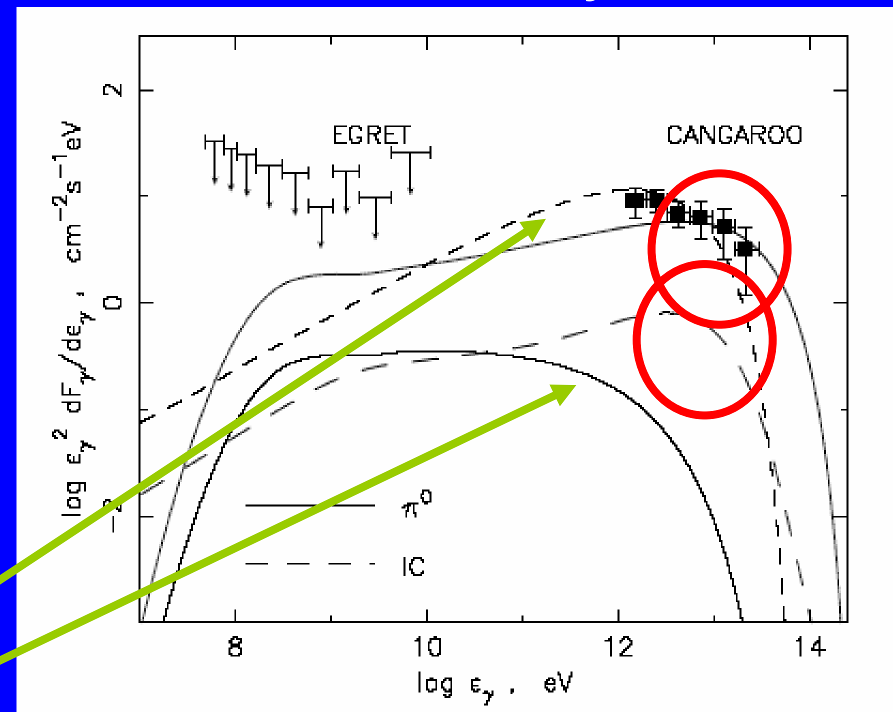
High injection rate for protons
η= 1E-4 (hard spectrum)
e/p ratio is set to be low.

Reproduced spectrum of X-rays and Gamma-rays

Radio and X-rays



Gamma-rays



Low injection rate for protons
η= 1E-5 (soft spectrum)
e/p ratio is set to be high.

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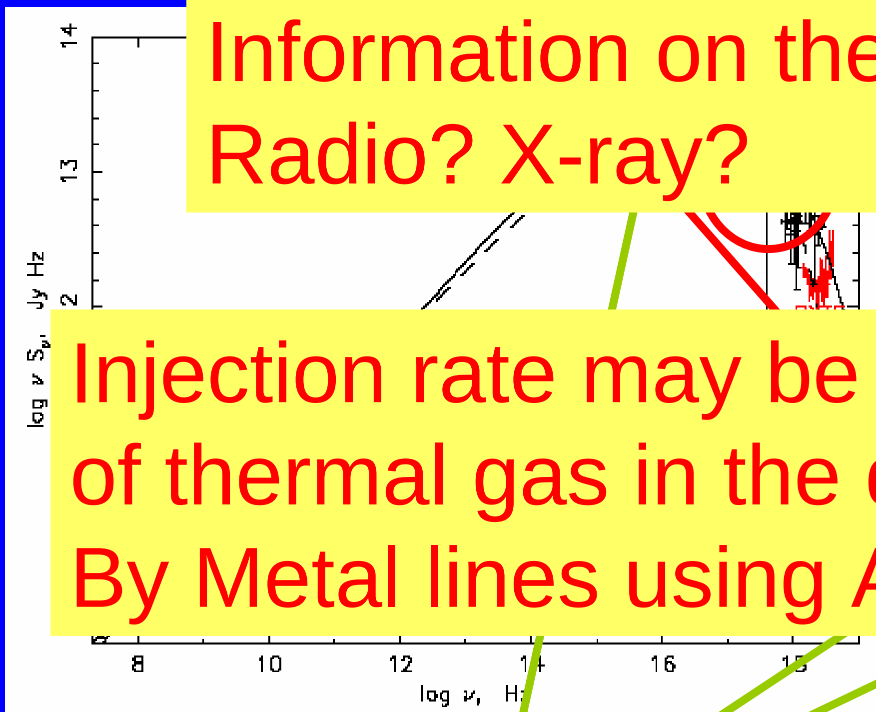
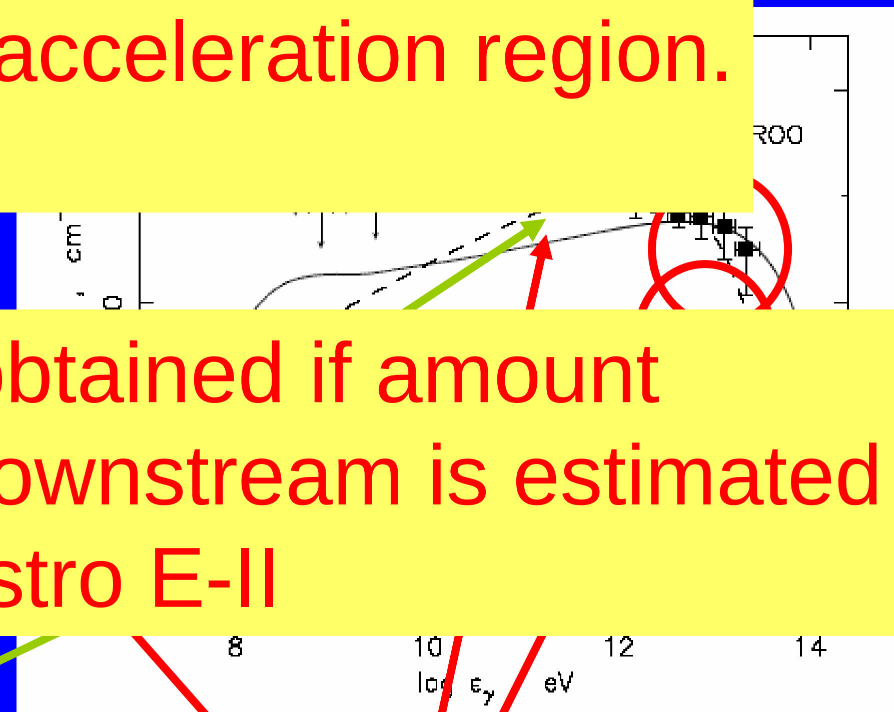
η= 1E-4 (hard spectrum)
e/p ratio is set to be low.

Reproduced spectrum of X-rays and Gamma-rays





Polarization will give us important
Information on the acceleration region.
Radio? X-ray?

Injection rate may be obtained if amount
of thermal gas in the downstream is estimated
By Metal lines using Astro E-II

Spectrum of gamma-rays is essential.

Low injection rate for protons
η= 1E-5 (soft spectrum)
e/p ratio is set to be high.

High injection rate for protons
η= 1E-4 (hard spectrum)
e/p ratio is set to be low.

Cerenkov Detectors of TeV-Gamma Rays

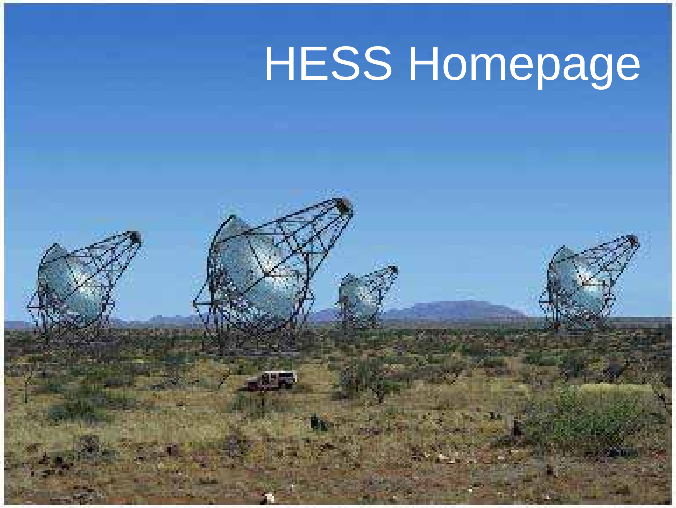
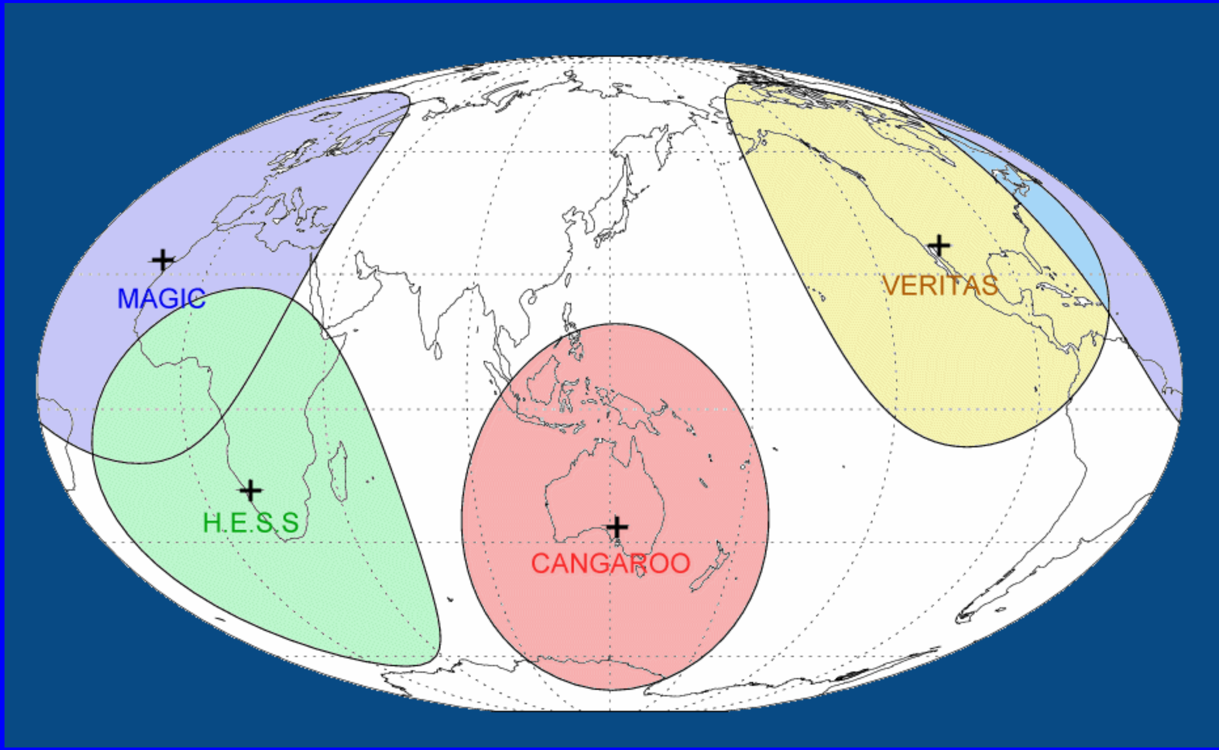
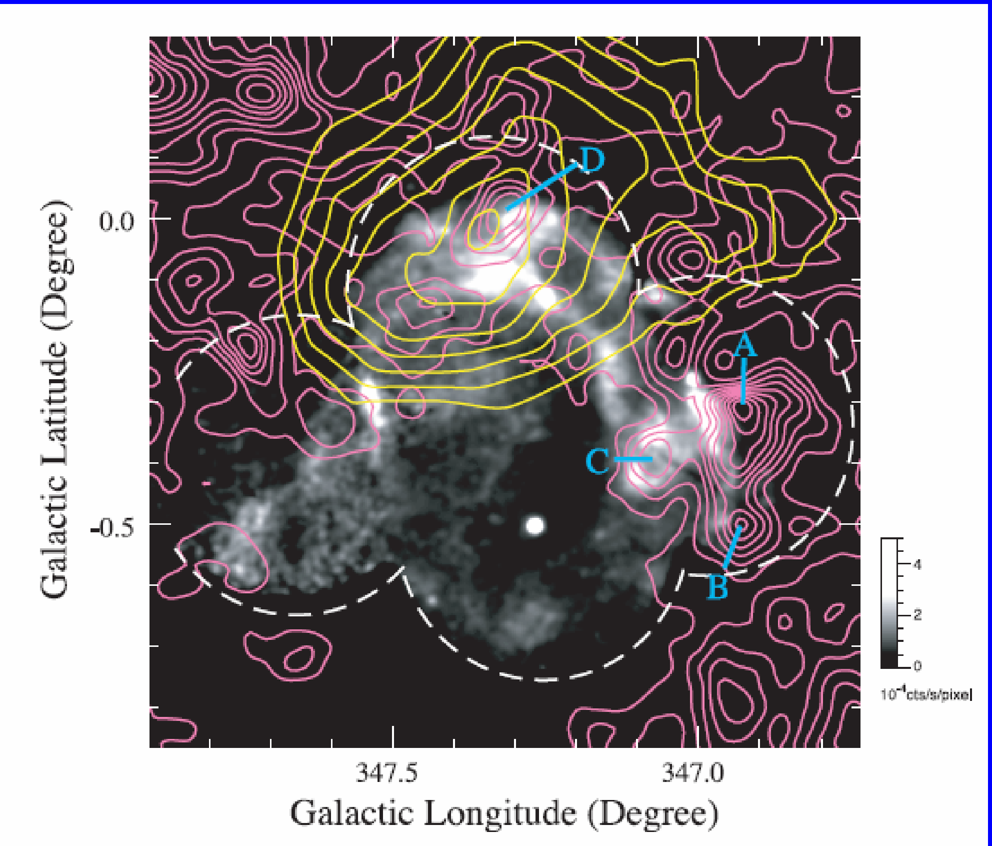


Fig 2. A photo montage showing the mechanical structure, space-frames and reflectors of the telescopes in their proper positions on the farm Gölschau.

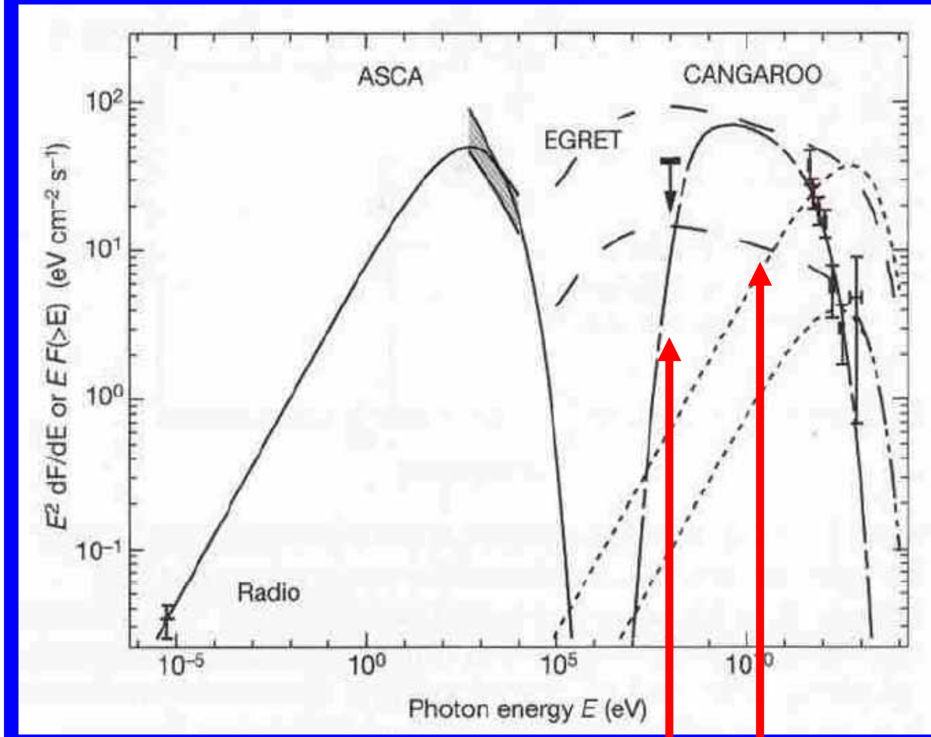


森正樹さんより

Gamma-rays from RX J1713.7-3946

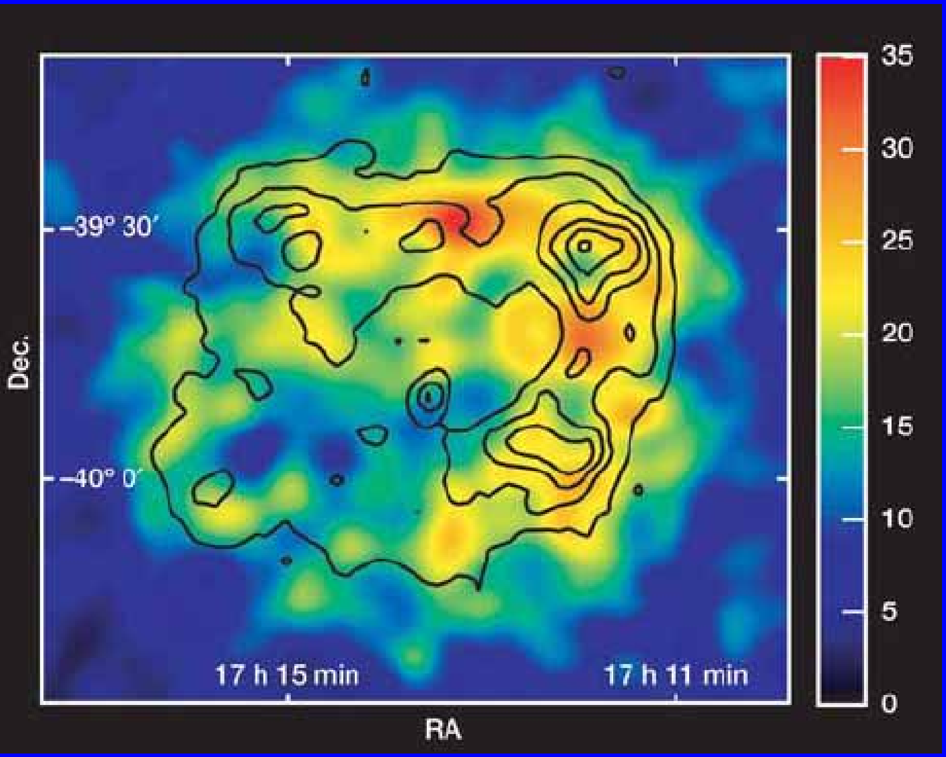


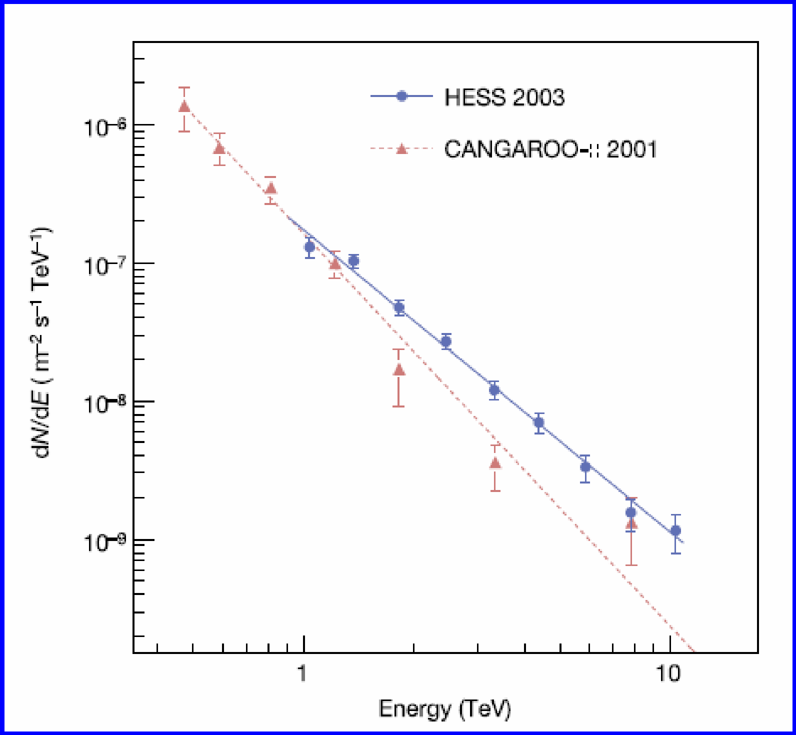
Red: CO(J=1-0) emission
Yellow: CANGAROO
Image: XMM
Fukui et al. PASJ 55 L61 (2003)



Solid: Gamma-rays from
Pion decays
Dot: Inverse Compton
Dash: Bremsstrahlung
Enomoto et al. 2002

H.E.S.S (two telescopes) **Aharonian et al. (2004)**



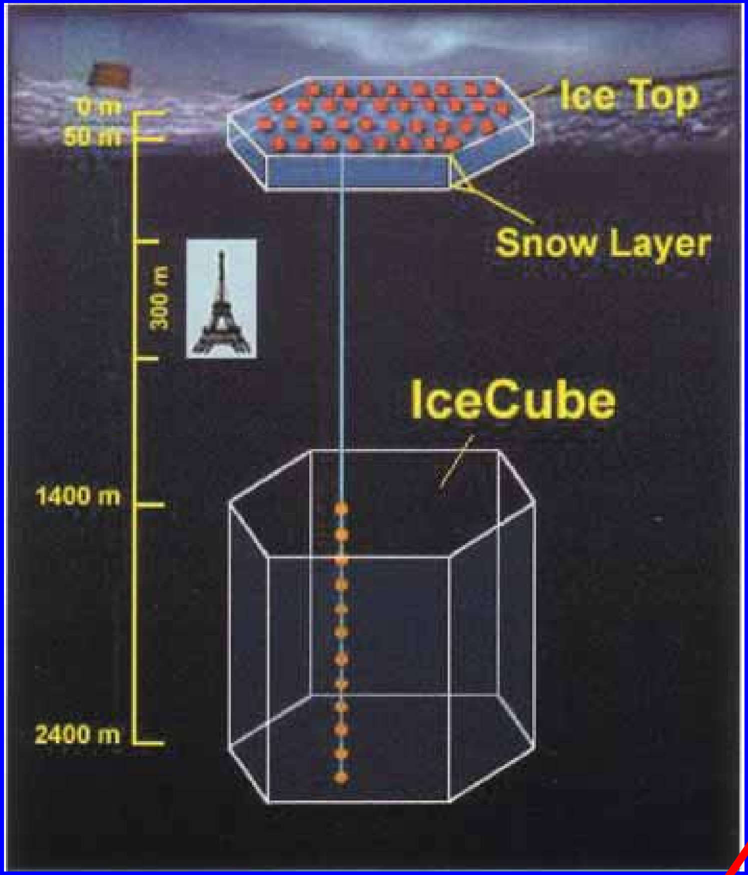


Color: Count map of HESS
Solid: ASCA (1-3) keV

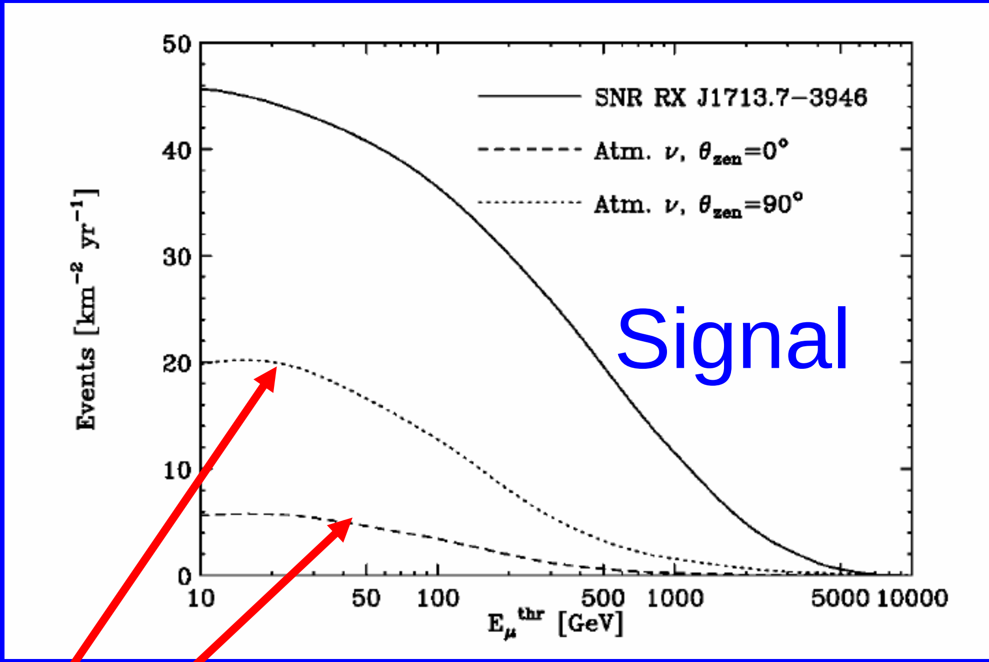
Spatially resolved multi-Wave length study is necessary (CANGAROO III; HESS four telescope).

Spectrum of HESS and CANGAROO
Consistent within 2-sigma level
(Mori, private communication)
Pion decays likely to exist, but non-Themal Brems of electrons could contribute.

High-Energy Neutrinos from SNRs



IceCube



Estimated Neutrino Signals from a source like RX J1713.7-3946

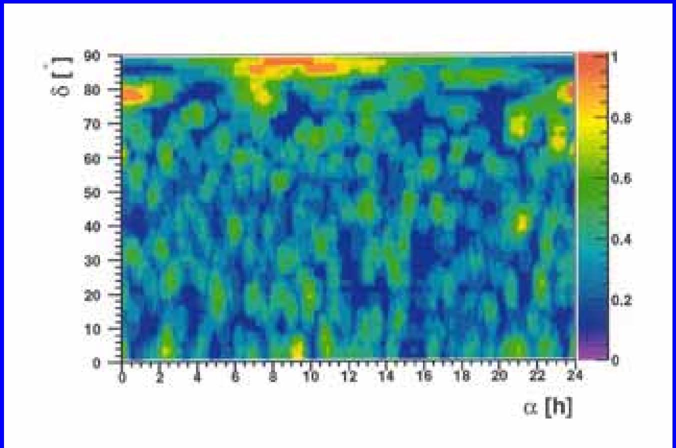
Muniz and Halzen 02

Atmospheric Neutrino

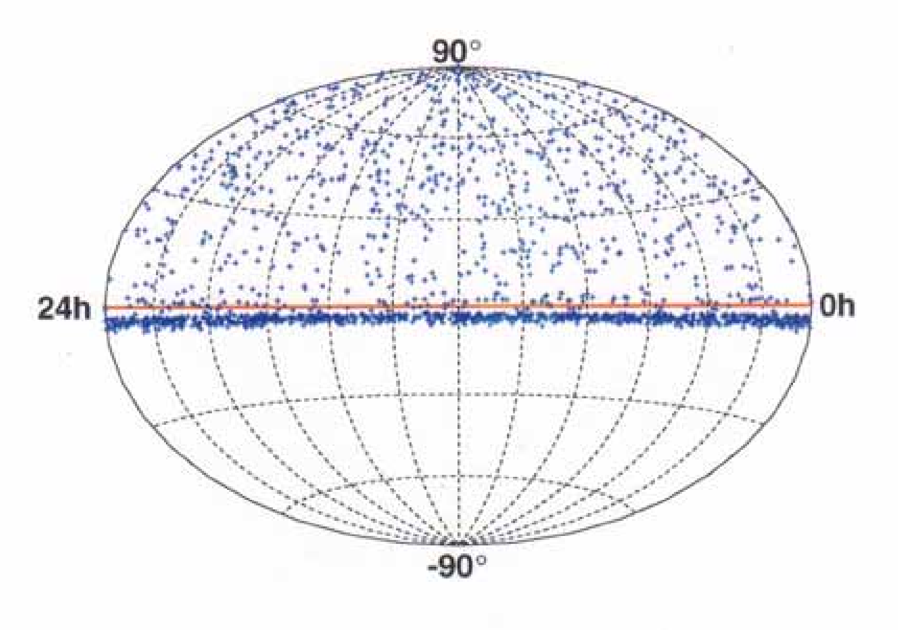
最新の観測状況：AMANDA-II

Rebordy et al. 04

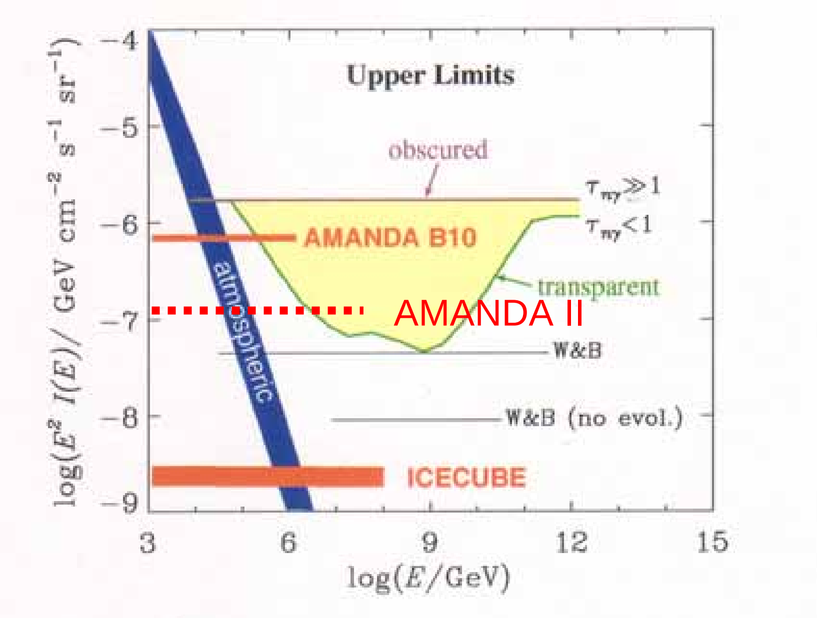
注：pole方向はfluxの上限値が高くなる傾向にある。



未だにpoint sourceは見つかっていない。



Fluxの上限値。E^-2仮定。単位は
10^-7 cm^-2s^-1Sr^-1 for above 10GeV



到来方向分布。699/3400 events
赤道面以下はdown-going Muonのcontamination

Note: SN1006, RXJ1713 are in the south heimsphere

最新の観測状況：AMANDA-II

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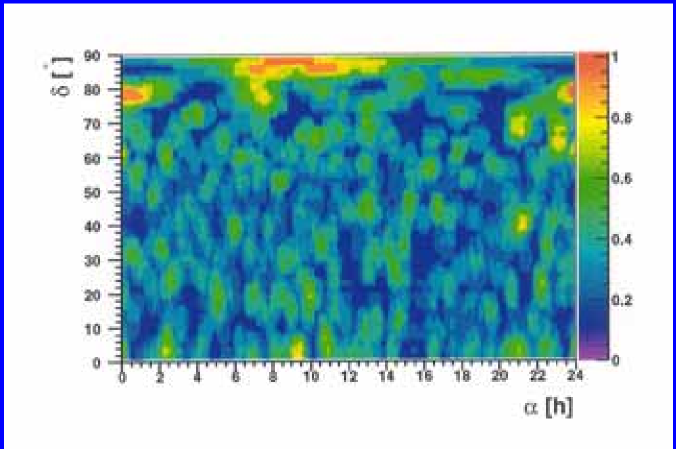

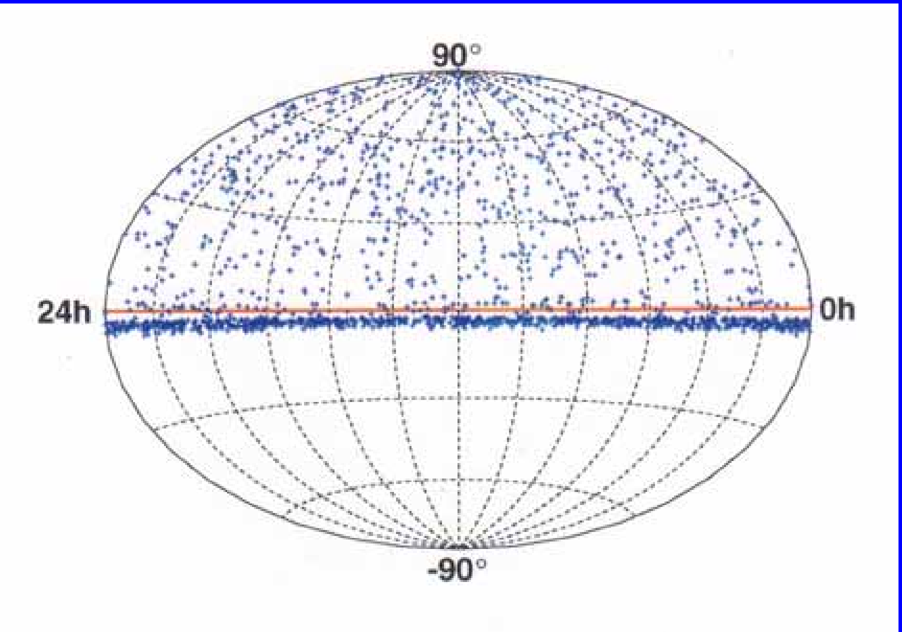

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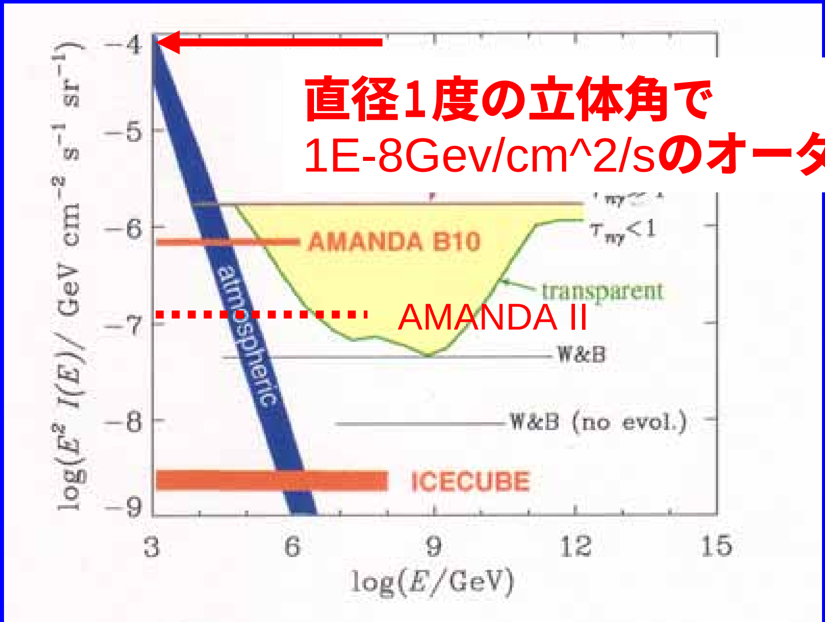


直径1度の立体角で
1E-8Gev/cm^2/sのオーダー

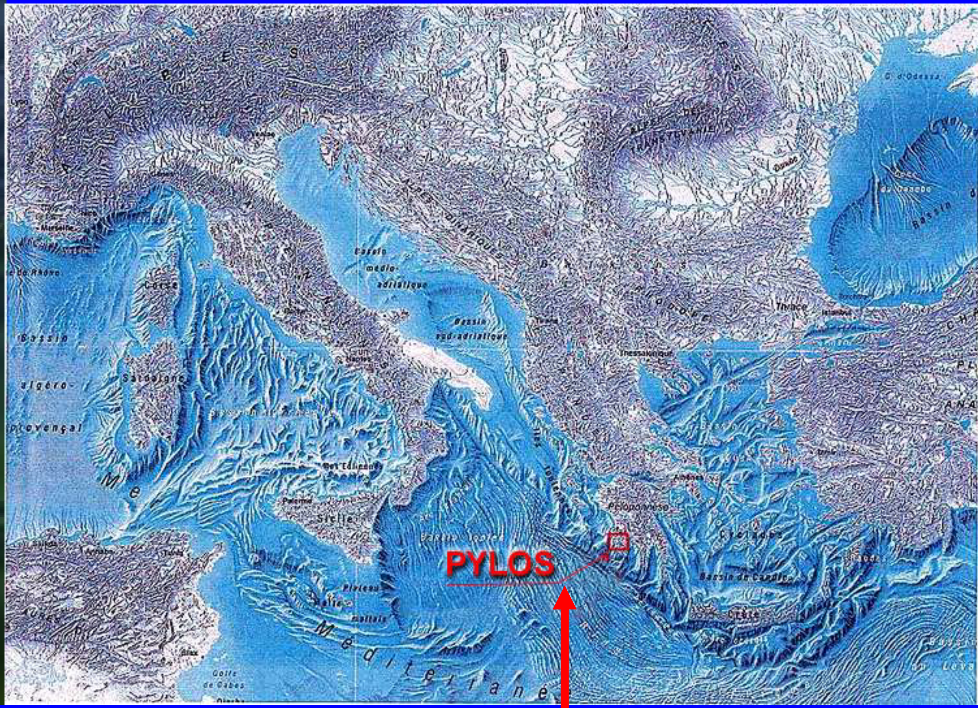
到来方向分布。699/3400 events
赤道面以下はdown-going
Muonのcontamination

Note: SN1006, RXJ1713 are in the south heimsphere

Other VHE Neutrino Detectors

ANTARES (R&D, Prototype)

NESTOR (proposal)



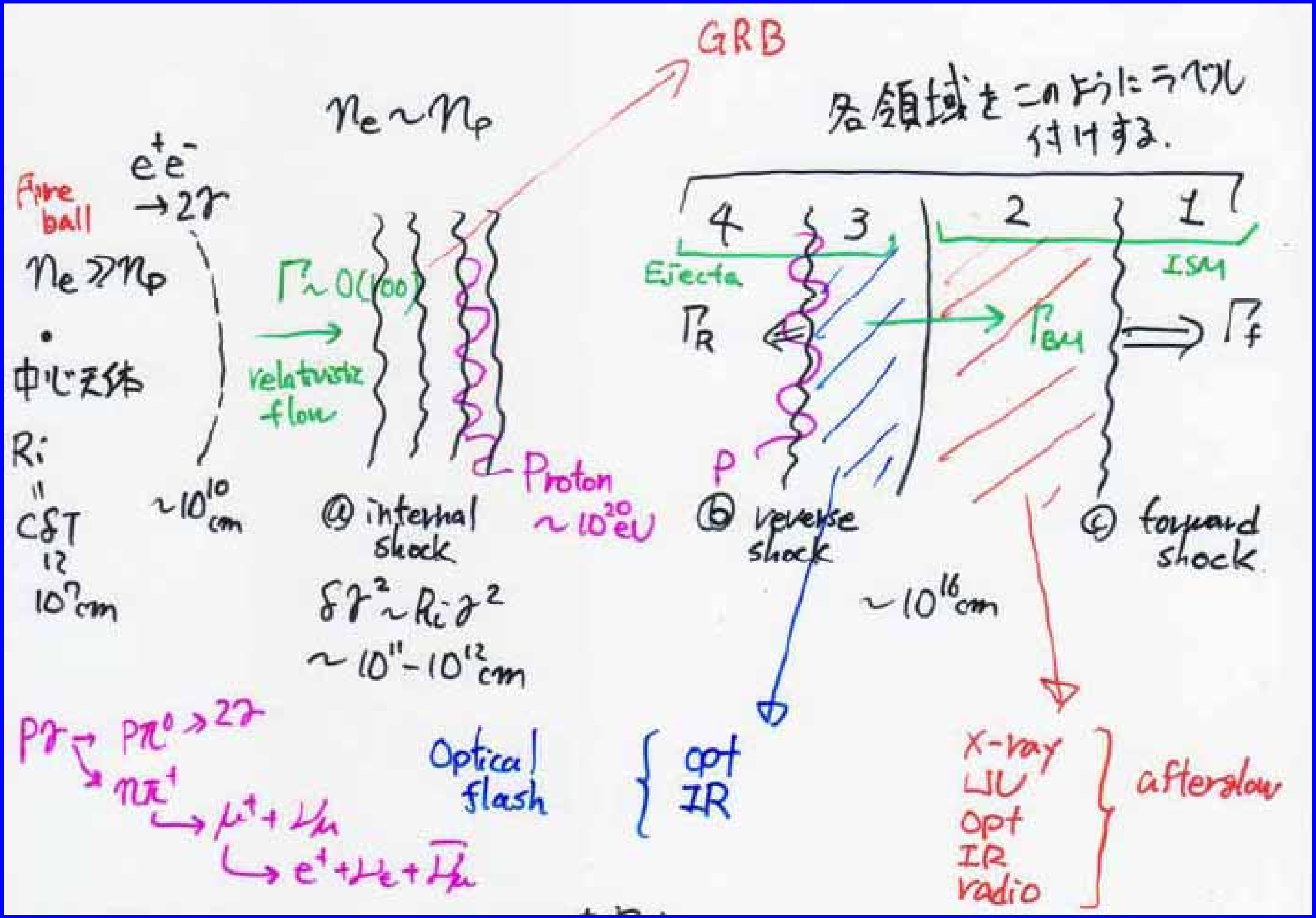
37 km from Marseille

Mediterranean Sea

他にもBIKALなど

Acceleration sites in GRBs: **Waxman & Bahcall 97,01; Dermer 02**

a. Internal shock b. reverse shock c. external shock



Procedure: 1. Estimation of soft photons 2. Acceleration limit
3. efficiency of photopion production

どれ位の量のProtonがGRBで作られるかは分からない.

⇓

GRBがUHECRをになっていると仮定する.

UHECR ($10^{19}-10^{21}$eV) ではAGASAを説明するために

$\sim 4\times 10^{44}$ erg/Mpc^3/yr (Waxman '95)

↑

BATSE range の GRB の γ-rays と同程度.

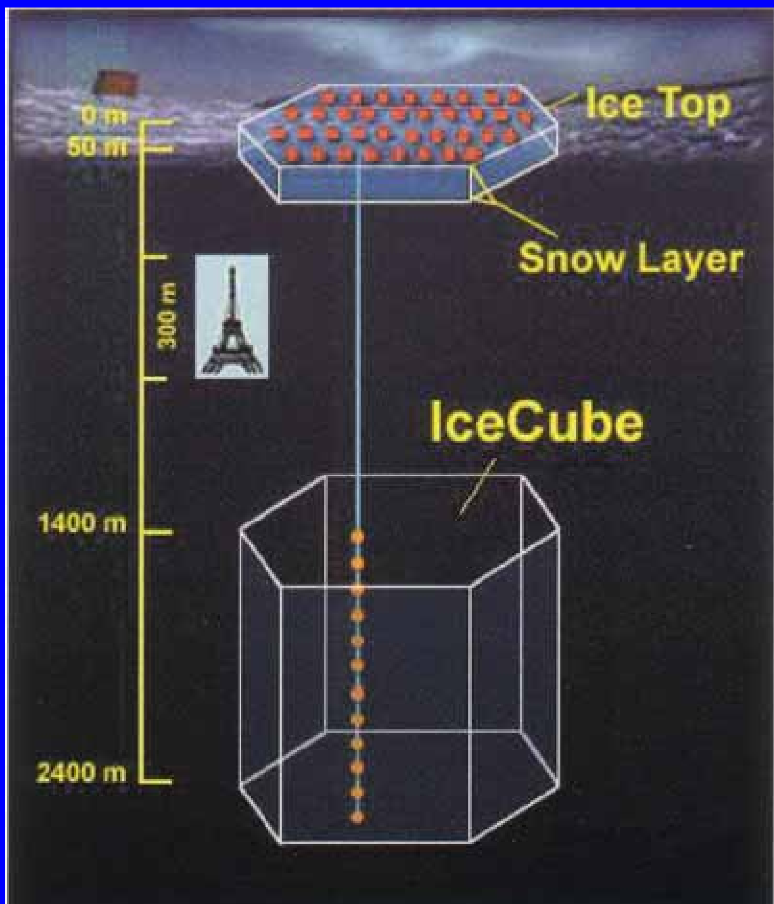
ここでは $E_p^{ob} \geq 10^{16}$eV で $\dot{E} \sim 4\times 10^{44}$ erg/Mpc^3/yr とする.

⇕

$E_\nu^{ob} \geq 5\times 10^{14}$eV $= E_{\nu b}^{ob}$

α=2.2で解析しているので1E19eVのCRがエネルギーを担っていると考えている

Event Rate at km^3 Detector



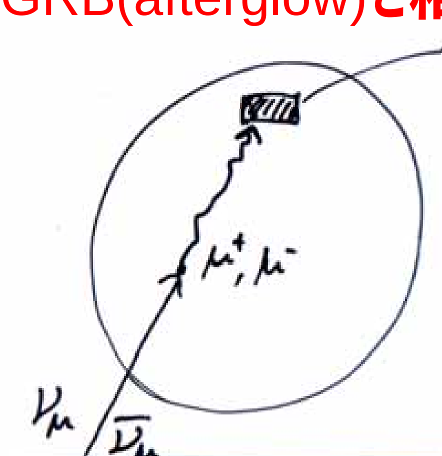
$$P_{\nu\mu}(E_\mu \gtrsim 2\,\mathrm{GeV}) \simeq 10^{-6}\left(\frac{E_\nu}{1\,\mathrm{TeV}}\right)$$

∴ Up-going muon の flux は

$$J_{\mu\uparrow} \simeq 2\pi\, P_{\nu\mu}(\varepsilon_{\nu b})\, J_\nu(\varepsilon_\nu > \varepsilon_{\nu b})$$

$$\sim 50\, \frac{f_\pi(\varepsilon_{pb}^{ob})}{0.2}\left(\frac{\dot{E}}{4\times 10^{44}\,\mathrm{erg/Mpc^3/yr}}\right) \mathrm{km^{-2}\,yr^{-1}}$$

GRB(afterglow)と相関あり

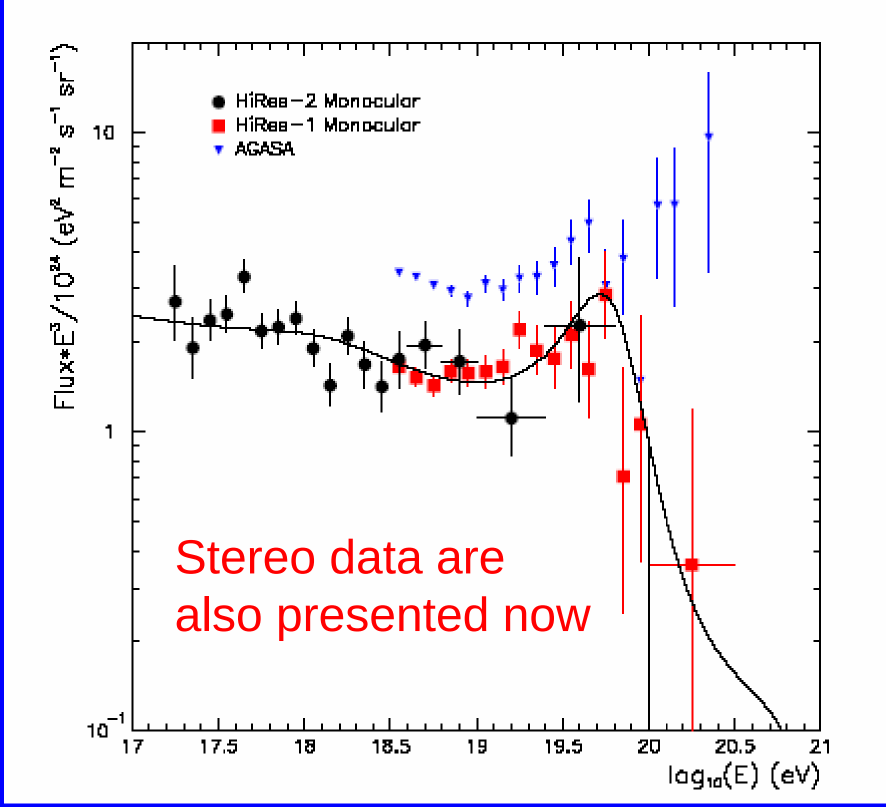


Up-going muon

※ down-going は大気μの影響が大きく、よくない。

Detectors of UHECRs

AGASA and HiRes



AUGER (Algentina)

Data will be shown on June 6, 2005

他にもTA、EUSO, ASHRAなど。

Abu-Zayyad et al. 02

n, p 2流体の decouple による π 生成と ν_μ $\bar{\nu}_\mu$ 生成

(Bahcall & Meszaros 2000; Meszaros & Rees 2000)

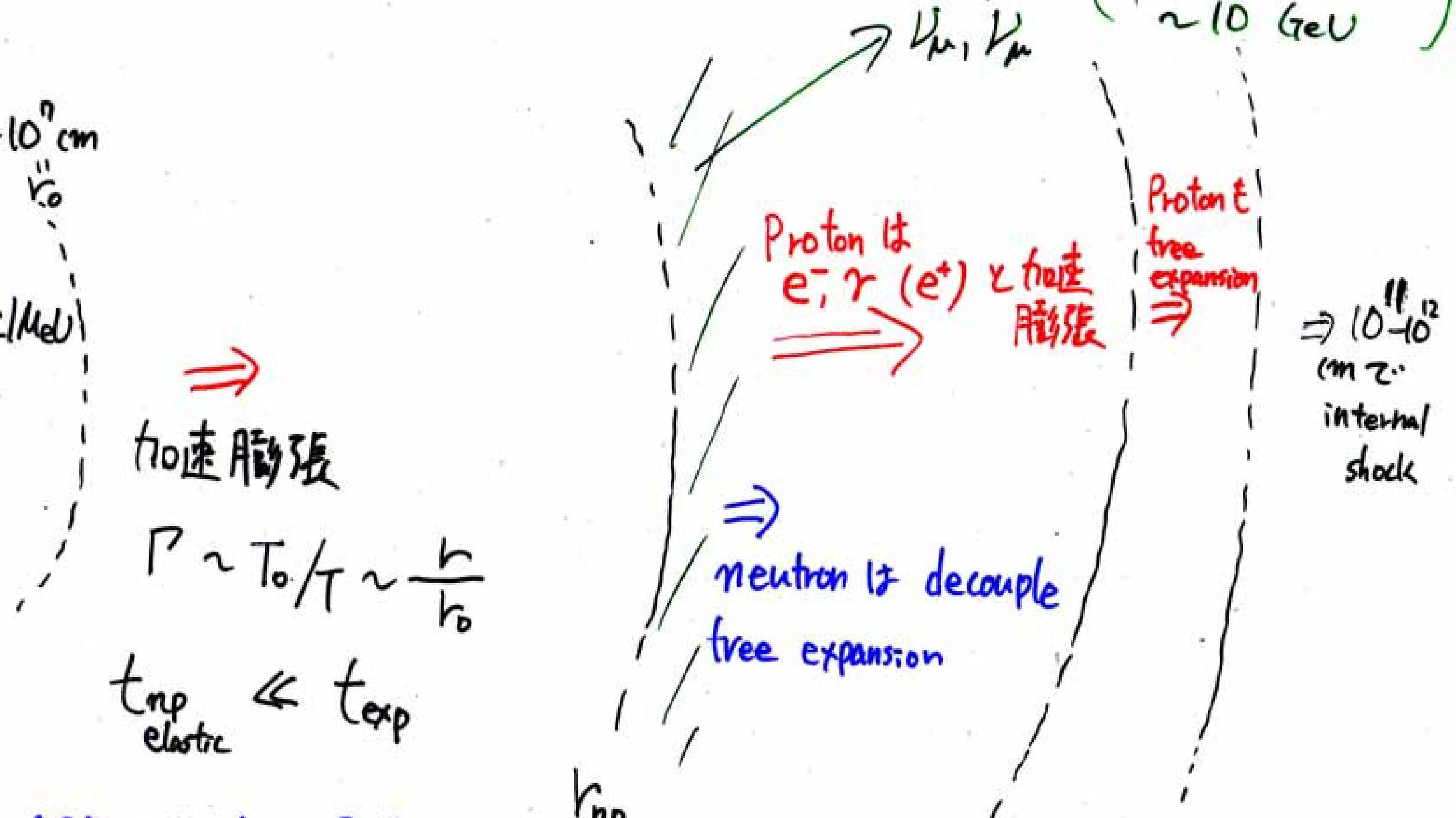
fire ball $\sim 10^7$ cm r_0

$\gamma, e^\pm, p, n$

$\Gamma \sim 1$, $T_0 \gtrsim 1$ MeV

$L/\dot{M}c^2 \equiv \eta$

中心天体



$r_s \leq r_{photo\ sphere}$ は GRB になるための条件

$r_{np} \leq r_s$ は $\nu_\mu, \bar{\nu}_\mu$ を生成するための条件

r_{np} $(t_{exp} \sim t_{np})$

r_s ↑ $\Gamma_{fp} \sim \eta$ となる場所

$r_s \simeq \eta r_0 = 10^9 \eta_{100} r_{07}$ cm

$r_{photo\ sphere} \sim 10^{10}$ cm

$$r_0 \sim 10^7 r_{07}\ \mathrm{cm}$$
$$\eta = (L/\dot{M}c^2) \text{ at } r_0$$
$$L \sim 10^{52} L_{52}\ \mathrm{erg/s}$$
$$\Gamma = 1$$

} 初期条件

⇓

$$\Gamma \sim T_0/T = r/r_0$$

$$T_0 = 1.2\, L_{52}^{1/4} r_{07}^{-1/2}\ \mathrm{MeV}$$

で 加速膨張

$\Gamma_f \lesssim \eta$　　で サチる.

その時の半径　$r_s = \Gamma_f r_0 = \eta r_0$ —①

一方, $n, p, \gamma, e^-, (e^+)$ で fire ball 構成していると考えて.

n, p の弾性散乱の cross section は

$$\sigma'_{el} v'_{el} \sim \sigma_0 c = \mathrm{const}$$

← n, p のバルクモーションとしての相対速度をCM系で評価.

$$\sigma_0 \sim 3 \times 10^{-26}\ \mathrm{cm}^2$$

∴ neutron が proton と散乱する time scale

$$t'_{np} \sim \frac{1}{n'_p \sigma_0 c} \quad \text{in wind-rest frame}$$

ダイナミカル タイムスケール

$$t'_{exp} \simeq \frac{r}{c\Gamma}$$

$$n'_n = \xi n'_p$$

$$n'_p = \frac{L}{(1+\xi) 4\pi r^2 m_p c^3 \Gamma \eta} \quad (\text{質量保存})$$

今, $r_0\eta = r_0\Gamma_f = r_s$ で ちょうど $t'_{exp} = t'_{np}$

となる η を η_π と書くと.

$$\eta_\pi = [L\sigma_0 / 4\pi m_p c^3 r_0 (1+\xi)]^{1/4}.$$

$$\sim 3.9 \times 10^2 L_{52}^{1/4} r_{07}^{-1/4} \{(1+\xi)/2\}^{-1/4}$$

$t'_{exp} \simeq t'_{np}$ となる場所を r_{np} とすると

$$\begin{cases} \eta \le \eta_\pi \Leftrightarrow r_{np} \ge r_s \\ \eta \ge \eta_\pi \Leftrightarrow r_{np} \le r_s \end{cases} \quad -②$$

∴ $\eta \ge \eta_\pi$ では.

$\Gamma \sim \eta$ となる前に n, p が decouple

⇓

n は free expansion

p は (e^+e^-, γ) と共に加速膨張を続ける

∴ n と p で速度差が生じる.

cf. Kamioka では $\sim 10^{-5}$ event /yr

∴ バルクモーションとして

$$(P_n^\mu + P_p^\mu)^2 = S \ge m_p c^2 + m_n c^2 + m_\pi c^2$$

を満たすようになると.

$\pi^\pm, \pi^0$ を生成する. //

Event rate は $n_\pi \sim n_0$ なので

$r \sim r_{np}$ に於て, n は O(1) コの ν_μ と O(1) コの $\bar{\nu}_\mu$ を生成すると考えられる.

Neutron の個数 in a GRB

$$N_n = \left(\frac{\xi}{1+\xi}\right)\frac{E}{\eta m_p c^2} \sim 10^{53} E_{53}\left(\frac{2\xi}{1+\xi}\right)\left(\frac{400}{\eta}\right)$$

$D \sim 3000\,\mathrm{Mpc} \sim 10^{23}\,\mathrm{km}$

flux $\sim 3\times10^{-9}$ /cm²/s at 10GeV

GRB rate $10^3 R_b$ コ/yr

$$P_{\nu_\mu}(\varepsilon_{\nu_\mu} = 10\,\mathrm{GeV}) \simeq 10^{-6}\left(\frac{10\,\mathrm{GeV}}{1\,\mathrm{TeV}}\right)^2 \sim 10^{-10}$$

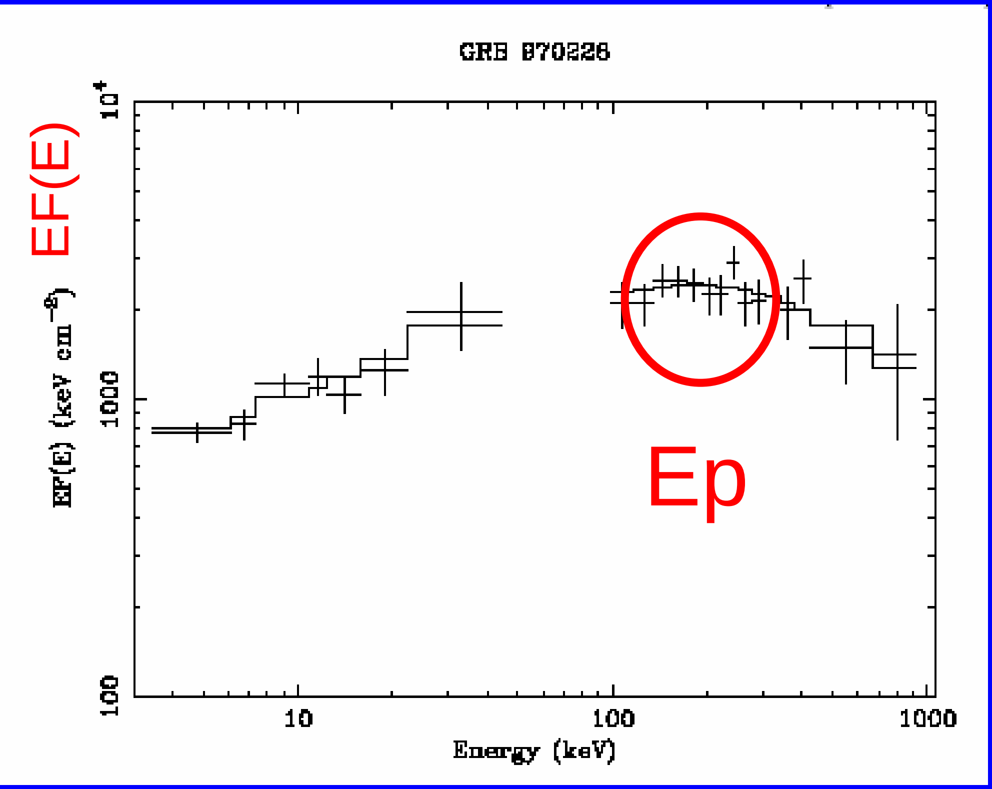
$$\therefore\ 4\pi P_{\nu_\mu}\frac{N_n}{4\pi D^2} R_b \sim O(1)\ [\mathrm{event/yr/km^2}]$$

→ 1年に1コ位. GRBと相関を持つ event がある.

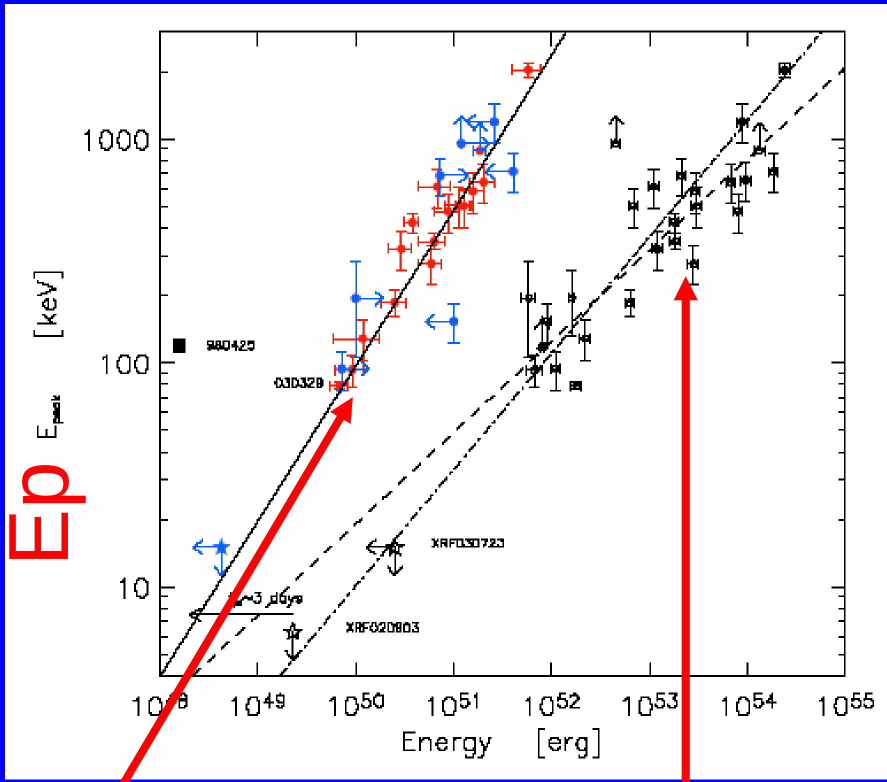
§ 宇宙論としてのガンマ線バーストと将来大型観測機器

Correlation between Epeak and Explosion Energy

Amati et al. (2002)



Ghirlanda et al. (2004)



Energy (keV)

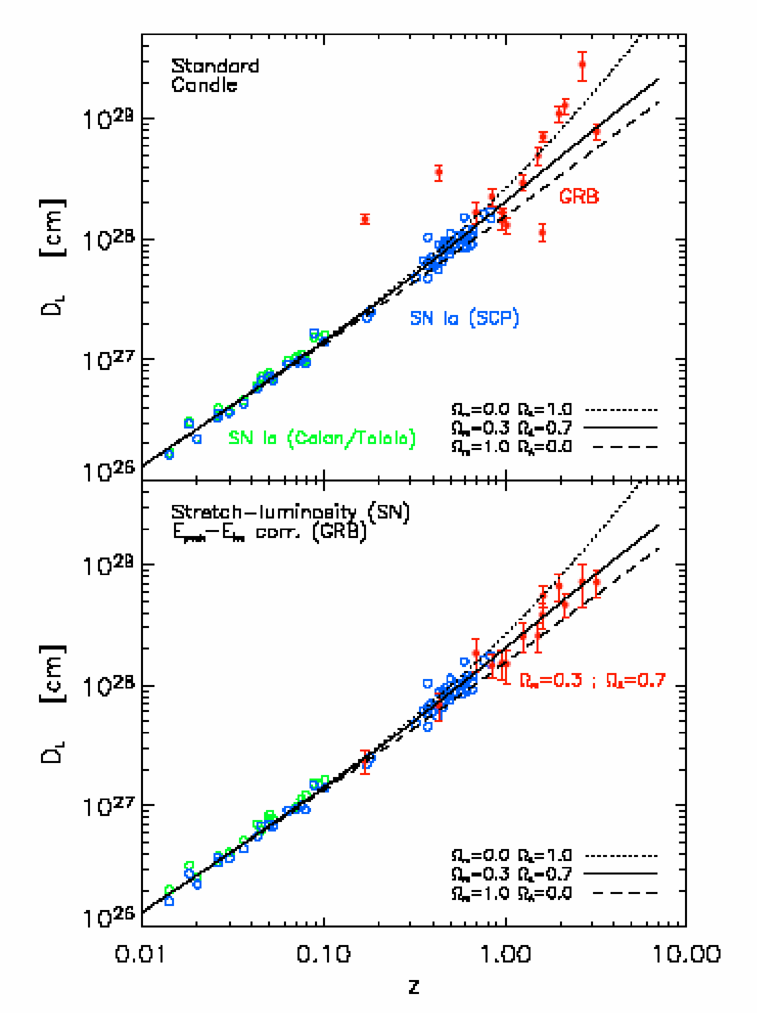
Energy (erg)

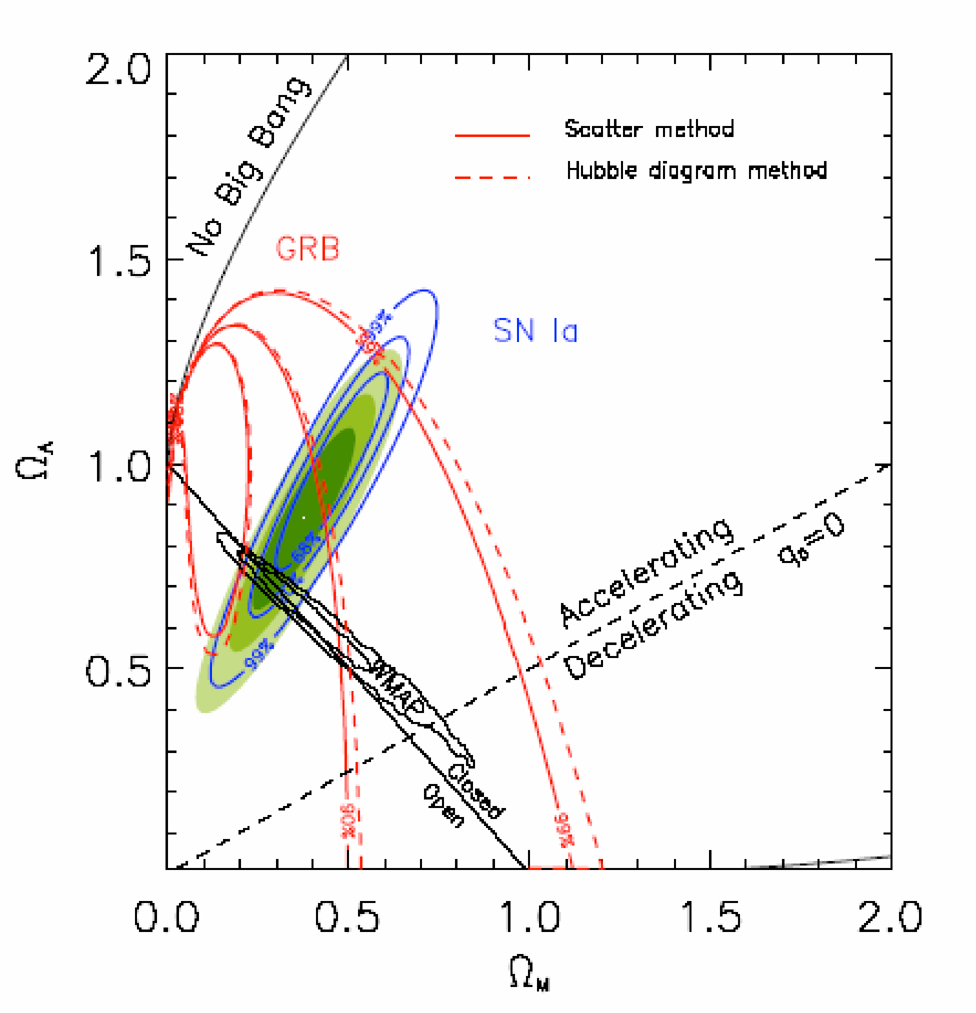
Collimation-Corrected Energy

Isotropic Energy

29GRBs are listed.
There are two (nearest) outlier:
GRB980425 (Z=0.0085/SN1998bw)
GRB031203(Z=0.106/SN2003lw)

Cosmological Parameters Might be Determined in an Independent Way





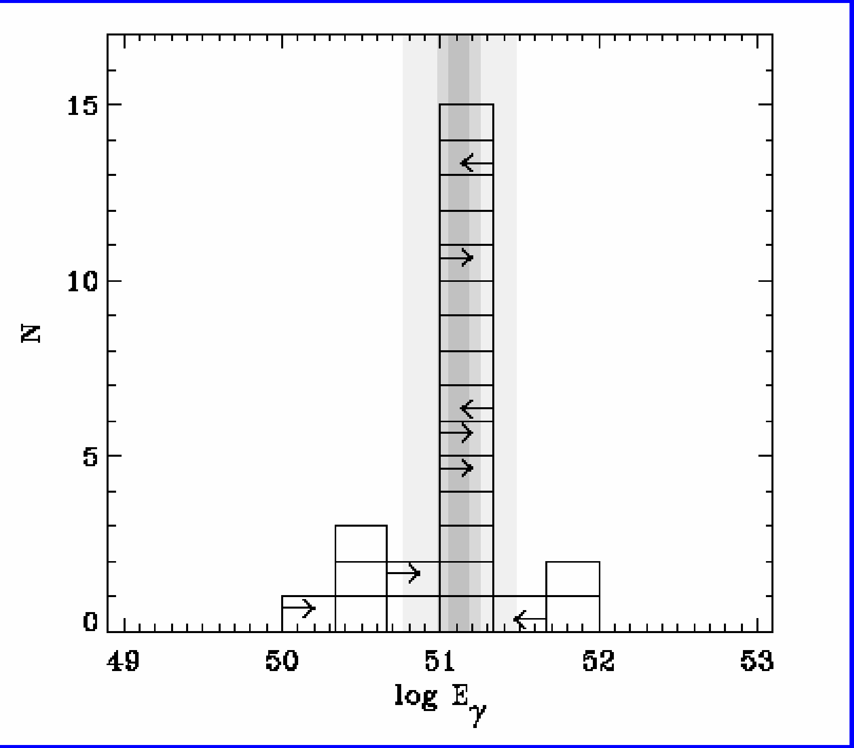
Upper:Eiso; Lower:Corrected
15GRBs are considered

GRBs are sensitive to Omega_m

Explosion Energy is Constant?

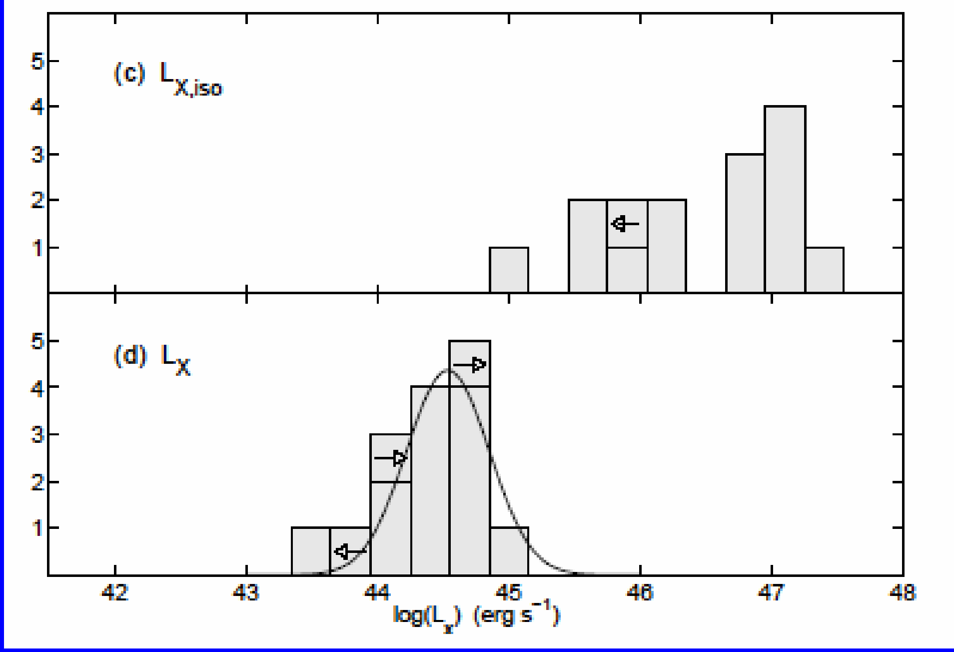
Corrected GRB energies

Bloom et al. 03



Luminosity of X-ray afterglow at t = 10hr

Berger et al. 03



16GRBs are considered.

Upper:Eiso; Lower:Corrected

41GRBs are considered.

Are GRBs(XRFs) Standard Energy Reservers?

Total Energy:

Energy scale must exist.

Ex. SN Ia: Nuclear binding energy of Fe56 relative to C12 with mass of 0.7Msolar is 1.4E+51 erg.

Collapse-driven SN: Gravitational binding enrgy of a neutrion star is 3E+53 erg.

Collapsar? Gravitational binding energy of a BH??... Rotation energy??...

Rather, it will be natural to consider that there is a variety of explosion energies of GRBs and progenitor stars.

ex. SN2002lt/GRB021211 Della Valle 2003

Conclusion

- Neutrino and GW astronomy should shed lights on central engines of collapse-driven supernovae and GRBs.
- Observations with high-resolutions should bring us further, fruitful discussions of compact objects.
- Multi wave-length observations may make a breakthrough of understanding compact objects, such as long GRBs and SNe.