Core Collapse

A star passes most of its lifetime burning H (main sequence). The resulting He builds up in the core and its mass increase, heating and contracting under the pressure of outer layer. The star contraction pauses as nuclear fusion provides the energy necessary to replenish the energy the star loses in radiation and neutrinos. When the T in the core is sufficiently large, He burning begins. After He burning the evolution is greatly accelerated by neutrino losses The scheme repeats for different stages

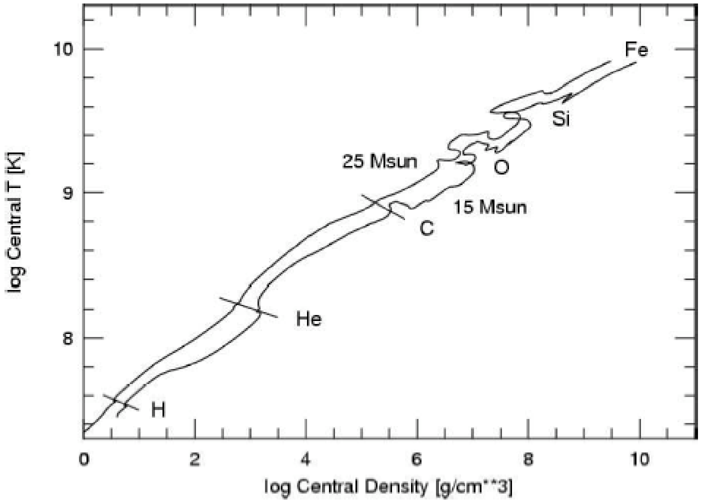
$$\left.\begin{array}{l}\text{(i) Hydrogen burning } 4p \to {}^{4}\mathrm{He} + 2\,e^{+} + 2\nu_e \\ \text{(ii) Helium burning } 3\alpha \to {}^{12}\mathrm{C} + 2\gamma \\ \text{(iii) Carbon burning } {}^{12}\mathrm{C} + {}^{4}\mathrm{He} \to {}^{16}\mathrm{O} + \gamma \end{array}\right\} \text{Million yrs}$$

$$\left.\begin{array}{l}\text{(iv) Oxygen burning } {}^{16}\mathrm{O} + {}^{16}\mathrm{O} \to {}^{28}\mathrm{Si} + \alpha \\ \text{(iv) Iron burning } {}^{28}\mathrm{Si} + {}^{28}\mathrm{Si} \to {}^{56}\mathrm{Fe} + \gamma \end{array}\right\} \text{Few weeks}$$

Evolution of a 15 M_{sun} star

Stage	Time Scale	Fuel or Product	Ash or product	Temperature (10^9 K)	Density (gm/cm^3)	Luminosity (solar units)	Neutrino Losses (solar units)
Hydrogen	11 My	H	He	0.035	5.8	28,000	1800
Helium	2.0 My	He	C,O	0.18	1390	44,000	1900
Carbon	2000 y	C	Ne,Mg	0.81	2.8×10^5	72,000	3.7×10^5
Neon	0.7 y	Ne	O,Mg	1.6	1.2×10^7	75,000	1.4×10^8
Oxygen	2.6 y	O,Mg	Si,S,Ar, Ca	1.9	8.8×10^6	75,000	9.1×10^8
Silicon	18 d	Si,S,Ar, Ca	Fe,Ni, Cr,Ti,...	3.3	4.8×10^7	75,000	1.3×10^{11}
Iron core collapse[a]	~1 s	Fe,Ni, Cr, Ti,...	Neutron Star	> 7.1	$>7.3 \times 10^9$	75,000	$>3.6 \times 10^{15}$

[a] *The presupernova star is defined by the time when the contraction speed anywhere in the iron core reaches 1,000 km s^{-1}.*



Collapse

Each cycle requires a higher T for ignition due to the stronger Coulomb repulsion between nuclei.For most stars the process stops when the pressure is not sufficient to heat the core at the necessary T for the next ignition and the stars turns into a white dwarf.
The most massive stars can develop an iron core of (iron is the “ground state” of nuclear matter, the most tightly bound of all nuclei and no further nuclear burning is possible). The Fe core is substained by the degenerate pressure of its electrons until it reaches the Chandrasekar mass of 1.4 M_{Sun}.After this limit the core collapses. photodisintegration (radiation melt down some of the Fe nuclei to He) contribute in reducing pressure:

$$\gamma + {}^{56}_{26}\mathrm{Fe} \leftrightarrow 13\,\alpha + 4\,n$$

$$\gamma + \alpha \leftrightarrow 2\,p + 2\,n$$

\

Collapse

Neutronization follows (time scale of ms): electron capture

$$e^- + p \to \nu_e + n$$

About 10^{57} ν_e are emitted contributing to the collapse.

The core collapses to a hot n rich sphere of about 30 km in radius (proto-neutron star).

The short range nuclear force halts the collapse when the density is about 2 x atomic nucleus density 4-5 10^{14} g/cm^3. Neutrinos remain trapped in the collapsing core and are in thermal equilibrium within the core. The energy is released in thermal processes like **(thermalization)**

$$e^+ + e^- \to \nu_j + \overline{\nu}_j$$

With an emission of the order of 10 s.

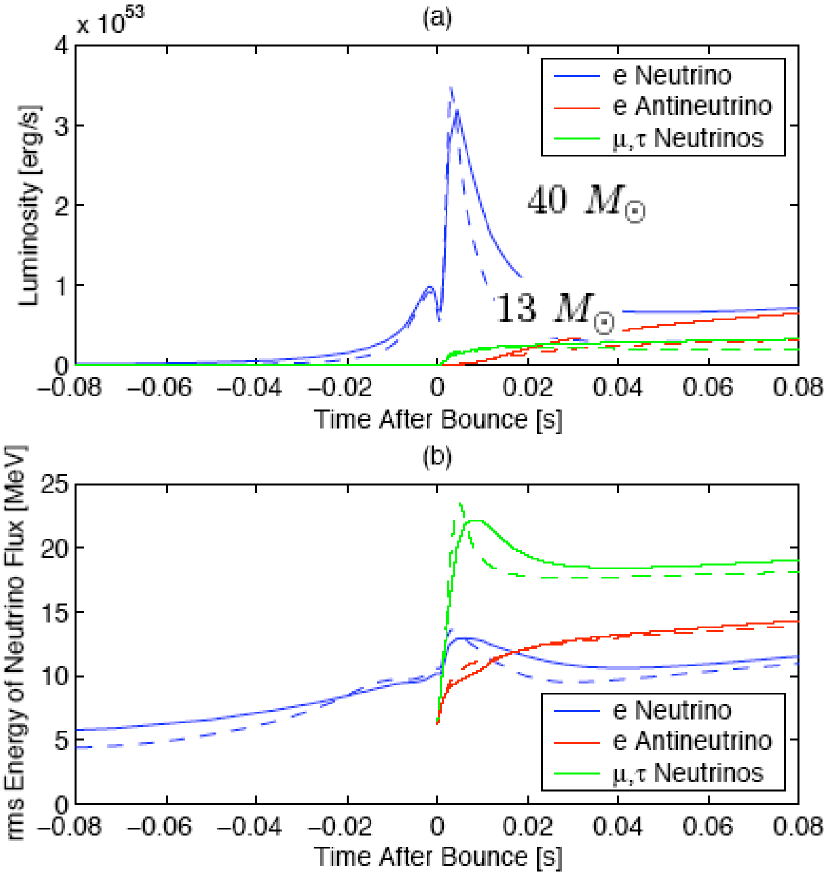
The shock wave produced by the abrupt halt of the collapse and the bounce of the core travels towards the surface of the star. This is the explosion visible in the optical.

Collapse

Neutronization follows (time scale of ms): electron capture

$$e^- + p \to \nu_e + n$$

About 10^{57} ν_e are emitted contributing to the collapse



Neutronization burst of ν_e

$$N_{\nu_e} \simeq N_e = N_p \simeq \frac{M_{\rm core}}{m_p} Y_e \simeq 0.9 \times 10^{57}$$

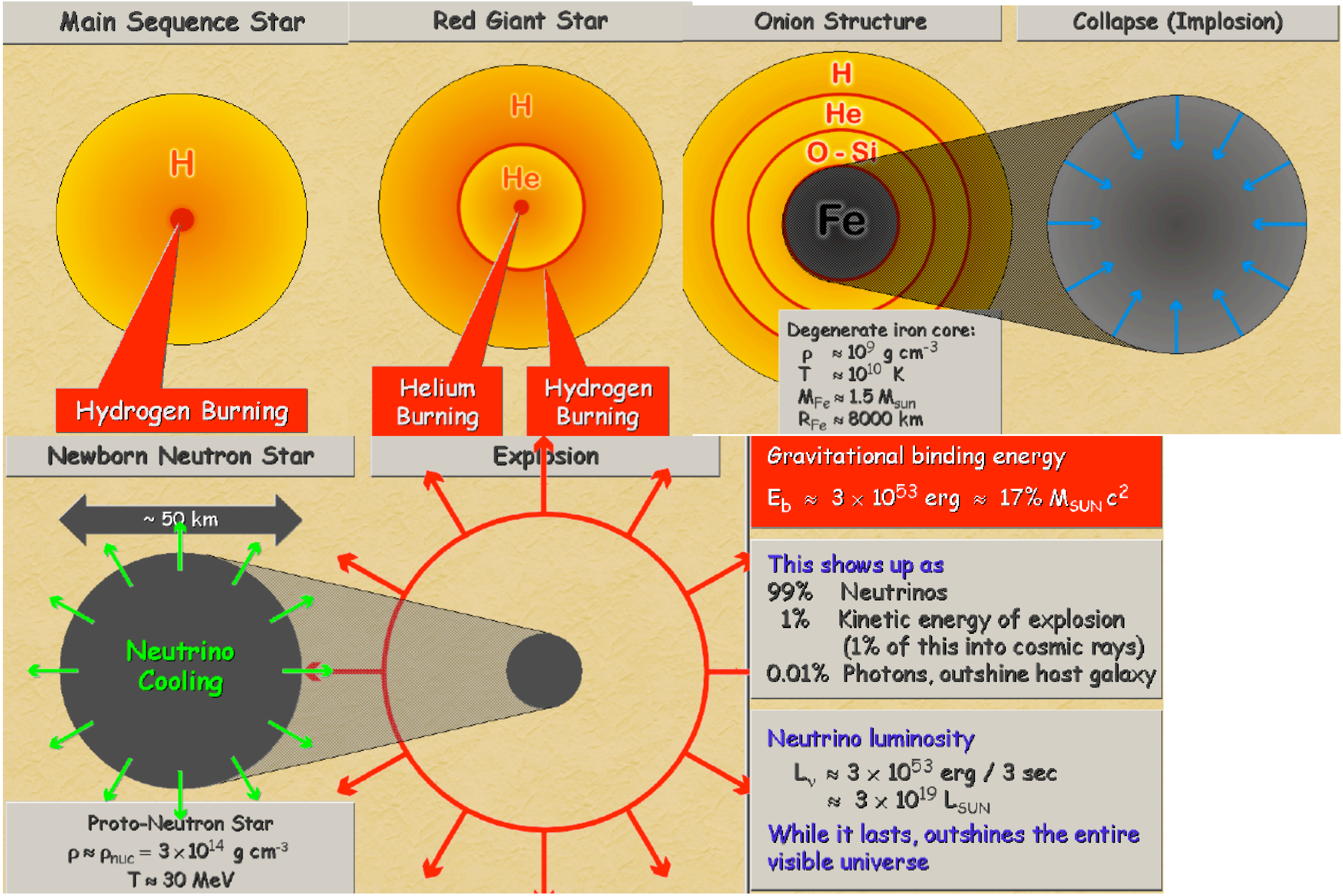
$Y_e \equiv n_{e^-} - e_{e^+}$ is electron fraction per baryon

The total energy

$$E_{binding} = G\frac{M^2_{core}}{R_f} - G\frac{M^2_{core}}{R_i} \approx G\frac{M^2_{core}}{R_f} \approx 3\times 10^{53} erg$$

is accounted for by neutrinos while the ejecta carry only 10^{51} erg (1%)

Stellar collapse and SN explosion



Main Sequence Star

Hydrogen Burning

Red Giant Star

Helium Burning

Hydrogen Burning

Onion Structure

Degenerate iron core:

$\rho \approx 10^9$ g cm^{-3}

$T \approx 10^{10}$ K

$M_{Fe} \approx 1.5\ M_{sun}$

$R_{Fe} \approx 8000$ km

Collapse (Implosion)

Newborn Neutron Star

Proto-Neutron Star

$\rho \approx \rho_{nuc} = 3 \times 10^{14}$ g cm^{-3}

$T \approx 30$ MeV

Explosion

Gravitational binding energy

$E_b \approx 3 \times 10^{53}$ erg $\approx 17\%\ M_{SUN}\, c^2$

This shows up as

99% Neutrinos

1% Kinetic energy of explosion (1% of this into cosmic rays)

0.01% Photons, outshine host galaxy

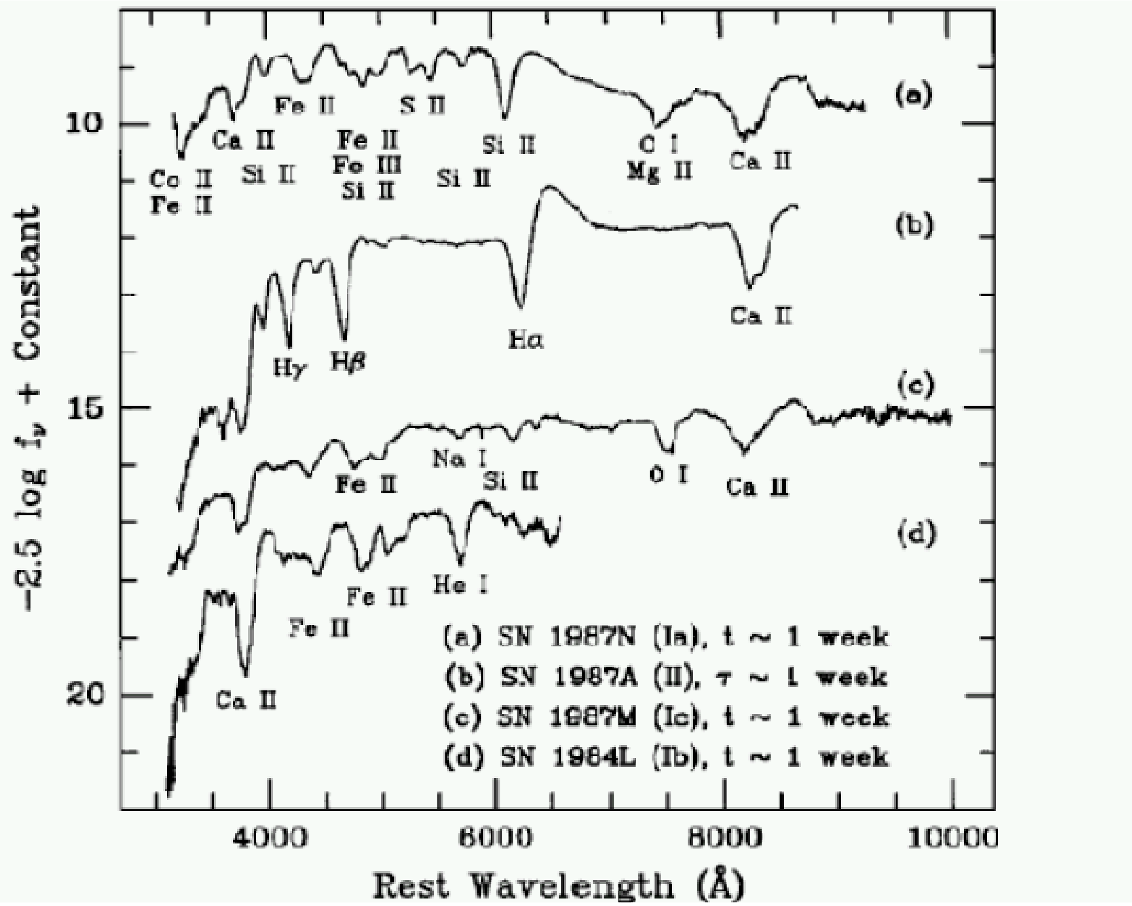
Neutrino luminosity

$L_\nu \approx 3 \times 10^{53}$ erg / 3 sec

$\approx 3 \times 10^{19}\ L_{SUN}$

While it lasts, outshines the entire visible universe

Classification of SuperNovae



Type I
(no H)

Type Ia
(no H, strong Si)

Type Ib
(no H, obvious He)

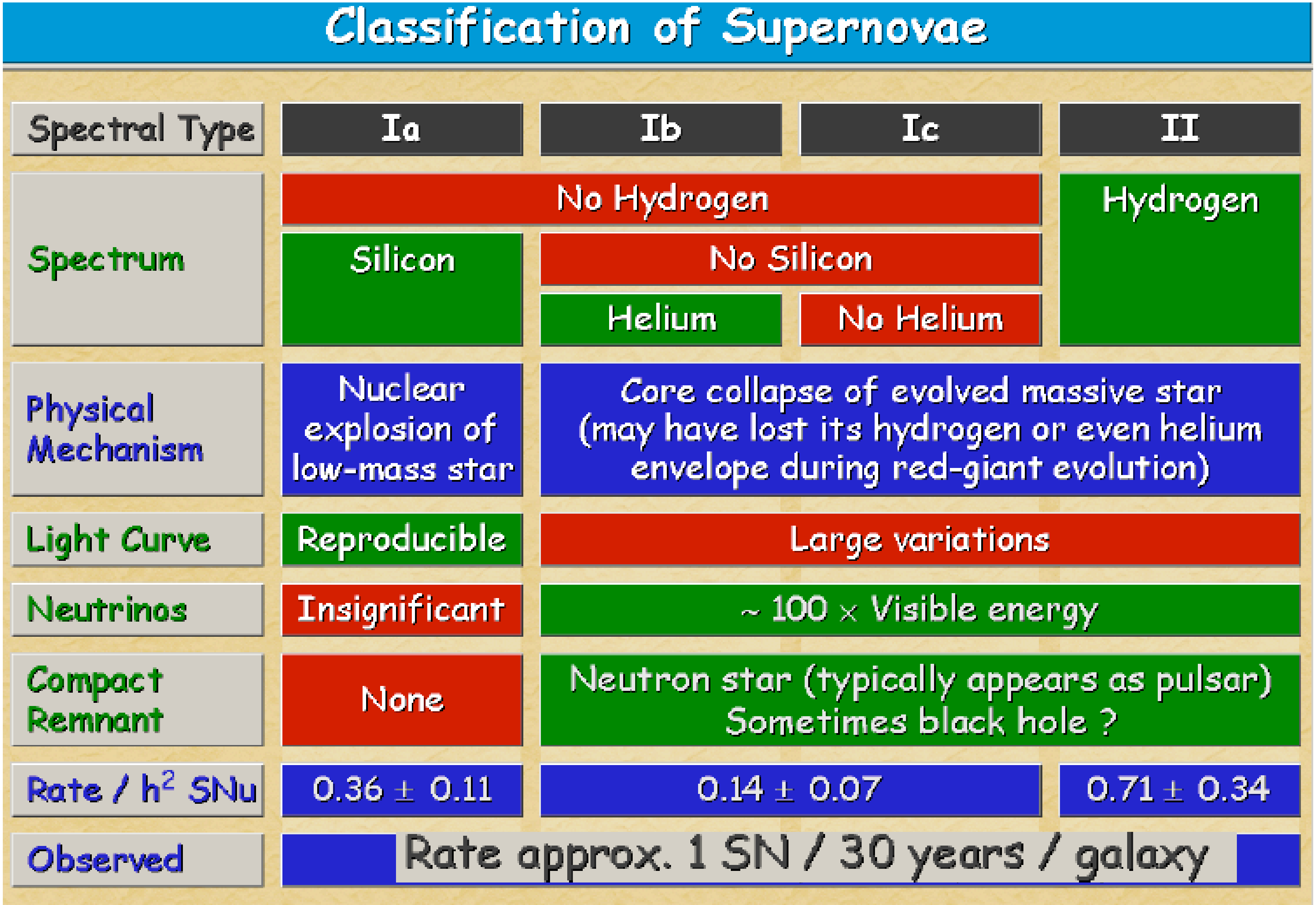
Type Ic
(no H, He, Si)

Type II
(obvious H)

Type II, outer H layer remains at collapse;

Type Ib, outer H layer stripped before collapse;

Type Ic, outer H and He layers stripped before collapse.

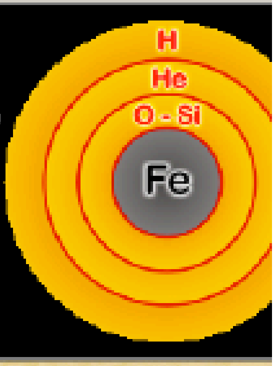


Classification of Supernovae

Spectral Type	Ia	Ib	Ic	II
Spectrum	No Hydrogen			Hydrogen
	Silicon	No Silicon		
		Helium	No Helium	
Physical Mechanism	Nuclear explosion of low-mass star	Core collapse of evolved massive star (may have lost its hydrogen or even helium envelope during red-giant evolution)		
Light Curve	Reproducible	Large variations		
Neutrinos	Insignificant	~ 100 × Visible energy		
Compact Remnant	None	Neutron star (typically appears as pulsar) Sometimes black hole ?		
Rate / h^2 SNu	0.36 ± 0.11	0.14 ± 0.07		0.71 ± 0.34
Observed	Rate approx. 1 SN / 30 years / galaxy			

$1\ \mathrm{Snu} = 1\ \mathrm{SN}/10^{10}\ L_{sun,B}/100\ \mathrm{yrs}$

Type Ia vs. Core-Collapse Supernovae

Type Ia	Core collapse (Type II, Ib/c)
Carbon-oxygen white dwarf (remnant of low-mass star) accretes matter from companion 	Degenerate iron core of evolved massive star Accretes matter by nuclear burning at its surface 

Chandrasekhar limit is reached - $M_{Ch} \approx 1.5\, M_{sun}\, (2Y_e)^2$

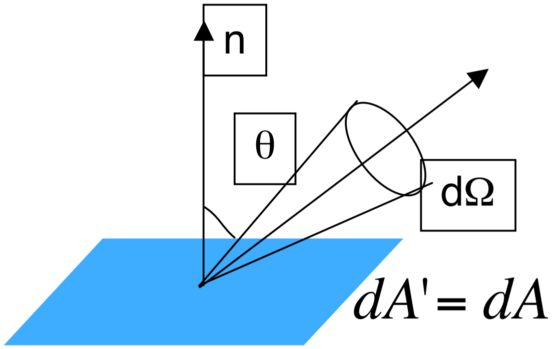
COLLAPSE SETS IN

Nuclear burning of C and O ignites → Nuclear deflagration ("Fusion bomb" triggered by collapse)	Collapse to nuclear density Bounce & shock Implosion → Explosion
Powered by nuclear binding energy	Powered by gravity
Gain of nuclear binding energy ~ 1 MeV per nucleon	Gain of gravitational binding energ ~ 100 MeV per nucleon 99% into neutrinos

Comparable "visible" energy release of $\sim 3 \times 10^{51}$erg

Some definitions

Definition of Specific intensity
Electromagnetic energy dE passing
Through surface dA and coming
from an angle θ within a solid angle
dΩ during time dt:



$$dA' = dA\cos\theta$$

$$dE = I_\nu(\theta,\phi)\cos\theta d\nu dA dt d\Omega$$

$$I_\nu = I_\nu(\theta,\phi)$$

$$\left[I_\nu\right] = W \cdot m^{-2} sr^{-1} Hz^{-1}$$

The Intensity (integral)

$$I\left(Wm^{-2}sr^{-1}\right) = \int_{\nu_1}^{\nu_2} I_\nu d\nu$$

Flux density = intensity integrated over the solid angle (of the source) is called:

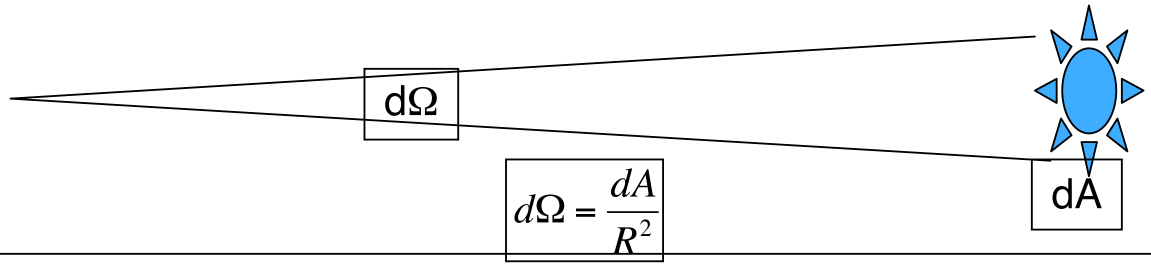
$$dF_\nu = I_\nu \cos\theta d\Omega$$

$$F_\nu = \int_\Omega I_\nu \cos\theta d\Omega$$

$$\left[F_\nu\right] = W \cdot m^{-2} Hz^{-1}$$

$$1 Jansky = 1 Jy = 10^{-26} W \cdot m^{-2} Hz^{-1}$$

Flux and Luminosity



$$d\Omega = \frac{dA}{R^2}$$

- Flux density at telescope

$$F_\nu = \int_{\Omega_{Source}} I_\nu \cos\theta d\Omega \approx \int_{\Omega_{Source}} I_\nu d\Omega$$

$$F_\nu = \frac{1}{R^2} \int_{\Omega_{Source}} I_\nu dA$$

- Luminosity (isotropic source):
  - differential
  - total

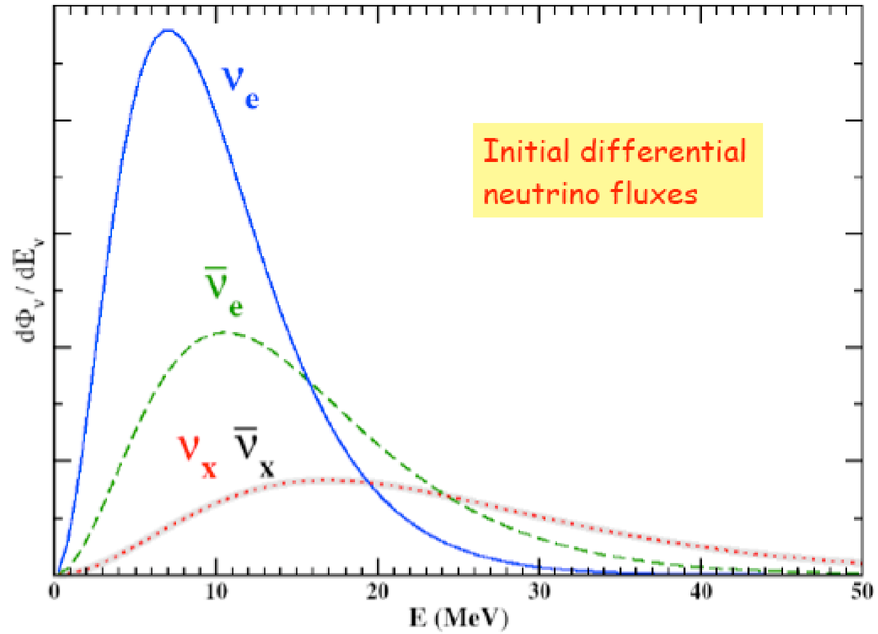
$$L_\nu = 4\pi R^2 F_\nu$$

$$L = 4\pi R^2 \int_0^\infty F_\nu d\nu$$

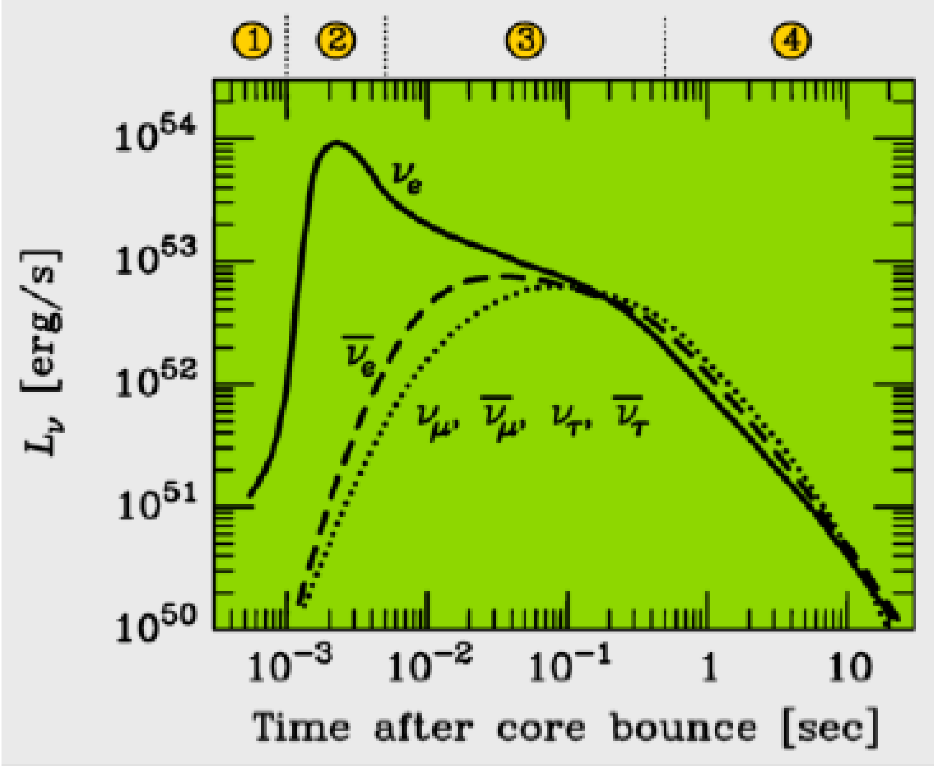
Thermal Spectra

1. Collapse (infall phase)
2. Shock break out
3. Matter accretion
4. Kelvin-Helmholtz cooling

$$\phi_{\nu_\alpha} \simeq C \frac{E^2}{e^{E/T_{\nu_\alpha}}+1}$$



Initial differential neutrino fluxes



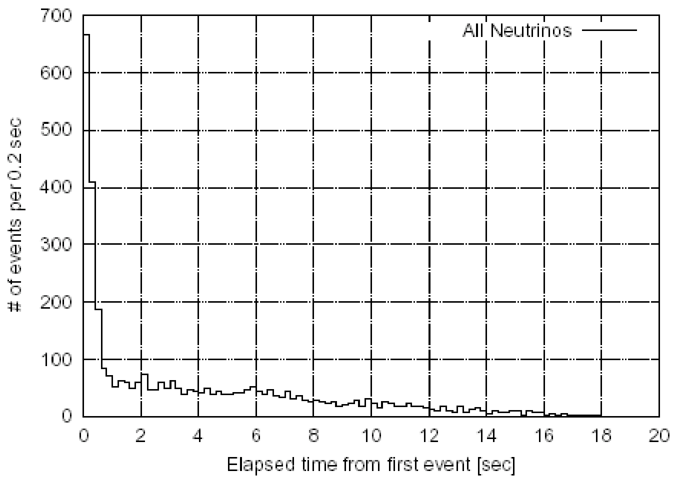
$$E^{tot}_{\nu_e} = E^{tot}_{\bar\nu_e} = E^{tot}_{\nu_\mu} = E^{tot}_{\bar\nu_\mu} = E^{tot}_{\nu_\tau} = E^{tot}_{\bar\nu_\tau} \simeq \frac{E_{binding}}{6}$$

What determines the time scale?

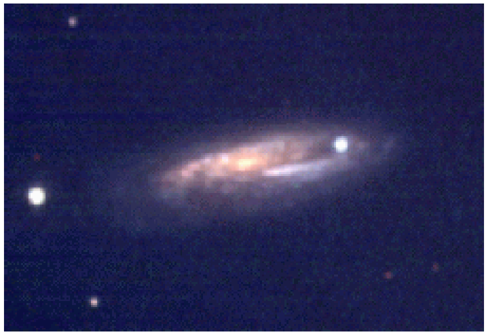
Main neutrino reactions	**Electron flavor**	$\nu_e + n \rightarrow p + e^-$ $\bar{\nu}_e + p \rightarrow n + e^+$
	Other flavors	$\nu + N \rightarrow N + \nu$
Mean free path	$\lambda = (\sigma n_B)^{-1} \approx 28\ \mathrm{cm} \left(\frac{100\ \mathrm{MeV}}{E_\nu}\right)^2$	
Nucleon density	$n_B = \frac{\rho_{nuc}}{m_N} \approx 1.8 \times 10^{38}\ \mathrm{cm}^{-3}$	
Diffusion time	$t_{diff} \approx \frac{R^2}{\lambda} \approx 1.2\ \mathrm{sec} \left(\frac{R}{10\ \mathrm{km}}\right)^2 \left(\frac{E_\nu}{100\ \mathrm{MeV}}\right)^2$	

ν_μ,ν_τ only NC so leave with highest T=8 MeV and <E>~25MeV

$\nu_e,\bar{\nu}_e$ also CC hence leave with lower T=3.5 MeV and 5 MeV ⇒16 MeV and 11 MeV. ν_e have lower energy since the material is n rich and thus they interact more



SN almost as bright as Galaxies!

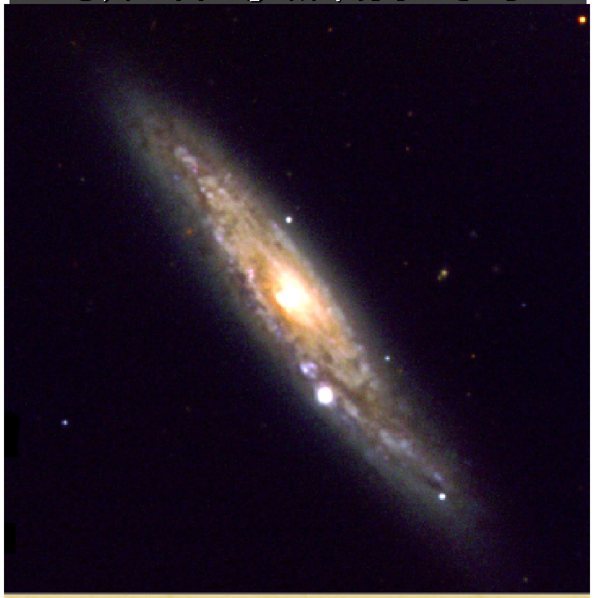




SN 1998dh
in NGC7541

: 2006

SN 1994D in NGC 4526



SN 1998S in NGC 3877

The historical SNs

Over the past 2000 yrs we have historical records of AD 185, 1006, 1054 Crab Nebula, 1181, 1572 Tycho’s SN,1604 Kepler’s SN

http://arxiv.org/pdf/astro-ph/0301603

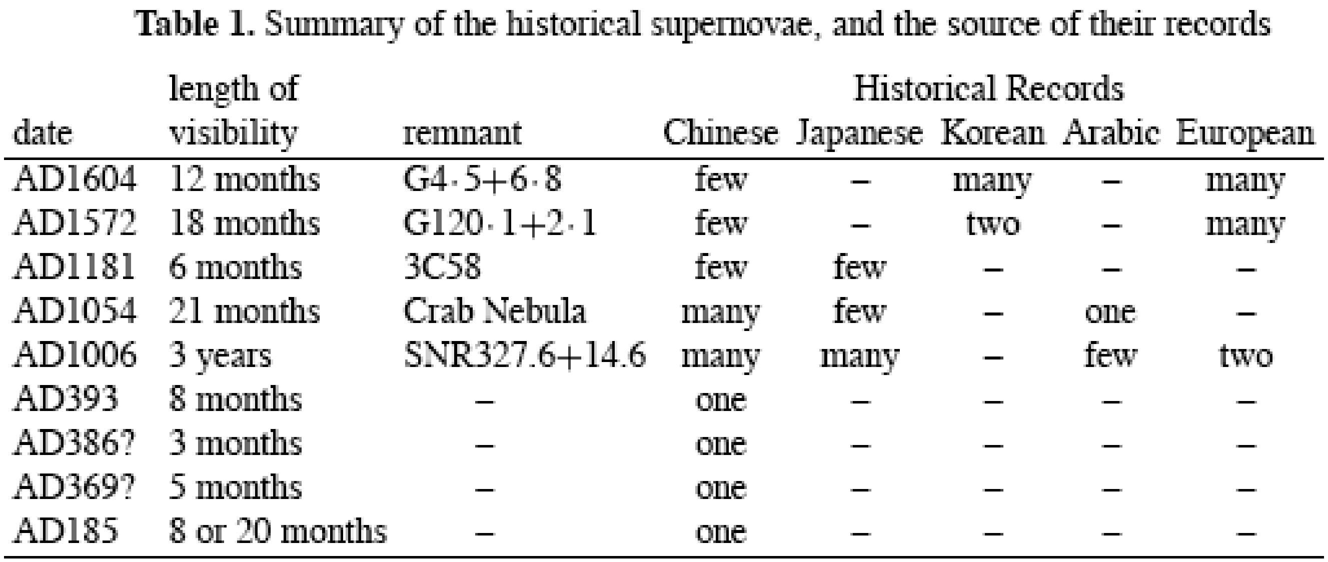
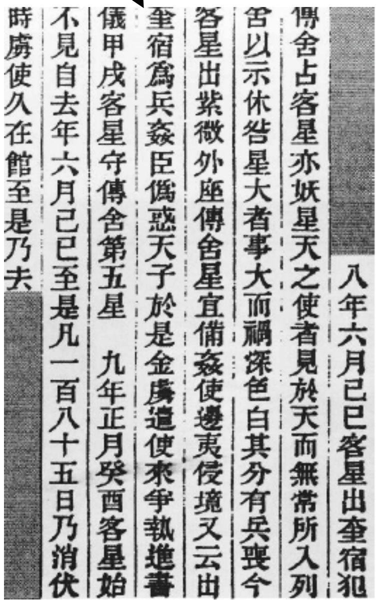


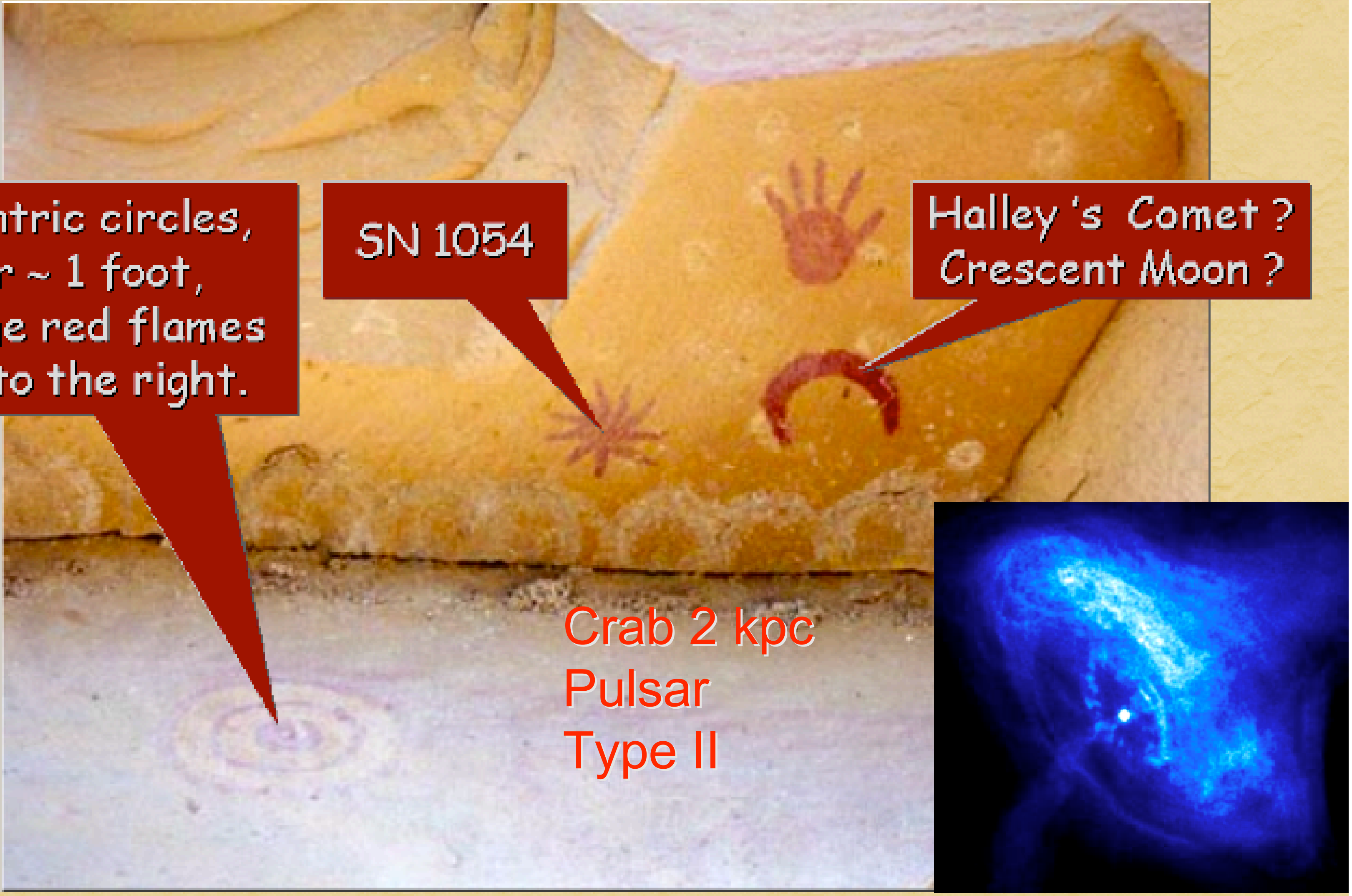
Table 1. Summary of the historical supernovae, and the source of their records

date	length of visibility	remnant	Historical Records				
			Chinese	Japanese	Korean	Arabic	European
AD1604	12 months	G4·5+6·8	few	–	many	–	many
AD1572	18 months	G120·1+2·1	few	–	two	–	many
AD1181	6 months	3C58	few	few	–	–	–
AD1054	21 months	Crab Nebula	many	few	–	one	–
AD1006	3 years	SNR327.6+14.6	many	many	–	few	two
AD393	8 months	–	one	–	–	–	–
AD386?	3 months	–	one	–	–	–	–
AD369?	5 months	–	one	–	–	–	–
AD185	8 or 20 months	–	one	–	–	–	–



八年六月己巳客星出奎宿犯
傳舍占客星亦妖星天之使者見於天而無常所入列
舍以示休咎星大者事大而禍深色白其分有兵喪今
客星出紫微外座傳舍星宜備姦使邊夷侵境又云出
奎宿爲兵姦臣僞惑天子於是金虜遣使來爭執進書
儀甲戌客星守傳舍第五星　九年正月癸酉客星始
不見自去年六月己巳至是凡一百八十五日乃消伏
時虜使久在館至是乃去

Supernova 1054 Petrograph



3 concentric circles, diameter ~ 1 foot, with huge red flames trailing to the right.

SN 1054

Halley 's Comet ?
Crescent Moon ?

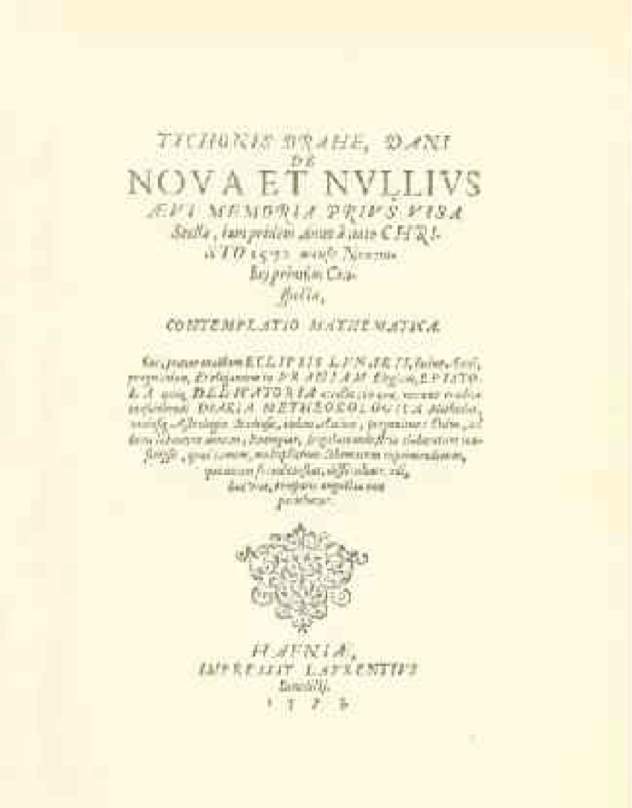
Crab 2 kpc
Pulsar
Type II

Possible SN 1054 Petrograph by the Anasazi people
(Chaco Canyon, South-Western U.S.)

Tycho Brahe 1572

3kpc Type Ia

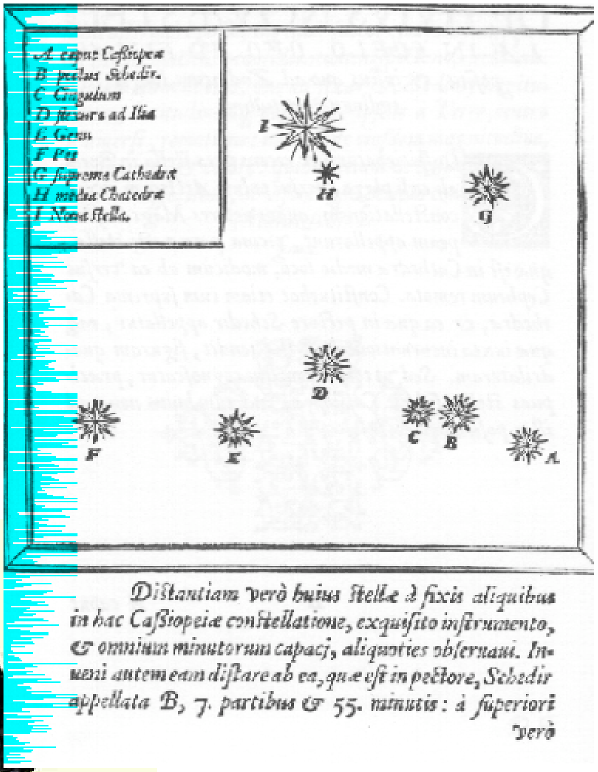
De Nova et nullius aevi
memoria prius visa Stella



TYCHONIS BRAHE, DANI
DE
NOVA ET NVLLIVS
ÆVI MEMORIA PRIVS VISA

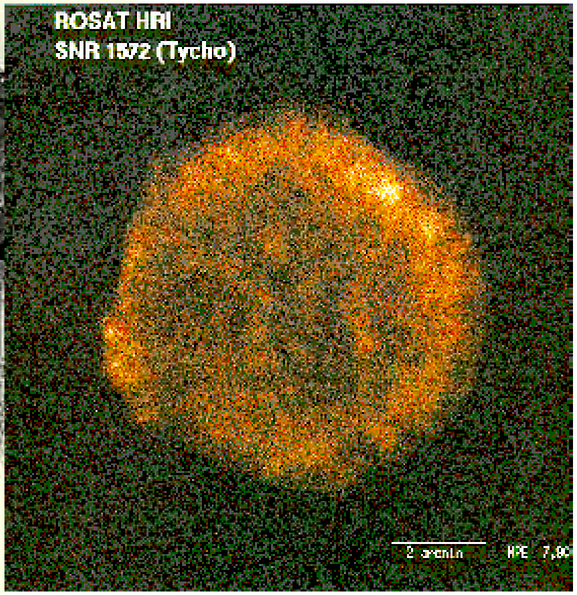
CONTEMPLATIO MATHEMATICA

HAFNIÆ,
IMPRESSIT LAVRENTIVS
Benedicti.
1573.



A caput Caſsiopeæ
B pectus Schedir.
C Cingulum
D flexura ad Ilia
E Genu
F Pes
G ſuprema Cathedræ
H media Chatedræ
I Noua ſtella.

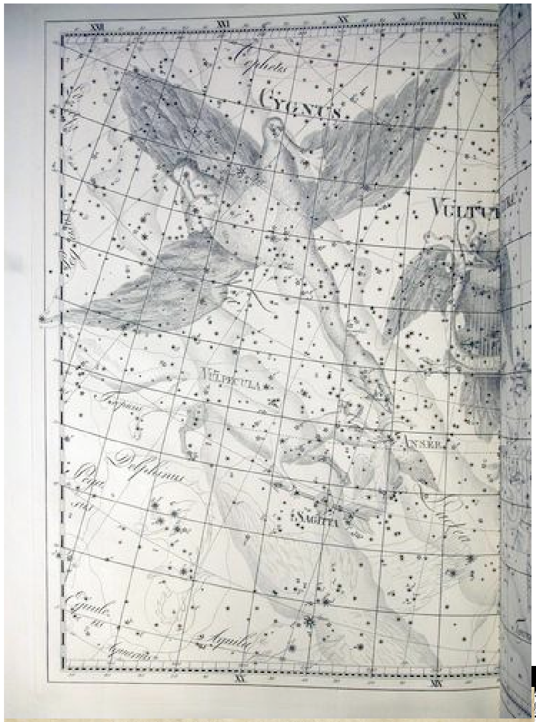
Diſtantiam verò huius ſtellæ à fixis aliquibus in hac Caſsiopeiæ conſtellatione, exquiſito inſtrumento, & omnium minutorum capaci, aliquoties obſeruaui. Inueni autem eam diſtare ab ea, quæ eſt in pectore, Schedir appellata B, 7. partibus & 55. minutis: à ſuperiori verò

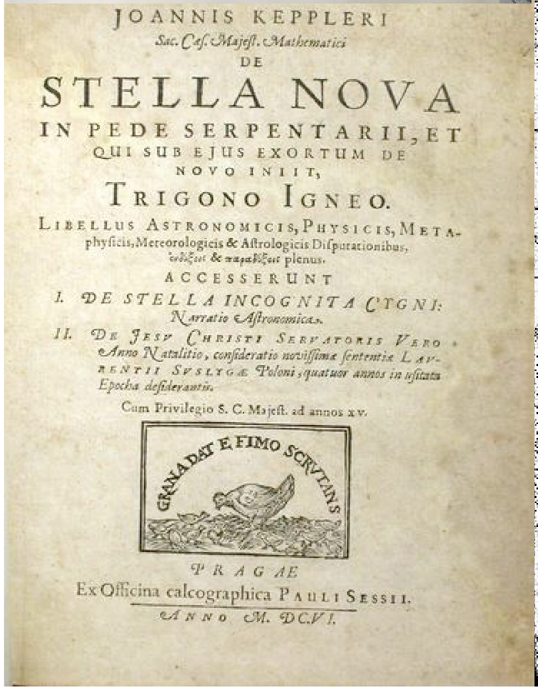


SN 1604

4-8 kpc Type II?

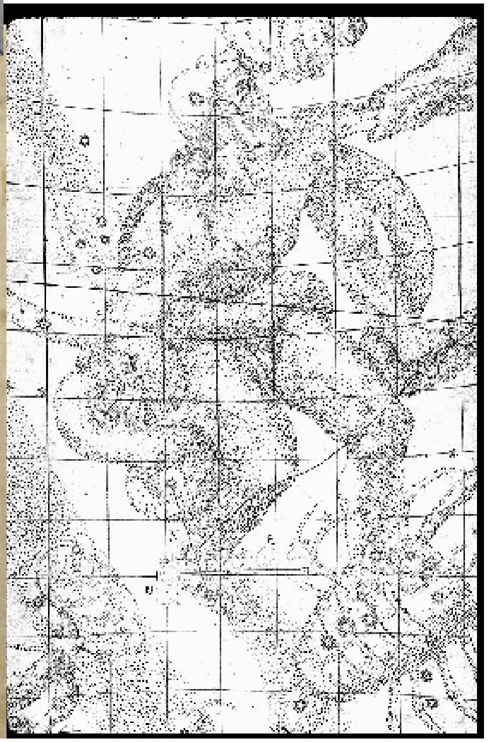
Johannes Kepler,
De Stella Nova in Pede Serpentarii, (1606)

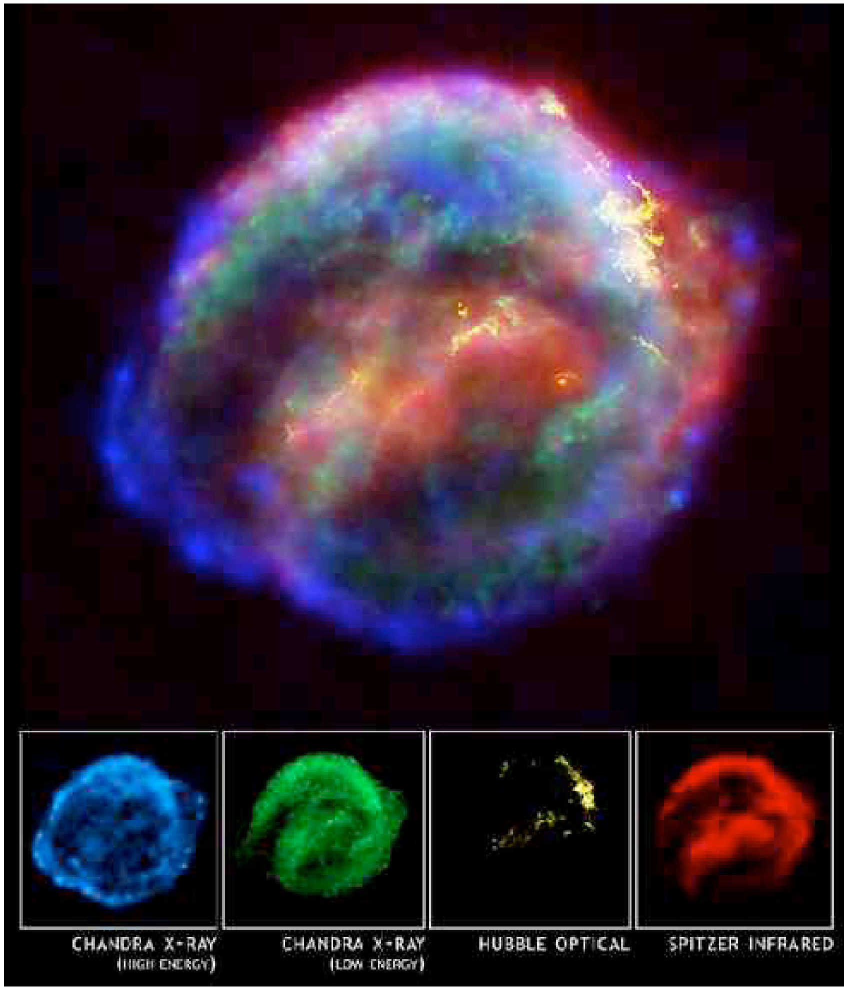




JOANNIS KEPPLERI
Sac. Cæſ. Majeſt. Mathematici
DE
STELLA NOVA
IN PEDE SERPENTARII, ET
QUI SUB EJUS EXORTUM DE
NOVO INIIT,
TRIGONO IGNEO.
LIBELLUS ASTRONOMICIS, PHYSICIS, META-
phyſicis, Meteorologicis & Aſtrologicis Diſputationibus,
ἐνδόξοις & παραδόξοις plenus.
ACCESSERUNT
I. DE STELLA INCOGNITA CYGNI:
Narratio Aſtronomica.
II. DE JESU CHRISTI SERVATORIS VERO
Anno Natalitio, conſideratio noviſſimæ ſententiæ LAU-
RENTII SUSLYGÆ Poloni, quatuor annos in uſitata
Epocha deſiderantis.
Cum Privilegio S. C. Majeſt. ad annos XV.

PRAGAE
Ex Officina calcographica PAULI SESSII.
ANNO M. DCVI.

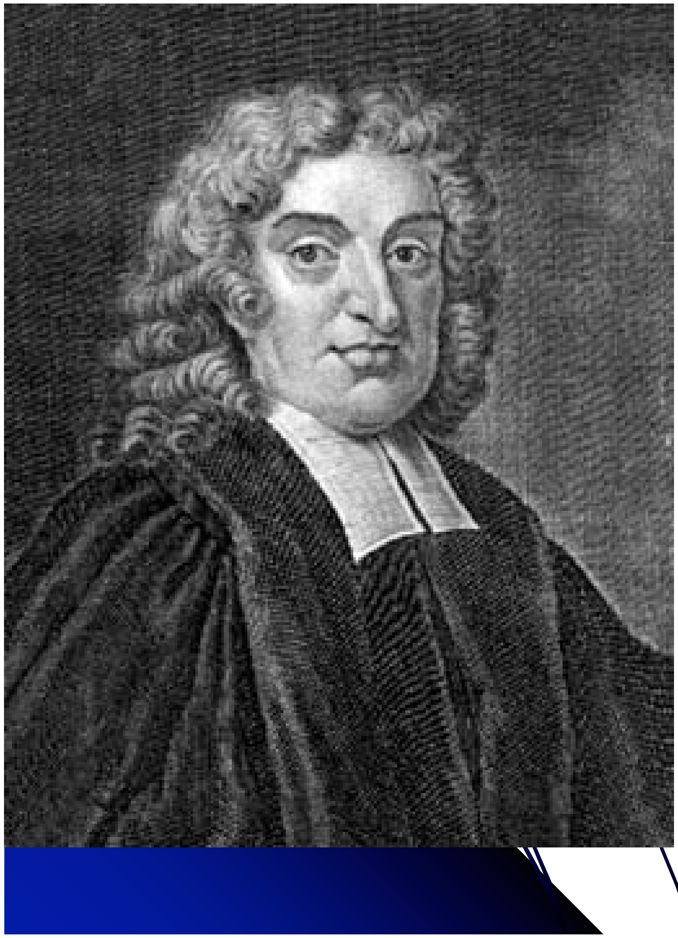


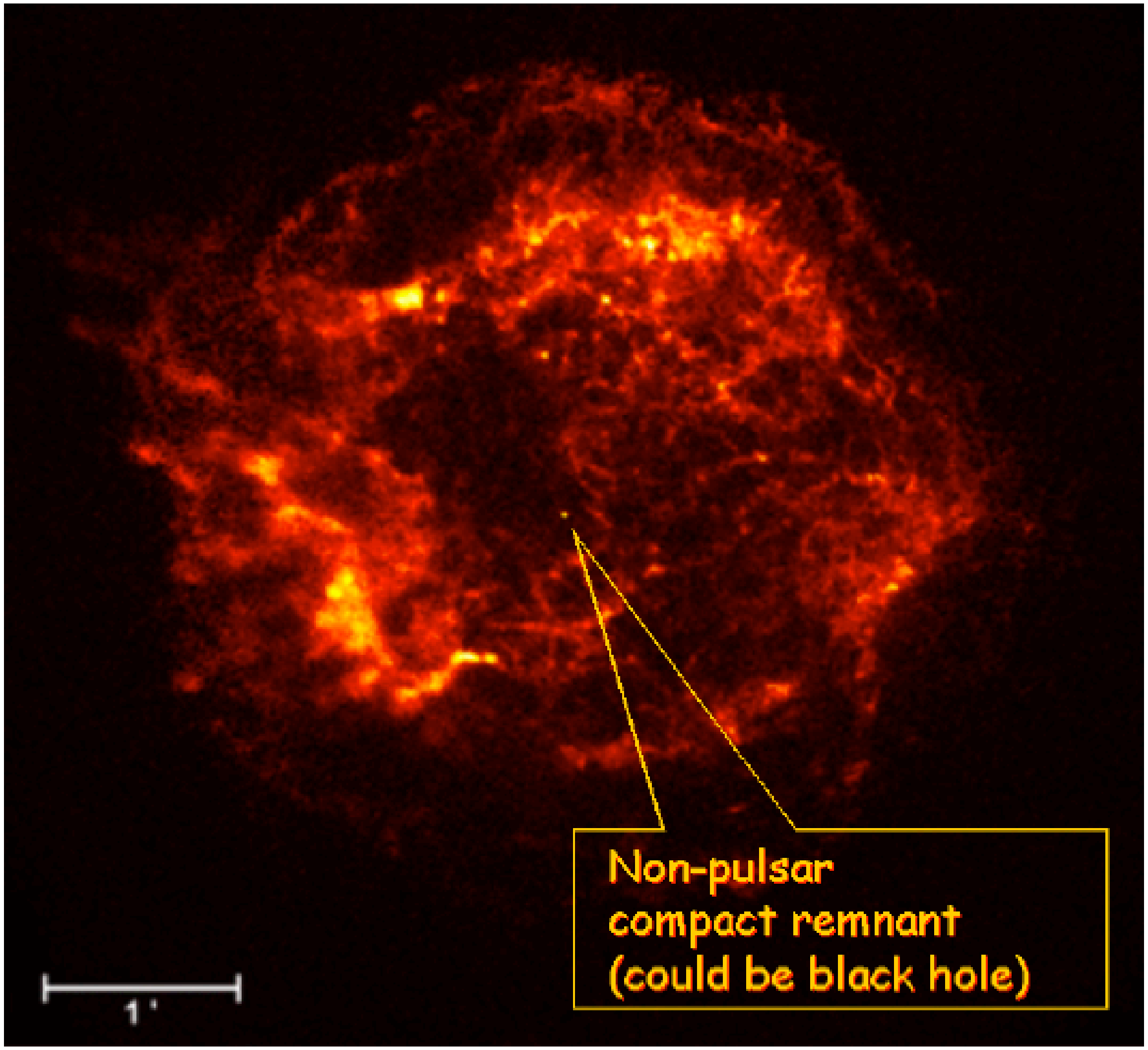


Cassiopeia A

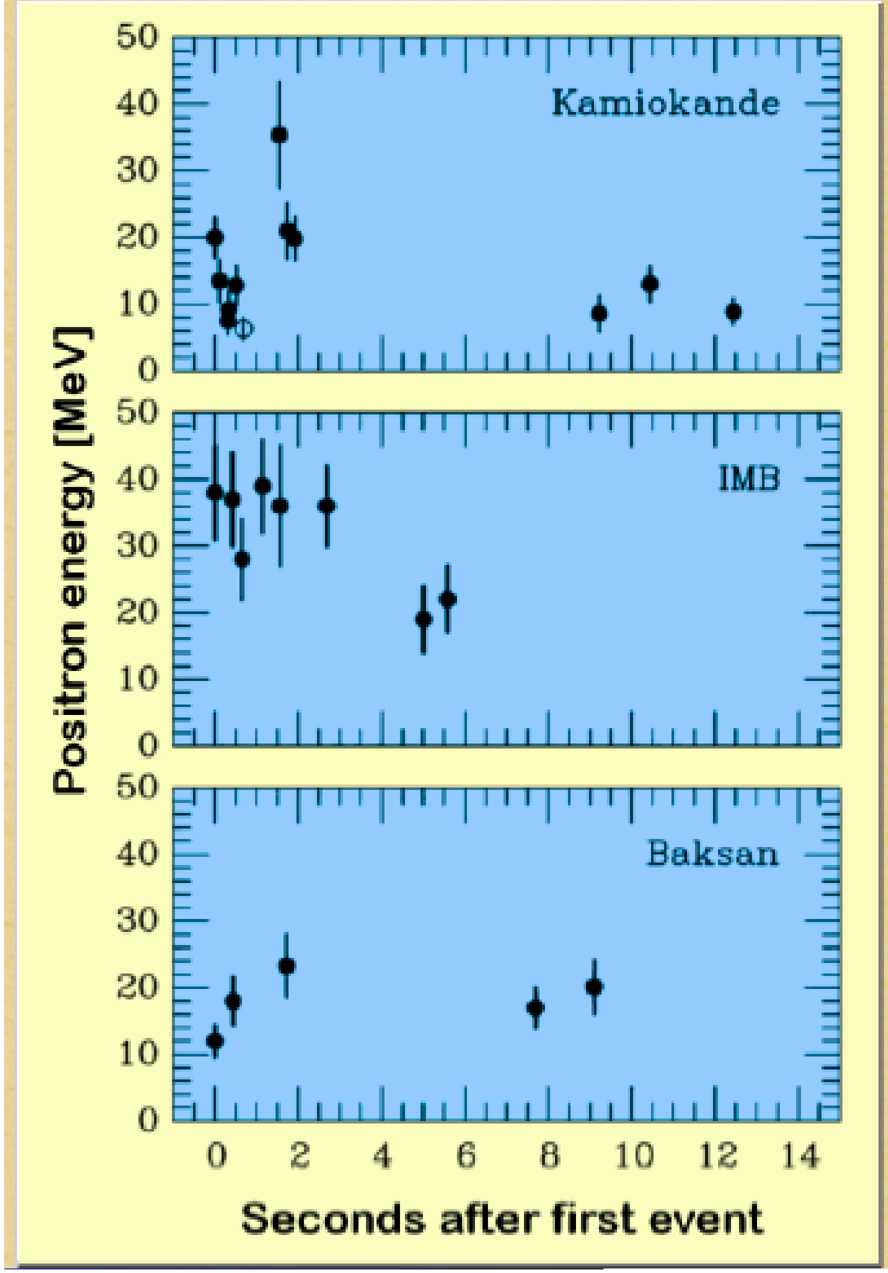
2.8 kpc, neutron star

John Flamsteed
August 16, 1680





Neutrino Signal of Supernova 1987A



Kamiokande (Japan)
Water Cherenkov detector
Clock uncertainty ±1 min

Irvine-Michigan-Brookhaven (US)
Water Cherenkov detector
Clock uncertainty ±50 ms

Baksan Scintillator Telescope
(Soviet Union)
Clock uncertainty +2/-54 s

Within clock uncertainties,
signals are contemporaneous

Detection of SN neutrinos

$E_e = E_\nu$ -1.3 MeV

Largest cross section $\boxed{\bar{\nu}_e + p \rightarrow n + e^+}$

~300 e^+/kt in water

$$\sigma_{\bar{\nu}_e p} \simeq \frac{G_F^2}{\pi} (1 + 3\, g_a^2)\, E_\nu^2 \simeq 9.77 \times 10^{-44} \left(\frac{E_\nu}{1\ \mathrm{MeV}} \right) \mathrm{cm}^2$$

expected rate in Galaxy: 2-4 /century

H₂O Detectors:

SK 22.5 kt (fiducial) 31 Apr 96-15 Jul 01 : search for ν bursts 1704 d E_{th} =6.5 MeV Expected: 3500 events for 10 kpc SN 12 Msun (2% decrease due to Eth changement in SK-II due to 1/2 PMTs), limit on number of explosions/yr: 0.49 SN/yr (90%c.l.) full efficiency up to 100 kpc in SNEWS

AMANDA II 677 Oms V_{eff}/OM~400-500 m^3 4.3 SN/yr (90%c.l.) in Galaxy (Ahrens et al, 2002): expect 15 fake/yr ⇒ SNEWS bckg < 1/week)

SNO 1+1.4 kt (D_2O+H_2O)

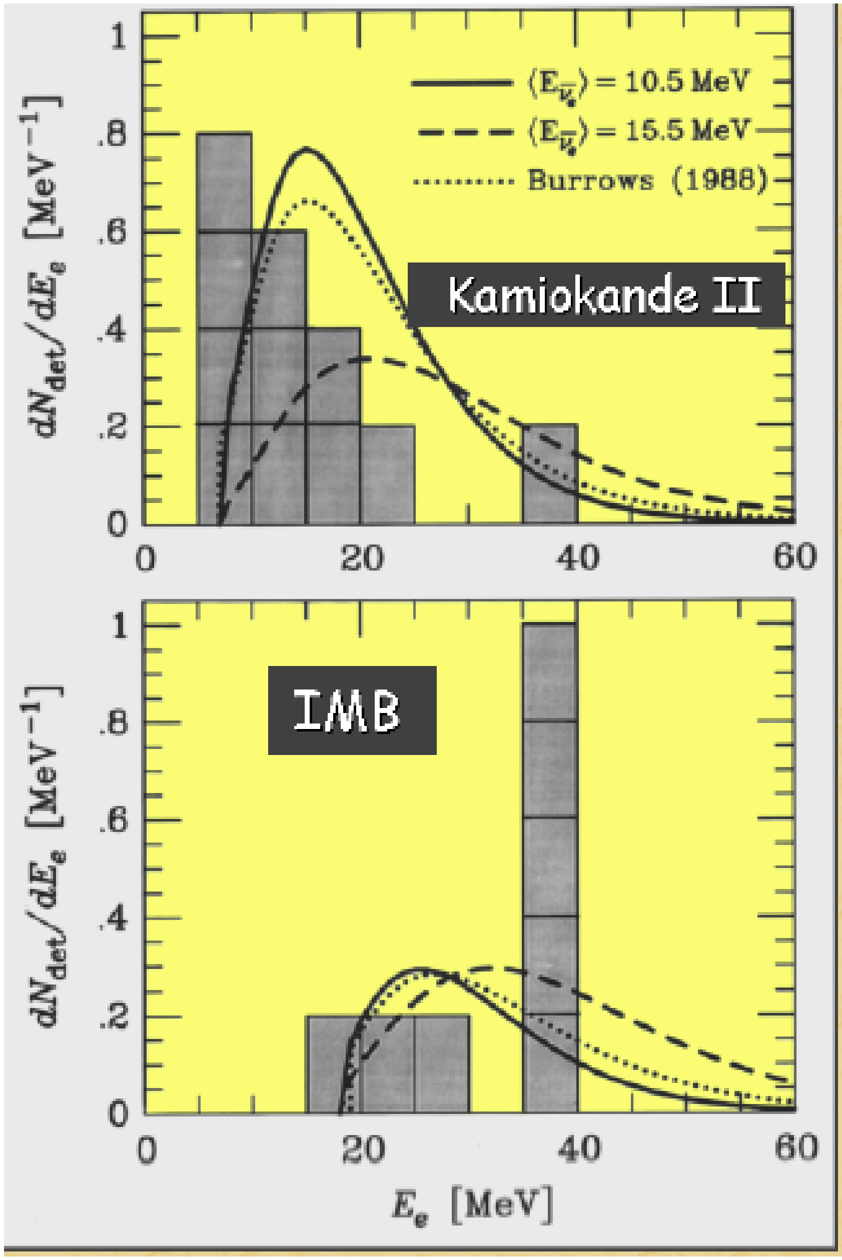
Scintillator detectors

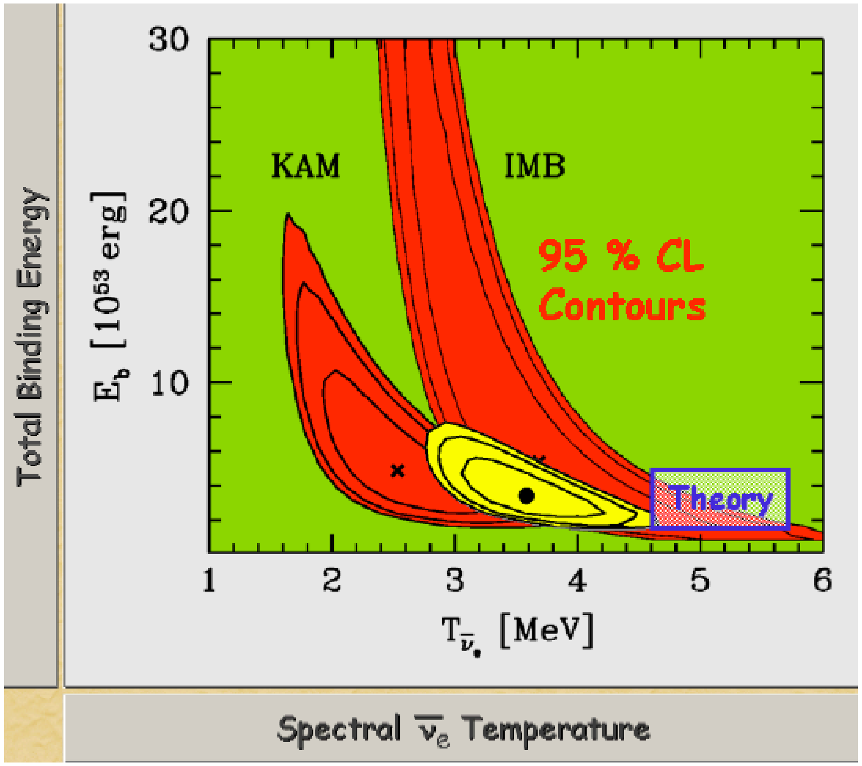
LVD 1 kt (Jun 92 - Mar 03 - Jan 01 final configuration) 3511 d E_{th} =4-7 MeV 0.2 SN/yr (90%c.l.) in Galaxy, in SNEWS since 98

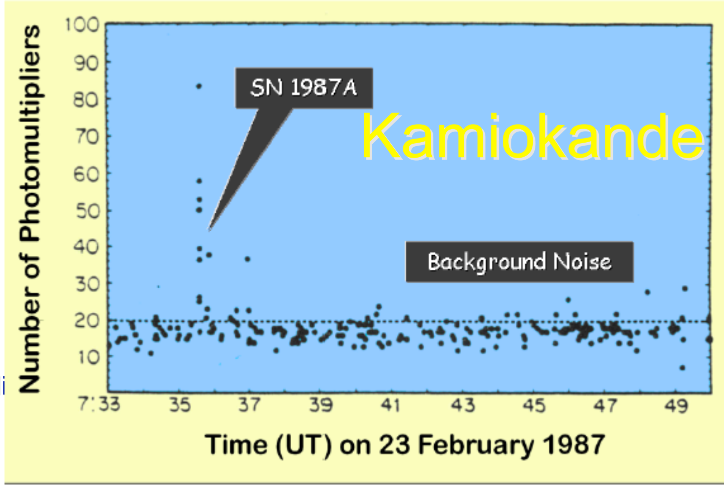
Expected events from SN at 8.5 kpc 320 (210 in MACRO upper limit 0.27 SN/yr)

Others: Kamland (1 kt), MiniBoone (0.6 kt), Borexino (0.3 kt),...

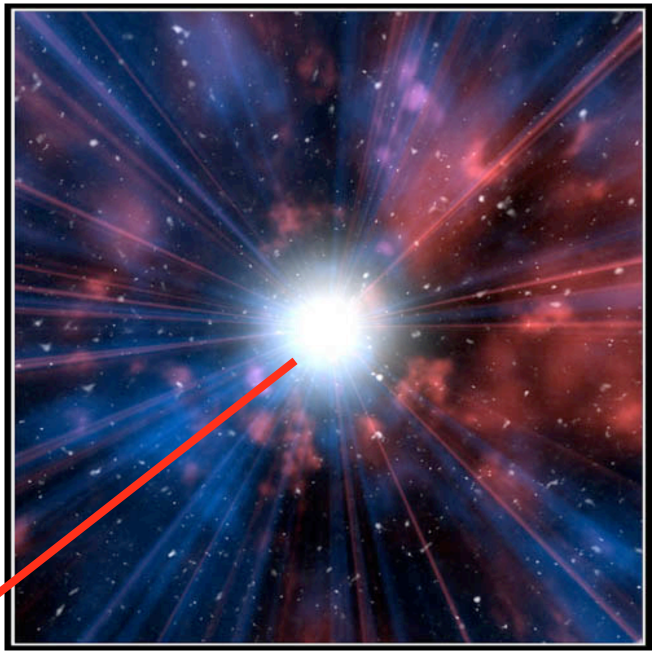
SN1987A

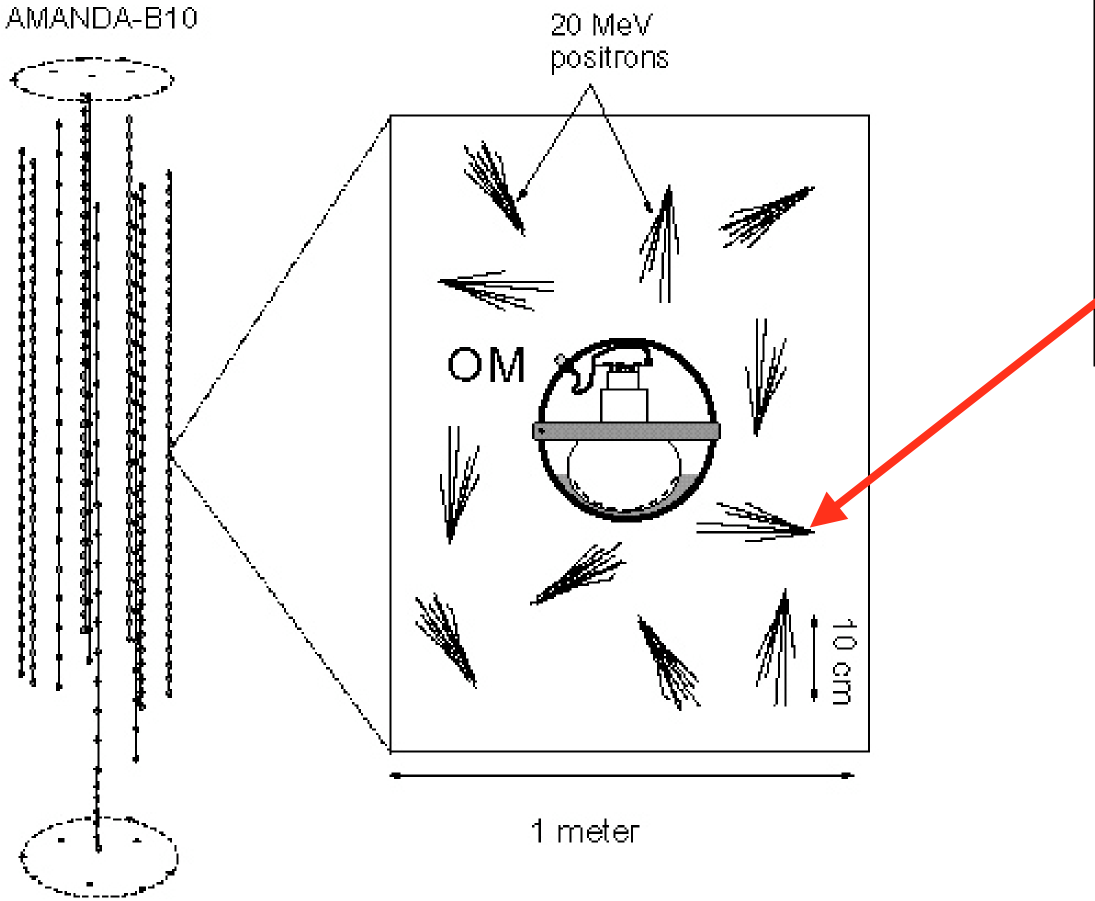

Kamiokande II
$\langle E_{\bar{\nu}_e} \rangle = 10.5$ MeV
$\langle E_{\bar{\nu}_e} \rangle = 15.5$ MeV
Burrows (1988)
dN_{det}/dE_e [MeV^{-1}]
1
.8
.6
.4
.2
0
0
20
40
60
IMB
dN_{det}/dE_e [MeV^{-1}]
1
.8
.6
.4
.2
0
0
20
40
60
E_e [MeV]


Total Binding Energy
E_b [10^{53} erg]
30
20
10
KAM
IMB
95 % CL Contours
Theory
1
2
3
4
5
6
$T_{\bar{\nu}_e}$ [MeV]
Spectral $\overline{\nu}_e$ Temperature

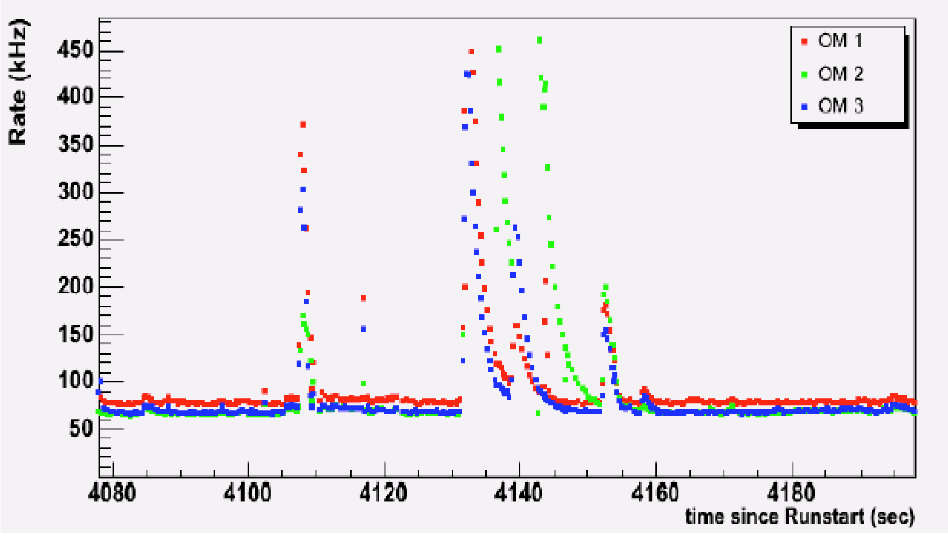

Number of Photomultipliers
100
90
80
70
60
50
40
30
20
10
SN 1987A
Kamiokande
Background Noise
7:33
35
37
39
41
43
45
47
49
Time (UT) on 23 February 1987

AMANDA as supernova detector

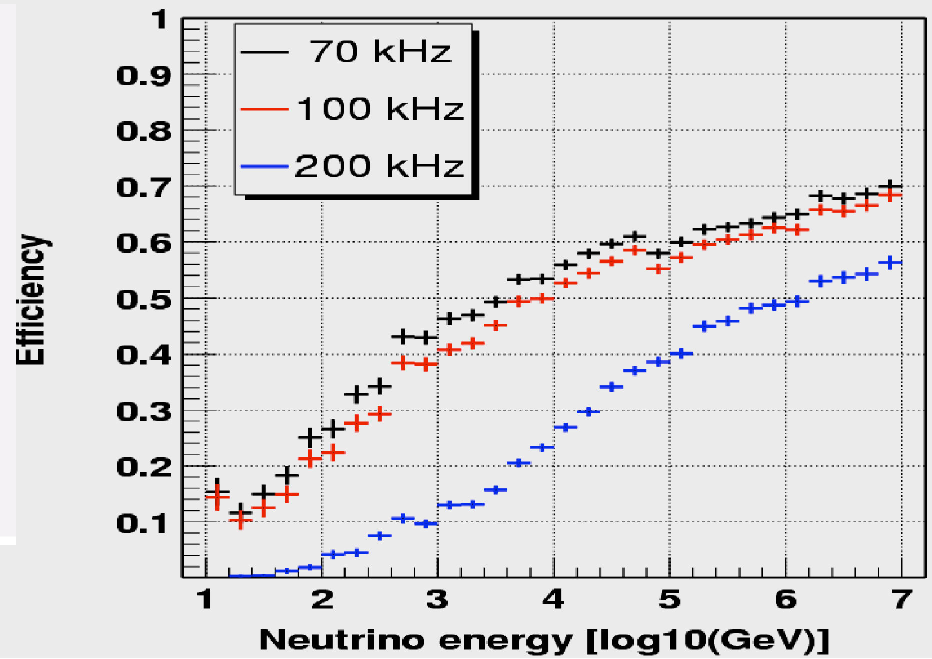




Optical Background and Filtering in ANTARES



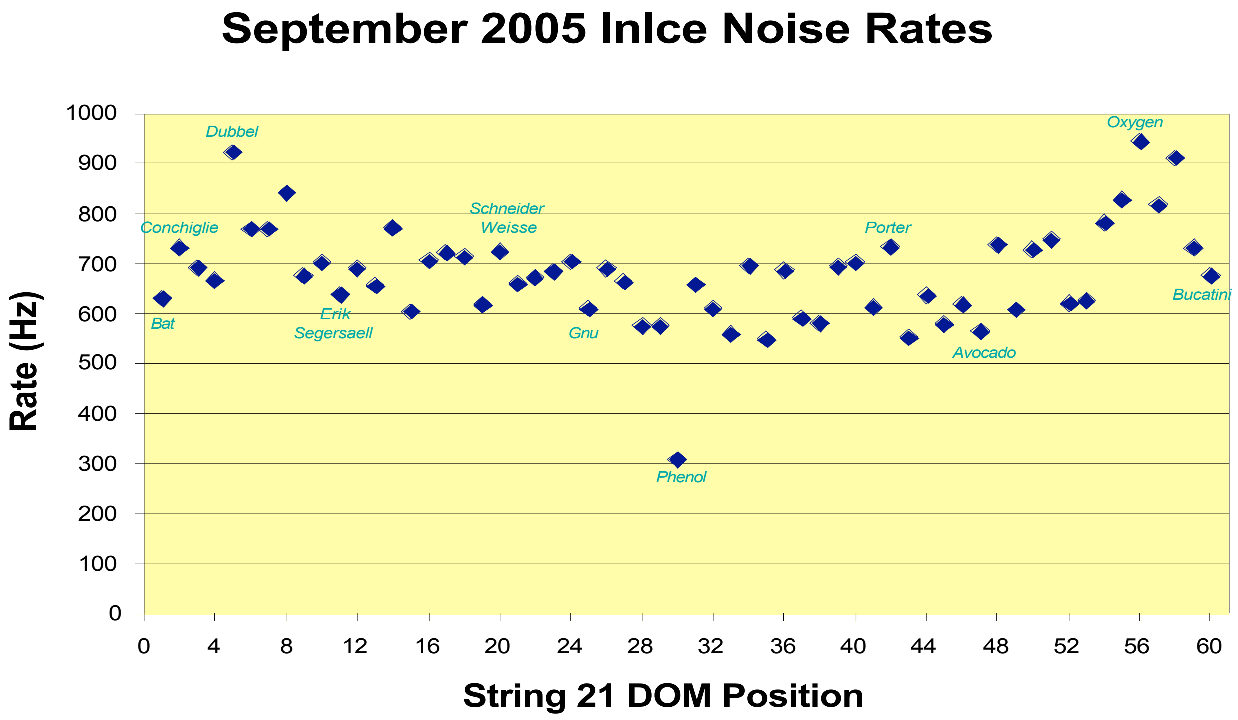
Counting rate due to ^{40}K β decay and bacteria bioluminescence. Bursts are due to macro-organism



All data (>0.3 pe) sent to shore 1GB/s
Offline filter: 1 MB/s casuality condition

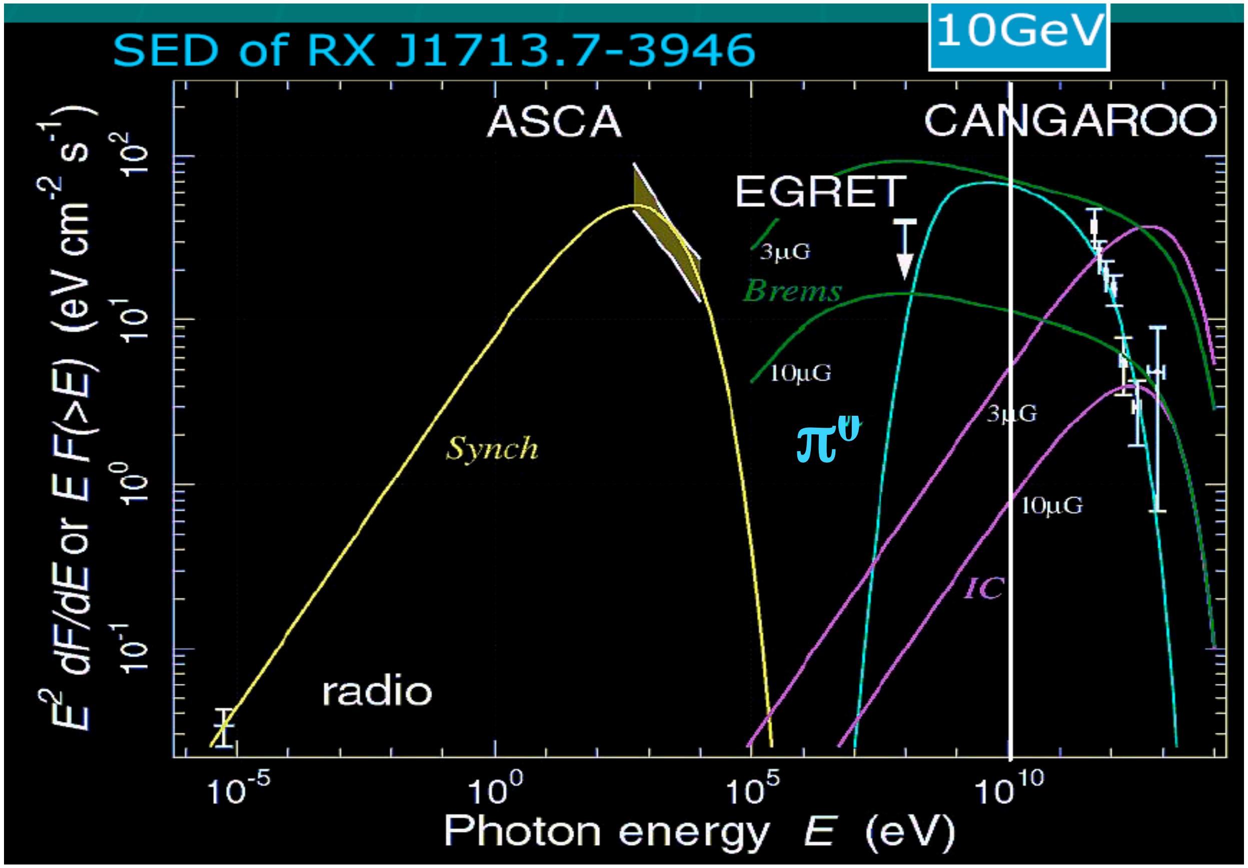
Ice is an extremely quite environment!
1st IceCube string

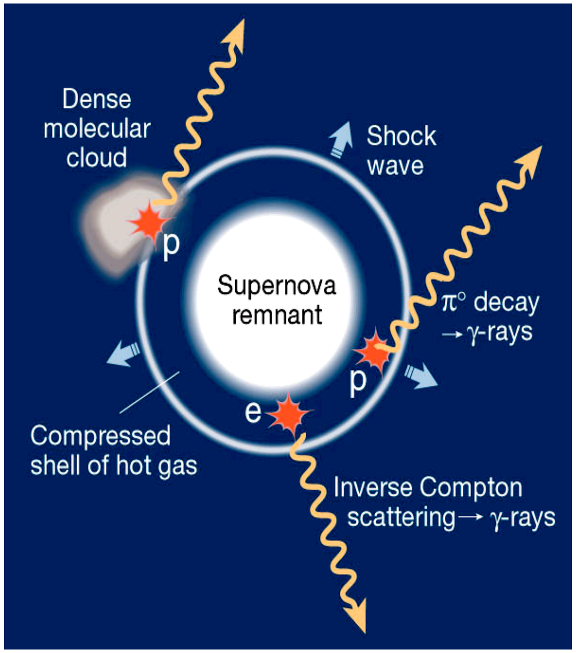
- The IceCube optical sensors were optimized for low noise.
- Research on glass material resulted in lower contamination with radioactivity.
- Fewer background photons from the glass.



Galactic point Sources
The case of RXJ1713.7-3946

Open problem: elusive π^0 produced in accelerated nuclei collisions with SN ambient material Still not a clear evidence BUT…CANGAROO claim

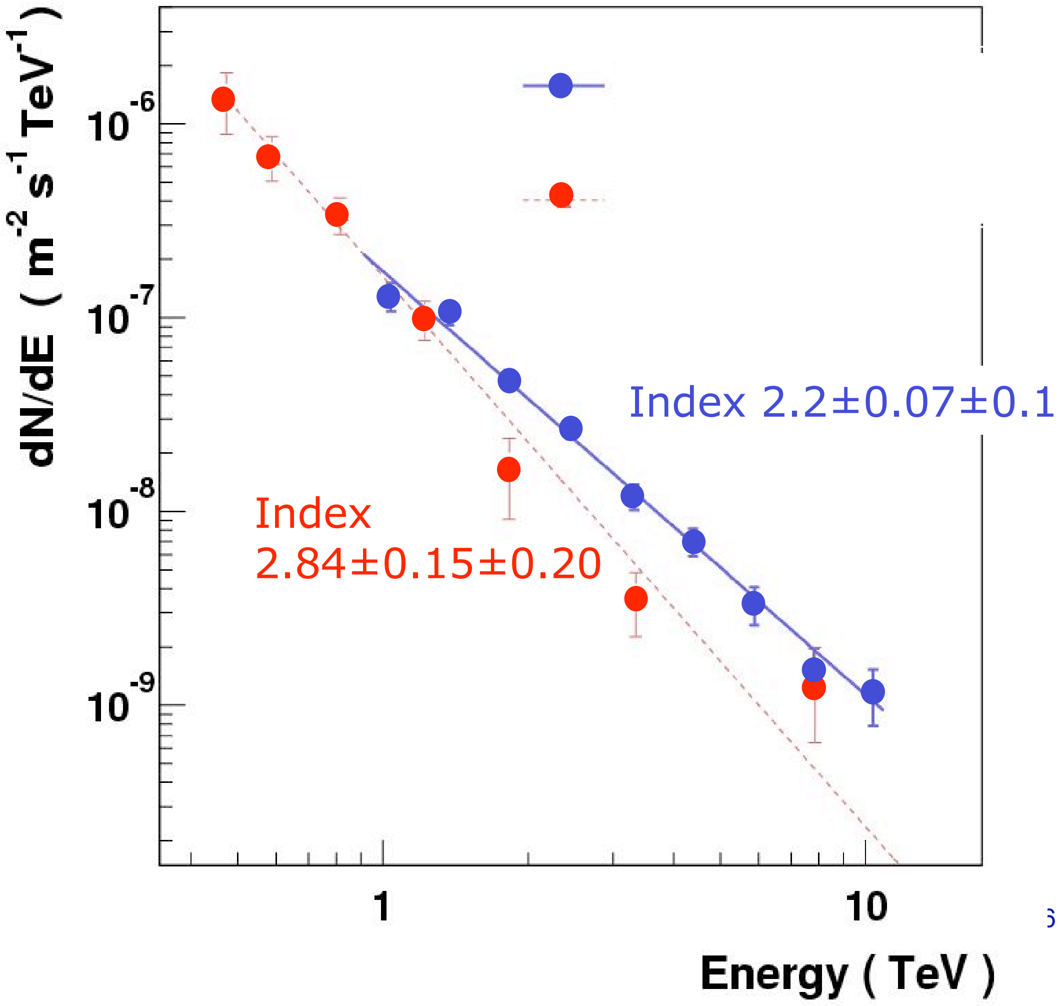


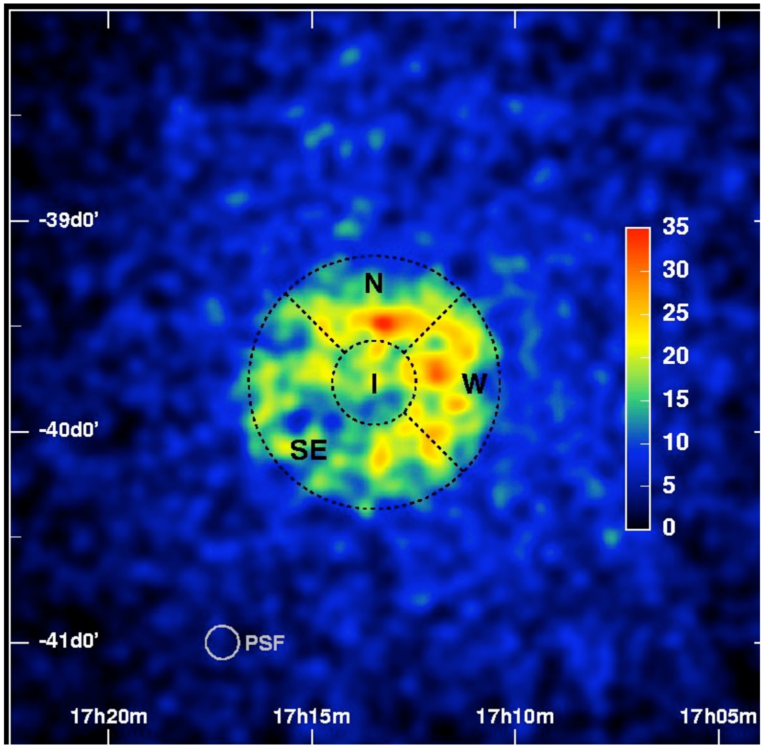


Controversial
Reimer et al., A&A390,2002
Incompatible with EGRET

RXJ1713.7-3946

No cut-off in the HE tail of HESS spectrum favors π^0 decay scenario respect to the case of em processes
Study of electron density and B can help





Predictions Galactic sources

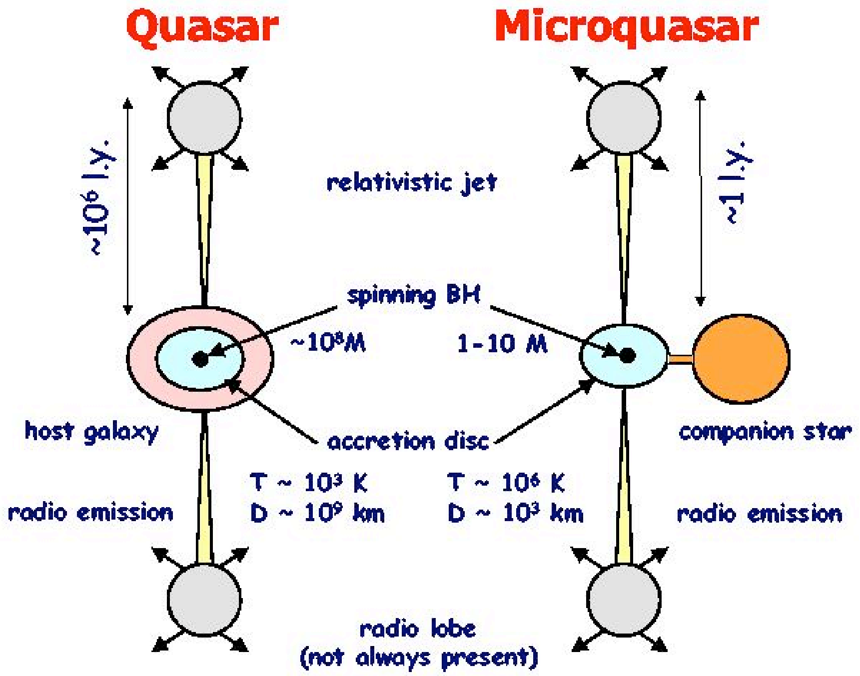
Burgio, Bednarek, TM, New Astron. Rev. 49, 2005

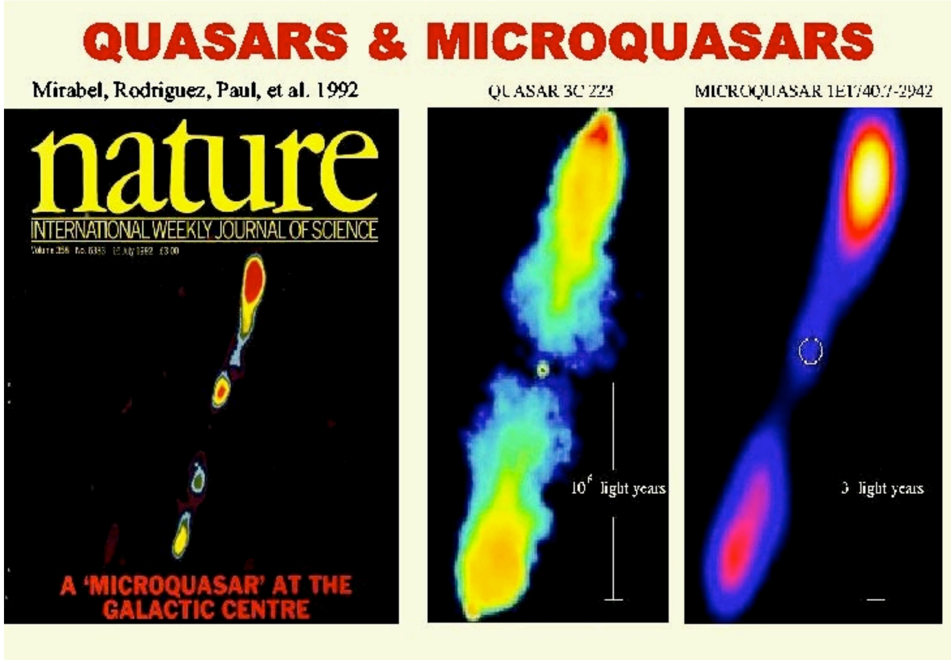
Source Type	Distance (kpc)	E_ν (GeV)	N_ν (km^{-2} yr^{-1})	Ref.
Supernovae	10	<~ 10^3	~100	Waxman & Loeb 2001
Shocks		~ $10^2 – 10^6$	50 – 1000	Protheroe et al. 1998
pulsars		~ $10^5 – 10^8$	~ 100 – 1000	Beall & Bednarek 2002
		~ $10 – 10^8$	<~ 1000	Nagataki 2004
Plerions	0.5 – 4.4	< $10^3 – 10^5$	~ 1 – 12	Guetta & Amatto 2003
		~ $10^3 – 5 \cdot 10^5$	<~ 1	Bednarek 2003
Crab	2	~ $10^3 – 5 \cdot 10^5$	a few	Bednarek & Protheroe 1997
		~ $10^3 – 5 \cdot 10^5$	~ 1	Bednarek 2003
		$10 – 10^6$	~ 4 – 14	Amato et al. 2003
Shell SNRs				
SNR RX J1713.7	6	<~ 10^4	~ 40	Alvarez-Muñiz & Halzen 2002
Sgr A East	8	<~ 10^5	~ 140	
Pulsars + Clouds				
Galactic Centre	8	$10^4 – 10^7$	~ 2 – 30	Bednarek 2002
Cygnus OB2	1.7	>~ 10^3	a few	Torres et al. 2004
		$10^4 – 10^7$	~ 0.5	Bednarek 2003
		<~ 10^6	~4	Anchordoqui et al. 2003
Binary systems				
A0535+26	2.6	$3 \cdot 10^2 – 10^3$	a few	Anchordoqui et al. 2003
Microquasars	1 – 10	$10^3 – 10^5$	1 – 300	Distefano et al. 2002
Magnetars	3 – 16	<~ 10^5	$1.7 (0.1/\Delta\Omega) (5/d^2)$	Zhang et al. 2003

Microquasars

Galactic X-ray binaries with radio relativistic jets: star transferring mass to a compact object (n star or BH). Their structure make them similar to quasars but ~10^6 times smaller. Most have bursting activity (hrs-days)

Persistent: SS433 GX339-4



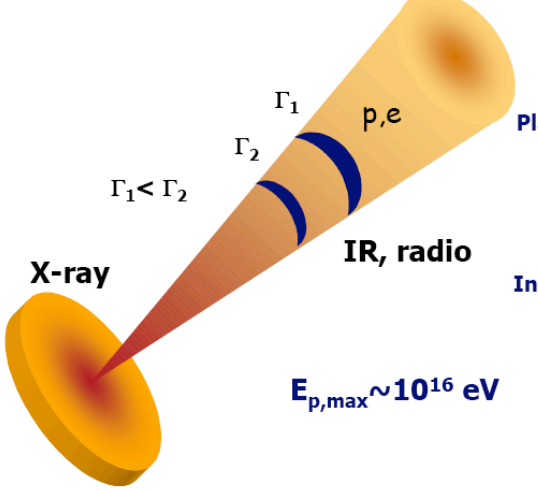


Microquasars

Neutrinos from p-γ interactions (photons from synchr. Emission of electrons accelerated in jet or from accretion disc) Distefano, Waxman et al 2002

Semi-continuous jets with internal shocks

Levinson & Waxman, 2001



Plasma shells with different Lorentz factors collide

Internal shocks propagating along the jet

Acceleration of p-e

$E_{p,max} \sim 10^{16}$ eV

7

Neutrino flux at Earth

ν_μ flux to the Earth

$$f_{\nu_\mu} \sim \frac{1}{2}\eta_p f_\pi \delta^4 \frac{L_{jet}/8}{4\pi D^2}$$

$$1\,\mathrm{TeV} \le E_{\nu_\mu} \le 100\,\mathrm{TeV}$$

Kinetic luminosity

$$L_{jet} \geq \frac{7c}{24}\frac{(\Gamma \ell B_*)^2}{\eta_e}$$

η_p~10%: fraction of the jet energy injected as Fermi protons

L_{jet}: kinetic luminosity of the jet

δ: jet Doppler factor $\delta=[\Gamma(1-\beta\cos\theta)]^{-1}$

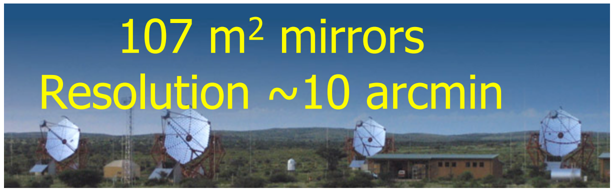
D: source-Earth distance

η_e: fraction of jet energy carried by e+B

$\Gamma \sim 1$

ℓ: linear size of the blob

\

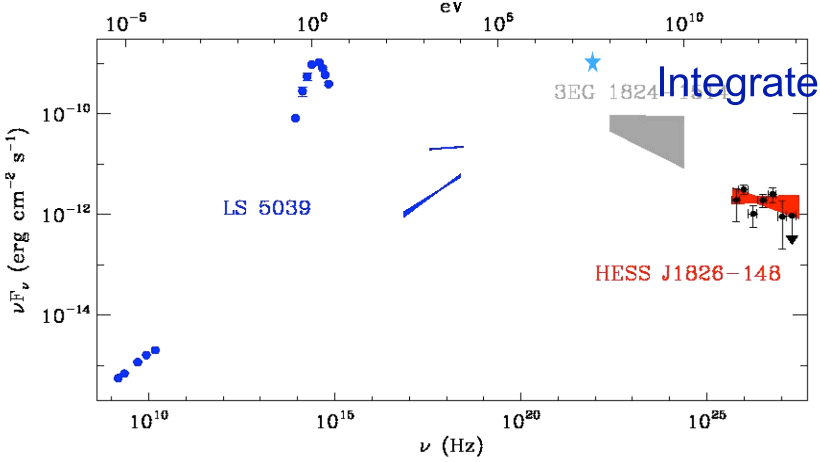


107 m² mirrors

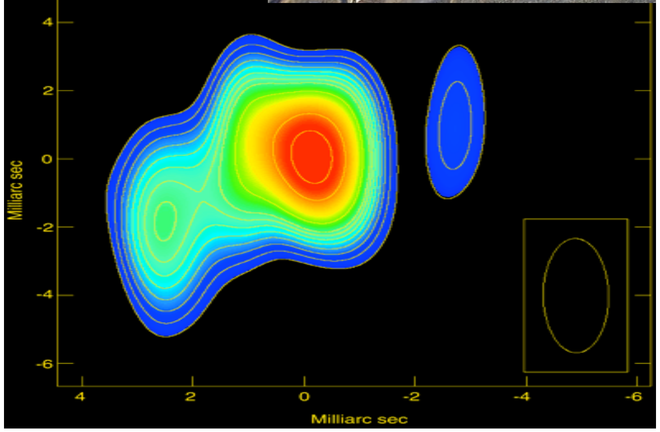
Resolution ~10 arcmin

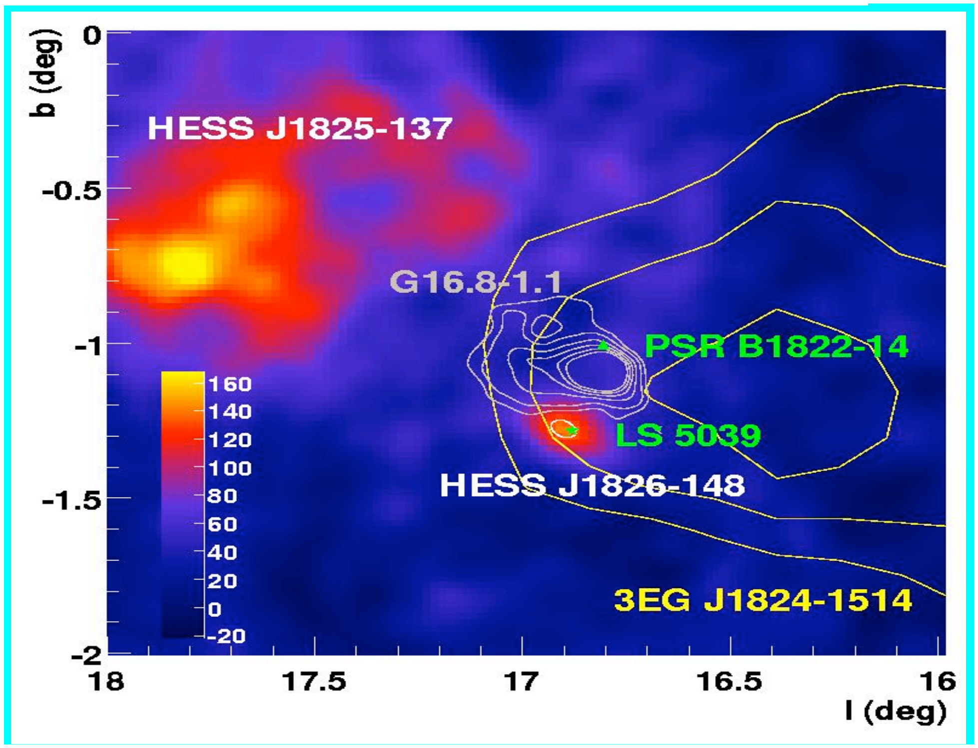
LS5039

Very Large Array



Integrated Comptel





Apr. 2006

Source angular size ~ 50 arcsec

Source distance ~ 2.5 kpc

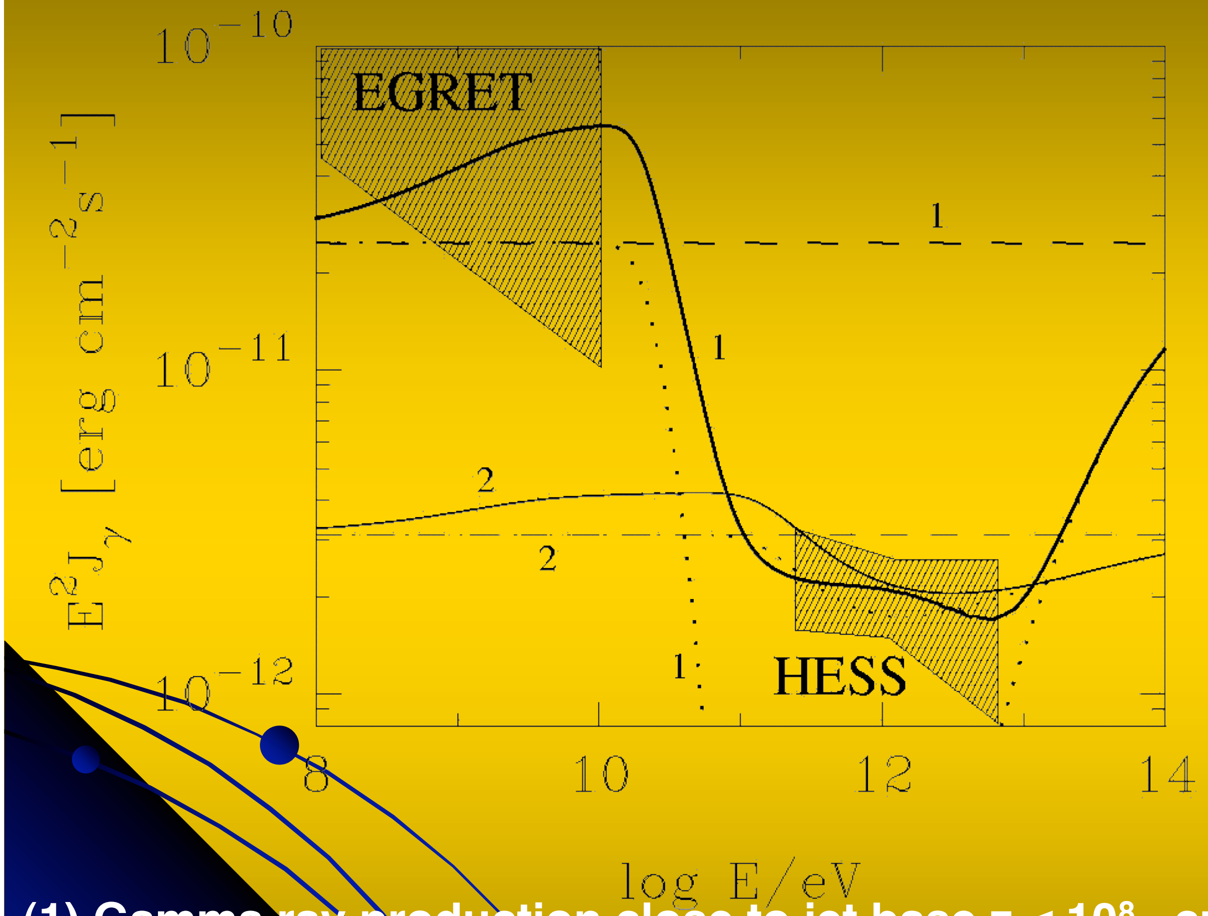
Gamma rays within radius ~ 0.6 pc

Likely to be associated to

3EG J1824-1514

Hard E^{-2} spectrum

Time averaged gamma ray spectra



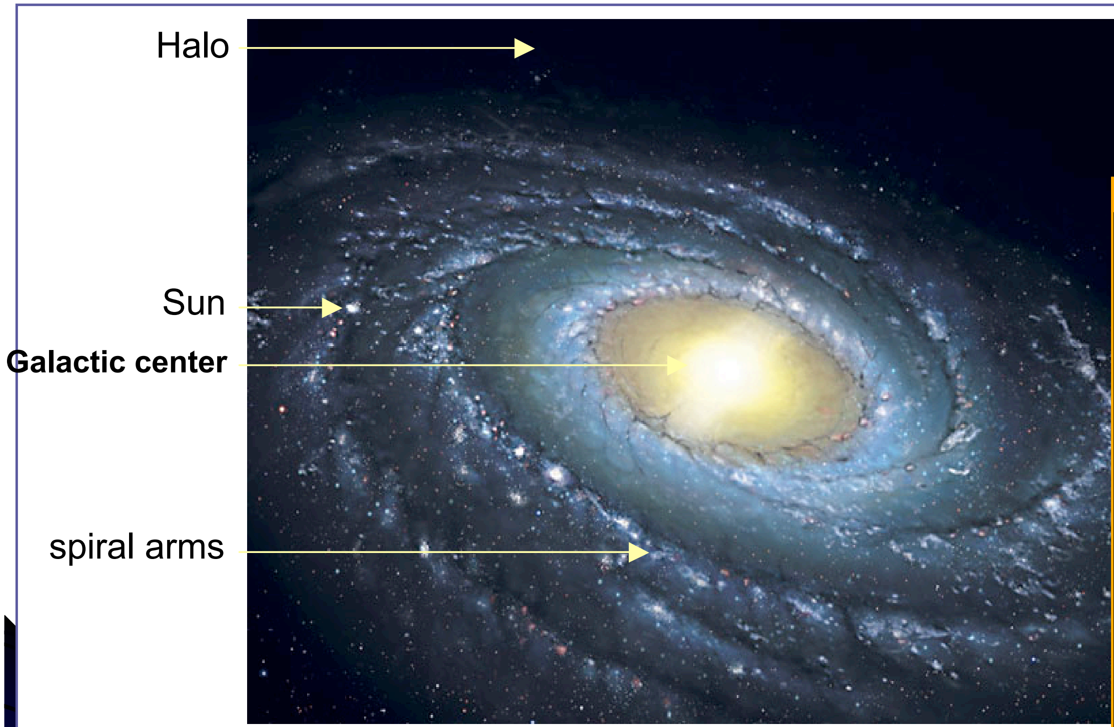
Absorption by synchrotron ….

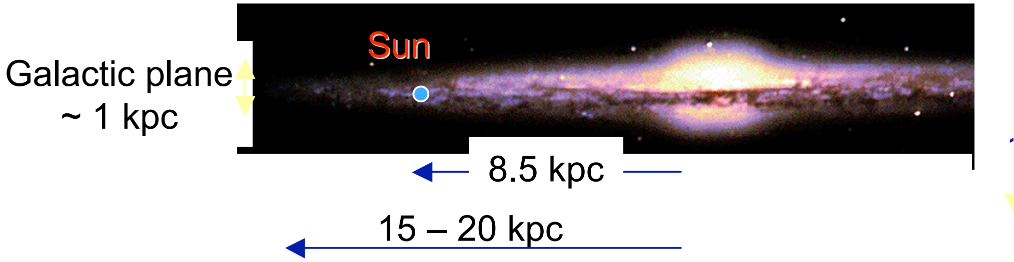
cascading __

(1) Gamma ray production close to jet base $z < 10^8$ cm (more absorption, larger flux at low energy)

(2) Gamma ray production far from jet base $z < 10^{13}$ cm

The Galaxy





1 pc = 3.3 ly

Theorical hypothesis

Equilibrium between CR, B and ISM.

Propagation

Electromagnetic interactions

- *Energy losses*
- *Diffusion on magnetic field and galactic winds*
- *Reacceleration*

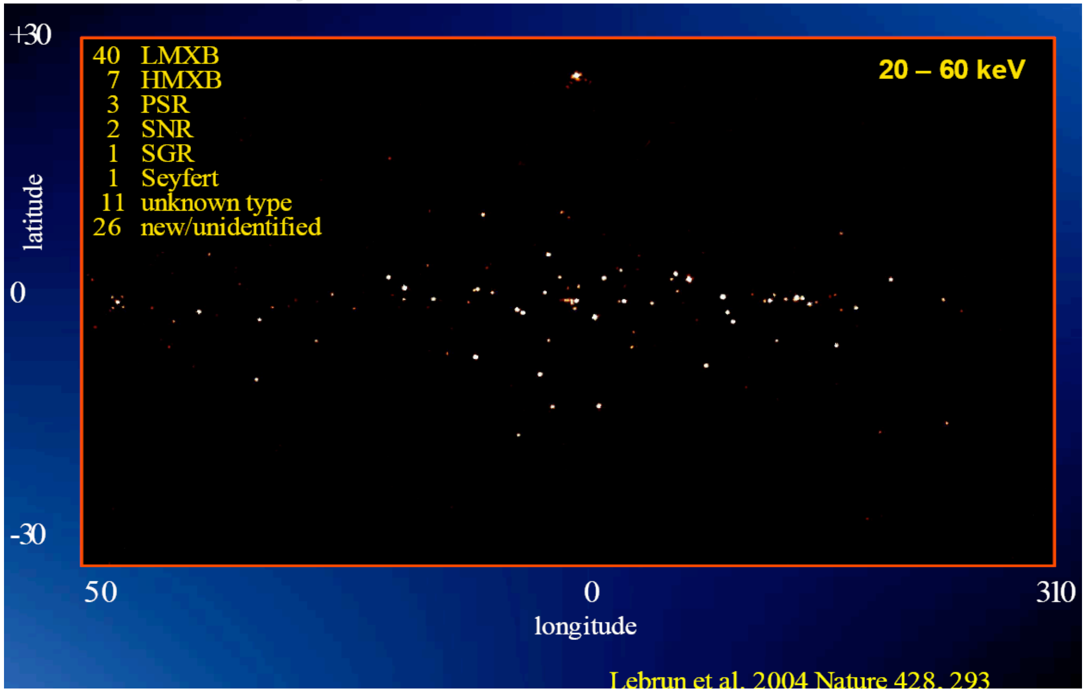
- *Decays*
- *Spallation*
- *Neutrinos from pp collisions*

γ observations

- EGRET observed a diffuse emission 100MeV-10 GeV from Galactic Centre region (300 pc): excess > factor 10 around 1 GeV
- *INTEGRAL: resolved 91 point sources. 90% of 'diffuse' flux can be due to point sources <100 keV*
- Milagro: discovery of TeV emission (astro-ph/0502303)

  4.5σ excess from $|b|<5^\circ$ and $l \in [40^\circ, 100^\circ]$

Covered pond with 2 layers of PMTs, from relative timing 0.75˚ shower direction resolution, gamma-hadron discrimination based on shape of Cherenkov light emitted by showers

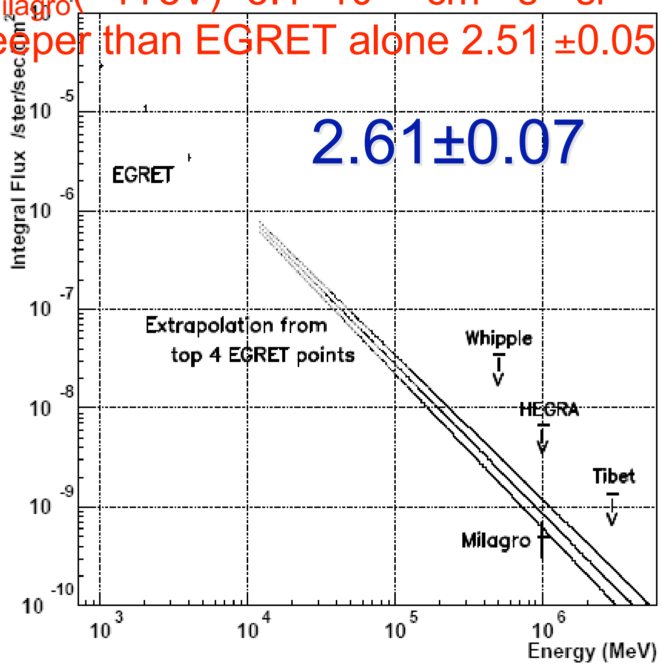


Lebrun et al. 2004 Nature 428, 293

$\Phi_{Milagro}(>1\text{TeV})=5.1 \cdot 10^{-10}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1}$

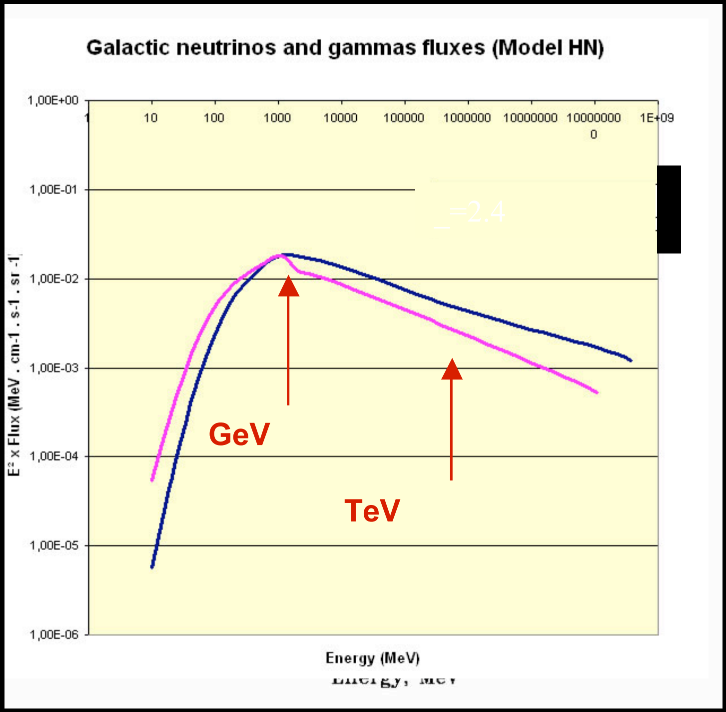
Steeper than EGRET alone 2.51 ±0.05

2.61±0.07

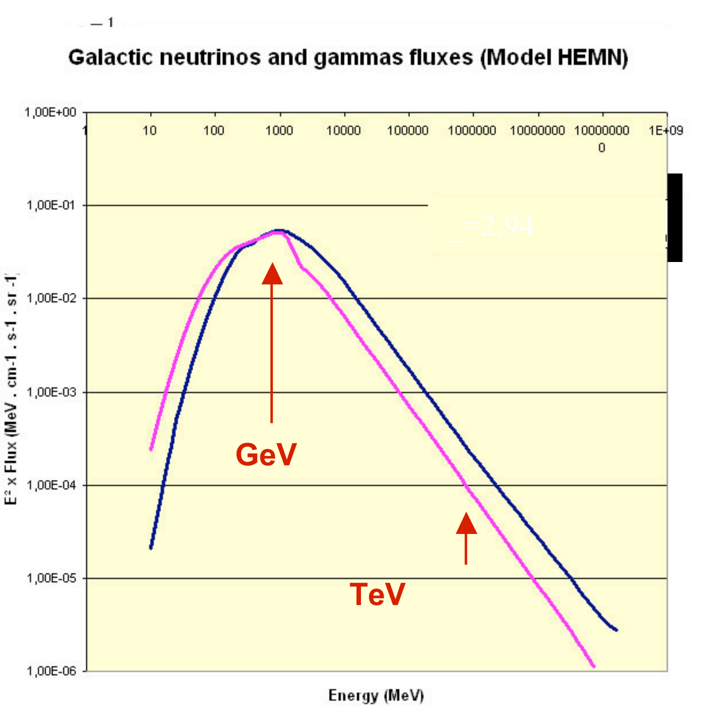


Extreme Models

Hard nucleus model $E^{-2.4}$



Hard electron model $E^{-2.9}$



For $E^{-2.4}$ 20 years of ANTARES to have 88% discovery prob

$$\frac{d\phi(E)}{dE} = A.E^{-\gamma}$$

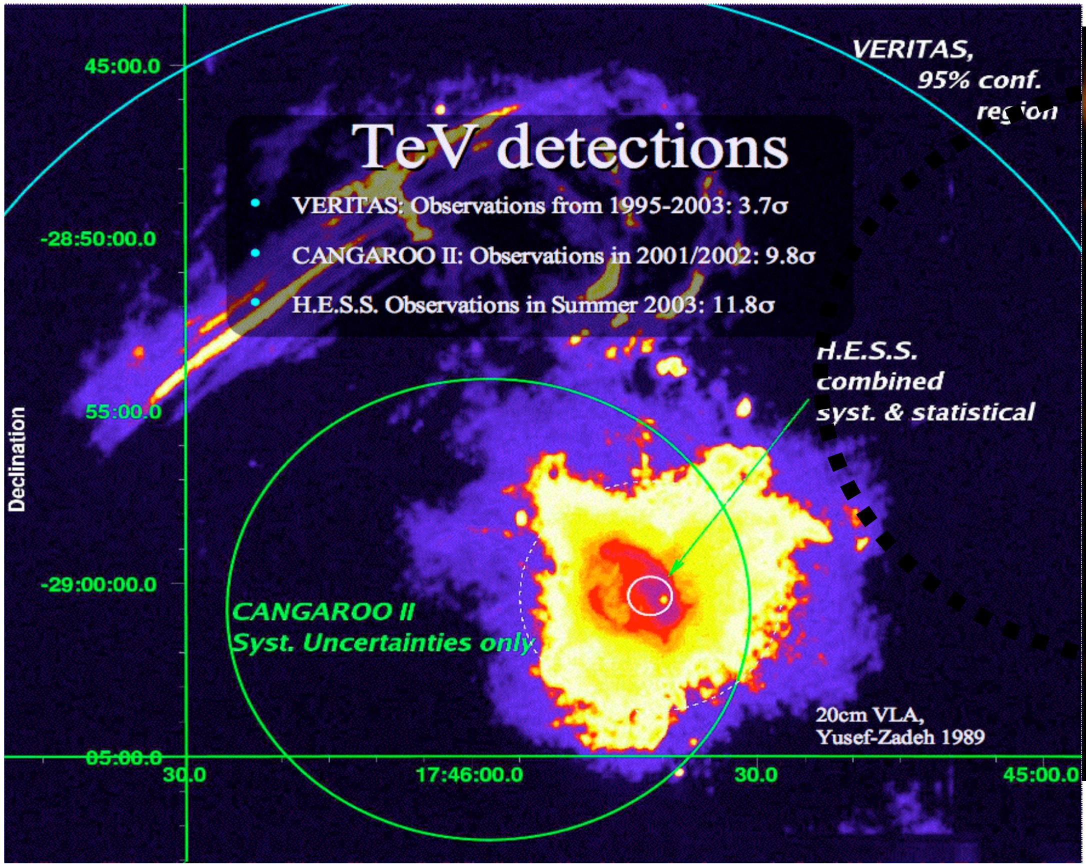
— Gamma from π^0

— Nu mu + anti nu mu

Galactic Centre

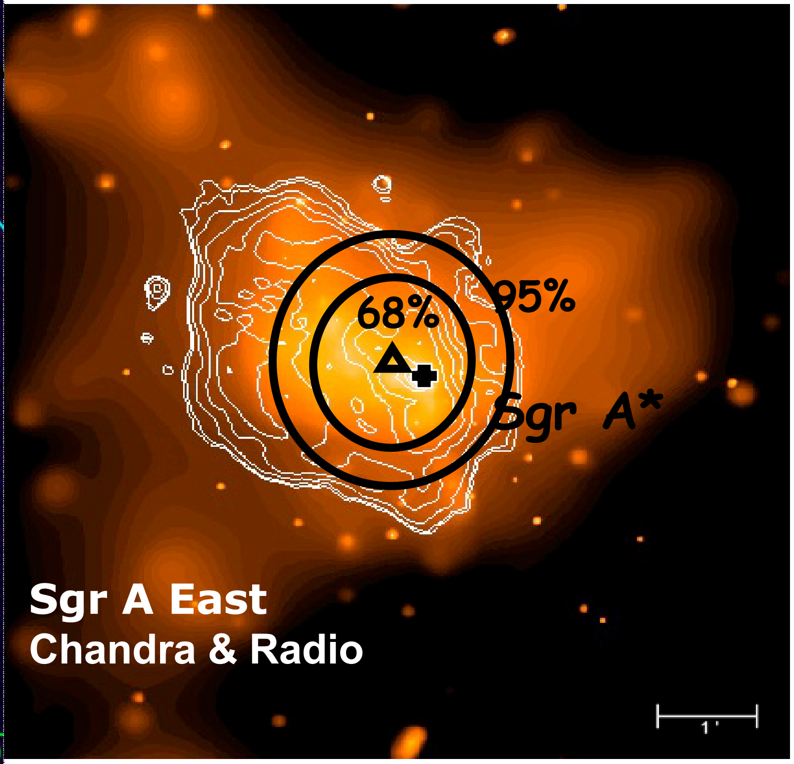
- High matter density and activity
- compact radio source Sgr A* possibly associated to black hole ~3 10^6 M_{sun} in the center
- Sgr A East SNR

HESS TeV-γ spectrum in disagreement with the other experiments Variability? localization? HESS 1 arcmin



TeV detections

- VERITAS: Observations from 1995-2003: 3.7σ
- CANGAROO II: Observations in 2001/2002: 9.8σ
- H.E.S.S. Observations in Summer 2003: 11.8σ

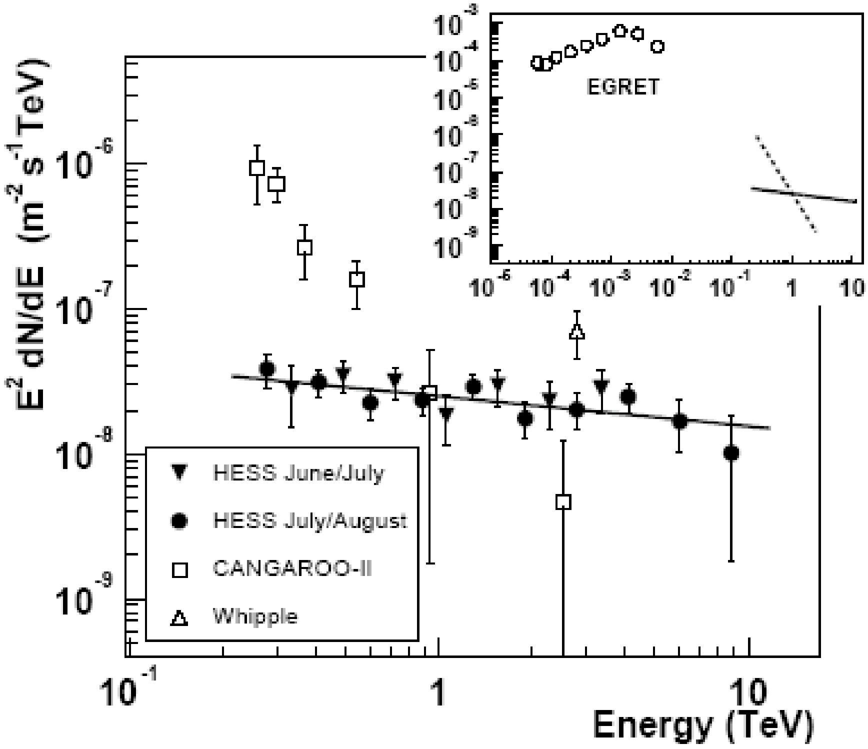


High Energy Stereoscopic System

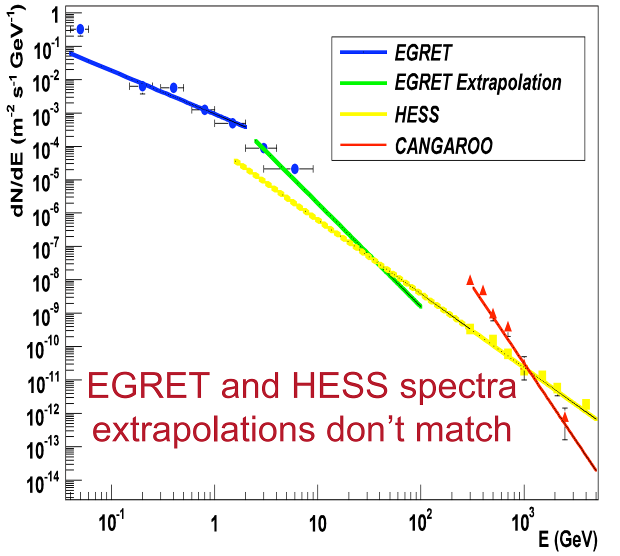
Four 12 m diameter telescopes running since ~ 1yr in Namibia (+1 large) E_{th} ~ 100 GeV

Cherenkov light is emitted by showers induced by high-energy gamma rays This light is very faint - about 10 γs/m^2 at Eγ=100 GeV - and the duration of the light flash is only a few nsec. Large mirrors, fast photon detectors and short signal-integration times are required to collect enough light from the shower, with minimal contamination from night-sky background light.

γ direction < 0.1°



Neutrinos flux with different constraints



EGRET and HESS spectra extrapolations don't match

Crocker, Melia, Volkas, 2005

E_μ>1TeV dΩ<0.5°		ANTARES			KM3
Not optimized **PRELIMINARY**		Signal events /year	Bkg events /year	Time for detection (4 σ CL)	Time for detection (4 σ CL)
GC	HESS	$2\ 10^{-2}$	$7\ 10^{-3}$	247 yr	6.2 yr
	HESS+EHECR	$5\ 10^{-2}$		64 yr	1.7 yr
	EGRET+EHECR	2.6		0.4 yr	week
RX J1713.7 -3946	Constantini et al (2005)	0.16	$9\ 10^{-3}$	15 yr	0.4 yr
	Halzen et al (2002)	0.95		1.8 yr	3 weeks
PSR B1509-58	HESS	0.11	$1.1\ 10^{-2}$	22 yr	0.6 yr

HESS+EHECR $dF/dE_{\nu\mu+\overline{\nu\mu}} = 1.3 \times 10^{-5}\ E^{-2.0}\ m^{-2}\ s^{-1}\ GeV^{-1}$

EGRET+EHECR $dF/dE_{\nu\mu+\nu\mu} = 4.1 \times 10^{-3}\ E^{-2.22}\ m^{-2}\ s^{-1}\ GeV^{-1}$

Upper bounds on X-galactic fluxes

Cosmic p accelerators produce CRs, γ's and ν's

Ultimate bound of any scenario involving ν and γ production from πs: diffuse extra-galactic γ background $E^2F_\nu < 6\ 10^{-7}$ GeV /cm^2 s sr (EGRET)

Measured UHECR flux provides most restrictive limit (Waxman & Bahcall (1999)

- optically thin sources: nucleons from photohadronic interactions escape
- CR flux above the ankle (>3 ·10^{18}eV) are extragalactic protons with E^{-2} spectrum ⇒ **$E^2F_\nu < 4.5\ 10^{-8}$ GeV /(cm^2 s sr)**

This bound does not apply to harder spectra or optically thick

Mannheim, Protheroe & Rachen (2000):
Magnetic fields and uncertainties in photohadronic interactions of protons can largely affect the bound as these effects restrict number of protons able to escape