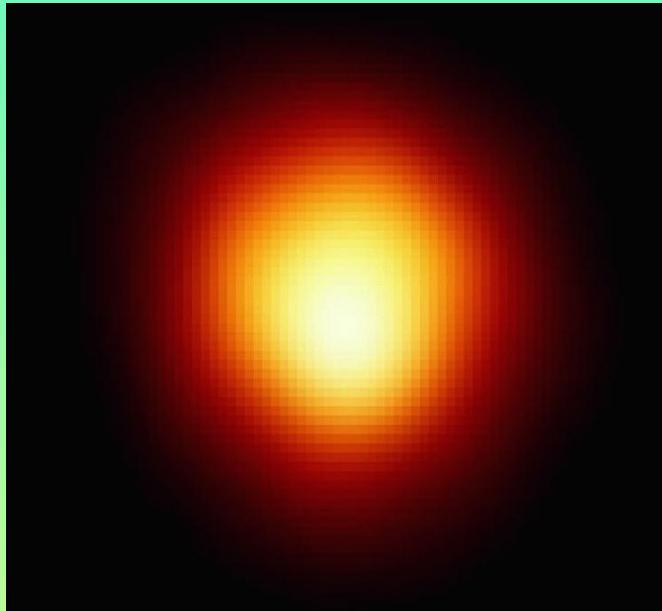


# NEUTRINO 2006

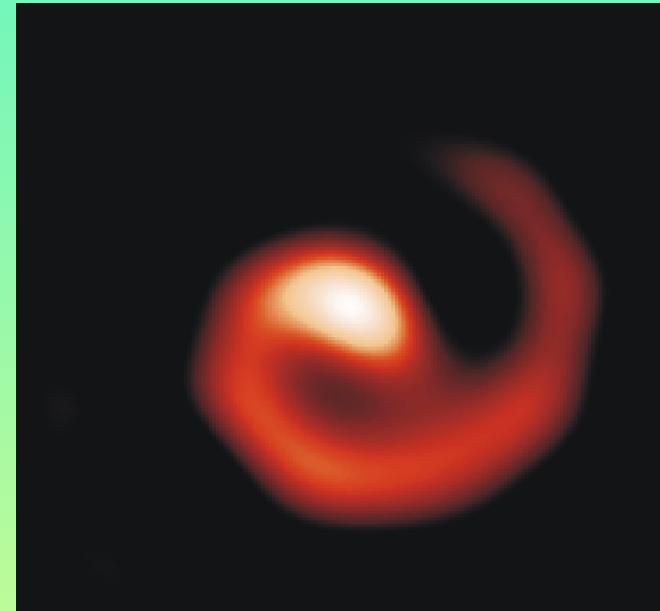
*The XXII International Conference on Neutrino Physics and Astrophysics*

Santa Fe, New Mexico, June 13-19, 2006

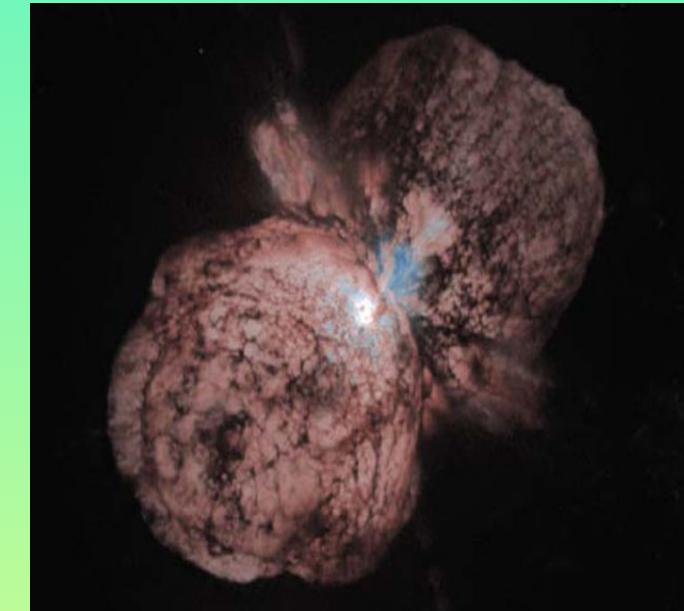
Betelgeuse 130 pc



WR 104 1.5 kpc



Eta Carina 2.7 kpc

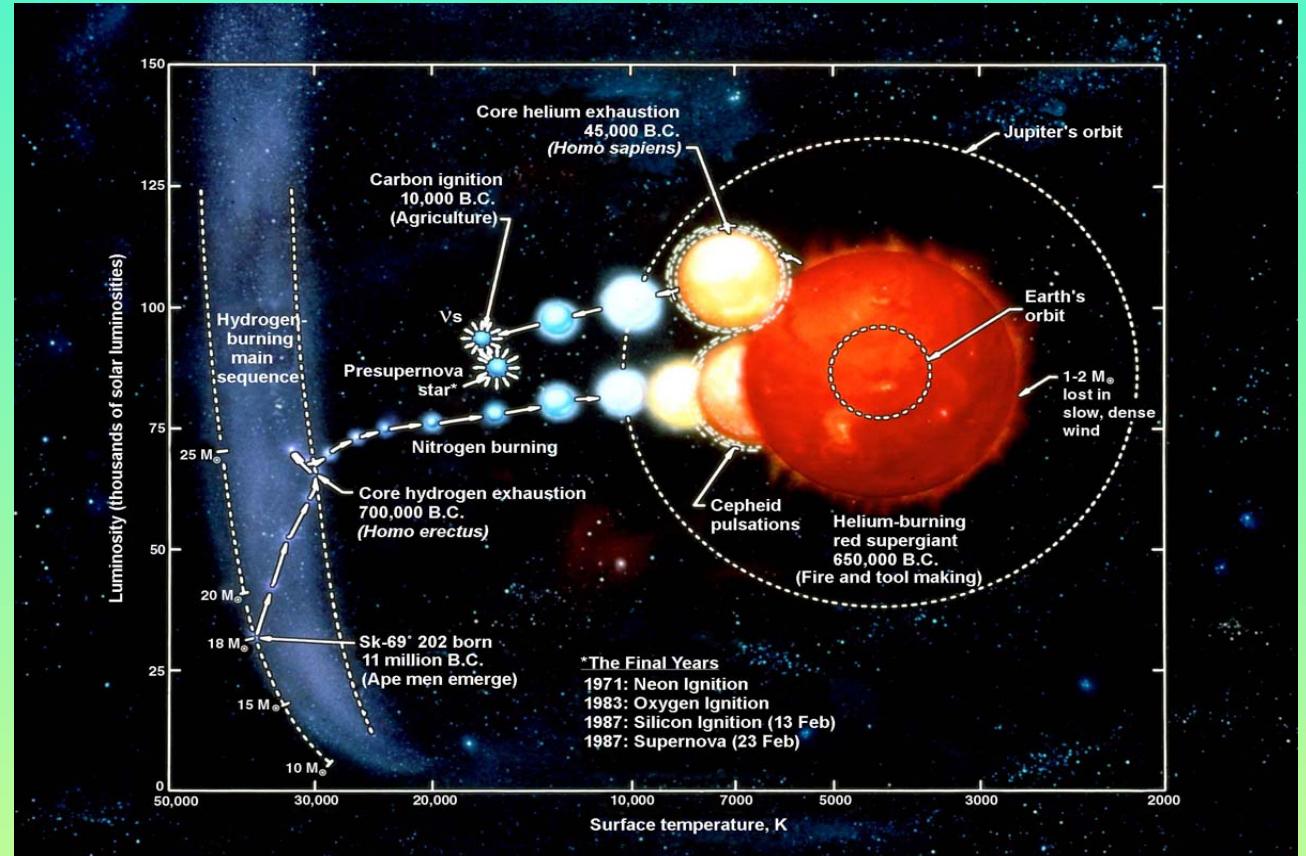


*Can we see these stars in neutrinos, accounting for  
50 years of progress in theory and experiment?*

# MASSIVE STAR BEFORE SUPERNOVA

No changes in star appearance hundred years before explosion.

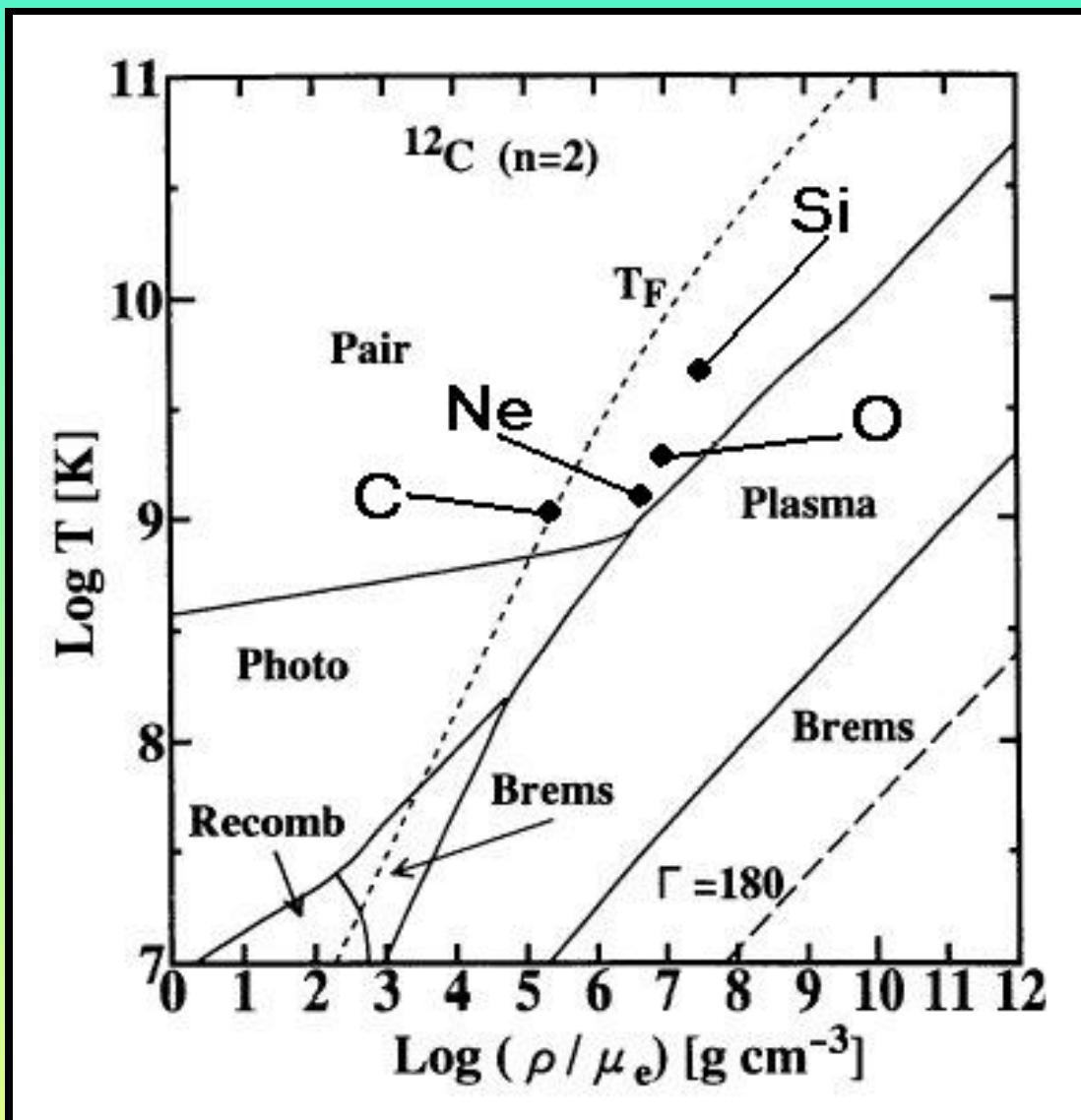
No way to predict supernova !



Source: [www.cococubed.com](http://www.cococubed.com)

*Confirmed by the analysis of pre-SN1987A supernova photographs back into XIX-th century.*

# NEUTRINO COOLING



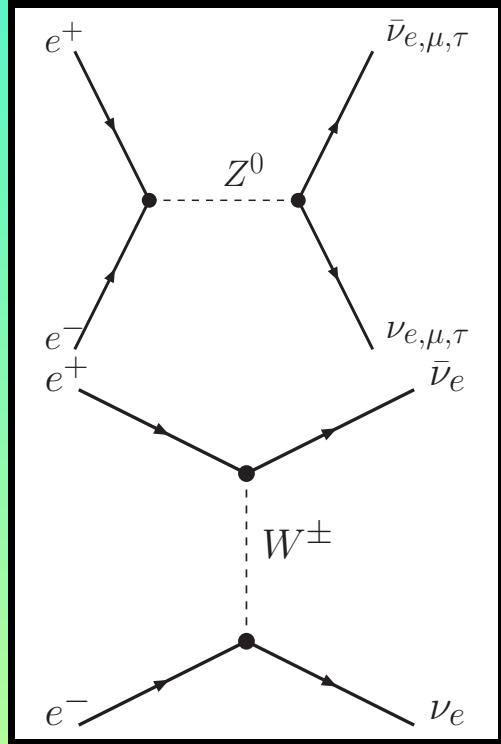
Thermal neutrinos balance thermonuclear and gravitational energy release.

*All flavors of the  $\nu$ - $\bar{\nu}$  pairs are produced*

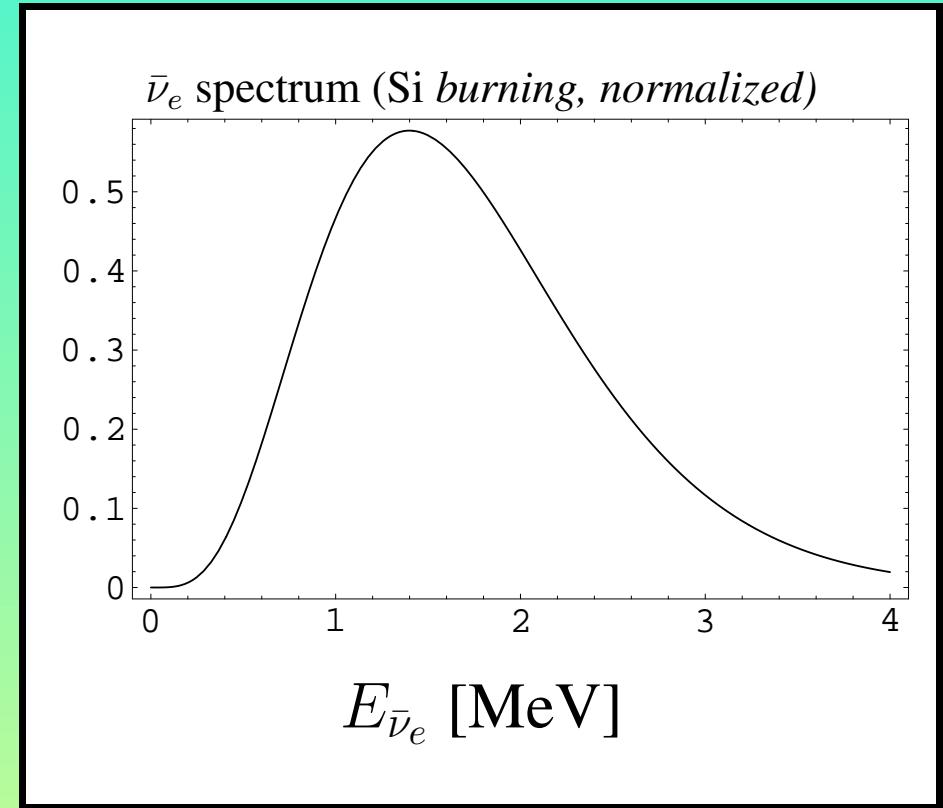
Three competing processes operate:

- **pair-annihilation**
- **plasmon decay**
- **photoproduction**

# PAIR-ANNIHILATION



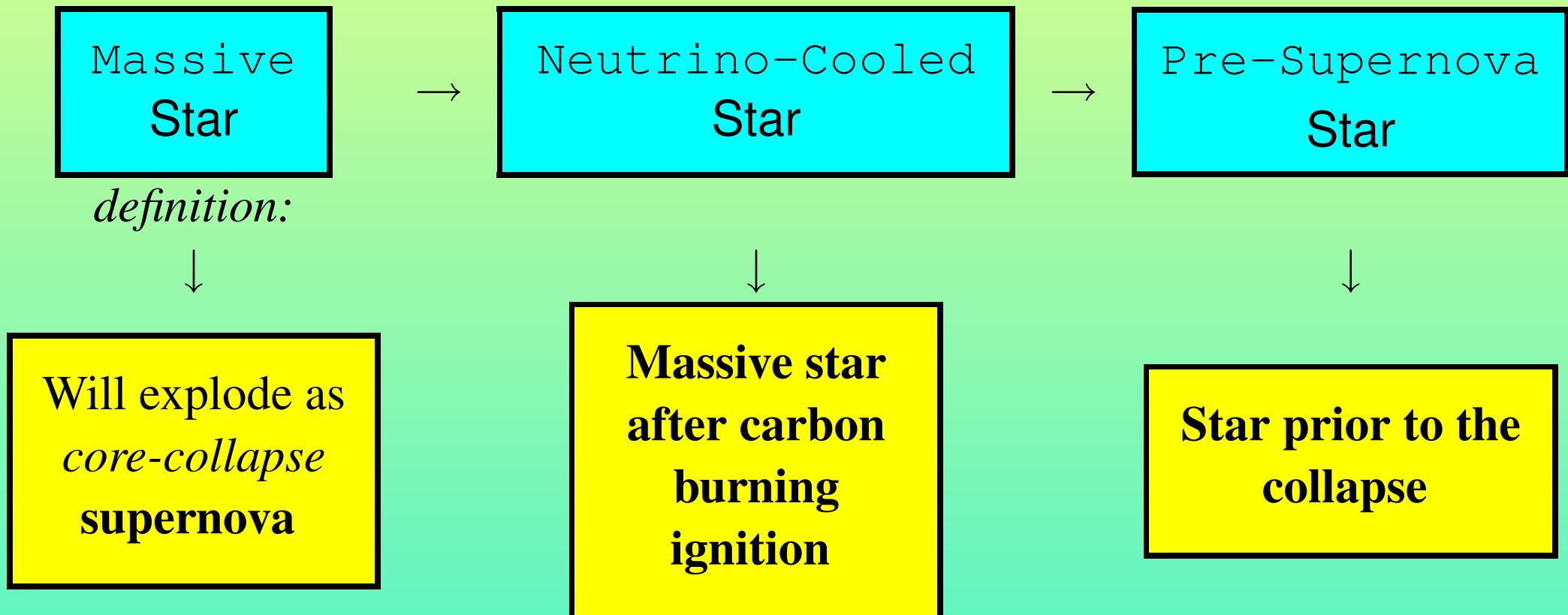
Average antineutrino energy during Si burning:  
 $E_\nu = 1.71 \text{ MeV}$



For many astrophysical objects average neutrino energy can be estimated using simple formulae:

$$\langle E_\nu \rangle = \begin{cases} 2/5 \mu + 2 kT + m_e/2 & (\text{degenerate}) \\ \frac{2700 \zeta(5)}{7 \pi^4} kT & (\text{relativistic, non-deg.}) \\ m_e + 3/2 kT & (\text{non-deg., non-rel.}) \end{cases}$$

# NEUTRINO-COOLED STARS

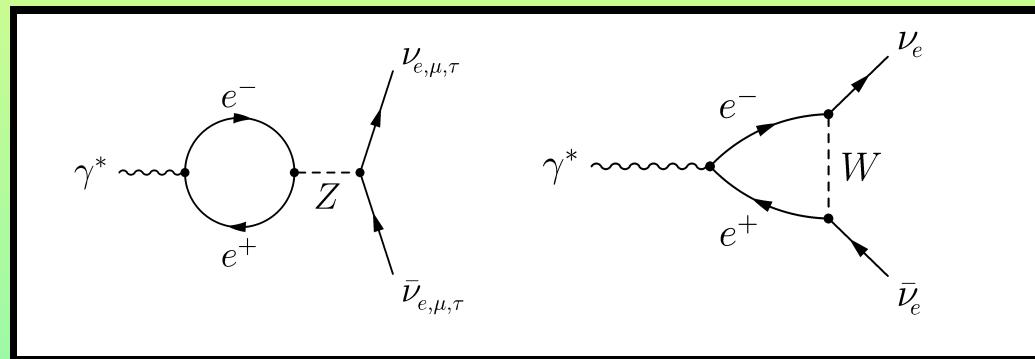


*Several hundred years before explosion, however,  
massive star becomes Neutrino-Cooled star*

Burning	$T_c [MeV]$	$\rho_c [g/cm^3]$	Duration	$L/L_\odot$	$L_\nu [erg/s]$
H	$3.3 \times 10^{-3}$	3.8	5.8 mln yrs	$40 \times 10^3$	$\sim 0.02L$
He	0.01	200	85 000 yrs	$115 \times 10^3$	$3.9 \times 10^{33}$
C	0.05	$10^5$	280 years	$165 \times 10^3$	$3.4 \times 10^{38}$
Ne	0.1	$2 \times 10^6$	300 days	$185 \times 10^3$	$6.7 \times 10^{41}$
O	0.15	$4 \times 10^6$	134 days	$185 \times 10^3$	$7.9 \times 10^{42}$
Si	0.24	$3.2 \times 10^7$	30 hours	$185 \times 10^3$	$3.4 \times 10^{44}$
Shell Si	0.29	$3.2 \times 10^8$	5.5 hours	$185 \times 10^3$	—
<i>Collapse</i>	0.14	$1.6 \times 10^9$	0.1 ... 0.5 s	$185 \times 10^3$	$> 10^{54}$

*Position in the HR diagram fixed (blue), but neutrino luminosity  $L_\nu$  evolves rapidly (red).*

# PLASMON DECAY

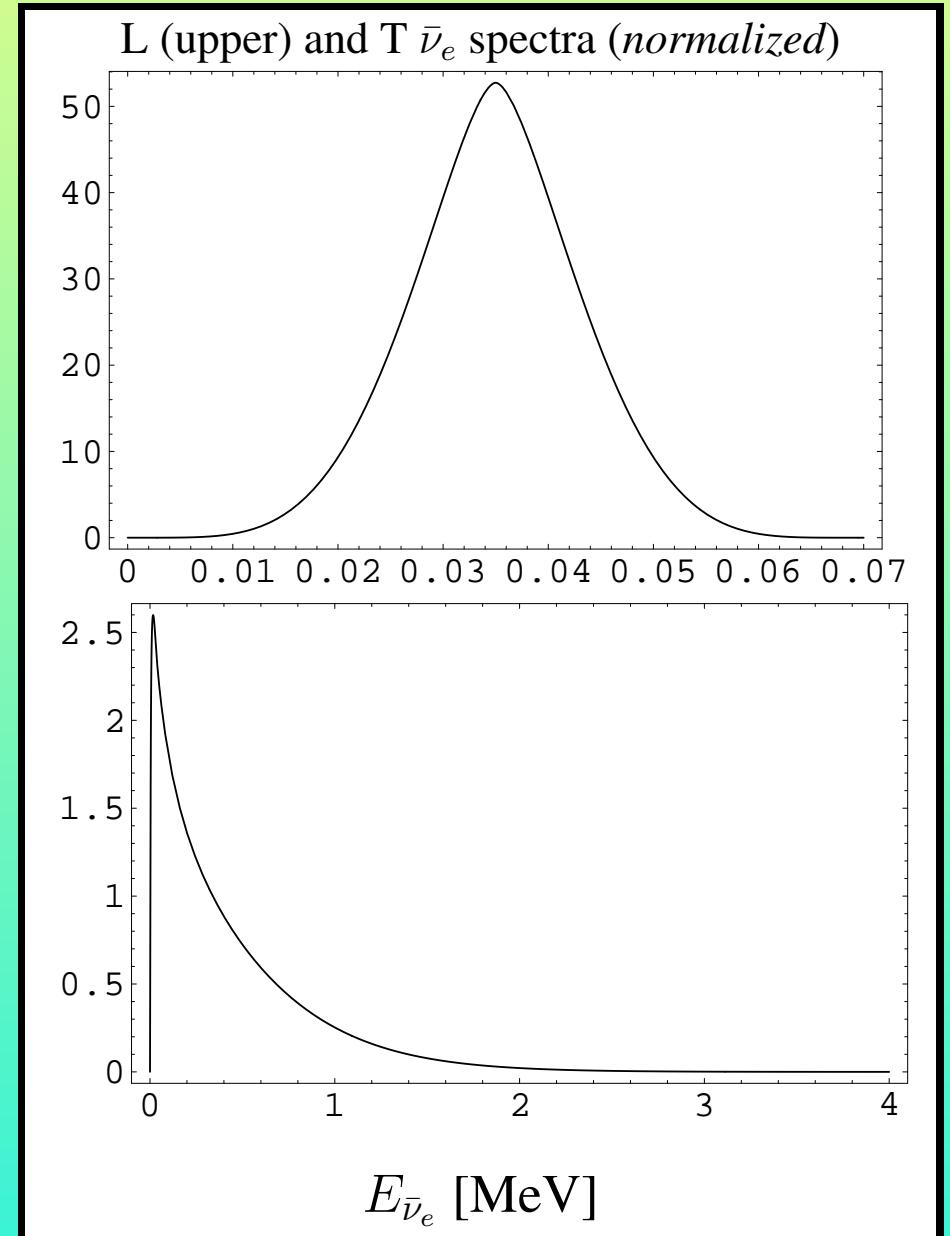


*Two modes of collective plasma excitations ( $\gamma^*$ ) can decay into  $\nu$ - $\bar{\nu}$  pairs:*

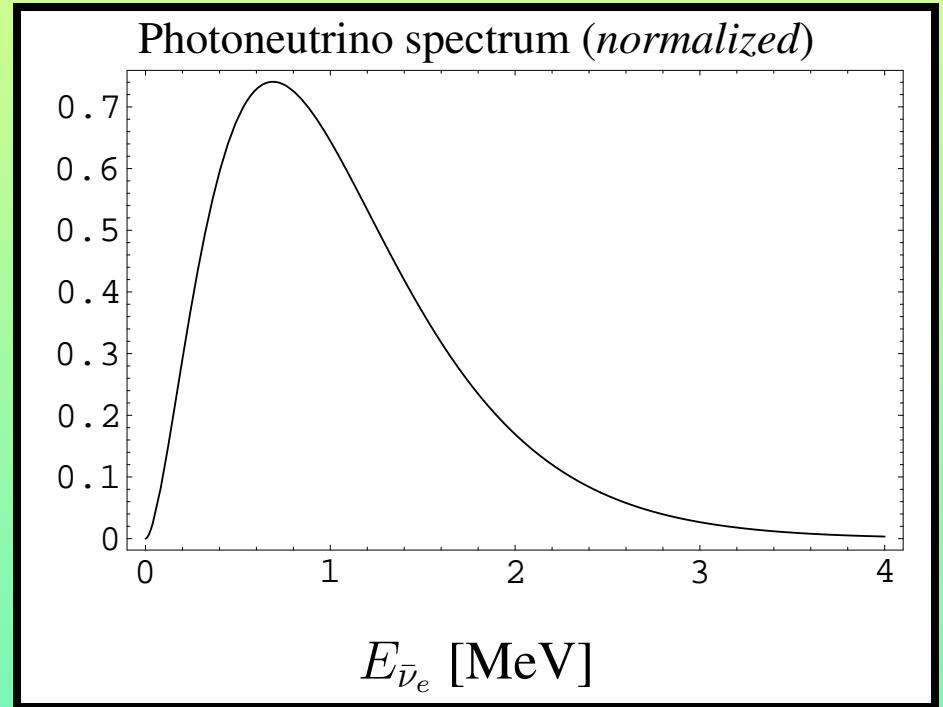
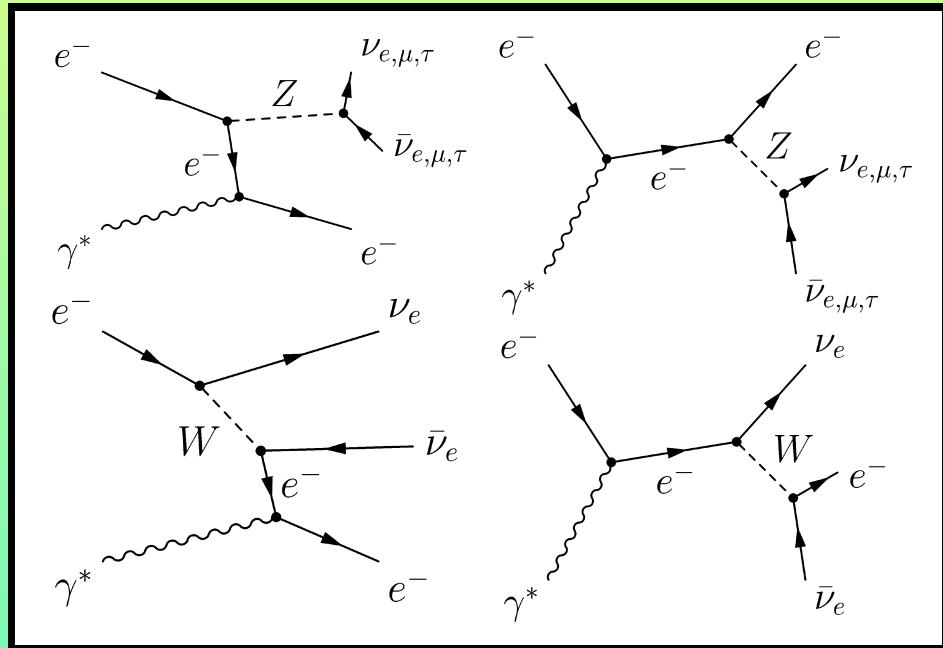
- Massive in-medium photon (T)
- Longitudinal plasmon (L)

Completely different dispersion relations for these 2 modes lead to the following neutrino energies:

$$\langle E_{\bar{\nu}_e} \rangle = 35 \text{ keV (L)}, \langle E_{\bar{\nu}_e} \rangle = 440 \text{ keV (T)}$$



# PHOTOPRODUCTION



- Spectrum of the photoneutrinos is computed assuming vacuum dispersion relation for photons.
- Spectrum is expressed in the form of 7-dimensional integral and computed using Monte Carlo method

Average antineutrino energy during Si burning  $\langle E_{\bar{\nu}_e} \rangle = 1.05$  MeV

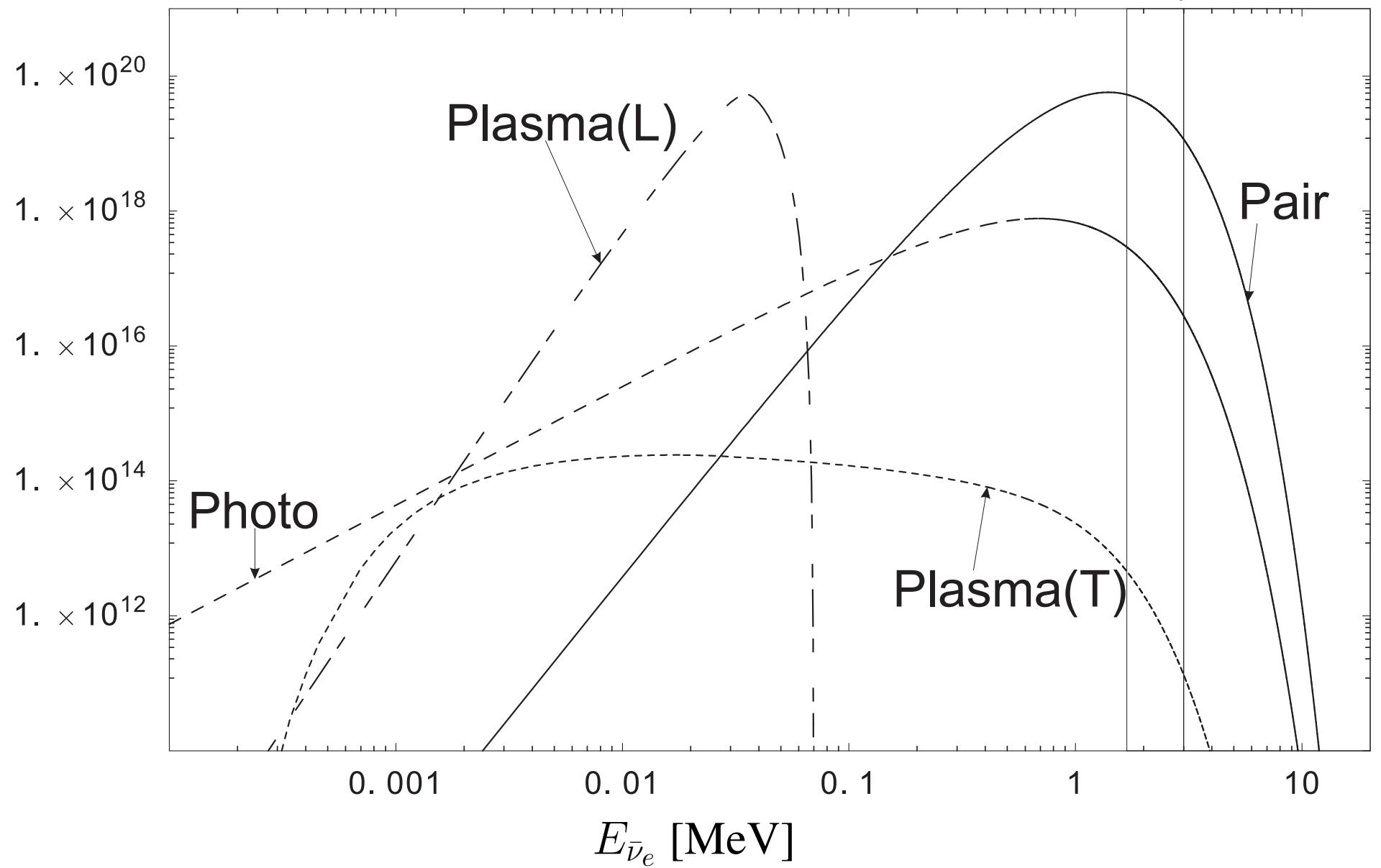
## ESSENTIAL DATA

- Neutrino luminosity ( $\sim 10^{12} L_{\odot} \simeq L_{\odot}$  @ 100 light years)
- Stage duration (0.7...14 days) for Si burning
- Distance to pre-supernova (0.1...30 kpc)
- Avg. time between Galaxy events (10...200 years)
- Detector target mass (1 kiloton ... 1 Gigaton)
- Detector threshold (1.8...5 MeV)

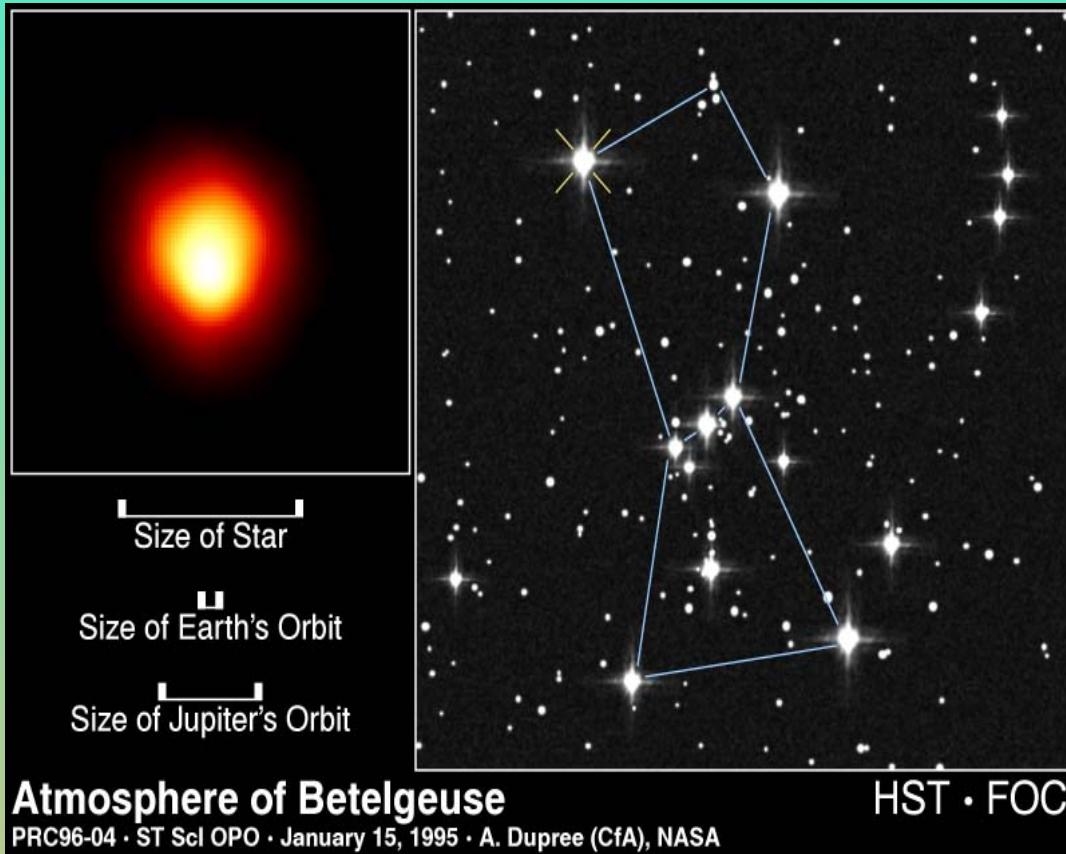
*The most important:* **anti-neutrino spectrum** →

# Combined thermal $\bar{\nu}_e$ spectrum during Si burning

1.8 4



If GAZDOOKS! will start in 2008 we could be able to  
**predict supernova explosion**  
for few nearby stars:  $\beta$  Ori,  $\alpha$  Her,  $\alpha$  Sco...

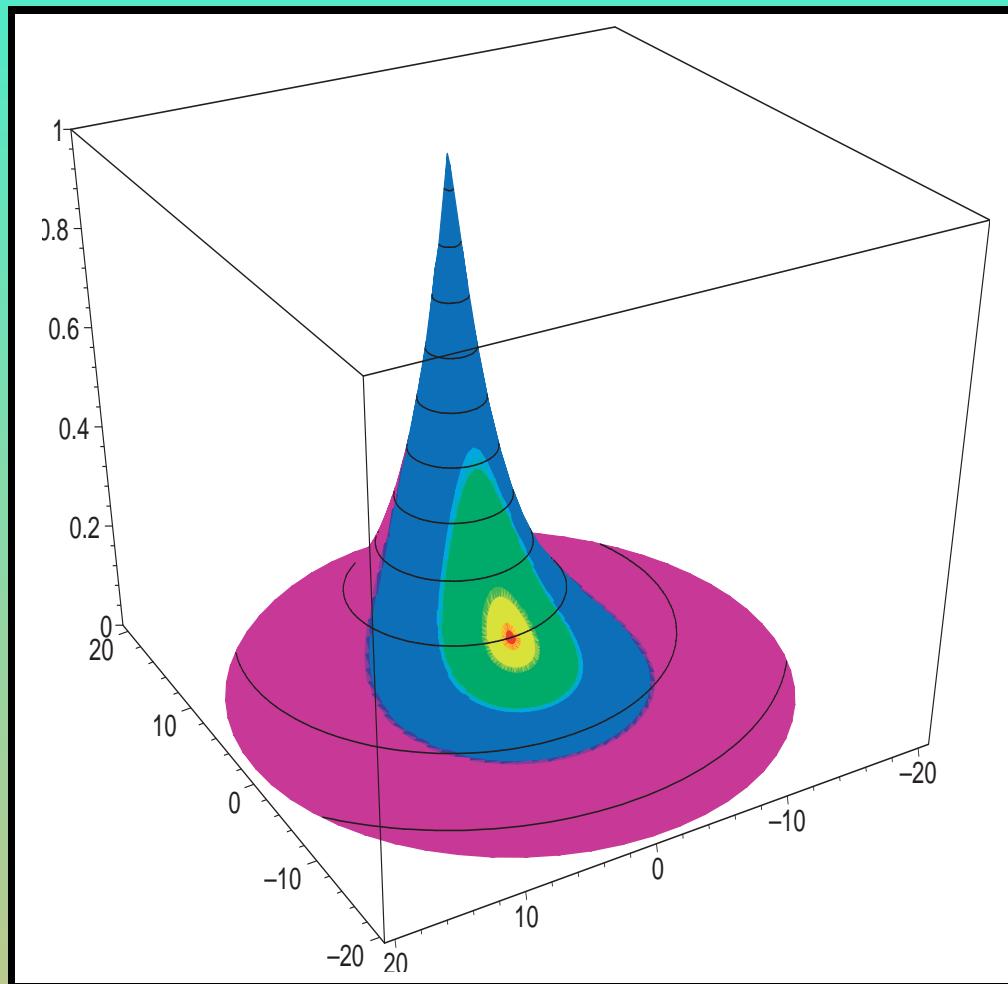


Source: NASA

Unfortunately, the explosion of the nearby star is  
**highly unlikely:**  
 $\sim 10^{-4} \times$  years of *continuous monitoring*

***Larger devices are required!***

## GALAXY COVERAGE



*Number of massive stars available to observations, according to simple Galaxy model*

### Observation range:

- Red – GADZOOKS! [32 kt]
- Yellow – Hyper-Kamiokande [0.5 Mt]
- Green - 2 Mt detector (very optimistic)
- Blue – Single ocean balloon [10 Mt]
- Purple – *Gigaton Array* [1 Gt]

## LOW-ENERGY ANTINEUTRINO DETECTION

Inverse  $\beta$ -decay threshold  $E_{th} = 1.8 \text{ MeV}$ ,  
while for water Cherenkov detectors  $E_{th} \simeq 4 \text{ MeV}$ .

**SOLUTION:** (M. Vagins, Neutrino 2004)

Dissolving in pure  $\text{H}_2\text{O}$  efficient neutron absorber (chloride):

$\boxed{\text{GdCl}_3}$  ( $\text{NaCl}$ ,  $\text{KCl}$ ) cause reaction:



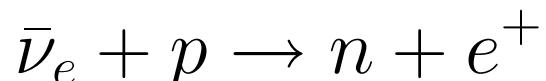
$E_{tot} = \sum_i E_{\gamma_i} \simeq 8 \text{ MeV}$

Gamma-rays scatter off electrons  $\Rightarrow$   
Electrons emit Cherenkov light  $\Rightarrow$   
Light detected by photomultipliers

# LOW-THRESHOLD ANTINEUTRINO DETECTORS

- KAMLAND (1 kt)
- BOREXINO (0.3 kt)
- SNO (1+1.7 kt)
- SUPER KAMIOKANDE (32 kt)
- HYPERK (540 kt)
- UNO (440 kt)
- GADZOOKS! (32 kt)
- “*Gigaton Array*” ( $10^6$  kt)

Utilizing Reines-Cowan reaction (inverse  $\beta$ -decay):



$\simeq 1$  event/kt H<sub>2</sub>O  
from 1 kpc

# PRE-SUPERNOVA MONITORING

	Detector mass	Maximum observation range	% of the Galactic <i>pre-supernovae</i> in the range
GADZOOKS!	32 kt	0.5 kpc	0.1%
HYPER-KAMIOKANDE	0.5 Mt	2 kpc	2%
SINGLE DEEP OCEAN BALLOON	10 Mt	10 kpc	50%
GIGATON ARRAY	1 Gt	100 kpc	100%

*Number of massive stars available to monitoring increases rapidly as we reach Galactic center*

## CONCLUSIONS & FUTURE PLANS

- *Pair-annihilation anti-neutrinos are dominant in the thermal neutrino spectrum of the pre-supernova star*
- *Other thermal processes do not produce neutrinos with energy above threshold of existing or planned big detectors*
- *Ability to get supernova warning from Si burning neutrinos will be limited to a few nearby massive stars ...  
... until new generation of the giant antineutrino detectors*
- Computer code computing complete thermal neutrino spectrum
- Improved physical input for photo- and plasmaneutrino spectrum (dispersion relations, squared matrix elements)
- Integration with stellar models  
*[Call for collaboration]*
- Neutrinos and antineutrinos produced in weak nuclear reactions