JUNO: A General Purpose Experiment for Neutrino Physics

Marco Grassi, IHEP, CAS, Beijing (*on behalf of the JUNO collaboration*) ❧ mgrassi@ihep.ac.cn

Understanding Our Universe: Supernova Burst Neutrinos

A supernova (SN) is a **stellar explosion** that briefly outshines an entire galaxy, radiating as much energy as the Sun or any ordinary star is expected to emit over its entire life span. During such explosion, 99% of the gravitational binding **energy** of the newly formed neutron star is **emitted in the form of neutrinos** (ν) and **antineutrinos** ($\bar{\nu}$).

Why

Questions that might be addressed in Astrophysics:

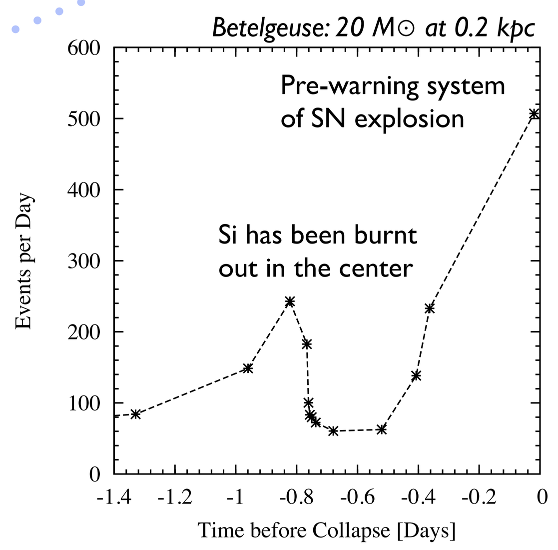
1) What are the conditions inside massive stars during their evolution?
2) What mechanism triggers the SN explosion?
3) Are SN explosions responsible for the production of heavy chemical elements?
4) Is the compact remnant a neutron star or a black hole?

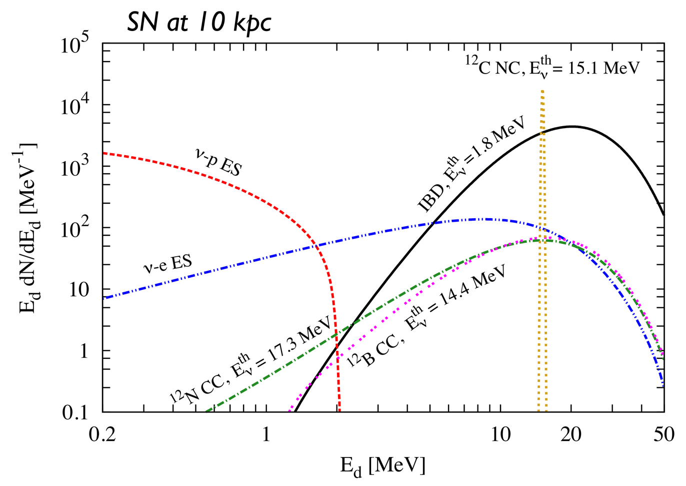
What

Stellar evolution model:

Star's temperature and density *vs* Radius and Time

- Hard to test using optical observations
- Info about the core is lost since photons diffuse
- Neutrinos are produced via thermal processes
- Neutrino rate increases significantly with temperature
- **Study of pre-explosion neutrinos** to discriminate progenitor star masses and develop warning system





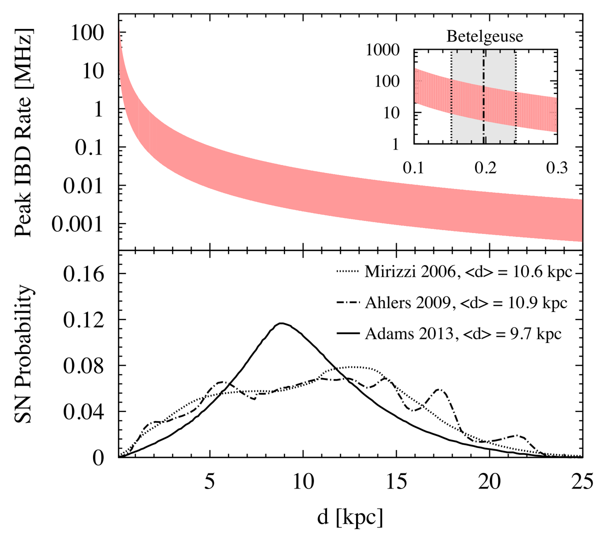
Process	Type	Events ⟨E_ν⟩=14MeV
$\bar{\nu}_e+p \to e^+ + n$	CC	5.0×10^3
$\nu+p \to \nu+p$	NC	1.2×10^3
$\nu+e \to \nu+e$	ES	3.6×10^2
$\nu+{}^{12}C \to \nu+{}^{12}C^*$	NC	3.2×10^2
$\nu_e+{}^{12}C \to e^- + {}^{12}N$	CC	0.9×10^2
$\bar{\nu}_e+{}^{12}C \to e^+ + {}^{12}B$	CC	1.1×10^2

NB Other ⟨E_ν⟩ values need to be considered to get complete picture.

Signal	Deposited Energy	Signature	Comment
IBD	E_ν - 0.8 MeV	prompt-delayed	
ES ν-p	p recoil energy	single	Only probe of ν_x spectrum
ES ν-e	e recoil energy	single	Most sensitive to ν_e
^{12}C Excitation	15.1 MeV	gamma line	Sensitive to ν_x
$^{12}C \succ {}^{12}N$	E_ν - 17.3 MeV	prompt-delayed	
$^{12}C \succ {}^{12}B$	E_ν - 13.9 MeV	prompt-delayed	

Challenges

Background is not a serious concern for a SN neutrino burst (event duration <10s):
(I) Natural Radioactivity (<10Hz above 0.7 MeV), (II) Cosmogenics (~3Hz muon rate), (III) Reactor Neutrinos (0.01 IBD in 10s), (IV) Geoneutrinos (0.0002 IBD in 10s)



Main Issue is represented by DAQ

- Handle huge number of overlapping events
- Baseline rate (based on MH determination): 1kHz
- Depending on SN distance, several scenarios occur:
- Typical SN is around 10 kpc (*bottom plot*)
- JUNO must handle Betelgeuse (*top plot*): best for physics, worst for DAQ (5~100 MHz)

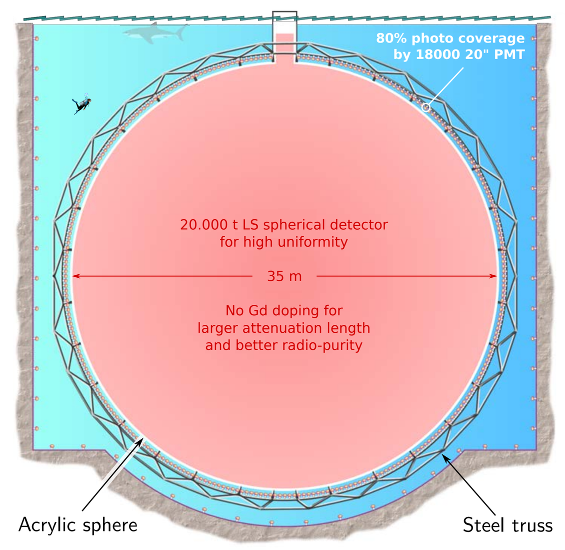
Currently investigating **trigger and reconstruction improvements when using 3" PMTs**

The JUNO Experiment

20 kt Liquid Scintillator (LAB)
in Acrylic Sphere

18000 20" PMTs
75~80% coverage
3%/√E Energy Resolution

Additional 35000 3" PMTs
(still under consideration)
to Improve Systematics

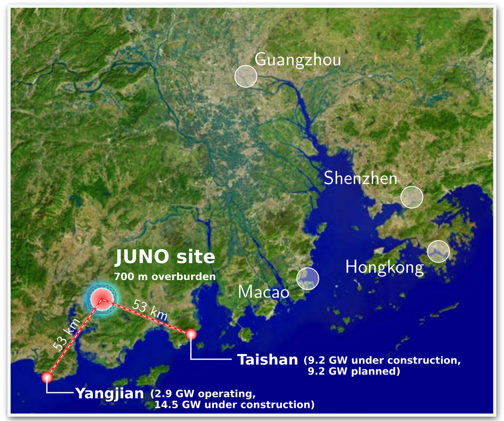


Water Buffer
Mitigate PMT Radioactivity
Suppress Fast Neutrons

Water Cherenkov (μ veto)
2000 PMTs

Top Tracker (μ veto)
Plastic Scintillator

700 m Overburden



Main Experimental Goal

Determine Neutrino Mass Hierarchy via disappearance of reactor $\bar{\nu}_e$ (see Wei Wang's poster)

Location optimized accordingly (53km from nuclear power plants)

More Information + References + Plot Credits:
The JUNO Collaboration, "*Neutrino Physics with JUNO*"
arXiv: 1507.05613

Understanding Our Planet: Geoneutrinos

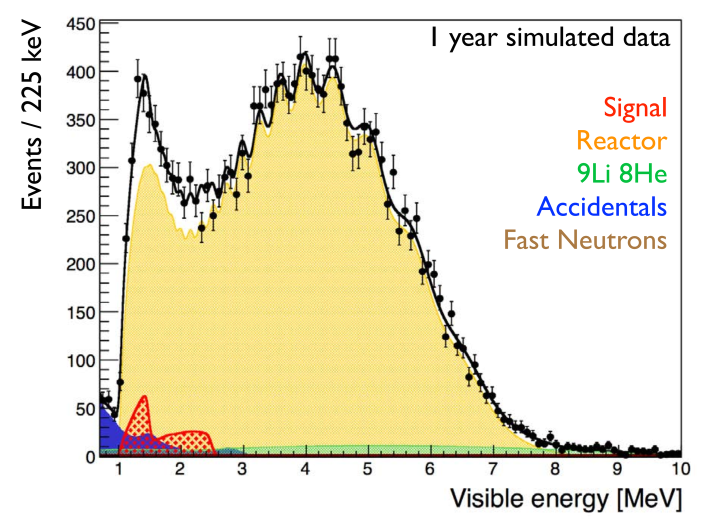
Why

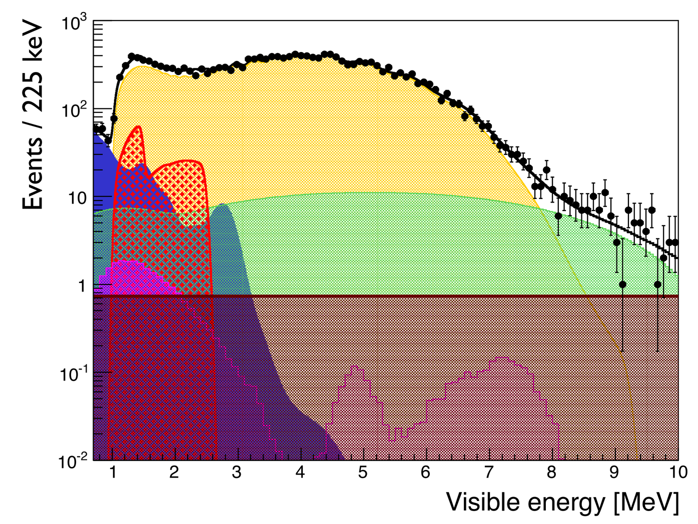
Earth's surface heat flow has been established to be 46±3 TW, but the community is still debating what fraction of this power comes from primordial vs radioactive sources. Such debate revolves around the understating of:

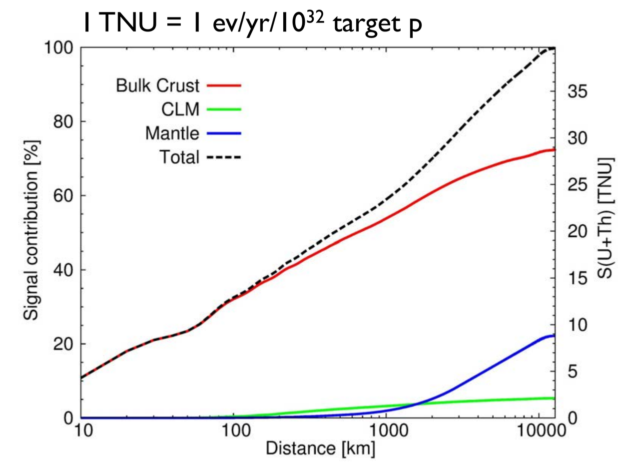
- the composition of the Earth (namely of the chondritic meteorites that formed our Planet)
- the chemical layering in the mantle and the nature of mantle convection
- the energy needed to drive plate tectonics

What

Detect **electron antineutrinos from the ^{238}U and ^{232}Th** decay chains via inverse beta decay







Challenges

Reduce the shape uncertainty in the low energy part of the reactor ν spectrum.

Disentangle the mantle from the crust contribution

Need for geological, geochemical and geophysical surveys of the area surrounding JUNO

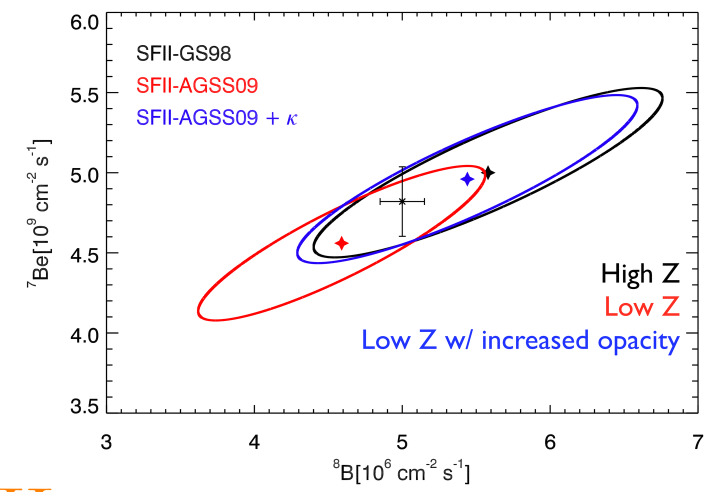
Understanding The Sun: Solar Neutrinos

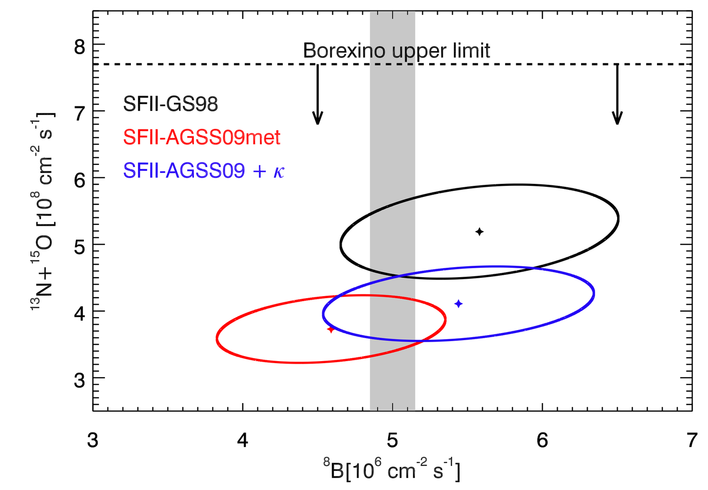
The Sun is a powerful source of electron neutrinos with O(1 MeV) energy, produced in the thermonuclear fusion reactions in the solar core. The JUNO solar neutrino program focuses on those emitted in the **^{7}Be and ^{8}B chains.**

Why

MSW effect: propagation of neutrinos through matter behaves differently than in vacuum. Such effect is **energy dependent** (being almost negligible for low-E neutrinos). The transition between the two regimes should be in the 1-3 MeV range. Super-K recently reported a mild evidence for such an **up-turn in the spectrum**, but a high-significance test is required to confirm the consistency of the LMA-MSW solution.

Solar metallicity problem: former agreement between Standard Solar Model and solar data has been compromised by the revision of solar surface heavy element content. Different abundances result in different **neutrino fluxes that can be used to constraint the model.**





How

High precision measurement of the ^{7}Be and ^{8}B ν flux
Detailed analysis of the low-energy part of the ^{8}B ν spectrum
Study of the day-night asymmetry in the ^{8}B ν rate

What

Solar neutrinos are detected via elastic scattering on electrons (**single flash of light**)

High **radiopurity** is a must for solar ν
1) *Baseline:* **S:B=1:3** (KamLAND solar phase)
2) *Ideal:* **S:B=2:1** (Borexino phase 1)
Even baseline is very hard with 20kt LS
Requirements for MH are worse than baseline

- External γ removed via **fiducial volume**
- Alpha decays: tagged via pulse shape discrimination and subtracted statistically
- Only β and γ decays considered in table

Reactor ν interacting via ES is a negligible (and well measured) background

^{7}Be: only detectable signal in case of baseline radiopurity

No Energy Threshold Applied

Internal radiopurity requirements	Baseline	Ideal
^{210}Pb	5×10^{-24}	1×10^{-24}
^{85}Kr	500 [counts/day/kton]	100 [counts/day/kton]
^{238}U	1×10^{-16}	1×10^{-17}
^{232}Th	1×10^{-16}	1×10^{-17}
^{40}K	1×10^{-17}	1×10^{-18}
^{14}C	1×10^{-17}	1×10^{-18}
Cosmogenic Background rates [counts/day/kton]		
^{11}C (τ=24.4 min)	1860	
^{10}C (τ=27.8 s)	35	
^{11}Be (τ=19.9 s)	2	
Solar Neutrino Signal Rate [counts/day/kton]		
^{7}Be ν	517	
^{8}B ν	4.5	

Long-lived spallation radioisotopes are hard to veto w/o introducing large dead-time.
Tagged via 3-fold coincidence (muon + n + isotope decay) and subtracted statistically