Silicon Burning Neutrinos at Super-K with Gadolinium

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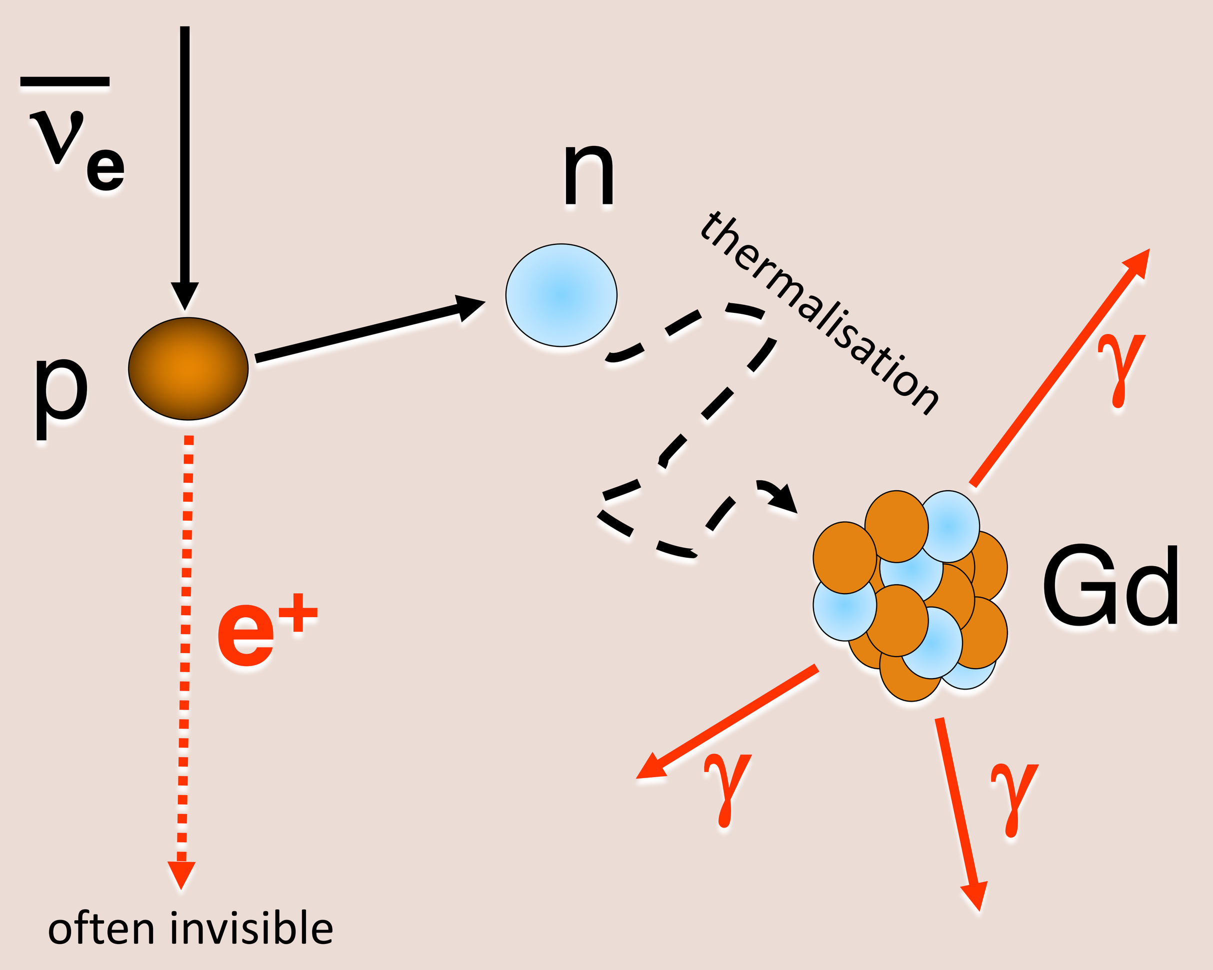
1. Super-Kamiokande

- 50 ktons water, 22.5 kton fiducial volume
- Instrumented with 11129 20 inch PMTs
- Detects Cherenkov light from charged particles passing though water
- Already hugely successful in proton decay searches and neutrino detection

- **Soon to be upgraded for next phase with Gadolinium doping**
- **By adding 0.2% Gd salt by mass, will detect up to 80% of neutrons [1].**



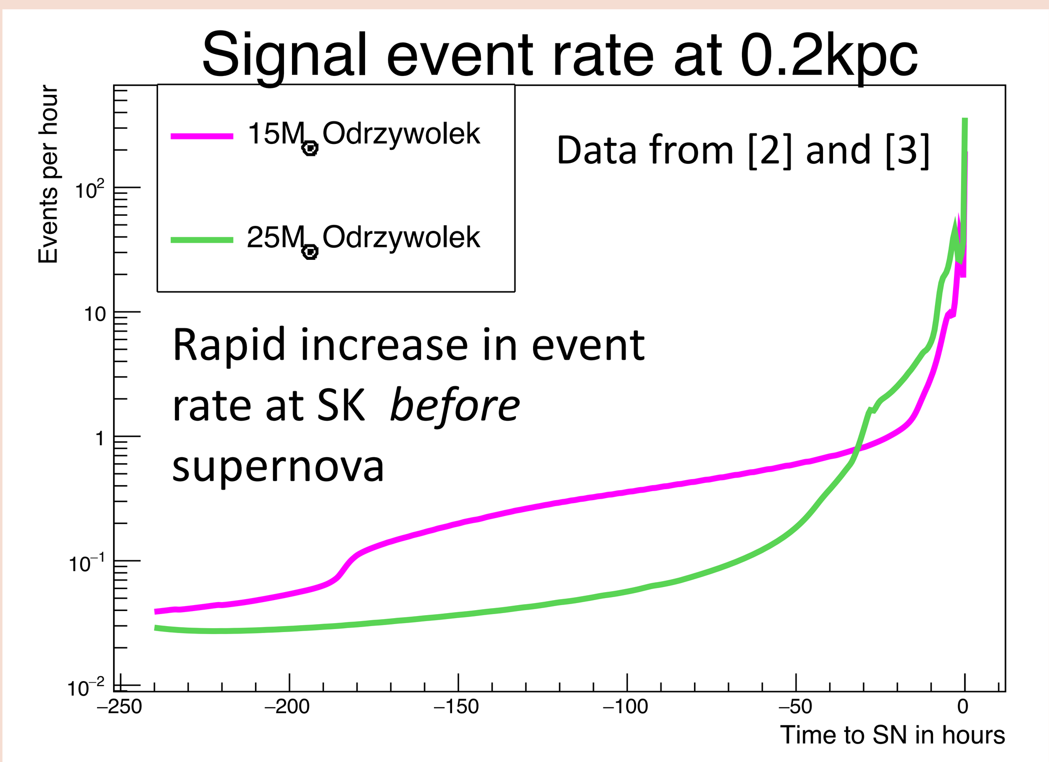
2. Thermal Neutron Capture on Gadolinium

- Isotopes of Gadolinium have some of the highest cross sections for **thermal neutron capture**[1].
- Neutron capture followed by **gamma ray cascade** of around 8 MeV within 20 microseconds; enough energy to be reliably detected in Super-K.

- Neutron capture gammas are studied using MC
- Background is modelled using real data taken in SK

3. Pre-Supernova Silicon Burning Neutrinos

- ***Extra early* supernova warning for nearby stars – before the usual supernova neutrino signal**
- **Never before seen astrophysical object, not visible to EM astronomy!**



Supernova Neutrinos	Silicon Burning Neutrinos
Mean Energy ~20 MeV	Mean Energy ~2 MeV
Hours before light from SN	Days before light from SN
Detected in 1987	Never detected before
1000s of events in seconds at SK at >10kpc	100s of events in a day at SK-Gd for stars at <1kpc

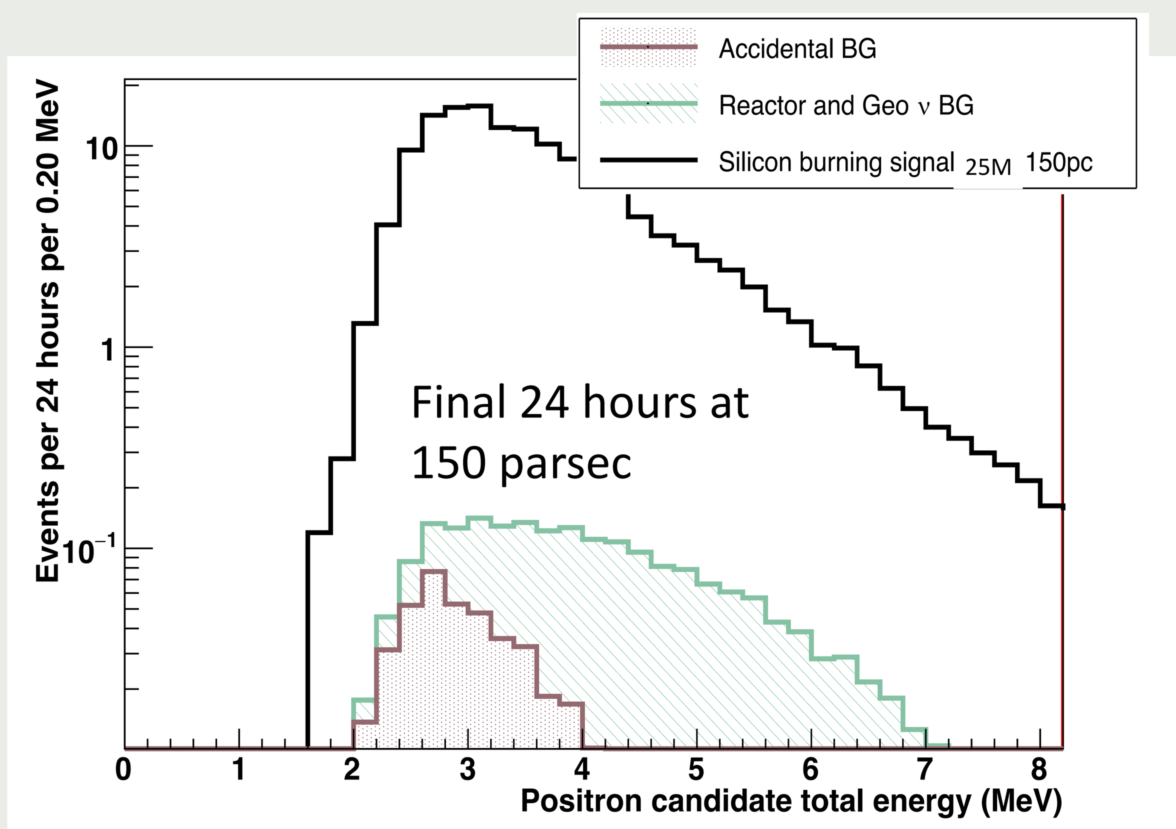
- Massive star prior to core collapse
- Star running out of H and He
- Contracts and gets hotter
- Heavier nuclei are fused

- Rapid increase to production of neutrinos and antineutrinos [2]
- At SK-Gd, detection efficiency for antineutrinos will be increased by neutron detection

4. Backgrounds

- Low energy backgrounds at SK are intrinsic radioactivity and cosmic muon spallation products
- Look for neutron capture candidates in coincidence with very low energy positron candidates

- Main background may be reactor neutrinos – will depend on Japanese nuclear reactors

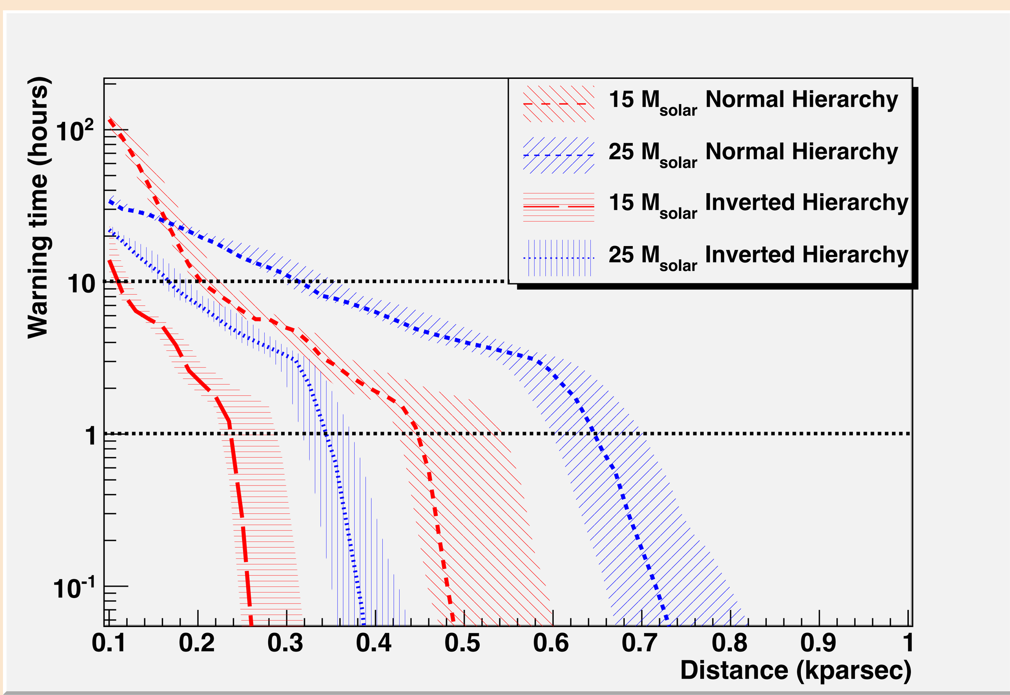


Reactor data from [4]

- Alarm would watch for an increase in the rate of candidate events
- Compare the last day with the last 30 days and do a hypothesis test on Poisson distribution

- Likelihood threshold set by type-II error rate: is 1 false alarm per month OK? 1 per year? 1 per 10 years?

5. How much warning and range?



- Depends on mass of star, and the mass hierarchy!

- Some uncertainty in intrinsic background and Japanese nuclear reactor situation
- **Max warning for Betelgeuse is ~60 hours** (1 per 2 year type-II error rate assumed)
- **Max range for 3σ discovery ~900 parsecs**
- **There are 41 red super giants in this range**

6. Summary and Conclusion

- The next stage of **Super-Kamiokande** is doping with **gadolinium** for efficient **neutron tagging**

- A **supernova** is often preceded by **silicon burning**
- Silicon burning rapidly increases the electron antineutrino luminosity and average energy – can be detected by SK-Gd
- Main backgrounds are intrinsic radioactivity and reactor neutrinos

- SK-Gd would detect this for a star up to 900 parsecs away
- Up to 60 hours early warning *before* Betelgeuse goes supernova

References

[1] GADZOOKS! Anti-neutrino spectroscopy with large water Cherenkov detectors, J.F. Beacom and M.R. Vagins, PRL 93 (2004)
[2] Odrzywolek et al. doi.org/10.1063/1.2818538
[3] Odrzywolek th.if.uj.edu.pl/~odrzywolek/
[4] A. Barna and S. Dye, "Web Application for Modeling Global Antineutrinos," arXiv:1510.05633

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