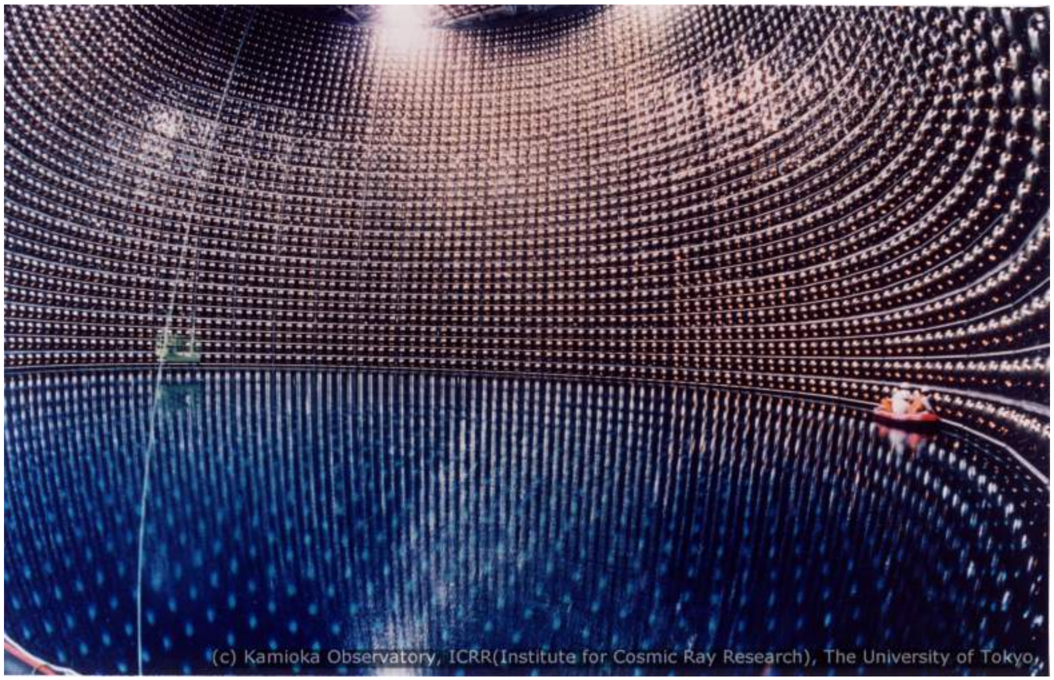
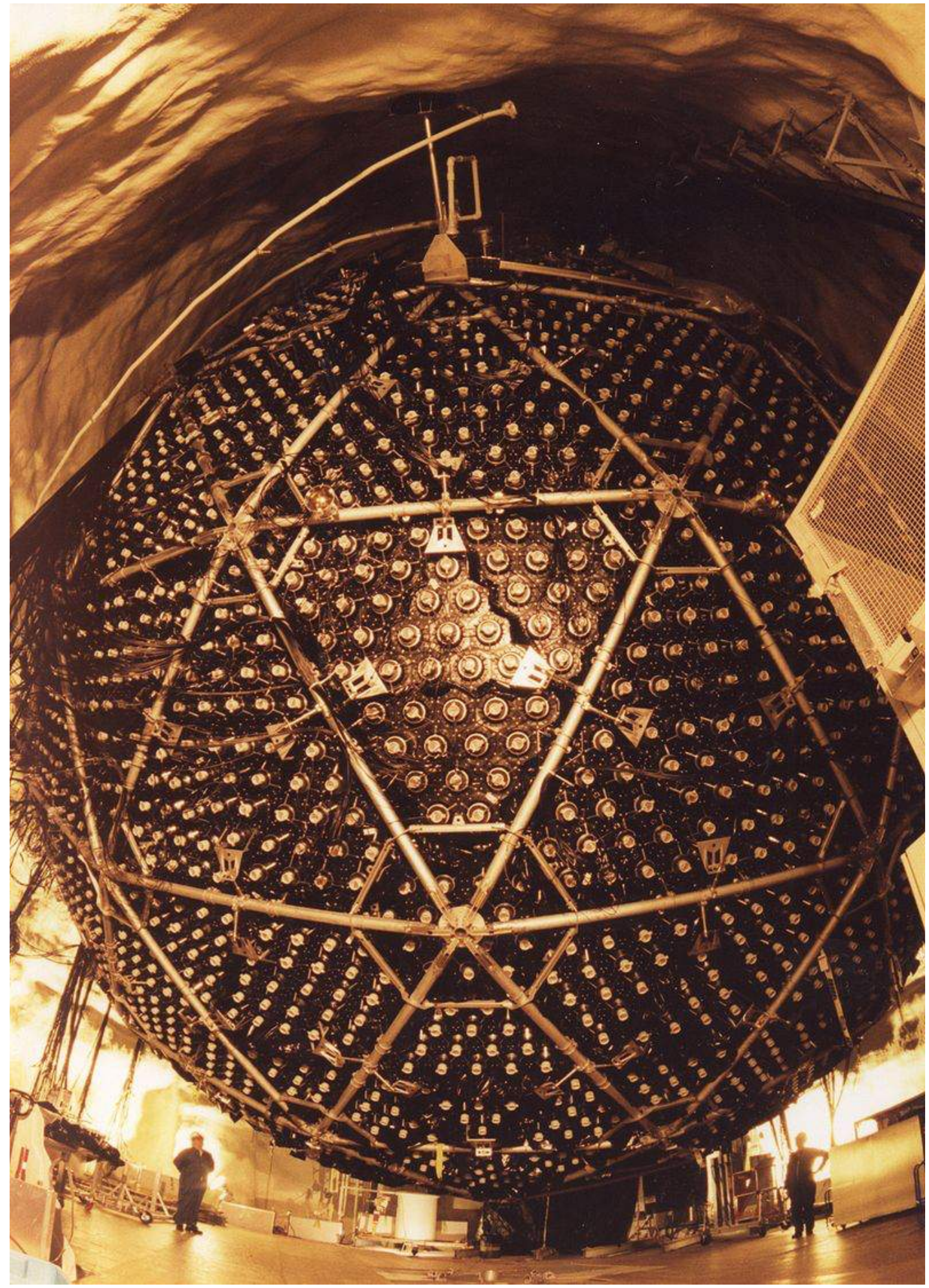
Super Kamiokande



Sudbury Neutrino Observatory



The Nobel Prize in Physics 2015

Photo: A. Mahmoud

Takaaki Kajita

Prize share: 1/2

Photo: A. Mahmoud

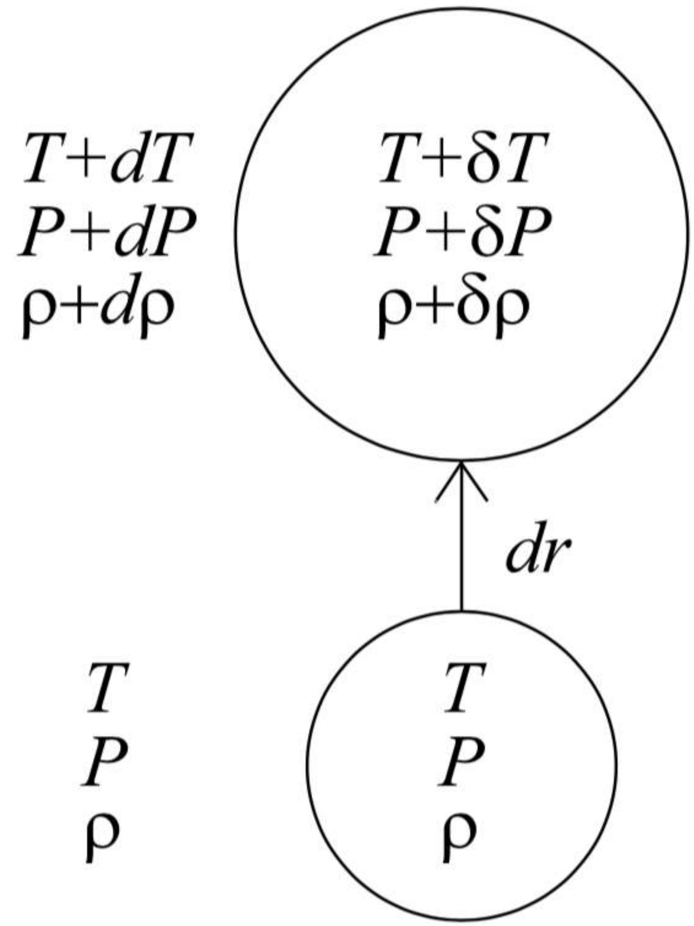
Arthur B. McDonald

Prize share: 1/2

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald *"for the discovery of neutrino oscillations, which shows that neutrinos have mass"*

Convection

- Hydrodynamic instability that transports mass & heat
- Driven by buoyancy
- Convectively unstable if mass element displaced upward from equilibrium wants to continue to rise (i.e., less dense than surroundings after coming into *P* eq.)



Convection criterion

- For ideal gas, adiabatic displacement *convectively unstable if*

$$\left|\frac{dT}{dr}\right| > \frac{\gamma - 1}{\gamma}\frac{T}{\rho}\left|\frac{dP}{dr}\right|$$

i.e., for *T* profile that decreases "fast enough" with *r*

- Adiabatic index $\gamma = 1 + \frac{2}{f};\ f = \#\text{degrees of freedom}$

$$\text{e.g.,}\ \ f = 3\ \text{(translational) for monatomic gas}$$

$$\Rightarrow \gamma = 5/3$$

- As $f \to \infty,\ \gamma \to 1,\ (\gamma - 1)/\gamma \to 0 \Rightarrow$ more prone to convection

e.g., in cool regions of stars where bound atoms & molecules exist

(electronic, rotational, vibrational d.o.f.'s)

Places where convection is important, effects

- Low-mass stars
- Outer layers of intermediate-mass stars (outer 28% of the Sun's radius)
- Envelopes of red giants

Convection is very effective at transporting energy so also tends to set in where rapid energy transport is needed, e.g. cores of massive stars $\epsilon \sim T^{18}$

Also *mixes* material at different *r* within convection zones, can bring heavy elements synthesized in core to the surface (e.g., 'dredge up' events during post MS)

Re-arranges stars so that marginally stable within convection zones:

$$\frac{dT}{dr} = \frac{\gamma - 1}{\gamma} \frac{T(r)}{\rho(r)} \frac{dP}{dr}$$