Particle physics & astrophysics with ice

*Ice as an observatory*

Polar ice for sub-atomic particle detectors:

- **Transparent**
- **Low-noise**
- **Clean**
- **Low-activity**
- **Stable**
- **Abundant**

Technologies and drills for:
- *IceCube*
- *Low energy physics experiments*
- *Ultra-high energy neutrino astronomy*
IceCube Completed – December 18, 2010
IceCube Enhanced Hot Water Drill

- Power: 5 MW
- 50 cm \( \times \) 2500 m \( \times \) 30 h holes
- Rate: <48 h per hole
  20 per 2 mo. season
- Personnel: 30 drillers
- Good safety record
Laser particulate stratigraphy
IceCube Enhanced Hot Water Drill

- Thermal power: 5 MW
- 880l/min @ 135 bar
- 45cm diam. 2500m, 30h lifetime
- production rate: <48h/hole
- 20 holes per season
IceCube drill in long term storage

Not included:
- 1 generator (of 3)
- the hose (McMurdo, warmer)
- drill heads, smaller pieces (Madison)
Future projects using IceCube drill

- IceCube DEEPCORE upgrade - PINGU phase I
  ~20 strings
- Low energy detector – PINGU phase II
  ~100 strings
- DM-ICE
- IceCube high-energy upgrade

Drill currently stored at Pole
NSF will decide based on expected future needs
Mobilization cost: $3M
Future Low Energy physics in IceCube
Future Low Energy physics in IceCube

- **Backfilling** a core within IceCube
- Physics:
  - Neutrino oscillations
  - Proton decay
  - Neutrino beams
  - Dark Matter
  - Supernovae detection
  - Geo-neutrinos

**PINGU Overhead (zoom 0)**

**PINGU Overhead (zoom 3)**
Multi-PMT Imaging Systems (KM3NeT)

Discriminate signal vs. background
But PMTs are expensive...

Alternative optical detectors / amplifiers / concentrators:

Hybrid Photon Detectors (HPDs)
- photocathode + APD
- scintillator + Geiger-mode APD

Flat-panel photocathodes
- Transmission-mode
- Reflection-mode

Significant progress over last 2-3 years...
Wavelength shifters to save $$$ ?
Neutrino profiling of the Earth

Source: Neutrino factory from Fermilab
Neutrino profiling of the Earth

Measure density of Earth's core to 1%
Long distance experiments (no drilling):

- **ANITA-like**

- **ARIANNA-like**

- Askarayan Radio Array (ARA)
• Radio Cherenkov (Askarayan) radiation

• $10^{16}$-$10^{17}$ eV threshold sensors *in ice*

• Need $100$ km$^3$ to detect $100$ events in 3-5 years

• Imaging Askarayan cone 100m detector spacing

• Full (constant) density ice deeper than 150 m

• Sensitivity $\geq 150$ MHz 15 cm holes, antennas
As expected, firn air loss is a serious problem

RAM has potential, probably not suitable for ARA
Drilling technology for ARA

• For now, mini-hot-water drilling

ARA Hot Water Drill: Main Components

• Pumping unit 16 gpm @ 1000 psi
• 4 Whitco brand horizontal burner design hot water generators with a total of 250 kW input / 200 kW output
• 1,500 gallon insulated water tank
• 120 gallon insulated melting tank
• Hose Reel
• Fuel System
• 30 kW / 460 volt generator set

• Future: Reverse circulation drilling
• High Power Radio Beacon (Bob Morse, U. Hawaii)
  Minimum 1 km deep to illuminate ARA
  (200 m array 5 km radius)
  Passive downhole electronics
  - low-loss cable 100 MHz – 1 GHz
  - 20 year service life

• South Pole ice core
  Core: radio / optical / acoustic ice characterization
  Borehole: access point for beacons
Neutrino Beams

Near detector: 980 ton
Far detector: 5400 ton

735 km

Source: MINOS
Borehole laser dating

South Pole log data

Intensity

Dome C log data

EDC3 Age[ka]

Ash

Age[kyr]