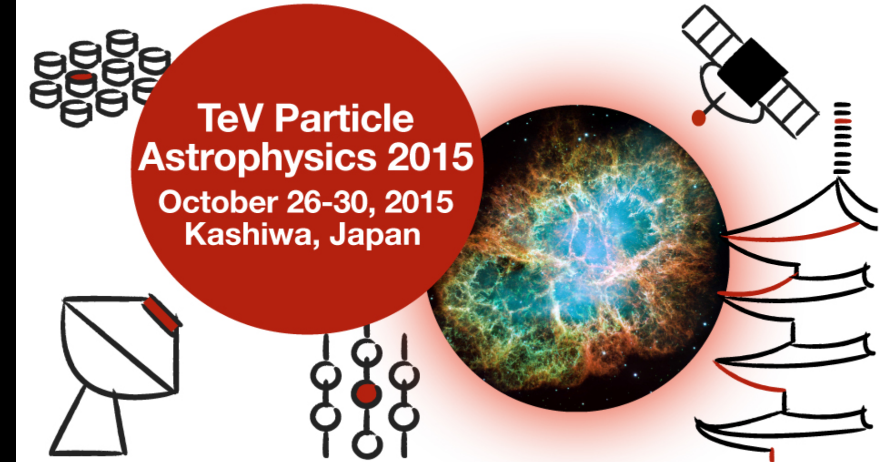
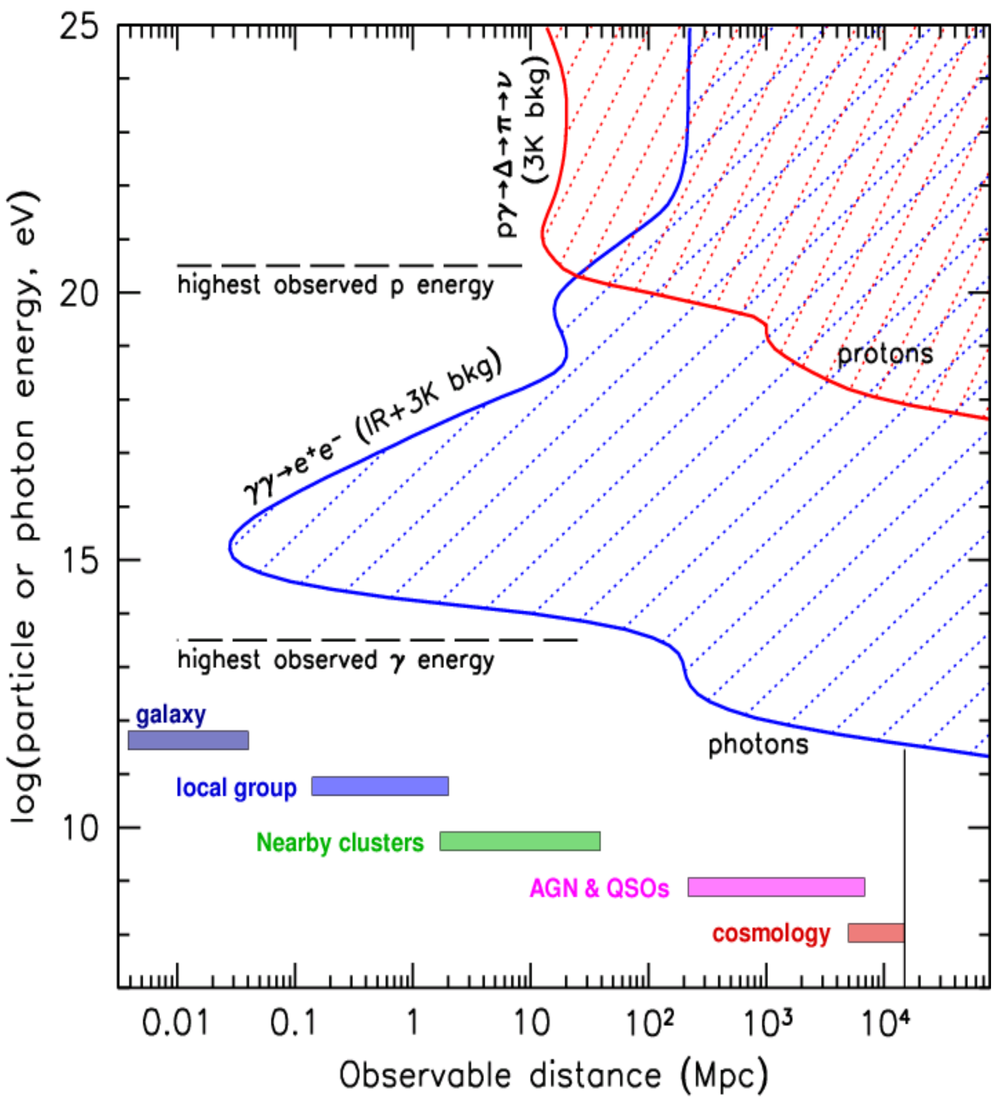


Next Steps in
~~The Future of~~ High-energy Neutrino Astronomy

John Kelley
Univ. of Wisconsin–Madison
October 30, 2015

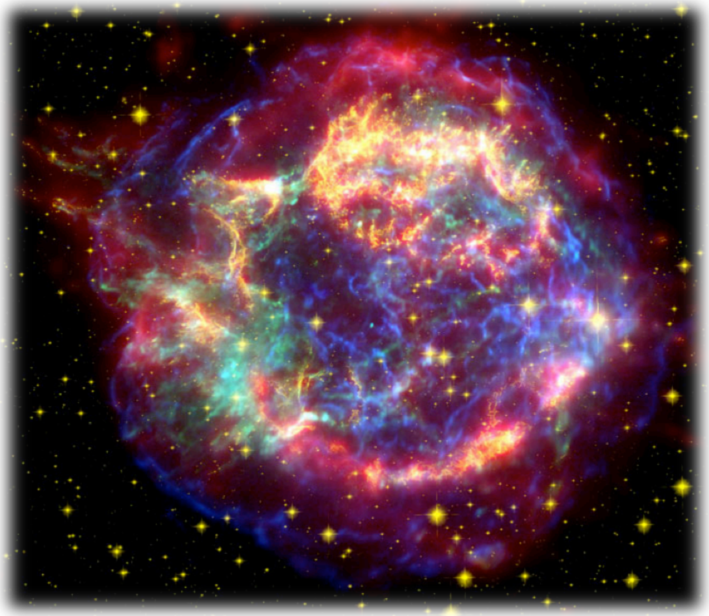
TeV Particle Astrophysics 2015
Kashiwa, Japan

Neutrinos as Messengers



- Above 100 TeV, neutrinos are *the* option for astronomy
- Benefits:
  - point back to source
  - unimpeded by intervening matter + photon fields
- Challenges:
  - difficult to detect
  - fluxes very low at high energies

Cosmic Ray Acceleration and Neutrino Production



Fermi shock acceleration: $\mathrm{d}N/\mathrm{d}E \sim E^{-2}$

$$p + \gamma \rightarrow p + \pi^0, n + \pi^+$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

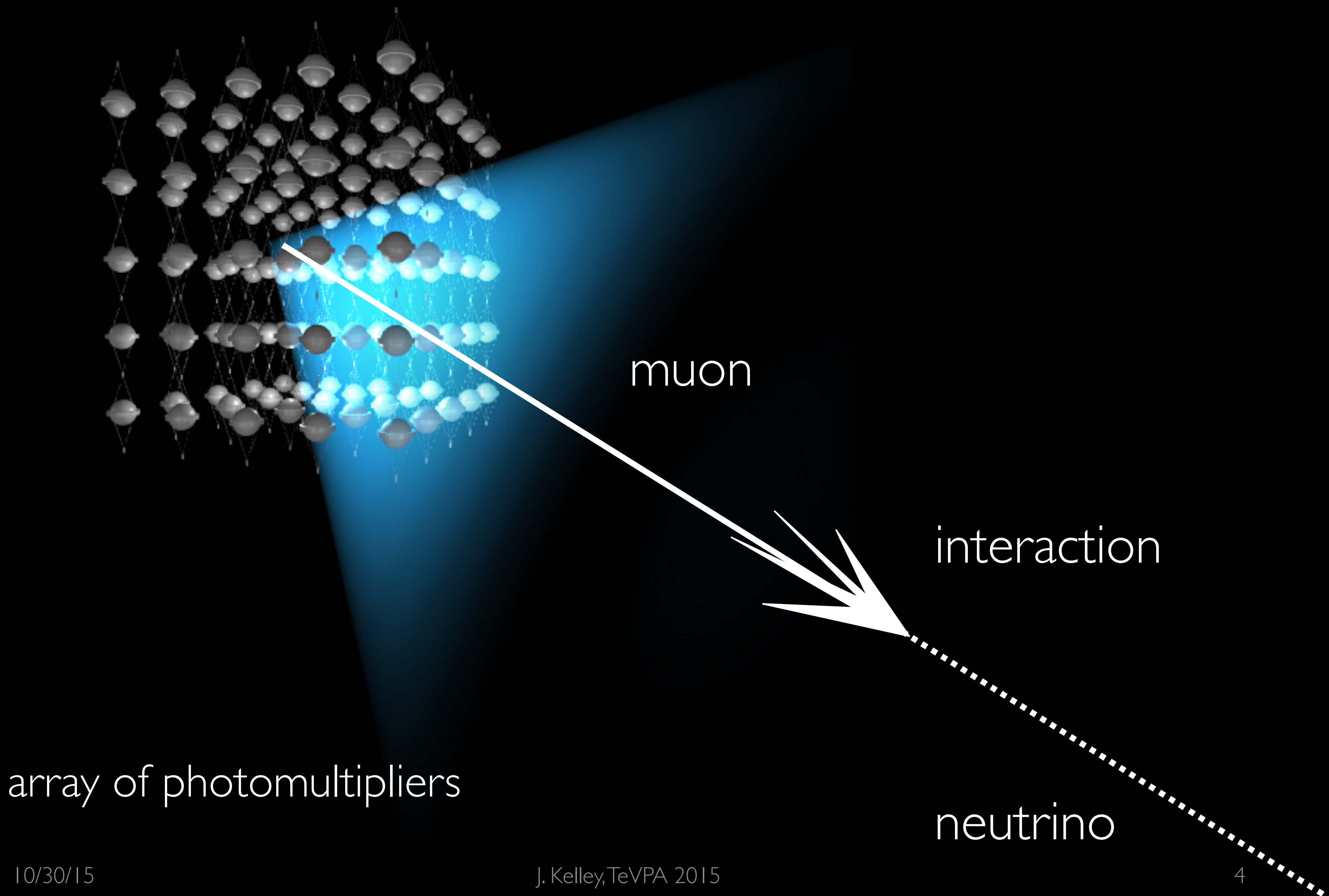
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

1:2:0 flavor ratio at source

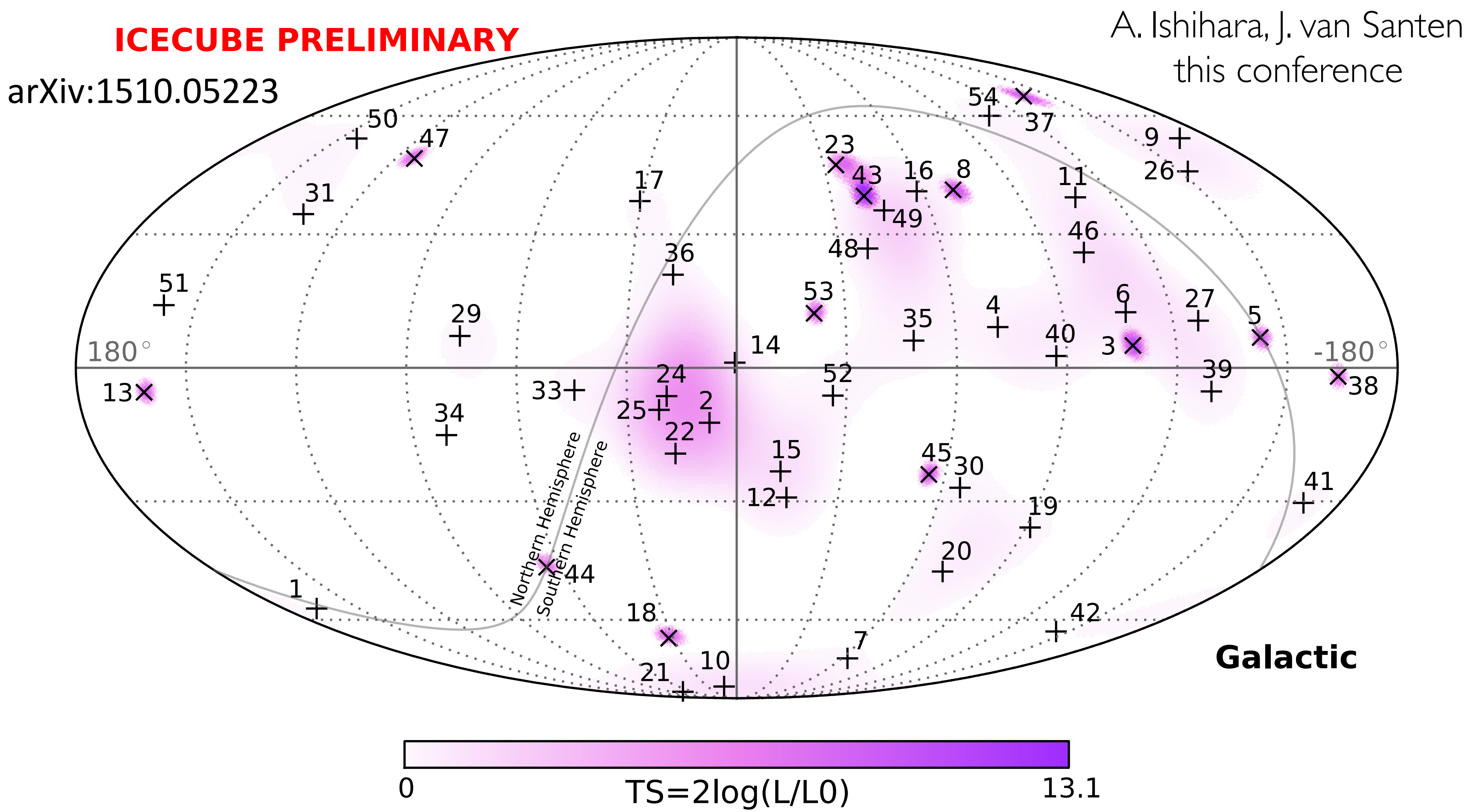
Similar processes (incl. p+p) happening in:

- cosmic ray sources (ambient light, gas) — astrophysical source neutrinos
- outer space (cosmic microwave background) — cosmogenic neutrinos
- Earth's atmosphere (N, O, etc. nucleus) — atmospheric neutrinos

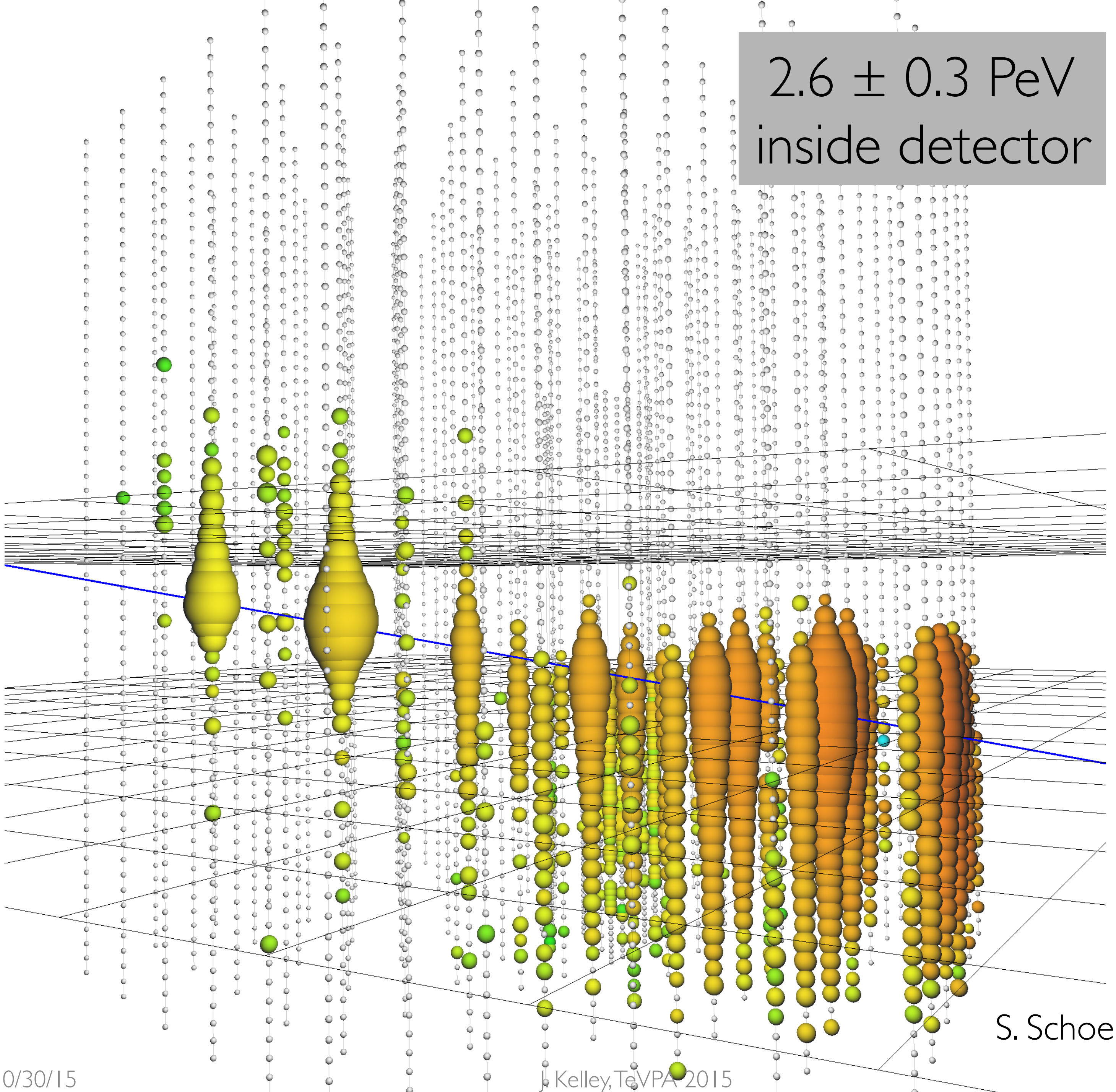
Water/Ice Cherenkov Neutrino Detectors



Neutrino Astronomy "First Light"

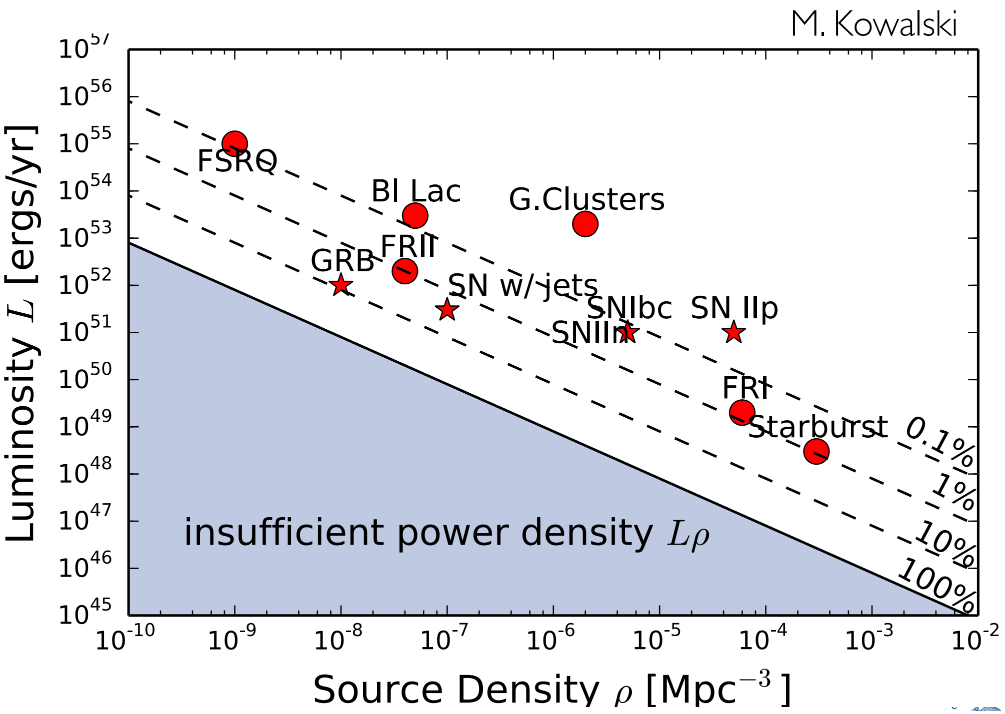


No significant clustering; no point sources in any channel; confirmation of diffuse flux in muon neutrino channel



ATEL #7856
S. Schoenen, this meeting

Looking Forward

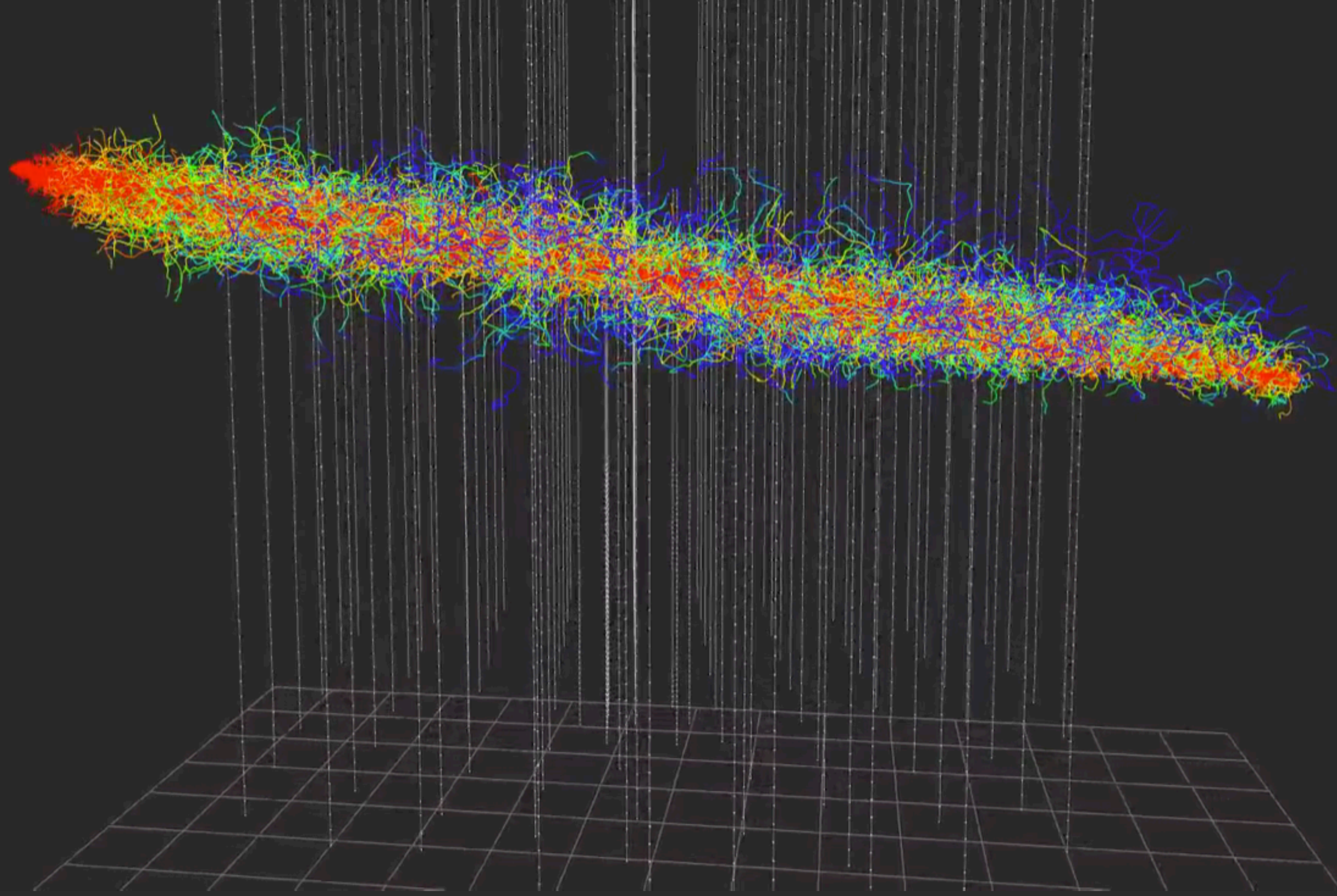


disfavored from lack of point-source discovery

see also: K. Murase, this meeting
Ahlers and Halzen, arXiv:1406.2160

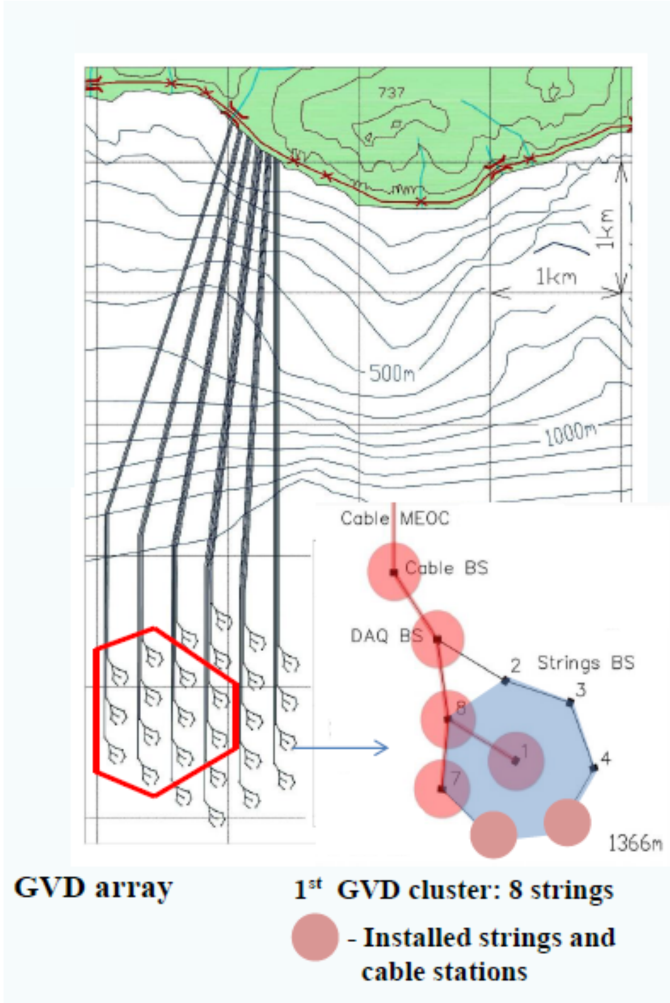
- IceCube has much more to contribute
  - flux characterization beyond simple power law
  - subdominant Galactic contribution?
  - flavor ratio?
  - bright, rare extragalactic point source sources within reach in a few years?
  - renewed emphasis on multi-messenger program
- Dim + populous sources will require larger detectors (~10 km^3)
- First detection of cosmogenic neutrinos may require even larger detectors (~100 km^3)

Future Water/Ice Cherenkov Neutrino Detectors

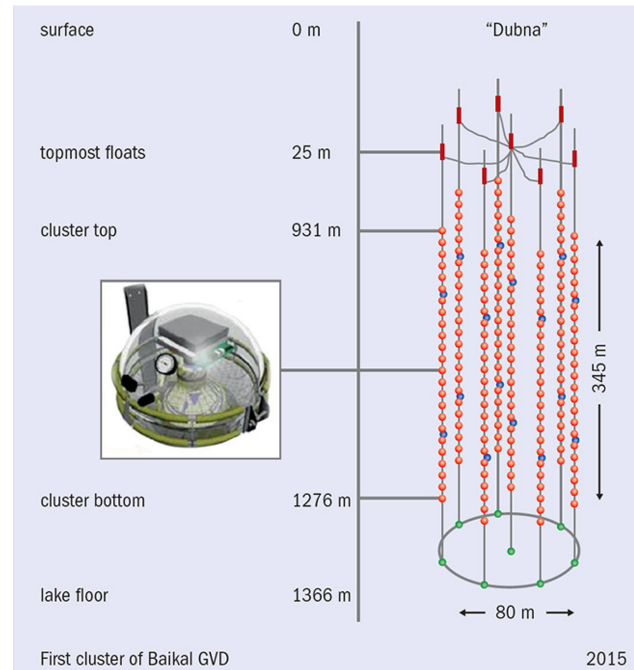


Lake Baikal: GVD

- First of 12 clusters operational since April 2015
- Plan: completion by 2020
- Instrumented volume: ~0.4 km^3



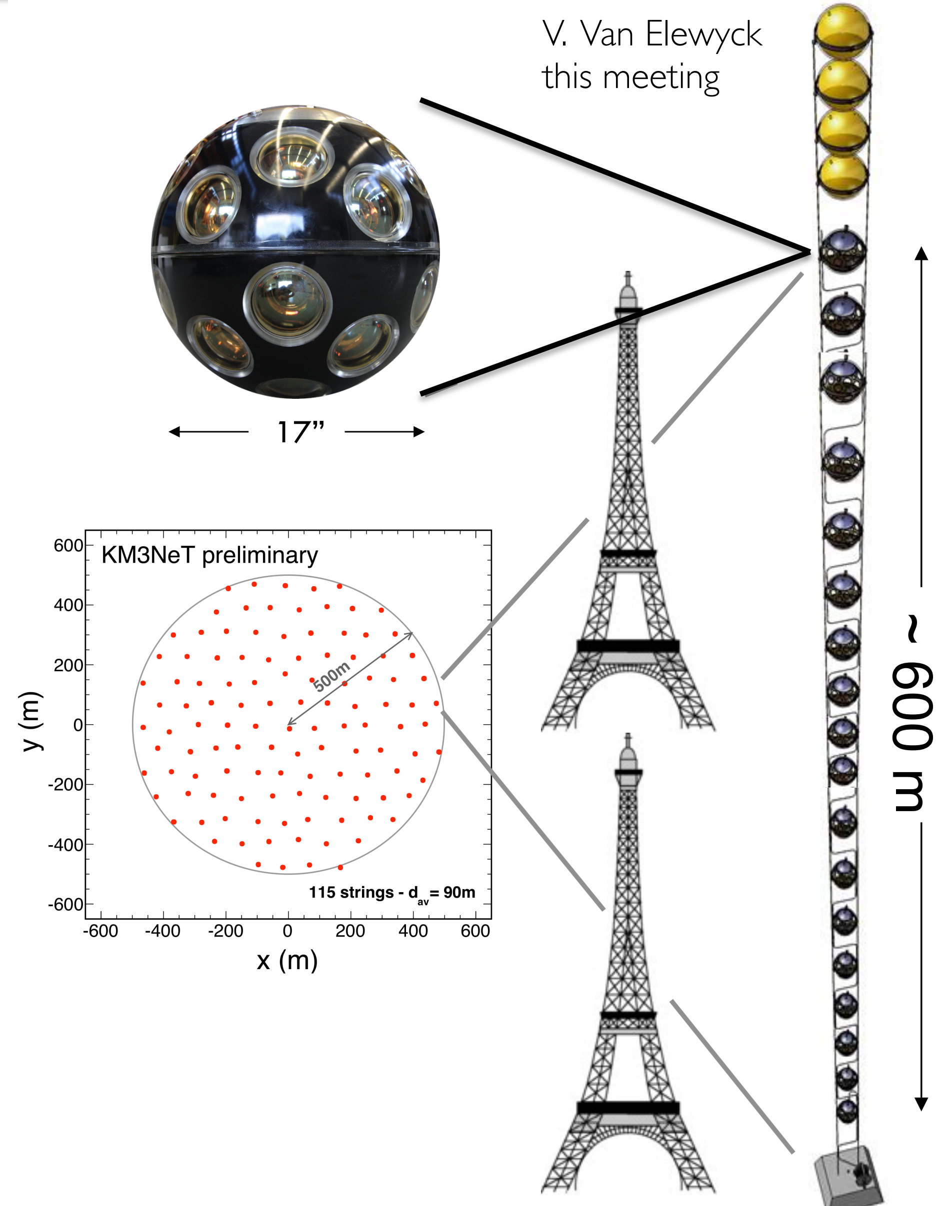
GVD cluster



courtesy C. Spiering

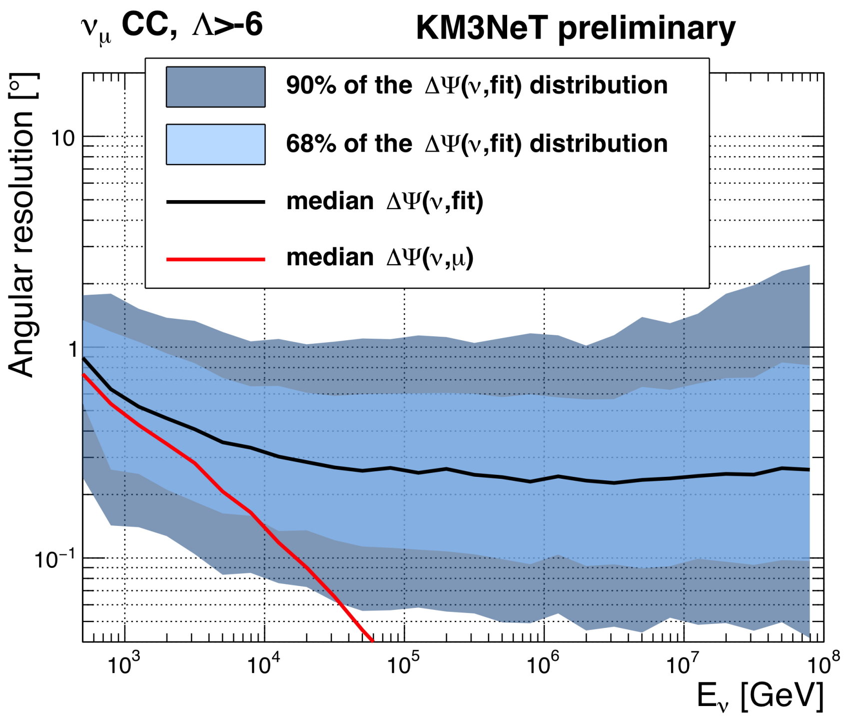
KM3NeT

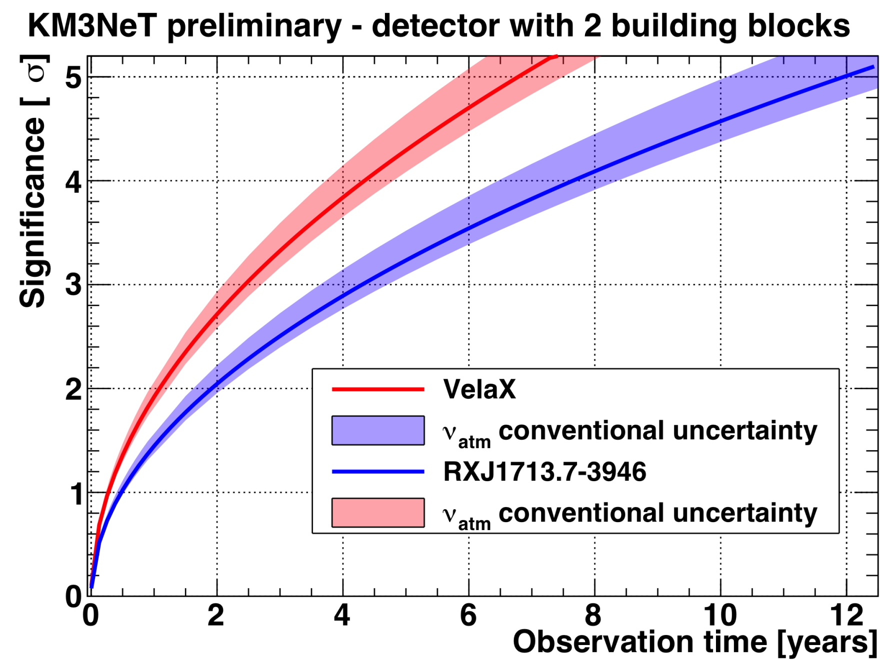
- Multi-site array in the deep Mediterranean
  - ARCA (E > 100 GeV): 2 “blocks” at Italian site, ~1 km^3
  - ORCA (1 < E < 100 GeV): 1 block at French site
- Phase 1 funded and under construction
  - 10% ARCA, 5% ORCA
  - completion 2017
- Phase 2: completion in 2020+
  - additional 95M€
- Phase 3: ARCA x3 (6 blocks)



KM3NeT/ARCA Sensitivity

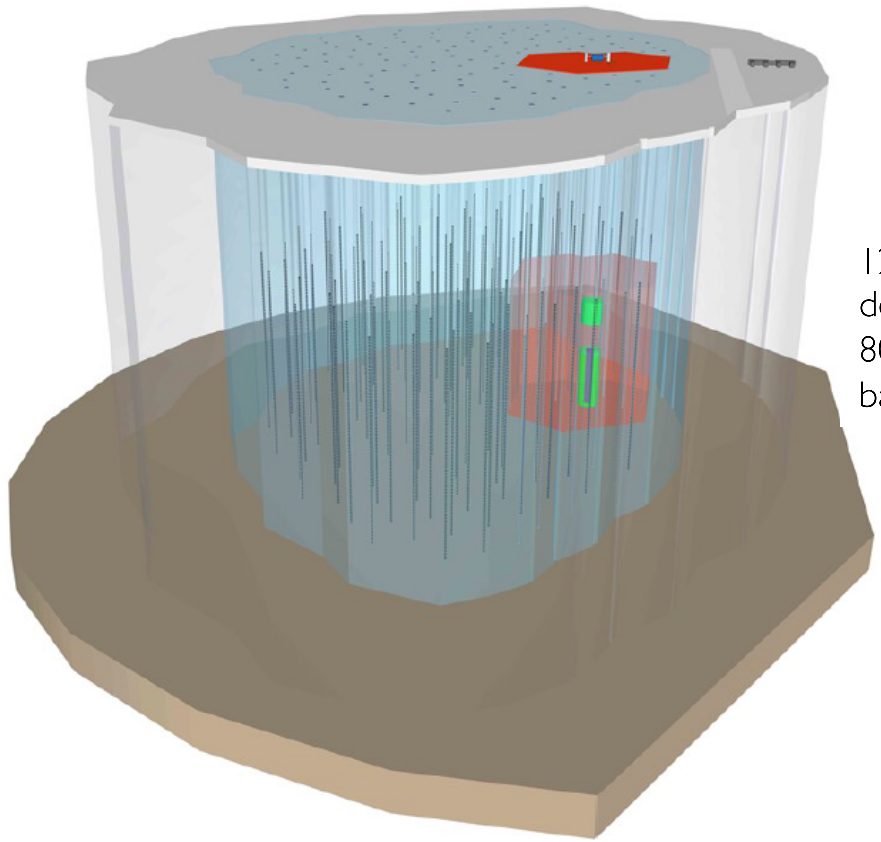
V. Van Elewyck, this meeting



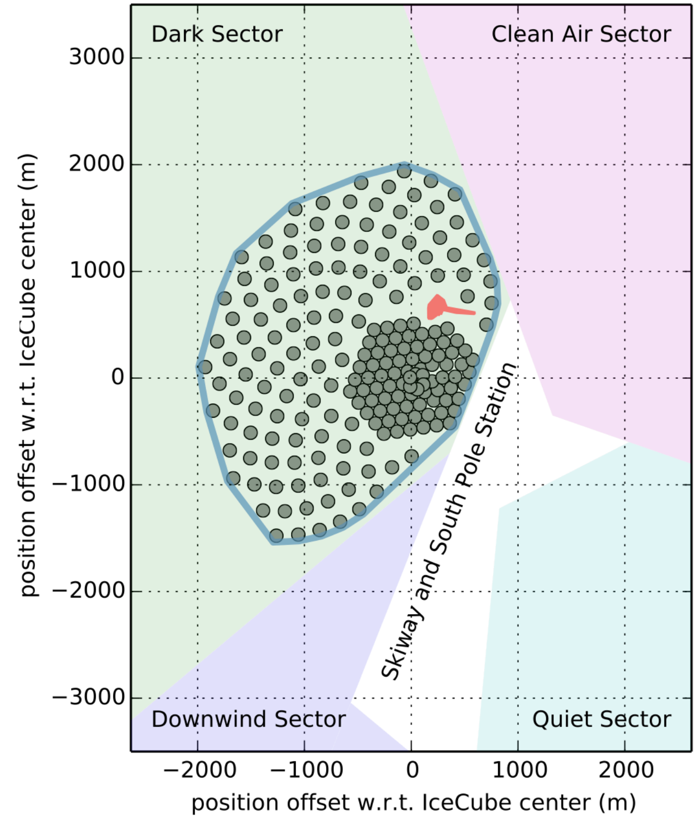


- Point-source sensitivity enhanced by ~0.2° angular resolution (low scattering length in water)
- Cascade directional resolution ~2°
- Possible sensitivity to Galactic sources in 2–3 years

IceCube Gen2



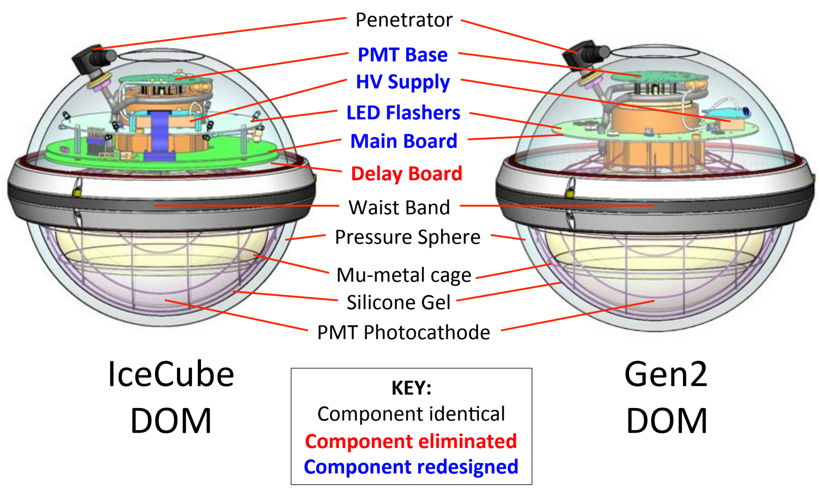
120 strings
depth 1.35 to 2.7 km
80 DOMs/string
baseline: 240m spacing

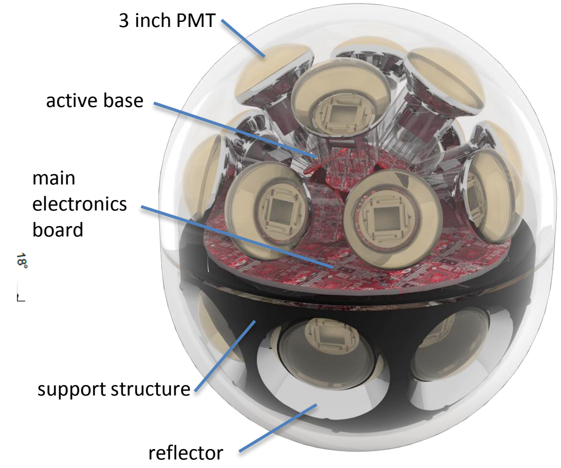


- Neutrino facility including high-energy array (HEA), low-energy infill (PINGU), surface array / veto, and radio
- HEA: 10x instrumented volume of IceCube
- Increased energy threshold (OK)
- Approximately the same budget (~$300M)

IceCube–Gen2 Sensor Development

arXiv:1510.05228



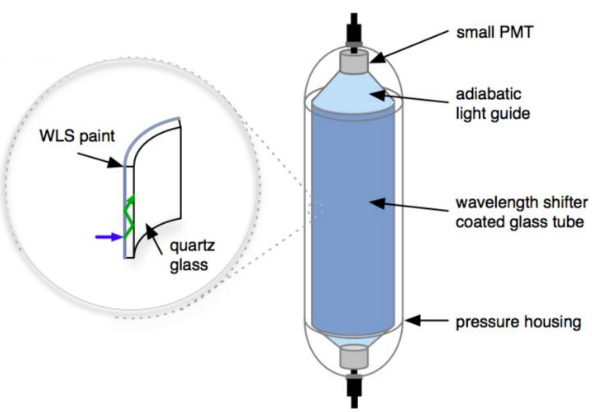


baseline: Gen2 DOM
10" HQE PMT

D-Egg
2 8" PMTs

mDOM
24 3" PMTs

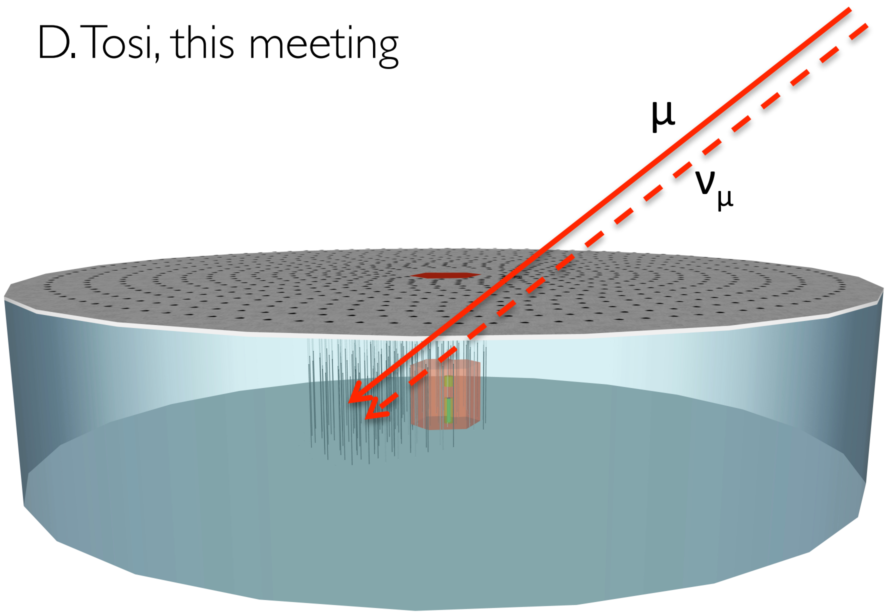
WOM (Hebeker ICRC2015)

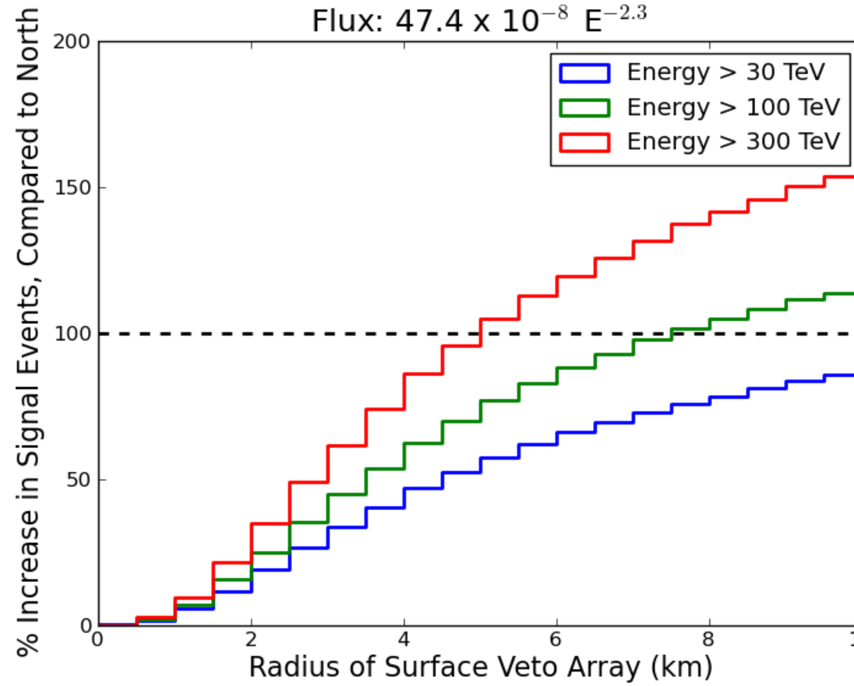


Surface Veto

K. Hanson, VLVnT 2015

D. Tosi, this meeting

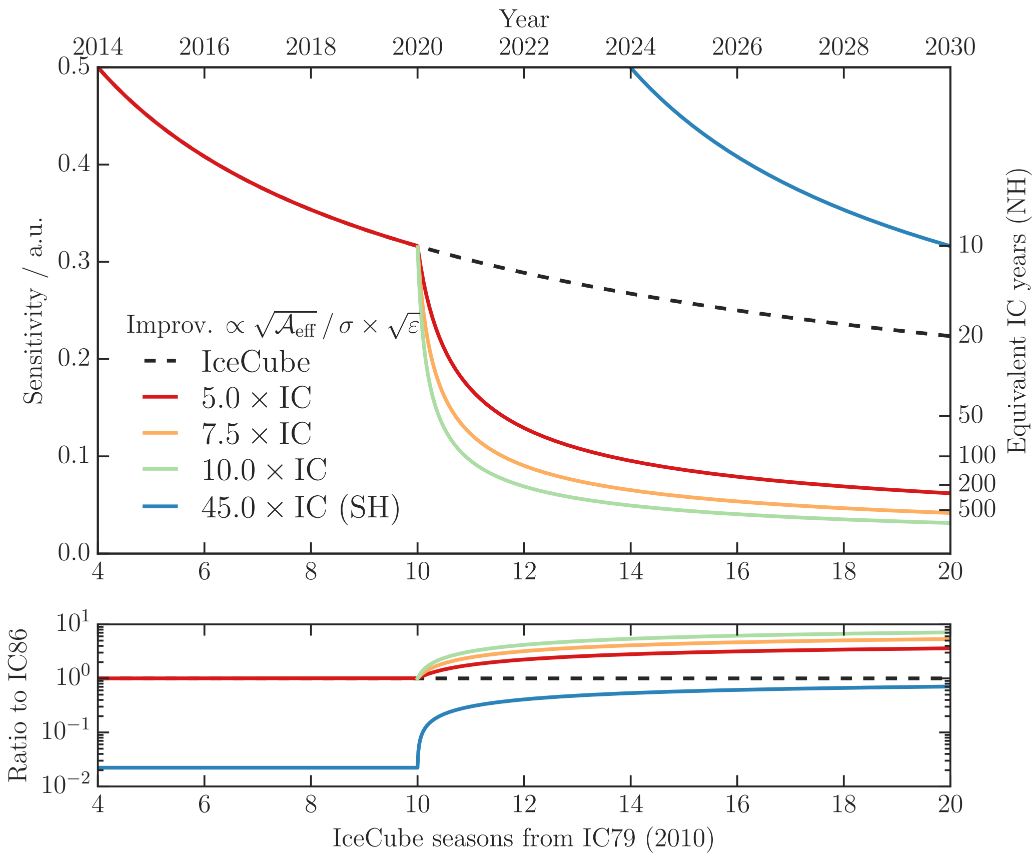




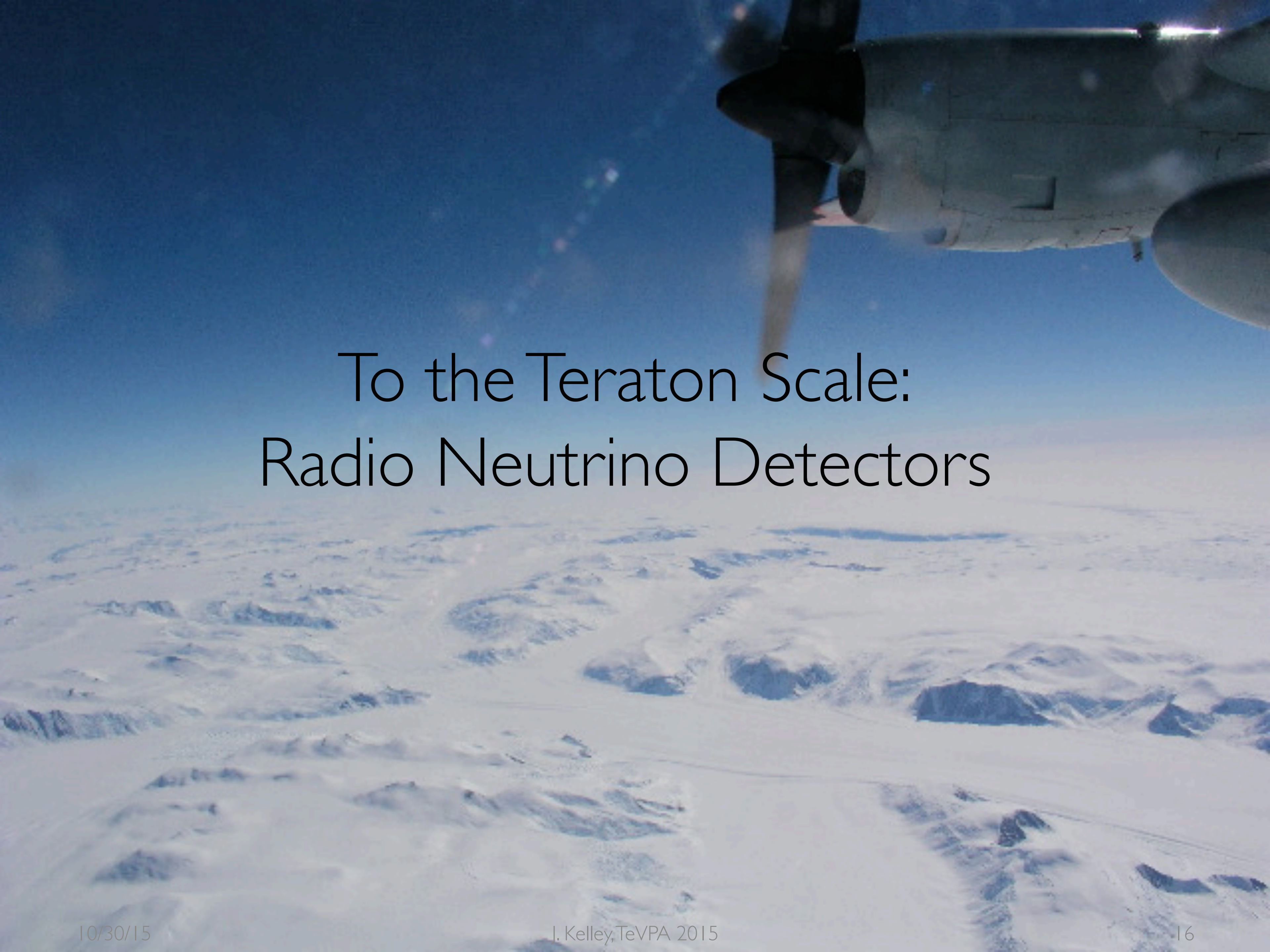
- Extended surface array can veto atmos. muons *and atmos. neutrinos*
- Signal rate improvement of +100% in Southern Hemisphere
- Logistics and necessary coverage still being optimized

IceCube Gen2 Sensitivity

E. Blaufuss, ICRC2015

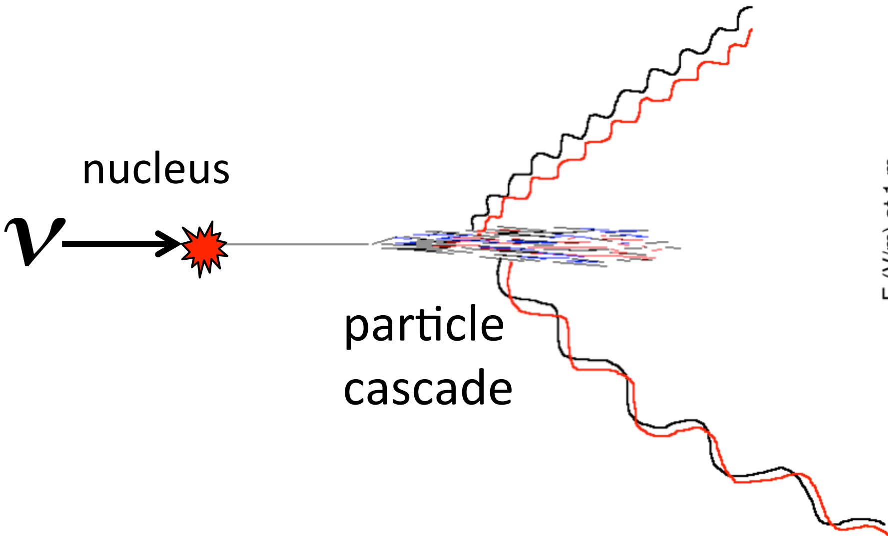


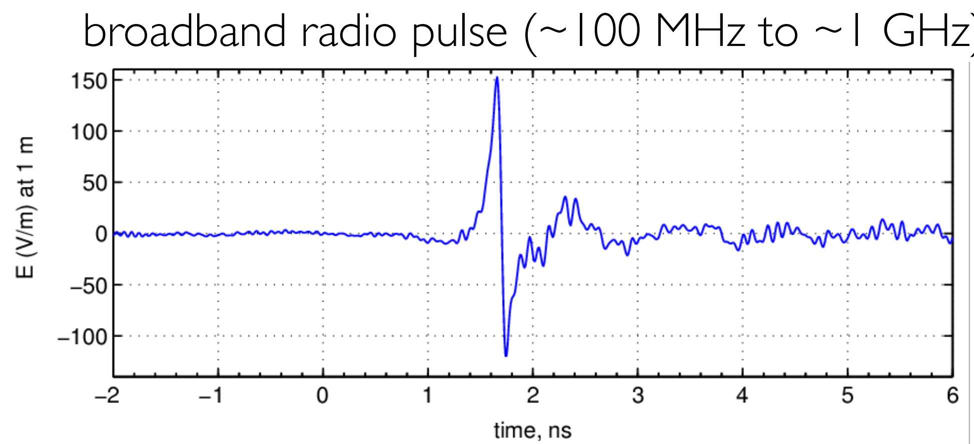
- 10 years of Gen2 HEA equivalent to > 200 years of IceCube
- Construction: 2021–26 (2-drill scenario)
- White paper: arXiv: 1412.5106



To the Teraton Scale: Radio Neutrino Detectors

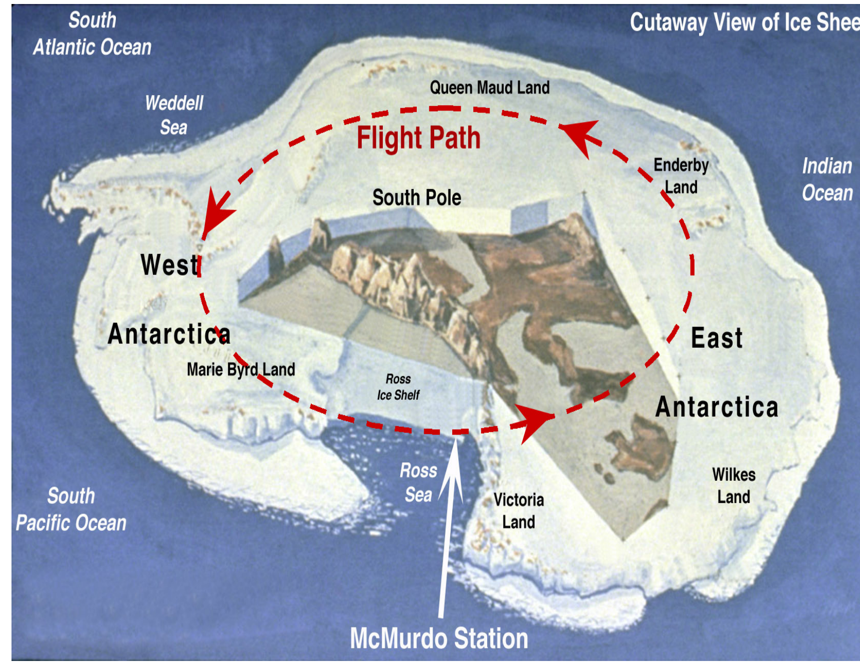
Radio Neutrino Detection





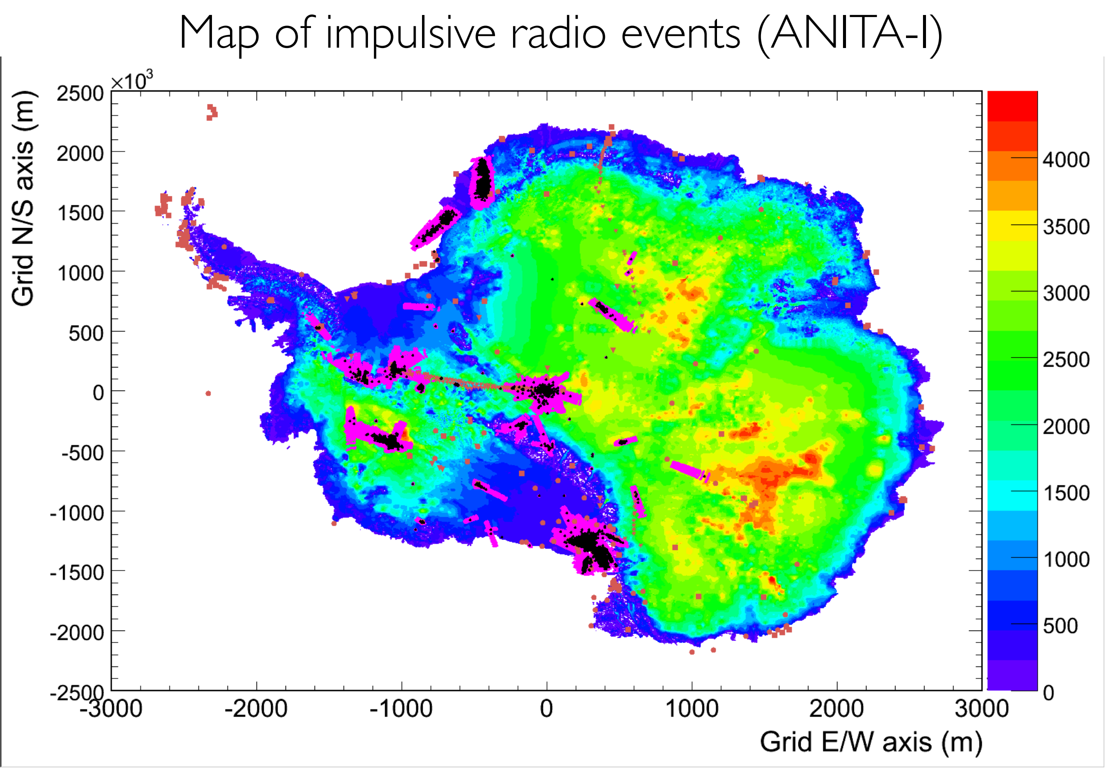
- Optical technique is not very scalable beyond O(10 km3)
- Askaryan effect: charge excess from particle shower produces a coherent radio pulse
- Energy threshold determined by average distance to vertex + thermal noise, generally > 10 PeV
- Cold ice is exceptionally radio-transparent (L_{atten} ~ 1km)

ANITA



- Long-duration balloon-borne radio array launched from McMurdo
- Lots of target material; flight time 20–30 days

ANITA Neutrino Searches

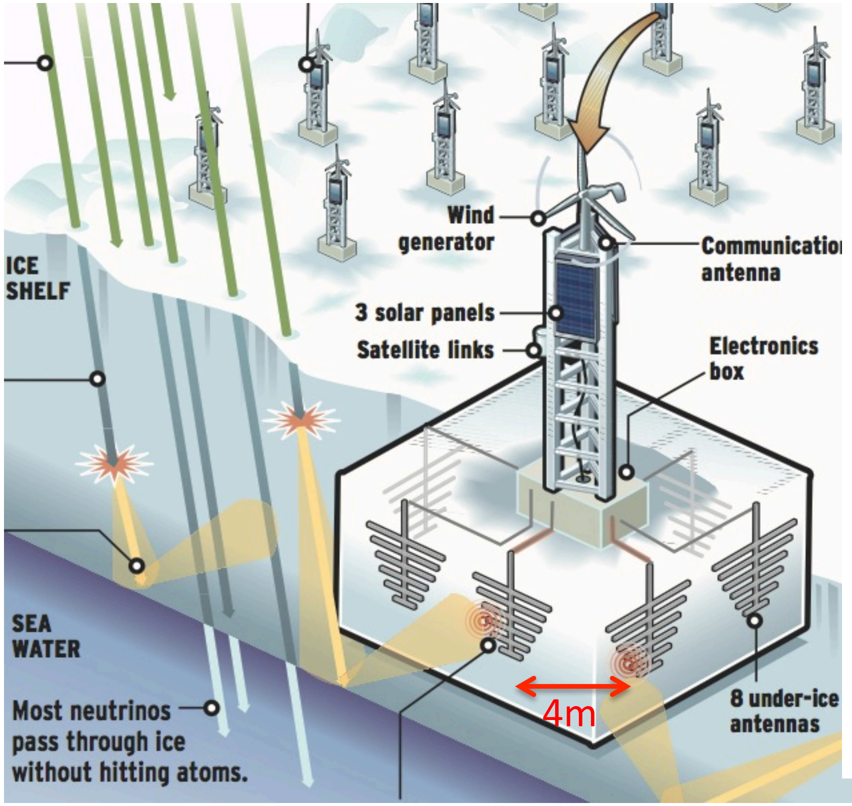


- Flight 2 (2009): 1 event on background of 0.97±42
- UHECR air showers detected via geomagnetic emission
- Third flight 2014–15; analysis underway

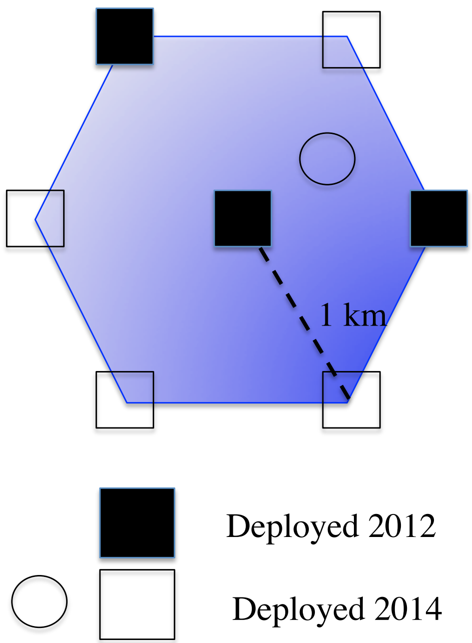
ARIANNA

S. Barwick, ICRC2015

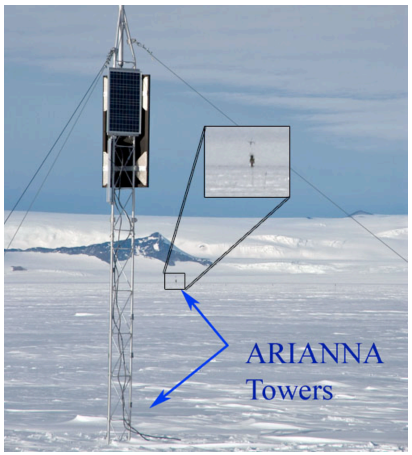
1 station in array of 36 x36, 1km spacing



Completed in Dec 2014



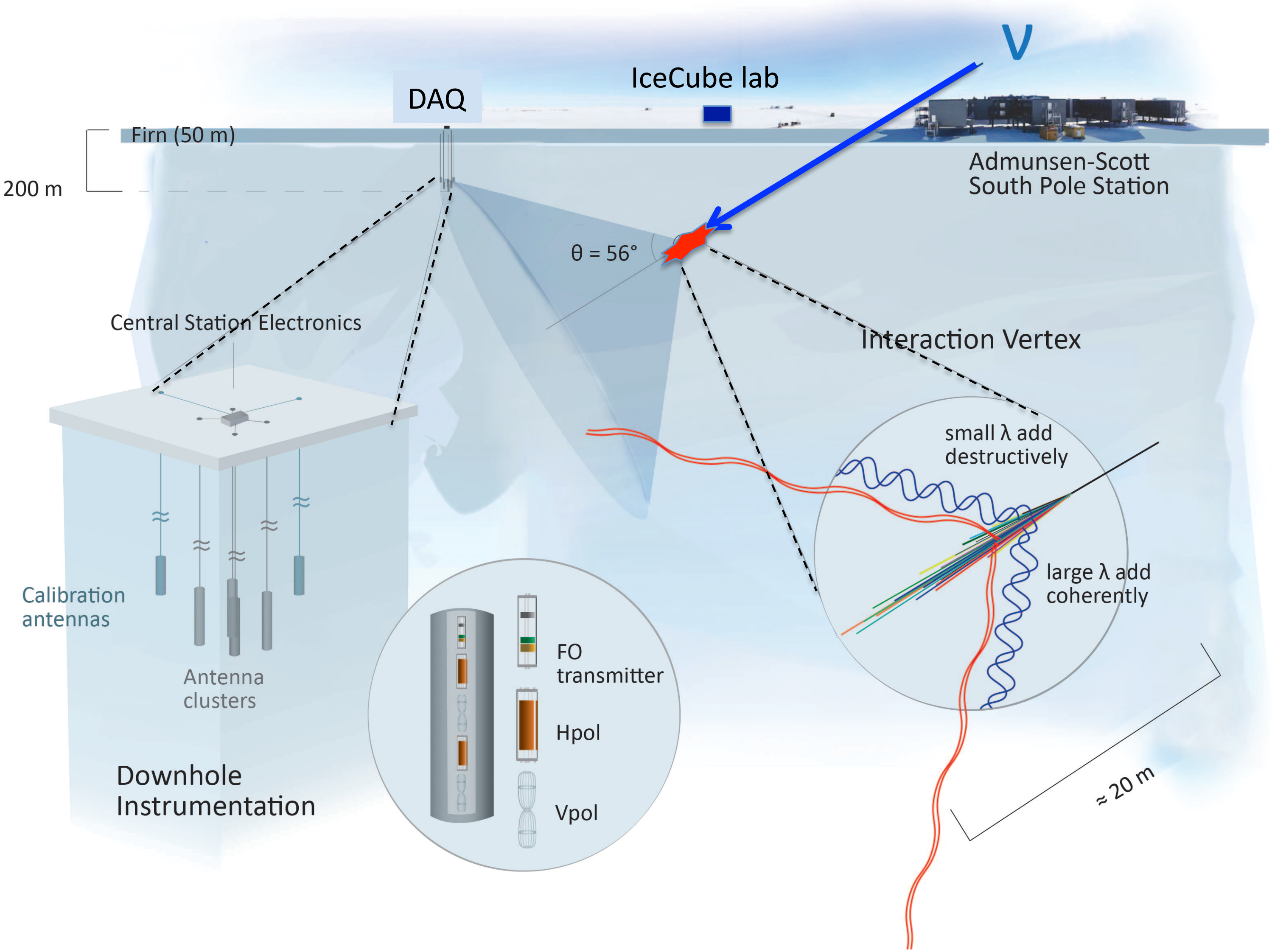
ARIANNA HRA



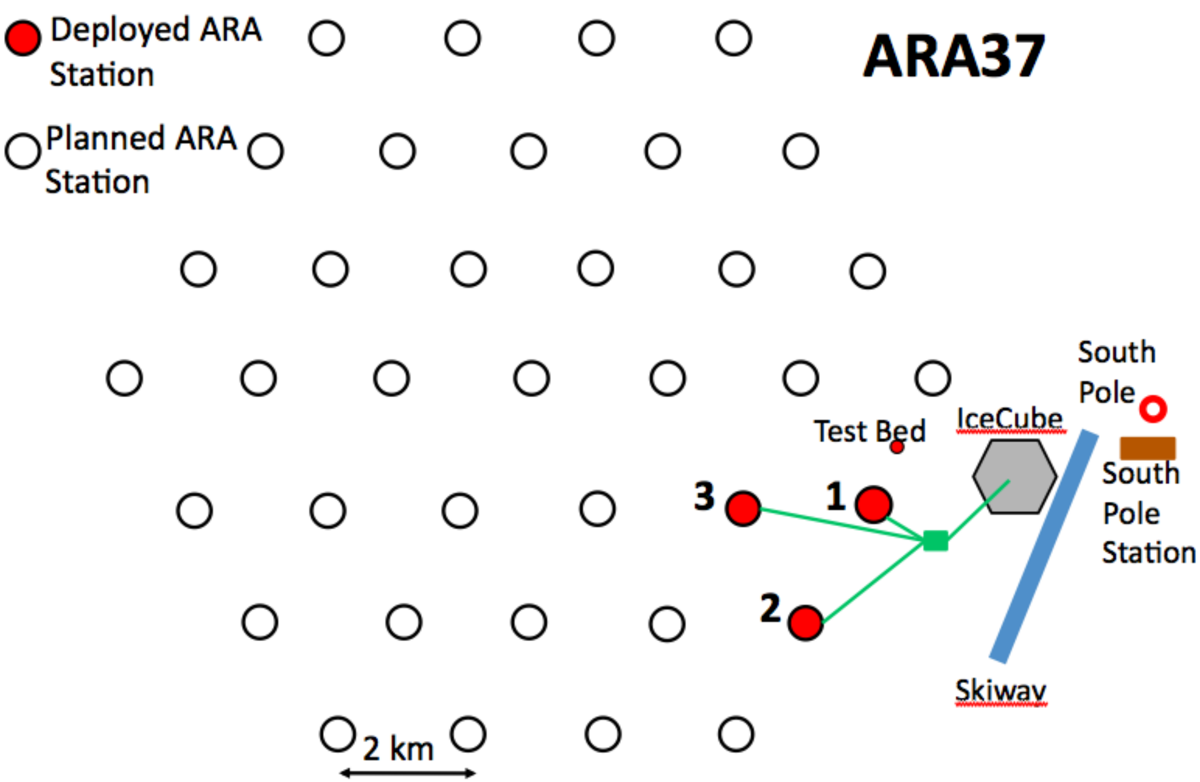
- 1296 autonomous antenna stations on the Ross Ice Shelf
- Radio reflections from ice–sea boundary increase acceptance
- 7-station HRA deployed and taking data

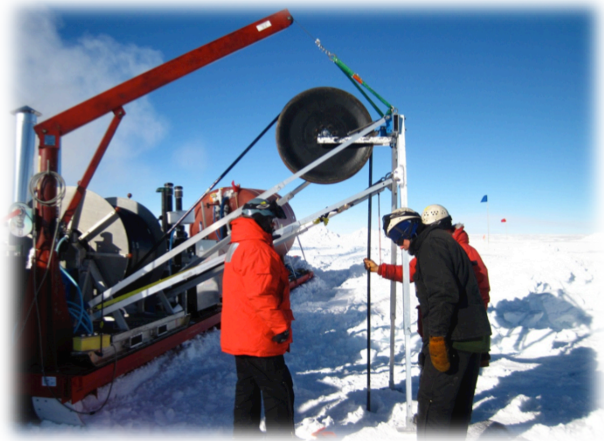
Askaryan Radio Array (ARA)

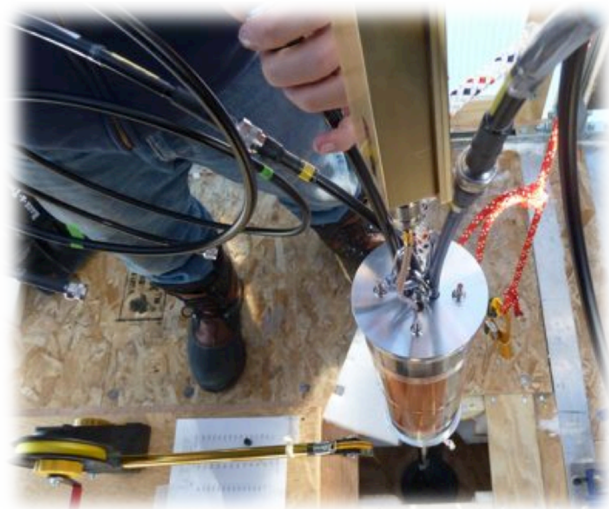
M DuVernois, this meeting



ARA Status



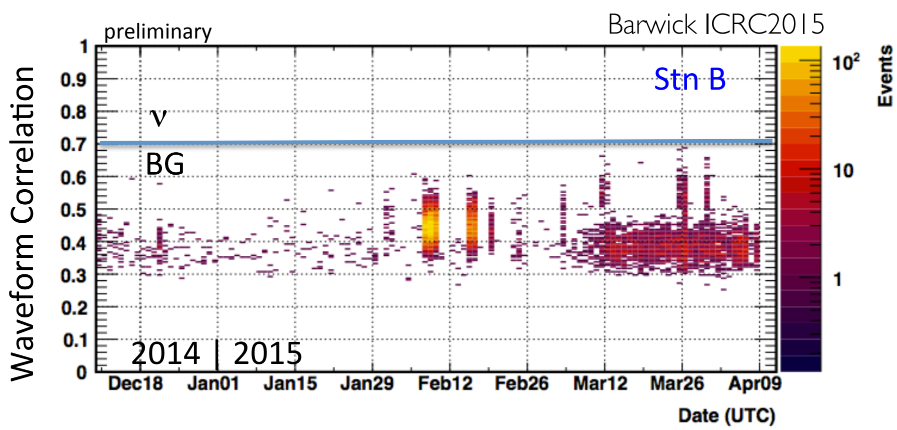




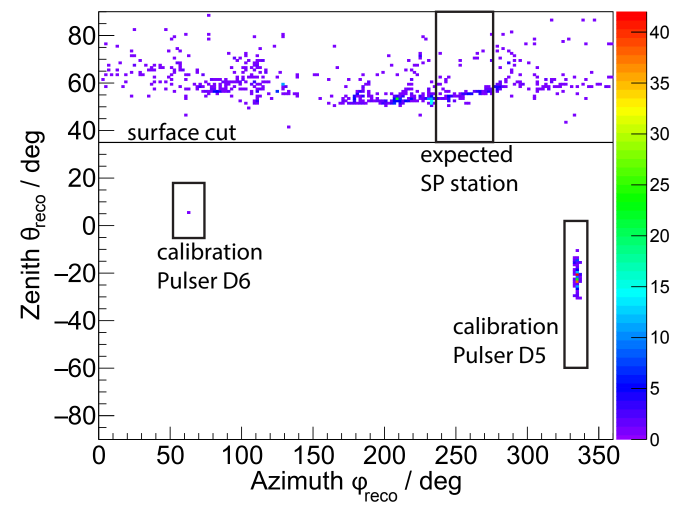
- Next deployment: 2016–17 or 17–18 polar season
- Cost of total project: ~$10M

ARA and HRA Neutrino Searches

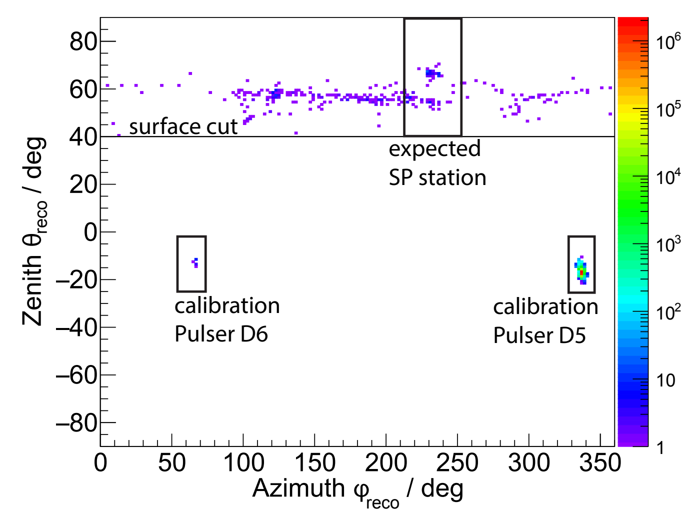
HRA event template correlation



ARA event candidate directions



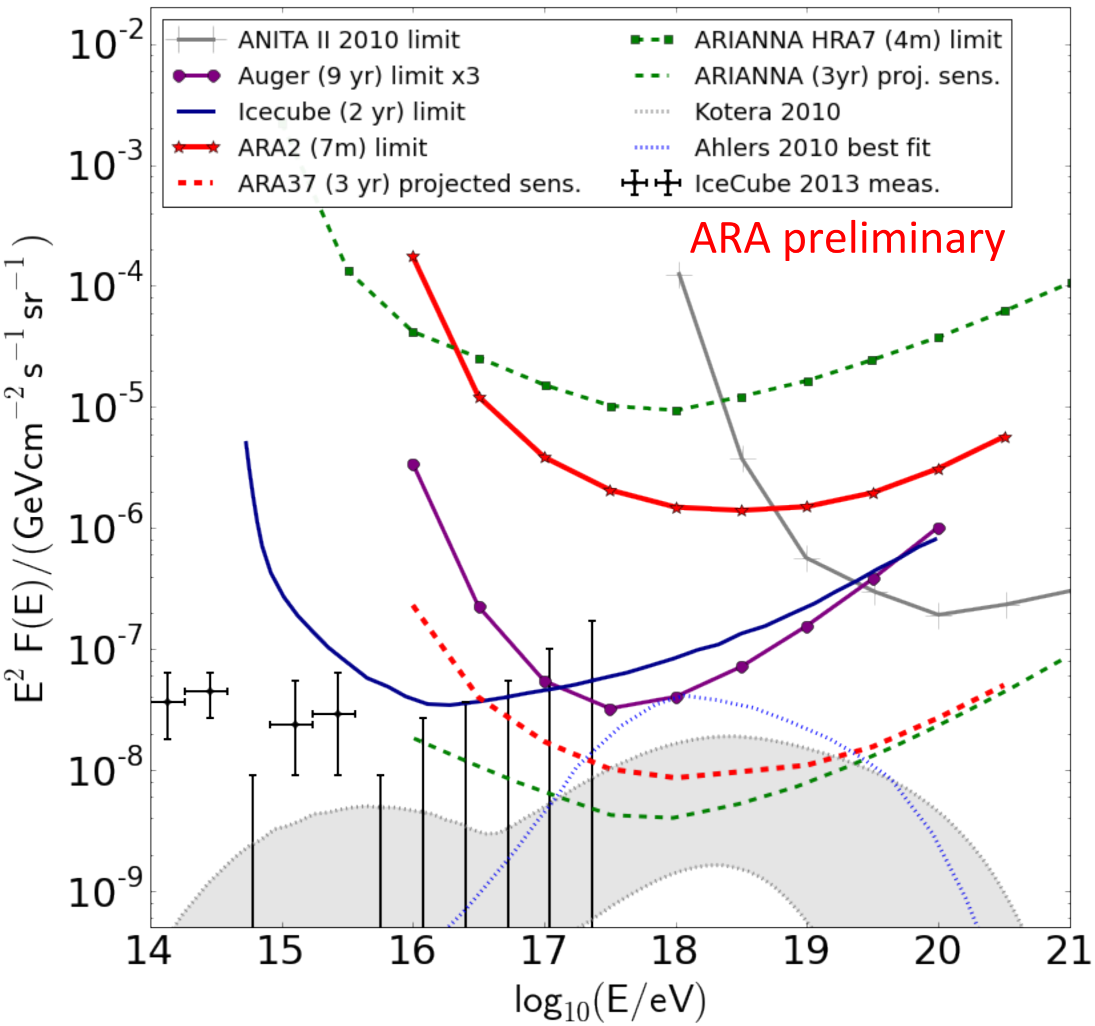
(a)



- Analyses reject thermal and anthropogenic noise
- Directional resolution of both arrays is ~1°

Upper Limits and Future Sensitivity

all experiments: no cosmogenic neutrinos yet



courtesy T. Meures
all-flavor limits;
decade energy bins

ANITA-II:
arXiv: 1011.5004

ARA:
arXiv:1507.08991

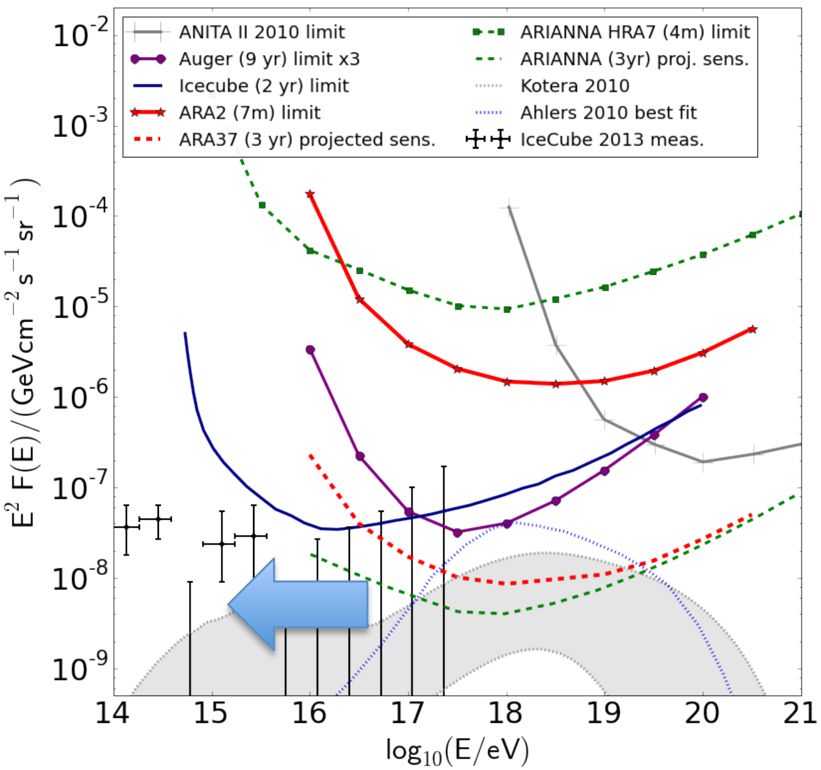
ARIANNA HRA:
arXiv 1410.7352

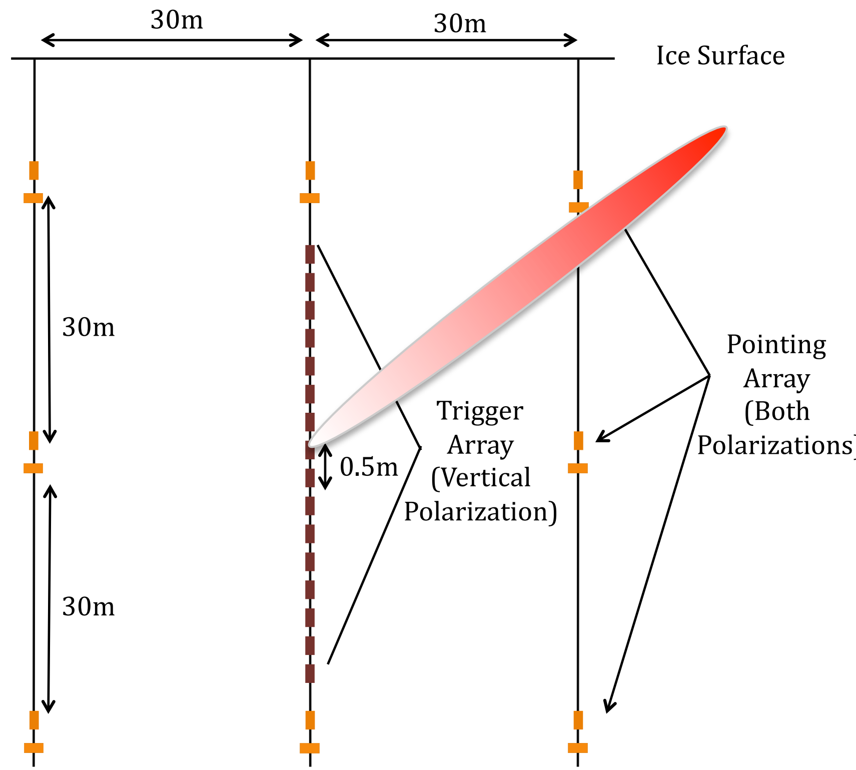
Auger:
arXiv: 1504.05397

IceCube EHE:
see also A. Ishihara, this conference

Innovative Concepts

Bridging the Energy Gap



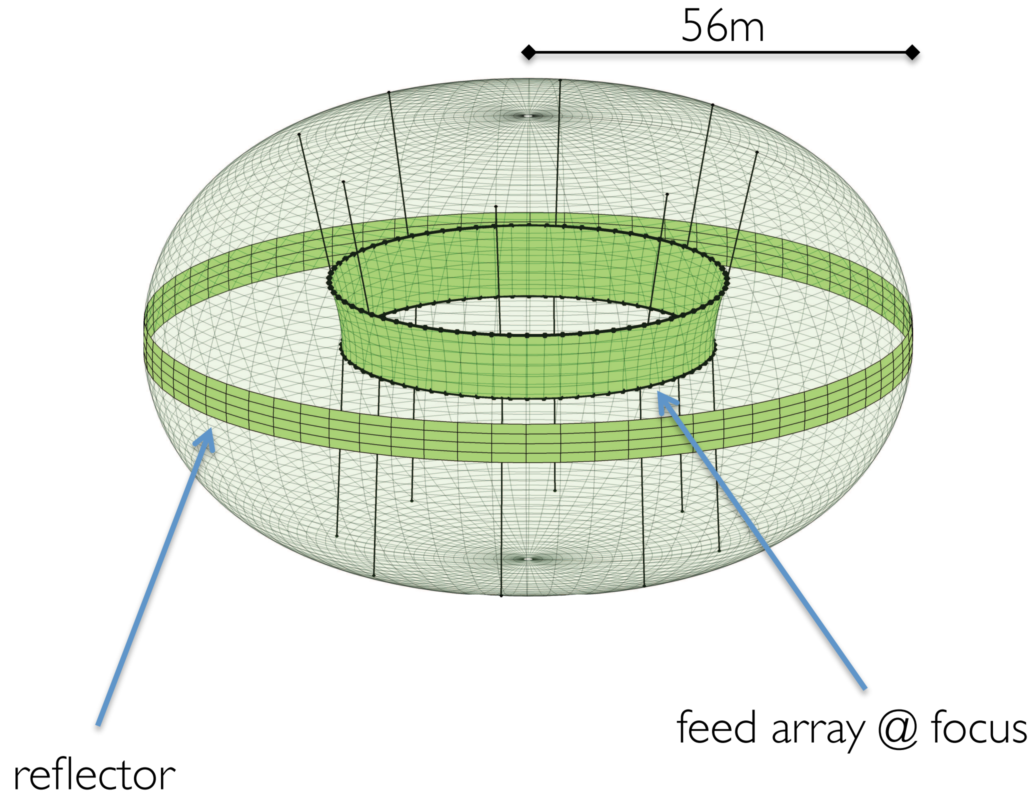


A. Vieregg, K. Bechtol, and A. Romero-Wolf
arXiv: 1504.08006

- Lower radio threshold to 1 PeV to detect diffuse neutrino flux
- Phased-array trigger: simultaneous high-gain beams in all zenith angle sectors
- Field testing in Greenland (GNO program)

ExaVolt Antenna (EVA)

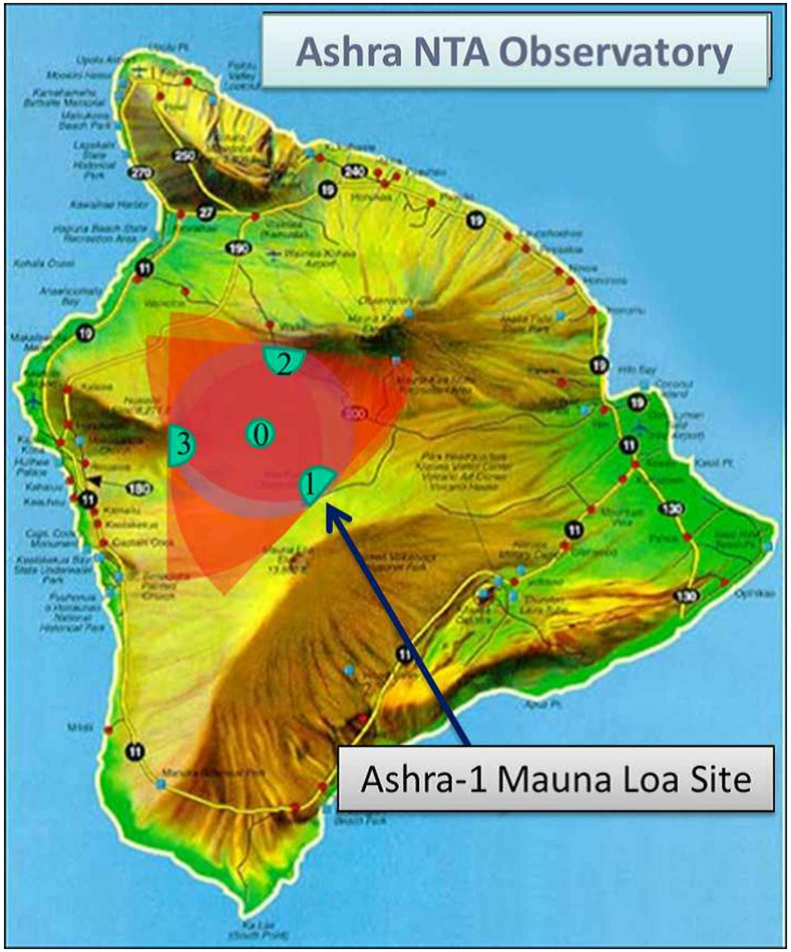
Gorham *et al.*, arXiv:1102.3883



- NASA super-pressure balloon with *integrated* toroidal antenna
- Sensitive to wider range of mixed-composition UHECR models
- 3-year design study funded (1/5 scale)

Neutrino Telescope Array (NTA)

G. Hou, arXiv:1409.0477



- Concept for dedicated ν_τ observatory
- Cherenkov-fluorescence telescope search for τ-induced air showers
- Mountains provide both CR shield and neutrino target
- Peak sensitivity ~30 PeV

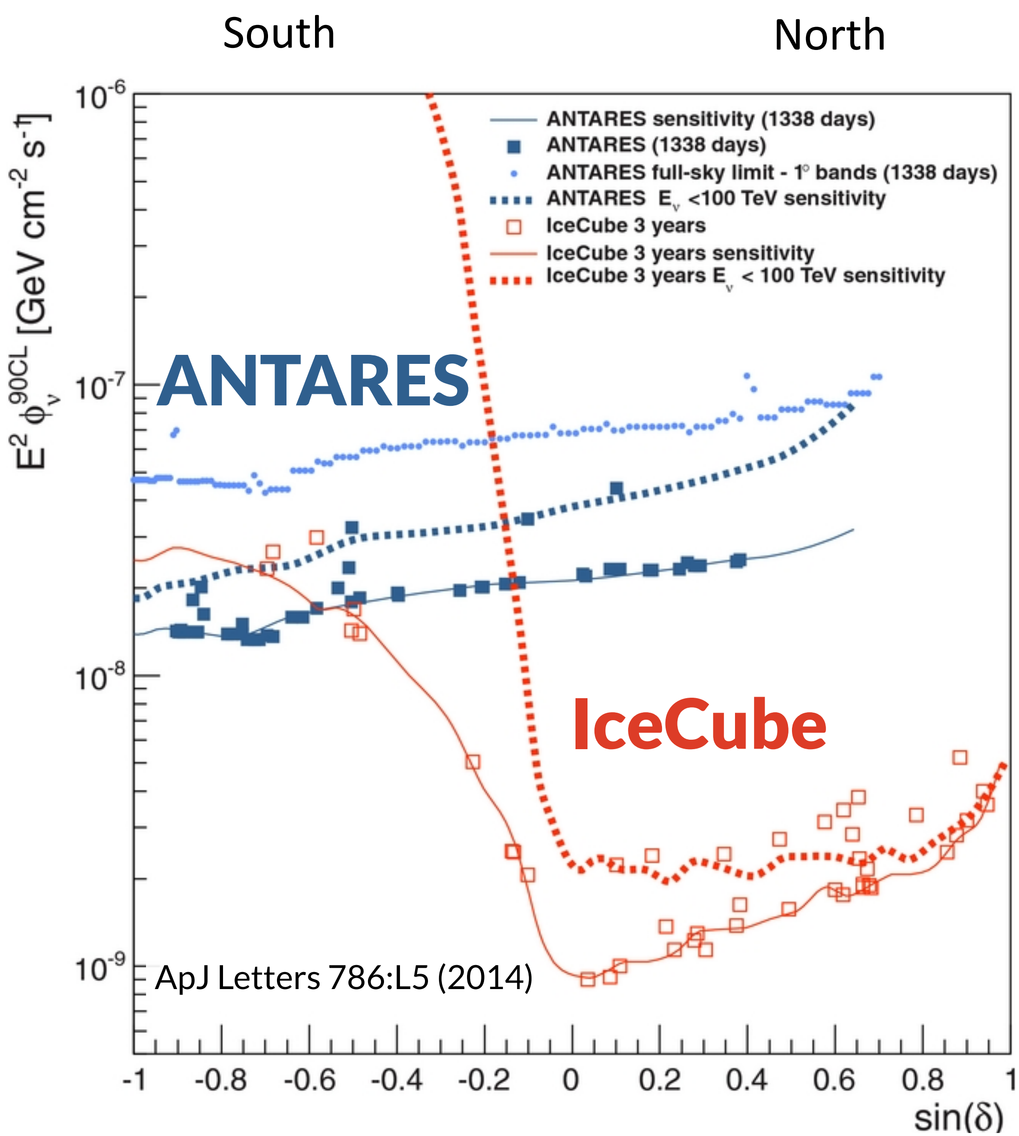
Summary

- IceCube discovery of a diffuse astrophysical neutrino flux has energized the field of neutrino astronomy
- Large new optical arrays will push forward the search for neutrino point sources
  - KM3NeT/ARCA Phase 1 under construction
  - IceCube–Gen2 design studies in full swing
- Radio technique allow extension to 100 km^2 and beyond
  - prototype arrays taking data (ARIANNA, ARA)
  - lowering energy threshold may allow detection of diffuse astrophysical flux

Thank you!

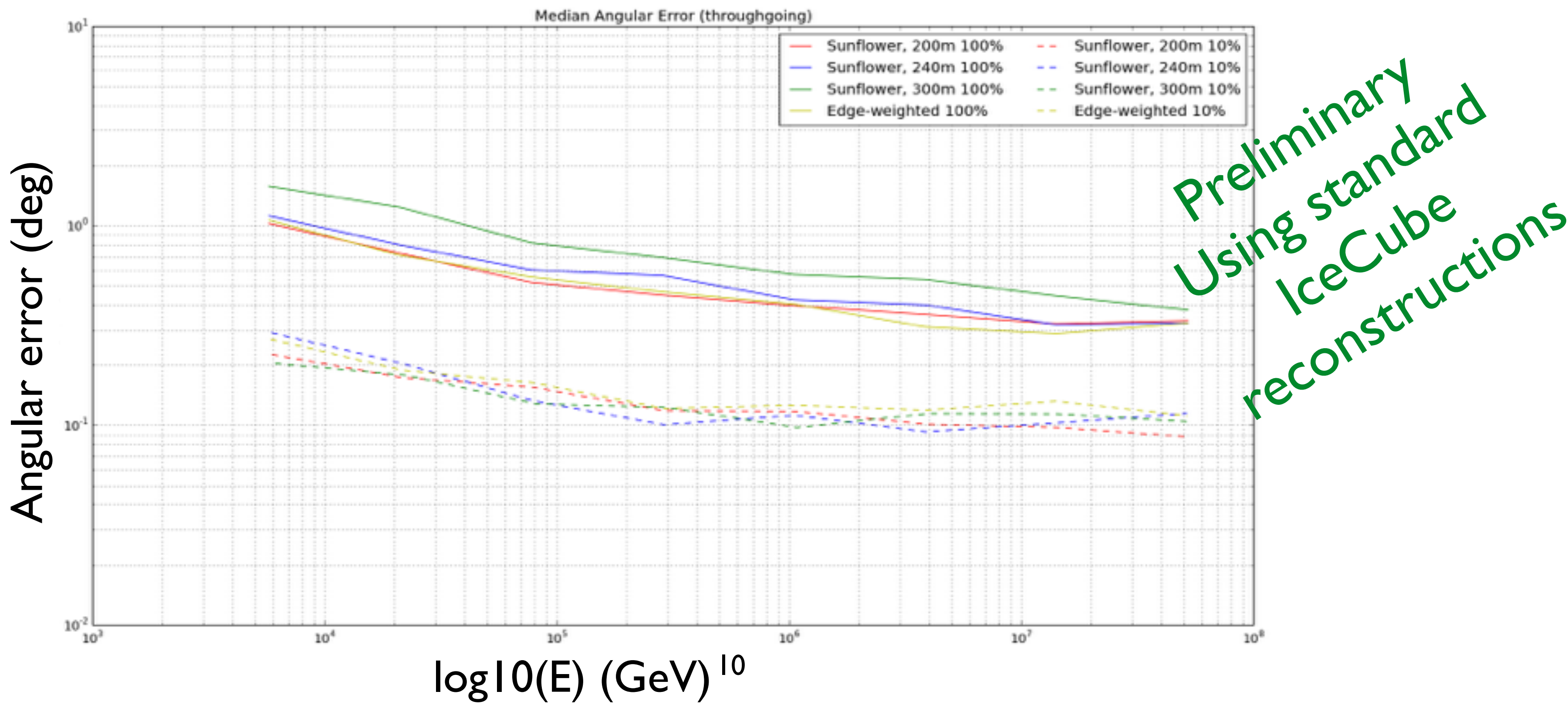
Backup

Neutrino Point Source Limits



IceCube Gen2 Angular Resolution

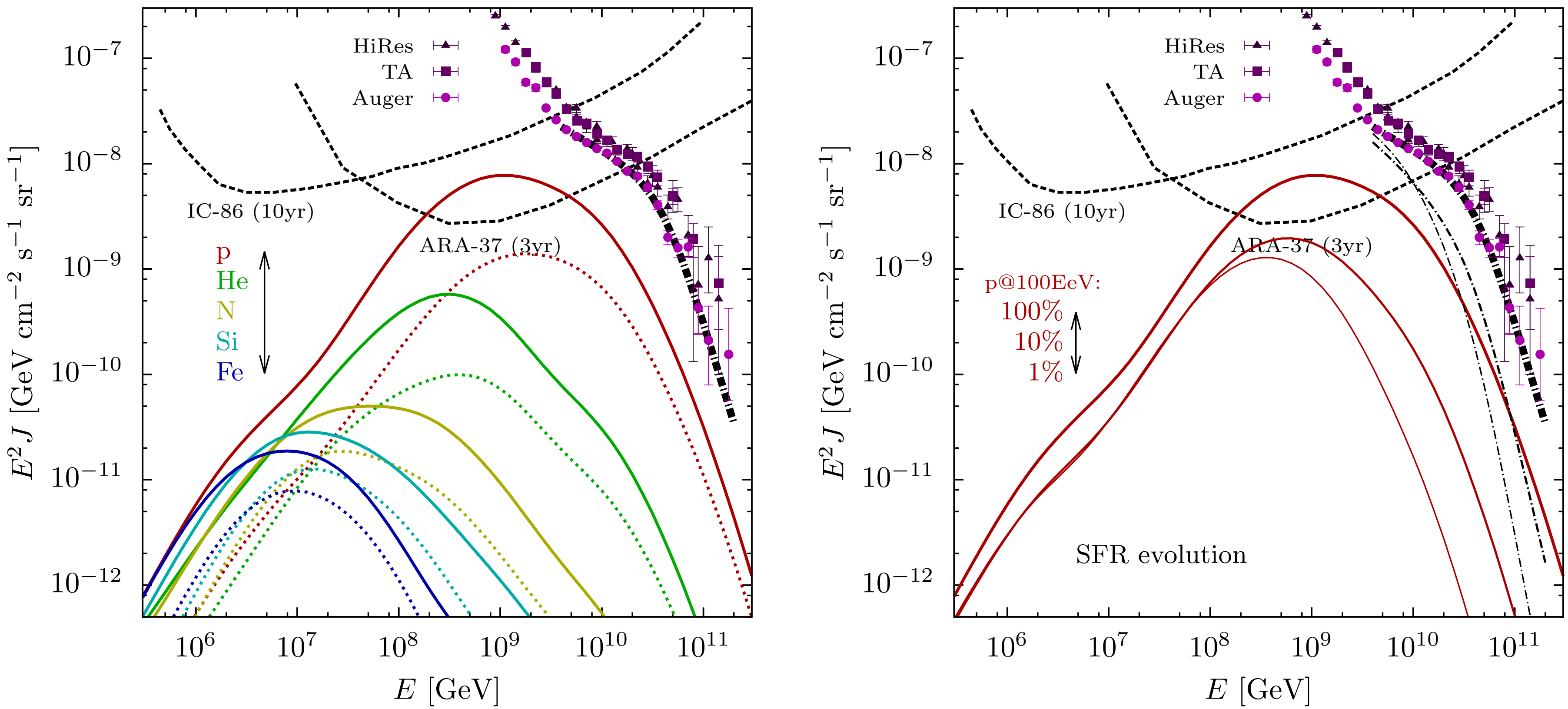
- Track directional resolution 0.3-0.5° (highest-quality events: 0.1°)
- Improvements from reconstruction methods still expected



E. Blaufuss, ICRC2015

Impact of Composition

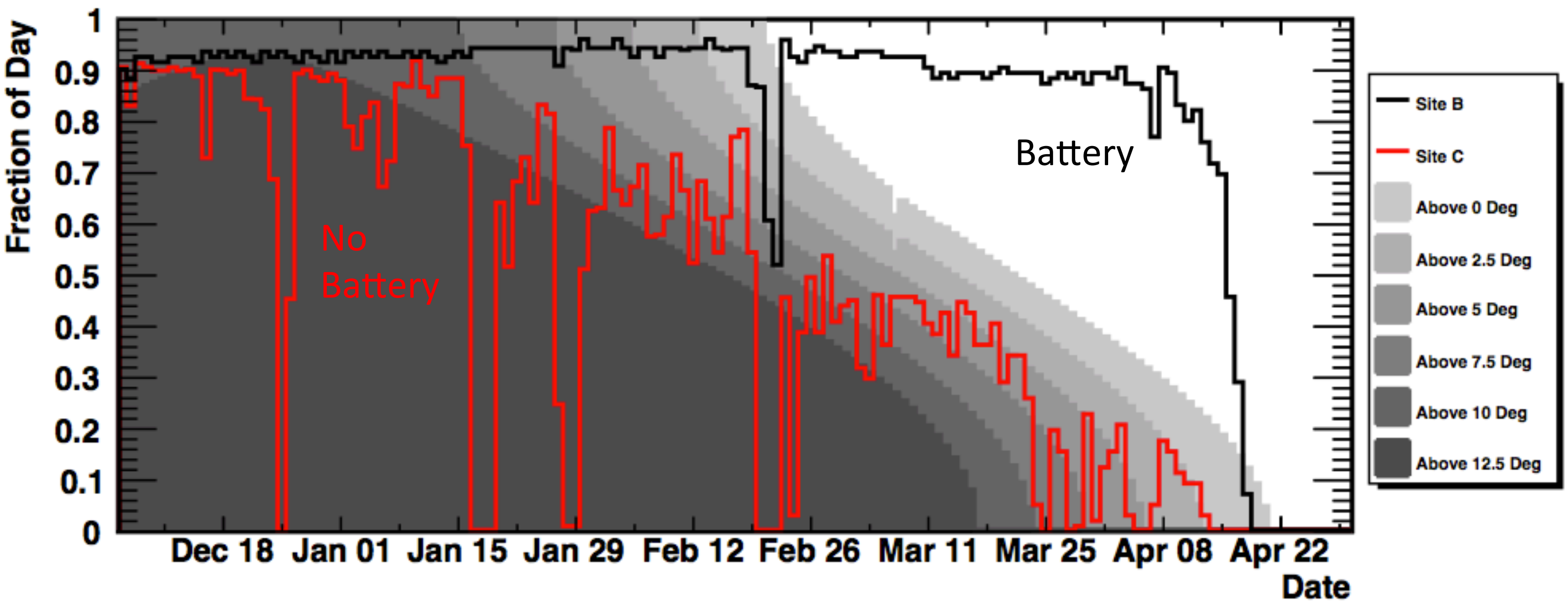
Strong dependence of cosmogenic neutrino flux on UHECR composition



Ahlers & Halzen, aXiv:1208.4181

ARIANNA Station Livetime

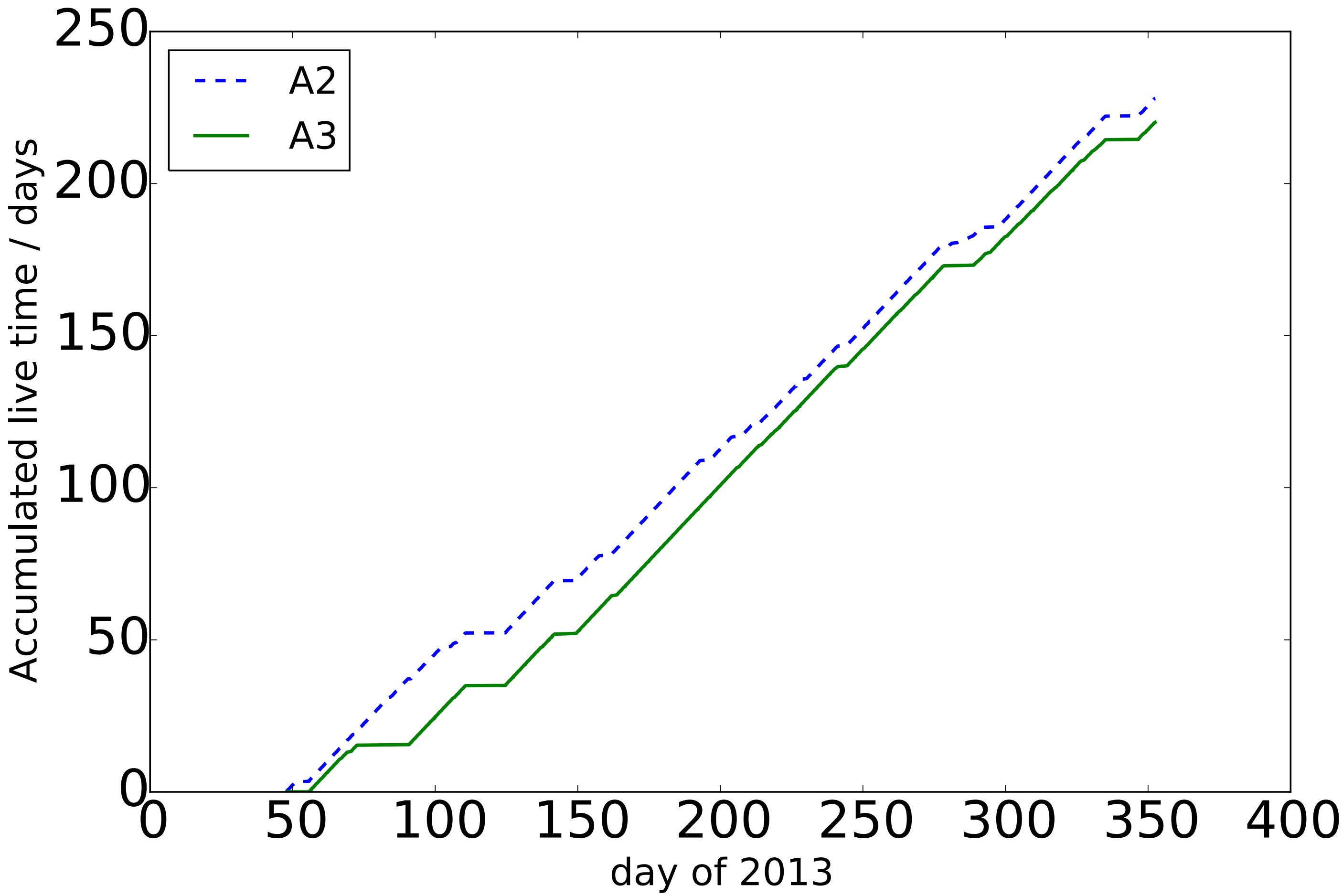
S. Barwick / A. Nelles, ICRC2015



Site B station, with battery, achieves ~92% livetime, 8% loss from data transmission
Site C station, gaps due to un-transferred data. Requires sun >2-5^{o} above horizon

ARA 2013 Livetime

arXiv:1507.08991



NTA Diffuse Sensitivity

G. Hou, arXiv:1409.0477