Muon Modulation due to atmospheric temperature variation

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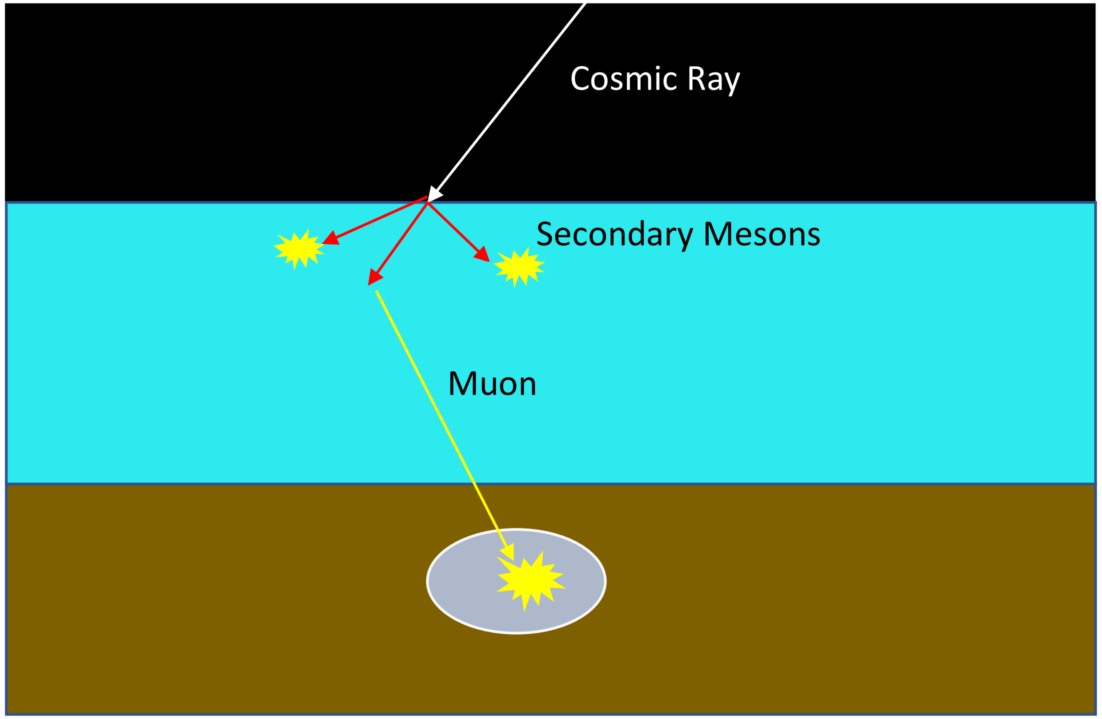
Muons from Cosmic Rays

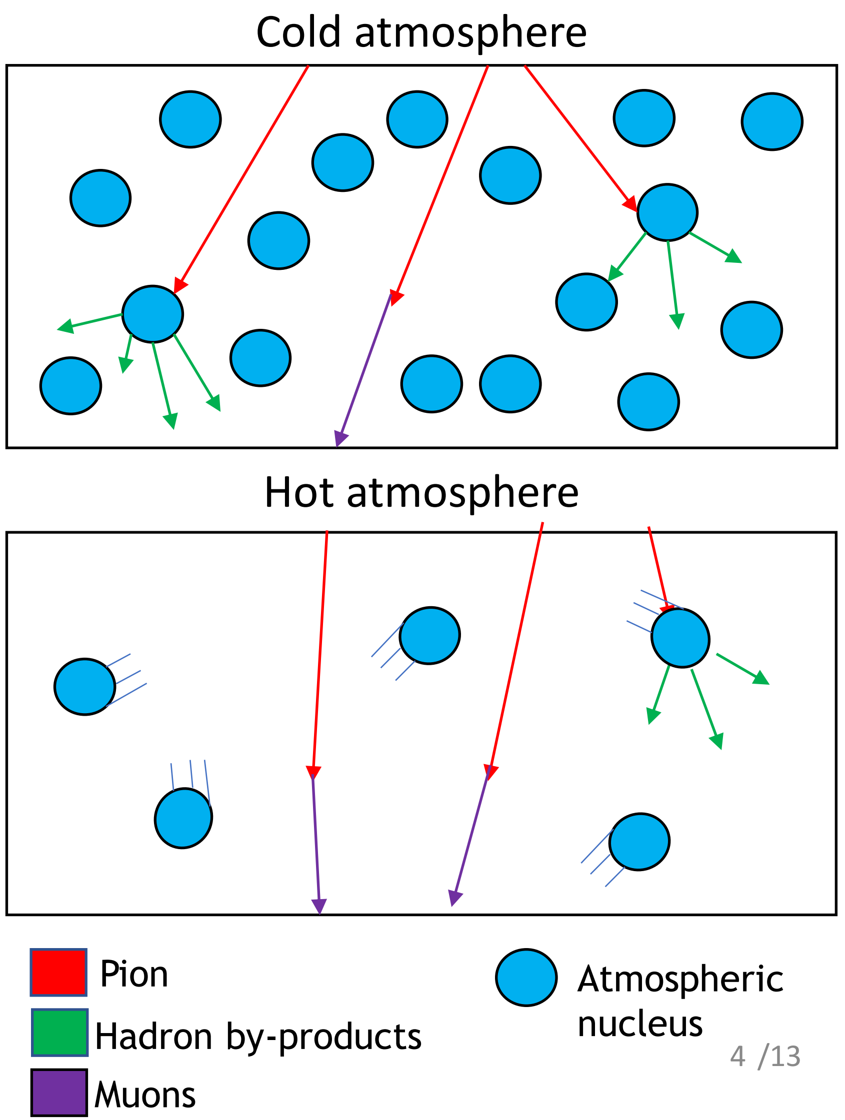
- Cosmic rays impact the atmosphere, producing mesons, which decay to muons or interact hadronically
- These muons can be detected at ground level and below in practically any detector



Seasonal Variation of Muons

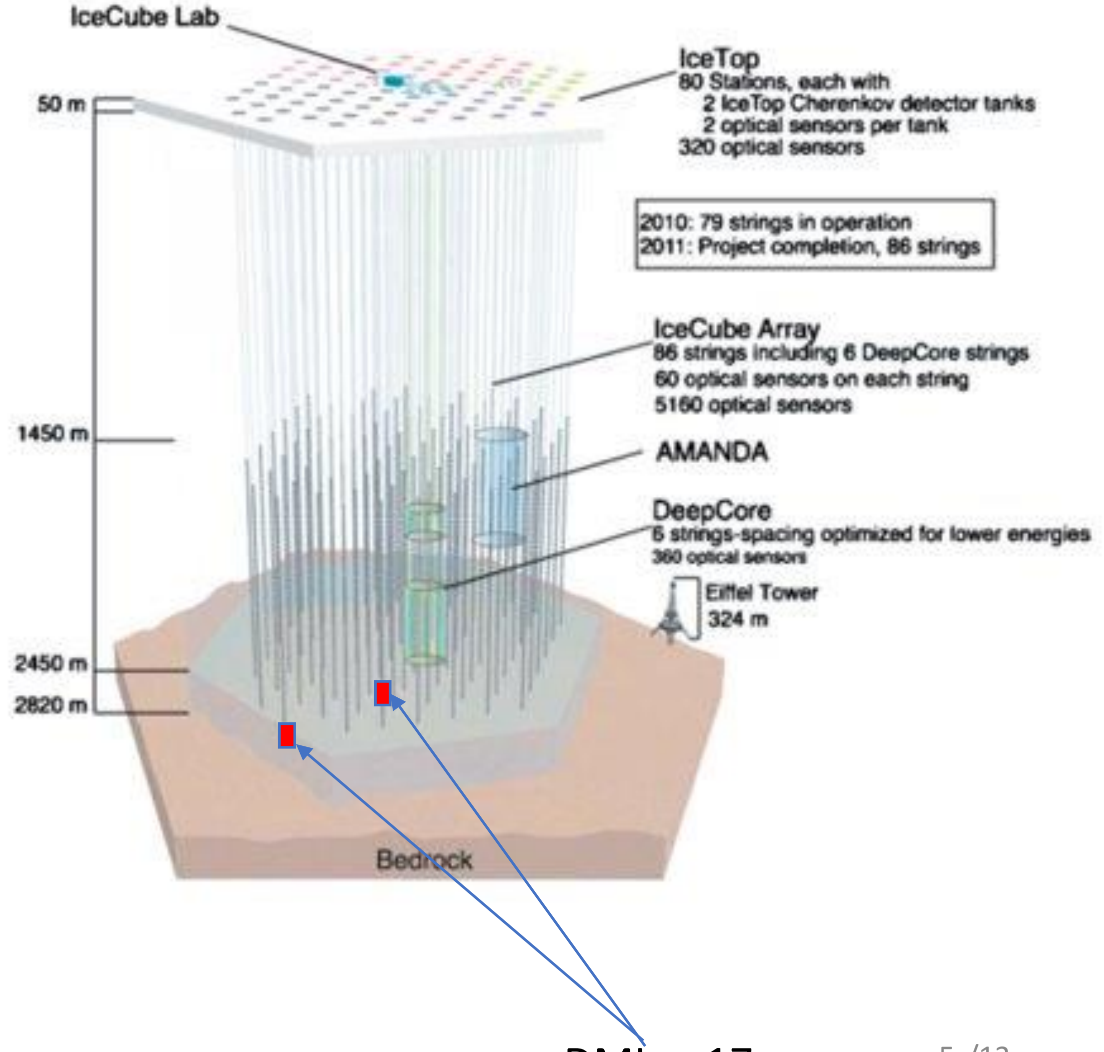
- In local summer, atmosphere is warmer, less dense. This means cosmic ray daughter mesons are less likely to interact hadronically with atmosphere, and more likely to decay to muons.

- This modulation in rate should have ay early period, and is of a large enough fraction to be detected compared to the average flux.



Muons in IceCube / DMIce-17

- IceCube is a neutrino observatory, situated within the Antarctic ice cap.
- DMIce-17 is a pair of modules, each with an 8.5kg scintillation crystal, located at the bottom of two IceCube strings.
- We aim to show the muon modulation using these two detectors

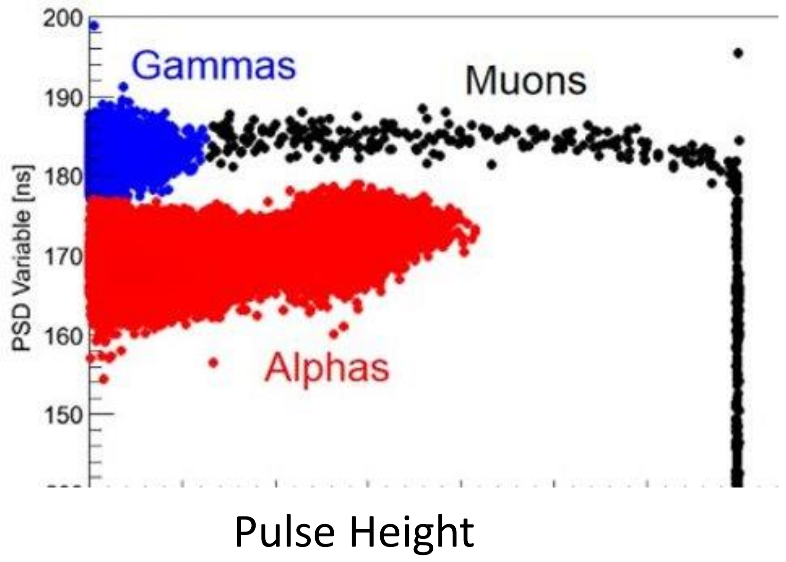


DMIce-17

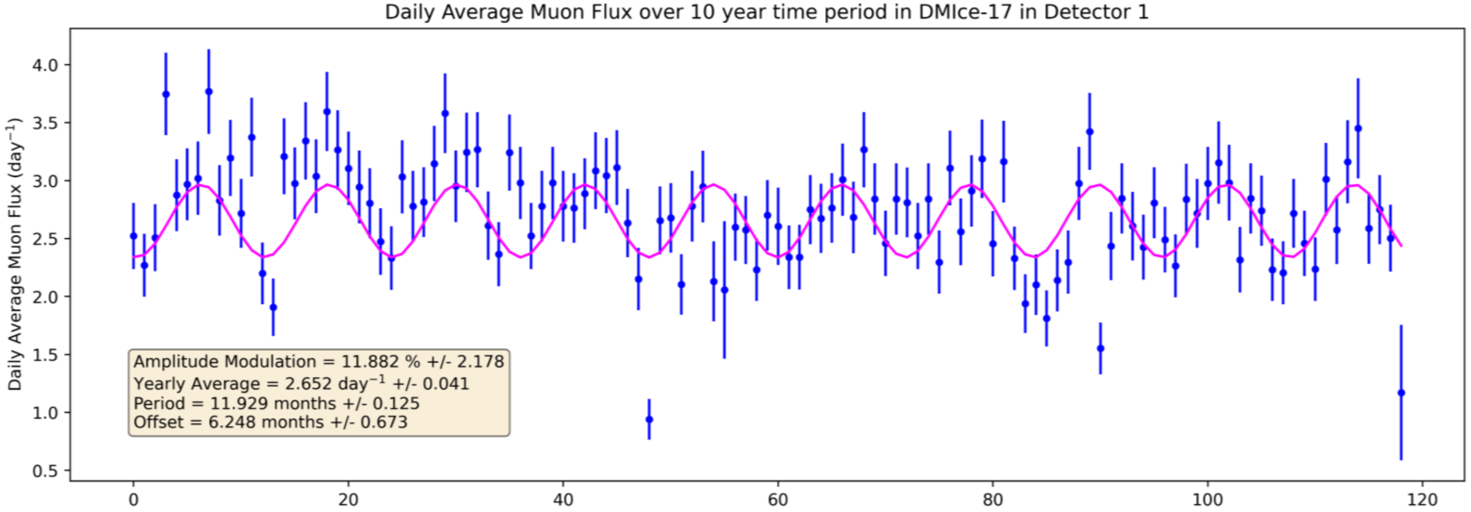
Source: IceCube Collaboration

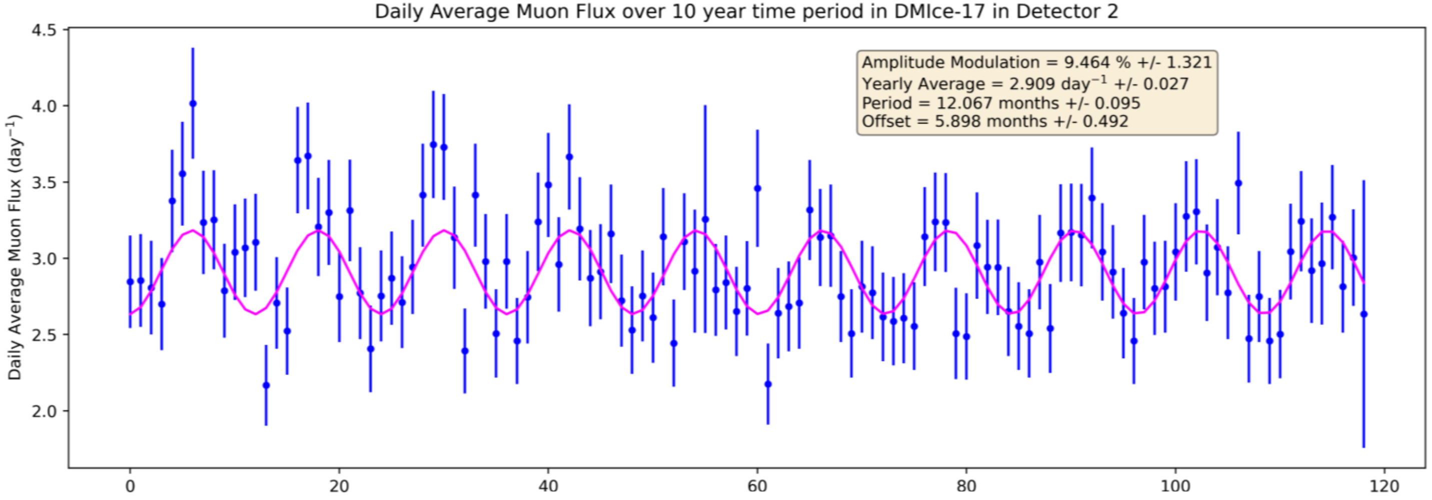
DMIce-17 – an improvised muon detector

- Implemented to look for direct Dark Matter modulation signal (none seen), repurposed to look for muon signals
- Use phase space of pulse height pulse width to isolate muon population.
- Theoretical calcs show ~3 muons a day
  - Low statistics mean we take a monthly average
  - We have data from each detector covering 2011-2021



Modulation – Dets 1 and 2





Time since July 2011 (months)

- Period of both consistent with 1 year
- Modulation peak in local Summer, minima in local winter, as expected

- See average of ~3 muons /day/ detector
- Modulation on both ~10%

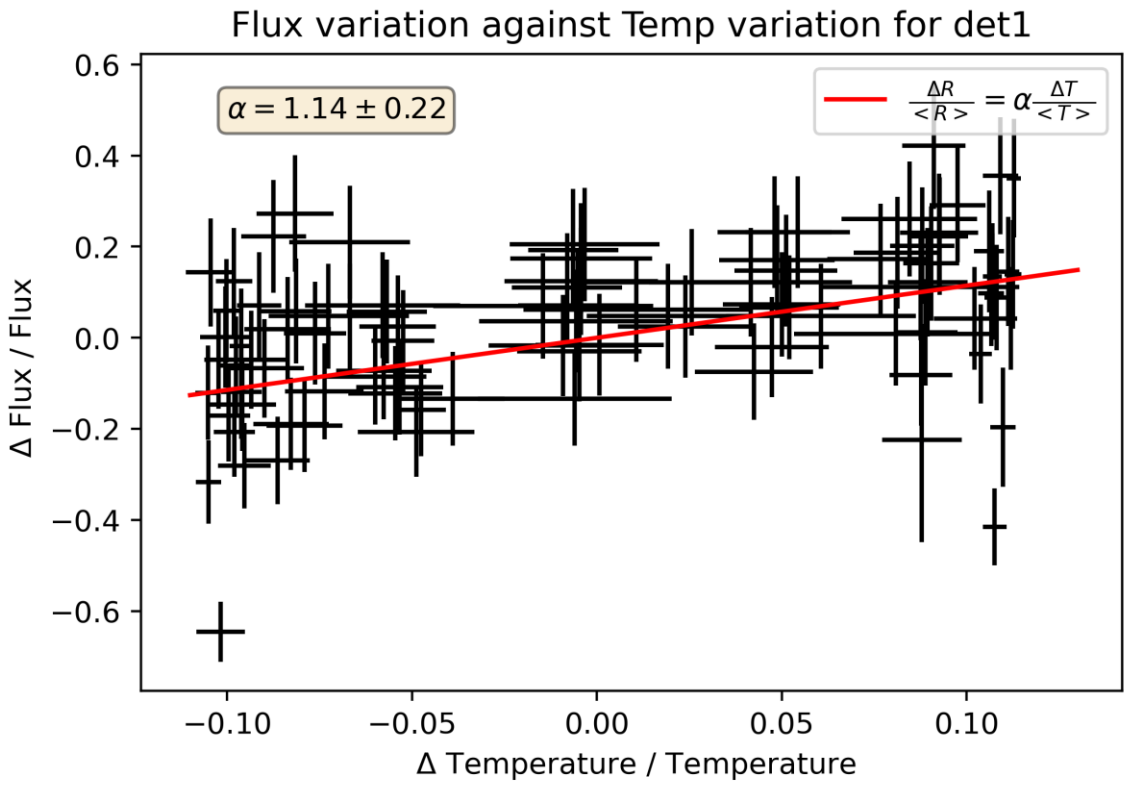
Link directly to temperature

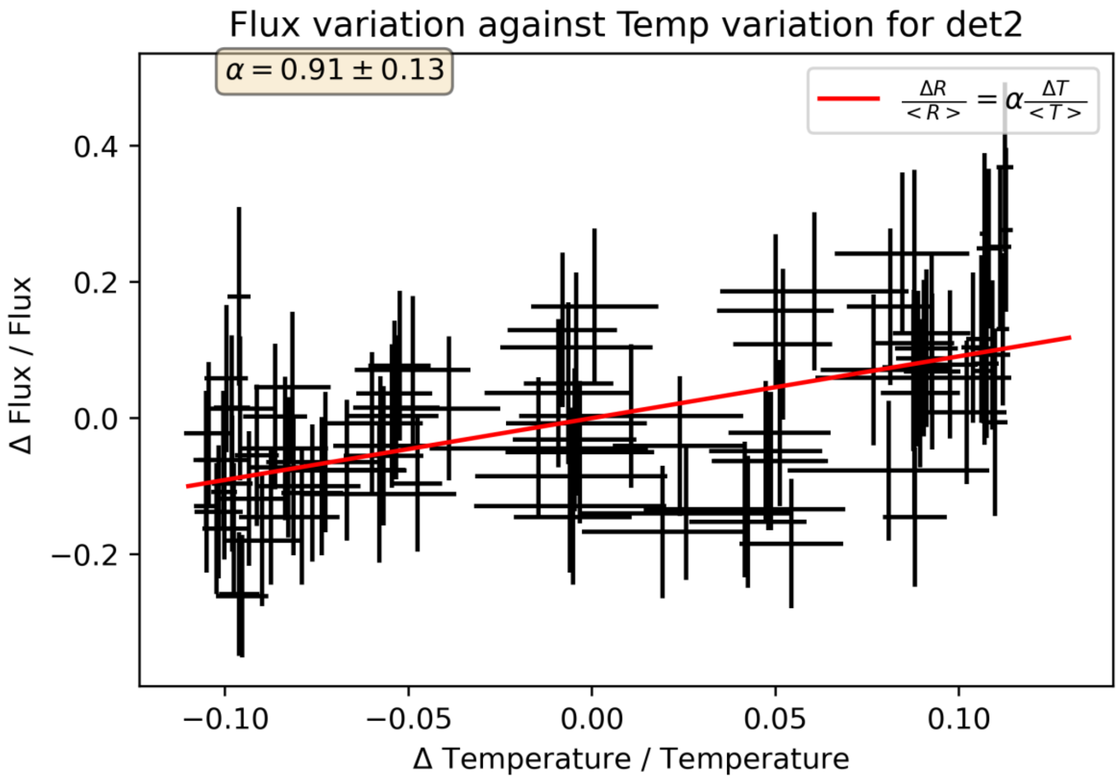
- Model the correlation between rate and temperature variations with simple linear dependence

$$\frac{R(t) - <R>}{<R>} = \alpha \frac{T(t) - <T>}{<T>}$$

- In this case, $T = T_{effective}$ taken as an effective temperature relevant to muon production throughout the atmosphere

Plotting this variation

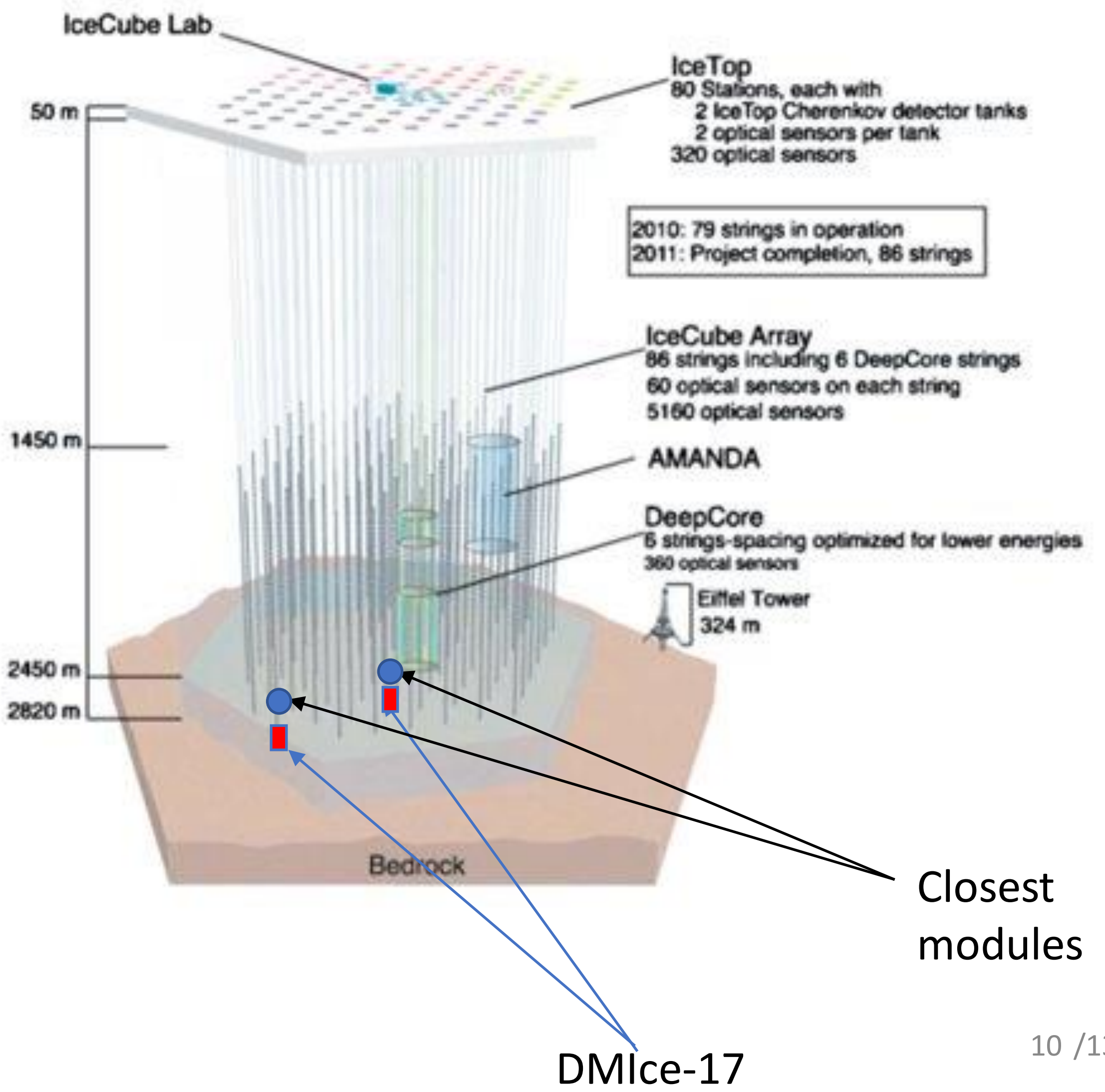




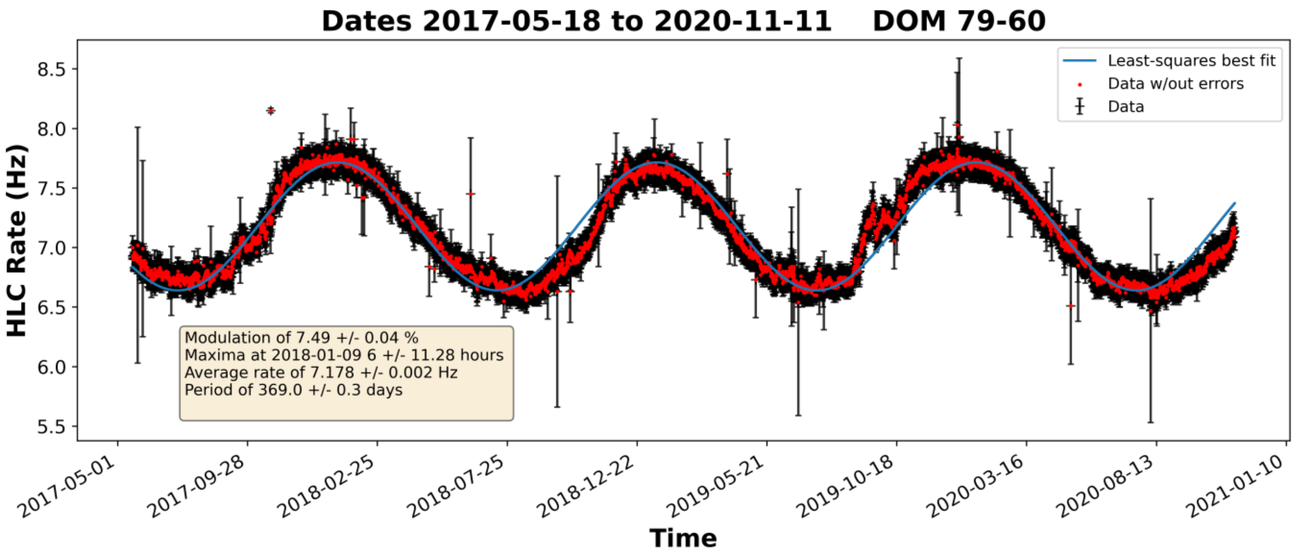
IceCube as a whole sees ~0.8, DMIce may be slightly higher due to preferentially seeing the higher energy muons which modulate more, as lower energy ones are screened by the 2km of ice above

IceCube Hard Local Coincidence

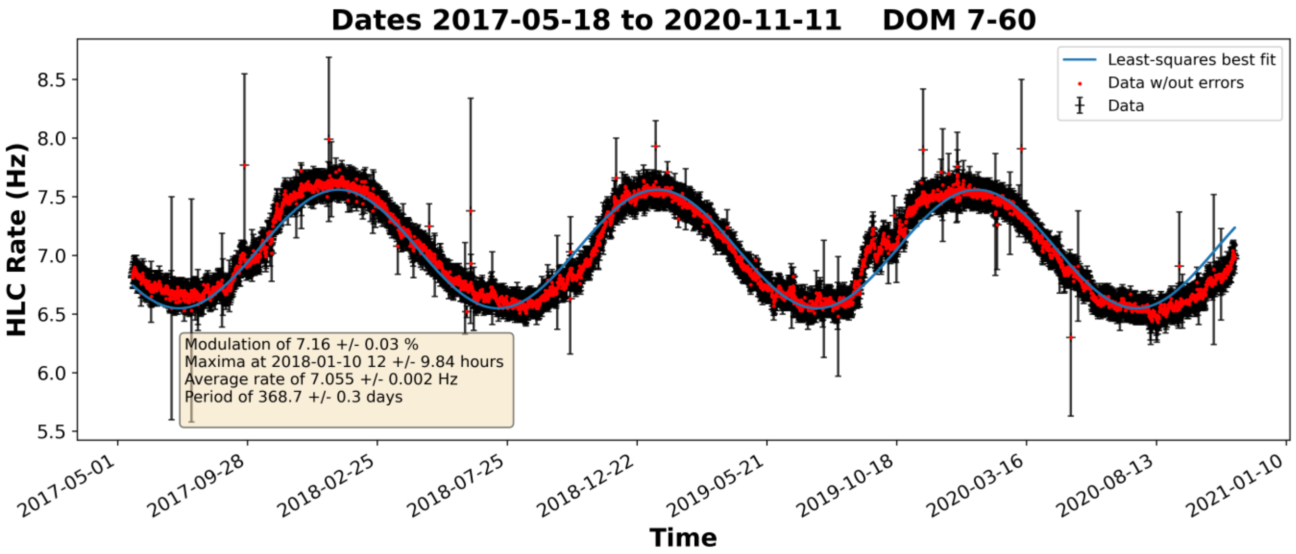
- IceCube modules trigger if they have a local coincidence with a neighbour, or a neighbour of a neighbour.
- This should primarily be due to cosmic ray muons, so if we plot the rate in modules closest to DMIce, they should be similar



Modules closest to DMIce-17



Det1



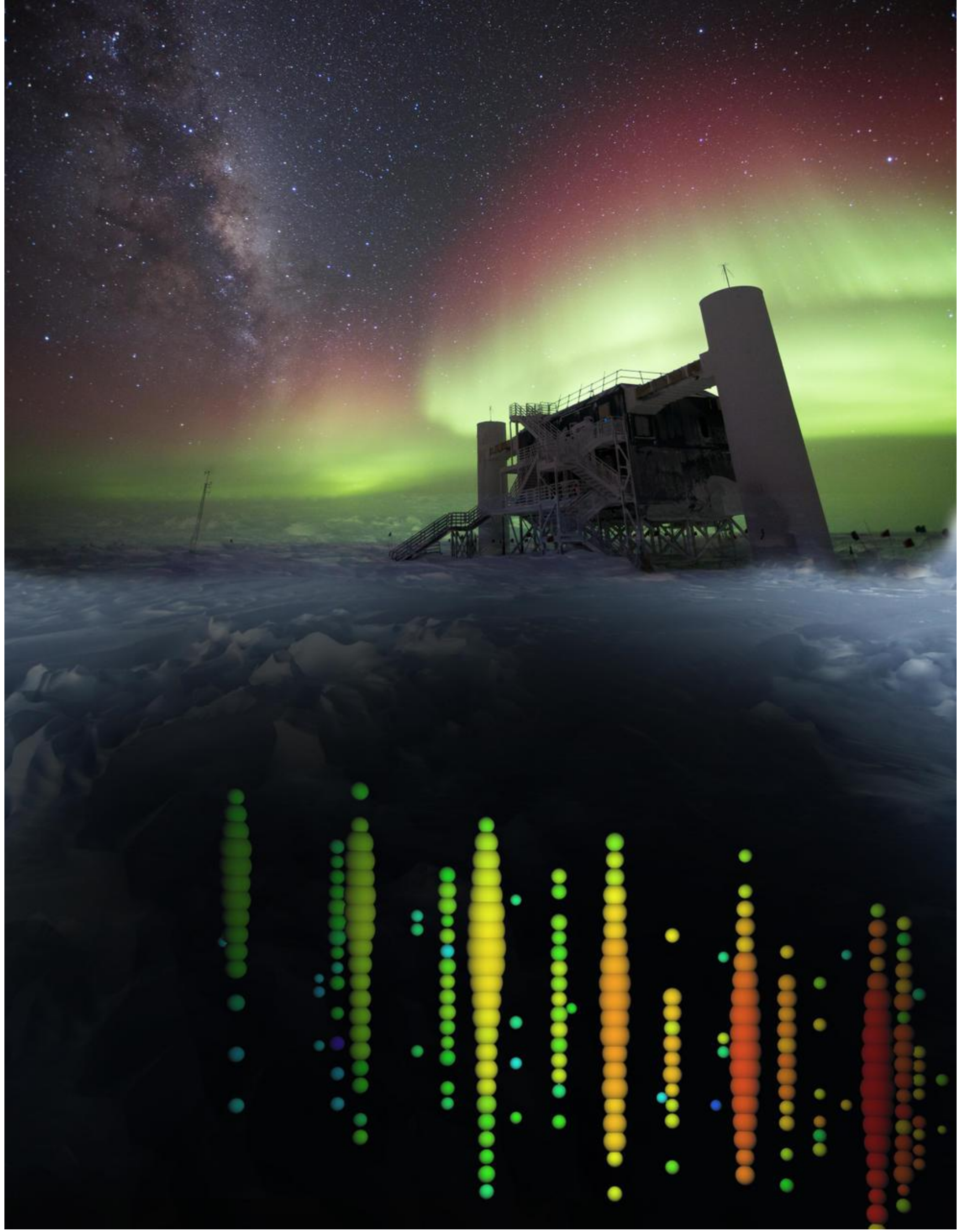
Det2

- Both show lower modulation than the relevant DMIce-17 module
  - Potentially due to a constant background which hasn't been filtered out?
- Period of slightly >365 days?
  - Could be due to smaller range of data
- Phase matches

What happens next?

- Closer integration of DMIce-17 with IceCube
- Looking at modulation across the height of IceCube, and potential variation across the width at the lowest height
  - Check for variance in data
- Aim to improve reconstruction of muons found in both DMIce-17 and IceCube

Any questions?



Source: IceCube Collaboration