http://blogs.nature.com/onyourwavelength

Final version:

Introduction

There are almost 400 people working on T2K, many of us spending years building our bit of the experiment, from physical objects like detector or beamline instrumentation, to abstract items like data analysis frameworks. Looking at the author list, you'll see that T2K consists of collaborators from all over the world. Our daily communications happen online; in video meetings, emails, and chats. Although it's sometimes a challenge to find good time slots for connecting people over 16 time zones, most collaborators have several meetings a week, some as early as 6 am, some as late as midnight. It's not uncommon to sign-off from a meeting with a good-night, only to be met with a good-morning, and vice versa (as the contributors to this blog can attest, with one contributor in Tokyo, some in Europe, and one in Chicago).

Shifting

A critical part of this result was the taking of the data itself, which has been a project two to three decades in the making. The Super-Kamiokande (SK) detector started construction in 1991, and operates 24 hours a day, 365 days a year, in Kamioka (just West of the Japanese alps) so as not to miss rare cosmic events, such as supernova bursts. The neutrino beam and the near-detectors started construction 2001 (beam) and 2007 (near-detectors) in Tokai (on the East coast), and are continuously operating when we have pre-allocated beam time, sometimes up to seven months per year. The operations systems are developed by physicists and engineers, from graduate students to professors, and we take shifts in person to monitor the systems whenever they are operational. International collaborators frequently fly to Japan to spend a week or two shifting in either Tokai or Kamioka, where we get to witness—in addition to flashing computer screens and sounding alarms—the beautiful mountains and rivers, eat delicious and mysterious foods, and experience the local villages with all they have to offer. Minimising the risk of data loss often occurs at the cost of sleep for the operations experts (as the contributors to this blog, again, attest)—but all is forgotten after an early morning visit to the local *onsen* (hot-spring).

Japan

It's impossible to overemphasise the fantastic experience of Japanese culture as an added bonus of partaking in T2K. Many of the restaurants in the Tokai and Kamioka areas are familiar with members of the collaboration, and are very accommodating to international collaborators. The owner of one particular restaurant in Tokai always recognises Sam and remembers that he can speak a small amount of the language (*chotto*), and indulges him to order in broken Japanese (we like to think it's for good practice, and not solely their entertainment). A favourite annual event is the sweet potato (*satsuma-imo*) festival, a community event in Tokai held in November to celebrate the root vegetable that the Ibaraki prefecture is renowned for.

The analysis
When not on shift in Japan, most collaborators work on analysing data or performing upgrades and maintenance studies of the experiment, often done from our universities or laboratories. The oscillation analysis is actually just one part of T2K's scientific output, and many of us work on other analyses too, such as precisely measuring how often neutrinos interact with matter, and how we can use existing data and theories to better understand neutrinos; for instance how they are produced in our beam.

The oscillation analysis, whose final results were published in Nature, is the last link in a long chain of work. It amalgamates the effort of the entire collaboration, from those constructing the experiment 20 years ago, to the countless hours of operations shifts taken by people all over the world, to the development of the analyses. To do the analysis, we have to construct a model of the entire experiment, painstakingly quantifying how we think each component behaves and how certain we are of that description. This includes everything from the neutrino beam (and the proton beam collisions that creates it), the neutrino interactions in our detectors, the density of the Earth between Tokai and Kamioka, to how good our detectors are at measuring the particles.

The near detector
To characterise the neutrino beam with neutrino data, we have two detectors ("ND280" and "INGRID") 280m from the neutrino source, which have a staggering amount of neutrinos passing through them. Occasionally these neutrinos interact at the near-detectors, occasionally they interact 300km later in Super-K, but most of the time they continue out through Earth's atmosphere, propagating deep into space. To put things into perspective, this analysis used about 3,000,000,000,000,000,000,000 (3×10^{21}, or three billion trillion) proton interactions to create the neutrino beam. We used 60,000 neutrino events at ND280 and observed about 500 at Super-Kamiokande over the course of nine years. In the early neutrino beam experiments in the 1970s, the data are often on less than 500 neutrino events, with the experiments sitting right next to the neutrino source for tens of years. Today we have about the same number of neutrino events in a similar amount of time, but sitting 300km away from the source at Super-Kamiokande. It's only recently that we have the technology, funding support, and scientific community to produce such powerful neutrino beams, which are the backbone of these precise measurements.

The far-detector
Once the neutrinos are characterised at the near detector, the oscillation analysis takes all the models of the neutrino beam, the detectors, and the neutrino interaction, combines it with their constraints, and blends them together to describe our observations. The analysis turns numerous PhD students', postdocs', scientists' and professors' lives into many cycles of communication-implementation-validation, over the course of more than a year. Once the cycles are completed and all the validations and tests are satisfied, we finally get to look at the data and make our measurement of the neutrinos' oscillations. That last link in the long chain has the privilege to see the final result first in the collaboration. That moment when the plot pops onto your screen and you're the only person who knows what it shows is pretty special. For this result, published in April 2020, we first saw the plot internally in Autumn

2018, and spent the time between then and now extensively validating and testing alternate explanations, finally writing the paper.

The future

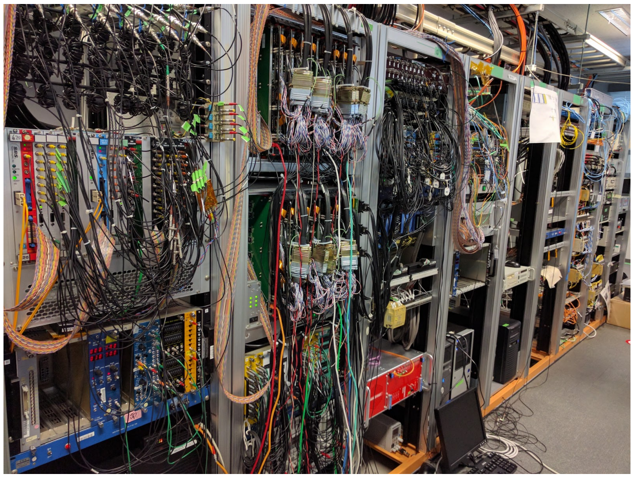
On T2K, we're currently in the process of updating the analysis using more data taken during 2019/2020, and using better models of the experiment, all thanks to the continuing dedicated work of all our collaborators. Many of us are also working on upgrades of the neutrino beamline, the near-detectors and the far-detector, to squeeze out more science from the neutrino beam. Our results published in Nature are the strongest constraint on the CP violating phase in neutrinos to date, but we have only taken about half of our allocated data. There is much more to come and the prospects are truly exciting. As we continue, we're including the work of even more people than the analyses that came before, and we hope they too get their share of the pleasant, stressful, lovely, frustrating, and ultimately rewarding experience of being on an international science collaboration such as T2K, just like we have.

Cheers and Happy Golden Week, from

Ciro Riccio (Postdoc, Stony Brook), Patrick Dunne (Postdoc, Imperial College London), Pruthvi Mehta (PhD student, University of Liverpool), Sam Jenkins (PhD student, University of Sheffield), Tomoyo Yoshida (Graduated PhD student, Tokyo Institute of Technology), Clarence Wret (Postdoc, University of Rochester)




ノーベル賞受賞 実験施設 スーパーカミオカンデ
宇宙科学最先端の町
北都神岡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Strong
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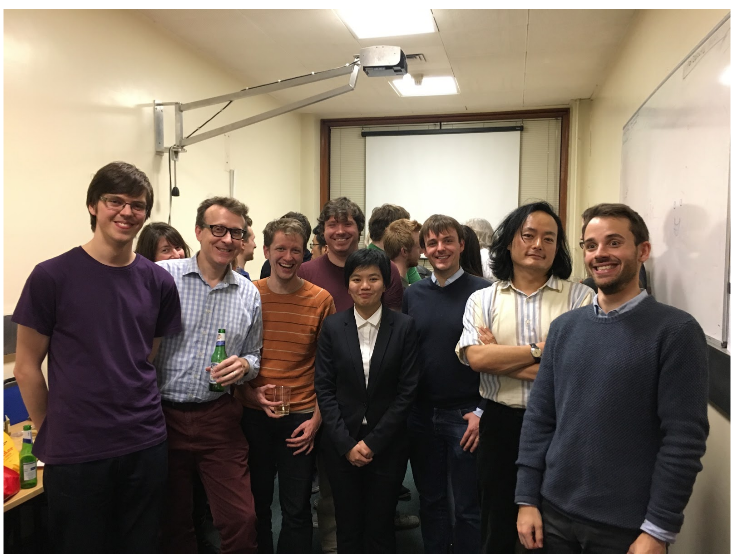

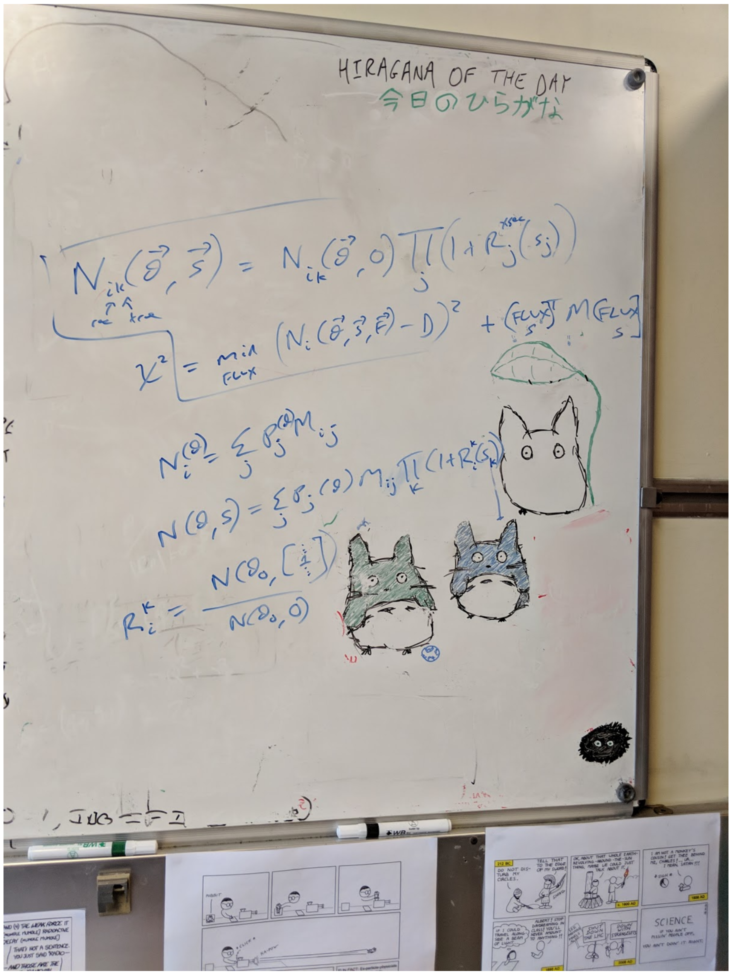
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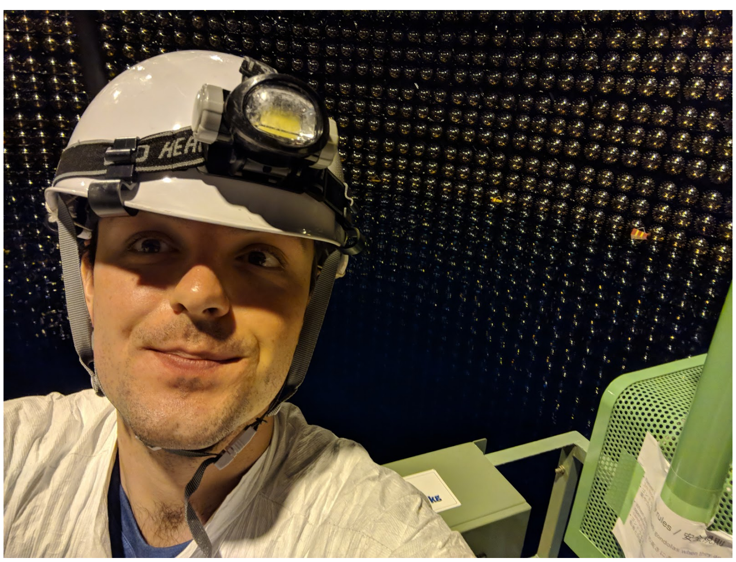


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