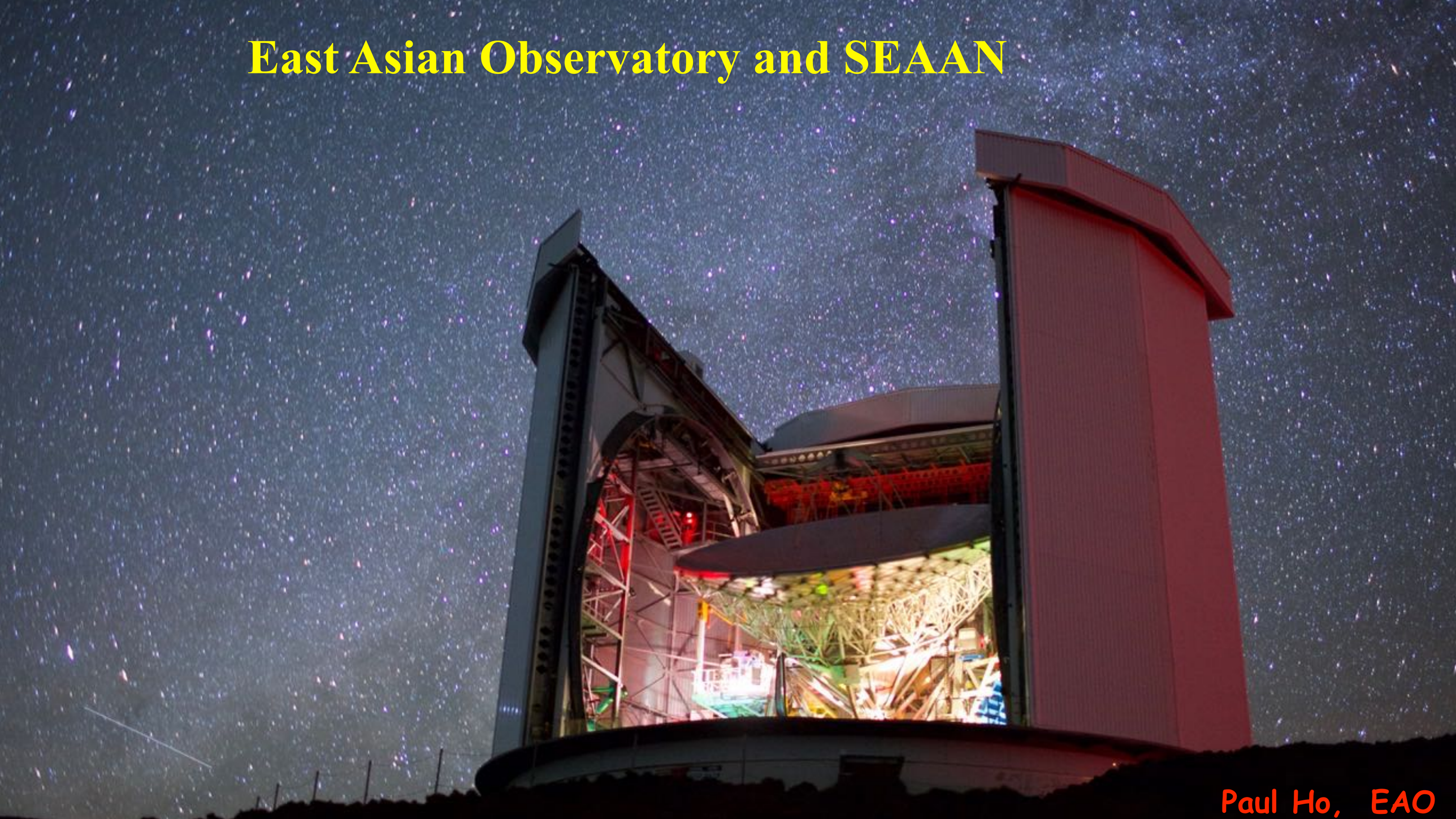
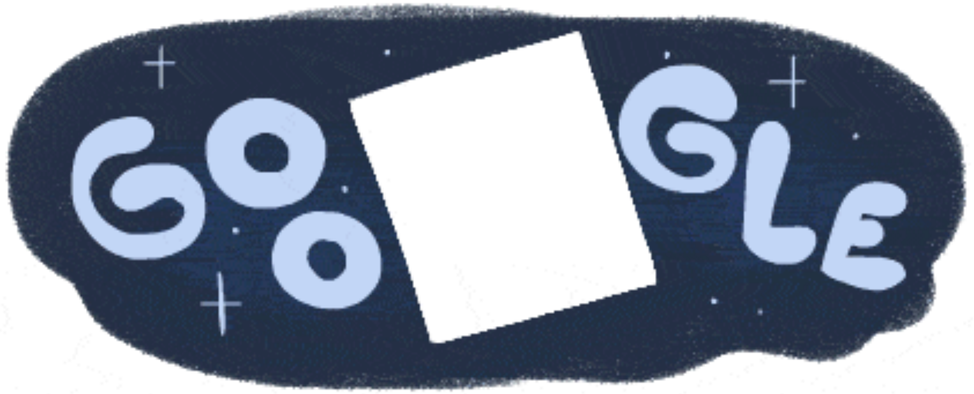
East Asian Observatory and SEAAN



Paul Ho, EAO

2019.4.10： First Image of SMBH Shadow

— “Not Seeing” the Black Hole



Breakthrough Prize in Fundamental Physics, Einstein Medal, Bruno Rossi Prize, CTCI Award, NSF Diamond A
Award…..


Optical light

Event Horizon Telescope

Asia is partner on ALMA, SMA, and JCMT

- Atacama Large Millimeter Array (ALMA), Chile
- ALMA Pathfinder Experiment (APEX), Chile
- James Clerk Maxwell Telescope (JCMT), Hawaii
- Large Millimeter Telescope (LMT), Mexico
- IRAM 30-meter Telescope, Spain
- South Pole Telescope (SPT), South Pole
- Submillimeter Array (SMA), Hawaii
- Submillimeter Telescope (SMT), Arizona

M. Johnson/SAO

EAO is part of Event Horizon Telescope since 2017

East Asian Observatory

- **History of Development: Established 2014** (N.Kaifu)
- **Model: Asian Counterpart to ESO**
- **EAO Members: NAOC, NAOJ, KASI, ASIAA, NARIT** [2021]
- **Goals and Aspirations: Looking to the Future**
- **Current Status: Operating JCMT, Partner on EHT**
  (Access SMA, Access UKIRT)
- **Current Plans: Construct Next Generation Instruments - SCUBA3**
- **Future Plans: Expand EAO to All of Asia**

  (Observer: Vietnam, Malaysia, Indonesia)

  other SEAAN regions ? India ?

  Observer Status: Access EAO Facilities

  Observer to become Partner in the Future

Goals of EAO - Repositioning

Mission Statement

The EAO (East Asian Observatory) is formed by EACOA (East Asian Core Observatories Association) for the purpose of pursuing joint projects in astronomy within the East Asian region. In the era of very large scale astronomical instruments, East Asia will be competitive internationally by combining their funding resources, their technical expertise, and their manpower. The intention of EAO is to build and operate facilities, which will enhance and leverage existing and planned regional facilities. The intention of EAO is to raise funding and to build an observatory staff, separate from that of the EACOA institutions. As partners of the EAO, the EACOA institutes will help to establish the funding and to oversee the governance of EAO. The communities represented by the partners in EAO, would have full access to all EAO facilities.

Lessons from ESO

- **ESO Declaration (1954) predates EEC (1958) and EU (1993)**
- **ESO is more than 50 years old**
- **ESO Annual Budget comes from "Government Budgets"**
- **ESO Annual Budget is on the order of NAOJ or NAOC**
- **ESO Supports Large and Small Facilities**
- **ESO has "EU" Facilities and "Joint" Facilities (eg ALMA)**
- **ESO Facilities "Complement Member Facilities"**
- **ESO has ~730 staff members**
- **EU Scientists are very mobile within EU**
- **Budget ~10^{-5} "total" GDP (~10^{-3} %)**

- **EAO Founding Members are "Better Prepared ?" than ESO Founding Members in 1962 (technically, financially)**

How to Build up EAO?

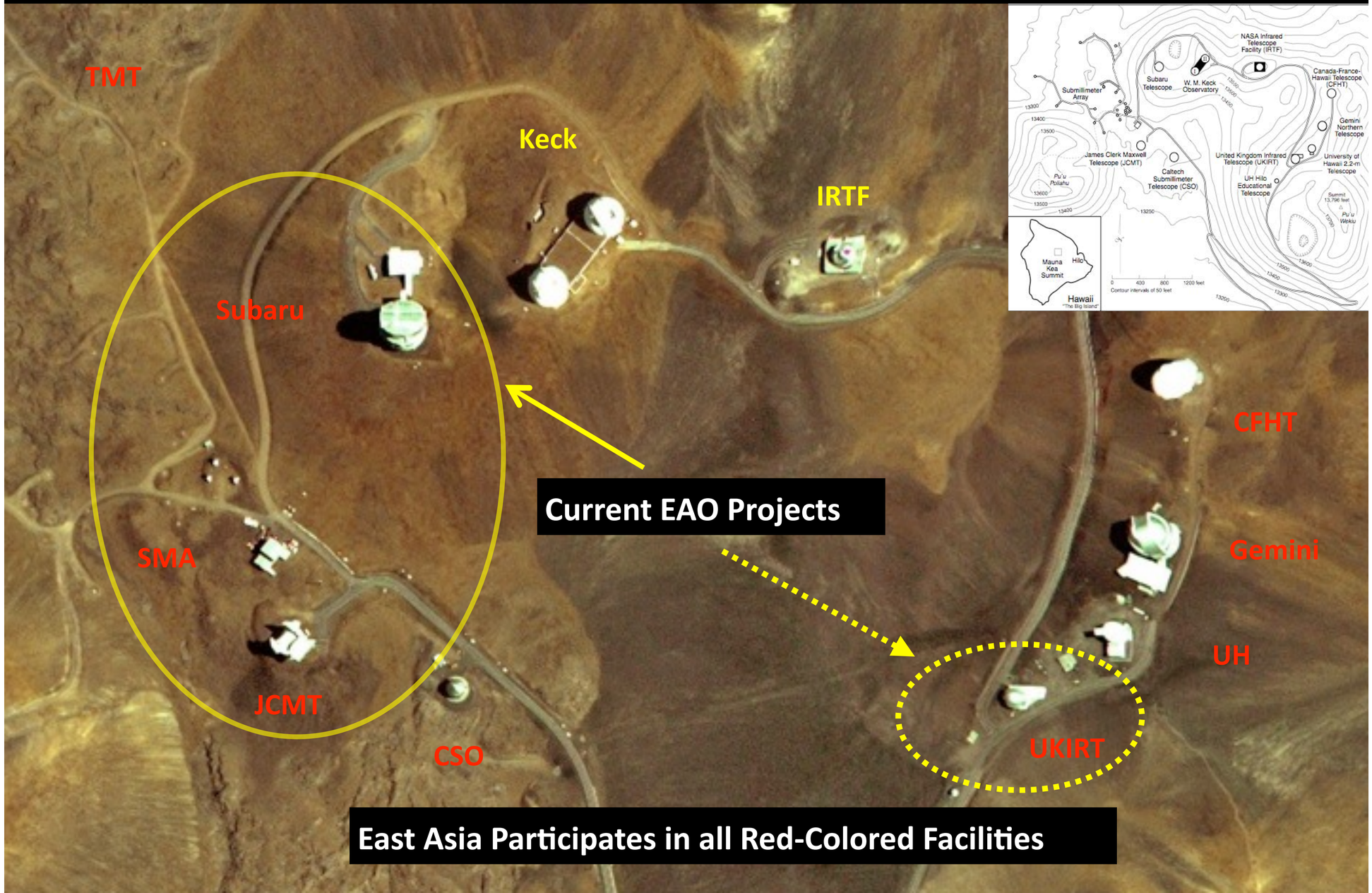
We address Fundamental Issues:

- **Site Survey and Development:** Ali Site in China; started 2002?
- **Joint Funding:** EACOA Fellows (5 year posts); started 2012
- **Asymmetric Funding:** CSO (90 nights); started 2013
- **Joint Operations:** JCMT; started 2015
  - — EA regions: 3.3M; UK + Canada: 1M
- **East Asian Observatory:** Why JCMT and ?

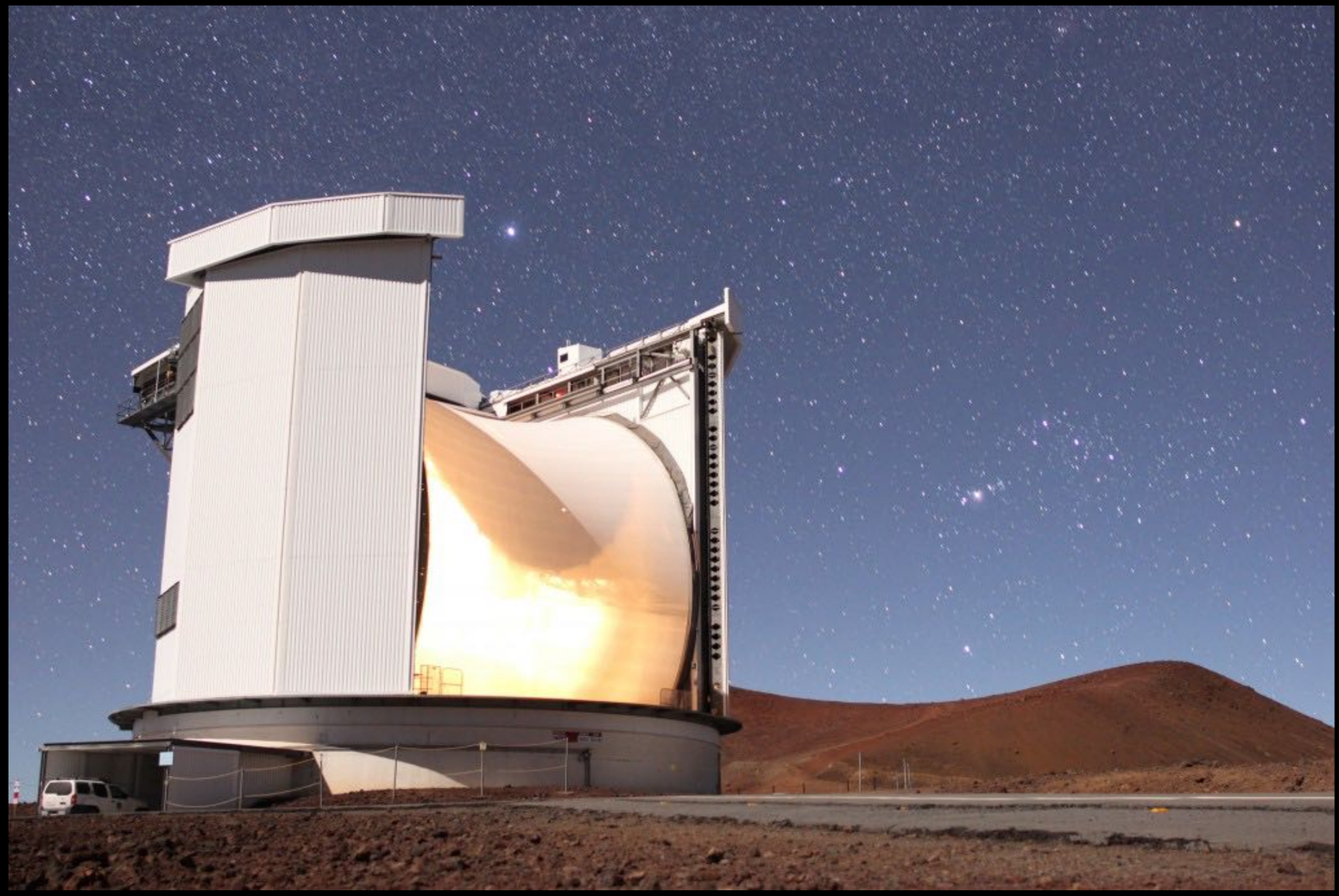
  (UKIRT, Subaru, SMA, CFHT, TMT)
- **Main Goal:** Unify Asian Interests and Large Scale Operations

  — to be part of SEAAN program

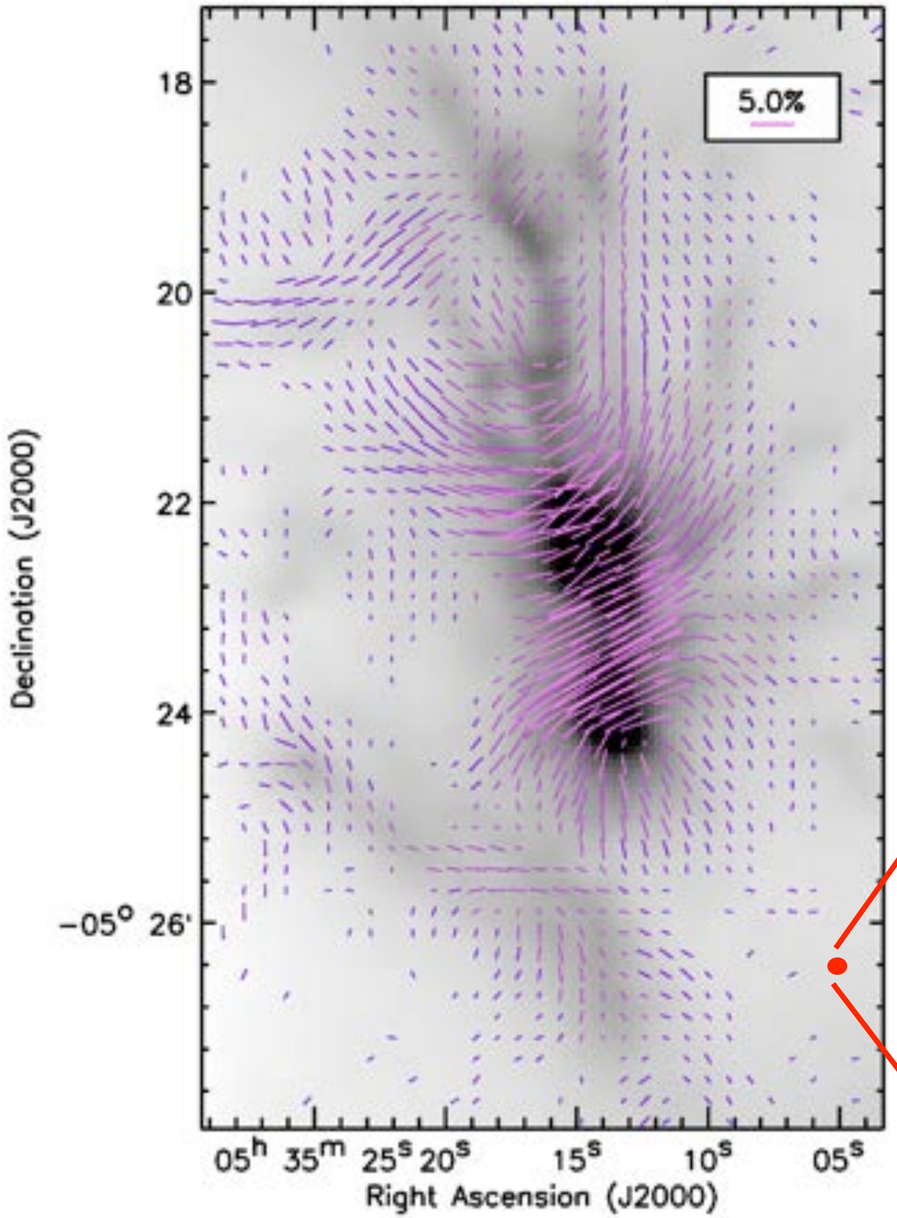
EAO Operates on top of Mauna Kea



2022 JCMT Science Highlights



BISTRO: B-Fields in Star-forming Region Observations

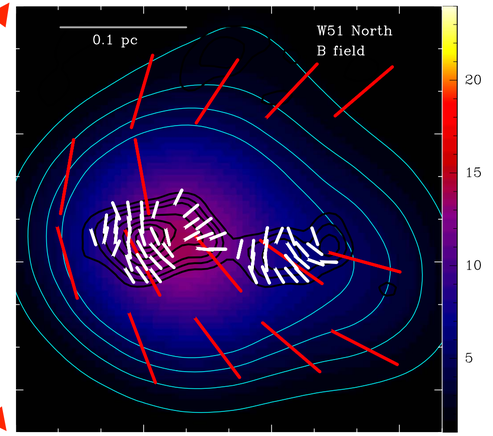


Orion A:

- Survey paper: Ward-Thompson et al. 2017, ApJ in press
- Chandrasekhar-Fermi and energetics analyses: Pattle et al. 2017, ApJ submitted.

Tracking B-Fields into Faint Regions:

Shaping Molecular Outflows?



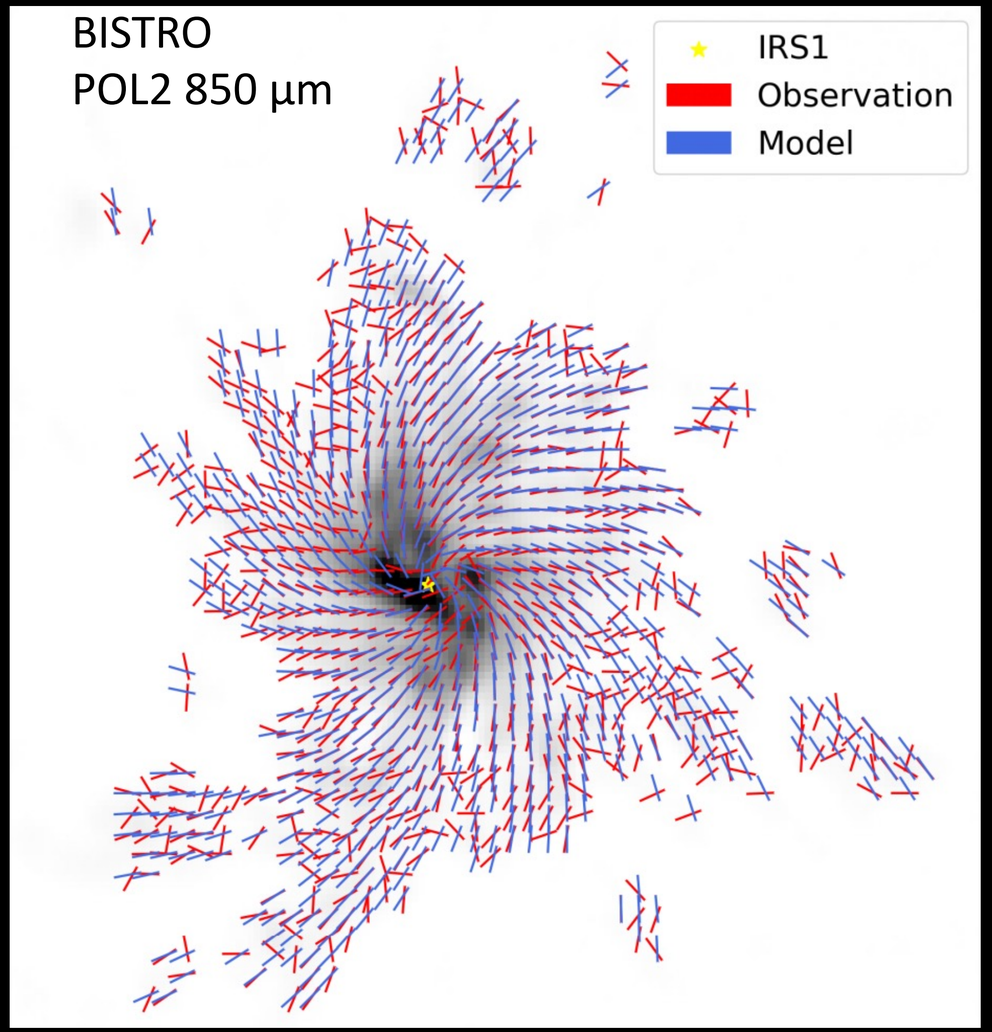
W51: SMA

JCMT BISTRO Survey: A Spiral Magnetic Field in a Hub-Filament Structure, Monoceros R2

Hwang, J. et al. The Astrophysical Journal, 2022.

Goal: Studying the magnetic field in the hub-filament system Mon R2

Magnetic field orientations obtained from the polarization observations and from the best-fit model are shown as red and blue segments, respectively. The background gray-scale image shows the total intensity at 850 μm. The intensity scale of the background image is shown in the gray bar on the right side. A yellow star indicates the position of IRS 1 source.



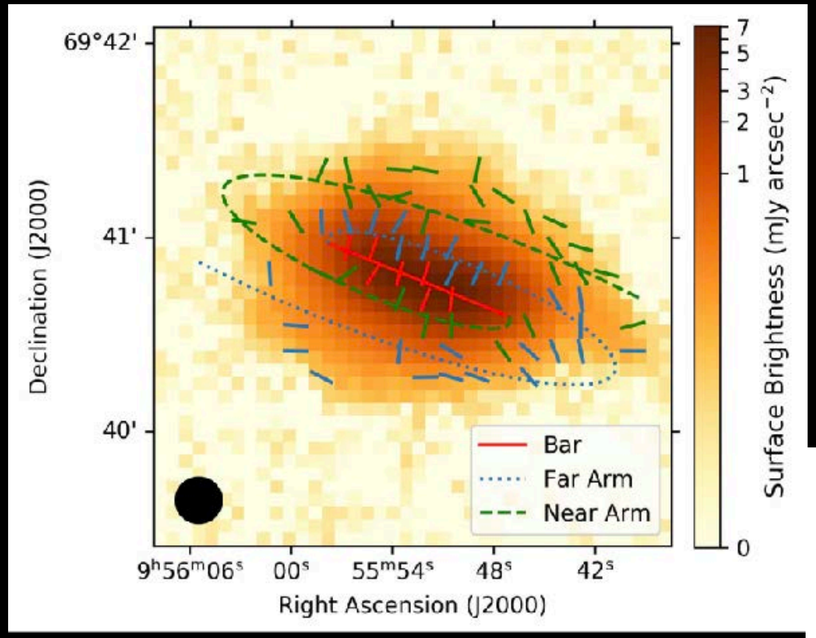
Results

- A spiral magnetic field structure
- The filaments are converging on the IRS 1 source. Their overall shape shows a spiral structure
- The overall magnetic field structure of Mon R2 is well represented by a magnetized rotating disk model.

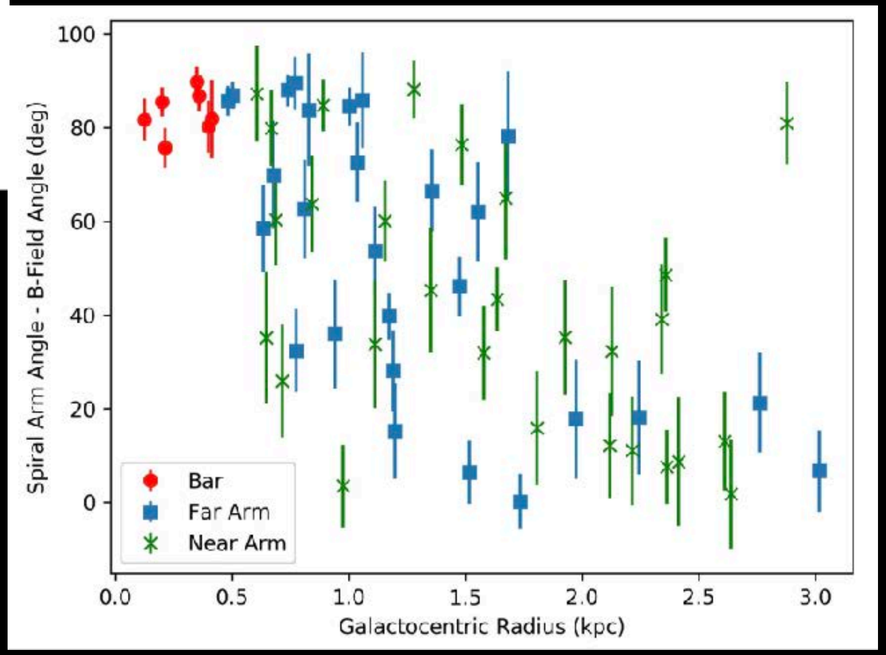
M82's Two-Component Magnetic Field

Pattle, K et al. MNRAS. 2021

Goal: Trace the magnetic field of the Starburst Galaxy using POL-2 and compare with HAWC+ observations in different galactic regions



Left: Positions of M82's Bar and spiral arms with POL-2 850 micron magnetic field vectors overlaid



Right: Angular difference between spiral arm structure and B-field as a function of galactocentric radius. The B-field transitions from being perpendicular to the bar in the galactic centre to parallel to the spiral arms, or toroidal, at high galactocentric radii.

Results

★ A two-component B-field is seen:

1. A Poloidal B-field in the central starburst region
2. A B-field in the disc that is parallel to the spiral arms at galactocentric radii >2 kpc

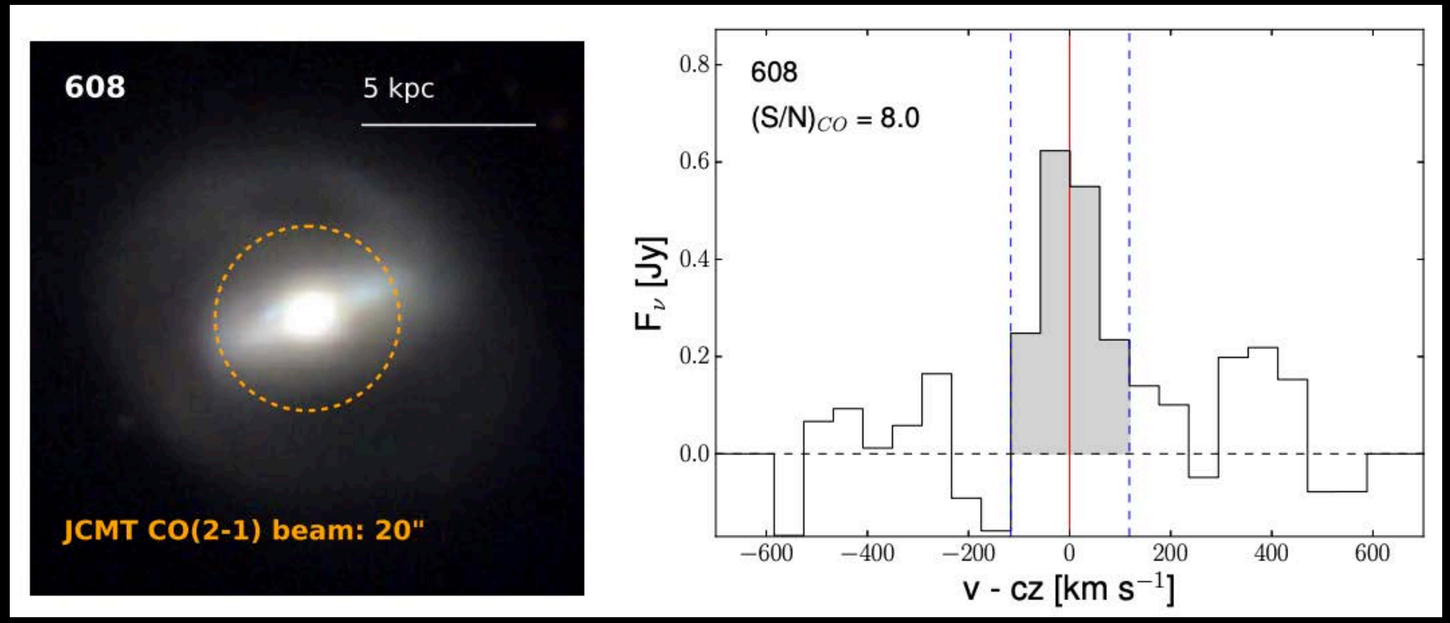
★ Good agreement between POL-2 (850μm) and HAWC+ (154μm) in the central region, but a significant difference in the outer galaxy where HAWC+ traces hot dust entrained by the superwind

★ARCHIVE

AGN Host Galaxy Gas Properties

Koss et al. The Astrophysical Journal Supplementary Series. 2021

Goal: Determine the gas properties of 200 galaxies hosting hard X-ray selected AGN



Left: Pan-STARRS 1'×1' *gri* colour cutout with the beamsize of the JCMT marked in orange. Right: CO(2–1) spectrum of the galaxy. The spectrum is centered at the position of the CO(2–1) line. The solid red line marks the central velocity of the optical redshift of the AGN. The dashed blue lines indicate the velocity range within which the CO(2–1) line fluxes are integrated

Results

★ Galaxies with AGN have more molecular gas and higher gas mass fractions than inactive galaxies

★ There is no evidence of AGN feedback affecting the host galaxy cold molecular gas

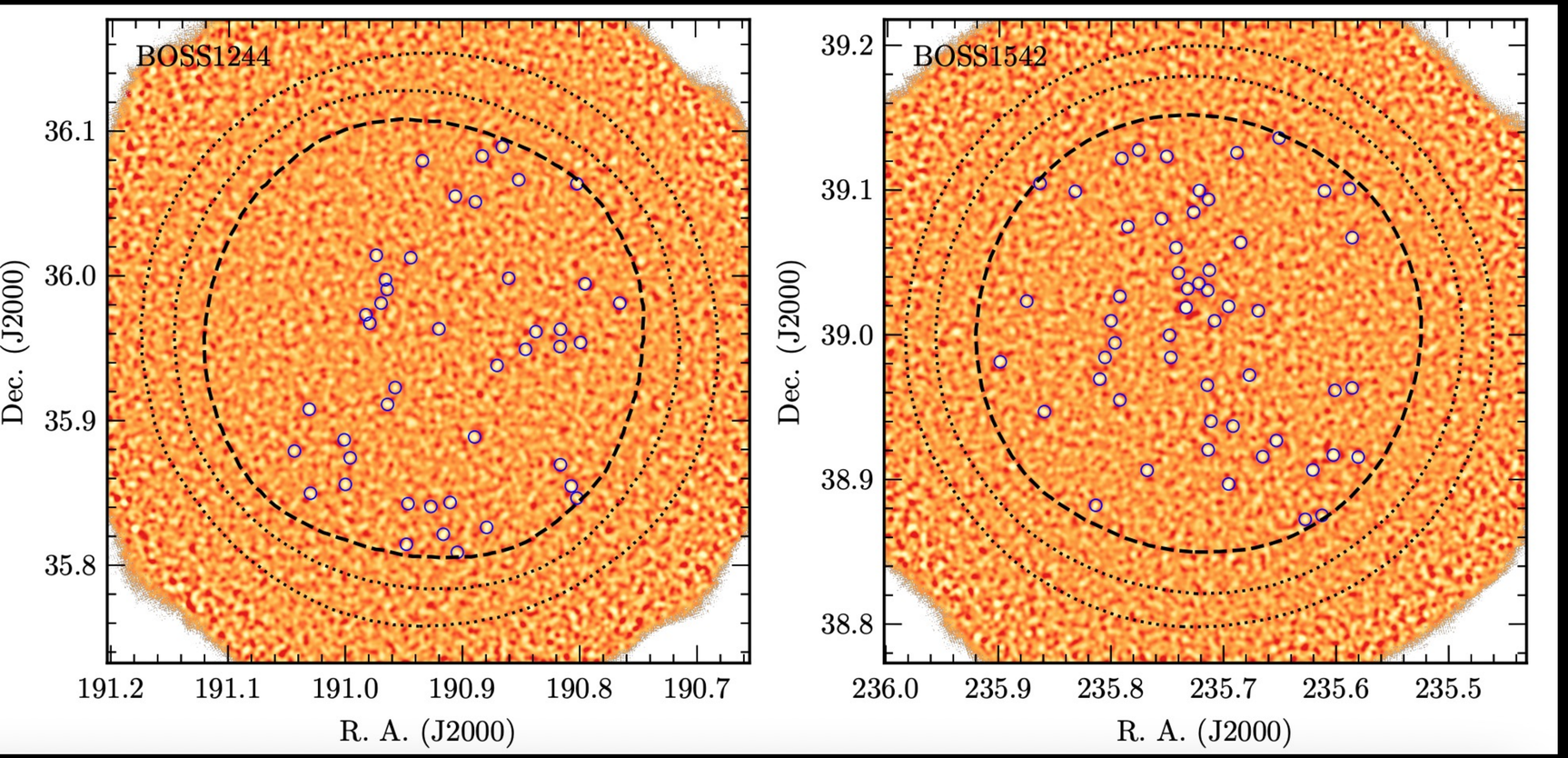
★ Higher column density AGN galaxies are associated with lower depletion timescales

★ Molecular gas plays critical role in black hole growth

Witnessing the enrichment of extreme starbursts in the outskirts of HAE density peaks

Zhang, Y. et al. MNRAS, 2022.

Goal: Searching for starburst submillimetre galaxies in two massive protoclusters at z = 2.24



Deep SCUBA-2 850 μm mosaic maps of two MAMMOTH fields BOSS1244 (left) and BOSS1542 (right). Blue circles mark 43 and 54 detections at the level of S/N>4 (S_{850} > 4 mJy) within the effective area enclosed by the thick dashed lines. The dotted lines enclose the coverage where the noise levels are 2 and 3 mJy from inside to out. There are 35 and 39 sources detected with 3.5 < S/N < 4 in the effective area of BOSS1244 and BOSS1542, respectively. Due to a rapidly increasing rate of false sources at S/N < 4, they take sources with S/N>4 as the SMG samples.

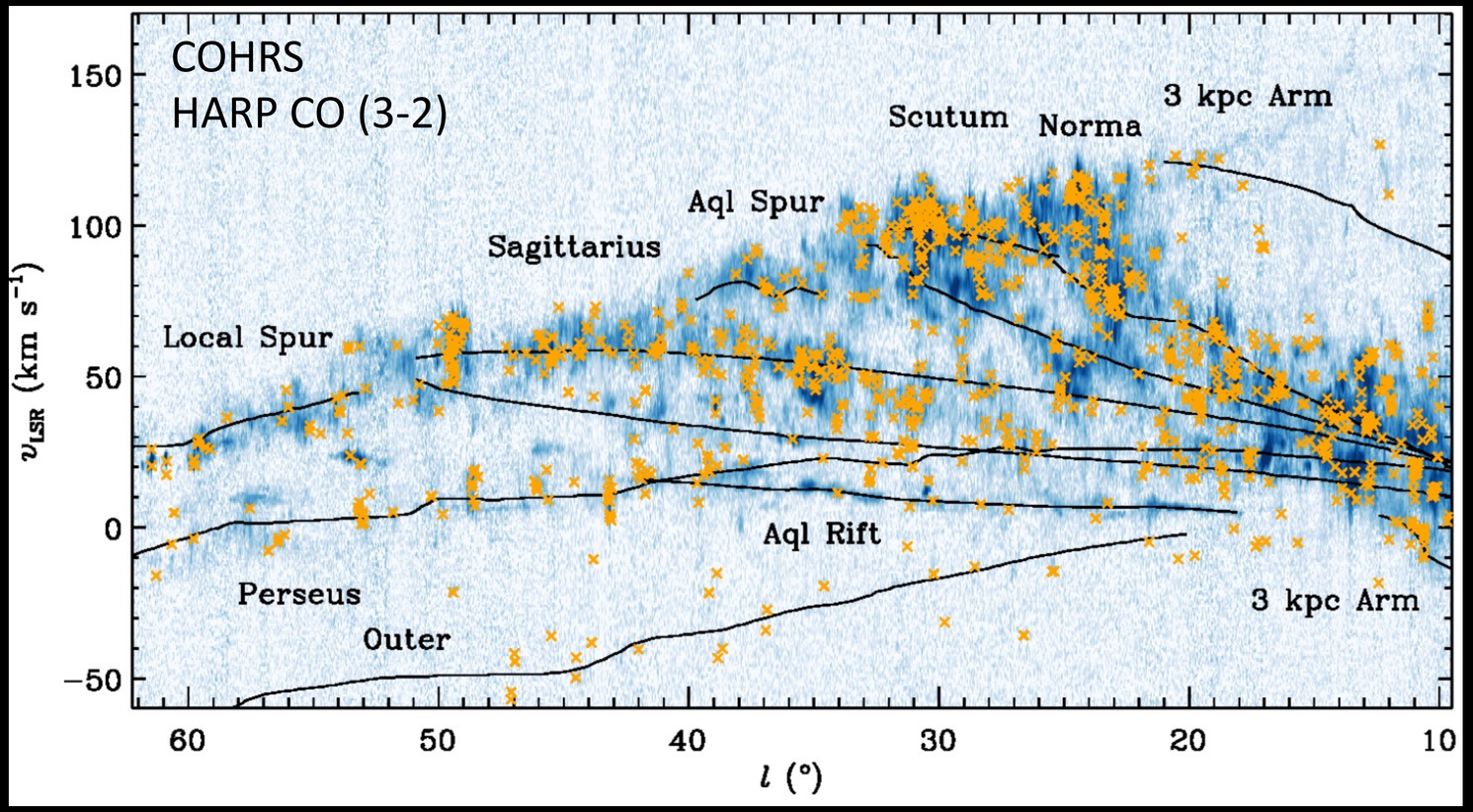
Results

- 43 and 54 submillimetre galaxies (SMGs) detected in BOSS1244 and BOSS1542
- BOSS1244 and BOSS1542 are extreme overdensities at z > 2
- The spatial distributions of the sample SMGs show obvious offsets from the high-density regions of Hα emission-line galaxies (HAEs)
- A first direct probe for the impact of the assembly of large-scale structures on galaxy formation.

JCMT ^{12}CO (3-2) High-Resolution Survey (COHRS) of the Galactic Plane: Complete Data Release

Park, G. et al. The Astrophysical Journal Supplement, 2022.

Goal: Mapping inner Galactic plane with ^{12}CO (3-2) observations over the range of 9.°5 ≤ l ≤ 62.°3 and |b| ≤ 0.°5.



Position-velocity (l – v_{LSR}) map for the ^{12}CO (3-2) emission (T_{mb}) in COHRS. This map is obtained by integrating over the latitude axis. The map is drawn on a square-root scale. The units on the intensity scale are K degrees. Cross symbols indicate WISE H ii regions. The traces of main spiral arms (Scutum, Sagittarius, Perseus, and Norma-Outer arms) and interarm features (Local Spur, Aquila Spur, Aquila Rift, and 3 kpc arm) from Reid et al. (2016, 2019) are overlaid using black curves.

Results

- ^{12}CO (3-2) survey of the first quadrant in the Galactic plane
- Gas distribution agrees with FUGIN ^{12}CO (1-0) or star-forming population (WISE HII regions and ATLASGAL star-forming clumps).
- Allowing studying the statistical properties of molecular gases along the Galactic plane as well as detailed structures and properties of individual objects.

Instrumentation: Nāmakanui

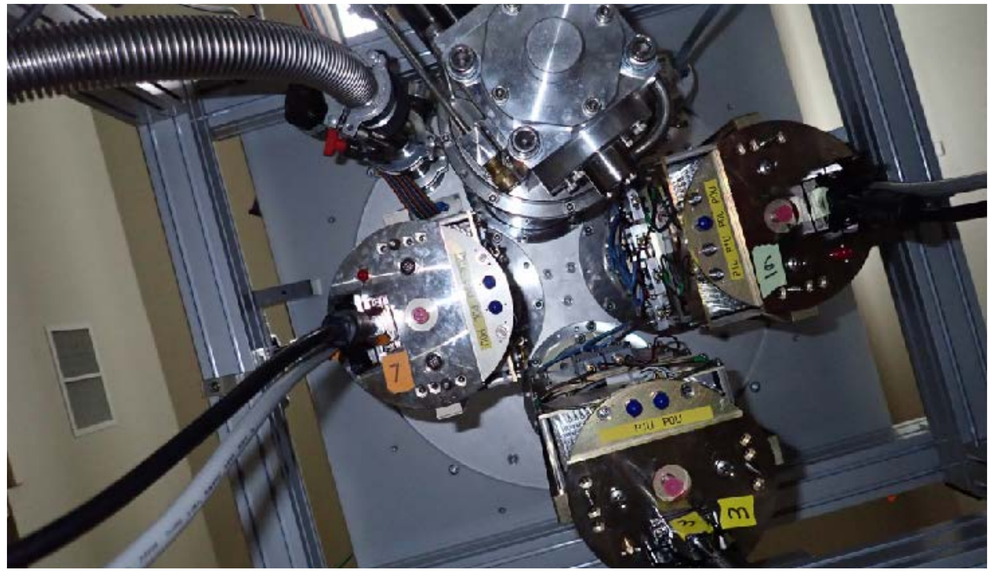
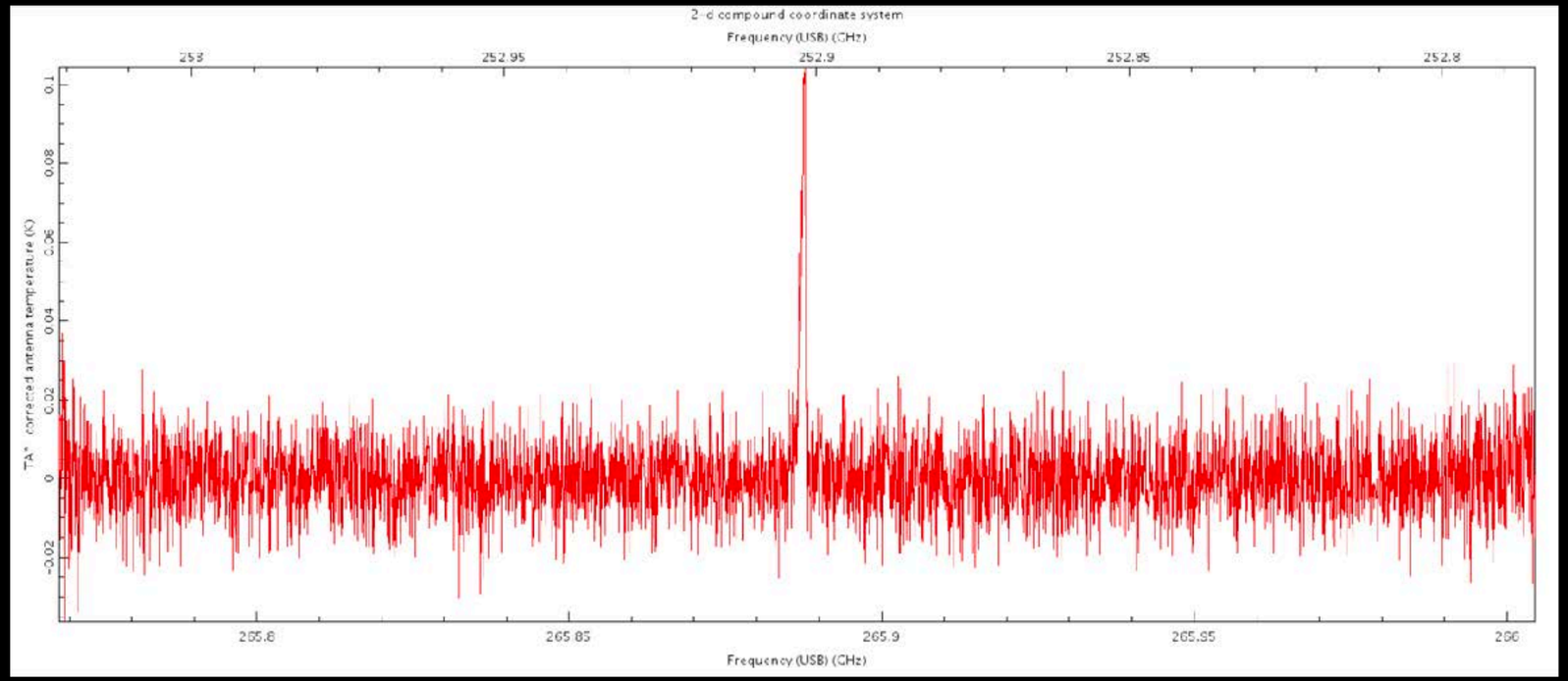


Figure 1. View of Nāmakanui instrument installed in cabin. Left picture shows the initial coupling mirror and ambient load mount, and right picture shows current mount. Three receiver inserts located in the Dewar at left forward (`Āweoweo/345GHz receiver), center behind (`Ala`ihi/86GHz receiver) and right forward (`Ū`ū/230GHz receiver). Each relay/coupling mirror is mounted above each receiver window. Rotation stage supporting the ambient load, is located at center on top of the Dewar.

HCN Variations in Comet 67P on 3-day Timescales

Confidential - Recent Detection - Do Not Distribute

Goal: Comet 67P is the only comet studied by an orbiting space probe (Rosetta). JCMT HARP data was obtained 6 years ago and now the investigators revisit this source near perihelion as part of a large in-situ global campaign



A first-pass data reduction of the strong HCN detection on the first night of observations. 6 years ago, the same investigators struggled to detect the comet with HARP. Now, ʻŪʻū has made this detection effortlessly. The team plans to use ʻĀweoweo in semester 22A to push the sensitivity Further at other interesting line transitions.

Results

★ The comet was observed for a total of 10 hours over 3 nights.

★ In this time, the V magnitude increased from ~10.1 to 9.8. This change in brightness is clearly reflected by the increasing spectral intensity of HCN from 90 to 105 mK.

★ ʻŪʻū has now pushed the limiting brightness of observable comets fainter by a factor of ~100

Event Horizon Telescope

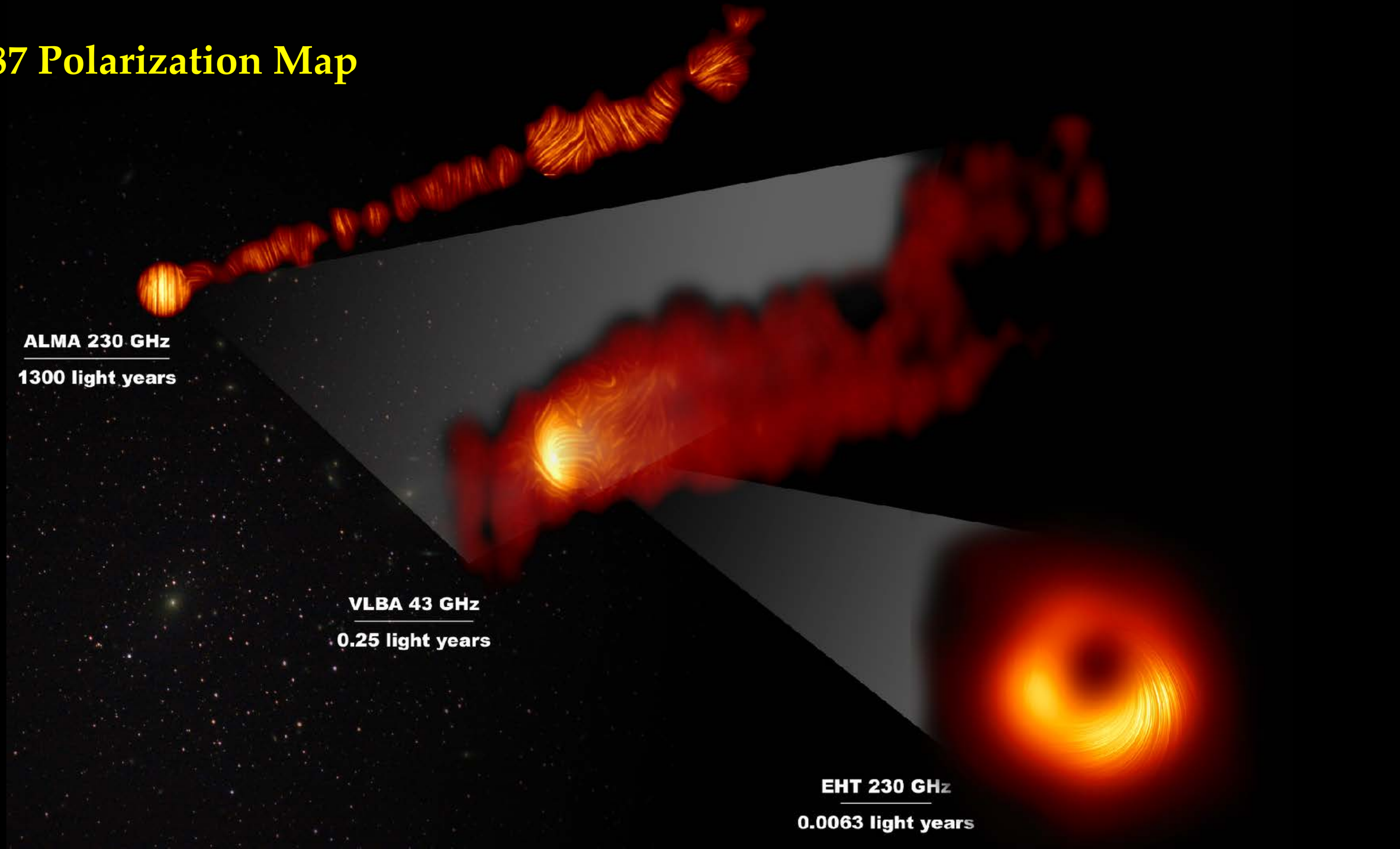
Asia is partner on ALMA, SMA, and JCMT

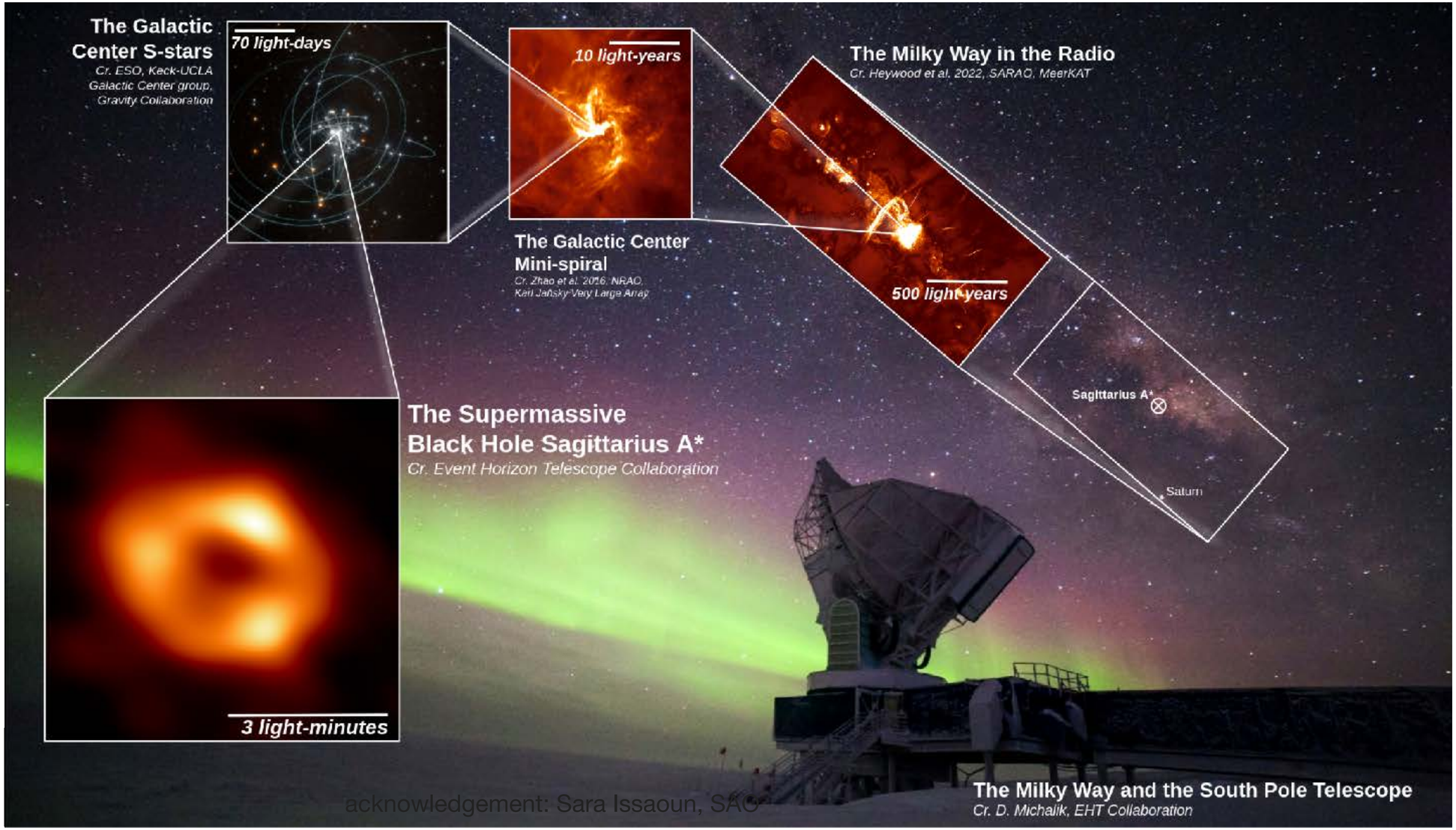
- Atacama Large Millimeter Array (ALMA), Chile
- ALMA Pathfinder Experiment (APEX), Chile
- James Clerk Maxwell Telescope (JCMT), Hawaii
- Large Millimeter Telescope (LMT), Mexico
- IRAM 30-meter Telescope, Spain
- South Pole Telescope (SPT), South Pole
- Submillimeter Array (SMA), Hawaii
- Submillimeter Telescope (SMT), Arizona

M. Johnson/SAO

Event Horizon Telescope in 2017

M87 Polarization Map





acknowledgement: Sara Issaoun, SAO

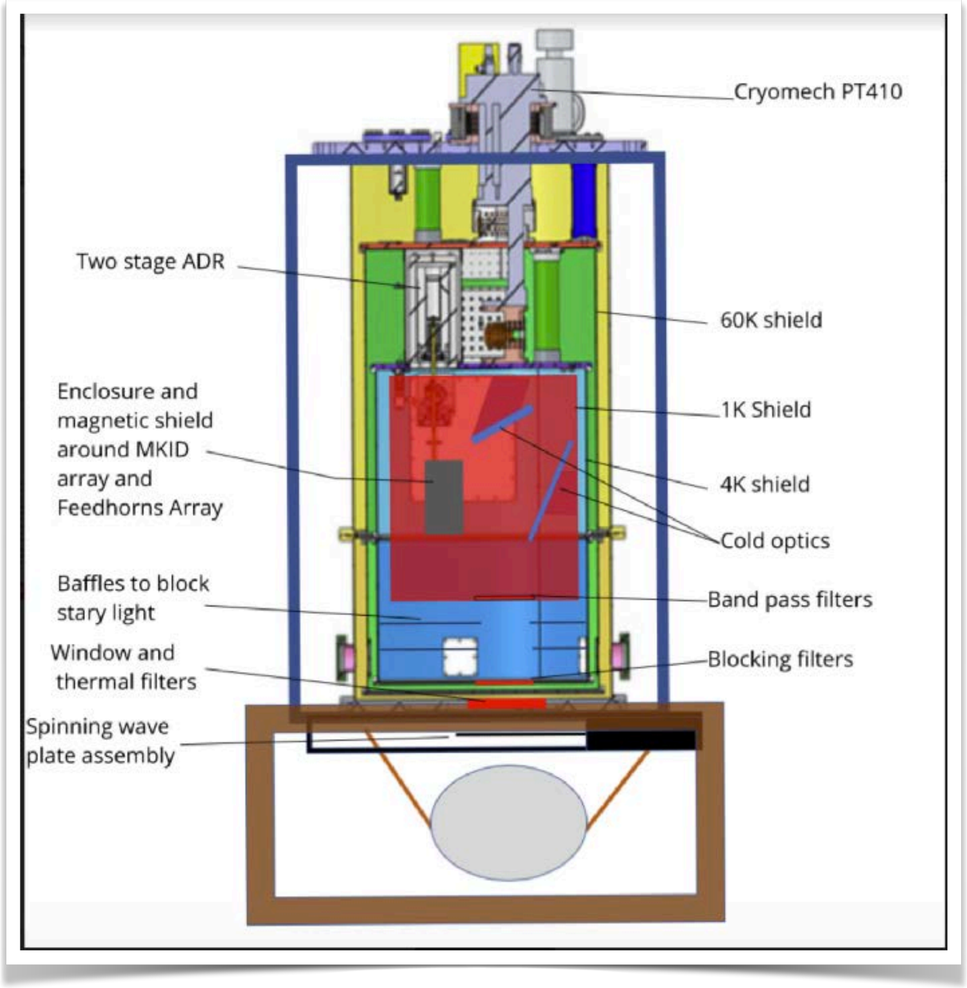
Recent BLACK HOLE Research
— Hear it, Feel it, (Not) See it

- **Detection of Gravitational Waves (tens of cases)**
- **Orbital Motions at the Event Horizon (one)**
- **Imaging of the Event Horizon (two)**
- **GR Effects**

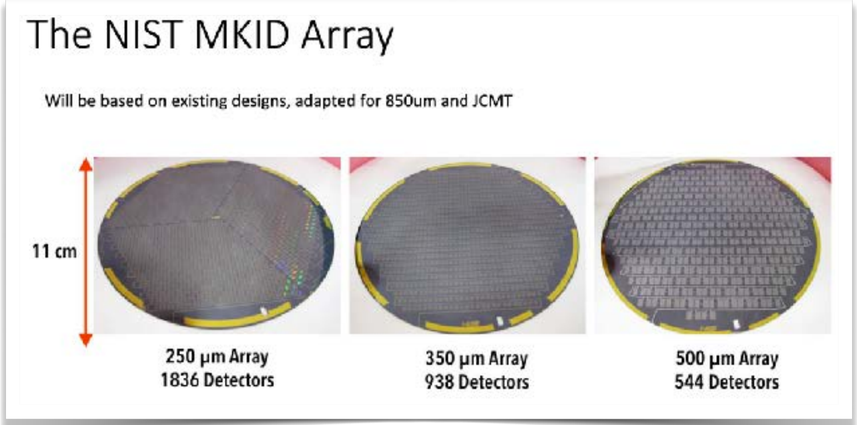
- **common technique: Lasers and Interferometry**
  (optics and missing information problem)
- **are these Nobel Prize winning work? 2017, 2020**

- **Emphasis: EAO as part of EHT is working on the real frontier of physics and astronomy**

Next: Build SCUBA-3



New 850 micron camera for JCMT



- 12’ FOV
- 3,636 pixels (7,272 detectors)
- Each pixel is comprised of two detectors, that measure orthogonal linear polarization
- On Sky October 2022

Guaranteed mapping speed increase	10x compact[1], 10x large[2] maps	20x for polarimetry mapping
Aspirational mapping speed increase	20x large maps	40x for large polarimetry maps

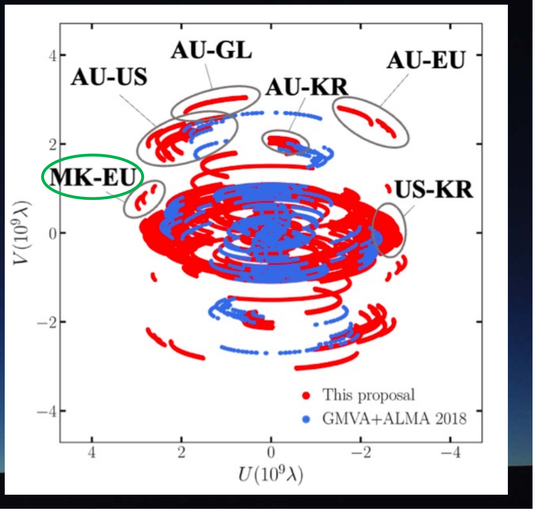
Next: Increase VLBI Program

EAVN-hi 2022 Observations

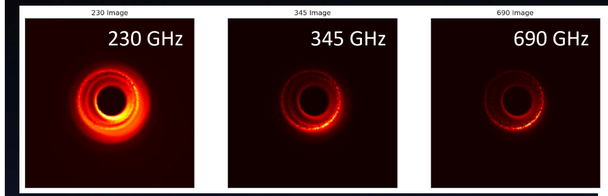
- Next week (2022/11), we will perform the EAVN-hi 2022 86/230 GHz VLBI observations with the JCMT, the KVN Yonsei, and the GLT.
- SMA & IRAM 30m will also join for 86/230 GHz Freq. Phase Trans. Test.
- Data will be correlated at the SHAO in China.

Global VLBI Observations

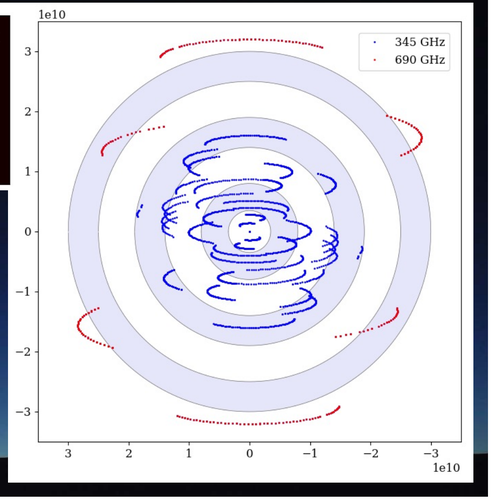
- Telescopes:
  - HSA (VLBA, GBT, EB) - ATCA/Mopra - KVN - Yb - Mh - On - GLT - JCMT
  - 86 GHz array with proposal base.
    - Led by Jongho Park & Keiichi Asada.
  - JCMT is again key telescope for the longest East-West baselines.
  - VLBA MK antenna has problems in sensitivity & pointing accuracy.
- Correlator:
  - SHAO DiFX software correlator



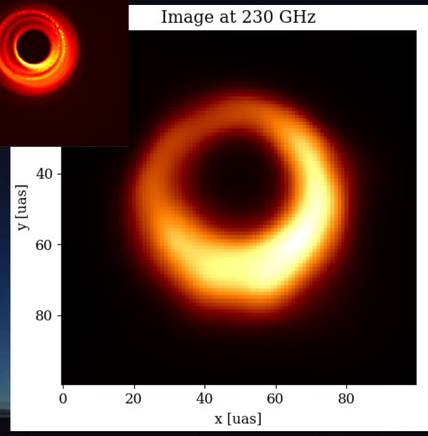
690 GHz VLBI to See Event Horizon

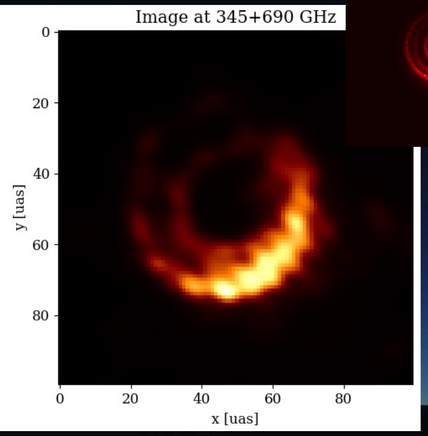


- 690 GHz VLBI telescopes:
  - GLT Summit, JCMT/SMA, & ALMA (LLAMA in the future).
- Two possible approaches:
  - Multi-Frequency Synthesis.
  - Frequency Phase Transfer.



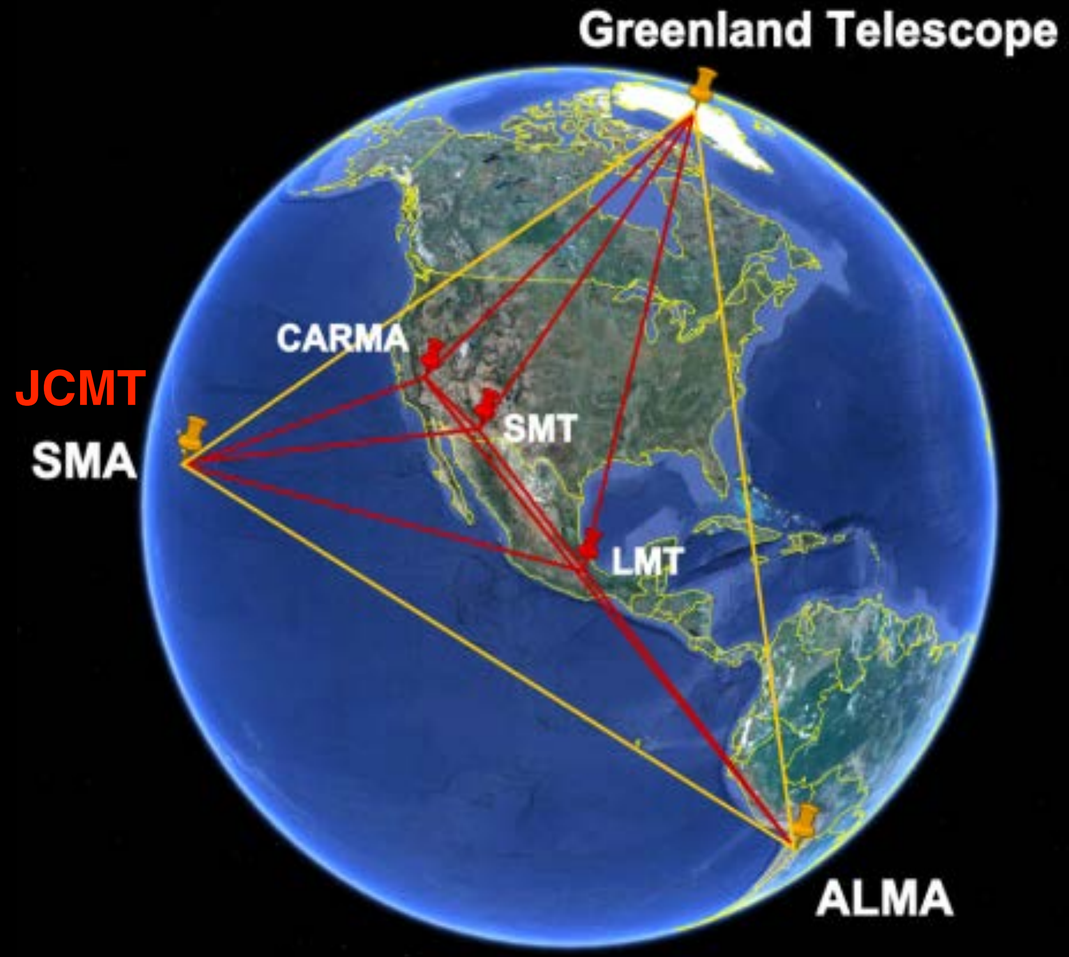
690 GHz VLBI to See Event Horizon

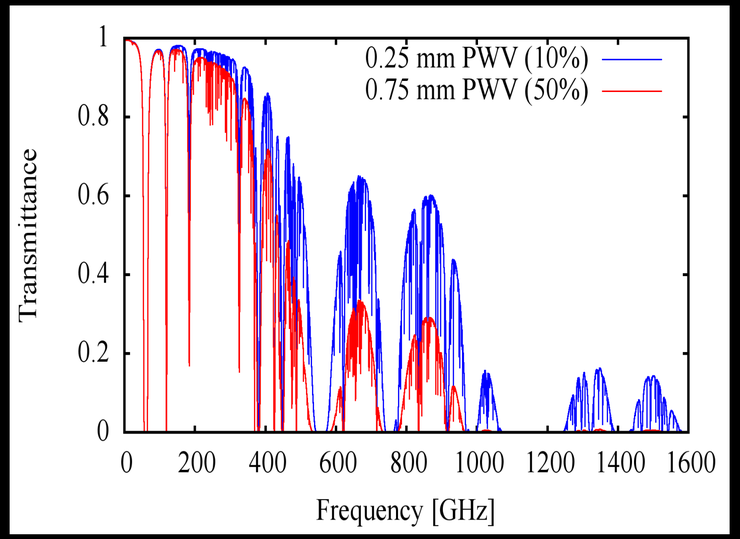




The Largest Telescope Ever:

Greenland Telescope leverages SMA and ALMA and JCMT





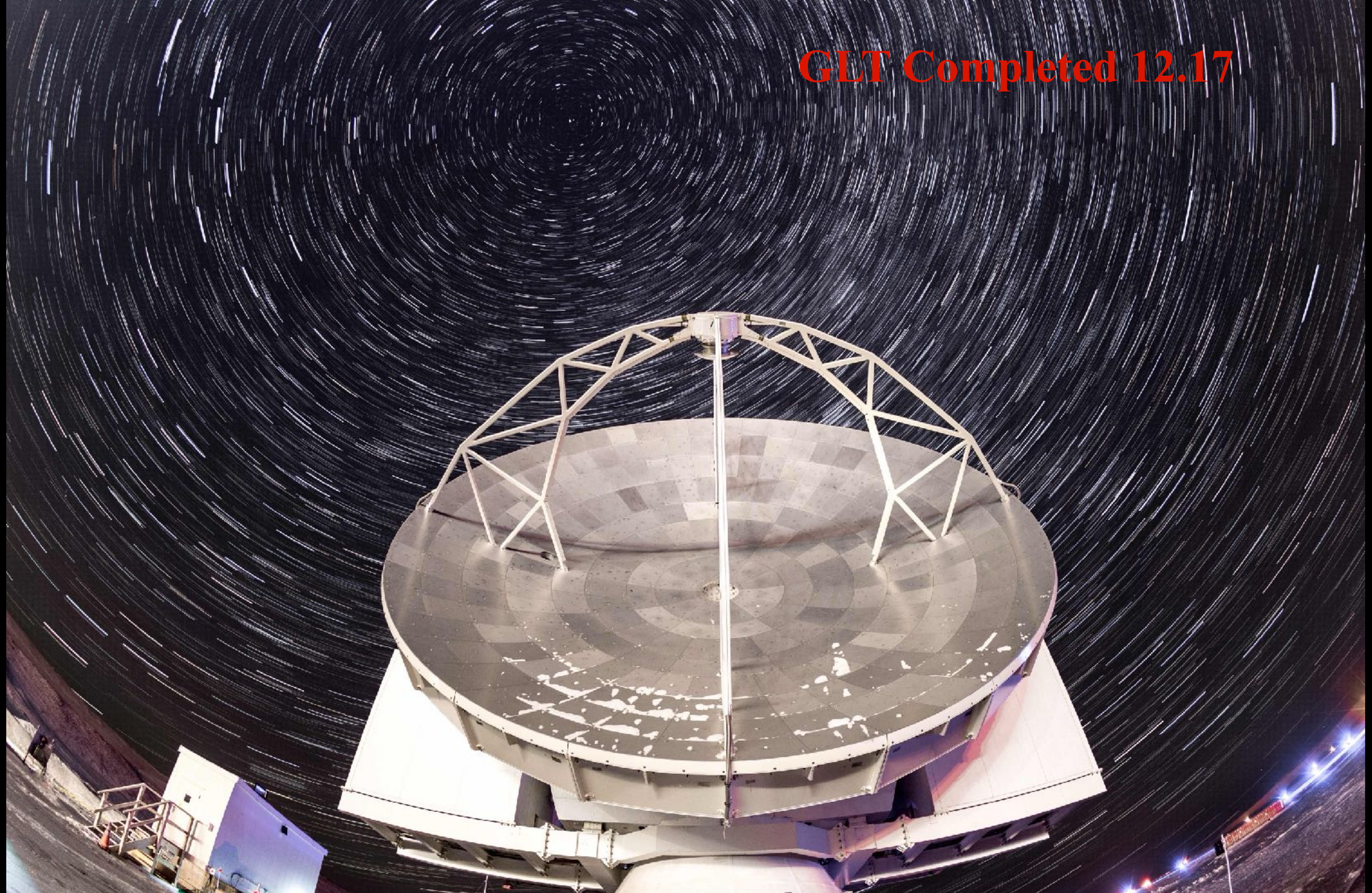
Aim: LOW PMV
Sensitivity: ALMA Surface Area

The Greenland Telescope Project

Starting The GLT Project

- **Recover ALMA-Taiwan Investment**
- **Extend ALMA Capabilities**
- **Recover ALMA Proto-Type Antenna**
- **Leverage ALMA Collecting Area**
- **Attain Highest Angular Resolution**
  — shortest λ, longest BL
- **VLBI Imaging instead of Fringe Fitting**

- **ALMA-Taiwan approved in 2008**
- **GLT Project began in 2009**


GLT Completed 12.17

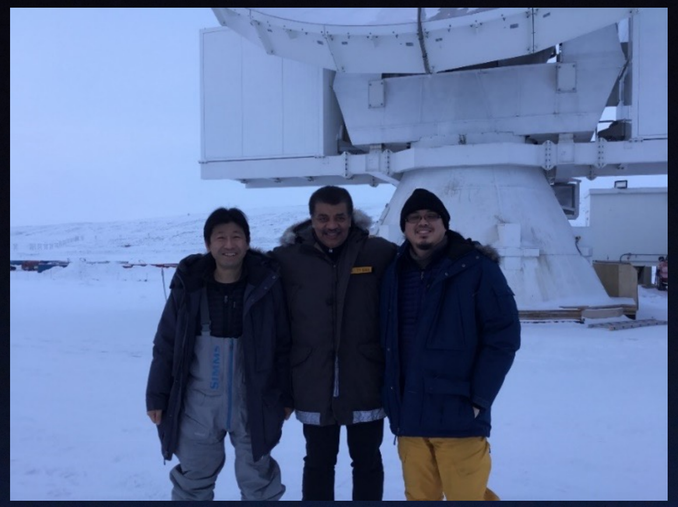
VIP Visits to the GLT

2018/10/29

The Prime Minister of Denmark

Niel deGrasse Tyson
(Carl Sagan in 21th Century)

2018/03/15



Nikolaj Coster-Waldau
(Jaime Lannister of Game of Thrones)

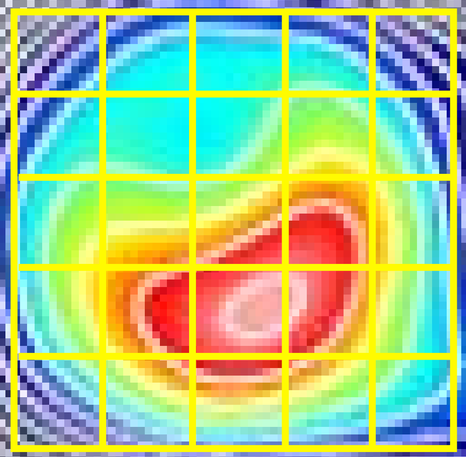
2018/08/09

Barbara Barret
(Secretary of US Air Force & Smithsonian Institution Board Member)

2019/11/29

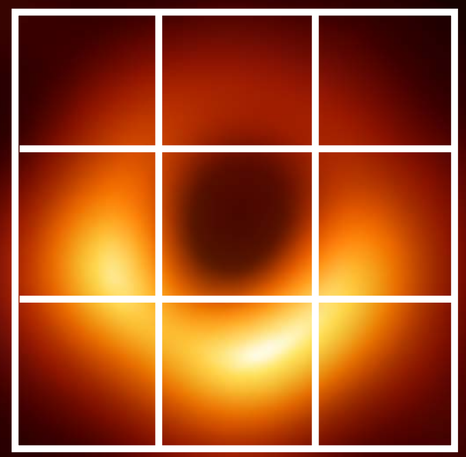
Current and Future Resolution of EHT

EHT with GLT
220 GHz
5 x 5 pix (25 pix)

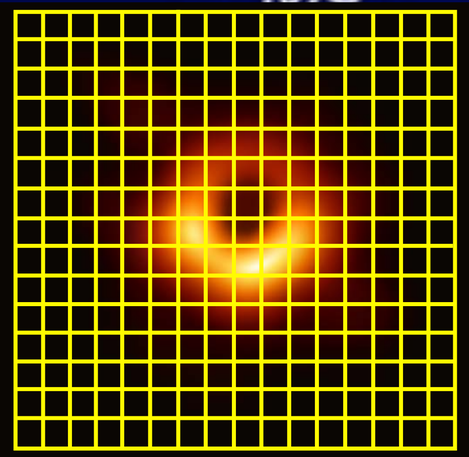


We will have better resolution & sensitivity on M87 black hole shadow & jet.

EHT 2017
220 GHz
3 x 3 pix (9 pix)



GLT @ Summit
660 GHz
15 x 15 pix (225 pix)



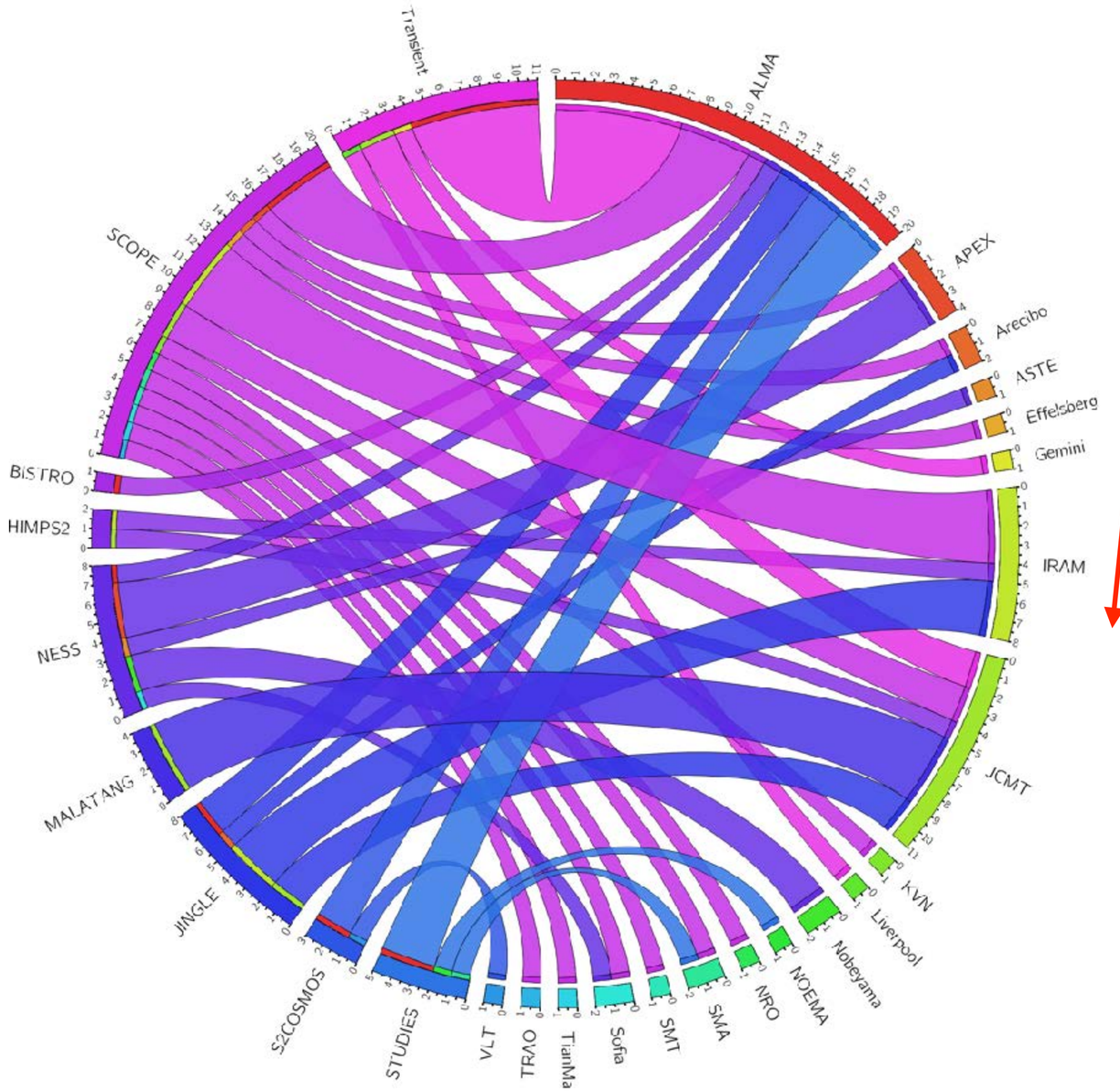
M31 (Andromeda)
Black Hole

We will have much better resolution for black hole shadows in various galaxies.

CASE for Joining EAO/JCMT

- **RADIO is a Different Window on the Universe**
- **Submm wavelength sees the Cold Matter**
- **Cold Dust can trace matter, but also Magnetic Field**
- **Distant Universe is red-shifted into the Submm Window, and are equally bright for all distances**
- **JCMT is part of Earth-Sized Telescope to See the Shadow of a Supermassive Black Hole — *Driver for Science Education and Science Policy***
- **SEAAN can participate in EHT and JCMT Large Programs, and other telescopes via Observer Status in EAO**

Successful Proposals at other Observatories due to JMCT Large Programs



SUMMARY OF ENGAGEMENT

- Pre-EAO: total investigators ~ 200 regular users from three countries and international
- Post-EAO: over 600 investigators in PI programs from six regions
- Pre-EAO: average subscription rates between 1.2 - 2.0
- Post-EAO: subscription rate of 3.5
- Pre-EAO: average PI proposal investigators between 3 - 5
- Post-EAO: average PI proposal investigators between 10 -20
- Pre-EAO: legacy program between 20 -50 investigators
- Post-EAO: Large Programs between 80 - 100 investigators
- Pre-EAO: minimal (<10%) of PI programs have cross-region collaboration
- Post-EAO: more than 50% of programs have cross-region collaboration

Status of EAO

- Asia recognizes Future Improvement will need more Funds
- EAO continues to work on coordinating/collaborating in Asia
- EAO consists first of ASIAA, KASI, NAOC, NAOJ
- Vietnam, Thailand, Malaysia, and Indonesia have been EAO Observers since 2019
- Thailand (NARIT) has joined EAO as partner in 2021
- Malaysia (UM) has sent LOI on joining EAO as partner in 2023
- India is considering becoming EAO Observer/Partner

- Asian economies have been impacted by Covid-19 in 2020-2021
- Asian Treaty Organization for Astronomy being worked on

Summary

In ~ last 4 years: Operations optimized

Staff stabilized in spite of retirements (17 staff left)

Budget balanced for last 2 years with small deficit

2015 Budget deficit almost reduced to zero

New Science Capabilities (POL-2)

Large Programs established (~7-10 programs each of 3 cycles)

EA Regional Community established

Science Production Increasing (majority papers led by EA)

Regional Instrumentation Program established (Namakanui, SCUBA3)

GLT receiver tested on JCMT and deployed to Greenland

Mid-Term Review: completed 2017

New EAO Partners: Thailand (partner),
Vietnam, Malaysia, Indonesia (observers)

EAO-UH JCMT Extension: completed to 2025, next?

next EAO Project: SMA and JCMT as operational partners

Most Important: A Working Model for Asian Linkage

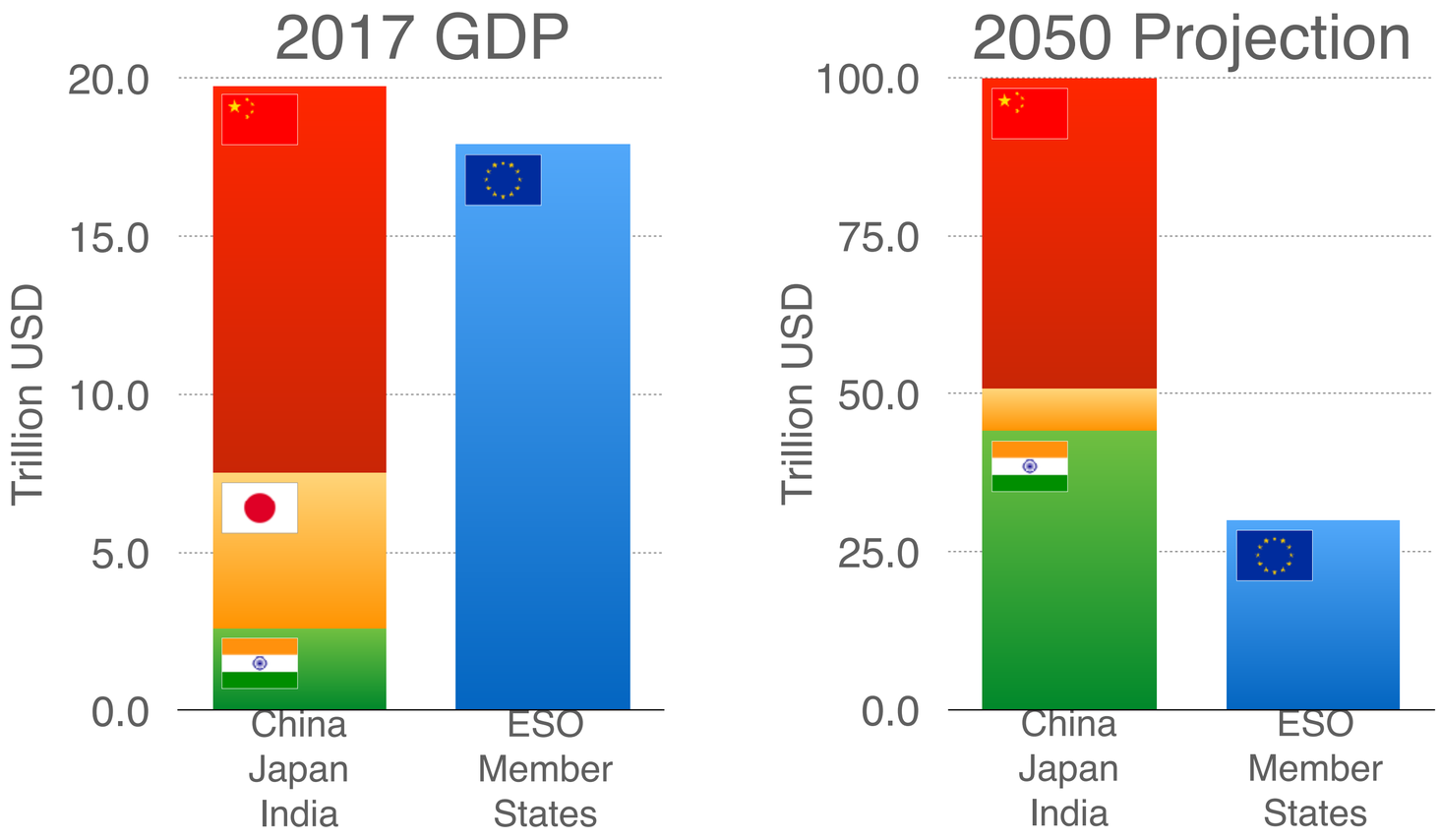
Why EAO? Is it for all of Asia?

- **EAO is for competition with the rest of the world**
- **EAO is an example for accessing the frontier of science**
- **East Asian regions grew rapidly in last 20 years**
- **South East Asia and India will be the engines for growth in the next 20 years**

- **Key: Population will drive Growth Rate**

Economic Centroid is Shifting to the East

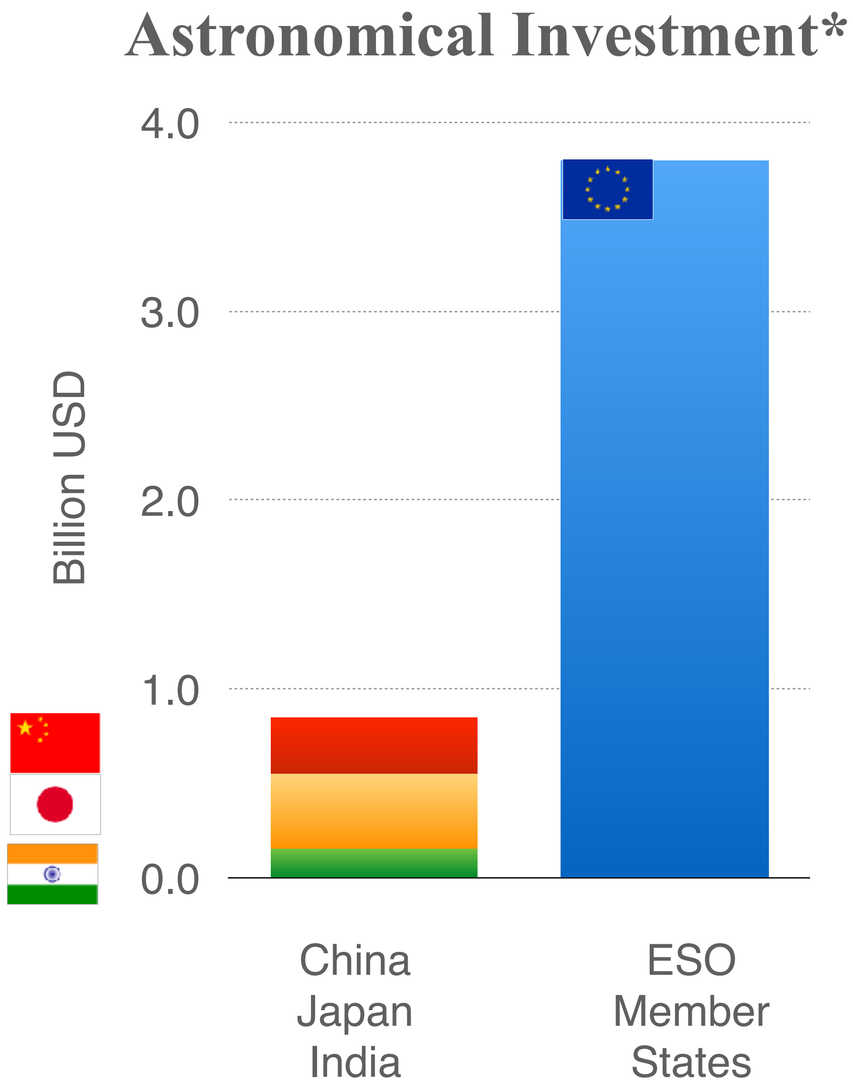
Investment in science is critical to realize the projected growth



PwC's "The World in 2050" (PPP)

A Proposal for Asian Treaty Organization

- **Asian Investments have followed the West**
- **Asia can Lead the Next Developments**
- **Develop and Control the new Technologies**
- **Asian Science for the Next Generation**



*Ground-based large astronomical research infrastructures (since 2010)

New Partners? Asian Regional GDP

	2018 GDP(IMF): B $	2021 GDP (IMF): B $	2026 projected GDP (IMF): B $	5-YR Growth Rate: %
USA	20,527	22,996	29,166	27
CHINA	13,841	17,745	24,295	37
JAPAN	5,041	4,933	5,010	2
SOUTH KOREA	1,725	1,811	2,048	13
TAIWAN	609	775	997	29
THAILAND	507	506	673	33
CAMBODIA	25	26	39	50
LAO	18	19	16	-12
MALAYSIA	359	371	577	56
MYANMAR	67	65	75	15
PHILIPPINES	347	394	531	35
SINGAPORE	377	397	513	29
VIETNAM	303	366	624	70
INDONESIA	1,043	1,187	1,762	48
INDIA	2,703	3,176	4,947	56

- South East Asian Economies are Expanding
- South East Asia also has Large Population
- East Asia + South East Asia >> U.S. or EU

Proposed Contributions ~ Ratio of GDPs

1% ESO means 10^{-7} GDP

A Call to the SEAAN Regions

- **Become EAO Observer**
  access JCMT, and strengthen EAO and Asian Partnerships

- **Become EAO Associate Partner**
  access: JCMT, SMA, UKIRT, (and Subaru)
  expand: Radio Astronomy to submm (consider ALMA)
  expand: Optical Astronomy to 10m class (before TMT)
  investment: 10^{-7} GDP; staff posting to EAO

- **Become EAO Full Partner**
  build: EAO together
  build: Next generation Instruments
  build: Next Asian Mega Projects
  investment: 10^{-6} - 10^{-5} GDP; staff posting to EAO

SEAAN regions will grow rapidly in economy, shall we grow together?

Return of Investment for Joining EAO

Posted Staff train in:

- **Administration of Personnel and Budget in International Operations**
- **Operation of Non-Profit Organization in the U.S.**
- **Design and Building of Advanced Instruments, Detector Technology**
- **System Engineering and Testing of Integrated Systems**
- **Linkage between Ground-Based Facilities and Space-Based Facilities**
- **Large Data Science and AI techniques in Imaging and Modeling**

International Cooperation and Collaboration:

- **EAO is a model for Astronomy Treaty Organization for Asia**
- **Linkage between regional technology developments**
- **Linkage between regional industries (large scale manufacturing, machining, electronics)**

Manpower and Personnel:

- **Access to Jobs in EAO regions — manpower capacity building in country**
- **Attract Next Generation Young Scientists to return to home countries via Access to Frontier Facilities**