Data transfer from ALMA to North America

National Radio Astronomy Observatory

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www.almaobservatory.org

NRAO and ALMA

ALMA is a multinational project with many partners, and three ALMA Regional Centers (ARCs):

- NA: NRAO, Charlottesville, VA, USA
- EU: ESO, Garching (Munich), Germany
- EA: NAOJ, Mitaka (Tokyo), Japan

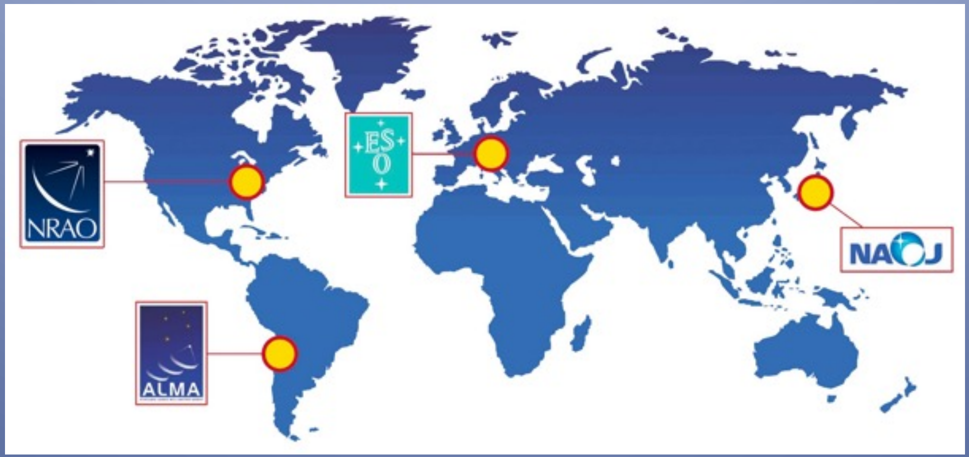


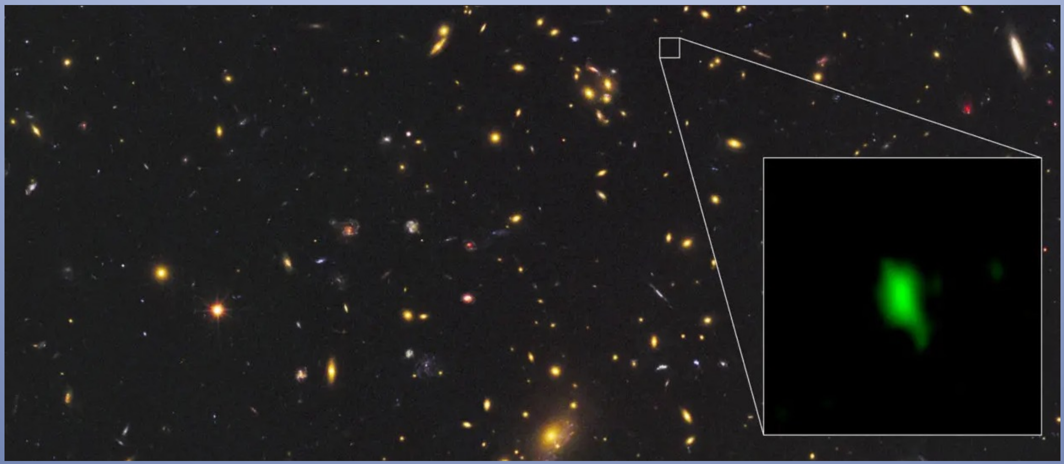
Image: https://science.nrao.edu/facilities/alma/images/arcs.jpg

ALMA telescope

- Largest mm/submm telescope ever built. As an interferometer, it combines signals from multiple antennas to form an image.
- All 66 antennas operational at high site (except for maintenance)
- Sub-arrays possible, and generally 3 projects observed at once:
  - 50 x 12m-antennas (main array)
  - 12 x 7m-antennas
  - 4 x 12m-antennas, observing in "Single Dish" mode ("Total Power")
- Operated "space mission" style, with pipeline data processing and a science archive at JAO in Chile and each ARC
- First PI projects released to public from the ARCs January 2013 (12-years!)
- Call for Cycle 12 proposals completed April 2025
- Cycle 11 observing started October 2024

ACHIEVEMENTS

ALMA Finds Most-Distant Oxygen in the Universe



- Astronomers detected a faint but definite signal of oxygen in a galaxy located 13.28 billion light-years away from us, through observations using the Atacama Large Millimeter/submillimeter Array (ALMA). Breaking their records, this marks the most distant oxygen ever detected in the Universe. Referencing infrared observations, the team determined that star formation in the galaxy started at an unexpectedly early stage: 250 million years after the Big Bang.

Radio Interferometry relies on pairs of antennae to emulate a much larger dish

Artificially create a large “dish” using many smaller ones...

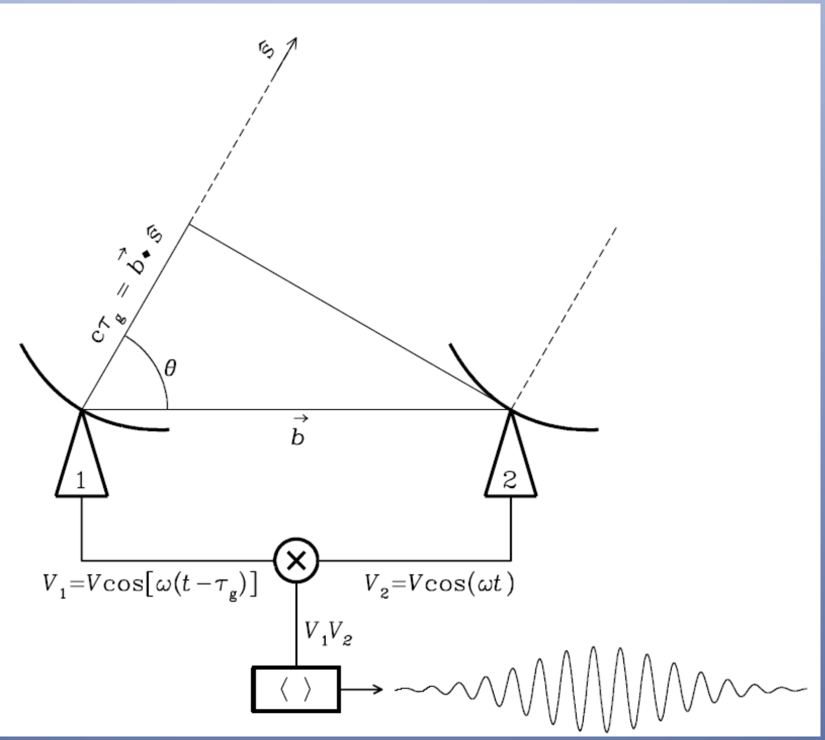
... this is called “Aperture Synthesis”

But ... this large “dish” is not a real reflecting surface.....

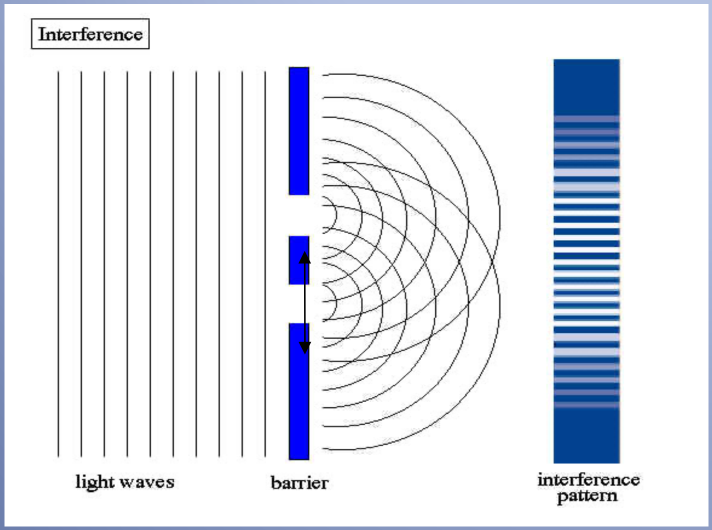
So how do you make it behave like one ?

... imitate the Physics of a lens.

Radio Interferometry: Relies on pairs of antennae to emulate a much larger dish

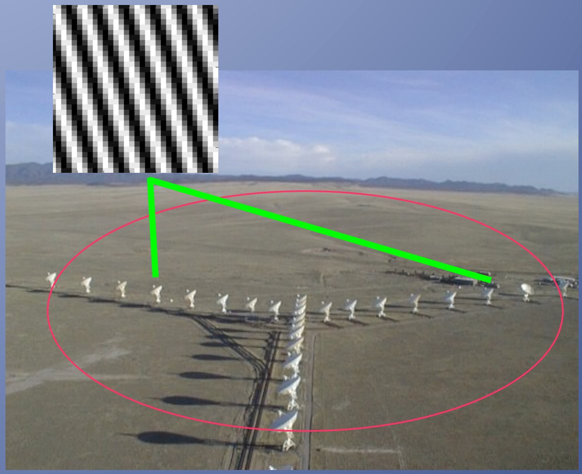


Measure interference fringes



Young's Double-Slit Experiment

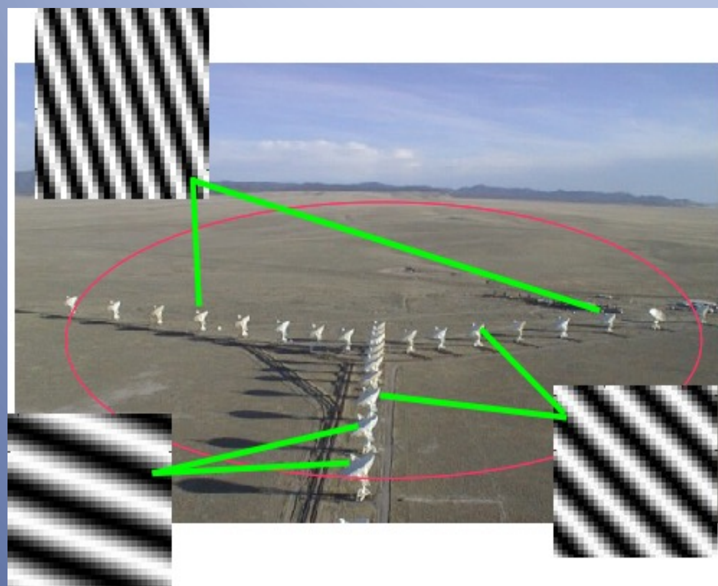
Distance between slits controls the wavelength of interference fringes



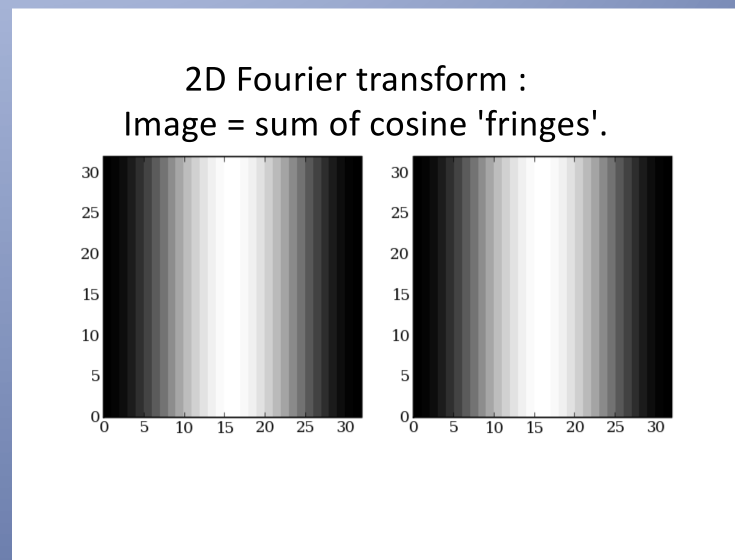
One dish = One slit

Each pair of antennas captures a different 2D fringe

Image Formation



Build an image by combining all measured fringes in a custom built High-Throughput SuperComputer called a Correlator.

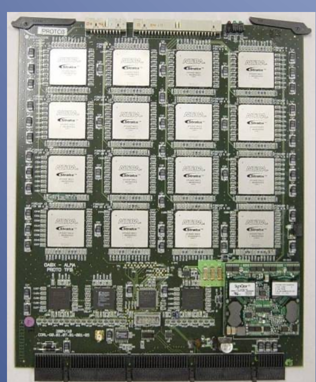


The number of fringe scales with the (number of dishes)^2

ALMA Correlator: HPC@ 16,200 feet

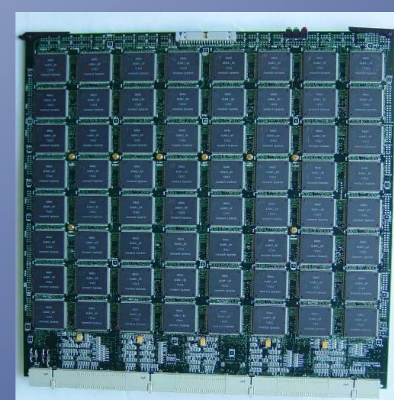
Correlator Quadrant

Tunable Filter Bank Card

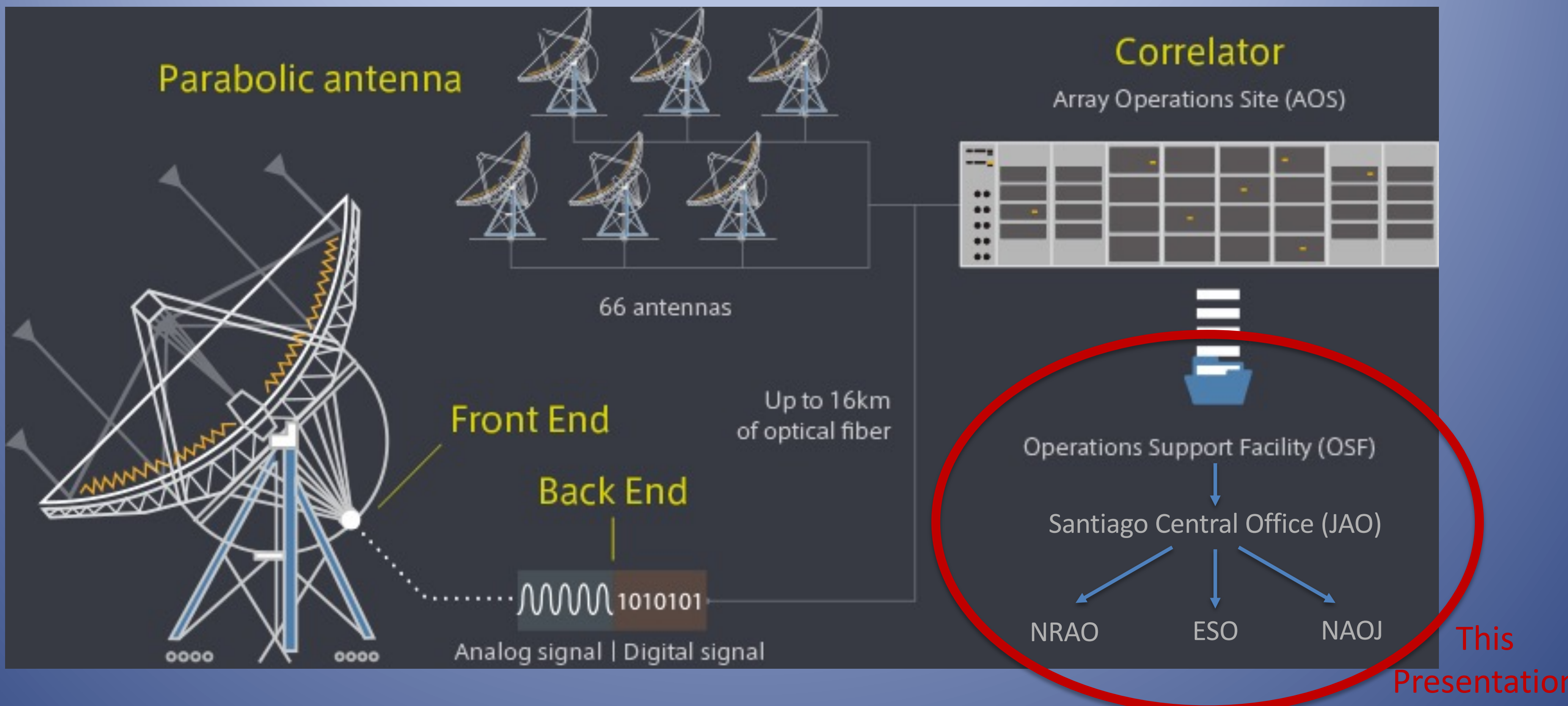


- Receives signals from 50x12m antennae
- 2551 printed circuit boards total in system
- 8192 Altera Stratix II FPGAs on TFB cards
- 32768 custom correlator chips with 4096 processors for multiply-and-add calculations
- Cross-correlation rate 17 Peta ops/sec
- Output specified at 6-60MBytes/sec

Correlator Card



ALMA Telescope Data Flows



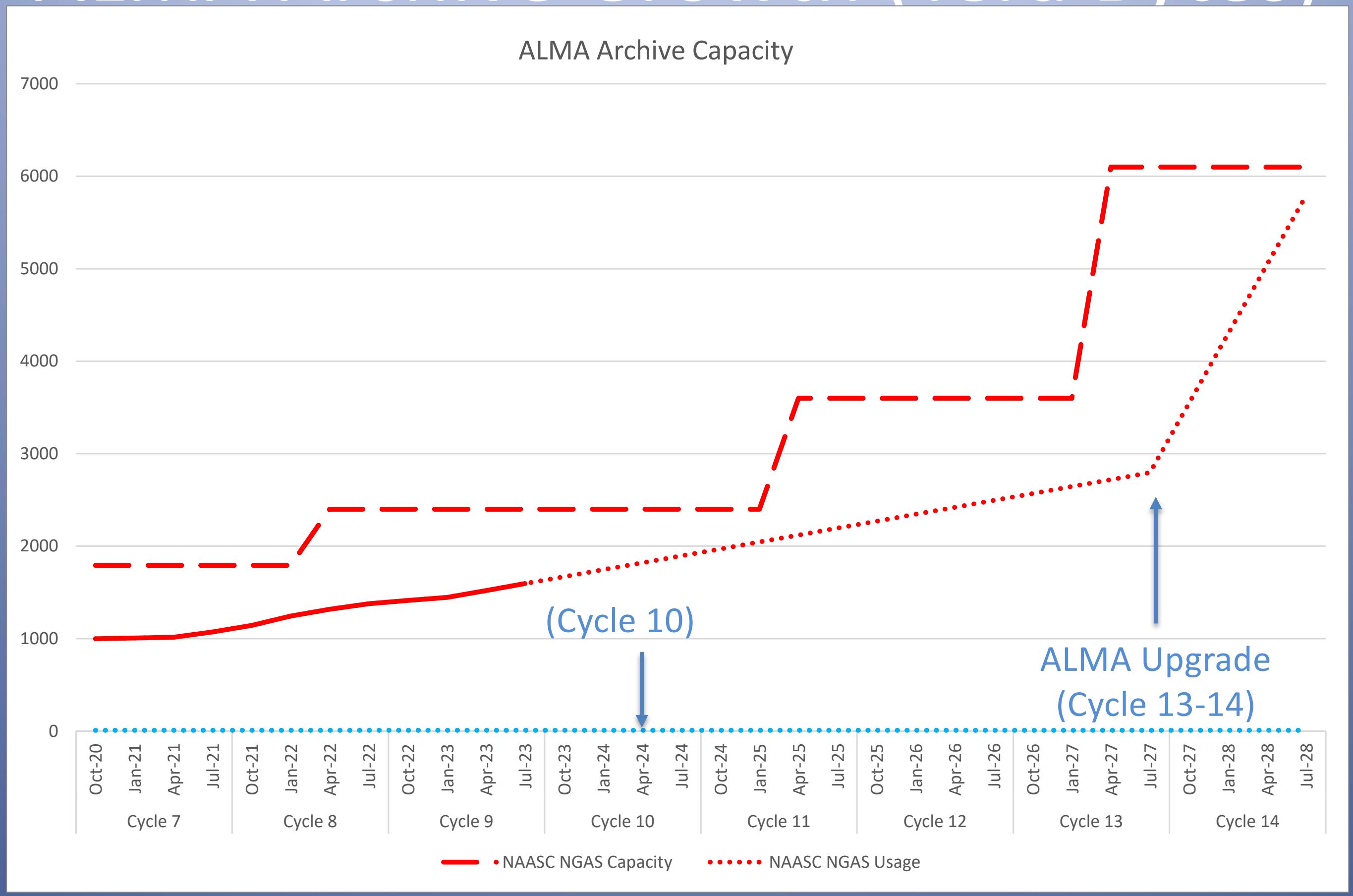
System diagram of ALMA. Various instruments including antennas, receivers, correlators, and data archive work in unison.
Credit: ALMA (ESO/NAOJ/NRAO)

Data transport

Chile to Charlottesville (NAASC)

- MOU between AUI/REUNA for Metro link to SCO
- Santiago to ARCs: individual ARC contracts with REUNA and NRENs.
  - NA: Joint AURA-AUI agreement for 1Gbps committed (burstable to 10 Gbps) from Santiago to I2 via AmLight
  - Link to NRAO HQ from Internet2 through UVa is 10Gb/s
- Typical rate obtained during peak data transfer periods is 2-300Mb/s, with bursts up to 600Mb/s
- Recent transition to most data processing being done in Santiago. Some manual processing at ARCs
- The North American ALMA Science Center (NAASC) hosts the ALMA Archive, and computing for NA users

ALMA Archive Growth (Tera Bytes)



ALMA Wideband Sensitivity Upgrade

- The WSU will provide three major improvements.
- Increased receiver bandwidth.
- Improved sensitivity (i.e., better receivers and improved digital efficiency).
- Increased spectral tuning grasp (i.e., no need to trade off bandwidth for spectral resolution).

[1] https://www.almaobservatory.org/en/publications/the-alma-development-roadmap
[2] https://science.nrao.edu/facilities/alma/science_sustainability/Specifications2ndGenCorrelatorV2.pdf

ALMA WSU Data Transmission System (DTS)

- The preliminary design review for the new Data Transmission System (DTS) for the ALMA radiotelescope has been completed. December, 2024.
- This system is being developed as part of the Wideband Sensitivity Upgrade (WSU).
- Systems and Networking personnel at the NRAO participated in creating the WSU Data Transfer and Archive Storage Working Group Report (WSU DTAS).
- The current SCO to ARC operational model can be kept. The software for data-transmission will need to be optimized. With those recommended optimizations in the transmission software, the currently available network bandwidth (1Gbps) would already be sufficient to transfer the Early WSU data-rate. Bandwidth upgrades are needed for the Later WSU scenario.
- The North America ARC is working on upgrading from 1Gbps to 10Gbps.

Expected Data Transfer

After the WSU, the assumed average data rate will be (in the 2030s) of the order of 3.6 PB/year - 6.6 PB/year.

In 2022, the size of an average downloaded dataset was 20 GB (maximum 2.5 TB). Expect 1TB to 125 TB after upgrade.

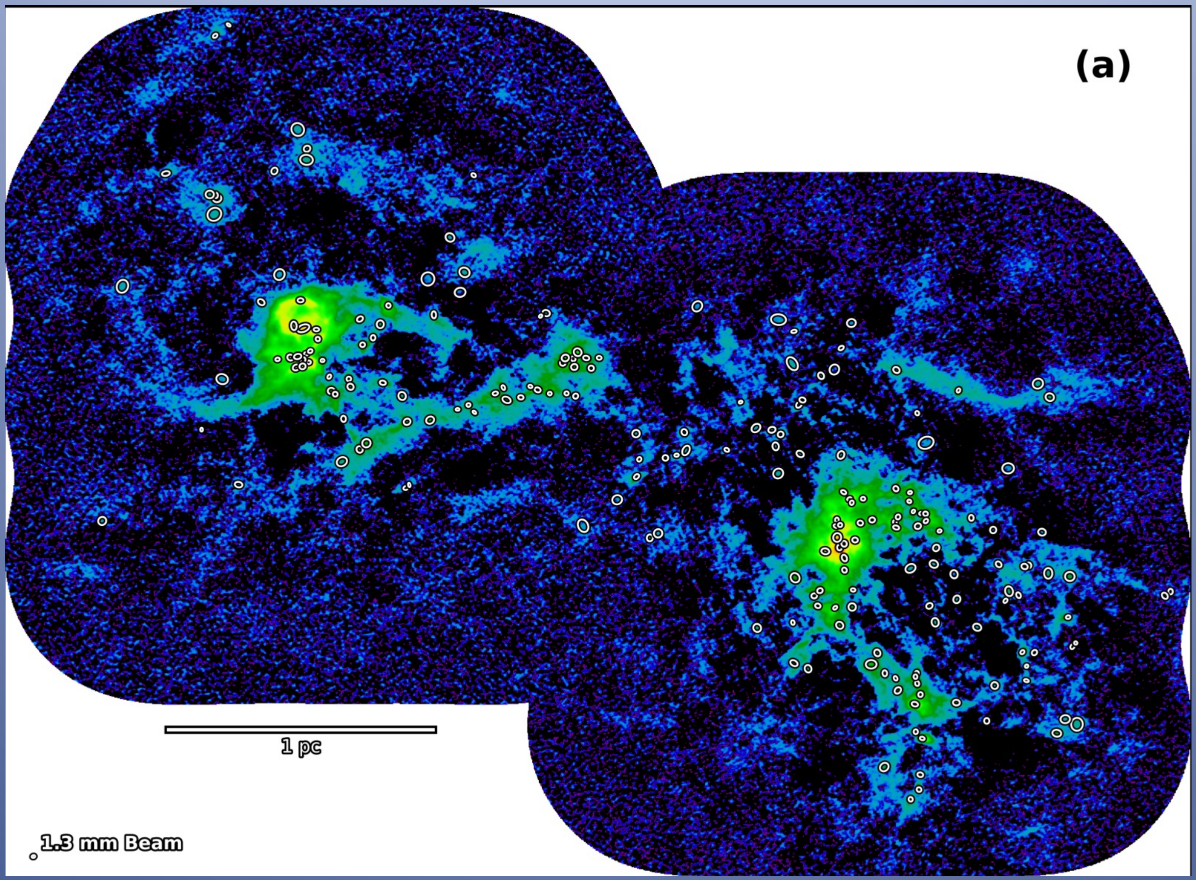
Disaster Recovery Concern

- The current NA ALMA archive is ~1.3 PetaBytes
- In the event of data loss, the Regional Centers would recover data from the primary ALMA Archive in Santiago
- Over the current 1Gbps link, this would take ~5-6months!
- NA ALMA archive access would be re-directed to ESO during any outage
- Additionally, recovery of the Oracle DataBase would take many weeks

Summary

- Ramp-up of the ALMA data rate has been slower than anticipated, allowing us to stay ahead of the curve.
- Data flow mostly from JAO to ALMA Regional Centers, with data processing mostly at JAO.
- Still monitoring how the network performs when transferring ~10TB/day in multiple parallel streams.
- We must establish a link with 10Gb/s of dedicated bandwidth within the next 1-2 years to improve transfer speed to and from Chile for bulk reprocessing, and to help with occasional large data and metadata transports (e.g. a DB export).
- Most new developments (e.g. next generation correlator) on ~5yr timescale can probably be accommodated without increasing the data rate by more than a factor ~4.

Questions?



Mini "star-burst" studied by Pouteau et al. (2022), based on ALMA Large Program data