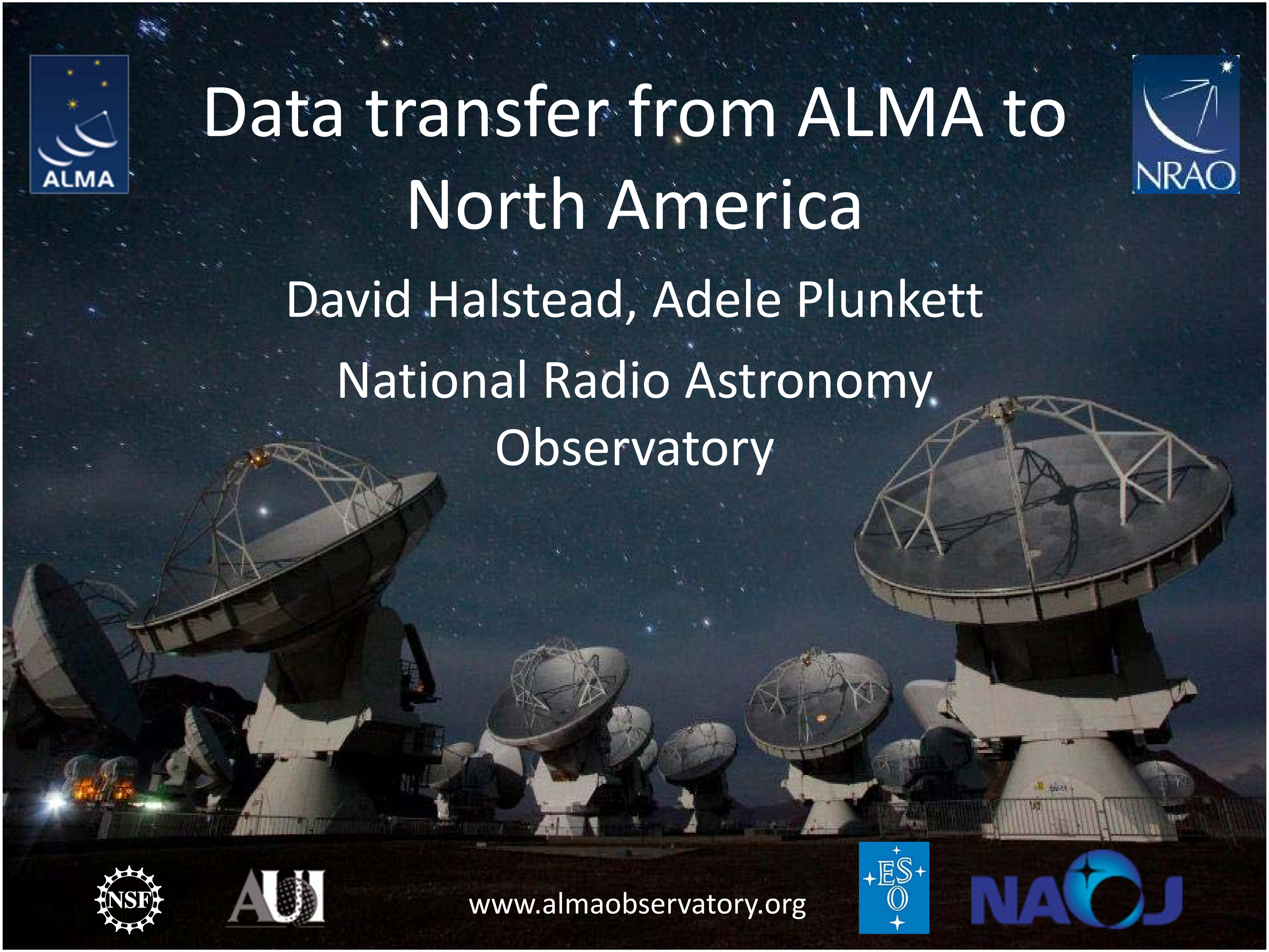

Data transfer from ALMA to North America

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National Radio Astronomy Observatory

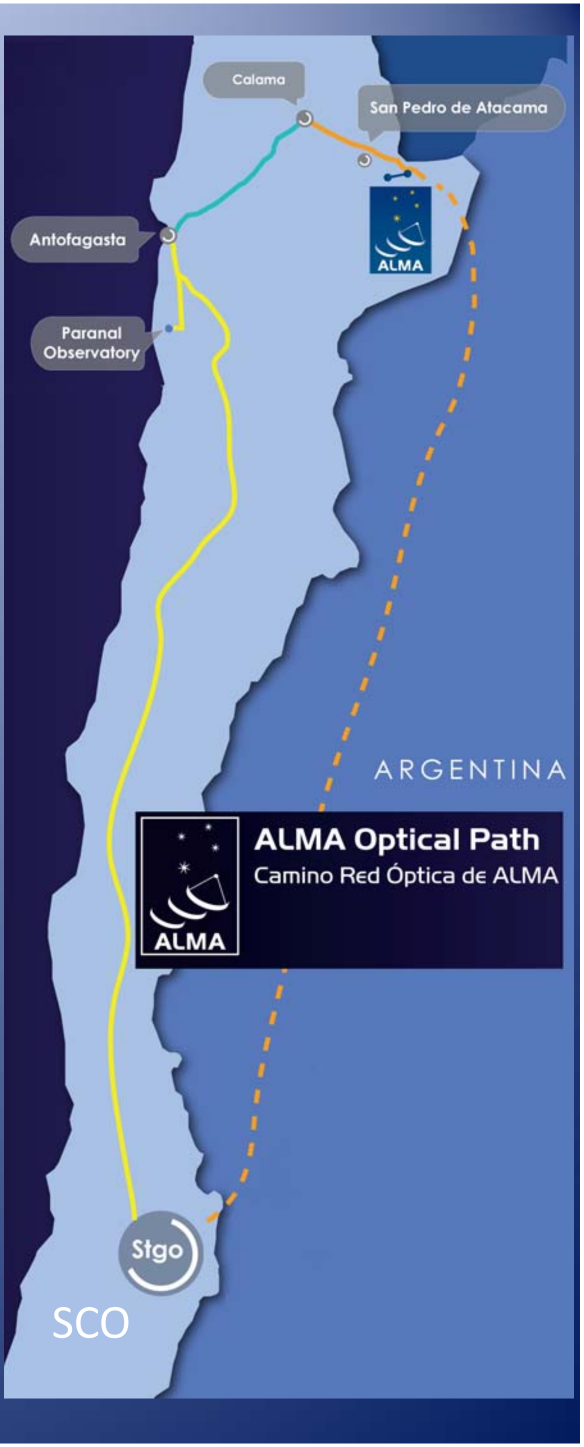
www.almaobservatory.org

ALMA telescope

- Largest mm/submm telescope ever built
- Interferometer – combines signals from multiple antennas to form an image
- All 66 antennas delivered, all at high site (except for maintenance)
- Multinational project with many partners, three ALMA Regional Centers (ARCs): US, EU and EA
- Operated “space mission” style, with pipeline data processing and a science archive at each ARC allowing data reuse
- First PI projects released to public from the ARCs January 2013
- Cycle 6 observations began in October 2018

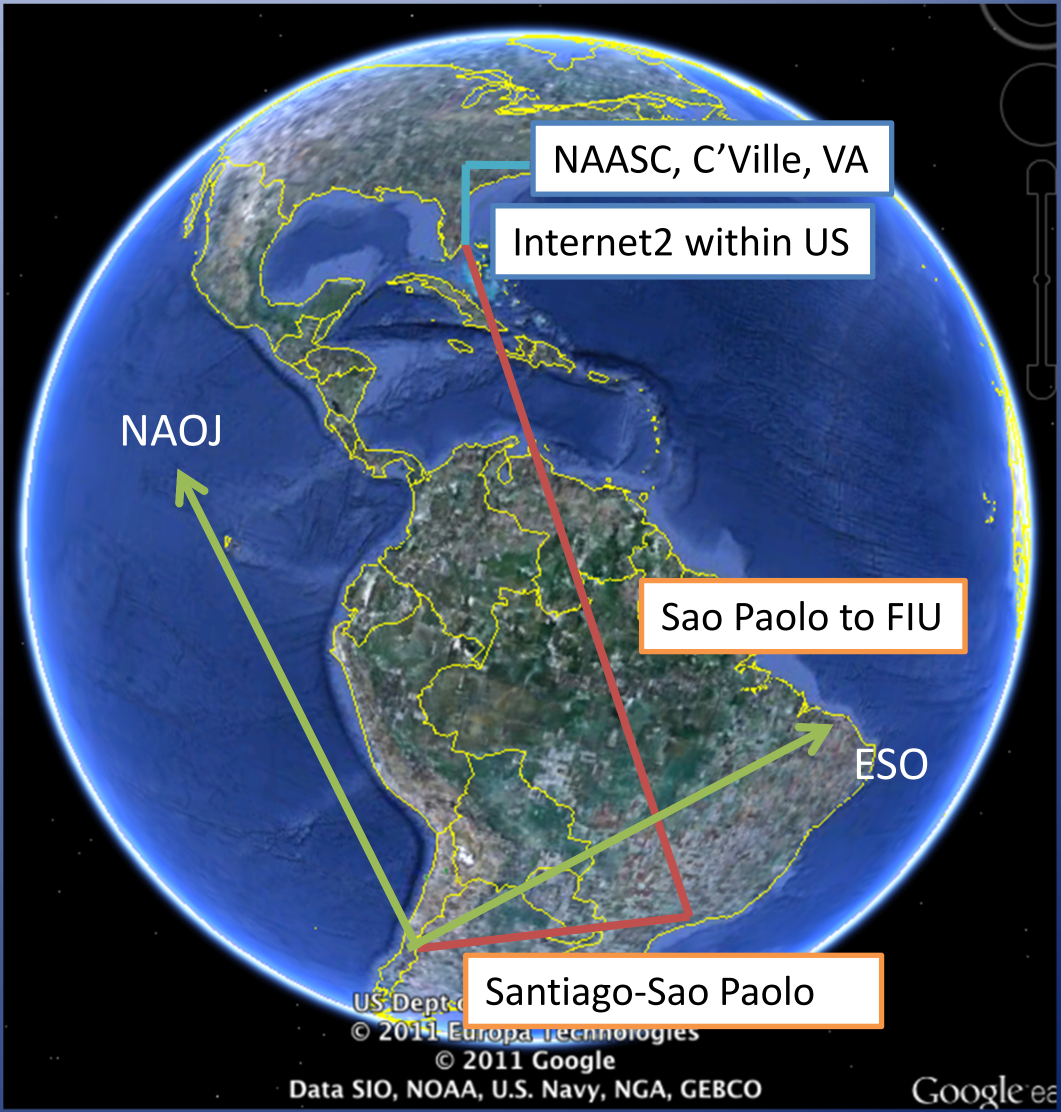
Data Transfer within Chile

- AOS to Santiago 2.5Gb/s (fiber to Calama, commercial fiber Calama to Antofagasta, EVALSO/REUNA from Antofagasta to Santiago
  - Redundant fiber loop via Argentina planned
- Santiago to ARCs: individual ARC contracts with REUNA and NRENs
- Data processing to produce Level 2/3 products shared between Santiago and the ALMA regional centers
  - Pipeline is run at 4 locations worldwide, including Santiago
  - Data packages ingested into the archive in Santiago
  - Pipeline products ~ same size as raw data
  - A significant amount of data (~100TB/yr) is thus being uploaded from the NA ARC to JAO. Bi-directional speed is thus important
- Long-term plan is that all data processing will take place in Santiago



Data transfer – Chile to NA

- Joint AURA-AUI agreement for 100Mb/s committed (burstable to 1 Gb/s capacity) of AURA's link to Chile through Sao Paolo and Miami (FIU/AmLight) to the US research network backbone (NREN)
- MOU signed between AUI/REUNA for local link to SCO
- Link from NRAO to Internet2 through UVa is 10Gb/s
- Typical rate obtained during peak data transfer periods is 2-300Mb/s, with bursts up to 600Mb/s
- Currently working on establishing network monitoring, and improving our understanding of how the link performs in typical load conditions (~1TB/day)
- The North American ALMA Science Center (NAASC) hosts the ALMA Archive and Computers for NA users



NAASC, C'Ville, VA

Internet2 within US

NAOJ

Sao Paolo to FIU

ESO

Santiago-Sao Paolo

US Dept
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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ALMA Science data rate evolution

Cycle 0
(Oct 2011-Jan2013)

- 16-24/50 antennas used (data rate proportional to square of antenna number)
- ~5-10% of array time for science
- Total data volume was about 20TB

Cycle 1
(~Aug 2013-Jun2014)

- 32-40/50 antennas, plus 7/12 compact array
- ~10% of array time for science
- 40TB over 1yr (ALMA archive hit 50TB in March 2014)

Cycle 2
(June 2014-Sept 2015)

- ~34 main array antennas, 10 compact array
- ~15% of array time for science (but some carryover from Cycle 1)
- 70TB in a 17 month Cycle.

Cycle 3
(Oct 2015-Sept 2016)

- 36 main array antennas, 10 compact array
- ~25% of array time for science
- Total of 140TB, mostly raw data (manual imaging and imaging pipeline products only ~20%).
- Data volume artificially high as two data streams are kept with different corrections.

Cycle 4
(Oct 2016-Sept 2017)

- 40 main array antennas, 10 compact array
- ~33% of array time for science
- Total of 210 TB, mix of raw and pipeline image products
- Data volume artificially high as two data streams are kept with different corrections.

Cycle 5
(Oct 2017-Sept 2018)

- 43 main array antennas, 10 compact array
- Still taking data in 2 streams (WVR corrected and uncorrected)
- ~45% of array time for science
- Total volume was 275TB, including image products (which are ~30% of total data volume).

Cycle 6

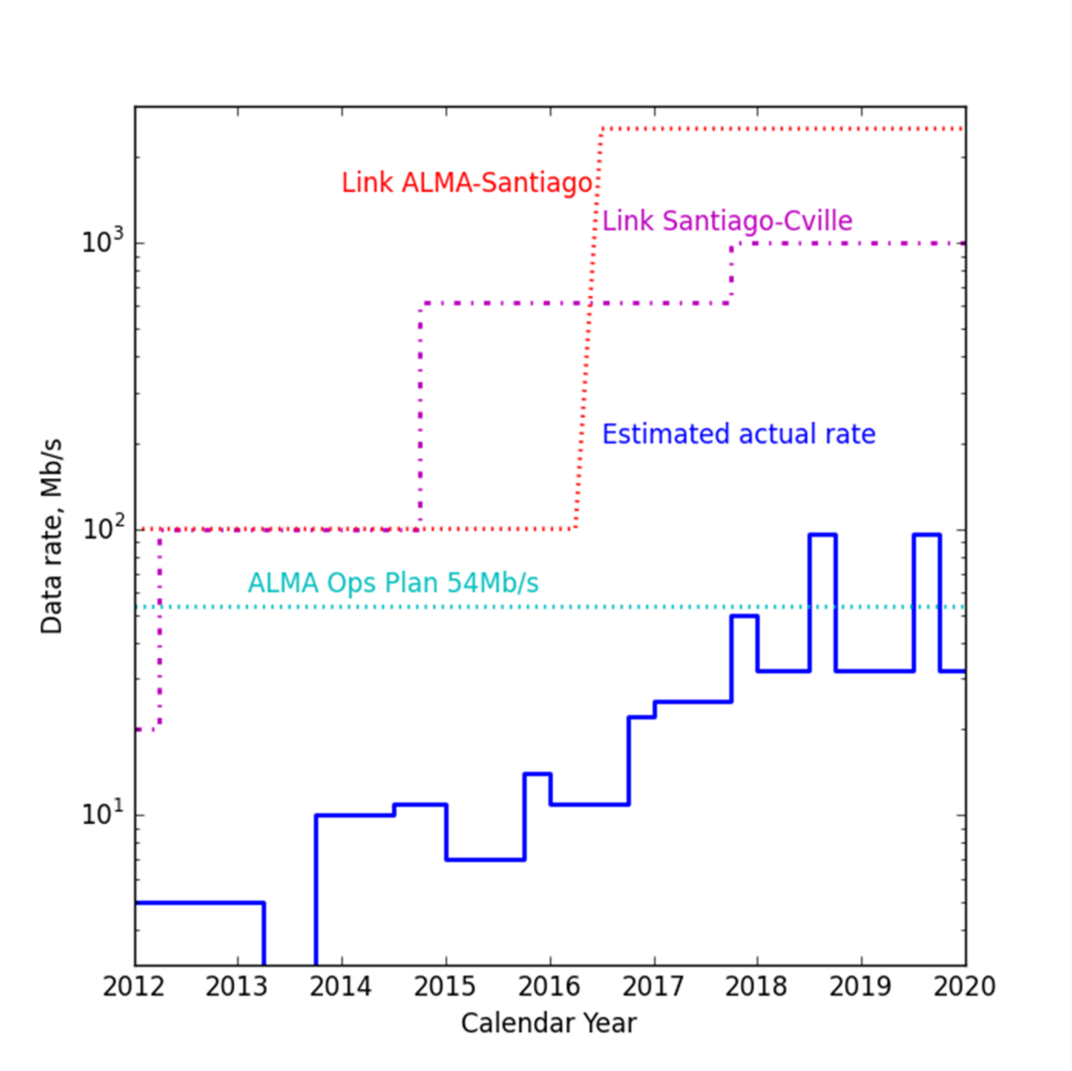
- No longer taking data in 2 streams (Water Vapor Radiometer duplication eliminated)
- ~55% of array time for science
- 43 antennas as minimum; sometimes achieved 66
- Total volume will be ~220TB, including image products (which will constitute about 30% of the total data volume).

Future Cycles

- Now running in “Full Science” state, with mean data rates ~100Mb/s during observations
  - “Duty cycle” of observations will slowly increase as testing and maintenance procedures improve.
- Best guess estimate for the next 3 years (including product size mitigation) is around 250TB/yr (125TB raw, 125TB products)
- Important to note that data rates vary through the configuration cycle. When long baseline configurations are scheduled the data rate goes up for these reasons:
  - Data sampling needs to be faster to prevent beam smearing at the field edges
  - The data products, which are also mirrored from Santiago, also increase in size, to become larger than the raw data in the largest configurations
  - So far, long baseline campaigns have tended to have low observing efficiencies, however this may change

Current data rate projections

- Assumes no imposed limit on data rate (cyan line is current Operations Plan rate)
- Blue line is for data generation
- Data transmission is per ARC
- Does not include emergency data replication (NGAS or Oracle DB)



Correlator upgrade

- A correlator upgrade is scheduled for 2022
- This will allow up to 8x more channels
- Expected data rate increase is about a factor of four, corresponding to a data rate of ~1PB/yr (not all projects will need the extra channels).
- Some increase in data rate can be expected in the build up to this as the network at the AOS is upgraded (but should only be modest, ~10% overall)

Summary

- Ramp-up of the ALMA data rate has been slower than anticipated, allowing us to stay ahead of the curve
- Bidirectional data flow will continue to be needed to support data processing at the ALMA Regional Centers
- Still learning how the network performs when transferring ~1TB/day in multiple parallel streams
- Would like to establish a link with 1Gb/s available bandwidth (out of a 10Gb/s pipe) 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. correlator upgrade) on ~3yr timescale can probably be accommodated without increasing the data rate by more than a factor ~4