# A campaign of atmospheric characterization at ESO sites in Northern Chile

*Florian Kerber*

# European Southern Observatory

- Intergovernmental organisation established in 1962
  - Access to Southern Skies and the Galactic Center – Nobel Prize 2020
- Basic facts:
  - Headquarters: Garching near Munich, Germany & Santiago, Chile
  - ~750 employees from 30+ countries, HQ: ~480, Chile: ~270
  - Annual budget: ~170 M€
- Three major telescope sites:
  - Paranal (VLT & VLTI – 4x 8m) / Armazones (ELT under - 39 m)  - 2600 & 3000 m
  - La Silla (3.6m, NTT) – 2400 m
  - Chajnantor (ALMA, APEX) – 5000 m

# European Southern Observatory

## Vision

- ESO's vision is to deliver the Extremely Large Telescope (ELT), while keeping the Very Large Telescope (VLT), VLT Interferometer, and the Atacama Large Millimeter/submillimeter Array (ALMA) at the forefront of worldwide astronomy.

# European Southern Observatory

## Mission

1. Enabling major scientific discoveries by constructing and operating powerful ground-based observational facilities that are beyond the capabilities of individual member states
2. Fostering international cooperation in astronomy

# The Extremely Large Telescope ELT – elt.eso.org

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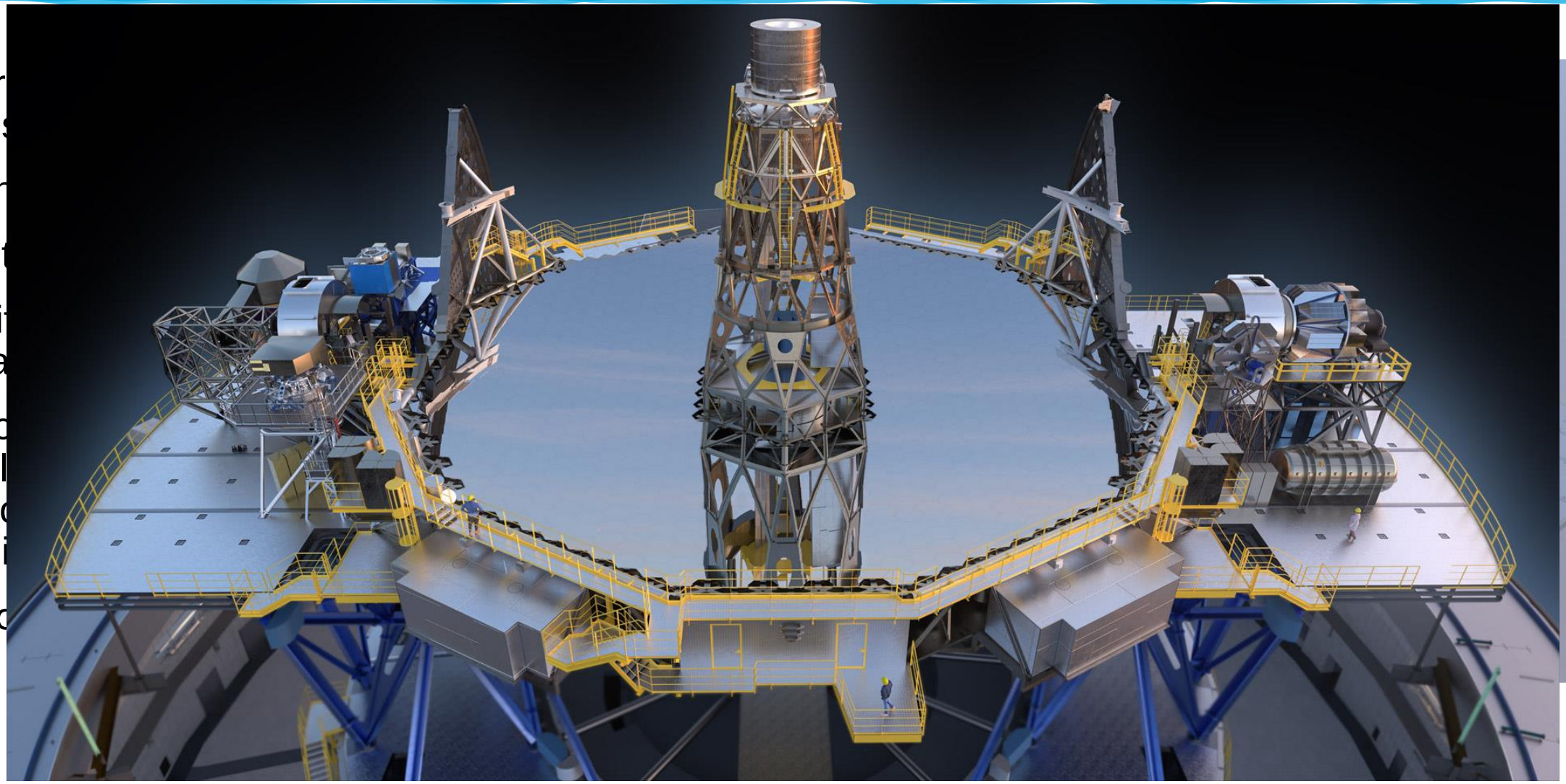
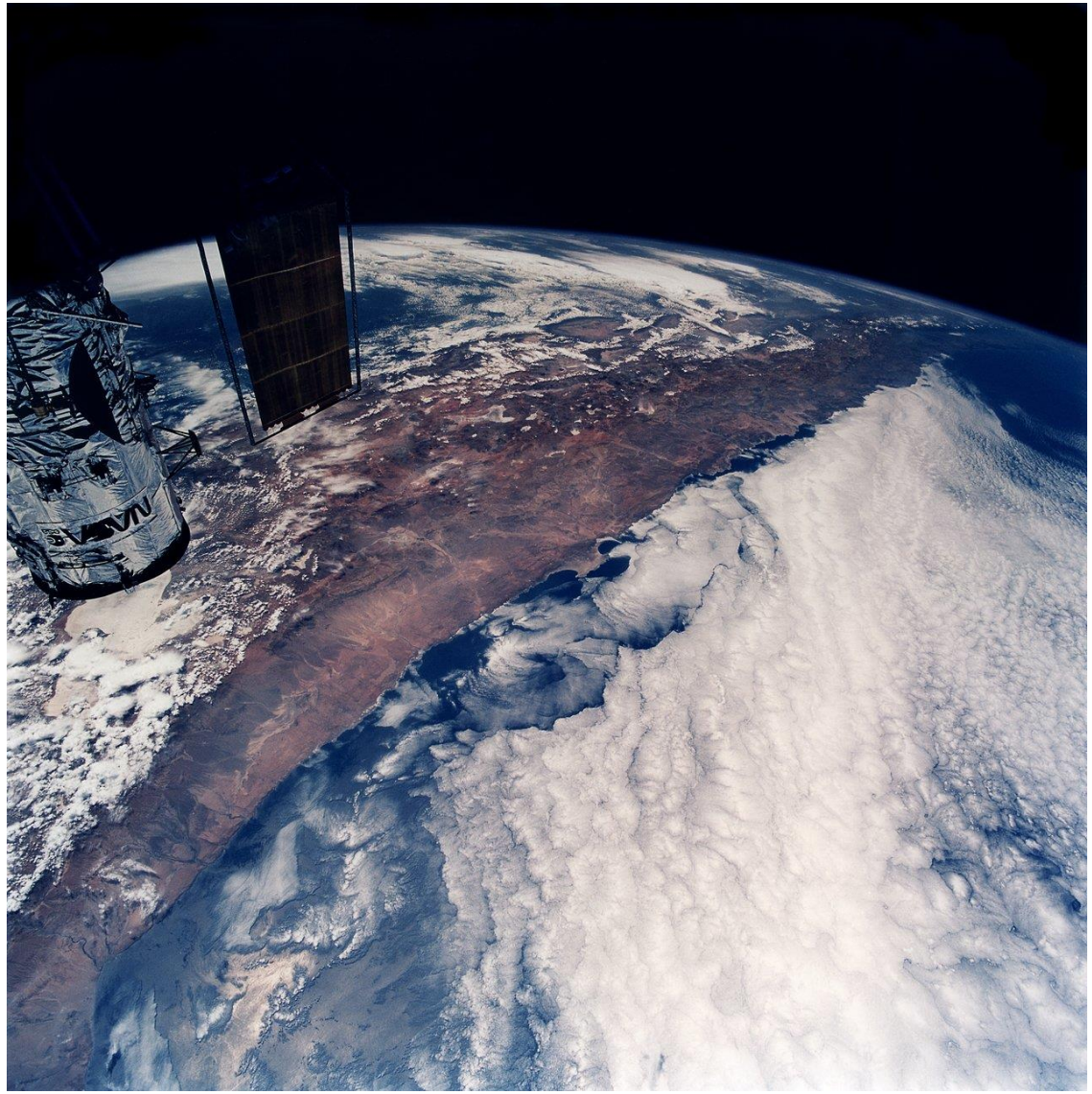
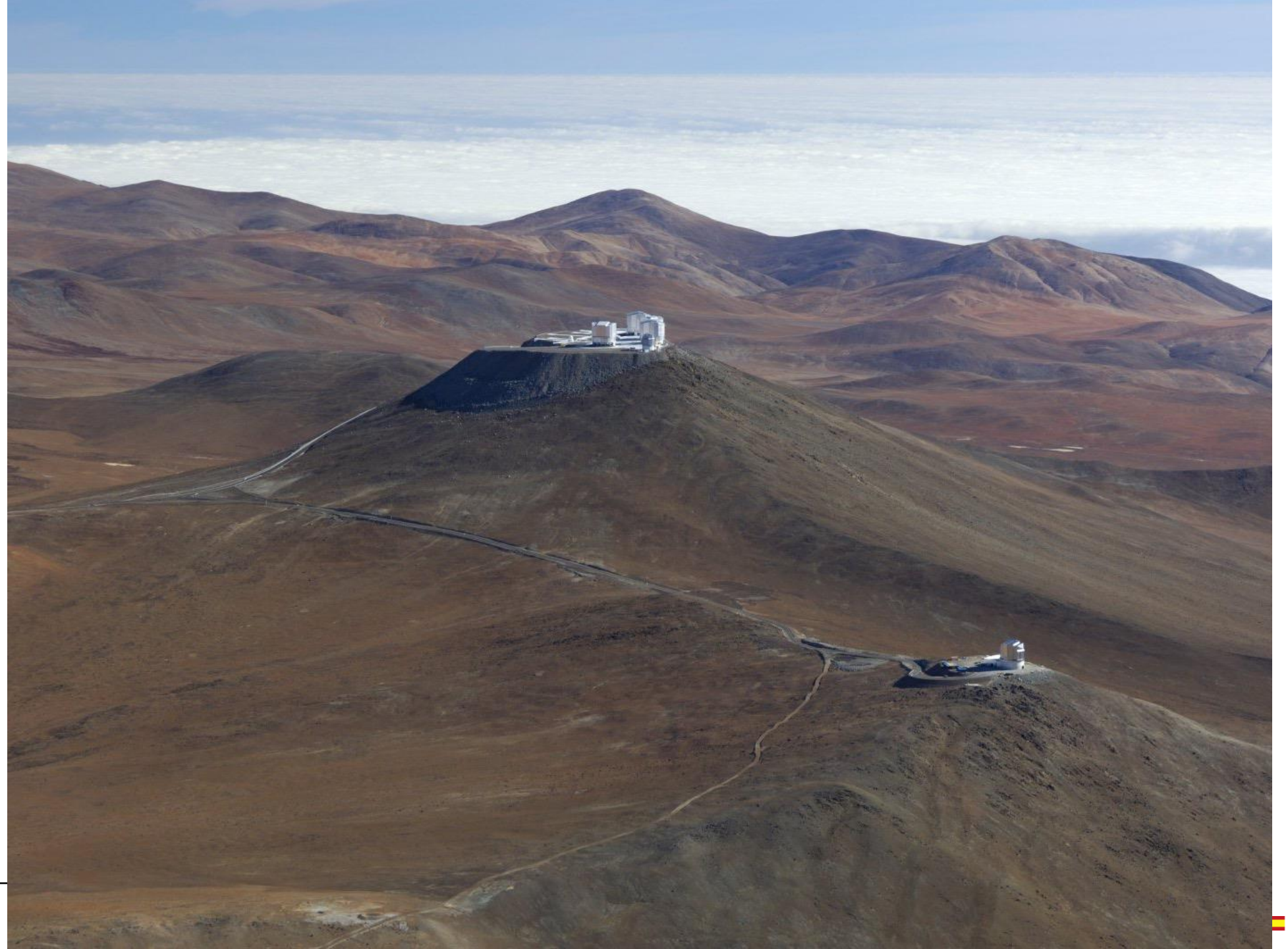


# ESO sites in Chile – why we're there

- VLT on Co Paranal
- Cloud cover: 85% of the nights are clear
- Median PWV: 2.4 mm
- Median seeing: 0.66 arcsec (FWHM); very stable atmosphere
- Wind speed: median 6.6 $ms^{-1}$ (10 m)
- Remote, pristine site, 2635 m asl





# ESO – science operations

- Visitor mode:
  - astronomers come to site & conduct their observations
- Service Mode:
  - astronomers prepare observations at home (not unlike for satellite observatories)
  - user-specific constraints for observing conditions: lunar phase, image quality, water vapour
  - ESO: executes observations using real-time info on atmospheric conditions and forecasts
  - If conditions change for the worse, we will repeat the observations
- Efficiency and enable quantitative science

# Campaign 2024/25 - objectives

Top Level Requirement: Produce a comprehensive data set covering a parameter set suitable for characterising properties of the atmosphere above our existing and future observatory sites. The data need to be relevant for astronomical observations and forecasting with a view to future science operations of the VLT and ELT

1. **Validate existing capabilities:** operate the existing remote sensing equipment at Paranal and Armazones in parallel with the best available balloon-borne radiosondes to validate their performance at the highest precisions possible;
2. **Future capabilities:** operate atmospheric measurement equipment that are planned and\or hold promise for future observatory science operations and make intercomparisons;
3. **Measurements vs models:** validate existing atmospheric and weather forecasting models with respect to the data sets and,
4. **Improve science operations:** explore synergies between measurements and methods with a view to improve science operations and scheduling.

# Campaign 2024/25 – flow down of requirements

1. **Validate existing capabilities:** operate the existing remote sensing equipment at Paranal and Armazones in parallel with the best available balloon-borne radiosondes to validate their performance at the highest precisions possible;

    1. Observations in campaign mode – 2x 10 days/nights – cover seasons
    2. Use best commercially available radiosondes - gold-standard for in-situ atmospheric sensing
    3. Apply additional calibration step to deliver GRUAN data-products
    4. When available use multiple independent measurements of the same parameter to allow for intercomparison
    5. Apply appropriate data analysis to allow intercomparison between in-situ and remote sensing equipment – cf WMO UAII2022
    6. Use established procedures and measurement protocols to limit complexity and minimise risk

# Campaign 2024 – flow down of requirements

2. **Future capabilities:** operate atmospheric measurement equipment that are planned and\or hold promise for future observatory science operations and make intercomparisons;

    1. Cover relevant parameters space with different methods and tools
    2. Establish feasibility of new or emerging methods and tools on a best effort or shared risk basis
    3. Evaluate calibration needs of new equipment to ensure quantitative results
    4. Ensure compatibility of data formats
    5. Require proof of readiness of equipment by partners – ~TRL 7

        - Conscious decision on acceptance if at more experimental level

# ESO – Paranal & Armazones

CTA site in relation to Paranal Observatory and the site of the ELT. Credit: Marc-André Besel, CTAO / ESO

# Campaign 2024 – basics

Sample ~20 km wide slab of atmosphere between our sites

- Radiosondes launched from CTA site ca 2100 m,
- fixed sensors at Paranal 2635 m & Armazones 3046 m, additional sensors on drones
- Ceiling 12 km or higher

10-day radiosonde campaign(s) (cover seasons)

- Ca 20 day & night launches - one or two campaigns 3-6 months apart
- Automated Weather stations 4 sites, Microwave radiometers, LIDAR
- Different lines of sight – 3D view – tomography
- Coordinate with satellite overpasses (tbc)
- GNSS (tbc)

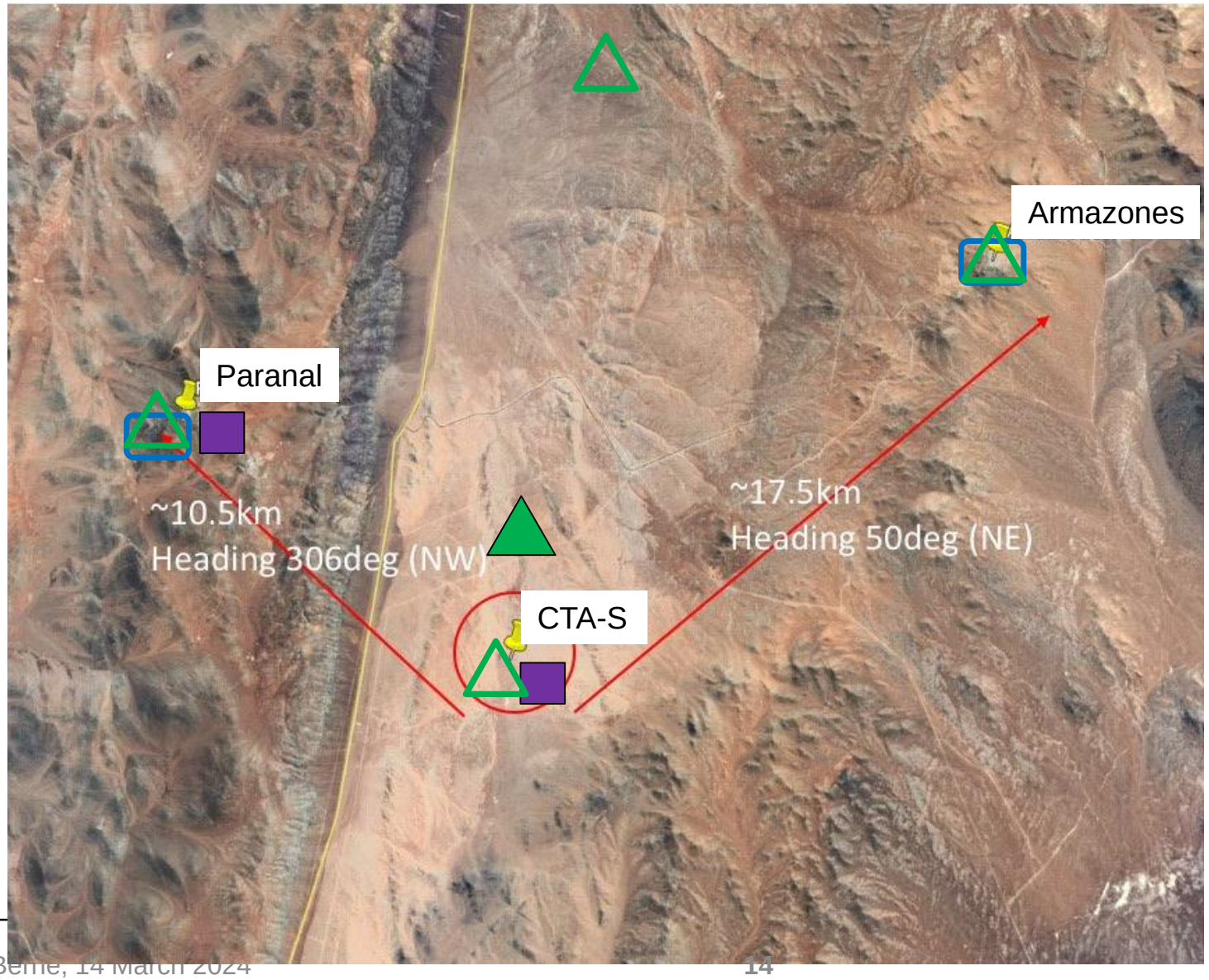
# ESO campaign – possible layout

Meteo-Station

Radiometer

LIDAR

Radiosonde



# Tools and capabilities

- AWS: Temperature, pressure, relative humidity, wind
- All-sky cameras: transparency, clouds, air glow
- MWR: profiles (10 km), Temp, RH, PWV,
- LIDAR: aerosols, water vapour,
- MASS-DIMM: turbulence $C_n^2$ profiles,
- High fidelity local forecast: 24 h at 10-min resolution for 3 days,
  - turbulence - seeing, ground layer fraction and coherence time
  - Meteorological parameters (T, P, RH, Wind Speed & direction)
  - Sky cloud coverage (at 1-hour time resolution)
- Nowcasting (machine learning): 1 h for seeing, PWV

# NIST & CTA

- NIST: spectrometric standard stars - Link to laboratory standard – SI
  - 380 nm – 1000 nm, absolute standard uncertainty of 1%, NIR 2%
  - repeated spectroscopic measurements & simultaneous measurements of the properties of the terrestrial atmosphere along the line of sight
- CTA: Cosmic radiation 20 GeV – 300 TeV - Air showers
  - *Atmosphere is the detector*
  - Ground-based weather stations
  - Profiles T, RH, P, molecular composition (radiosondes, MVR)
  - Cloud detection (all-sky cameras), aerosols (Raman LIDAR)

# Campaign 2024/25 – update

- ESO funding for 2024 & 2025 allocated as requested
- Visit on site Nov/Dec 2023

# Campaign 2024/25 – update

- Interaction with vendors and commercial partners
  - Offer for standard humidity chamber received – procurement Q2 2024
  - Interaction with Vaisala: radiosondes and wind LIDAR – offer received
  - Interaction with Windsonde – swarm of radiosondes – pricing available, further interaction needed
  - Interaction with Meteomatics for meteodrone
- Interaction with Univ Bern: A. Murk – Ozone measurements
  - VLT data – correlation, application for CUBES (new UV spectrograph – 2026)
  - Radiometer for campaign or extended period - visit Berne 15 March 2024
- ELT WG Astroweather – presentation of status – 25 March 2024

# Campaign 2024/25 – update

- Interaction with academic partners - Chile
  - Universidad La Frontera – sensors on drone – experimental run comparison with ESO meteotower - Nov 2023 – agreement – details to be discussed
  - Universidad de Chile: potential contributions: drone, LIDAR, tethered balloon – clear interest but further discussion needed
- Main Issues:
  - Site infrastructure – CTA schedule - security
  - Funding cycles of partners
  - Readiness of contributions
  - Logistics and complexity
  - Planning of data analysis and science exploitation – science advisory committee

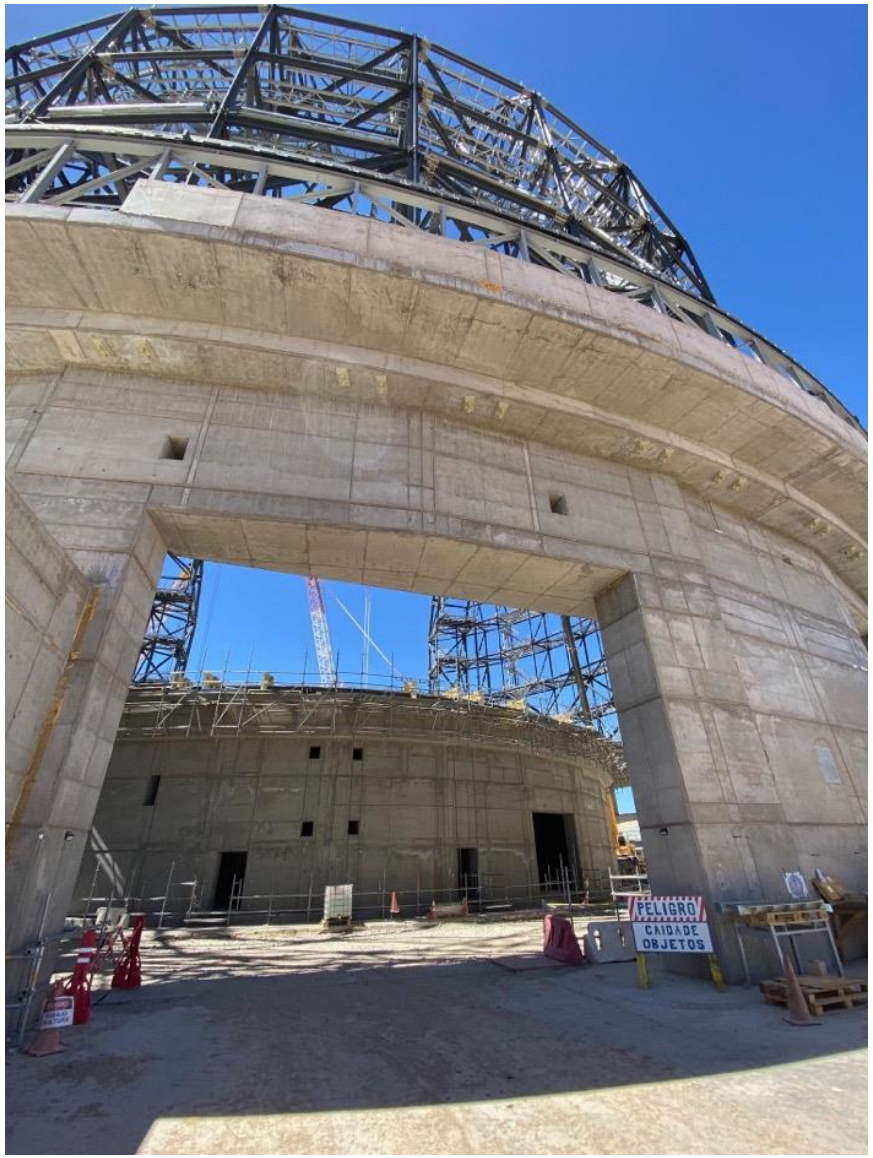
# Summary and next steps

- ESO funding secured for 2024 & 2025
- CTA and NIST as partners – additional funding confirmed
- Commercial partners & vendors – on-going interaction - procurement Q2 & Q3
- Check of complexity, required logistics and procedures
- Request technical time – ESO observatories April 2024
- Iterate with partners and finish project plan - end of April 2024
- Establish schedule based on input from suppliers and partners - Q2 2024
- Proper plan for data analysis and exploitation – Q3/4 2024
- Campaigns: Full moon: 12 April & May – 7 Sep & 6 Oct 2025

# ESO and GRUAN

- Let me thank you for the support given so far – MeteoSwiss and DWD
- GSRN – ground-based equipment – Chile interest in pilot phase
- GRUAN – remote sensing and GDPs: radiosondes, MWR, LIDAR, GNSS, Ozone
  - relevant for campaign and beyond
  - Scarcity of sites in the Southern Hemisphere
- Distributed site – collaboration with MeteoChile
  - Closest radiosonde launch site in Antofagasta: ~120 km distant
  - Standard humidity chamber
- Request: better understand requirements for a GRUAN site

# Paranal & Armazones



# Paranal & Armazones

# Thank you!

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