

Concept of a campaign of atmospheric characterization at ESO sites in Northern Chile

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European Southern Observatory

■ Intergovernmental organisation established in 1962

➤ Access to Southern skies and the Galactic Centre

■ 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.



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- Values
 - ESO strives for **excellence** through **innovation**.
 - ESO provides outstanding **services to its communities**.
 - ESO fosters **diversity & inclusion**.
 - ESO believes in the key role of **sustainability** for its future.

■ 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)

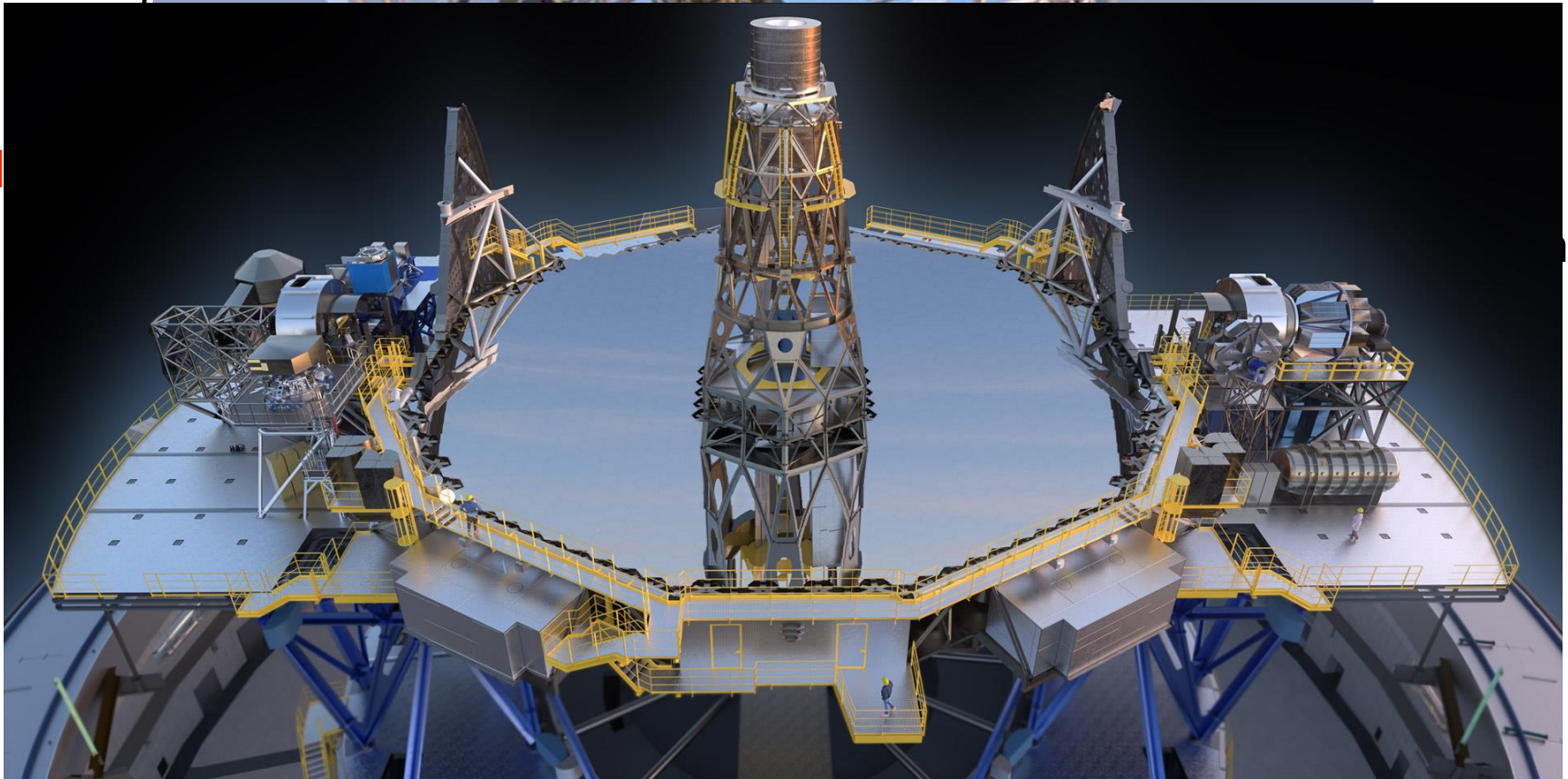
- Primary mirror: 39 m diameter, 798 segments, shape: few 10s of nm
- Enclosure: 88 m diameter, 80 m tall, rotating mass 6100 t
- Site: Cerro Armazones: 3046 m asl, 23 km from VLT
- Diffraction limited imaging: adaptive optics and laser guide stars
- Science: design reference mission – solar system, extra-solar planets, resolved stellar population and galaxy evolution, first stars, black holes, expansion of the universe, cosmology and dark matter
- Construction budget: €1.3 billion, technical 1st light 2027

■ Mission

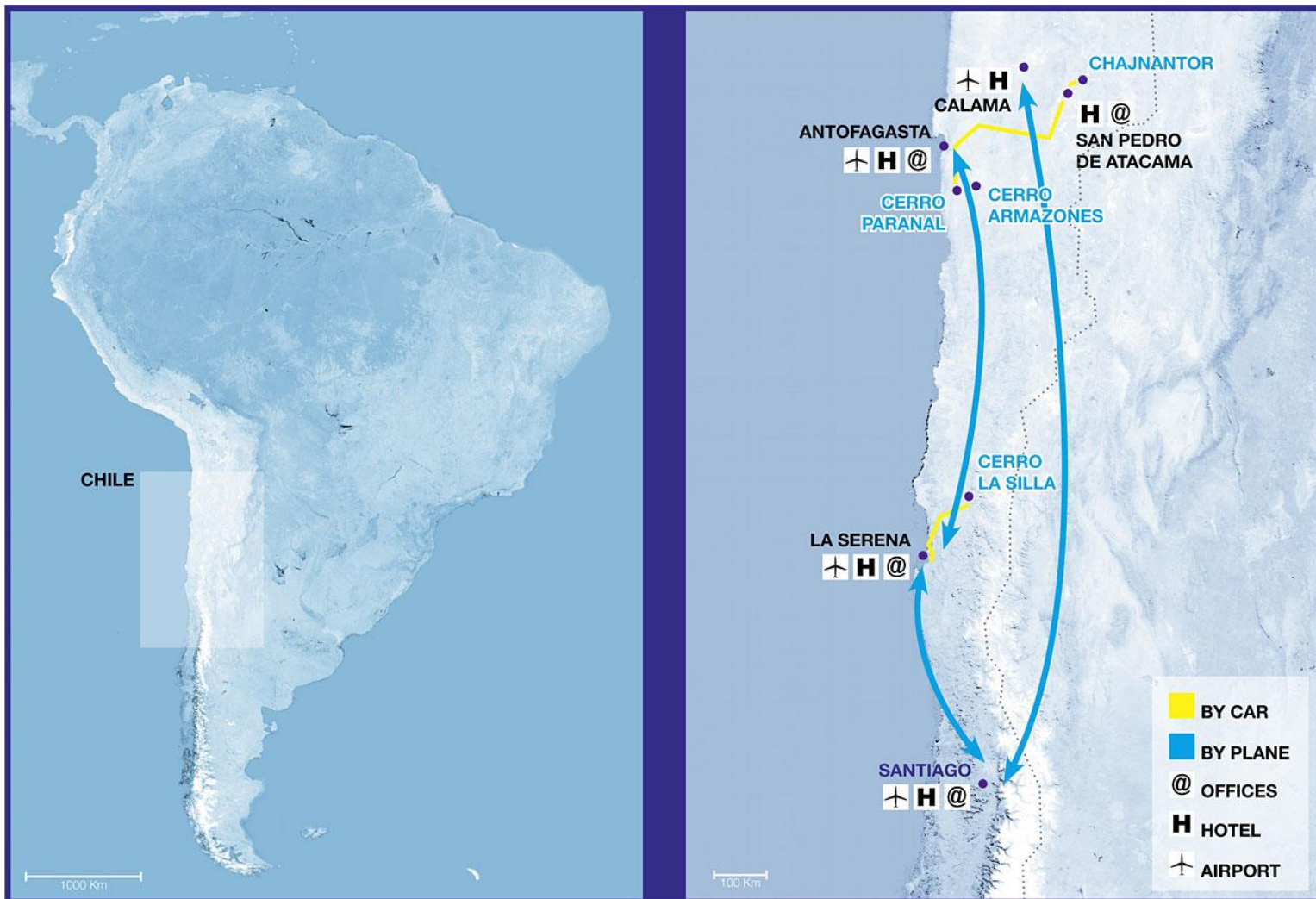
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operating
beyond the



ESO sites in Chile



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

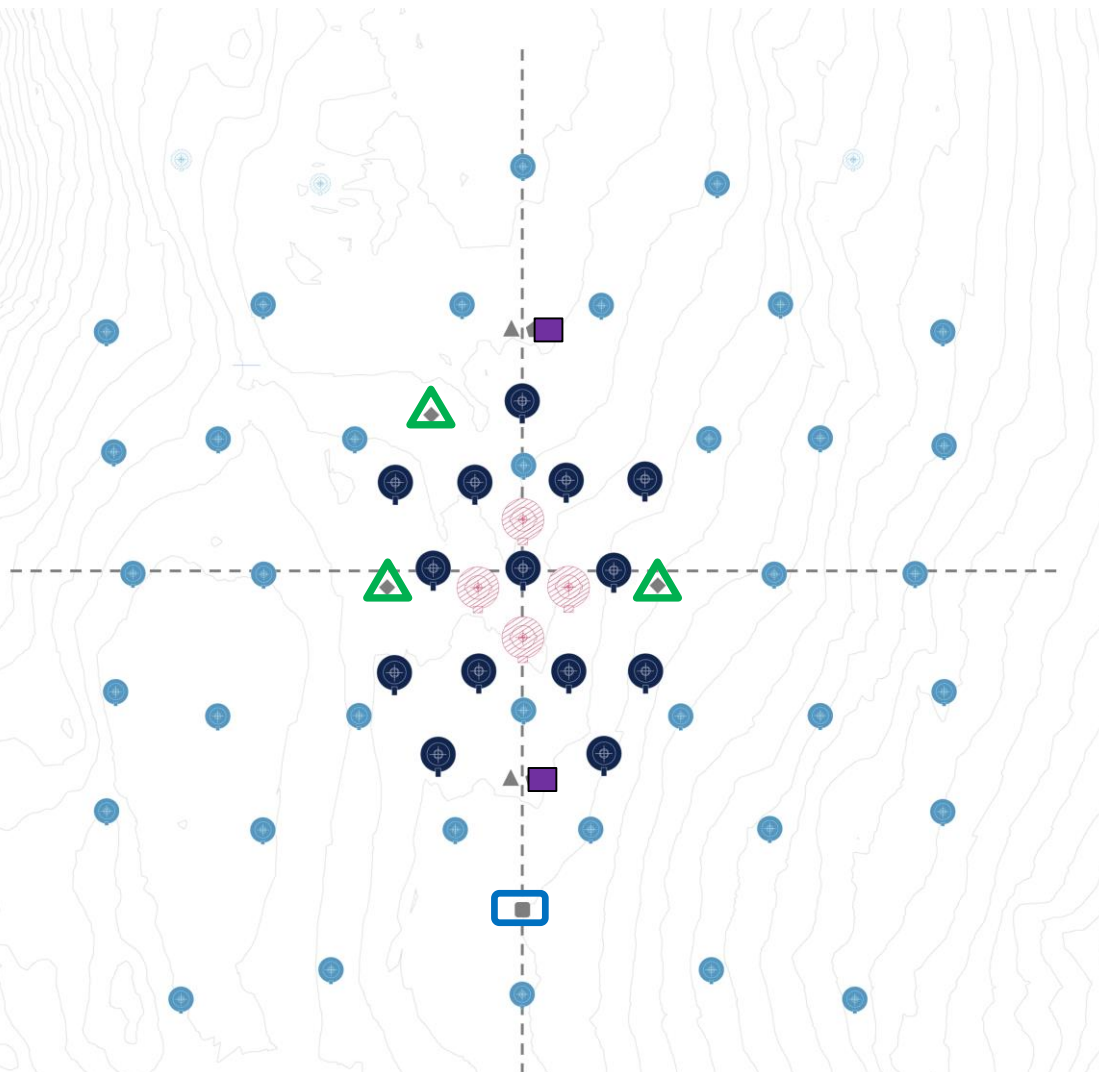
■ Service Mode:

- astronomers prepare observations at home (not unlike for satellite observatories)
- user-specific constraints for observing conditions: lunar phase, Seeing (image quality), water vapour
- ESO staff executes observations using real-time information on atmospheric conditions and forecasts
- If conditions change for the worse, we will repeat the observations

Cerenkov Telescope Array CTA

- Cosmic radiation 20 GeV – 300 TeV
- Air showers (several 10 km) – *atmosphere is detector*
- 2 arrays: North (La Palma), South (Paranal)
 - N: 4 large (45 m), 9 medium size telescopes: 0.25 km²
 - S: 14 medium, 37 small-size (8 m) telescopes: 3 km²
 - Start operations 2025/26, cta-observatory.org
- Ultrafast response: telescopes and detectors
 - Up to 4 ns sampling, 300 – 600 nm,
- Needs in terms of atmospheric information
 - Profiles of temperature, humidity, pressure, molecular composition (radiosondes, MVR)
 - Cloud detection (all-sky cameras), aerosols (Raman LIDAR)
 - Ground-based weather stations

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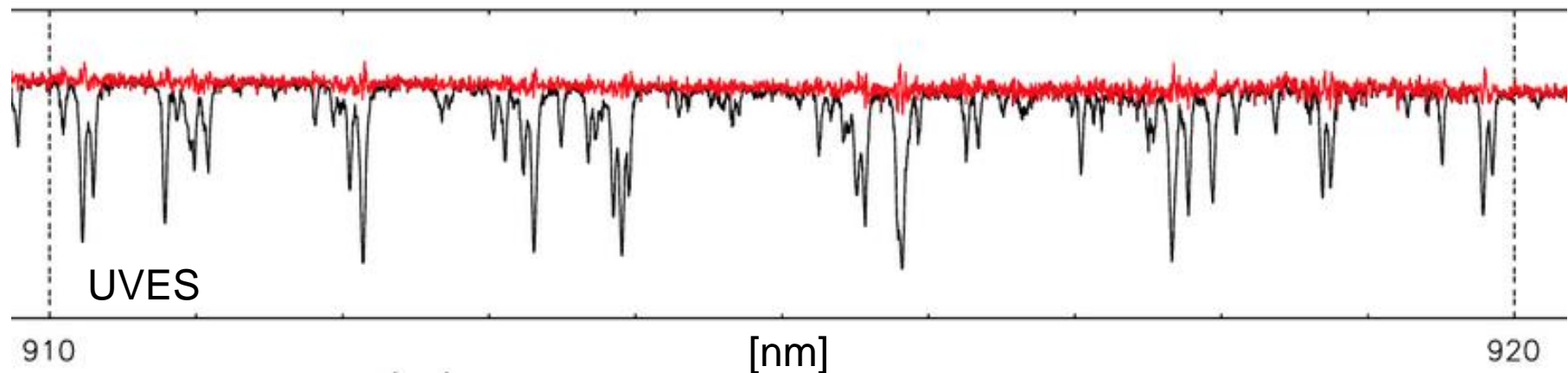
LEGEND	
Medium-Sized Telescope (MST)	
Small-Sized Telescope (SST)	
Large-Sized Telescope (LST)	
Foundation	
SST Foundation	
Weather Station	
Stellar Photometer	
Raman LIDAR	
Other Calibration Devices	

Use of our measurements

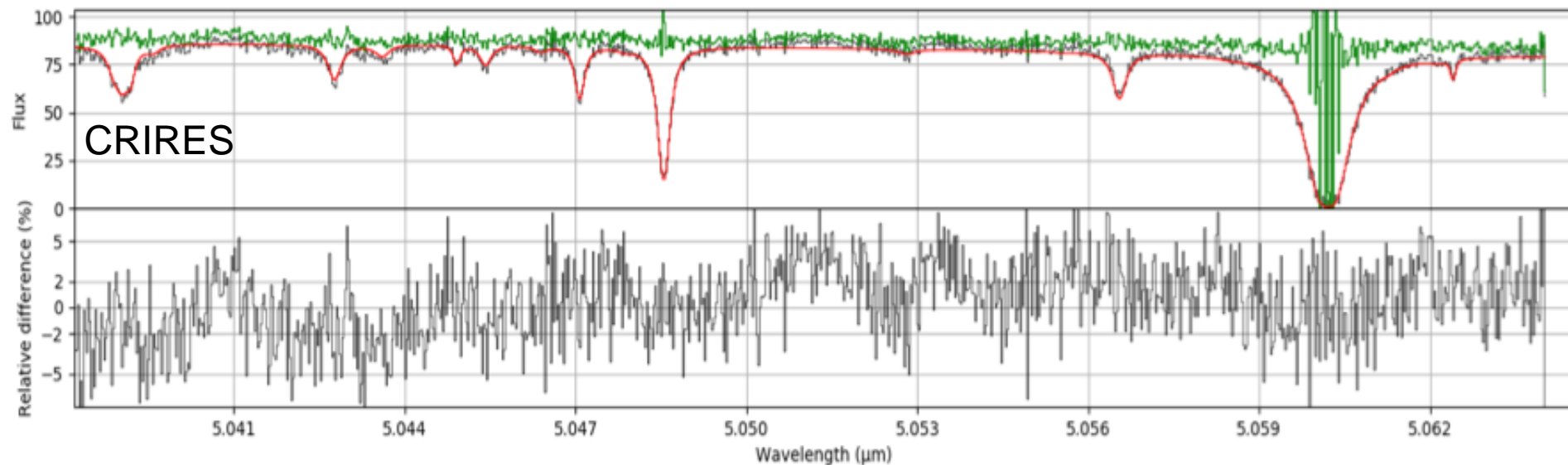
- Real-time use – scheduling next hour
 - Match atmospheric status with needs of astronomical observations – user-specified constraints
 - Select what to observe, switch instrument if needed
- Medium time - Scheduling next 72 h - planned
- Post-processing - *molecfit*
 - Correction of telluric features in astronomical spectra
 - <https://www.eso.org/sci/software/pipelines/skytools/molecfit>
- Better understanding atmospheric properties relevant for astronomy >> ELT, CTA
 - Angel Otárola, Atmosphere Scientist at ESO

Use of our measurements

■ *Molecfit* - temperature and humidity profiles LHATPRO



file: M.CRIRES.2014-01-21T13:09:33.218.fits DATE-OBS: 2014-01-20T05:35:56.5255 Instrument: CRIRES
H2O: 2.9100e+00 mm Reduced chi2: 8.8



Use of our measurements

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Campaign 2024 - requirements

- Produce comprehensive data set for characterising properties of the atmosphere relevant for astronomical observations and forecasting
 - Seeing (integral of atmospheric turbulence – Kolmogorov), coherence time, isoplanatic angle
 - Turbulence surface layer c_n^2 , outer scale
 - Humidity, temperature, pressure, wind speed, direction, – surface and up to 30/40 m, altitude-resolved profiles
 - Transparency, aerosol content, cloud detection, all-sky maps
 - PWV, IR sky brightness, air glow
- by
 - Combining in-situ measurements (RS and UAV) and remote sensing
 - Bring communities together: astro, fore/nowcasting, modelling

Campaign 2024 - requirements

- Produce GRUAN data products for reference and comparison
 - Fully understand requirements, framework >> way forward
 - GRUAN data products for MW radiometers in progress
- Data analysis combining in-situ (radiosondes/UAV) and remote sensing
 - How to do this best ? - cf WMO UAI2022
- High fidelity local short-term forecast
 - Real-time and post facto
- Produce comprehensive data set that is also relevant for meteorological (modelling & forecasting) and climate communities – hyper-arid site in Northern Chile





ESO – Paranal & Armazones

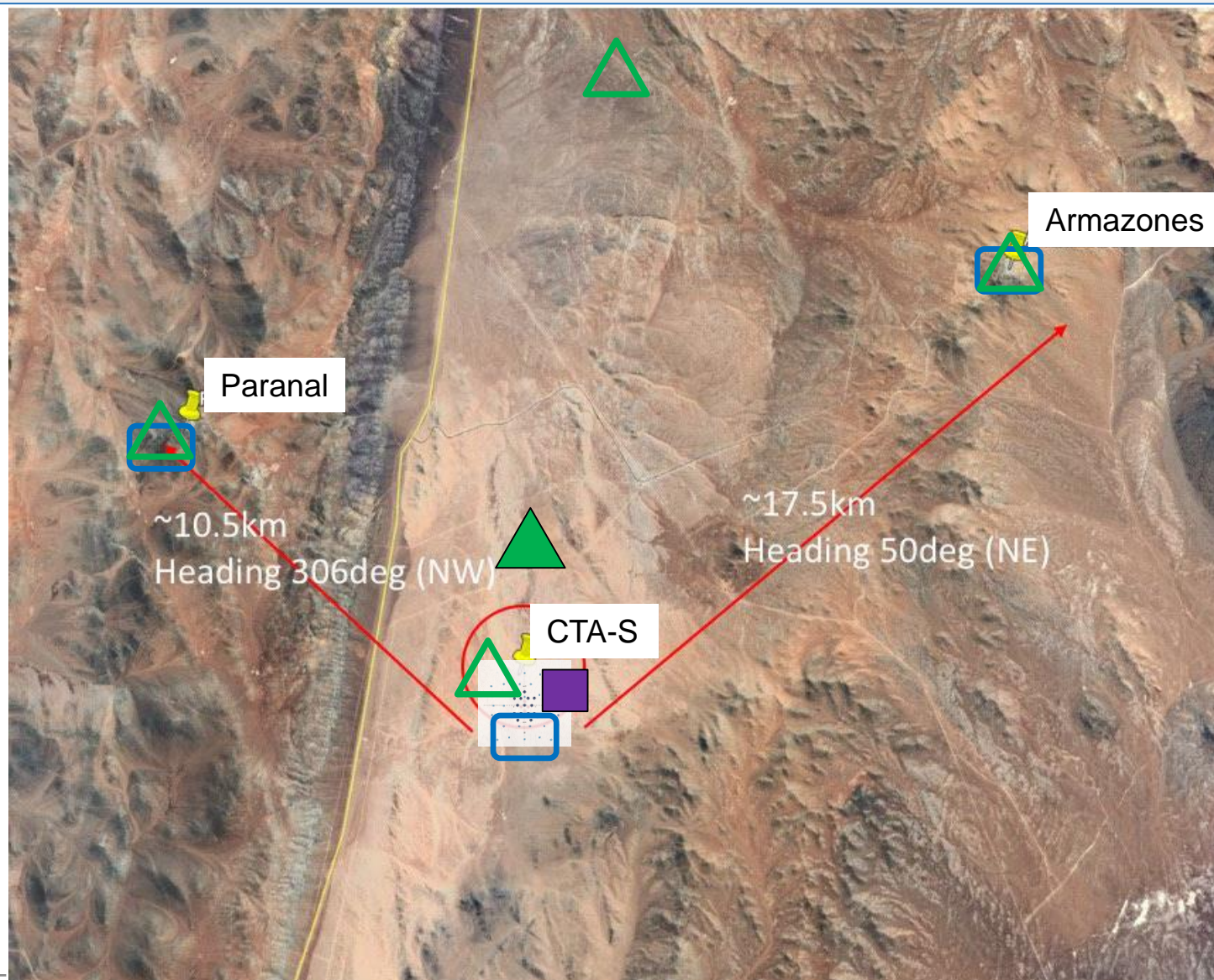


Campaign 2024 – concept basics

- 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 (tbc)
 - Ceiling 12 km or higher
- 10-day radiosonde campaign(s) (cover seasons)
 - Ca 20 day & night launches - one or two campaign 6 months apart
 - Option: twin launches for reproducibility, CFH for reference
- Ground-based and remote sensing – airport model
 - Automated Weather stations 4 sites, Microwave radiometers, LIDAR
 - Different lines of sight – 3D view – tomography
 - GNSS (tbd)

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
 - non-hydrostatic numerical model, 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)
 - From day 4th, and up to 10 days: simpler 1-hour time resolution forecast of atmospheric parameters (T, P, RH, WS, WD and Cloud Coverage).
 - Nowcasting (machine learning): 1 h for seeing, PWV

Campaign 2024 – invitation

- Create value for the communities – join us
 - We solicit input to developing details of campaign
 - Invitation to interested partners to participate
 - Provide additional sensors/equipment, also experimental ones
 - Coordinate radiosonde launches with satellite overpass ?
 - Local GNSS network ? Historical data in preparation ?
 - New CFH without RS23 ? Ceiling: helium vs hydrogen ?
 - Exploit data set for models and now- & forecasting
 - Produce GRUAN data products
 - Antofagasta radiosonde archive
 - ESO to provide logistics on-site and support with customs
 - Trained technicians, power, internet, technical facilities, accommodation
 - Outcome will be incorporated in planning for science operations of the ELT and CTA

Summary and next steps

- Reaching out to community
 - CTA and NIST as partners
- Visit in Lindenberg (DWD) and Payerne (MeteoSwiss)
- Invitation – Letter of Interest Q2 2023
- Detailed planning through Q3 2023
- ESO internal decision end 2023
- Preparation of logistics etc
- Campaign 2024/25