アルマの運用保全10年から見えてきた課題と今後の大型望遠鏡、観測所の保守のあり方について

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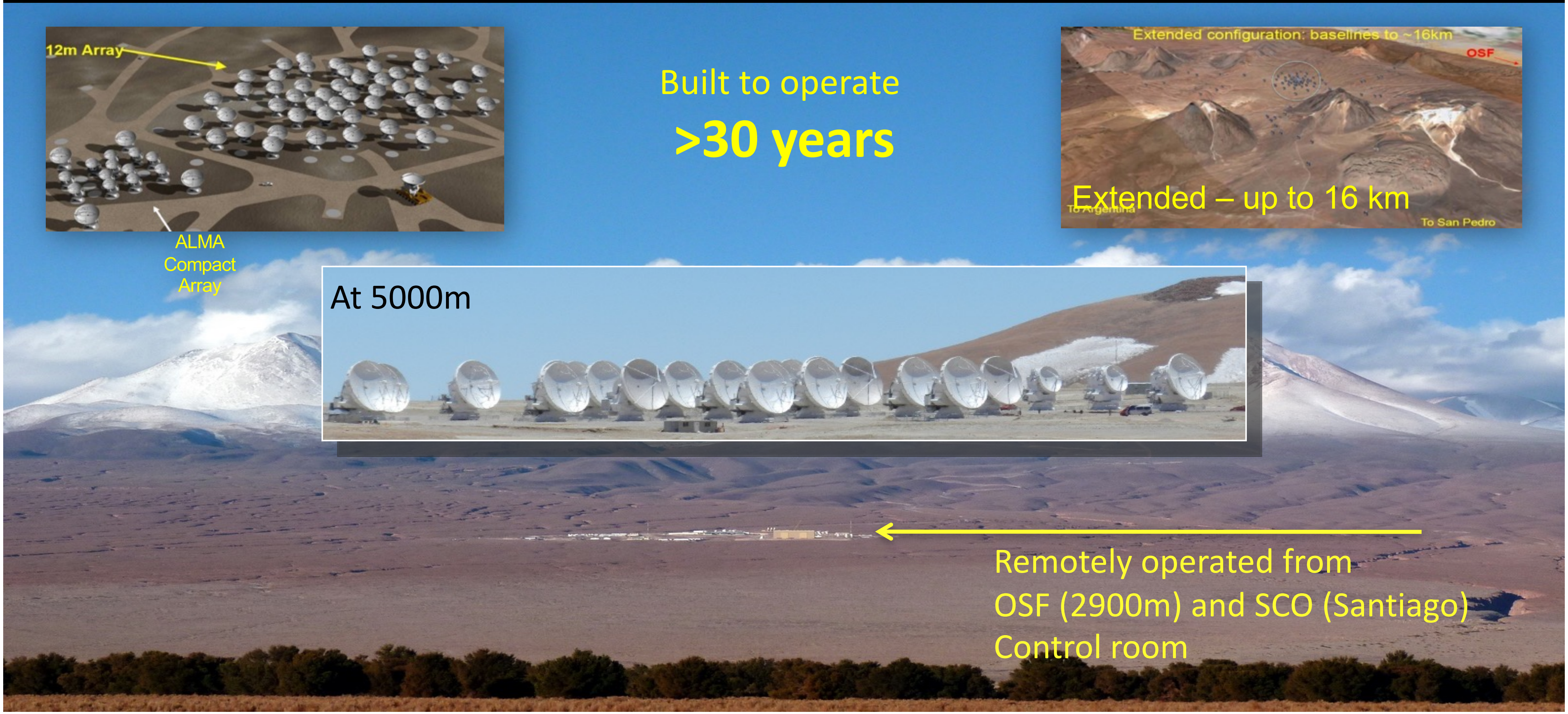
The 42nd Symposium on Engineering in Astronomy

本日の内容

- ALMA望遠鏡の運用、保守範囲
- ALMAの運用における保守マネージメントの問題
  - ４つの課題
- ALMAの目指す次世代の保全体制（戦略と取り組み）
  - 産業界の手法の導入、データに基づく意思決定
- 国立天文台の運用、保守体制は今後、どうあるべきか？

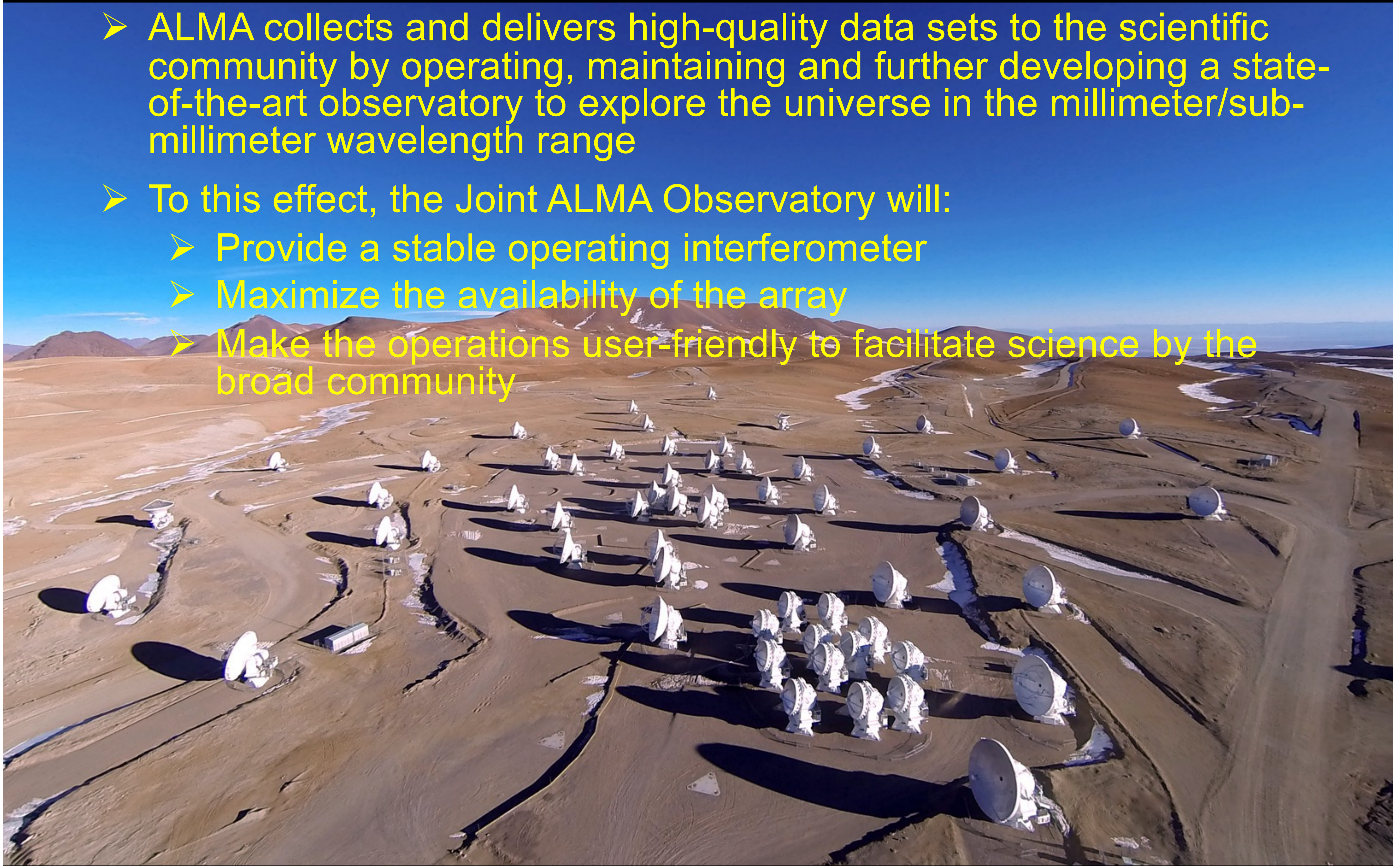
ALMA

An array of **66 antennas,**
using *aperture synthesis*, *as a* "zoom telescope"
over the *entire accessible mm/submm* wavelength range up to 1 THz



Mission Statement of ALMA

- ALMA collects and delivers high-quality data sets to the scientific community by operating, maintaining and further developing a state-of-the-art observatory to explore the universe in the millimeter/sub-millimeter wavelength range
- To this effect, the Joint ALMA Observatory will:
  - Provide a stable operating interferometer
  - Maximize the availability of the array
  - Make the operations user-friendly to facilitate science by the broad community



ALMA Key Technical Requirements

These are derived from the science goals based on the choice of an interferometer

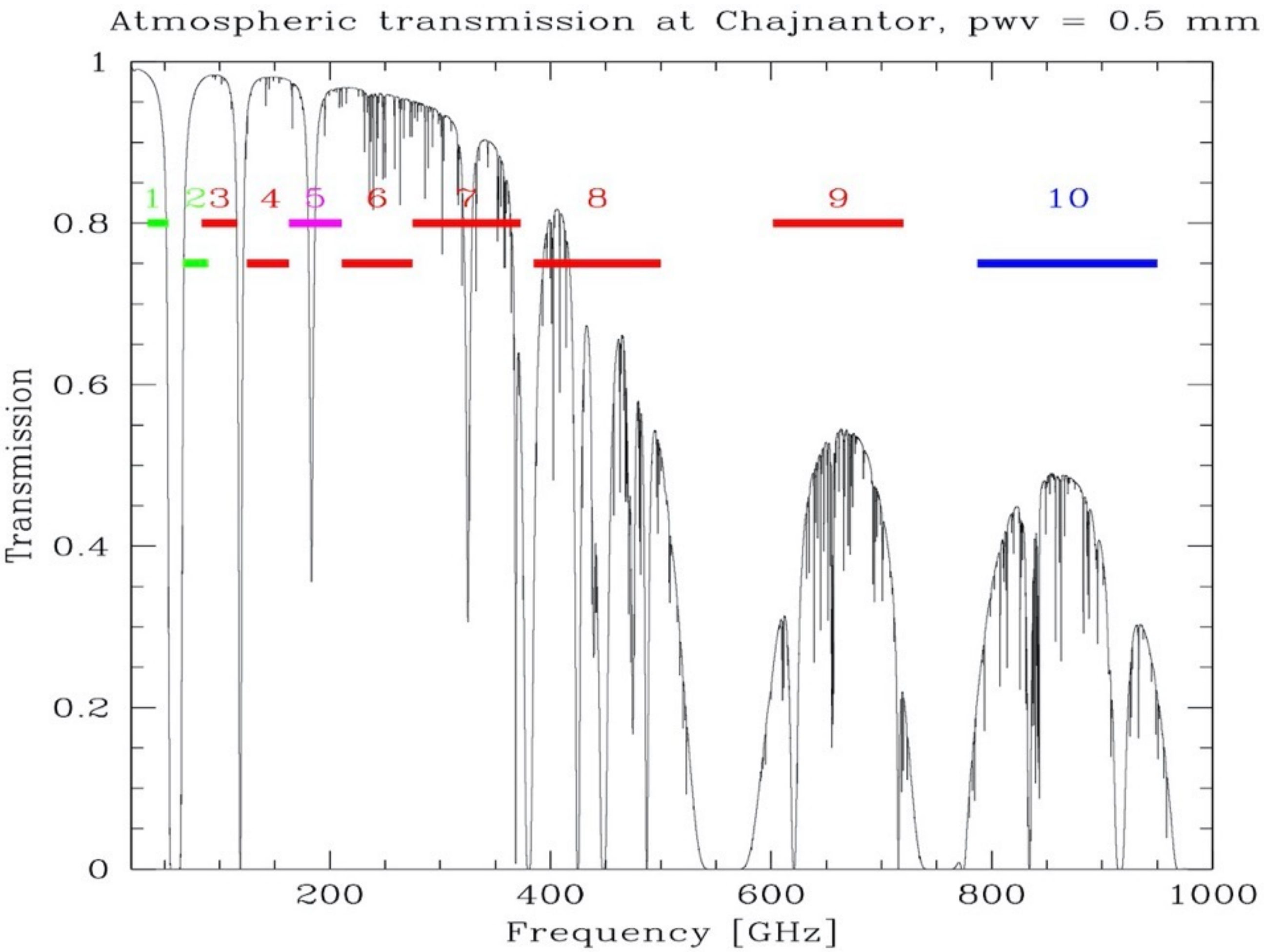
Characteristic	**12m array**	**Morita Array or ALMA Compact Array - ACA**	
Number of antennas	50	12	4
Antenna diameter	12m	7m	12m
Total collecting area	5655m^2	462m^2	452m^2
Surface accuracy	25μm	20μm	25μm
Number of antenna stations	175	18	4
Maximum baseline	15.5km	44m	-
Minimum baseline	14m	8m	-
Angular resolution §	0.015”·λ	5”·λ	-
Correlator inputs	64	16	
Bandwidth per polarisation	8GHz	8GHz	
Spectral channels	32768	32768	
Frequency coverage *	35 – 950GHz	35 – 950GHz	

§ λ is wavelength in mm.

* The lower frequency limit has been revised from its original value of 31.3GHz.

ALMA Bands and Atmospheric Transmission

Band	Coverage	Status
1	35-50 GHz	Integration on-going
2	70-90 GHz	In development
3	84-116 GHz	Operational
4	125-163 GHz	Operational
5	163-211 GHz	Completion May 2017
6	211-275 GHz	Operational
7	275-370 GHz	Operational
8	385-500 GHz	Operational
9	602-720 GHz	Operational
10	787-950 GHz	Operational



Overview of the ALMA site

Array Operation Site – 5000 m asl

- 66 antenna array
- 192 antenna stations
- Technical Building with critical systems

Operation Support Facility – 2900 m asl

- Control room for operating the array
- 7000 m² offices, laboratories, workshops & warehouse facilities
- Accommodation for ~200 operations staff
  - 120 room residencia + cabañas
- 7 MW power station & utilities

Plus

- 140 km of private roads
- Power distribution system with 180 km of MV power lines and substations

Antenna & Transporter


Antenna mass: 100 t
Transporter + antenna: ~250 t
Max speed: 6 km/h

Diameter: 12 m & 7 m
Pointing accuracy: 2 arcsec
Location repeatability: 100 µm

ALMA Antennas

	EA 12m (x4)	EA 7m (x12)	EU 12m (x25)	NA 12m (x25)
Vendor	MELCO	MELCO	AEM	Vertex
Main ref. Panel	Al casting	Al casting	Ni honeycomb	Al casting
Main. Ref Bus	CFRP Truss	Steel Truss	CFRP Box	CFRP Box
Receiver Cabin	Steel	Steel	CFRP	Steel
Drive System	Direct drive	Direct drive	Direct Drive	Gear Drive
Metrology	Ref. frame	Ref. frame	Thermocouple	Tiltmeter, linear gauge


JLG LIFT
JLG LIFT

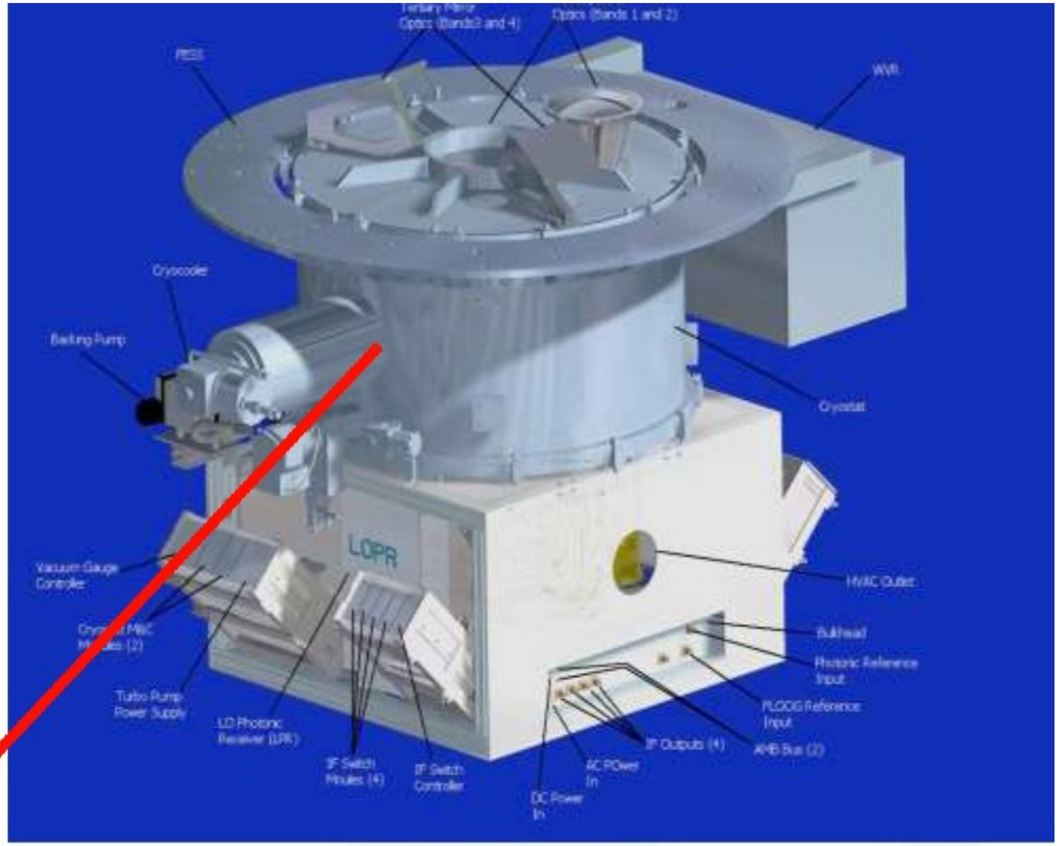
Array Configurations

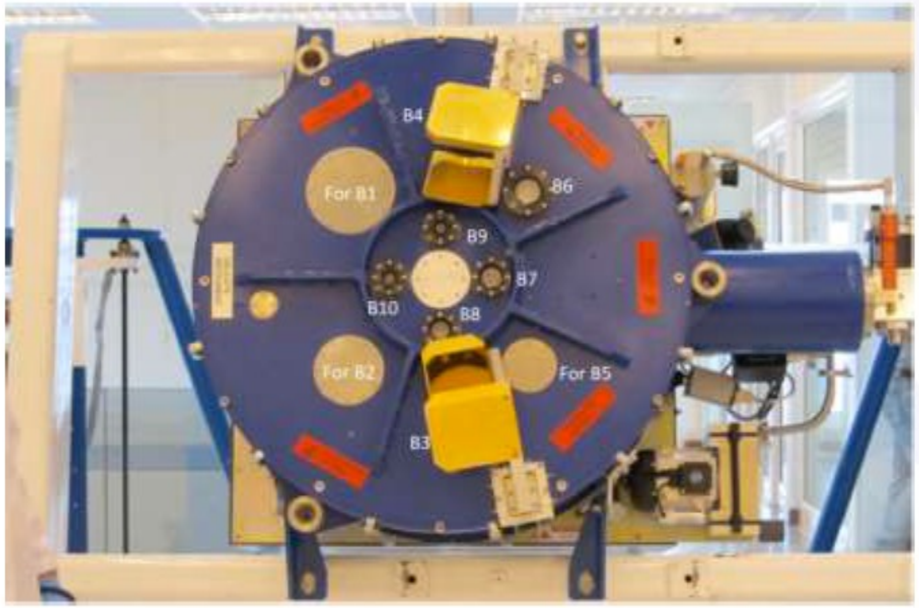
- Around 10 different array configurations using ~170 antenna stations are defined giving the astronomers different image resolutions and sizes
  - Works like a zoom-lens
- Each configuration is optimised for imaging quality at a specified resolution
- Measurements from different configurations are combined to improve image quality
- The overall configuration of antenna stations has been optimised within the constraints imposed by the topology of the site
- In operations the antennas are moved periodically through all the configurations every two years
  - 200 antenna moves per year.

Antenna Relocation

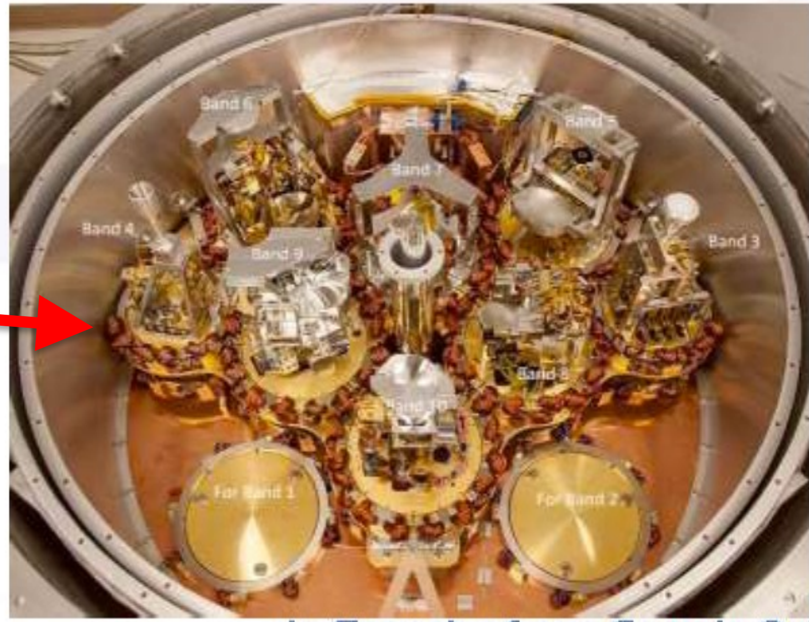
ALMA FE System

- The ALMA Front End system is a low-noise cryogenically-cooled 10-band receiver from 30 GHz to 950 GHz in one cryostat





4K

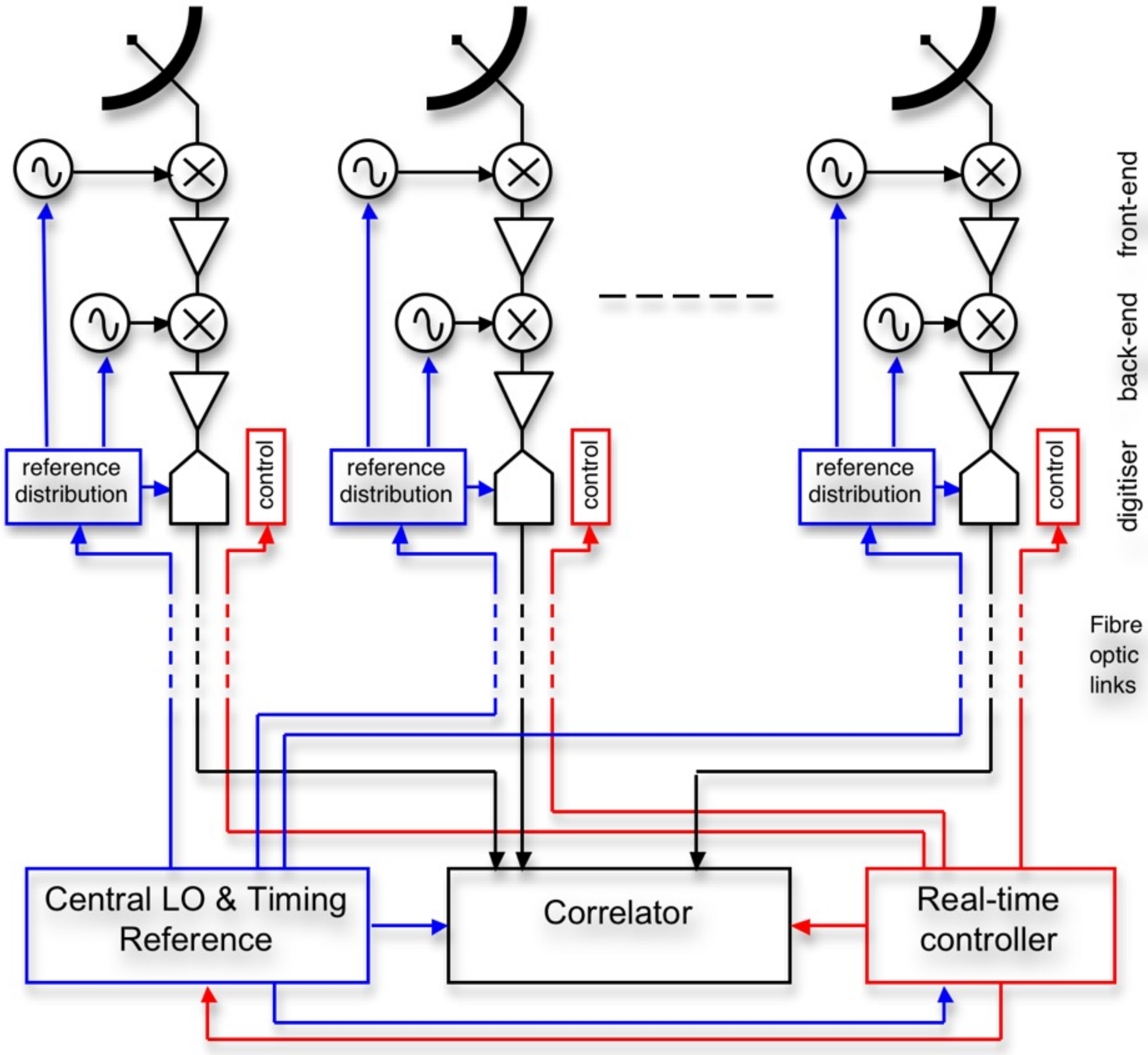



FESV 1

Schematic Diagram of the ALMA

Antennas in
the Array

Elements in the
Technical building



How is ALMA Operating

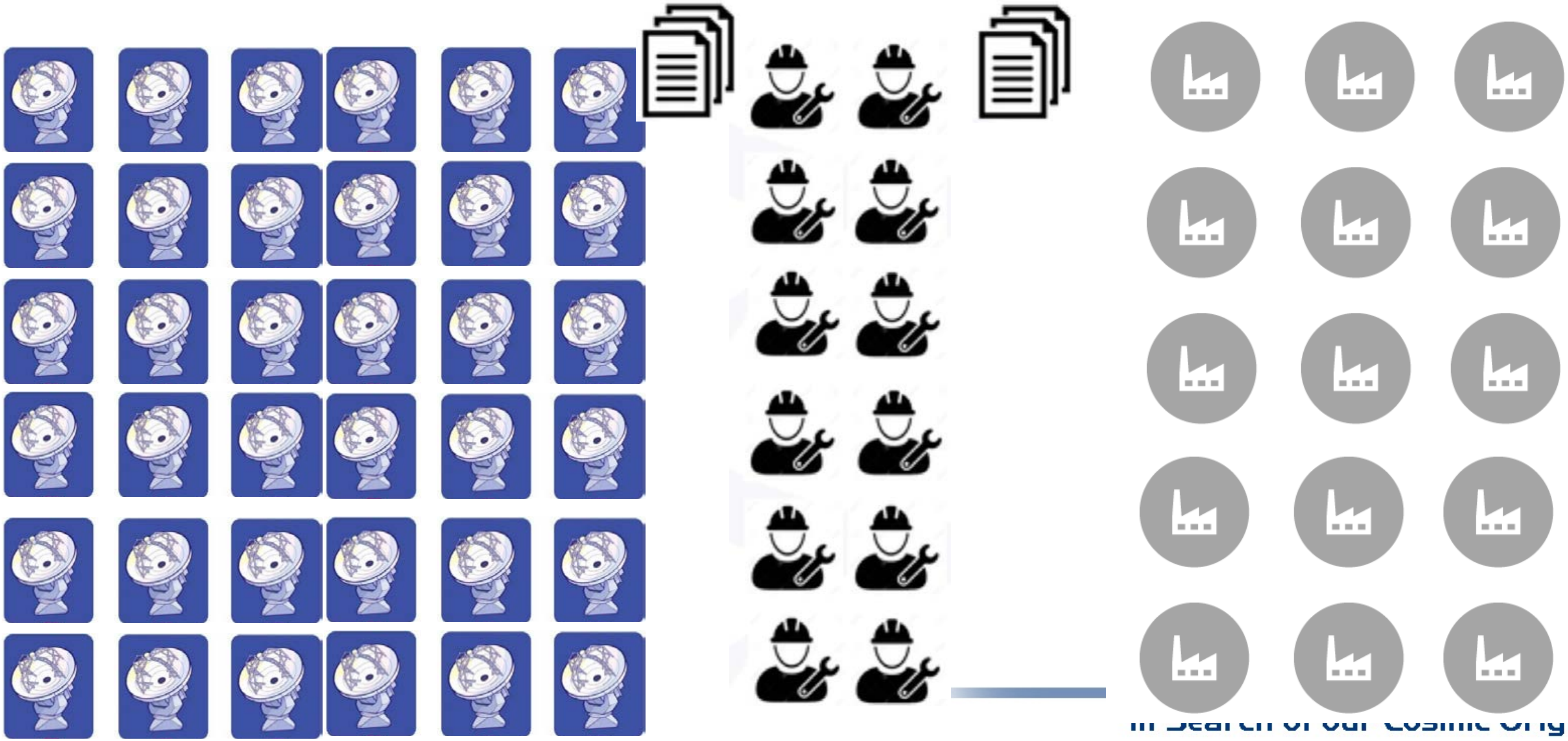
- 24-hr Science Operations:
  - Maintenance activities as possible within the antenna availability boundaries
- 20-hr Science Operations (Computing Test Time 1300-1700):
  - At least once a week
  - Testing window in poorer phase stability period
  - Maintenance activities as possible within variable requirements
- 16-hr Science Operations (Engineering Test Time 0900-1700):
  - At least once a week
  - Major technical interventions (e.g., Correlators, HVAC, etc.)
  - Maintenance activities have priority

Observatory Operations Management

- Science observations and related calibrations
- Maintenance activities (infrastructure, hardware and software)
- Commissioning and/or validation tests of new hardware and software
- Upgrades and/or the incorporation of new capabilities/instrumentation
- **Data quality assurance, processing and delivery**
- **Operations and maintenance planning**
- **Logistics and warehouse management**
- **Performance monitoring**
- **Problem reporting and tracking**

Scale factor change

In recent, large facilities, the number of telescopes or major elements/subsystems (e.g. antennas, instruments, mirror segments, etc.) is steadily increasing, meaning that the **scale factor** became much more relevant at time of preparing and executing operations.



Maintenance is a key to higher reliability

- Maintenance is usually considered as a cost-centre or necessary evil.

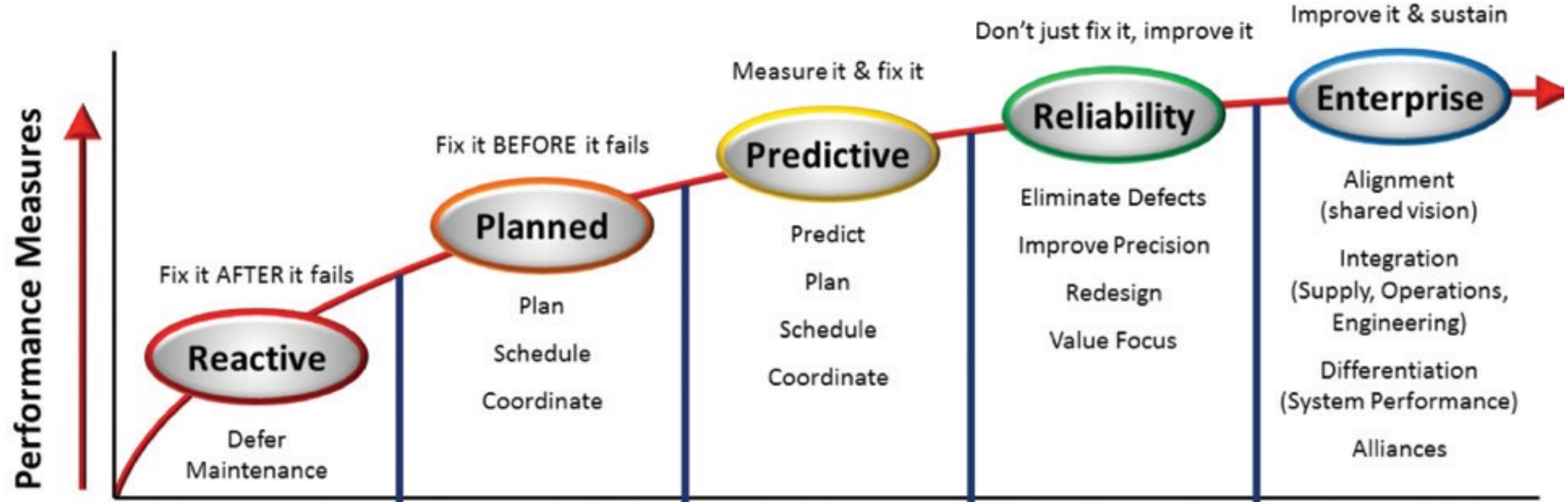
- Of course, we must aim to reduce maintenance costs. But we must remember that maintenance impacts the Observatory output (Data quality and productivity) and Safety (and Environment).

- Usually, this doesn't happen immediately. There is a time lag.

- ALMA is trying to **drive maintenance costs down** by:

  - increasing productivity through effective work management;
  - improving our preventive maintenance programs;
  - Eliminating defects;
  - and ultimately by real leadership

Where are we now ? Where we go ?

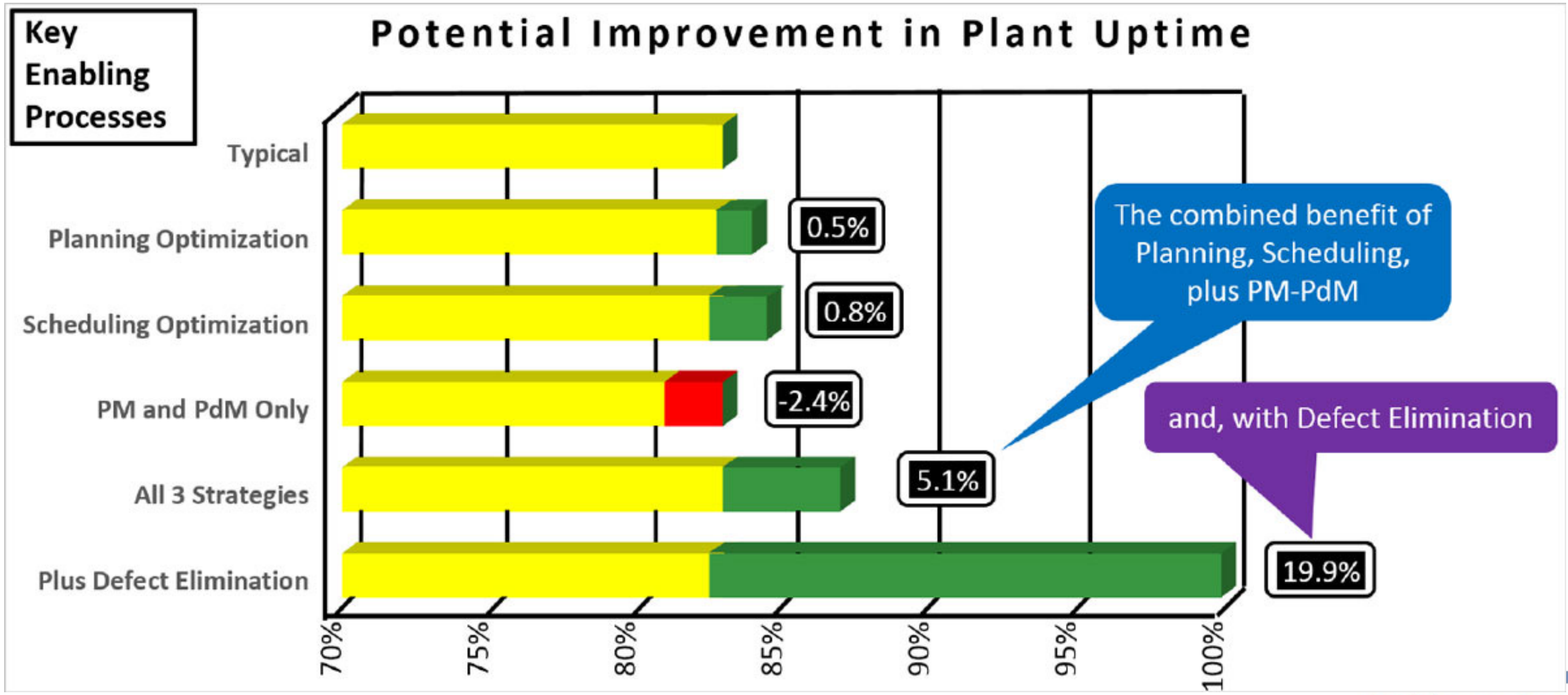


People	"Fire Fighting" Heroes	Overlapping Responsibilities	Role Based Training	Defined Roles & Responsibilities	Cross Trained / Bench Strength
Processes	Limited Development	Planning Materials & Inventory Management	Kitting Materials & Scheduling Technicians	Monitoring Technician Work Execution	Total Productive Maintenance
Systems	CMMS PM Management	CMMS Planning & Inventory Management	CMMS Scheduling & Robust Reporting	CMMS Automated Work Generation	CMMS Lifecycle Cost Tracking
Technology	Limited Utilization	Electronic Document Management Systems	Predictive Technologies	Mobile Handheld Devices	Barcoding & RFID Utilization
Governance	Minimal Performance Tracking	Lagging Indicators	Leading & Lagging Indicators	Continuous Improvement Efforts	Organizational Metrics Aligned

Maintenance Maturity model: Genesis (2016), Winston Ledet(1999)

Maintenance strategy, way forward

- **4 essential elements**
  - Planning and Scheduling
  - Defect eliminations (Fix forever, stop forever fixing.)
  - Preventive maintenance optimization (predictive maintenance)
  - Reliability leadership



study performed by Winston Ledet and MIT Sloan School of Management Senior Lecturer Mark Paich

Planning and Scheduling

- Maximize the maintenance productivity with proper planning and scheduling.
  - Increase wrench time (Time spent performing maintenance work) !
  - Reduce time spent getting tools/parts, travelling, review logs, manuals, on-site planning, coordination, waiting telescope/instrument available…

- Stick to the maintenance process flow

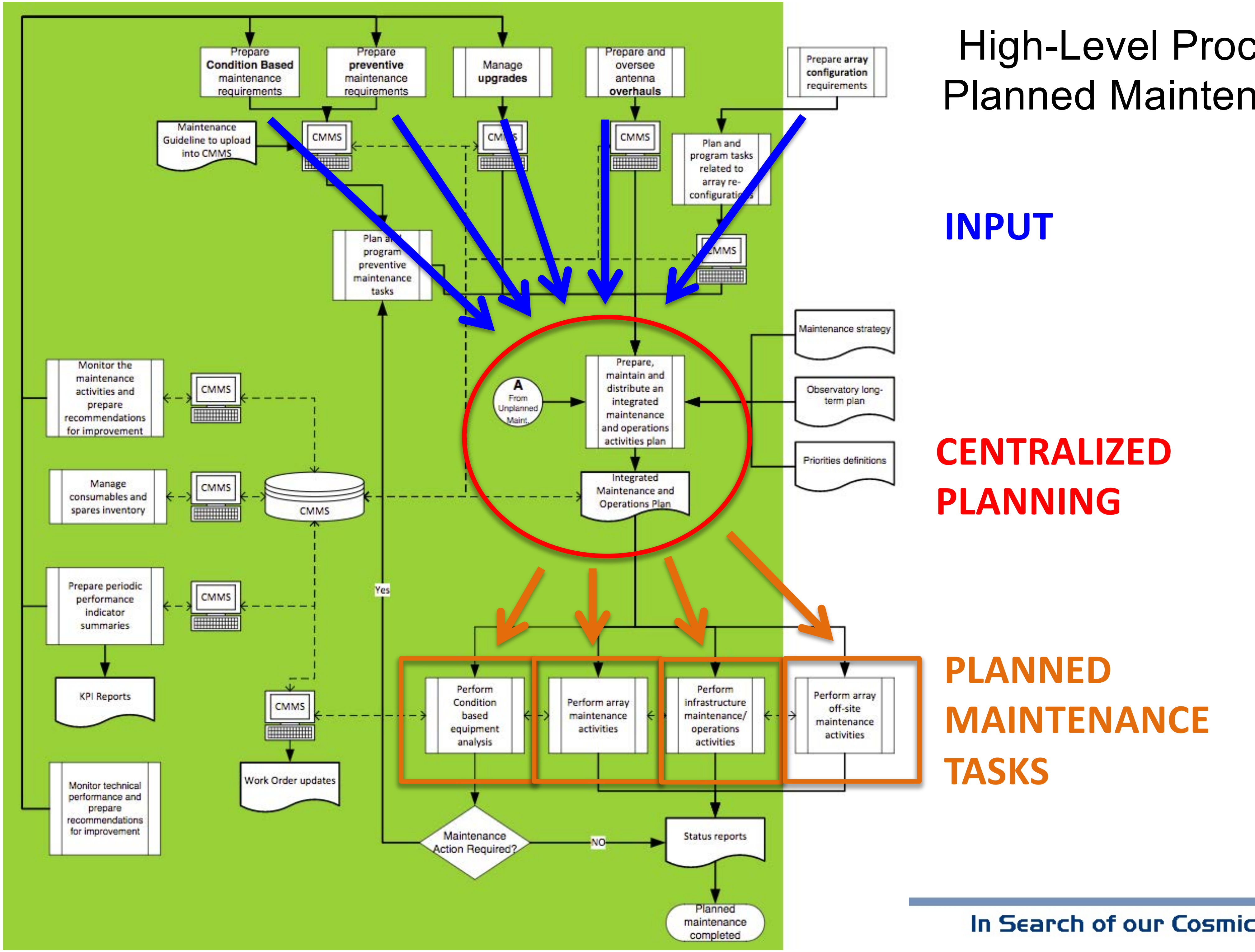
Centralized Maintenance Planning

- Even when a de-centralized approach (maintenance & its scheduling) enhances staff **ownership** it also makes it more difficult to steer away from **reactive** work (fire-fighting)

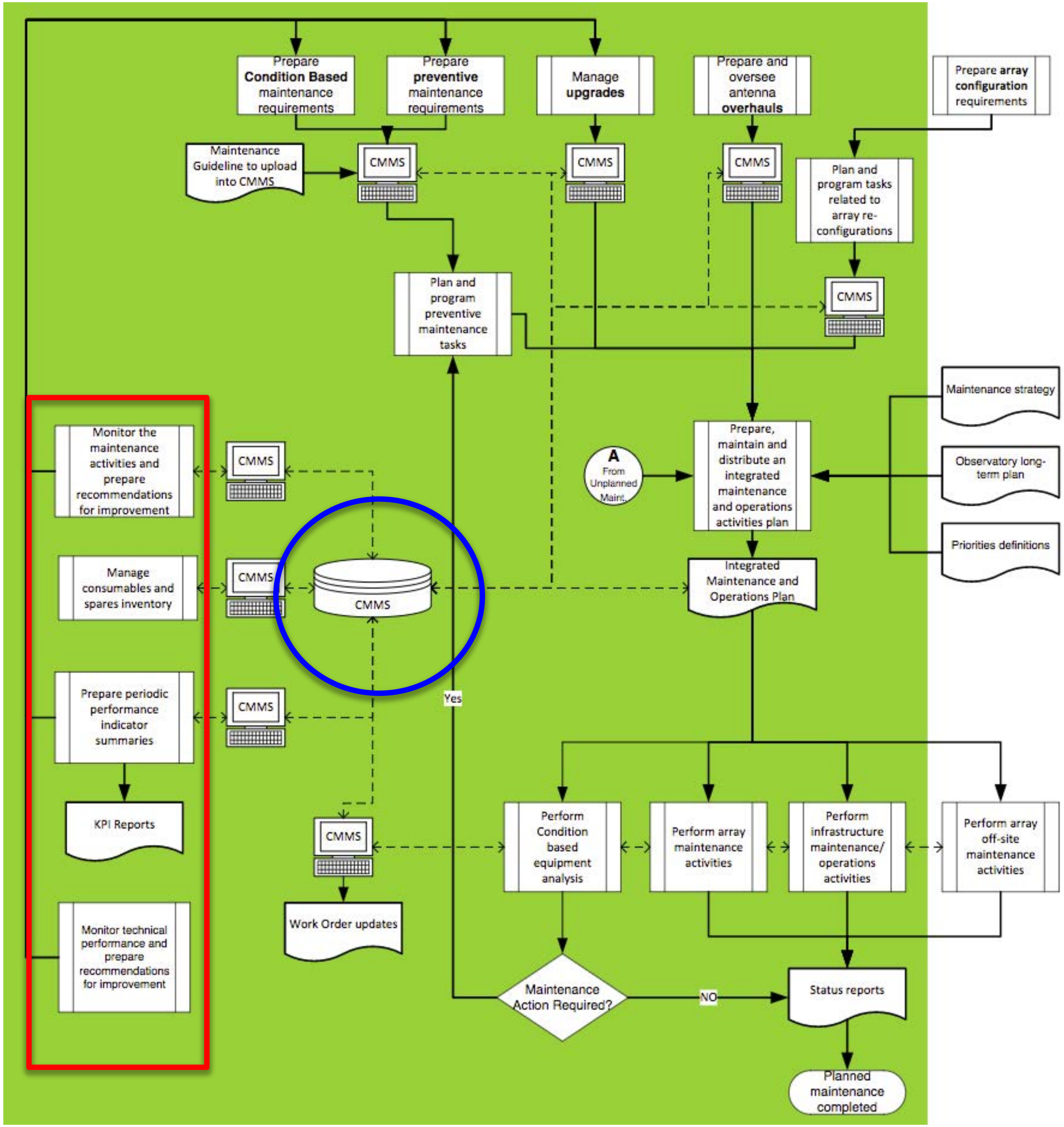
- There is a **strong interdependency** of systems at ALMA that requires thorough coordination with several stakeholders

- The definition, communication and application of **schedules and priorities** gets simplified and becomes more homogeneous if the planning is centralized

High-Level Process: Planned Maintenance



High-Level Process: Planned Maintenance



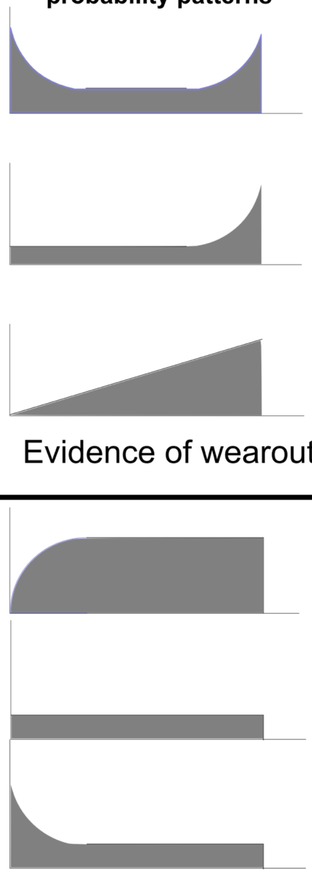
COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM (CMMS)

ACTIVITIES- AND PERFORMANCE MONITORING

Preventive Maintenance

- Most failures are not age-related! Failure characteristics of ALMA's telescopes and instruments are similar to those of aircraft and submarines.

The six conditional failure probability patterns



	Pattern	UAL 1978	Broberg 1973	MSDP Studies 1983	SSMD 1993
Age Related \ Wearout	**A.**	4%	3%	3%	6%
	B.	2%	1%	17%	0%
	C.	5%	4%	3%	0%
Evidence of wearout		11%	8%	23%	6%
Random \ No wearout	**D.**	7%	11%	6%	0%
	E.	14%	15%	42%	60%
	F.	68%	66%	29%	33%
No evidence of wearout		89%	92%	77%	93%

Periodic maintenance and replacement before entering the wearout area is effective.

Due to the random nature of the failures. Periodic maintenance is not effective.
Condition-based maintenance is necessary.

Reliability-Centered Maintenance (RCM) Handbook, United States Navy 2007

ALMA Data Science initiative in Operations

- Collaboration started in 2018 - part of Dataiku Ikig.ai program
- Becoming a data-centric organization to improve the observatory's operations
- March 2021: deployment of a data ecosystem (Hadoop lake, PostgreSQL warehouse + Dataiku)

&

Trend Analysis and Outlier detection

Insights Antenna Receiver Temperature in History

Goal: Identify outliers in antennas or trend analysis that can support the QA process by finding 'badly' operating antennas

→ Focus on data of the receiver temperature of the antenna during calibration measurements.

Can we find outliers per execution block?

Exploratory visualization shows that antenna's occupy distinct space in receiver temperature, even though theoretically they are build the same.

→ Find outliers based on the history of a single antenna, not as an ensemble in a single point of time.

Analysis Antenna Temperature

Change Point Analysis

Change point detection tries to identify times when the probability distribution of a stochastic process or time series change. It can identify changes in a distribution in the mean and variance (depending on the specific algorithm and cost function chosen).

Idea: A changepoint can indicate an early warning signal for an engineer that the performance of the device is getting 'worse' and maintenance should be planned. Implementing changepoint analysis online since last change of device history can aid an astronomer on duty.

antenna behavior in time with changepoints (blue line) and device changes (black line) for trec_x BB_1

Create New Operation/Maintenance Culture

- Stop firefighting ! Let’s shift from reactive to proactive.

Reactive → Proactive and Reliability Driven → JAO Culture / Sustainable Operations / ALMA2030

Reactive

- Fix it after it fails
- Given prev. maintenance

Proactive and Reliability Driven

- Measure and Predict failure
- Optimize maintenance programs
- Defect eliminations
  (Fix forever, stop forever fixing)

JAO Culture

Sustainable Operations

ALMA2030

- Leadership is vital to Culture change.

Inspire with with vision, motivate with passion, deliver as promised, and develop others

国立天文台の運用、保守体制は今後どうあるべきか？

- 国立天文台が携わる望遠鏡、施設の運用の多様性、国際化。
- 保全活動は、エンジニアリング部門だけでなく、科学運用、事務部など他の部門との連携も必要。
- 目指す姿（ビジョン）をはっきりさせる
  中身の改善に入る前に、保全戦略を明確にし、組織として合意した中長期計画に組み込む。
- 取り組みの実行現場を支える組織改編、リソース、インフラが整えることから始める。（現組織に合わせてシステムを構築しても、例えば 同じことがデジタル化されるだけで、プロセスの効率化につながらない可能性がある）。
- 技術的なスキルだけでなく、運用や保守に対する文化を変えていく。
  PM, SE、リーダーシップのスキルの向上。