From digital shadow to cognitive digital twin:

AI assisted operations at Gran Telescopio Canarias

Sebastián Fernández-García



with Luis Alberto Rodríguez-García · Romano L. M. Corradi · Josué Toledo-Castro · Manuel Huertas-López
Raúl Domínguez-Domínguez · Henry Brito-Martín · Ismael Álvarez-Candelario · ULPGC · GRANTECAN

IBERGRID 2026 · Santiago de Compostela · 27-29 October 2026

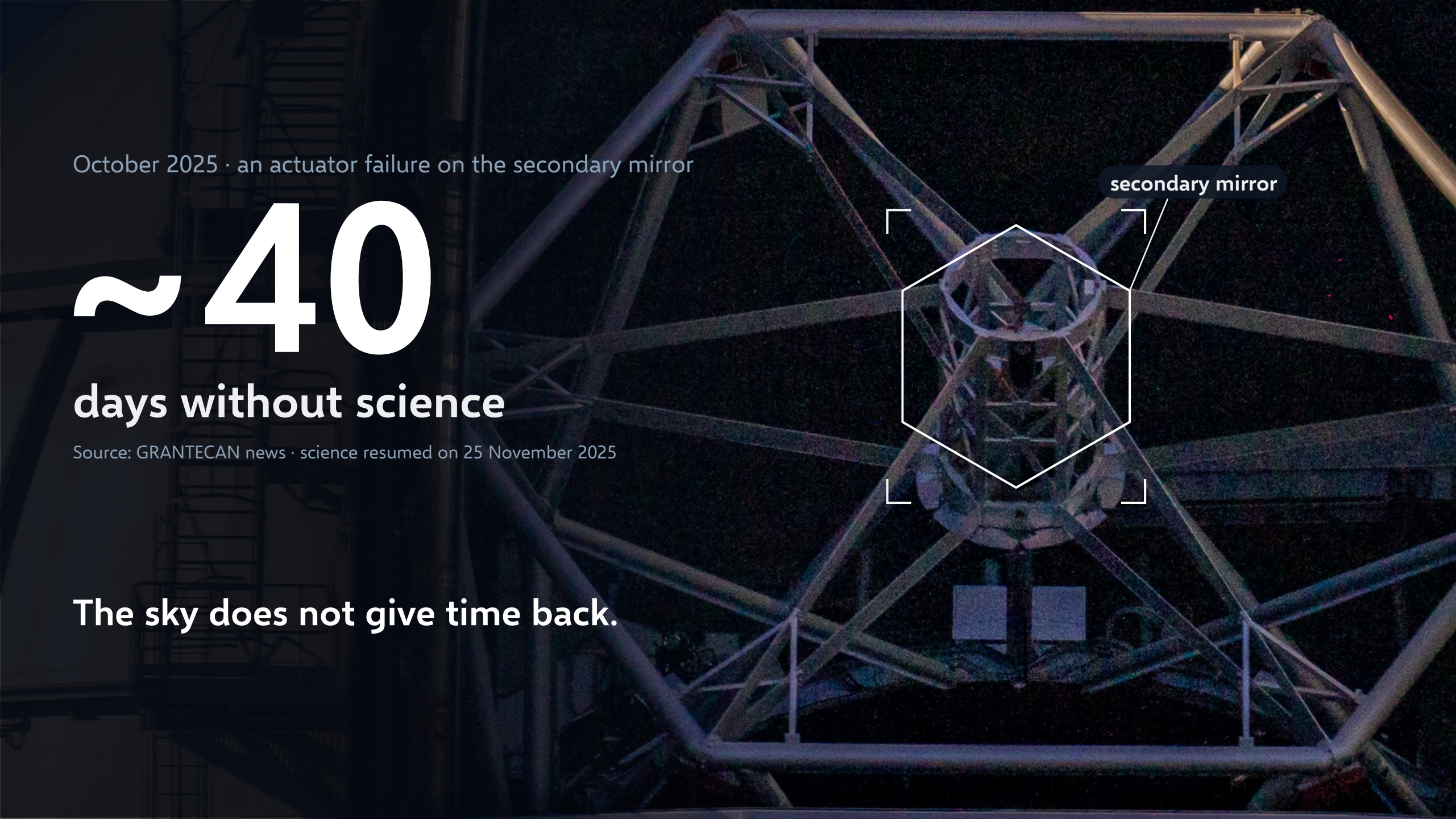
Photo: GRANTECAN

October 2025 · an actuator failure on the secondary mirror

~40

days without science

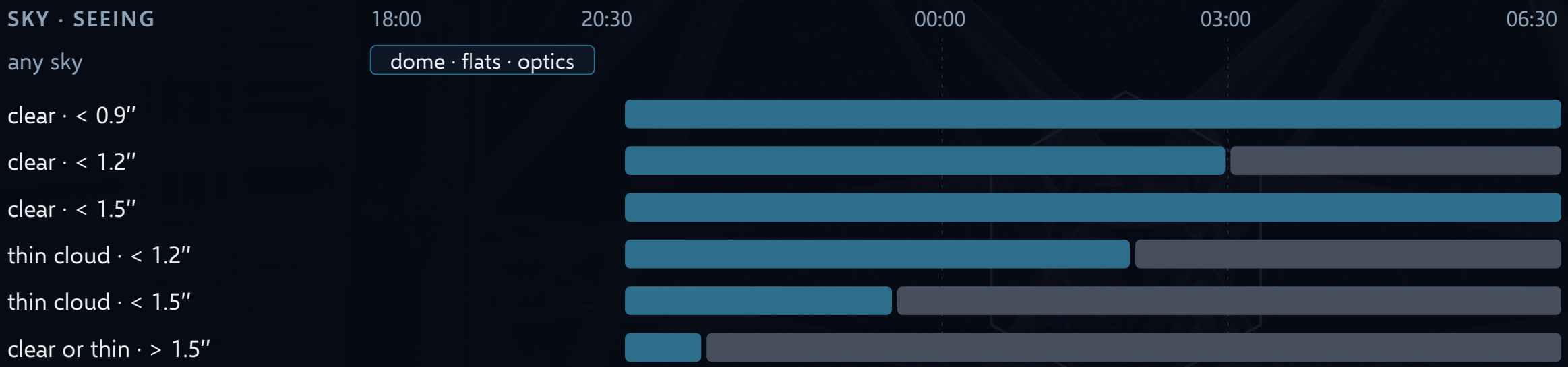
Source: GRANTECAN news · science resumed on 25 November 2025



The sky does not give time back.

Every night has a plan for any sky

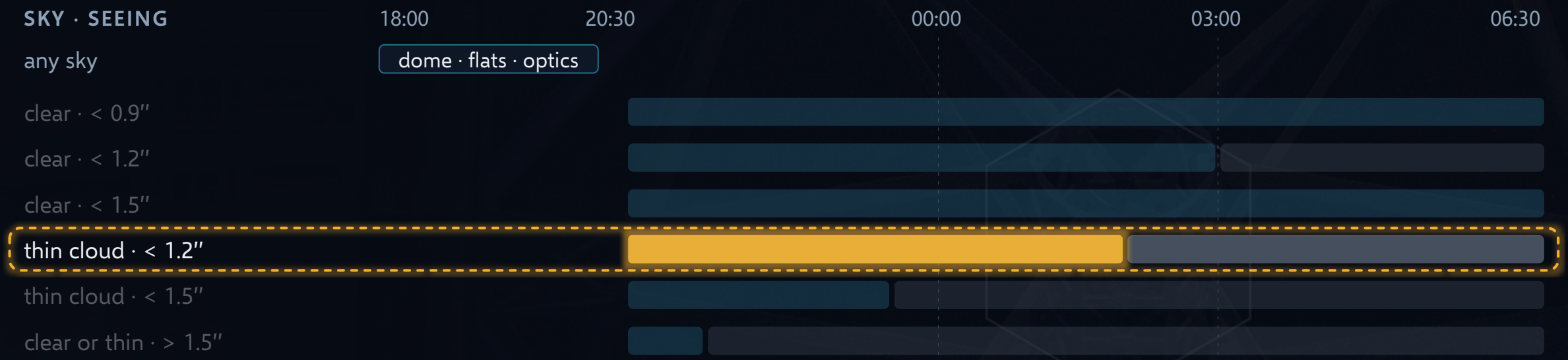
ONE REAL NIGHT PLAN · SIMPLIFIED, NO PROGRAMME NAMES



Seeing: how much the atmosphere blurs a star, in arcseconds. Lower is sharper.

Every night has a plan for any sky

ONE REAL NIGHT PLAN · SIMPLIFIED, NO PROGRAMME NAMES



A twin could try each option first, weighing sky · seeing · pointing · wind · instruments.

DESIGN · illustrative, not a result

Not only foresee. Optimise. Improve.

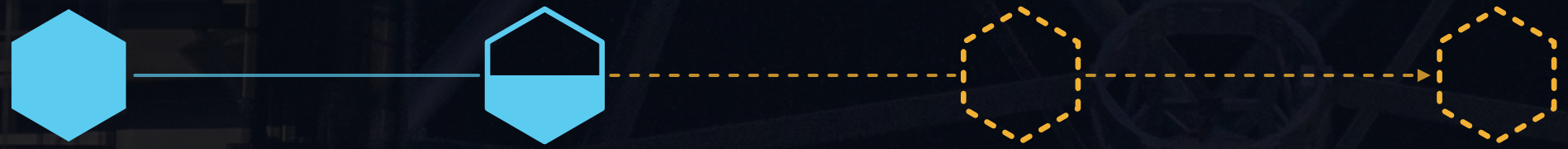
What if the telescope could warn us before it fails, and help us make the most of every night?



WHERE WE ARE

WHAT WE ARE WORKING ON

WHERE WE WANT TO GO



DESCRIBE

digital shadow

What is happening?

EXISTS · in production

EXPLAIN

cognitive digital twin

Why is it happening?

EXPERIMENT · in testing

RECOMMEND

AI assisted operations

What should we do?

DESIGN · in development

EXECUTE

governed action

How do we act, safely?

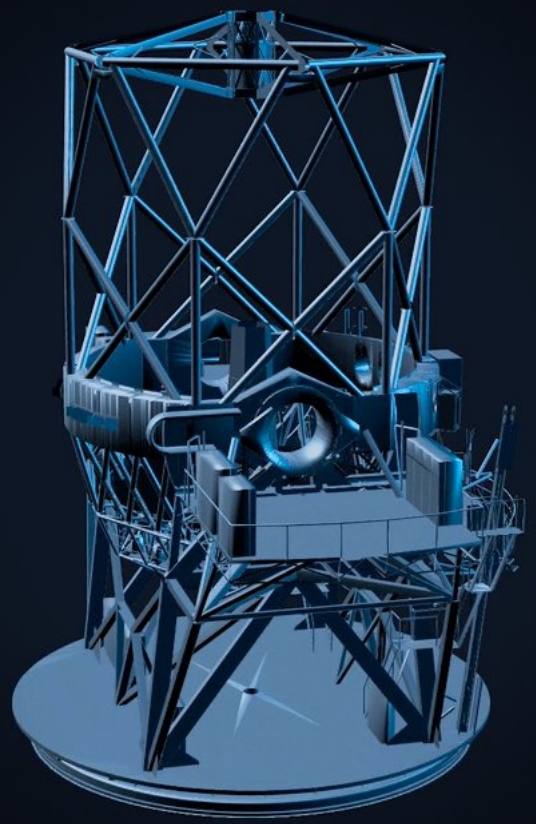
DESIGN · proposed

People decide, at every step.

Solid, half or dashed: every status claim that follows carries one of these marks.

Describe: what is happening?





Digital shadow

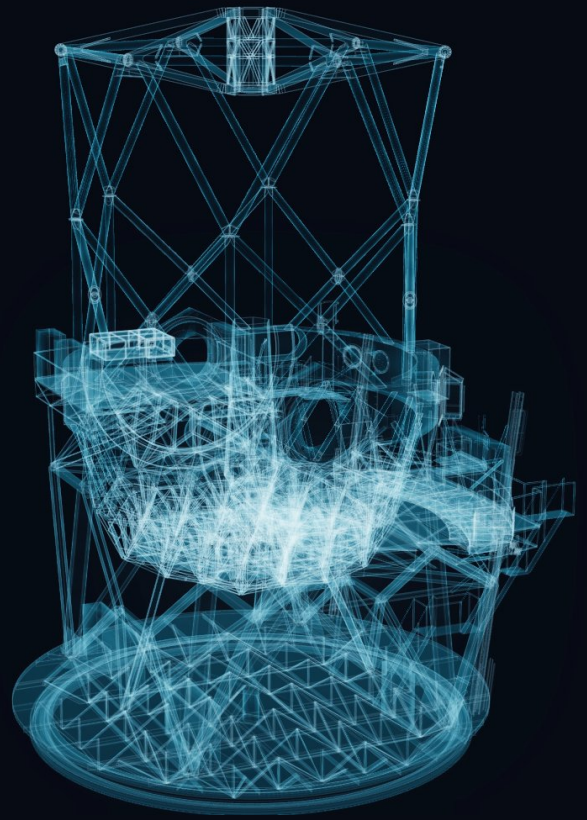
Measurements update the digital side automatically. One way.



PHYSICAL TELESCOPE

automatic

manual



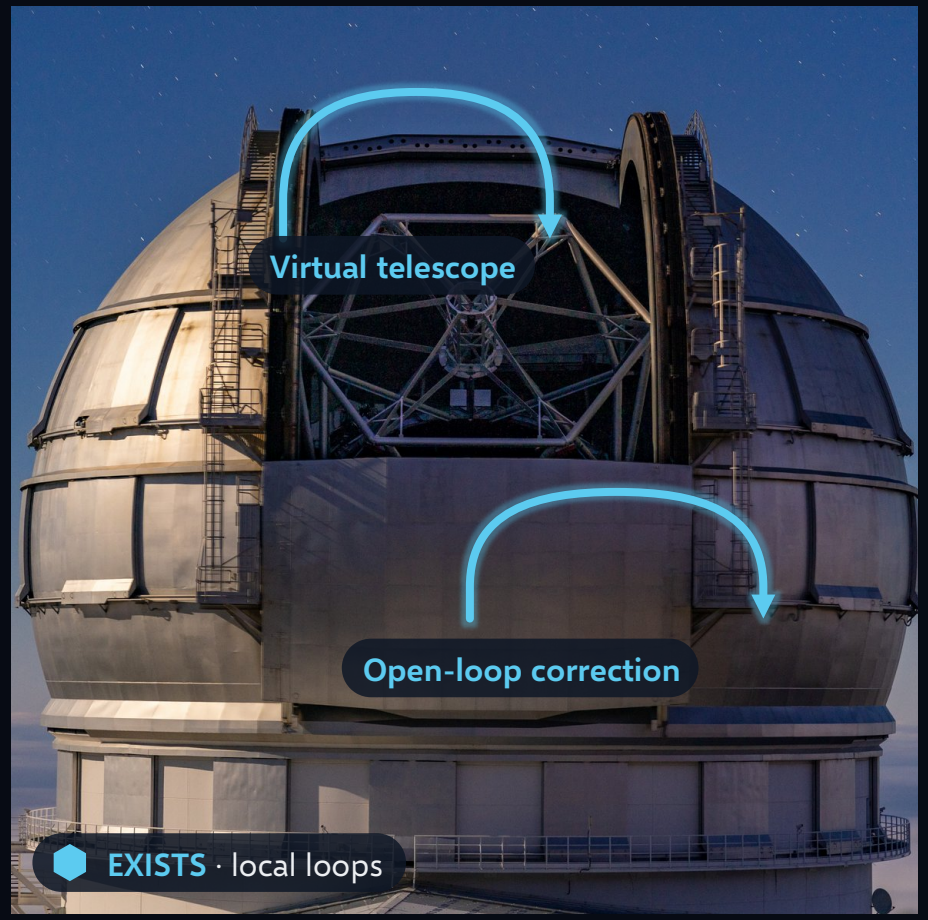
DIGITAL REPRESENTATION

DESCRIBE EXPLAIN RECOMMEND EXECUTE · shadow

DESIGN · observatory-scale way back, proposed

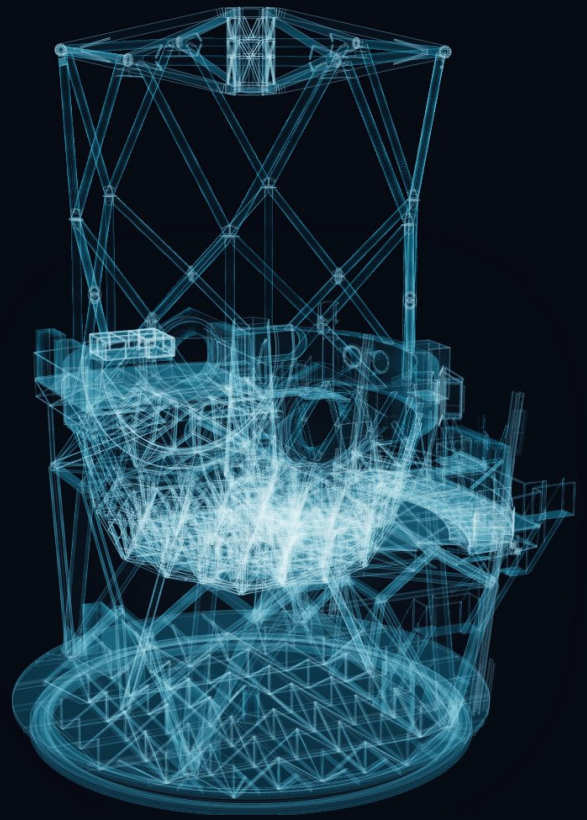
Digital twin

Decisions also flow back. Both ways.



automatic

the way back
proposed



PHYSICAL TELESCOPE

DIGITAL REPRESENTATION

We already had twins.
We just didn’t call them that.

Virtual telescope

reads time, weather, the guide star
writes where each axis must point

Open-loop correction

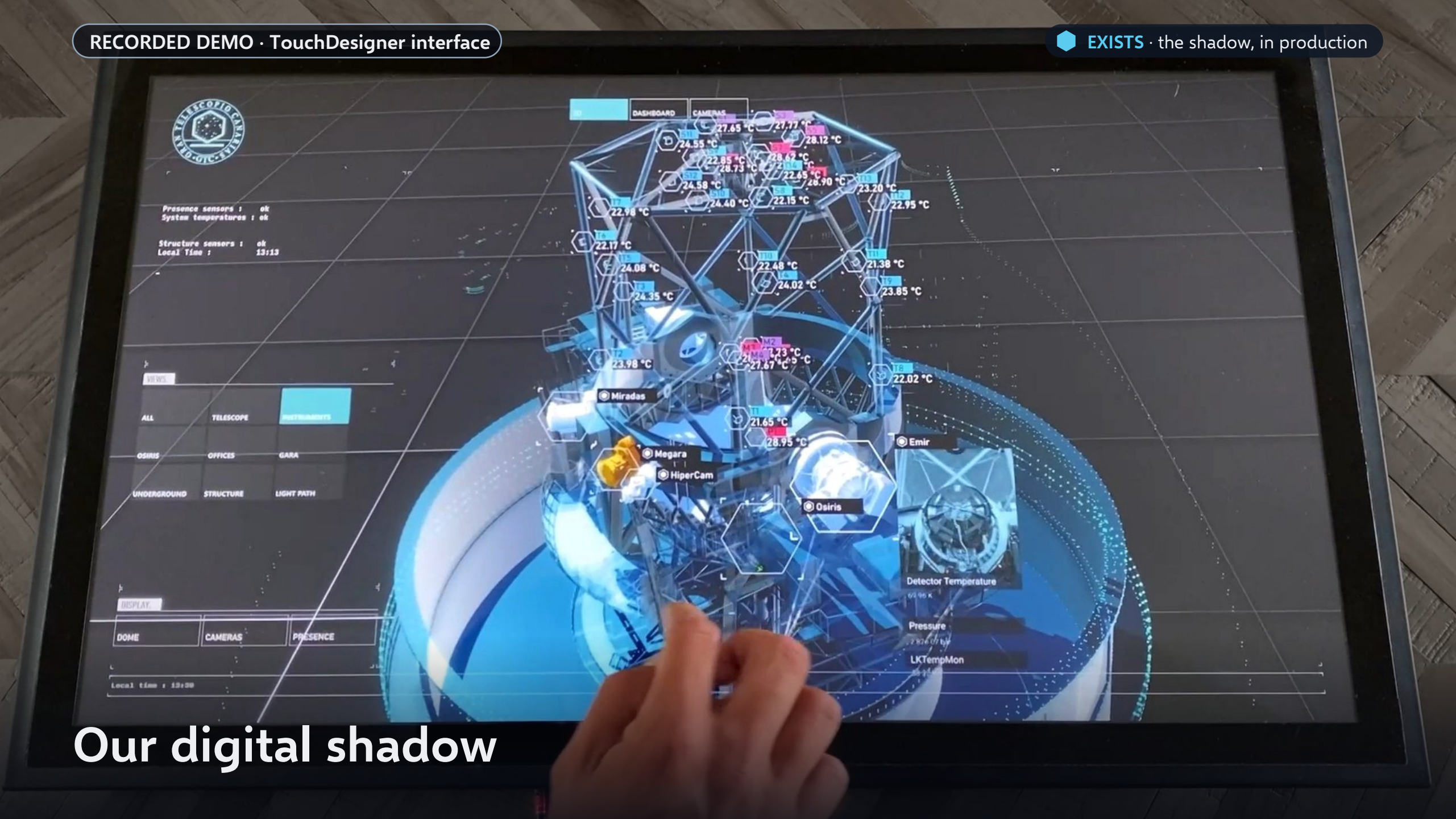
reads elevation, temperatures
writes how the structure behaves

They don’t warn. They improve, every night.

EXISTS · local loops, every night

RECORDED DEMO · TouchDesigner interface

EXISTS · the shadow, in production



Our digital shadow

DESCRIBE EXPLAIN RECOMMEND EXECUTE · data river

EXISTS · runs today

From sensor to people



- Sensors · cameras
- Telescope control
- Environment · weather

The present
what is happening now?

which component · which value and when



the shadow
recorded demo frame

People decide
shadow · dashboards

Streams
telemetry

Data lake
memory: what happened?
telemetry · logs · alarms
versioned tables

Models · statistics

AI agents
investigate the lake in plain language

DESCRIBE · EXPLAIN · RECOMMEND · EXECUTE · data river

EXISTS · runs today

From sensor to people



- Sensors · cameras
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The present
what is happening now?

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shadow · dashboards

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telemetry

Data lake
memory: what happened?
telemetry · logs · alarms
versioned tables

Models · statistics

AI agents
investigate the lake in plain language

This river runs today. It tells us what is happening.

And AI agents already connect to the lake, to investigate.

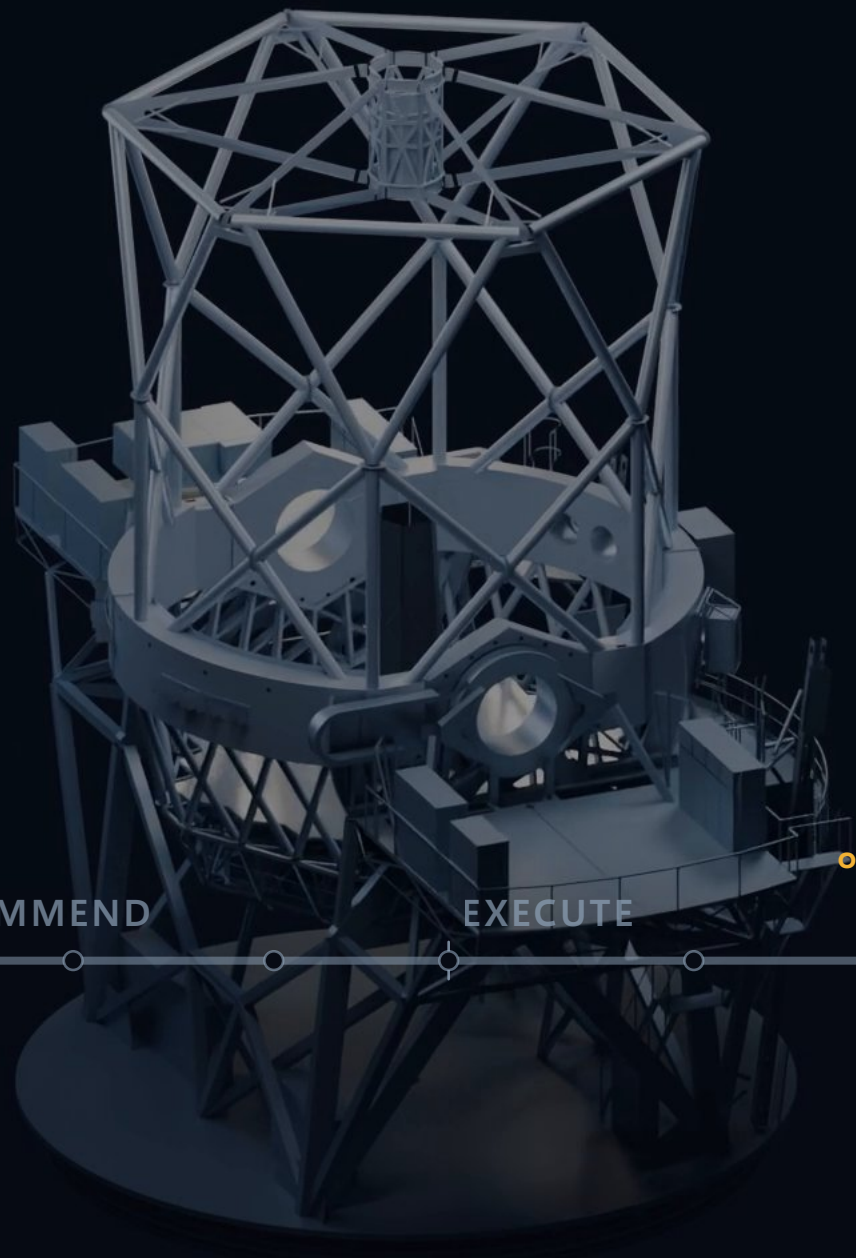
Three in the morning, something breaks: what changed before?

PART TWO

EXPLAIN

Why is it happening?

WHERE WE ARE · WHAT WE ARE WORKING ON





Our question: warn us before it fails · help us make the most of every night

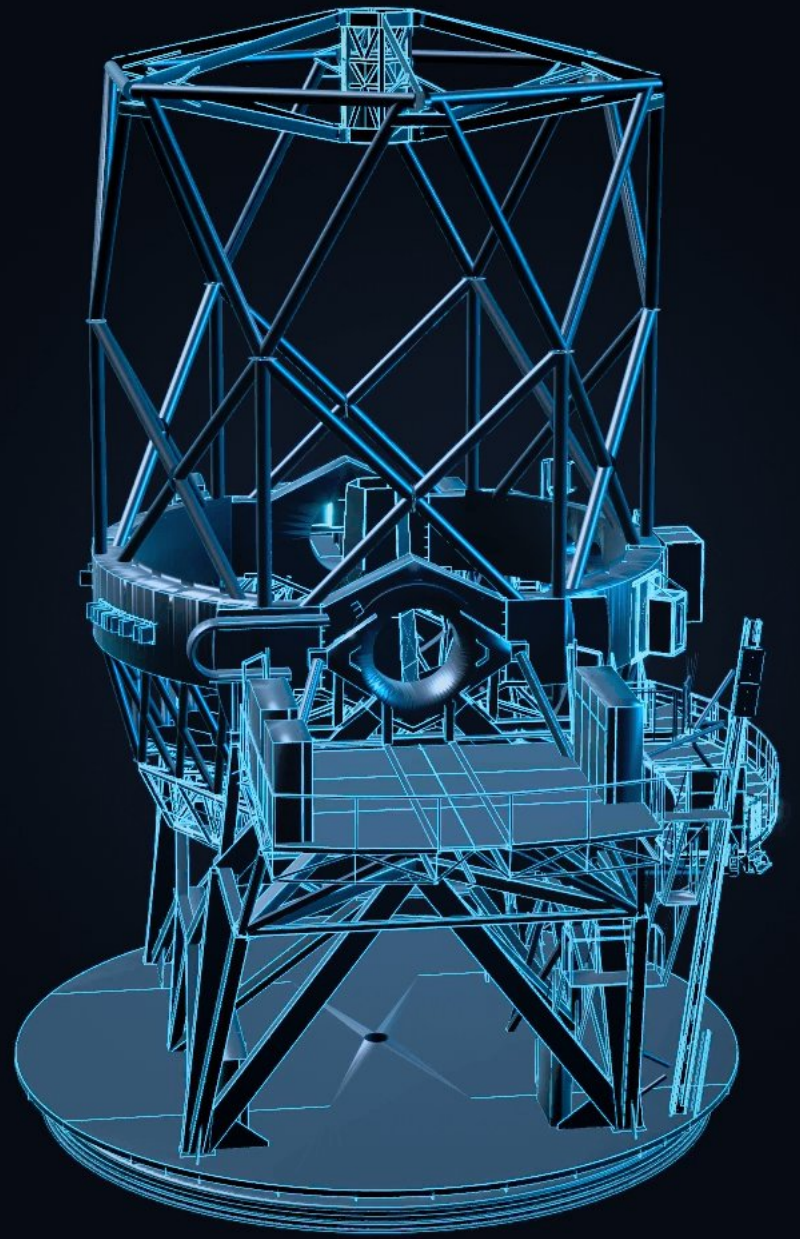
EXPERIMENT · pieces in testing

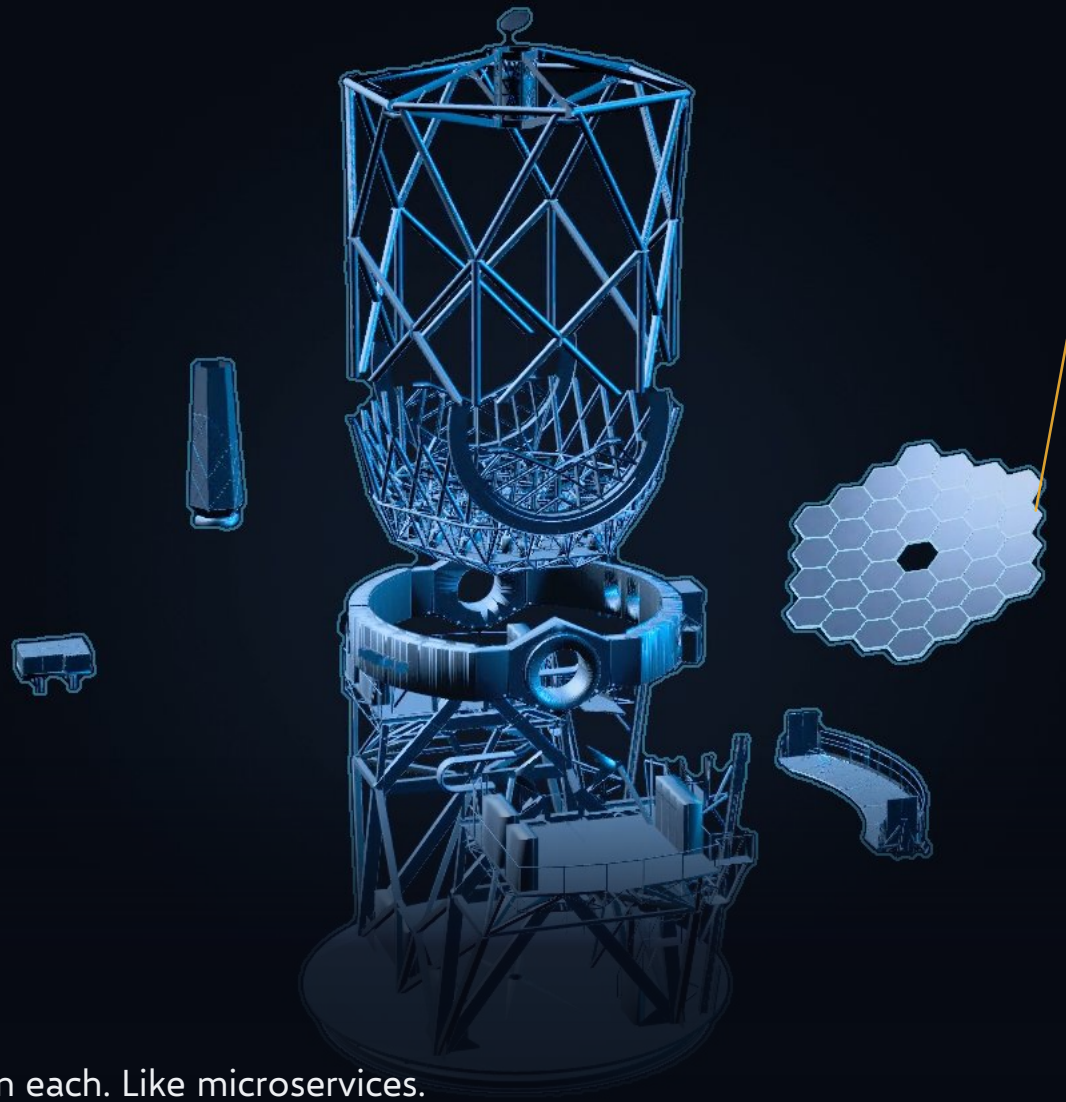
Cognitive

after Zheng, Lu & Kiritsis, Int. J. Production Research, 2022

- **Perceives** the shadow
- **Remembers** data lake · document assistant
- **Reasons** an AI agent testing pointing fits
- **Learns** an azimuth anomaly detector

DESIGN · all four in one shared twin





Primary mirror
why does a segment drift?

Axes
demand → response

Structure
how it bends

Cabinets
thermal behaviour

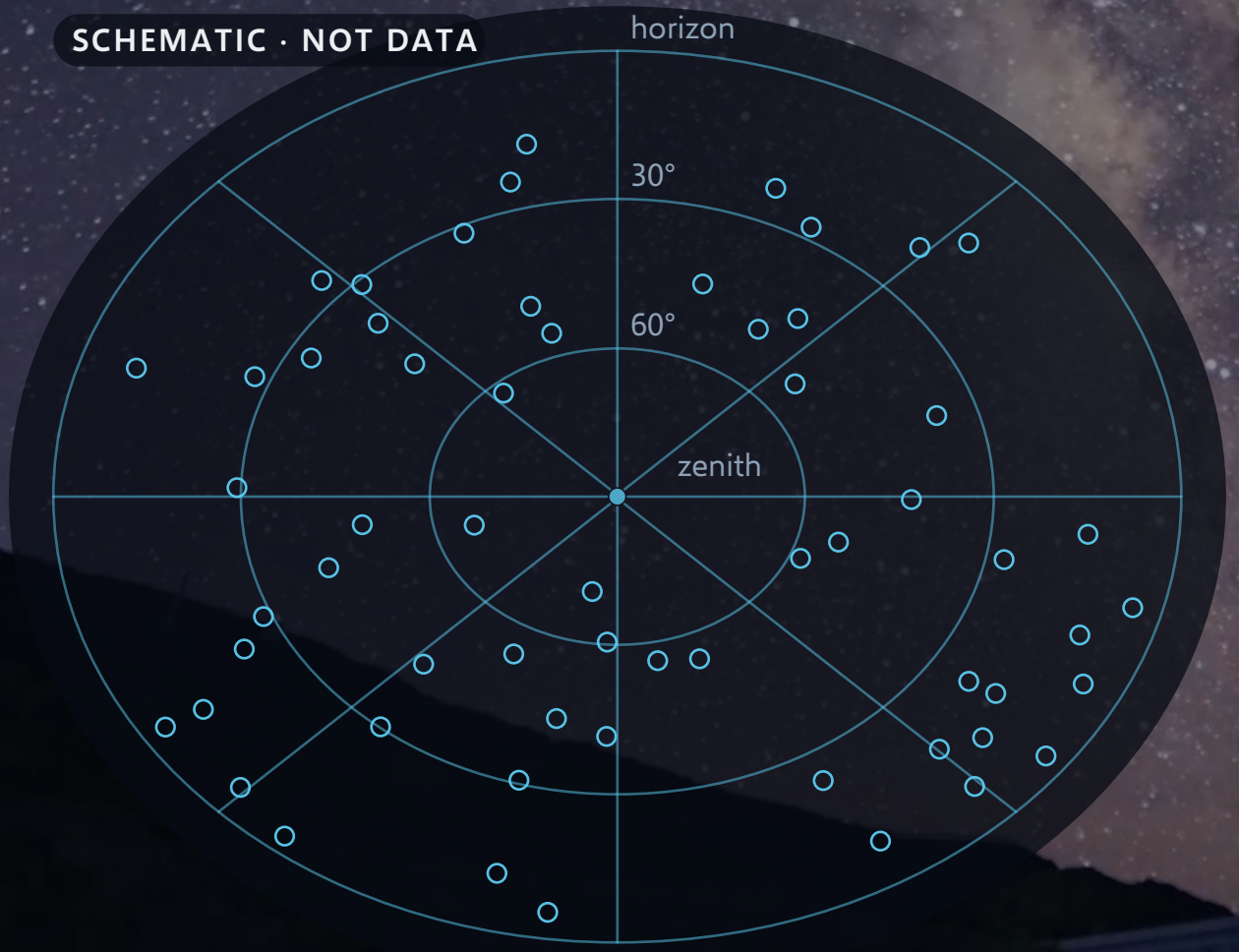
solid: runs today
dashed: design scope

One mastodon, or puzzle pieces?

Puzzle pieces: small twins, one question each. Like microservices.

Where does the telescope really point?

SCHEMATIC · NOT DATA



acquisition camera

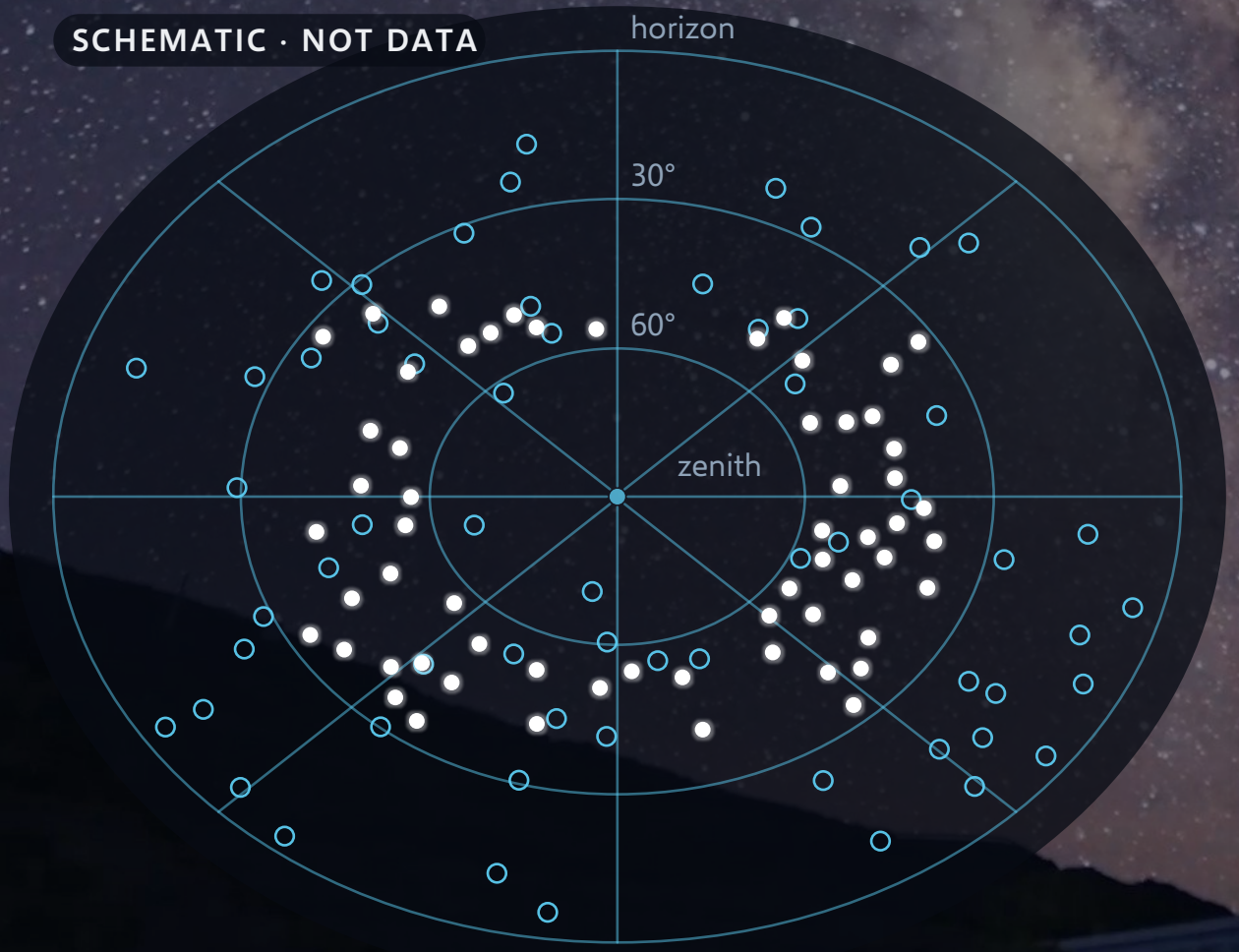


\+ where we asked it to point
• where the star fell
→ centre it, record the encoder readings

EXISTS · pointing model, a local correction

Where does the telescope really point?

SCHEMATIC · NOT DATA



rings: a dedicated run · dots: stars acquired in night plans

acquisition camera



\+ where we asked it to point
• where the star fell
→ centre it, record the encoder readings

THE CHALLENGE

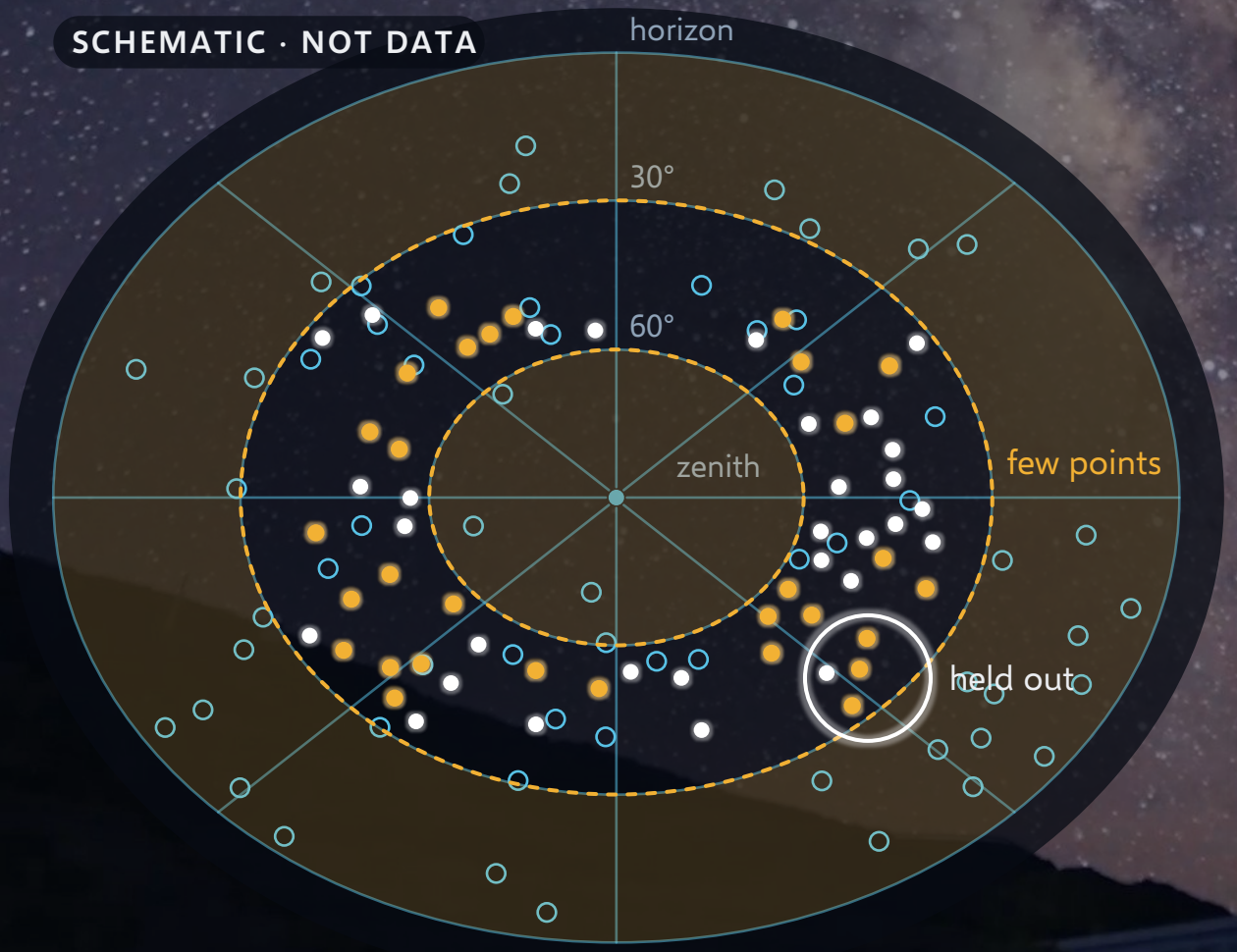
Refitting the pointing model takes dedicated runs: science time. What if the stars acquired in the night plan kept it current?

Challenge, and the idea of a twin: Romano L. M. Corradi

DESCRIBE · EXPLAIN · RECOMMEND · EXECUTE · pointing

EXPERIMENT · test fits, no validated numbers

Where does the telescope really point?



rings: a dedicated run · dots: stars acquired in night plans

An AI agent fitted elevation subsets and compared them with the full fit.

1 · Coverage
few points near the zenith or low

2 · Coherence ● before · ● after a machine change
do not mix machine states

3 · Validation
our rule: independent observations before any number

Under test: the fits and the agent.

THE CHALLENGE

Refitting the pointing model takes dedicated runs: science time. What if the stars acquired in the night plan kept it current?

Challenge, and the idea of a twin: Romano L. M. Corradi

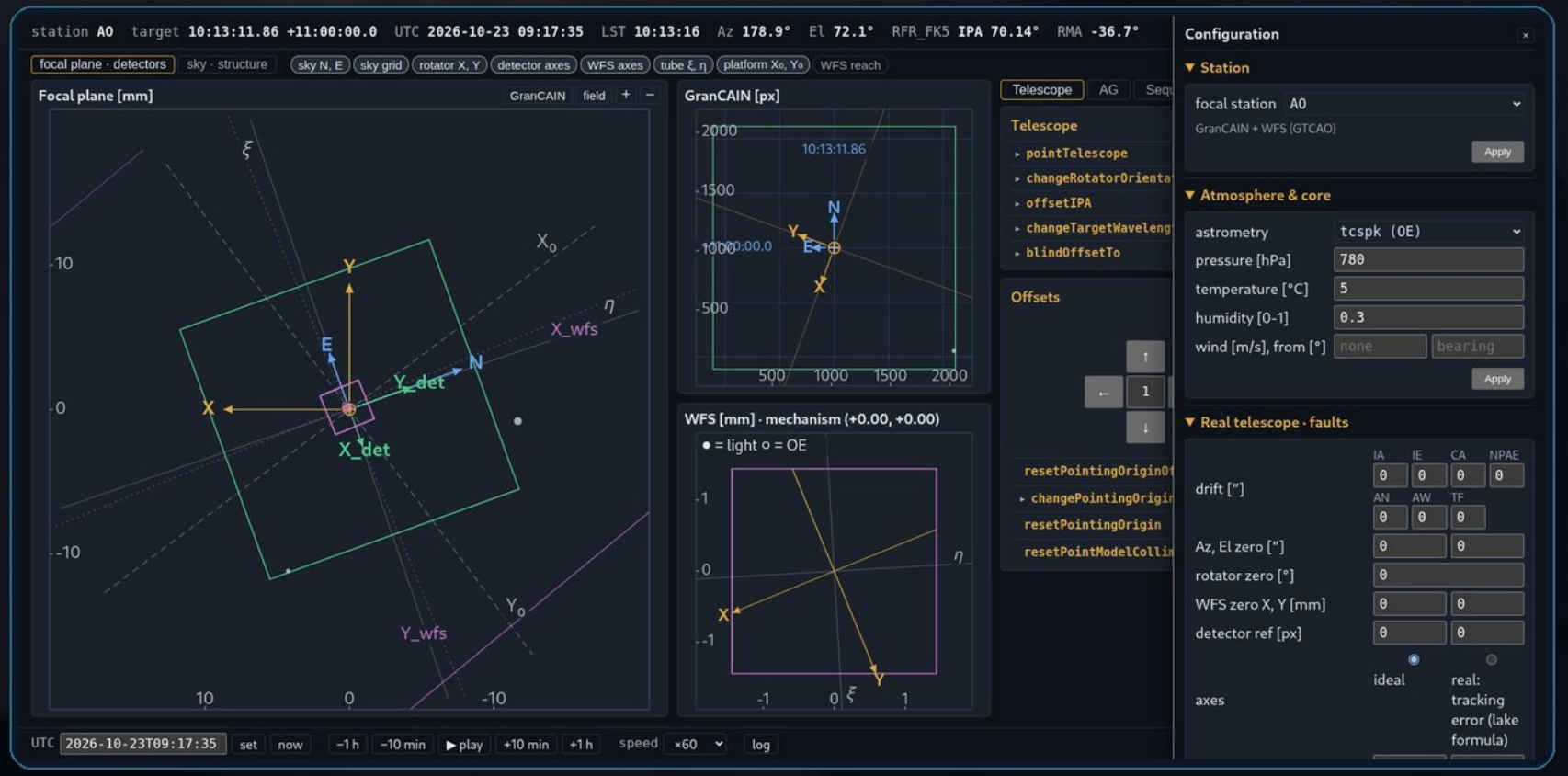
Where does the telescope really point?

THE TOOL

A twin of our tracking system, on our real pointing libraries.

1. **The star's coordinates**
2. **Sky, telescope, detector**
3. **The target, in pixels**
4. **Pointing-model terms**

Why: answer the challenge without telescope time.

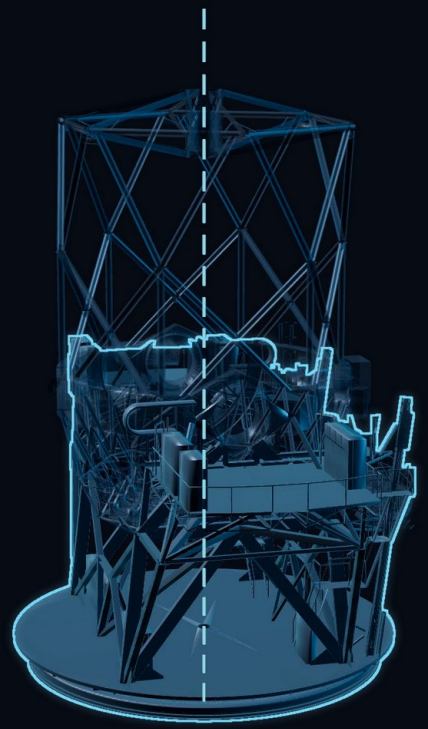


One screenshot, guided view · CC BY Manuel Huertas-López · early prototype, not validated · Oct 2026

Wind, or wear?

Anomaly detectors

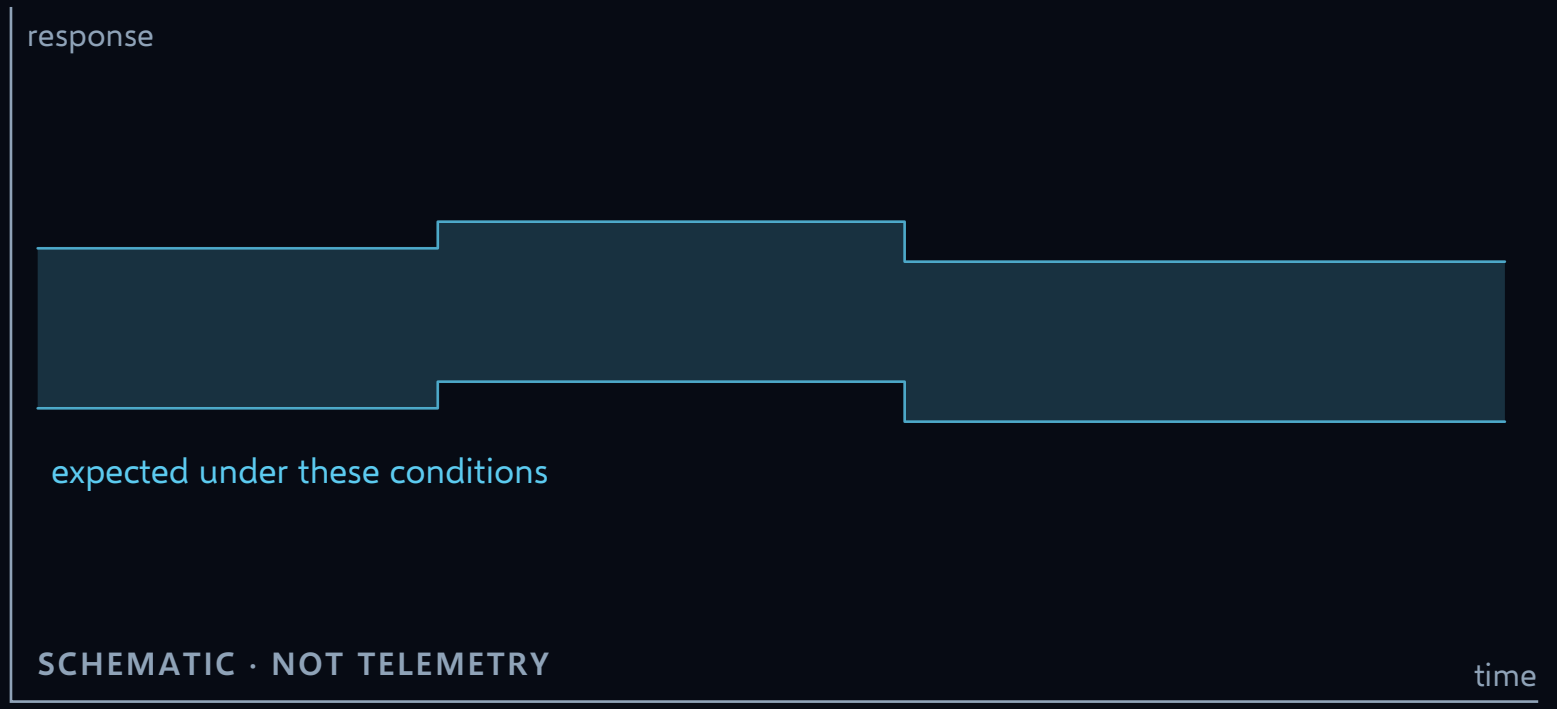
by Manuel Huertas-López



AZIMUTH AXIS

Idea: run the twin alongside the telescope.

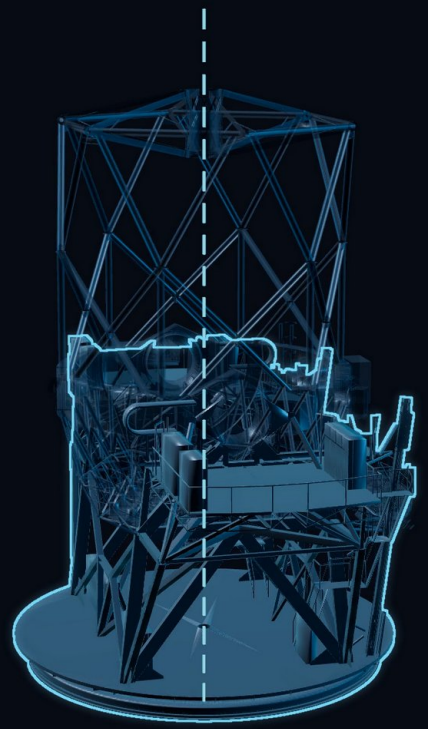
elevation · wind · temperature · load



Wind, or wear?

Anomaly detectors

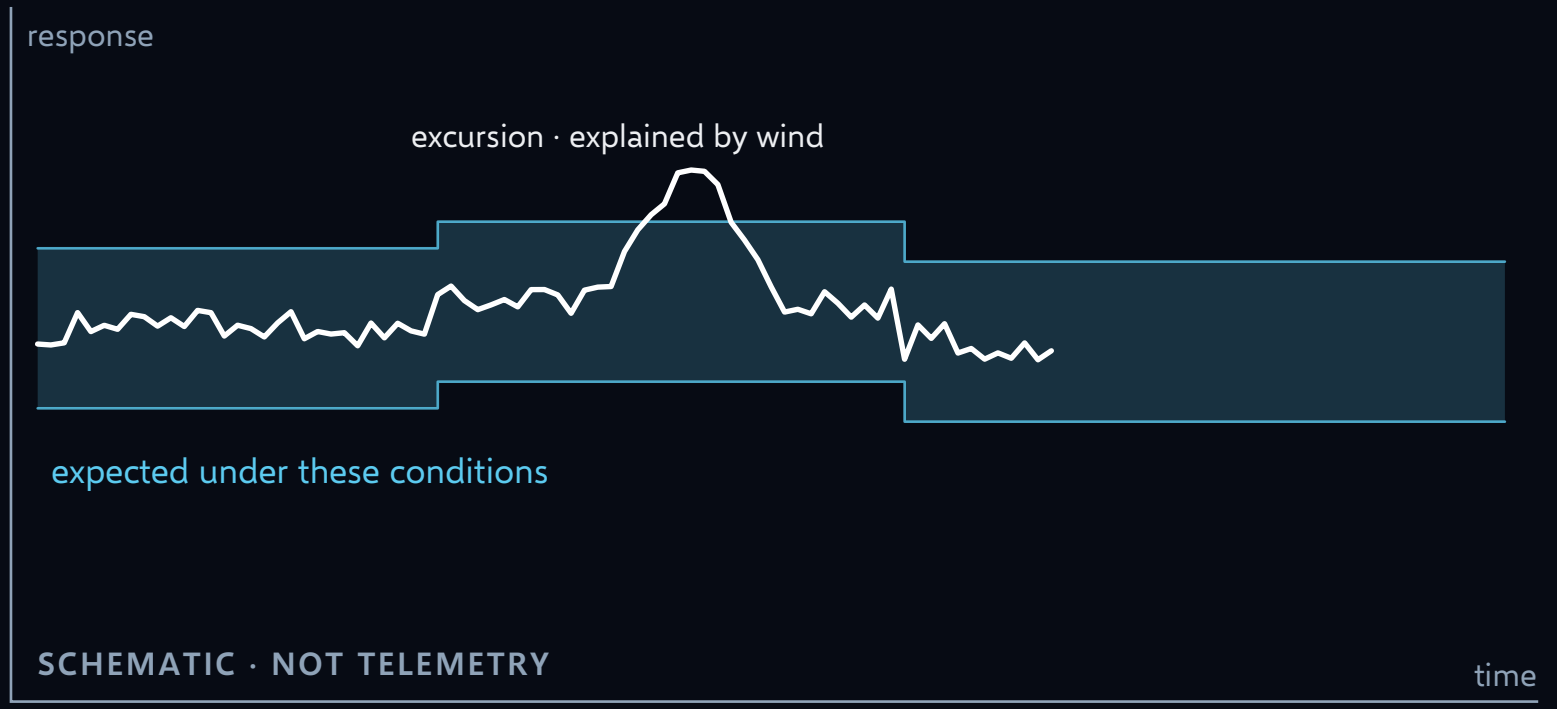
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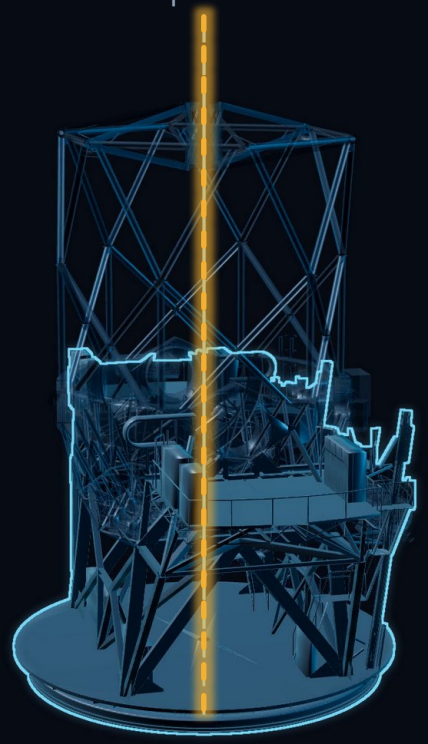
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Wind, or wear?

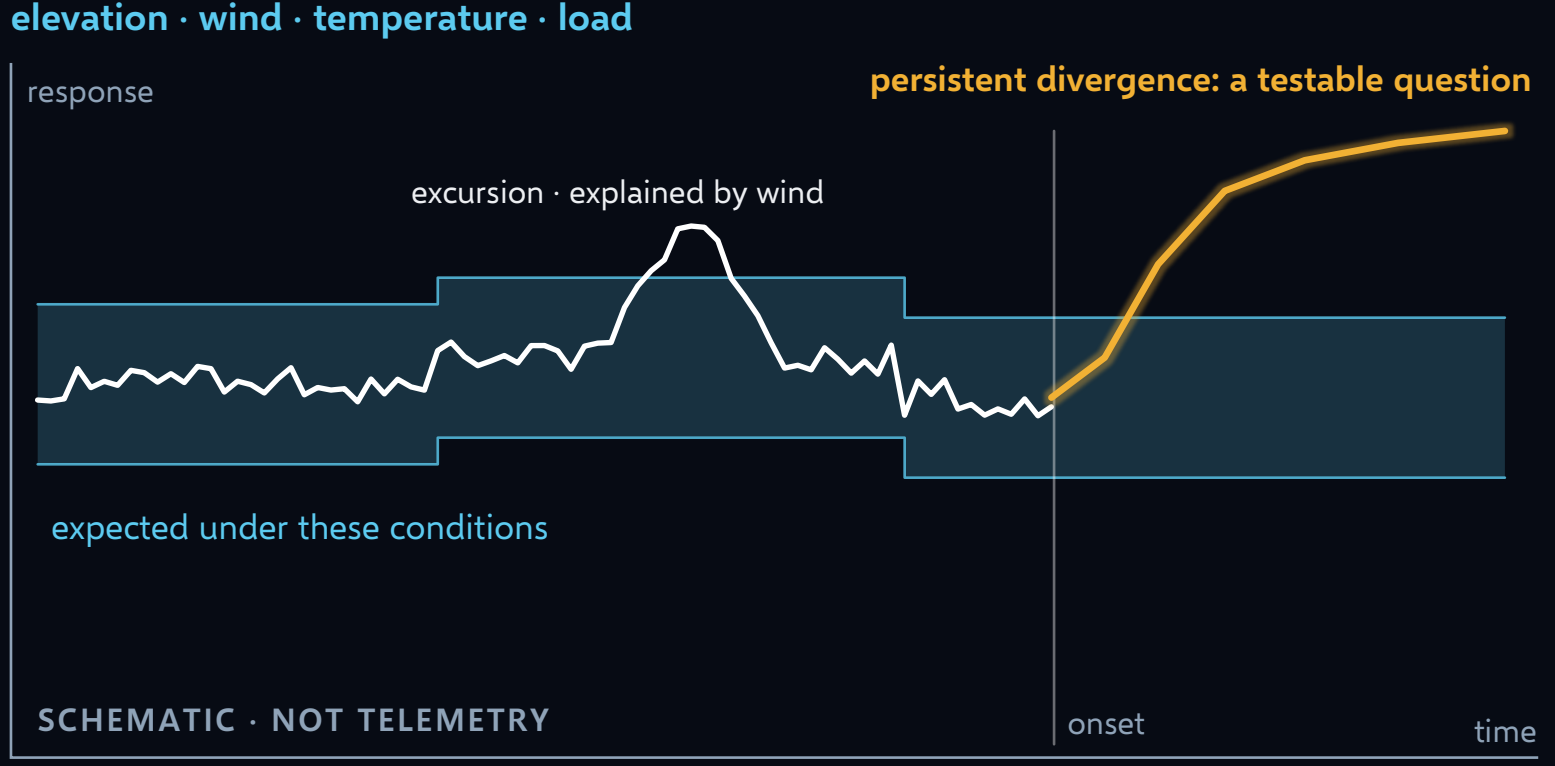
Anomaly detectors

by Manuel Huertas-López



AZIMUTH AXIS

Idea: run the twin alongside the telescope.



"...to distinguish potential mechanical degradation from wind-induced or enclosure-driven effects."

Luis Rodríguez et al. 2026 · detector by Manuel Huertas-López

Fluency is not evidence.

EXPERIMENT · the rule in our agent tests

Evidence or silence

Our agent harness for faults · read-only · deterministic · no language model in the evidence



Evidence or silence

Our agent harness for faults · read-only · deterministic · no language model in the evidence

- Fault reports
- Telemetry · data lake
- Control-system logs
- Component states
- What we were observing
- Anomaly detectors
  e.g. wind · weather · axes
- Map of the control system
- Units and meanings



EVIDENCE · EACH FACT WITH ITS SOURCE

“The elevation axis drops.”

the fault report · 18 May 2026

`state` axis to fault · 23:23:13

`telemetry` following error peaks, 3.5 s later

`log · verbatim` “Fatal following error”

SILENCE · WHAT IT CANNOT KNOW

No root cause is determined here.

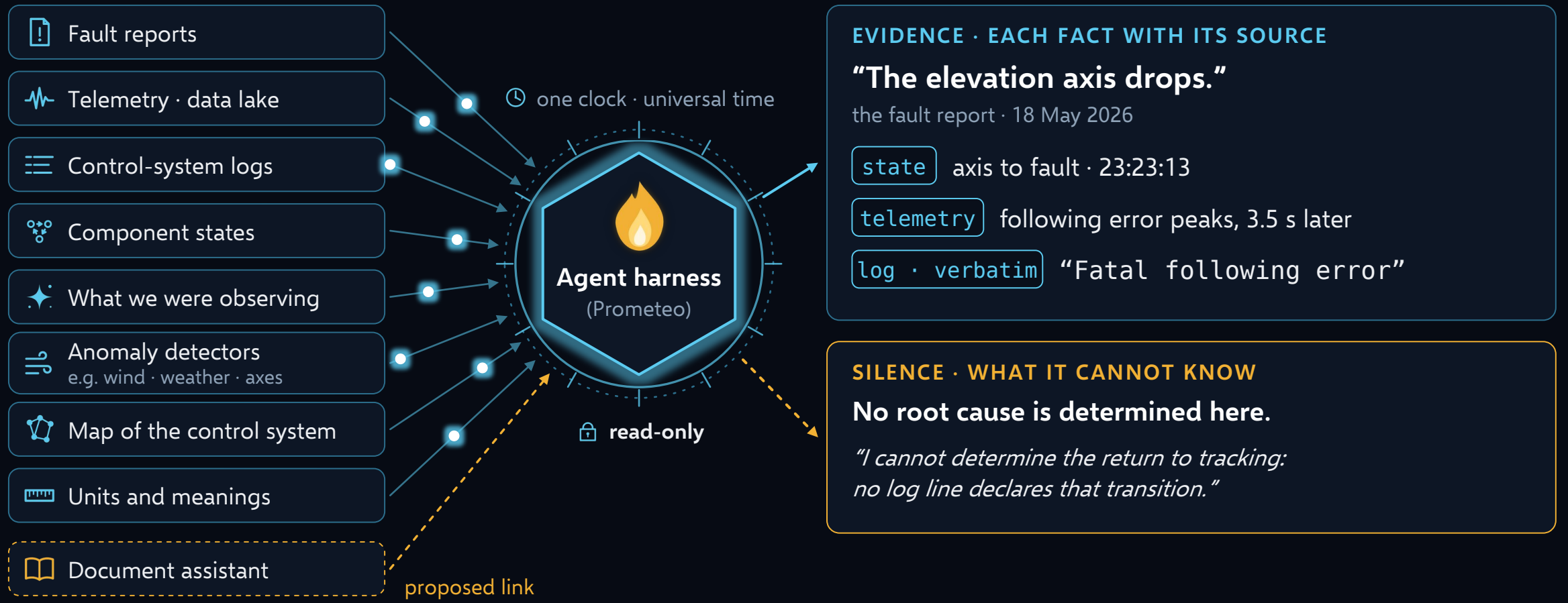
“I cannot determine the return to tracking: no log line declares that transition.”

DESCRIBE · EXPLAIN · RECOMMEND · EXECUTE · evidence

EXPERIMENT · phase 1 · DESIGN · the link, proposed

Evidence or silence

Our agent harness for faults · read-only · deterministic · no language model in the evidence



EVIDENCE · EACH FACT WITH ITS SOURCE

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SILENCE · WHAT IT CANNOT KNOW

No root cause is determined here.

“I cannot determine the return to tracking: no log line declares that transition.”

The document assistant remembers what was written. **The agent harness reconstructs what happened.**

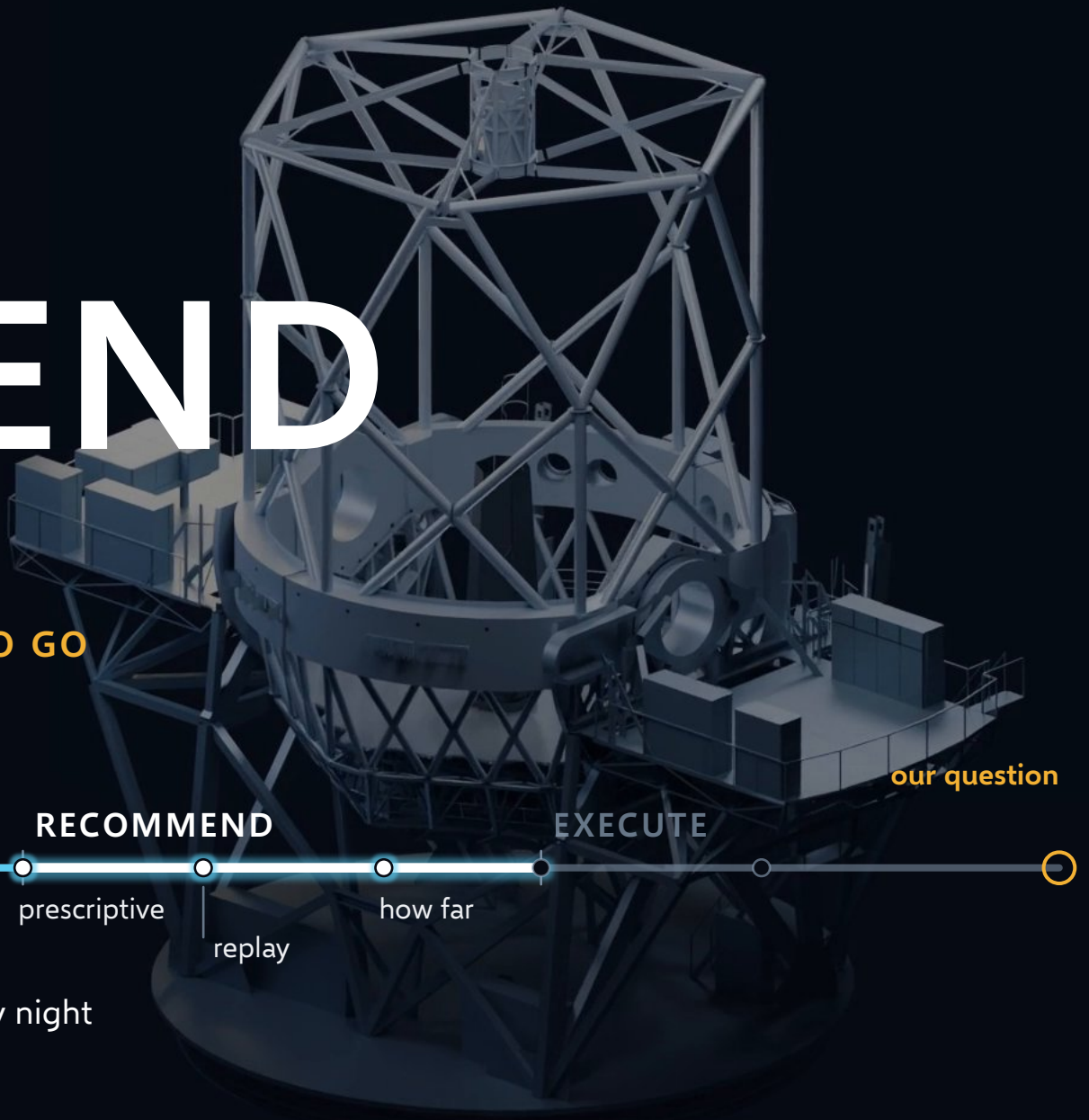
Next, by design: during the night · every morning · how similar faults were closed

PART THREE

RECOMMEND

What should we do?

WHAT WE ARE WORKING ON · WHERE WE WANT TO GO



DESCRIBE · EXPLAIN · RECOMMEND · EXECUTE

our question

prescriptive · replay · how far

Our question: warn us before it fails · help us make the most of every night

AI ASSISTED OPERATIONS

Prescriptive

Recommends actions and scenarios.

Does not execute.

RECOMMENDATION · ILLUSTRATIVE

WARN OPTIMISE

Proposes	refit the pointing model
Why	residuals drift after a state change
Evidence	cited acquisitions and versions
Uncertainty	stated, not hidden
Alternatives	wait · schedule a dedicated run

Engineer decides

no execute button

AI ASSISTED OPERATIONS

Prescriptive

Recommends actions and scenarios.

Does not execute.

TONIGHT'S PLAN · THIN CLOUD, < 1.2″



RECOMMENDATION · ILLUSTRATIVE

WARN **OPTIMISE**

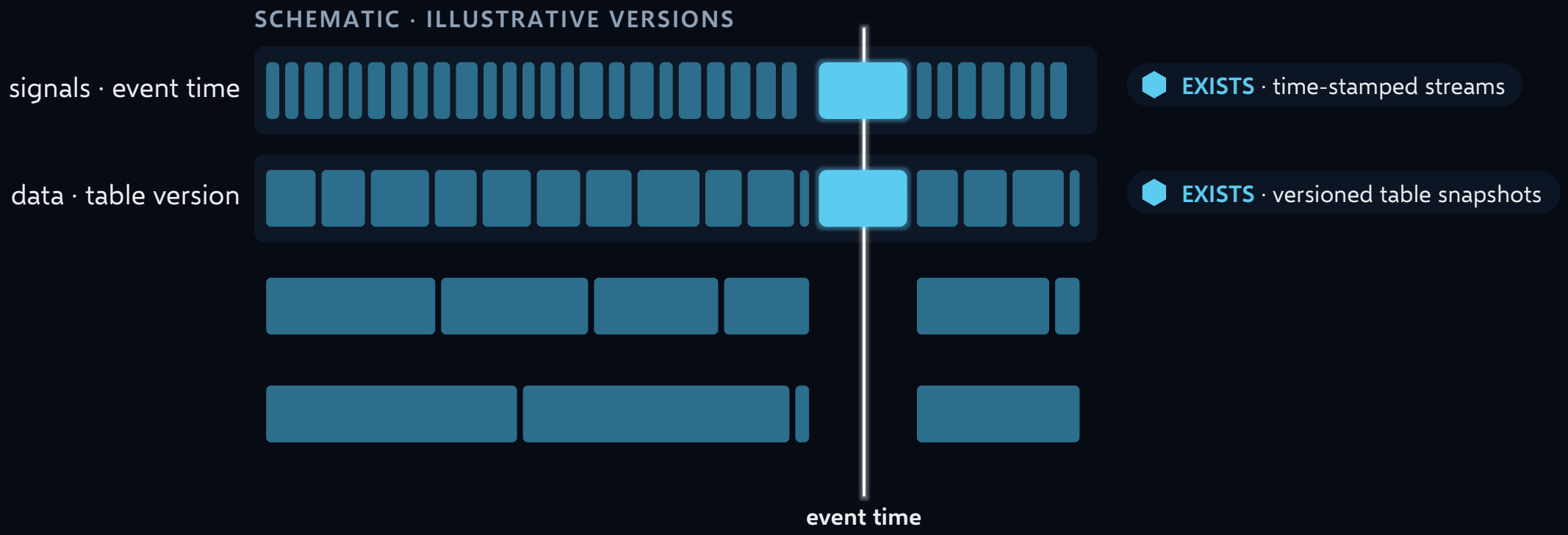
Proposes	move to the thin-cloud, < 1.2″ option
Why	thin cloud arriving, wind rising
Evidence	sky · seeing · pointing · wind · instruments
Uncertainty	stated, not hidden
Alternatives	stay on this option one more block

Operator decides

no execute button

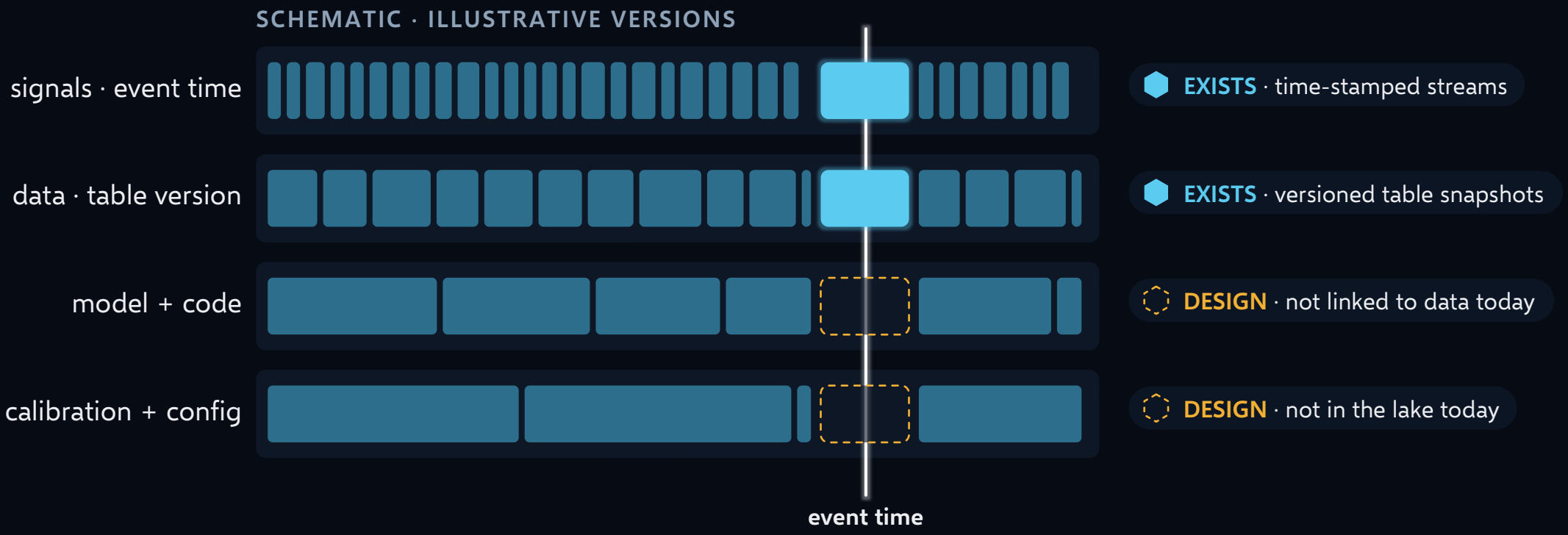
DESIGN · replay, proposed

To rerun a night, freeze the machine state



DESIGN · replay, proposed

To rerun a night, freeze the machine state



DESIGN · replay manifest, proposed

A snapshot is not a replay.



REPLAY MANIFEST

- event time
- data version
- model + code version
- calibration + config

The same problem, in any infrastructure that repeats analysis on changing data.

How far will the twin go?

WHAT IT CAN DO

capability scale · Stadtmann 2023, San 2026

- 5 Autonomous
- 4 Prescriptive
- 3 Predictive
- 2 Diagnostic
- 1 Descriptive
- 0 Standalone

WHAT IT MAY DO

what we may let it do · our concept of operations, preliminary, June 2026

- Bounded automatic protection
- Authorised actuation
- Supervised orchestration
- Recommendation
- Diagnosis
- Query
- Observation

How far will the twin go?

WHAT IT CAN DO

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WHAT IT MAY DO

what we may let it do · our concept of operations, preliminary, June 2026

- Bounded automatic protection
- Authorised actuation
- Supervised orchestration

Pilot
supervised
bounded
rehearsed

- Recommendation
- Diagnosis
- Query
- Observation

Lookout
watches
warns
recommends

DESCRIBE EXPLAIN **RECOMMEND** EXECUTE · how far

DESIGN · mapping is ours

How far will the twin go?

WHAT IT CAN DO

capability scale · Stadtmann 2023, San 2026

WHAT IT MAY DO

what we may let it do · our concept of operations, preliminary, June 2026

Captain · a person: validates, authorises, last word



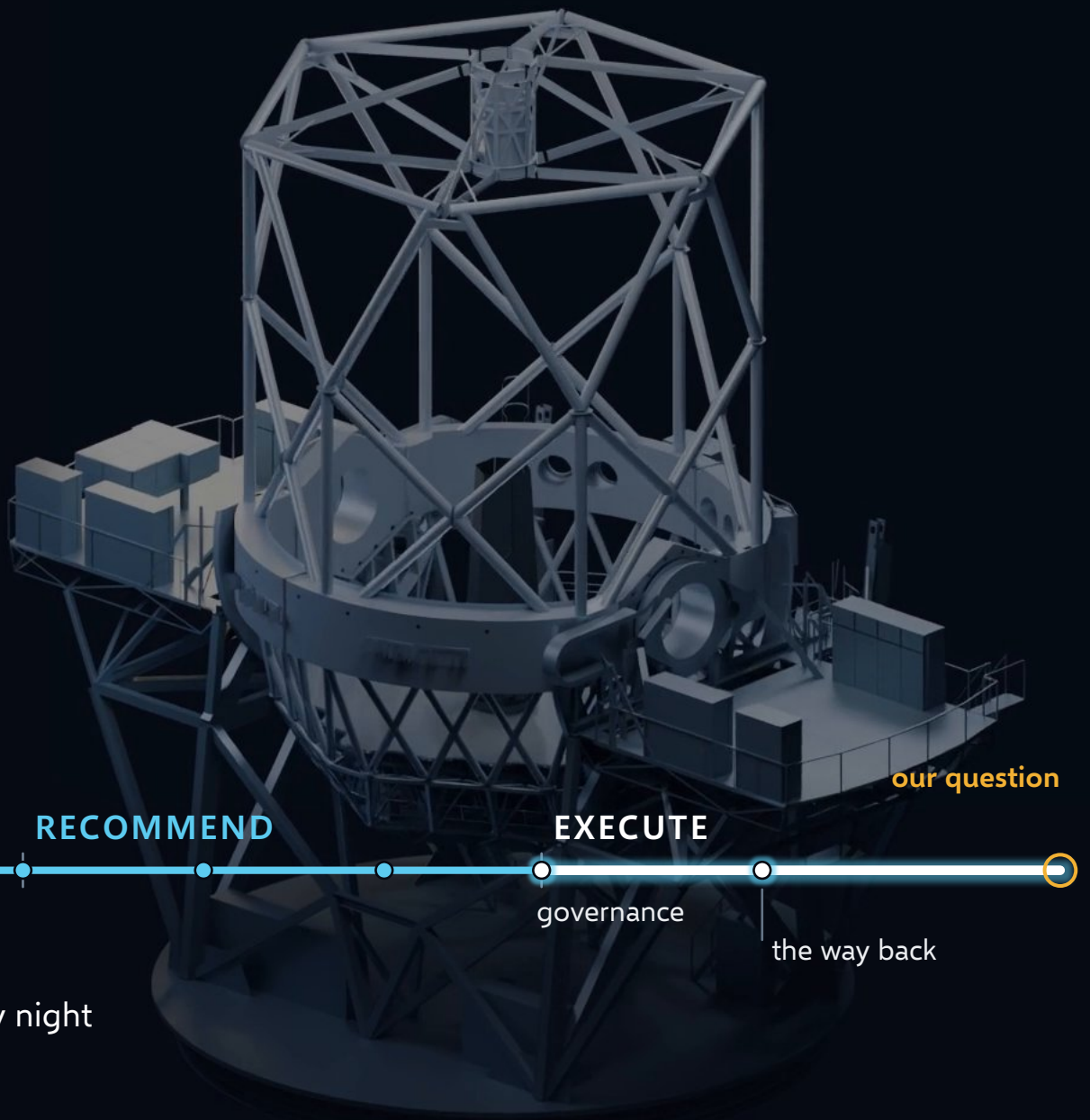
Rung 3, prediction: a capability, not a permission level

PART FOUR

EXECUTE

How do we act, safely?

WHERE WE WANT TO GO



DESCRIBE · EXPLAIN · RECOMMEND · EXECUTE

our question

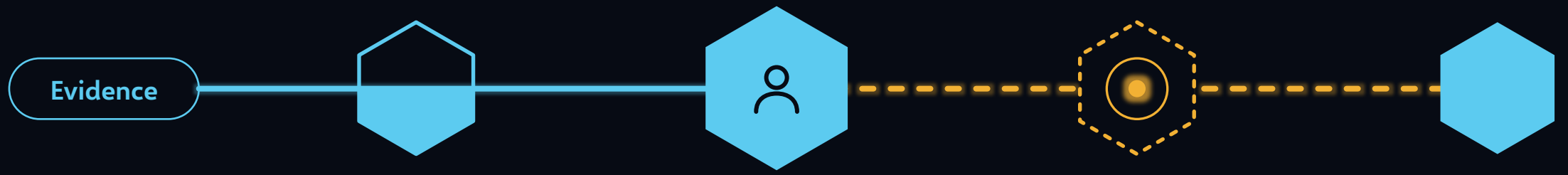
governance

the way back

Our question: warn us before it fails · help us make the most of every night

DESIGN · proposed

From recommendation to action



Reasoning

AI agents + models

EXPERIMENT · in testing

Judgment

operator or engineer

EXISTS · people decide

Governance

COMET procedures

DESIGN · in development

Execution

control system + protections

EXISTS · deterministic

Reasoning, judgment, governance, execution: after Luis Rodríguez et al. 2026

DESCRIBE · EXPLAIN · RECOMMEND · **EXECUTE** · governance

DESIGN · proposed

From recommendation to action

Evidence

Reasoning
AI agents + models

EXPERIMENT · in testing

Judgment
operator or engineer

EXISTS · people decide

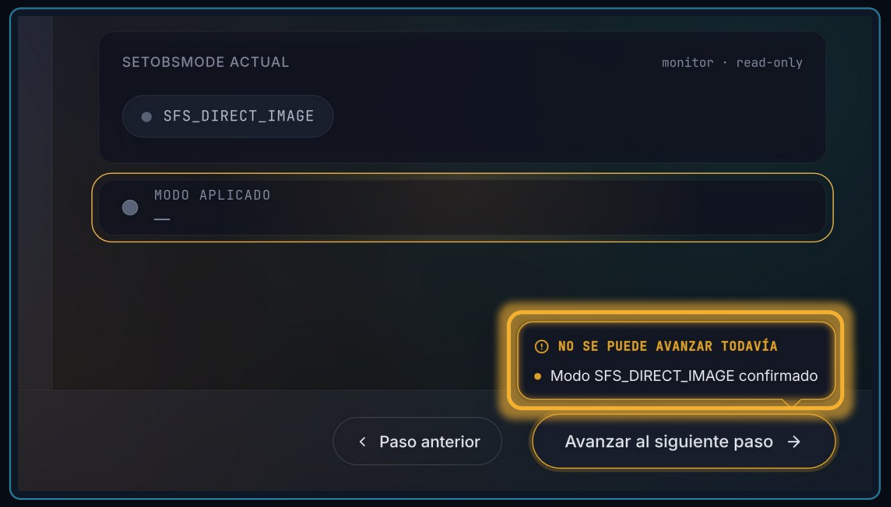
Governance
COMET procedures

DESIGN · in development

Execution
control system + protections

EXISTS · deterministic

Reasoning, judgment, governance, execution: after Luis Rodríguez et al. 2026



COMET · OUR PROCEDURE ORCHESTRATOR

A step cannot advance until its check passes.

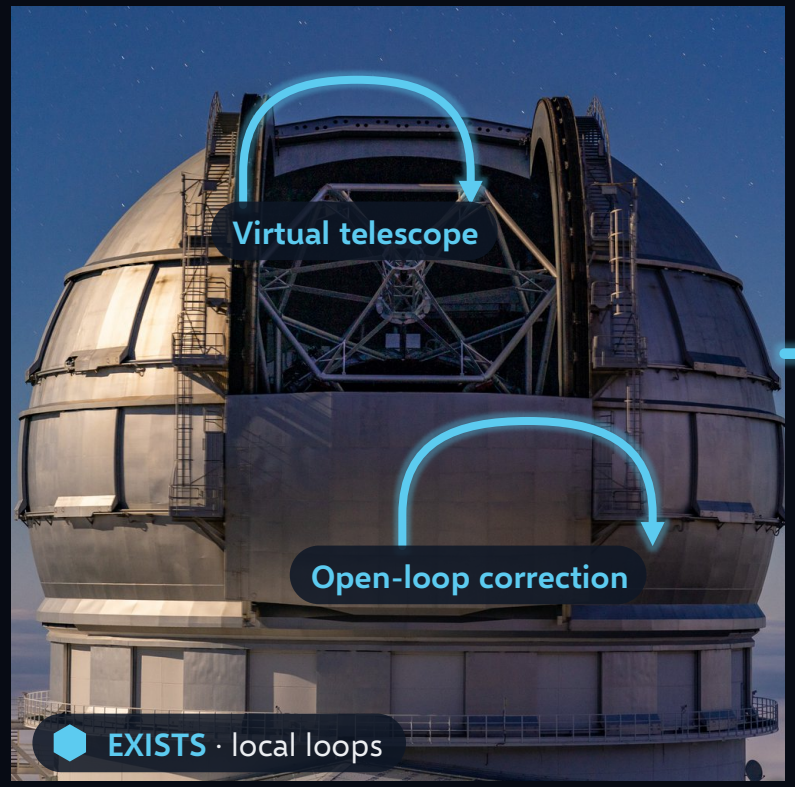
By design, every step is recorded:
who · when · which version · the result.

Prototype · real screens, sample data, no telescope

DESIGN · the way back, proposed

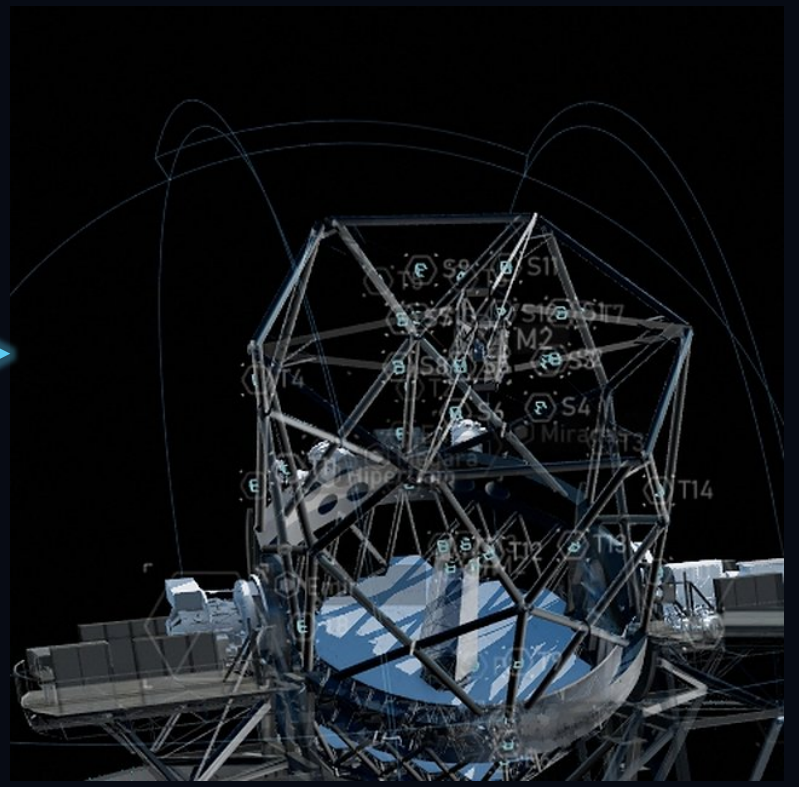
The way back

PHYSICAL TELESCOPE



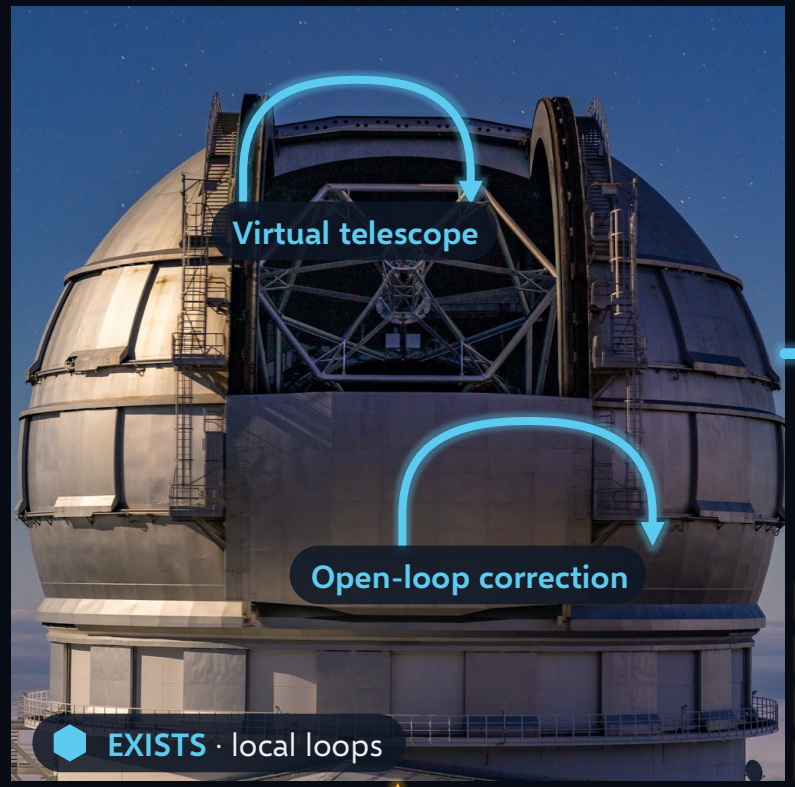
observation → shadow

DIGITAL SHADOW · ARCHIVE CAPTURE



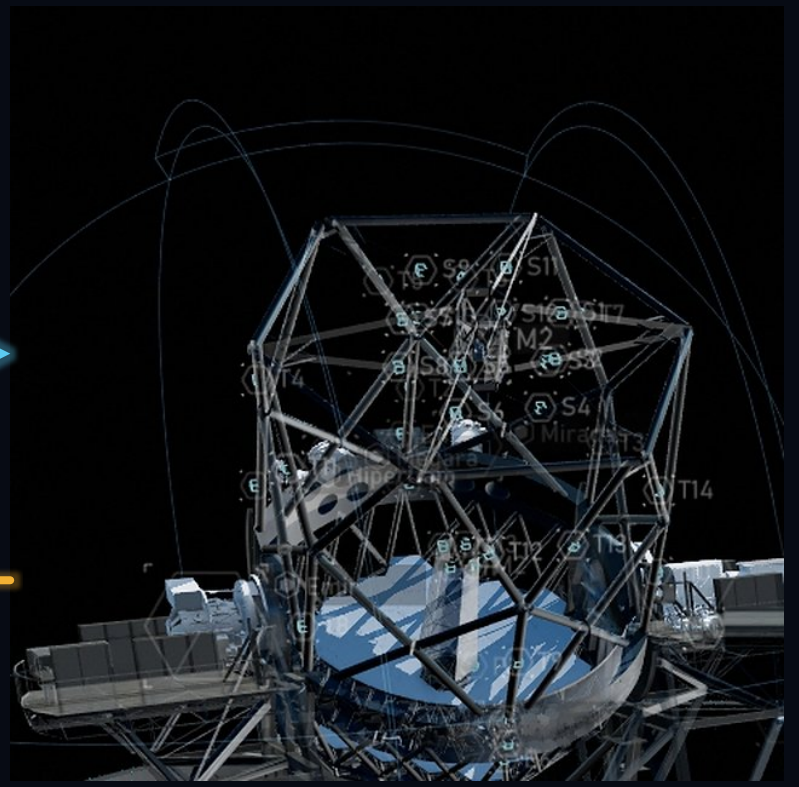
The way back

PHYSICAL TELESCOPE



observation → shadow

DIGITAL SHADOW · ARCHIVE CAPTURE



HUMAN IN THE LOOP

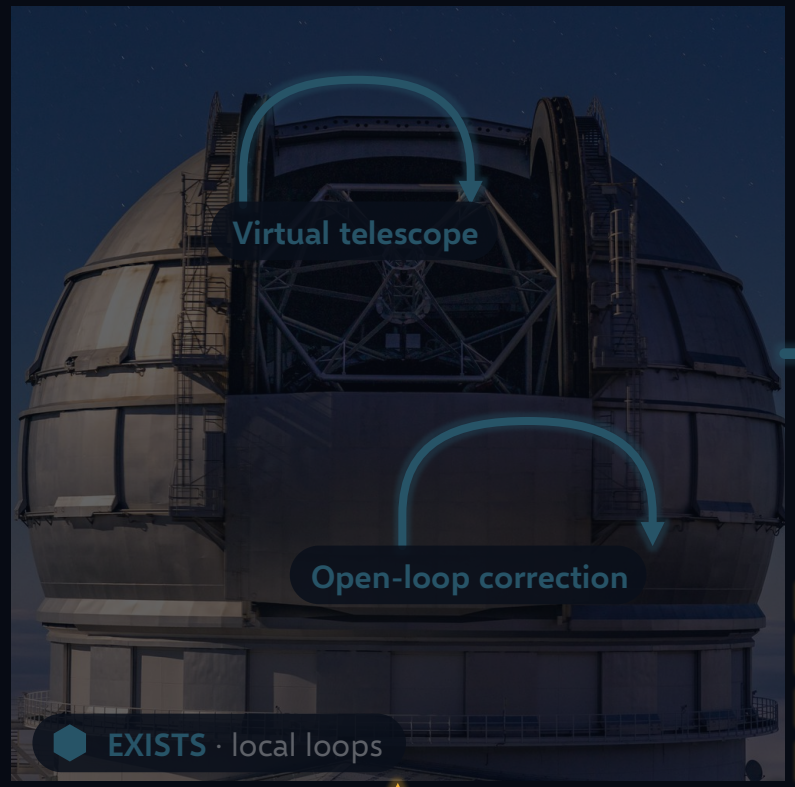
a person decides

safe connector

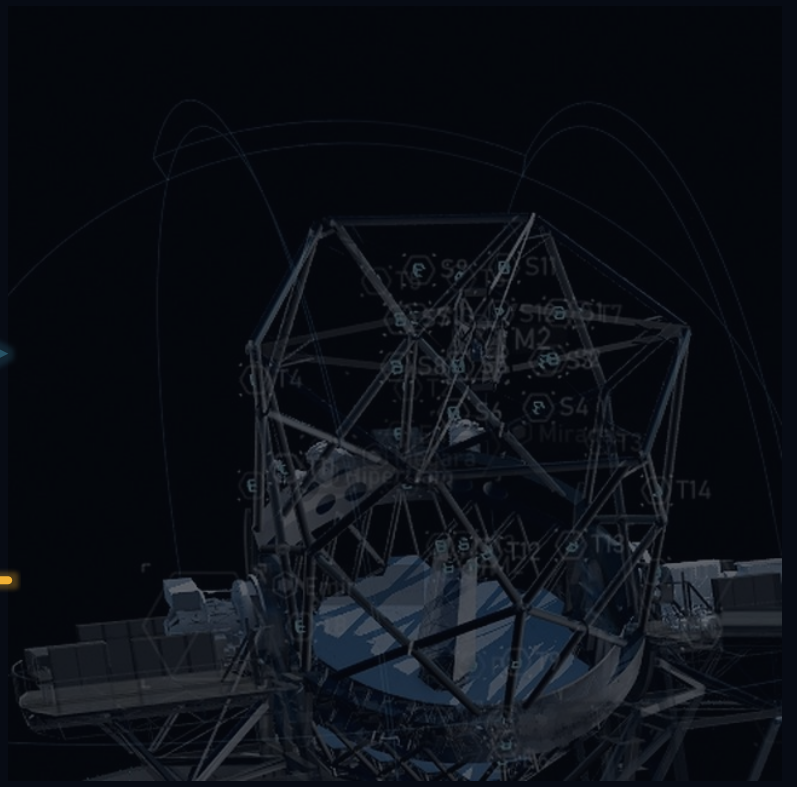
COMET procedures

The way back

PHYSICAL TELESCOPE



DIGITAL SHADOW · ARCHIVE CAPTURE



Knowing is not permission to act.

observation → shadow

HUMAN IN THE LOOP

a person decides

safe connector

COMET procedures

COMET · WHEN SOMETHING FAILS

No AI inside, isolated from the agents.

Step by step, like the procedures of pilots and NASA.

The honest summary

WHERE WE ARE

describe, and part of explain

EXISTS · today

Digital shadow · data lake

AI agents · document assistant

Virtual telescope · open-loop correction

Time-stamped signals · versioned tables

Axes anomaly detection

WHAT WE ARE WORKING ON

explain, and part of recommend

EXPERIMENT · in testing

Agent harness for faults (Prometeo)

Tracking twin · AI agent test fits

Recommendations, in development

WHERE WE WANT TO GO

recommend, and execute

DESIGN · proposed

Night-plan advice

Replay of a night

COMET procedures

The governed way back

Human in the loop: people decide, today.

The honest summary

WHERE WE ARE

describe, and part of explain

EXISTS · today

- Digital shadow · data lake
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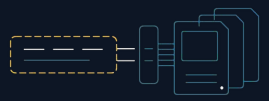
Human in the loop: people decide, today.

WHAT CAN TRAVEL TO YOUR INFRASTRUCTURE



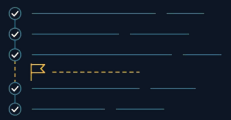
Experiment packages

a lock file for a night:
data, code, machine state



Model contracts

keep the contract,
swap the model



Agent evaluation

fluency is not
evidence

We propose a real case: the pointing model. We ask: co-design these packages with us, and rerun them.

What if the telescope could warn us
before it fails, and help us
make the most of every night?



What if the telescope could warn us before it fails, and help us make the most of every night?



Warn us before it fails?

An anomaly detector is in testing.
Next, we look back: did the secondary mirror leave early signs?

EXPERIMENT · in development

Make the most of every night?

By design: a twin that would try the night first. People decide.

DESIGN · proposed

Lose fewer nights.
Make the most of every night.

Thank you

Scan to e-mail us



DESCRIBE EXPLAIN RECOMMEND EXECUTE

A telescope that also observes itself.

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