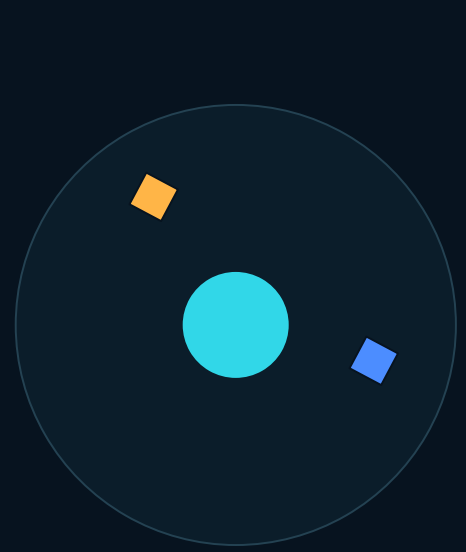
REAL-TIME SPECTRUM ANALYSIS

Real-Time Spectrum Analysis and IQ Capture for Monitoring LEO Satellite Signals



Measurement strategy for short, Doppler-shifted and adaptive emissions

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27th International Space Radio Monitoring Meeting • Bucharest, Romania

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A LEO pass compresses the measurement window

≈ 7.5 km/s

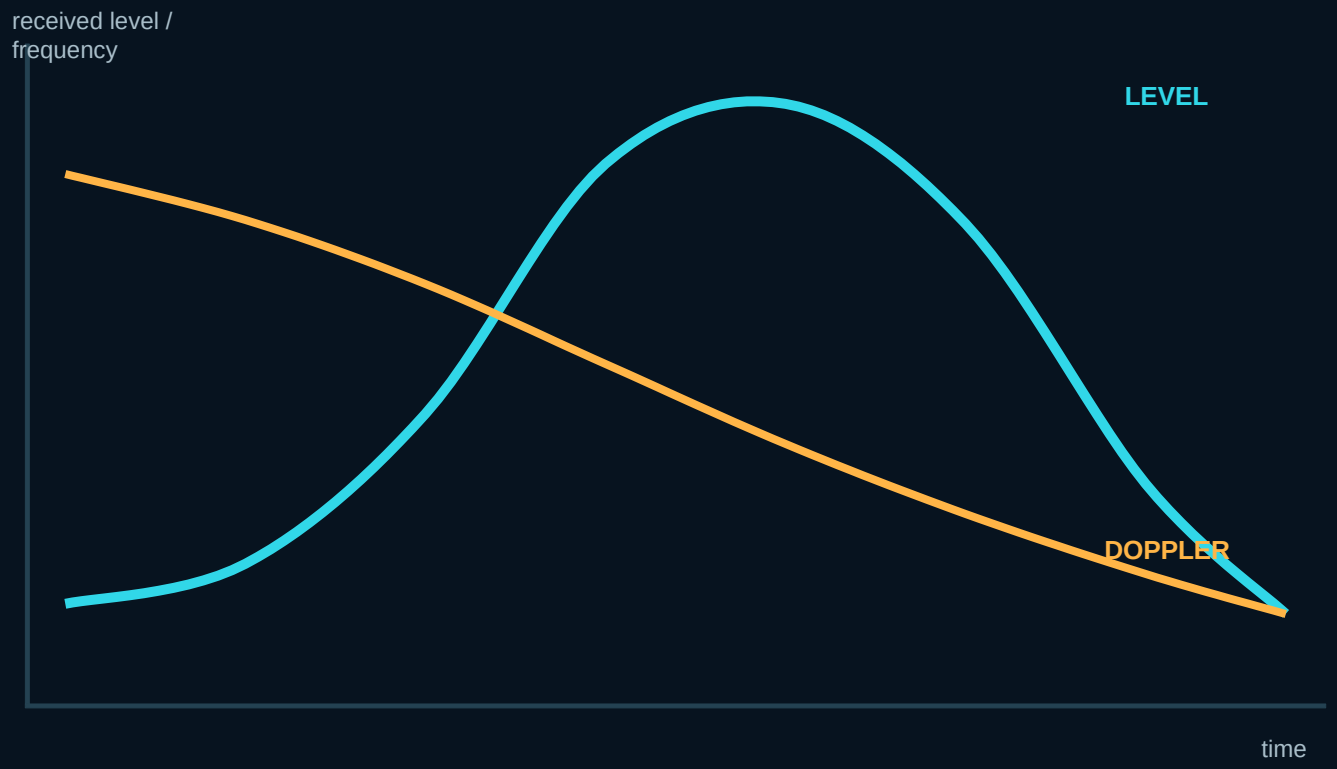
Typical orbital speed at low altitude

minutes

Useful visibility, not continuous access

continuous

Change in level, frequency and geometry

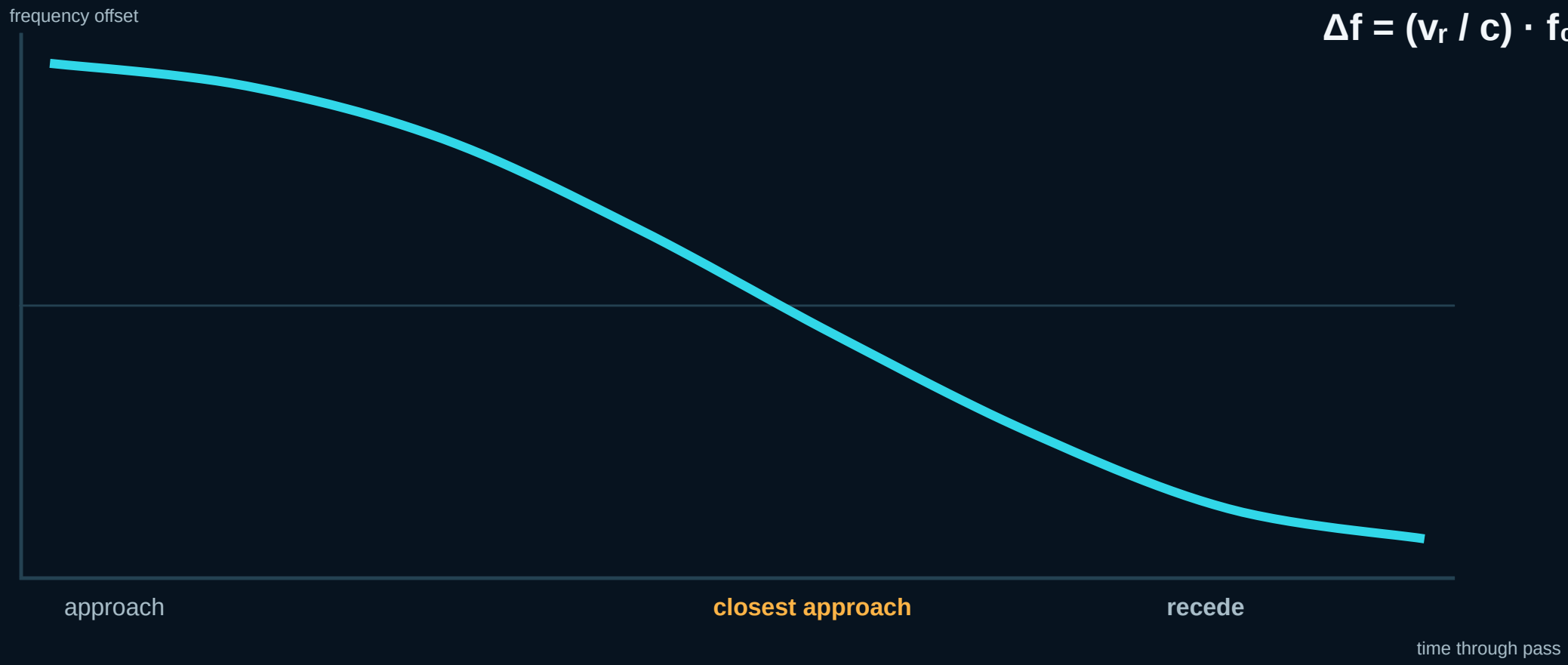


GEO assumptions fail when the emitter moves

GEO MONITORING		LEO MONITORING
Geometry	Nearly fixed	Rapidly changing
Visibility	Continuous	Short pass
Doppler	Small / stable	Large / time-varying
Occupancy	Repeatable	Burst and beam dependent
Acquisition	Tune, dwell, refine	**Detect first; analyse later**

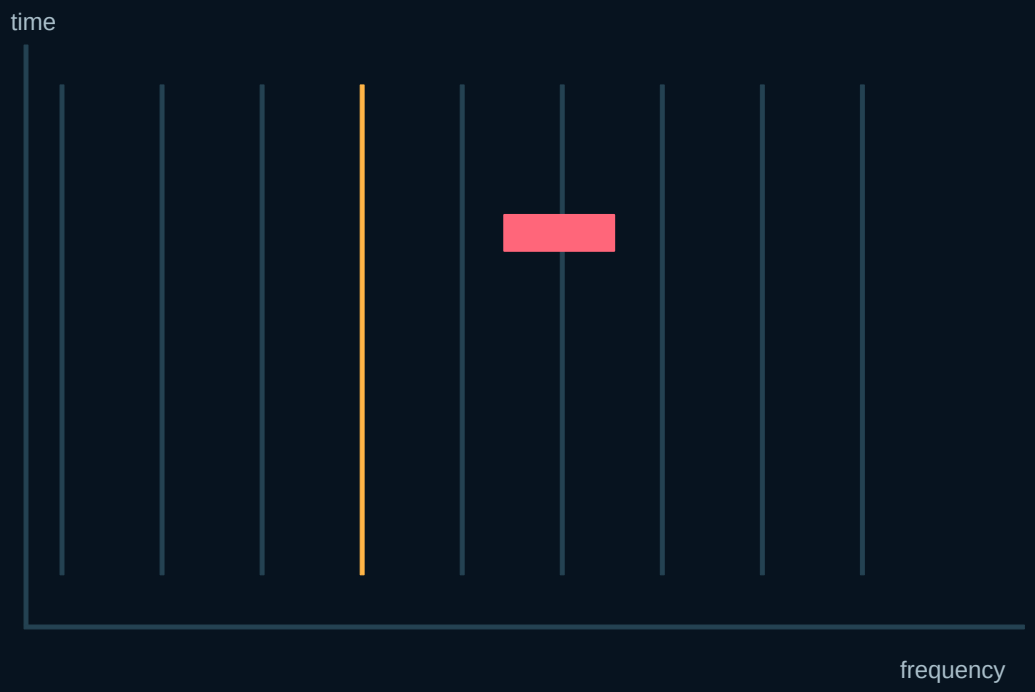
Doppler is a trajectory, not a correction value

$$\Delta f = (v_r / c) \cdot f_o$$



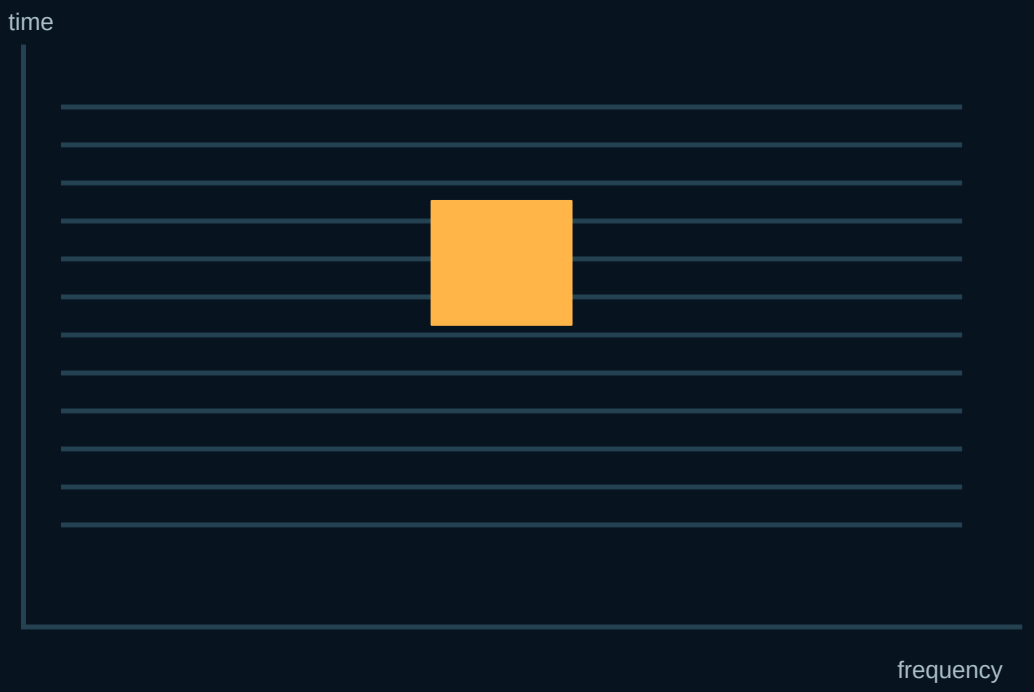
A swept trace can be correct—and still miss the event

SWEPT ANALYSIS



event occurs between sweeps

REAL-TIME ANALYSIS



event retained

Real-time bandwidth defines the observable scene

- Instantaneous bandwidth must cover signal, Doppler and uncertainty.
- FFT rate must exceed the event dynamics.
- Trigger and memory determine what survives for analysis.

Probability of intercept needs an event definition

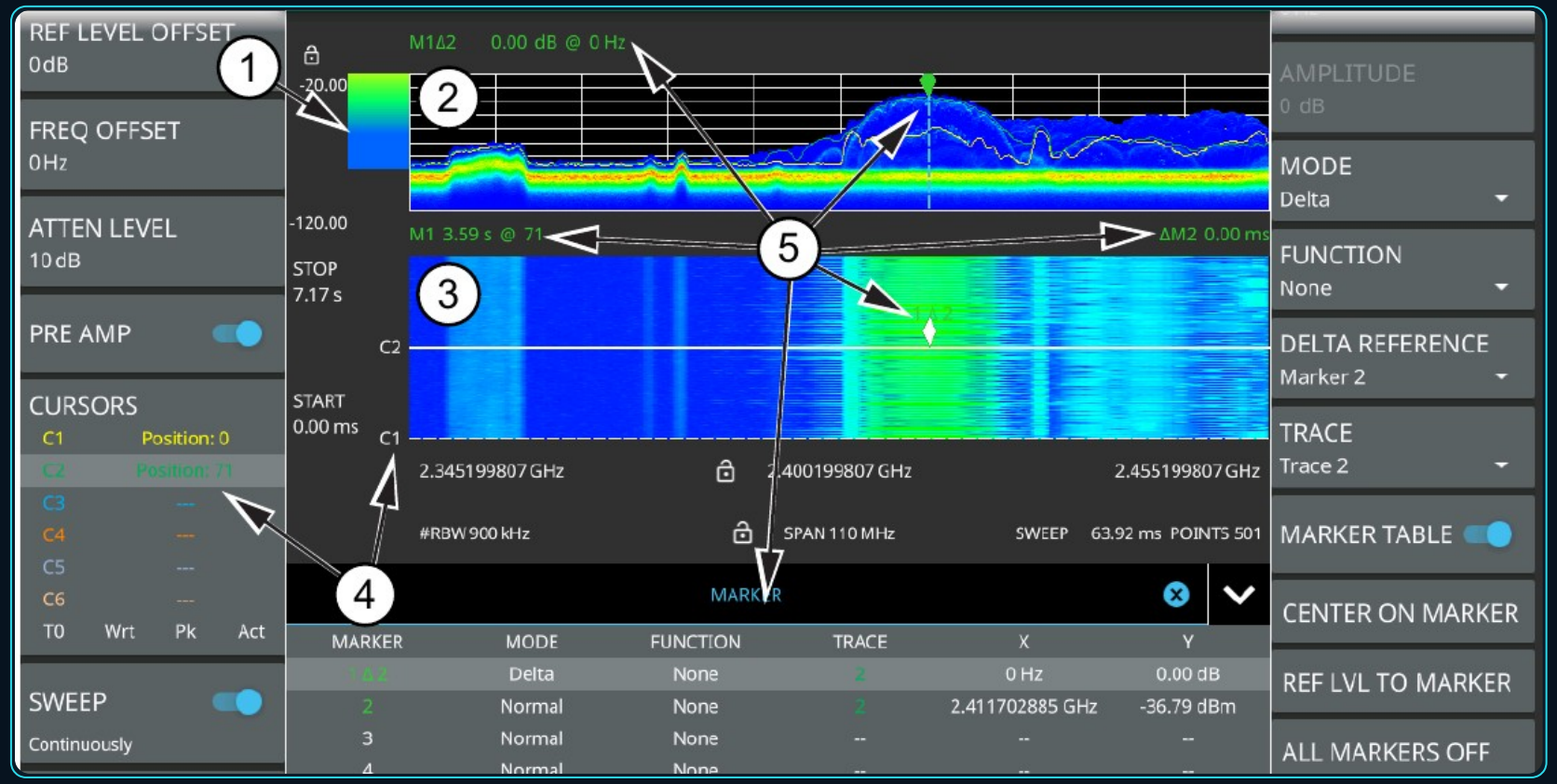
POI is meaningful only when these are stated:

EVENT DURATION	Minimum time the signal is present
AMPLITUDE	Level relative to noise and competing signals
SPAN / RBW	Analysis bandwidth and spectral resolution
DETECTOR	Criterion used to declare detection

POI

not a single
universal number

The spectrogram preserves behaviour that a trace removes



Representative Anritsu RTSA display — not a LEO field recording

- Slope → Doppler rate
- Colour → relative power
- Texture → burst structure
- Discontinuity → handover, blockage or interference

IQ capture keeps the measurement reversible

Spectrum

Power vs frequency

Fixed detector choices

IQ recording

Amplitude + phase

Reprocess at any RBW

Post-analysis

Demodulation clues

Correlation / classification

Capture once. Ask new questions later.

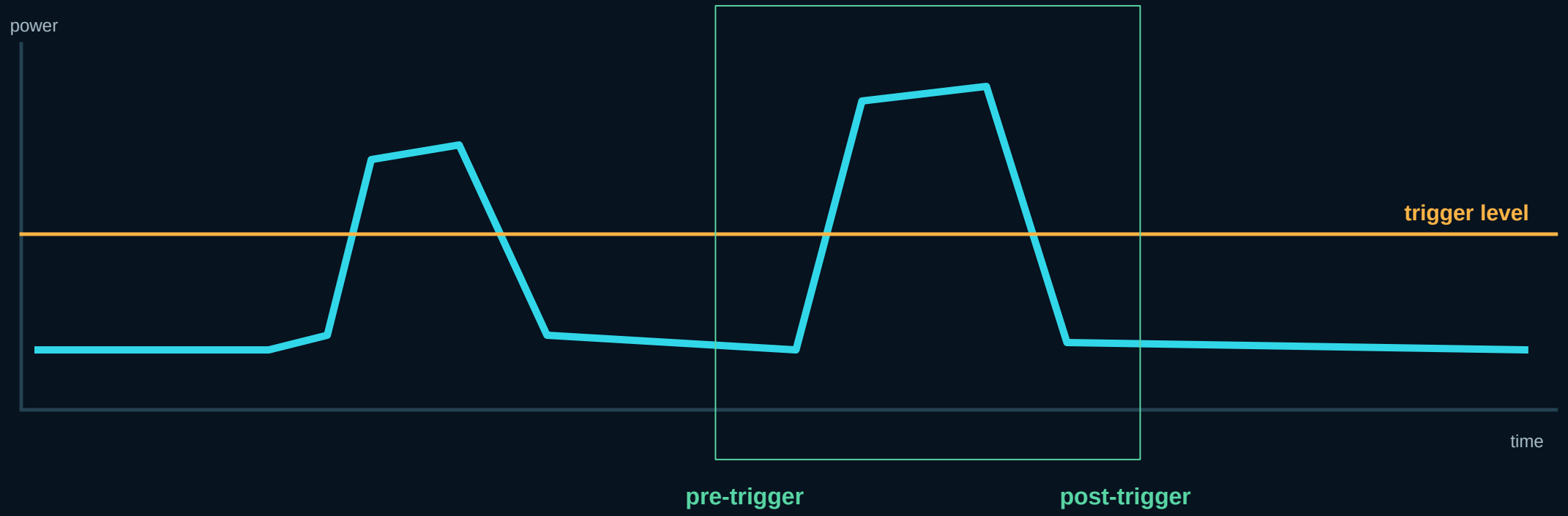
Capture bandwidth and duration compete for memory

Data rate ≈ 2 × sample rate × bits per sample

40 MS/s	16-bit I + 16-bit Q	**≈ 160 MB/s**
100 MS/s	16-bit I + 16-bit Q	**≈ 400 MB/s**
200 MS/s	16-bit I + 16-bit Q	**≈ 800 MB/s**

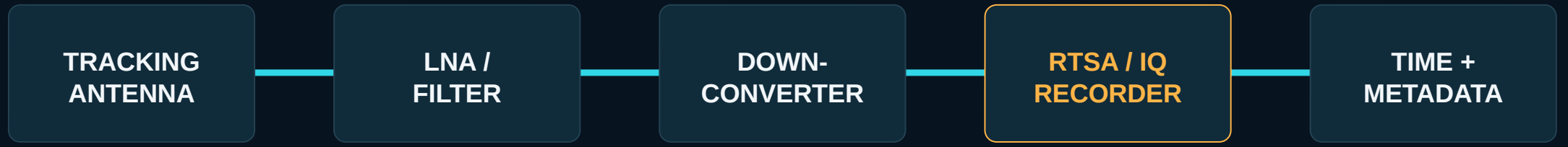
Illustrative raw throughput; file headers, packing and compression vary.

Triggering turns memory into evidence



- Power mask
- Frequency mask
- External event / pointing cue
- Scheduled pass window

The RF chain sets the credibility of every screenshot



Gain

avoid compression

Noise figure

retain weak signals

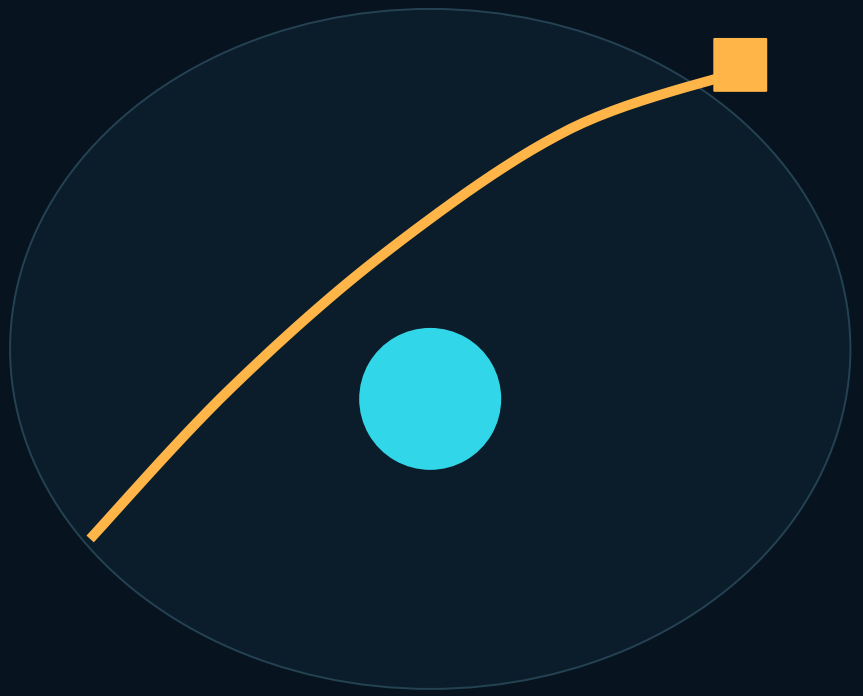
Frequency reference

support Doppler estimates

Time reference

align multi-sensor data

Antenna tracking and RF capture must share time



az / el / range

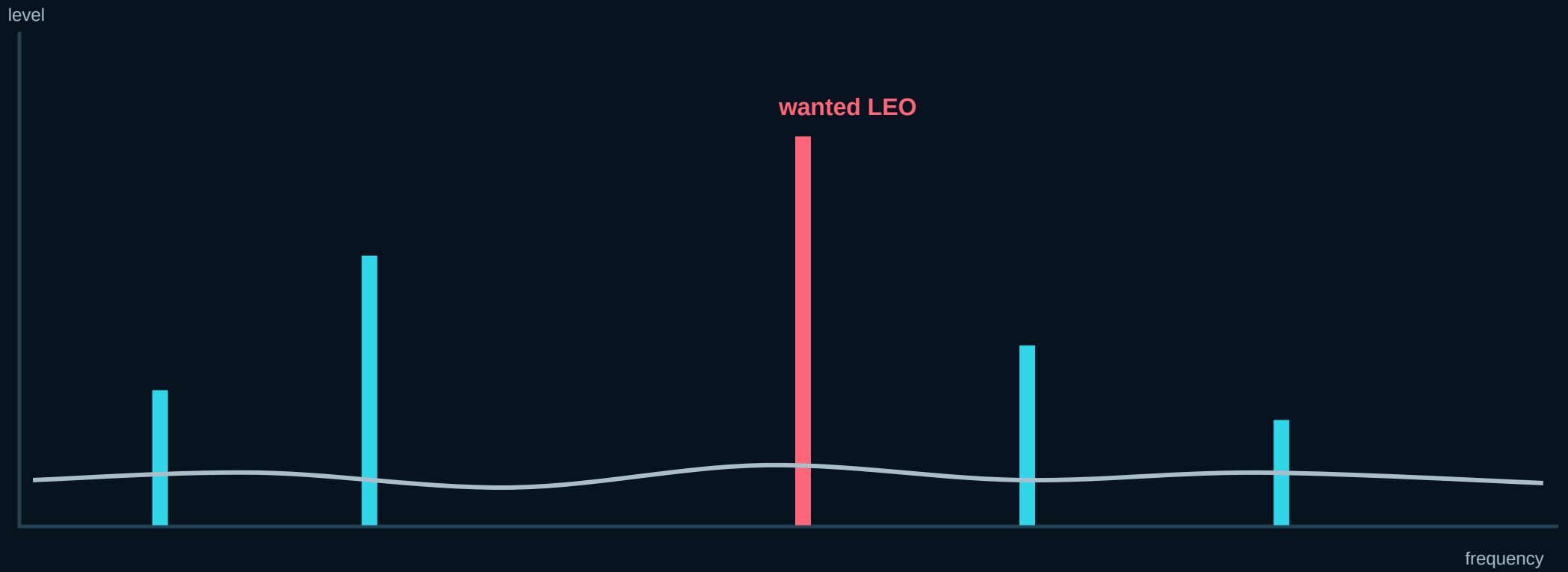
TLE / ephemeris

antenna position

RF samples

trigger / events

Dynamic range matters more than a clean noise floor

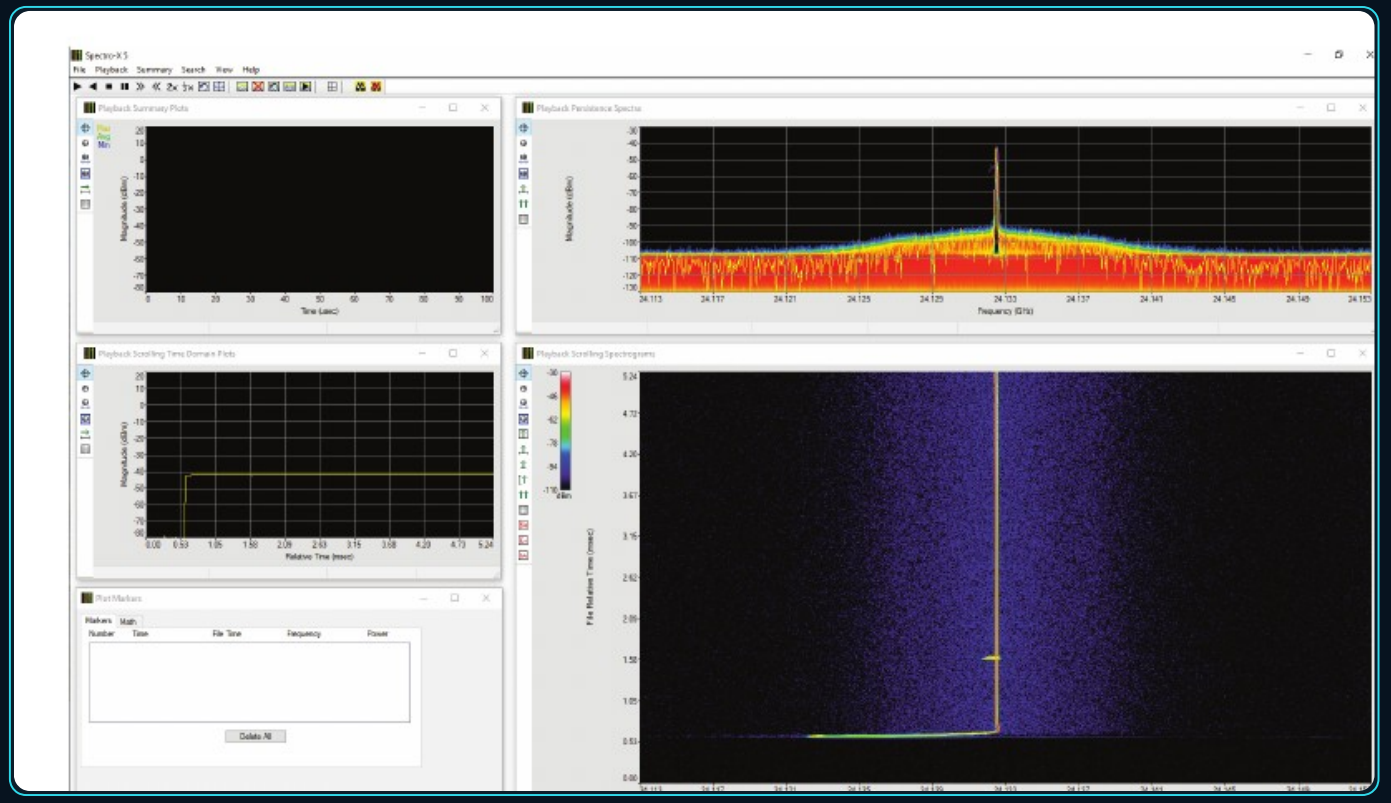


- Check input attenuation and preamplifier state.
- Verify no compression with a level step.
- Use preselection when the RF environment demands it.

Measurement settings are part of the result

UTC start / stop	MANDATORY
Centre / span	MANDATORY
RBW / FFT length	MANDATORY
Detector / averaging	MANDATORY
Ref level / attenuation	MANDATORY
Preamp / preselector	MANDATORY
Antenna az / el	RECOMMENDED
Ephemeris source	RECOMMENDED
IQ format / scale	MANDATORY
Calibration state	MANDATORY

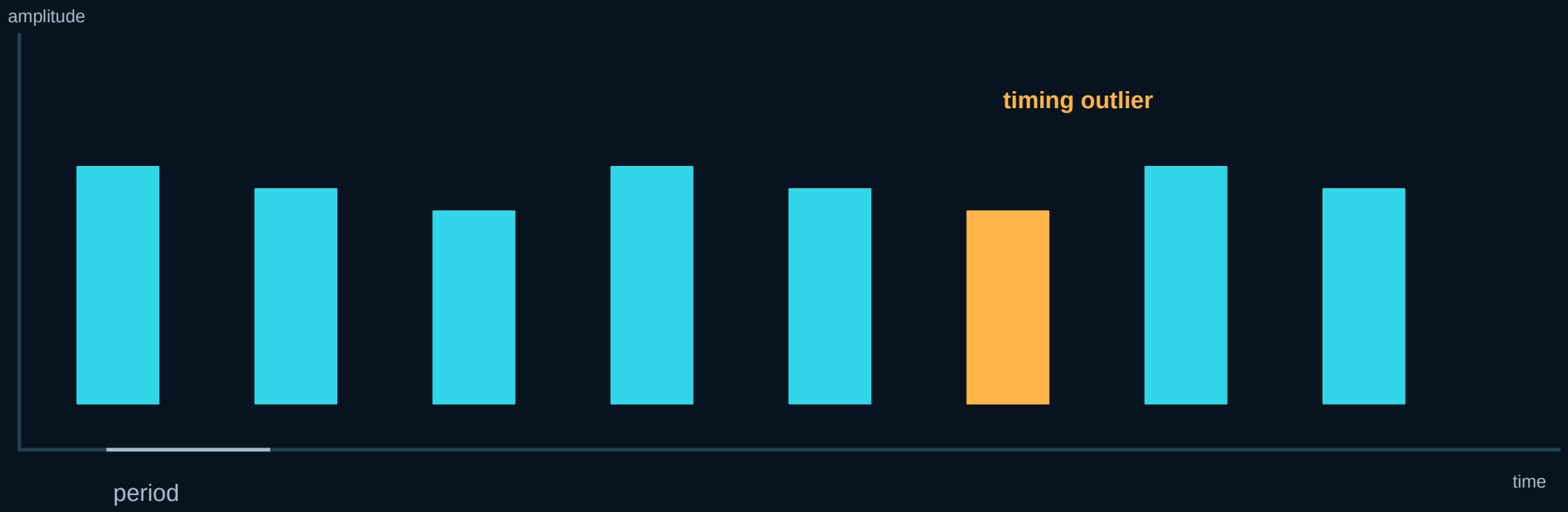
Case pattern: a chirp may be orbit, control or interference



Representative IQ playback display — not a LEO field recording

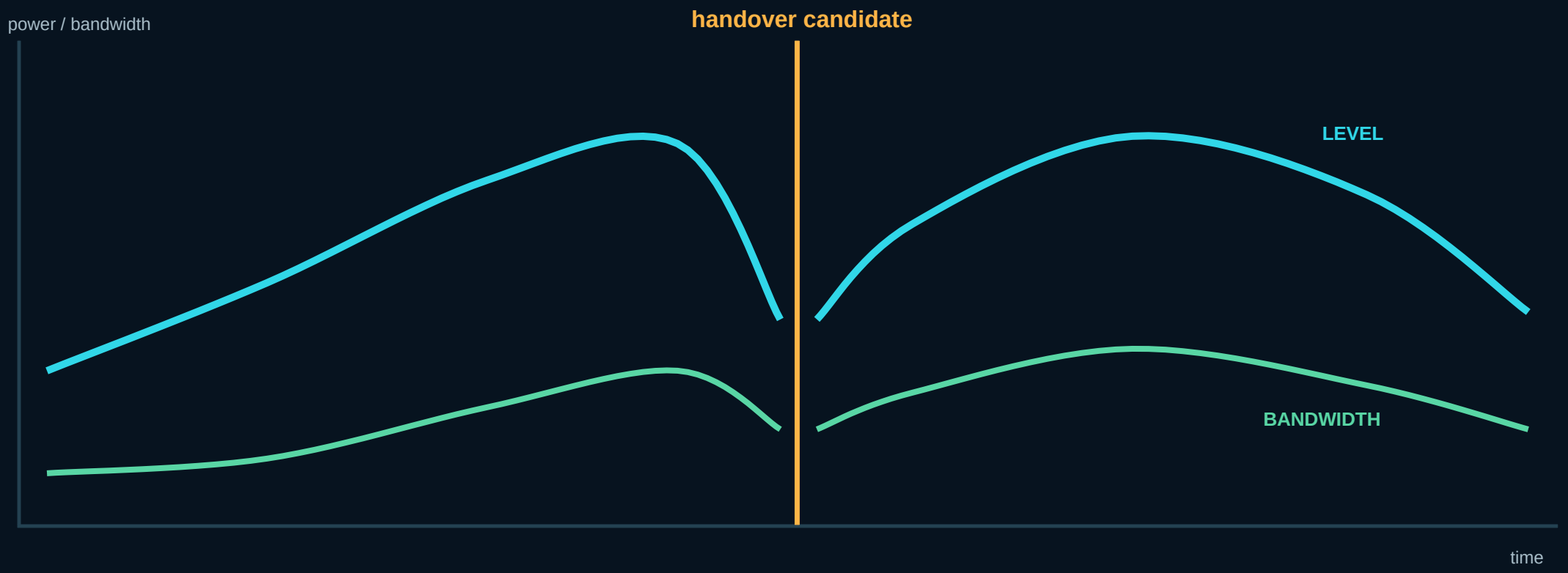
- Does the slope match predicted Doppler?
- Is the feature coherent across sensors?
- Does timing align with pointing or beam handover?
- **Can the IQ replay reproduce the anomaly?**

Case pattern: burst timing reveals access behaviour



- Estimate repetition interval and duty cycle.
- Compare occupied bandwidth per burst.
- Export IQ around onset and termination.

Case pattern: beam handover leaves a measurable seam



Interference diagnosis starts with correlation

TIME

When?

FREQUENCY

Where?

SPACE

Which direction?

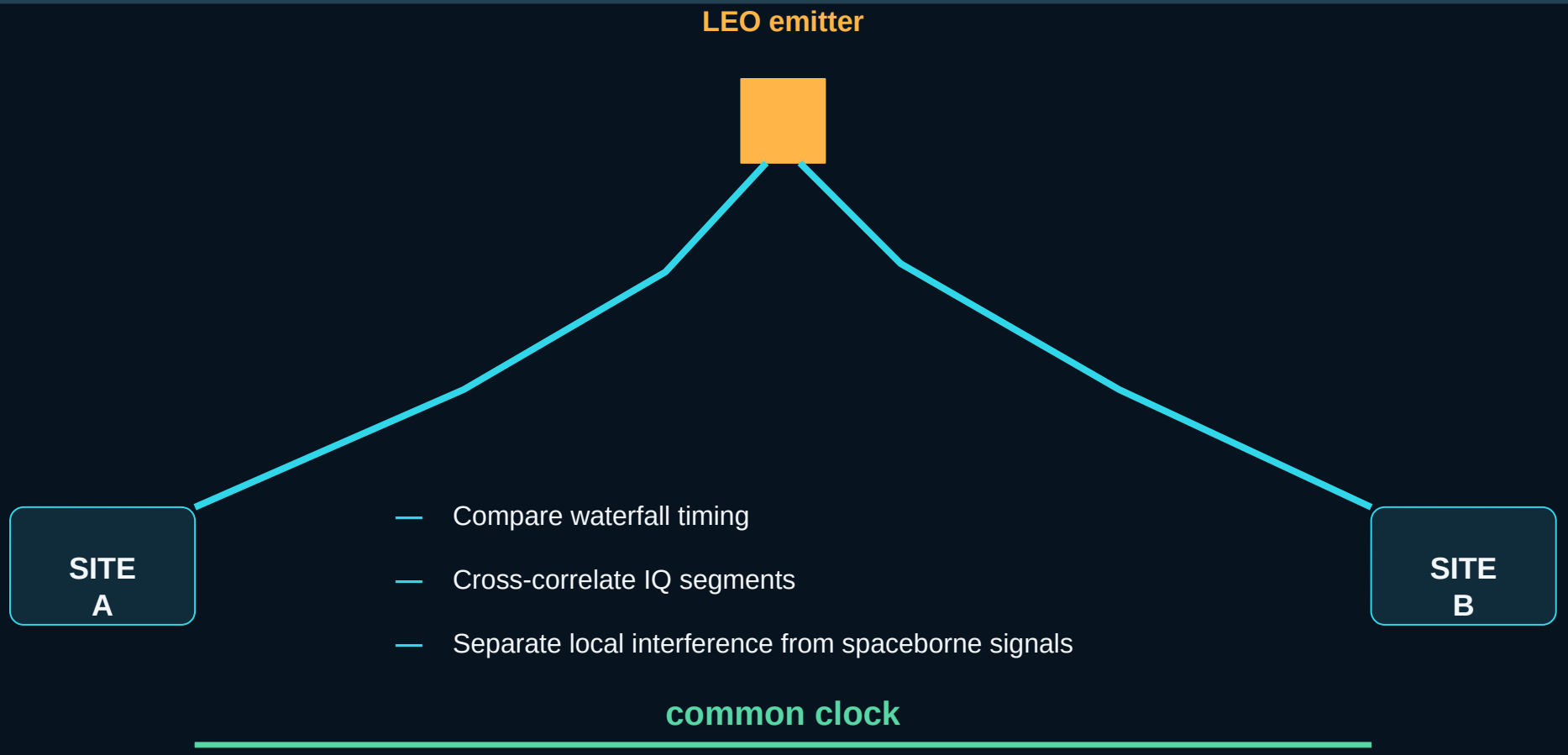
SIGNAL

What waveform?

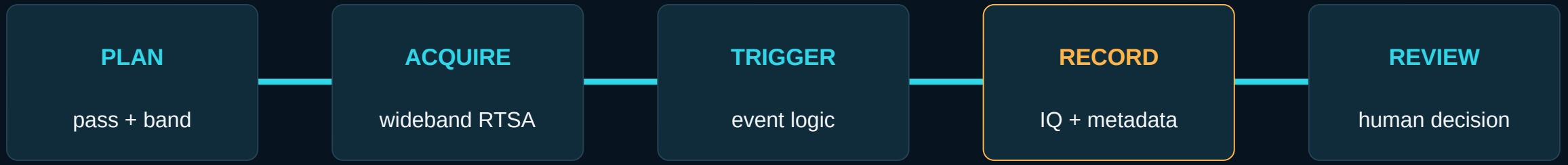
ATTRIBUTION

No single screenshot establishes origin.

Two synchronized sites add more than two screenshots



Automation should preserve context, not only alarms



Archive raw evidence, settings and decision trail together.

- Automate pass scheduling and file naming.
- Keep thresholds version-controlled.
- Flag, do not silently discard, borderline events.

Instrument selection starts with the signal envelope

FREQUENCY	band + converter plan	**RT BANDWIDTH**	signal + Doppler + margin
POI	defined event conditions	**DYNAMIC RANGE**	actual RF environment
IQ MEMORY	bandwidth × duration	**CLOCKING**	10 MHz / PPS / PTP needs
TRIGGERING	mask, level, external	**EXPORT**	open IQ + metadata

Ask for a representative capture—not only a specification sheet.

Portable RTSA turns a short pass into reviewable evidence

150 MHz

maximum RTSA bandwidth
(option dependent)

9 kHz–54 GHz

frequency coverage
(model dependent)

FIELD ROLE

- Portable monitoring at the antenna site
- Density / spectrogram for transient detection
- IQ capture and streaming for offline replay
- Timing options for coordinated measurements

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Advancing beyond

22 MHz RTSA is standard; wider real-time bandwidths require options.

Selection should follow the signal envelope and the required probability of intercept.

Wide analysis bandwidth exposes the complete waveform context

1 GHz

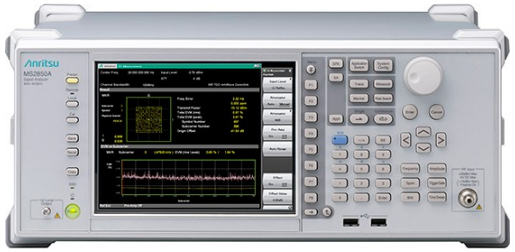
maximum analysis bandwidth (option)

255 MHz

standard analysis bandwidth

LAB ROLE

- Wideband waveform and multicarrier analysis
- Spectrum, spectrogram and FFT inspection
- Amplitude and phase analysis across wide signals
- Satellite, broadcast and mmWave development



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Advancing beyond

Important: 1 GHz is analysis bandwidth — not RTSA bandwidth.

Frequency coverage is configuration dependent: up to 44.5 GHz.

A field procedure should fit on one page

BEFORE

Load pass data
Check references
Set gain / span

DURING

Verify tracking
Watch overload
Mark anomalies

AFTER

Validate files
Export metadata
Create evidence hash

Rehearse the workflow with a known signal before the target pass.

Three principles make LEO monitoring defensible

01

Detect without dead time

RTSA finds the event.

02

Record IQ with context

IQ keeps it open to analysis.

03

Correlate before attribution

Metadata makes it evidence.

The objective is not a better screenshot. It is a repeatable measurement.