

Turning 6G Satellites into Sensors:

Joint Communications and Sensing in Non-Terrestrial Networks



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Presentation Outline

01 The Macro Problem — Overcrowding & single-purpose constraints

02 The MFSS Paradigm — Multi-Functional Satellite Systems

03 Operational JCAS-NTN Applications — Weather, altimetry, maritime & SAR

04 Physical-Layer Realities — Radar link budgets & waveforms

05 Signals of Opportunity — Near-term bistatic sensing

06 Research Ecosystem — Projects & hardware demonstrators

Section 1: The Macro Problem

Overcrowding & The Sustainability Challenge

The State of Earth's Orbit: Overcrowded & LEO-Dominated

■ The LEO SatCom Explosion

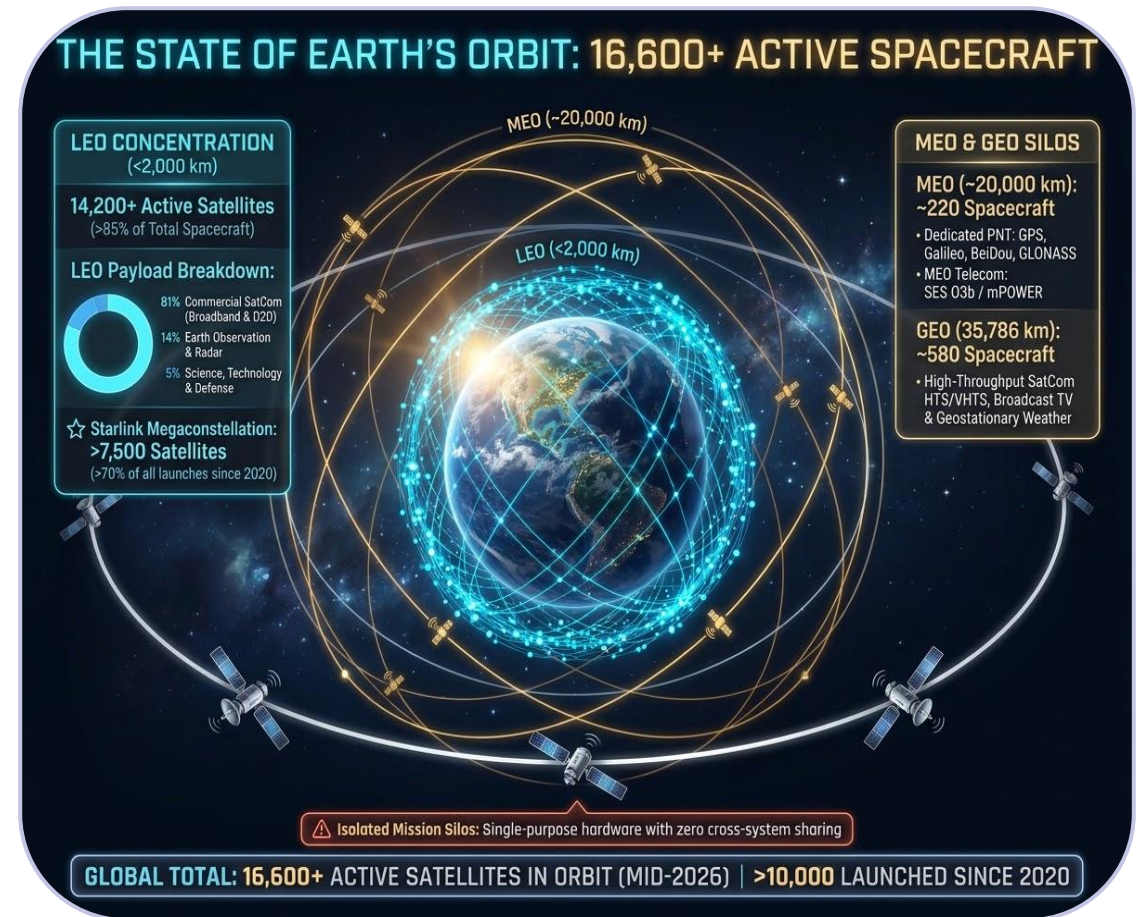
- ~16,000+ spacecraft in orbit (Starlink >67%)
- >90% concentrated in <2,000 km LEO orbits

■ Severe Mission Imbalance

- SatCom represents >81% of all LEO payloads
- Earth Observation (EO) is only ~14%

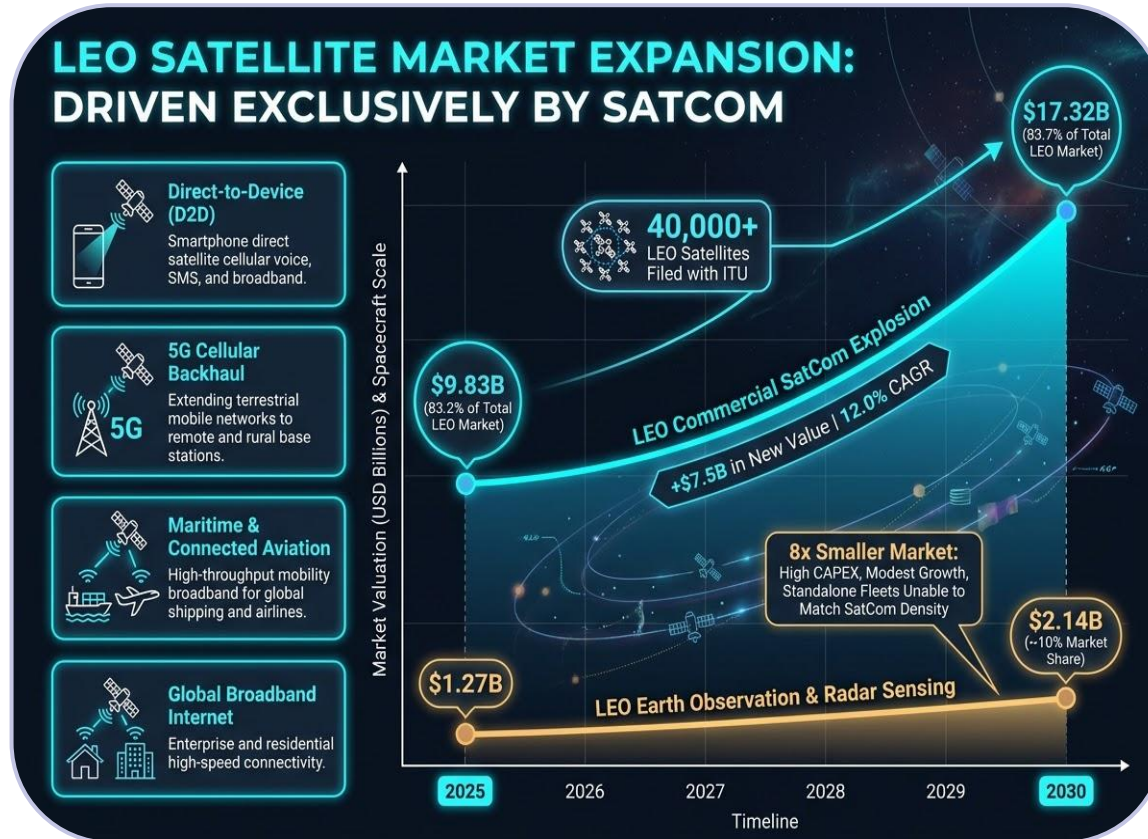
■ The Architectural Flaw

- Isolated mission silos: Single-purpose/operator fleets
- Drives extreme overcrowding and spectrum saturation



Reference: Celestrak & J. McDowell space catalogues (Oct. 2026); UCS Satellite Database (historical baseline); MarketsandMarkets. Counts are estimates.

LEO Satellite Market Expansion: Driven Exclusively by SatCom



■ SatCom Dominates Commercial Space

- Projected \$17.3B by 2030 (12% CAGR)
- Captures >80% of LEO market value

■ The Earth Observation (EO) Bottleneck

- EO market is 8× smaller than SatCom

■ Overcrowding by 2030 and beyond

- 40,000+ commercial SatCom filings approved for single-operator silos
- 1,000,000+ satellites in regulatory pipelines (ITU & SpaceX FCC filing)

■ Where is the limit?

- Measures urgently needed for the sake of Space Sustainability

Source: MarketsandMarkets (2025); A. Falle et al., Science (2023); D. Lei & A. Saeed, ACM LEO-NET (2024); SpaceNews / FCC (2026).

The Sustainability Crisis: The Need for Convergence

■ The Dual Paradox

- EO revisit gap: Days/weeks to revisit targets
- Irregular demand: SatCom idles over poles and oceans (>70% of Earth) or day/night operations

■ Multi-Functional Satellite Solution (MFSS)

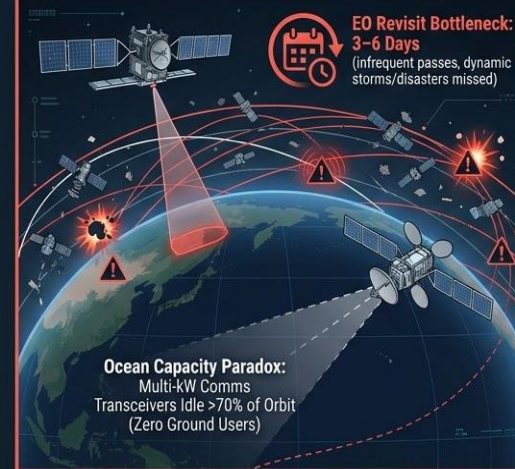
- Unifies 5G/6G (multi-tenant), radar, and PNT on shared hardware and launch

■ Strategic Advantages

- Sub-hourly planetary revisit times / PNT diversity
- Drastic CAPEX reduction via shared buses
- High spectral and energy efficiency

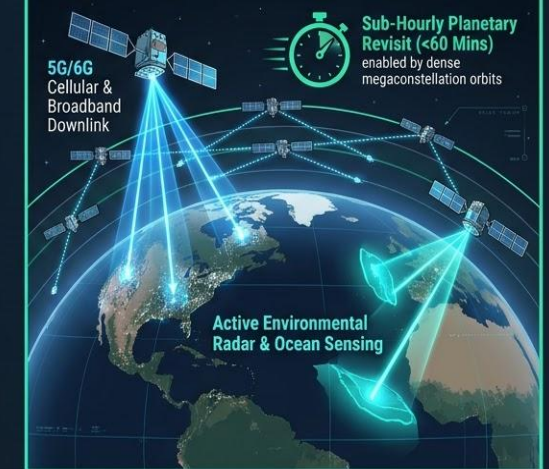
ORBITAL SUSTAINABILITY: THE CONVERGENCE IMPERATIVE

CURRENT REALITY: DEDICATED MISSION SILOS



- ⚠ **Temporal Gaps:**
Days to weeks between radar/optical revisit passes
- ⚠ **Wasted Payload Capacity:**
High-power comms payloads idle over oceans & poles
- ⚠ **Unsustainable Fleet CAPEX:** Multiplying single-purpose fleets escalates Kessler syndrome risks

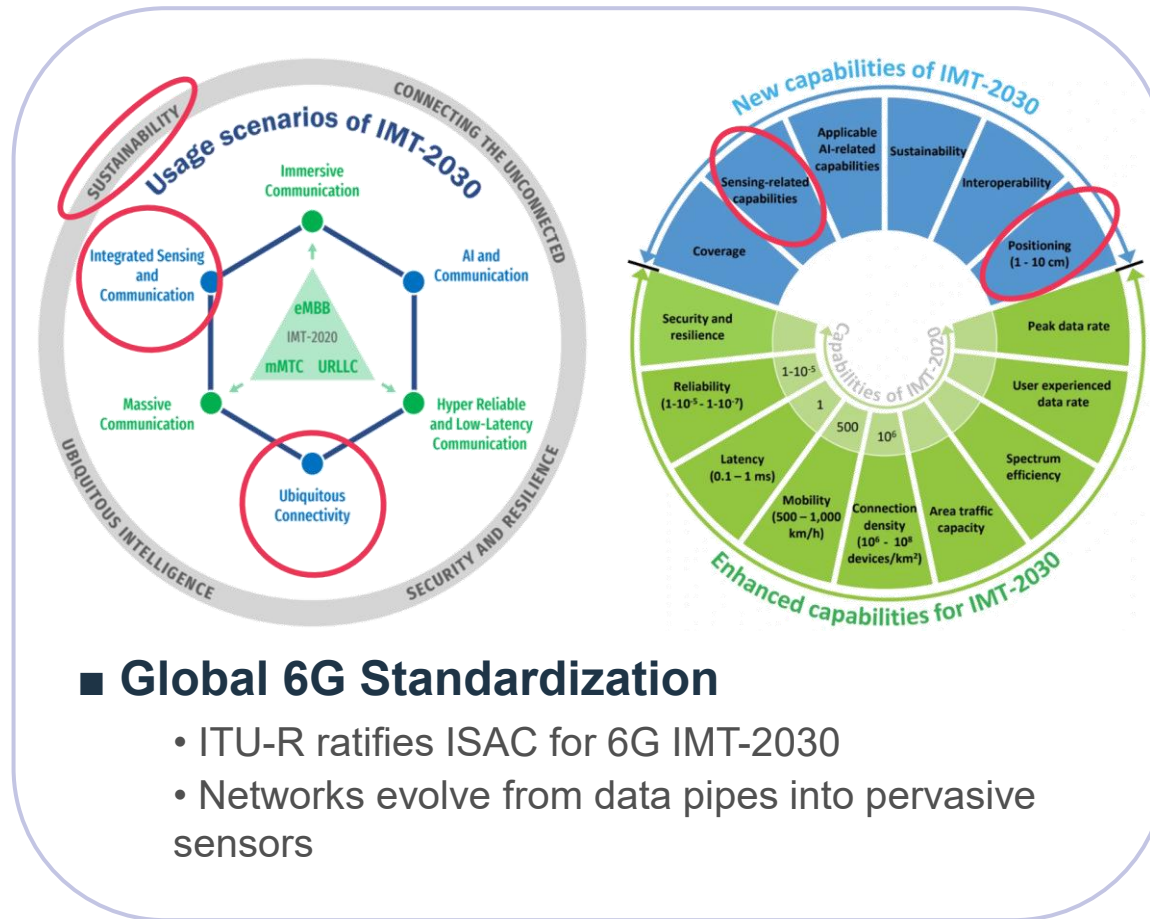
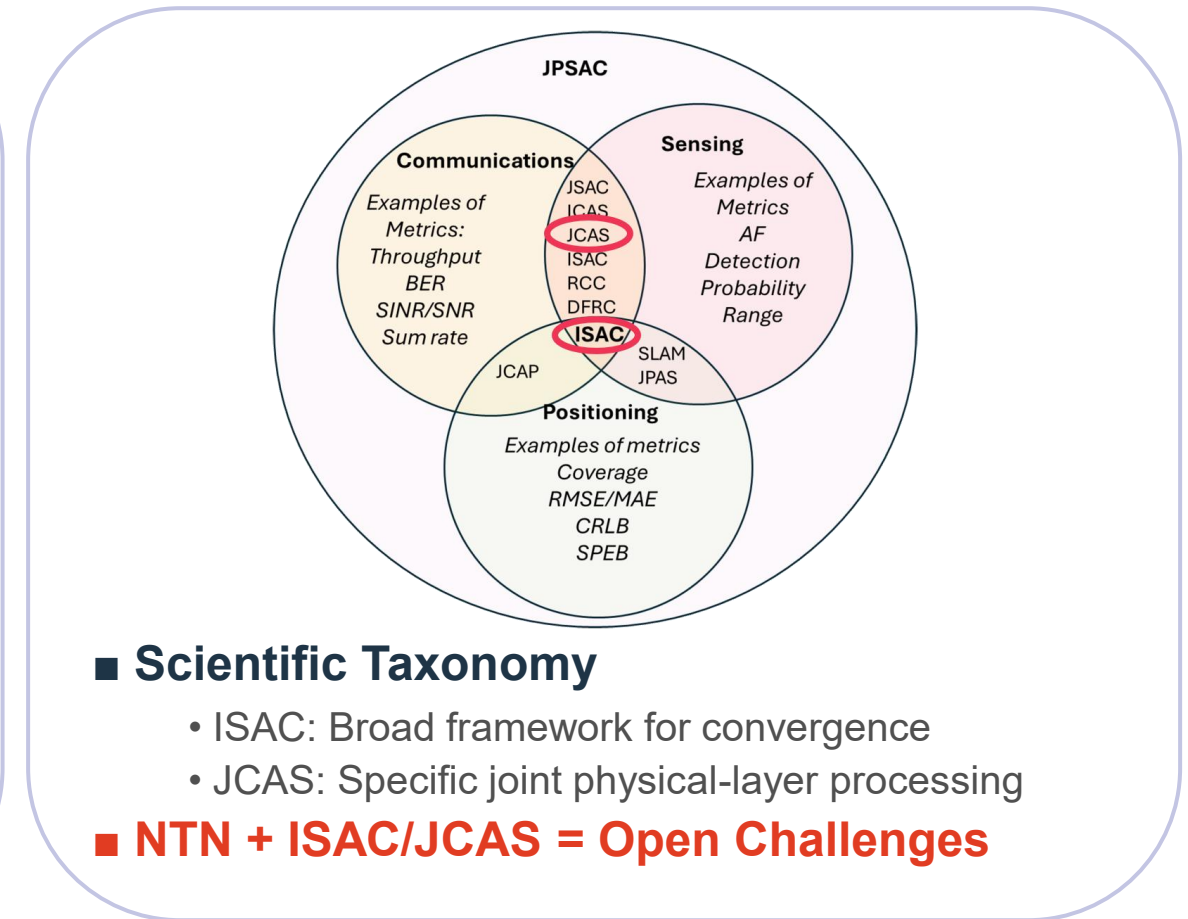
THE FUTURE: MULTI-FUNCTIONAL SATELLITE SYSTEMS (MFSS)



- ✓ **Sub-Hourly Planetary Revisit:**
Continuous global environmental and disaster tracking
- ✓ **Shared Hardware & Spectrum:**
Wideband SDR and phased array antenna reuse
- ✓ **Halved Fleet CAPEX & Launch Mass:**
Maximized orbital sustainability and spectral efficiency

Reference: ESA Space Environment Report 2025; J. Querol et al., IEEE ISAC 2026. Values in graphic are illustrative.

The 6G NTN Vision: Standardizing ISAC as a Native Pillar



Reference: Rec. ITU-R M.2160-0 (11/2023); F. Liu et al., "Integrated Sensing and Communications: Toward Dual-Functional Wireless Networks for 6G and Beyond," IEEE JSAC, 2022.

Section 2: The Architectural Paradigm

Multi-Functional Satellite Systems (MFSS)

Level 1: Co-Located Systems (Hosted Payloads)

■ Shared Satellite Bus

- Shared power, thermal, and structure
- Zero RF sharing: Separate antennas and basebands

■ Hosted Payloads

- Guest instrument on primary commercial spacecraft
- Operates fully independently

■ Flight Benchmark: Aireon on Iridium NEXT

- Aireon ADS-B receiver for air traffic
- Iridium L-band communications payload



Reference: Sheemar, Querol et al., arXiv:2509.25937 (2025); Aireon / Iridium NEXT.

Level 2: Cooperative Systems (Payload Characteristics)

■ Shared Digital OBP and RF Front-End

- Shared payload and wideband SDR
- Antenna & processing remains decoupled

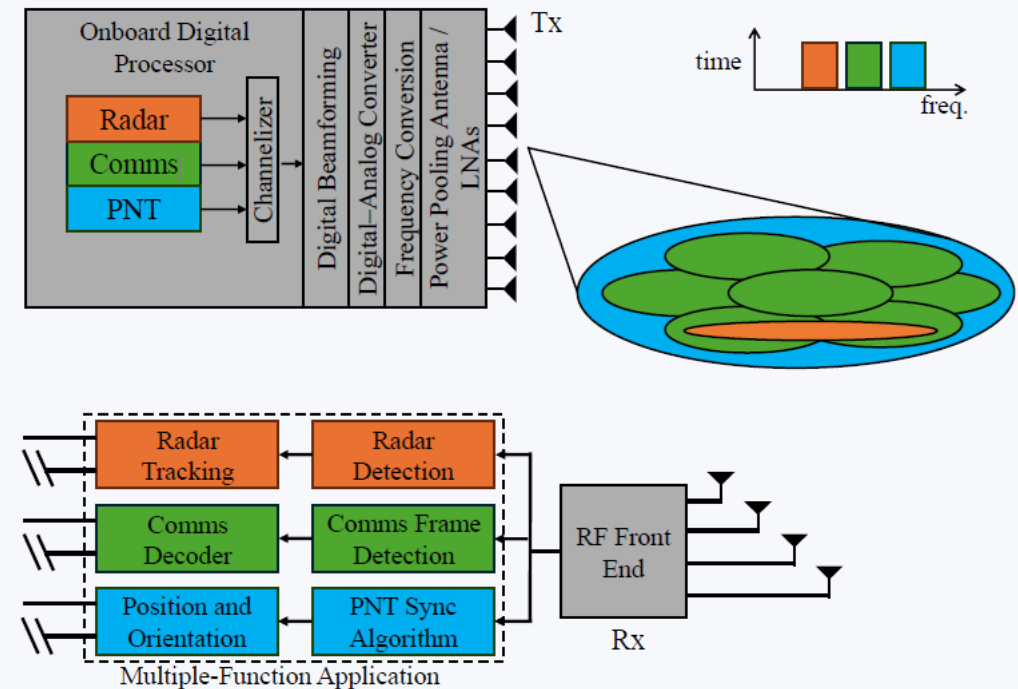
■ Constellation Implementations

- Spire Global: Shared front-end for GNSS-RO & AIS
- EU IRIS²: Sovereign comms & resilient PNT

■ Engineering Bottlenecks

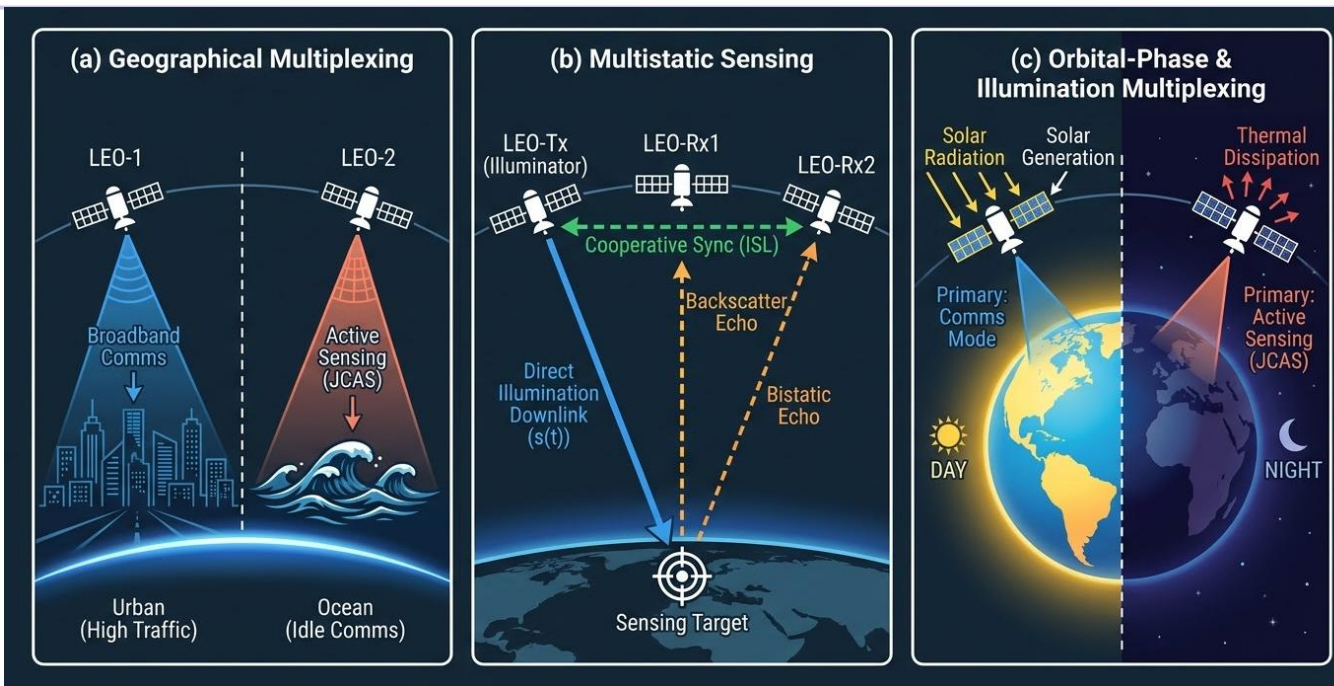
- Adjacent Channel Interference (ACI) limits Rx
- Analog filtering imposes bandwidth overhead

Generic Level 2 Payload Architecture



Level 2: Cooperative Systems (Non-Simultaneous Operations)

- **(a) Geographical Multiplexing:** Repurposes idle comms beams over oceans/poles into sensors.
- **(b) Multistatic Cooperation:** Decouples illuminators from receivers (Coordinated or Opportunistic).
- **(c) Orbital-Phase Balancing:** Schedules active sensing during optical eclipse to save power.



Orbital Power Concepts:

Solar beaming & day/night ops

 **STAR CATCHER**

 **AETHERFLUX**

Source: J. Querol, C. K. Sheemar, S. Chatzinotas, "Joint Communications and Sensing in Non-Terrestrial Networks," IEEE ISAC, 2026.

Level 3: Integrated Systems (Dynamic Multiplexing)

■ True Co-Channel Operation

- Comms, radar, and PNT share the exact same carrier frequency
- Eliminates spectral guard-bands and insertion losses
- Independent waveforms

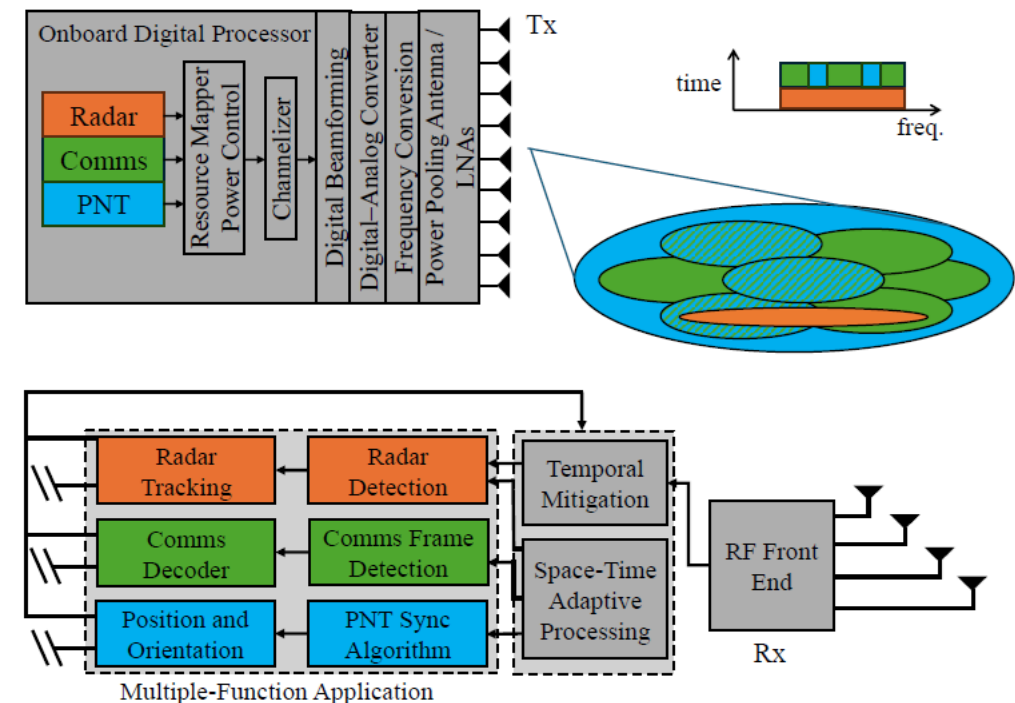
■ Shared Satellite Payload and Antenna

- Unified digital processing schedules dynamically
- Reuses phased-array beamforming hardware

■ Dynamic Resource Slicing

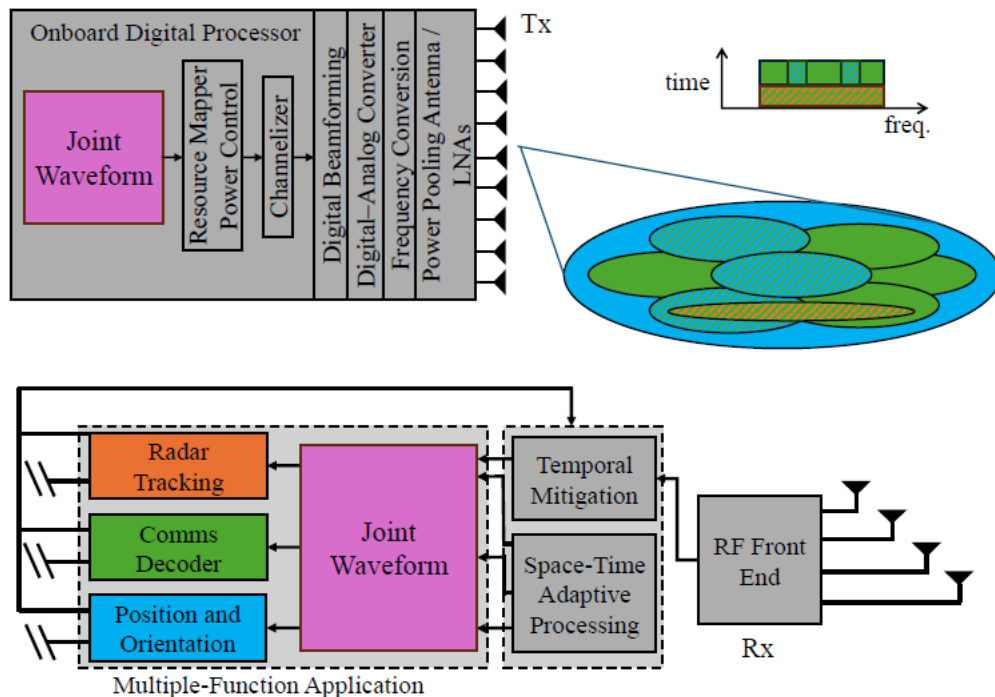
- Fast time-hopping interleaves comms and radar
- High-gain arrays project spatial nulls for isolation
- Beam-hopping per service

Generic Level 3 Payload Architecture



Level 4: Jointly Designed Systems (True JCAS)

Generic Level 4 Payload Architecture



■ Unified Dual-Functional Waveform

- Single signal conveys comms bits and probes environment
- 100% spectral and energy reuse

■ Dynamic Waveform Optimization

- Software trade-off: Throughput vs. radar ambiguity (ISLR)
- Adapts subcarriers and pilot lattices in real time

■ Frontier Research Status

- Requires full-duplex self-interference cancellation
- Lacks operational in-orbit flight heritage

Reference: C. K. Sheemar, J. Querol et al., "Joint Communications, Sensing, and Positioning in 6G Multi-Functional Satellite Systems: Survey and Open Challenges," arXiv:2509.25937 (2025).

Section 3: Operational JCAS-NTN Applications

Satellite Use Cases & Modalities

Use Case 1: Joint SatCom & Weather Sensing

■ The Oceanic Meteorological Gap

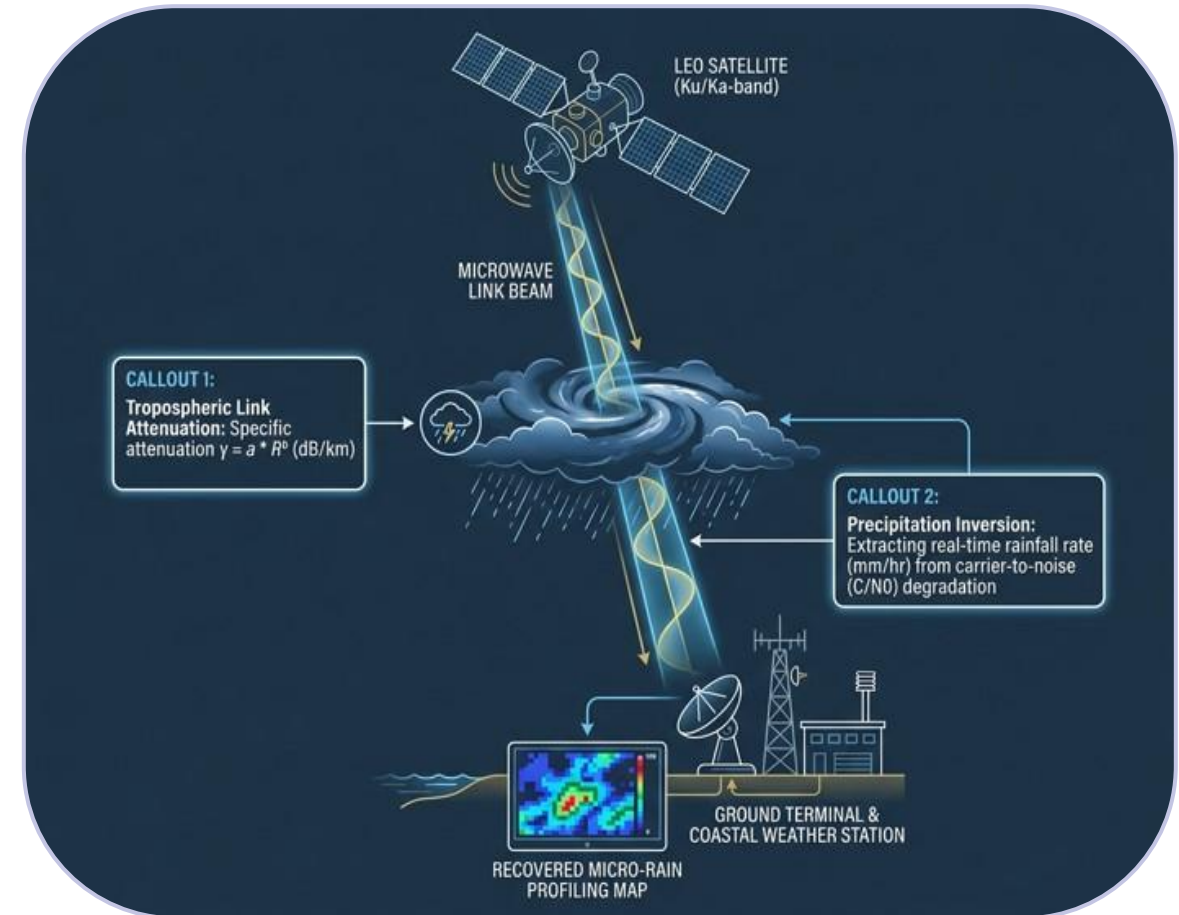
- Terrestrial radars leave ocean storms unmonitored
- SatCom provides continuous planetary-scale coverage

■ Opportunistic Observables

- Atmospheric attenuation: Measures specific Ku/Ka fading
- CSI: Inverts attenuation and phase to profile rain rate

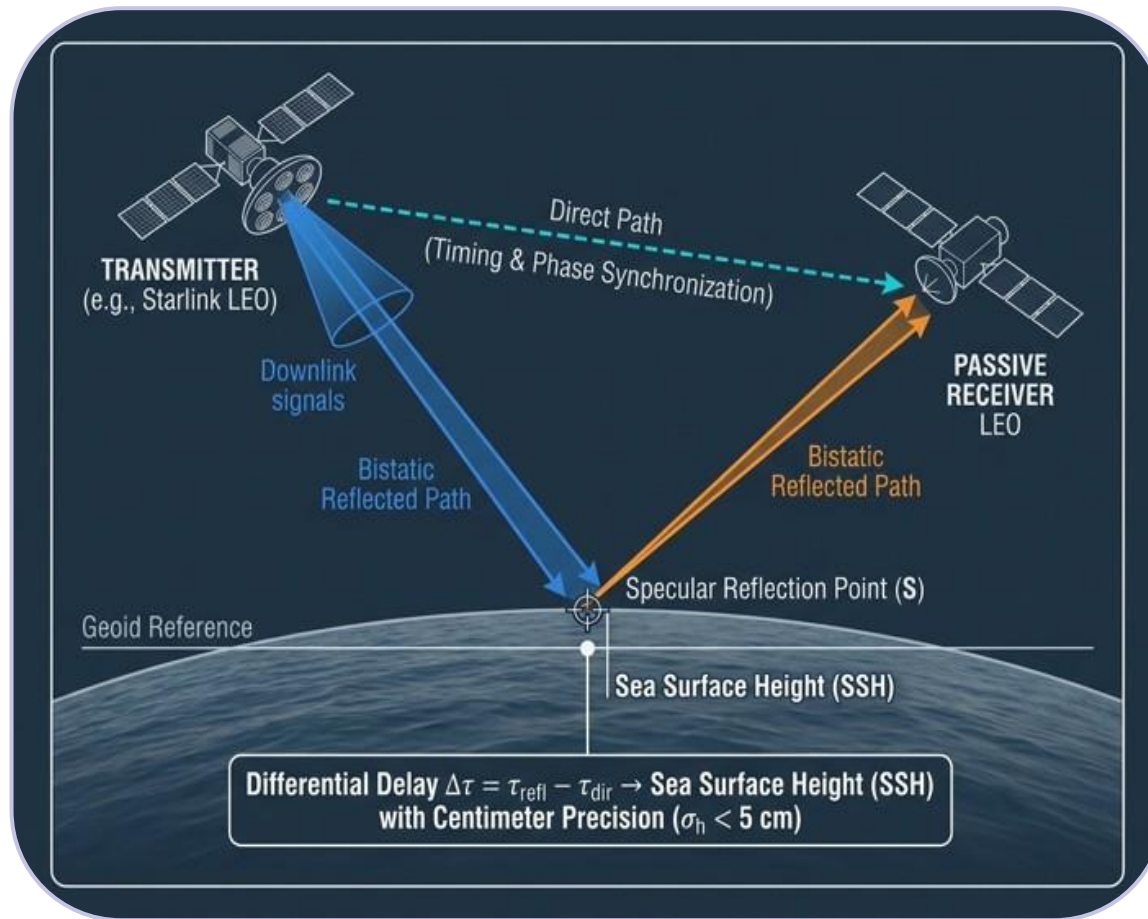
■ Level 2 Implementation

- Receive-side processing of existing downlinks
- Zero modification to the transmitted waveform



Reference: ESA ARTES J-CROSS; A. Messer et al., Science, 2006 (rain sensing with comms links); SnT SIGCOM (2026).

Use Case 2: Joint SatCom & Altimetry



■ Overcoming Altimeter Scarcity

- Dedicated altimeters are scarce (~20-day repeat cycles)
- Commercial SatCom delivers sub-hourly temporal revisit

■ Elevation Retrieval

- Differential delay ($\Delta\tau$) to specular echo
- Surface height mapped via delay-Doppler retracking

■ Payload Requirements

- Dedicated nadir antenna + precise timing (Level 2)
- Digital baseband processing refines delay to cm (Level 3)

Reference: M. Martin-Neira, ESA J., 1993 (PARIS concept); J-CROSS System Requirements Review; Sheemar, Querol et al., ESA (2026).

Use Case 3: Joint SatCom & Maritime Sensing & Vessel Detection

■ Dual-Observable Architecture

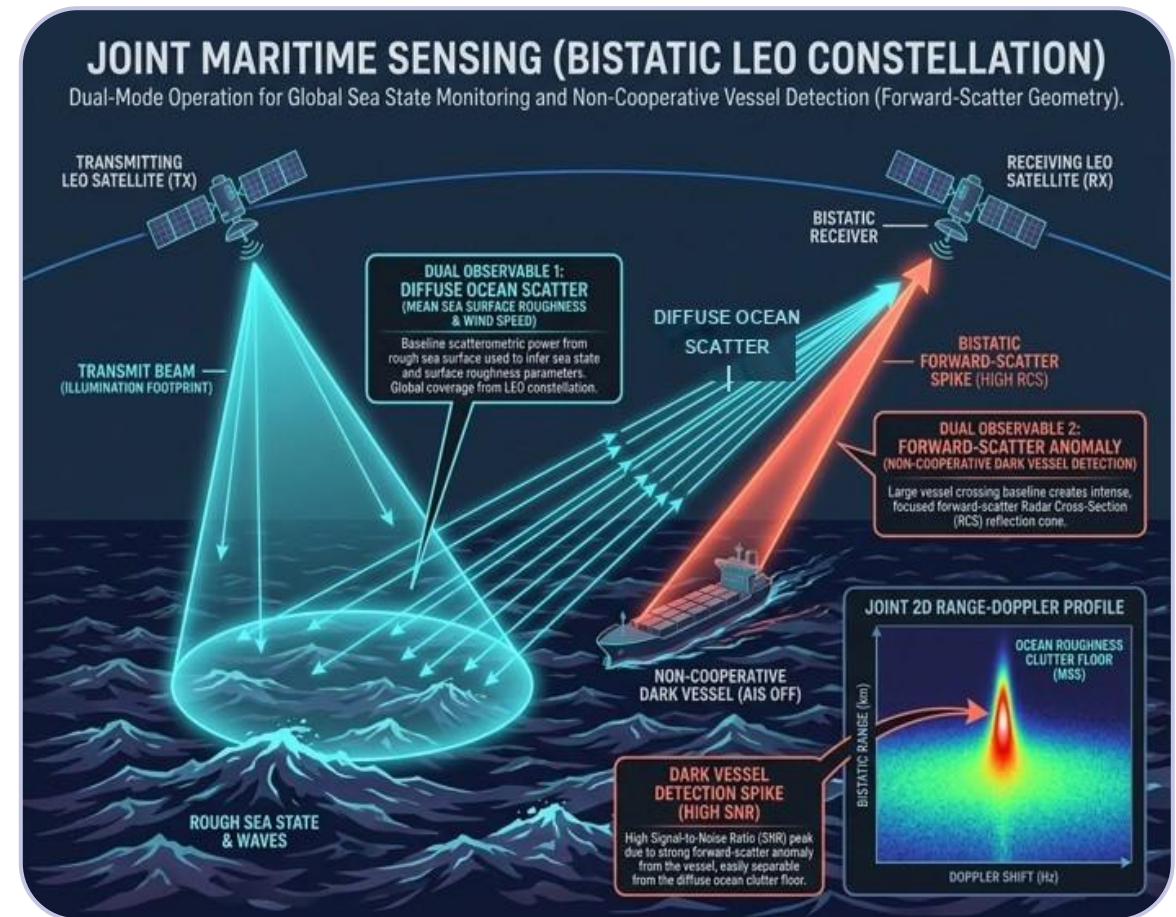
- Simultaneously monitors sea state and vessels
- Provides continuous wide-area maritime surveillance

■ Sea Surface State

- Diffuse scatter inverts mean surface roughness and wind

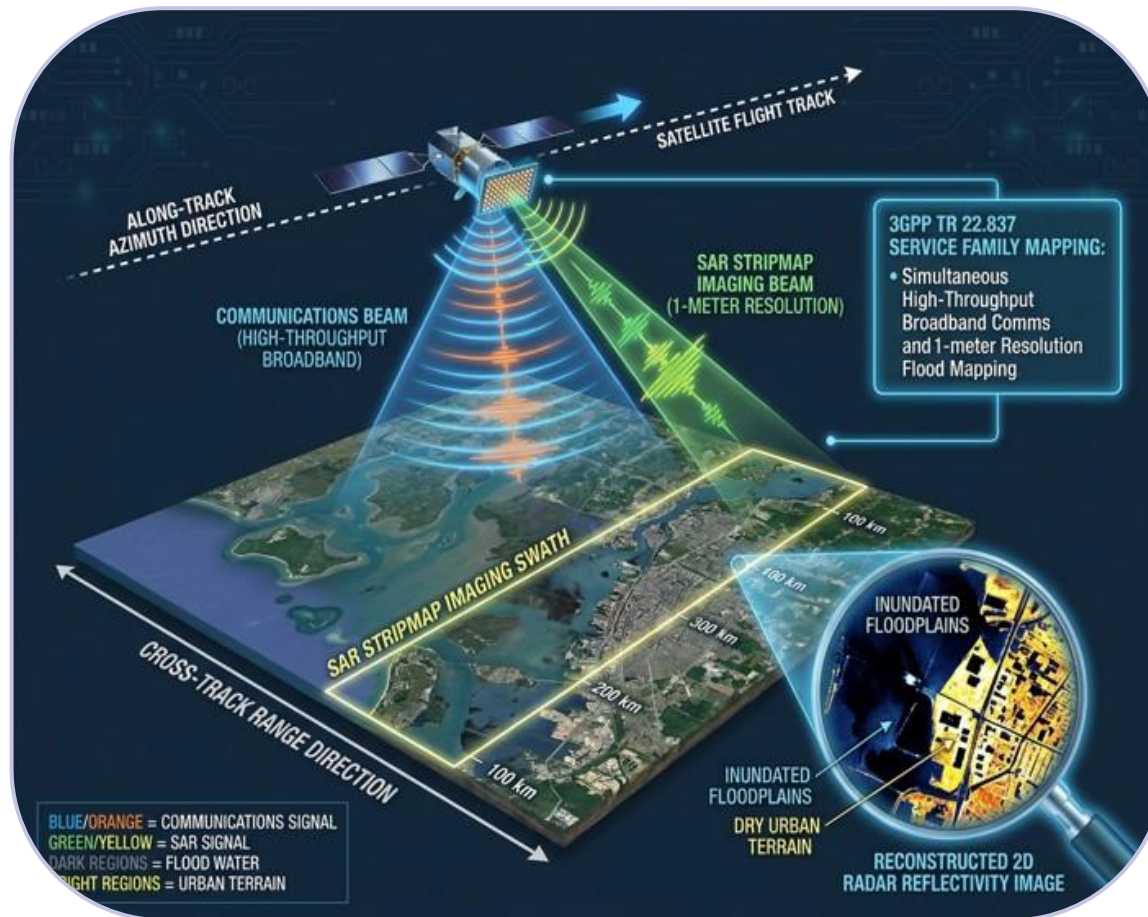
■ Forward-Scatter Vessel Detection

- Detects 'dark' vessels without AIS transponders
- Vessel crossing creates intense forward-scatter RCS peaks



Reference: ESA J-CROSS WP2 Technical Baseline; M. Clarizia et al., IEEE TGRS, 2014 (GNSS-R wind); SnT SIGCOM Maritime Studies.

Use Case 4: Joint SatCom & SAR Imaging



■ Broadband Comms Downlink SAR

- Reuses 5G/6G OFDM downlinks for synthetic aperture radar
- Target resolution: Meter-class (~ 1 m)

■ All-Weather Capability

- Microwave illumination penetrates thick clouds and night
- Eliminates dependence on solar illumination

■ Near-Zero Latency

- Radar echoes are focused onboard and routed directly
- Enables sub-daily interferometric change detection

Reference: Y. Cui et al., IEEE TAES, 2024; J. Querol et al., arXiv:2501.05243 (2025); 3GPP TR 22.837 (terrestrial ISAC requirements).

Section 3 Summary: Use Cases at a Glance

Use Case	Physical Observable	RF Spectrum	Min. Level	Core Technical Challenge
Weather	Rain attenuation & CSI	Ku / Ka	Level 2	Isolating rain from tropospheric multipath
Altimetry	Delay ($\Delta\tau$) to specular echo	L / Ku / Ka	Level 2-3	Centimeter resolution vs. bandwidth
Maritime	Forward-scatter RCS & diffuse clutter	L / C / Ku	Level 2-3	Vessel detection in high sea-state
SAR Imaging	Focused OFDM radar backscatter	C / X / Ku	Level 3-4	Path loss & ambiguity vs. throughput

Indicative mapping; see J-CROSS WP2 and Sheemar, Querol et al., arXiv:2509.25937 (2025).

Section 4: Physical-Layer Realities

From Radar Limits to Spaceborne JCAS

The Link Budget Reality: The R⁴ Radar Bottleneck

■ The 80 dB Link Deficit

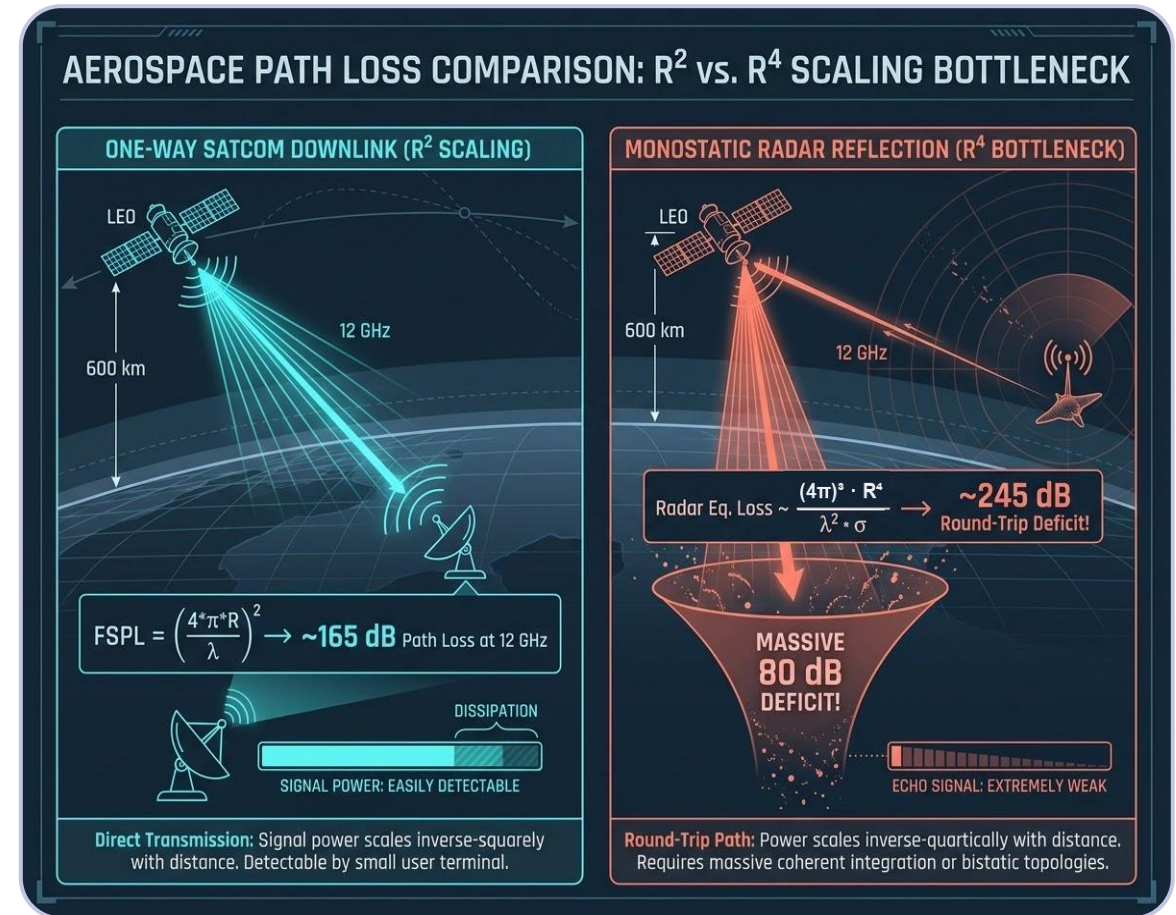
- One-way comms FSPL: ~170 dB (Ku-band)
- Two-way radar loss: ~250 dB (for distributed clutter)

■ Power Is Not the Limit

- Commercial SatCom is kW-class (matches dedicated SAR)

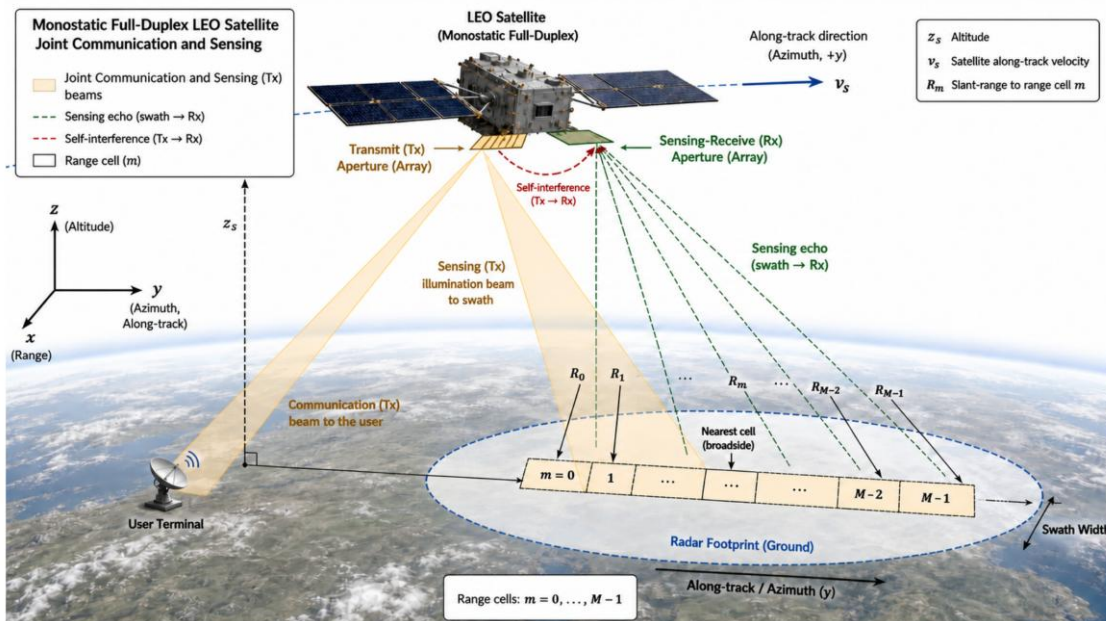
■ The Continuous-Wave Dilemma

- Dedicated EO satellite: High peak pulses, listens during gaps
- SatCom: 100% CW duty cycle (usually). Can beam-hopping help?



Source: C. K. Sheemar et al., "Joint Communications and Sensing for 6G Satellite Networks: Use Cases and Challenges," arXiv:2501.05243 (2025); M. Skolnik, Radar Systems.

Monostatic SIC & Optimal Beamforming



Full-Duplex Monostatic Architecture

- Separate planar Tx and Rx arrays on the same bus
- Enables simultaneous transmission and monostatic reception

The 120–150 dB Self-Interference Barrier

- High-power Tx leaks massive power into co-located Rx LNAs
- Rx blindness occurs from LNA saturation

Null-Space Beamforming

- Projects self-interference entirely into the spatial null-space
- Goal: interference-free sensing while serving ground UEs

Source: G. Iacovelli, C. K. Sheemar, J. Querol, and S. Chatzinotas, "CRB-Optimal Beamforming for Full-Duplex LEO Satellite JCAS," *IEEE Trans. Wireless Commun.* (2025).

Bistatic JCAS: Architectural Trade-Offs & Challenges

■ Monostatic vs. Bistatic Topologies

- Monostatic: Simple geometry, crippled by 150 dB self-interference
- Bistatic: Decoupled platforms; zero bus self-interference

■ Bistatic Challenge 1: Direct-Path

- Direct LOS blast is 40–60 dB stronger than ground echoes
- Requires sharp spatial nulling and digital cancellation

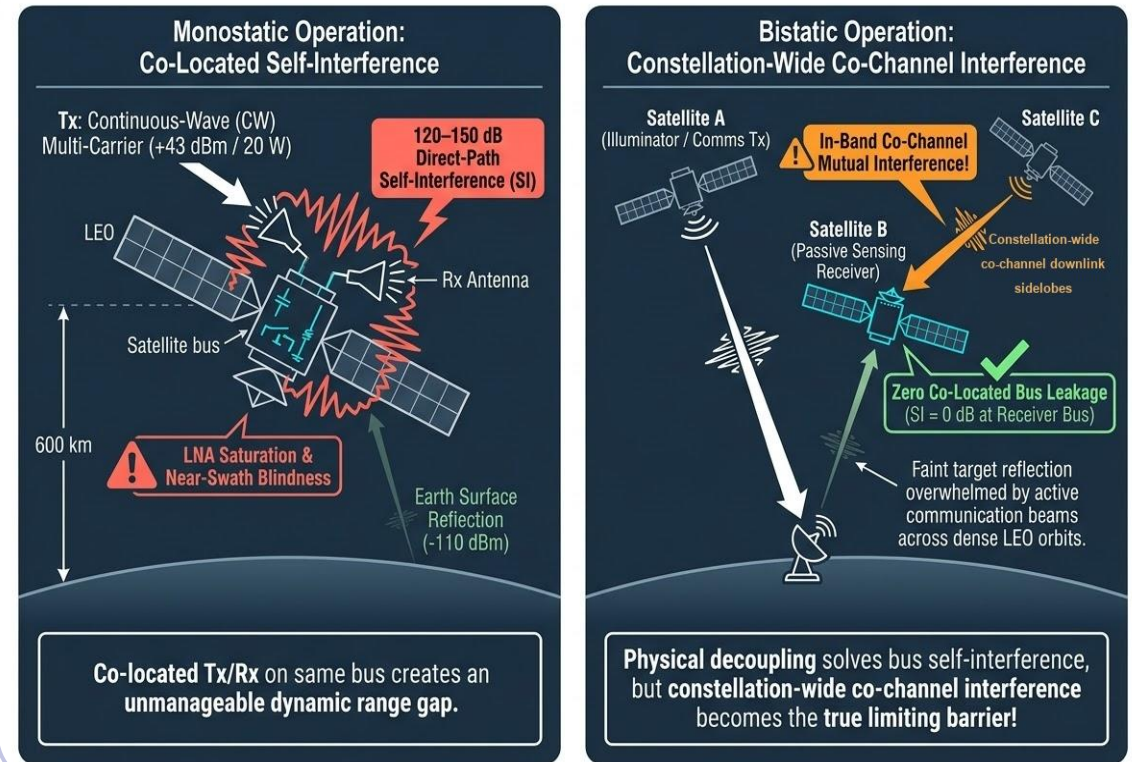
■ Bistatic Challenge 2: Synchronization

- Independent oscillators induce severe phase incoherency.

■ Bistatic Challenge 3: Dynamic Geometry

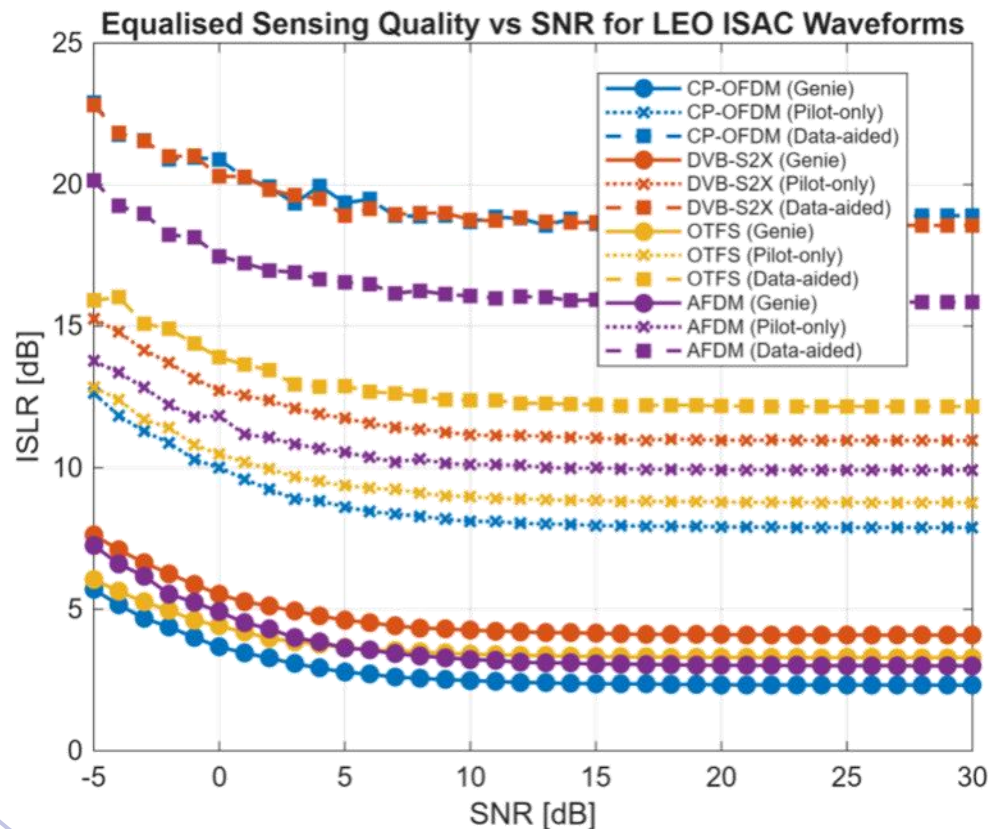
- Moving Tx beam and Rx footprints must dynamically intersect

SPACEBORNE CW RADAR: MONOSTATIC SELF-INTERFERENCE VS. CONSTELLATION MUTUAL INTERFERENCE



Reference: FNR TREK PULSE Project (PI: Dr. Jorge Querol); G. Iacovelli, C. K. Sheemar, J. Querol, S. Chatzinotas, *IEEE Trans. Wireless Commun.* (2025).

Continuous-Wave Radar: Ambiguity & Pilot-Only Sensing



Continuous-Wave Radar & ISLR

- 100% duty cycle – Ambiguity func. (delay/Doppler)
- KPI: ISLR (Integrated Side-Lobe Ratio) suppresses sidelobes that mask weak targets

Waveform Comparison (Pilot-Only)

- CP-OFDM: 2D pilot lattices yield 7.9 dB ISLR
- DVB-S2X: Sparse single-carrier block pilots yield 10.9 dB ISLR

The Direct-Path Breakthrough

- Pilot-only correlates solely on pilots (more numerous in 5G)
- Data-aided fails due to decision errors (18.6 dB floor) in uncoded case. Coding adds processing overhead
- Interferometric processing (direct-path reference) enables 100% use of the waveform

Reference: C. Sturm & W. Wiesbeck, *IEEE Proc.* (2011); J. Querol, C. K. Sheemar, S. Chatzinotas, "Technical Enablers for 6G ISAC from Space," *IEEE ISAC* (2026).

The Waveform Dilemma: PAPR Under Non-Linear Satellite SSPAs

■ SSPA Saturation & Non-Linearity

- SSPAs run near saturation for DC-RF efficiency
- This induces severe AM-AM and AM-PM signal distortion

■ The PAPR Penalty

- CP-OFDM suffers high PAPR (11.7 dB) vs. DVB-S2X (5.3 dB)
- Clipping generates spectral regrowth that violates ITU masks

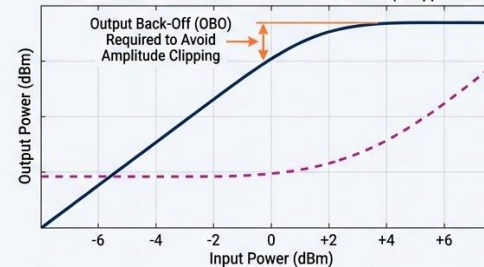
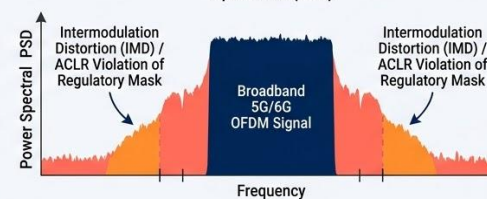
■ The Back-Off Dilemma

- Peak Cancellation reduces PAPR but introduces EVM penalty
- Input Back-Off (IBO) restores linearity but wastes valuable RF power

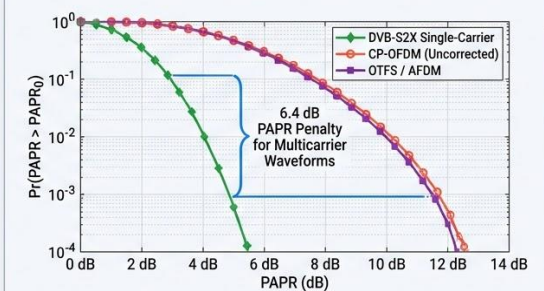
Satellite SSPA Non-Linearity & High PAPR in Spaceborne JCAS

RF Amplifier Distortion & Spectral Regrowth

SSPA AM-AM and AM-PM Transfer Characteristics ($\approx$ Rapp Model)



Waveform PAPR Divergence & Back-Off Trade-Off



The Back-Off Dilemma

- Peak Cancellation reduces PAPR to 9.5 dB but causes irreducible EVM ($\sim 16\%$)
- Input Back-Off (IBO) restores linearity but wastes 6-8 dB of RF transmit power, directly shrinking radar detection range.

► Engineering Takeaway (The Waveform Dilemma):

To meet ITU masks, we must sacrifice either signal quality (EVM via Peak Cancellation) or radar detection range (RF power via IBO).

More Open Physical-Layer & System Challenges in Spaceborne JCAS

**In bold only the ones covered in previous slides*

01. RF Front-End

- 80 dB R^4 deficit (monostatic)
- 120–150 dB self-interference
- PAPR → 6–8 dB SSPA back-off

02. Waveform & Processing

- Throughput vs. sidelobes (ISLR)
- Data-aided vs. pilot-only vs interferometric
- Comms / sensing / PNT scheduling

03. Orbital Dynamics

- Dynamic multi-beam management
- Fast-changing bistatic geometry
- Tropospheric phase variations

04. Constellation & Regulation

- Co-channel mutual interference
- Inter-satellite time & ephemeris sync
- ITU PFD limits & spoofing/jamming

Reference: C. K. Sheemar, J. Querol, et al., "Joint Communications, Sensing, and Positioning in 6G MFSS: Survey & Open Challenges," IEEE COMST (2025); ESA J-CROSS WP2.

Section 5: Practical Near-Term Solution

Bistatic Sensing & Signals of Opportunity (SoOp)

Signals of Opportunity (SoOp): The Near-Term Paradigm Shift

■ Receive-Only Opportunistic Architecture

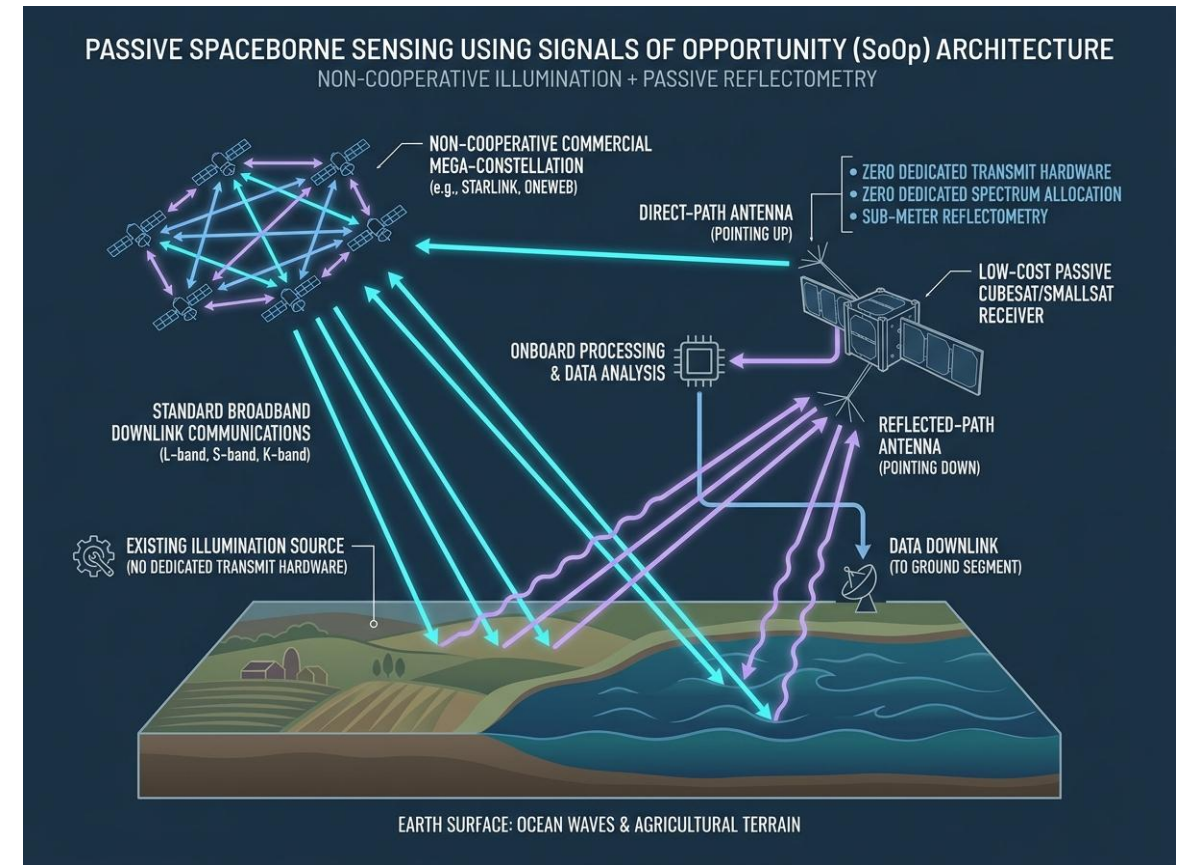
- Payloads carry lightweight passive receivers (< 10 kg)
- Completely solves platform self-interference

■ Exploiting Commercial Mega-Constellations

- Captures forward-scattered downlinks (Starlink, OneWeb, SES, ASTS)
- Zero spectrum licensing costs and zero RF Tx power consumption

■ Space-Proven Heritage (GNSS-R)

- Builds on 20+ years of GNSS-R flight heritage
- Upgrades from narrowband (1-20 MHz) to broadband (250 MHz)



References: V. Zavorotny et al., *IEEE GRSM* (2014); P. Gomez-del-Hoyo & P. Samczynski, *IEEE JSTARS* (2024); R. Blazquez-Garcia et al., *IET Radar Sonar Navig.* (2024).

iGNSS-R vs. Starlink iSoOp-R: Illumination Power & Signal Quality

■ The iGNSS-R Bottleneck

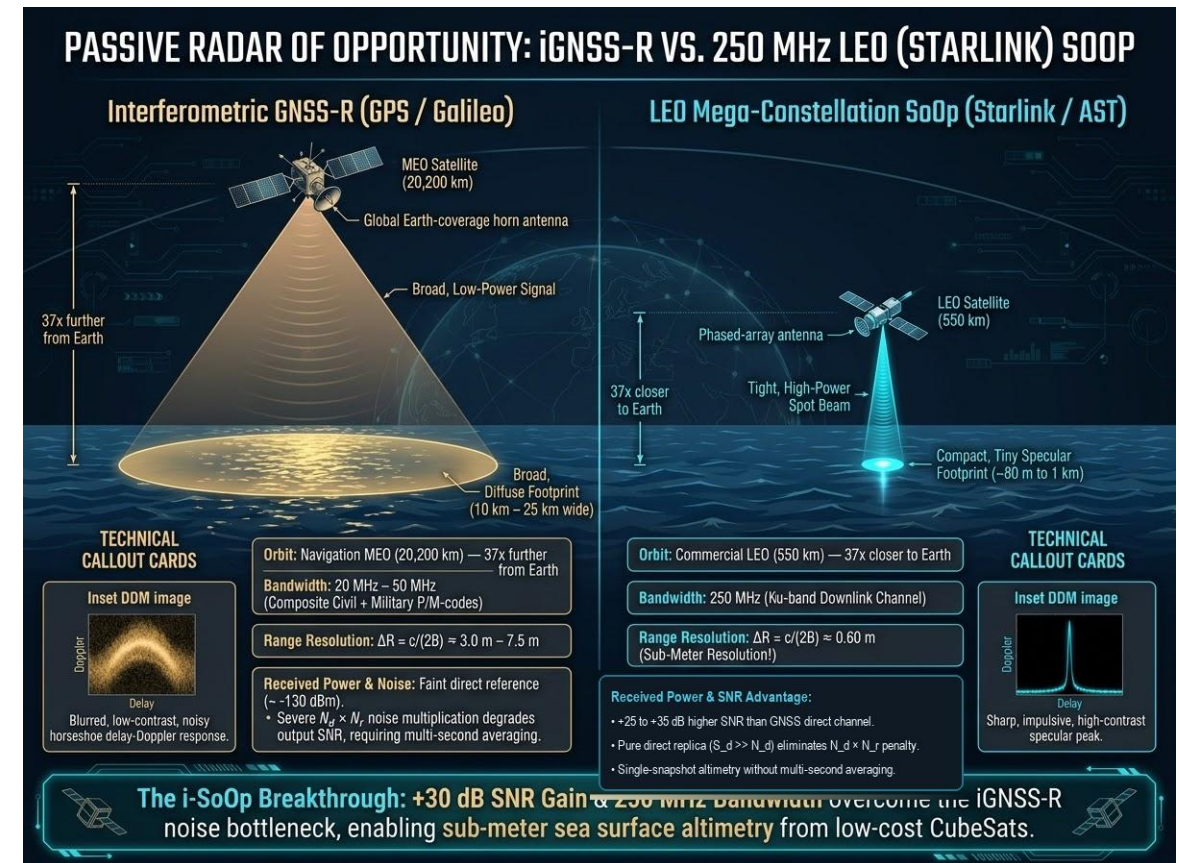
- Uncooperative downlinks correlate direct reference with surface echo
- Faint MEO signals (-130 dBm) cause severe noise penalty

■ The LEO Advantage

- LEO orbit wins +31 dB range proximity over MEO
- Phased-array spot beams deliver +25 dB higher EIRP

■ The Breakthrough: +30 to +35 dB Net SNR Gain

- Direct signal is overwhelmingly strong; direct noise vanishes
- Enables wideband remote sensing from small satellites



Source: Analytical derivation; J. Querol et al., "LEO Satellite Signals of Opportunity for High-Resolution Remote Sensing" (2025).

Spatial Resolution Across Scattering Regimes: 1D Range vs. 2D Footprint

■ 1D Range vs. 2D Surface Footprint

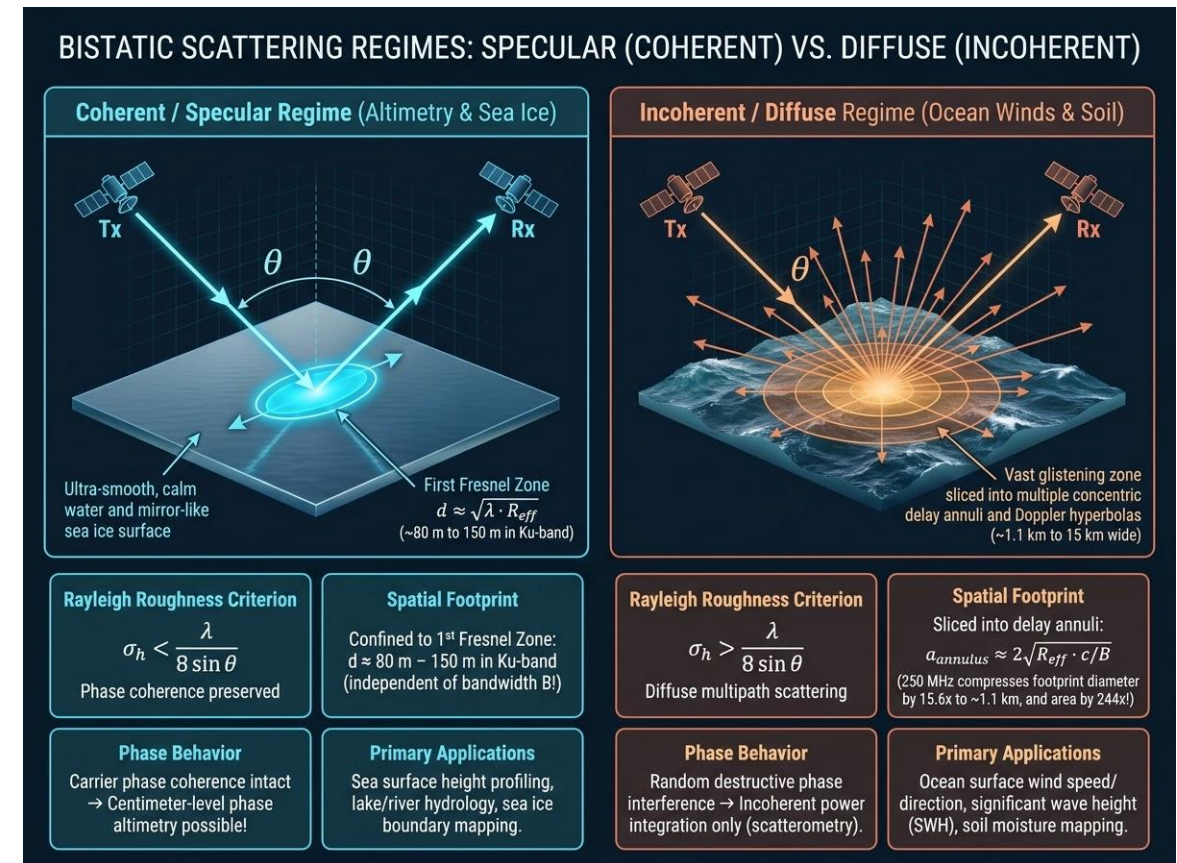
- 1D range precision: $\Delta R = c/(2B)$ (150 m $\rightarrow$ 0.60 m)
- 2D footprint governed entirely by surface scattering regime

■ Specular Regime (Calm Water & Ice)

- Confined to 1st Fresnel Zone (~80–150 m in Ku-band)
- Enables centimeter-level phase altimetry

■ Diffuse Regime (Rough Oceans & Soils)

- Scattered across delay-Doppler glistening zone
- Wide bandwidth compresses footprint diameter by 15 $\times$ (iSoOp-R vs iGNSS-R)



Reference: V. Zavorotny & A. Voronovich, *IEEE TGRS; Remote Sensing* 2020, 12(23), 3910.

Example: Passive Spaceborne Altimetry Applications

Metric	Sentinel-3 SRAL	GNSS-R	LEO SoOp (Ku)
Transmitter on board	Yes (active)	No (passive)	No (passive)
Bandwidth	350 MHz	1–20 MHz	~240 MHz
Range resolution	~0.43 m	7.5–150 m	~0.6 m
Footprint	~0.3 km	0.3–25 km	~0.1–1 km
Revisit	27 days	Hours	Hours

■ Ocean Dynamic Topography

- Centimeter-to-decimeter sea surface height profiling
- Monitors currents, storm surges, and tides

■ Inland Hydrology

- Resolves elevation of inland lakes and narrow rivers
- Overcomes land-contamination limits of traditional altimeters

■ Sub-Daily Revisit

- Cuts revisit intervals from weeks down to hours
- SatCom operators can monetize idle downlink spillover

Reference: J-CROSS Altimetry WP2 Report; SnT SIGCOM Hydrology Studies (2026).

Section 5 Summary: How SoOp Answers the Section 4 Barriers

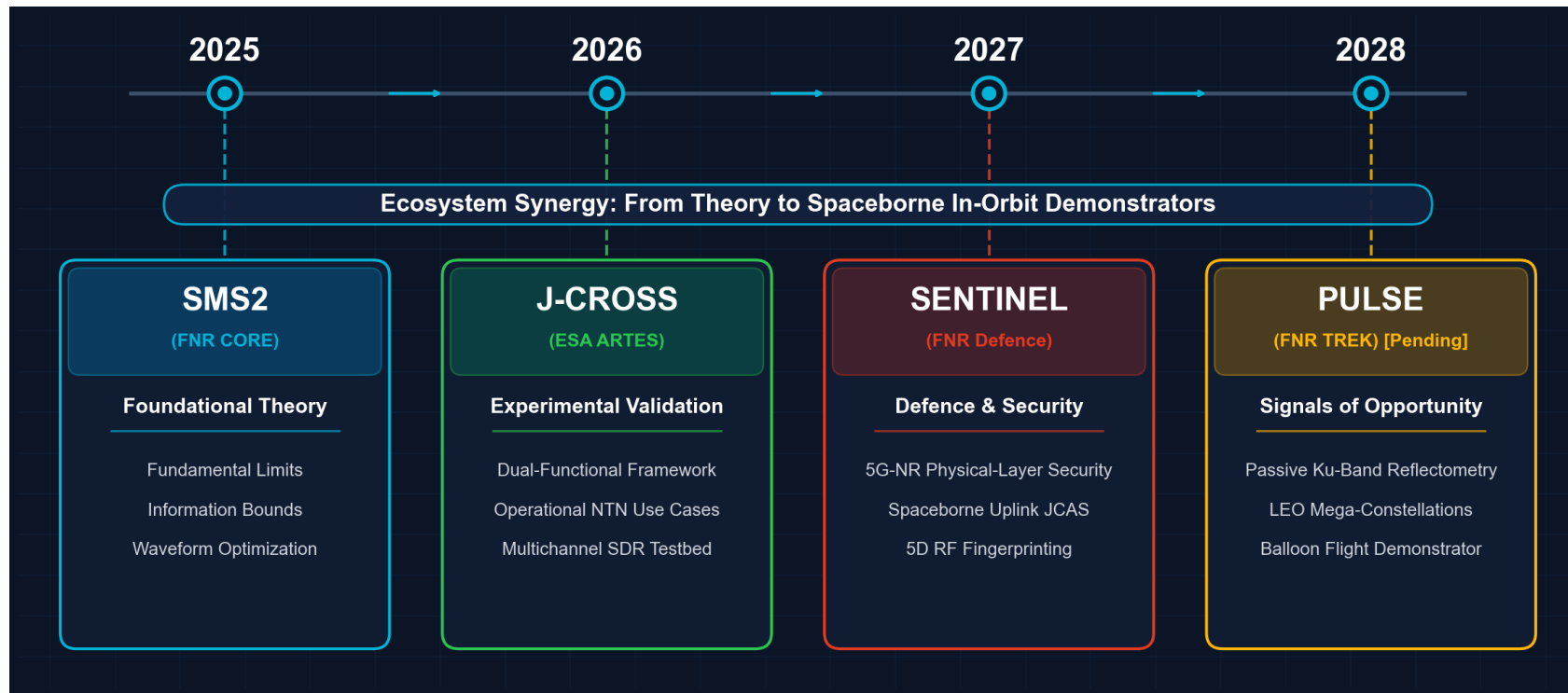
Physical-Layer Barrier (Sec. 4)	Signals of Opportunity (SoOp) Solution	Remaining Research Frontier
80 dB R ⁴ deficit	✓ Bistatic Geometry: Detects strong forward echoes	⚠ Weak diffuse echoes over land
120-150 dB self-interference	✓ Decoupled Spacecraft: 0 dB co-located leakage	⚠ Direct-Path Interference (DPI)
Mutual interference	✓ Delay-Doppler Nulling: Rapid velocity isolates beams	⚠ Dense mega-constellations
Unknown data & noise	✓ +30 dB Direct-Path: Eliminates noise multiplication	⚠ Proprietary waveforms
SSPA non-linearity	✓ Distortion Captured: Correlates with actual waveform	⚠ Reference channel SNR
Orbital dynamics & sync	✓ Direct-Path Tracking: Instant clock reference	⚠ Along-track blurring

Section 6: Our Research Ecosystem

Projects, Laboratories, & Open Frontiers

Active JCAS-NTN Project Portfolio

- **End-to-End Strategic Trajectory:** Progression spans foundational theory (SMS2), SDR testbeds (J-CROSS), 5G security (SENTINEL), and SoOp (PULSE).
- **Multi-Agency Validation Ecosystem:** Synergizes Luxembourg FNR funding with ESA ARTES 4.0 contracts, bridging theory with flight demonstrators.



Source: SIGCOM Research Portfolio 2025–2028; FNR CORE, ESA ARTES, and FNR Defence Programmes.

6GSPACE Laboratory: Real-Time NTN Emulation

■ Full-Stack 5G NR Protocol

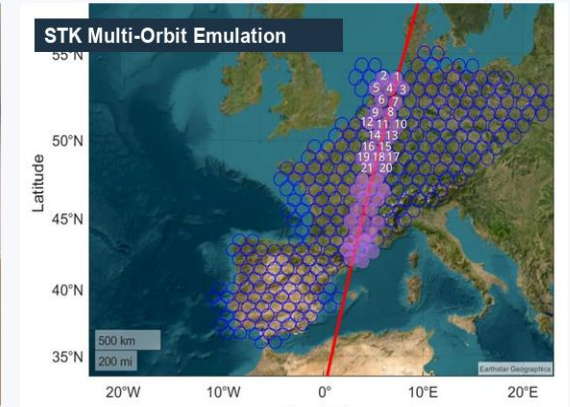
- End-to-end gNodeB and UE via OpenAirInterface (OAI)

■ Hardware-in-the-Loop Emulation

- RF emulators driven by AGI STK orbital models
- Emulates extreme LEO Doppler dynamics (± 1.5 MHz)

■ FPGA Hardware Acceleration

- AMD/Xilinx RFSoc platforms for real-time beamforming



Key Takeaways: Turning 6G Satellites into Sensors

- 1 • PLATFORM CONVERGENCE** | MFSS unifies payloads to reduce orbital debris and fleet CAPEX.
- 2 • ORBIT ECONOMICS** | JCAS enables flexibility to meet user communications requirements and quasi-continuous planetary monitoring.
- 3 • PHYSICAL LIMITS** | Monostatic is bounded by self-interference. Bistatic brings geometric and synchronization challenges. Waveforms are not optimal.
- 4 • SIGNALS OF OPPORTUNITY** | Broadband LEO SoOp can overcome GNSS-R limitations and deliver commercial-grade EO products.
- 5 • OPEN FRONTIER** | True JCAS-NTN still has multiple challenges to solve to become a reality.



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Backup Slides

Additional Technical Details & Reference Material

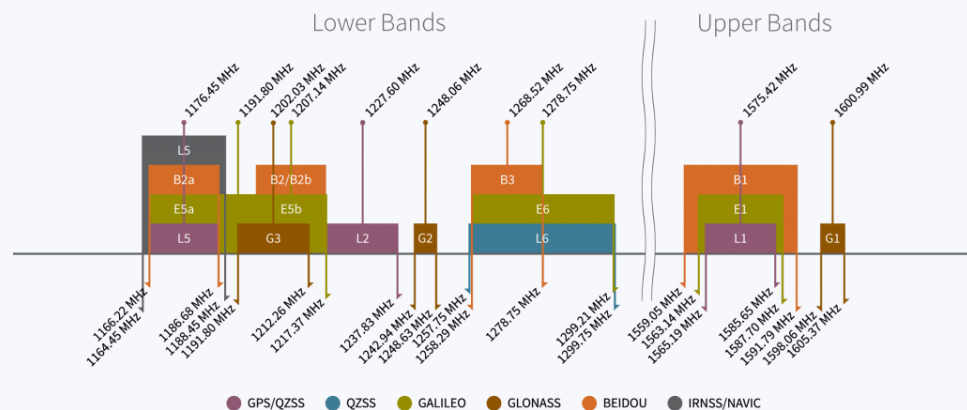
Backup: Level 2 Spectrum Coexistence & Radar Allocations

Key Enabler: ITU allocations reveal adjacent and overlapping frequency bands suitable for shared antenna apertures and wideband SDR payloads.

Satellite Communications Frequency Bands (MSS / FSS / BSS)

Frequency band	Frequency range (GHz)	Satellite service type	Applications
L-band	1.518-1.675	MSS (mobile satellite services)	Civil mobile communication services, global positioning system, weather radar systems
S-band	1.97-2.69	MSS	Satellite TV, mobile broad band services, radio broadcasting, in-flight connectivity
C-band	3.4-7.025	FSS (fixed satellite services)	Data services, satellite TV networks, unprocessed satellite feeds
X-band	7.25-8.44	FSS	Military operations, pulse radar systems, weather monitoring, air traffic control
Ku-band	10.7-14.5	FSS, broadband satellite service (BSS)	Fixed satellite television data services
Ka-band	17.3-30	FSS, BSS	Two-way broadband services, fixed satellite data services
Q/V band	37.5-51.4	MSS, BSS	High-speed broadband services, in-flight connectivity

GNSS Frequency Bands (GPS, Galileo, BeiDou, GLONASS)



Spaceborne Radar Frequency Allocations (ITU-R Article 5)

Satellite Frequency Bands	Allocated Frequency for Active Sensing	Assigned Bandwidth for Sensors				
		Scatterometer	Altimeter	SAR	Precipitation radar	Cloud profile radar
P (0.3-1 GHz)	432-438 MHz			6 MHz		
L (1-2 GHz)	1215-1300 MHz	5-500 kHz		20-85 MHz		
S (2-4 GHz)	3100-3300 MHz		200 MHz	20-200 MHz		
C (4-8 GHz)	5250-5570 MHz	5-500 kHz	320 MHz	20-320 MHz		
X (8-12 GHz)	8550-8650 MHz	5-500 kHz	100 MHz	20-100 MHz		
	9300-9900 MHz	5-500 kHz	300 MHz	20-600 MHz		
Ku (12-18 GHz)	13.25-13.75 GHz	5-500 kHz	500 MHz		0.6-14 MHz	
	17.2-17.3 GHz	5-500 kHz			0.6-14 MHz	
K (18-27 GHz)	24.05-24.25 GHz				0.6-14 MHz	
Ka (27-40 GHz)	35.5-36 GHz	5-500 kHz	500 MHz		0.6-14 MHz	
W (75-110 GHz)	78-79 GHz					0.3-10 MHz
	94-94.1 GHz					0.3-10 MHz
G (110-300 GHz)	133.5-134 GHz					0.3-10 MHz
	237.9-238 GHz					0.3-10 MHz

■ L-Band Spectrum Convergence (1-2 GHz):

- **Shared Apertures:** Mobile SatCom & radar share deployable mesh reflectors
- **Triple Synergy:** Unifies 5G-NTN comms, GNSS PNT, and radar scatterometry

■ High-Band Opportunities (Ku & Ka Bands):

- **Ku-Band:** Commercial downlinks match bistatic reflectometry & altimetry
- **Ka-Band:** Multi-gigabit downlinks overlap directly with fine-resolution SAR

Reference: ITU Radio Regulations (RR) Article 5; Tallysman Wireless GNSS Spectrum Guide; C. K. Sheemar, J. Querol et al., arXiv:2509.25937 (2025).