Non-redundant HexSat formations for improved L-band data

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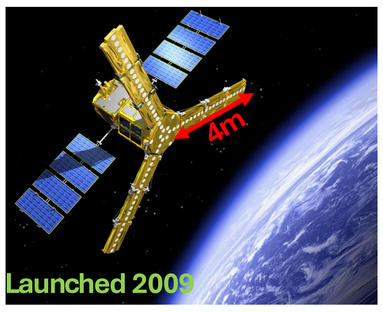
Introduction

- **Soil moisture** and **ocean salinity** are key factors in hydrology.
- These variables are **best observed** using **L-band** (1.4GHz) frequencies.
- The **large wavelength** of L-band **requires extremely large antennas** to achieve **reasonable** angular resolution.
- **Synthetic aperture radiometry** can help reduce the need for large antennas.
- To **improve resolution**, mission concepts like **SFASIL** [1] and **TriHex**[2] suggest using **three large satellites.**
- We are exploring whether a **larger number** of **smaller**, more **affordable satellites** can deliver similar or even better resolution **L-band data.**

Soil Moisture Active Passive (SMAP) mission [3]



Soil Moisture and Ocean Salinity (SMOS) mission [4]

Synthetic aperture radiometry

- **Synthetic Aperture radiometry** is a technique of synthesizing a **large antenna** by combining measurements from **multiple small antennas.**
- It involves **correlating** signals between antennas at various **relative spacings**, known as **baselines**.
- These measured correlations are then **converted** into an image of the target scene using an **inverse Fourier transform:**

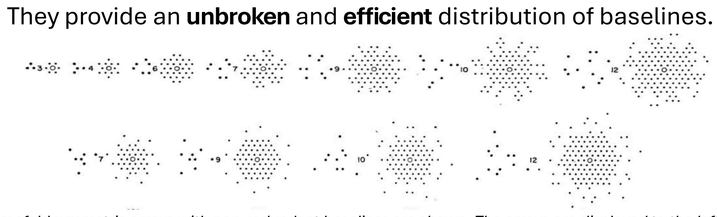
$$T'_B(\xi,\eta) = \int_{-\infty}^{\infty}\iint V(u,v)\, e^{j2\pi(u\xi+v\eta)}\, dudv$$

Want to know — What is measured — Inverse Fourier transform

- The **more baselines** are measured, the **higher the quality** of the resulting conversion.

Golay point arrays

- M. Golay (1971) – "Point Arrays Having Compact, Non-redundant Autocorrelations" [7].
- **Non-redundant** means no baseline is repeated **more than once.**
- These point arrays can serve as **reference locations** for hexagonal satellite configurations.
- They provide an **unbroken** and **efficient** distribution of baselines.



Threefold symmetric arrays with non-redundant baselines are shown. The arrays are displayed to the left of each number, while their corresponding baselines are shown to the right of each number [7].

Golay formation performance

- Different satellite formations are compared based on their **Array Factor** (also known as the Point Spread Function or Point Response).
- The total **number of antennas** in each case is kept **constant at 216**, in line with TriHex (Golay3 formation).
- Golay6 offers **11% more** unique **baselines** than Golay3.
- Other formations have even more unique baselines but **offset the benefits** by introducing **gaps in their baseline coverage.**

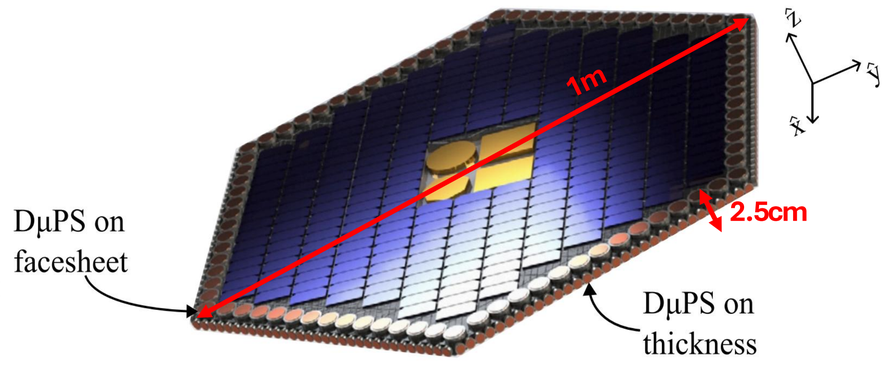
	Maximum sidelobe, dB	3dB Beamwidth
Golay3, from [2]	-14.2	1.55 °
Golay6	-14.8	1.47 °
Golay9	-14.4	1.36 °
$Golay9_2$	-11.1	1.29 °
Golay12	-13.8	1.33 °
$Golay12_2$	-12.5	1.23 °

Conclusions

- **Hexagonal** satellites in **Golay formations** provide an **efficient** method for covering a large range of baselines.
- Arranging the **same number** of antennas across more satellites improves performance by **reducing** the number of points with **high (4+) redundancy**.
- Larger formations also benefit from **satellite redundancy**, allowing them to be rearranged into the next Golay formation after a **failure.**
- A constellation of **nine** HexSats could offer **6km ground resolution** from an **altitude of 250km**.

HexSats

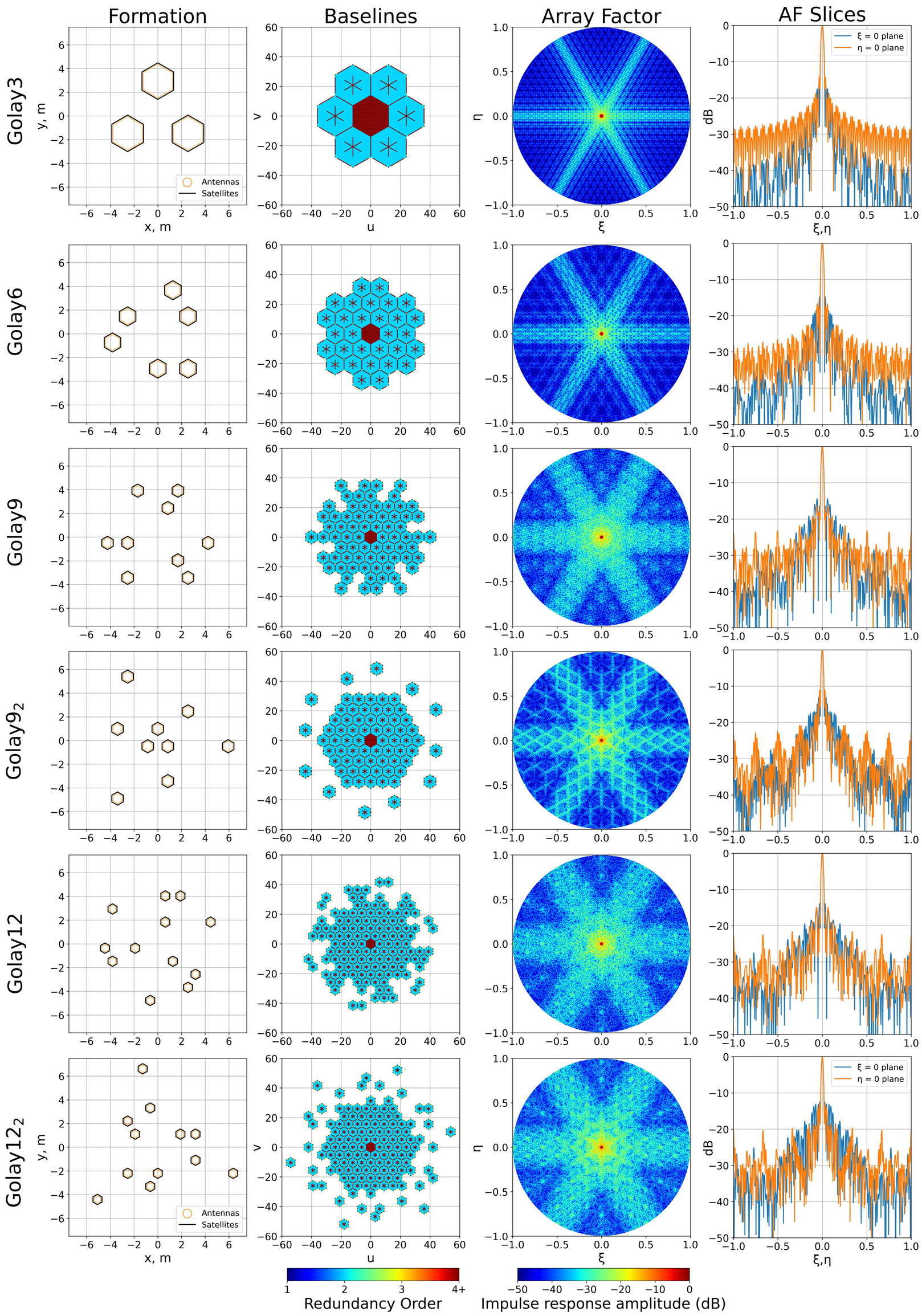
- **HexSats** are a proposed flat hexagonal nanosatellite platform [5].
- HexSats were derived from The Aerospace Corporation's **DiskSat.**
- Four DiskSats **set to launch** in 2026 [6].
- Developed for **high power** and **large aperture** applications.
- HexSats provide superior **packing efficiency** when launching more than **three** satellite stacks.
- They use a Distributed Micro-Propulsion System (**DμPS**) for orbit maintenance and formation keeping.
- HexSats can operate in **very low Earth orbit** due to their **thin** form factor.



HexSat concept: A flat hexagonal satellite using the DμPS for orbital and attitude actuation [5]

Golay formation performance

Same nr. of antennas



References

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[2] M. Martín-Neira et al., "TriHex: Combining Formation Flying, General Circular Orbits, and Alias-Free Imaging, for High-Resolution L-Band Aperture Synthesis," in IEEE Transactions on Geoscience and Remote Sensing, vol. 61, pp. 1-17, 2023, Art no. 1000317, doi: 10.1109/TGRS.2023.3268560
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