ADCSS 2017: Sodern presentation

17 Oct 2017

SODERN

Agenda

Star trackers road map: a wide range of products

- **End of CCD star trackers: SED26 replaced by Horus as standalone multi-mission star tracker**
- **Hydra maintained beyond 2030 for high end applications**
- **Auriga for constellations: how to produce 150 STR per month**
- **Auriga Stand-Alone for small-sat**

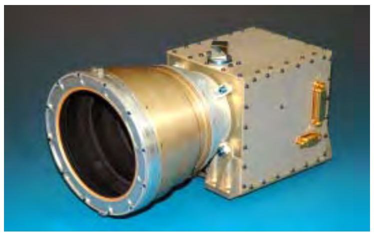
High fidelity of simulation tools

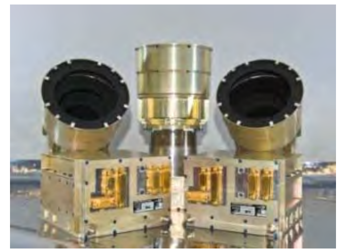
- **Demonstrated thanks to Hydra REX on board Spot-6, Sodern simulation tools fidelity allow an accurate prediction of next generation STR performances (Horus, Auriga)**

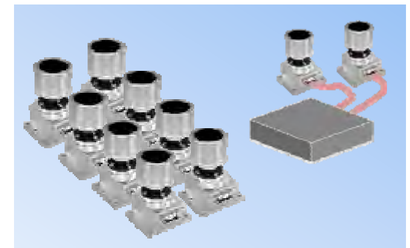
Horus : the new high-end star tracker for telecom market

- **Starting with a high TRL thanks to Sodern heritage**
- **Performances**

Star Tracker Offering - full market coverage







2020

2010

End of Life
~ 2020-2021

Telecom GEO
Earth Observation LEO

SED 26 - Single Box
Standalone

Telecom GEO
Earth Observation LEO

2019

HORUS - Single Box
Standalone

Earth Observation LEO
High End Applications

Beyond 2030

Telecom GEO
Earth Observation LEO

HYDRA series - Multi Box
Standalone - Available in
different form factor for EU

Mega
Constellation
Telecom LEO

2017

AURIGA

Single Box
S/W in OBC

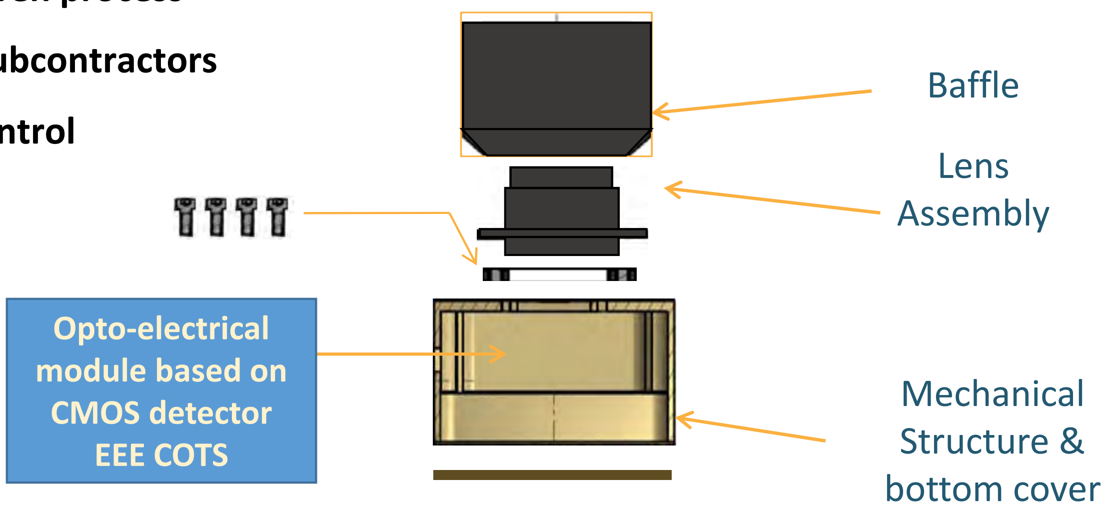
SmallSat
LEO

2019

AURIGA -
Standalone
Multi Box
S/W in EU

AURIGA - Cost driven Design

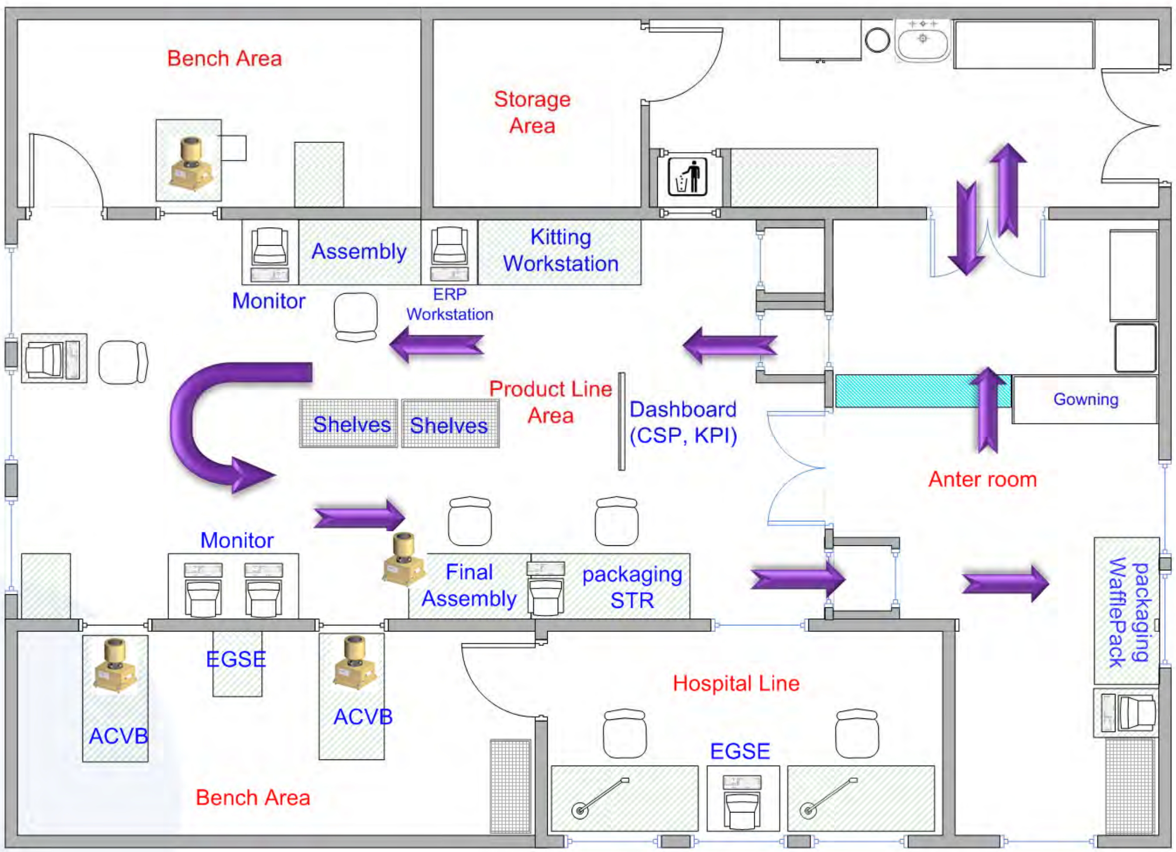
- **Modular Architecture allows a verification approach at the lowest level and a basic integration process to secure final assembly line**
  - **Only 5 subassemblies**
  - **Well known and proven process**
  - **Limited number of subcontractors**
  - **Easy integration / control**
  - **Lean production**

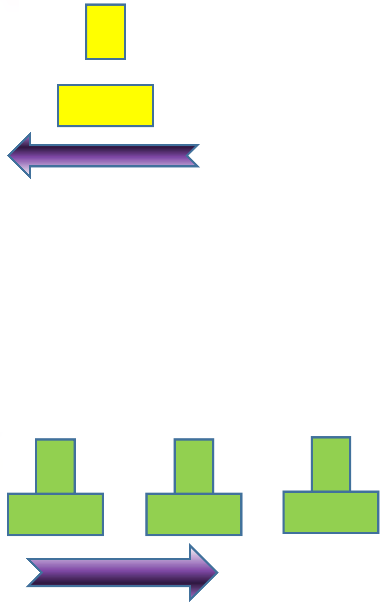


AURIGA Vs HYDRA

Environmental characteristics	AURIGA	HYDRA
Operating range	-30°C to +45°C; up to +60°C	-30°C to +60°C
Storage temperature	-40°C to +70°C	-40°C to +70°C
Volume / mass	56 x 66 x 94 mm3 / <210g	113 x 119 x 283 mm3/ 1400g
Reliability, Availability and Lifetime		
EEE component class	Level 3 equivalent	Level 2 or Level 1
Reliability	<1000 fit (RDF 2005 method)	241 / 190 fit
Outage	7.10^{-2} Per day	No
Lifetime	7 yrs in LEO	7 yrs in LEO / 15 yrs in GEO
Performance & Robustness		
Bias	110 arcsec	11 arcsec
FOV error Yaw, pitch / roll	2 / 11 arcsec	0.5 / 4 arcsec
Space-time noise Yaw, pitch / roll @1s	6 / 40 arcsec	4 / 30 arcsec
Time from lost-in-space @EOL 0.06°/s, @99%	< 12s	< 4s
Kinematics in Acq / Tracking @EOL	up to 0.2 / 3 deg/s	15 deg /s
Moon effect	No effect of Moon	No effect of Moon
Baffle SEA / EEA (half angle)	34 / 29 deg	26 / 18.5 deg
Electrical Interfaces		
Power Supply / Consumption	5 V / 1 W	5V / 1W
Output data / Output rate	SpaceWire / 5Hz	SpaceWire / 30Hz

AURIGA production - Lean Manufacturing facilities



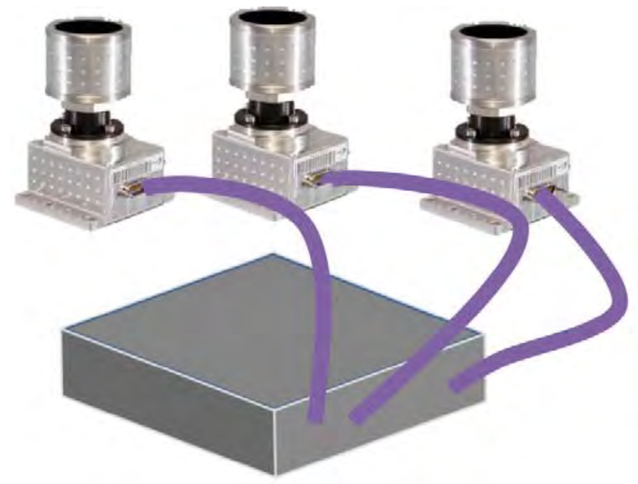


Ramping up production up to 150 STR / month in 2018

AURIGA Standalone

Multi-box solution based on Auriga Optical Head :

- Optical Head 56 x 66 x H94 mm^3, <210g
- Electronic Unit 120 × 90 × H22 mm^3, <350g
- EU connected to up to 3 OH through SpW I/F
- RS422 I/F ;
- +5V input; 4W + 1W per OH
- Designed for LEO 10 years
- Single head and blended quaternion at 5 Hz



- **Same performances as Auriga OH**

FOV error

1 OH		2 or 3 OH
X/Y (" 3 σ)	Z (" 3 σ)	X/Y/Z (" 3 σ)
6	35	6

V (°/s)	High Frequency Spatial Error			Temporal NEA		
	1 OH		2 or 3 OH	1 OH		2 or 3 OH
	X/Y (" 3 σ)	Z (" 3 σ)	X/Y/Z (" 3 σ)	X/Y (" 3 σ)	Z (" 3 σ)	X/Y/Z (" 3 σ)
0.06	7	45	7	15	90	15

Noise Equivalent Angle

HYDRA Family

CMOS detector Star Tracker solutions based on :

Same 23 deg FOV Optical Head - Spacewire I/F
Same electronic design, only different Electronic Unit packaging , 1553/RS422
Same S/W with 3 Fields Of View data fusion at up to 30 Hz

Hydra baseline

up to 4 OH + 1 or 2 EU in cold redundancy

TRL9 achieved with Spot6 launch

Hydra-TC

2 OH + fully redundant EU

TRL8 in Q4 2012
1st launch in 2014

Hydra-M

2 OH + EU without TEC

TRL8 in Q3 2013
1st launch in 2015

Hydra-CP

OH + S/W Hosted into S/C OBC

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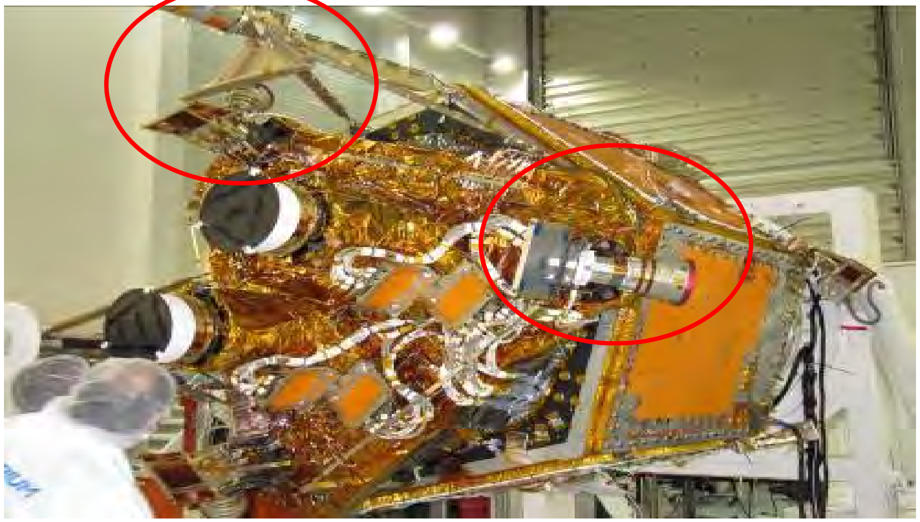
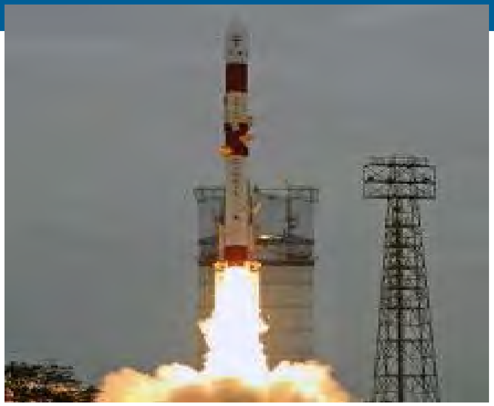
SPOT Satellites

SPOT6: first Satellite of AstroTerra program based on Astrium AS250 P/F
Daily global revisits: 1 day to 5 days with off-track capability
10 years - LEO @ 700km - phased on the same orbit as Pleiades 1A&1B

HYDRA CMOS Multiple Head Autonomous Star Tracker

SPOT6&7 configuration





Successful Launch from India
September 2012 with PSLV-C21

2 Electronic Units in cold redundancy with 3 Optical Heads
90 deg LOS angle between Heads
CMOS detector (HAS-2) maintained @ +15 Celsius with Thermo Electric Cooler

Electronic Unit operates three Optical Heads simultaneously
and delivers quaternion TM at **16Hz**
45 stars used for the blended solution (15 per OH)
Enhanced robustness in tracking when one/two OH not available

In-orbit validation

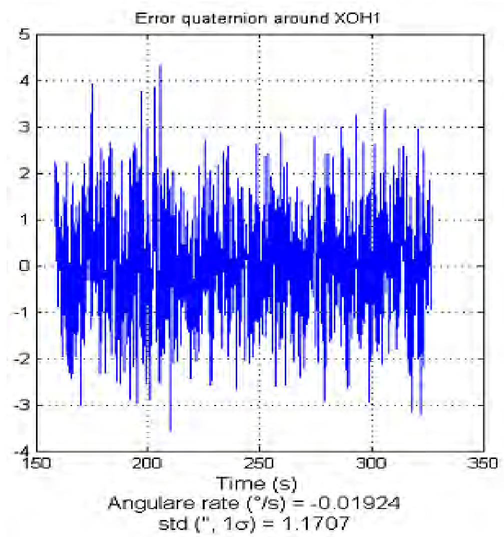
Monitoring during a period of 3 months with ASTRIUM & CNES support

- Good-Health diagnostic after switch "ON" of 3 OH and 1 EU:
  - house-keeping: All TM OK,
  - Detector cooling down temperature reached in 15 sec,
  - Quick acquisition in "lost in space" mode with 3 OH in few seconds

- Performance in tracking mode: star tracker is in tracking since beginning of the mission thanks' to multiple head robustness
- Sun and Earth limb exclusion angles
- Moon in the Field of View
- Robustness during maneuver
- Catalogue and photometric calibration
- Quality Index

➔Confirm ground test & simulation

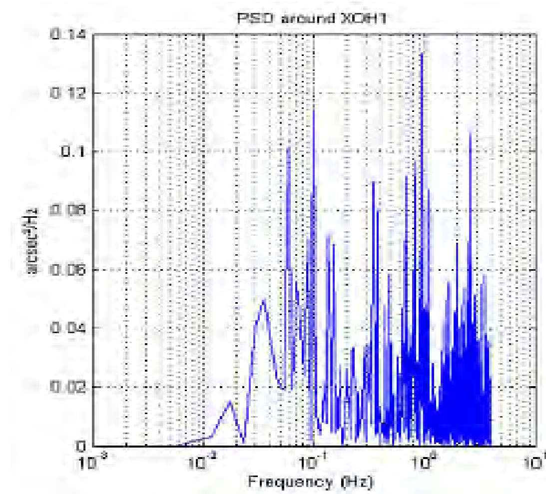
Performance in Tracking mode



Fast Fourier Transform on 3 axes

Quaternion attitude error $\mathcal{E}$ ⟶

At 0,06 deg/s



$\mathcal{E} = Q_{measured} - Q_{fifth\ order\ polynomial\ law}$

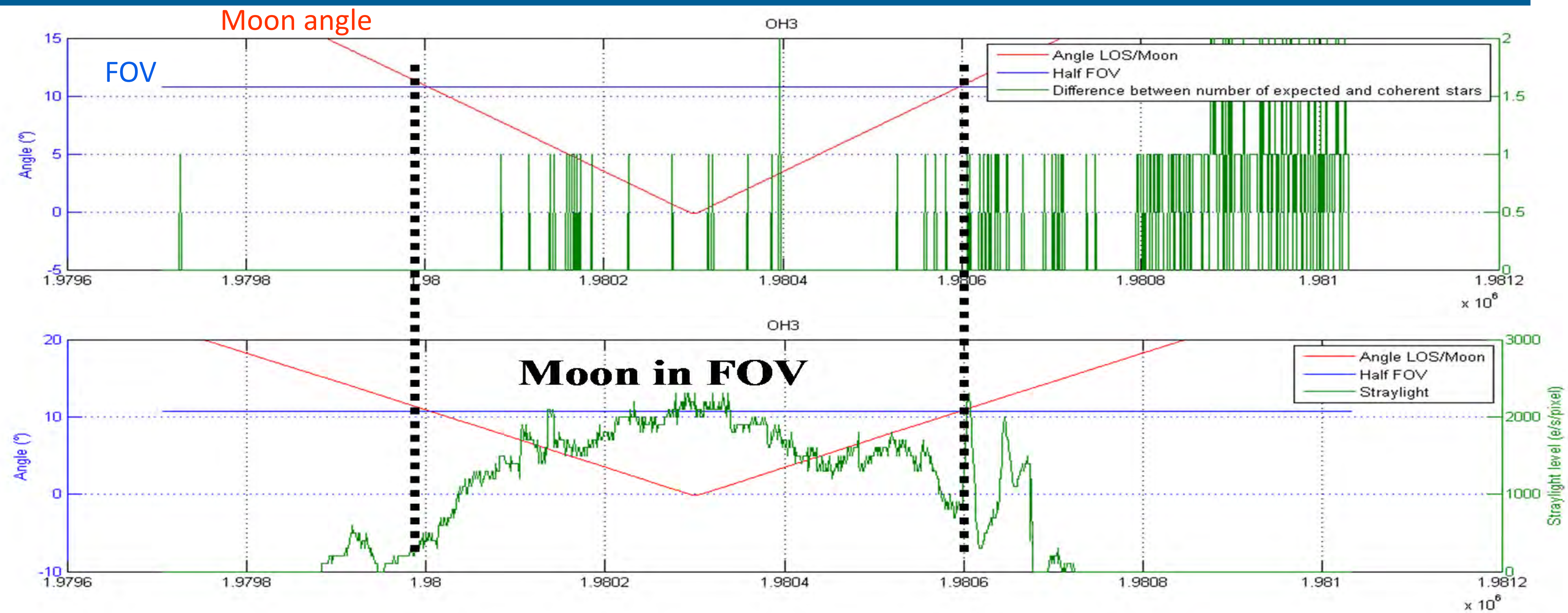
- Noise Equivalent Angle ➔temporal noise
- High Spatial Frequency Error ➔ Non-Uniformity & interpolation response
- Low Spatial Frequency error ➔ FOV error = Geometric & Thermal residual Distortion, Catalogue

Performance in tracking mode @0.06deg/s

Arcsec @ 3 Sigma **3 Head solution** (1 Head solution)	**Axes**	**Measurement**	**Performance Prediction**
NEA temporal noise @16Hz	Around X_{OH}	**1.7** (2.7)	**1.9** (2.9)
	Around Y_{OH}	**1.1** (2.6)	**1.9** (2.9)
	Around Z_{OH}	**1.7** (23.8)	**2.0** (22.9)
High Spatial Frequency Error	Around X_{OH}	**1.4** (2.1)	**1.4** (2)
	Around Y_{OH}	**2.0** (2.8)	**1.4** (2)
	Around Z_{OH}	**1.7** (15.8)	**1.5** (15.7)
Low Spatial Frequency error	Around X_{OH}	**0.2** (0.3)	**0.5** (0.7)
	Around Y_{OH}	**0.4** (0.5)	**0.5** (0.7)
	Around Z_{OH}	**0.3** (2.2)	**0.5** (4.7)

Results offered by Hydra are fitting the predicted performance

Moon in the Field Of View



Number of coherent stars still 15 per OH – Stray-light background level increased

The Moon in FOV with CMOS detector has negligible impact on performances

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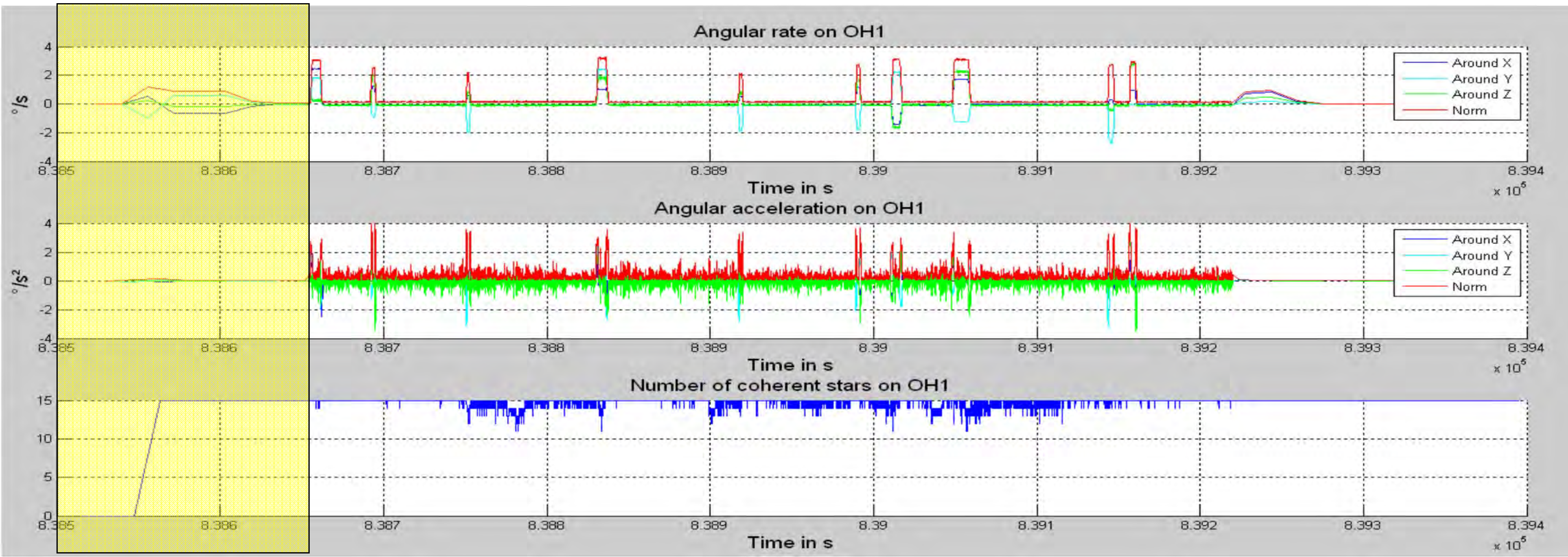
Robustness during satellite maneuver



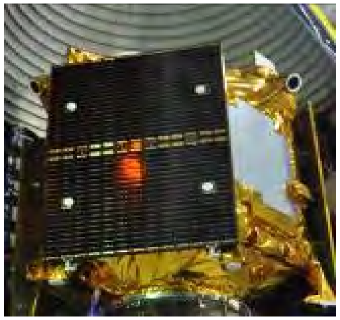
Blinding of OH1

Angular rate up to 3 deg/s – acceleration up to 4 deg/s^2

Star tracker robustness up 8 deg/s and 7 deg/s^2

Conclusion for Hydra

First Hydra on-board Spot6 Astrium AS250 P/F



Agile Satellite with Sun/Earth Star Tracker occultation, High rate

Hydra offers high performances, availability and robustness

thanks to multiple FOV blended solution at 16Hz

Performances with blended solution: **LSFE=0.4 arcsec,** HFSE<2 arcsec, NEA=0.4 arcsec/√Hz – Simulation fits measurement

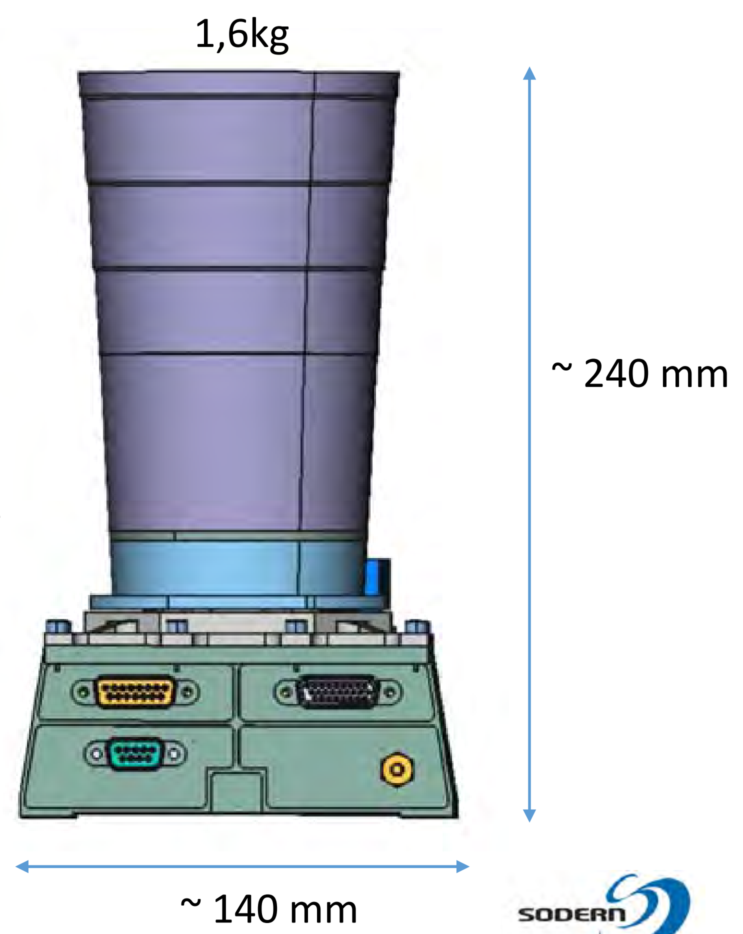
Sun&Earth exclusion angle validated with few degrees margin

Robustness toward kinematics up to 3°/s and 4°/s²

Negligible impact of Moon in the FOV on performances

HORUS Overview

- Best of autonomous and single box star tracker
  - Blend of HYDRA and AURIGA
  - Life Time: 18 years, Weight: 1600 g, Power: 5 W, Accuracy: 2 arcs
  - primary power line 20-100V - 1553 dialog interface
  - 24° baffle
  - New APS generation
- Acquisition and tracking data
  - Acquisition & tracking for worst peak solar flares and for radiation belts
  - Tracking is operational at **2 °/s** & **2°/s²**
  - Acquisition and Tracking **Robust to the Moon in the field of view**



HORUS Key Data

Performance & Robustness in End Of Life (EOL) conditions (18 years GEO)		
Performances		
Power	W	5
Volume	Cm^3	4000
Mass	Kg	1.6
Bias	Arcsec (3 sigma)	10
Thermo-elastic error	Arcsec / °C (3 sigma)	< 0.05
Low Frequency Spatial Error on XY / Z	Arcsec (3 sigma)	0.9 / 6
High Frequency Spatial Error on XY / Z	Arcsec (3 sigma)	2 / 15
Temporal noise on XY / Z	Arcsec (3 sigma)	8 / 60
Baffle SEA (Sun Exclusion Angle)	°	<24
Baffle EEA (Earth Exclusion Angle)	°	<17
Time to switch to tracking from lost-in-space	Second	<10
Robustness		
Kinematics in Tracking (EOL)	° / sec, °/sec^2	2, 2
Full Moon in the Field of view	-	No performance degradation
Robustness to transient protons	-	Robust to worst case of transient protons in both acquisition and tracking