Developments for the next generation of Radio Occultation instruments in ESA

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  - MetOp-SG, Jason-CS and others
- Conclusions

Baseband GNSS processor developed under ESA guidance and contracts

AGGA = Advanced GPS / Galileo ASIC
(formerly: Advanced GPS/Glonass ASIC)

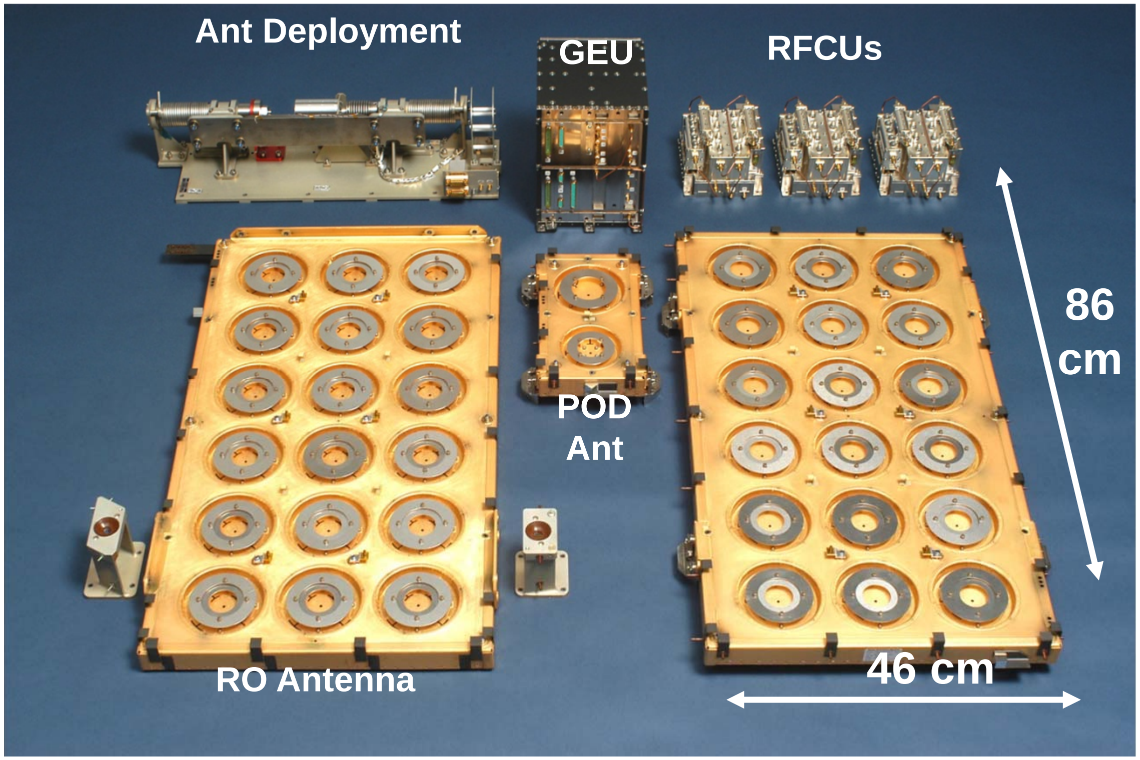
AGGA-2:

- ✓ Started in ~1995 and manufactured by Atmel [T7905E standard component] in 2000
- ✓ Targeted to EO applications: POD, Radio Occultation (RO), attitude determination.
- ✓ Used successfully in many missions (RO in bold):
  - ESA: e.g. **MetOp-Gras a / b / c** for RO, GOCE, Sentinels 1/2/3, Swarm, EarthCARE, etc.
  - Non-ESA: e.g. **ROSA** in Oceansat, MeghaTropiques, Radarsat-2, Cosmo-Skymed, …

AGGA-4: Reasons for a new generation

- ✓ new scientific requirements and experience from instruments like MetOp GRAS
- ✓ new enhanced GNSS signals (GPS / Galileo / Compass-Beidou / Glonass)
- ✓ ASIC (electronics) technology allows more on-chip integration

METOP GRAS: GNSS Receiver for Atmospheric Sounding
(developed by RUAG Space for ESA and operated by Eumetsat)



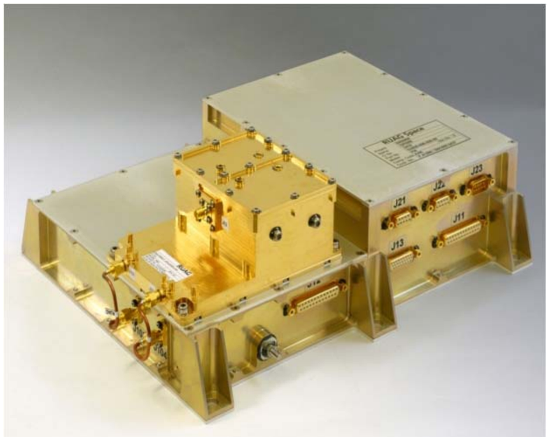
- GRAS: GPS based Atmospheric Sounder
- Electronics and antennas
- Receiver (GEU) Mass: 6 kg
  - GEU = GRAS Electronics Unit
- Power ~40 W
- ~20 MB per orbit / ~280 MB per day
- 650 – 700 occultations / per day
- Setting & Rising Occultations
- GPS dual frequ., semi-codeless tracking
- AGGA-2 based (only three chips, each processing four dual-frequ. channels)

MetOp-A launched 19th Oct 2006; switched on 27th Oct 2006, worked 'out-of-the-box': ~650 occultations / day

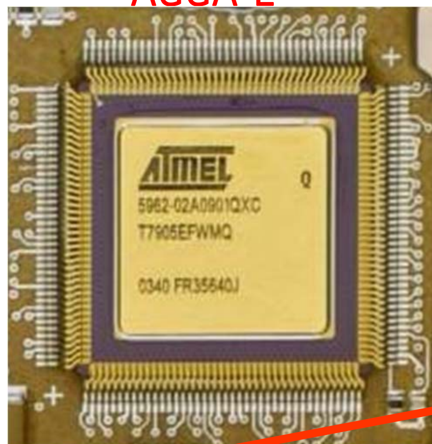
MetOp-B to be launched mid 2012 (same HW as MetOp-A) **: > 1200 occultations/day soon!**

MetOp-C will follow, launch in 2017

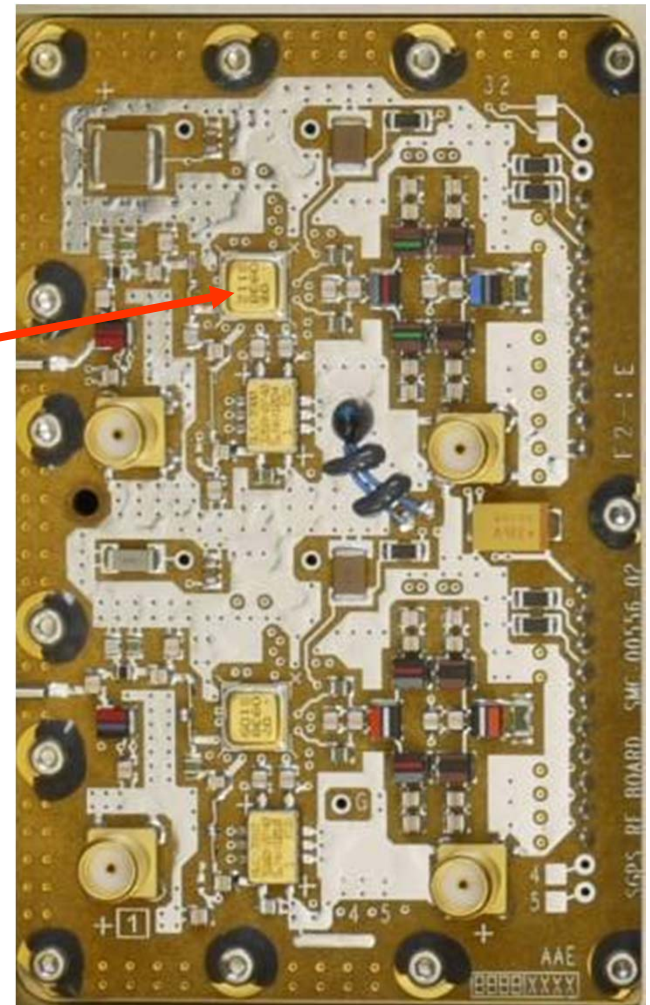
EQM model
(example with AGGA-2 for Swarm, POD only)

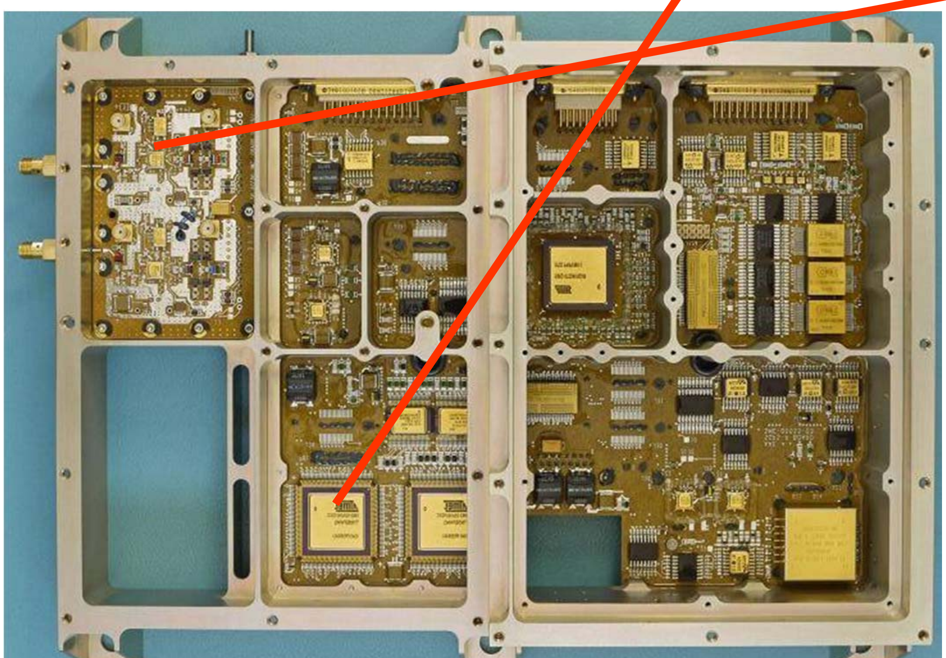


AGGA-2



RF Front End





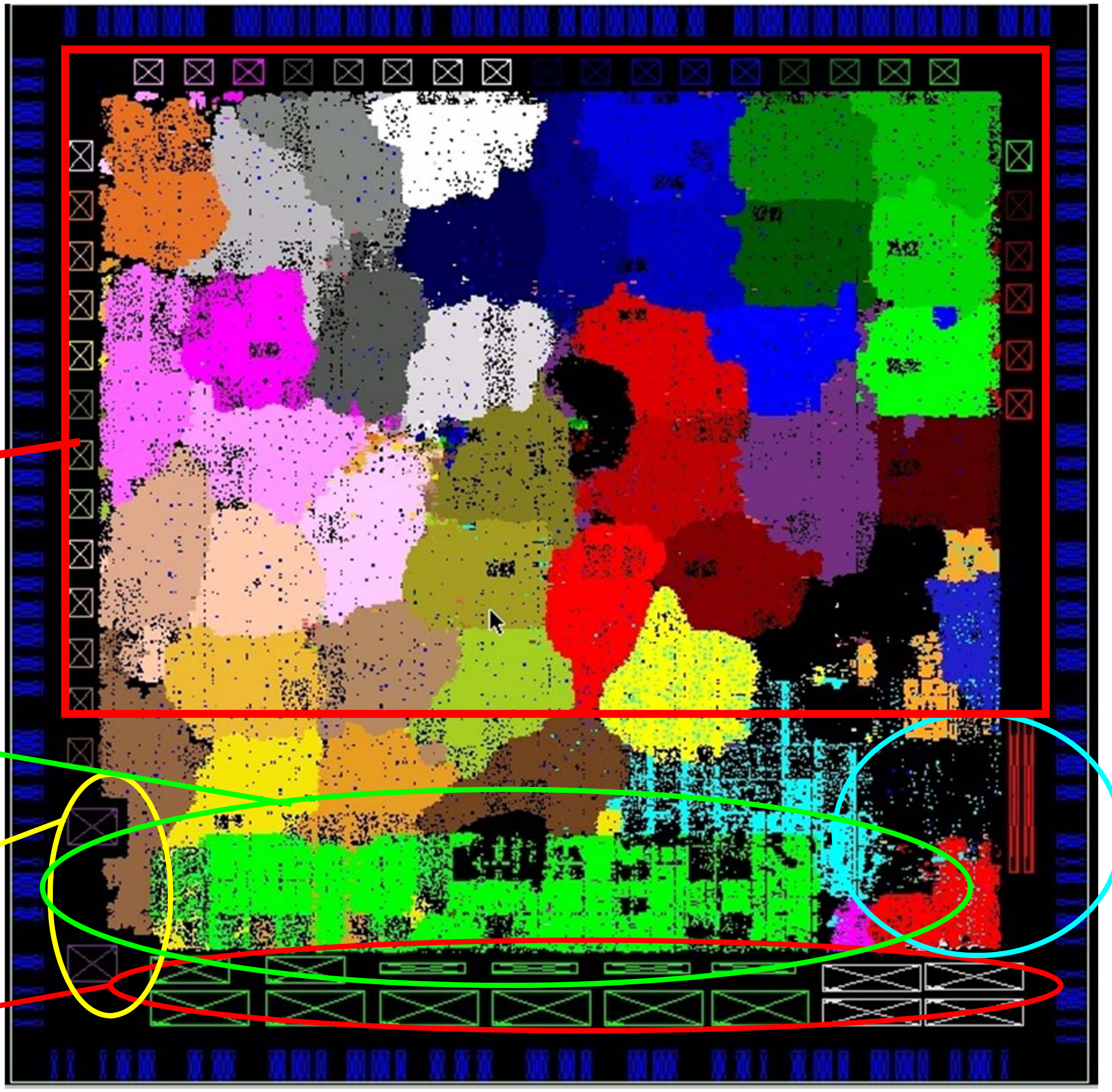
AGGA-4 vs AGGA-2

	Feature	AGGA-4	AGGA-2
GNSS CHANNELS	# of channels	**36** Single Freq. or 18 Dual Freq (target)	**12** SF or 4 DF
	Compatible signals	**Galileo Open Service**: E1bc, E5a, E5b Modernized GPS: L1 C/A, L1C, L2C, L5 Existing FDMA Glonass Potentially: Beidou-Compass, modernized Glonass	GPS L1 C/A **Semi-codeless** L1/L2 Existing FDMA Glonass
	Semi-codeless P(Y)code	**No**, (priority given to new signals and larger nb. Channels)	**Yes** (4 P-code units) – ESA patent
	Code Generators	(**2 code generators** per channel for Pilot and Data) Primary: LFSR and **memory based** **Secondary codes** and **BOC(m,n)** subcarriers	1 code generator per channel Fixed LFSR for certain primary codes only No secondary code and no BOC.
	Correlators per channel	**5** complex (I/Q) with **EE**, E, P, L, **LL** (E=Early ; P=Punctual) and autonomous NAV data bit collection in HW	**3** complex (I/Q), with E, P, L (L=Late) NAV data bit collection requires software interaction
	Channel Slaving	Hardware and software slaving	Hardware slaving
	Aiding Unit per channel	**Yes**: Code and Carrier aiding	No. Done in software
	Observables	16 Integration Epoch (IE) observables - DMA capable 5 Measurement Epochs (ME) observables – DMA capable	6 IE observables (no DMA – interrupt based) 2 ME observables (no DMA – interrupt based)
	Common to all channels	Antenna Switch Controller (ASC) Time Base Generator (TBG)	ASC TBG
MICRO-PROCESSOR		**LEON-2 FT on-chip** with IEEE-754 compl. GRFPU Floating Point Unit	**Off-chip** (typically ERC-32, ADSP 21020)
INPUT FORMAT		**3 bit** (0.17 dB loss) (I/Q, real sampling and **interface for IF ~ 250 MHz**)	**2 bit** (**~0.55 dB** loss) (I/Q and real sampling)
CRC MODULE		Check Redundancy Code in **hardware On-chip**	No
FFT MODULE		128 point **FFT in hardware** on-chip	No
INTERFACES		Two DMA capable UART, **Mil-Std-1553, 4 SpaceWire** SE, SPI I/F, DSU, S-GPO, 32 GPIO, SRAM I/F	Microprocessor I/F, Interrupt controller and I/O ports
BEAMFORMING		Yes (2 **Digital Beam Forming**)	No
TECHNOLOGY		**0.18 Micron** ATC18RHA process from ATMEL, **352 pins** MQFP GNSS clock up to 50 MHz (target) – LEON clock target 80 MHz	0.5 micron from ATMEL, 160 pins GNSS clock up to 30 MHz

AGGA4 ASIC

ASIC Manufactured in February 2012 ; available in April 2012 ; 1st mission with launch in 2015

Floorplan Picture taken in Nov. 2011)



GNSS core : 2.7 Mgates

Clocks + I/F + Back End: 1.9 Mgates

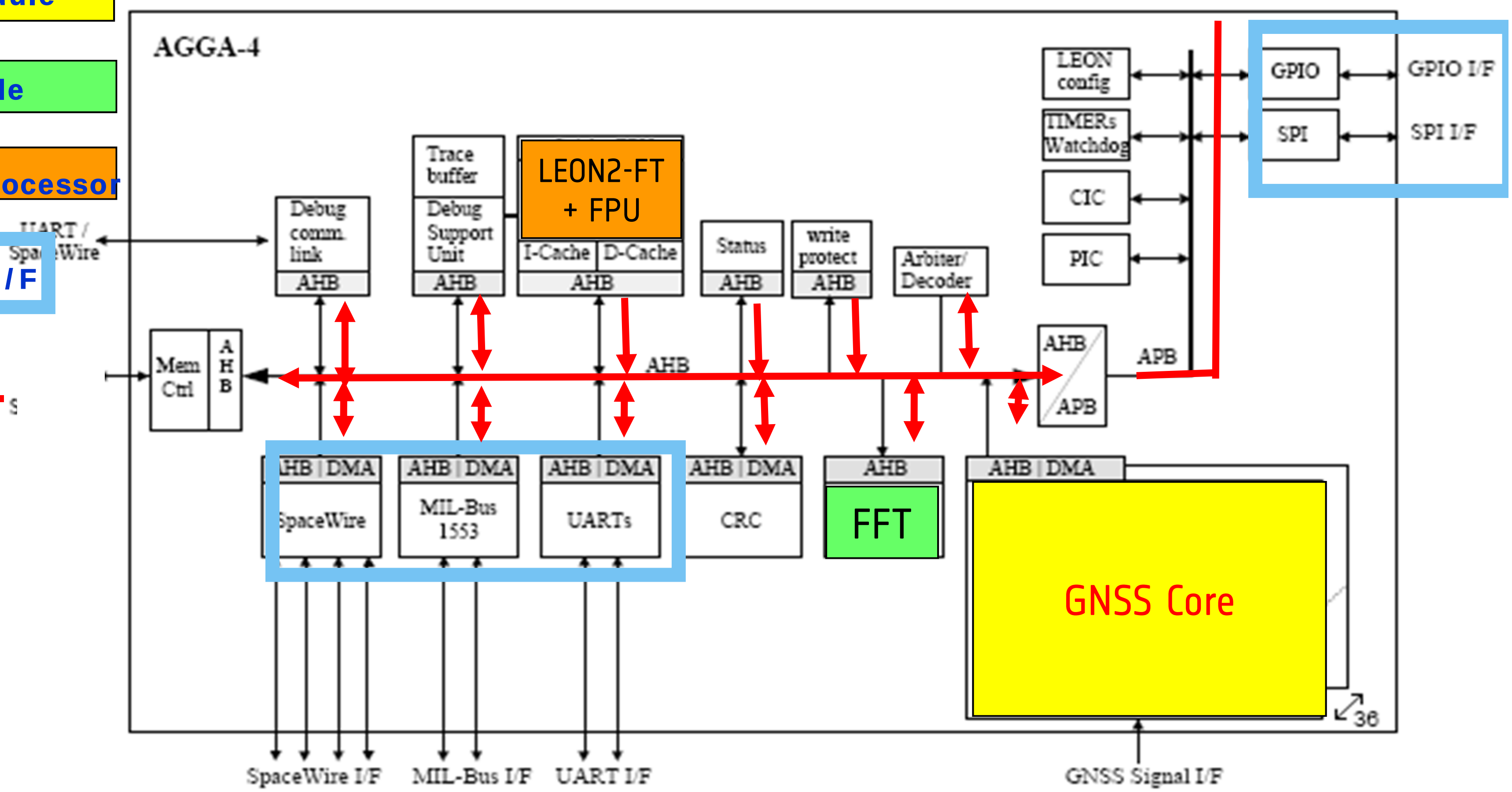
Design : 4.6 Mgates

Pads+others : 1.4 Mgates

Total : 6 Mgates

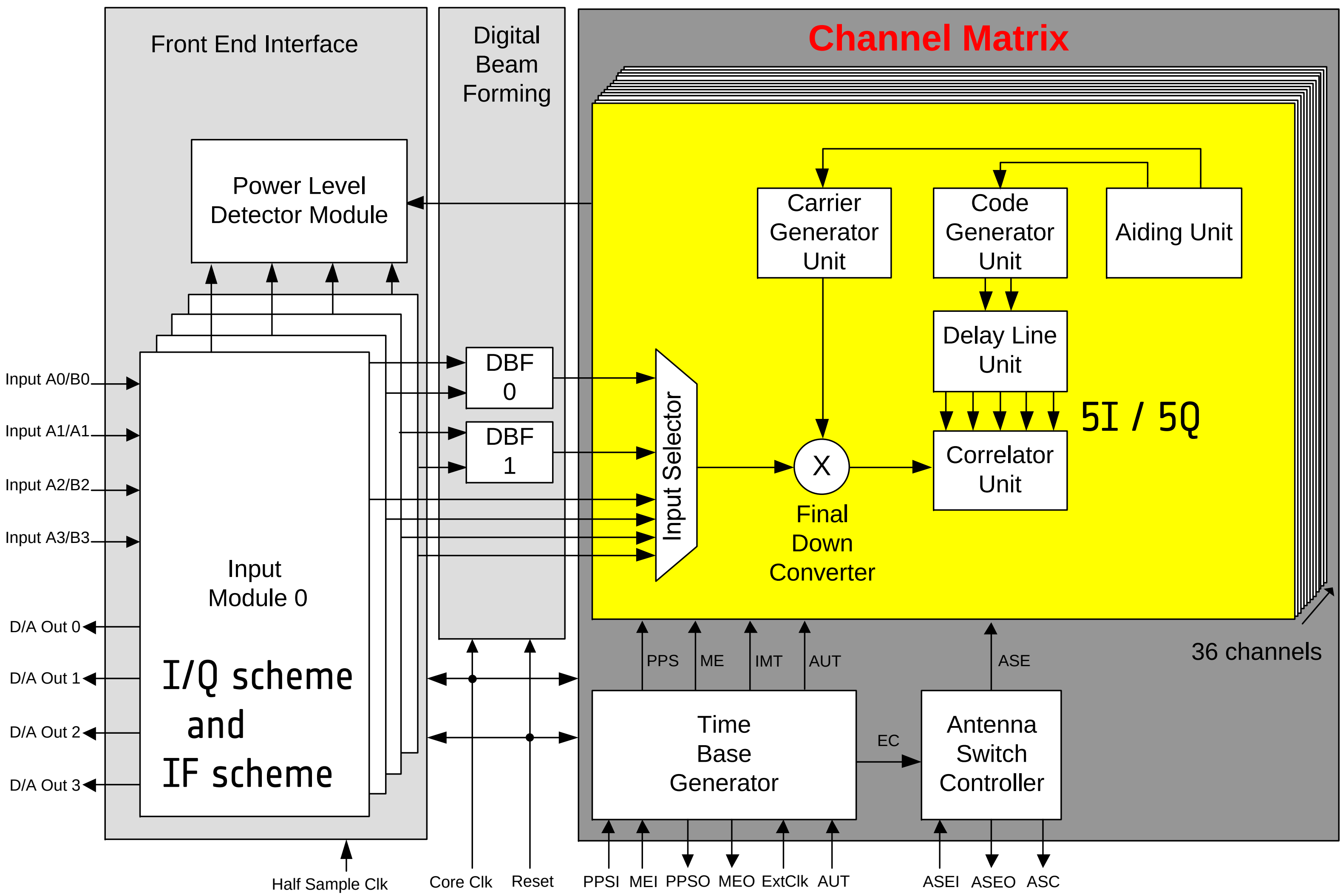
Overview of AGGA-4

- GNSS module
- FFT module
- LEON μ-processor
- external I / F
- AMBA I / F
- DMA I / F

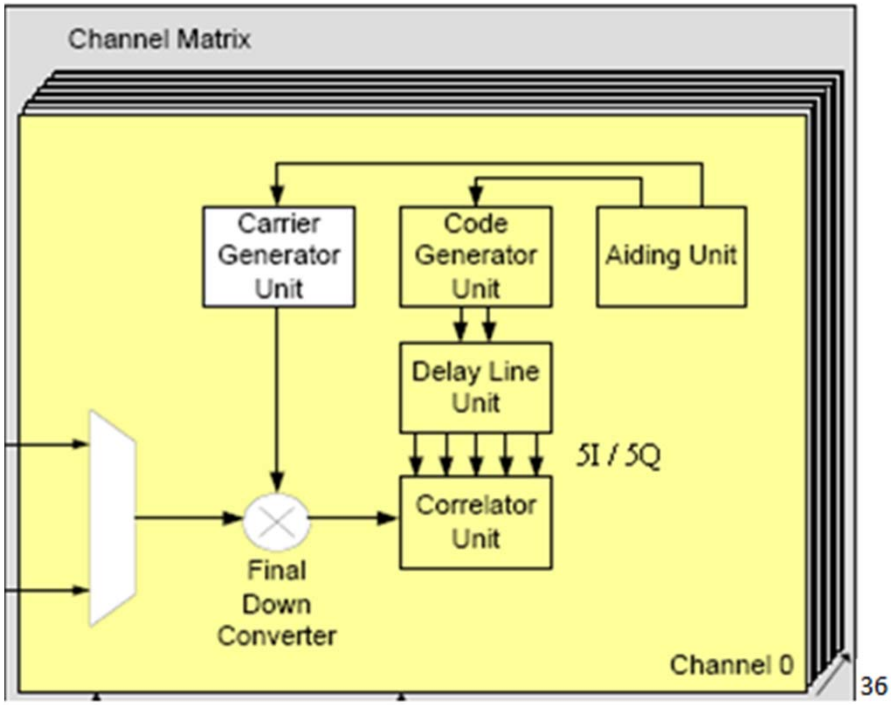


Legend:
GIC: GNSS Interrupt Controller
CIC: Communication Interrupt Controller
PIC: Primary Interrupt Controller

AGGA-4 GNSS Core



AGGA-4 Channel matrix



* **36 single-frequency / double-code channels**

* Very flexible primary **code generator** units:
  – a LFSR (Linear Feedback Shift Register) for L2CL
  – memory-based codes for Galileo E1b/c

* Support of Binary Offset Carrier – **BOC(m,n)** and **secondary codes** for modernized GPS & Galileo signals (and Beidou, Glonass as known today)

* **5 complex (I/Q) code correlators**, to allow the EE, E, Punctual, L, LL for BOC signals.

* **hardware Aiding Unit**, allowing autonomous CODE and CARRIER aiding (for high orbit dynamics)

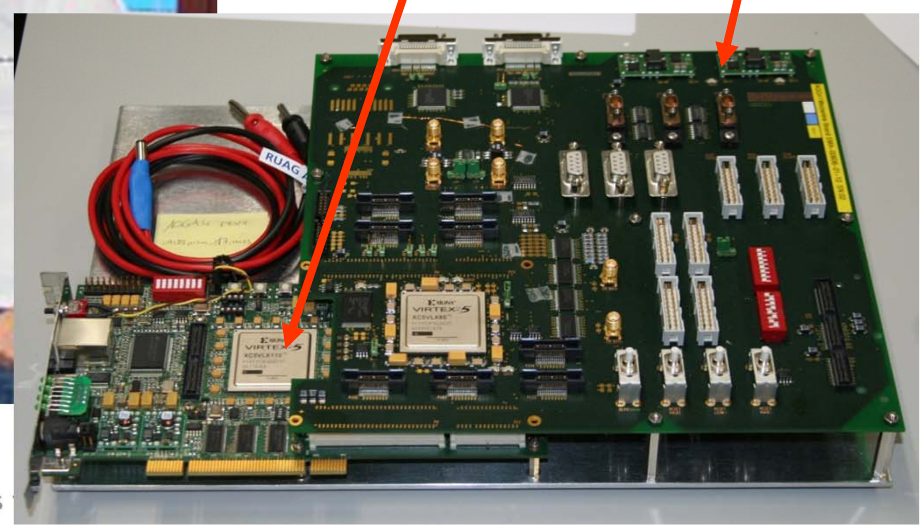
Signals processed with AGGA-4

- relying on public signals (not encrypted) and compatible with GLONASS and Beidou (as known today)
- two component (pilot/data) signals in one channel (thanks to double code generator)
- 36 SF channels = 9 occultations (dual-frequency ; open and closed-loop tracking simultaneously)

Band	Freq. (MHz)	Component	Code Rate (Mcps)	Primary code length (chips)	Secondary code length (chips)	Symbol/ Data Rate (sps / (bps)	Replicas in AGGA-4	LFSR/ Memory (config. AGGA4)	AGGA4 Nb. Channels
E1	1575.42	E1 B	1.023	4,092	No	250/125	BOC(1,1)	Memory	**1 SF** (Sing. Freq.)
		E1 C	1.023	4,092	25	Pilot	BOC(1,1)	Memory	
E5a (E5b)	1176.45 (1207.14)	E5a-I (E5b-I)	10.23 (idem)	10,230 (idem)	20 (4)	50/25 (250/125)	BPSK(10) (idem)	LFSR (idem)	**1 SF** **(idem)**
		E5a-Q (E5b-Q)	10.23 (idem)	10,230 (idem)	100 (idem)	Pilot	BPSK(10) (idem)	Memory (idem)	
L1c	1575.42	L1Cd	1.023	10,230	No	100/50	BOC(1,1)	Memory	**1 SF**
		L1Cp	1.023	10,230	1800	Pilot	BOC(1,1)	Memory	**1 SF**
L1	1575.42	L1 C/A	1.023	1,023	No	50	BPSK(1)	LFSR	**1 SF**
L2C	1227.6	L2CM	10.23	10,230	No	50/25	BPSK(0.5)	Memory	**1 SF**
		L2CL	10.23	767,250	No	Pilot	BPSK(0.5)	LFSR	
L5	1176.45	L5-I	10.23	10,230	10	100/50	BPSK(10)	LFSR	**1 SF**
		L5-Q	10.23	10,230	20	Pilot	BPSK(10)	Memory	

AGGA-4 design and validation

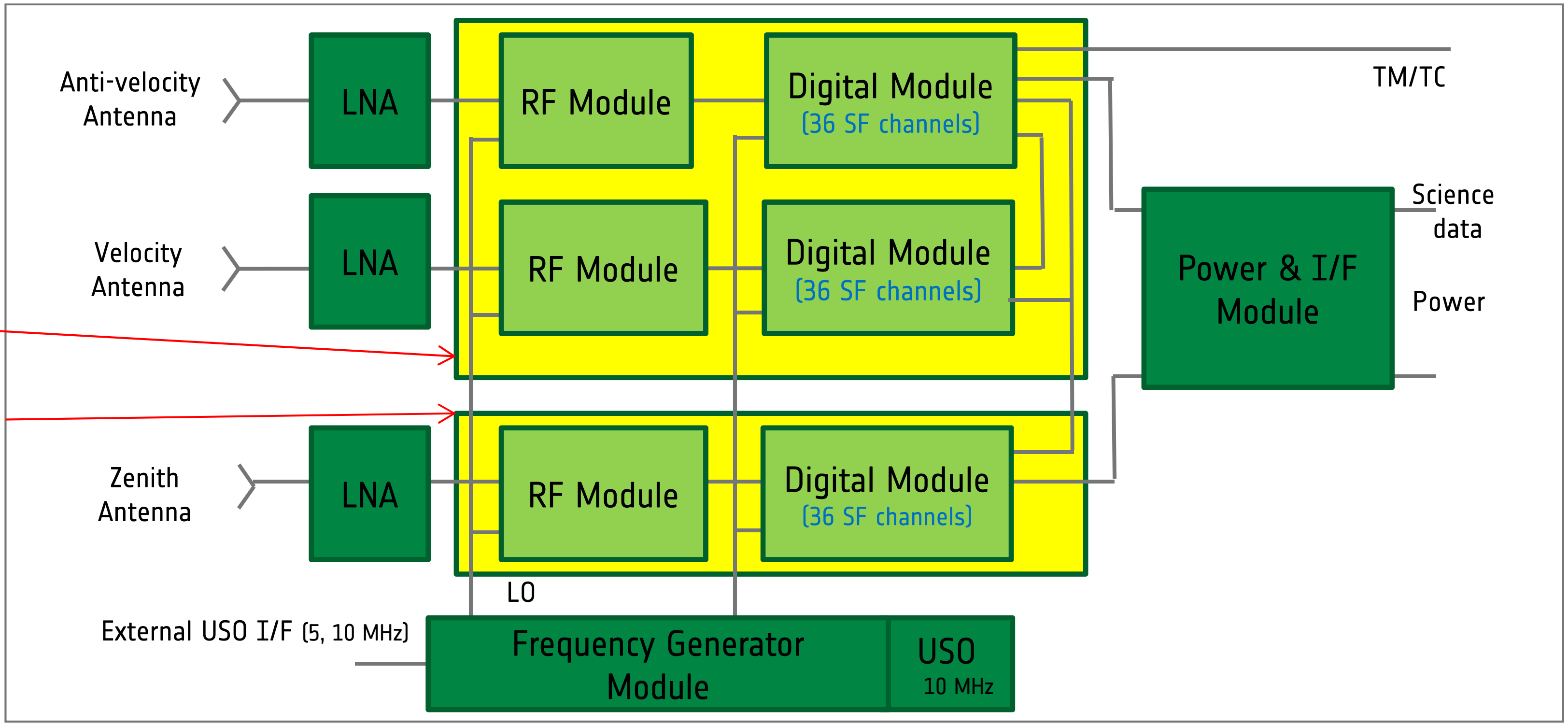
- ✓ AGGA-4 developed by **Astrium GmbH** (Germany) under ESA guidance and Contracts.
- ✓ Extensive independent **validation** (block testing, and also acquisition & tracking) with **FPGA version** (same as ASIC but with **only 4 GNSS channels**) at ESTEC in Aug-2010 by **RUAG Space Austria**
- ✓ The FPGA already allowed substantial SW development for future receivers



Modular and scalable RO instruments

RO Receiver(s)

POD Receiver



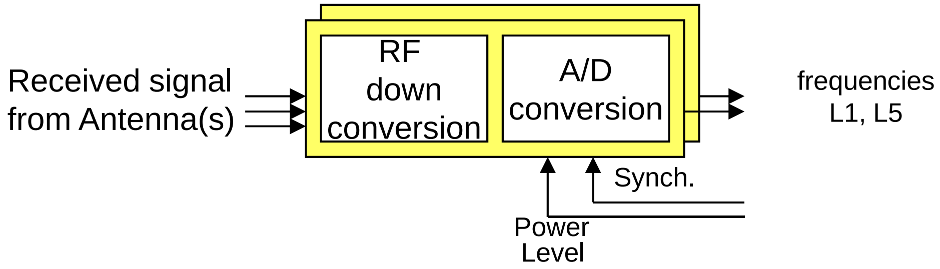
As modular as possible (reproducibility and re-use, adapting to e.g. small carriers)
Difference between POD and RO limited to software and antenna

Two developments of POD receiver with AGGA-4 under negotiation
Development of GRAS-2 instrument prototype expected to start in 2Q / 3Q 2012

RF Module & Antennas

- ✓ Saphyrion (CH) chips (down-converter SY1007 ; ADC SY1017): highly integrated
  - used in a high number of satellites (Swarm, 6 Sentinels, …) for POD
  - however, phase noise requirements for RO are more stringent than for POD

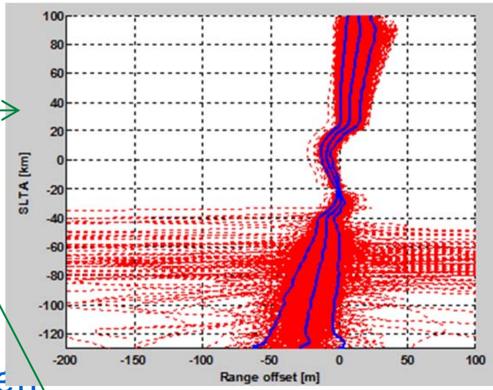
- ✓ RF chain in future RO instruments:
- innovative architecture for coherent clocks with existing components under study
- new devices with improved phase noise also under development



- ✓ Scalable antenna design
  - more radiating elements (for high performance reference – e.g. MetOp-SG)
  - less radiating elements if antenna to be accommodated in smaller satellites

Innovative processing

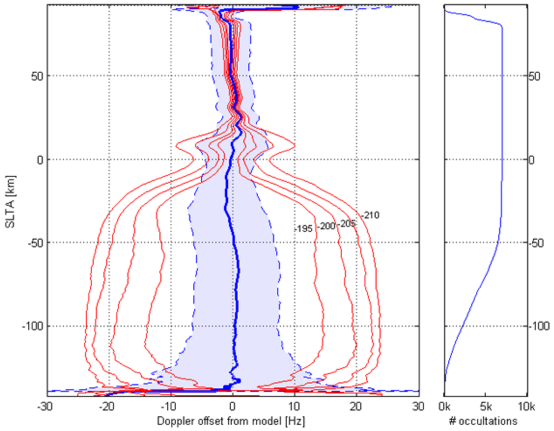
- ✓ ESA study with RUAG, DMI, DLR, Graz, GFZ-Postdam and Eumetsat revealed:
  - better performance of MetOp-GRAS than initially specified
  - open loop models (both in **Range, Doppler**) validated
  - some issues can be improved (e.g. data gaps)



- ✓ New study to minimise data gaps in **MetOp-GRAS** with RUAG Sweden
  - Development of a **receiver simulator** (based on L1, P1/P2 and AGGA-2 specifics)
  - Use of simulated data (derived from ECMWF profiles) from a Eumetsat study
  - corrected parameters to be patched in the on-board MetOp software

- ✓ New study to minimise/avoid data gaps in **MetOp-SG** initiating
  - Development of a receiver simulator

    (based on L1/E1, L5/E5a and AGGA-4 specifics)
  - More flexibility in the operation of Open Loop (more channels)
  - Use of simulated data from a Eumetsat study
  - output relevant to tune MetOp-SG requirements



RO opportunites for future missions

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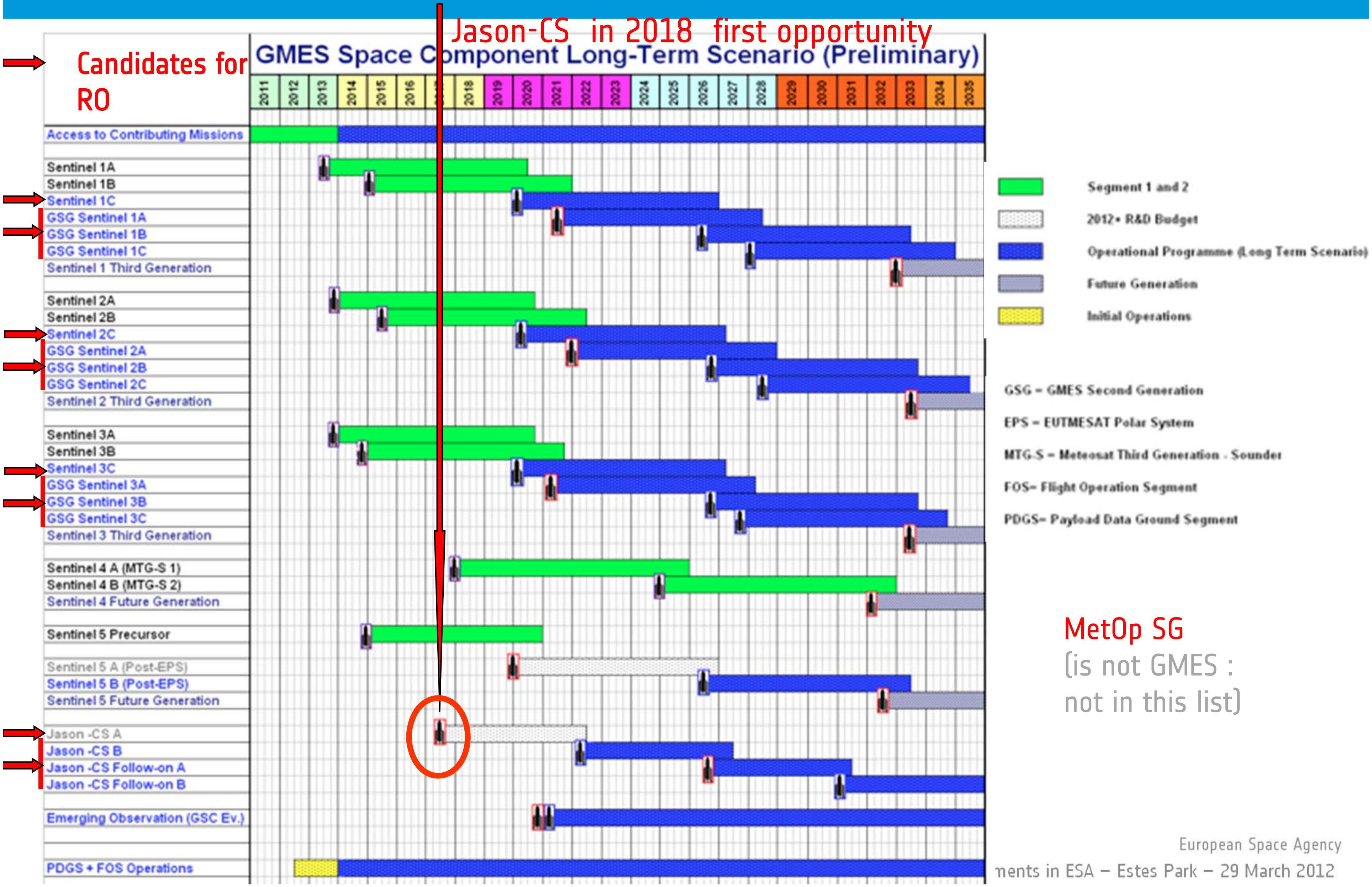


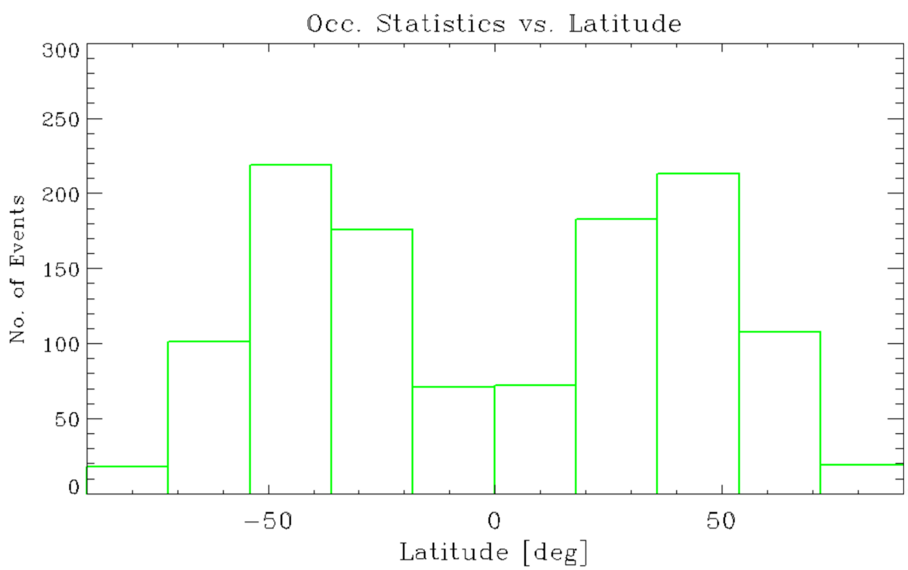
Jason CS

A 66° inclination orbit as of Jason CS has the maximum number of events at mid latitudes with an increase of events in the tropical regions at the expense of the high latitude events

Jason-CS alone

no. occ events: 1180=583 set +597 rise

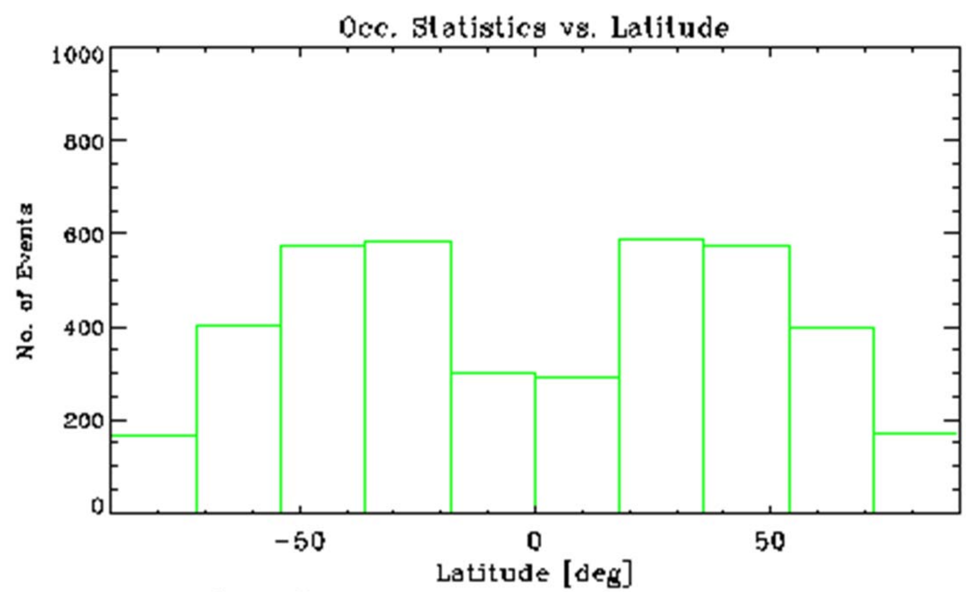
Tx: GPS + Gal



Jason CS & MetOp-2G A & B

no. occ events: 4044 = 2016 set + 2028 rise

Tx: GPS + Gal



New GNSS signals and constellations (Galileo, modernized GPS, others)

More **robustness** thanks to **more and better signals in Open Service**

- ✓ error detection , correction and re-acquisition easier
- ✓ no semi-codeless needed: dual frequency available also with low SNR
- ✓ pilot components (no bit wiping) => very good for EO, needing robust carrier measurements
- ✓ secondary codes: 'lengthen' the spreading code, better autocorrelations while fast acquisition

Some (small) improvement in accuracy (better codes, but similar carrier measurement)

The new GNSS signals imply:

- ✓ **Components more flexible** (as AGGA-4) and **with more digital processing**
  - more channels + more functions (e.g. carrier and code aiding).
  - Flexibility (e.g. LFSR and memory-based code generators)
- ✓ Different software: no codeless processing or bit wiping, but more available signals; tracking in both open and closed-loop

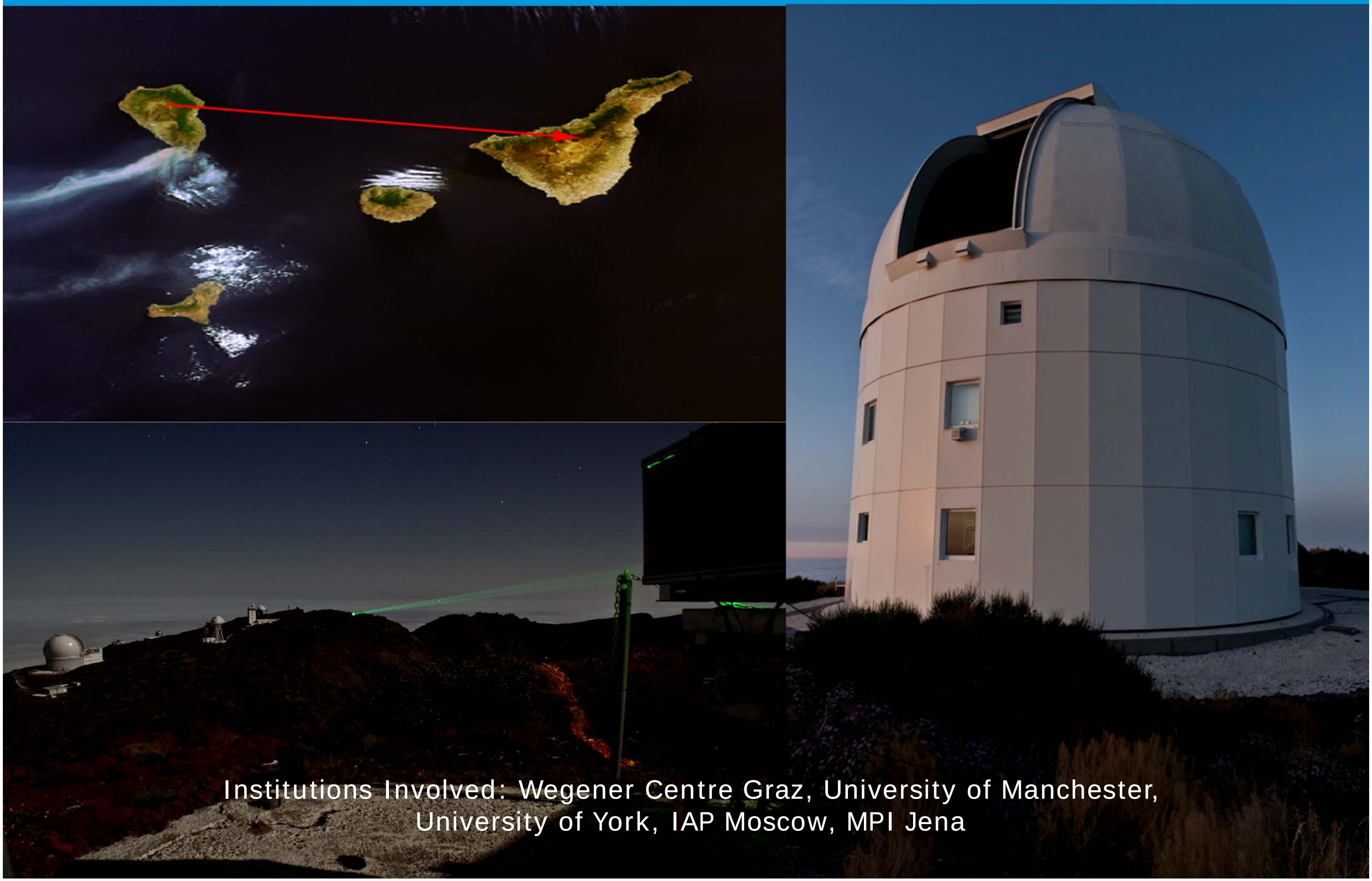
ESA preparing the AGGA-4, RF ASICs and antenna **components** compatible with new GNSS.

Developing the new **receivers** (ASIC final pin layout known)

Active Limb Sounding Beyond Radio Frequencies in ESA

- investigated limb sounding using higher RF frequencies (~10, 22, 27 GHz) under ACE+, WATS,.. project concepts
- investigated limb sounding using SWIR lasers (ACCURATE concept)
  - suitable for vertical profiling of Greenhouse Gases using a differential absorption technique
  - 2-2.5 micron SWIR band allows probing of CO_2, CO, CH_4, H_2O, N_2O, O_3 and isotopes at high vertical resolution
  - Technique allows to measure line of sight wind as additional parameter
- Experiment to test concept implemented 2011:
  - 150 km baseline used to probe CO_2 (2.1 micron) and CH_4 (2.3 micron) between Tenerife and Gran Canaria
  - Concept successfully demonstrated
  - Final results from data analysis expected in Q2 2012
  - Ongoing projects to advance the processing

Active Limb Sounding Beyond Radio Frequencies



Institutions Involved: Wegener Centre Graz, University of Manchester, University of York, IAP Moscow, MPI Jena

Other ESA activities

OPS-GRAS Project with Wegener Center in Graz:

-Mostly new implementation of the Level 1b/2 processing chain

-Allows modernization and optimization of code

- Immediate benefit: significant improvement of processing speed

-Harmonization of background information used

-Reduction to a baseband:

- Potentially increases numerical stability
- Potentially allows for more efficient filtering
- New “clean” and improved system will be compared against the old one

Project with ECMWF

– Estimating the Optimal Number of GNSS Radio Occultation Measurements for Numerical Weather Prediction and Climate Reanalysis Applications

Conclusion

AGGA-2 baseband processors: widely used in ESA and non-ESA missions

- ✓ cm accuracy in POD demonstrated (GOCE,..)
- ✓ RO: excellent performance of MetOp GRAS; data used operationally

ESA preparing the next generation of RO instruments

- ✓ **AGGA-4** : compatible with Galileo, modernized GPS, Glonass, Beidou, and higher number of channels. ASIC samples in April 2012
- ✓ RF ASICs, antennas
- ✓ innovative processing
- ✓ New receivers

Generic developments aiming at MetOp-SG, Jason-CS, next generation of GMES Sentinels, and open to others

Collaboration with European partners (Eumetsat, others) working very well