Crisa

The strategy for qualification and mission validation of a mixed ASIC developed for next NASA Mars Mission

AMICSA 2010, ESTEC

Jose F. Moreno-Alvarez / Sept. 5th, 2010

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Table of Content

1 Crisa overview

Crisa

- Founded in 1985, Crisa has contributed to most of the European Space Agency (ESA) programmes.
- The leading company in Spain in space Flight Electronics design and production.
- Located in Tres Cantos, ~15 km north of Madrid.
- > 400 persons in three buildings.
- More than 700 flight units have been delivered.
- Strong reputation as high technology firm in Space (satellites, launchers and space vehicles), Telecommunications, Defence, and Audiovisual sectors.

Facilities

2.000 m^2 Clean Room
Class 100.000

Class 100 Clean Room
area inside class 1.000

Design & Test Laboratories

Thermal Vacuum Chamber

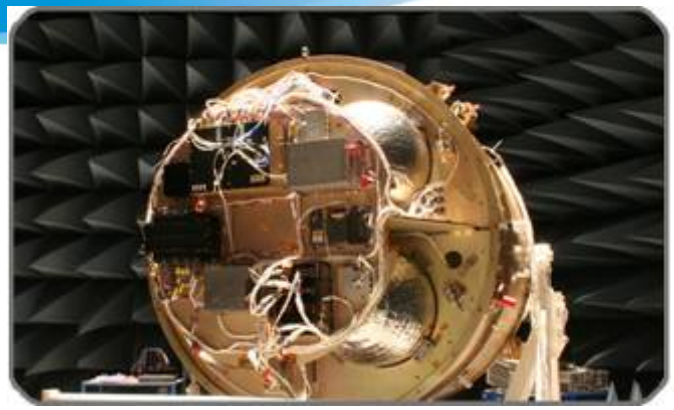
EMC testing facilities

High-voltage room

Wave Soldering Machine

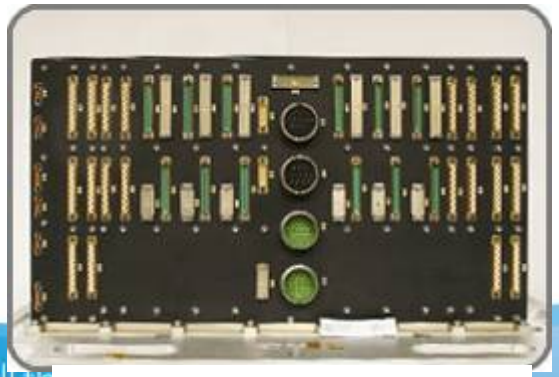
Space qualified Surface Mounting
Technology

Shaker



VEGA avionics integration and test

JWST NIRSpec instrument controller



GOCE power subsystem

- Small EO/Sc payloads & System engineering
  - Science & EO instruments / payloads
  - System engineering
- Power Sytems
  - Electrical Propulsion PPU
  - Driving Electr. & Cooler electr.
  - Power Subsystems PCDU
  - DC/DC Converters
- Data Handling
  - On board computers (OBC/ICU)
  - Digital Signal Processing (DPU)
  - Remote Terminal controllers (RTU)
  - Star Tracker/Cam Electronics
  - Proximity Electronics
- Ground Segment
  - Mission Scheduling
  - Data Management
- Manufacturing
  - Recurrent production for E3000 & Launchers. Technology engineering

2

The REMS Instrument for '*Curiosity*'

Photo & logo: Nasa/JPL

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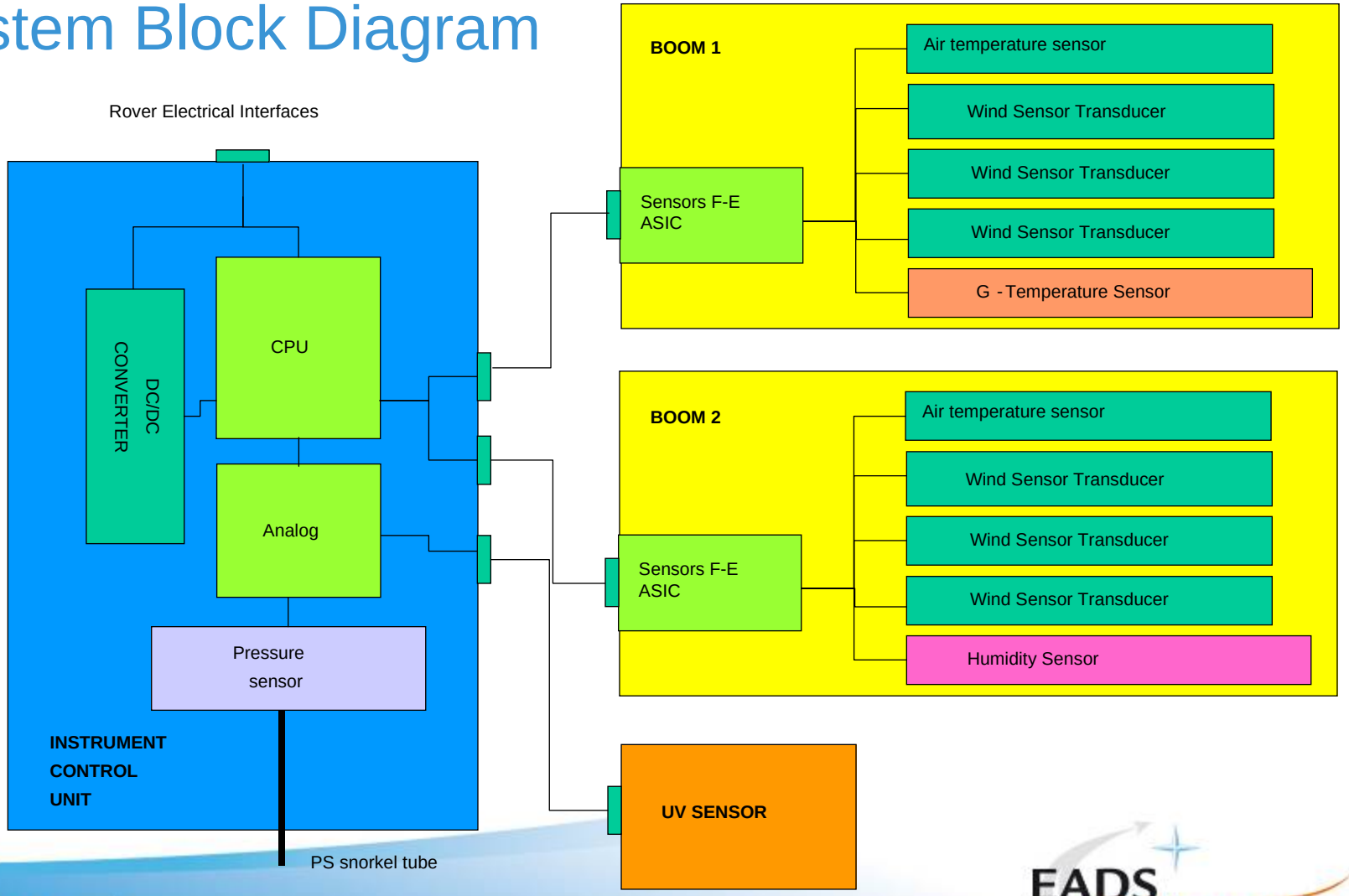
The „*Curiosity*“ rover (Mars Science Laboratory)

- Next NASA Rover for 2011
- A truly science mission
  - Many (>10) scientific payloads
- Step forward on Mars exploration
  - Enormous Rover: twice as higher and longer than MERs (2.7m length x 2.7m width x 2.2 m height)
  - Mass: ~800Kg, 78Kg for payloads
  - Using nuclear energy (Radiosiotope Thermal Generator)
  - High Mobility: more than 20 Km during Primary mission (1 Martian year or 2 Earth years)
  - Open to landing sites on higher latitudes ±40º (4 sites in final list)
  - Impresive entry-descent & landing system
    - Guided capsule
    - Parachute braking
    - Powered descent
    - Skycrane lowering rover
  - Preparatory for Mars Sample Return and manned missions

Rover Environmental Monitoring Station (REMS) System Block Diagram



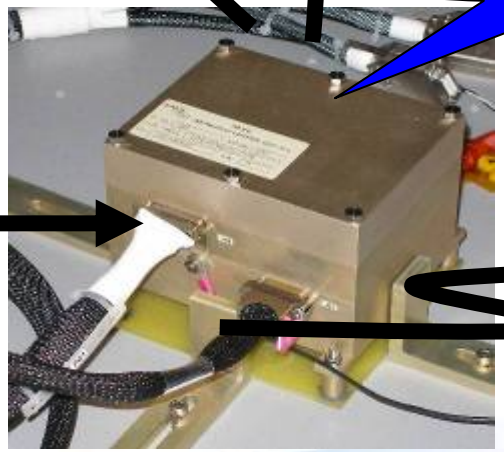
REMS Instrument Concept

Boom 1

Boom 2

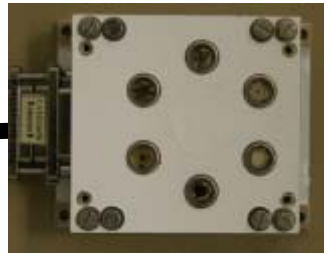
Intra-Instrument Harness

On Board Software



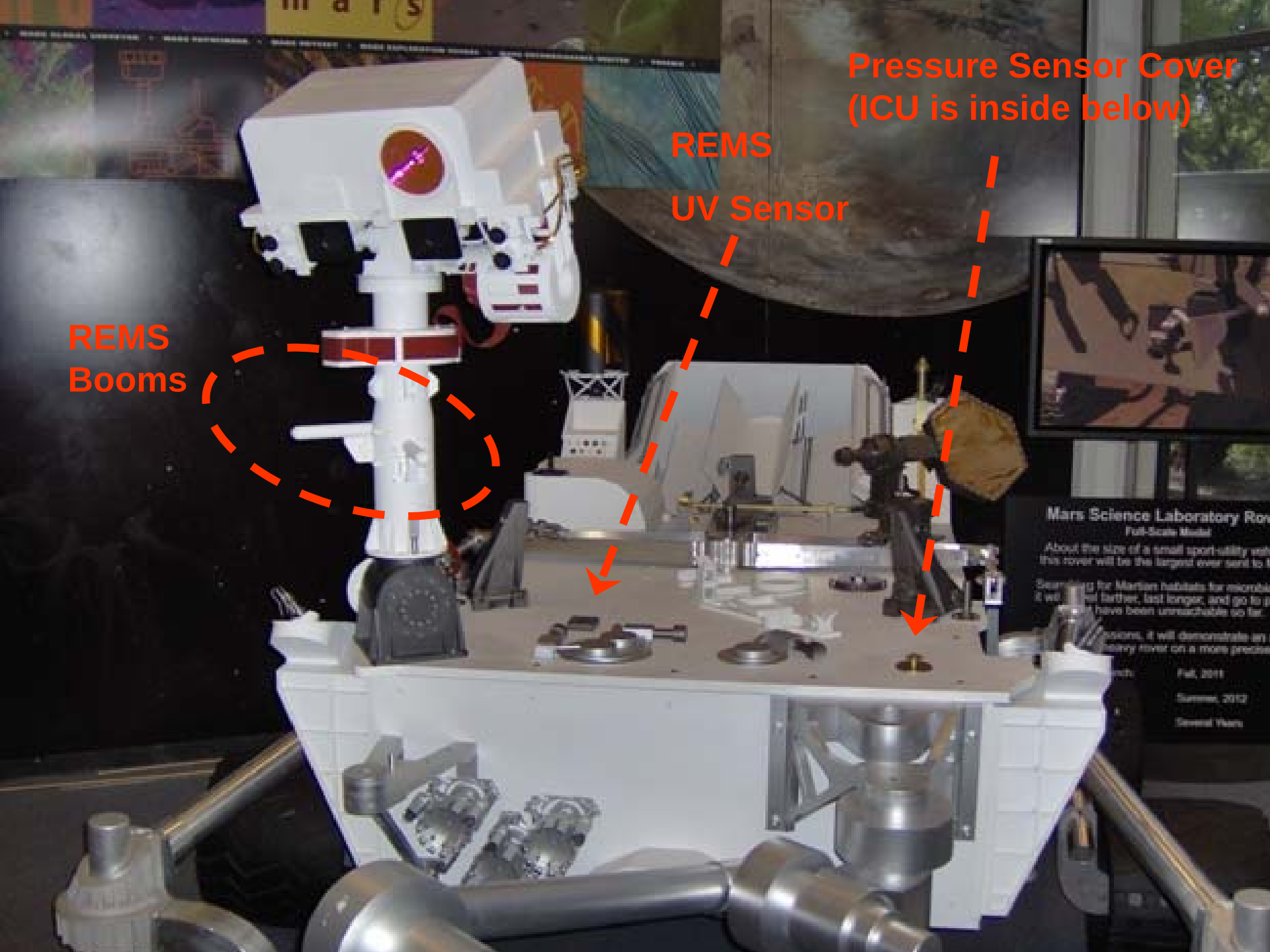
ICU

ROVER INTERFACE



UV Sensor

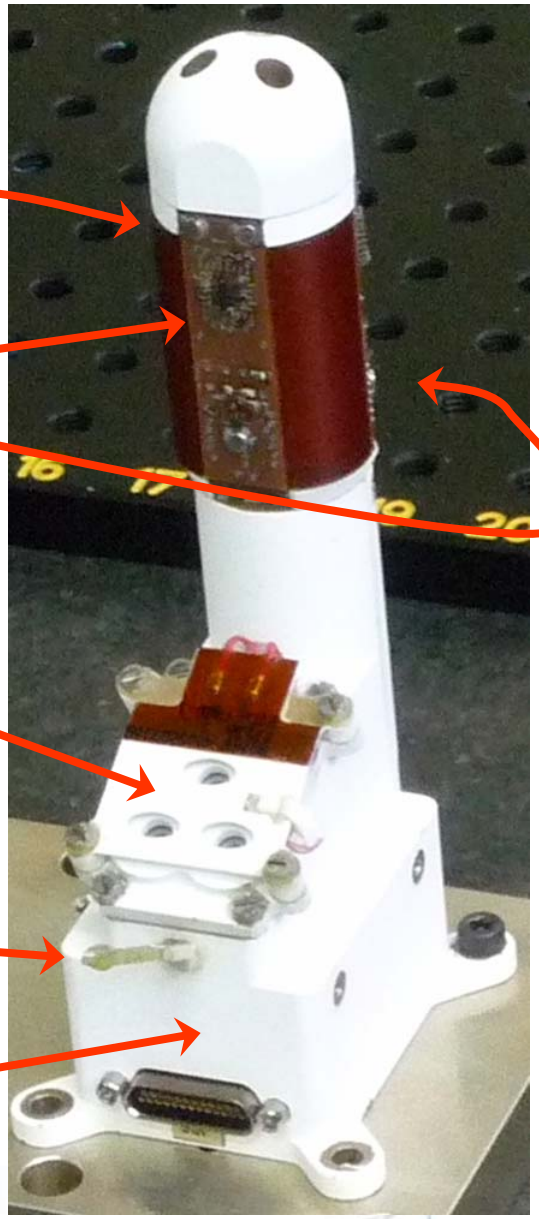
REMS DOES NOT CONTAINS MOBILE PARTS NOR JETISSONABLE PARTS


Pressure Sensor Cover
(ICU is inside below)
REMS
UV Sensor
REMS
Booms

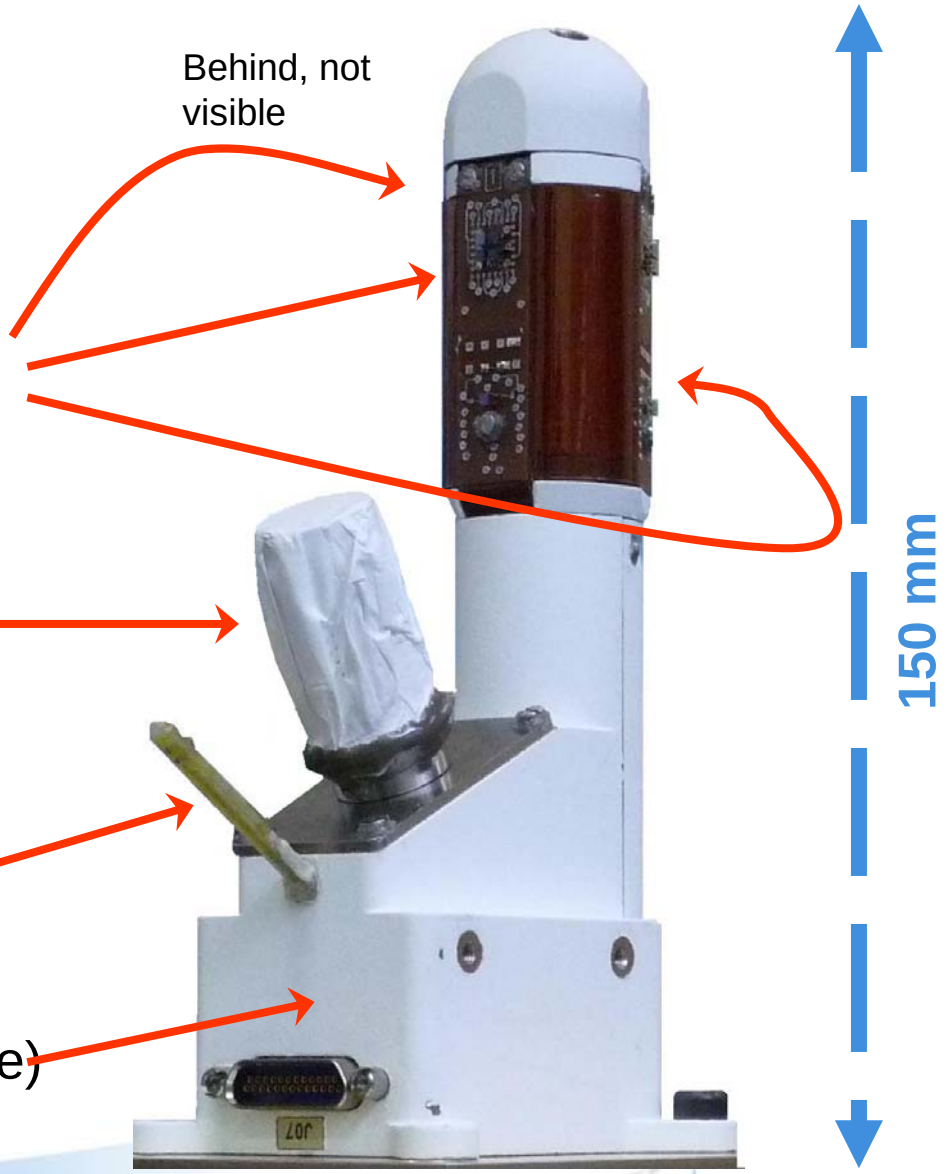
REMS Measurements

- Wind Speed and Direction (in a 3D geometry)
- Air Temperature
- Temperature of the surrounding terrain
- Pressure
- Relative Humidity
- Ultraviolet radiation, in 8 bands

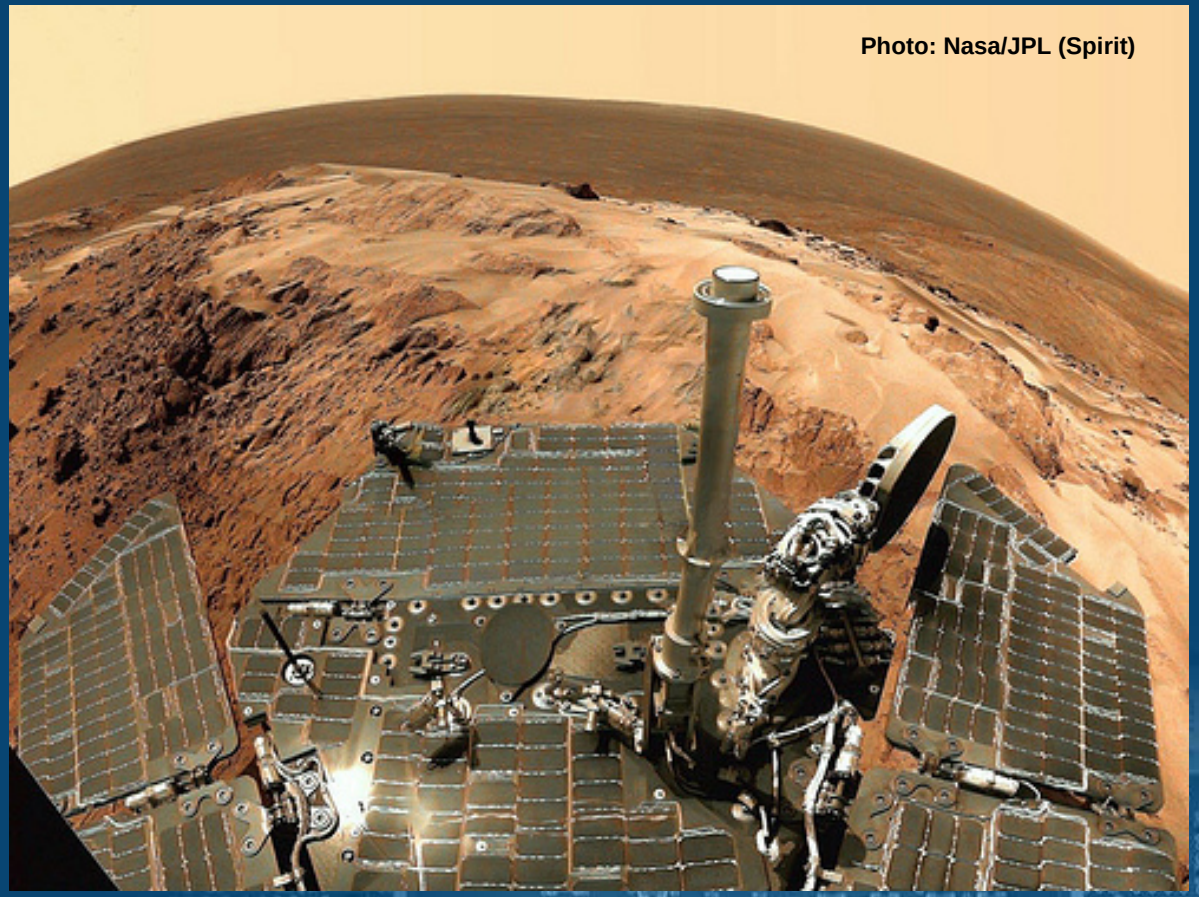
Boom 1 Sensors



Boom 2 Sensors



CRISA



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The Sensors Front-End Mixed ASIC

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Main ASIC functions

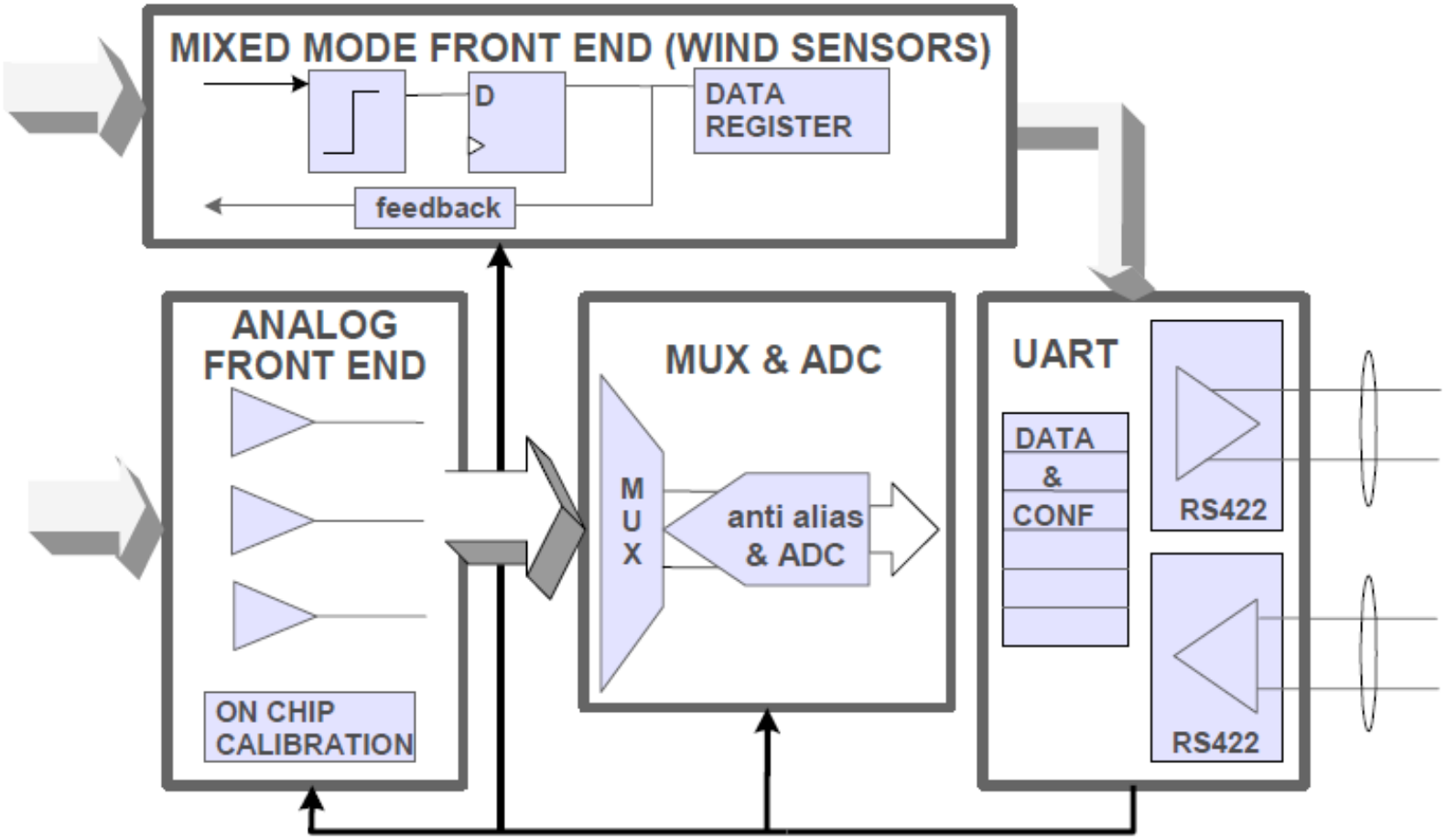


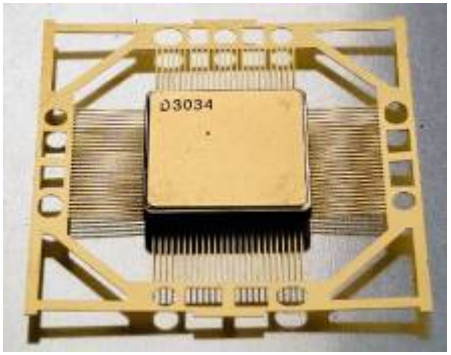
Diagram: Aurelia Microelettronica

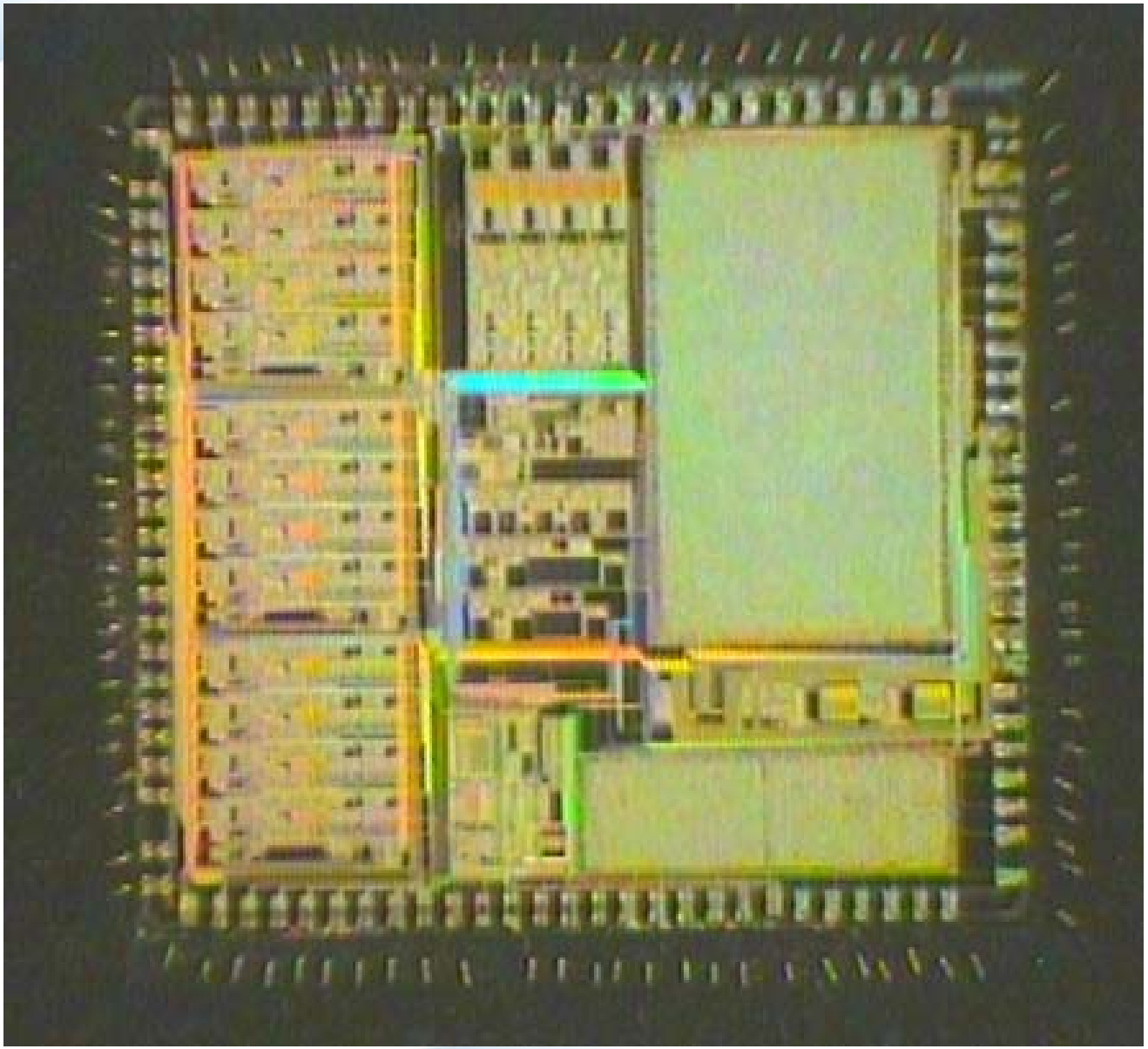
Sensors Front-End Mixed ASIC

- Main functions included:
  - 16-bit ADC (~12 bits effective) + 16 channel mux & buffer
  - PT1000 conditioning channels
  - Low-level voltage channels (millivolts)
  - Specific sigma-delta control loops for our Wind-Sensor
  - 100mA current driver for heater
  - Digital control part, including automated cyclic acquisition control and serial communications (RS422 interfaces embedded & UART based).
  - Ancillary functions: Power-up reset, band-gap reference, …

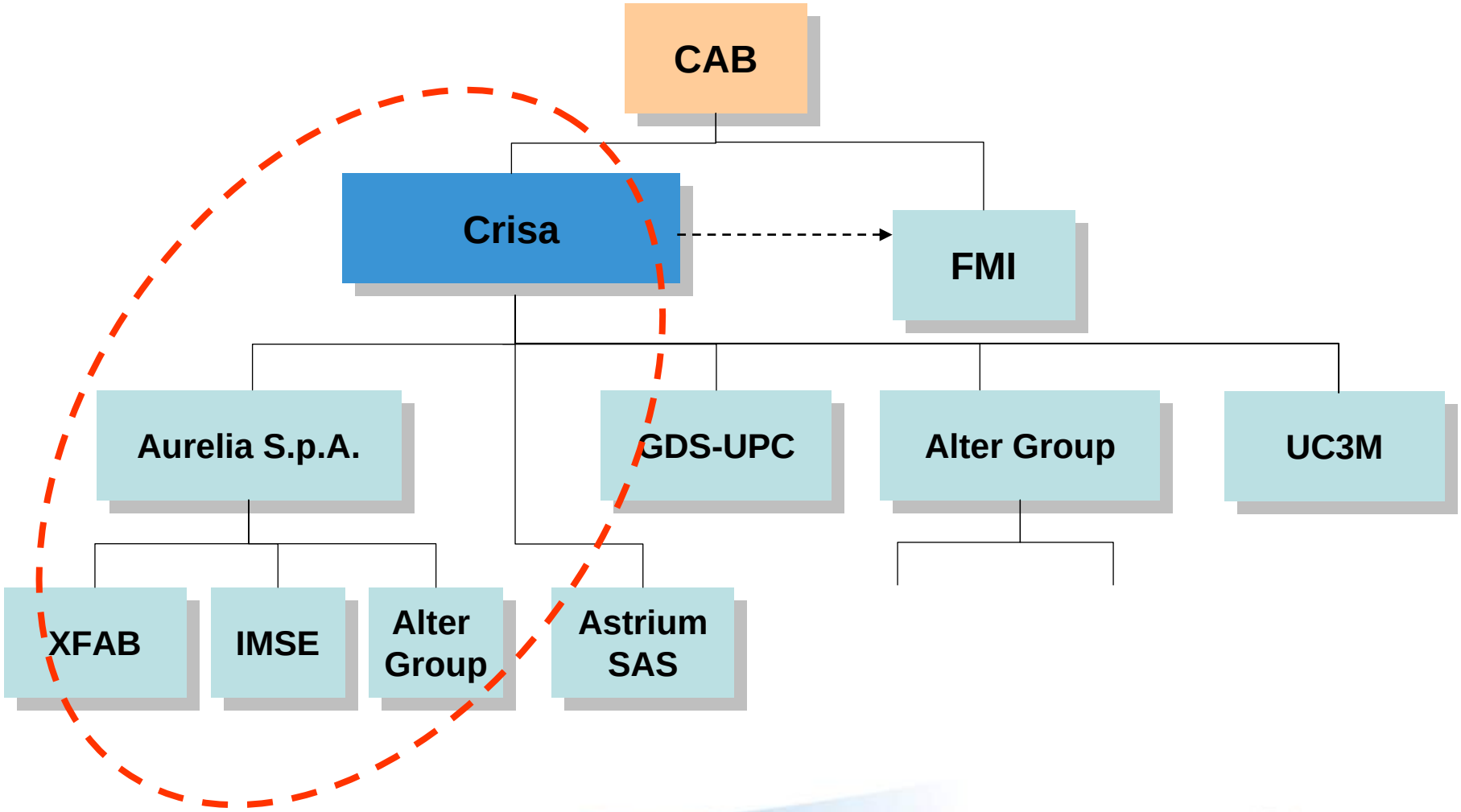
- Manufacturing details:
  - XFAB SOI 1um
  - ASIC die size ~ 9x9 mm
  - Multi-Level Mask Process
  - 6 Wafers (size: 6 inches)
  - ~150 ASICs per Wafer

- Tight Schedule limited to 2 design + foundry iterations, resulting in:
  - Some performances not fully met
  - Parametric dependencies with the T & Vcc
  - Poor ASIC to ASIC repetitiveness
  - ESD sensitivity (design error)





Engineering Project Organization



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The difficulties …

Environmental Requirements & Mission Definition

- Withstanding the temperature cycles
  - **-135ºC to +70ºC** for qualification of exposed elements
- Low-pressure CO2 environment
- Surviving one launch & one entry, descent and landing
  - Vibration and Pyroshock levels very high (e.g. 3000 g's for UVS)
- Vehicle vibrations: (traverse loads, microphonics…)
- The Martian Dust ! (and the Wind, …)
- Radiation (neutrons)
  - Use of a RTG + DAN instrument, then needing to test for **high neutron fluence**
- Contamination control & Planetary protection
  - +110ºC or +125ºC for sterilization
  - Need to manufacture in ISO-3 clean room
- 2 years primary mission life:
  - x 3 mission validation (PQV)
    - Need of test around 2000 cycles with thermal gradient > 145ºC
    - 10.000 cycles tested for mixed ASIC

ASIC constraints

- Mixed ASIC design …
  - Need for use a commercial ASIC process
  - Lack of libraries & data for designing below -55ºC
- & development
  - Target to validate it for operating at lower temperatures (-75ºC achieved)
  - Heating system to ensure warming-up before operation (to -55ºC)
  - Performance problems due mainly to parasitic layout effects
  - Need to validate it to 10.000 thermal cycles. ASIC on/off cycling 24 times/sol.
- Others aspects:
  - ITAR restrictions: NASA can talk about requirements, interfaces and problems, but not solutions hints!
  - Lack of Phase-A for REMS.
  - Instrument mass < 1.3 Kg
  - Available energy very limited: 20-30 Watt-day


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Photo: Nasa/JPL
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The validation approach
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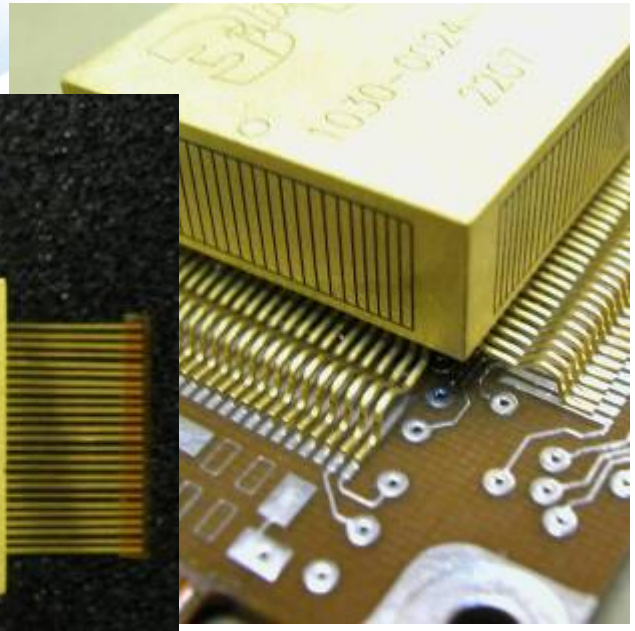
Validation and testing program

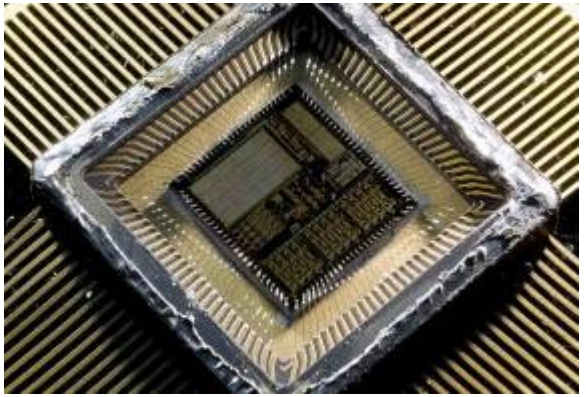
- Program run at 2 levels:

1. Technology validation program
   a. Pre-tests
   b. Concept/Sensors validation (functional / environmental)
   c. Package Qualification and Verification (PQV)

2. Screening and Qualification
   a. Screening and characterization in Temperature
   b. Qualification and acceptance of REMS elements

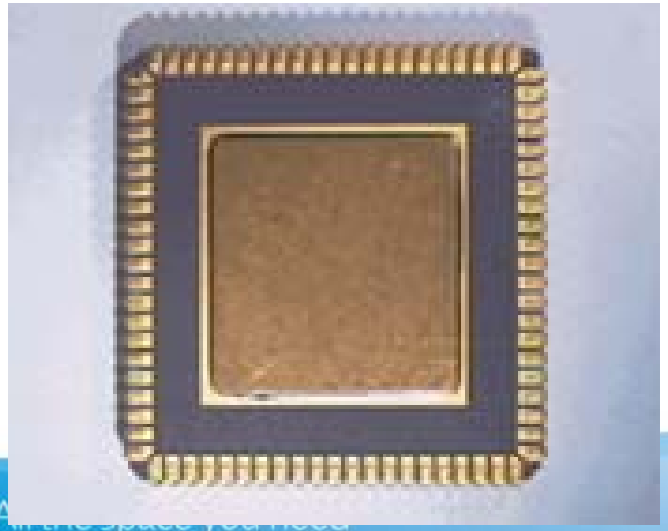
- Ready to fail. Use of several solutions in parallel

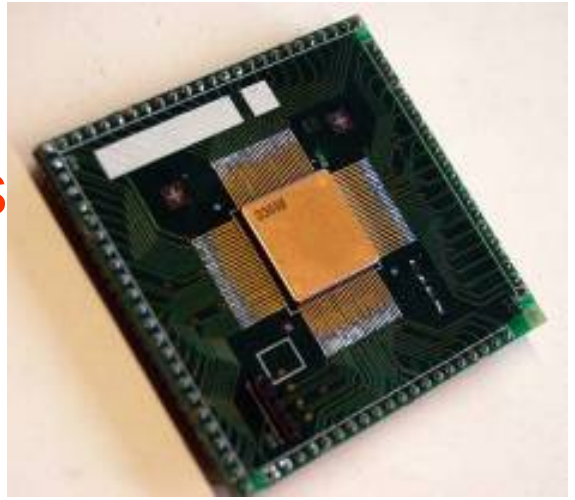




3D cube, JLCC84,
2 x CQFP100, …

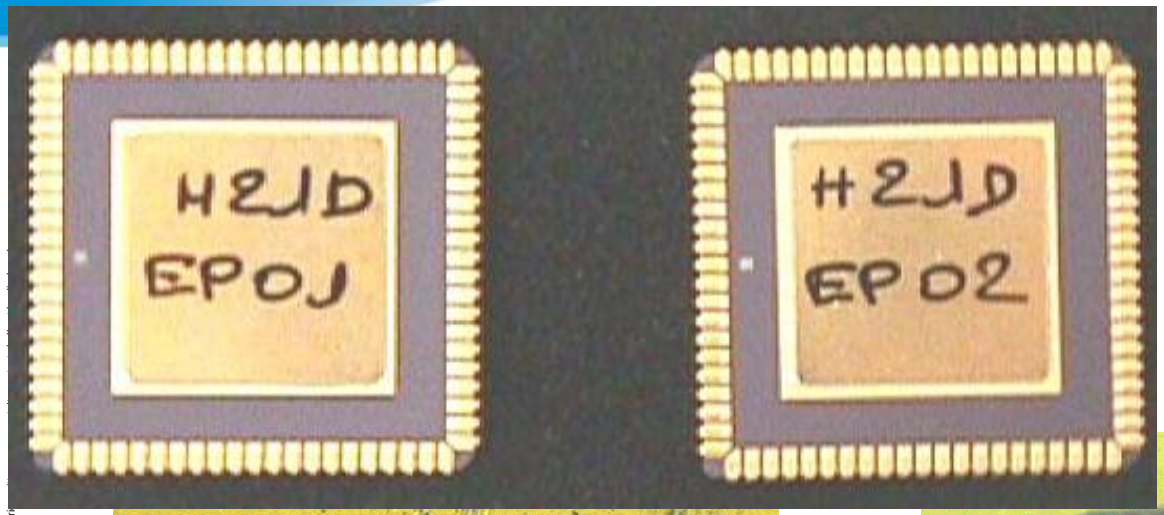
Several processes in Europe and US…

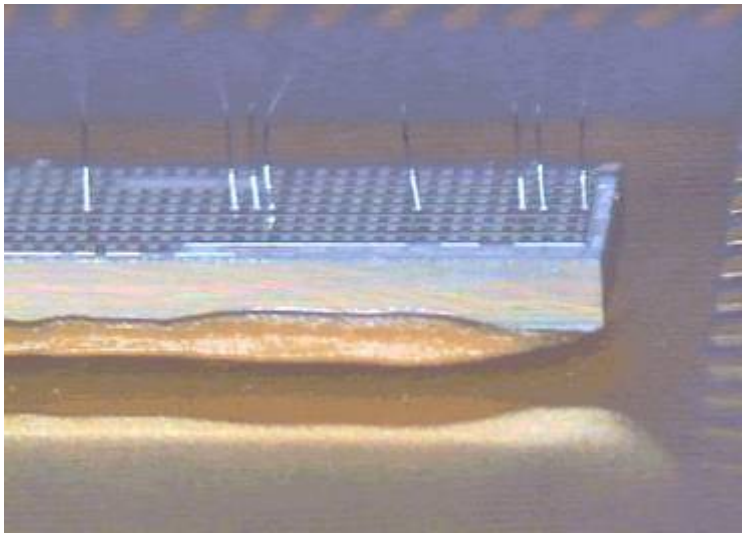


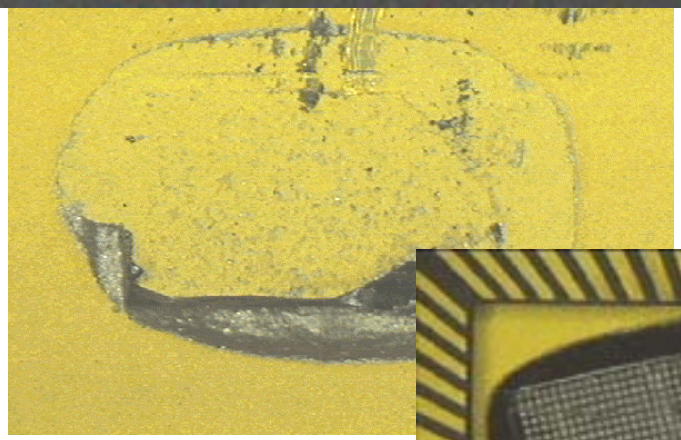


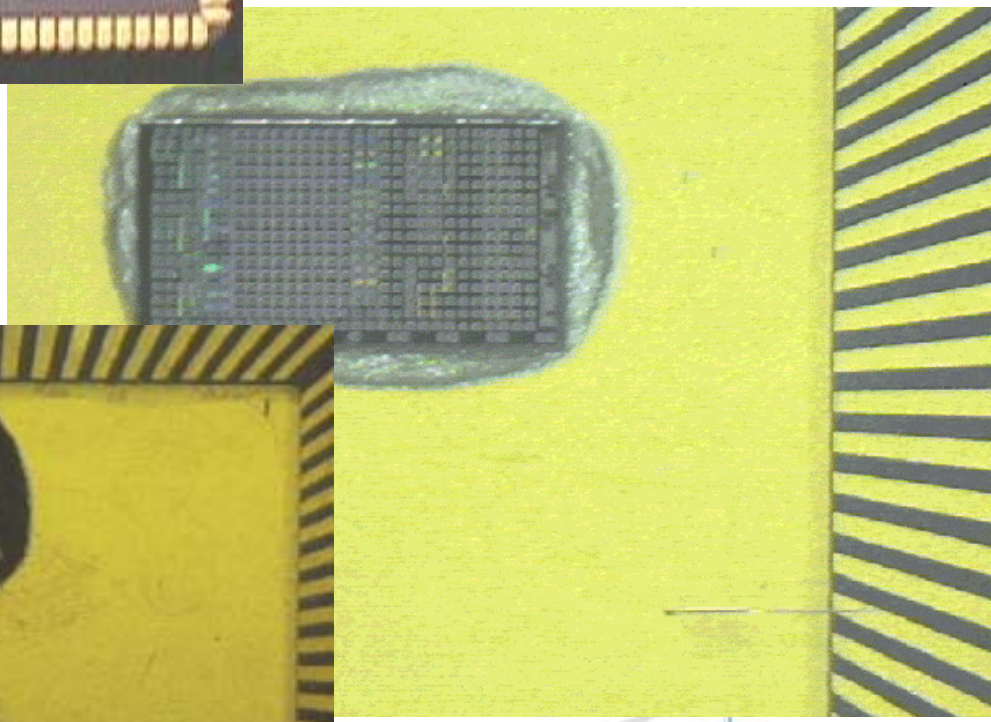
Technology Validation Program (I)

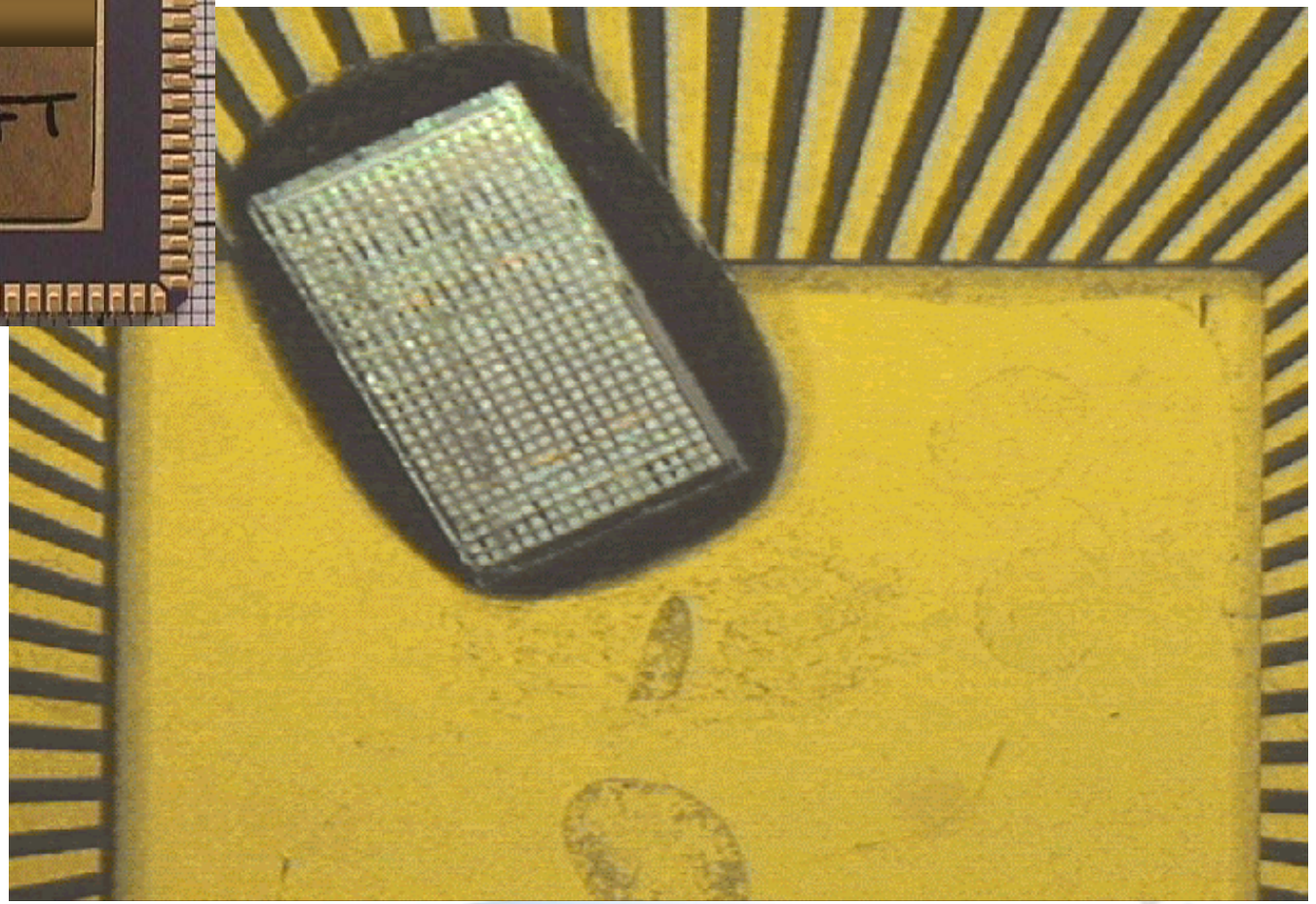
- a) Pre-tests
  - Aims to get early feedback on suitability of materials, processes & EEE parts for '*exposed*' elements.
  - Based on test samples submitted to TVT (few cycles), pyroshock and vibration
    - -135ºC to +110ºC; 4000g's shock
  - Test and Post analysis of the components

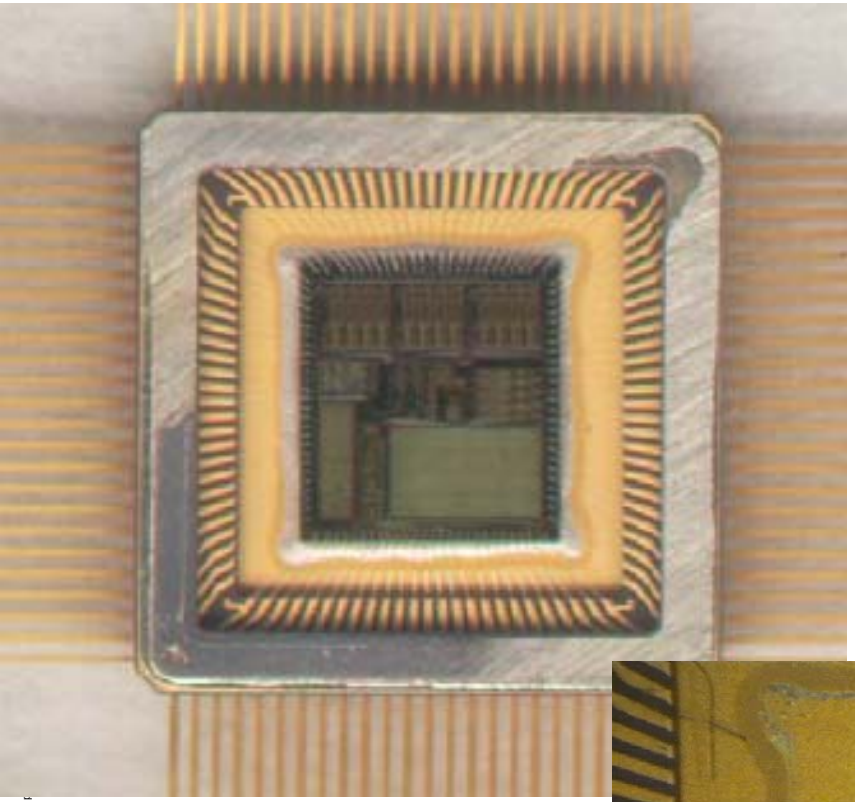


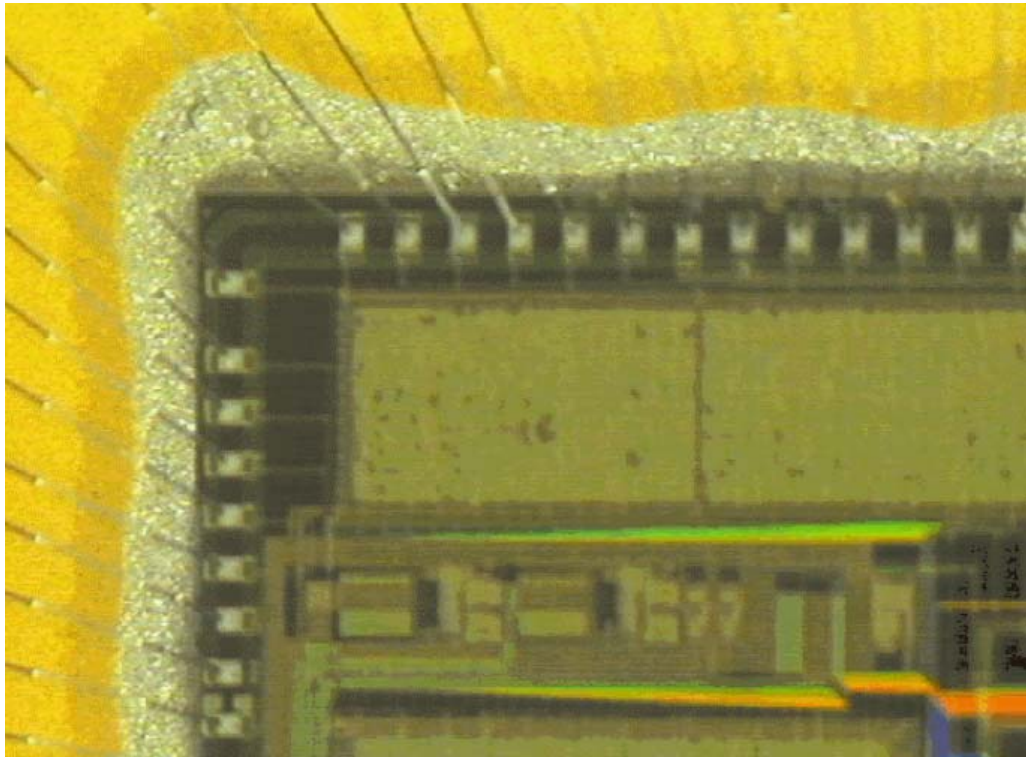


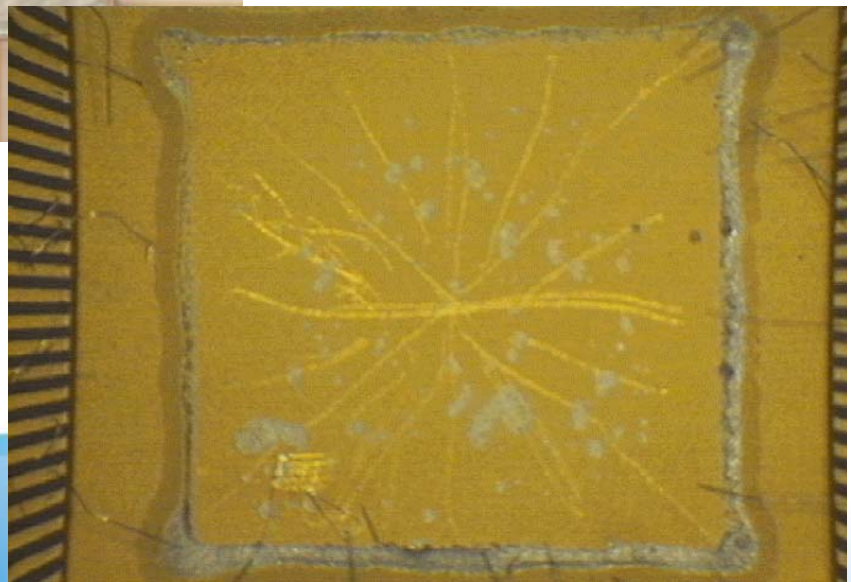












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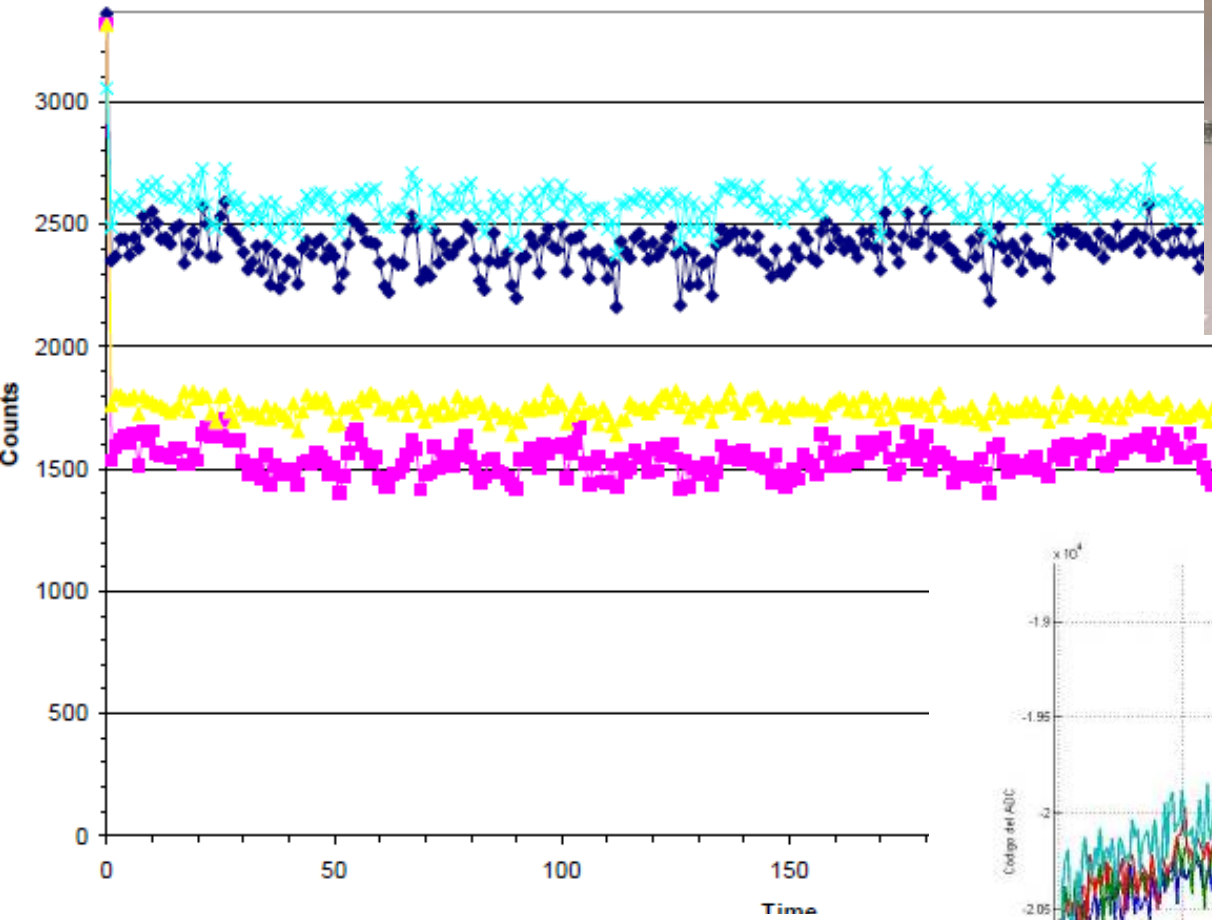
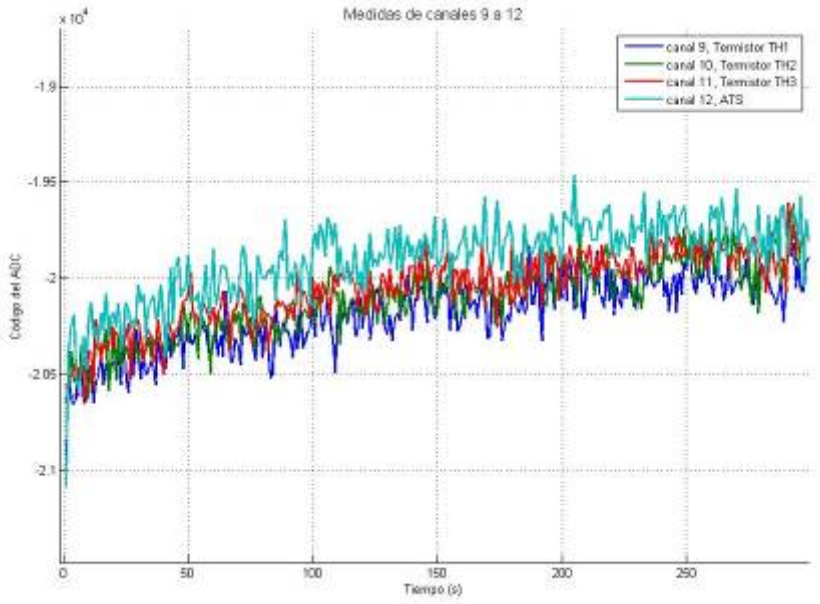
Technology Validation Program (II)

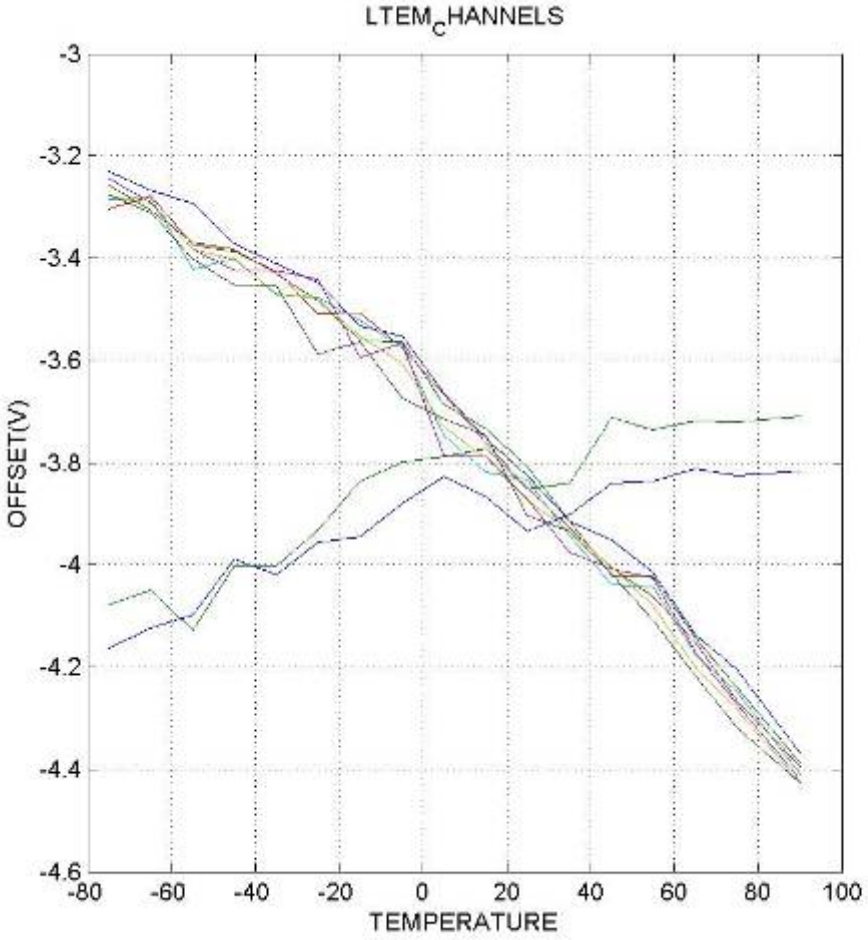
- b) Concept/Sensors Validation
  - WS Proto testing
    - At transducer level
    - Functional Testing
    - Tests in low-pressure/low temperature CO2 & with dust

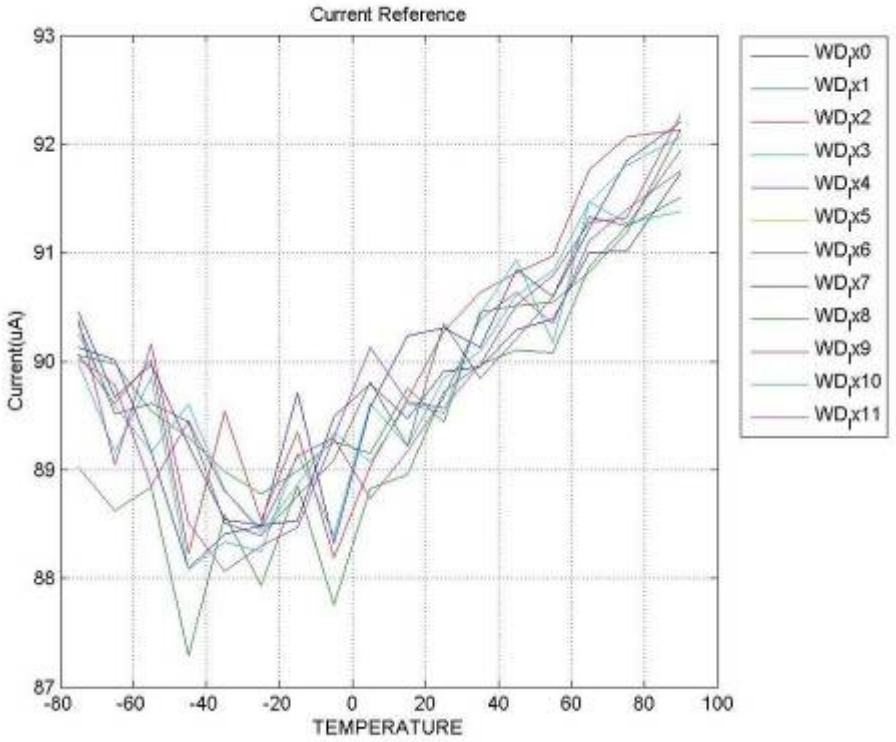
Functional testing



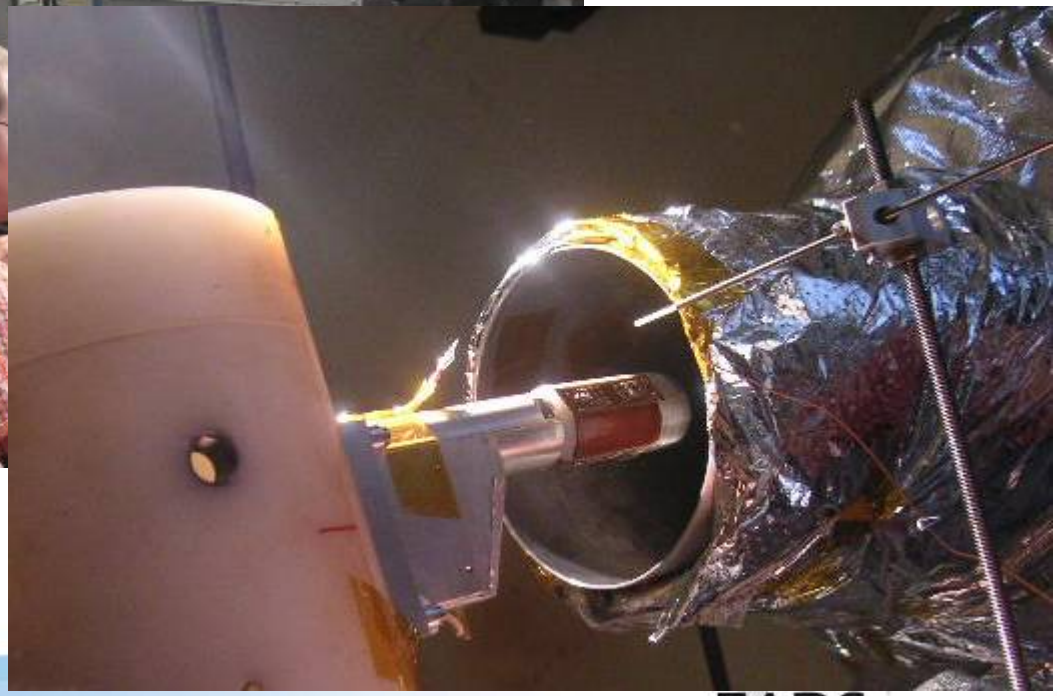


Testing with EM/EQMs





Example of sensors validation. WS Testing



Tests in UK

(CO2, low temp, low pressure)

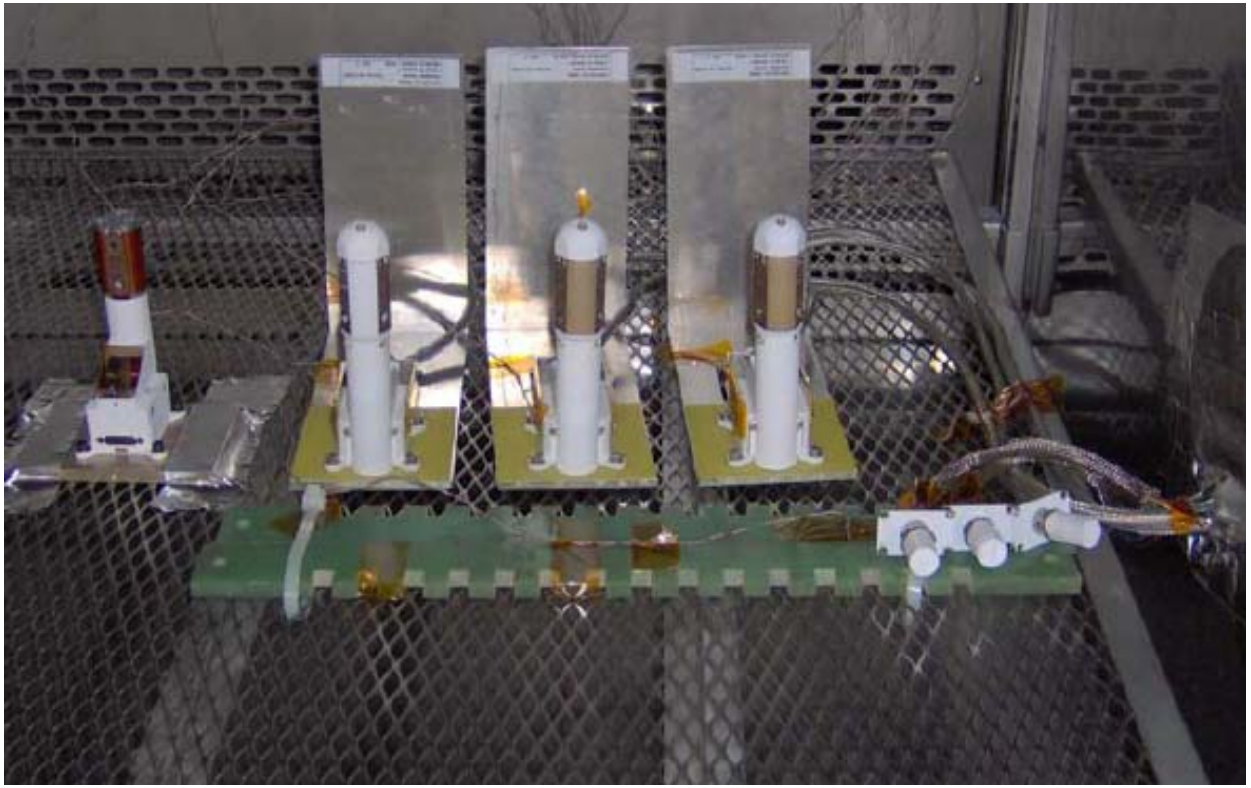
Technology Validation Program (III)

- c) Package Qualification and Verification
  - Validation of all assemblies and mounting methods for 3 times the Primary Mission
  - ASIC system, includes warming up heating to reach operation temperatures before switching it ON.
  - Nominal operation: once per hour, every day during 3 times the primary mission (2 years)= 52560 times !

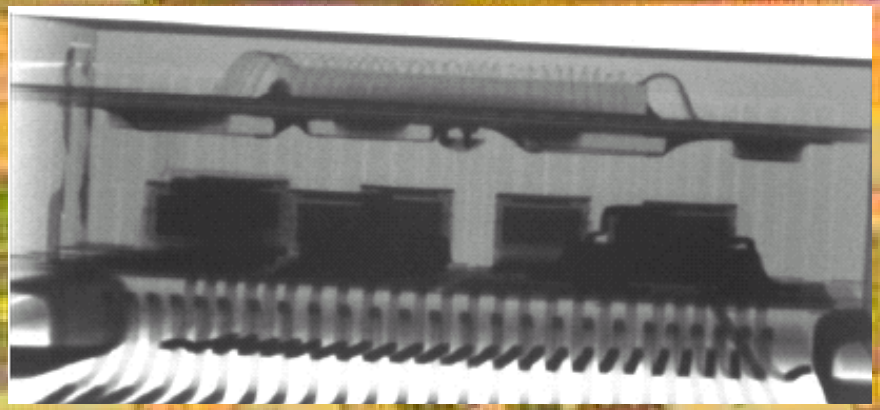
➔ Need for extra-fatigue testing!

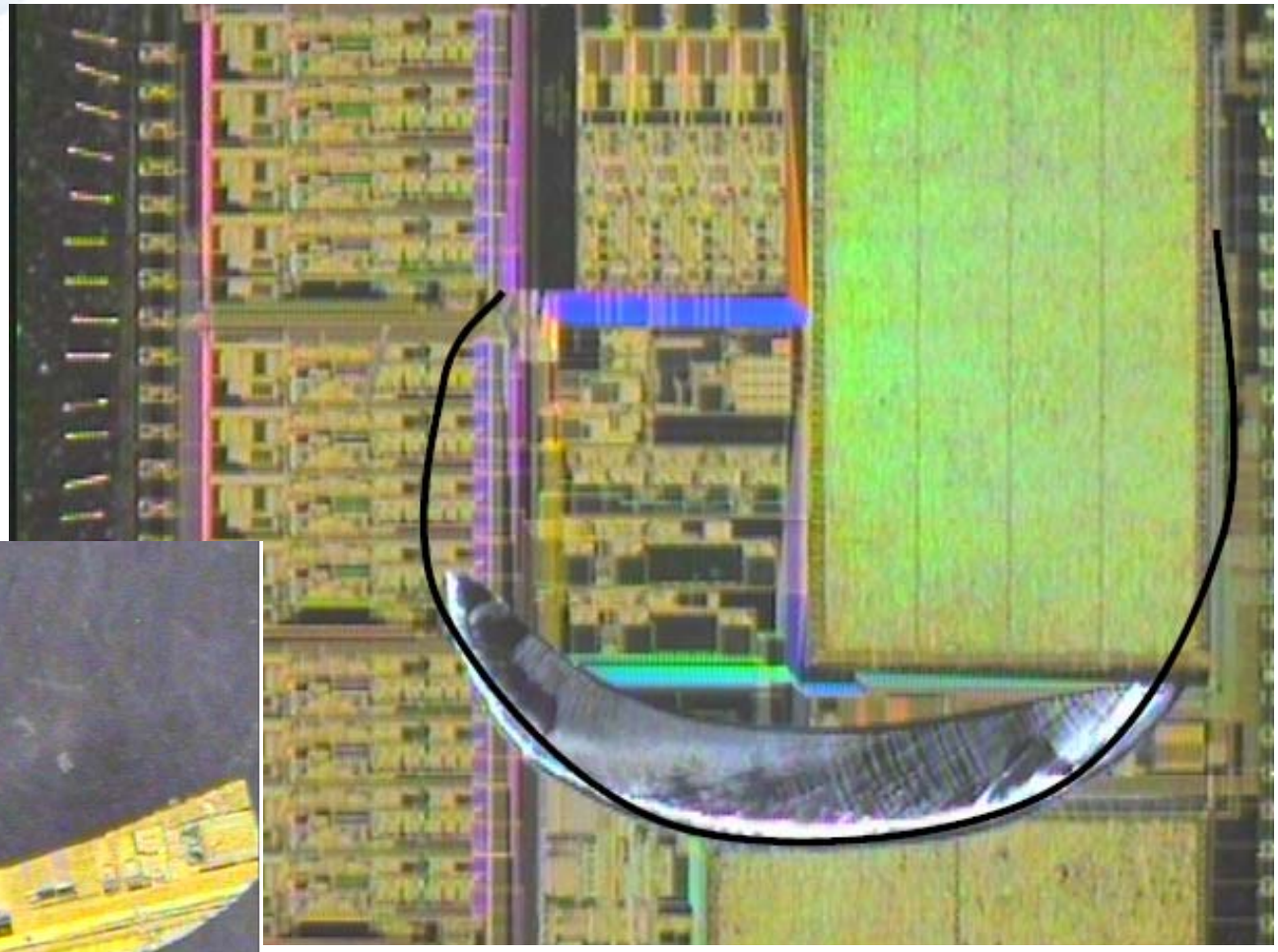
  - 2680 summer cycles & 8040 winter cycles.
  - From -135ºC to -55ºC, winter case.

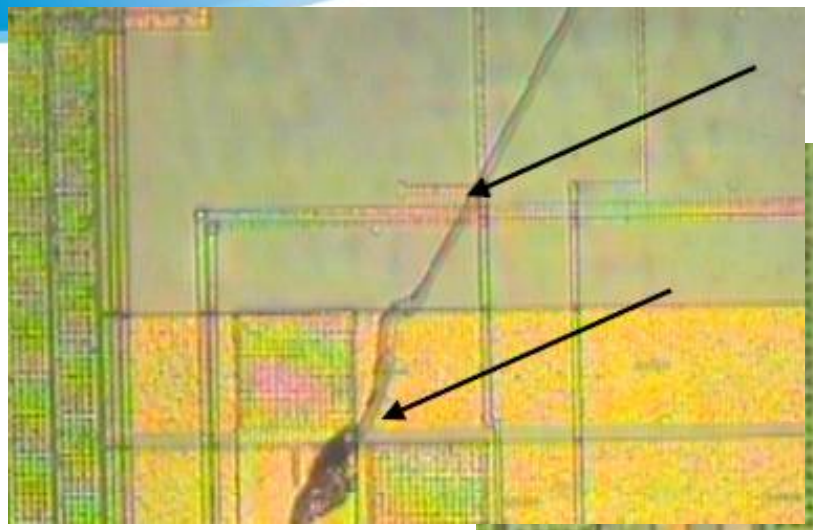
PQV tests for Booms

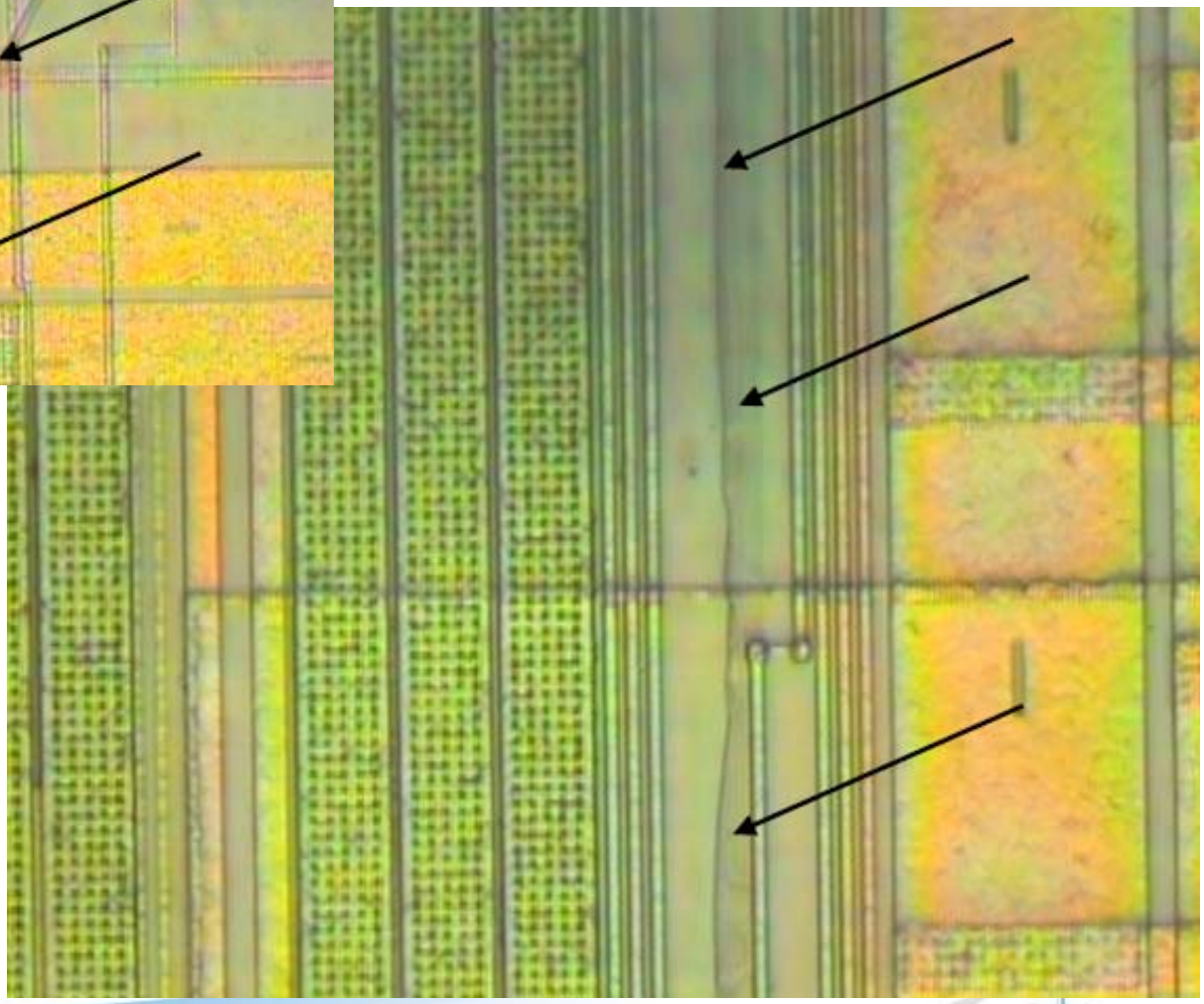


- To validate all assemblies for x3 times the primary mission
- 2000 cycles approx:
  - 600 winter cycles: -130ºC to +15ºC
  - 1400 summer cycles: -105ºC to +40ºC.





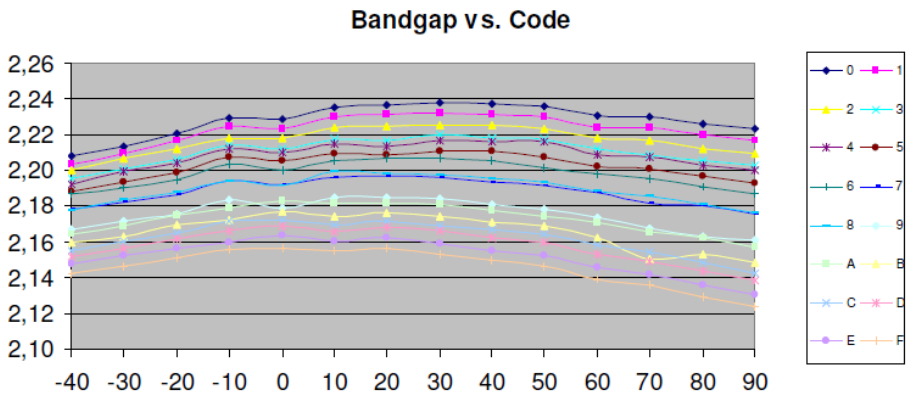




ASIC Screening and Qualification

- Test at ASIC level
- ASIC screening tests
- Detailed characterization of selected pieces in T
- Qualification tests
- FM Board level characterization

ASIC level testing



ASIC	2L_TEMP									IR_Cond				WD REF OUT	WD Currents											WD Total Counter	Random Registers Write
	R0	R1	R2	R3	R4	R5	R6	Air Temp	R_Therm Cal	IR0	IR1	IR2	IR3	CH2	CH0	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	CH11	All	All
D1004	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
D1006	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	OK	KO	OK	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	OK	KO
D2006	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
D1003	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
D1001	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
D2004	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
D2003	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
D1007	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	KO	OK	OK	OK	OK	OK	OK	OK	OK	OK	KO	OK	OK	OK	OK

ASIC screening & delta characterization

- Constant Acceleration
- PIND
- Electrical measurements amb. Temp (Go / No Go)
- Thermal cycles (10 cycles -135°C to +90)
- Burn-in
- Hermetic Seal
- Electrical measurements at amb. temp
- Electrical measurements at High & Low Temp

- Pre-selection of 30 samples
- Delta - characterization on 30 samples
- Capability of ASIC to work at -135°C (8 samples)
- Selection of 8 samples
- Final characterization of samples including 10° step from -135°C to +90°C including End- to End test
- Parts delivery to CRISA for FM equipment

SN	Wafer Area	COC REF.	GO / NO GO TEST	BI Batch	BI Results	Pre-selected (30 samples)	Delta screening results	Selected (8+2 samples)	Final Characterization Test Results	Delivered for FM equipmentt
141	3AY	60062	PASS	BATCH 1	FAIL					
142	3AY	60062	PASS	BATCH 1	FAIL					
143	3AY	60062	PASS	BATCH 1	FAIL					
144	3AY	60062	FAIL							
145	3AY	60062	PASS	BATCH 1	FAIL					
146	3AY	60062	PASS	BATCH 1	FAIL					
147	3AY	60062	PASS	BATCH 1	FAIL					
148	3AY	60062	PASS	BATCH 1	FAIL					
149	3AY	60062	PASS	BATCH 1	FAIL					
150	3AY	60062	PASS	BATCH 1	FAIL					
151	3BY	60063	PASS	BATCH 1	PASS	Y	PASS			
152	3BY	60063	PASS	BATCH 1	PASS	Y	FAIL			
153	3BY	60063	FAIL							
154	3AY	60063	PASS	BATCH 1	FAIL					
155	3BY	60063	PASS	BATCH 1	PASS					
156	3BY	60063	PASS	BATCH 1	FAIL					
157	3BY	60063	PASS	BATCH 1	FAIL					
158	3BY	60063	PASS	BATCH 1	PASS	Y	PASS	Y	PASS	Y
159	3BY	60063	FAIL							
160	3BY	60063	FAIL							
161	3BY	60063	PASS	BATCH 1	PASS	Y	PASS			
162	3BY	60063	PASS	BATCH 1	PASS					
163	3BY	60063	PASS	BATCH 1	FAIL					
164	3BY	60063	PASS	BATCH 1	FAIL					
165	3BY	60063	PASS	BATCH 1	PASS	Y	PASS			
166	3BY	60063	PASS	BATCH 1	PASS					
167	3BY	60063	PASS	BATCH 1	FAIL					
168	3BY	60063	PASS	BATCH 1	FAIL					

				SAMPLE 33			RESULTS		
REMS ASIC BLOCK	PARAMETER	LIMIT LOW	LIMIT HIGH	TEMP= 25ºC	TEMP= 90ºC	TEMP= -55ºC	TEMP= 25ºC	TEMP= 90ºC	TEMP= -55ºC
POWER SUPPLY AND REFERENCE VOLTAGE AND CURRENT	VCC (V)	4,90	5,10	4,980	4,980	4,980	PASS	PASS	PASS
	ICC (mA)	85,00	95,00	90,670	89,390	91,080	PASS	PASS	PASS
	VCM (V)	2,30	2,70	2,750	2,700	2,790	FAIL	PASS	FAIL
	VCM (V) max (16 bandgap register cond)	2,30	2,70	2,890	2,860	2,900	FAIL	FAIL	FAIL
	VCM (V) min (16 bandgap register cond)	2,30	2,70	2,750	2,700	2,790	FAIL	PASS	FAIL
	VL (V)	0,90	1,10	1,130	1,110	1,140	FAIL	FAIL	FAIL
	VH (V)	3,80	4,20	4,400	4,320	4,480	FAIL	FAIL	FAIL
	Iref (µA) after Vref Adjusted	97,5	102,5	100,0	98,2	102,0	PASS	PASS	PASS
AIR TEMP	Nominal Bias Current at MAX VOLTAGE (mA)	0,98	1,02	1,015	1,015	1,013	PASS	PASS	PASS
	Nominal Bias Current at MIN VOLTAGE (mA)	0,98	1,02	1,012	1,018	1,025	PASS	PASS	FAIL
	GAIN (Common mode)	1,50	1,70	1,670	1,666	1,743	PASS	PASS	FAIL
	PT Analog Ground MAX VOLTAGE 1.33 Kohm (V)	0,90	1,10	0,716	0,688	0,760	FAIL	FAIL	FAIL
	PT Analog Ground MIN VOLTAGE 470 ohm (V)	0,90	1,10	0,713	0,684	0,758	FAIL	FAIL	FAIL
	AMP RMS Noise Contribution (mVrms)	0,00	3,00	0,980	0,919	0,960	PASS	PASS	PASS
	OFFSET MAX VOLTAGE 1.33 KOHM (mV)	0,00	2,00	4,149	4,791	3,104	FAIL	FAIL	FAIL
	OFFSET MIN VOLTAGE 470 OHM (mV)	0,00	2,00	1,118	1,326	0,755	PASS	PASS	PASS
RTHERM CAL	Nominal Bias Current at MAX VOLTAGE (mA)	0,98	1,02	1,016	1,018	1,015	PASS	PASS	PASS
	Nominal Bias Current at MIN VOLTAGE (mA)	0,98	1,02	1,022	1,028	1,031	FAIL	FAIL	FAIL
	GAIN (Common mode)	1,50	1,70	1,727	1,658	1,747	FAIL	PASS	FAIL
	PT Analog Ground MAX VOLTAGE 1.33 Kohm (V)	0,90	1,10	0,680	0,646	0,734	FAIL	FAIL	FAIL
	PT Analog Ground MIN VOLTAGE 470 ohm (V)	0,90	1,10	0,677	0,640	0,732	FAIL	FAIL	FAIL
	AMP RMS Noise Contribution (mVrms)	0,00	3,00	1,151	0,908	1,101	PASS	PASS	PASS
	OFFSET MAX VOLTAGE 1.33 KOHM (mV)	0,00	2,00	1,152	1,354	1,452	PASS	PASS	PASS
	OFFSET MIN VOLTAGE 470 OHM (mV)	0,00	2,00	1,097	1,333	0,772	PASS	PASS	PASS
WD_COND	WD 1 COMPARATOR INPUT OFFSET (mV)	0,00	2,00	0,181	0,473	0,475	PASS	PASS	PASS
	WD 2 COMPARATOR INPUT OFFSET (mV)	0,00	2,00	0,210	0,431	3,009	PASS	PASS	FAIL
	WD 3 COMPARATOR INPUT OFFSET (mV)	0,00	2,00	0,131	0,638	0,583	PASS	PASS	PASS
WD Heater block	WD Heater 0 Inx-Imx Low Setting (mA)	4,40	4,70	4,615	4,528	4,696	PASS	PASS	PASS
	WD Heater 1 Inx-Imx Low Setting (mA)	4,40	4,70	4,547	4,460	4,618	PASS	PASS	PASS
	WD Heater 2 Inx-Imx Low Setting (mA)	4,40	4,70	4,495	4,397	4,571	PASS	FAIL	PASS
	WD Heater 3 Inx-Imx Low Setting (mA)	4,40	4,70	4,427	4,317	4,533	PASS	FAIL	PASS
	WD Heater 4 Inx-Imx Low Setting (mA)	4,40	4,70	4,506	4,404	4,632	PASS	PASS	PASS
	WD Heater 5 Inx-Imx Low Setting (mA)	4,40	4,70	4,439	4,344	4,534	PASS	FAIL	PASS
	WD Heater 10 Inx-Imx High Setting (mA)	4,70	4,90	4,868	4,752	4,986	PASS	PASS	FAIL
	WD Heater 11 Inx-Imx High Setting (mA)	4,70	4,90	4,781	4,683	4,884	PASS	FAIL	PASS
WD Ix x00	WD Ix 0 Current x00 code (µA)	87,50	95,00	90,1	88,6	91,2	PASS	PASS	PASS
	WD Ix 1 Current x00 code (µA)	87,50	95,00	89,6	88,2	91,0	PASS	PASS	PASS
	WD Ix 9 Current x00 code (µA)	87,50	95,00	89,9	88,8	92,7	PASS	PASS	PASS
	WD Ix 10 Current x00 code (µA)	87,50	95,00	90,5	88,9	92,5	PASS	PASS	PASS
	WD Ix 11 Current x00 code (µA)	87,50	95,00	89,9	88,4	92,0	PASS	PASS	PASS
IR_CHAIN	IR CHAIN 3 INPUT OFFSET (mV)	0,00	2,00	0,070	0,340	0,390	PASS	PASS	PASS
	IR CHAIN 3 Amp RMS noise (mV)	0,00	3,00	1,110	0,870	1,130	PASS	PASS	PASS
	IR CHAIN 3 GAIN x64	62,72	65,28	64,560	62,650	63,830	PASS	FAIL	PASS
	IR CHAIN 3 GAIN x256	243,20	268,80	253,700	253,000	259,000	PASS	PASS	PASS

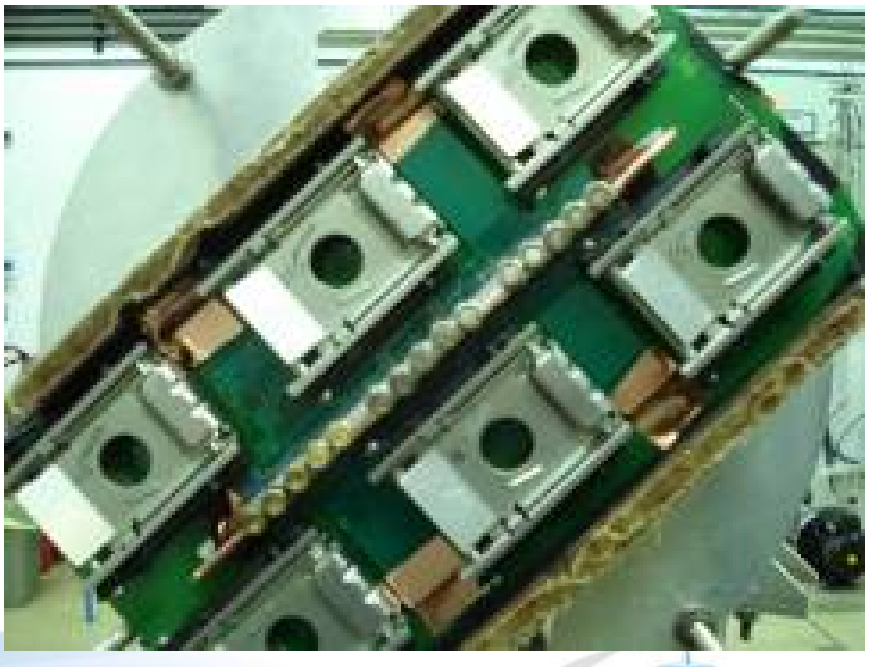
- Qualification programme
  - At component level, but also …
  - At assembly level
  - At REMS element level
  - At REMS system level

Mixed ASIC qualification

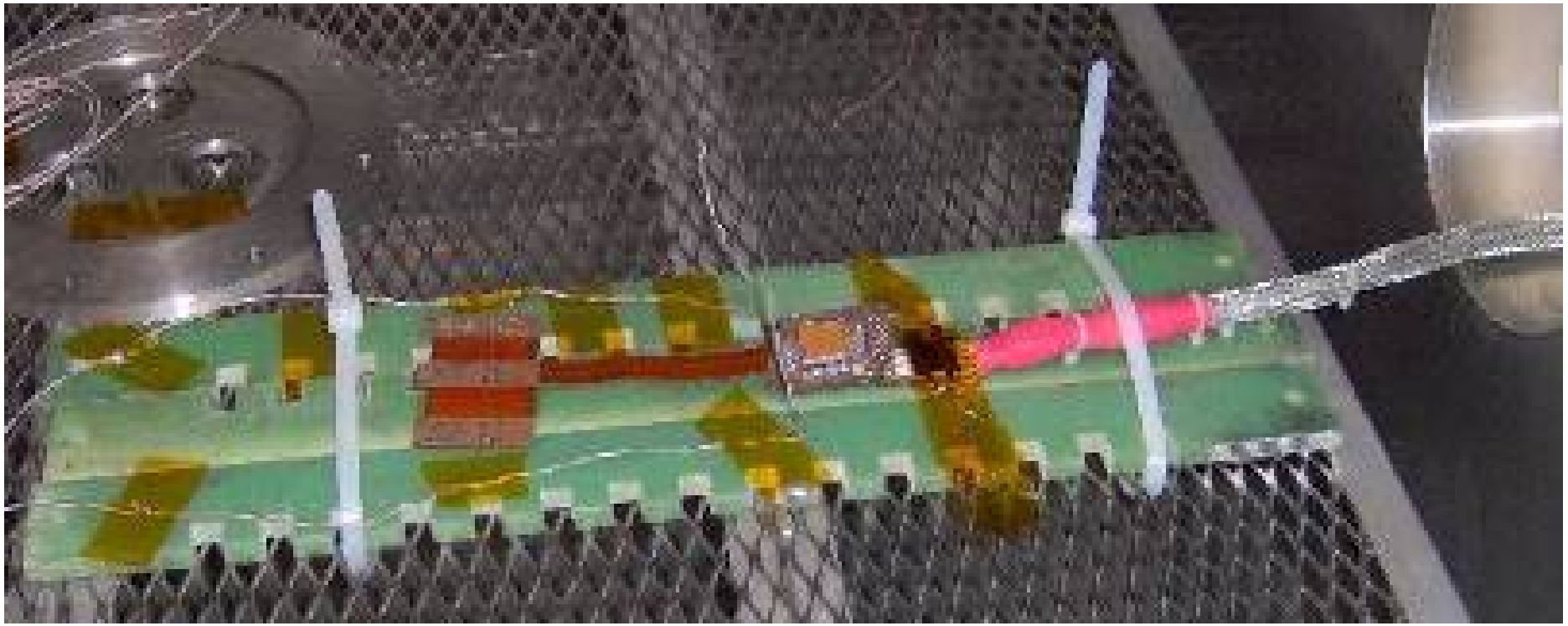
- Includes screening, characterization and formal qualification incl.
  - Mechanical verification
  - Long-term reliability tests
  - Package verification
  - Radiation tests (dose, SEE, …)

- Plus others REMS level qualifications:
  - REMS element level qual.
  - System level

ASIC radiation test board



ASIC board level characterization in T



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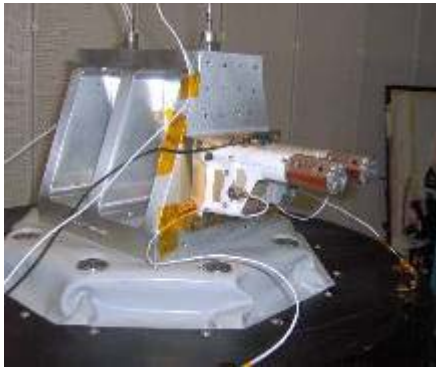
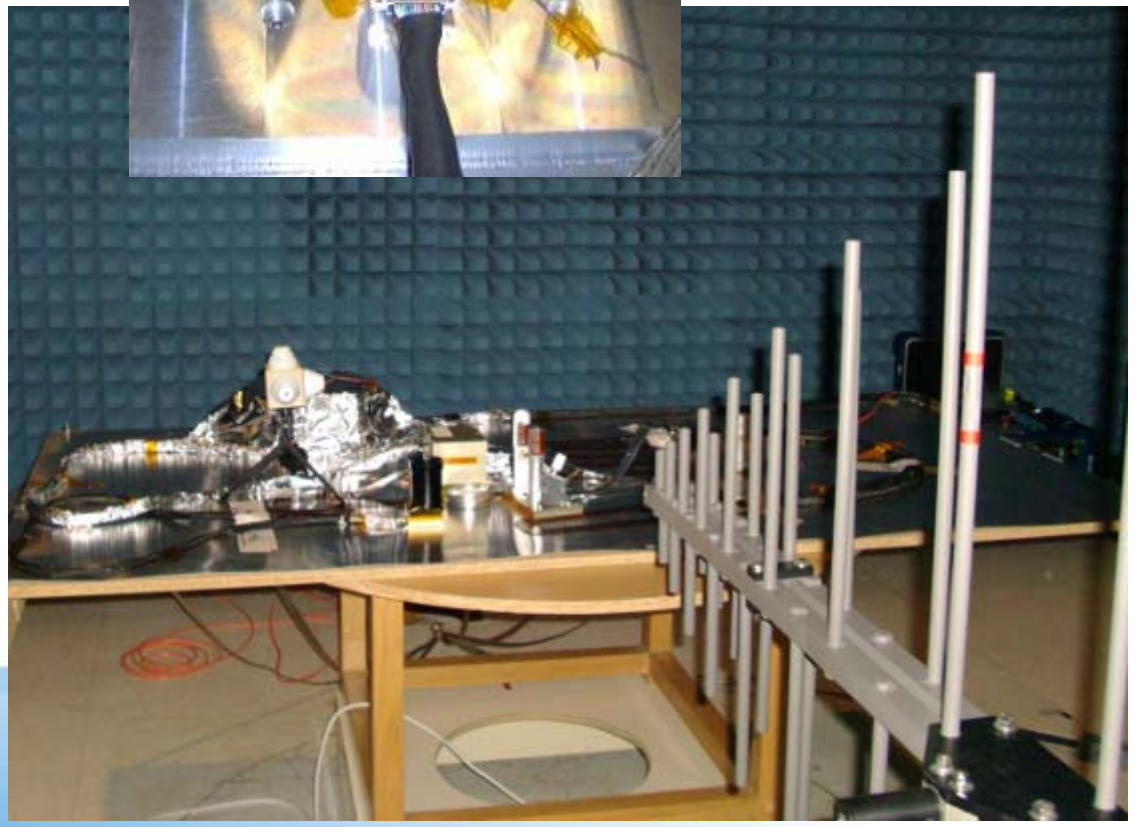
Qualification Tests

- Covering the usual …
  - Electrical and functional tests
  - Thermal Vacuum Tests
  - Quasi-static loads and Vibration tests
  - Pyroshock
  - EMC tests





6 Conclusions

Mars sunrise

Photo: Nasa/JPL (Spirit)

Conclusions

- We successfully developed and qualified a Mixed ASIC intended for Mars operation
  - The mission demands were very constraining in terms of performances, operation temperatures and mission life thermal cycling requirements.
  - It was a difficult, costly and long process. We followed a ‘trial and error’ approach; needed two design iterations and tried several manufacturing processes in parallel.
  - There was not data/heritage to design ASICs for operation below -55ºC, but it was possible to succeed.
  - We used a commercial process and custom packaging… but with a comprehensive qualification.
  - It was needed a thoroughly performance-based screening and samples characterization.
- The technology is available for Crisa reuse in other Mars missions.

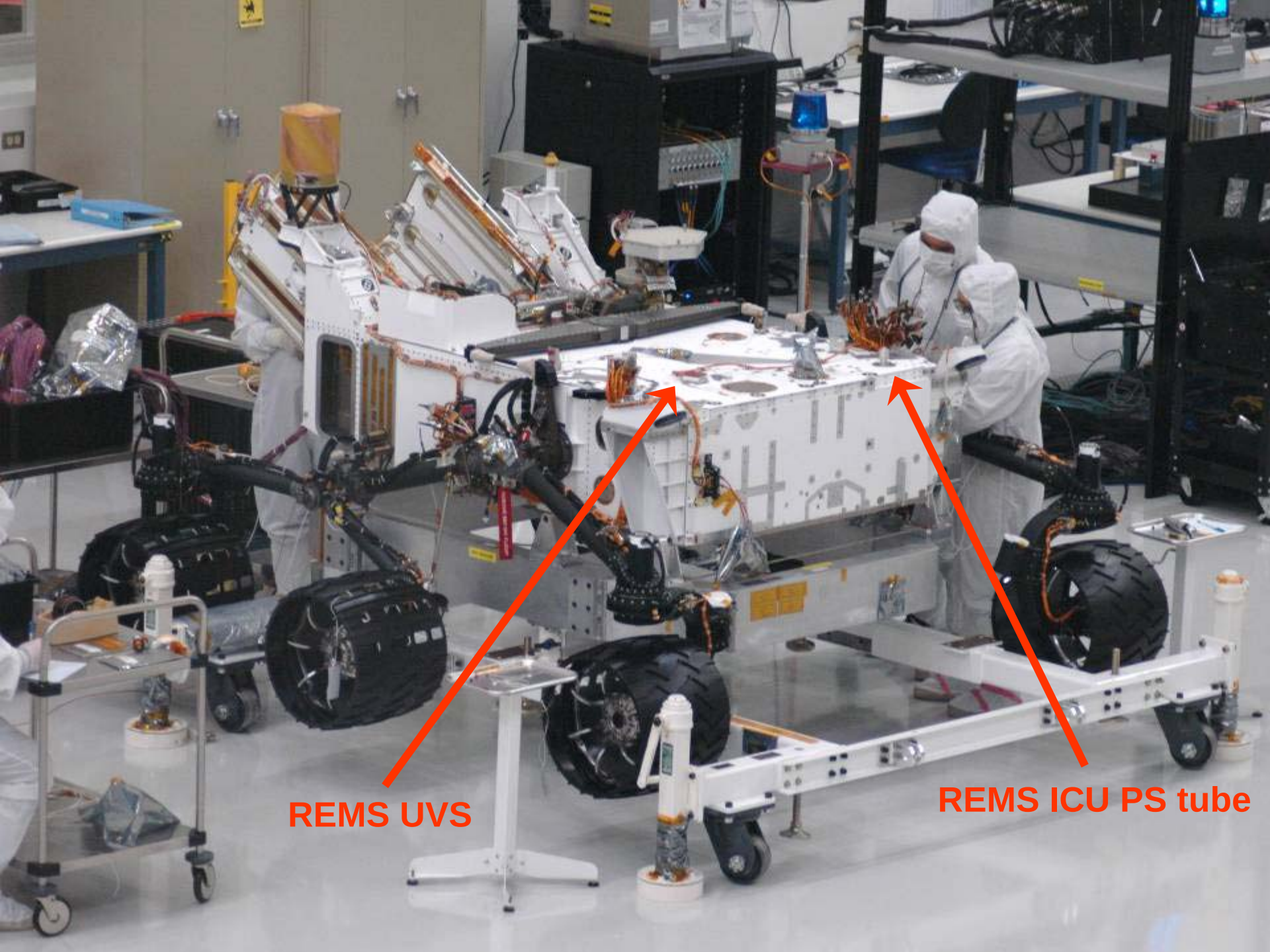
Status and acknowledge

- The project is now in the final development phase with the REMS FM being integrated in the Rover.

- The project is led by the investigators of the Centre of Astrobiology (CAB INTA-CSIC) in Madrid who coordinate a network of Co-investigators and Spanish collaborators (University of Alcalá de Henares, Polytechnical univ. of Cataluña and of the own Astrobiology Centre) and foreigners (University of Michigan, Ames Research Center & Caltech in the USA, and the Finnish Meteorological Institute).

- The project has been funded by the Spanish “Centro para el Desarrollo Tecnológico e Industrial” (CDTI) and the National Plan for I+D+I, both depending of the Ministry of Science and Innovation.

- I want to express my gratitude to the many people and collaborating institutions who contributed their time, energy and expertise to make REMS a reality.


REMS UVS
REMS ICU PS tube

CRISA

Thank you for your attention!

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