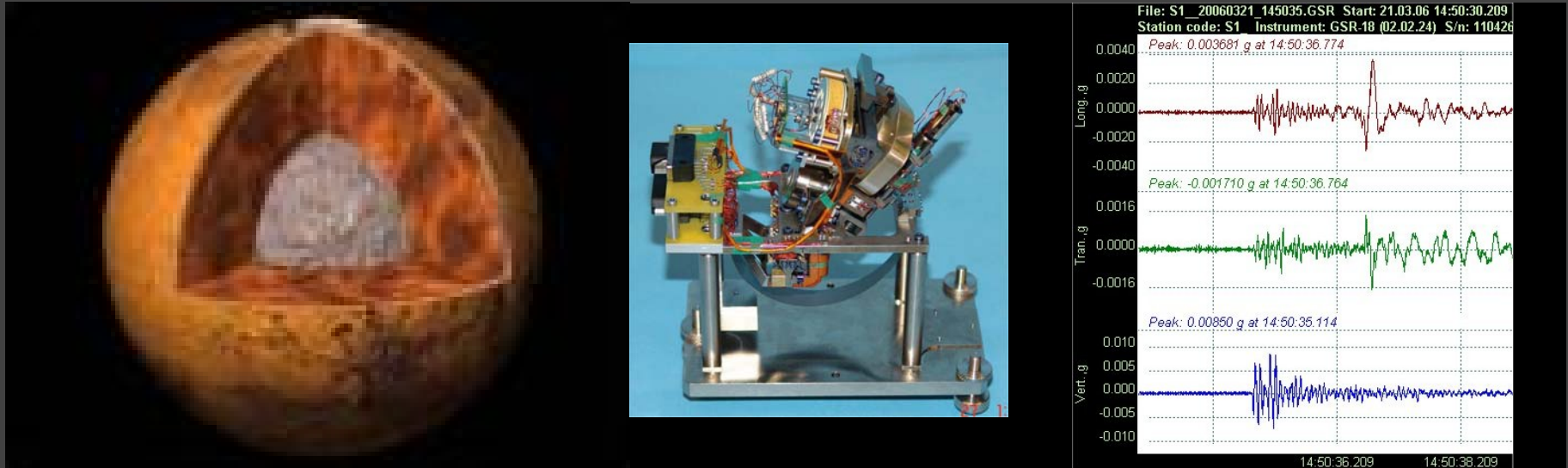


ExoMars Seismometer



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(SRON Netherlands Institute for Space Research)

SEIS-Team (IPGP France, ETH Zurich, IC London)

SRON
Netherlands Institute for Space Research



ETH SRON

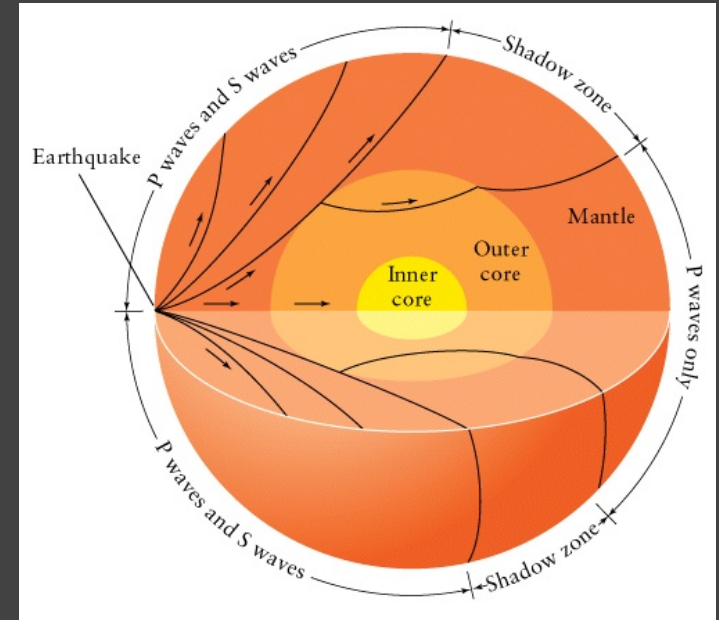
Imperial College
London

Outline

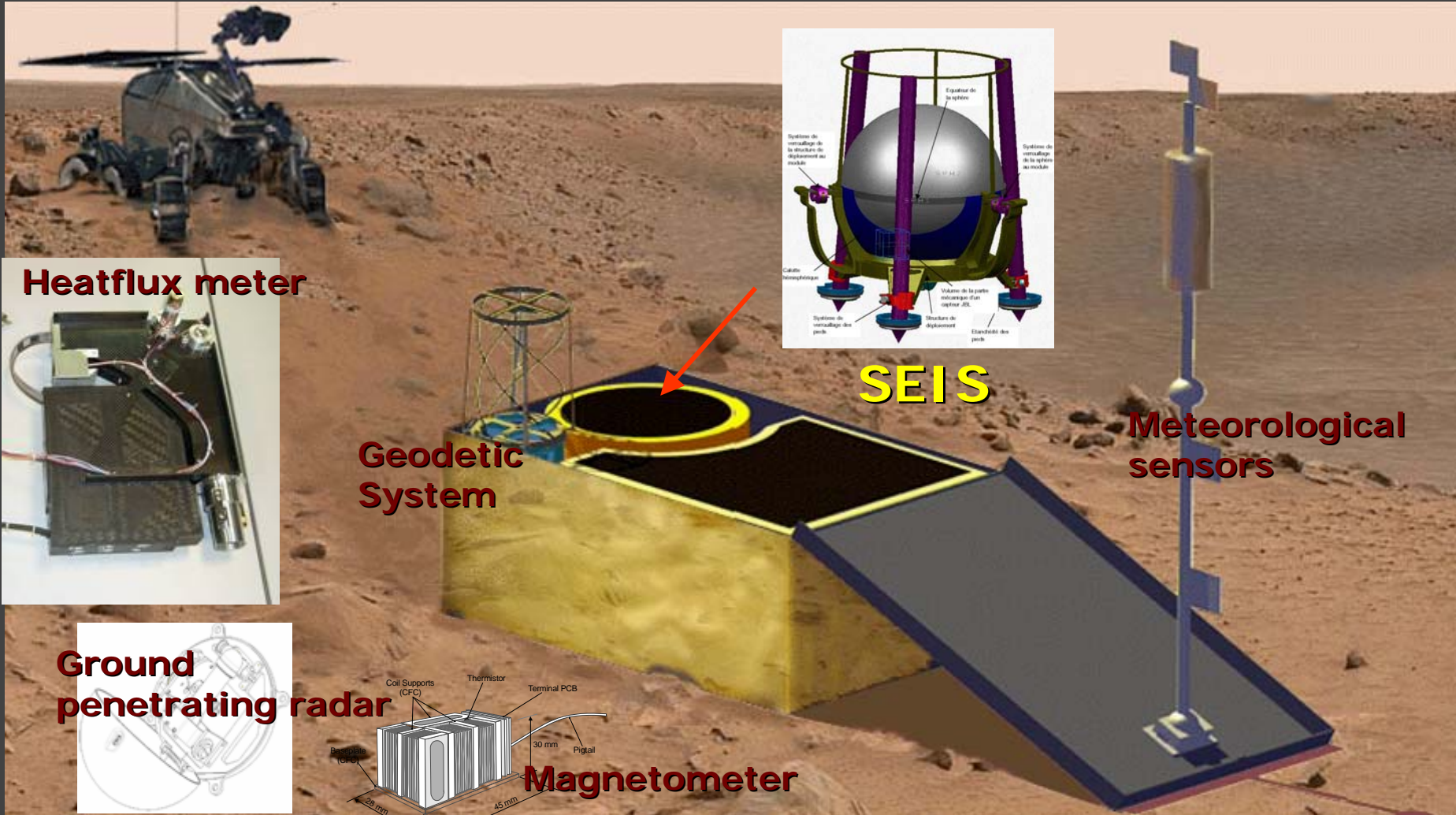
- Intro: Seismometry on Mars
- GEP Package
- The VBB-Seismometer
 - Principle of operation
 - Performance
- Read-out electronics / ASICs
- Conclusions

Introduction: Status Planetary Seismology

- At present:
 - Nothing
 - No data, only models
 - There is room for improvement
- The Moon:
 - Apollo Seismic Network 1969
Seismic recordings
(moonquakes) up to 1977
- Mars:
 - Viking (1975) seismometers
measured wind
 - Other attempts unsuccessful
 - Failure of mission (Mars69)
 - Failure of funds (Netlander)

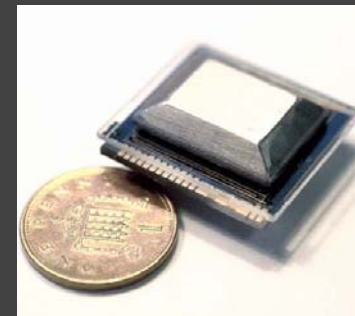
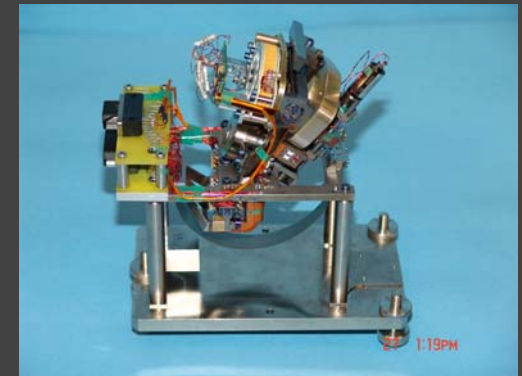
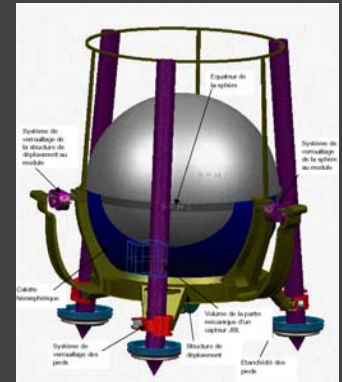


ExoMars lander: Rover+GEP Geophysical & Environmental Package

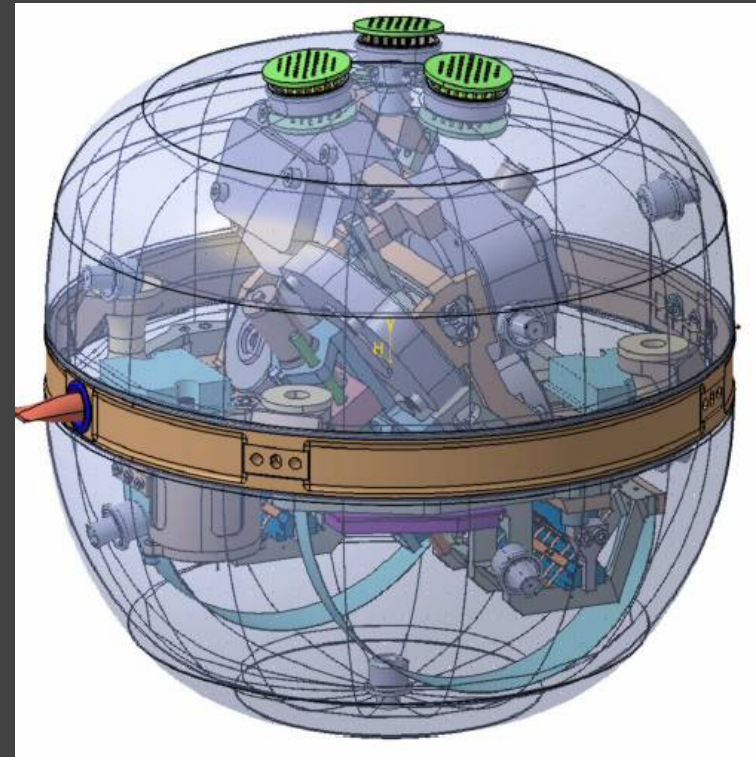
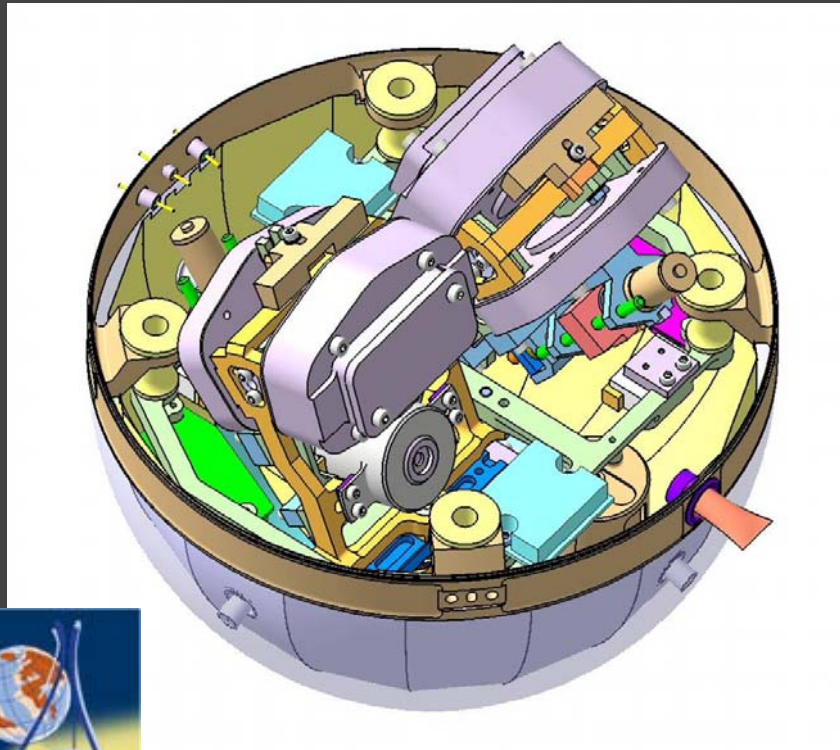


ExoMars-GEP-SEIS: Seismometer 'package'

- SEIS : a 2 kg « all included » planetary science seismometer compatible with tiny landers with low power
- SEIS is composed of :
 - Two Very Broad Band seismometers, in opposite sensing directions, PI=Philippe Lognonné, IPGP Paris.
 - 3 Short Period MEMS seismometers PI=Tom Pike, IC London
 - Environmental sensors (Temp., Press.)
- SEIS package main performances requirements :
 - VBB ($< 10^{-9} \text{ m.s}^{-2} \text{ Hz}^{-1/2}$ from 10^{-5} up to 10 Hz)
 - SP ($< 5 \cdot 10^{-8} \text{ m.s}^{-2} \text{ Hz}^{-1/2}$ from 10^{-2} up to 100 Hz)



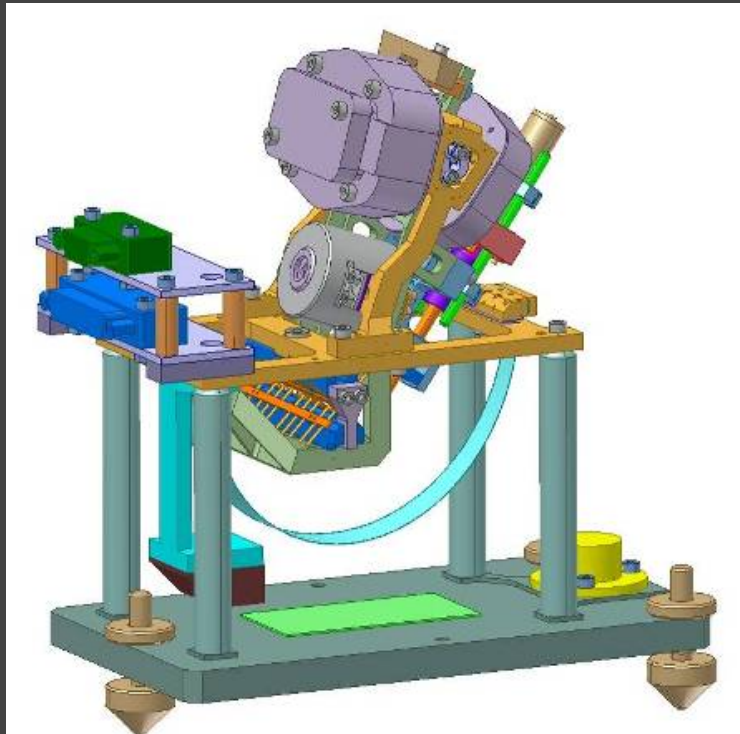
GEP-Sphere



15 cm

Sphere with 2 Very Broadband Seismometers

Very Broadband single axis seismometer



CAD view of sensing axis



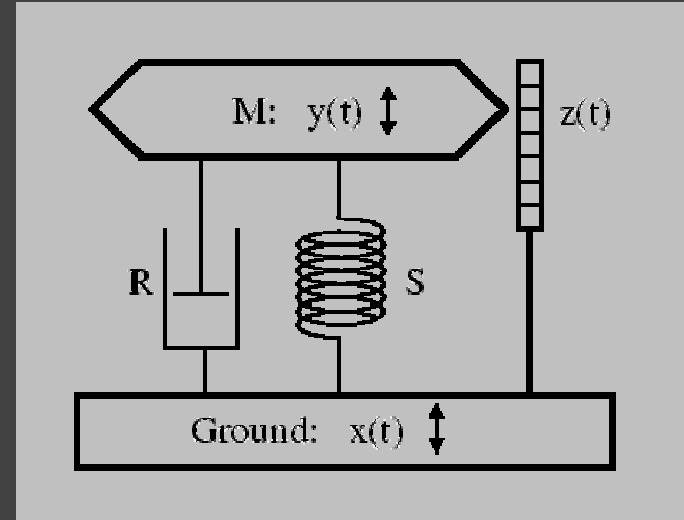
Test configuration

General seismometer operational principle

- Seismometer measures ground-motion $\mathbf{x}(t)$, $\mathbf{v}(t)$ or $\mathbf{a}(t)$
- Seismometer records principle: damped mass-spring system
- Input-output system:
 - Input: ground motion $x(t)$
 - (Sensor) Output: $z(t)$
- Equation of motion:

$$\ddot{z}(t) + 2\gamma\omega_0 \dot{z}(t) + \omega_0^2 z(t) = -\ddot{x}(t)$$

↙ Damping
 ↘ Natural frequency
 $\omega_0 = 2\pi/T_0$



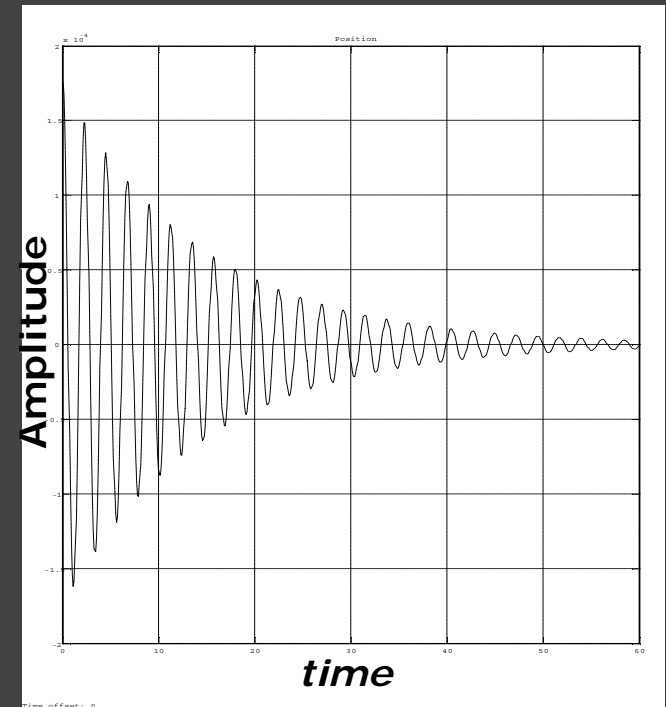
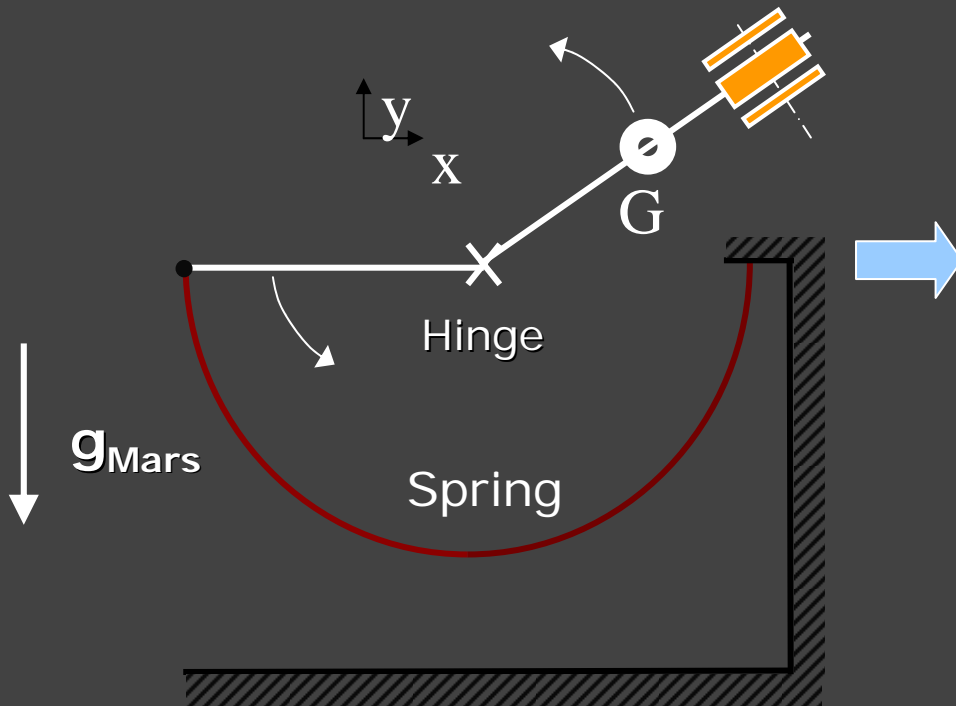
Slow ground motion:

$$z(t) = -\frac{\ddot{x}(t)}{\omega_0^2}$$

sensor output
proportional to ground
acceleration

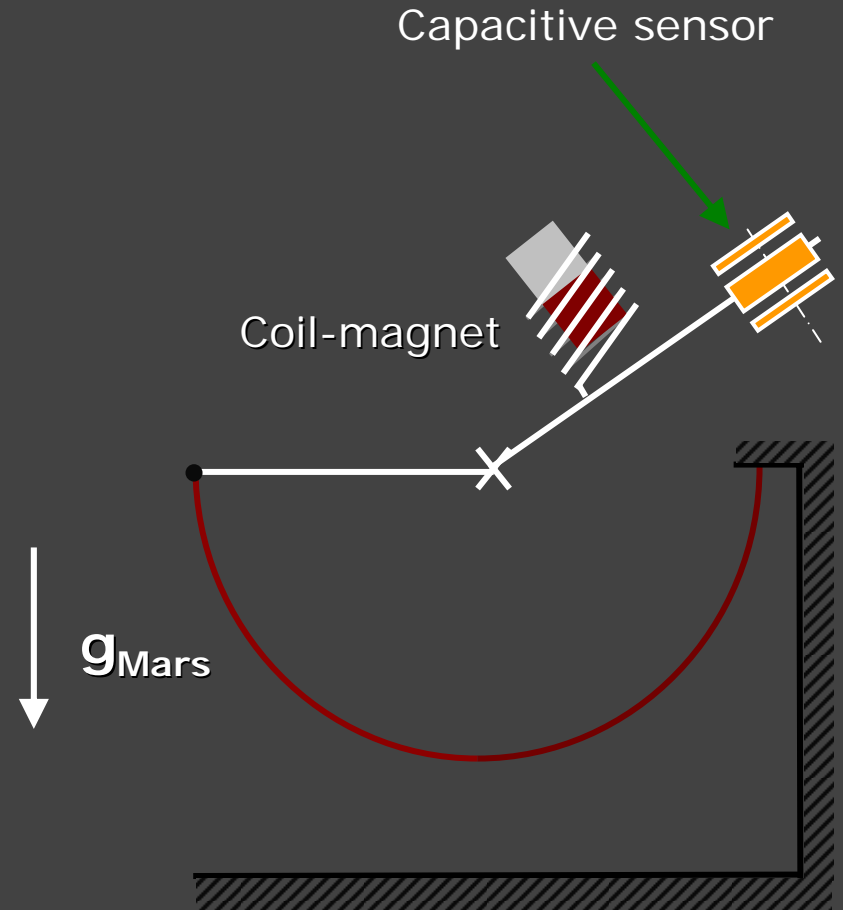
SEIS-VBB Operational Principle: Pendulum

- Mechanical pendulum.
 - A second order response (damped harmonic oscillator)
 - Based on STS-2 design (by Wielandt/Streckeisen)
 - Feedback using coils

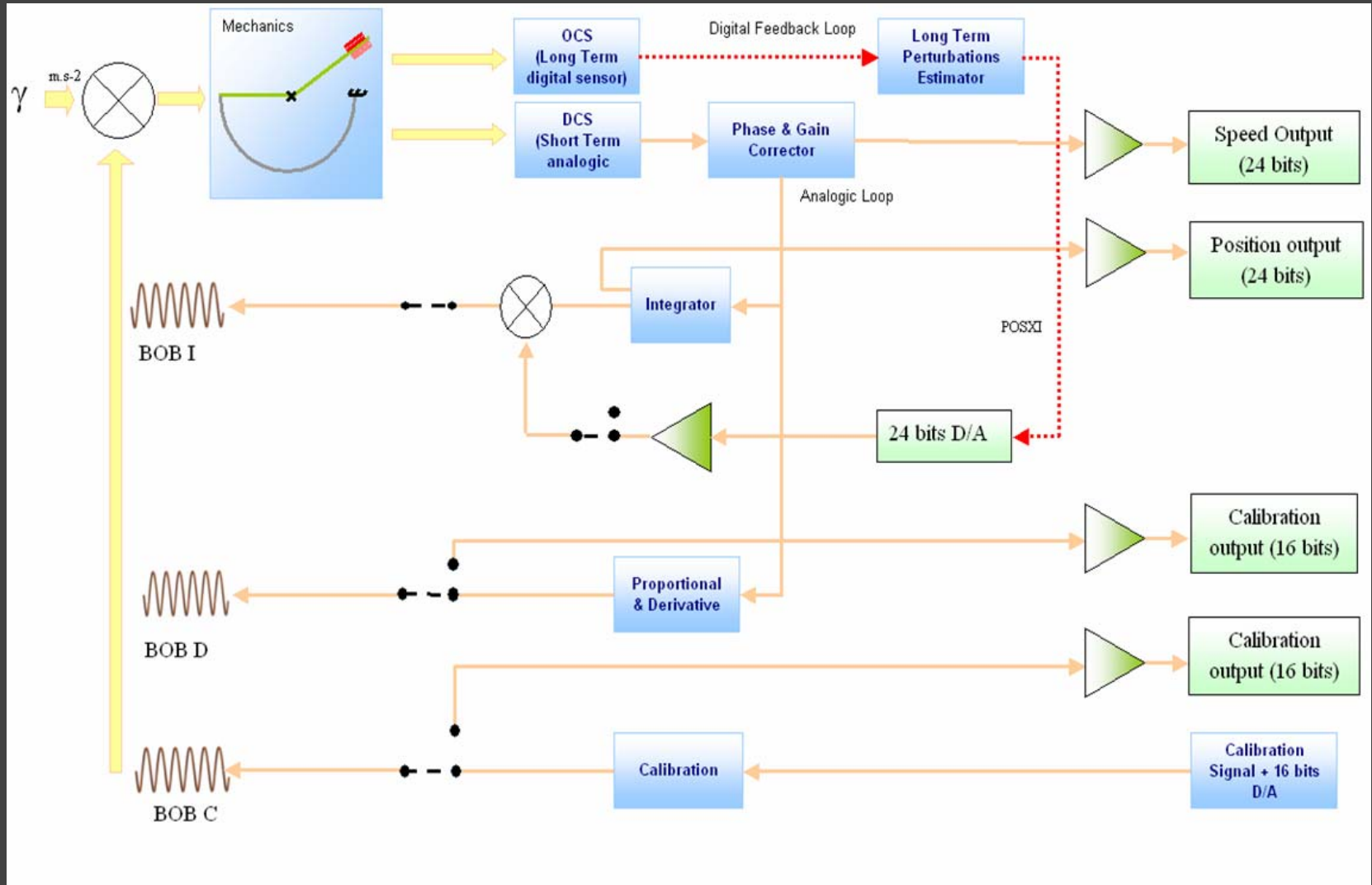


SEIS-VBB Operational Principle (con't)

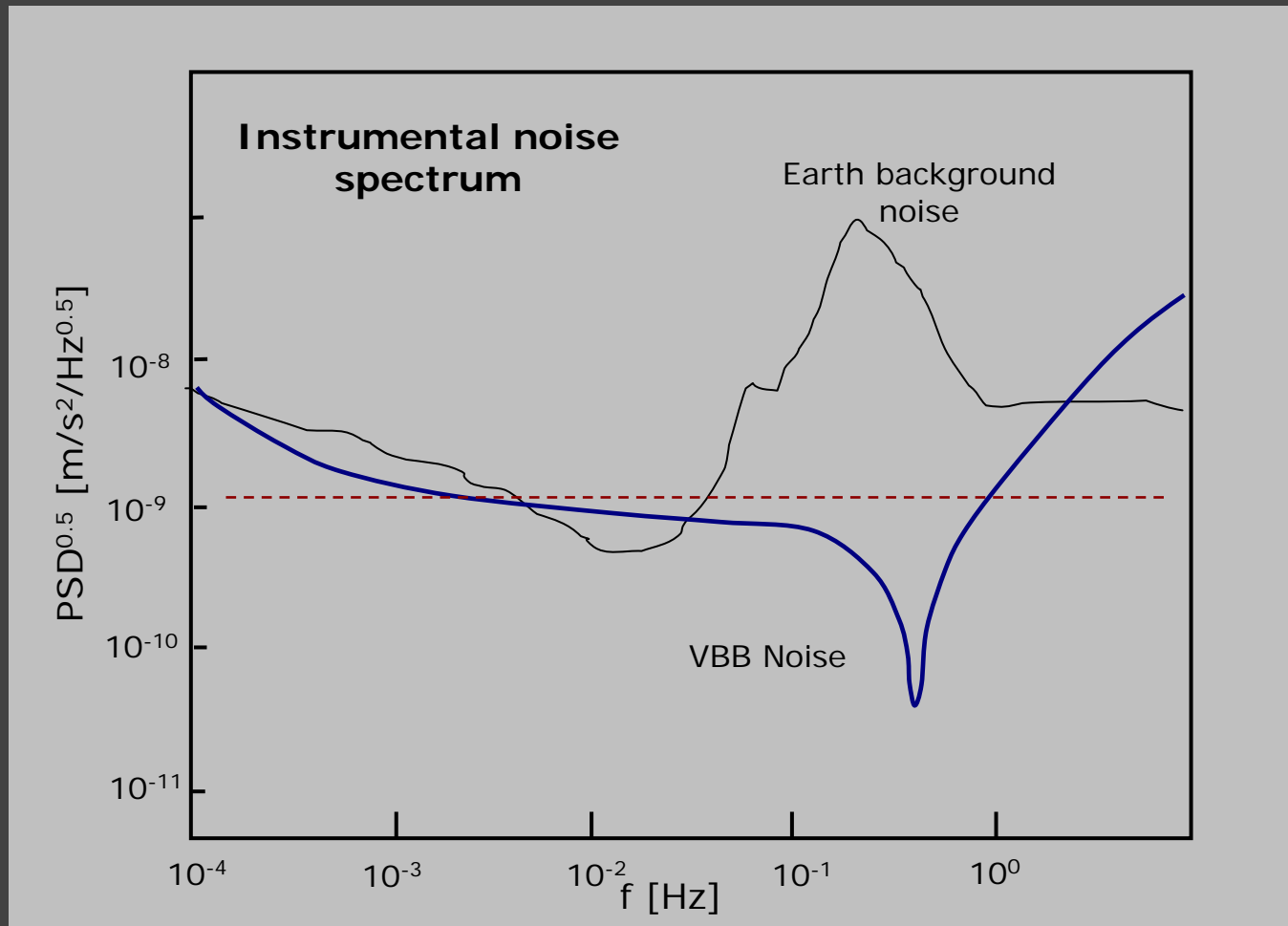
- Feedback: sensing by Capacitive Displacement Sensor is used to drive the mass back to the equilibrium position
- Linearity / dynamic range
- Science output: time-integral of capacitive displacement sensor, with 24 bits A/D
- Separate feedback for compensation of temperature drift using 24 bit D/A
- System acts as a ground velocity-sensor



SEIS VBB Schematics (feedback circuit)



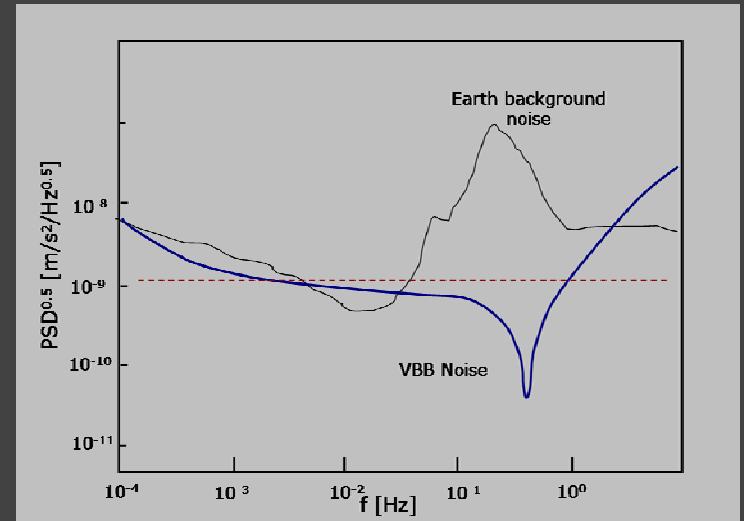
SEIS-VBB Resolution



Based on IPGP feedback control design

SEIS-VBB Resolution

- Target resolution:
Detect P-S waves from quake of M=4 at 180 degrees ->
Resolve ground accelerations down to 10^{-9} $\text{m/s}^2/\text{Hz}^{0.5}$



- Instrument noise = dominated by electronic noise (!)
 - Analogue elements in feedback loop
 - AD/DA Converters (!)
 - Brownian noise negligible
- Environmental noise (not in figure):
 - Pressure fluctuations -> buoyancy of seismometer mass
 - Tilt fluctuations
 - ...

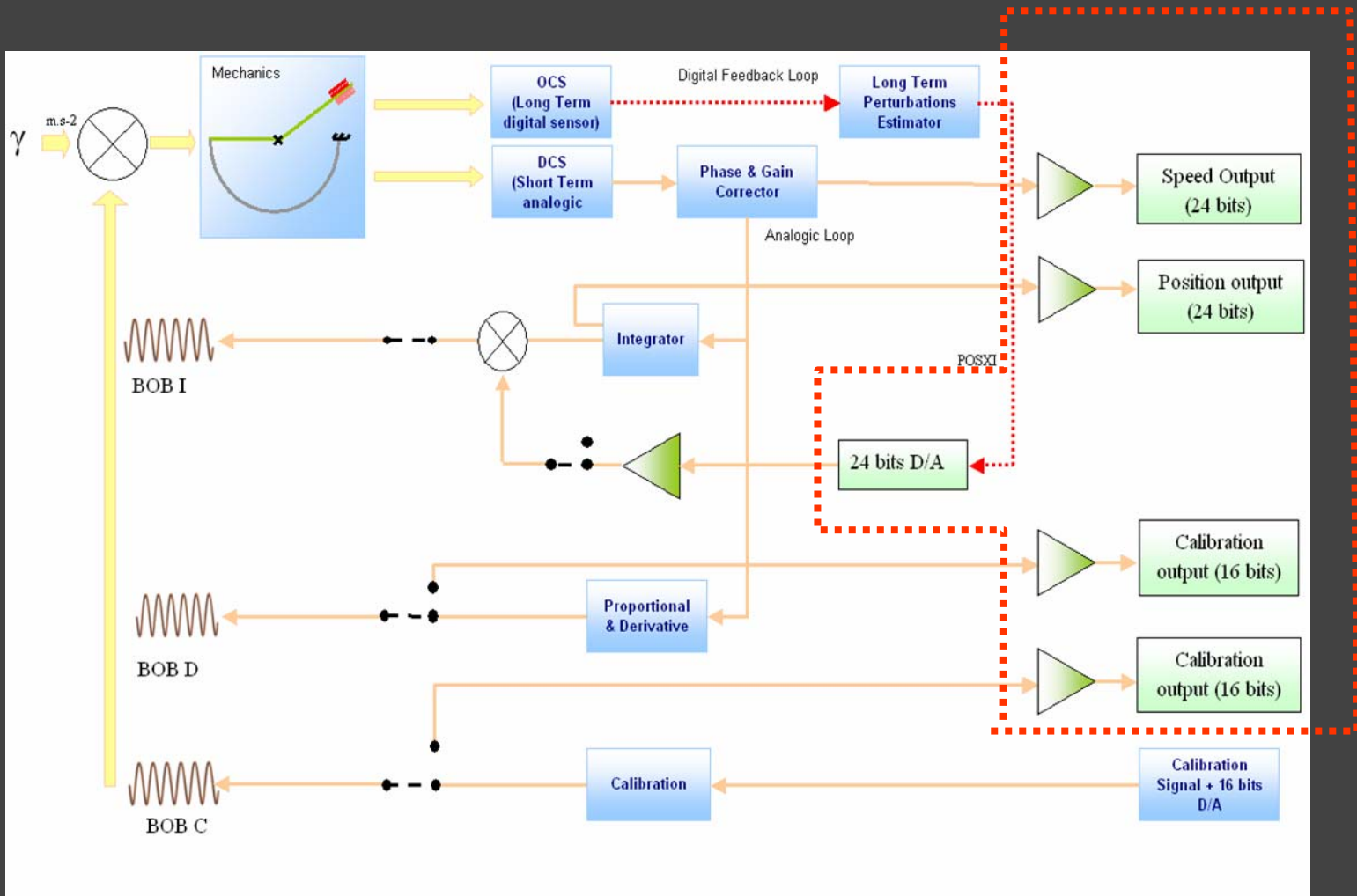
SEIS-ASIC for ExoMars

- SEIS Readout Electronics : ETH Zürich
- SRON+Xensor (Delft) Partnership to develop
- Application Specific Integrated Circuit (ASIC)
- For (a.o):
 - Acquisition of VBB-Seismometer science channel:
 - Differential Capacitance Sensor output, which includes
 - Analogue to Digital Conversion with effective resolution of 24 bits,
 - In a bandwidth of 10^{-5} -10 Hz.
 - D/A Conversion for temperature feedback-compensation
 - Various monitoring and housekeeping signals



SEIS Electronics Breadboard ETH

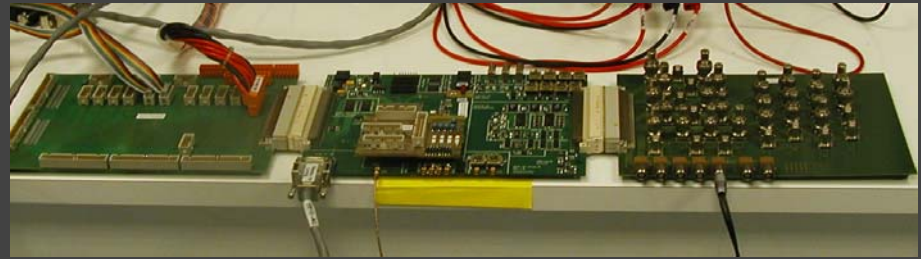




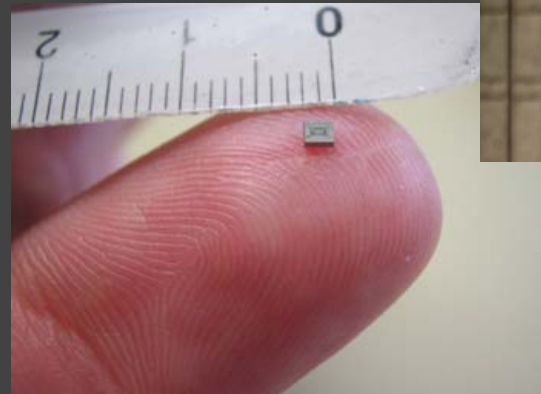
Subsystems in SRON-ASIC

ASIC Development

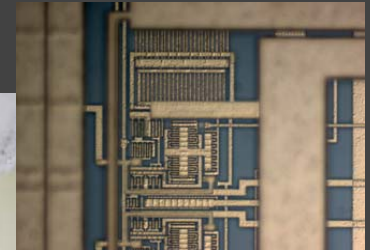
- Why mixed-signal ASIC?
- Compared to conventional electronics
 - Performance
 - Mass
 - Volume
 - Power (! Critical for SEIS)
 - Reliability
- Commercial "24" bits ADC: not really 24 bits
- Space-qualified 24 bits ADC: does not exist
- Challenge: ultra-high resolution electronics for
 - ultra-broadband frequency
 - ultra-low frequency $f < 1\text{mHz}$, where
 - $1/f$ electronic noise is the Goliath to deal with.



SEIS Electronics Breadboard ETH



ASIC for A/D SRON



SRON's ASICs:

See Poster Johan Haanstra !

Concluding

- ExoMars+GEP-SEIS will provide the first ever seismic data from Mars
- SEIS Science requirements are ambitious -> electronic requirements are challenging
- SRON(+Xensor) part of SEIS-Team
- To develop space-qualified ASIC for 24-bits AD/DA science channels for VBB seismometer
- Challenge=Opportunity
 - ASIC for high-resolution and low freq. +broadband MBW AD/DA will provide state-of-the art **unique** solution
 - Applicable to data acquisition of many future space-missions; Earth-gravity (gradiometry), Planetary Gradiometry (micro-gradiometer mission), LISA, Darwin, ...

