Cage instability of XMM-Newton's reaction wheels discovered during the development of an Early Degradation Warning System

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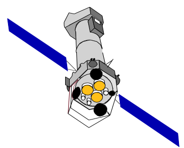

menu

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- XMM Early Degradation Warning System
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- what about INTEGRAL?
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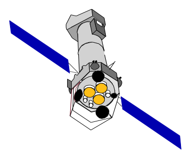
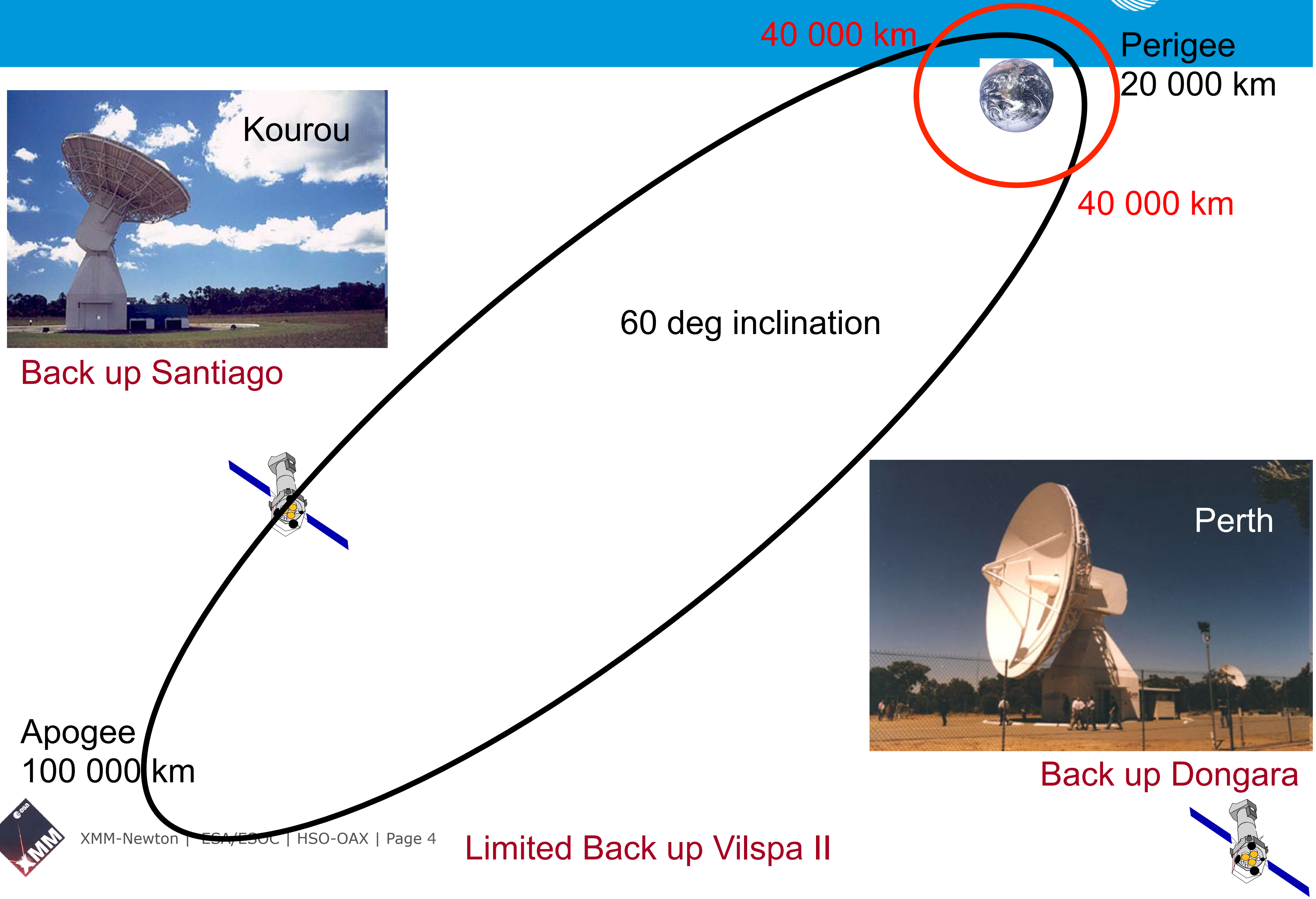


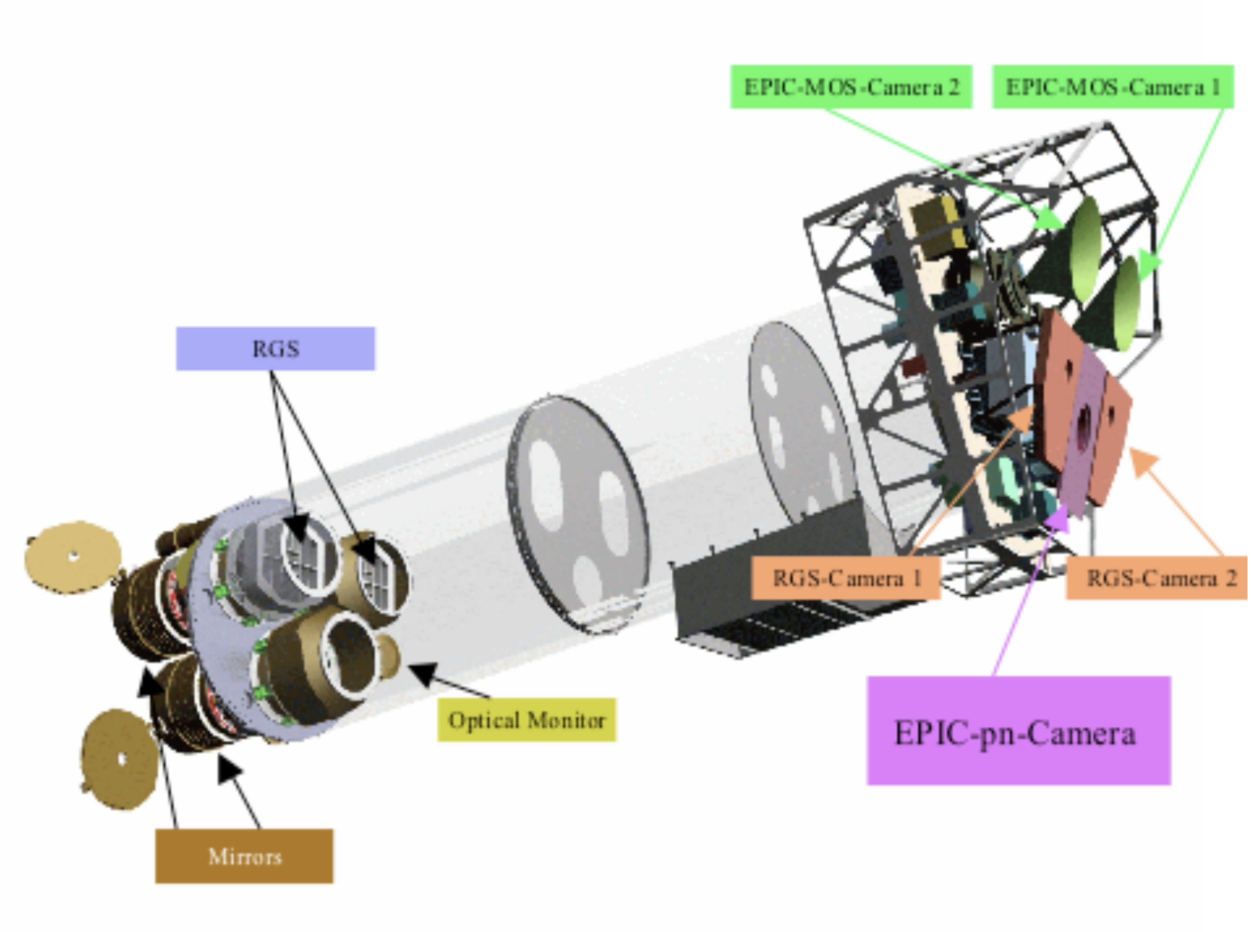
XMM-Newton

observes objects that radiate in X-ray energies from 0.2-15 keV

orbit

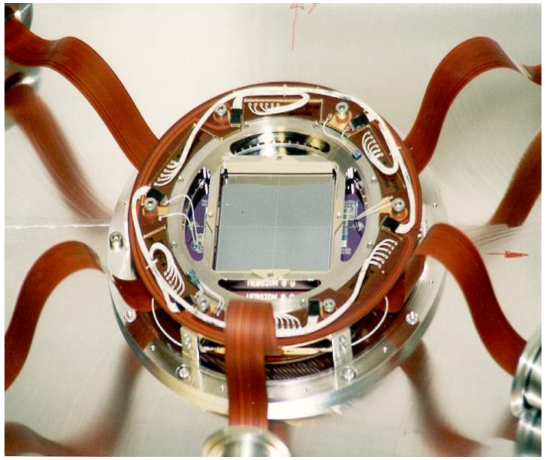

40 000 km
Perigee
20 000 km
Kourou
40 000 km
60 deg inclination
Back up Santiago
Perth
Apogee
100 000 km
Back up Dongara
Limited Back up Vilspa II

payload features



- EPIC:
  - 3 independent CCD-cameras (2 MOS & 1 PN), observing simultaneously the same field
  - 3 different light filters for both camera types
  - different modes to accommodate brightness and timing
- 2 Reflecting Grating Spectrometers
  - high-resolution spectroscopy of bright sources in the energy range from 0.3 to 2.1 keV
- Optical Monitor
  - extends the spectral coverage of XMM-Newton into the UV and optical
  - six broadband filters
  - two grisms, one in the UV and one in the optical

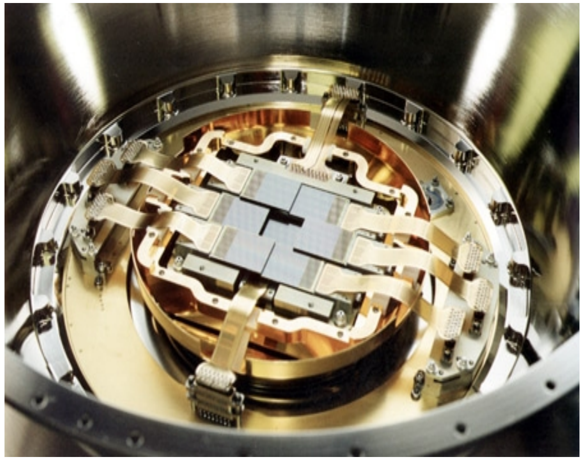
detector technology: CCDs



pn

12 back illuminated pn-junction CCDs, each with :

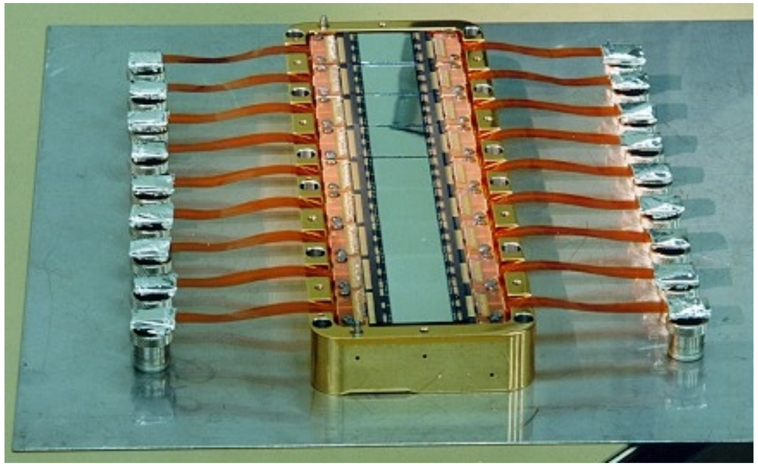
- 280 µm fully depleted Si
- 200 lines
- 64 columns
- pixelsize: 150 µm x 150 µm



MOS

7 front illuminated Metal-Oxide Semi-conductor CCDs, each with:

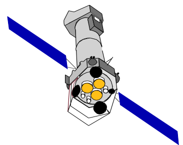
- 100 µm Si
- 600 lines
- 600 columns
- Pixelsize: 40µm x 40µm



RGS

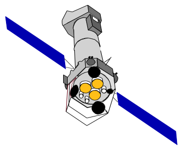
9 back illuminated CCDs, each with:

- 100 µm Si
- 384 lines
- 1024 columns
- Pixelsize: 27µm x 27µm



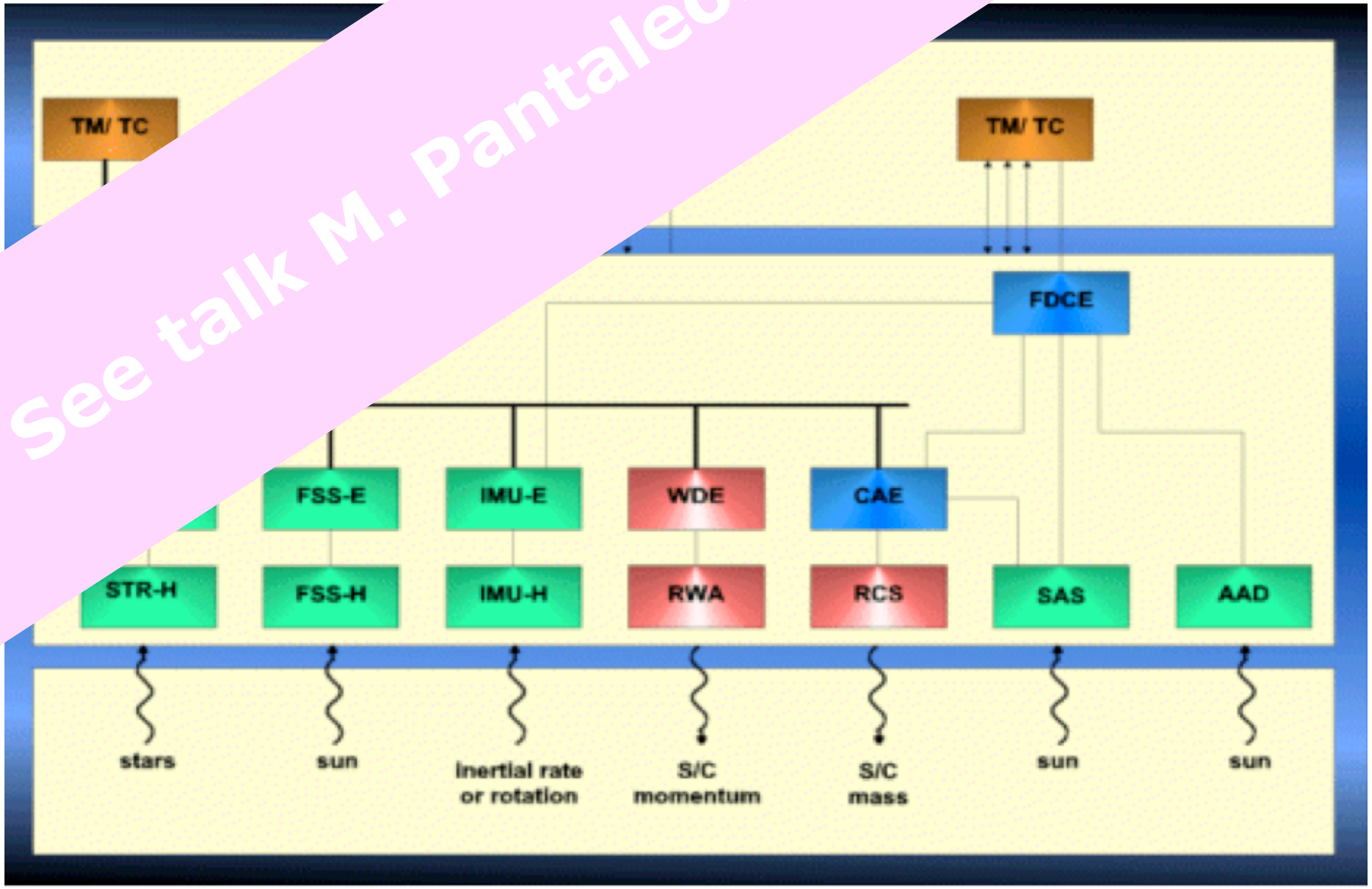
the spacecraft

- weight: 3.8 t, length: 10 m
- 3 Wolter telescopes with 58 mirrors each at one, detectors at the other end
- **4 Reaction wheels**, 4 IMUS (gyros), 2 star trackers
- Redundant reaction control system using hydrazine thrusters
- 2 solar panels with 16 metre span
- active temperature control of mirrors and instruments
- redundant OBDH, however no data/ commanding storage
- 2 Low Gain antennae



AOCS

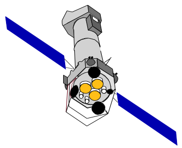
See talk M. Pantaleoni



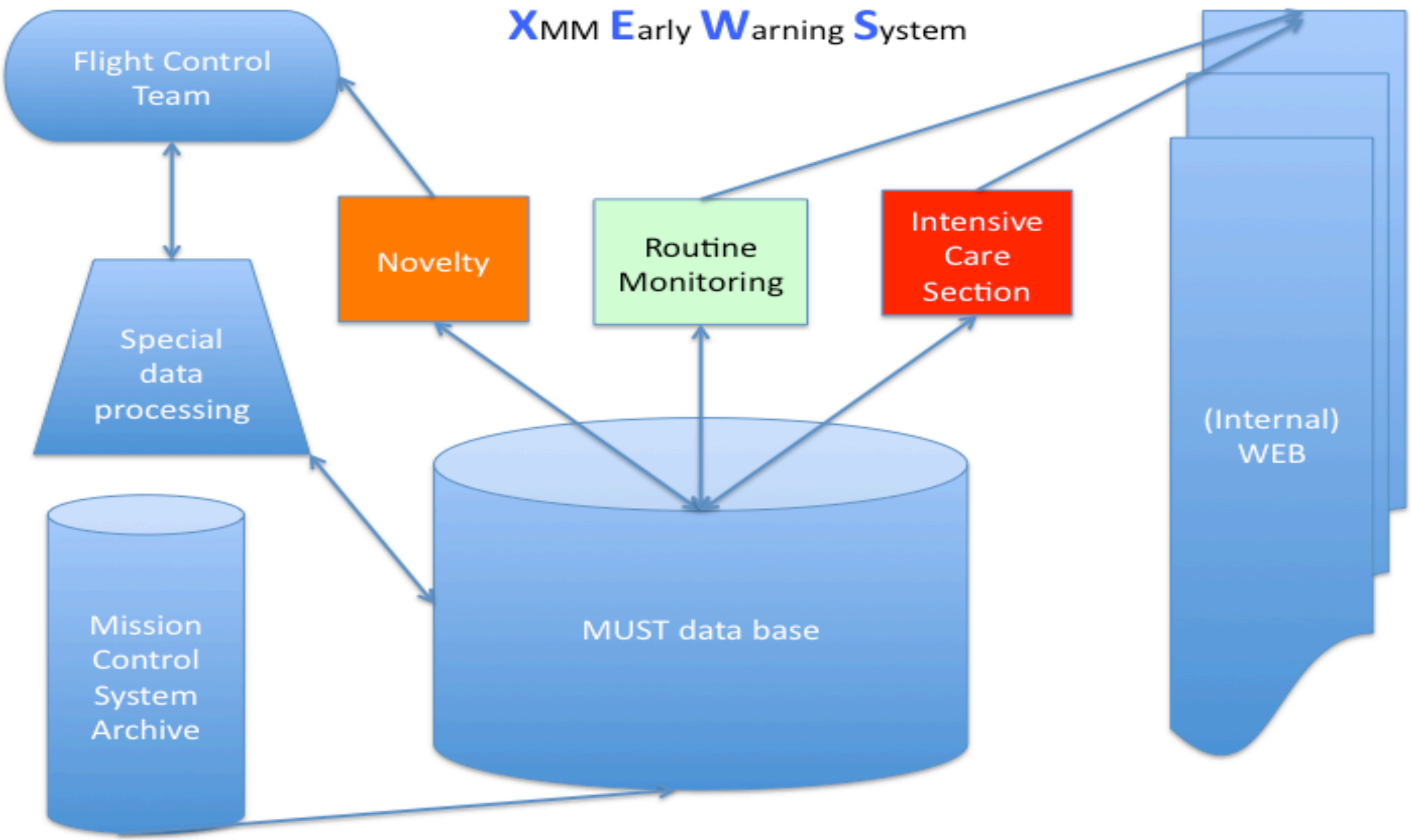
AOCS Block Diagram

spacecraft/mission status

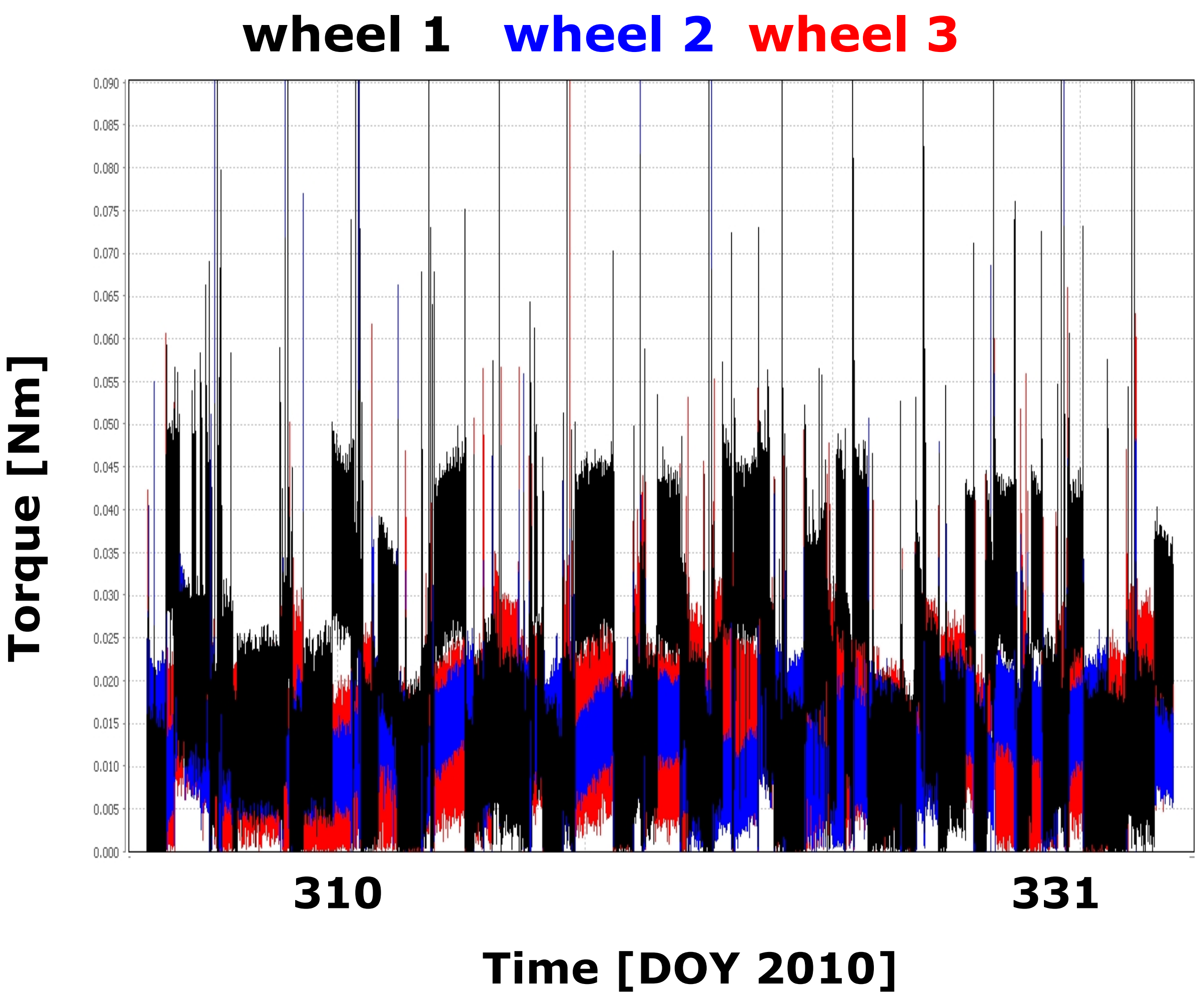
Money	Funded until next extension request	End 2012/14 in 2012→2016
Fuel	remaining Use per year Mileage left	63 kg 6 kg →2020+
Solar array power	Maximum required Current margin Margin end of 2018	1350 W 545 W 350 W
Battery	According to UHB	15+ y
Gyros/(IMUs)	Usage	< 20 %
Reaction wheels	Usage	< 44 %
RF switches **Transponder switches**	Usage	Stuck at one position Back up not used instead transponders are switched TX A LCL switches 584 TX B LCL switches 595 (Qualified to 25000)



XEWS


XMM Early Warning System
Flight Control Team
Special data processing
Mission Control System Archive
Novelty
Routine Monitoring
Intensive Care Section
MUST data base
(Internal) WEB

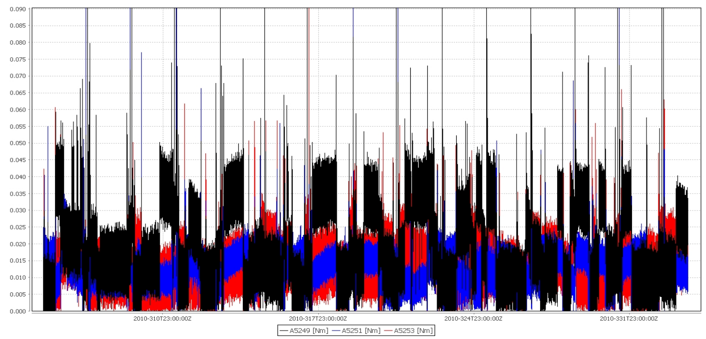
cage instability: symptoms



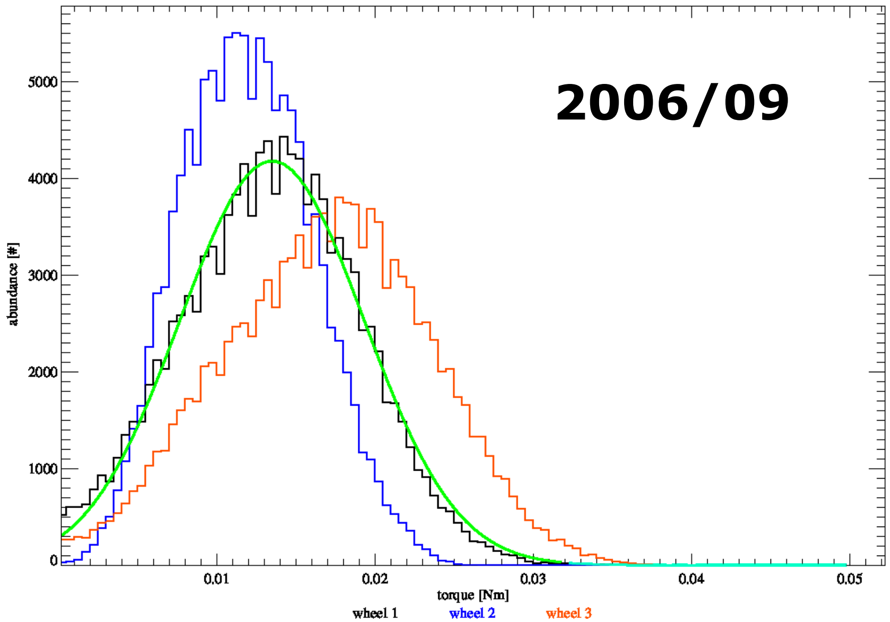
- RW1 commanded torque and RWDE1 current sometimes during stable pointing suffers a jump
- the reason for these jumps is most probably a sudden increment of the bearing friction level.
- well known phenomena with bearings running in marginally lubricated regimes
- chaotic vibration of cage
- caused by too much or too little oil (late in the mission can only be due to reduction in oil quantity)
- vibration causes increased friction, causes bearing to run hotter, oil gets thinner and gets ejected from bearing as micro droplets, oil runs hotter, oil starts to degrade, lighter fats boil off, oil runs hotter, oil degrades further, oil runs hotter, more complex fats boil off, bearing runs hotter, bearing fails

cage instability - analysis technique

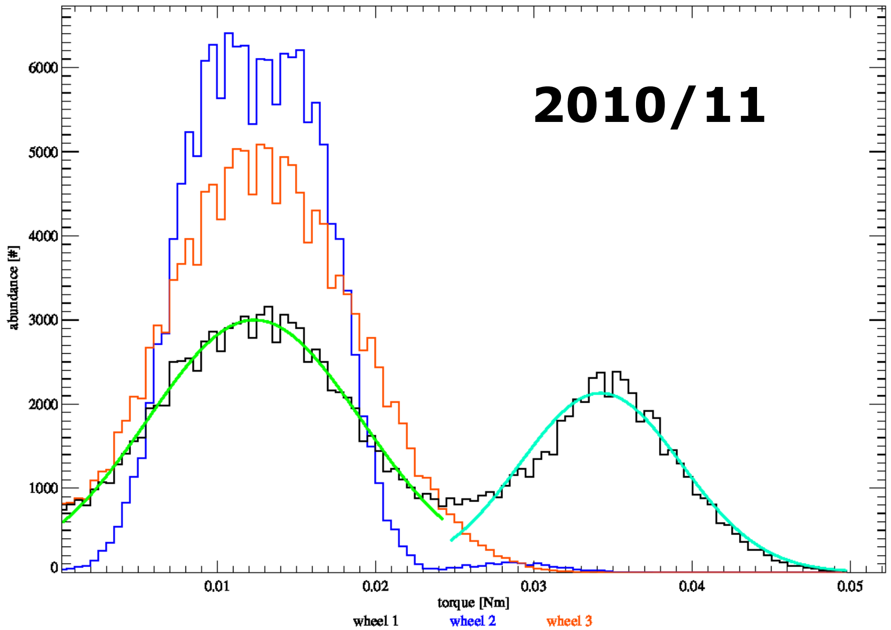
- screen data for non slew and non RWB times
- produce monthly histograms of commanded torque
- first peak shows nominal torque distribution
- if there is second peak, this shows cage instability
- height/integral of second peak gives indication of amount of caging
- difference of peak position between 1st and 2nd peak gives strength of cage instability



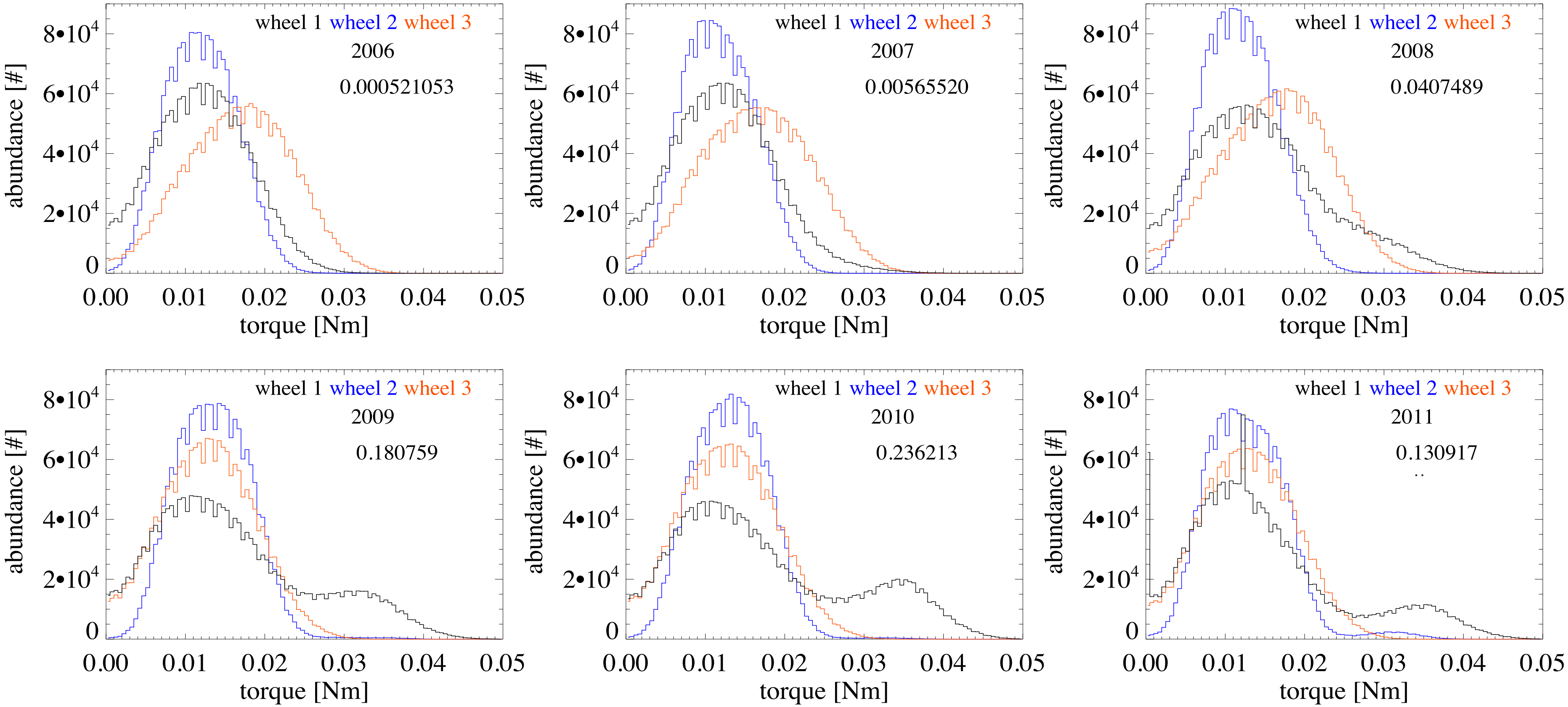
no cage instability



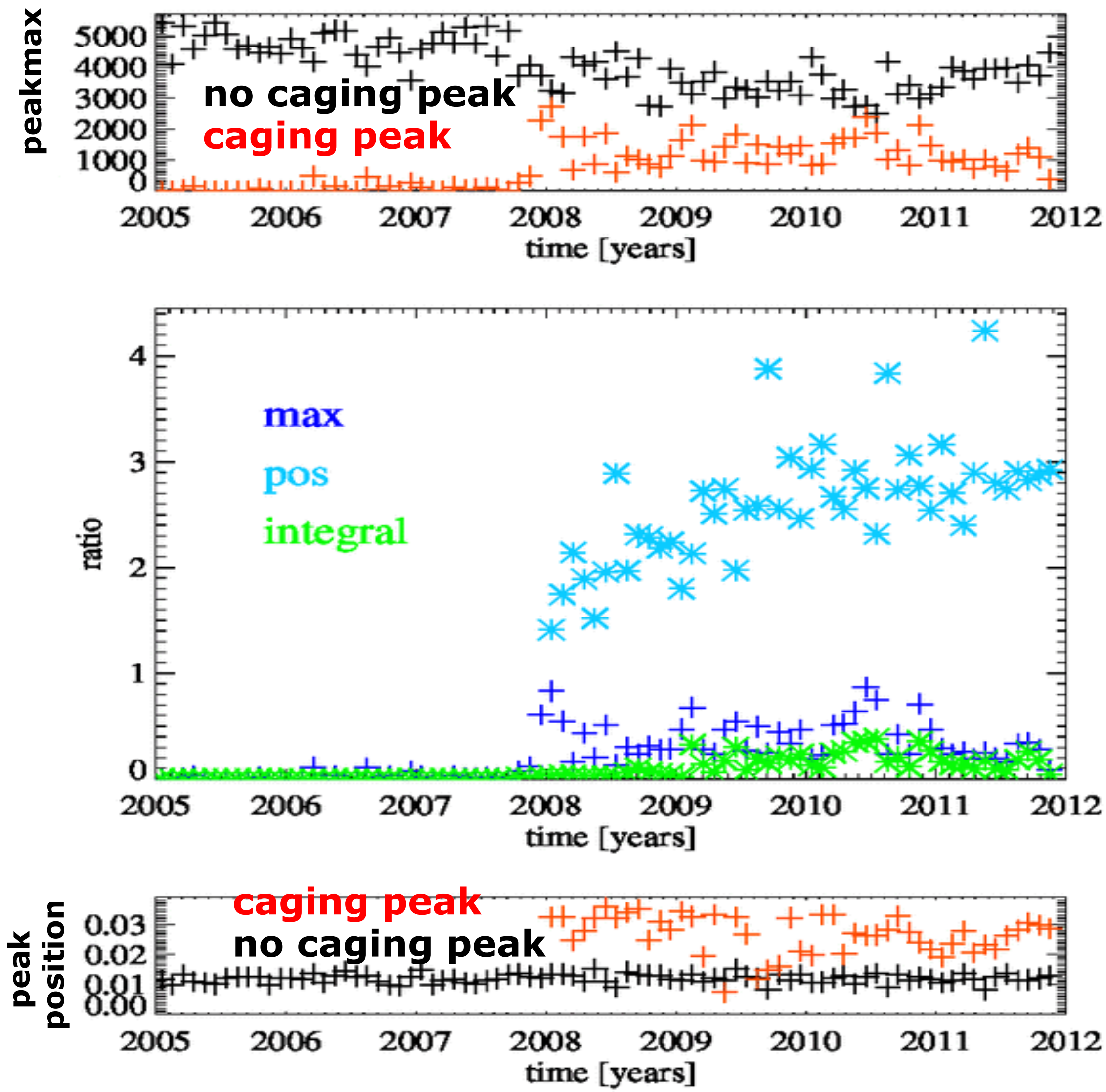
cage instability RW1



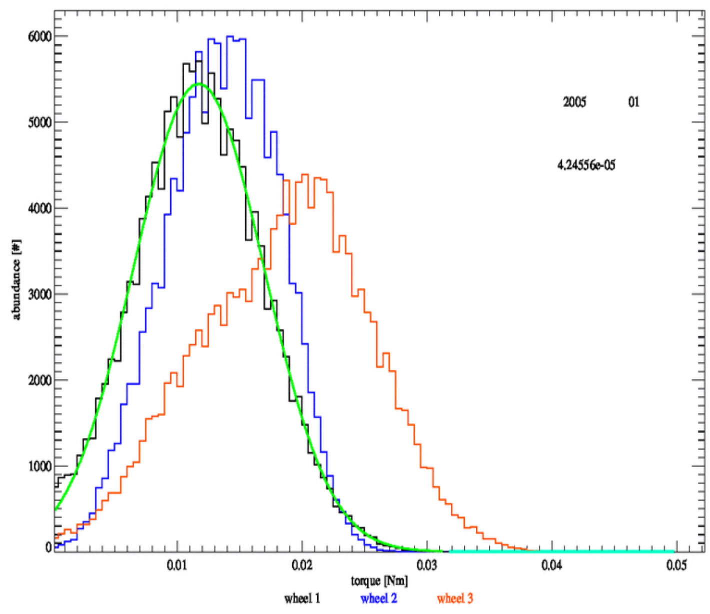
cage instability - evolution



cage instability - evolution



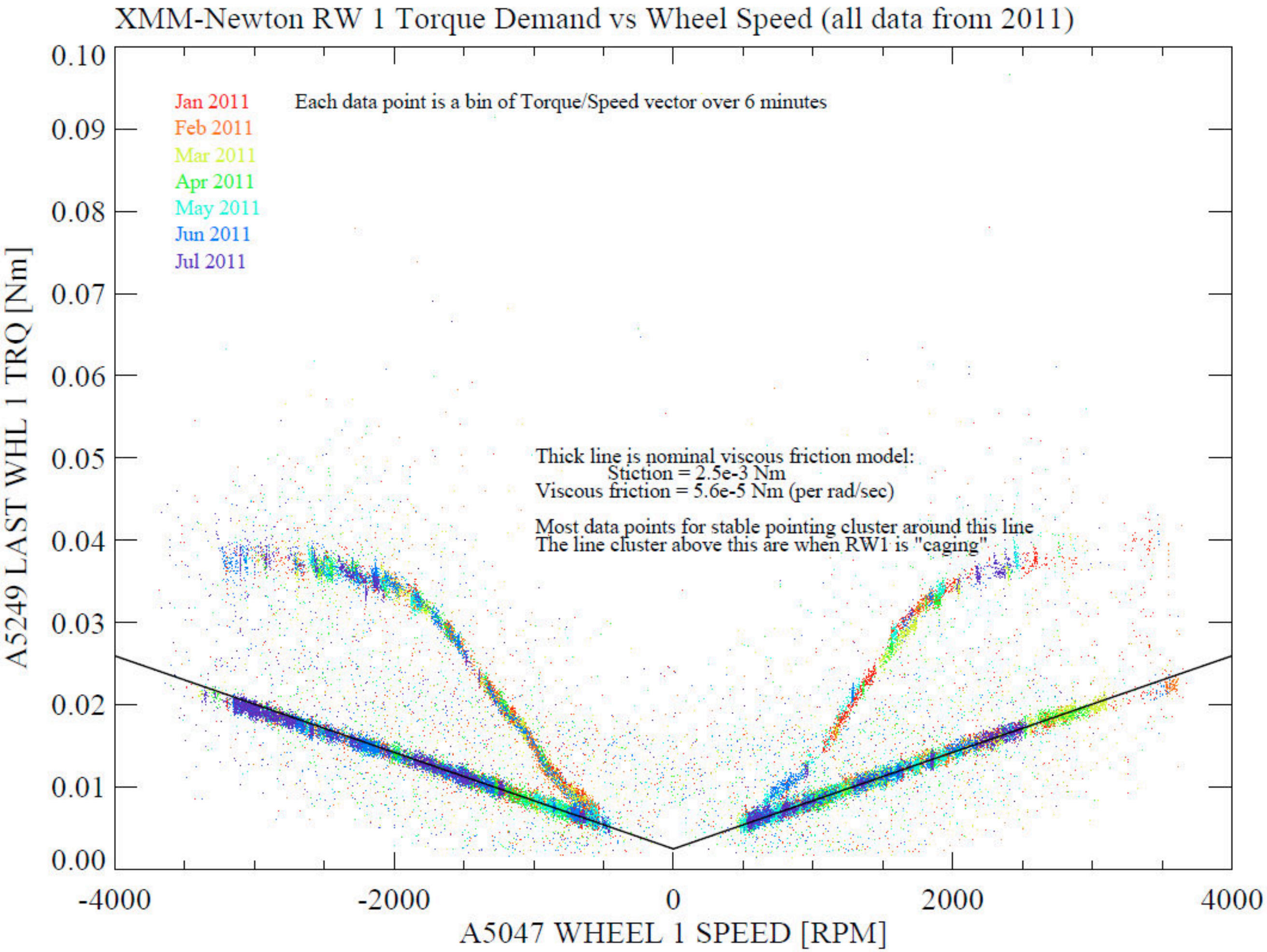
- analysis of histogram plots for each month from 2005 until now
- clear on-set of cage instability in 2008
- evolution over the last 2 years shows no significant further degradation



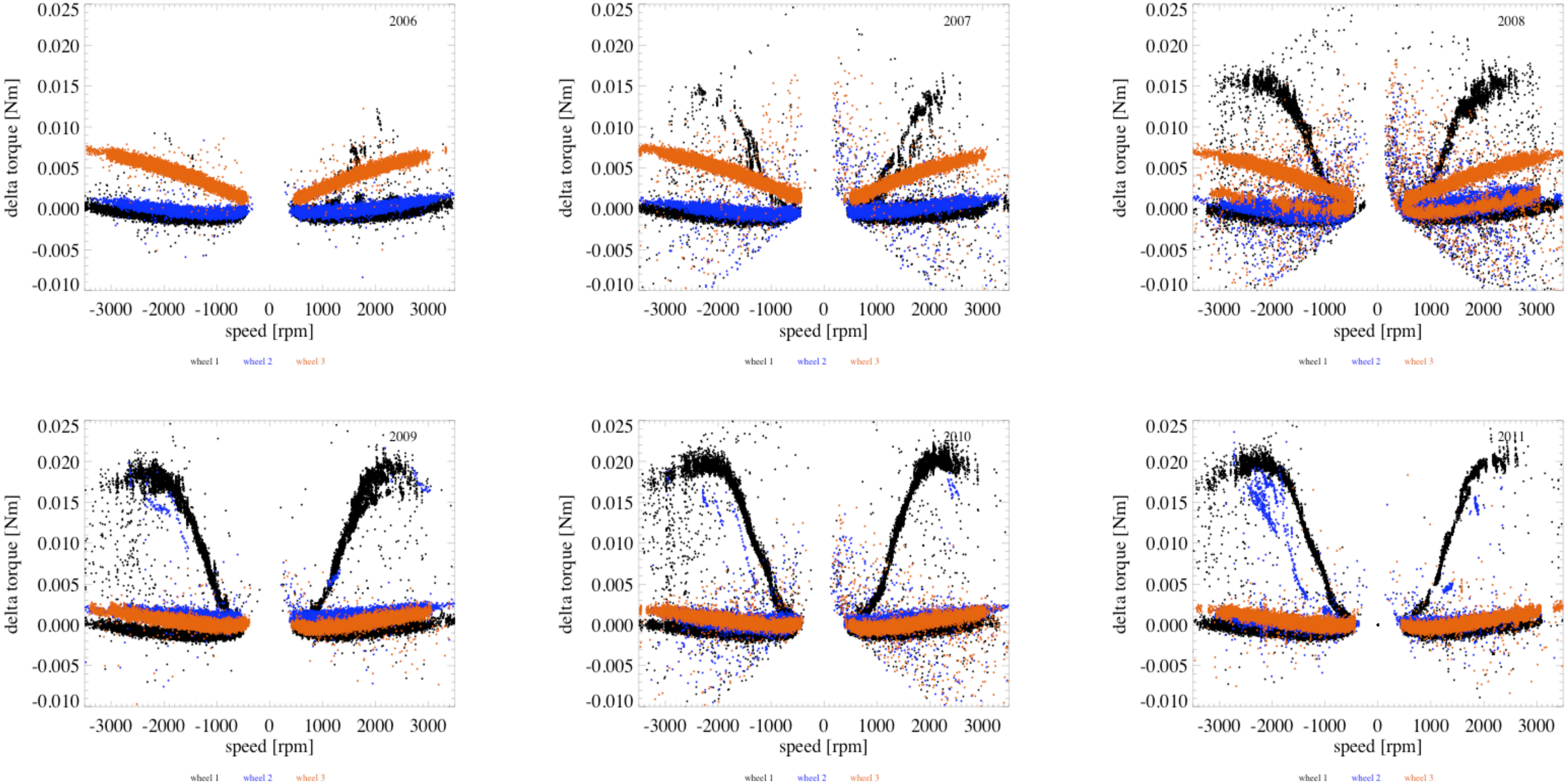
wheel1 wheel2 wheel3

cage instability – speed-torque correlation

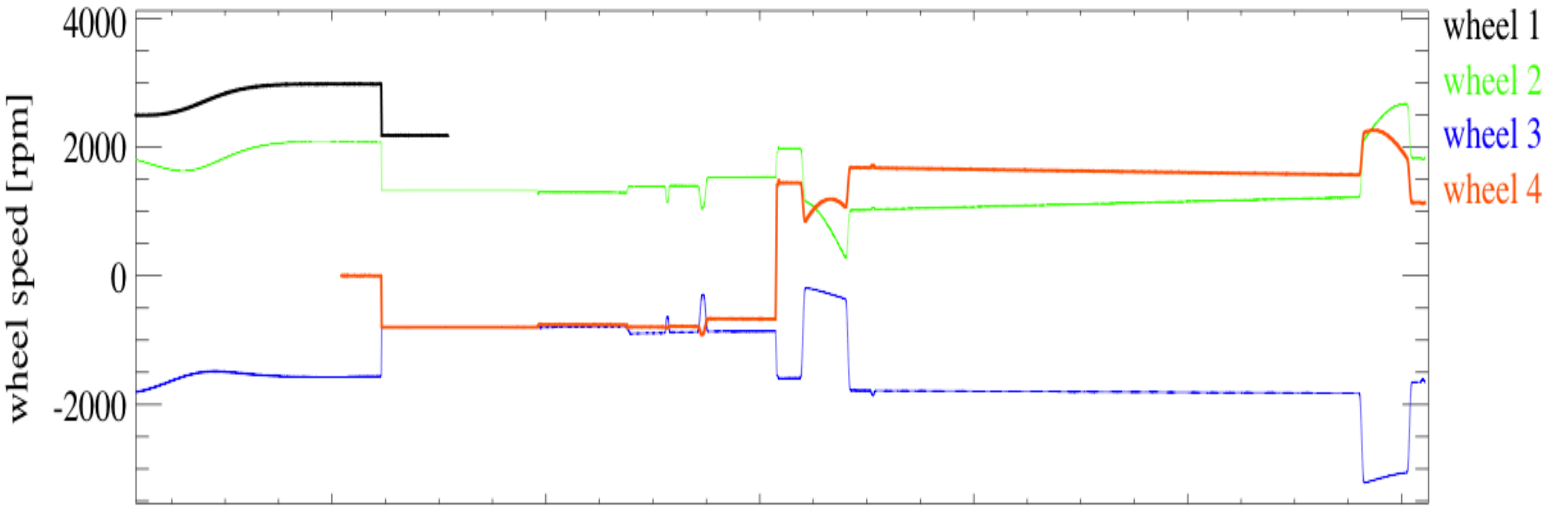
- plotting wheel speed versus torque indicates if the cage instability is present for all wheel speeds
- for higher speeds the factor in torque increase during the caging state does flatten off



cage instability - speed versus delta-torque



cage instability: actions taken

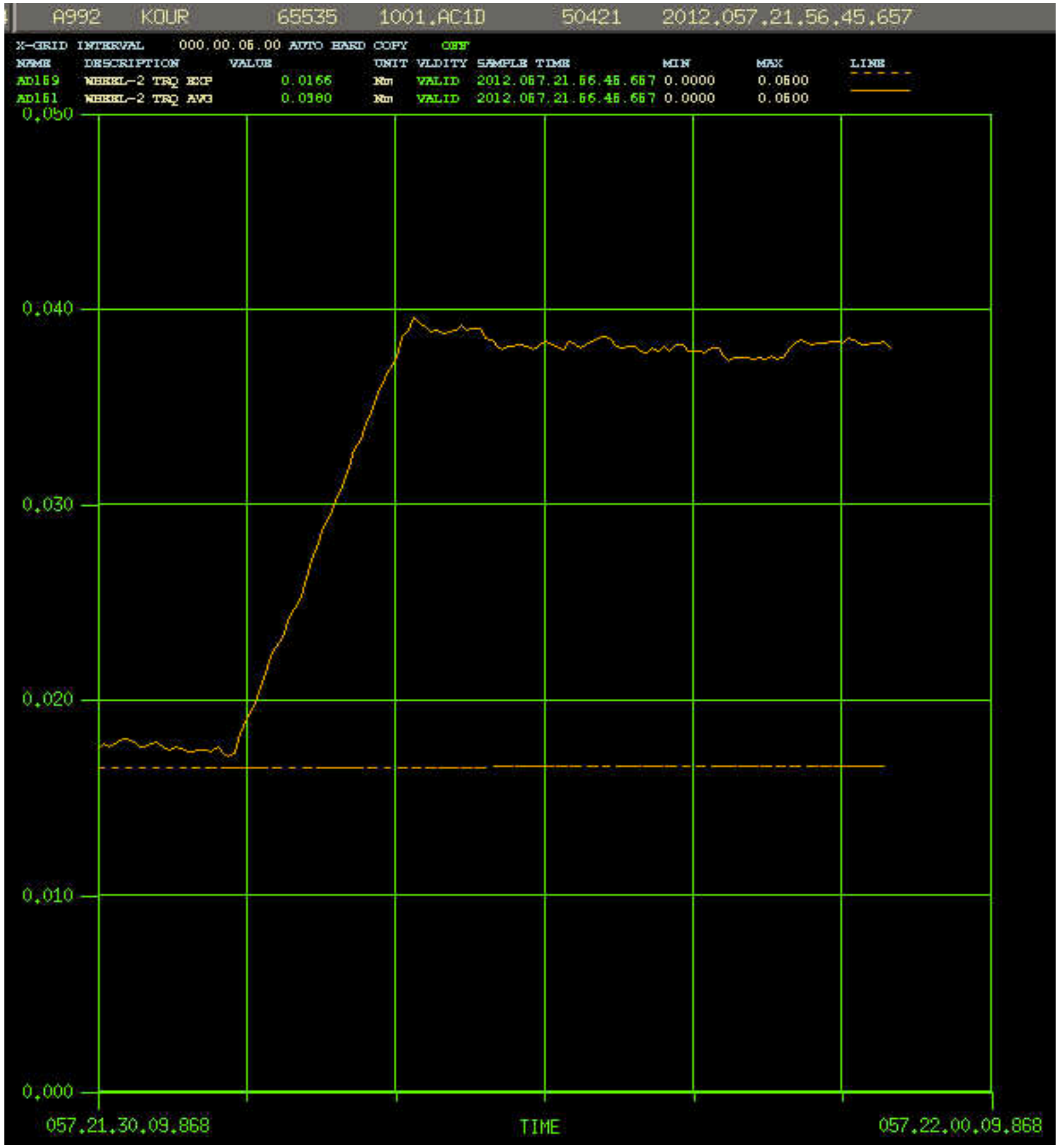


- ASU recommended to go ASAP from wheel 1-2-3 to 2-3-4 control
- after testing on the simulator wheel 1 has been switched off and wheel 4 has been put into control
- wheel 1 is now waiting for “re-lubrication”: each reaction wheel has an oil reservoir, that allows injecting oil in the bearing. This should cure the cage instability
- currently Astrium/Bradford in combination with ESOC are working on a procedure to perform this re-lubrication

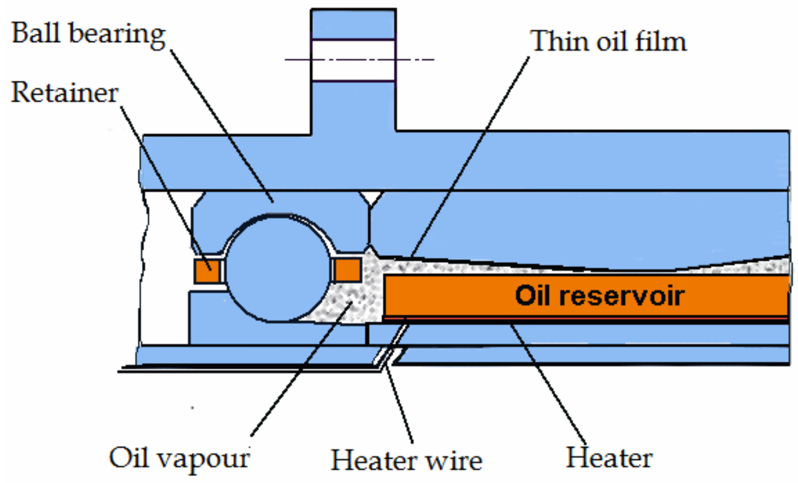
cage instability - monitoring

- comparing the predicted torque as a function of wheel speed with the actual speed over time indicates when a wheel is in caging stage
- can be used near real time
- weighting cage states with 1 and one cage stages with 0 gives as well the cage fraction in a certain time interval
- implemented as monitored derived parameter on the MCS

future: use delta torque measurement to detect cage instability and future new mode of the AOCS system to perform active de-caging

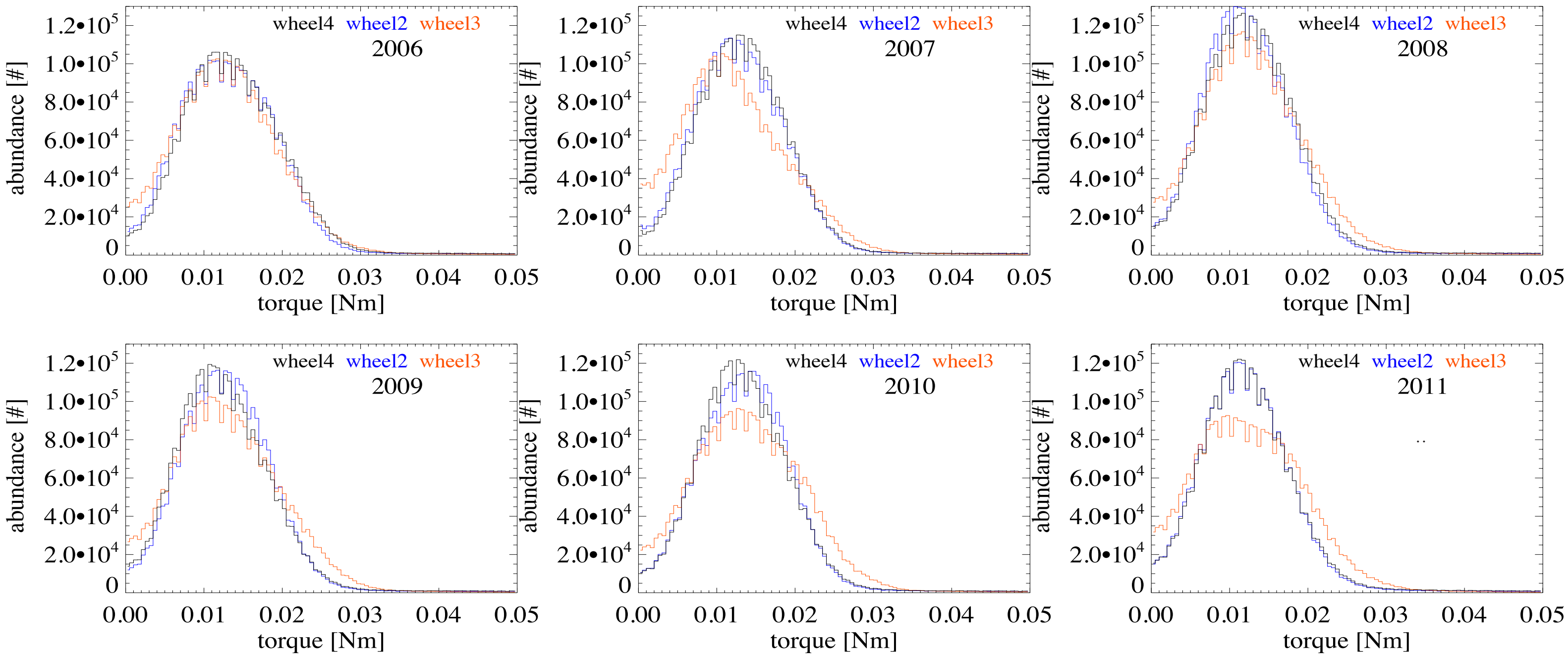


possible cure - re-lubrication

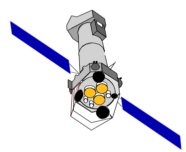


- a static oil reservoir is foreseen for in-situ lubrication
- reservoir is mounted on the static part of the bearing unit
- it consists of a cylindrical porous material reservoir surrounded by an aluminum sleeve. Incorporated into the aluminum sleeve there is a heater that on demand heats up the oil inside the reservoir
- due to the different thermal expansion factors, of aluminum and the porous reservoir, oil is pressed out. The oil gets to the cages and the ball bearings by surface migration and vapor condensation
- when using this method of re-lubrication the heater activation time has to be progressively increased after each operation to press out each time the same quantity of oil from the reservoir

INTEGRAL



- **same analysis done for integral shows: NO effects**
- plausible reason
  - age of the reaction wheels (INTEGRAL wheels are 3 years younger)
  - INTEGRAL has more slews and maneuver. So far we see the caging instability only starting during a stable pointing, i.e. during periods where the wheels spin at constant speeds.



conclusions

- ESA's X-ray cornerstone mission XMM-Newton is operating in its 13th year.
- reaction wheel cage instability is present
  - since 2008 for wheel one with a mean abundance of ~20 %.
  - since 2011 for wheel two with a mean abundance of only ~5 %.
- since December 2011 wheel one has been replaced by the redundant wheel four in the control loop awaiting now a re-lubrication procedure that may cure the effect
- investigations underway how to cope with the effect in case the re-lubrication exercise would not be fully successful:
  - use the statistical analysis of this work to define operations of the wheels outside the regions of maximum cage instability
  - use delta torque measurement to detect cage instability and future new mode of the AOCS system to perform active de-caging
- the XMM Early Warning System is put in place to detect early degradation of spacecraft components in order to be able to develop counter measures as soon as a small degradation is actually detected.