A Precise Attitude Determination and Control Strategy for Small Astrometry Satellite "Nano-JASMINE"

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Agenda

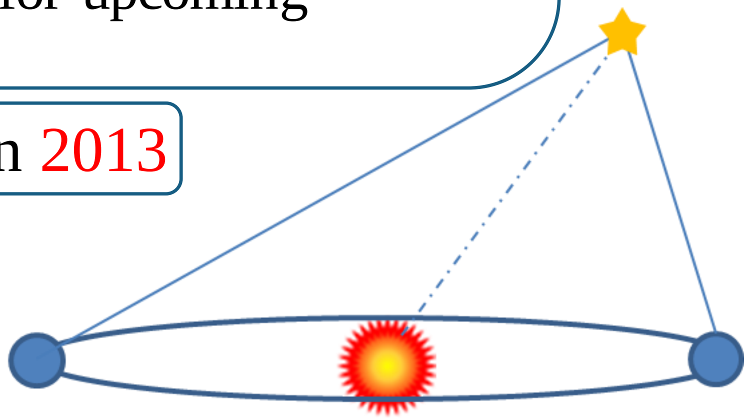
* Overview of Nano-JASMINE
* Two unique solution for precise attitude control
  * Compensation of magnetic attitude disturbance
  * Precise spin rate estimation using mission telescope
* Conclusion

Overview of Nano-JASMINE(NJ)

- **<u>Nano</u>** **<u>J</u>**apan **<u>AS</u>**trometry **<u>M</u>**ission for **<u>IN</u>**frared **<u>E</u>**xploration
  - Space astrometry （update star catalogue）
    - Perform all-sky survey in infrared during two years
    - Estimate positions of stars to an accuracy of three milli-arc second (mas) from observation data
  - Verification of observation systems for upcoming large satellites, JASMINE

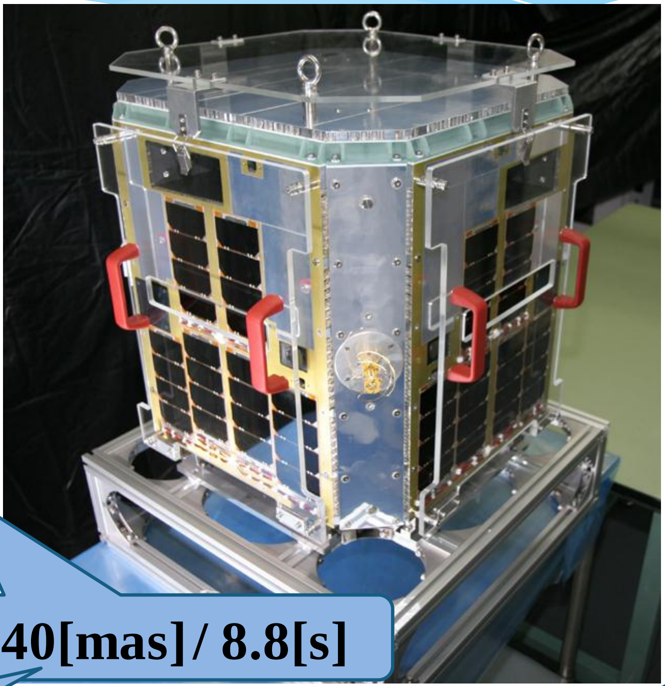
- Nano-JASMINE will be launched in 2013

Positions of stars are measured by utilizing stellar parallax



Overview of Nano-JASMINE(NJ)

Item	value
Size	508 × 508 × 512 mm^2
Mass	35 kg
Orbit	Sun-synchronous Orbit
Mission	Infrared astrometry
Focal length	1.67 m
Diameter	5 cm
Detector	CCD in TDI method
Attitude rate requirement	4 × 10^{-7} rad/s (TDI scanning direction)
	2 × 10^{-6} rad/s (The other direction)
Sensor	Sun sensor, Magnetometer, FOG, STT
Actuator	RW, MTQ, Magnetic Canceler



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Sevier attitude requirement for small satellite

Precise attitude control is required

Precise attitude control strategy

* Two requirements for precise attitude control

Precise attitude control

Compensate and reduce attitude disturbance

Estimate spin rate precisely for precise feed back control

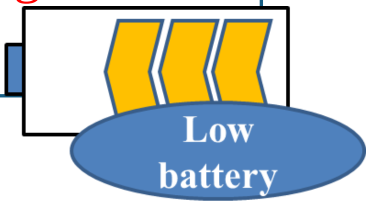
Attitude disturbance compensation
and
precise spin rate estimation
are essential for precise control

For these two requirements, two unique methods are adopted in the NJ mission

Unique attitude control methods in NJ

- Magnetic disturbance compensation method
  - Attitude stability of small satellites are easy to disturbed
    - Because of small inertial moment of the satellite
  - Dominant disturbance is magnetic disturbance

- Spin rate estimation method using mission telescope
  - Conventional high-accuracy sensors are difficult to use
    - Because of limited capacity of the satellite on power generation
  - Using mission component is power saving



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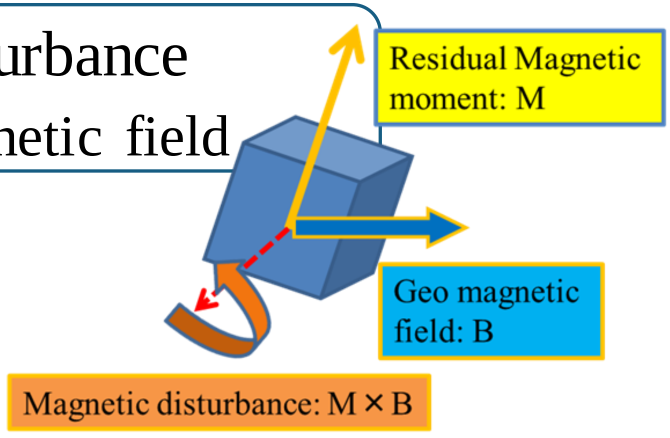
Attitude disturbances in the NJ mission

- Main attitude disturbances
  - Gravity gradient disturbance
  - Solar pressure disturbance
  - Magnetic disturbance
  - Air pressure disturbance

Disturbances	Magnitude (Nm)
Magnetic	$5.0 \times 10^{-6*}$
Gravity gradient	1.0×10^{-9}
Air pressure	1.6×10^{-9}
Solor pressure	1.0×10^{-9}

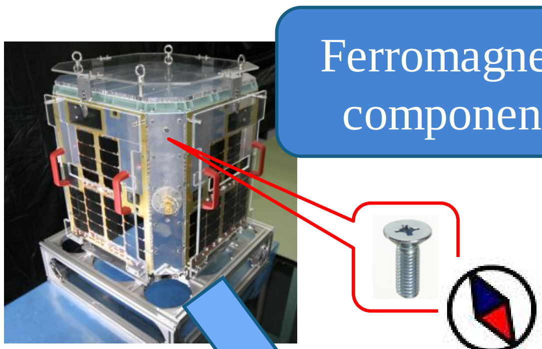
* Residual Magnetic Moment : 0.1 Am^2

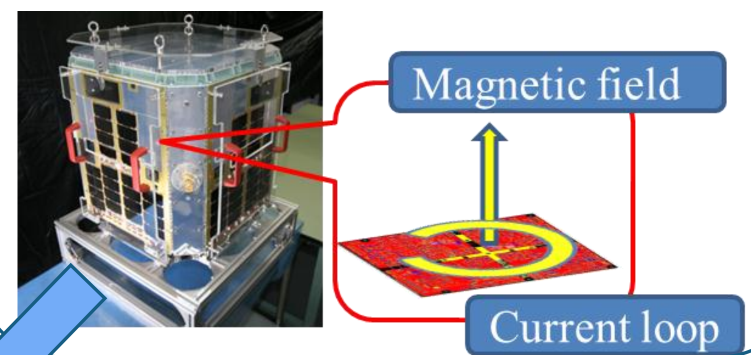
- Magnetic disturbance is dominant disturbance
  - interaction between RMM and geomagnetic field
- RMM: residual magnetic moment of satellite



Source of Residual Magnetic Moments

- Main causes of RMM
  - Ferro-magnetic components
    - screws, nuts, connectors… etc.
  - Current loops in the satellite
    - circuit boards, harnesses… etc.





Alignment change

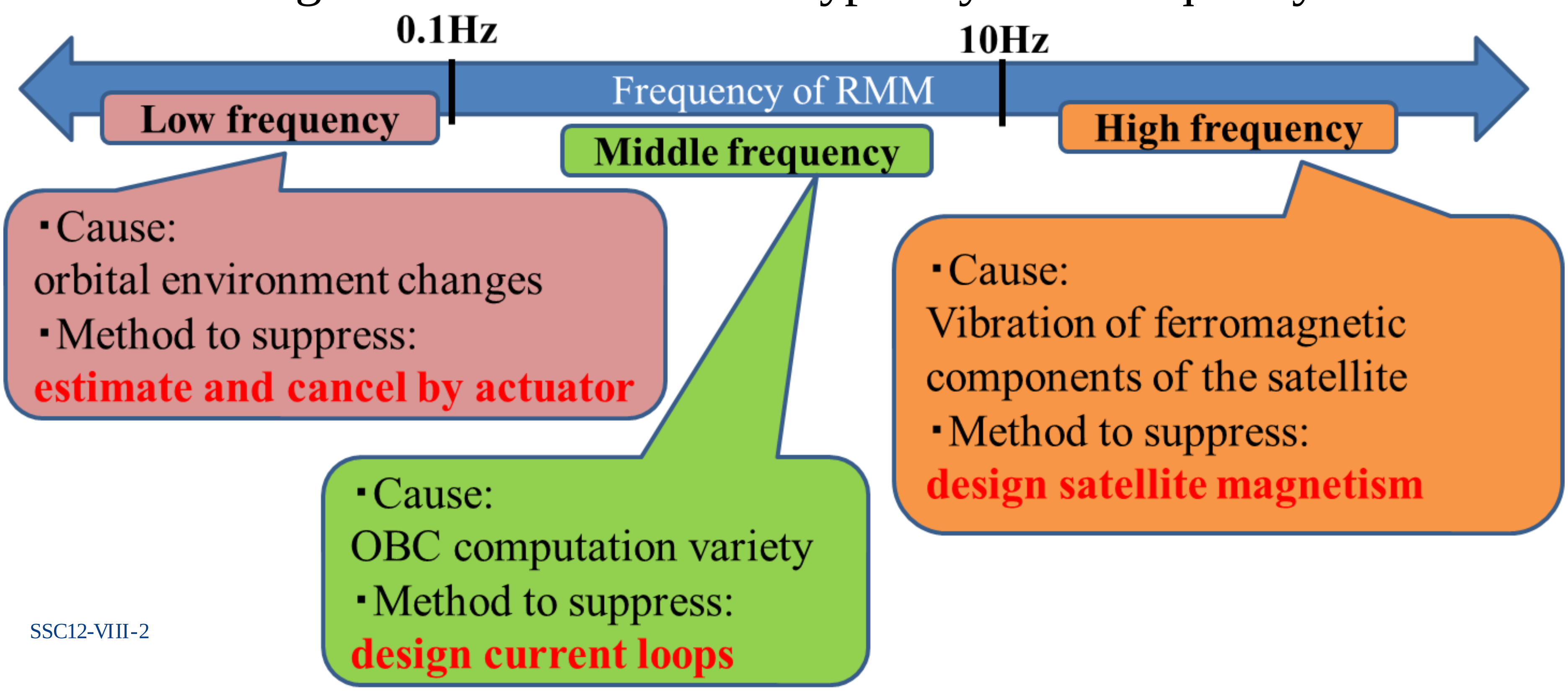
Amount of current change

RMM is time variable

Need to deal flexibly with each frequency

RMM compensation strategy

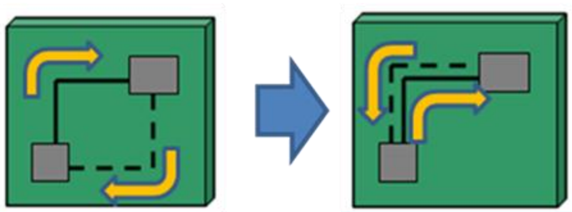
* Categorize RMM into three types by their frequency



Satellite design for RMM suppression

Current loop regulation

Printed circuit boards



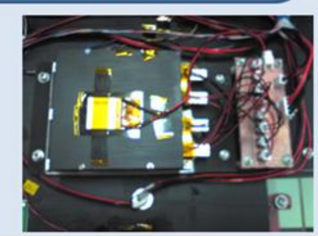
Reducing areas of current loops

Harness cables

Twisting lead wire to cancel out current flows

Structural material selection

Select structural materials (connector, bolt, nut… etc.) made from non-magnetic material



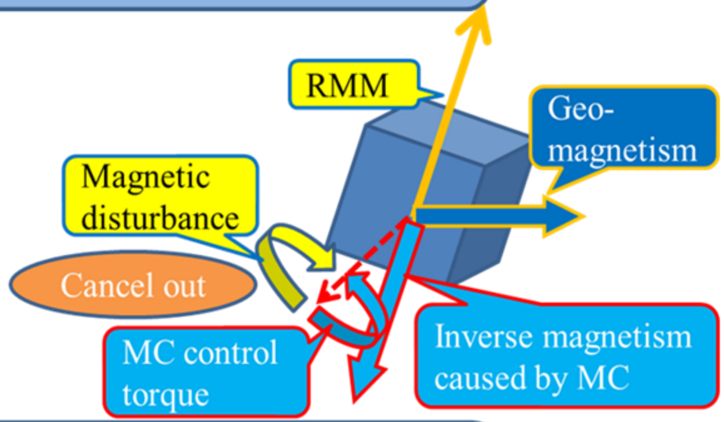
Material	Relative Permeability
Silver	0.99993
Copper	0.999991
Alminium	1.00002
Cobart	250
Ni	600
Iron	5000

＊Vaccum: 1.0

Causes of RMM

Estimation and cancelation of RMM

Cancel out RMM by inverse magnetic moment



inverse magnetism is caused by magnetic canceler (MC), high-accuracy MTQ

Specification of MC

Item	value
Max output	0.6 Am^2
Accuracy	5.0×10^{-5} Am^2
Mass	686 g
Power consumption	1.2 W

Estimate RMM from equation of motion

$$I\dot{\omega} + \omega \times (I\omega + h_{RW}) = M \times B + \dot{h}_{RW}$$

$$M = M_{const} + M_{control} + M_{time\_varying}$$

Off-line estimation

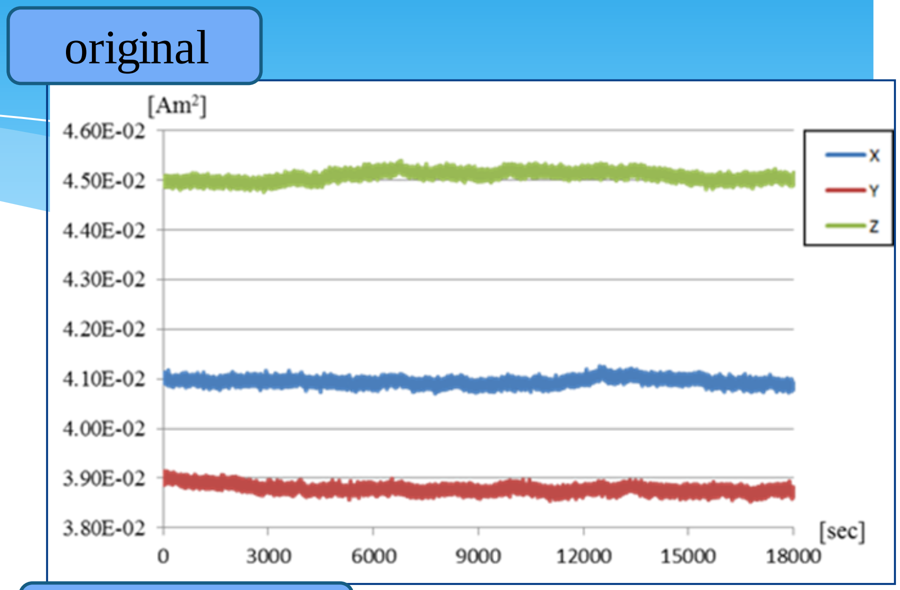
Constant RMM (M_{const}) estimation at the ground station with batch process

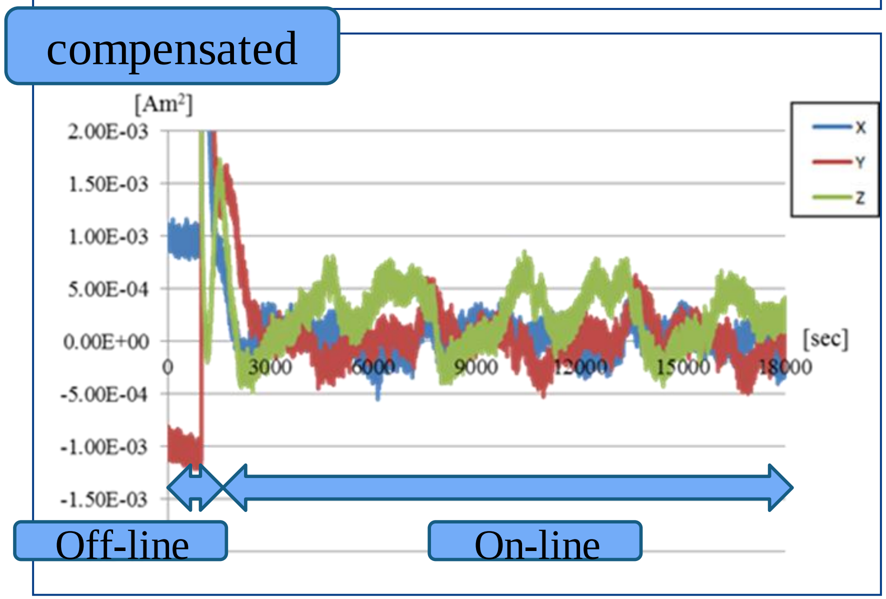
On-line estimation

Time-varying RMM ($M_{time\text{-}varying}$) estimation in the orbit with extended kalman filter

Verification examination with SCLT

- SCLT verification
  - Control torque:
    - calculated in OBC
  - Orbital environment:
    - calculated in PC
- Empirical model of RMM
  - Using experimental results
- RMM estimation
  - after 1500 sec
    - On-line estimation
  - before 1500 sec
    - Off-line estimation only





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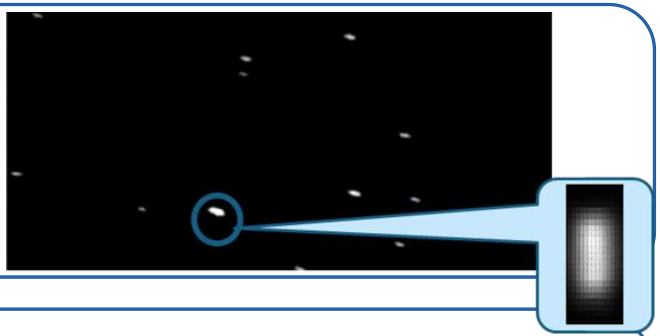
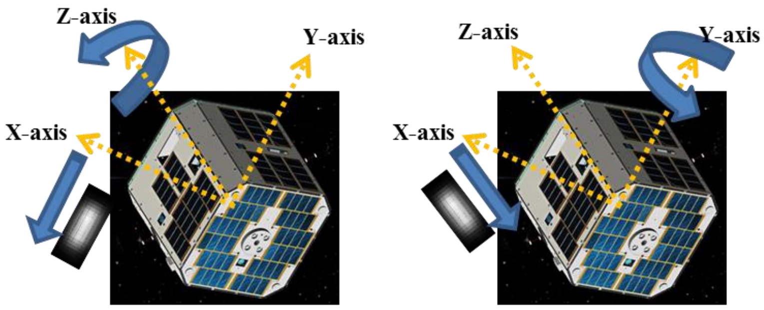
Precise spin rate estimation

- Spin rate estimation using mission telescope
  - Each star image is picked up and extracted from a view field of mission telescope



  - blur of a star image is caused by satellite spin rate



Satellite spin rate is estimated from the star images

Assessing the blur of the images

Calculate Line Spread Function (LSF) for each axis from the luminosity of a star image

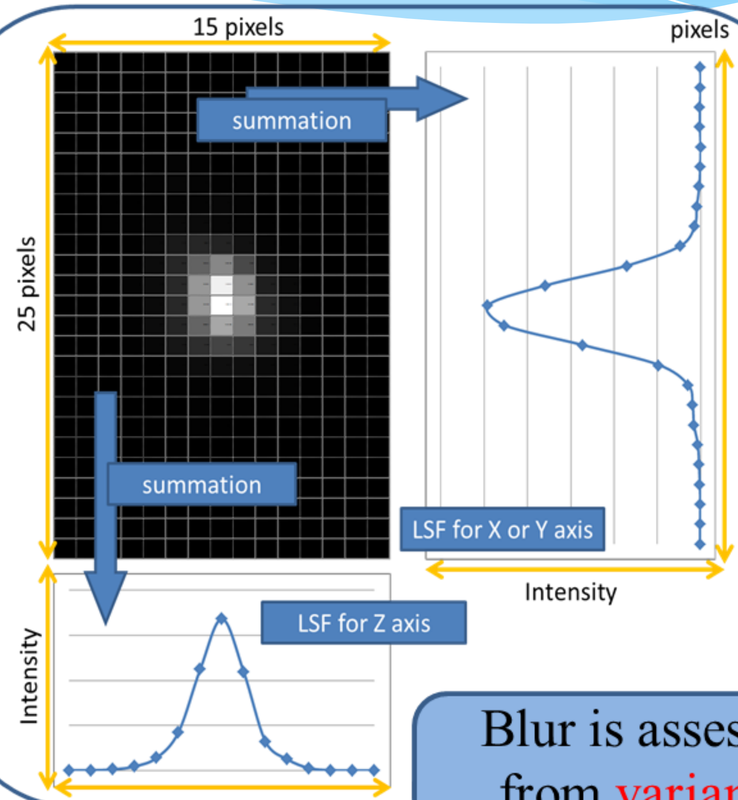
$$LSF_x(x) = \left(\sum_{y=0}^{25} (\mathbf{luminacity}(x, y))\right)$$

$$LSF_y(x) = \left(\sum_{x=0}^{15} (\mathbf{luminacity}(x, y))\right)$$

Compute variance of LSF

$$\sigma^2 = \left(\sum_{x=0}^{Max} (x^2 LSF(x))\right) - \mu^2$$

$$\mu = \sum_{x=0}^{Max} (xLSF(x))$$

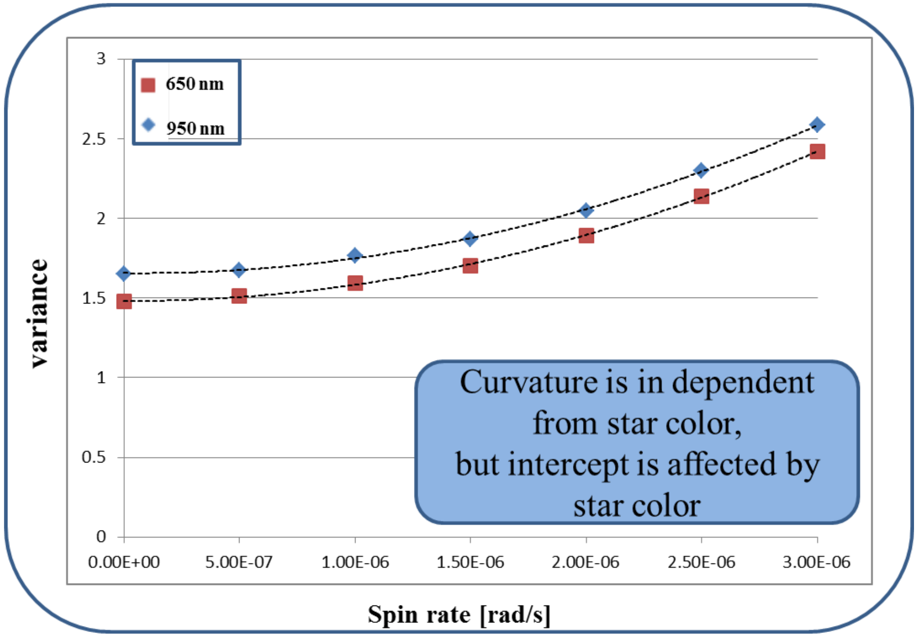


Blur is assessed from variance of the LSF

Variance - spin rate relationship

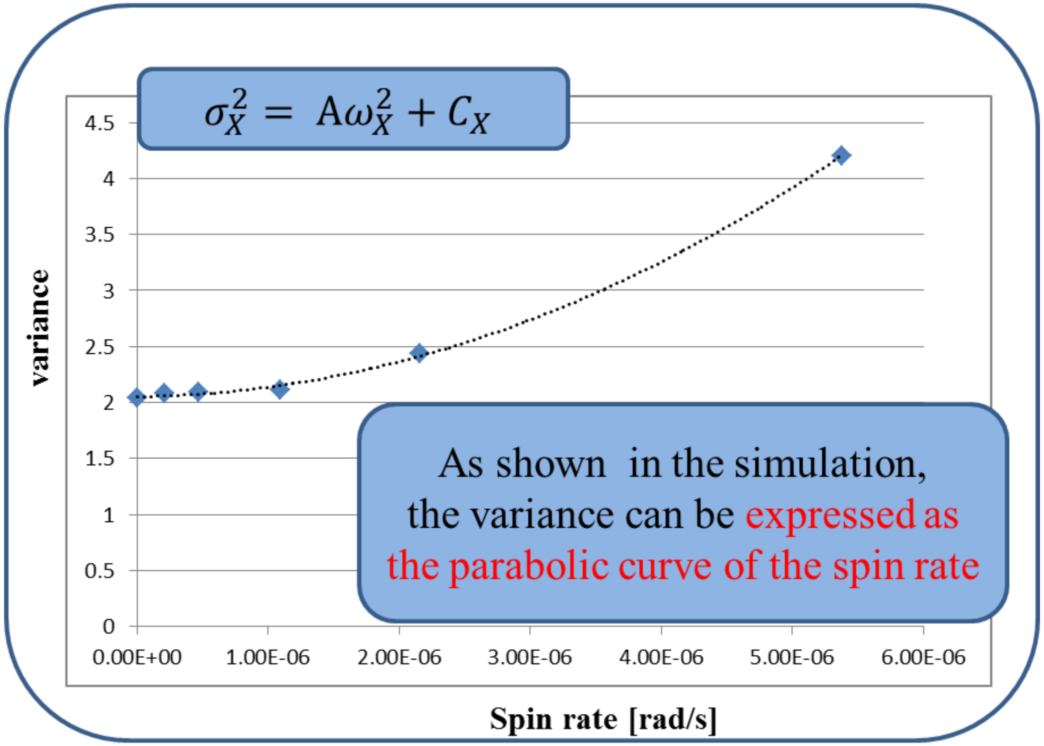
- Relationship between the variance and satellite spin rate
  - Simulation results shows the variety is parabolic curve of the spin rate
  - $\sigma^2 = A\omega^2 + C$
    - A : constant optic parameter
    - C : variable of wave length

The spin rate can be calculated from the variety



Verification using FM telescope

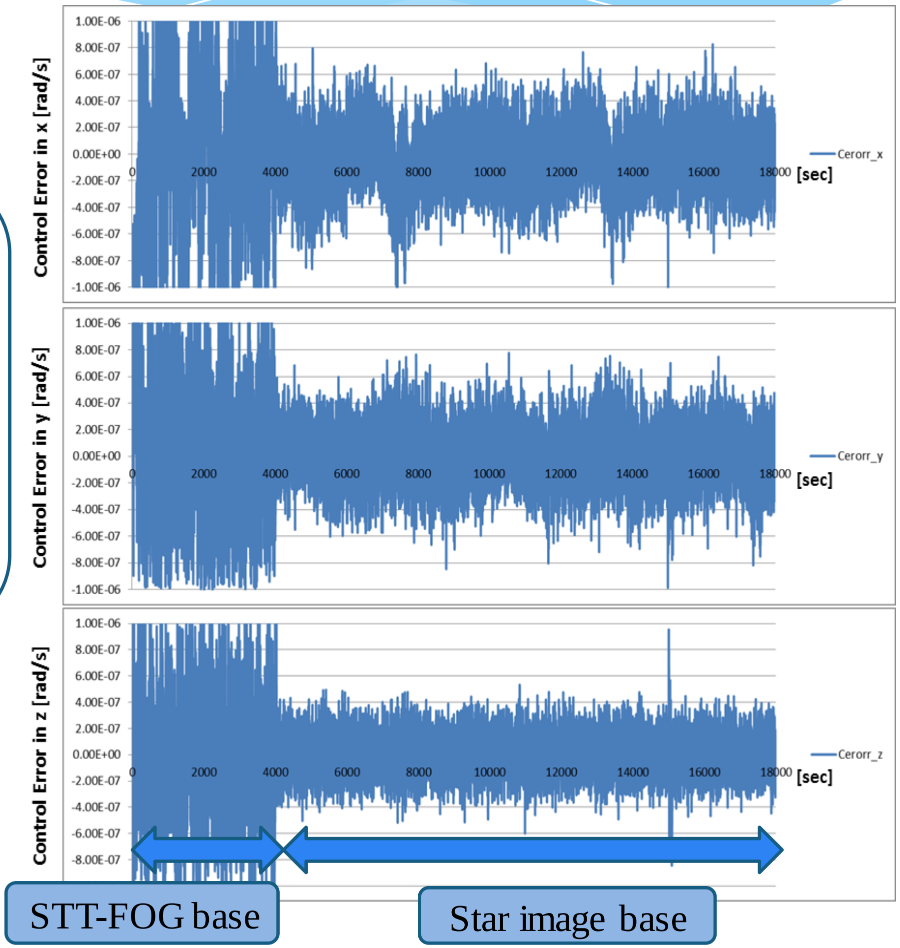
- Experimental results
  - Variances are calculated from star images obtained from FM telescope
    - As light source, LED is utilized
  - Difference in the value of the variance at $\omega = 0$ comes from the size of the light sources



Verification examination with SCLT

* Verification with SCLT
  * After 4000 sec:
    spin rate is estimated with the star images
  * Before 4000 sec:
    spin rate is measured with the combination of STT and FOG

Star image based estimation is more accurate than conventional method



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Conclusion

* Propose Two attitude control methods for NJ
  * Magnetic disturbance compensation
    * RMM suppression with satellite design and feedback/feedfoward control

→ RMM is suppressed to hundredth part of original value

  * Precise spin rate estimation
    * Spin rate estimation with star images from mission telescope

→ Estimation accuracy is adequate for the NJ mission

* These methods are useful to small satellites for precise attitude control

Thank you for listening

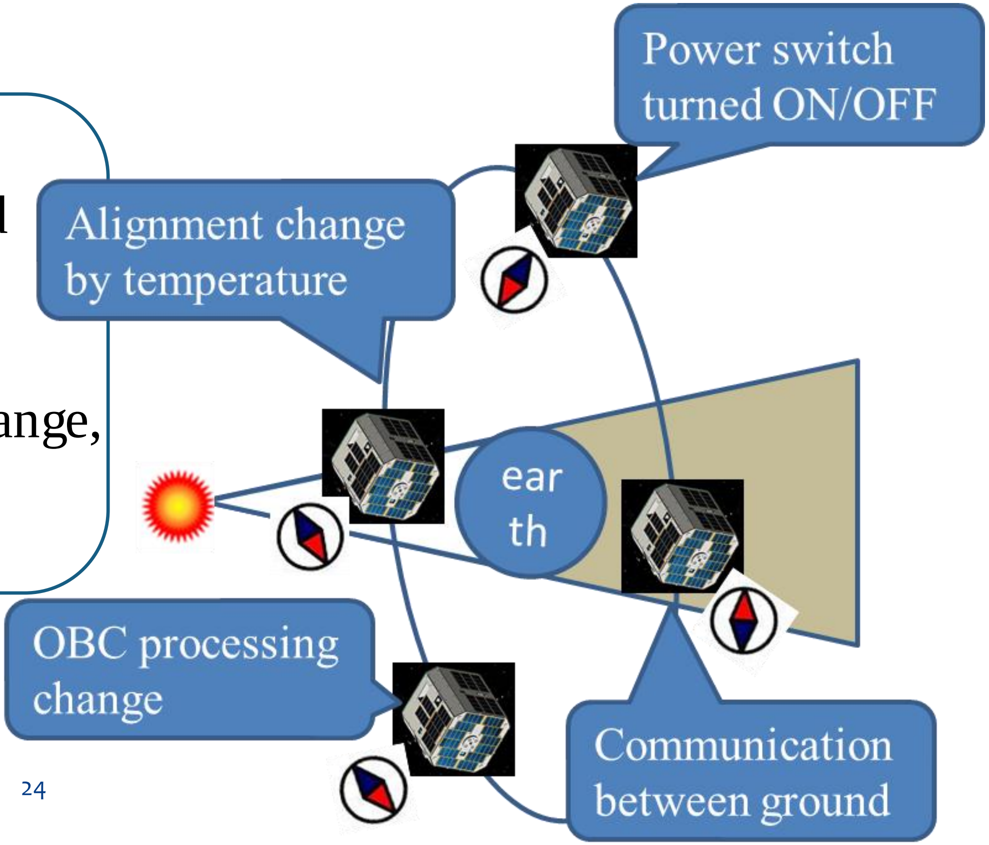
Appendix

Time-variable RMM

* RMM are time-variable
  * Several causes
    * Alignment change caused by orbit environment
    * Current loop change caused by power state change, OBC processing change

    …etc.

Need to deal flexibly with each frequency



Star color compensation

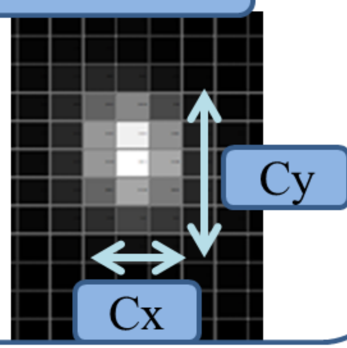
* Two additional relationships to solve the star color issue

Aspect ratio of a star image at $\omega = 0$

$$C_y = RC_x$$

R: constant optic parameter

Independent from star colors



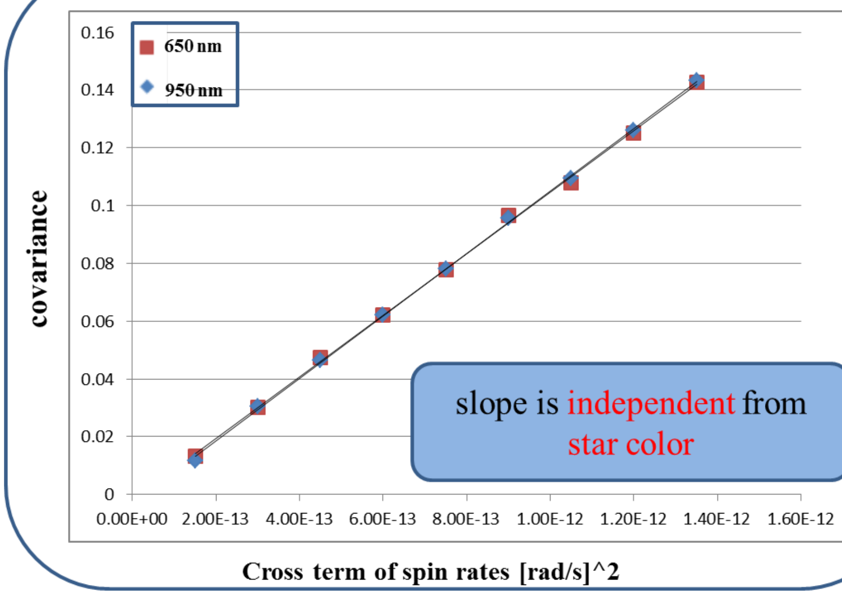
Covariance of a star image

$$Cov = \sum_{x=0}^{15} \sum_{y=0}^{25} \left(xy\left(luminacity(x,y)\right)\right) - \mu_x \mu_y$$

$$Cov = L\omega_x\omega_z$$

L: constant optic parameter

Independent from star colors



Four equations and Four parameters can be obtained from a star image

Verification using FM telescope

- Experiment using flight model (FM) of telescope
  - Verify the relationship between the spin rate and variety
  - Utilizing TDI motion instead of the satellite motion
    - Signals on the CCD are transported to the neighbor CCD by a definite time span (TDI rate)
    - The TDI rate is adjustable

Blurring of the star images can be simulated by adjusting exposure span of the light source