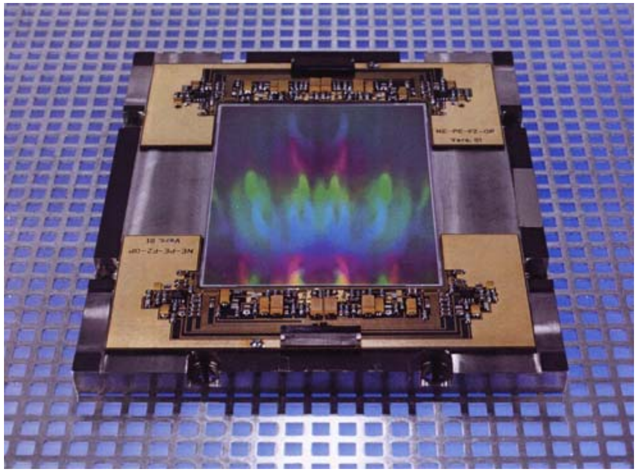
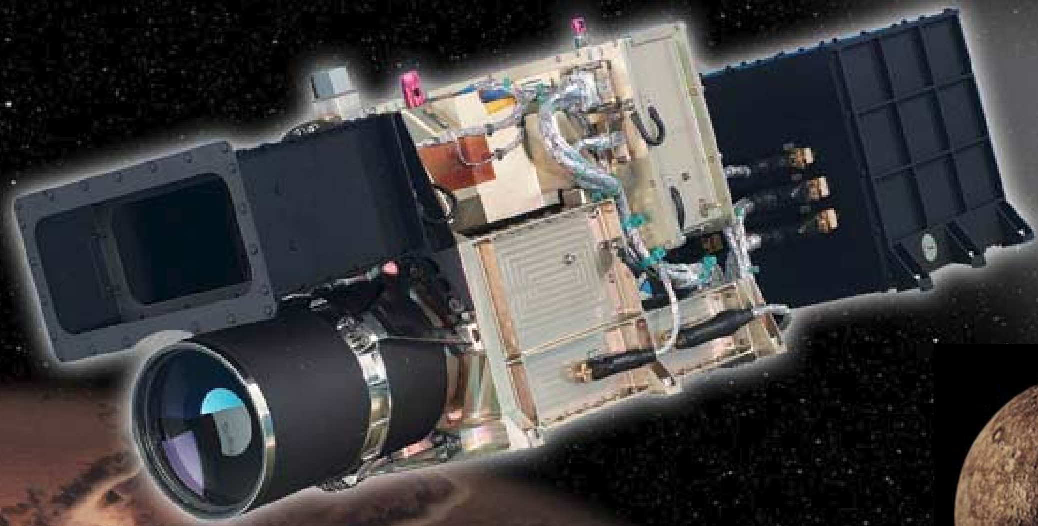


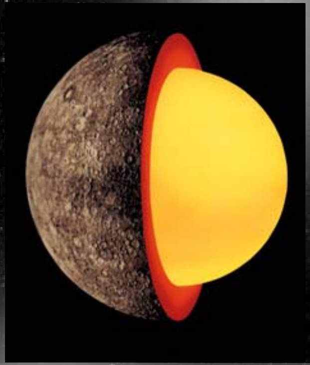
# *Selecting an image sensor for the EJSM VIS/NIR camera systems*

*presented by*

*Harald Michaelis (DLR-PF)*

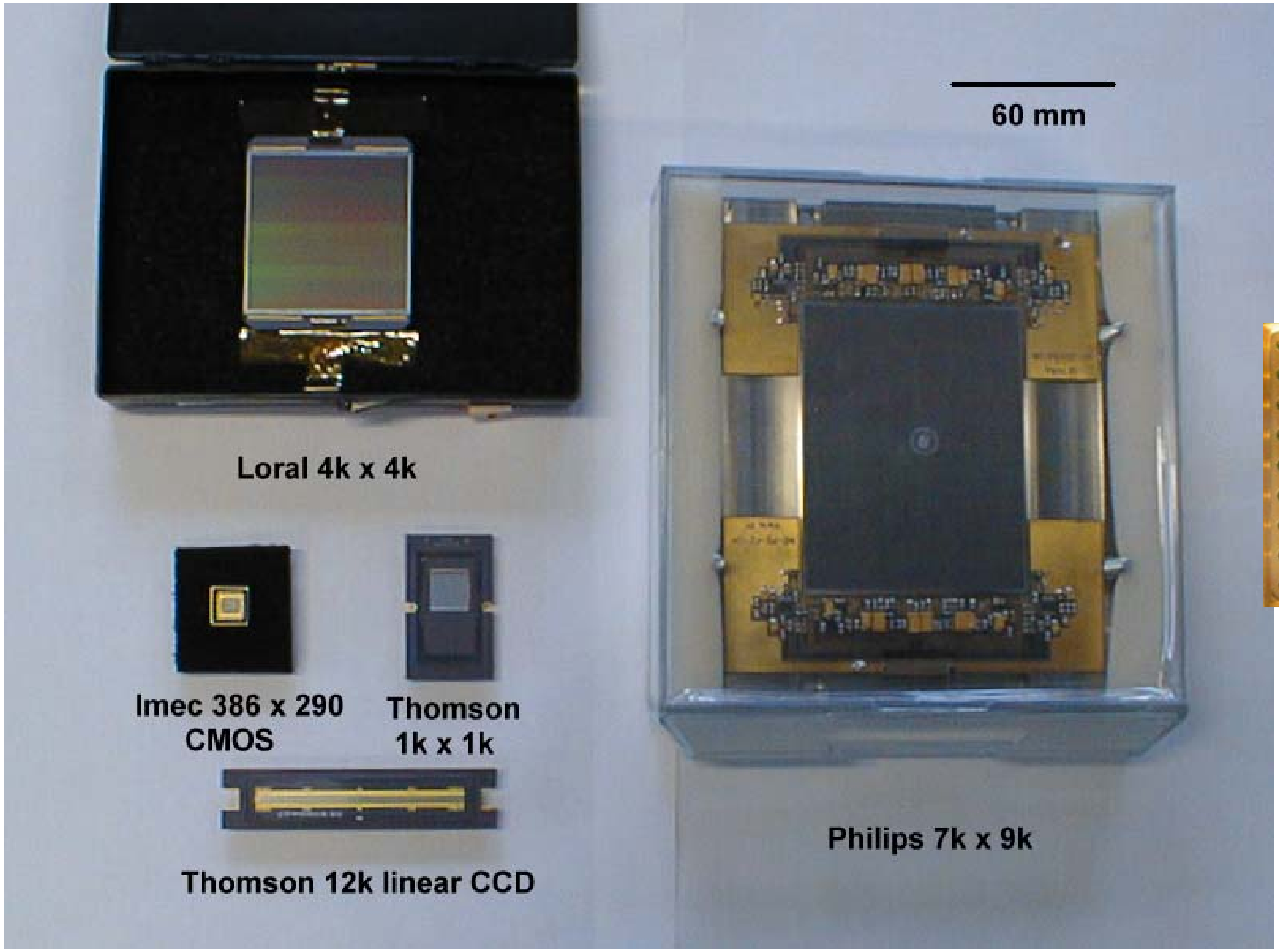
# What for a detector / sensor we shall chose for EJSM?

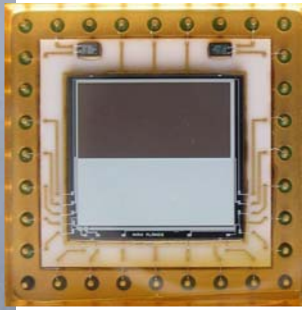




Institut WP - Abteilung Sensortechnologie

# Used Linear CCD, CCD Arrays and CMOS Detectors at DLR



Cassini-Huygens- DISR
MPS; 512x512

## Contents

- Introduction
- **General performance requirements**
- Environment
- **Draft analysis and estimations**
- The current baseline **sensor candidates**
- Alternatives
- Conclusions and outlook

# Introduction

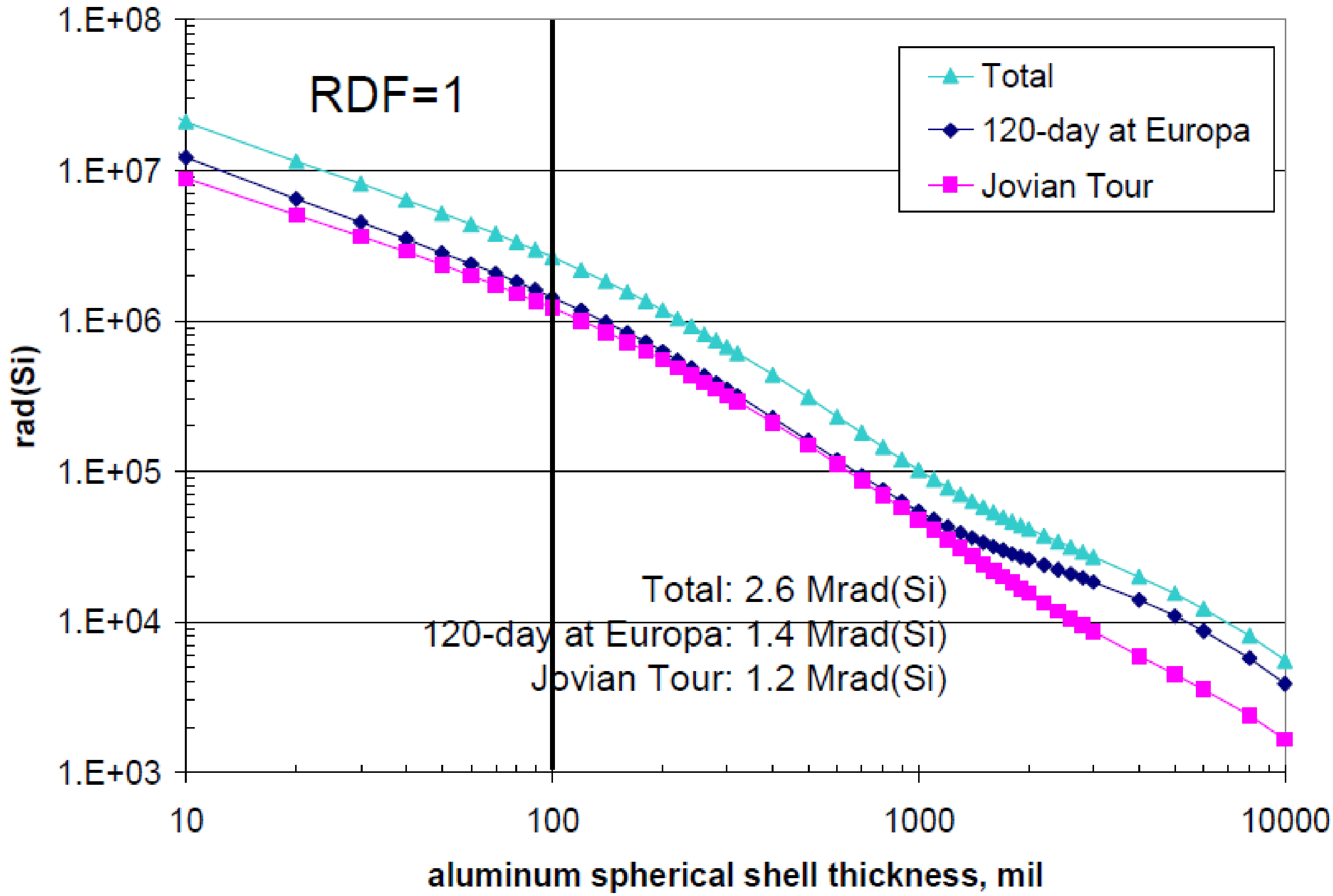
- What are the performance requirements for the **high resolution camera**
- What is the radiation environment and the resulting effects on the detector performance
- What are the current detector- candidates and what for a performance they provide

# *Image sensor for the EJSM VIS/NIR camera systems*

## General performance requirements (HRC)

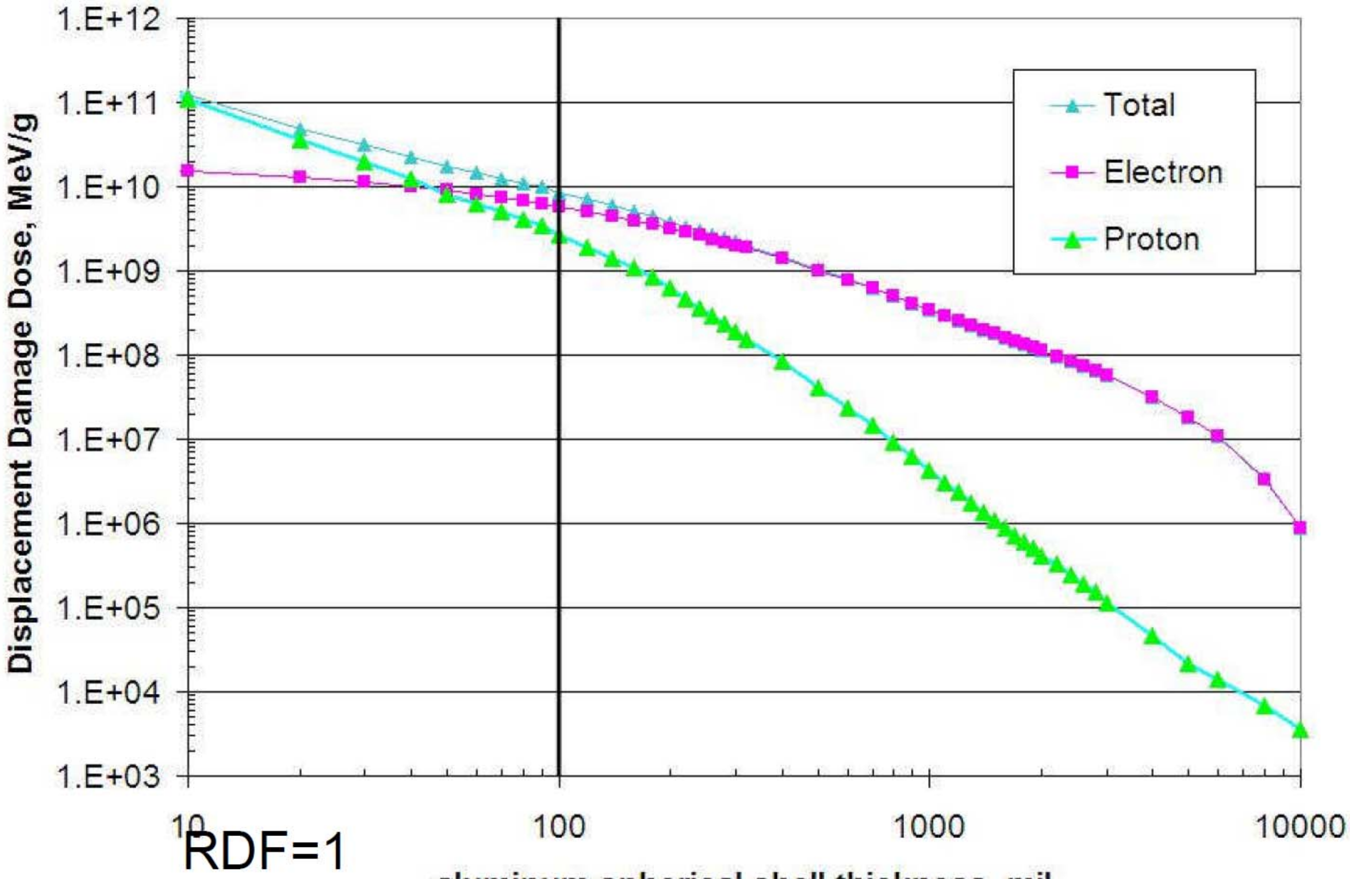
- **Resolution (IFOV): 1m/px…5m** @ 200km
- swath width: ~1km …10km) → >1000px
- Spectral range (channels): 350nm …1050nm; filter channels: PAN, TBD
- SNR: ~100
- (mapping capability)

# EE2007 Mission Dose-Depth Curve by Mission Segment



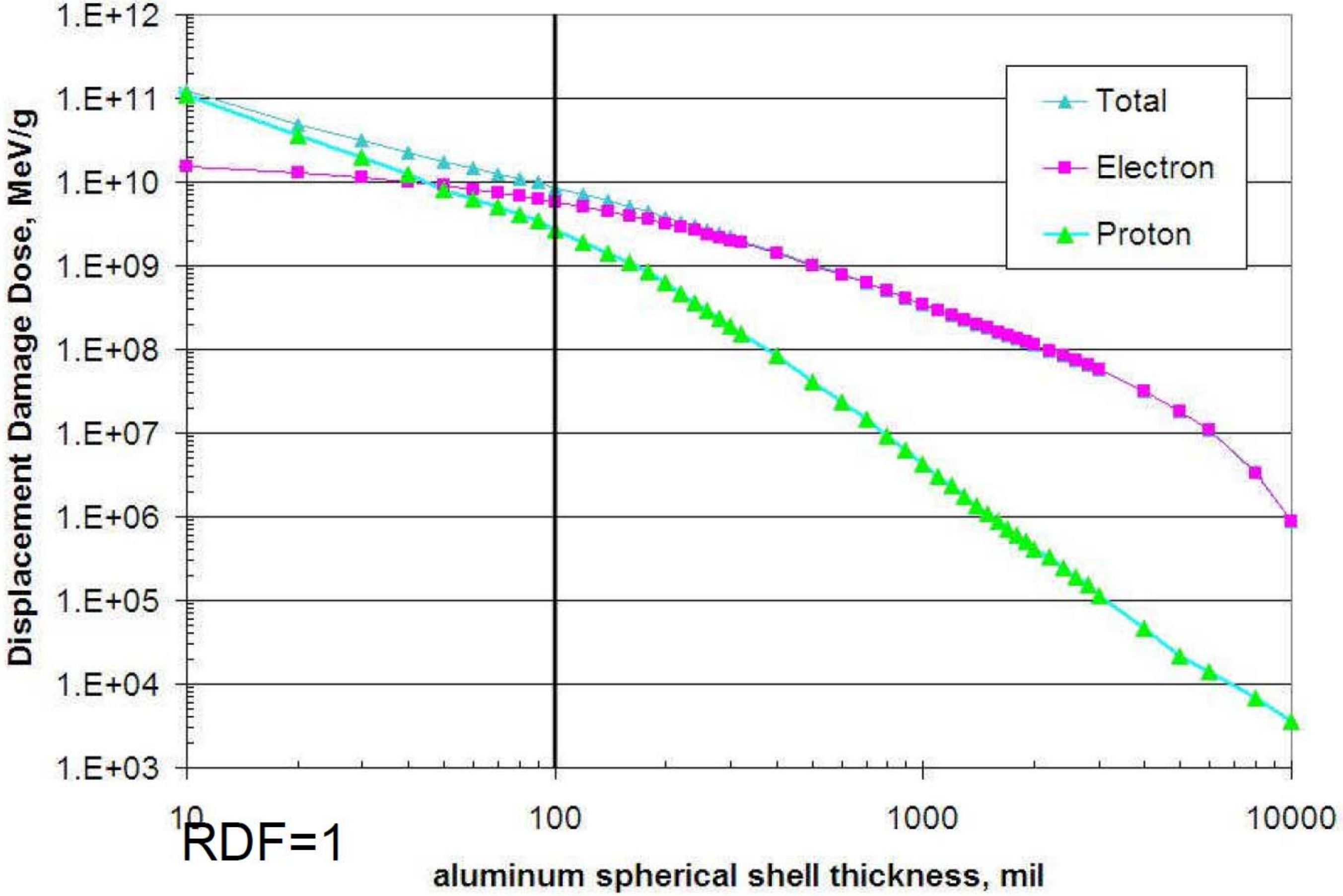

**- Copy from presentation 'Characterization of Radiation Environments- Europa Orbiter'; Insoo Jun; June 2008; JPL**

# EE2007 Displacement Damage Dose [2]




**- Copy from presentation 'Characterization of Radiation Environments- Europa Orbiter'; Insoo Jun; June 2008; JPL**

# EE2007 Displacement Damage Dose [2]




**- This shows the contribution of different particle species to the damage dose. As shown, the electron is the dominant contributor to the damage dose. -**

## Radiation Environment – Europa / Ganymed

- radiation belt with 100KeV…50MeV protons and electrons

- deep penetrating electrons cause high TID

~1MRad(Si) @ 5mm - JEO
~0.1MRad(Si) @ 5mm – JGO

-High energetic particles (ions, protons, neutrons, $e^-$) cause DDD

~1.3 $10^{08}$ MeV/g (behind 1cm Ta shielding - JEO)
*~3 $10^{08}$ MeV/g (behind 1cm Al shielding – JGO)*

## Radiation effects on the detector and impact on instrument performance

- Increase of dark current and dark current shot noise
- Hot spots ↑; transients↑ (dark spikes)
- Decrease of CTE (CCDs)
- Degradation of QE
- Latch up effects (CMOS)

→ Big impact on noise and signal level
→ **SNR will suffer**
→ Danger of total damage

# *Image sensor for the EJSM VIS/NIR camera systems*

## Draft analysis and estimations

' What is the **signal level and the SNR** that I get with the detector'?

→

Impact on sensor **performance requirements** and sensor **design architecture**

*Image sensor for the EJSM VIS/NIR camera systems*

## Draft analysis and estimations

### 1. Assumptions

- IFOV: **1m** and 5m/px @200km
- **10µm** pixel size

→ Focal length: ~2m…0.4m

- aperture: 0.1…0.2m (max.; because of mass)

→ F#: 2…10

- vg: ~1870m/s ; Tdwell: 0.5…2.5ms; **Tint: ¼ Tdwell**
- Albedo: 0.43
- Spectral range: PAN (550nm…800nm); **FWHM: 250nm**
- QE: ~80%; optical efficiency: 0,8
- Detector noise: 2, 10, 100e rms

# *Image sensor for the EJSM VIS/NIR camera systems*

## Draft signal analysis and SNR estimations

- 1. Signal level @ 1m/px and 5m/px

| F#: | 2 | 4 | 10 |
|---|---|---|---|
| signal[ke] @ **1m** | 11 | 2,8 | 0,4 |
| @ **5m** | 56 | 14 | 2,3 |

Colour code legend

**High**
**+++**

**Low**
**---**

# Image sensor for the EJSM VIS/NIR camera systems

## Draft analysis and estimations

1. SNR estimations @ 1m

| F# /: Noise [e rms] | 2 | 4 | 10 |
|---|---|---|---|
| 2 | **106** | 53 | 21 |
| 10 | **105** | 52 | 19 |
| 100 | 77 | 25 | 4 |

# *Image sensor for the EJSM VIS/NIR camera systems*

## Draft analysis and estimations

1. SNR estimations @ 5m

| F# /:<br>Noise [e rms] | 2 | 4 | 10 |
|---|---|---|---|
| 2 | **237** | 118 | 47 |
| 10 | **237** | 118 | 46 |
| 100 | 218 | 90 | 20 |

# *Image sensor for the EJSM VIS/NIR camera systems*

## Draft analysis and estimations – First Conclusions

If **1m resolution** is required then

→a **very low noise sensor** with high QE and **fast optics (~F/2)**

or

## *Image sensor for the EJSM VIS/NIR camera systems*

**Draft analysis and estimations – First Conclusions**

If **5m resolution** is sufficient then

→**a** medium fast optics (~F/4)

→ Readout **noise sensor** of **≤50e** rms is sufficient

# *Image sensor for the EJSM VIS/NIR camera systems*

## SYMBIO-SYS and STAR1000 sensor characteristics

1. **'SYMBIO-SYS' (Data TBC)**

| | |
|---|---|
| Heritage | Bepi Colombo |
| Type | Si-PIN-CMOS (Hybrid) |
| Format and pixel size | 2kx2k; 10µm |
| QE | >80% |
| Noise [e rms] | <100 (TBC) |
| Radiation Tolerance | ~100 krad (TBC) |
| others | off-chip ADC;<br>global shutter, no TDI |

# *Image sensor for the EJSM VIS/NIR camera systems*

## SYMBIO-SYS and STAR1000 sensor characteristics

### 1. STAR 1000

| | |
|---|---|
| Heritage | ROKVISS,<br>many star trackers |
| Type | CMOS- APS |
| Format and pixel size | 1kx1k; 15µm |
| QE | ~30% |
| Noise [e rms]*<br>*: temporal readout noise | ~40e |
| Radiation Tolerance | >230 krad; |
| others | on-chip ADC;<br>**rolling shutter**, no TDI |

## Image sensor for the EJSM VIS/NIR camera systems

# HRC with STAR1000 sensor → instrument characteristics

| **Goal** | **SNR: >100** |
|---|---|
| Focal length needed: | 3m |
| F# | ~1.2 |
| Total aperture: | >2.5m |
| Mass*: | >500kg |
| Others: | *rolling shutter is not applicable* |
| | |

# *Image sensor for the EJSM VIS/NIR camera systems*

## HRC with 'SYMBIO-SYS' sensor → instrument characteristics

| | |
|---|---|
| **Goal** | **SNR: >100** |
| Focal length needed: | 2m |
| F# | ~2 (…4) |
| Total aperture: | ~50-100cm* |
| Mass**: | >100kg |
| Others: | |
| | *: depends on assumed detector noise level<br>**: 20cm telecopes:>10kg |

# *Image sensor for the EJSM VIS/NIR camera systems*

## Conclusion II (1m- HRC)

- STAR1000 **is NOT applicable** *for 1m- HRC*

- SYMBIO-SYS: **appears as difficult or not applicable** (only applicable with trade-offs - FWHM, $T_{int}$, IFOV);

→ It would be much better to have a **TDI- sensor** architecture and (high QE, low noise-)

# *Image sensor for the EJSM VIS/NIR camera systems*

## Conclusion II - continued

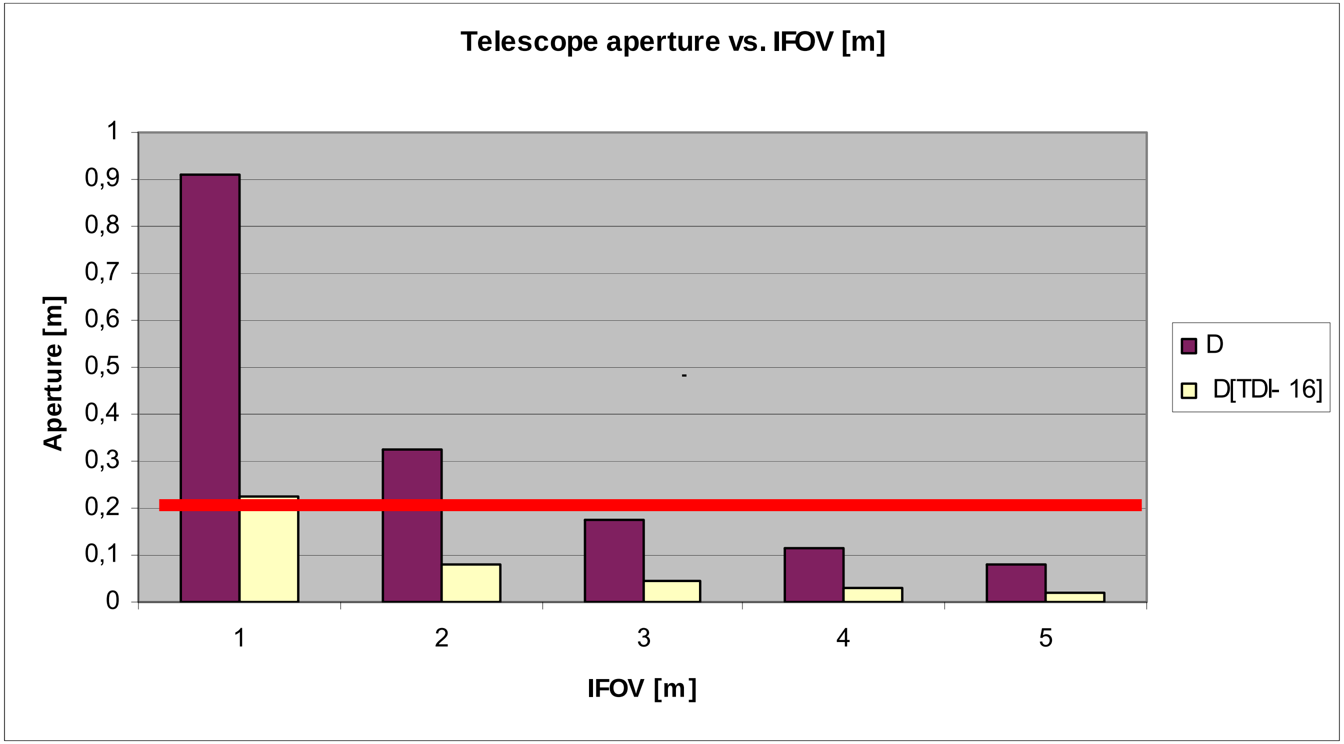
- Either we can relax the 1m- resolution requirement

or

- we have to apply **TDI** or motion compensation

# *Image sensor for the EJSM VIS/NIR camera systems*

## TDI and its effect on needed telescope aperture (SNR=100)

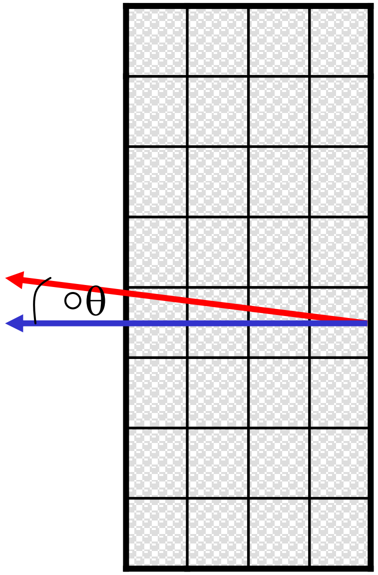


## Conclusion II - continued

TDI or motion compensation requires that the S/C motion vector is parallel to the pixel (charge- transport-) vector

$\theta \leq 0.5/n_{TDI}$

$n_{TDI}=8\ldots64$




$f_{readout} > n_{pxl}/T_{dwell})$

$f_{readout}$ : detector readout frequency

$n_{pxl}$: number of pixel per line

# *Image sensor for the EJSM VIS/NIR camera systems*

## CCD vs CIS –few words

**- Both are silicon detectors with capacitors and transistor(s) -**

| CCDs |
|---|
| Capacitors are the dominant components |
| Ionizing radiation → oxid charging→flatband voltage shift |
| DDD have big impact on CTE |
| Insensitive to SE-latch-up |
| High QE is standard |
| Low noise at low readout rates |
| TDI is straightforward |
| High performance customized design and manufacturing is rather easy |

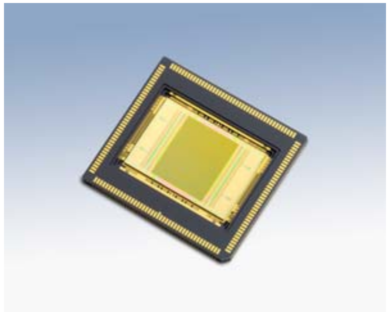
## *Image sensor for the EJSM VIS/NIR camera systems*

# CCD vs CIS –few words

| CIS |
|---|
| transistors are the dominant components |
| Complex electronics can be integrated in customized designs |
| No CTE issue |
| Sensitive to SE-latch-up |
| High QE only for customized components |
| Low noise event at high readout rates is feasible |
| TDI is feasible but not straightforward |
| High performance customized design and manufacturing is very difficult |

## *Image sensor for the EJSM VIS/NIR camera systems*

# CIS – some additional remarks (s-CMOS)



☺ High performance science CMOS- sensors are now reality

☺ QE: ~90%

☺ Readout noise: <2 e rms @ readout frequency of 30fps ( 150MHz!!!)

☺ on-chip readout electronics and ADCs

☹ 'ESA-Science' is a too small customer for the big CMOS-players

## Conclusions and further study actions

- (Re-)definition of HRC resolution requirement (IFOV) + trade-offs
- If 1m: Investigate motion compensation vs. TDI
- Analyze CMOS- TDI capabilities and performance
- Comparison of CCD-TDI with CMOS- TDI
- Analyze radiation environment
- Analyze (and test) CCD radiation hardening options and limits
- Investigate procurement possibilities of a customized CIS (access to high performance CIS- process)

# Image sensor for the EJSM VIS/NIR camera systems

## Example: Focal Plate with two sensor types