Detector Developments for Space Astronomy at ESA

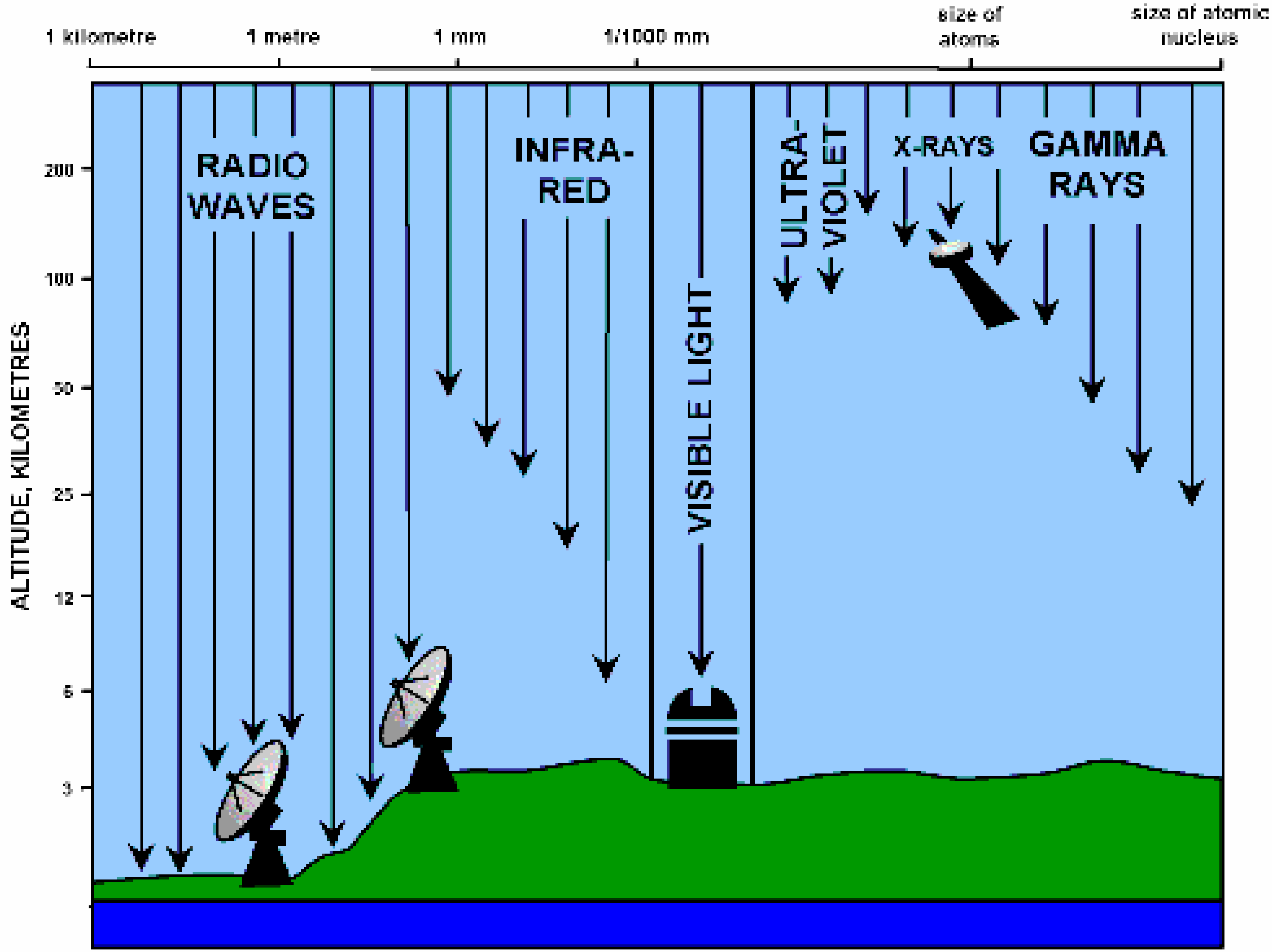
Advanced Technology and Mission Preparation
European Space Agency

12 Oct 09

Introduction

- Space astronomy may exploit different wavebands than ground based & detector requirements for very long and short wavelengths are briefly discussed.
- For traditional astronomy regimes, the challenges of observations in space include the radiation environment, the engineering constraints and development schedules.
- ESA Cosmic Visions 2015-2025 programme, Medium class missions are constrained by a launch date in the 2017-18 period, and a relatively low mass observatory.
- In this context review Plato and Euclid missions, and the detector solutions and developments for these optical /near-IR payloads

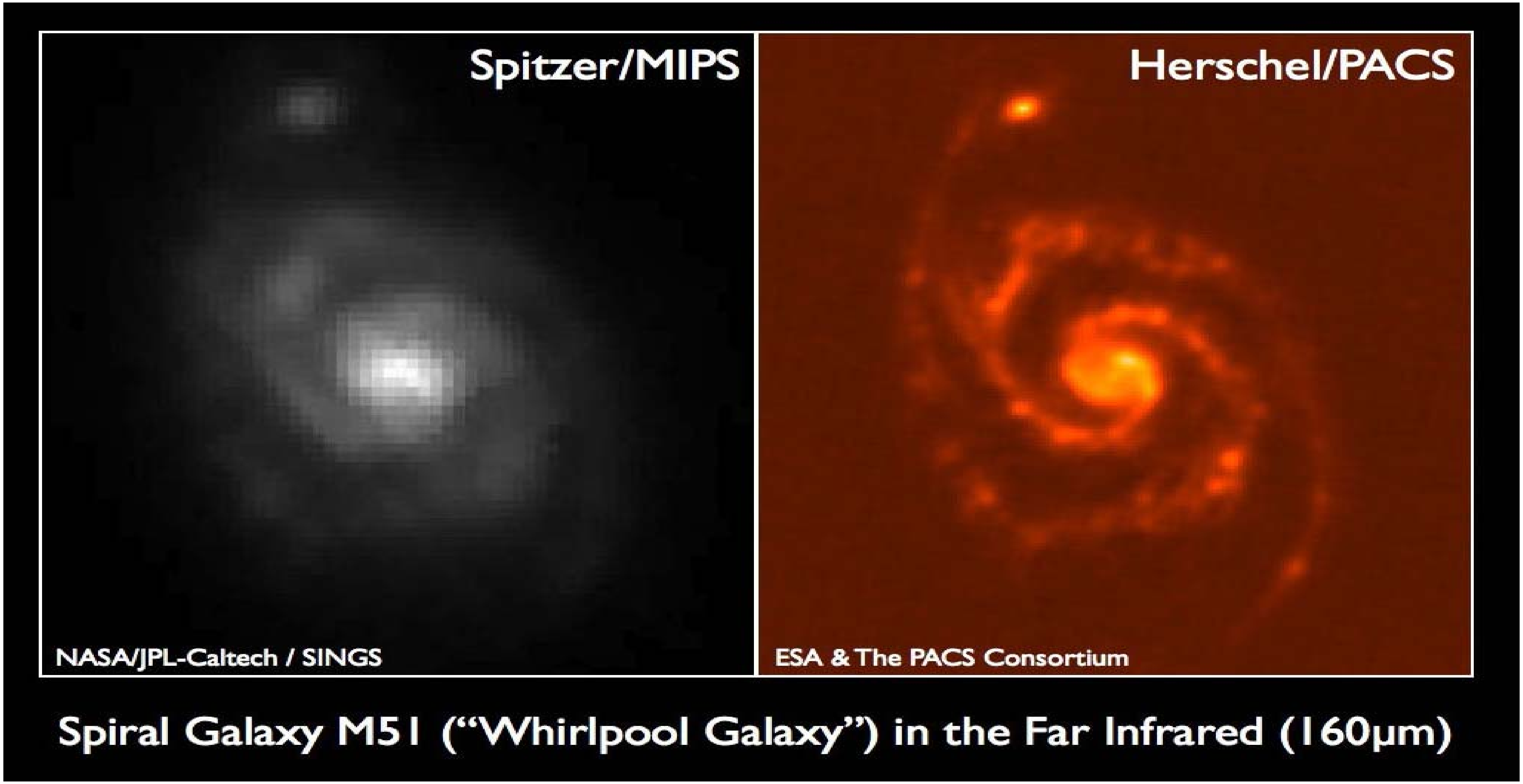
Wavelengths



Planck & Herschel

Launch 14 May

First Light

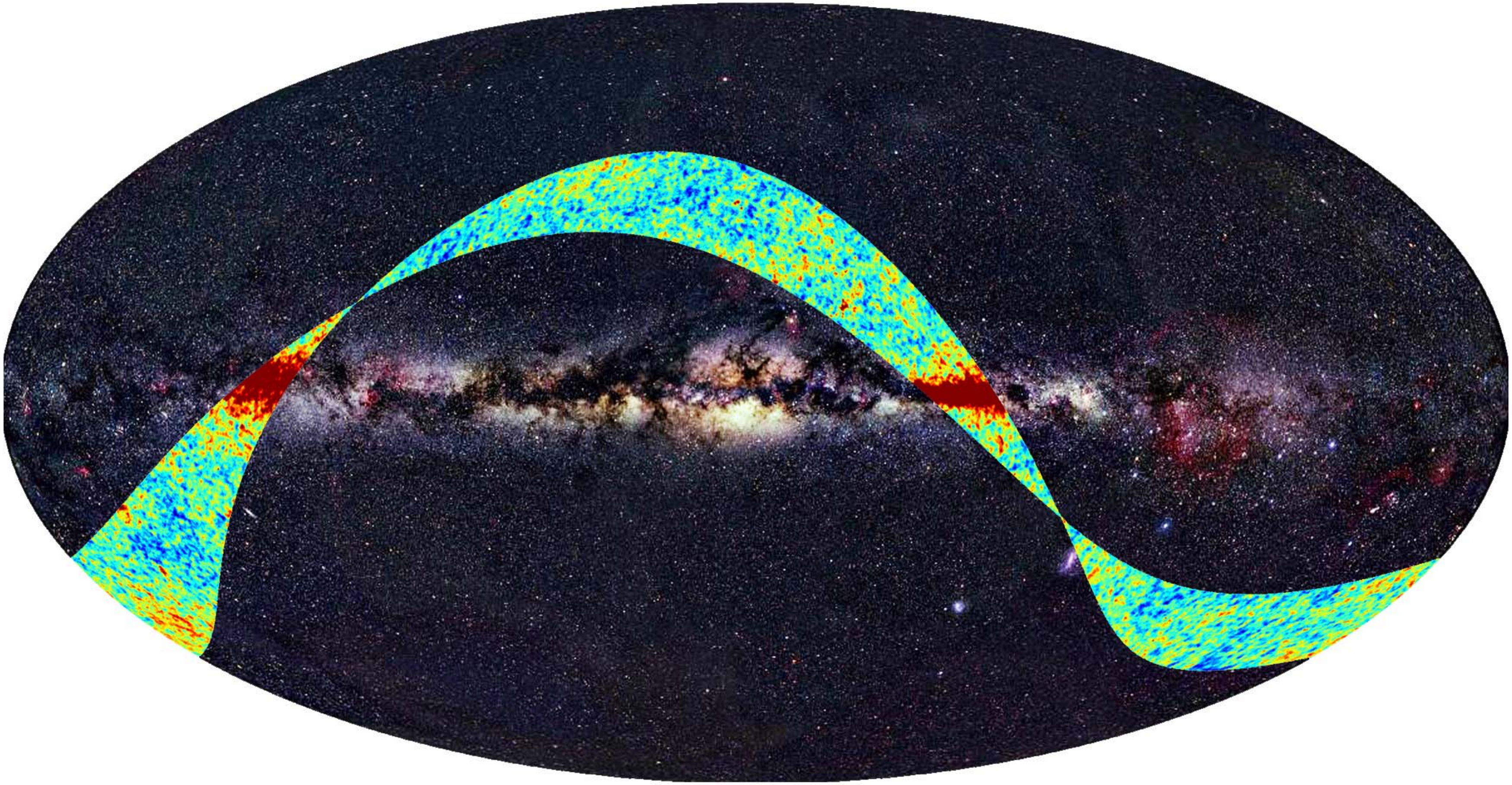

Spitzer/MIPS
Herschel/PACS
NASA/JPL-Caltech / SINGS
ESA & The PACS Consortium
Spiral Galaxy M51 ("Whirlpool Galaxy") in the Far Infrared (160µm)

IR Image

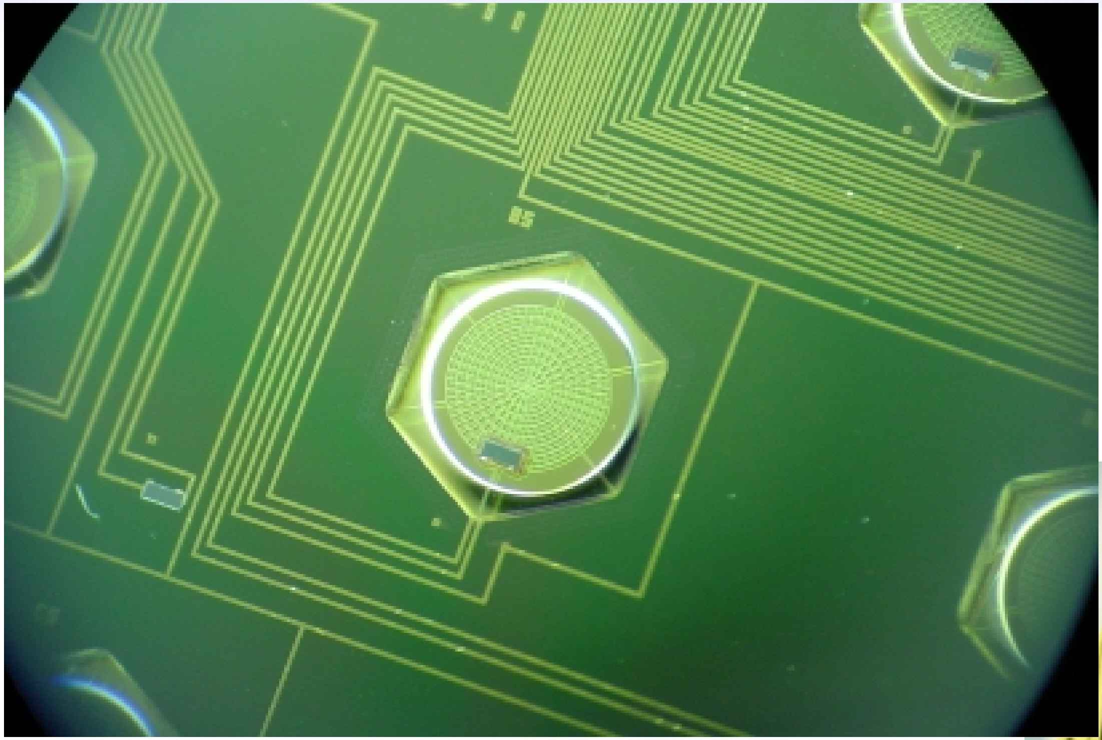
- **Five-colour IR image of a reservoir of cold gas in *Crux*. (~60° from GC, 2°x2°)**

  SPIRE and PACS images combined: blue= 70 μm and green= 160 μm emission, red is combination of emission from all three SPIRE bands at 250, 350 and 500 μm .

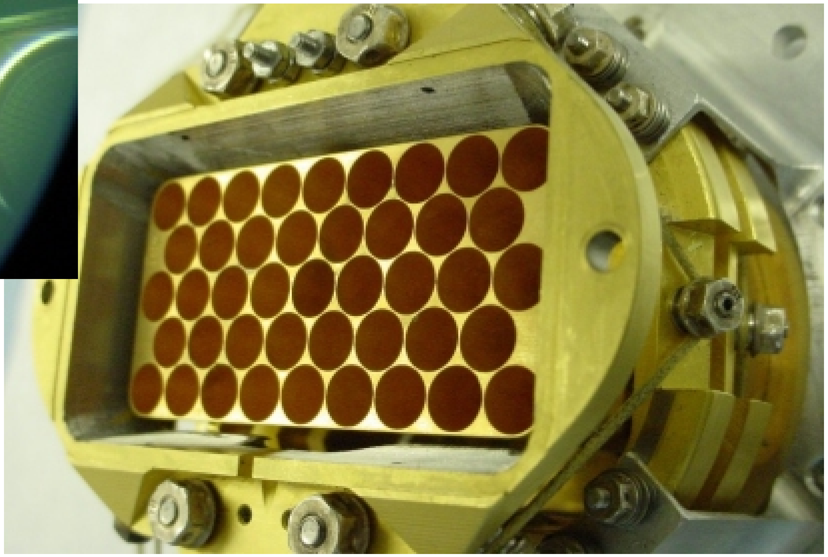
Planck first scans – 2 weeks



Spire Detectors



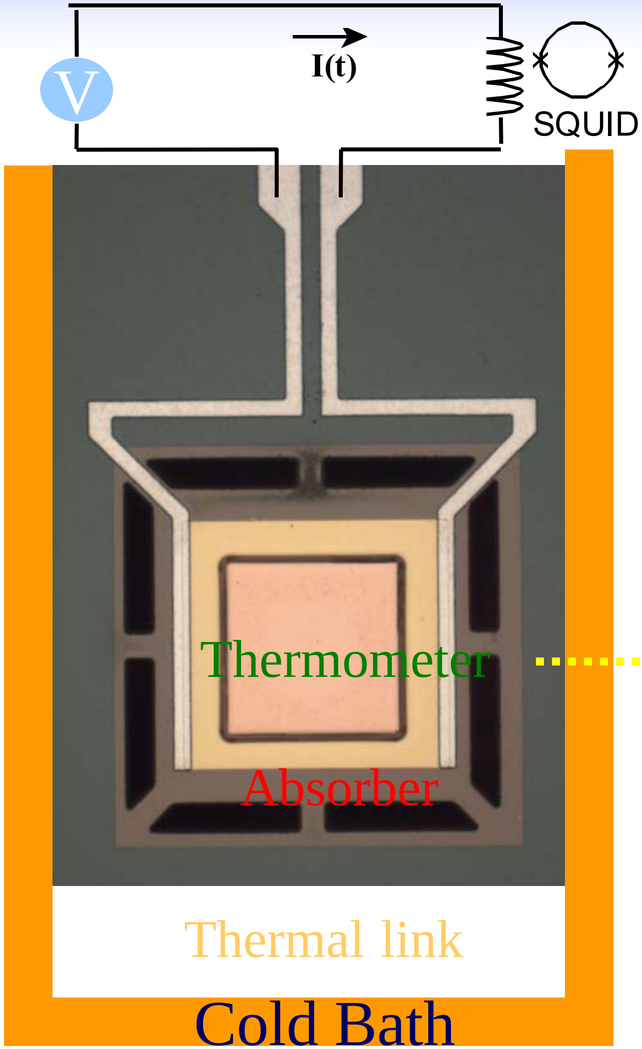
Far IR developments revolve around micro bolometers

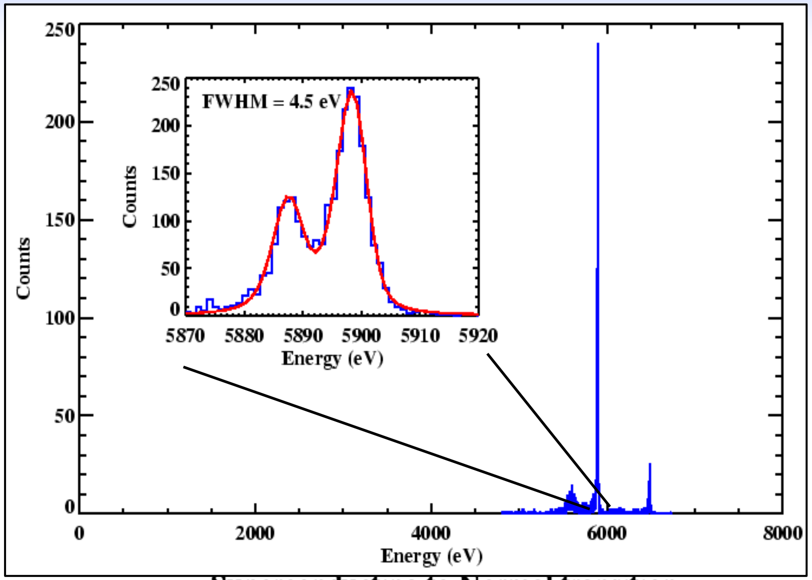


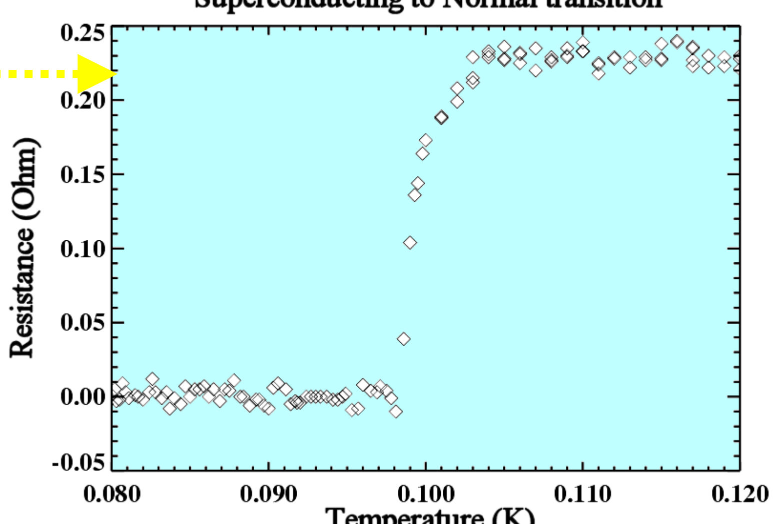
Challenge of cryogenics in space, leading to closed cycle coolers (ADR)

High Energy Bolometers

Similar technology for X-ray band





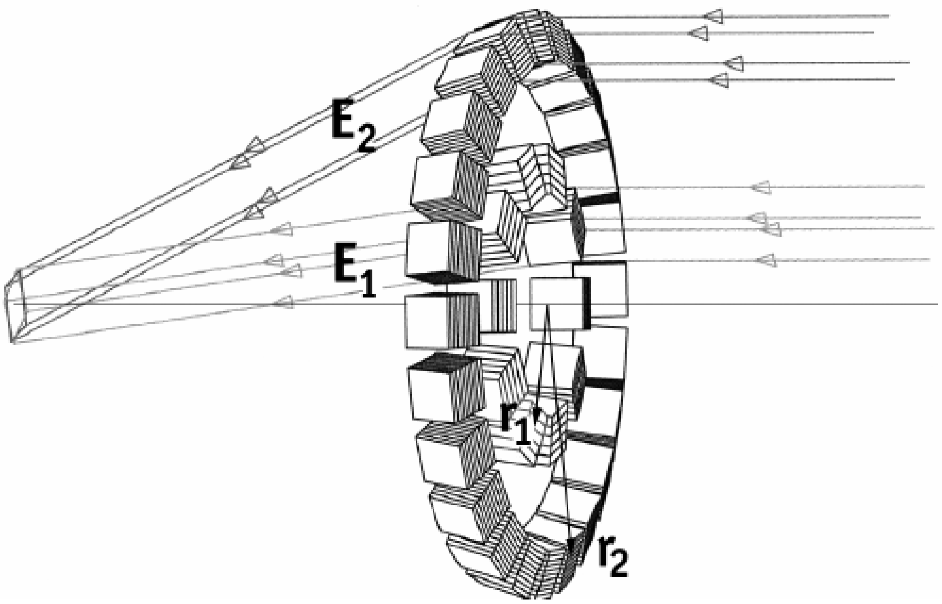


Single pixel calorimeter

Advanced Technology & Mission Preparation Division

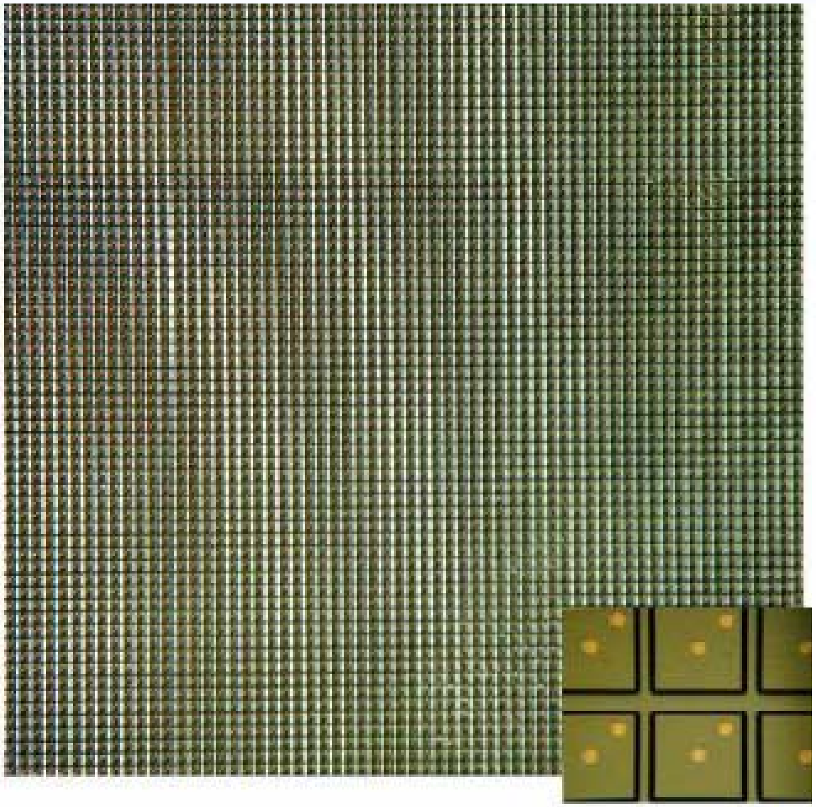
Gamma Ray focusing

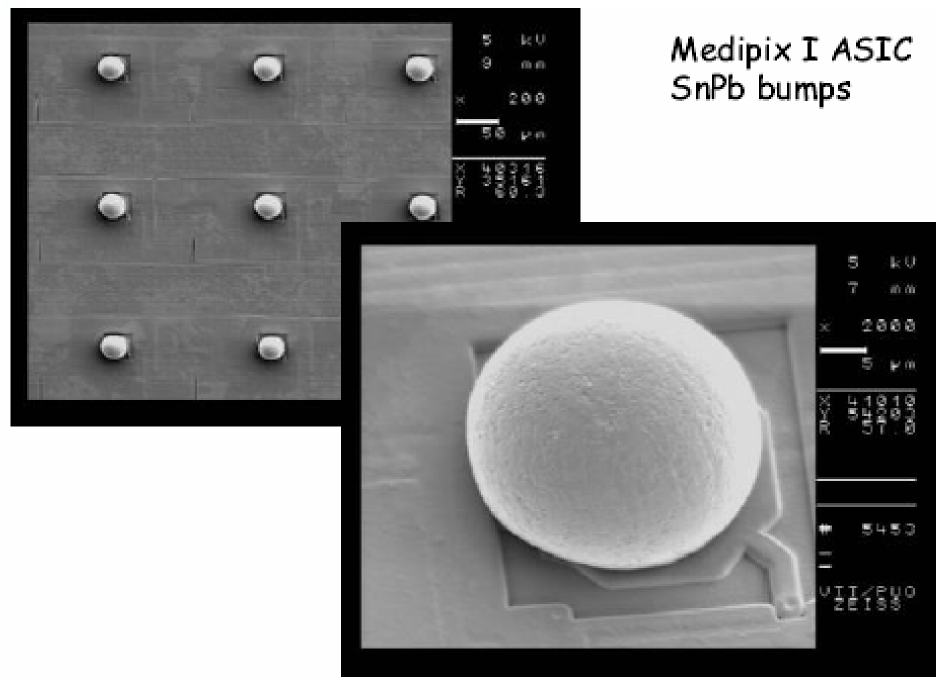
- Coded mask telescopes have only 50% open factor, and detectors must have frontal area equivalent to collecting area
- Large background could be decoupled by focussing advantage – but gamma ray focussing is not easy.
- Then pixellated detectors become interesting (CdZnTe, GaAs etc.)



- Tested out bump bonding with Medipix ASIC
- A back-thinned GaAs 64 x 64 pixel array with pixel size is 170 x 170 μm^2 and epi-layer thickness of ~150 microns.
- This ASIC comprises a CSA and shaper. Charge amplified and compared with a threshold for event counting
- Photomicrograph of reverse side of MEDIPIX ROIC prior to bonding with SnPb bumps (25 µm dia)
- Developing photon counting spectrally resolved analysing ASIC (use with any compound semiconductor arrays)

Medipix 1

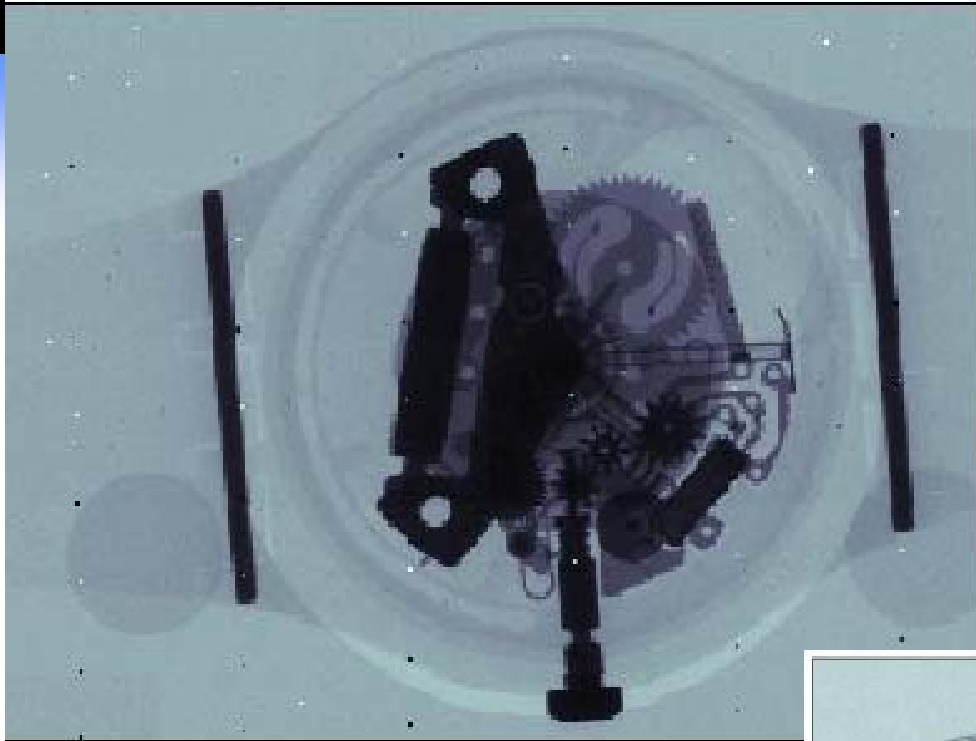


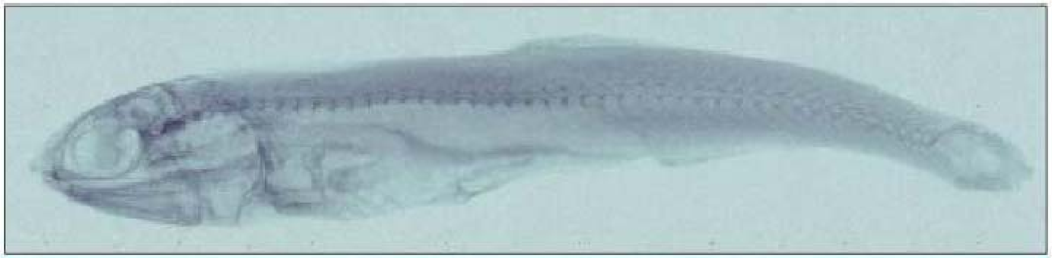


Medipix I ASIC
SnPb bumps

Imaging Performance

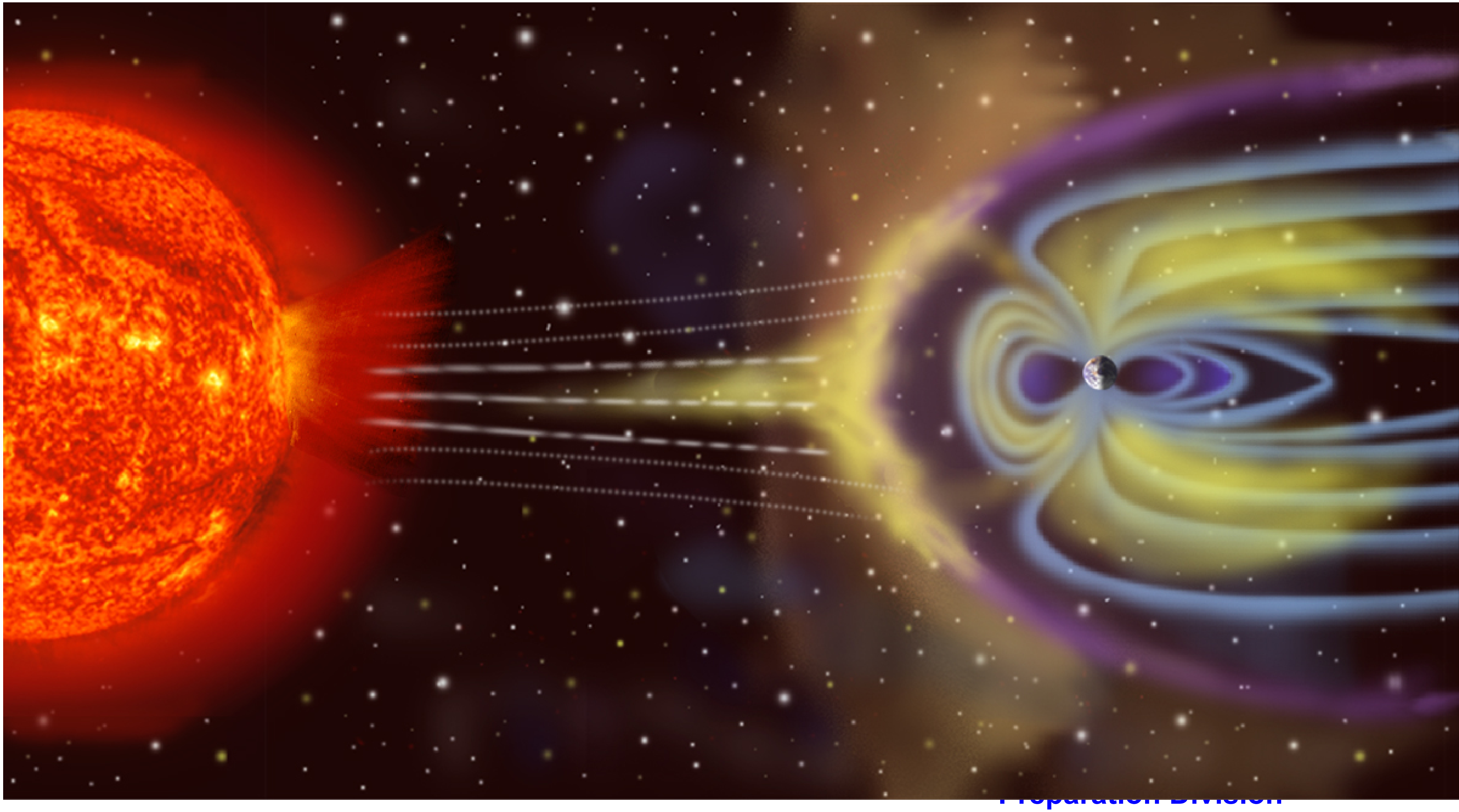
- The data were taken with a conventional X-ray tube using a tungsten target and a 2.5 mm Al filter.
- The objects were mounted on a sample holder and the detector on a precision $x - y$ stage.
- The detector was then scanned past the object in steps of 0.8 of the detector width using the so-called "move and tile" method.
- The resulting composite images have been flat-field corrected and a 3 x 3 median filter applied locally around defective pixels.





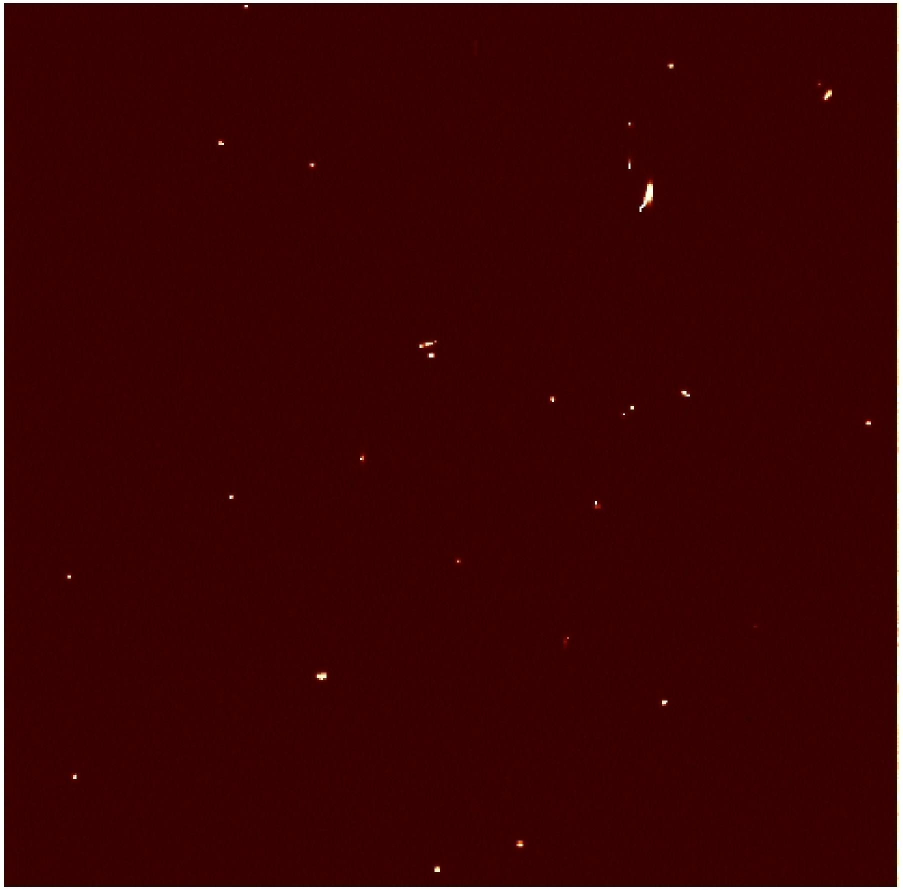

1 2 3 4 5 6

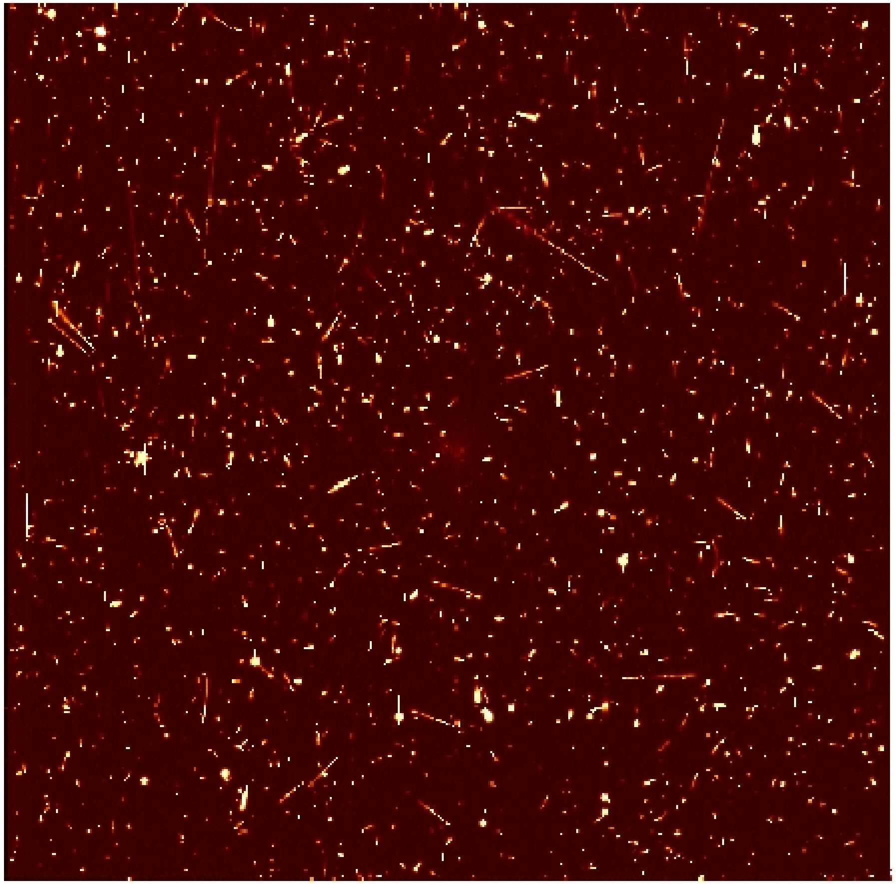
Environment



CCDs and Cosmic Rays

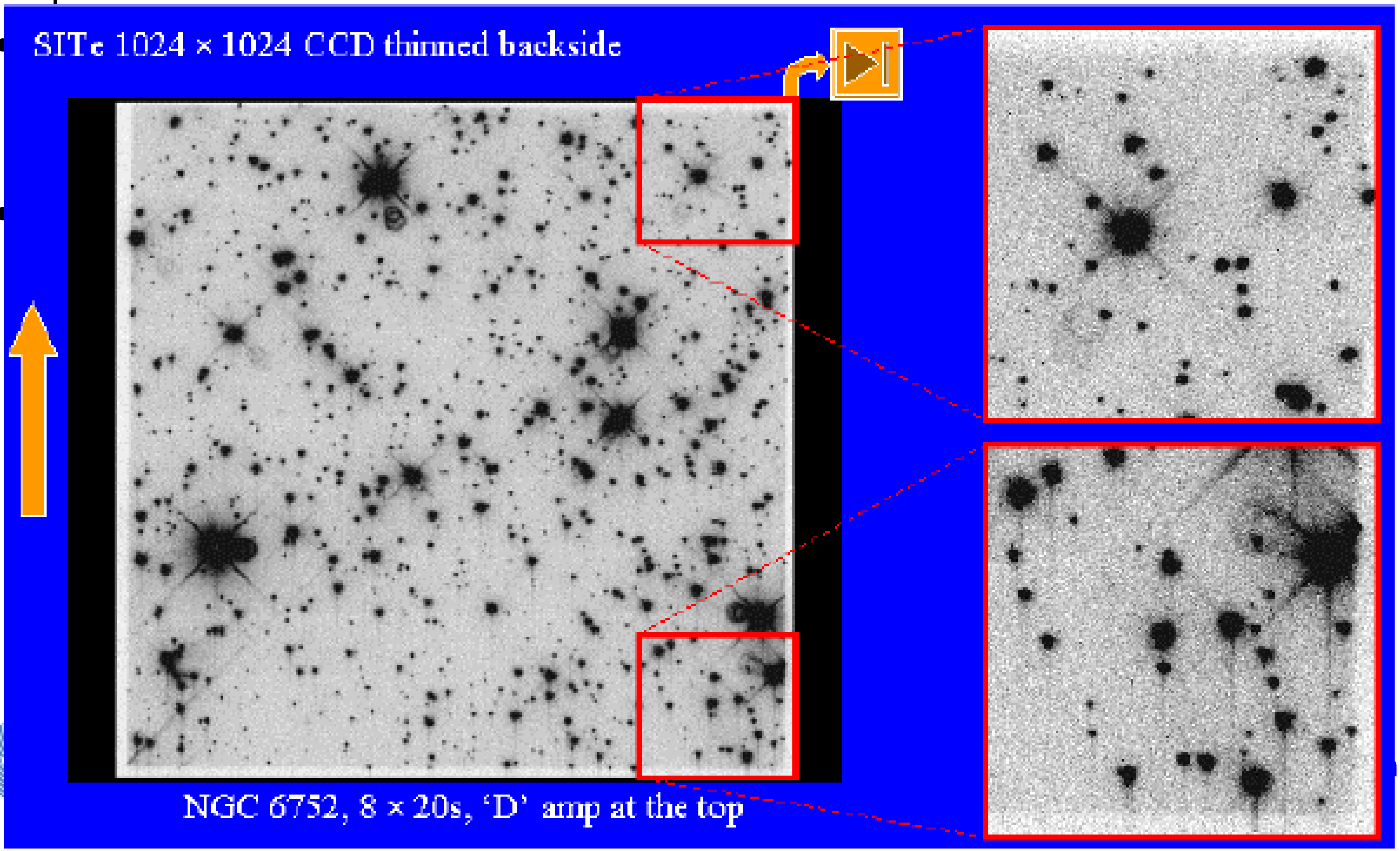
- Ground based – muons with rate varying with altitude
- In orbit – order magnitude higher in LEO, several times more again in interplanetary space





CCDs and Radiation Damage

- Early tests of ~krads Co60 showed no major ionising damage problems



Cosmic Visions 15 - 25

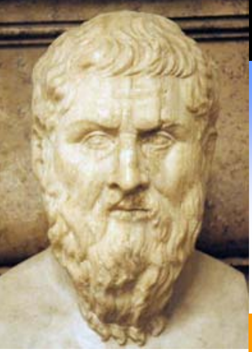
- ~50 proposals received in summer 2007. Classified as Medium (M = 400M€) or Large (L = 650M€)
- Internal review and pre-selection of a number of 'M' missions to go into assessment studies 2008-2009
- Plato (asteroseismology and planet finding), Cross Scale (magnetospheric physics), Marco Polo (asteroid sample return), Spica (mission of opportunity to provide IR telescope for JAXA), Solar Orbiter (co rotating observations ~0.25AU)
- Two proposals addressed the important and timely topic of investigating the dark component that comprises 96% of mass-energy content of Universe
- Advisory structure suggested to merge DUNE and SPACE to one mission
- Concept Advisory Team defined the goals of merged mission, to be called Euclid & became last M mission to start into Assessment

Schedule

- Science Program Review Team mandated that Nationally funding of instruments will be favoured and that Technology Readiness Level shall be ≥5 at mission selection
- TRL5 = "*Component and/or breadboard validation in relevant environment* "
- Typically for launch in 2017 need TRL 5 at 2012, and completed instrument deliveries in 2015
- Difficult for National institutes to fund expensive detector development before down-selection and securing of commitments

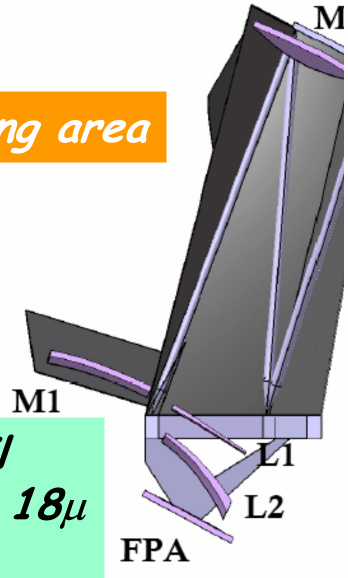
CV M-Class Astronomy

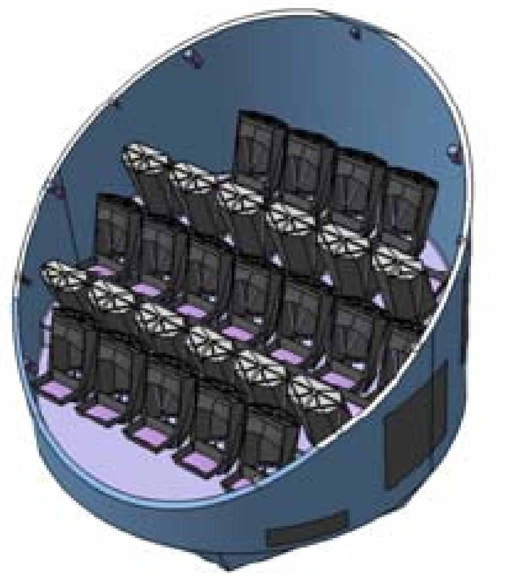
- **PLATO – planet finder (transits and asteroseismology)**
- *Stable conditions in space for accurate photometry*
- *Long duration (2yr) high duty cycle (95%) at one field*
- *Low background*
- **Euclid Dark Energy/Matter**
- *Weak lensing signal not subject to systematics of atmosphere stable & smaller PSF*
- *Wide waveband for Vis/near-IR to cover redshift range*
- *Simultaneous field spectroscopy to calibrate redshift sample*
- *Baryon Acoustic Oscillations in correct redshift range to measure standard ruler (spectroscopy with low background)*



The instrumental concept of PLATO (model payload industry)

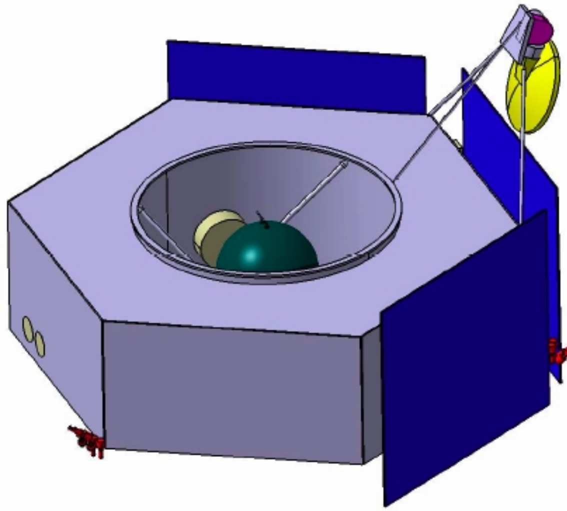
wide Field-of-view + large collecting area





- ensemble of 28 telescopes with 10cm pupil
- each equipped with 4 CCD 3584 x 3584 x 18μ
- all telescopes observe the same field

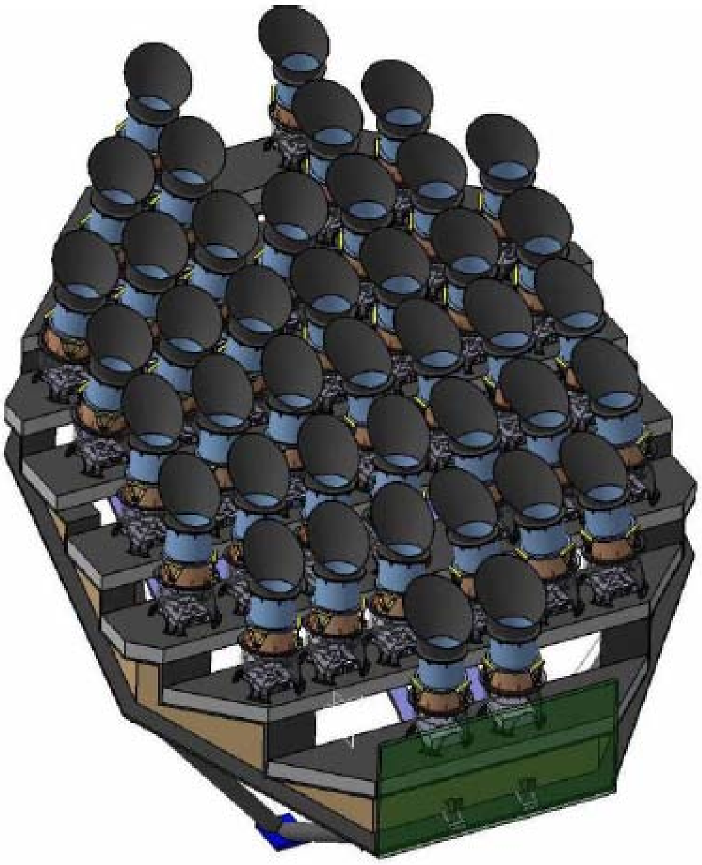
2 tonnes spacecraft – implies ~35kg per telescope



injection into large Lissajous L2 orbit
continuous observation, field rotation every 3 months

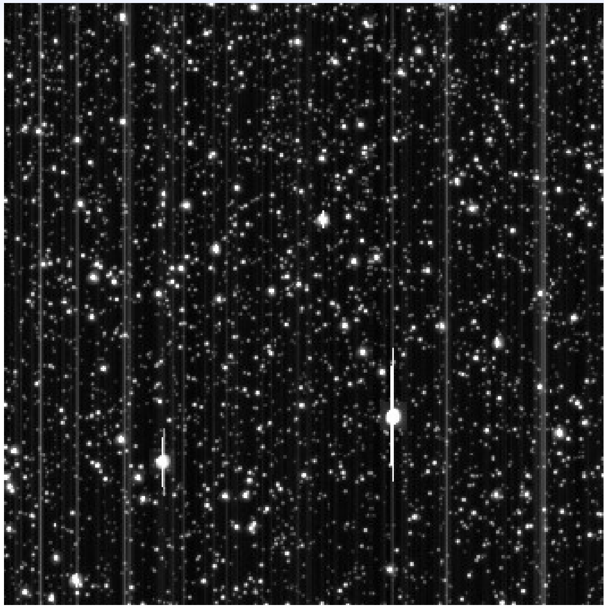
Plato – instrument consortium

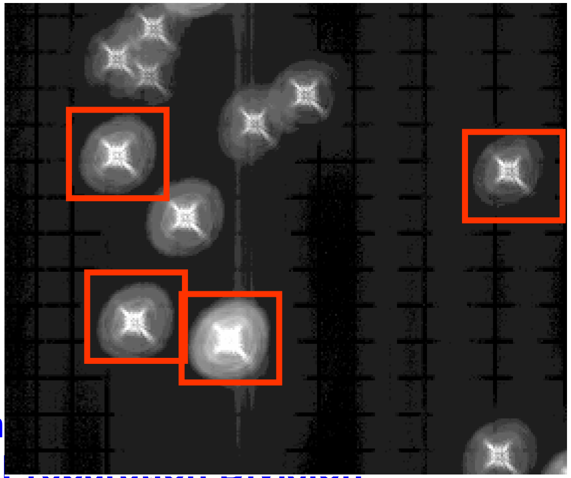
- 42 telescopes each 28°x 28°
- Different field overlaps with coverage to >800sq deg
- Sampling time 25s
- 20,000 dwarfs/subgiants at 27ppm/hr (m<11)
- 250,000 dwarfs/subgiants at 80ppm/hr (m<14)
- One field observed ~3yrs
- Programme needs 168 CCDs
- Straightforward development 18μm pixels , 1Me⁻ full well,
- 4MHz and 15 e⁻ rms, with 2 outputs



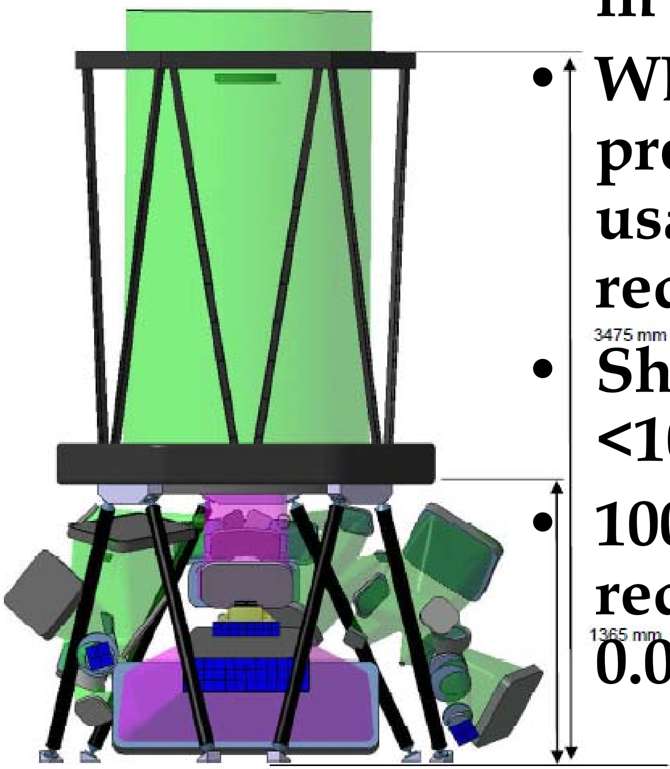
PLATO – observed fields

- Target star always subject to the same precursor stellar content in its CCD column
- *Change* in CTI is small over relatively long timescales.
- Average signal levels quite high (100 el/background pixel /frame, typical star 10^5 electrons/pixel)
- CCD frame times are short (~25s), such that traps also tend to remain filled.
- Affect on performance of radiation damage determined by the *absolute* loss of signal
- Charge injection schemes will not significantly improve the trap-filling properties.
- -80°C, and a mission dose of 2×10^9 p cm^{-2} the expected CTI at end of life (6 years in orbit) is ~5×10^{-5} leading to a S:N degradation.
- The science requirement at the limiting magnitude (m_v=11.5) of 27 ppm photometry in 1 hour would be degraded to ~29ppm per hour.





Euclid

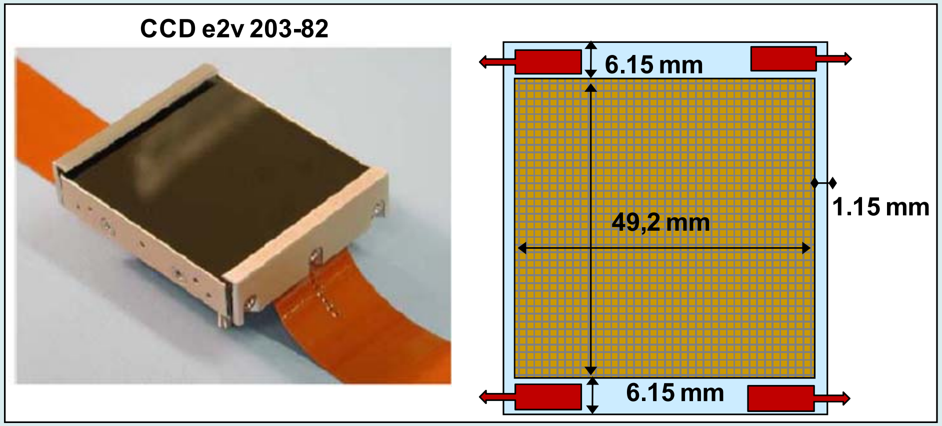


- 3 instruments viewing 0.5 sq deg in parallel
- WL survey cover 20,000 deg^2 and provide 40 galaxies per $amin^2$ usable for WL with a median redshift z>0.8.
- Shear systematics variance $\sigma_{sys}^2 < 10^{-7}$
- 100M galaxies spectroscopic redshift measurement shall be $\sigma_z < 0.001$

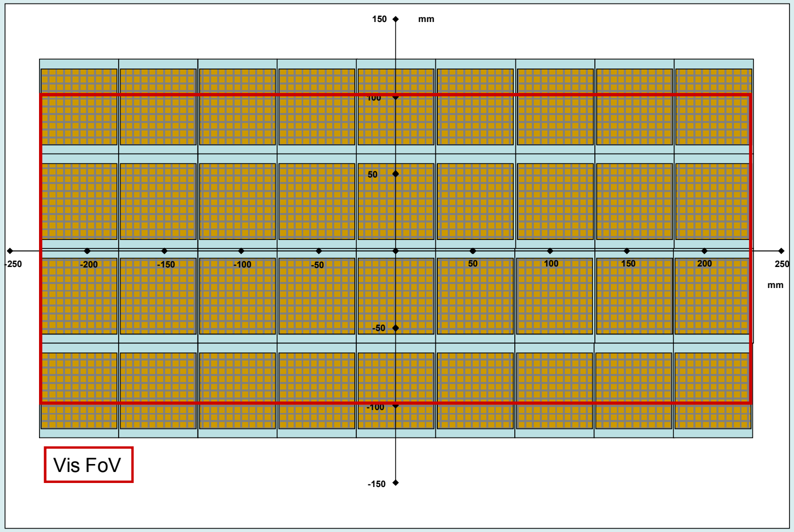
VIS camera

- Lots of heritage from GAIA
- Baseline 9 x 4 array of CCD 203-82 (4k x 4k)
- Measure shapes of faint galaxies
- PSF ellipticity stable at L2, but can calibrate with stars

CCD Unit



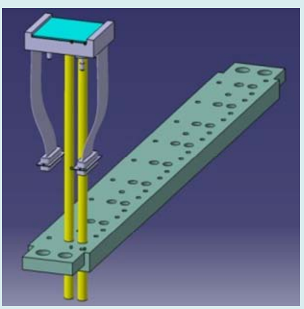
9x4 CCD assembly



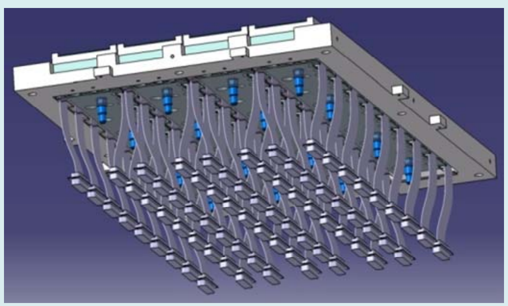
GAIA heritage for FPA

- Passive radiator at L2 for 150K operation

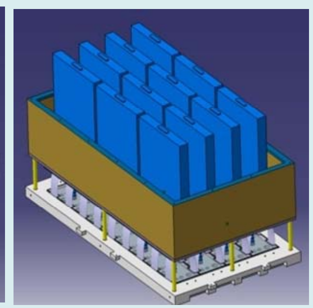
FPA integration steps



CCD integration

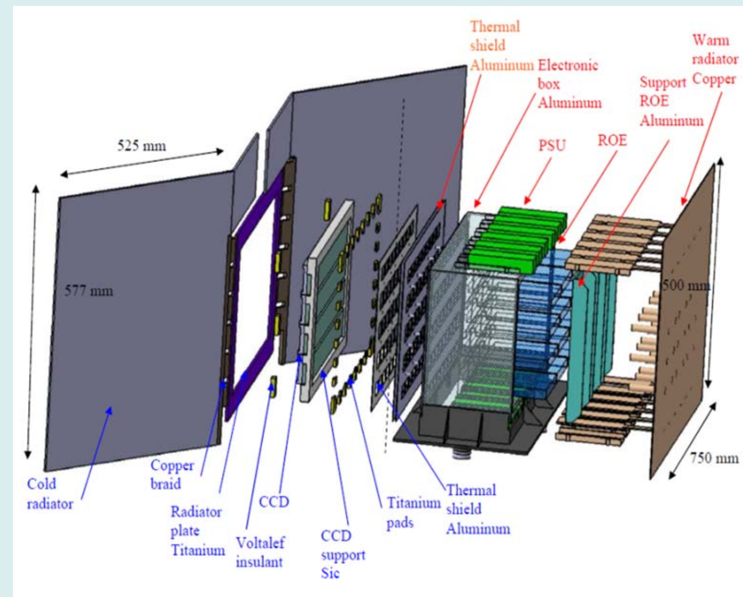


CCD Support Structure



ROE integration

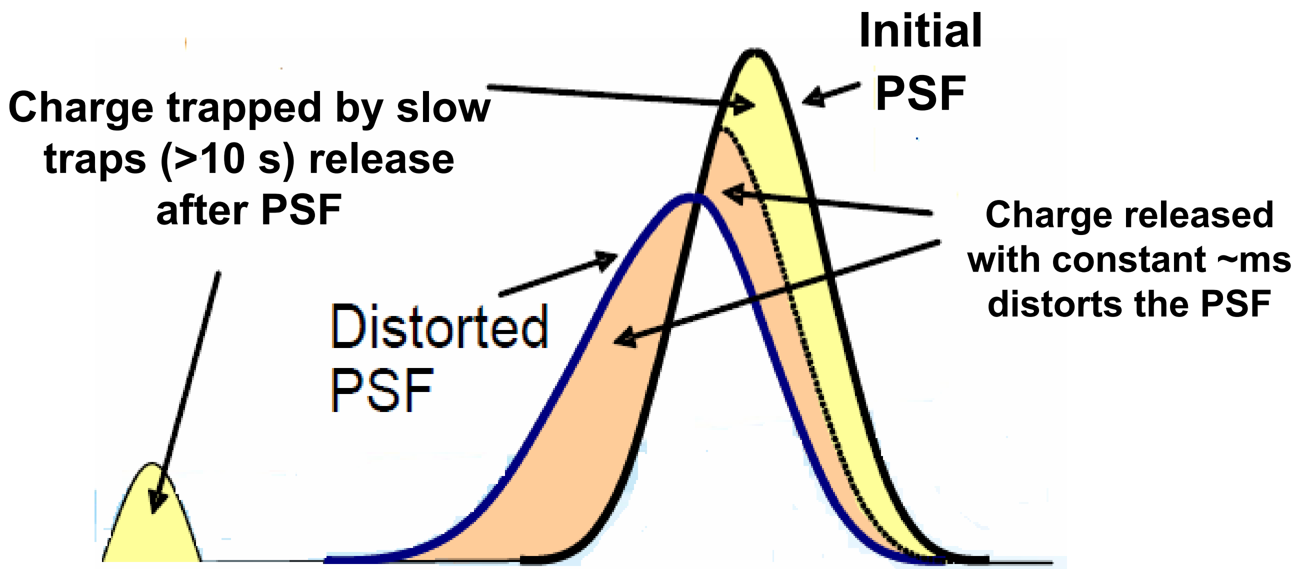
VIS Channel



Euclid – trap speeds

- At 150 – 170 K, serial direction charge transfer (~4µs per pixel), most traps will be "slow" but A-centre traps (10% of all species TBC) will have an emission time <⅓ a pixel transfer time.
- For parallel direction transfer time (~5ms) the divacancy emission time will be <20% of a row transfer duration, but E-centres will appear as slow traps.

- For the critical issue of CTI distortion of PSF ellipticity, majority of trap types will not defer significant signal into pixels on the trailing edge of the PSFs.

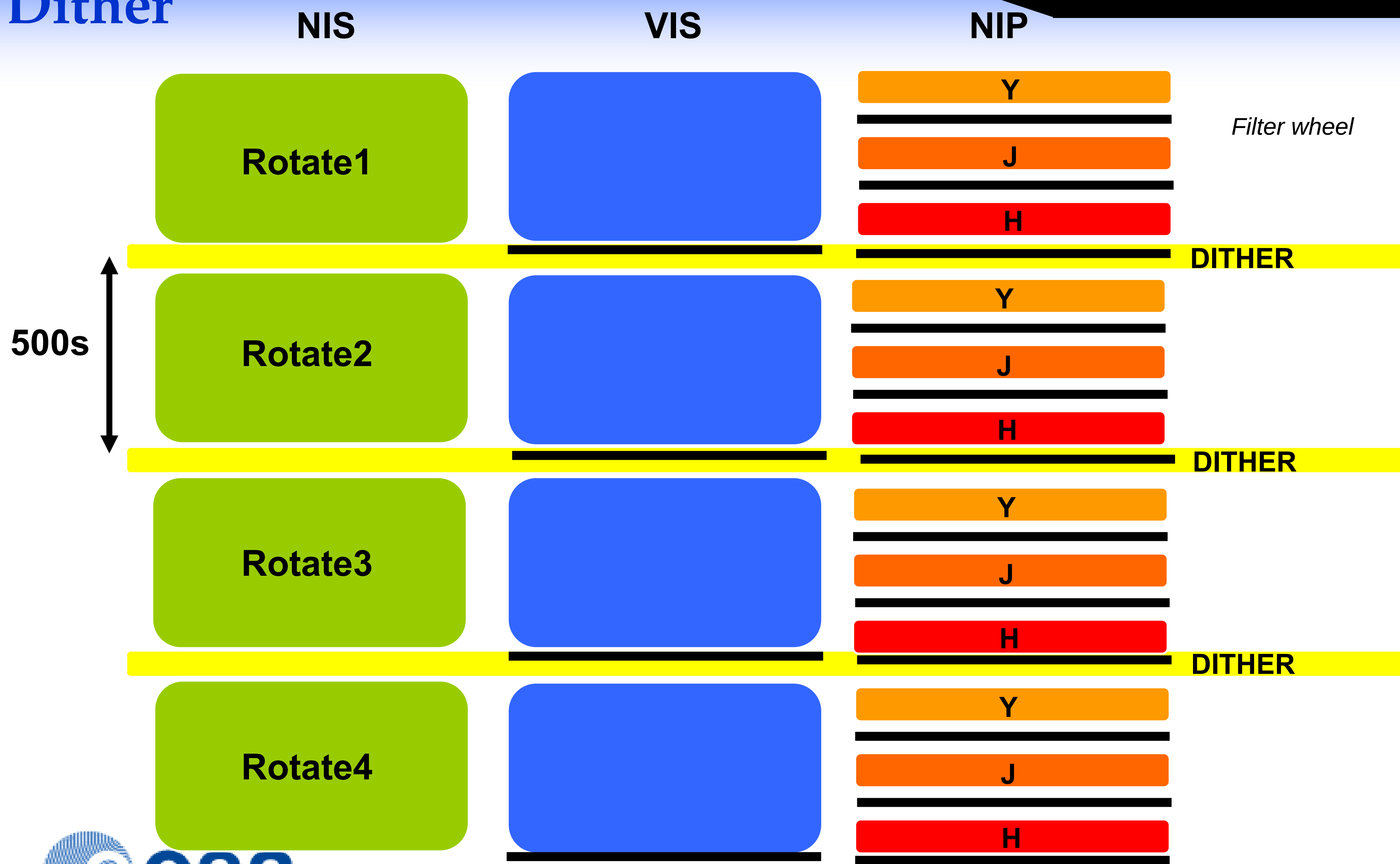


- Assessment needs to be made for the effect of other (unidentified) defects

Euclid – S:N loss ?

- Major issue likely to be total effect of trap losses on the achieved signal:noise.
- Operational mode requires image frames of duration ~400 - 500s.
- At the lowest envisaged temperature, the filled E-centre traps will re-emit during image integration and be mostly empty at the start of the transfer phase.
- Typical galaxy signal separated ~ 100 pixels and signal ~1000 electrons. The zodiacal background ~30 electrons/pixel.
- Charge injection (as used on GAIA) ineffective, as the traps filled by injection will also depopulate on this timescale shorter than the image accumulation.
- Periodic injection has to be sufficiently high frequency (~second) that most traps stay filled. But then stripe will start to affect the image area fill factor
- Initial measurements for a Euclid baseline device @ mission lifetime dose & 160K is estimated ~4 x 10^{-5} (X-ray signal stimulation at typical galaxy separation) which represent a ~10% signal loss.
- Again it is emphasized that the critical measurement parameter (PSF ellipticity) must be addressed

Dither

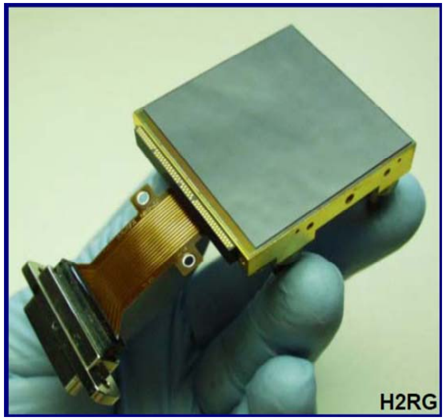

NIS
VIS
NIP
Rotate1
Y
J
H
Filter wheel
DITHER
500s
Rotate2
Y
J
H
DITHER
Rotate3
Y
J
H
DITHER
Rotate4
Y
J
H

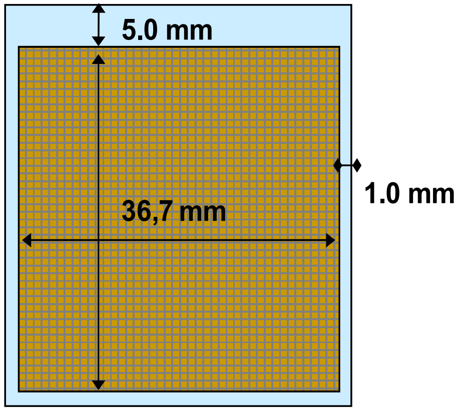
Near IR Photometer

- Same field as VIS channel 3x6 Hawaii 2RG array + Sidecar
- Many more detectors than JWST
- 3 filters , Y J H (~2μm cutoff). PSF undersampled so response uniformity needs to be assessed

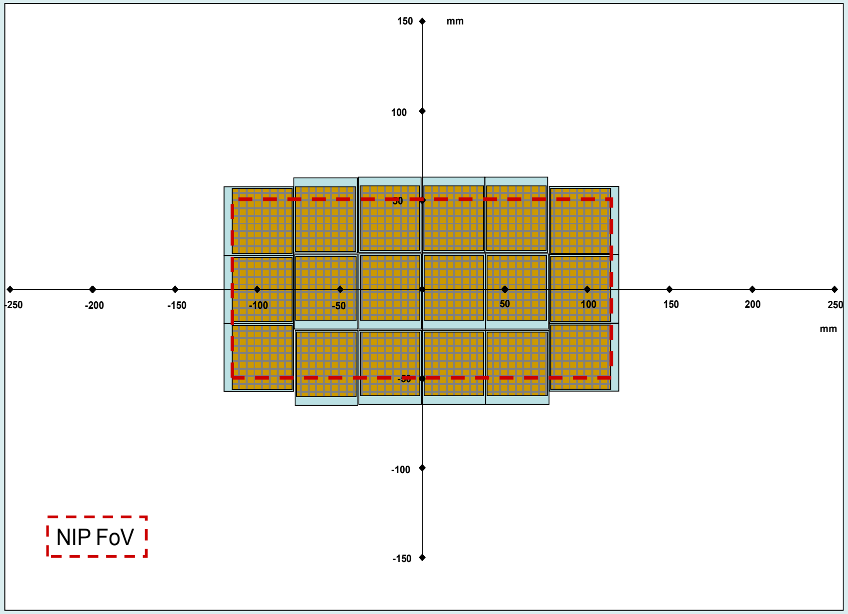
NIR array Unit

Teledyne Hawaii 2RG



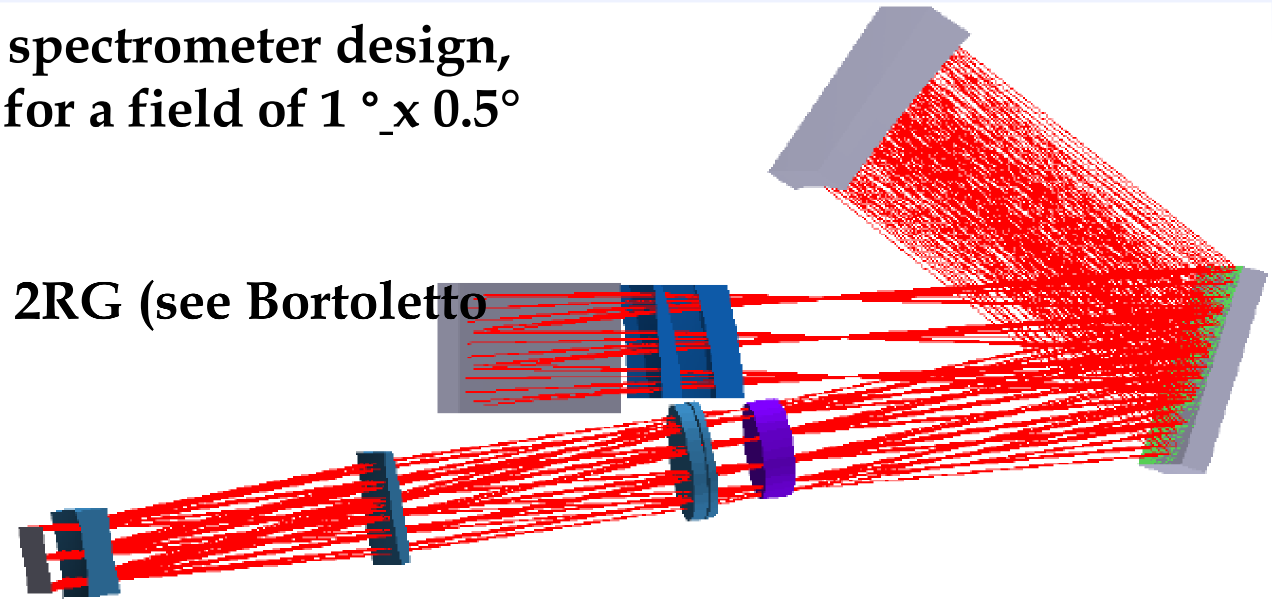


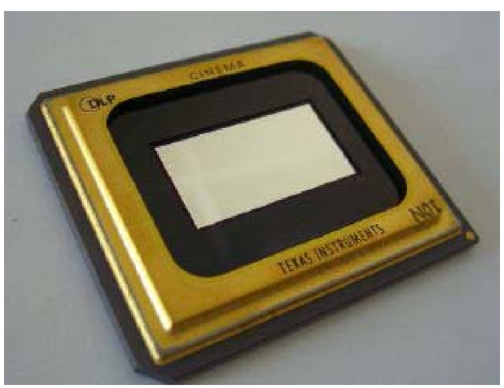
3x6 NIR arrays assembly



Euclid Near IR Spectrometer

- Baseline is a slitless spectrometer design, resolving power ~500 for a field of 1 ° x 0.5°
- 1 – 2 µm
- 2 x 4 array of Hawaii 2RG (see Bortoletto Friday session)

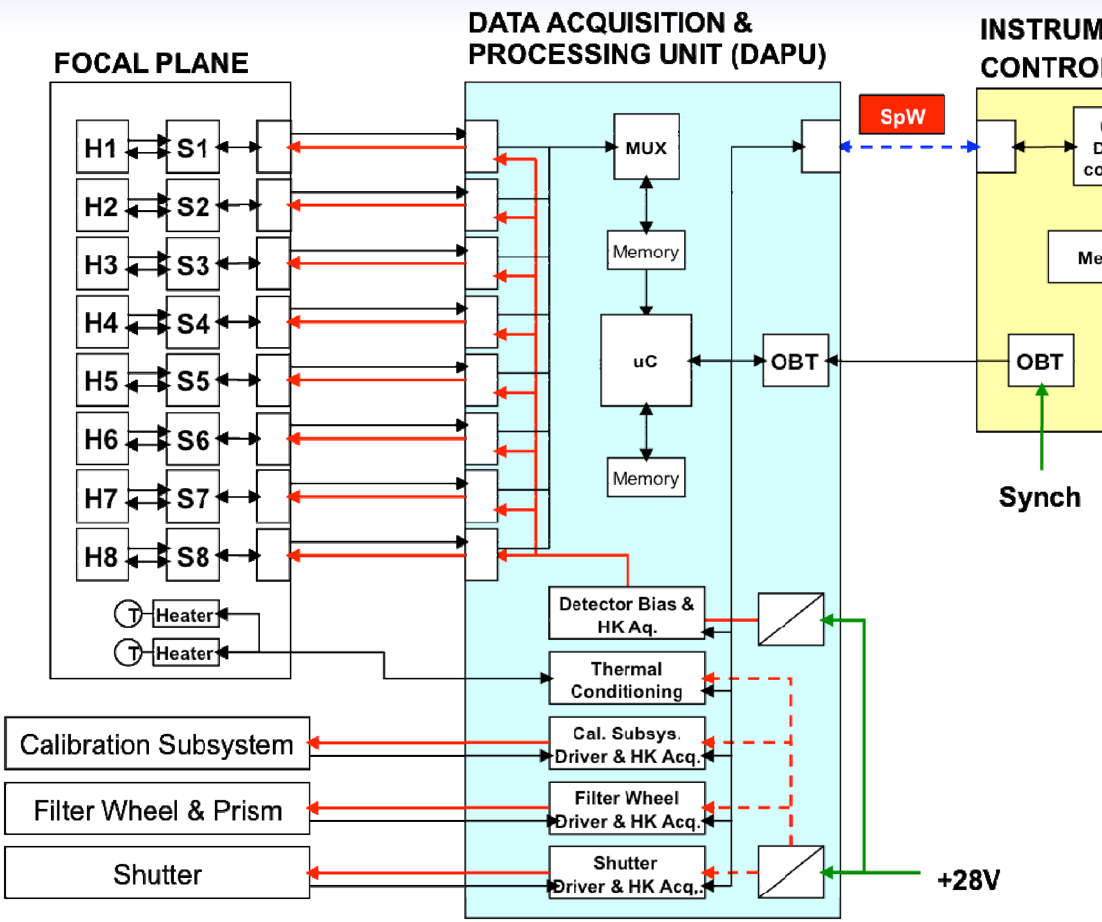


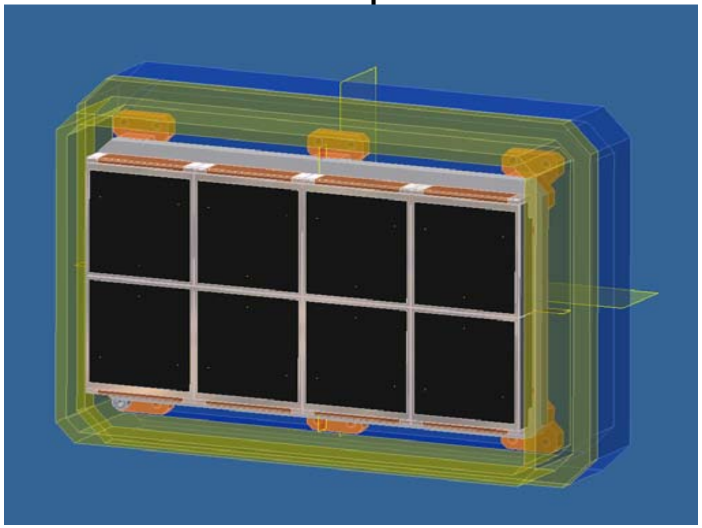


- Back-up study for slit spectrometer based on TI Cinema chip (Digital Micromirror Device)
- Again the TRL is an issue here for 2017 launch

Advanced Technology & Mission Preparation Division

NIS Readout





Advanced Technology & Mission Preparation Division

Hawaii Array Radiation Issues

- **Cosmic ray hit rate ~1% / exposure * event size**
- **Cosmic ray removal (has to be on board) sampling up ramp on 26 detectors is huge processor load**
- **(***Already estimated data rate incl compression 850Gb/day***)**
- **Image persistence – generation of additional traps in depletion and interface layers**
- **Dark current – need to operate at as high temperature as possible (~110K)**
- **Radiation tests for JWST at ~40K**

European IR detector Developments

- Existing heritage in HgCdTe arrays and bolometers, but not tuned for low noise astronomical levels
- SELEX , AIM, Sofradir, Qinetiq are potential suppliers
- A strategic issue - hostage to the US suppliers & especially potential ITAR issues
- ESA starting a development for HgCdTe low noise arrays and associated ASIC readout
- 2 or 3 parallel contracts – kick off October 2009

Developments Required?

- Mission down selection (2 or 3) in Feb 2010
- Plato and Euclid pre-development issues to ensure instrument breadboards can start during definition phase (up to 2012)
- Needed for array geometry (Plato), charge trap mitigation features, P-channel (Euclid)
- Also radiation hard, fast controller & ADCs necessary
- Instrument breadboards (incl IR arrays) have to assess robust data processing concepts and radiation hardness to the science parameters of interest
- Science detector programmes (10-20Meuro per mission or instrument) not only key for performance and schedule but typically the single most expensive sub-system