A mapping of Large IR Detector Array for scientific space missions

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Workshop "What future for European Large Format IR Detectors", 07/12/22

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Context

- **Mapping of existing Large IR Detectors for Scientific Space missions : what exists today and what developments are ongoing ?**
- **Performance :What is the wavelength coverage ? What are the available format ? The flux rates ? Dynamics ? Limiting factors ?**

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Scientific Space projects in Europe

French space budget

space budgets
other countries

French contribution

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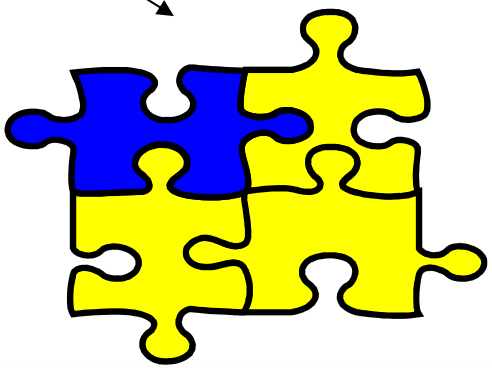
National
and multilateral missions
with other countries

Funds the development
of French **instruments**
for ESA missions



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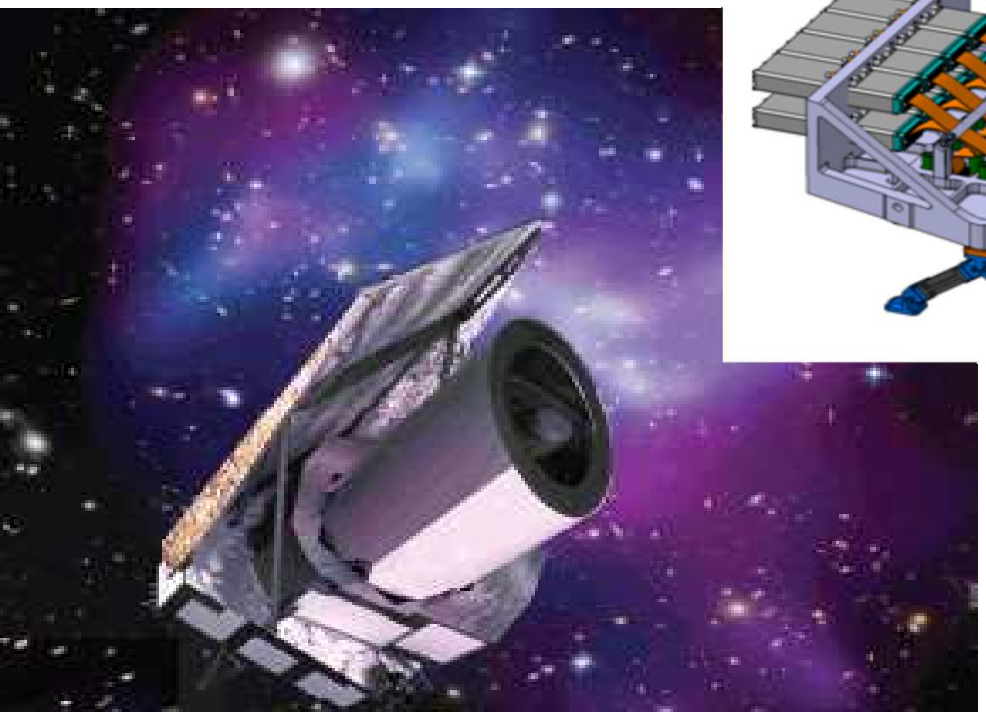
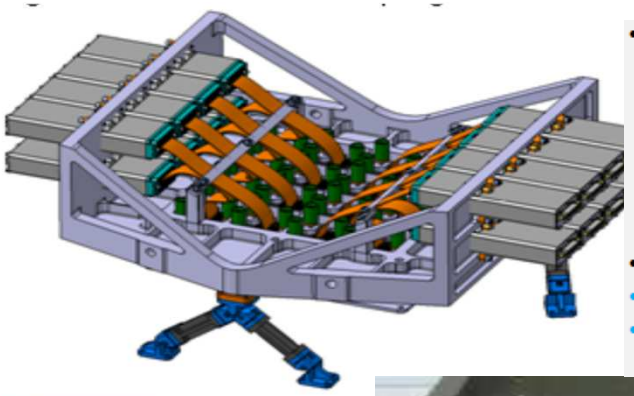
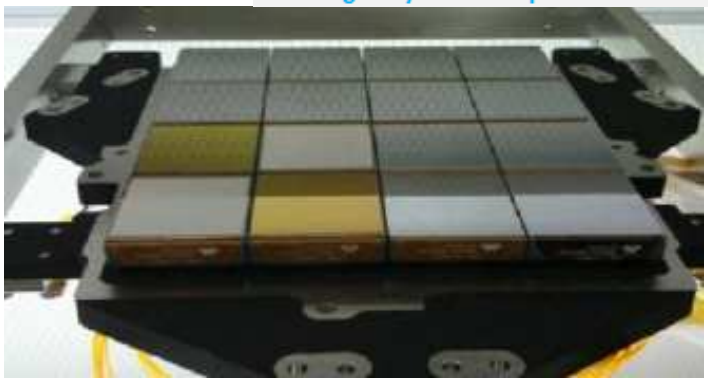
Euclid





- Euclid has a 1.2-m diameter large field of view telescope with visible and infrared arrays produced by Teledyne:
  - 600 million visible pixels
    - 36 4K×4K (16 Mpix) CCDs
  - 64 million infrared pixels
    - 16 H2RG (4 Mpix) SWIR arrays
    - 16 SIDECAR ASIC modules
- Largest IR focal plane array when it launches
- 24 flight candidate H2RGs delivered to NASA
- NASA tested and delivered 20 flight grade H2RG arrays to ESA, all of which greatly exceed requirements



Cosmic vision M2
Expected Launch
July 2023

H2RG, 100kHz readout frequency
Sidecar Asic
4x4 mosaic
Cutoff wavelength ~2µm
Background flux 0.5é/s/pixel

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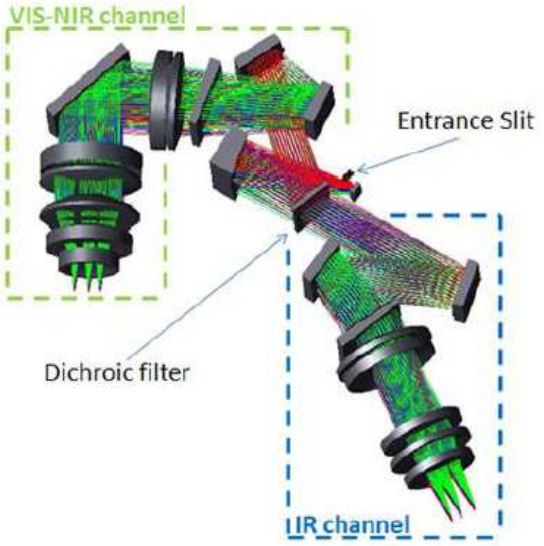
MAJIS JUICE

H1RG, 100kHz and 1MHz readout frequency
Sidecar Asic
2 channels cutoff wavelength ~2.35µm and 5.56µm
Fluxes from 20000 e-/s/pix to 2 10^6 e-/s/pix
Trade-off with NGP in early project phase



Cosmic vision L1
Expected Launch April 2023

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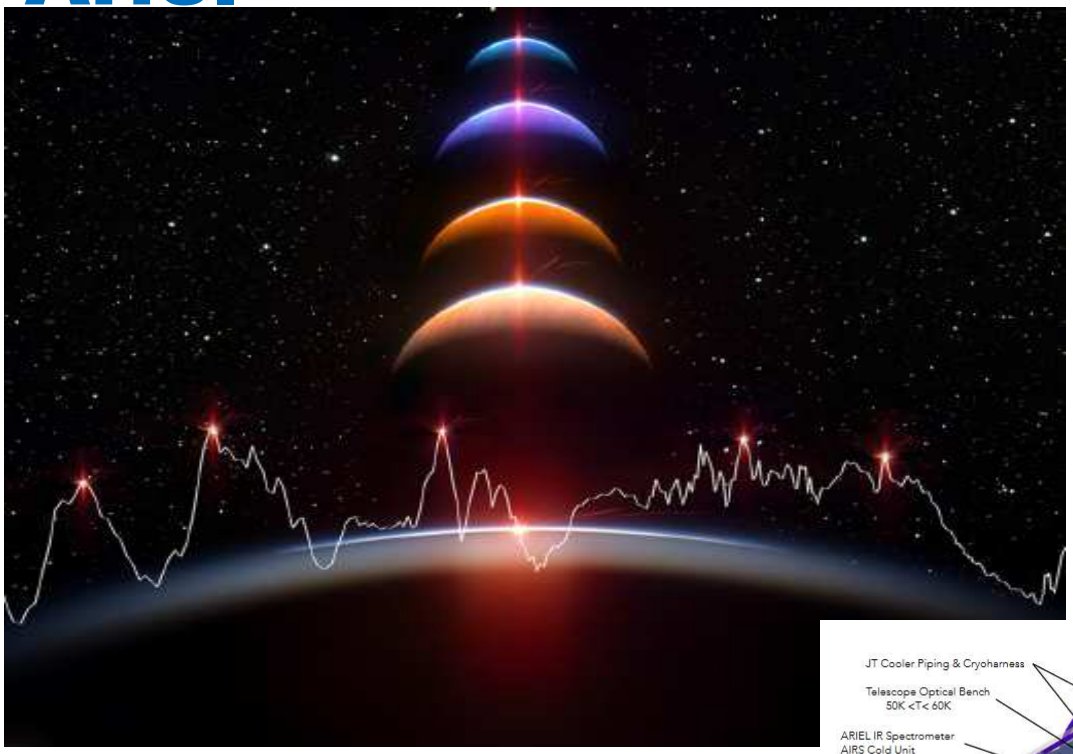
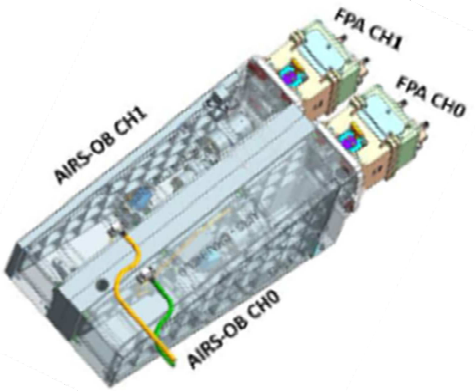
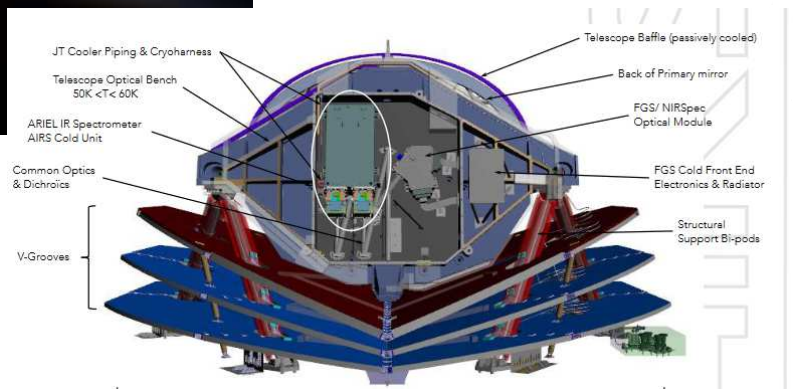
Ariel



H1RG
2 channels cutoff wavelength ~4µm and 8µm
Discrete readout electronics
Fluxes from 100 e-/s-pix to 250 000 e-/s/pix
Trade-off with CTIA+n/p technology in early project phase





Cosmic vision M4
Now in PDR
Expected Launch 2028

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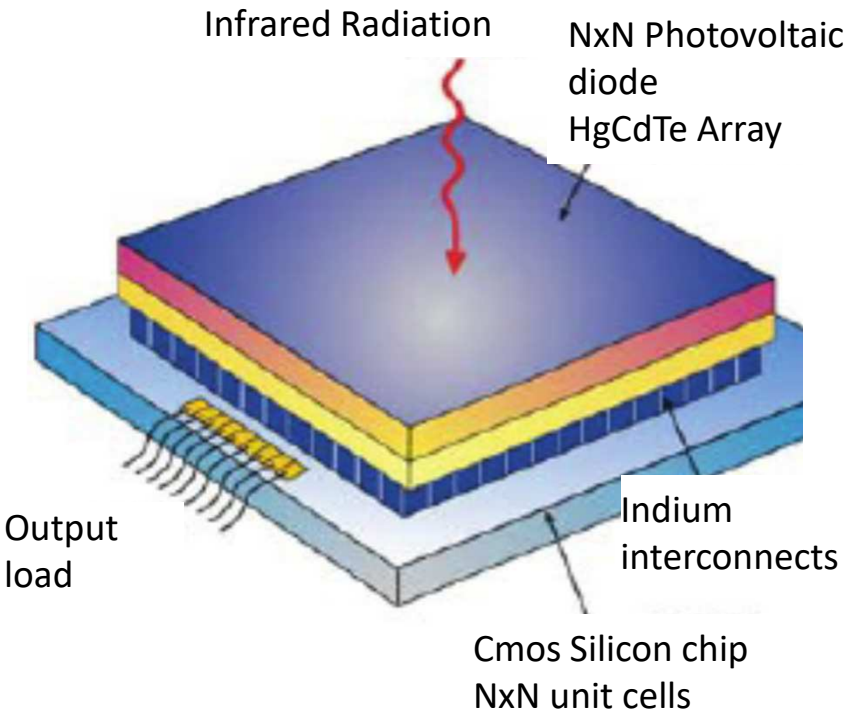
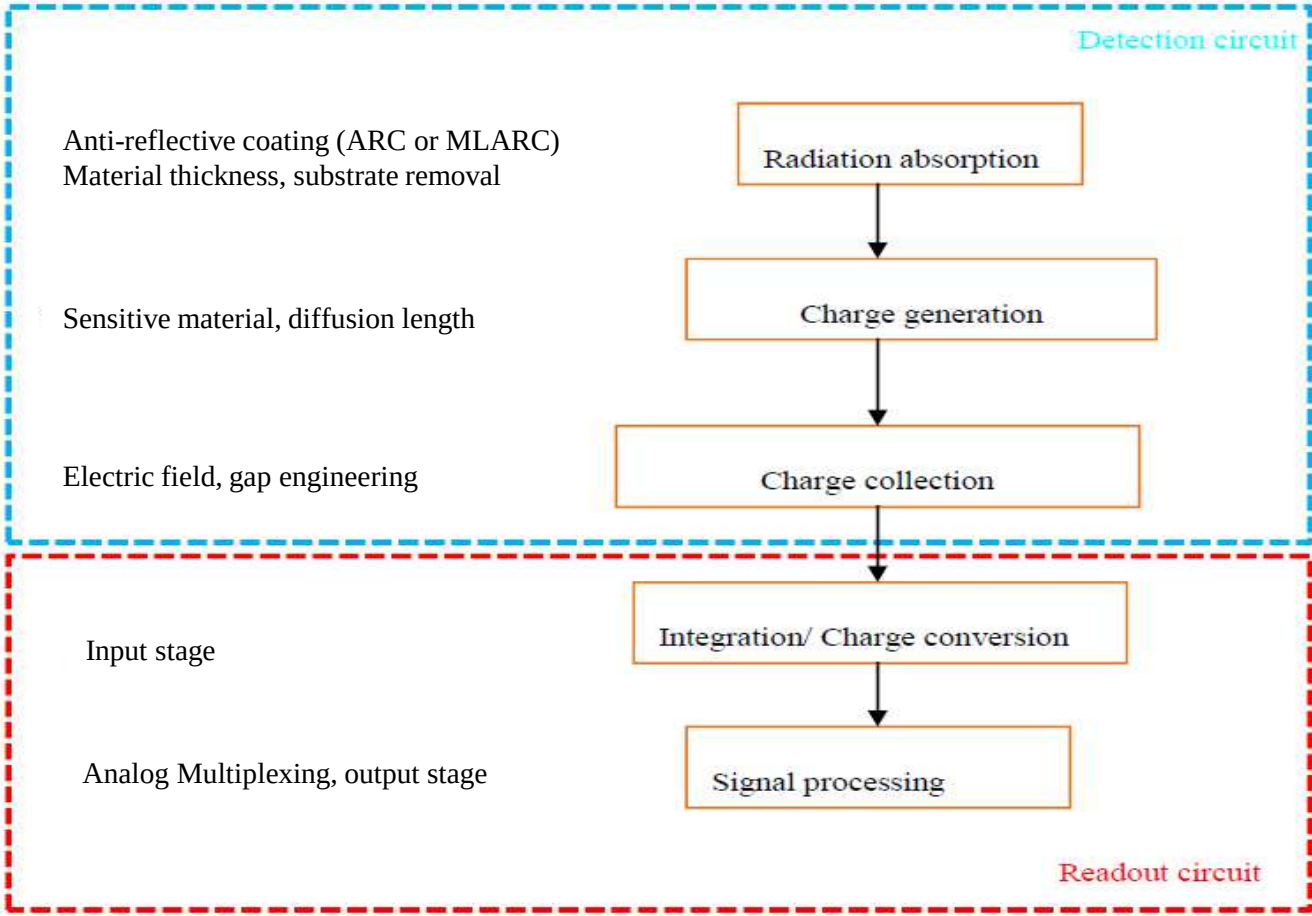
The HgCdTe Infrared Detector





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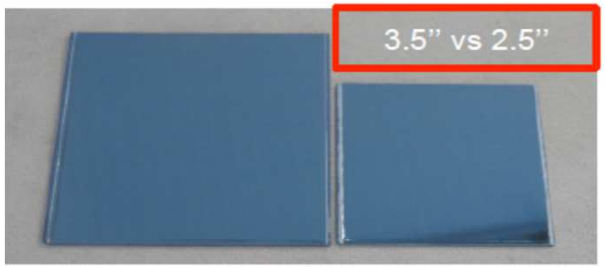
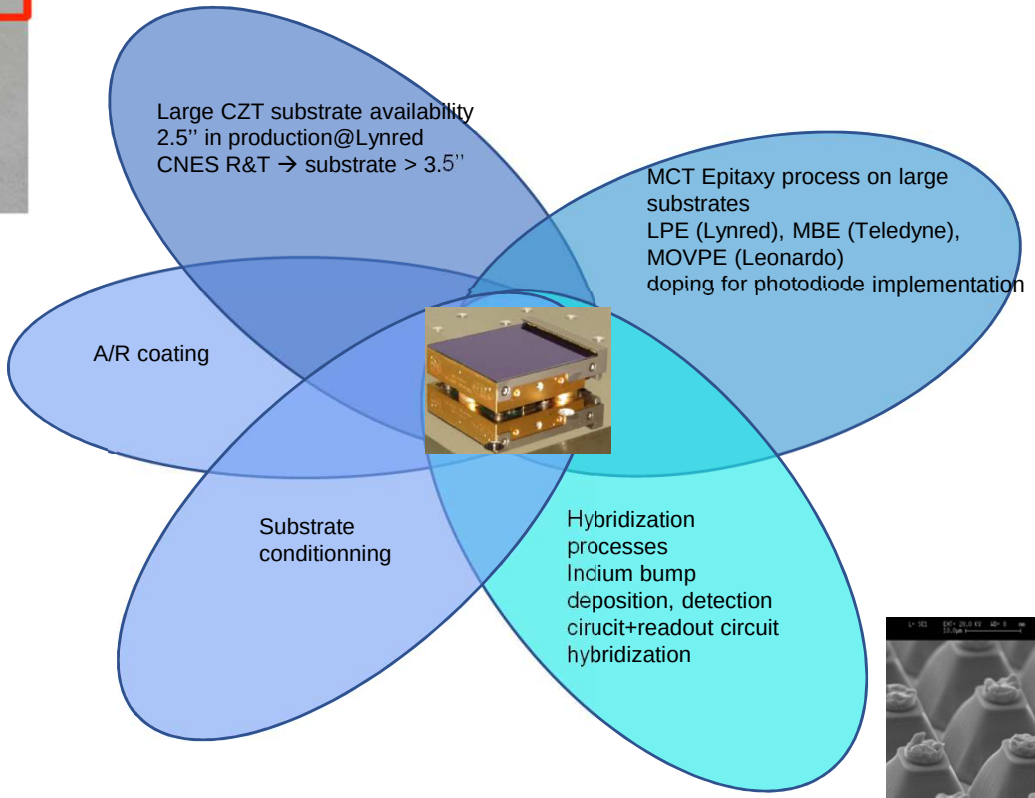
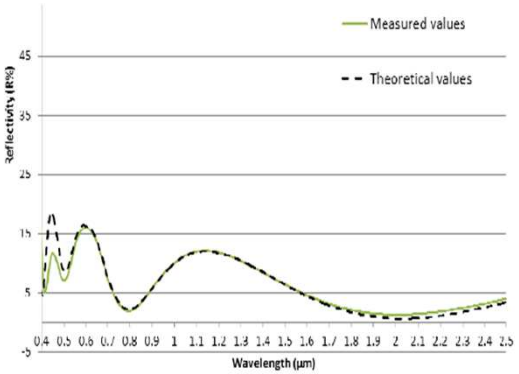
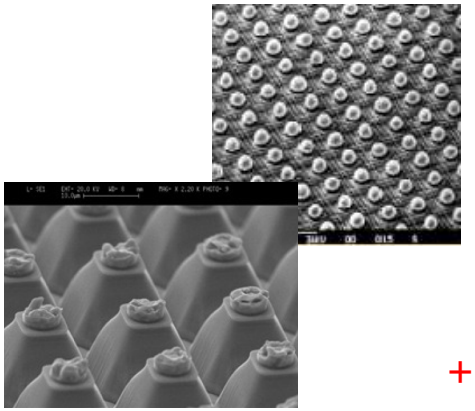
Large format IR detectors: need to overcome strong technological limitations





All those processes require industrialisation phase





+ packaging….

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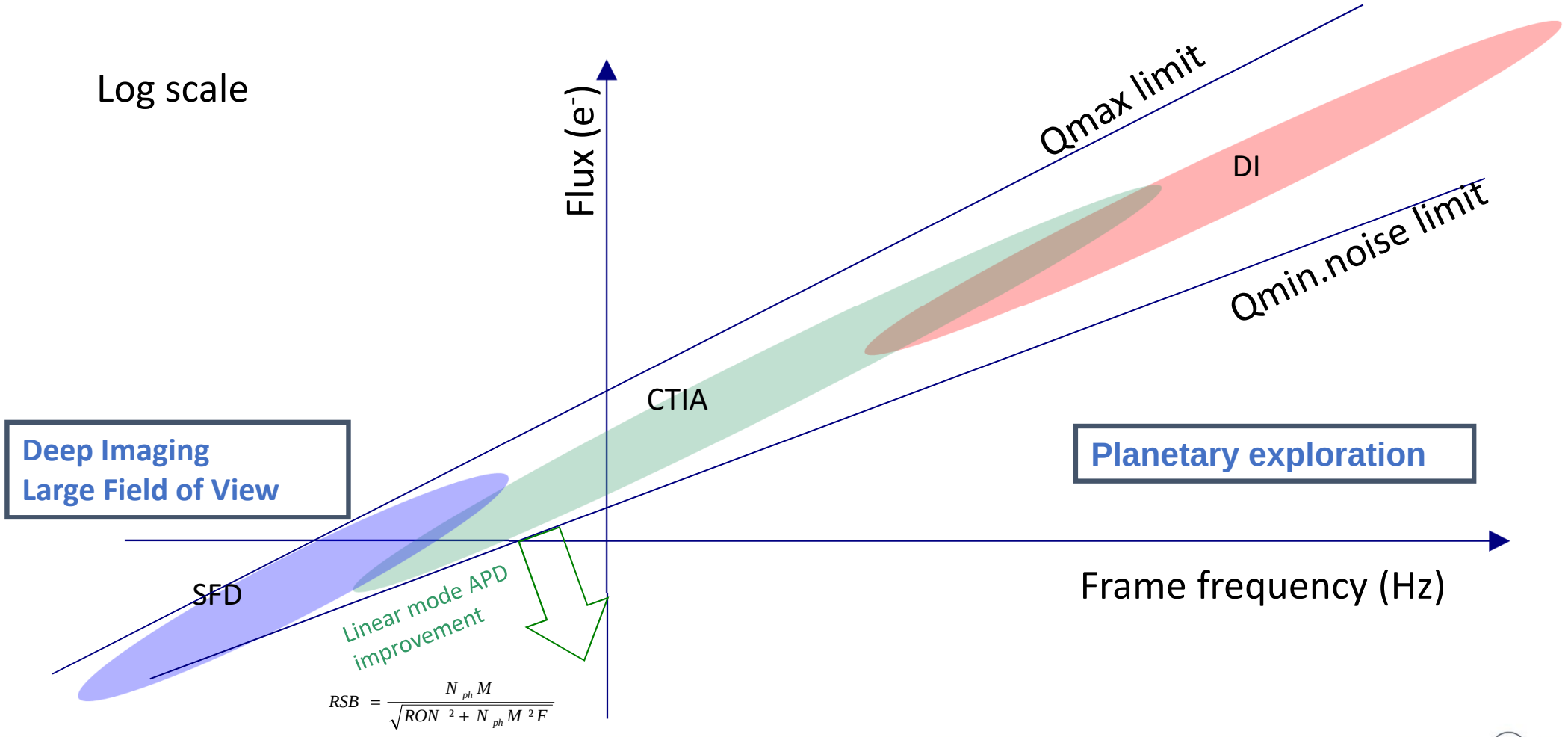
Low readout noise detectors and flux/frame frequency diagram



$$RSB = \frac{N_{ph} M}{\sqrt{RON^2 + N_{ph} M^2 F}}$$

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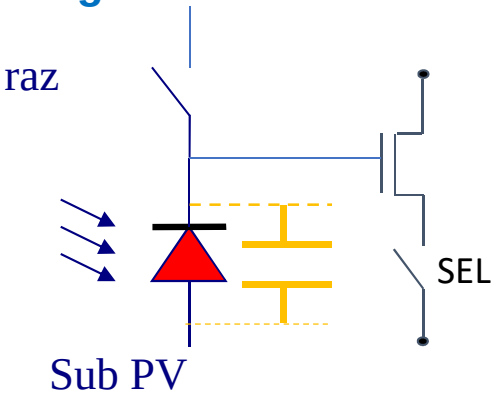
IRCMOS Read Out Circuit input stage

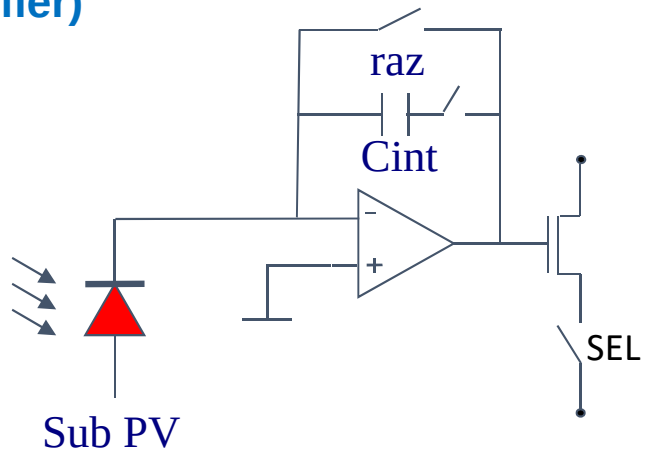
SFD (Source Follower Detector) Integration on detector node



low noise
low power consumption

small charge capacitance/non-linear C(V) characteristic
Electronics set-point difficult to optimise
low frequency readout /require cold electronics (persistence effects)

CTIA (Capacitive Transimpedance Amplifier)



versatile charge capacitance/good linearity
high frequency readout
large impedance driving capability
Electronics set-point easier to handle

High power consumption
Very low fluxes ?

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IRCMOS ReadOut Integrated Circuits input stages

Performance	SFD	CTIA	comments
Noise without CDS	15-20e- rms typ.	30-150 é rms (lower limit)	The noise figure can be lowered with CDS or multiple (and non-destructive) readout. Few e- rms noise can be reached with SFD
Flux range	0.01 e-/s/pixel to <10^4 e-/s/pixel	few 10^3e-/s/pixel to few 10^8 e-/s/pixel typ.	
Charge capacity	< 10^5 e- typ.	10^5 e- to few 10^6e- typ.	Charge capacity depends on the photodiode wavelength detection range for SFD
Readout frequency	up to 500 kHz	up to 20 MHz	SFD ROIC drive an output capacitance of ~2pF, whereas CTIA ROIC can drive ~100 pF capacitance
Power dissipation	1 mW typ.	50-150mW	

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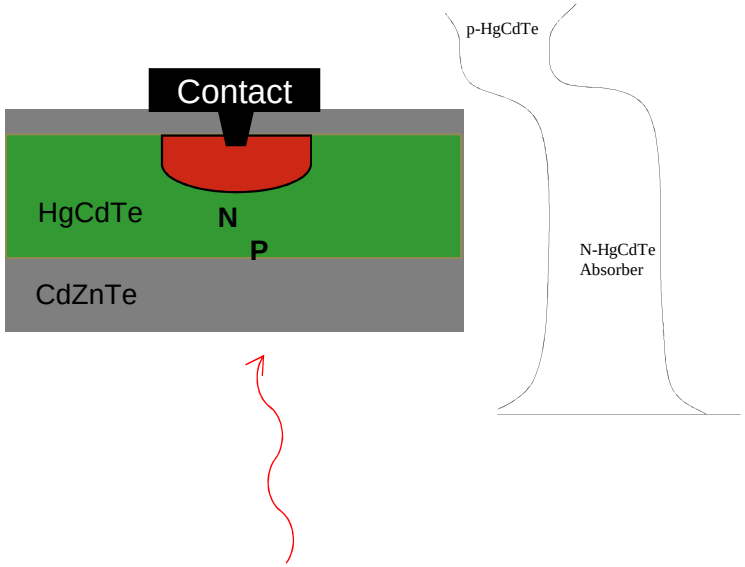
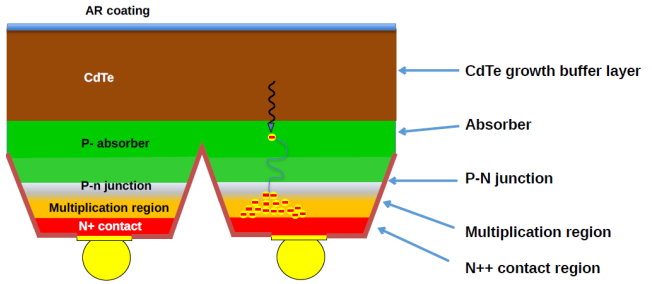
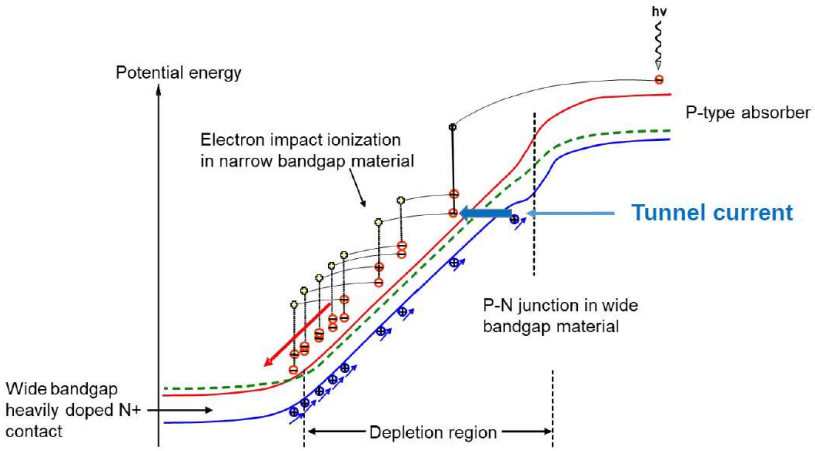
Photodiode p/n technology is necessary to achieve low dark current and allows good signal to noise ratio performance



- High quality HgCdTe material
- Optimized junction process
  - Bandgap junction
  - control of the doping level
- Passivation layer





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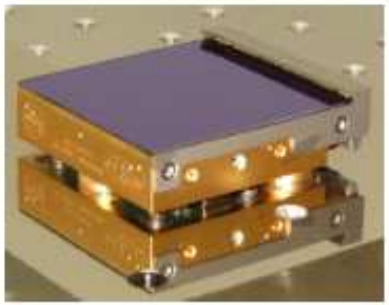
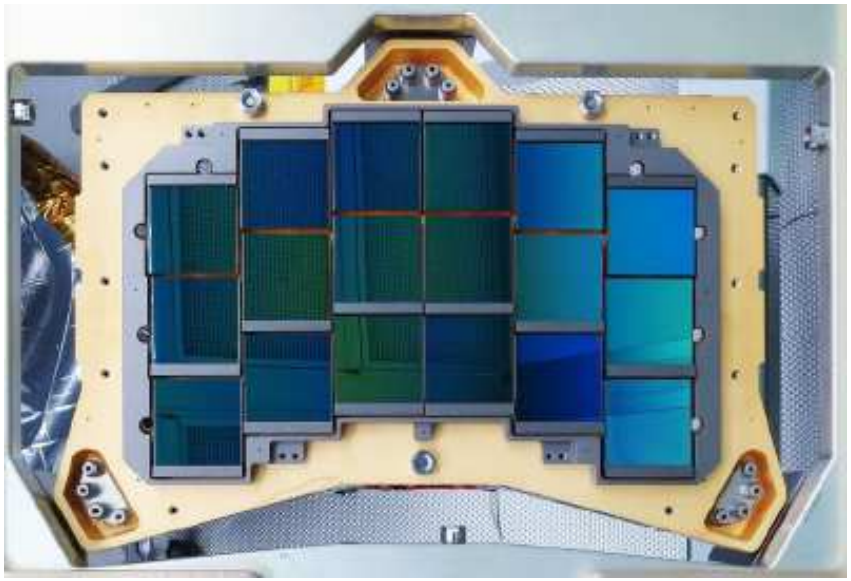
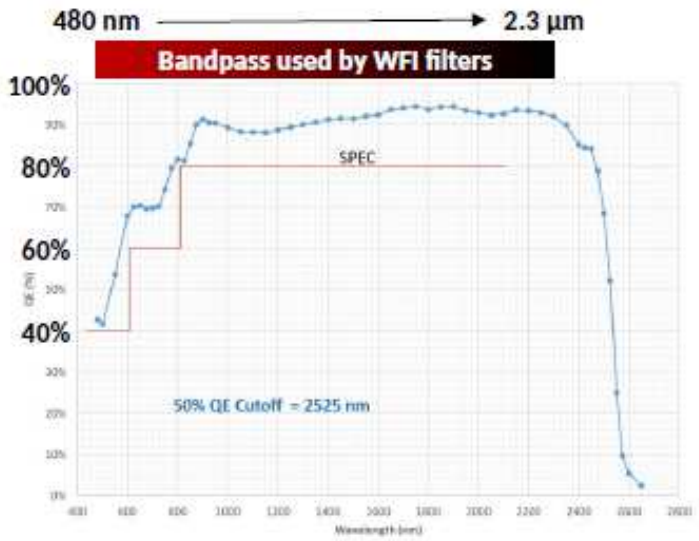
SFD for space pojects : H4RG



H4RG 10 µm pixel pitch





> 300 million pixels

28 flight grade delivered for the Roman Space telescope
– 18 SCAs will be flown
Improvement on the passivation layer : low (no) persistence

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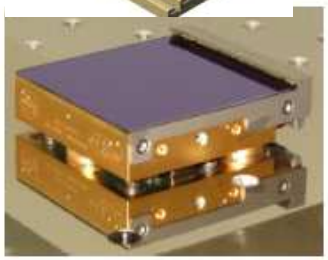
HxRG vs wavelength

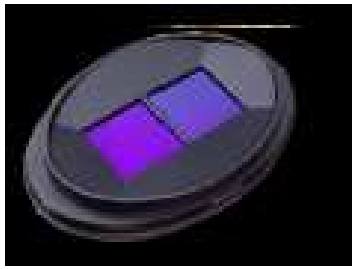
NIRCAM
H2RG

SWIR



H4RG 10 µm

MWIR



NIR SPEC
H2RG

H1RG JUICE
5.56µm

H1RG ARIEL
8 µm

LWIR

H2RG NEO
10 µm

Alfa 2k², 15µm SWIR under developemnt

Demonstration of photodiode coupling to SFD from SWIR to 10µm cutoff wavelength

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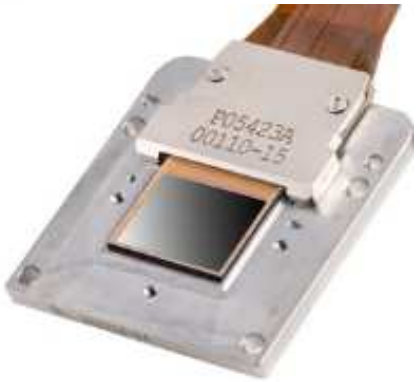
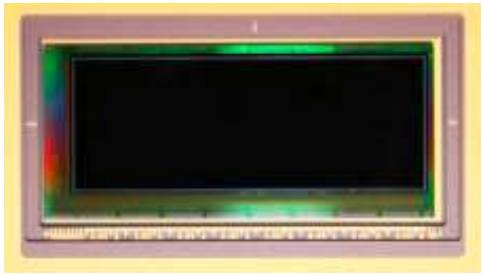
CTIA for space projects
Hyperspectral imaging

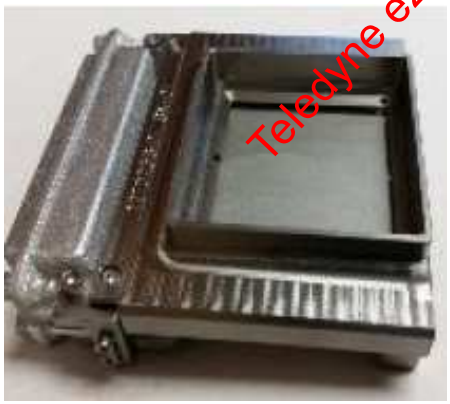
Lynred NGC 1k²
µCARB, S5, CO2M
15µm n/p SWIR



Lynred COBRA under dvt
920x1112 →
1840x1112
20µm
n/p SWIR
190 ke-, 80 e-rms



Teledyne GeoSnap SWIR, MWIR
p/n
1280×480, 1600×480, 30µm
700 ke-, 80 e-rms



Teledyne GeoSnap
1K×512, 2K×512, 2K×2K, 3K×512, 18 µm
SWIR (2.5 µm), MWIR (5.3 µm), VLWIR (14.5 µm)
p/n
used in 12 flight programs

Main intrinsic limitation of the SFD input stage :
- **Relatively small integration capacity (associated with a large potential offset dispersion) which limits its use for “medium input fluxes”.**
- **Low frequency readout**

Main limitation of the CTIA input stage :
- **higher noise,compatibility with input fluxes in the range <10^2 e-/s/pixel?**

Competition at European market level

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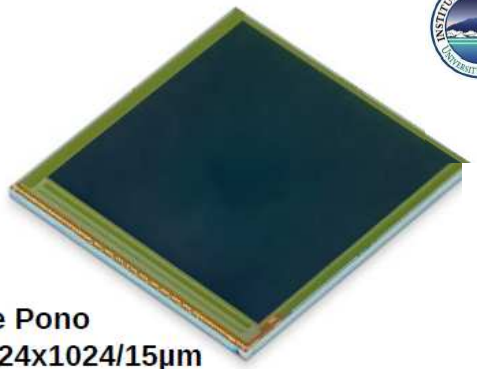
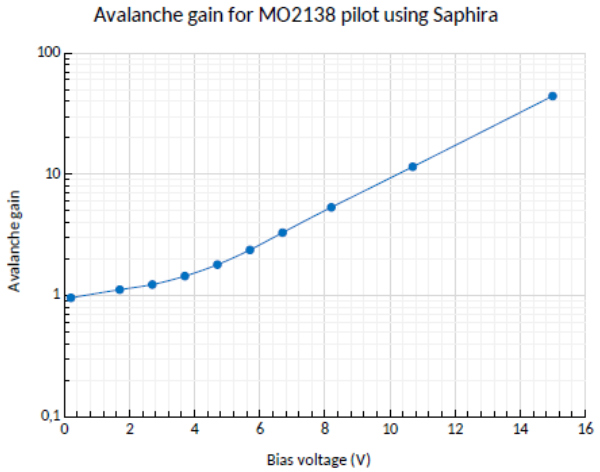
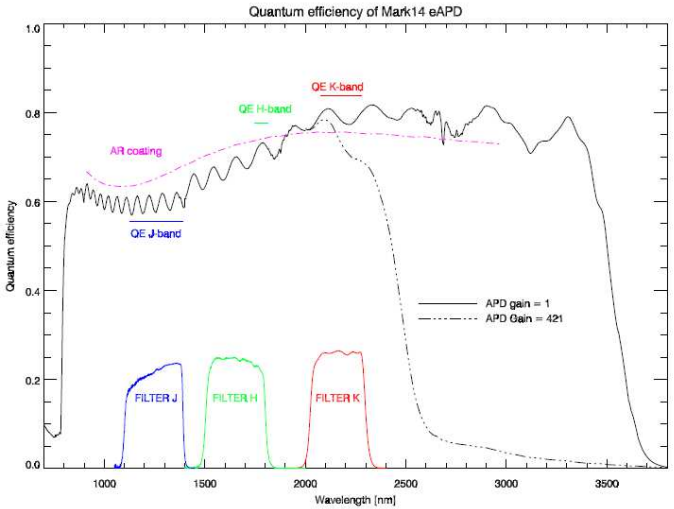
Under development : LmAPD+SFD Leonardo

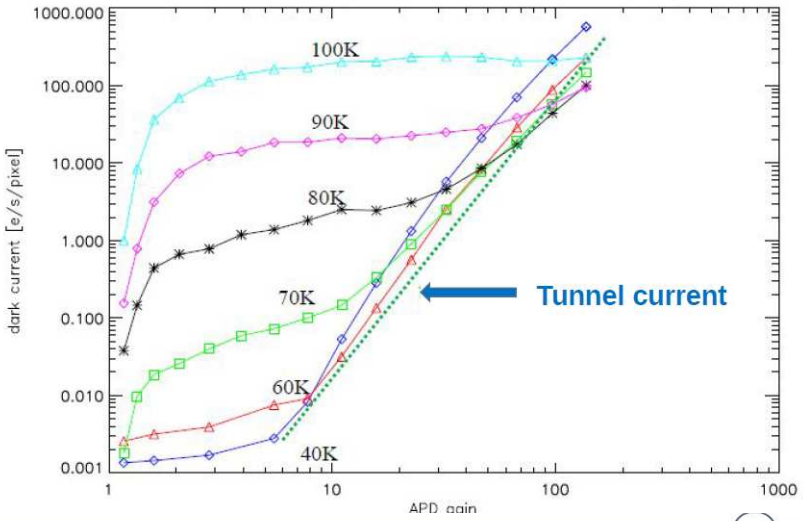


Ike Pono
1024x1024/15µm

IBEX
2048x2048/15µm







Solution under dvt : Widen the bandgap where the field is highest
Can photon counting limit be reached ?

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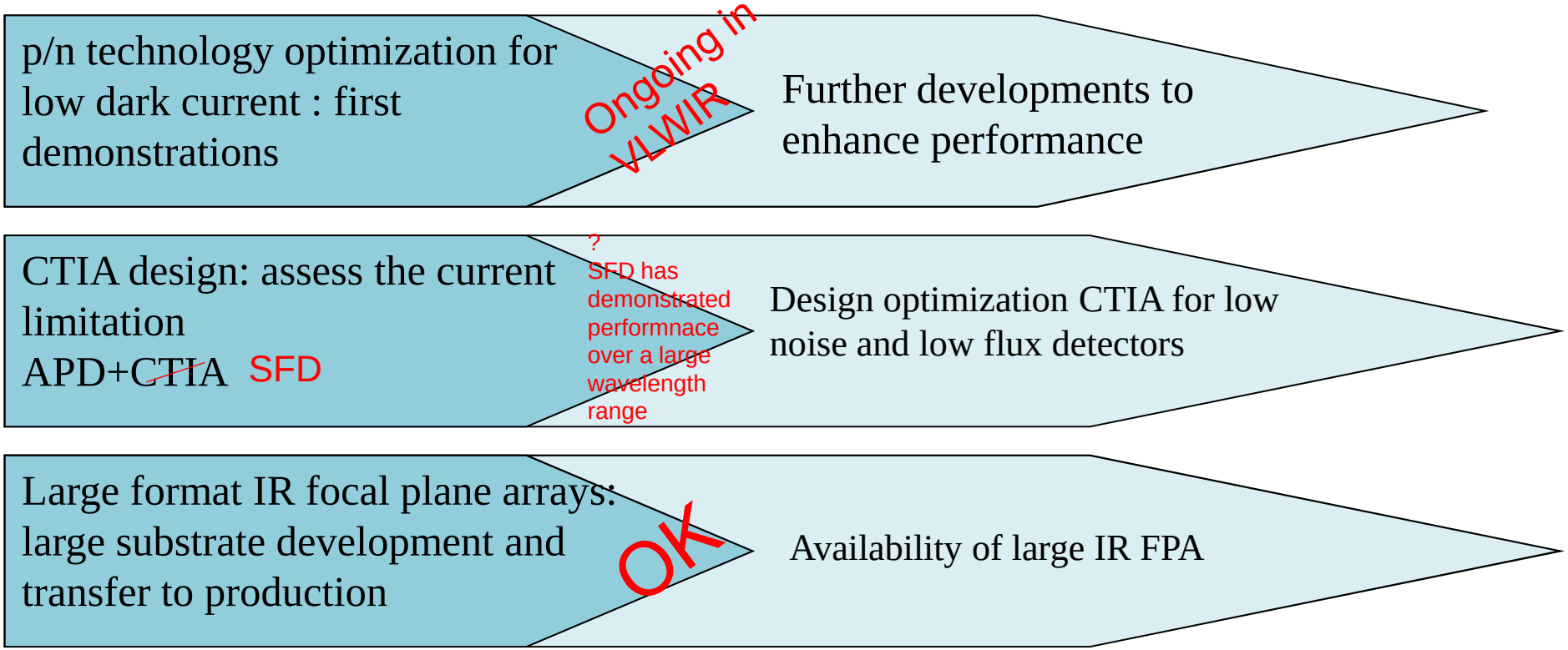
Back to 2017 CNES roadmap



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Take away messages

- **H4RG has reached a high TRL level (cf Roman Space Telescope)**
- **H1RG and H2RG available in a large range of wavelength, from ~2µm to ~10 µm**
- **Large Format IR Detectors with SFD ROIC and CTIA ROIC provide complementary performances**
- **Teledyne Large Format IR Detectors with CTIA ROIC offer for the European market**
- **Promising development in Europe with Leonard LmAPD large format array with RON close to 1 e- rms**

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