

# On-orbit MTF and defocus assessment methods applied to SPOT5 cameras

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return on innovation

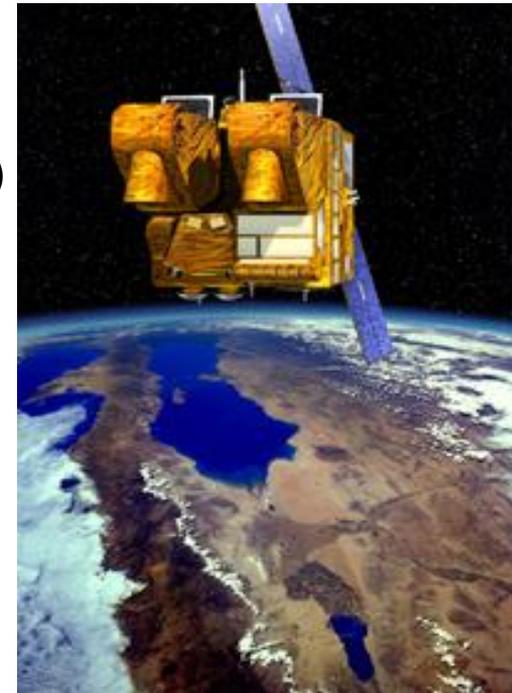
## □ Objective

- **To maintain best image quality (sharpness)**
  - **Periodical assessment of cameras MTF during satellite life**
    - » **To verify cameras requirements**
  - **Assessment of possible slight defocusing**
    - » **To propose refocusing, if any**
  - **MTF assessment after refocusing**
    - » **To verify MTF increase**

- ❑ Spot 5 cameras outline
- ❑ MTF assessment methods
  - Absolute
  - Relative
- ❑ MTF results over the years
  - Field center, right field
- ❑ Defocusing assessment methods
- ❑ Results of defocusing assessment
- ❑ MTF results after refocusing
- ❑ Summary

## □ Main features of SPOT 5

- Two cameras (HRG)
  - Pointing mirrors to set viewing angle
- THR (2.5m), **HM (5m)** **B1**, **B2**, **B3** (10m), **B4** (20m)
  - HM used for MTF quality control
- Panchromatic mode HM : two linear arrays
  - HMA and HMB shifted 0.5 pixel (cross-track) and 3.5 pixel (along track)



## □ Absolute MTF

- Measurement of Modulation Transfer Function  
→ MTF value at Nyquist frequency
- Slanted edge method
- Artificial checkerboard target

## □ Relative MTF

- Comparison of two HRG cameras
  - Both cameras image the same landscape

# Absolute MTF measurement method

- ❑ Artificial edge target
  - Salon de Provence (south of France)
  - 60m x 60m
  - White:  $\rho = 0,50$  - Dark:  $\rho = 0,05$
  - Inclination versus satellite track :  $\sim 18^\circ$

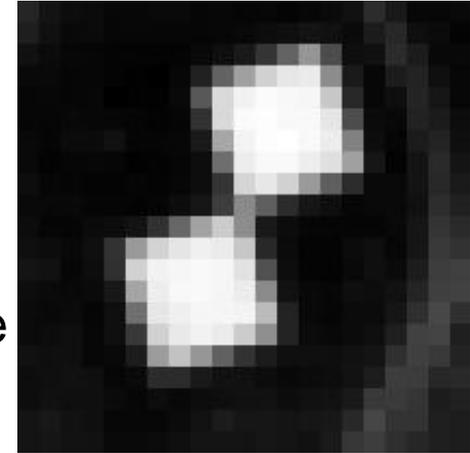


**SPOT5 HRG1 (THR)**



## ❑ Slanted edge method

- Due to inclination angle
  - 3 lines needed for oversampling purpose
- Due to the PSF width
  - Only 2 lines available without side effect from other squares or surrounding area
- One point out of three is missing in ESF
  - Missing points obtained by spline interpolation
- MTF obtained by calculating the ratio of FFT of ESF to FFT of Heaviside function
- Mean of upward and downward edges
- Mean of HMA and HMB results

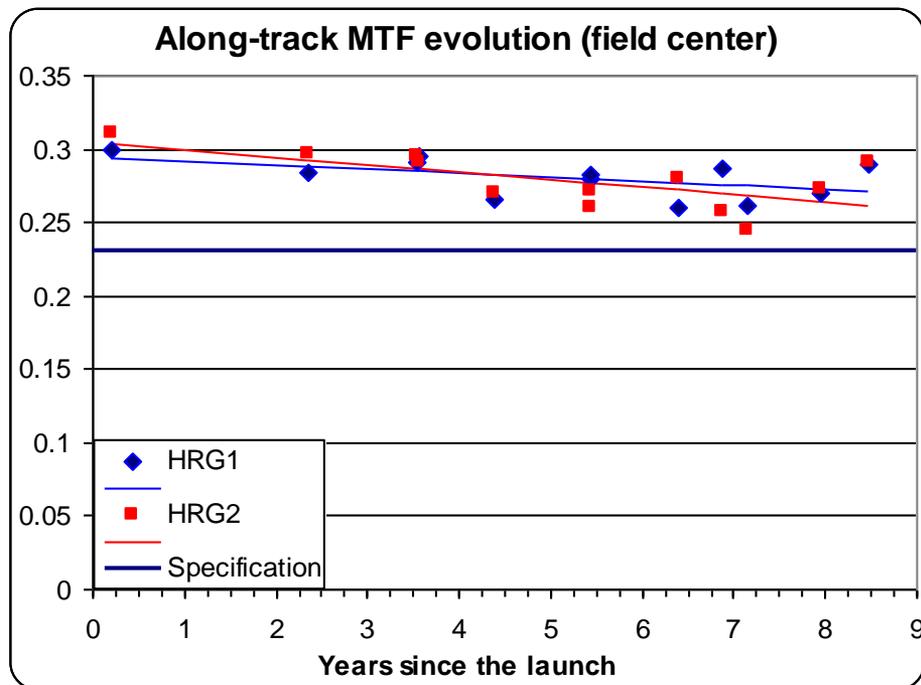
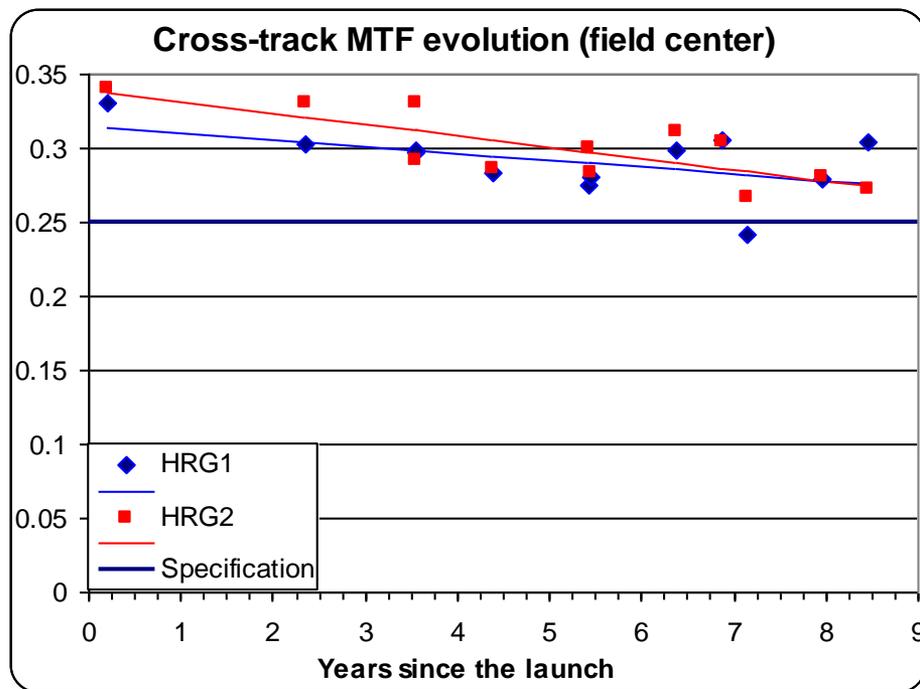


- Comparison of frequency content of two HRG images
    - Both cameras image the same landscape
      - Landscapes with a large frequency content (e.g. big cities)
    - Frequency content comparison between homologous areas
      - Field center, field edges
- |      |   |  |   |  |   |
|------|---|--|---|--|---|
| HRG1 | L |  | C |  | R |
| HRG2 |   |  |   |  |   |
- Integration of image spectra near  $0.3 f_s$ 
    - » From  $0.25 f_s$  to  $0.35 f_s$
  - Calculation of MTF ratio HRG2/HRG1

# MTF assessment results

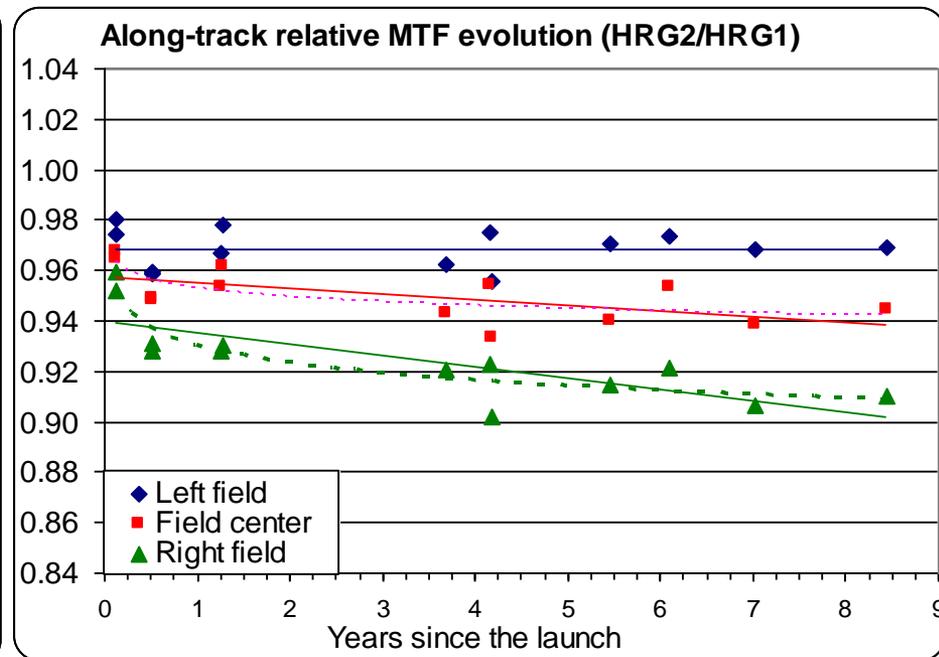
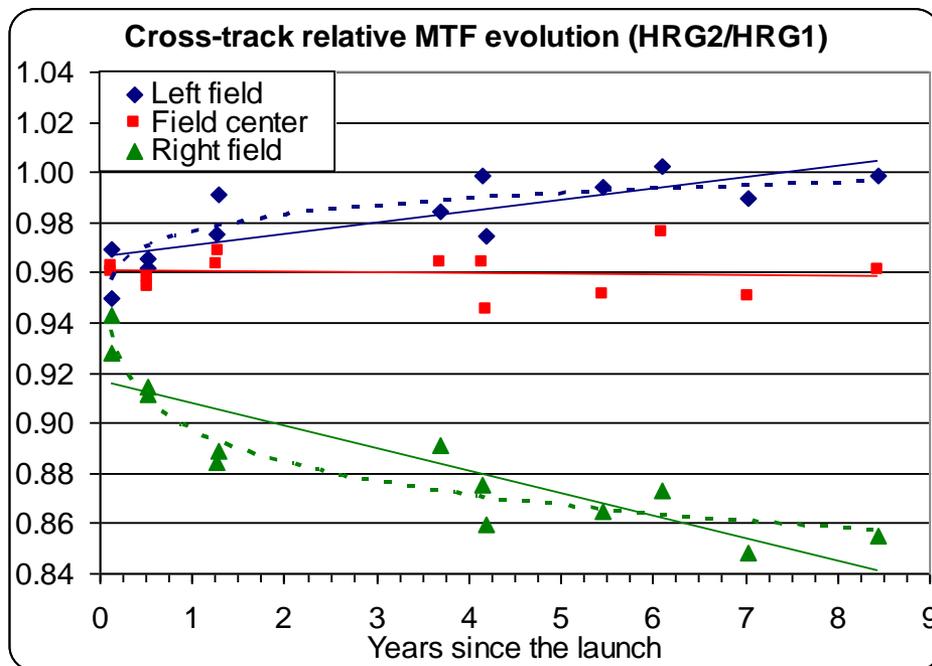
## □ Absolute MTF – field center (2002-2010)

- Slight decrease since the beginning of life
- It remains above requirement specification



# MTF assessment results

- Relative MTF – field center and two field edges
  - Decrease of right field value (cross-track direction)  
→ Absolute measurement MTF since 2008

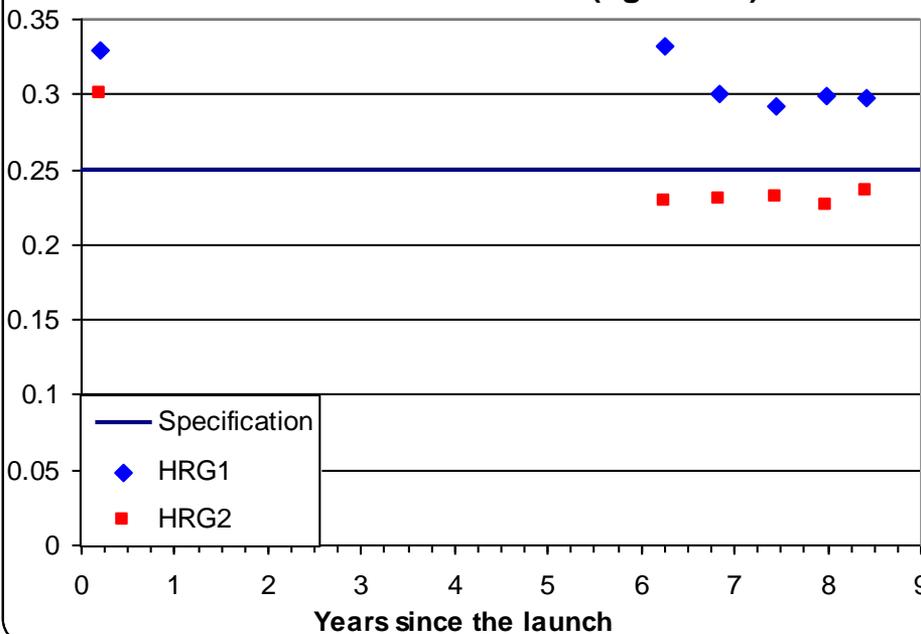


# MTF assessment results

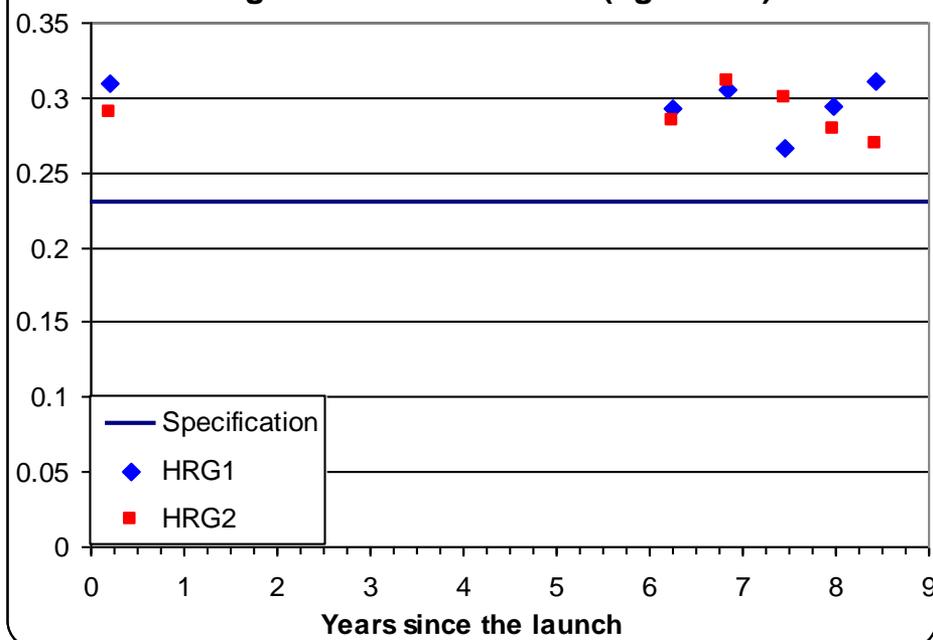
## □ Absolute MTF – right field (2008-2010)

- Decrease in cross-track direction compared to the beginning of life
- It has become slightly under requirement specification

Cross-track MTF evolution (right field)



Along-track MTF evolution (right field)

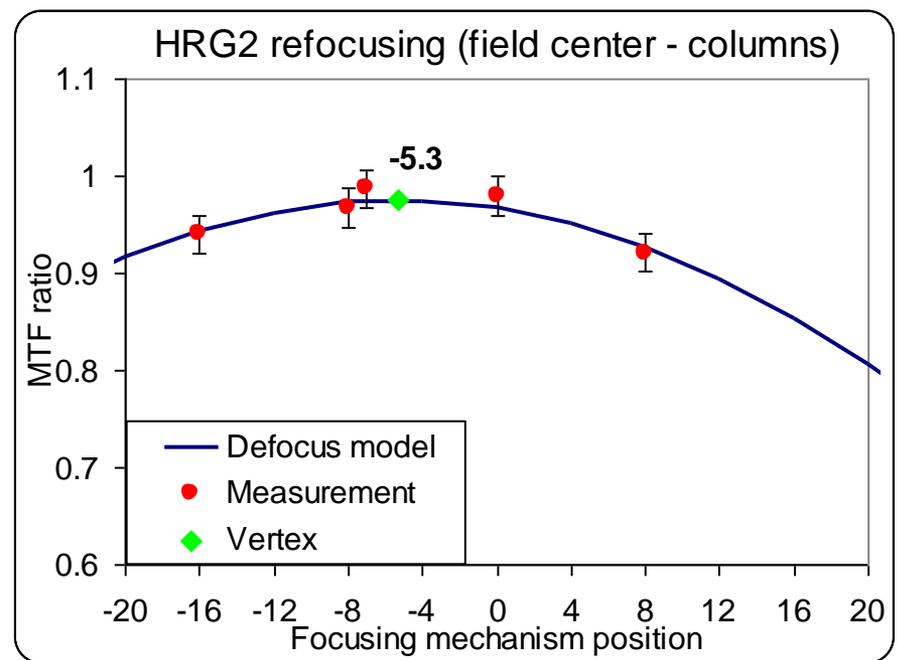
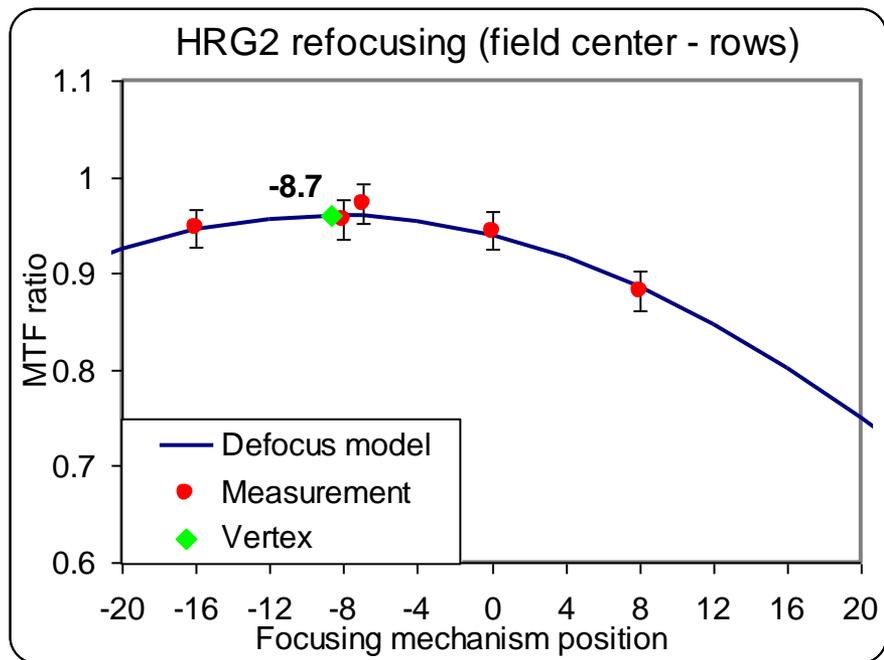


- ❑ With refocusing mechanism activation
  - Relative MTF for several mechanism positions of **one** camera
  - Method used in the commissioning phase
  - Precise measurements of best focus position
  - Too cumbersome in commercial context
  
- ❑ Without refocusing mechanism activation
  - Use of an onboard test target (autotest)
  - Defocus estimate using a focusing model
    - Combining initial focusing measurements and observed MTF decrease

# Refocusing in the commissioning phase

## □ Results of HRG2 refocusing operations (2002)

- Best focus (field center):  $p_0 -7$ 
    - Astigmatism: -3
- (one focusing step =  $1.2 \mu\text{m}$ )



# Refocusing in the commissioning phase (full results)

## Best focus vs field area with respect to p0

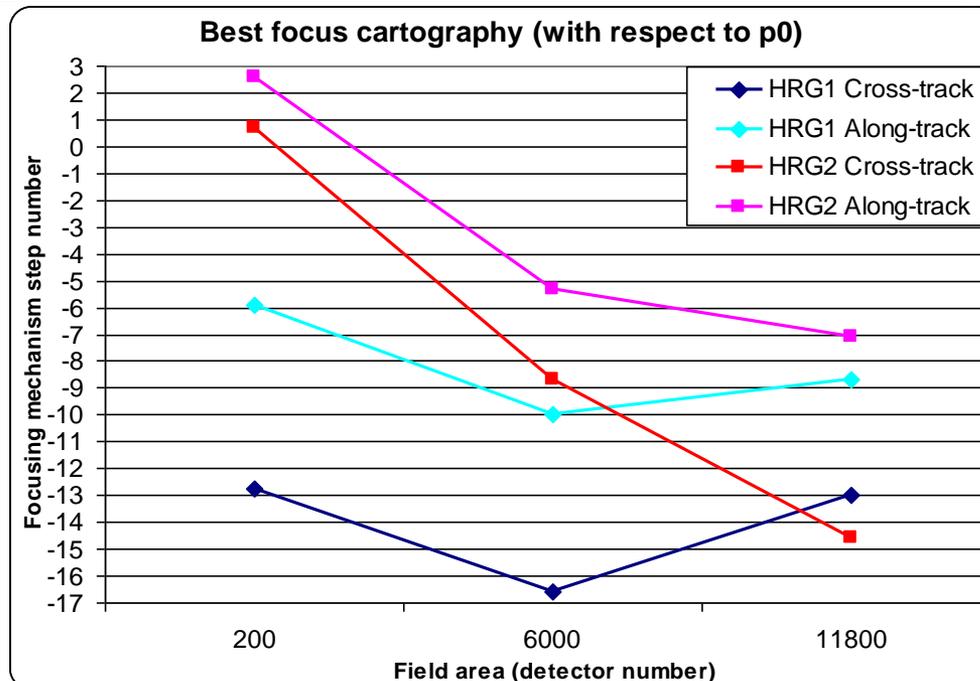
- Astigmatism and field curvature different between instruments

Field area	HRG1			HRG2		
	Left	Center	Right	Left	Center	Right
Cross-track	-13	-17	-13	1	-9	-15
Along-track	-6	-10	-9	3	-5	-7
Mean	-9	-13	-11	2	-7	-11

Final focusing

HRG1: p0-12

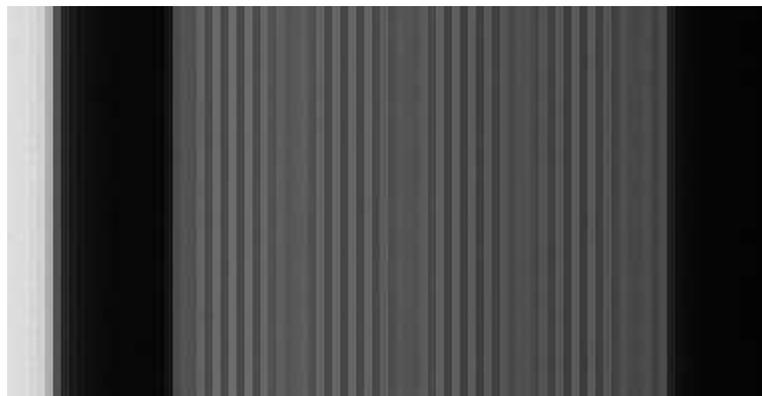
HRG2: p0-7



- Defocusing assessment methods
  - HRG2 "Autotest"
    - Use of an on-board target
  - HRG2 absolute MTF
  - HRG1 and HRG2 relative MTF

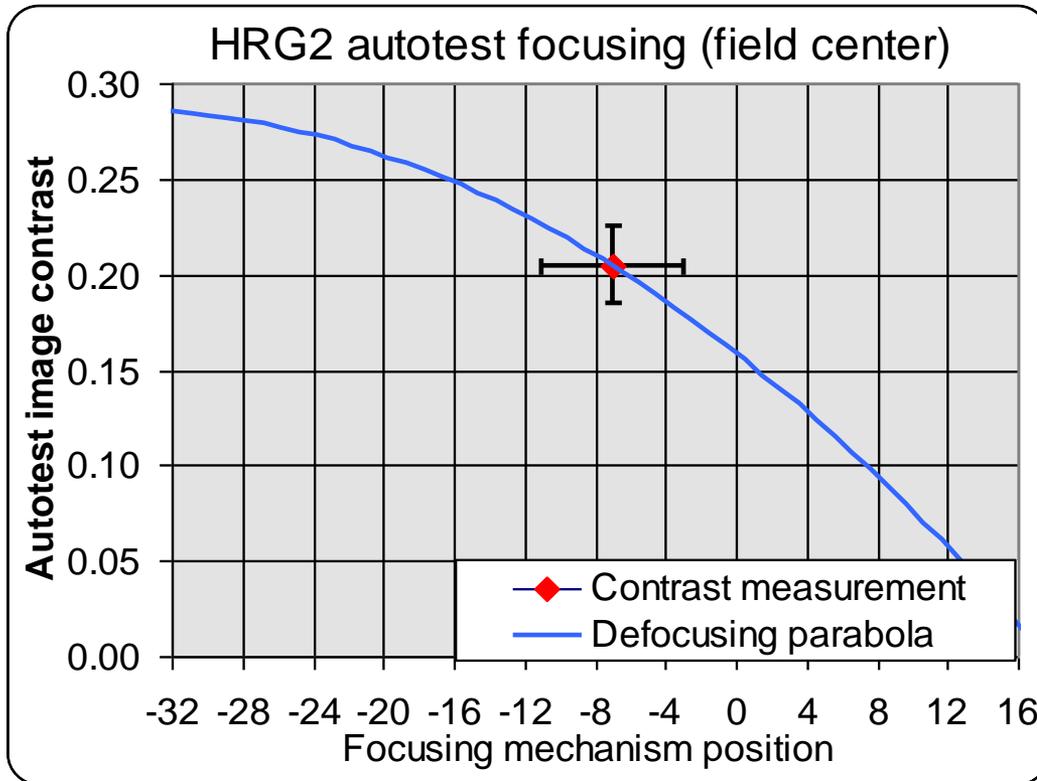
# Defocusing assessment (autotest method)

- ❑ "Autotest" is a method to check the focusing monthly
  - a periodic pattern (autotest) located in the focal plane is imaged on the HM array
  - the image contrast is maximum for the best focus
  - as the pattern frequency is near to the Nyquist frequency, there is a moiré effect in the image
    - the maximum contrast area must be searched
  - the autotest is not exactly in the focal plane
    - difference between camera focusing and autotest focusing



# Defocusing assessment (autotest method)

- The autotest pattern is imaged without any focusing mechanism movement
- We merely measure the autotest image contrast

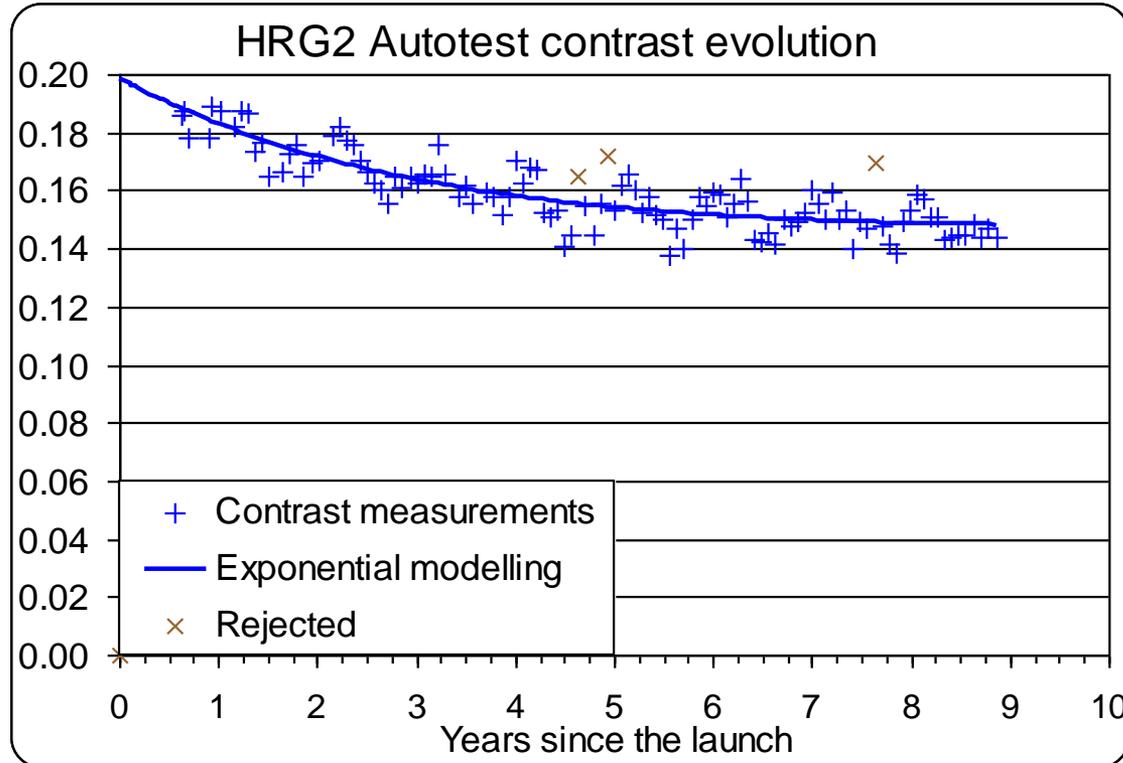


- A contrast change should point a variation of camera focusing
- The sensitivity is :  
contrast variation 0.01  
⇔ 2 focusing steps

# Defocusing assessment (autotest method)

## □ Evolution of autotest contrast

- Decrease 0.04 since the beginning of measurements
- Corresponding to 8 steps focusing change



# Defocusing assessment (using HRG2 absolute MTF)

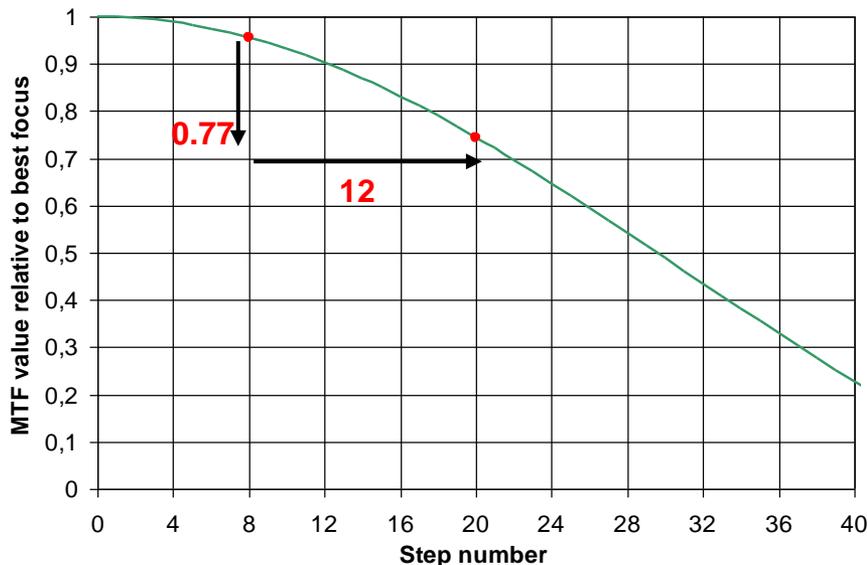
## Defocus after initial focusing

HRG2		
Field area	Center	Right
Cross-track	-2	-8
Along-track	2	0

## MTF evolution (2002 – 2010)

HRG2		
Field area	Center	Right
Cross-track	0.81	0.77
Along-track	0.86	0.99

MTF decrease versus defocusing ( $f_s = 0.5$ )



## Defocusing evaluation

HRG2		
Field area	Center	Right
Cross-track	-15	-12
Along-track	-16	-4

Mean : -12

Some discrepancies

## Defocusing assessment (using relative MTF)

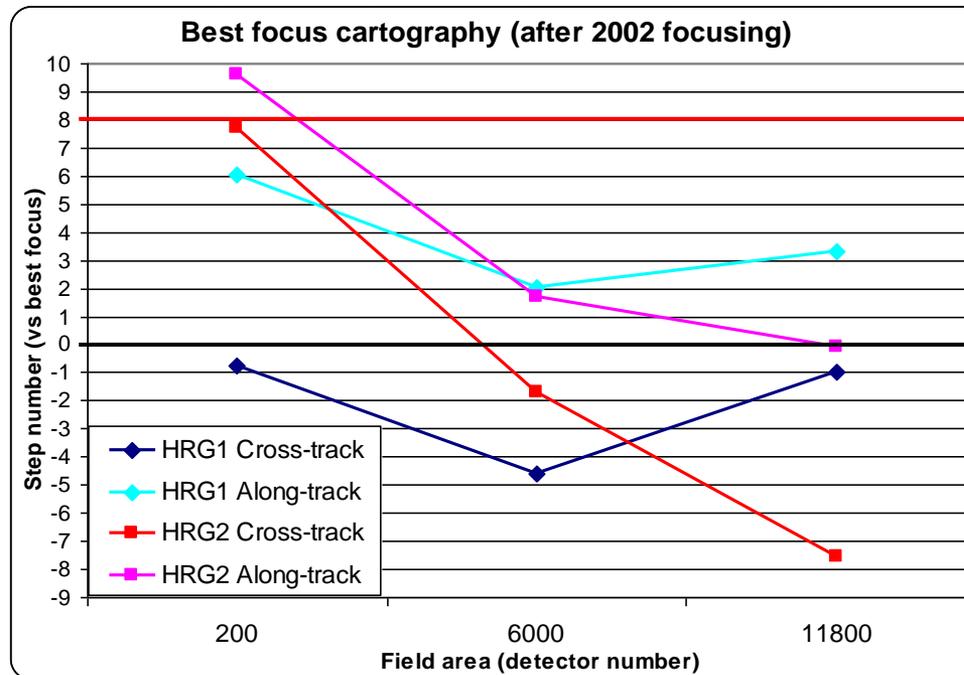
- ❑ Difficult to analyze two instruments together
- ❑ Need to have an hypothesis about HRG1
  - HRG1 absolute MTF shows also defocusing
  - Absolute MTF not precise enough to assess HRG1 defocusing
  - We do suppose similar defocusing for HRG1 and HRG2
  - Relative MTF evolution is observed because of differences between initial focusing due to astigmatism and field curvature

# Defocusing assessment (using relative MTF)

- Best focus vs field area with respect to mean best focus after 2002 focusing

Field area	HRG1			HRG2		
	Left	Center	Right	Left	Center	Right
Cross-track	-1	-5	-1	8	-2	-8
Along-track	6	2	3	10	2	0
Mean	3	-1	1	9	0	-4

Best focus  
 HRG1: p0-12  
 HRG2: p0-7



8 step defocus

Best focus

# Defocusing assessment (using relative MTF)

## □ Evaluation algorithm

- Supposing mean defocus of  $p$  steps
- Calculating defocusing for each field area
- Calculating MTF evolution using defocus modelling
  - *Steel, W. H., Optica Acta (1956)*
- Calculating relative MTF
- Searching  $p$  for best fitting between calculated relative MTF and measured relative MTF

## □ Result of assessment

- $p = 10$

# Defocusing assessment (using relative MTF)

Defocus vs field area for  $p = 8$

Field area	HRG1			HRG2		
	Left	Center	Right	Left	Center	Right
Cross-track	-9	-13	-9	0	-10	-16
Along-track	-2	-6	3	2	-6	-8

MTF evolution

Field area	HRG1			HRG2		
	Left	Center	Right	Left	Center	Right
Cross-track	0.977	0.959	0.977	1.019	0.972	0.945
Along-track	1.009	0.991	0.995	1.028	0.991	0.982

Calculated relative MTF evolution

Field area	Left	Center	Right
Cross-track	1.04	1.01	0.97
Along-track	0.95	0.97	1.00

Measured relative MTF evolution

Field area	Left	Center	Right
Cross-track	1.04	1.00	0.91
Along-track	0.99	0.97	0.95

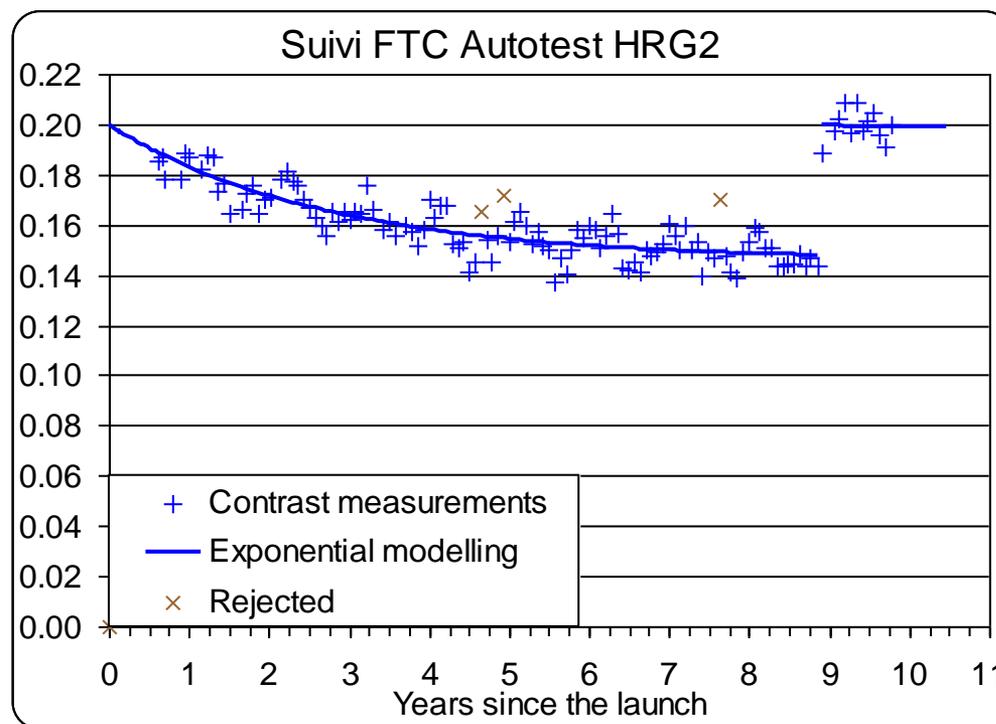
# Defocusing assessment (synthesis)

- ❑ Three defocusing assessment methods
  - Results from 8 to 12 steps
    - Autotest contrast evolution → 8
    - Absolute MTF evolution → 12
    - Relative MTF evolution → 10
  - Each method not quite precise, but rather coherent results
- ❑ Decision about refocusing by CNES
- ❑ Strategy
  - Moving focusing mechanism cautiously
    - Minimum value refocusing
  - If not enough, second refocusing
    - Choice of refocusing HRG2 using a value of – 8 steps
    - HRG2 refocused 1<sup>st</sup> april 2011

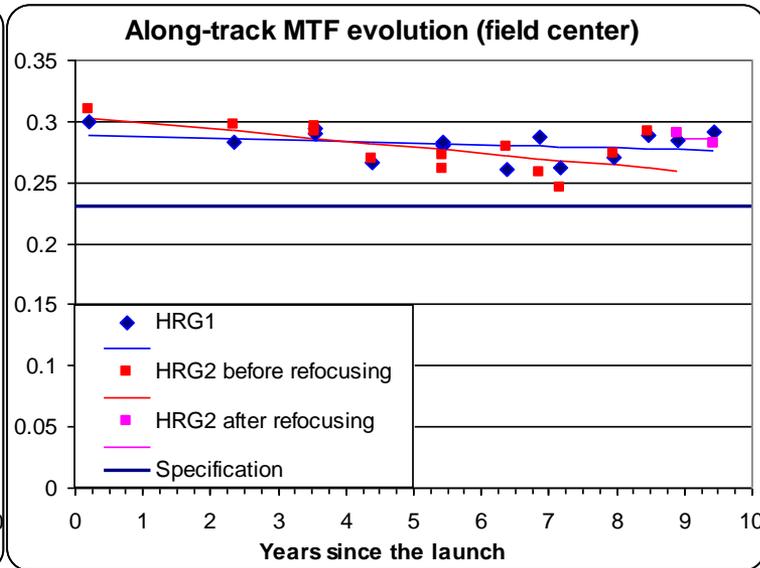
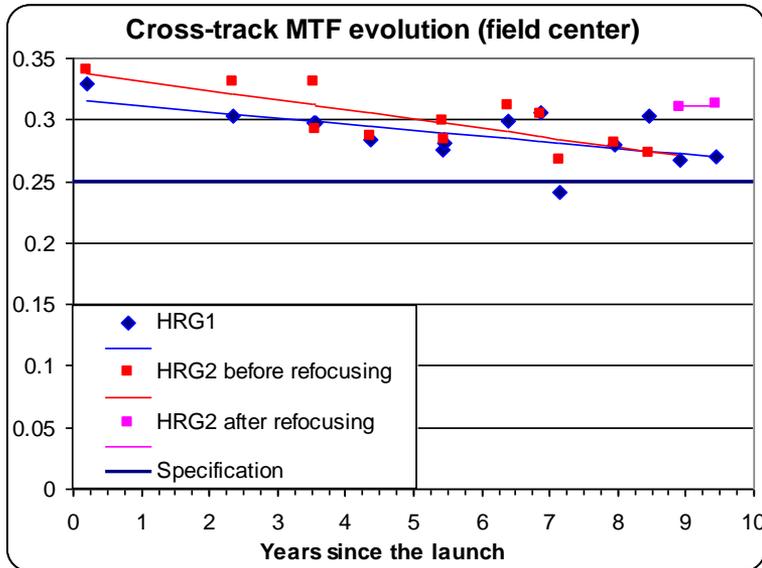
# Refocusing results : autotest contrast

## □ Evolution of autotest contrast

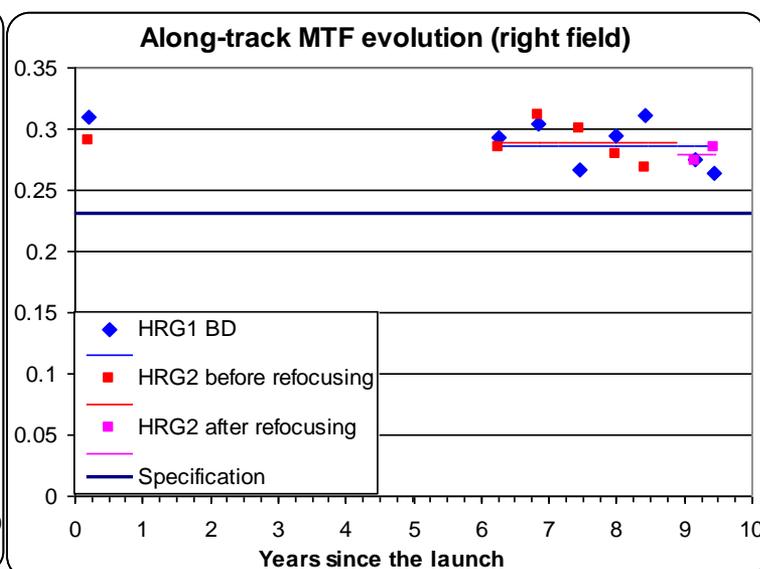
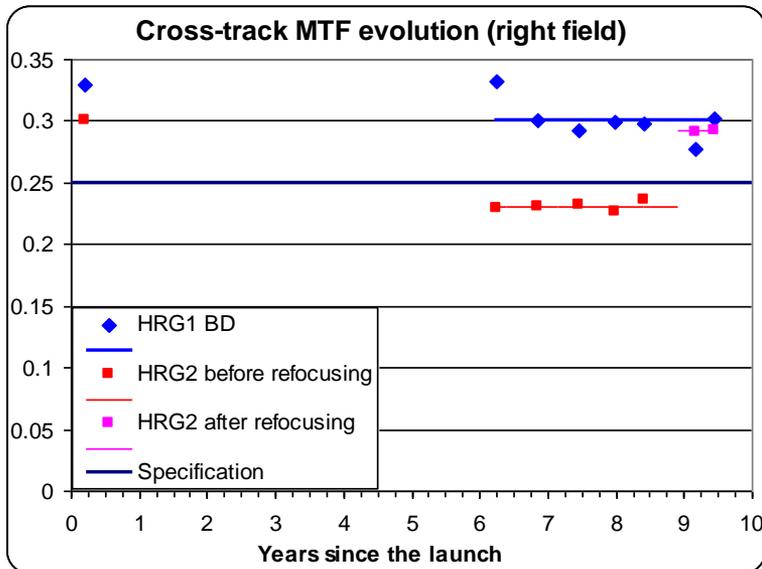
- Increase 0.05 after refocusing
  - Shows a small error about sensitivity
  - contrast variation 0.01  $\leftrightarrow$  1.6 focusing steps
- Return to initial level



# Refocusing results : absolute MTF



Increase of field center MTF value

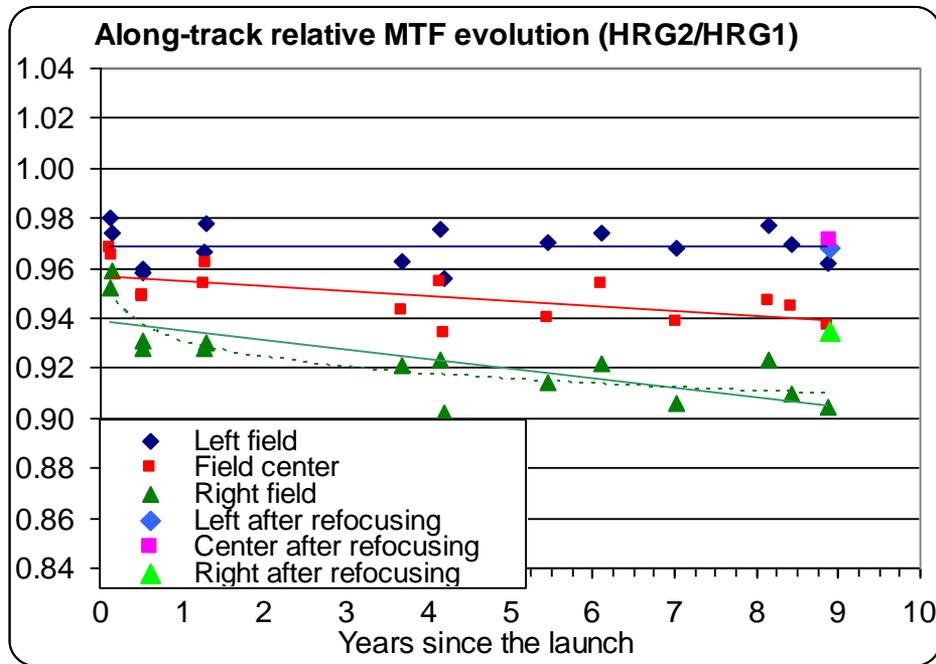
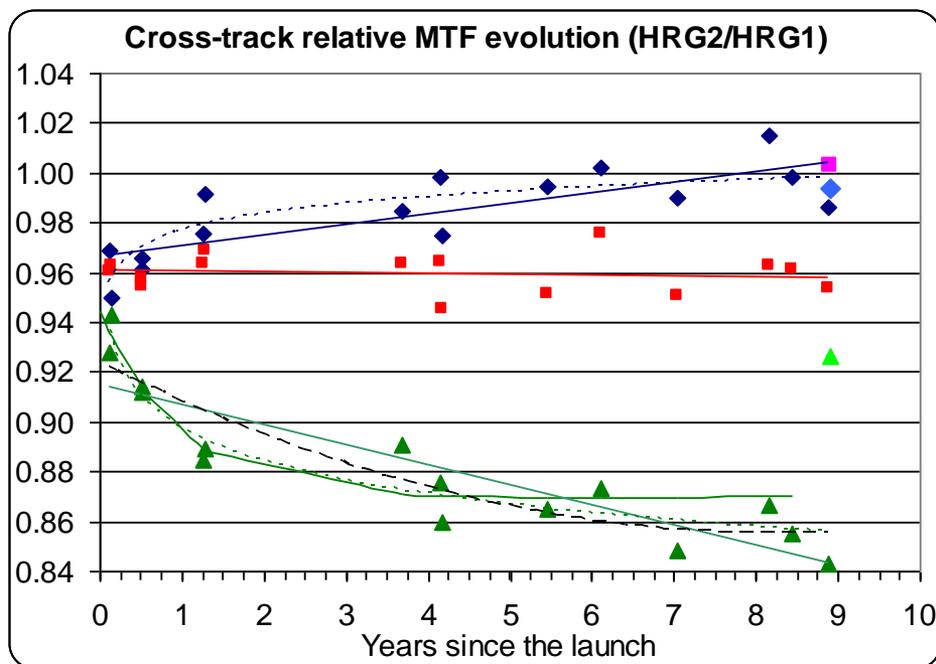


Return to initial level for cross-track right field MTF value  
→ above specification

# Refocusing results : relative MTF

## Relative MTF – field center and two field edges

- Increase of right field value (cross-track direction)
- Also increase of field center value



# Summary

- Periodical cameras MTF assessment showed a slight defocusing for HRG2 (2002 -2010)
- Defocusing value assessed combining several methods
- MTF assessment after refocusing shows refocusing is sufficient
  - HRG2 MTF specification is again satisfied in the whole field
- MTF HRG1 specification is satisfied, therefore no refocusing is needed
- Autotest method is specific to SPOT 5 satellite
- Relative MTF measurement is easy to use because of two cameras
- Relative MTF method could also be applied with nimble satellites, e.g. Pleiades

# Acknowledgement - References

## □ Grant

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## □ Acknowledgement

- The author is grateful to Françoise Viallefont for all the works done together in the field of MTF and defocusing assessment

## □ References

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