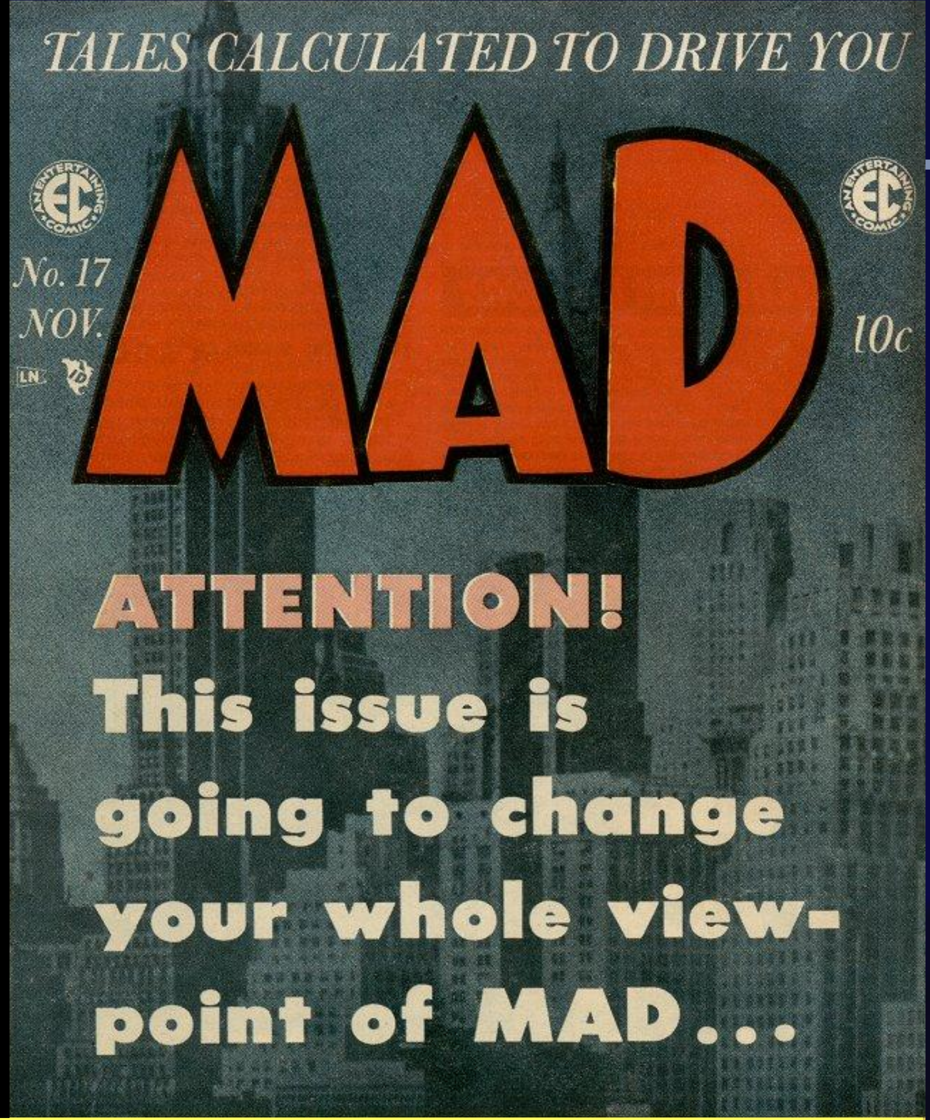


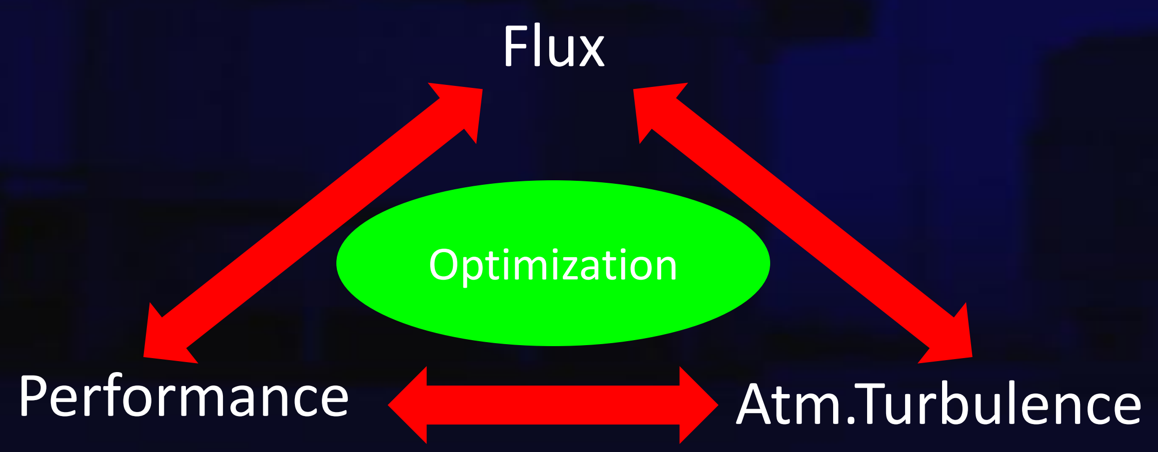
E.Marchetti, J.Kolb, E.Fedrigo

MAD Upgrade proposal

Concept & correction performance

The problem

- Main limitation of Natural Guide Star AO based instrumentation (MAD included): low Sky Coverage → small number of accessible targets
- Culprit: wavefront sensing
  - Balance between photon flux per sub-aperture and degree of correction
  - Noise (Read-Out Noise) in the wavefront sensor detectors
- Signal drowning in the noise → Limiting Magnitude

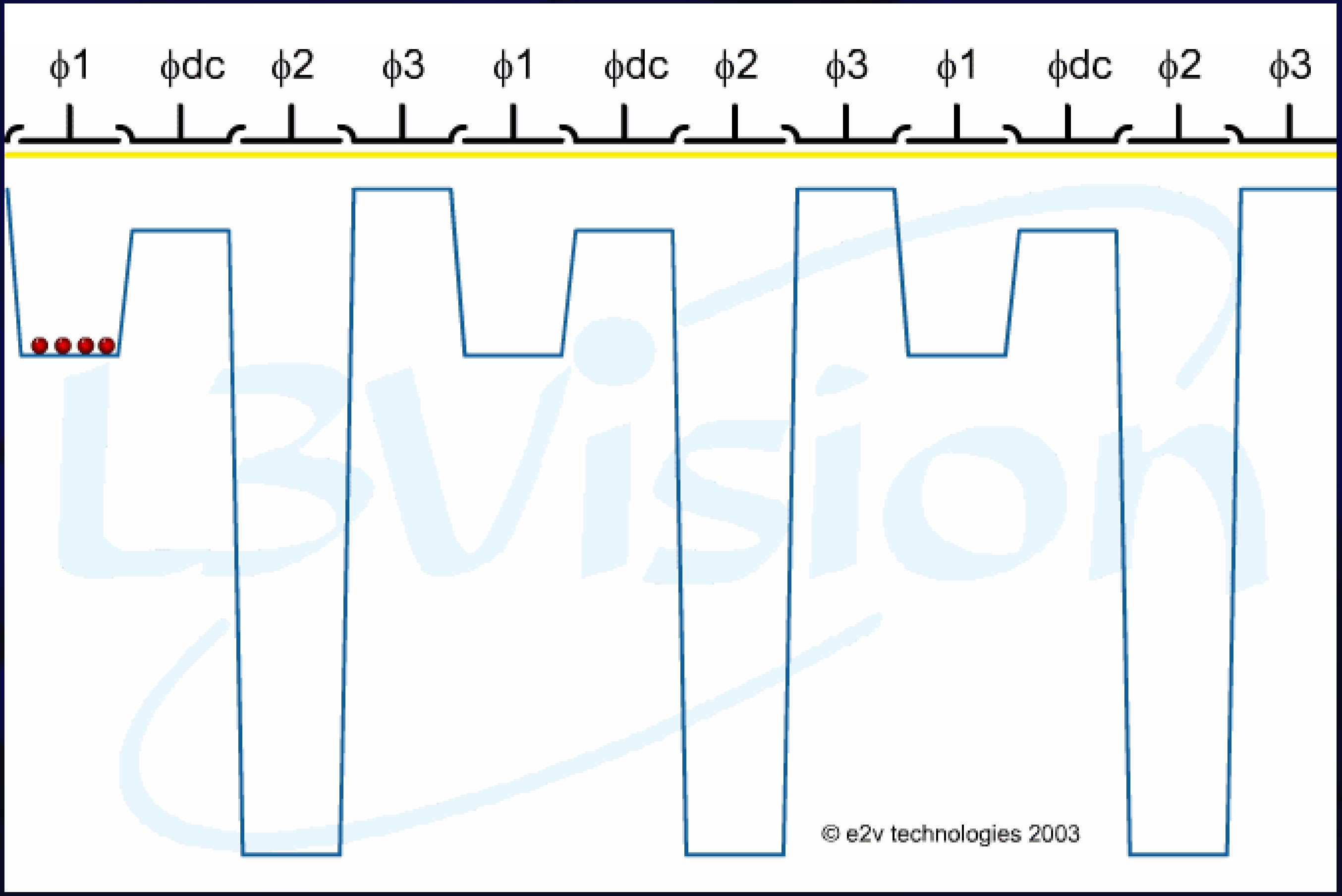


Pushing the MAD limiting magnitude

- Improve detection efficiency of the Shack-Hartmann wavefront sensors
  - Increase throughput → technically very difficult, limited gain margin
  - Lower detector Read-Out Noise → technically available, large gain
- EMCCDs commercially available on market: ANDOR Technology (iXon^{EM} + 860), equivalent sub-electron Read-Out Noise
- Proposal: substituting actual MAD wavefront sensor detectors system with EMCCDs from ANDOR
- Constraint: no or minimal impact for all other MAD subsystems
- Not discussed here: upgrade schedule

EMCCDs working principle

- Gain register before output amplifier: signal amplification by impact ionization



Detector cameras comparison

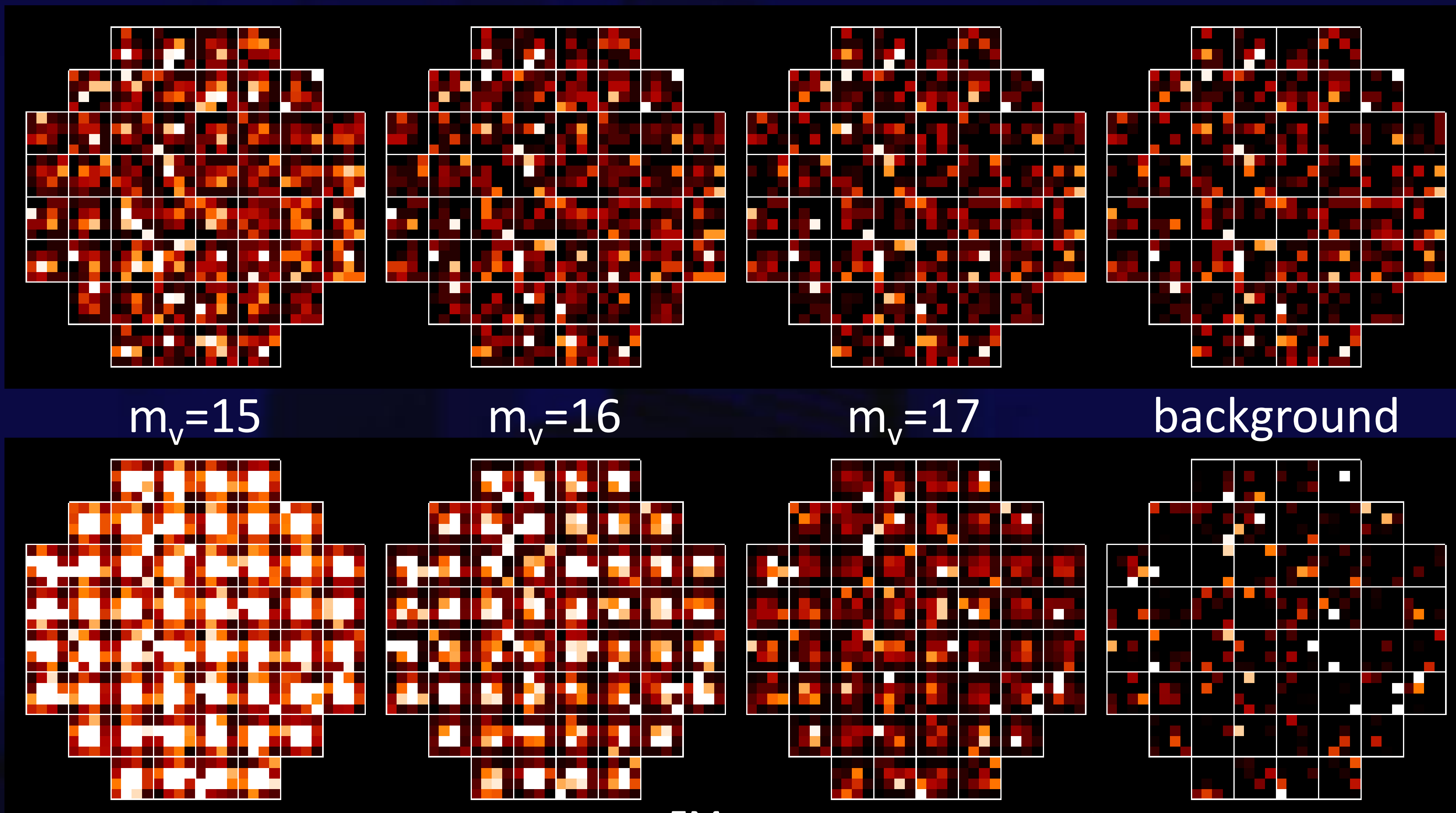
MAD CCD39

ANDOR iXon^{EM} + 860 (EMCCD)

Parameter	MAD	ANDOR iXon^{EM} + 860
Detector type	CCD39	CCD60
Pixel size	24 μm	24 μm
Detector format	80 $\times$ 80	128 $\times$ 128
RON	7 e^-/pixel	0.07 e^-/pixel
Dark current	100 e^-/pixel/s	0.03 e^-/pixel/s
Clock Induced Charge (CIC)	-	0.2 e^-/pixel/frame
Frame rate	383 frames/s	500 frames/s
Excess noise factor	-	sqrt(2)
Temperature	-20° C	-85° C

Laboratory comparison (no turbulence)

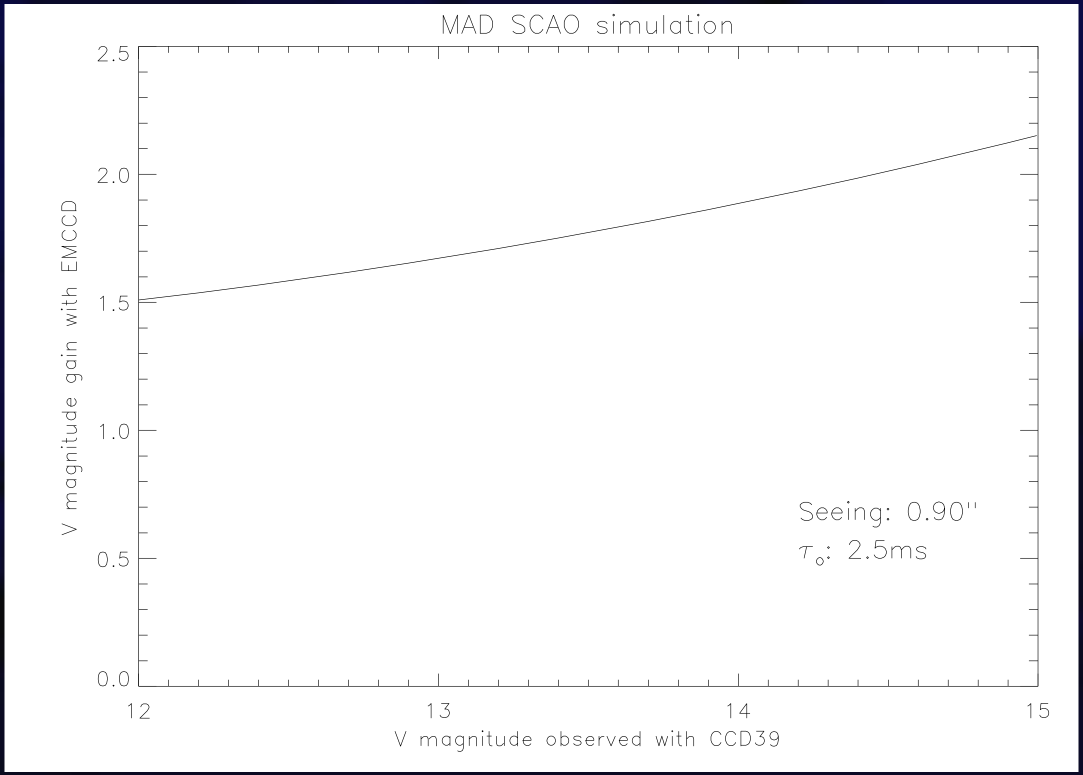
MAD CCD39



ANDOR iXon^{EM} + 860 (EMCCD)

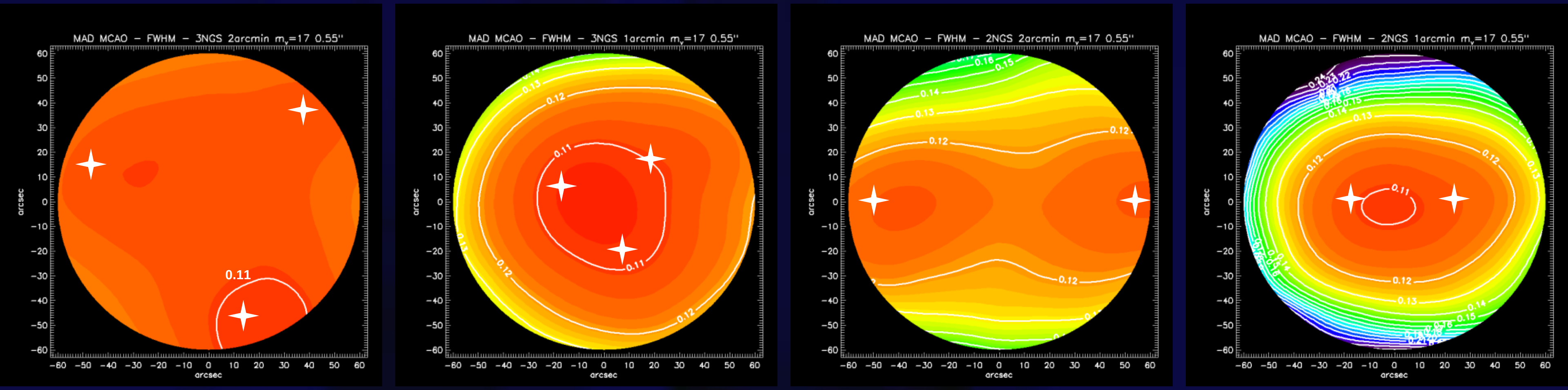
Simulated performance

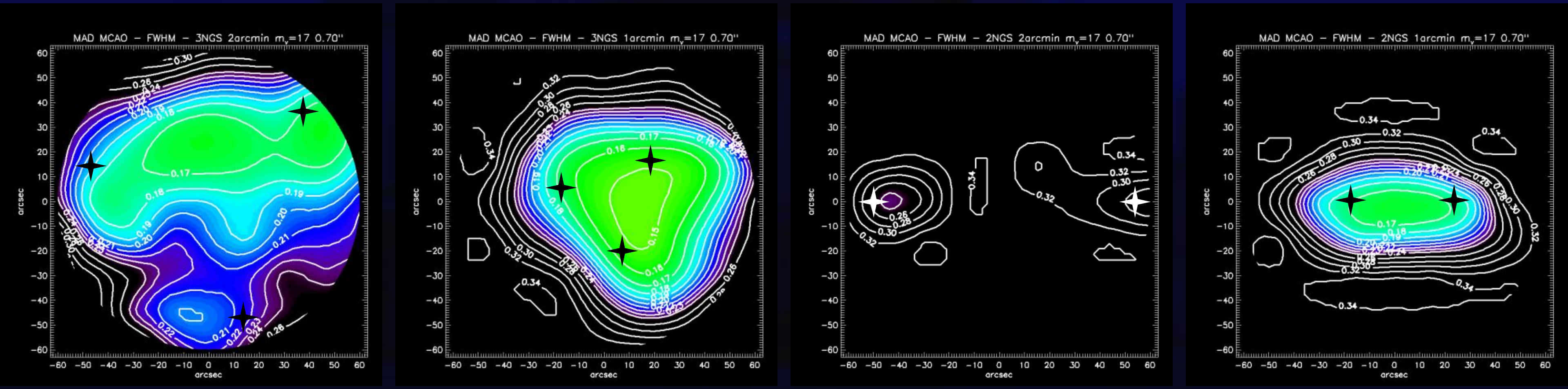
- Numerical end-to-end code (YAO)
- Calibrated with MAD on-sky results
- Several case studies: number of guide stars (2→3), magnitudes (15→17), FoV (1'→2') and DIMM seeing conditions (0.55"→0.9")



Simulated performance (K band): $m_V = 17$

DIMM seeing: 0.55”

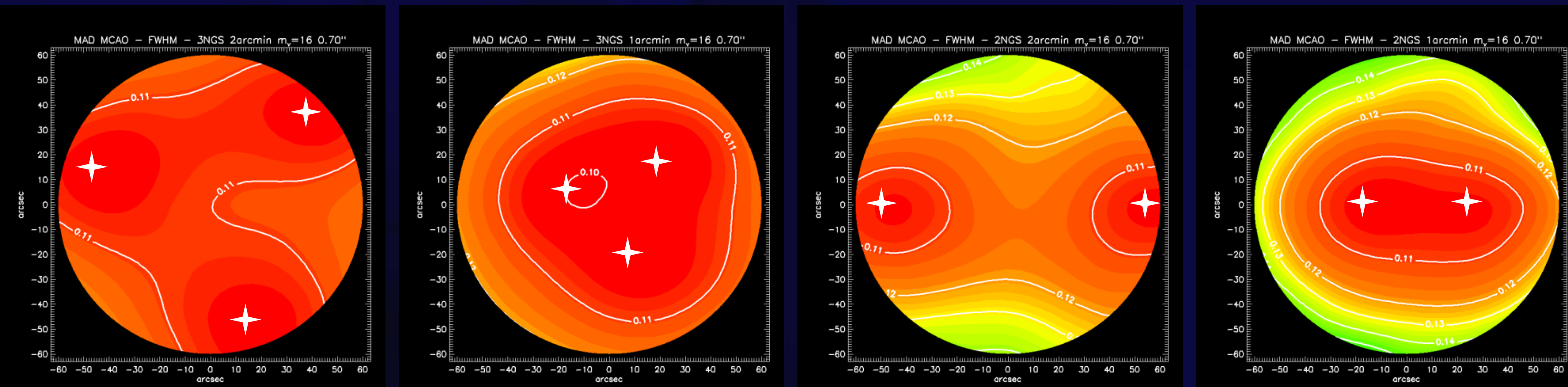


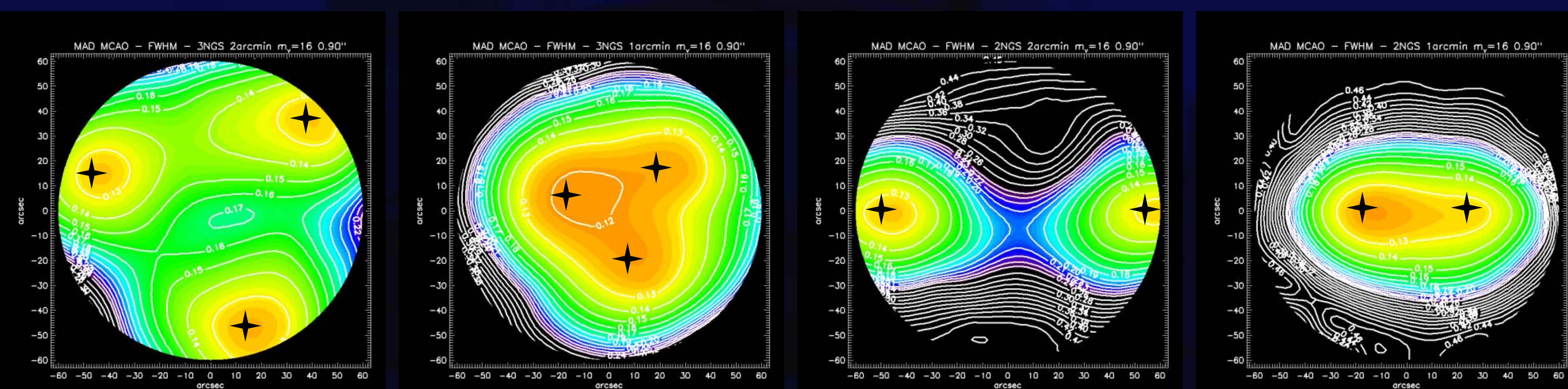


DIMM seeing: 0.70”

Simulated performance (K band): m_v= 16

DIMM seeing: 0.70”

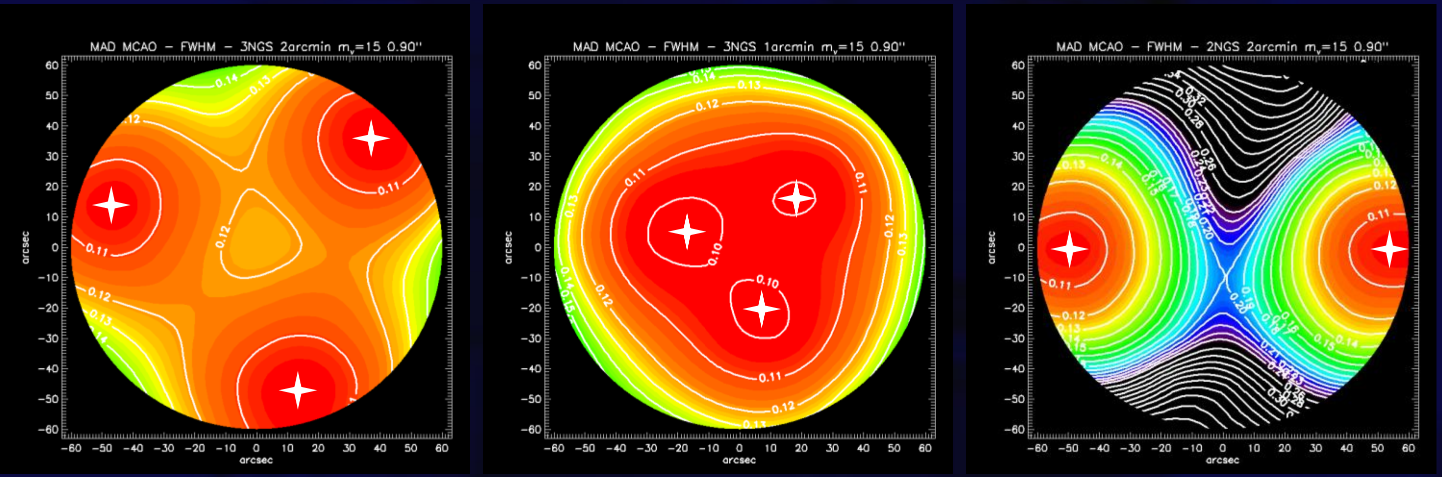




DIMM seeing: 0.90”

Simulated performance (K band): m_v= 15

DIMM seeing: 0.90”



Caveat on wavefront sensing

Spectral type	V magnitude difference at fixed Zero Point
B0V	-0.4
B5V	-0.3
A0V	-0.2
F0V	-0.1
G0V	0.0
K0V	+0.1
K5V	+0.3
M0V	+0.5

Influence of the Moon (ph/px/frame)						
Days	d=90º	d=75º	d=60º	d=45º	d=30º	d=15º
4	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.1	0.1	0.1	0.1
11	0.1	0.1	0.1	0.2	0.2	0.4
15	0.2	0.2	0.3	0.5	0.7	1.0

Other considerations

- Correction at different wavelengths
  - AO performance worsen at shorter wavelengths
  - Not enough statistics to accurately calibrate Strehl ratio and FWHM values

Band	FWHM
J	K x 2 … K x 3
H	K x 1.5 … K x 2

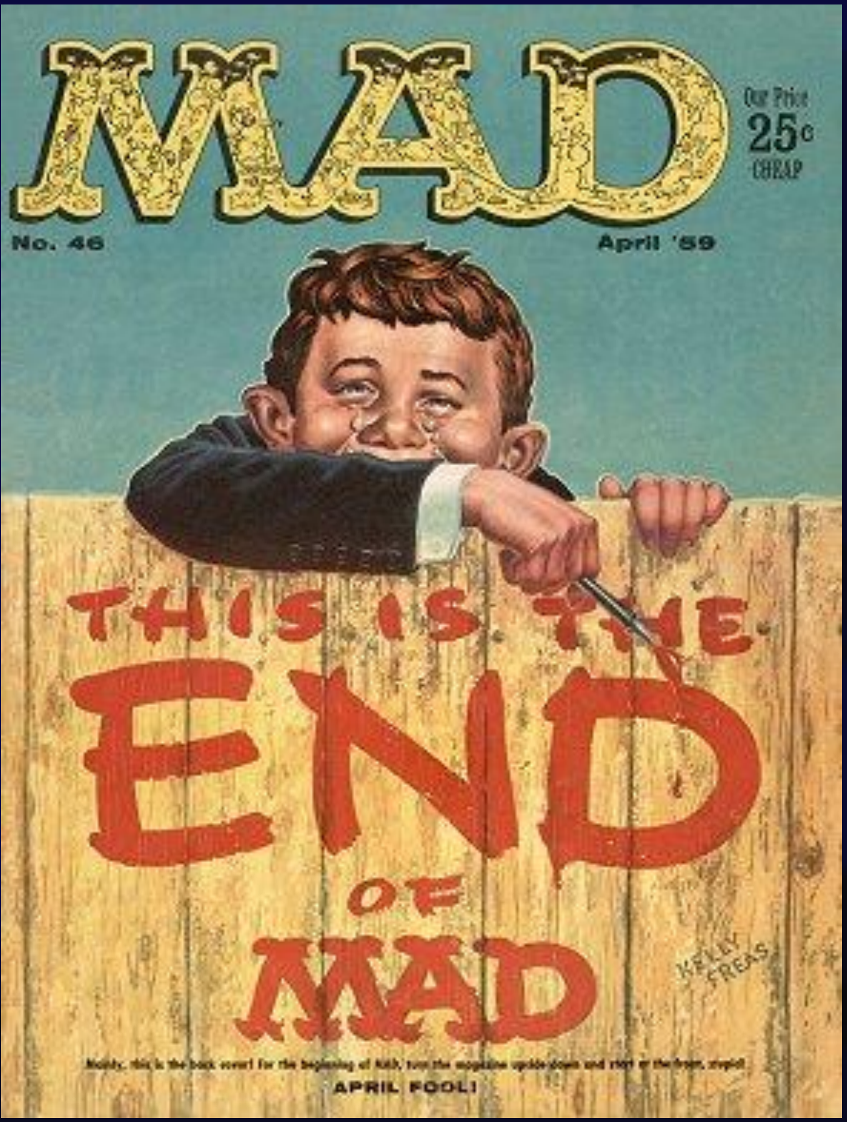
- CAMCAO exposure time calculation
  - No internal study performed
  - Rely on feedback from Science Demonstration users

Other functional upgrades

- Motorization of CAMCAO filter wheel (painful operations during SD…)
- New and/or additional CAMCAO IR filters
  - Feedback from potential users required
- Optimization of CAMCAO read-out modes
  - Improve data quality and optimize observing time
- FITS headers improvement
  - Feedback from potential users required
- New acquisition and observing templates

- *Acquisition time reduction (~2min) by optimization of opto-mechanics at wavefront sensor area (coming with detector upgrade)*

… a name



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