Deep & Accurate NIR Photometry in Crowded Fields: Why?

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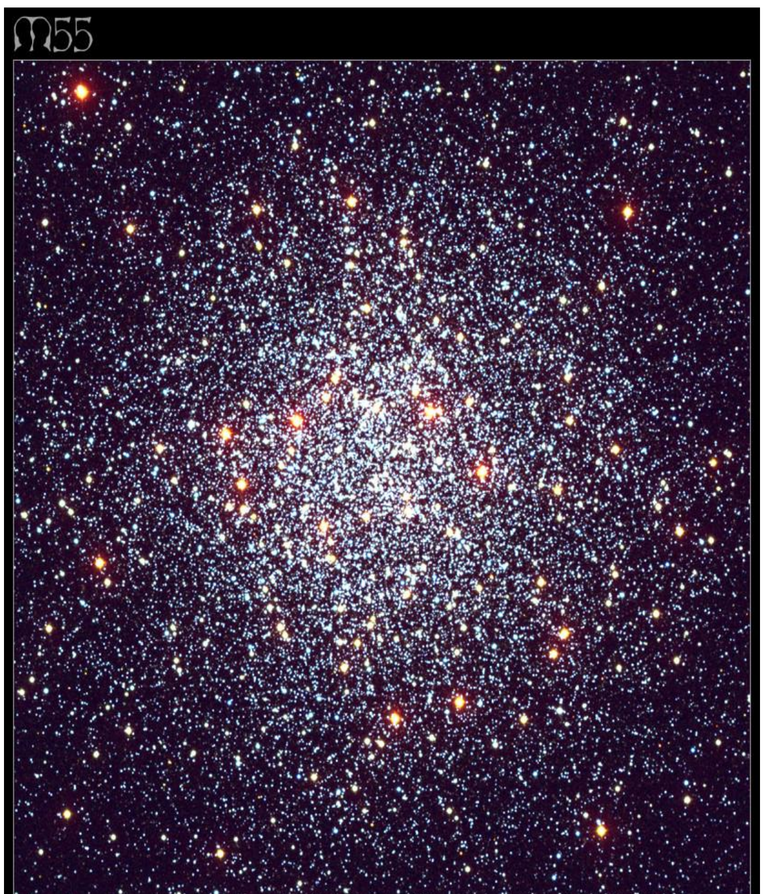
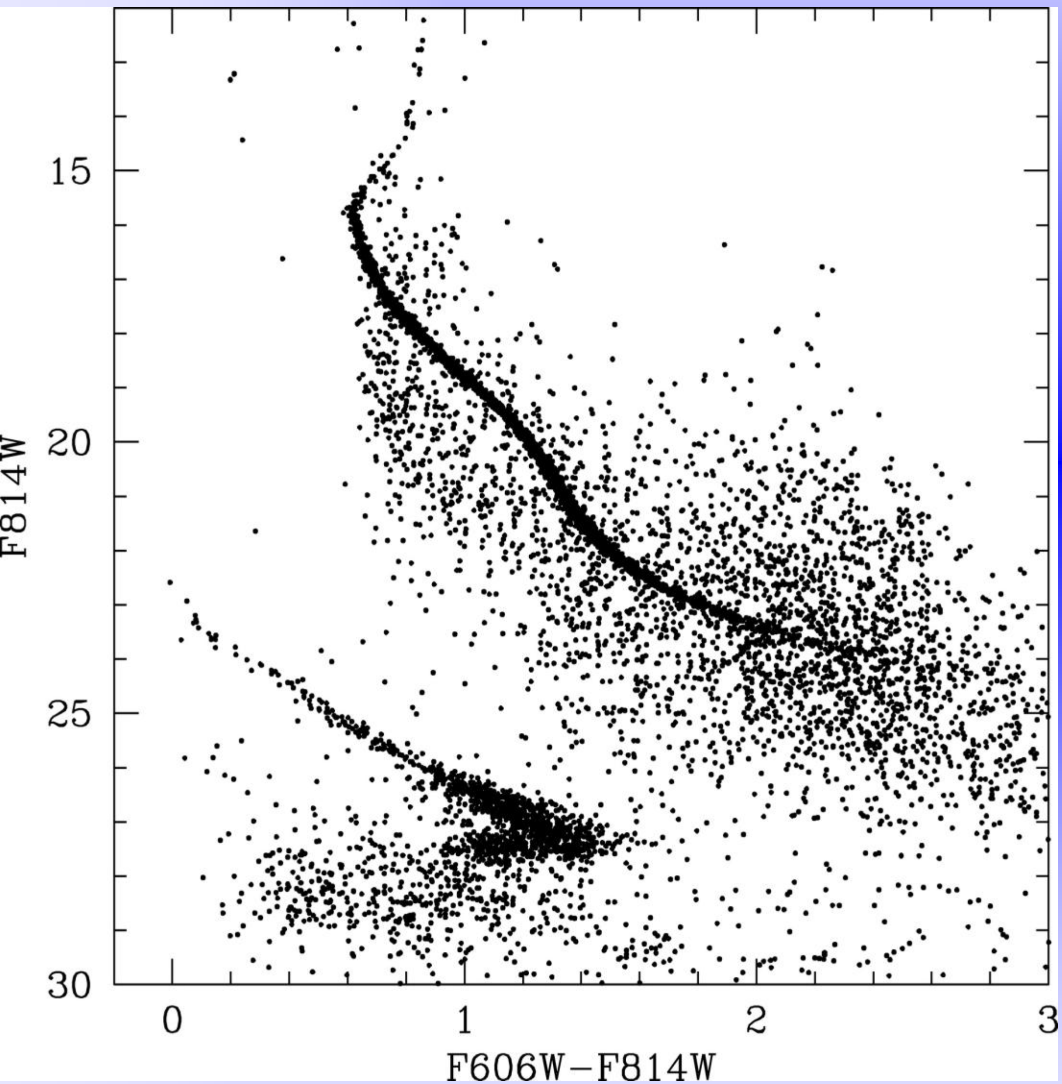
+ P. Amico, A. Calamida, E. Marchetti + ESOens



OUTLINE OF THE TALK

- → Introduction
- → Absolute ages of GCs
- → NACO vs MAD photometry
- → Conclusions

Popular stellar clocks



Absolute ages of stellar systems (GC, Old/Interm. OCs)

#) MS Turn-Off

#) WD Turn-off

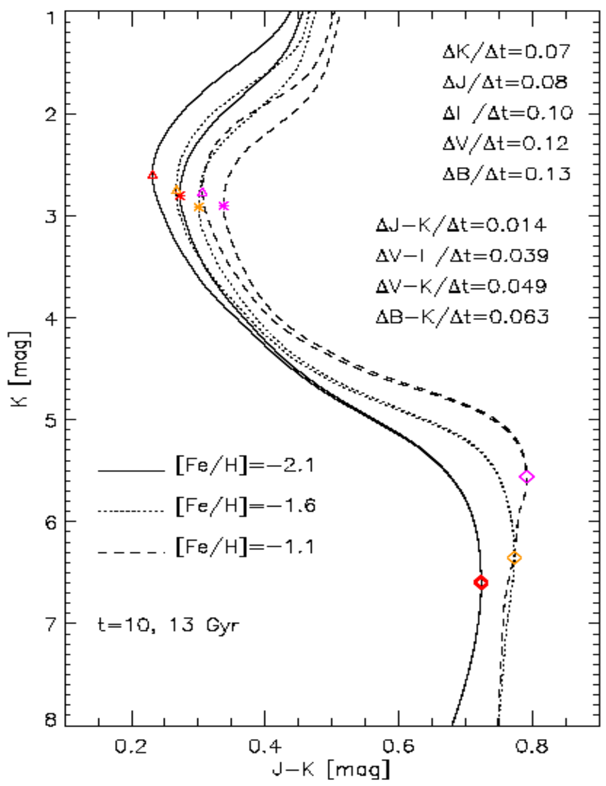
Isochrones AND Luminosity functions (different systematic)

Different evolutionary diagnostic

Hansen **et al. 2008, ACS@HST, NGC6397**

MAD@VLT

i.e. looking for something new, but avoiding fishing expeditions ….



Cluster isochrones for different ages and chemical compositions

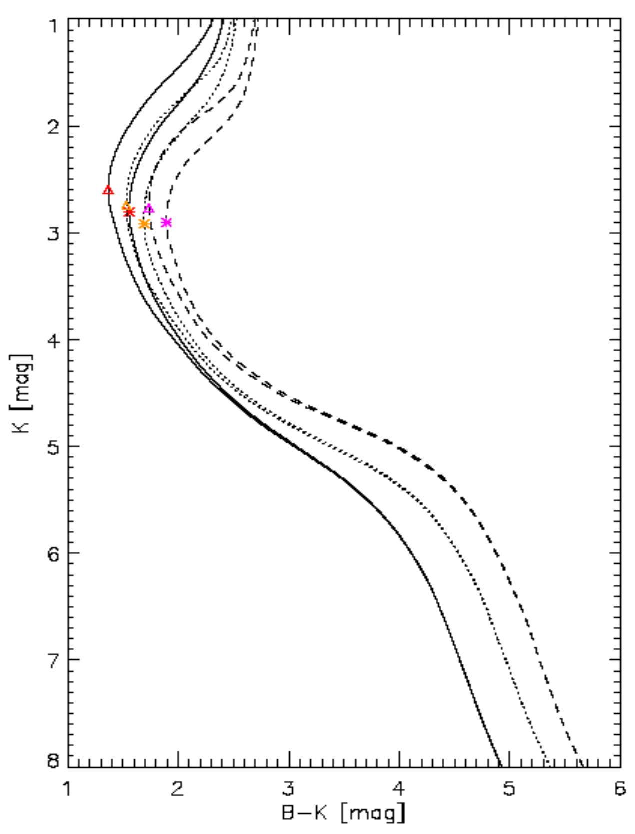
The MS shows a well defined knee for M~0.3-0.4 Mo

Absolute GC ages using either the color or the magnitude difference between MSTO and knee …..

Pisa + Teramo + Dotter + VandenBergh

MAD@VLT

i.e. looking for something new, but avoiding fishing expeditions ….

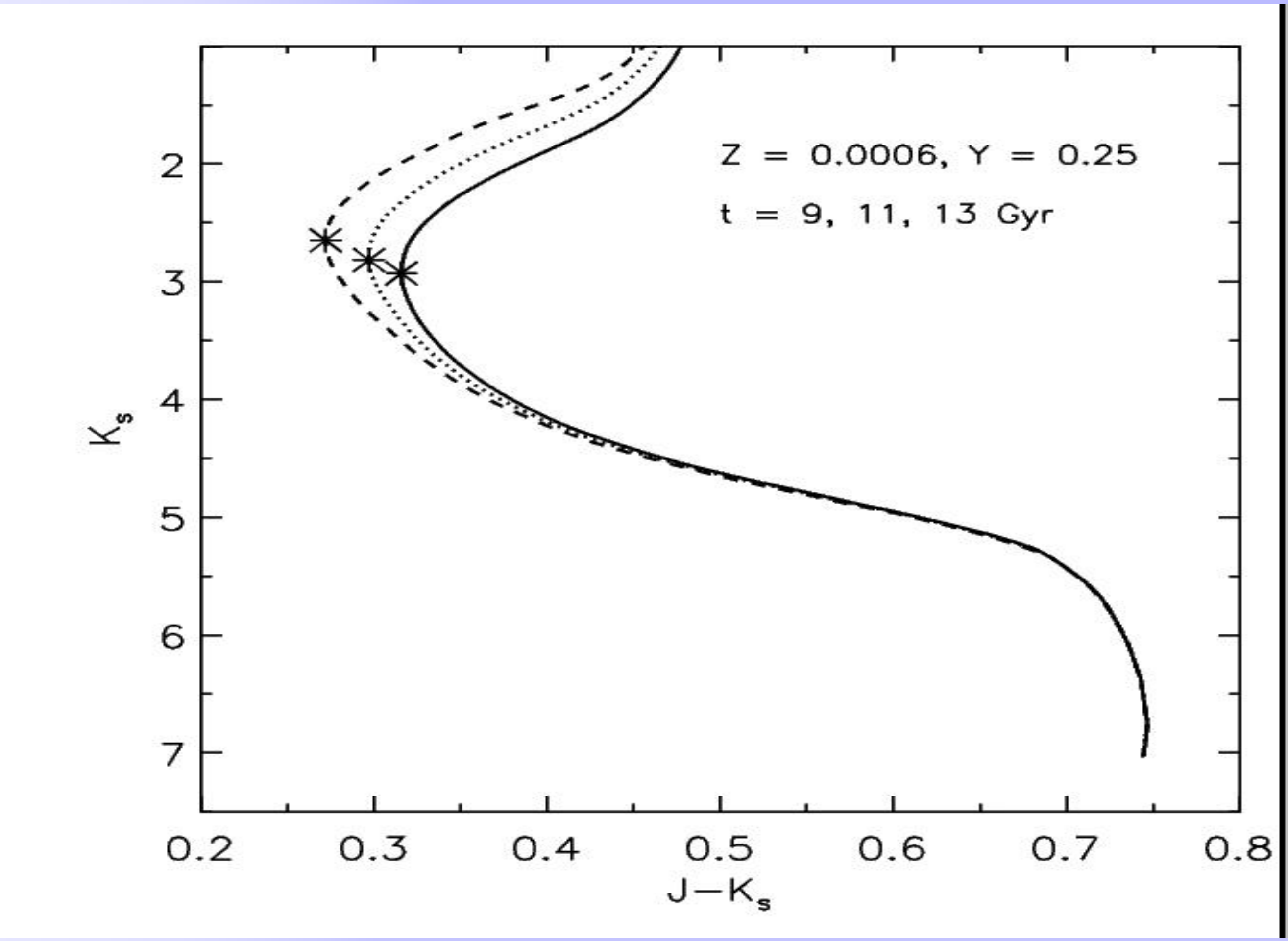


Current Ages estimates are affected neither by uncertainties on the distance nor on the reddening correction ……..

CT transformations need to be improved in this metallicity range

Pisa + Teramo + Dotter + VandenBergh

MS stars for M≤0.40-0.45 M⊙ show in NIR CMDs a well defined veer toward fainter magnitudes and fixed color



The difference in color between the TO and the NIR veer is, at fixed Z, a robust zbsolute age indicator.

NO DISTANCE NO REDDENING DEPENDENCE!

CULPRIT: H2 opacity at high density

Collisional Induced Absorption (CIA, Saumon et al. 1994)

REAL OBSERVATIONS

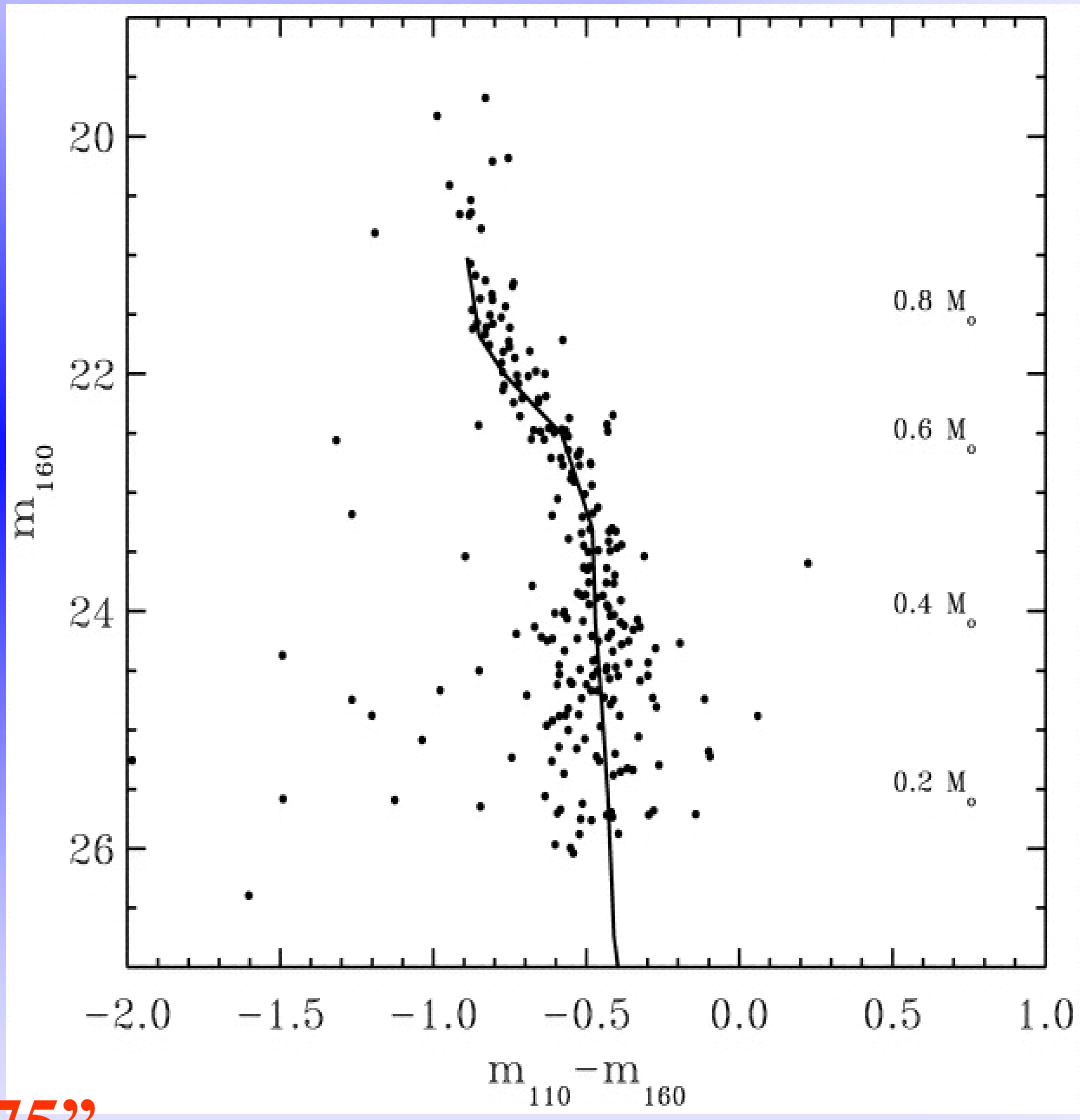
NICMOS J,H data for ω Cen

Pulone et al. (1998)

TO stars saturated
μ=13.45
E(B-V)=0.15

t=10 Gyr
[M/H]=-1.3
(Chabrier, Baraffe 1997)

H



J-H

FOV=20”X20” pixel scale=0.075”

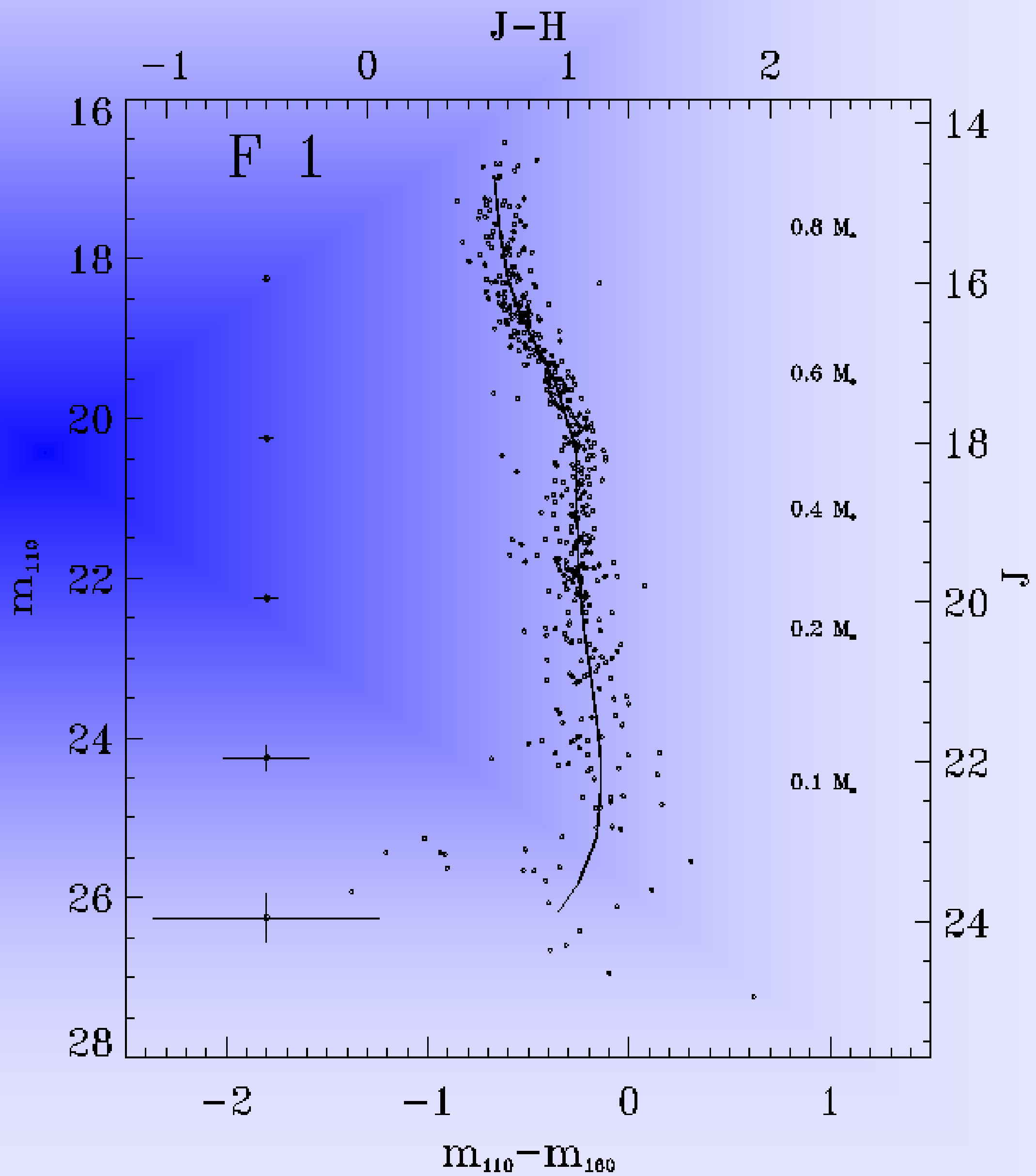
REAL OBSERVATIONS

NICMOS J,H data for M4

Pulone et al. (1999)

TO stars ~ saturated
μ=11.51
E(B-V)=0.40

t=10 Gyr
[M/H]=-1.3
(Chabrier, Baraffe 1997)



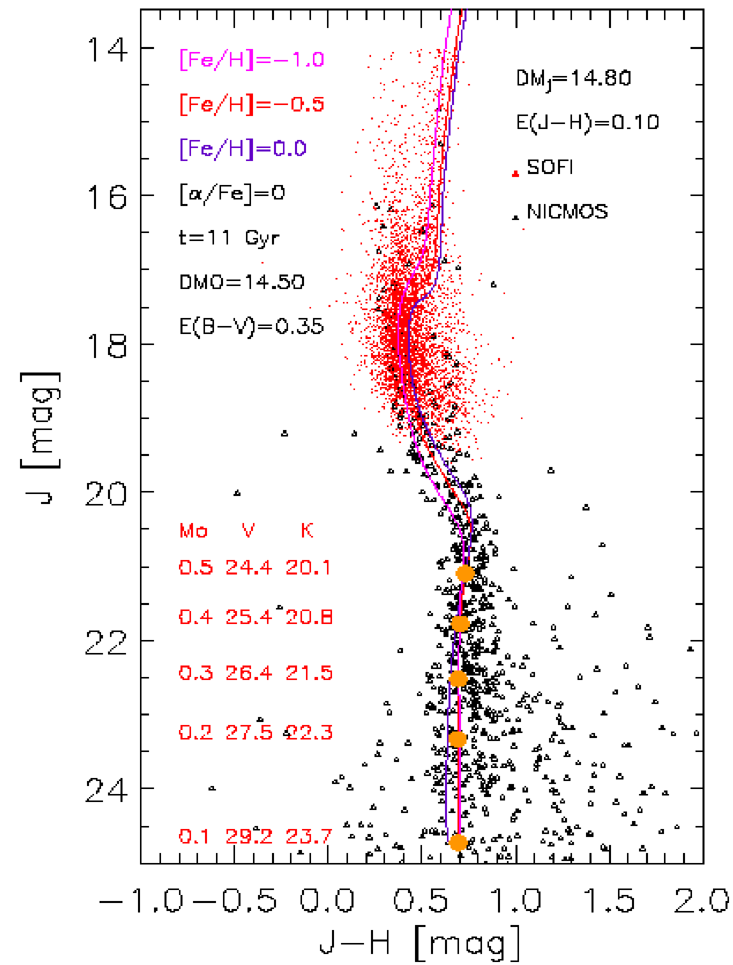
The agreement between theory and observations is better in the metal-rich regime

With NIR MAD data of GCs we are exploring a new regime …..

We are dealing with new problems, but the road is VERY PROMISING for stellar astrophysics …. the H-burning limit for μ~14.50 is at

V~29 and K~24!!!

Baade-Window Galactic Bulge



Zoccali et al. (2000, 2003)

Absolute ages of GCs

Comparison between Theory & Observations:

NIR CONS

→ Photometric precision (repeatability)

→ Sky subtraction (T←→S) in crowding regions

NIR PROS

→Minimally affected by reddening & diff. redd.

→Faint MS stars are brighter in NIR than in optical

→Calibration: 2MASS, but ……

→Intrinsic features of the MS

WHY NGC3201?

- **Distance & reddening:**
  - **RR Lyrae → Piersimoni et al. (2002)**
  - **SX Phoenicis → Leiden et al. (2003), Mazur et al. (2003)**
  - **W UMA Blue Straggler → von Braun & Mateo (2002)**

- **Chemical composition:**
  - **[Fe/H] +[α/Fe]→ Kraft & Ivans (2003), Covey et al. (2003), Pritzl et al. (2005)**

- **Kinematics:**
  - **retrograde orbit → Gonzalez & Wallerstein (1998), Casetti-Dinescu et al. (2007)**
  - **probably connected either with "orphan stream" (Belokurov et al. 2007) or by Grillmair (2006) [Bell's talk]**

- **Absolute age: quite poor → differential reddening**

MAD J,K Images of NGC3201 [SD2]

Four pointings (T1,T2,T3,T4) :
J-band: seeing from 0.6” to 0.9”
Ks-band: seeing from 0.8” to 1.3” (T3)
3J+5Ks per pointing = 12(J) + 20(Ks) min=0.5 h

→5 guide stars V~11.7-12.9

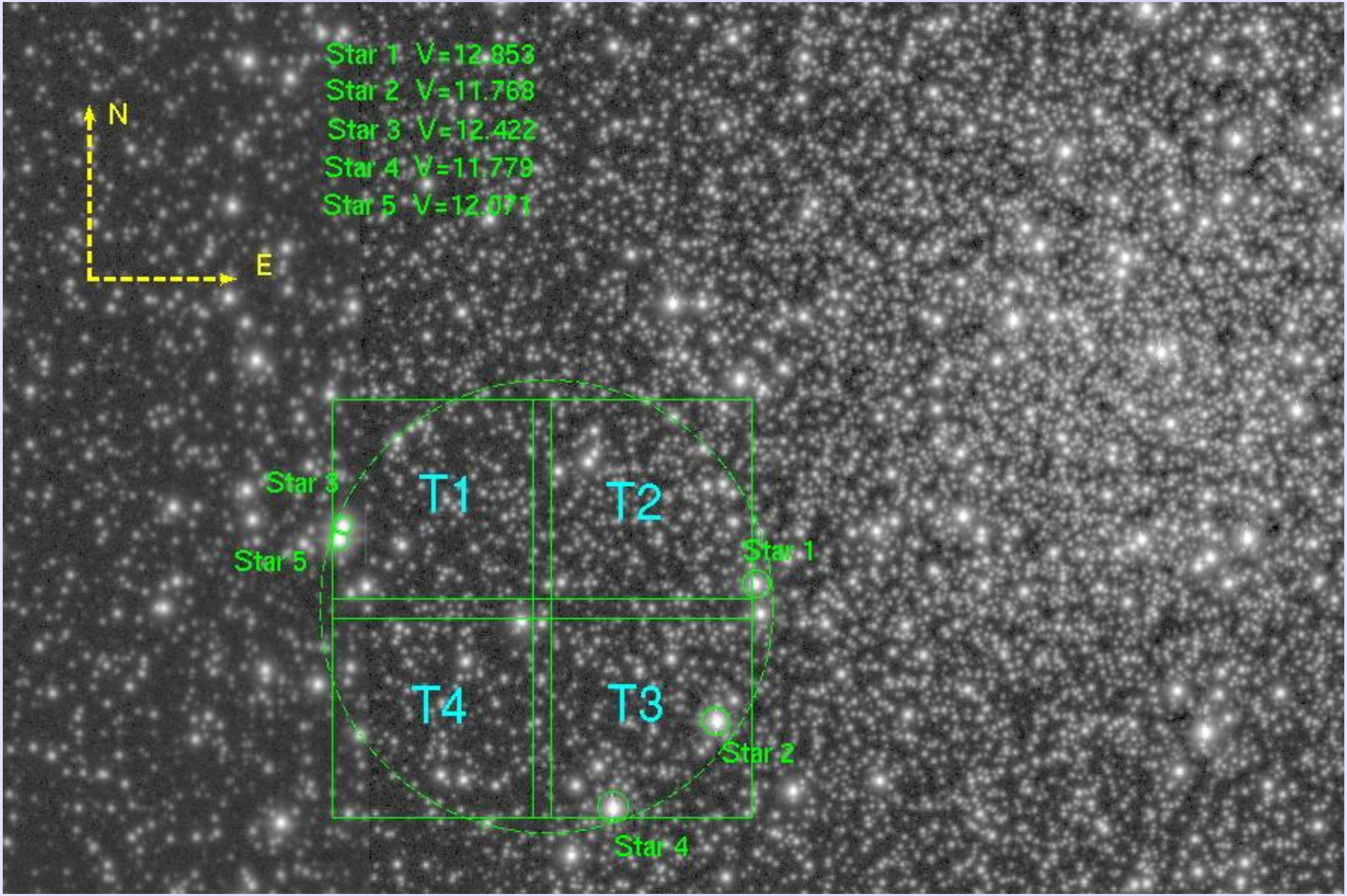
→FWHM on images ≤0.07-0.10” [Ks, J]

→FOV 2’X2’, pixel scale 0.028”

Significant improvement in sky subtraction

[Marchetti et al. 2007, The Messenger, 129, 8]

MAD J,K Images of NGC3201



Reduction Strategy

PSF Photometry on Individual Images

Simultaneous reduction of NIR and optical images

DAOPHOT → ALLSTAR → DAOMASTER → ALLFRAME

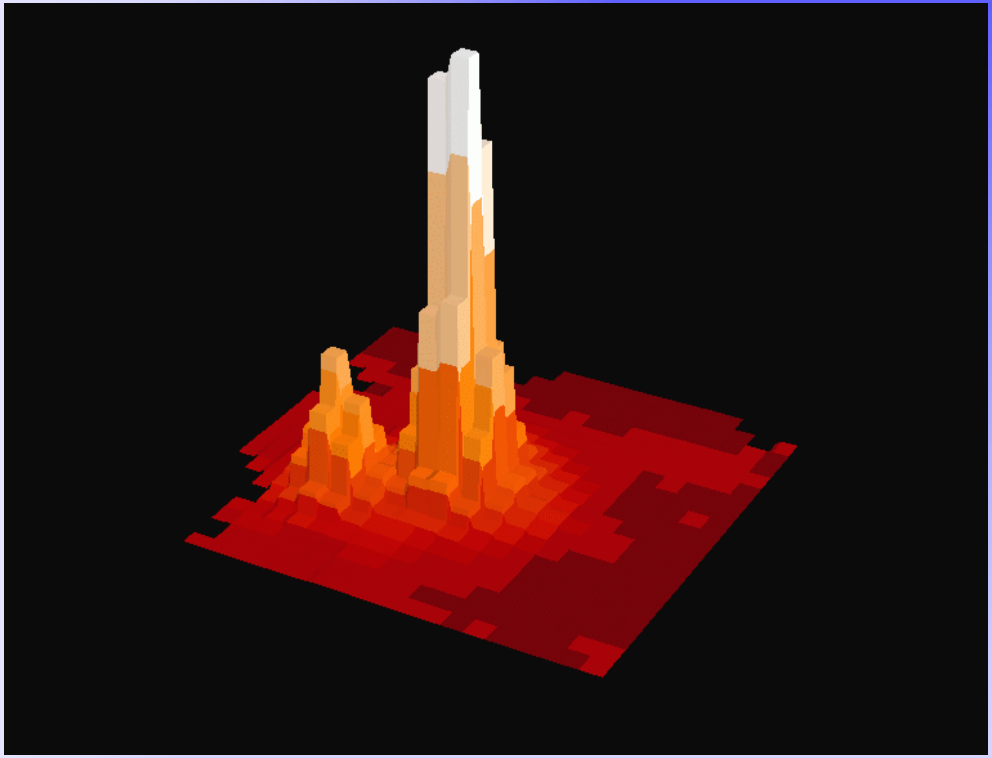
Specific Targets (WDs in ω Cen) → ROMAFOT →

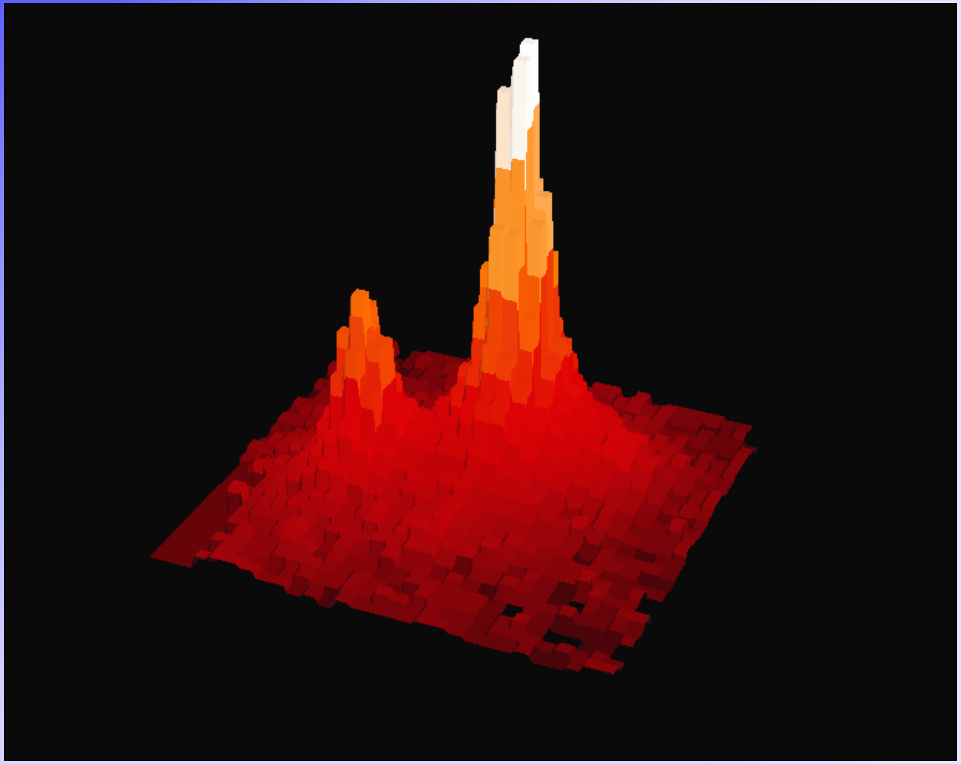
visual check one-by-one

Reduction strategy: data

MS located two magnitudes below the TO region

ACS **MAD**

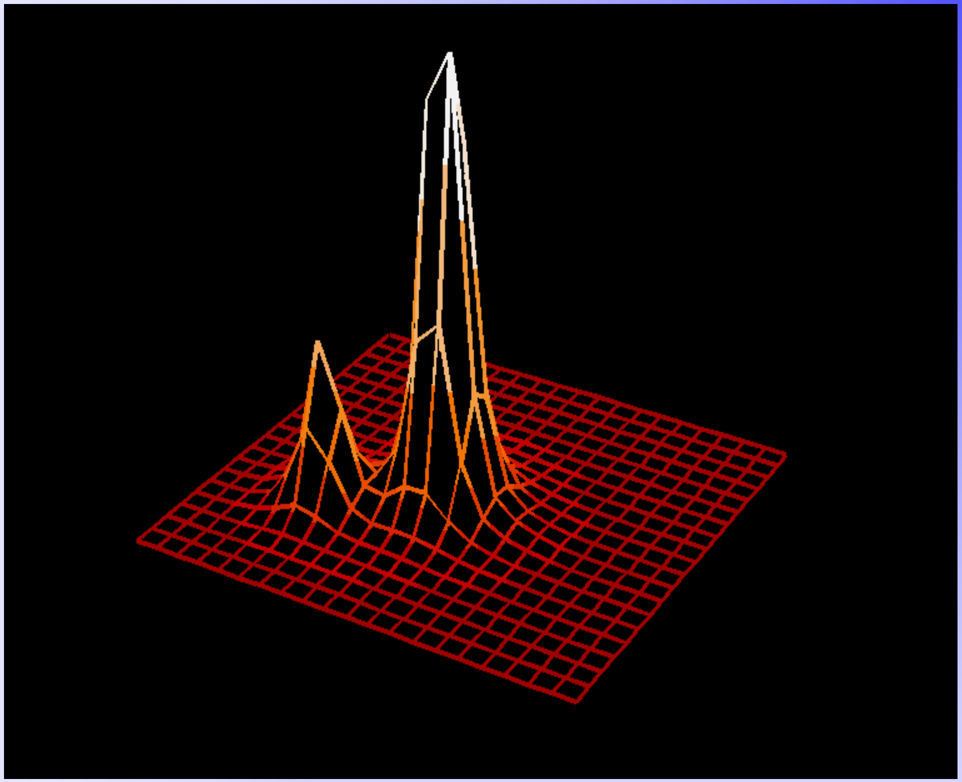




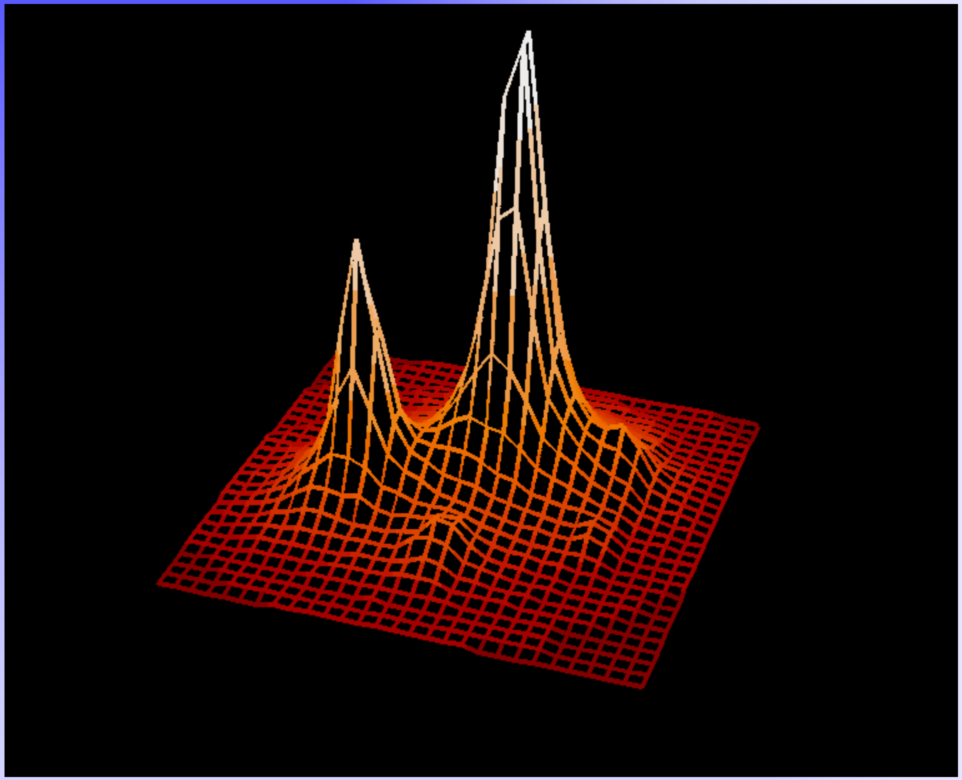
Smaller FoV, lower dynamical range but better sampling 0.05" vs 0.028"

Reduction strategy: Analytical PSF

ACS



MAD



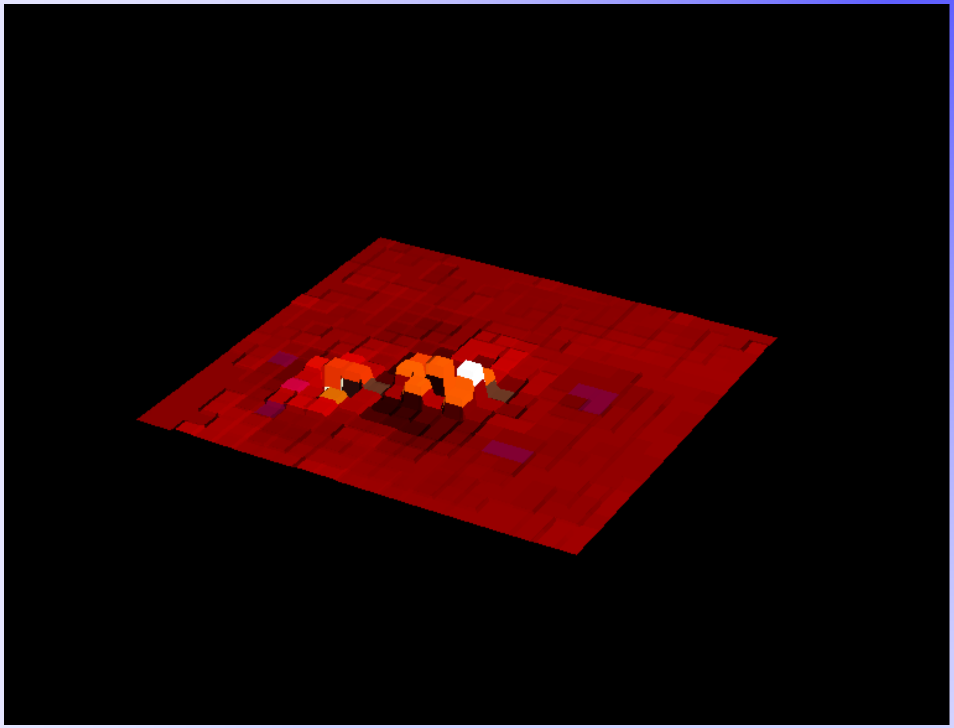
ALLSTAR

→ PSF(Ks): quadratic Moffat function β=2.5

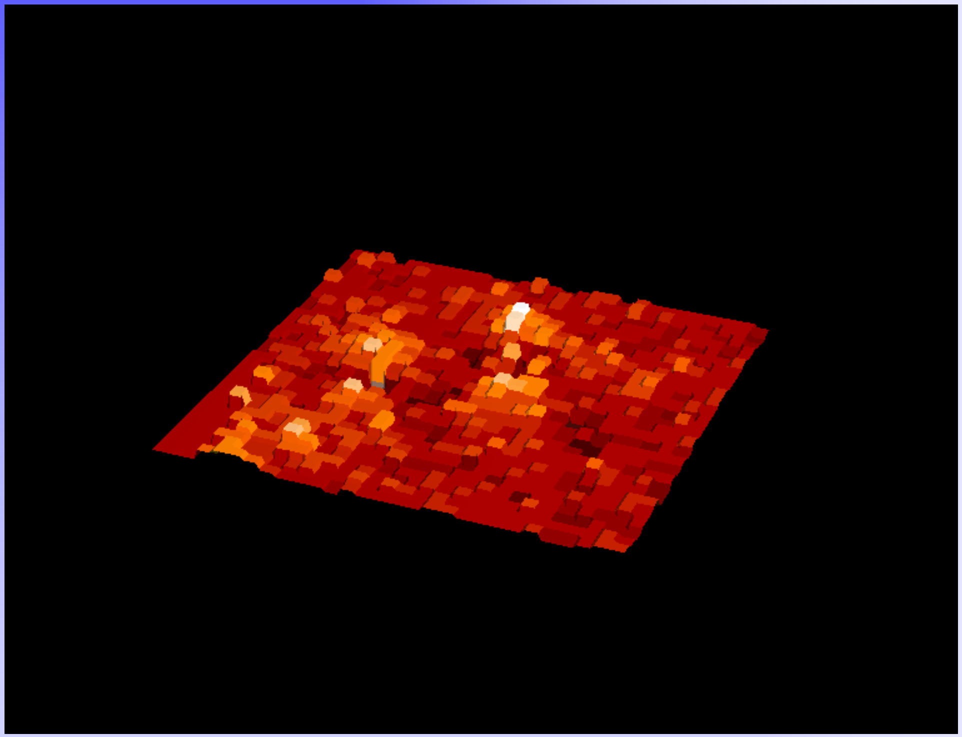
→ PSF(J): linear Moffat function β=1.5 or Lorentian

Reduction strategy: residuals

ACS

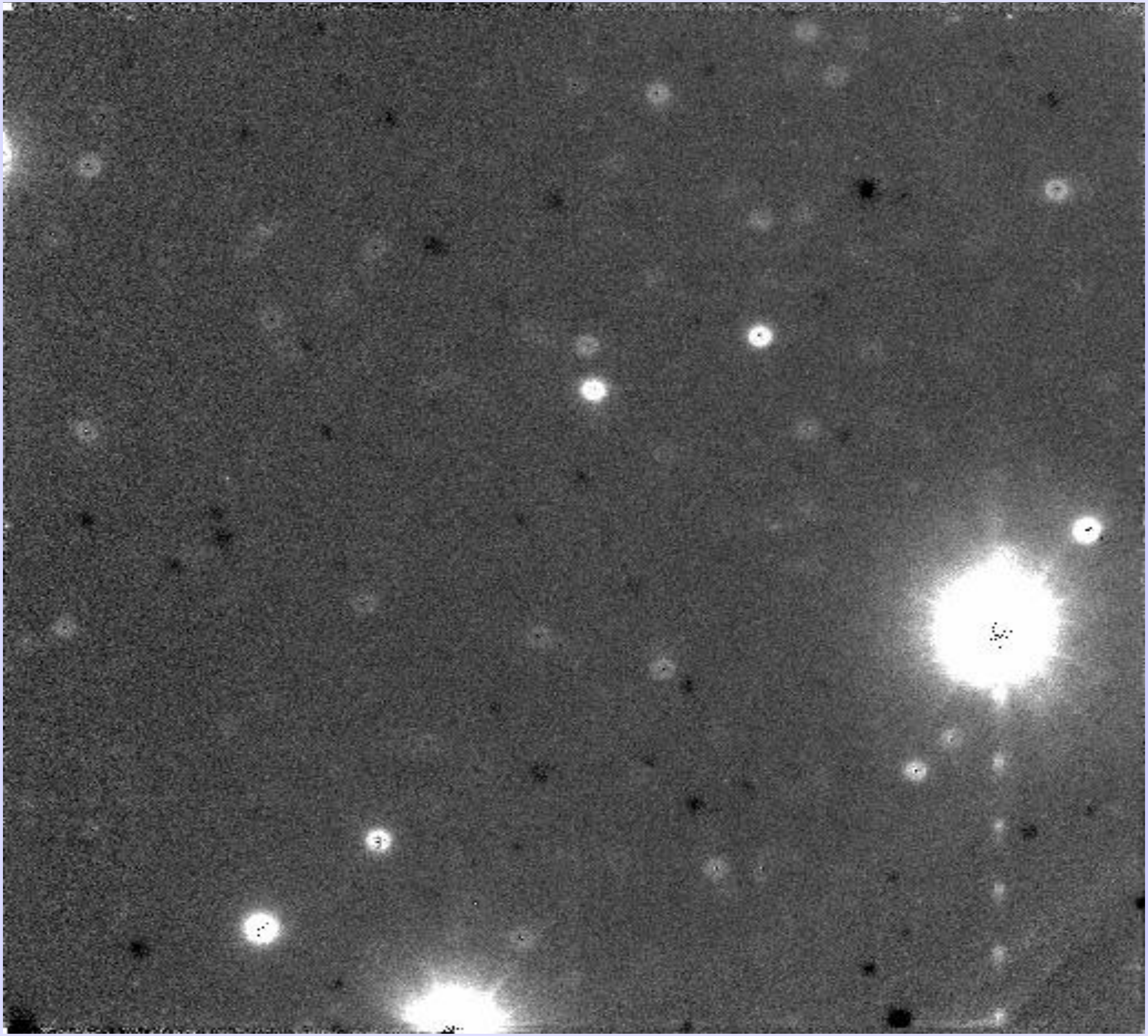


MAD



DAOMASTER/ALLFRAME/DAOMASTER

Simultaneous reduction of optical & MAD (J,Ks) images [→ NO IMAGE STACK ←]

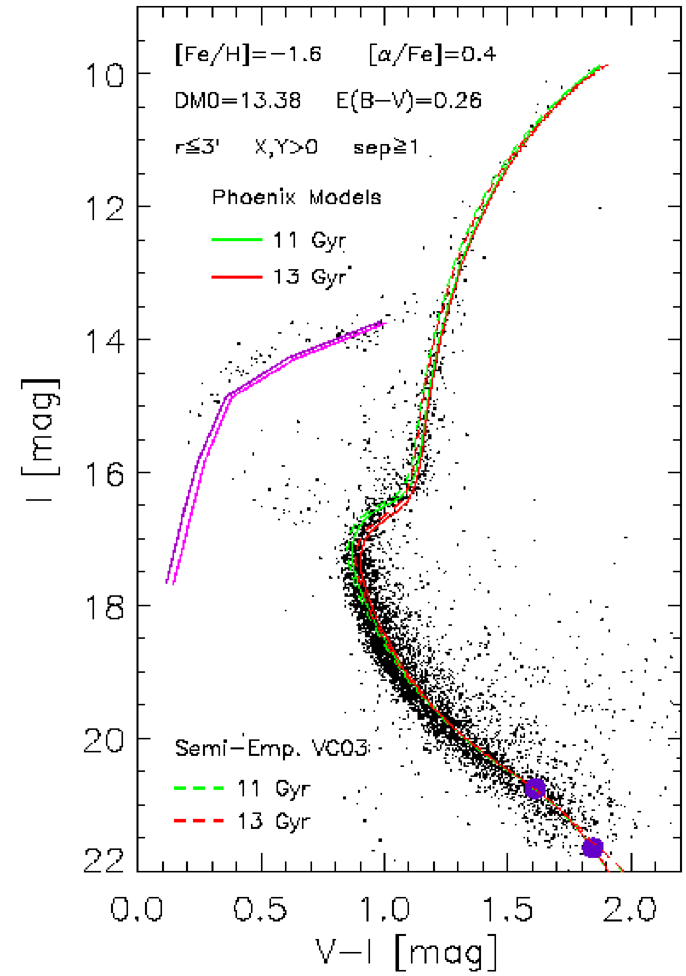


Isochrone validation (1^{st} step)

By assuming everything
(distance, reddening, metallicity)
canonical and optical photometr

Cluster age confirmed
t=12 1 Gyr

Isochrones from
Dotter & Chaboyer (2004)
+
Phoenix atmosphere models
solid lines (Brott et al. 2000)
+
Semi-empirical CT transformations
Dashed lines (vandenBerg & Clem 20( )

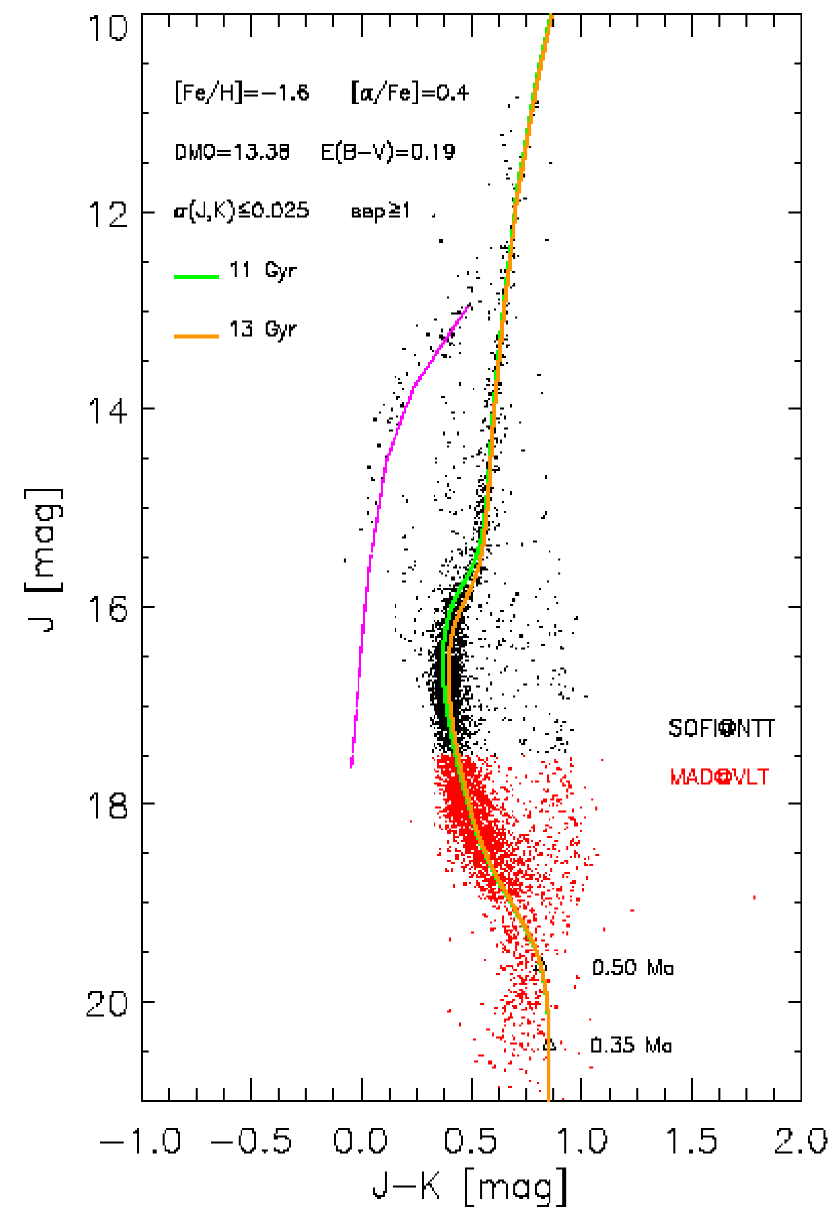


Data show expected evolutionary features

J~21 and K~20.5

Cluster age t=12 1 Gyr

Tested Z⊙ and all available CT transformations



Problems:

- Reddening is 30% lower
  Culprit: Reddening law
- Isochrones are redder than observations in the lower MS
  Culprit: NIR CT transformations

Double-Triple Check on possible systematics

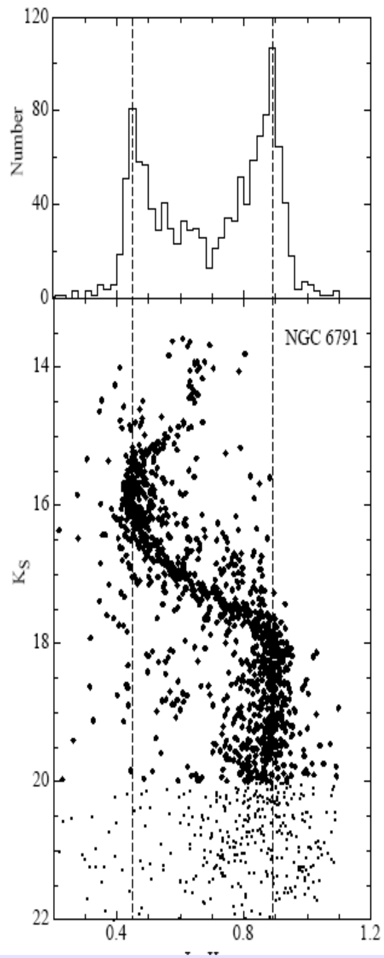
#) Linearity
#) Sky subtraction at the 1% level (M. Dall'Ora)
#) Detailed check of the residuals (position …..)

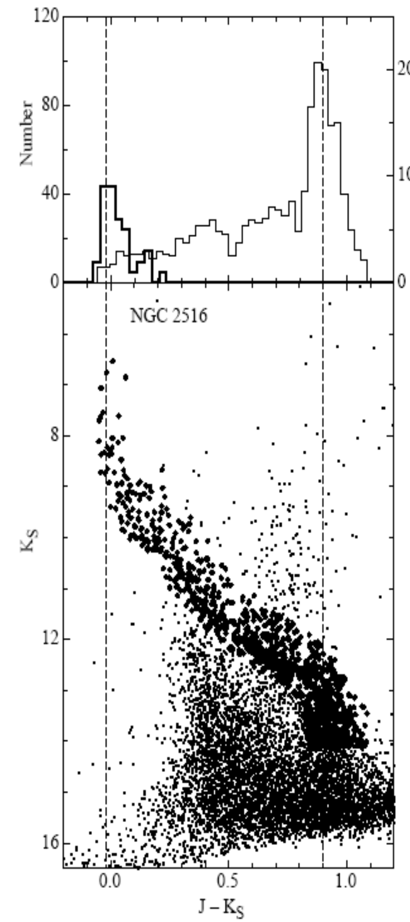
#) Calibrations [zero-points & color terms]
2MASS → SOFI → HAWK-I → MAD

#) Simultaneous reduction of optical (HST) and NIR data (when possible!)

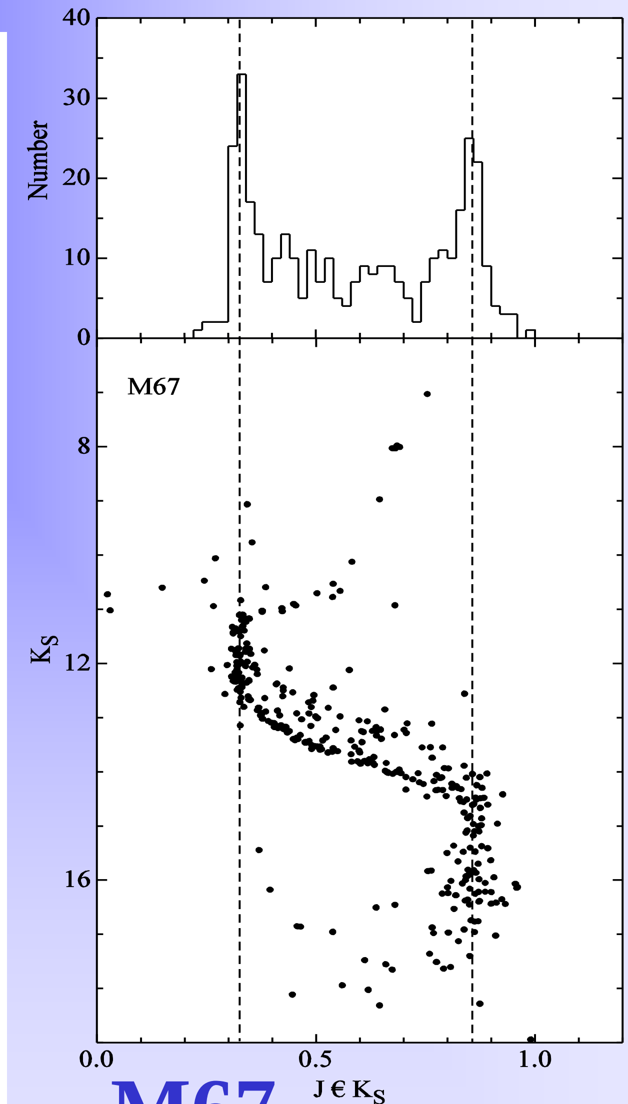
Prompt reaction from the community!!

NGC6791





NGC2516



M67

Sarajedini et al. 2009

All current packages deal with symmetric analytical PSFs

Once the shape of the PSF and the residual matrix have been fixed we are left with three unknowns per stars:

→Moffat function (fixed σ & β): x_i, y_i, h_i

→This is the crucial reason why accurate PSF photometry needs at least 2X2 and possibly 3X3

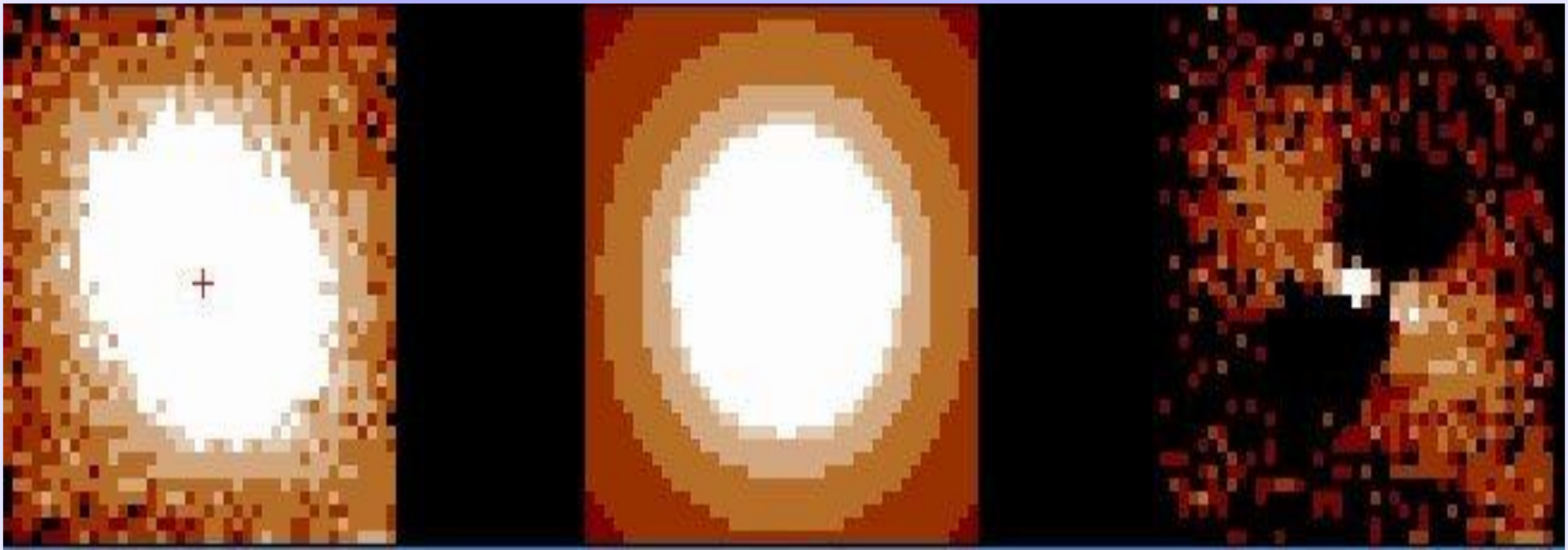
→Recent NIR images from AO systems are (quite) far from being symmetric (circumstantial evidence!)

NACO images of Omega Centauri

9 K-band images t=40 sec (DIT=4, NDIT=10)
FOV=28x28 “^2 pixel scale=0.027 ”/px
FWHM=0.36 “ (13 px) **Moffat Function (fixed σ,β)**

TOP VIEW

Datum PSF Residuals



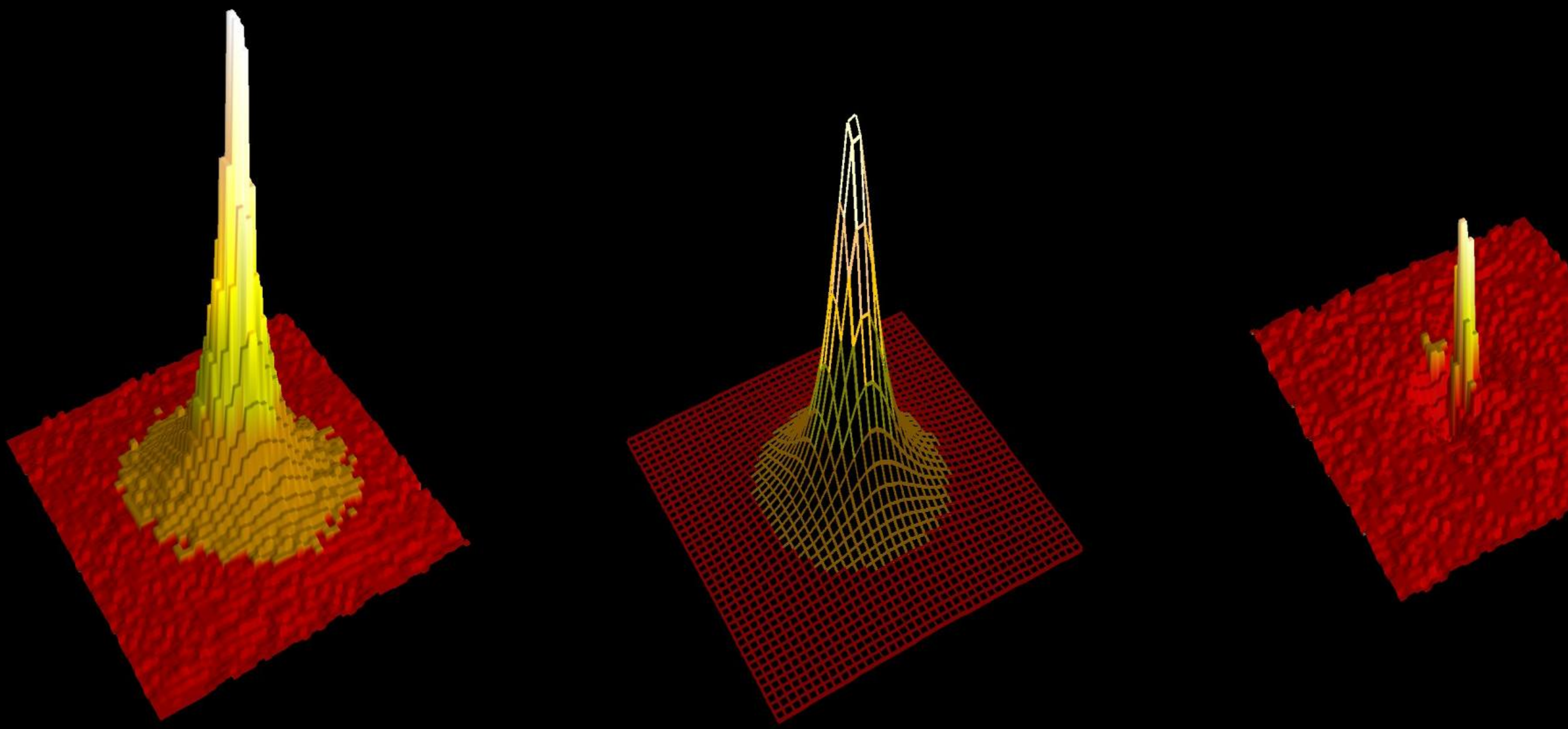
NACO images of Omega Centauri

3D view

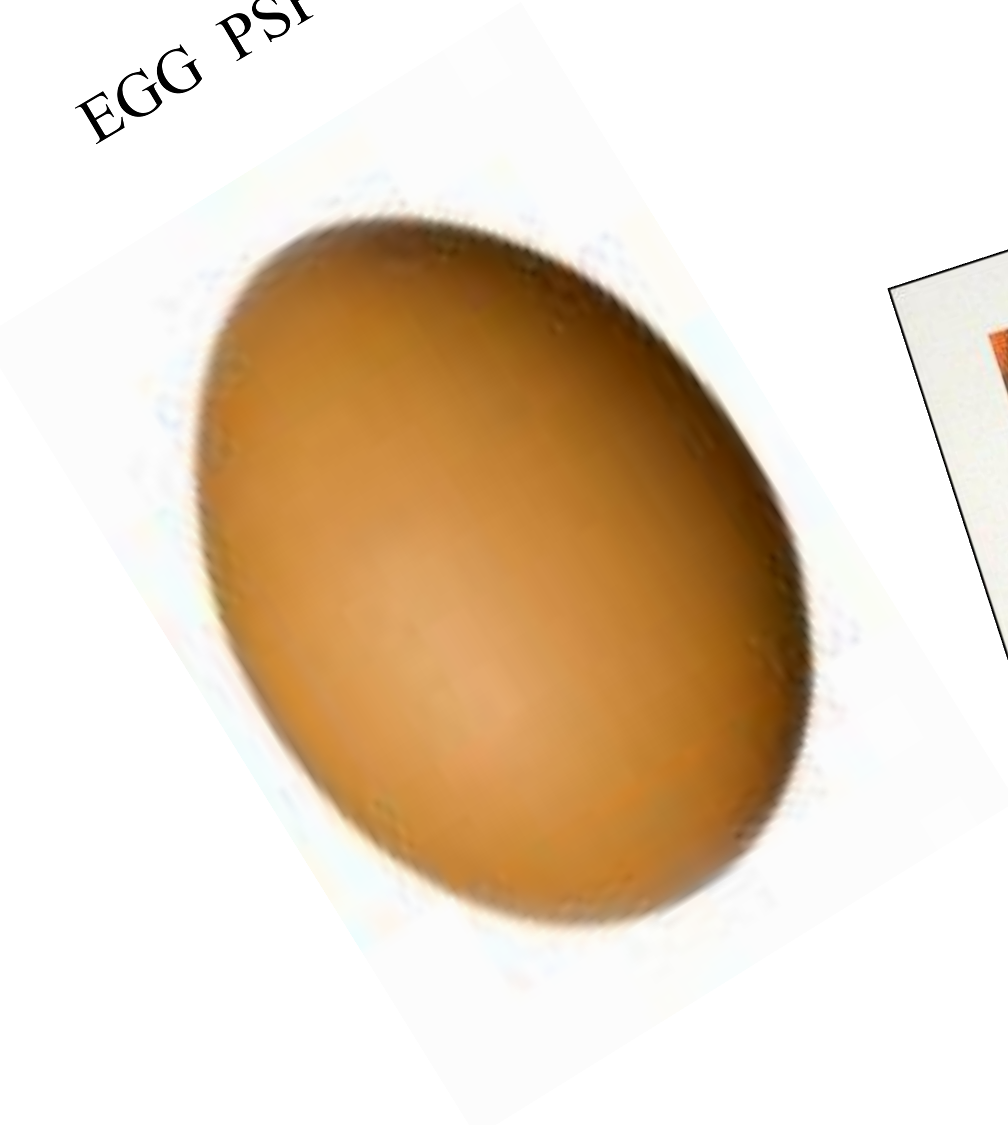
Datum

PSF

Residuals
Δm~0.9



EGG PSF



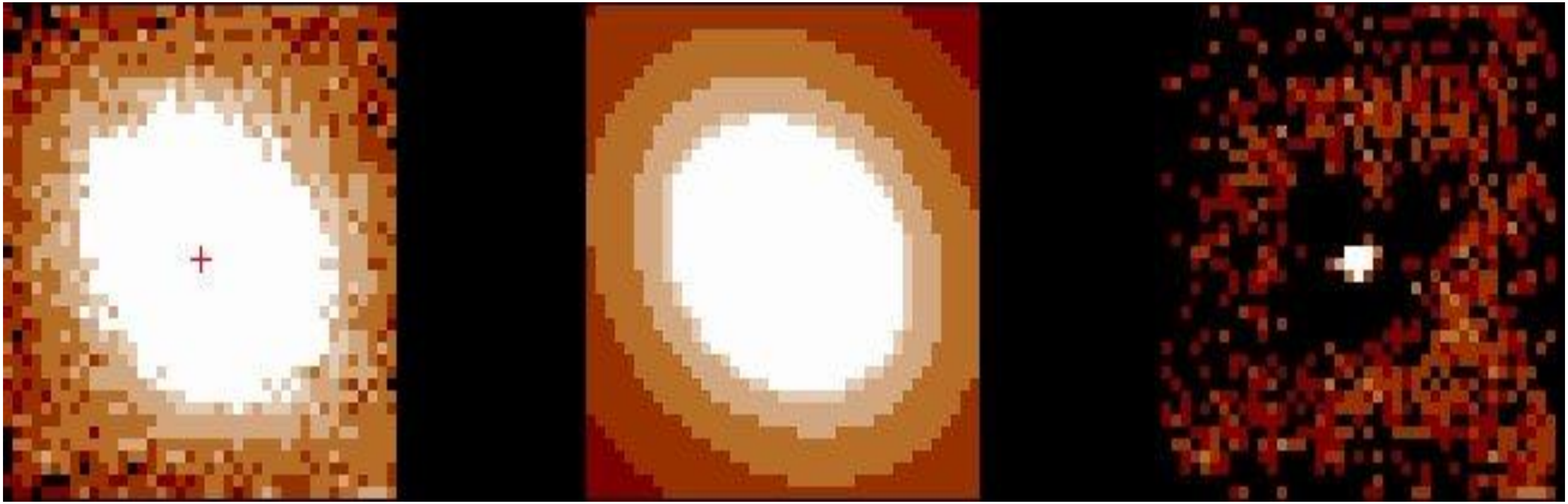
Ballerina PSF

EGG PSF

Fixed σ & β

Unknowns:
x, y, a, b, Θ, ω, h

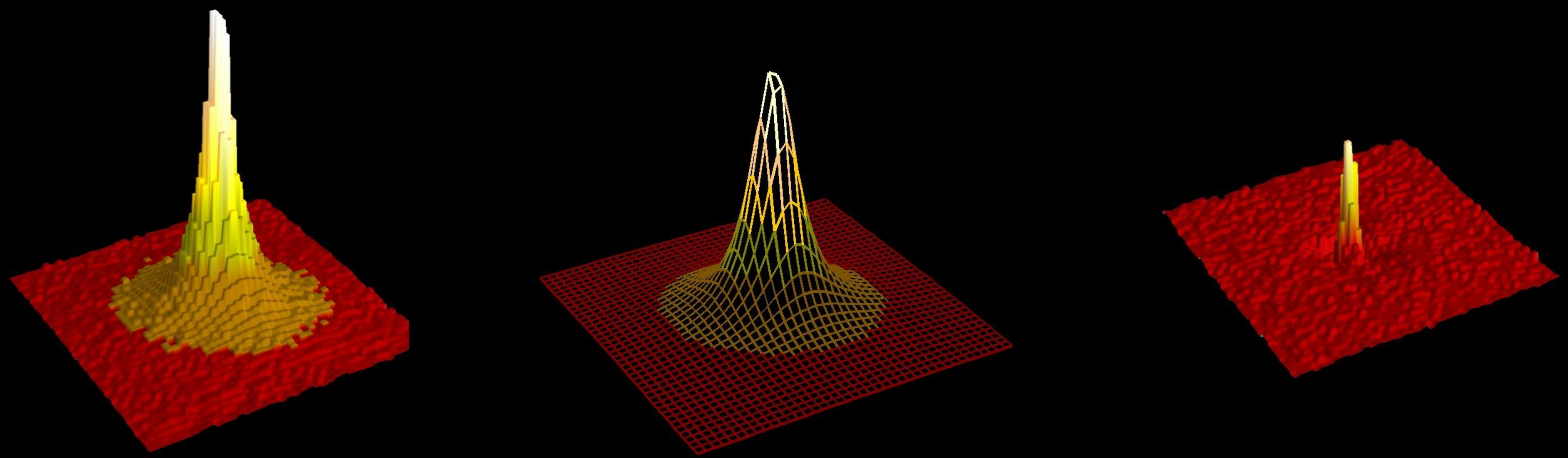
Residuals
Δm~0.1



EGG PSF

Fixed σ & β

Unknowns:
x, y, a, b, Θ, ω, h



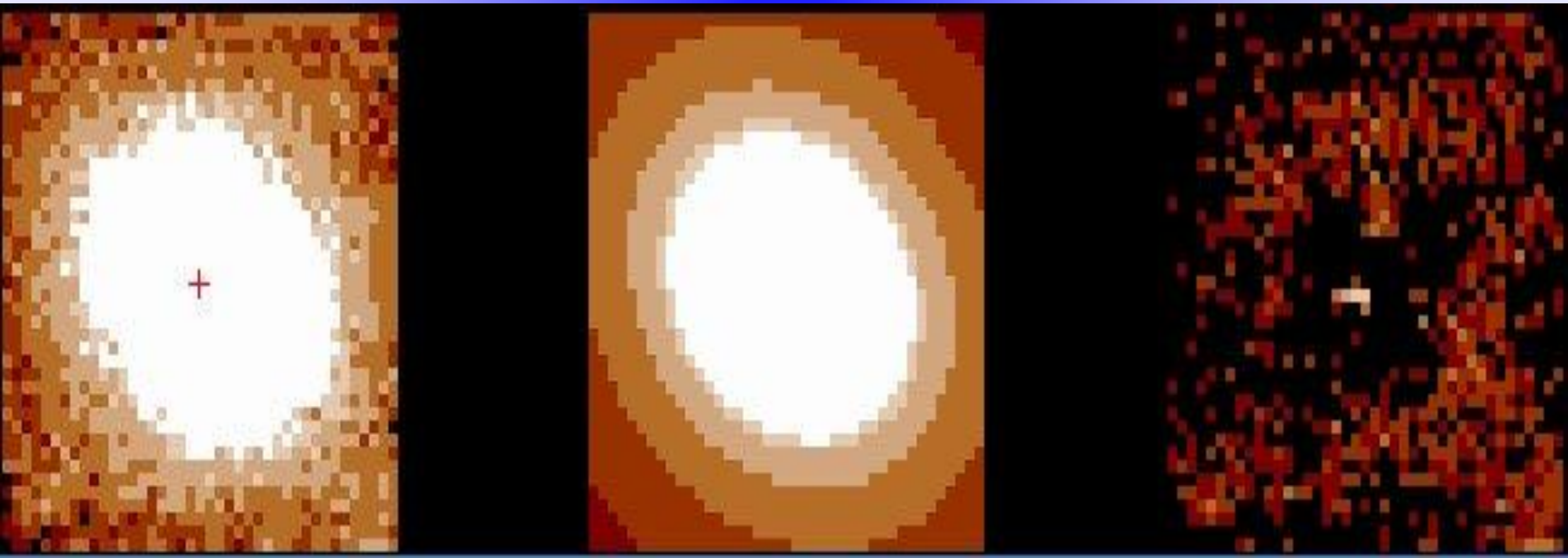
EGG yolk & white

PSF = M1 (x, y, a, b, Θ, ω, h1) +
M2 (x, y, σ=b, h2)

M1 = wings → asymmetric → white
M2 = core symmetric → yolk

Unknowns (Fixed β for M1 & M2):
x, y, a, b, Θ, ω, h1,h2

Residuals
Δm~0.09



EGG yolk & white

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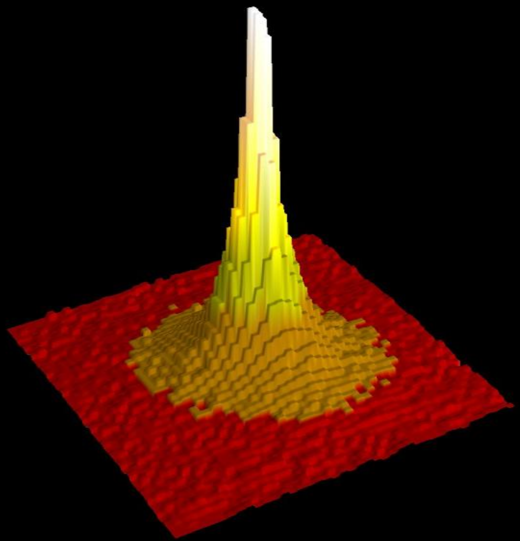
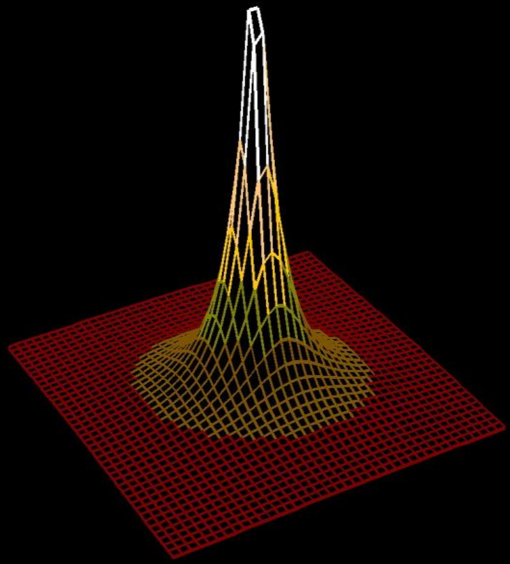
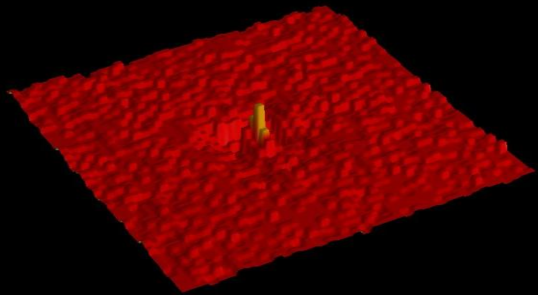
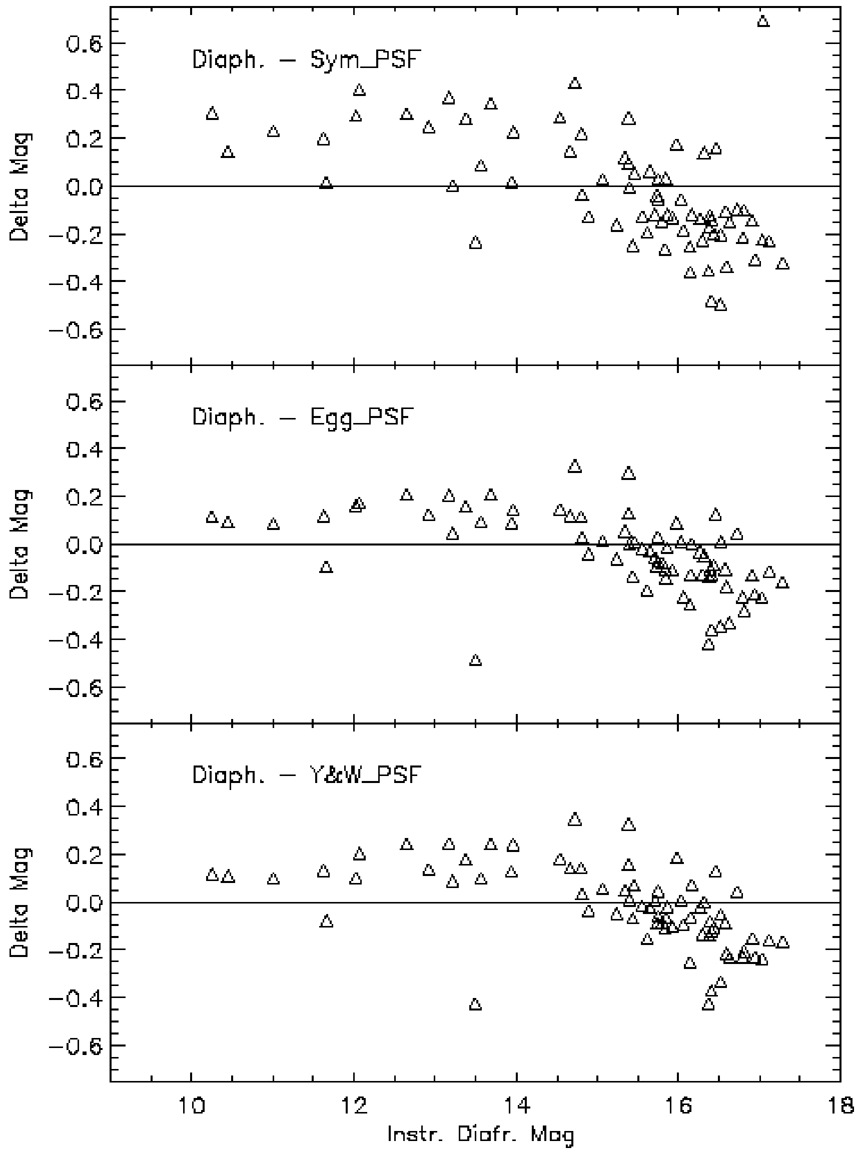






Difference between Diaphragm and PSF magnitudes



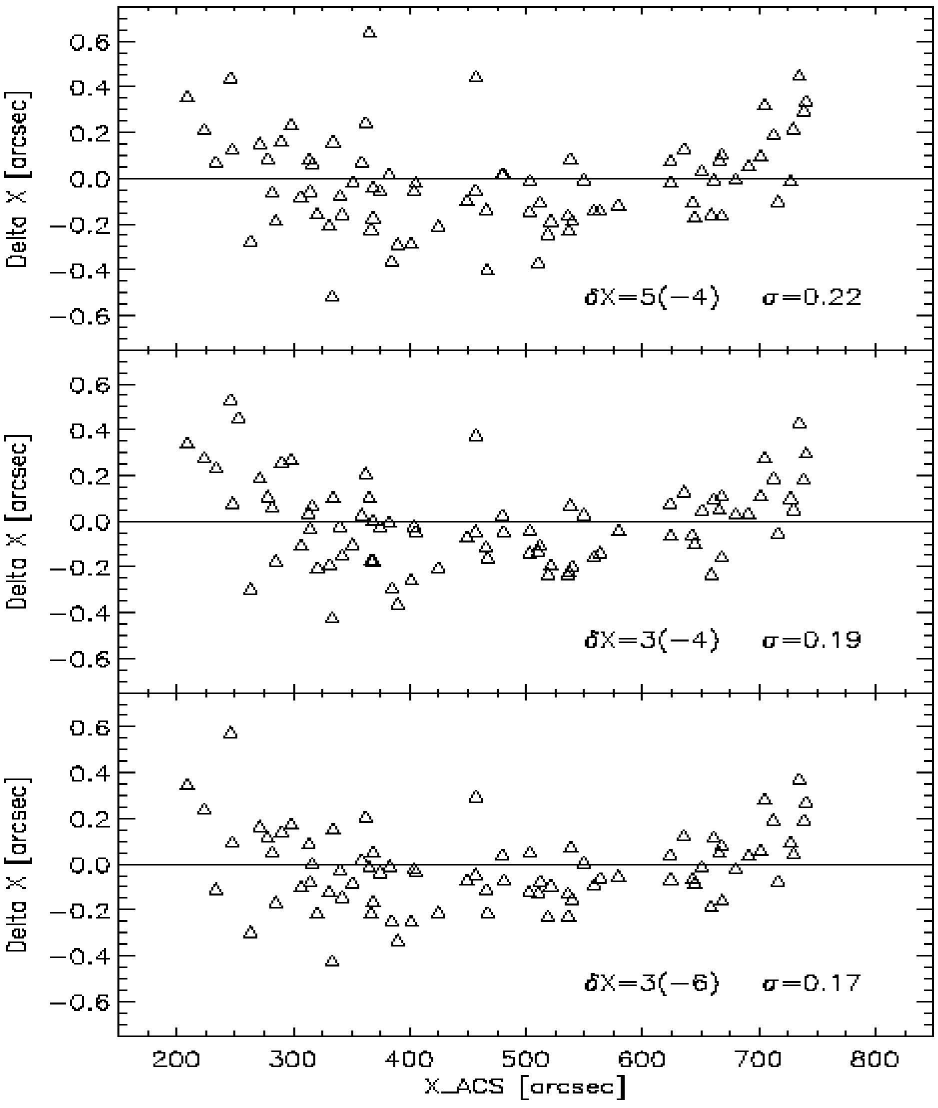
<δM>=0.77 σ=0.22

<δM>=0.03 σ=0.16

<δM>=0.01 σ=0.16

Difference in centroid positions

Along X-axis

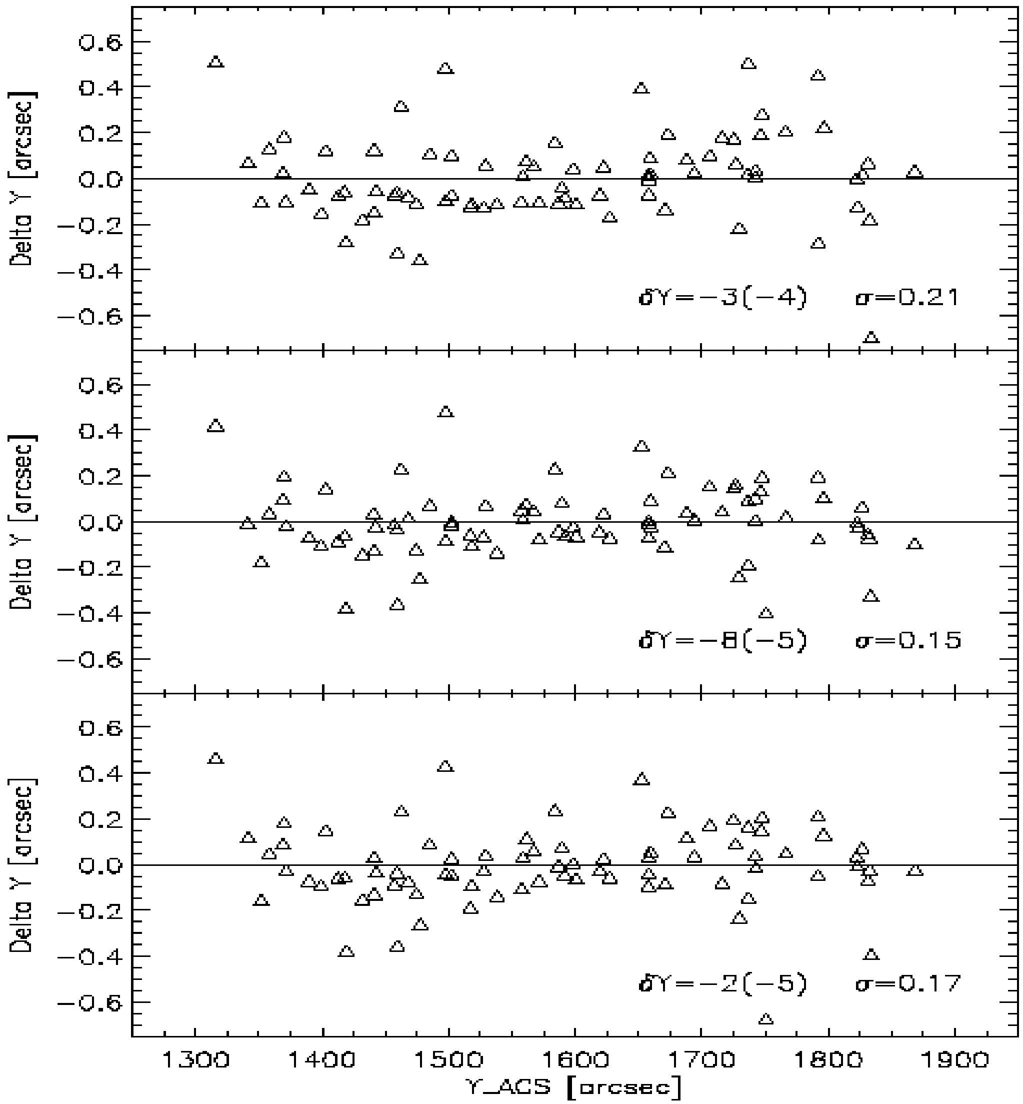


Difference around zero but dispersion decreases ~30% when moving to

Asymmetric PSF

Difference in centroid positions

Along Y-axis



Difference around zero but dispersion decreases ~30% when moving to

Asymmetric PSF

OPEN ISSUES:

→ CROWDING

→STATISTIC J,K images

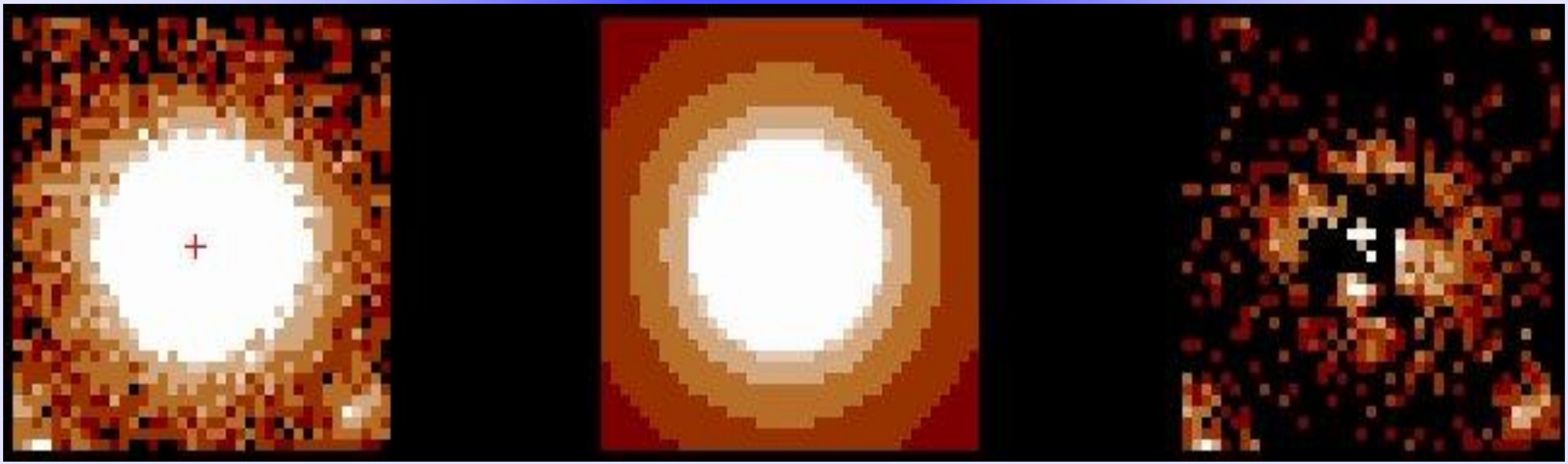
→CMD evolutionary features

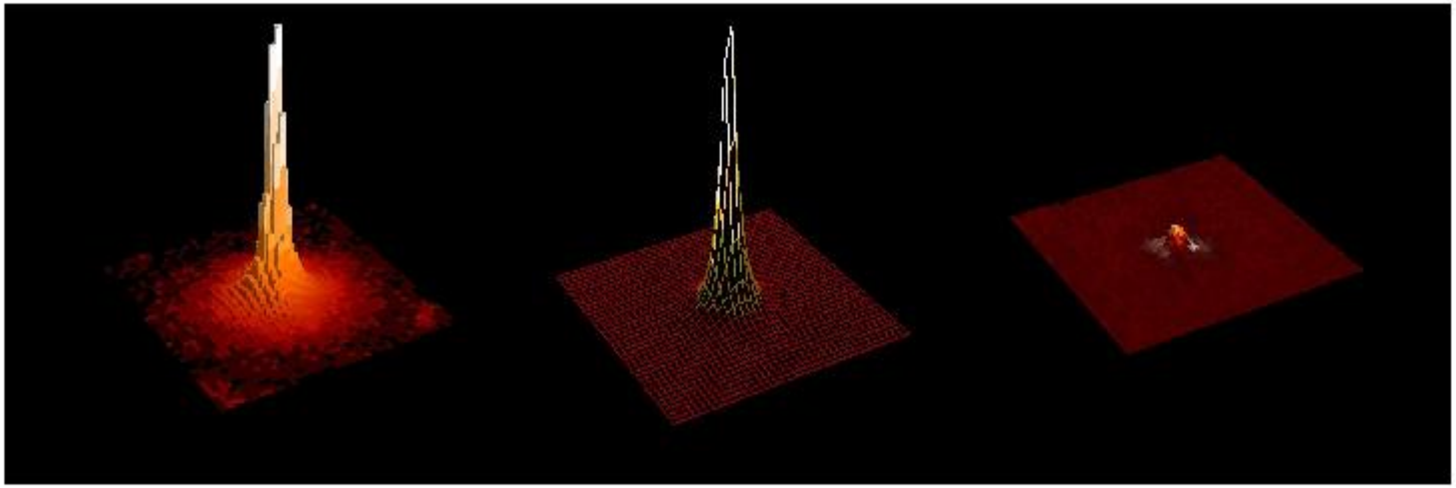
→Independent parameters:
ω - Θ – $\beta 1$, $\beta 2$

Comparison with MAD JK images of the same region collected during the same nights (same external seeing)

MAD DATA of the same field but collected in a different night [talk by Annalisa C.]

Residuals
Δm~0.08





On route to use asymmetric PSFs

PROS

→ Photometric precision (smaller residuals)
→ Astrometric precision (smaller dispersions)

CONS

→ Larger number of pixels
→ Deconvolution less stable

TWO POSSIBLE ROUTES

→ High Strehl factor
small FoVs → symmetric PSF ~3x3

→ Low Strehl factors
large FoVs → asymmetric PSF ~4x4

CONCLUSIONS

- **A new method to estimate the absolute age of GCs based on deep and accurate NIR data homogeneous age scale for OCs & GCs**

- MADMAX is crucial to perform accurate photom. in crowded fields → road-map to E-ELT [NGS with V~17 are mandatory!!!]

- **Accurate absolute calibration is a relevant issue**

- **Current evidence indicate that image quality is based not only on the Strehl ratio isoplanatism but also on the PSF symmetry across the FoV.**

- **Preliminary good news concerning asymmetric PSF, but a higher spatial resolution (4X4 vs 3X3) is required**

Credits

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L. Pulone, D. VandenBerg