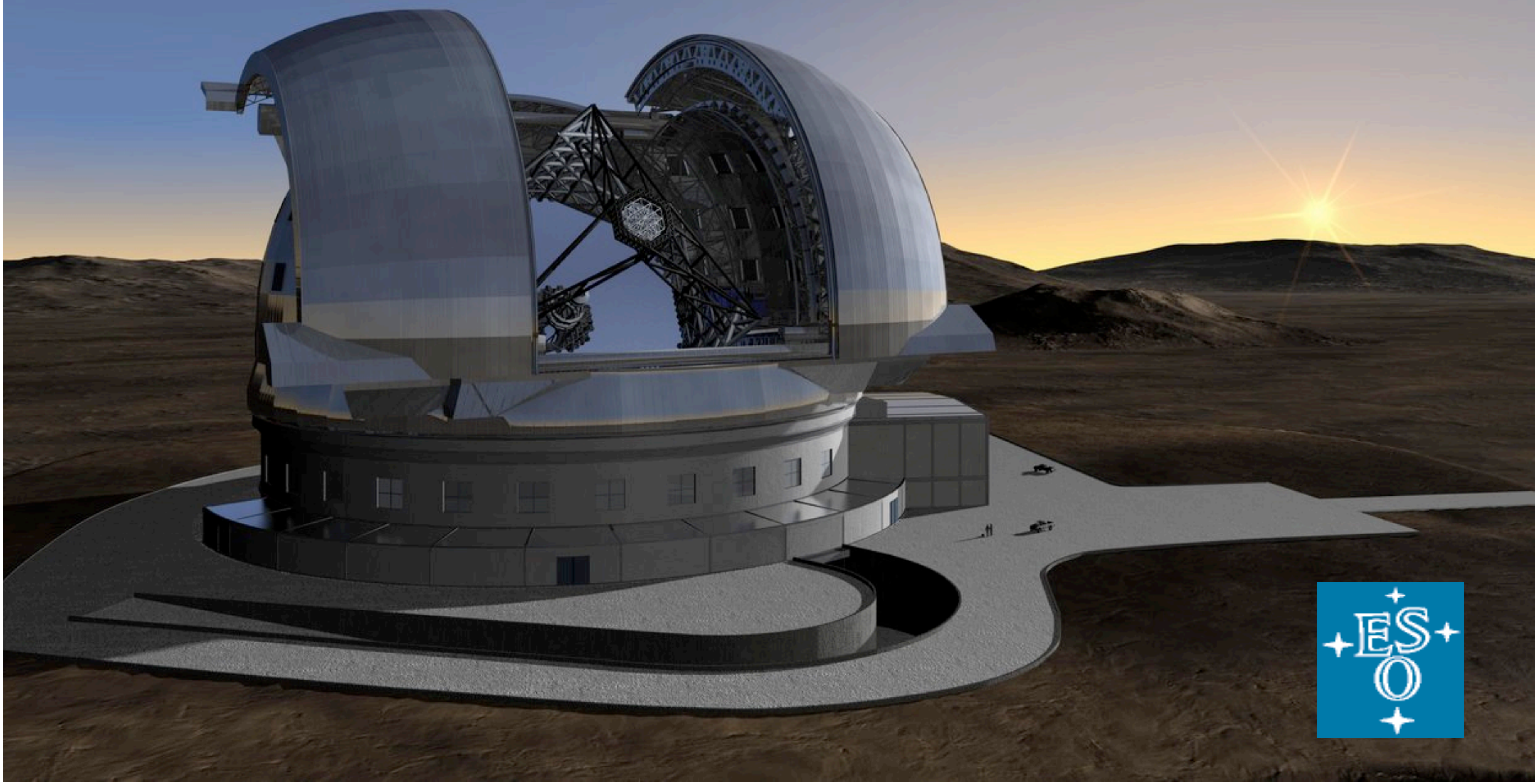
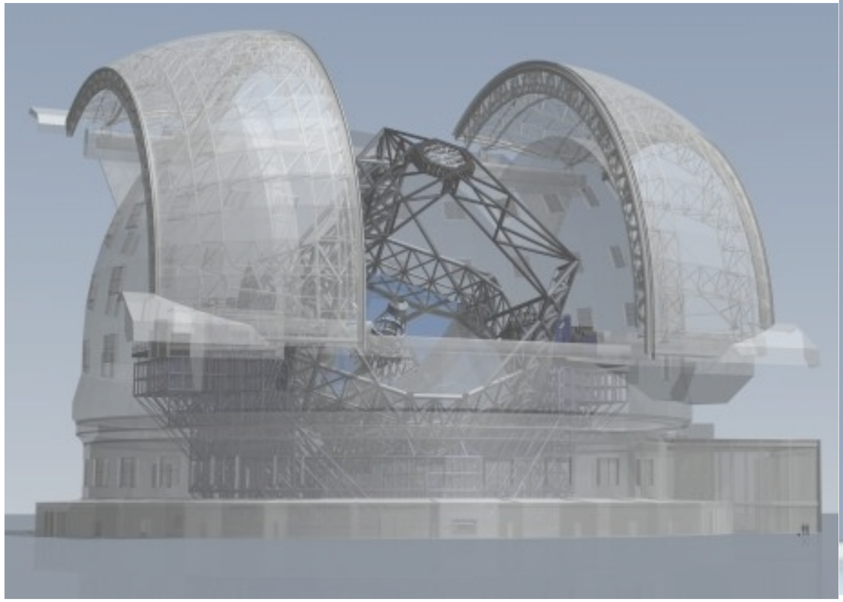
Observing giant-planet-mass objects in the LMC with E-ELT

Annalisa Calamida – E-ELT Science Office Post-doc



Garching, May the 28th, 2009

Is the E-ELT really big?! ;)



-8 yrs

1929 yrs

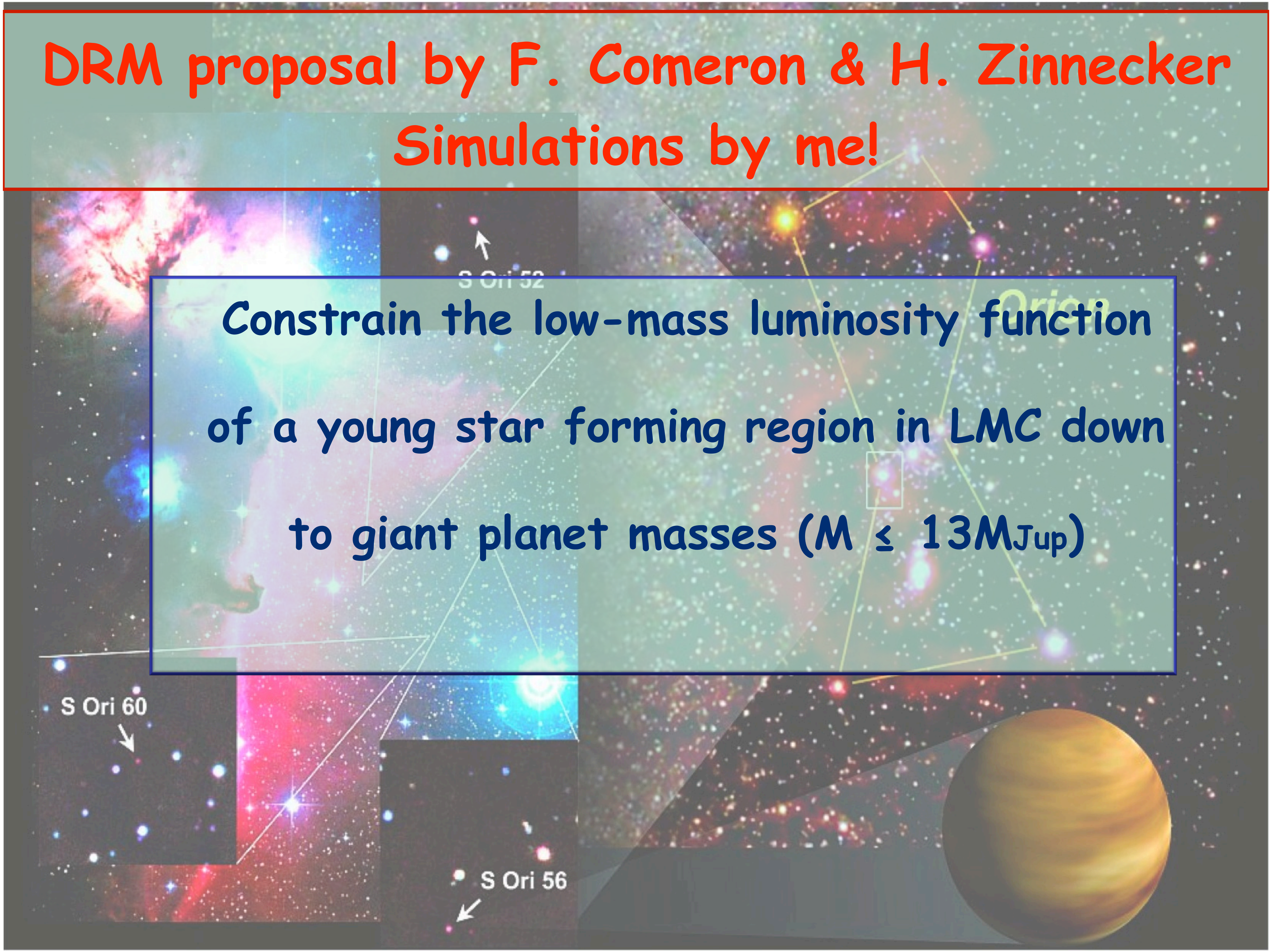
DRSP form

Are any of the targets variable? Do they require repeated observations?

No — Yes and requires sampling rate of 100 observations per millennium

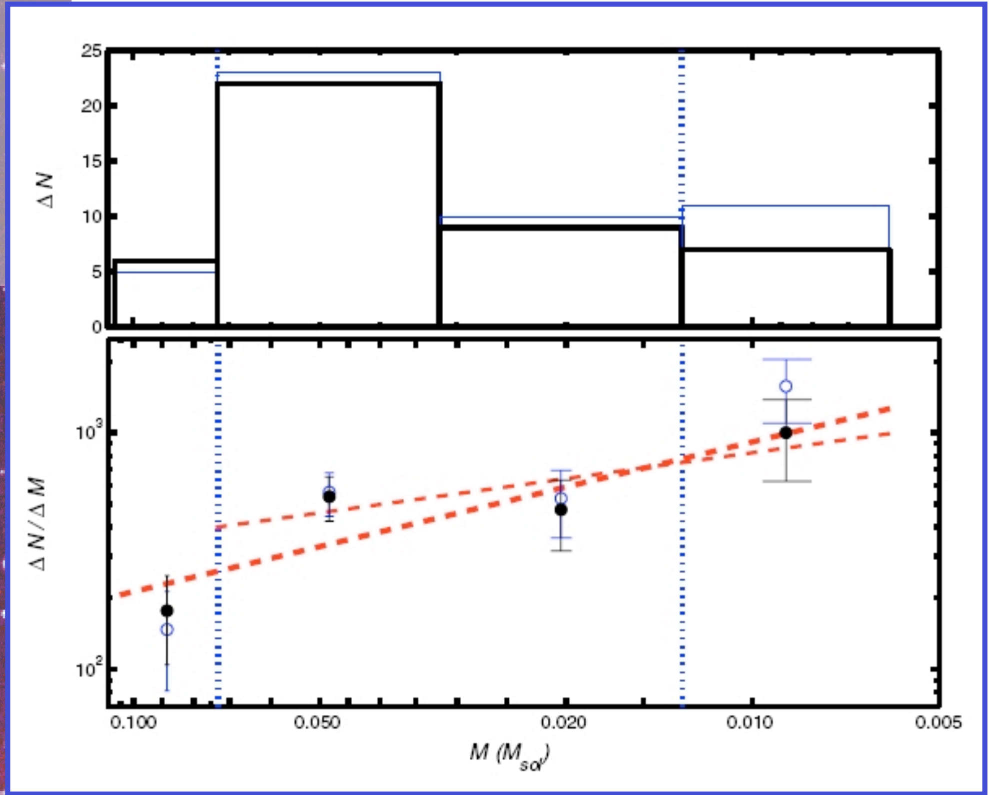
DRM proposal by F. Comeron & H. Zinnecker
Simulations by me!

Constrain the low-mass luminosity function of a young star forming region in LMC down to giant planet masses ($M \leq 13 M_{Jup}$)



Why LMC ?

Sub-stellar luminosity function in MW (~solar-metallicity): Planetary Mass Objects (PMOs) with M ≲ 13 M_{Jup} detected in σ Orionis (Zapatero-Osorio et al. 2000, Caballero et al. 2007)



Low-metallicity Brown Dwarfs (BDs) and PMOs are almost **invisible now in MW but accessible in LMC**

(a 5 M_{Jup} PMO of t = 1 Myr → K~28.2 mag)

Goals!

- Evolution of low-mass cut-off with metallicity
- What do low-mass, low metallicity BDs look like?
- How does the opacity limit depends on metallicity?

Challenges!

- coexistence of main targets with much brighter stars (18 < K ≤ 30 mag)
- very small sizes of star forming regions (~ 2” at the distance of LMC)
- crowding (~ 20 star/arcsec^2)

Need good on-axis AO correction

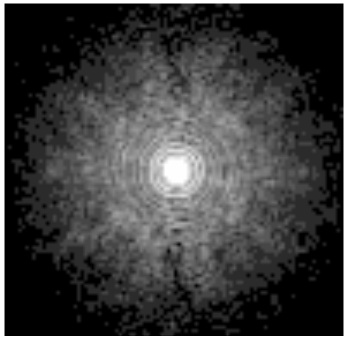
Some details on the simulations...

Technical data

- **J, H, K-band Laser Tomography AO (LTAO) simulated PSFs** (DRM technical database):

D=42m, 6 LGS, seeing = 0.8” at 0.5µm, zd = 0 (zd = 30,60 only for the K-band) → **PSF fits** by J. Liske

- Pixel scale: 2, 2.6, 3.5 mas (PSF sampling) and 5 mas



- **Fov = 2” × 2”** :

✓ The PSF does not vary in the region

✓ No contamination by field stars and galaxies

Technical data

Variable background

Due to stellar light reflected by dust:

Unresolved → variation lenghtscale < PSF FWHM

↓

additional source of noise

Typical emission nebulosity has blue colors: **(J-H) ~ -0.9, (H-K) ~ -0.6**

Background level of J ~ 23.9, H ~ 24.8 and K ~ 25.4

Scientific inputs

Input star catalog:

- Chabrier (2005) IMF + Baraffe (2003) evolutionary tracks for t = 5 Myr and solar metallicity:

100 stars from 2 to 0.003 $M_{\odot}$ uniformly distributed in a circular area with **R ≈ 1 arcsec**

DM_0 = 18.5 (LMC, Freedman et al. 2001)

Scienti

Input s

- Chabrier (2005) IMF + Ba

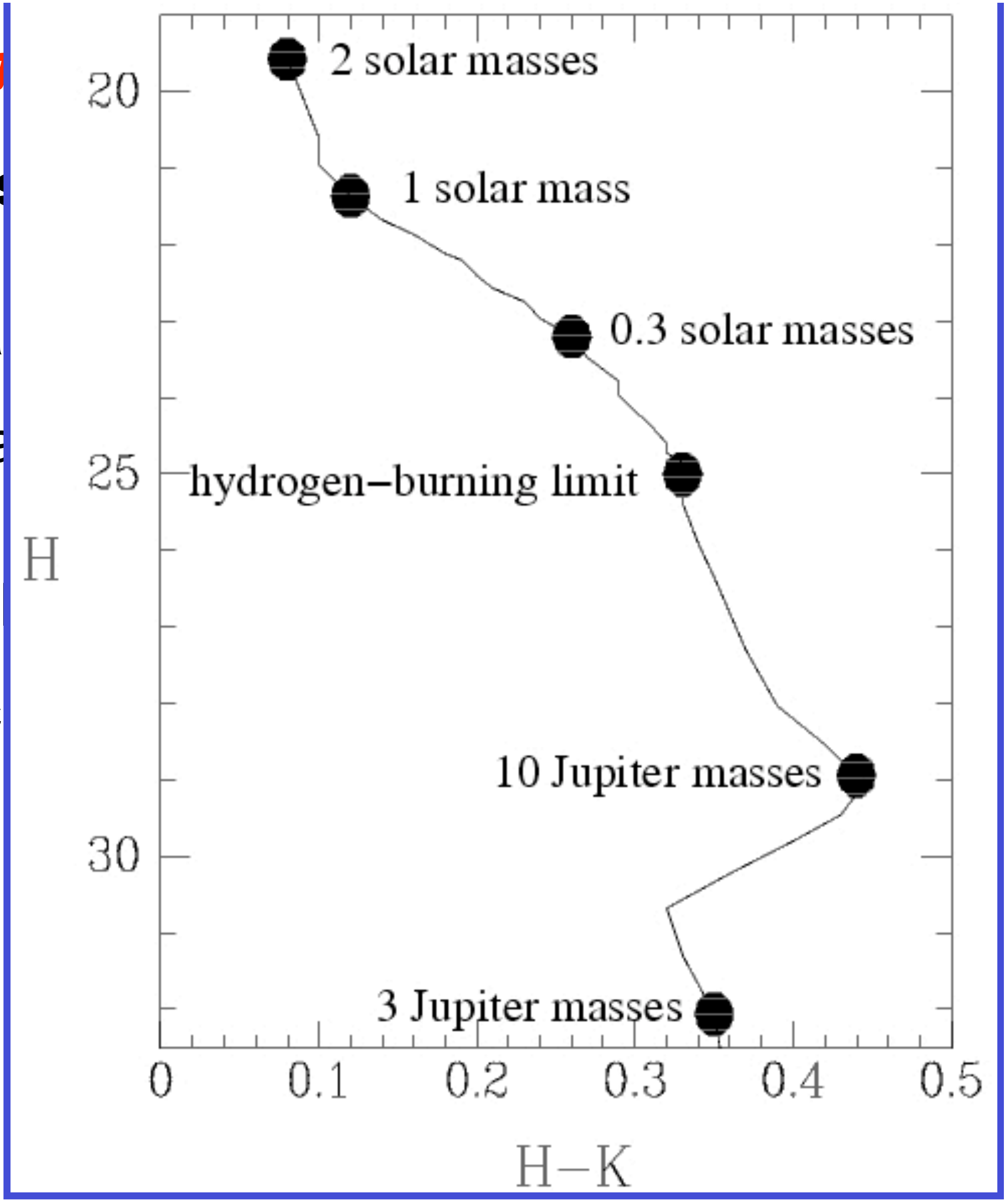
for t = 5 Myr and solar meta

100 stars from 2 to 0.003

circular area with **R ≈ 1 arc**

DM$_0$ = 18.5 (LMC, Freedman

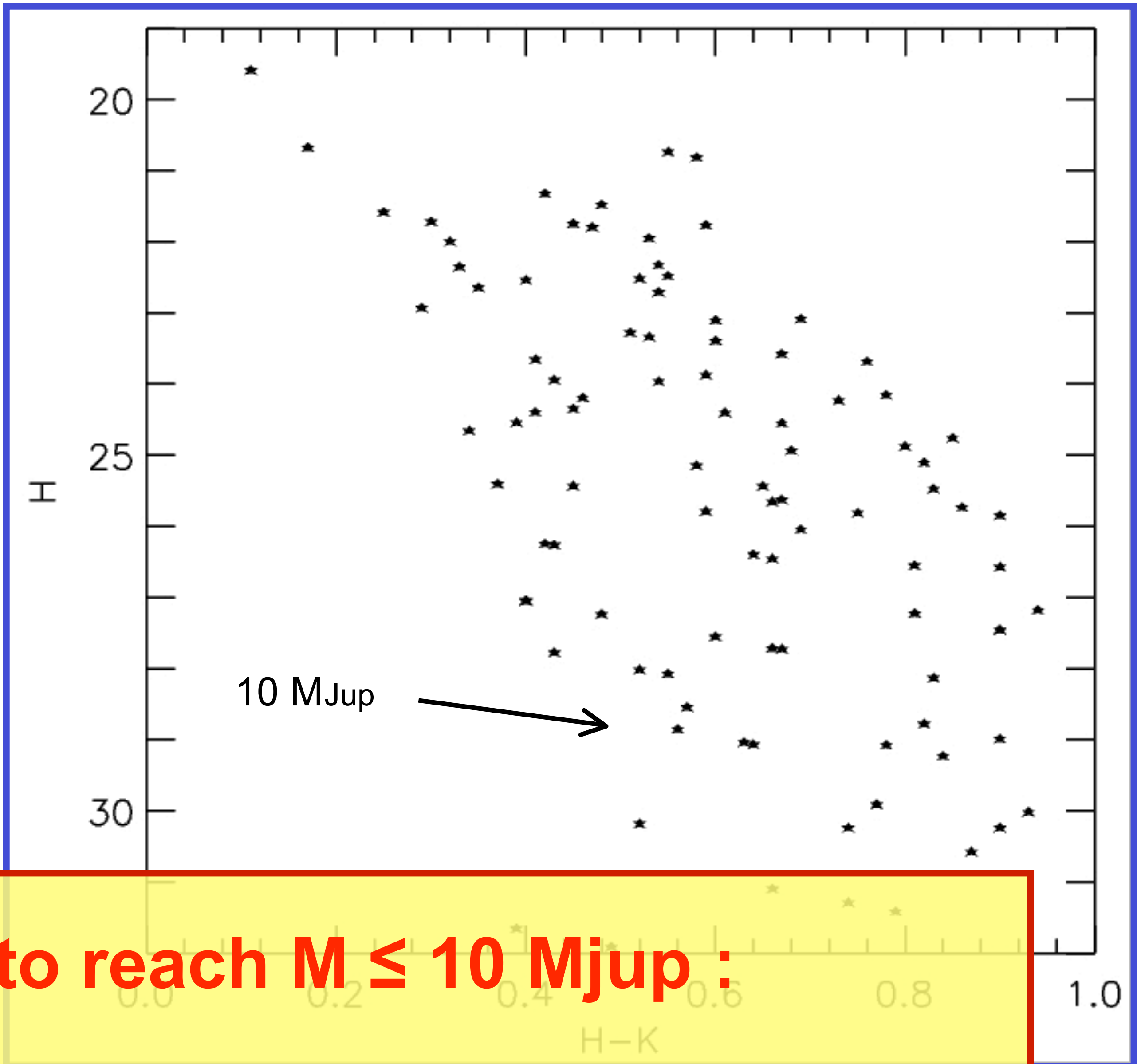
et al. 2001)



Scientific inputs

random extinction

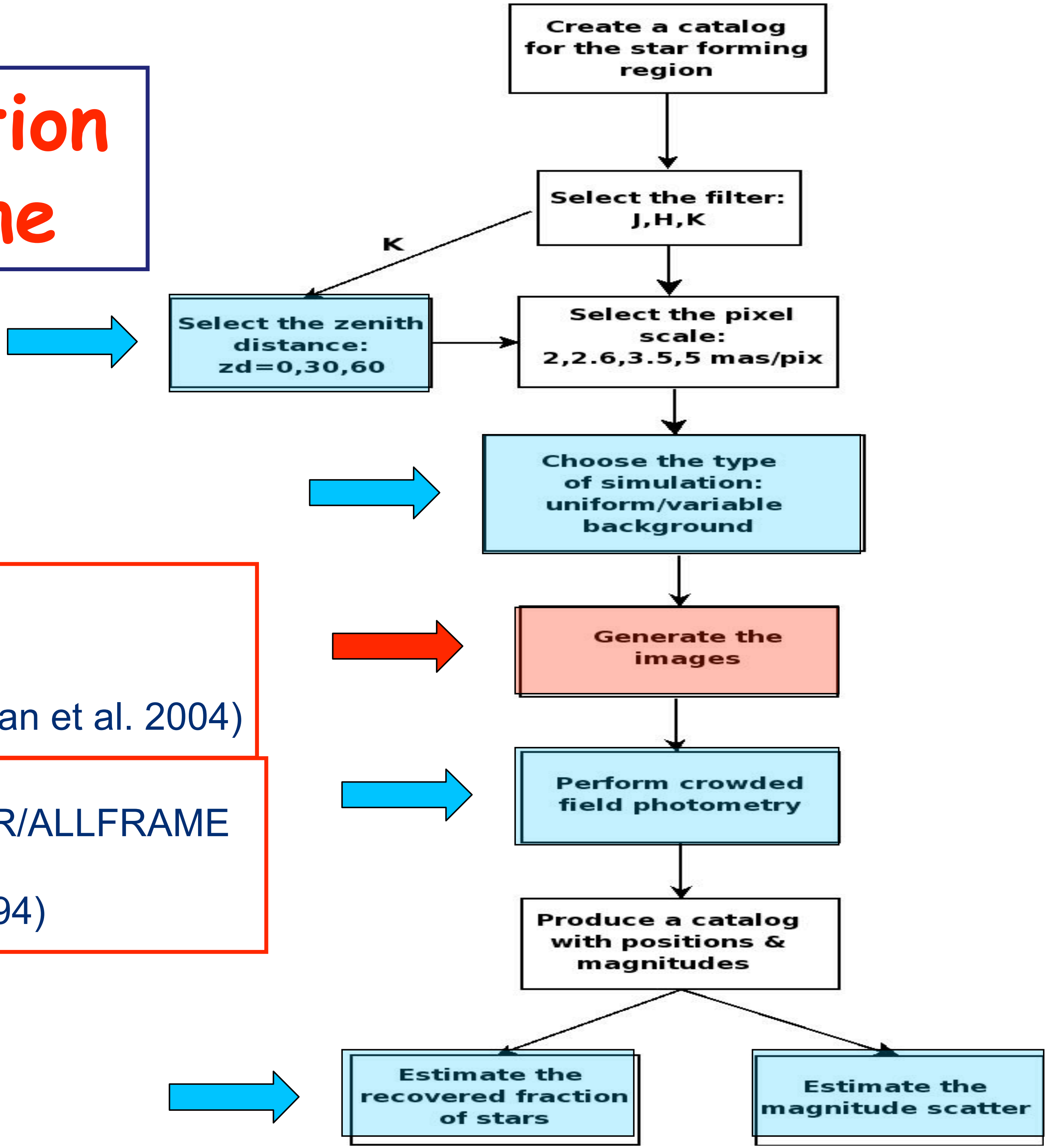
from A_K = 0 to 1 mag



Need to reach M ≤ 10 Mjup :

J ~ 29.1, H ~ 28.7 and K ~ 28.2 with S/N=10

Simulation pipeline



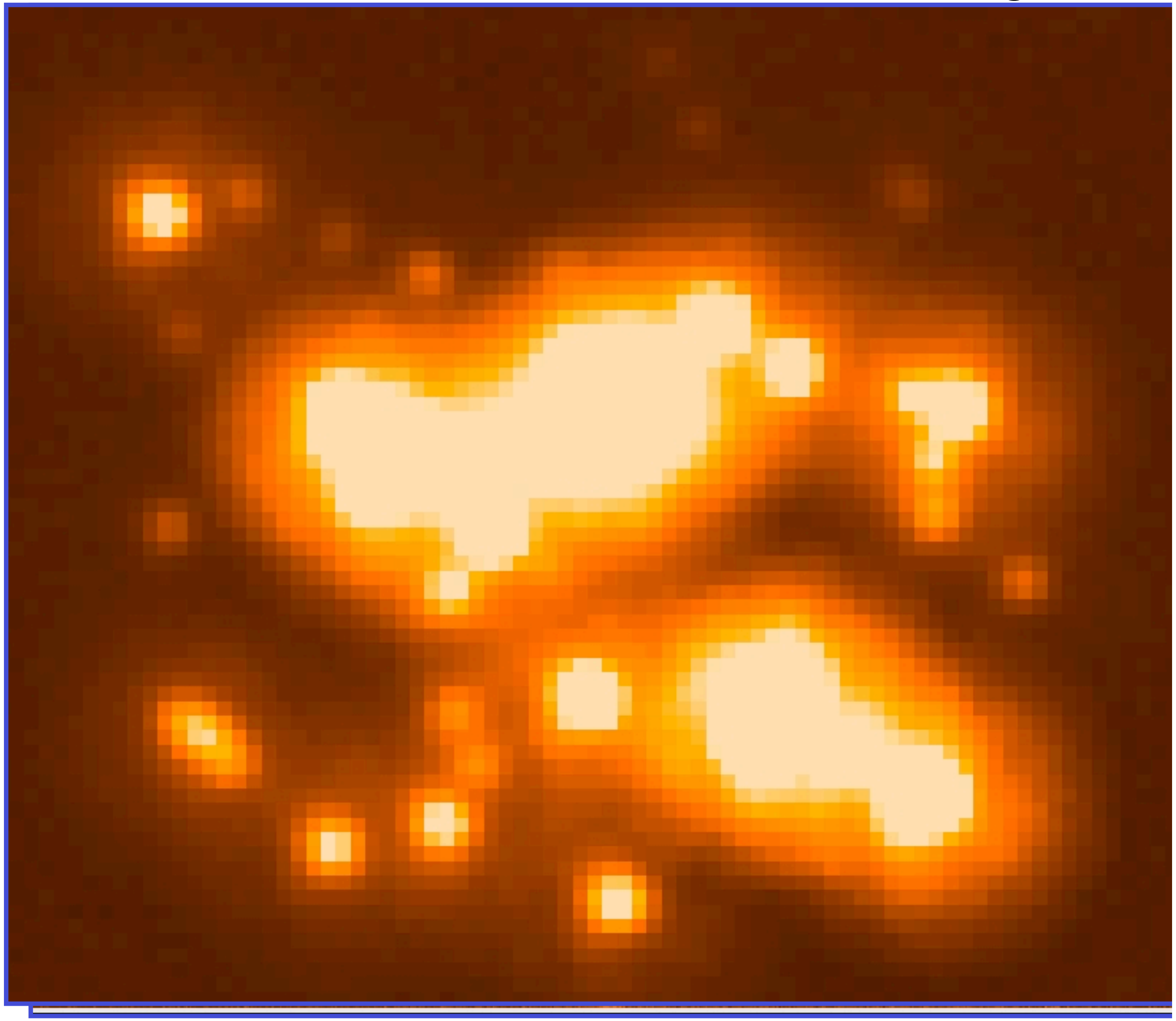
1. IRAF mkobjects
2. LBCImSim (Grazian et al. 2004)

DAOPHOT/ALLSTAR/ALLFRAME

(Stetson 1987,1994)

25 K-band images

Uniform background



t_{exp} = 1h

Sky = 13 mag/arcsec^2

Pixel scale = 3.5 mas

MAD

2”

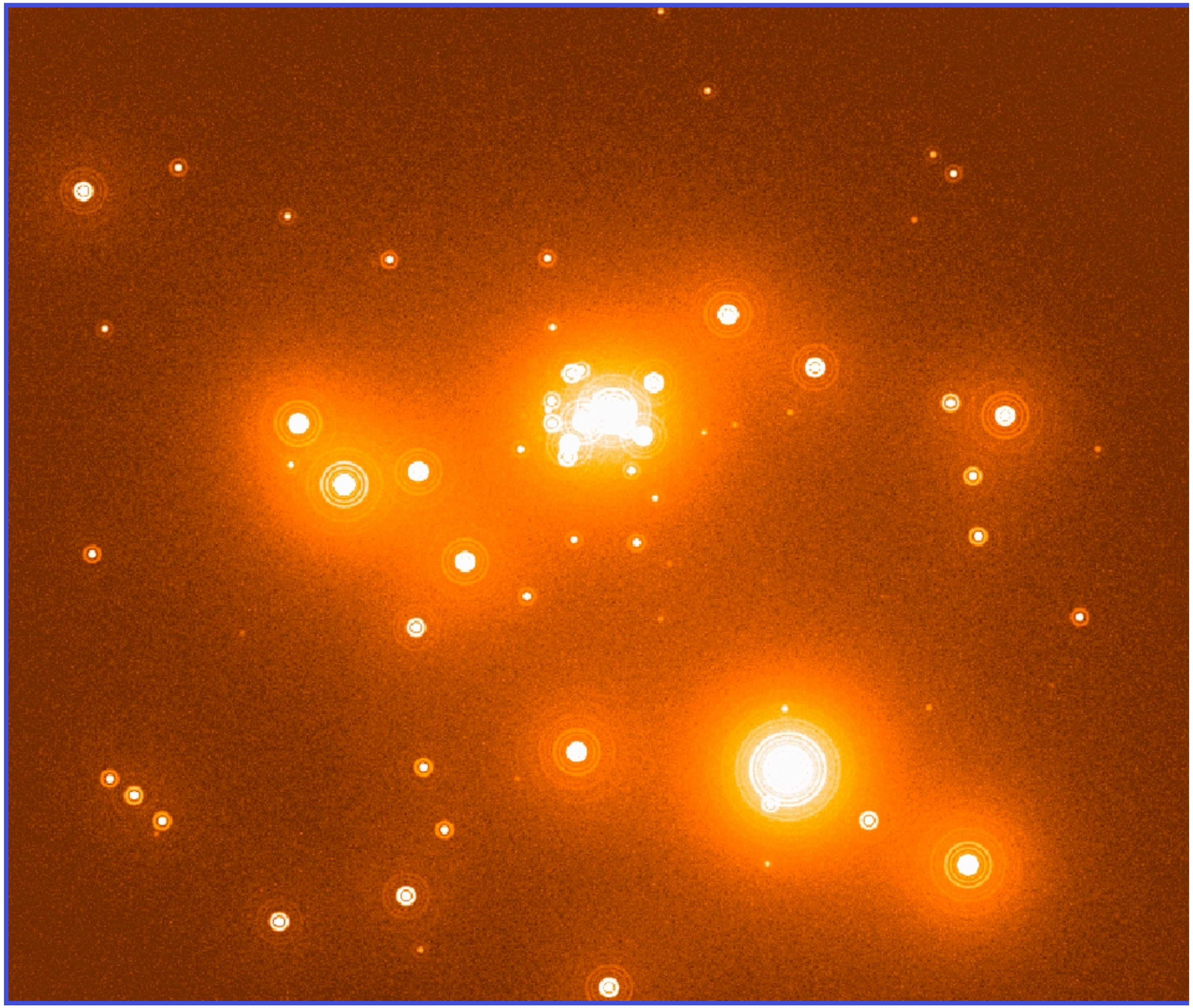
25 H-band images

Uniform background

t_{exp} = 1h

Sky = 14 mag/arcsec^2

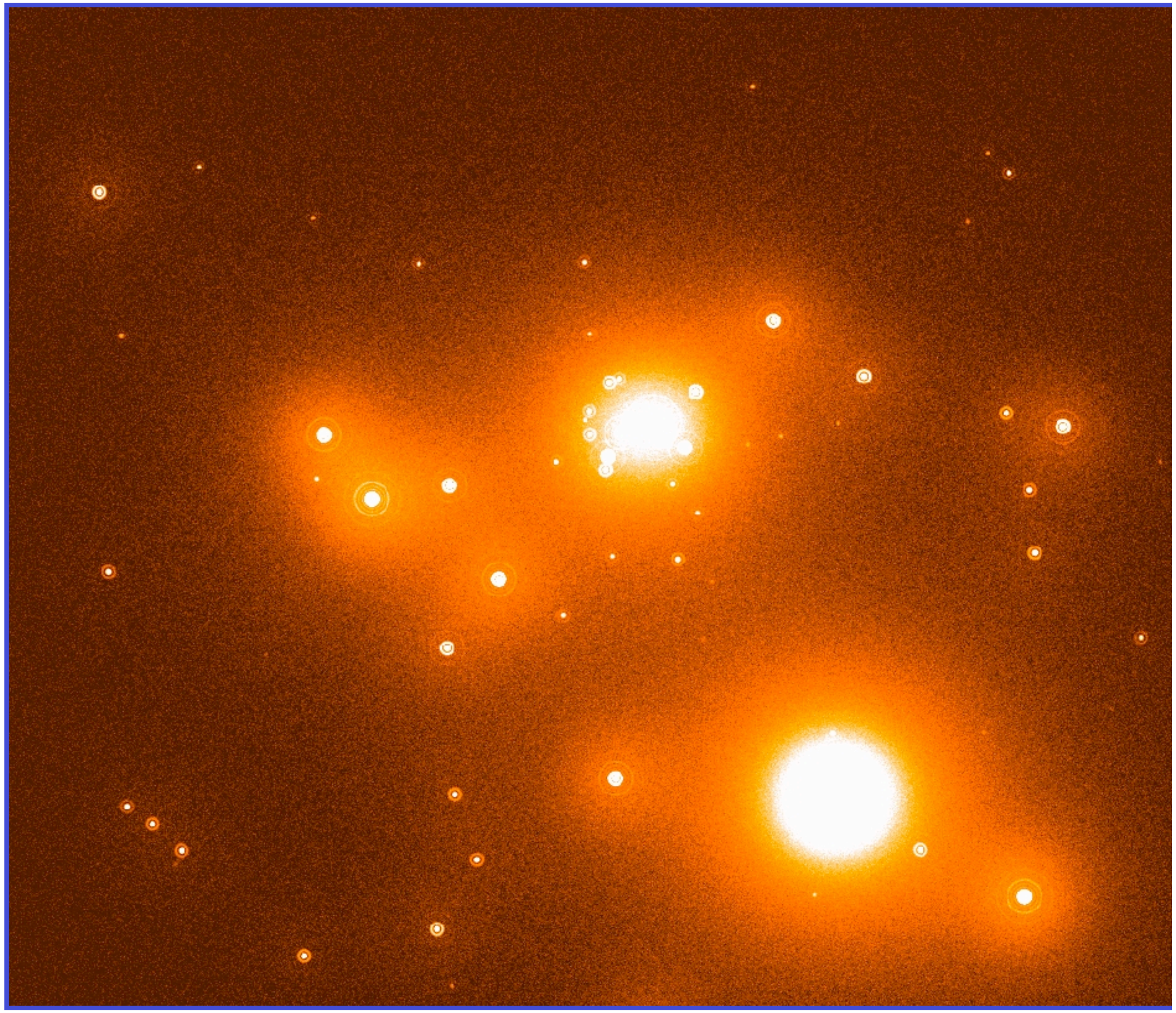
Pixel scale = 2.6 mas



2"

10 J-band images

Uniform background



t_{exp} = 1h

Sky = 16 mag/arcsec^2

Pixel scale = 2 mas

2”

Image reduction

PSF-photometry with

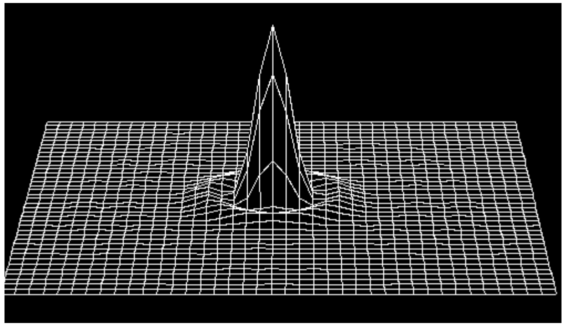
DAOPHOT/ALLSTAR:

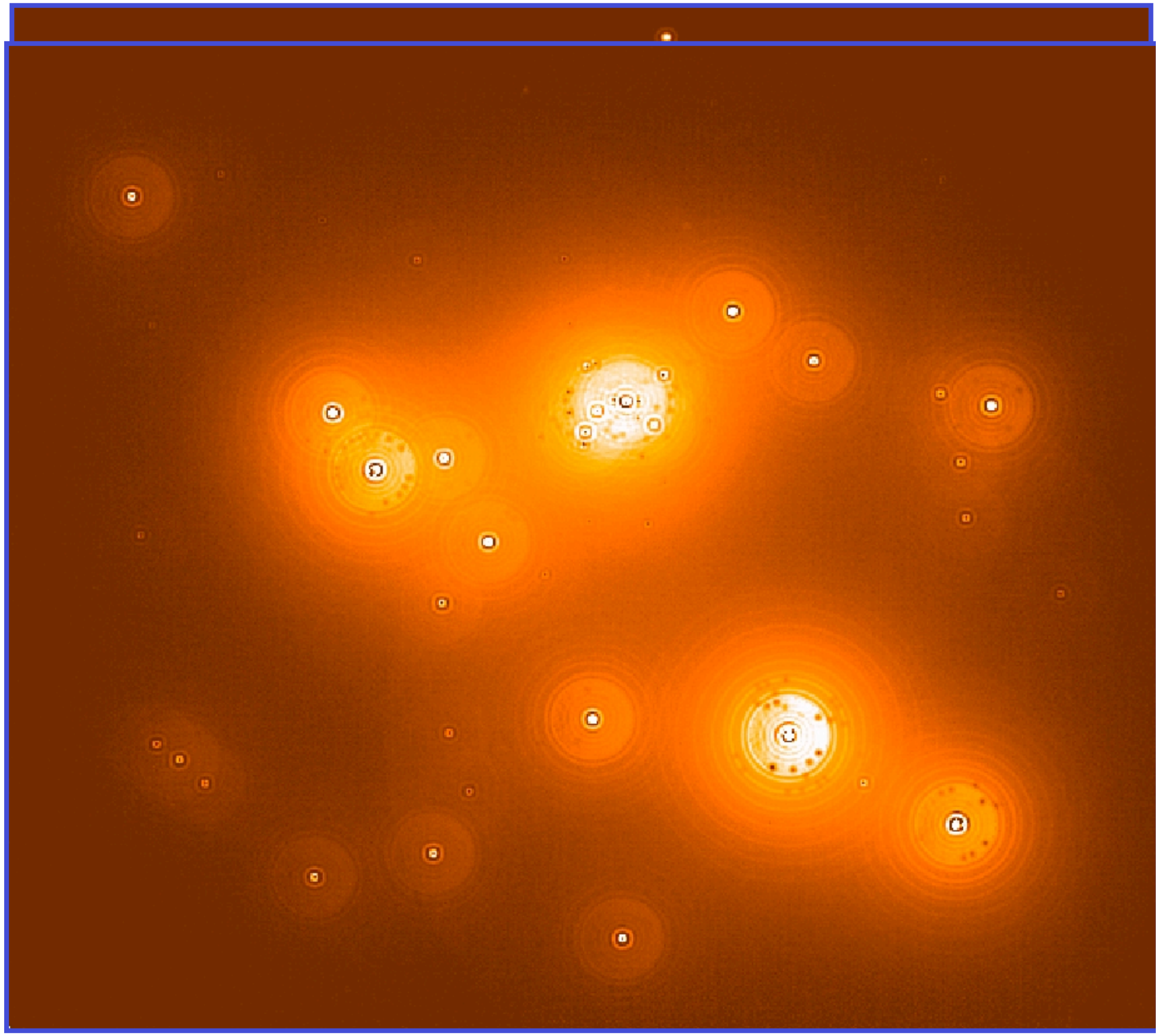
- Analytical + numerical

Moffat function
(β = 2.5)

Residual matrix

Median of the subtracted images





Magnitude scatter:

$$S = \sqrt{\frac{1}{N}\sum(input - recovered)^2}$$

Band	Pix scale (mas)	Lim . Mag (S/N~4)	Scatter 0.2 mag	Scatter 0.1 mag
Juni	**2**	**30.1**	**29.5**	**29.0**
Jvar	**2**	**29.0**	**28.7**	**28.0**
Jvar	5	26.0	25.5	24.0
Huni	**2.6**	**29.6**	**29.2**	**28.0**
Hvar	**2.6**	**29.0**	**28.6**	**27.3**
Hvar	5	27.6	25.8	24.0
Kuni	**3.5**	**29.8**	**29.3**	**27.6**
Kvar	**3.5**	**29.5**	**28.8**	**27.5**
Kvar	5	28.4	27.8	26.2
Kzd30	**3.5**	**28.8**	28.6	28.6
Kzd60	**3.5**	**28.6**	28.3	27.5

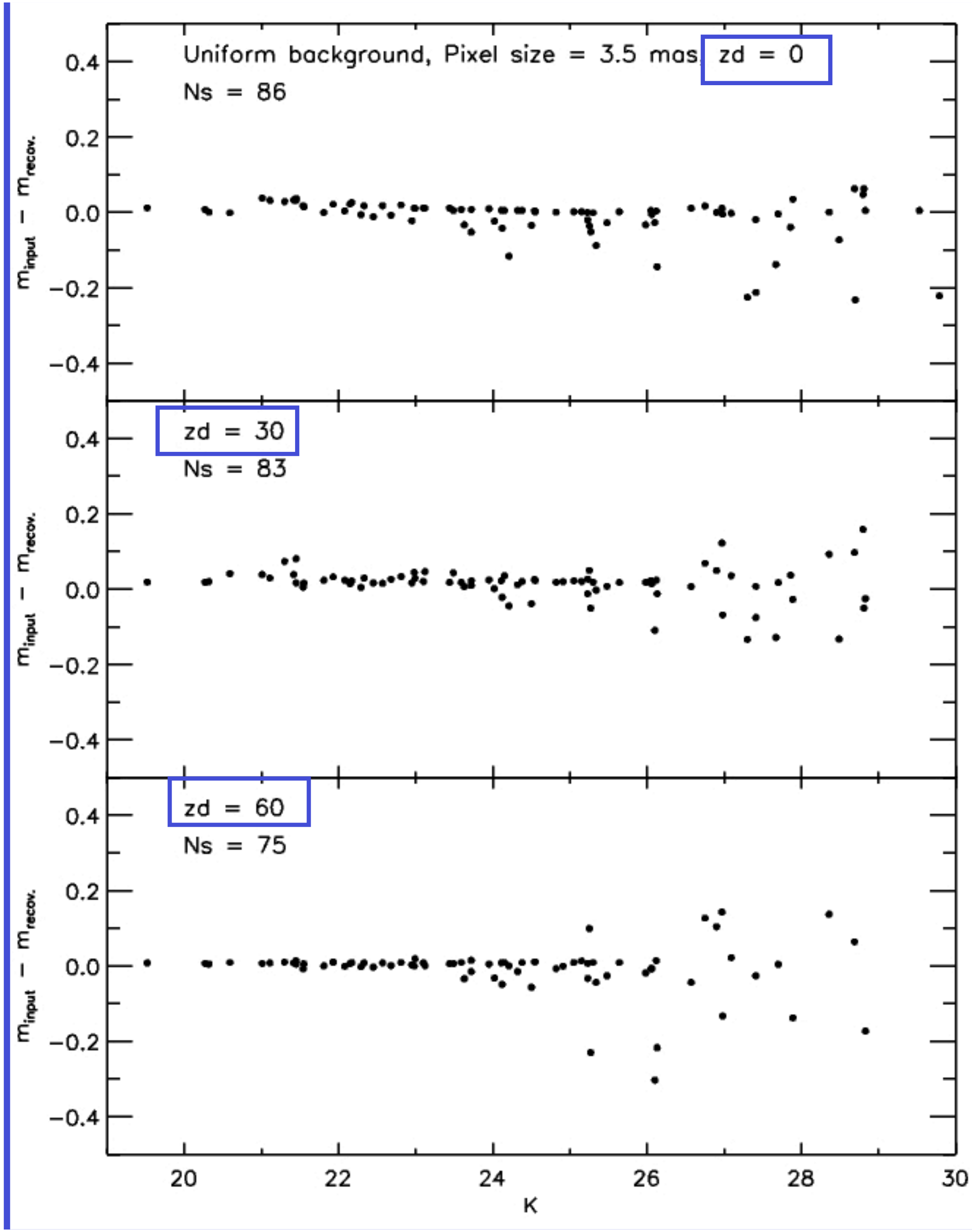
Zenith distance

Limiting magnitude

decreases of ~ 1 mag

Scatter increases for

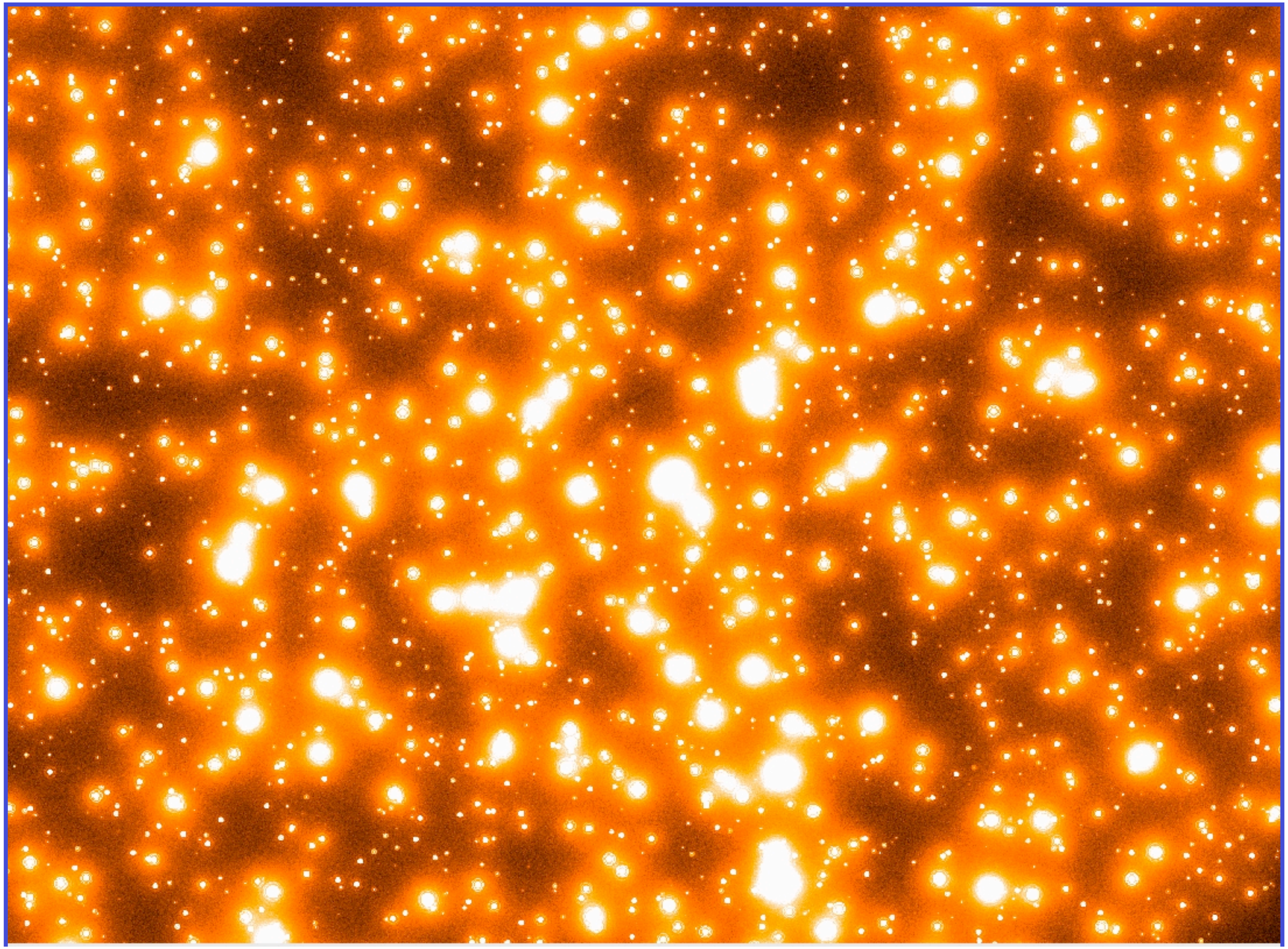
K > 26 mag



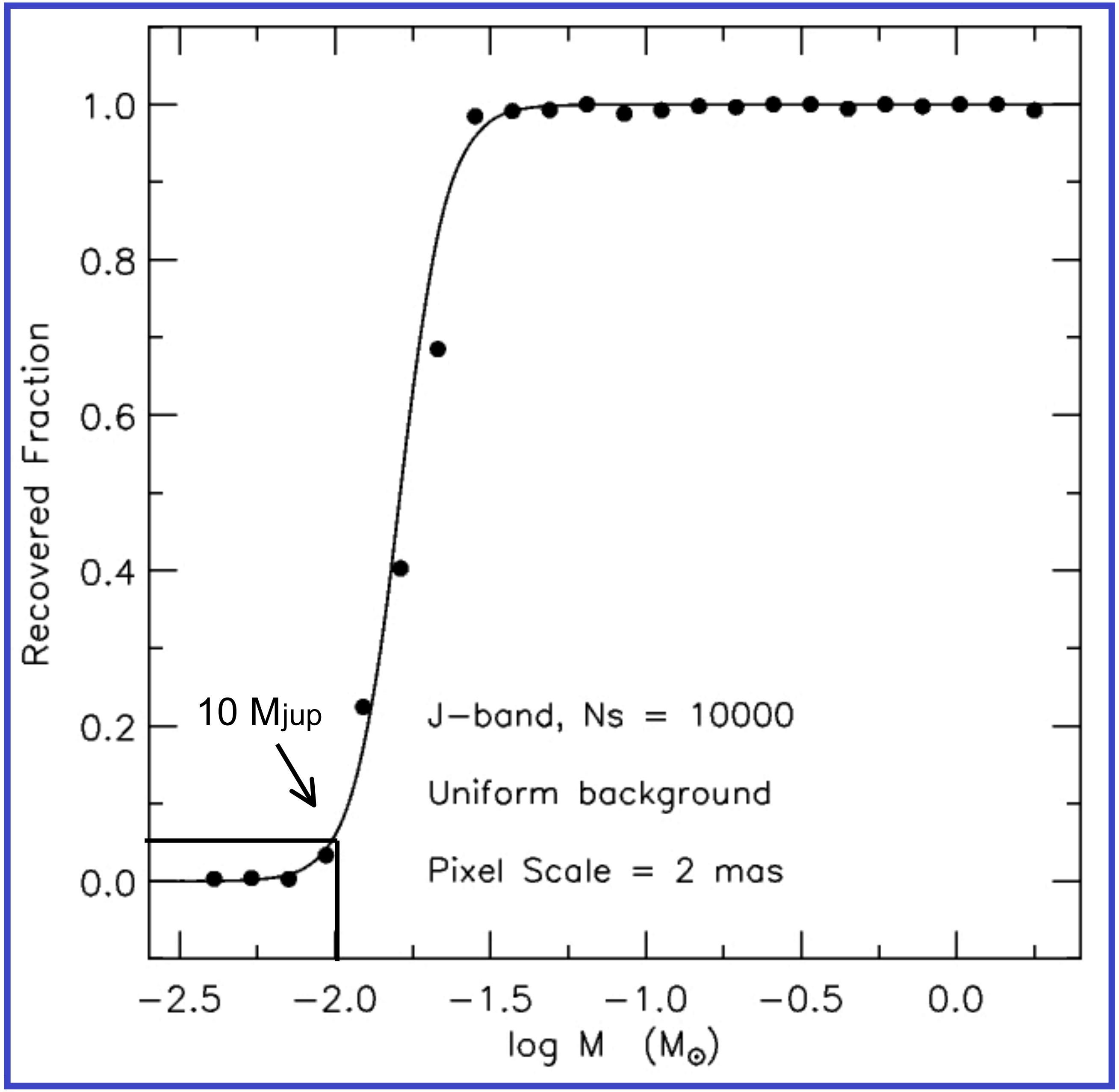
To increase the statistics: 10,000 stars in a circle of radius 10”

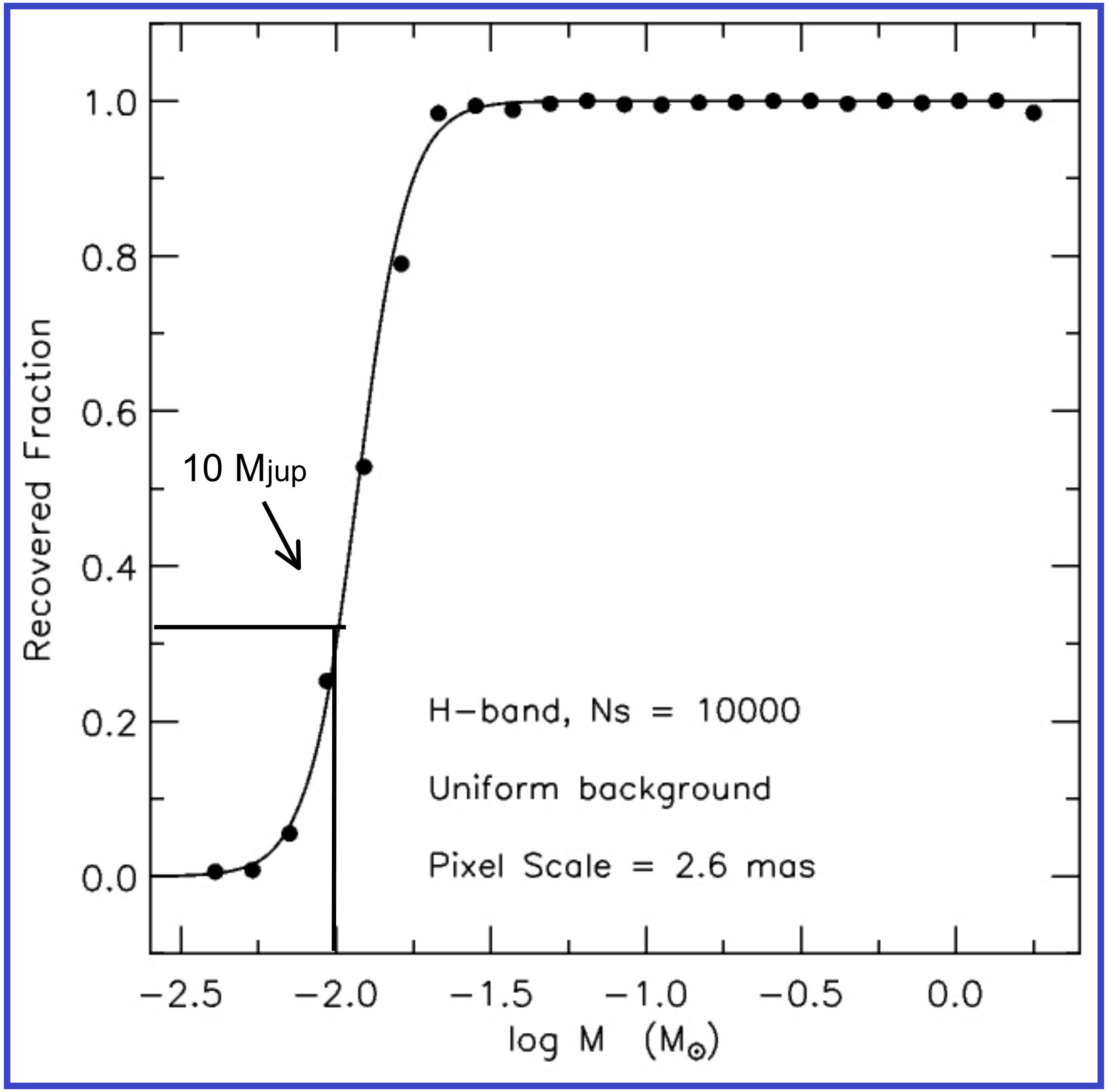
to preserve the stellar density

~ 10”

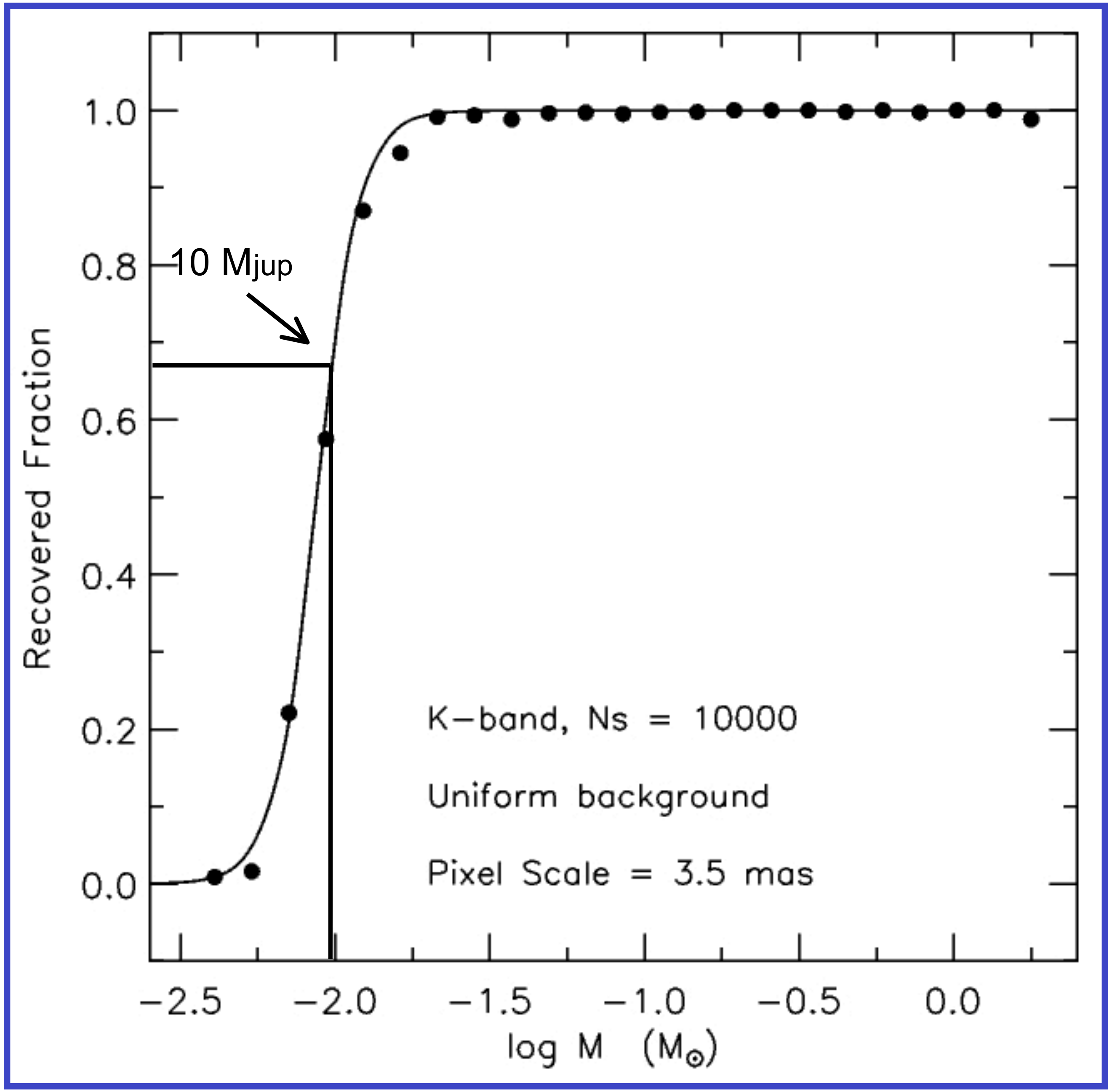


Completeness





1.0
0.8
0.6
0.4
0.2
0.0
Recovered Fraction
10 Mjup
H−band, Ns = 10000
Uniform background
Pixel Scale = 2.6 mas
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
log M ($M_\odot$)



Recovered Fraction
1.0
0.8
0.6
0.4
0.2
0.0
10 Mjup
K−band, Ns = 10000
Uniform background
Pixel Scale = 3.5 mas
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
log M (M⊙)

Recovered fraction of stars at different magnitudes and masses

Band	90% mag	50% mag	90% MJup	50% MJup
J	29.15	29.4	24	16
H	28.8	29.4	18	12
K	28.6	29.3	17	9

We accomplish proposal goal and reach:

J ~ 29.1, H ~ 28.8 and K ~ 28.6 with S/N=10

Variable background

The presence of variable background decreases the S/N at a certain magnitude

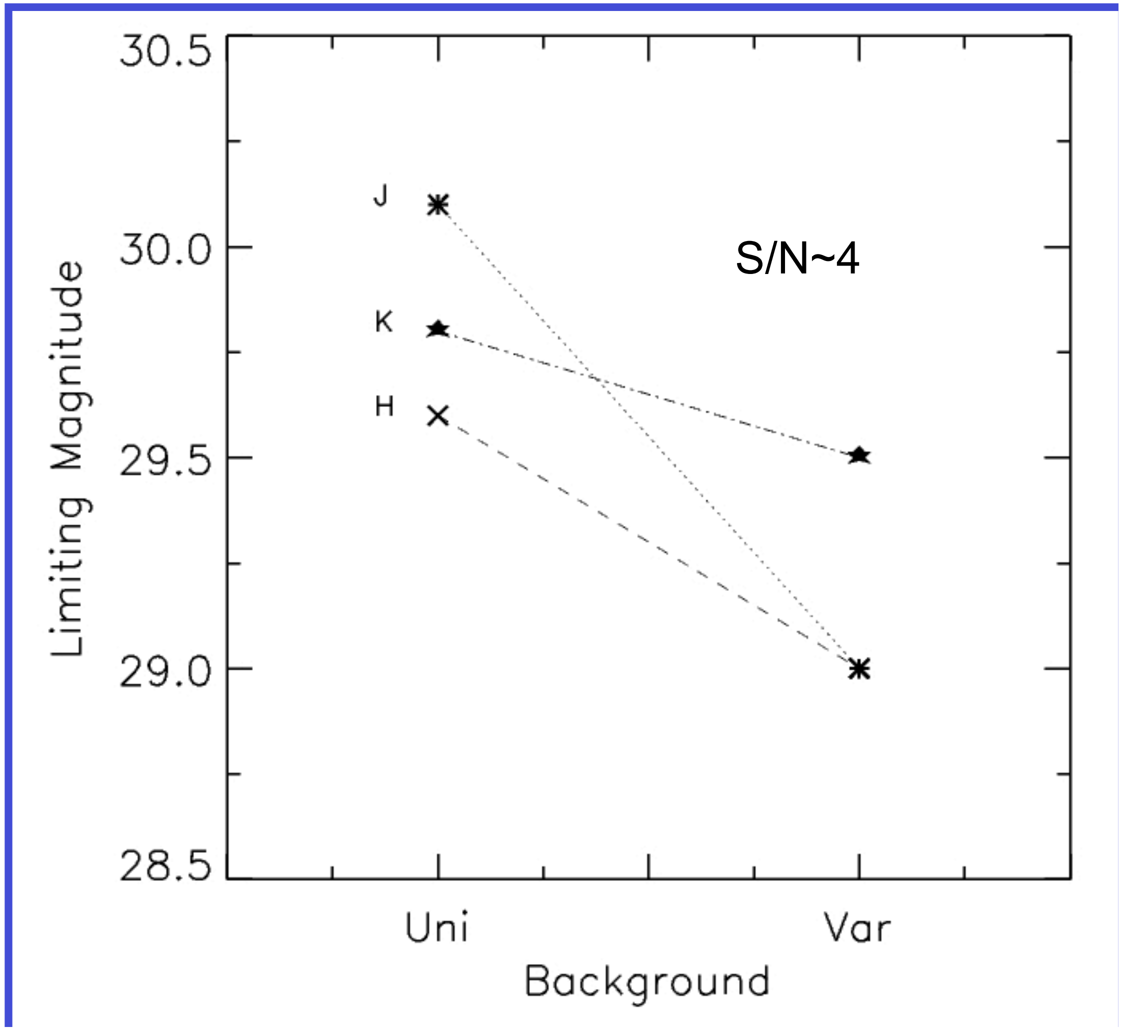
Typical emission nebulosity has blue colors:

(J-H) ~ -0.9, (H-K) ~ -0.6

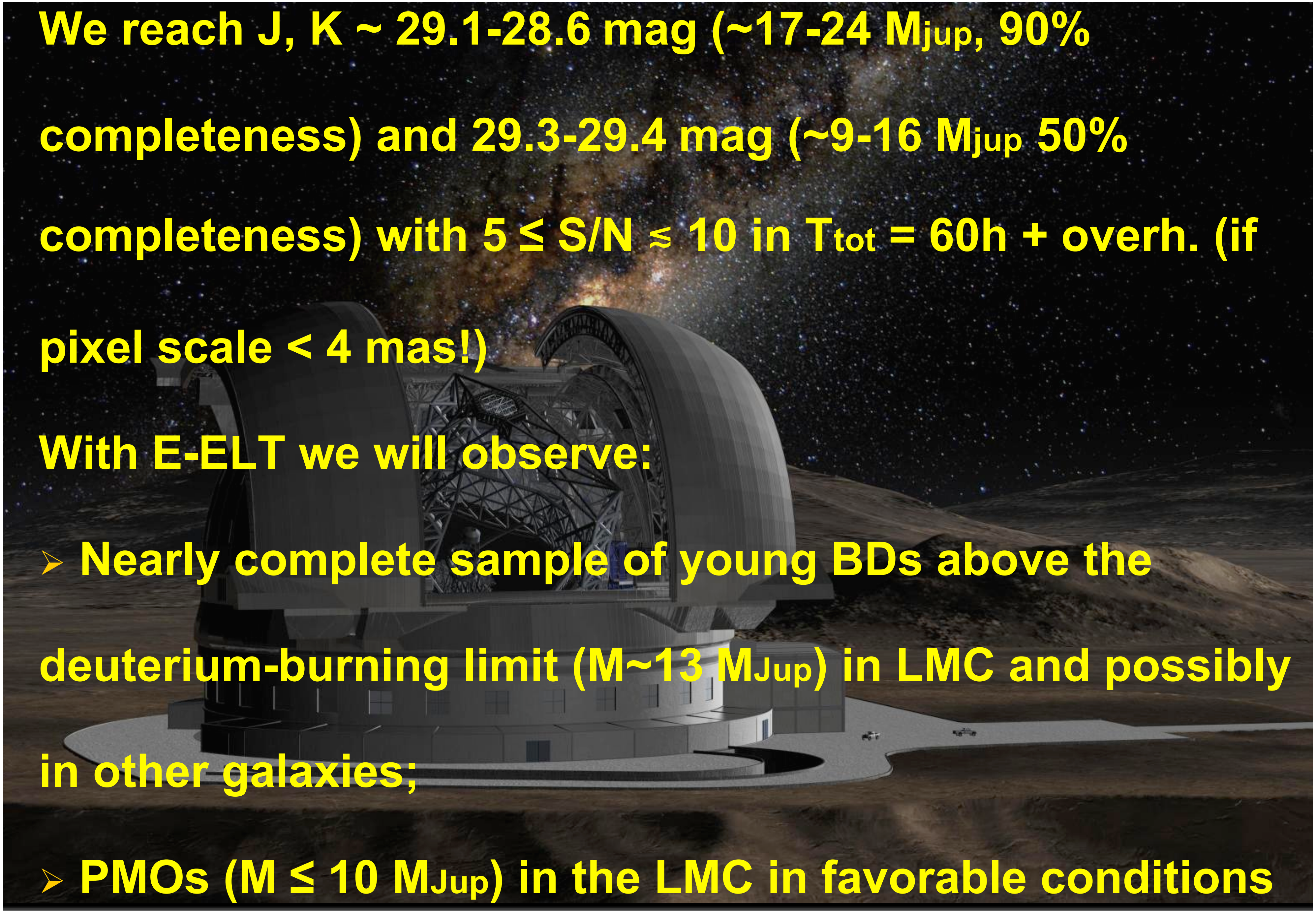
We reach

J ~ 29.1, H~ 28.8, K~ 28.6

but with 5 ≤ S/N < 10



Conclusions

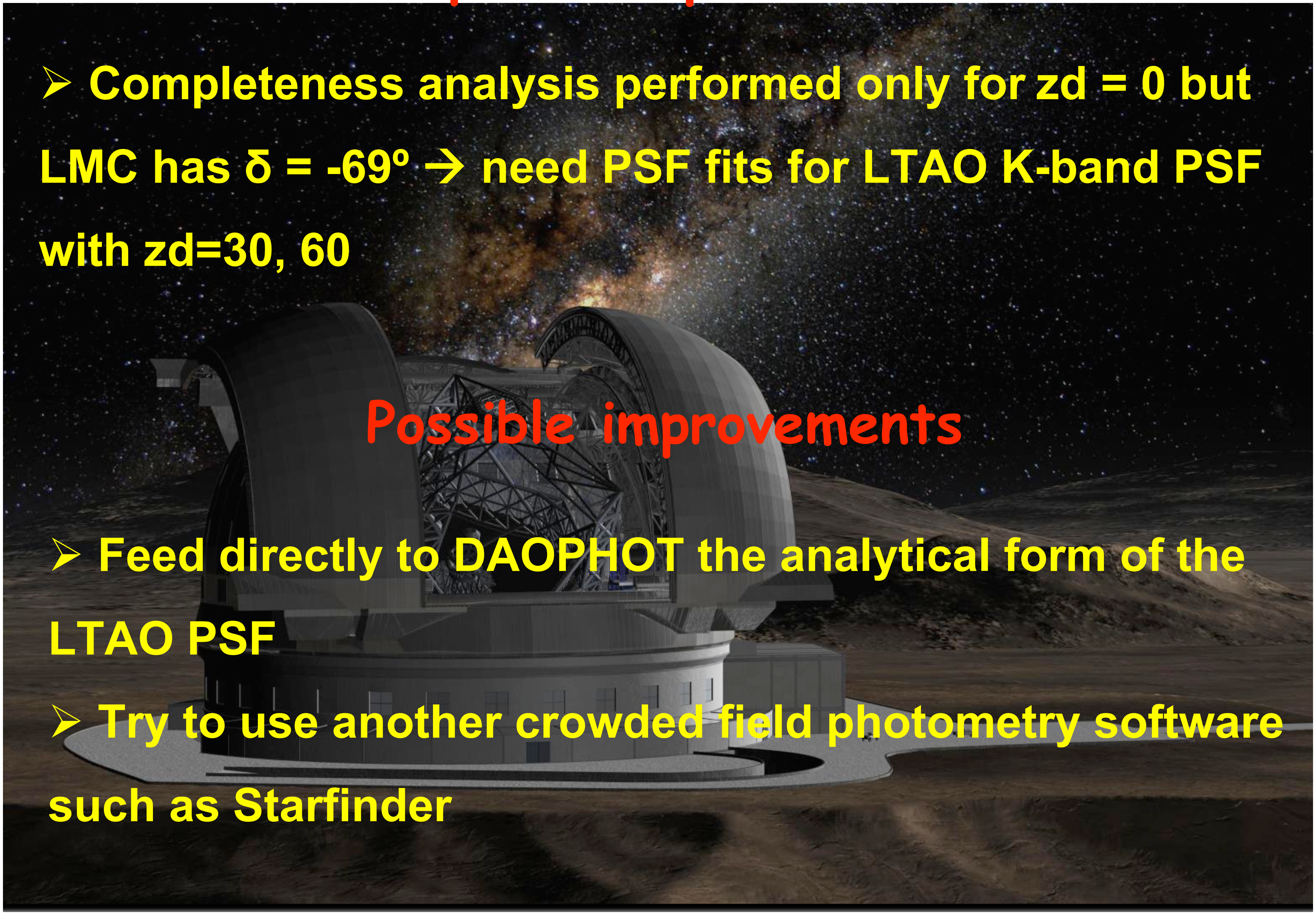


We reach J, K ~ 29.1-28.6 mag (~17-24 M_{jup}, 90% completeness) and 29.3-29.4 mag (~9-16 M_{jup} 50% completeness) with $5 \leq S/N \lesssim 10$ in T_{tot} = 60h + overh. (if pixel scale < 4 mas!)

With E-ELT we will observe:

- Nearly complete sample of young BDs above the deuterium-burning limit (M~13 M_{Jup}) in LMC and possibly in other galaxies;
- PMOs ($M \leq 10\ M_{Jup}$) in the LMC in favorable conditions

Required improvements



- Completeness analysis performed only for zd = 0 but LMC has $\delta = -69^{o}$ → need PSF fits for LTAO K-band PSF with zd=30, 60

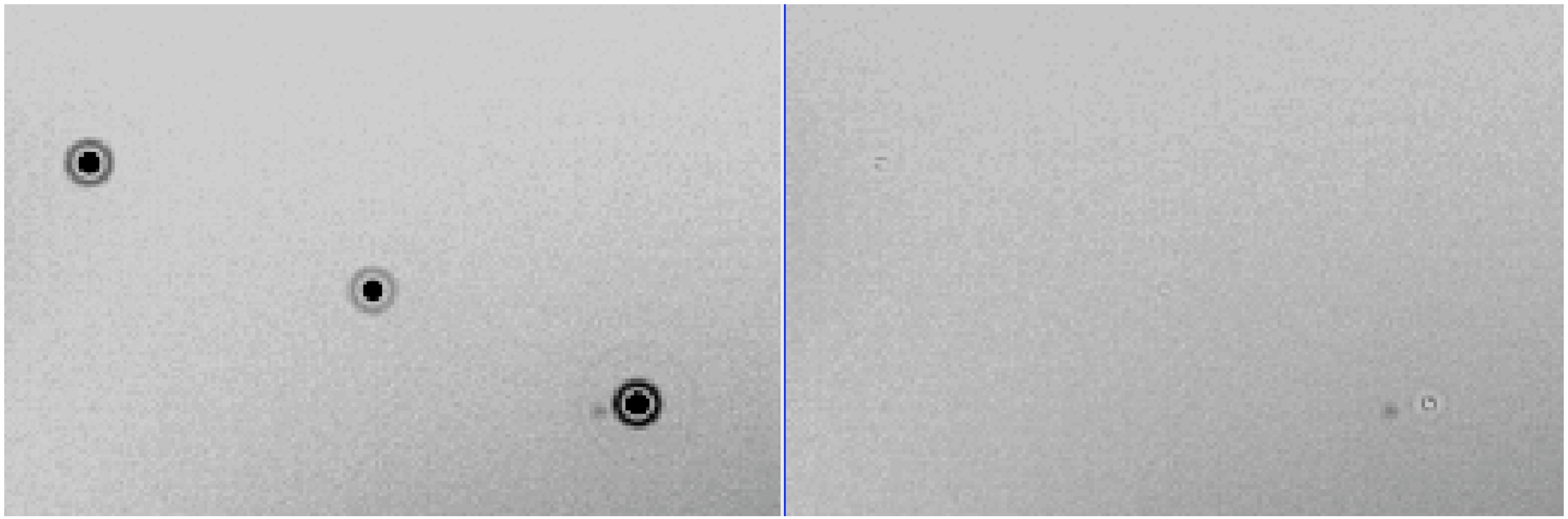
Possible improvements

- Feed directly to DAOPHOT the analytical form of the LTAO PSF
- Try to use another crowded field photometry software such as Starfinder

Stellar light reflected by dust: reflection nebulosity with a total reprocessed emission in the K-band equivalent to 1/10 of the solar luminosity in that band, and typical emission nebulosity blue colors (J-H)=-0.9, (H-K0)= -0.6, we obtain a background level of

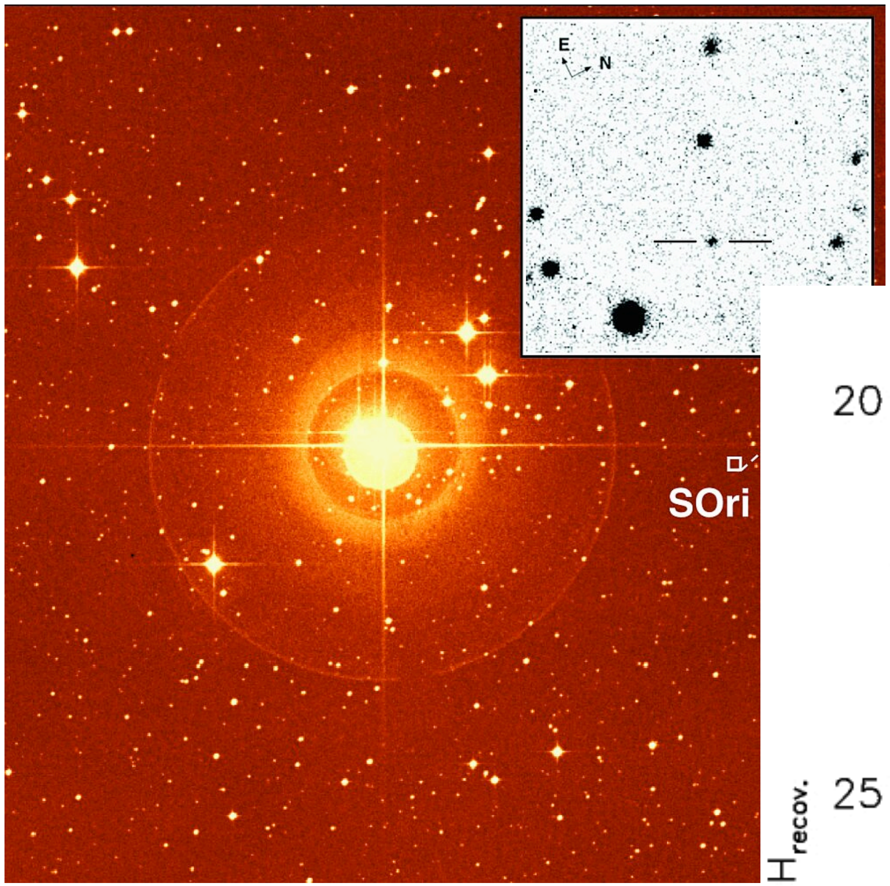
J = 23.9, H=24.8 and K = 25.4

5 Mjup with t = 1 Myr -> Mj~10.6, Mh~ 10.2, Mk~9.7



$$C = \frac{1}{e^{(mag - mag_{50})} + 1}$$

$$\Delta m \approx 2.5\log\left(\frac{S+N}{S}\right) \approx (2.5)(0.43429)\ln\left(\frac{S+N}{S}\right) \approx (2.5)(0.43429)\frac{N}{S} \approx 1.0857\frac{N}{S}$$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N
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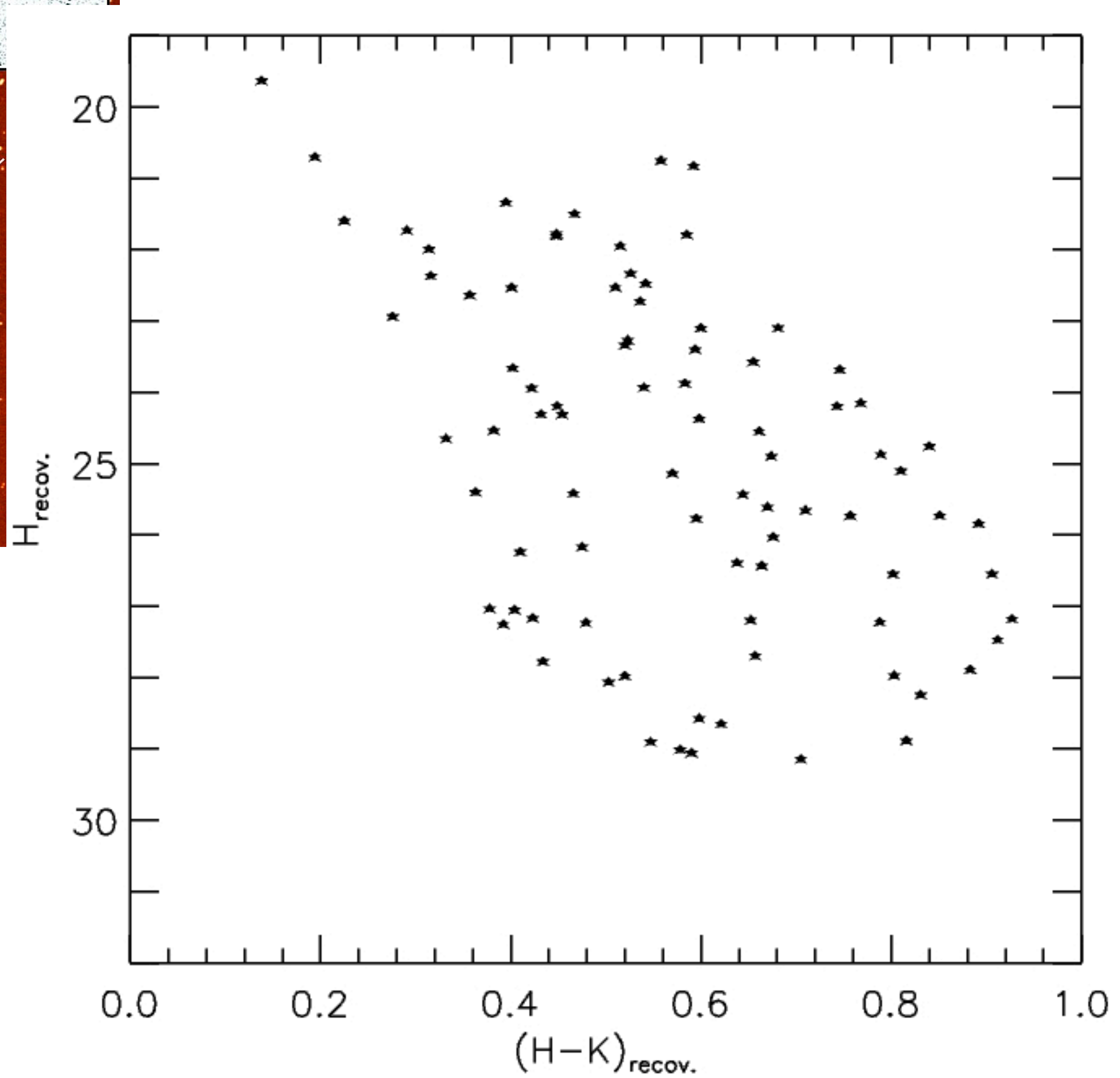
20
25
30
0.0
0.2
0.4
0.6
0.8
1.0
H recov.
(H−K) recov.