The distance to the Antennae using Cepheid variables

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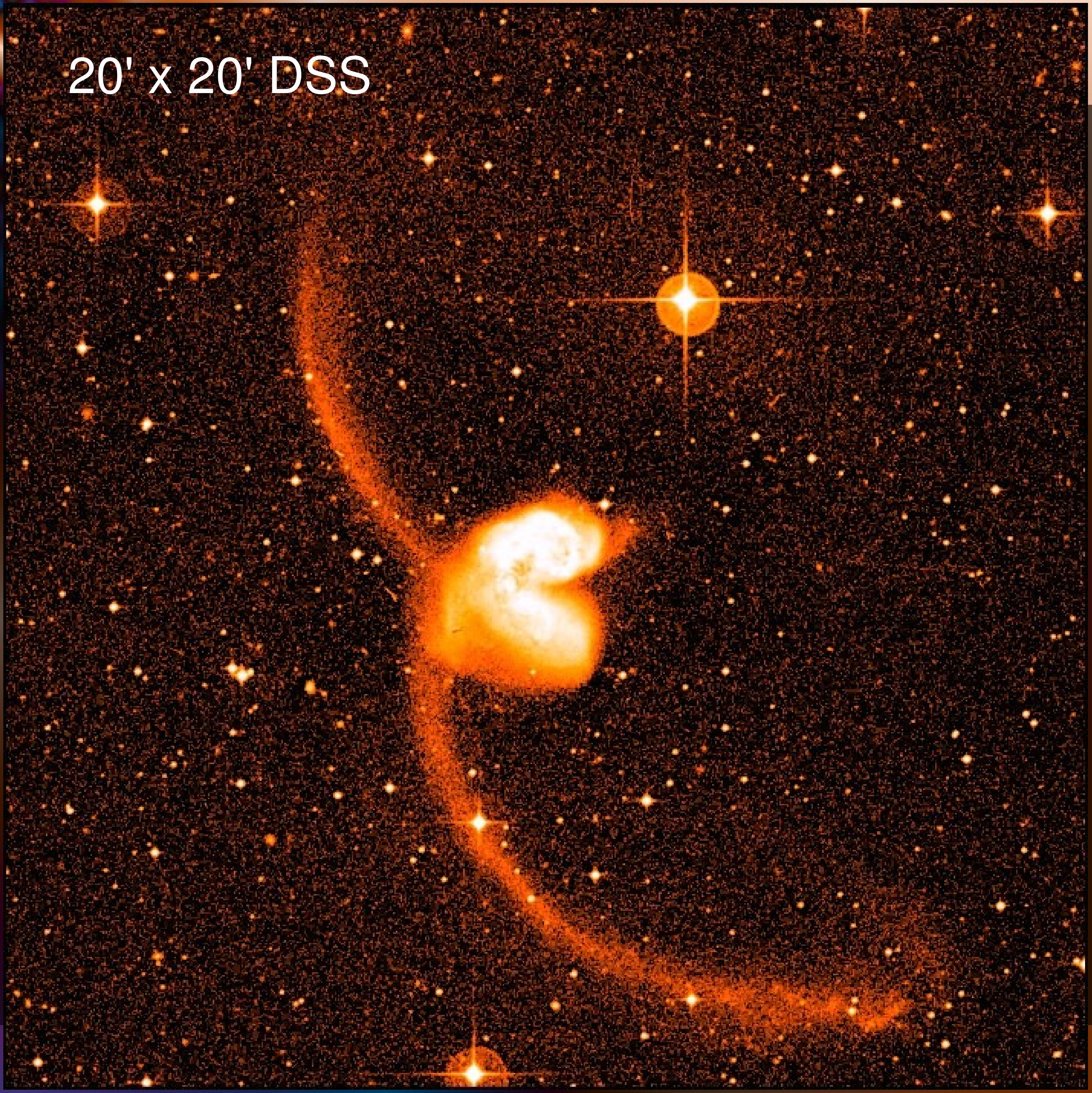
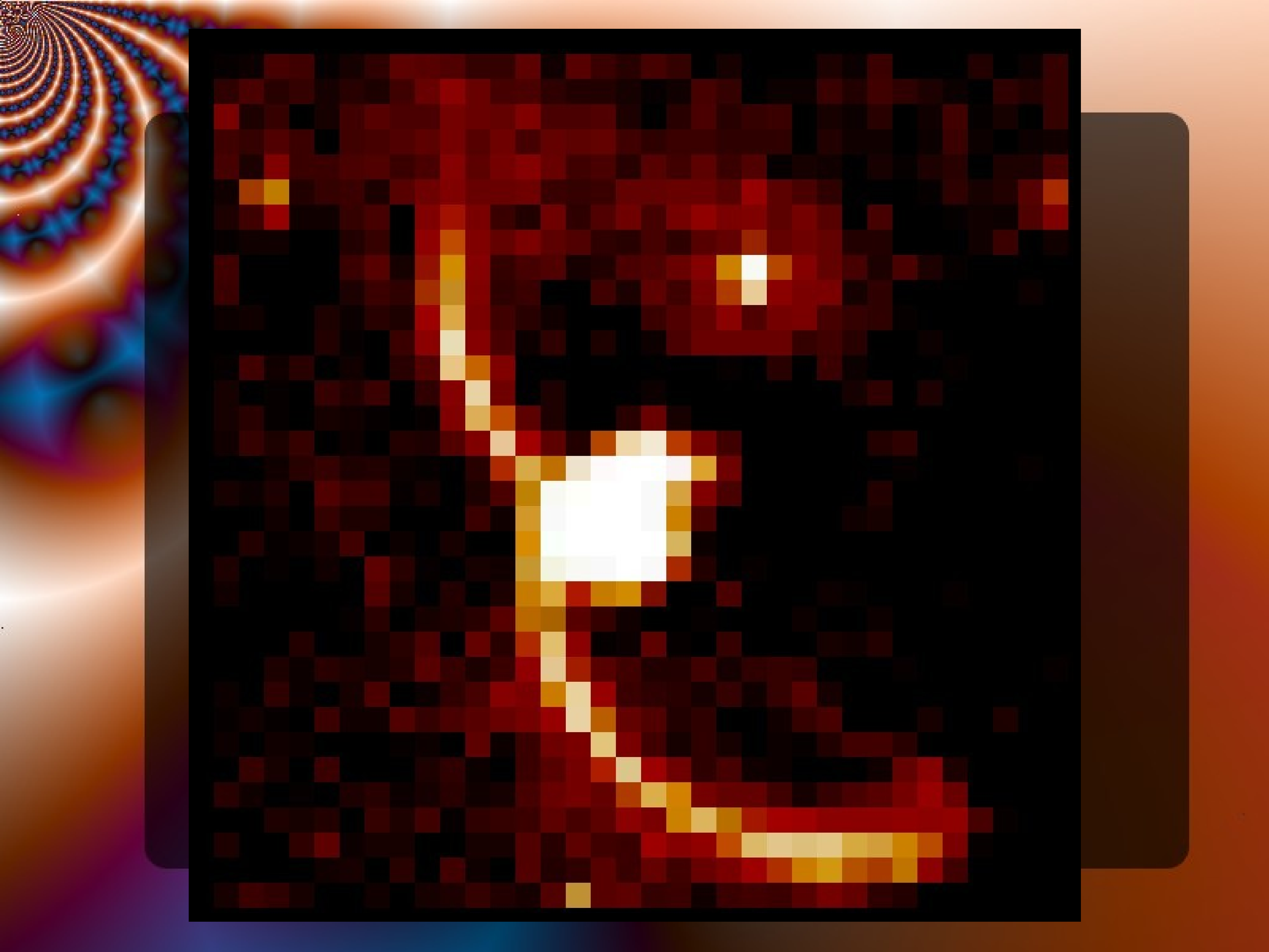
Why?

Distance is currently controversial:

- Saviane et al. (2008): 13.3 Mpc
- Based on TRGB method
- Schweizer et al. (2008): 23 Mpc
- Based on Type Ia SN 2007sr
- Factor 1.7 discrepancy
- Enough to substantially change our understanding of the system


20' x 20' DSS

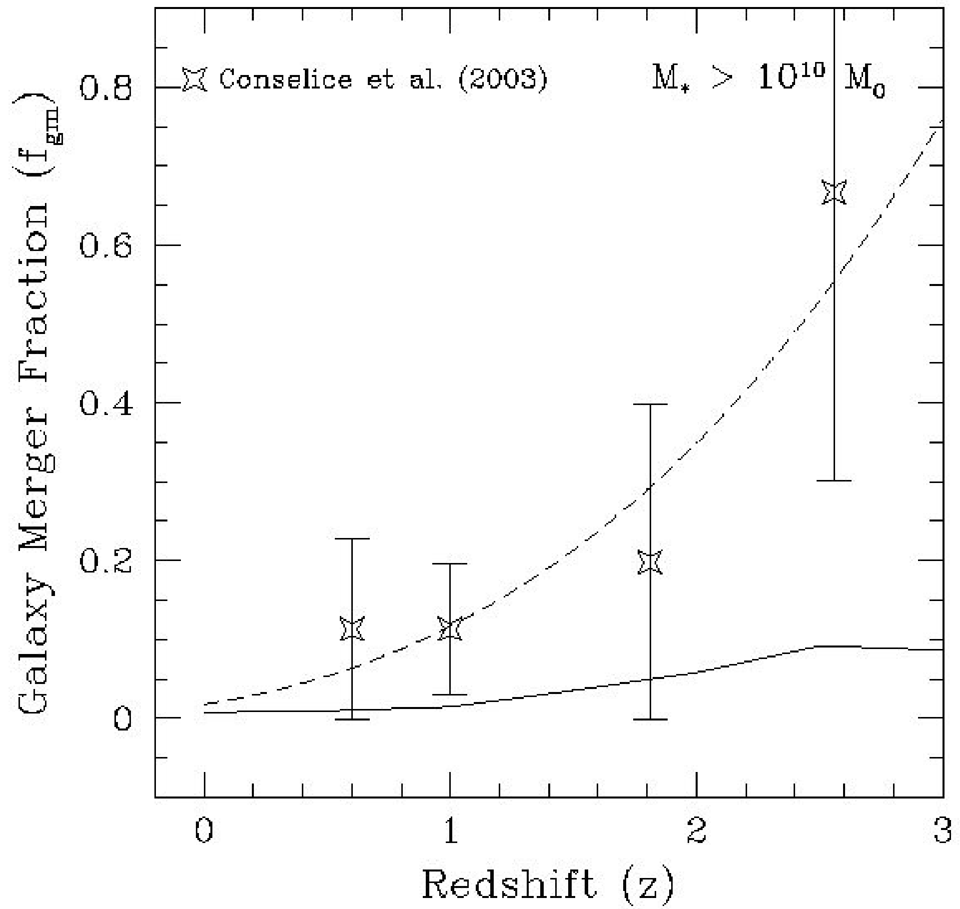


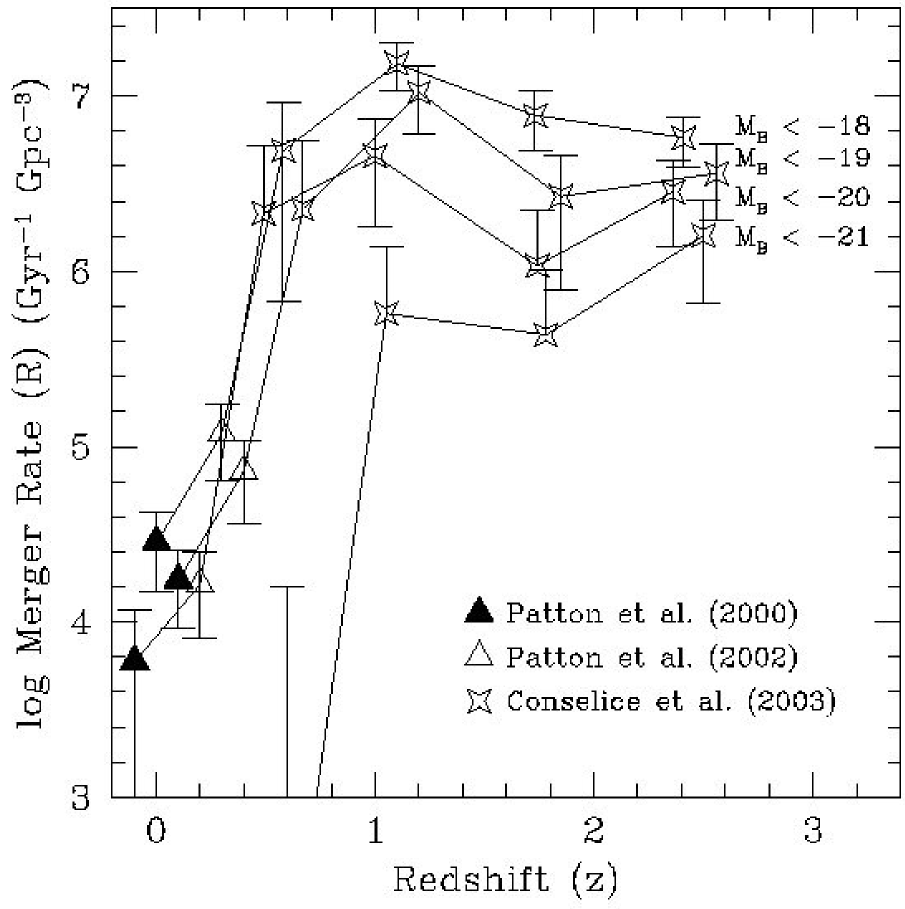
Mergers on cosmological scales

From Conselice (2006)

>50% of luminous galaxies are in a merger for z>2

Merger rate is 1000x higher at z>1





From Conselice (2006)

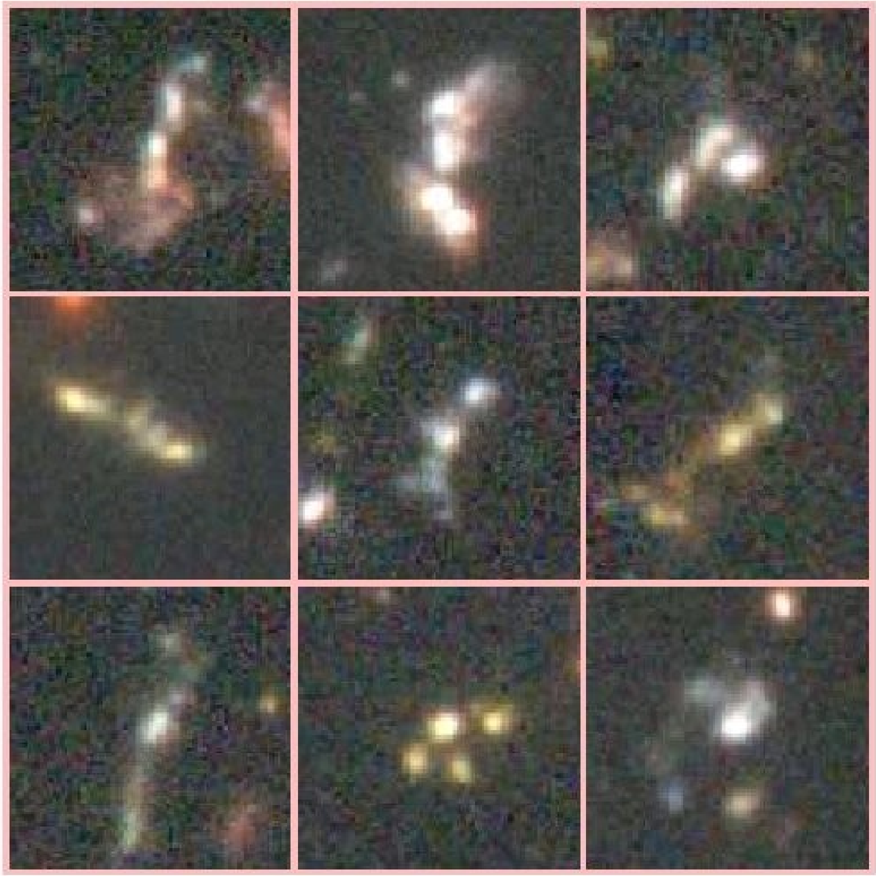
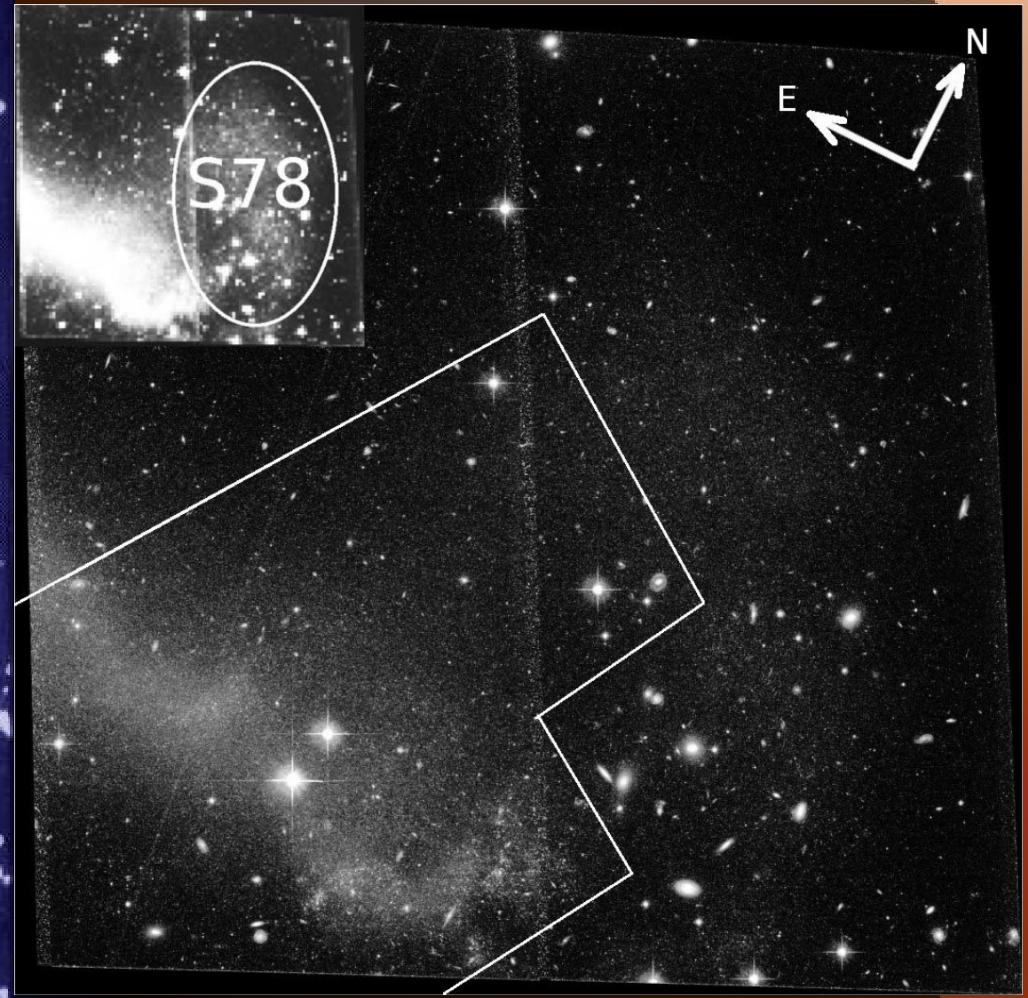


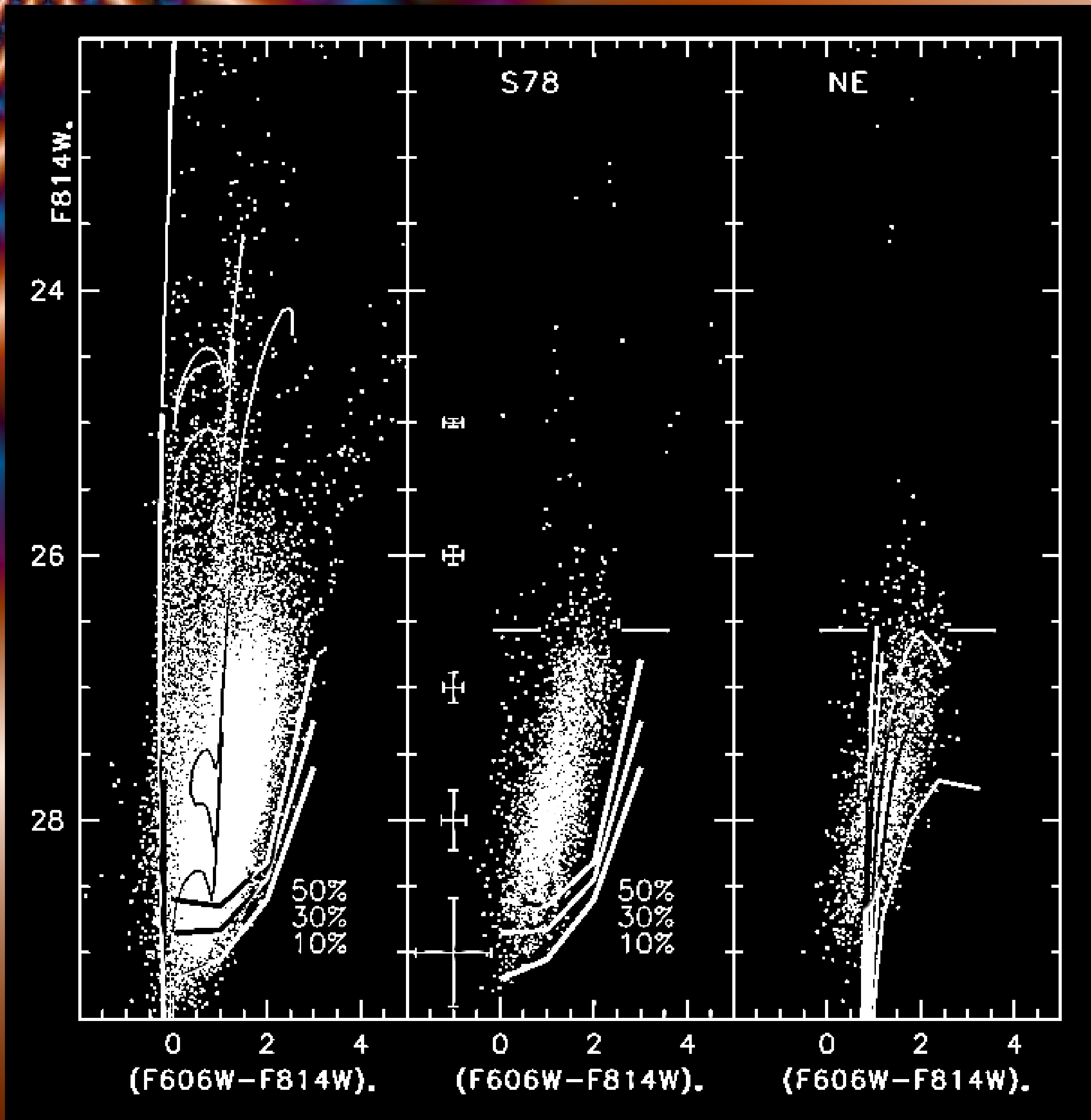
Fig. 4. Examples of high redshift bright galaxies as seen in the Hubble Deep Field. These types of galaxies are the most clustered and often shown direct signs through color gradients, and structures, for a recent merger origin.

Saviane et al. (2008)



from
Schweizer (1978)

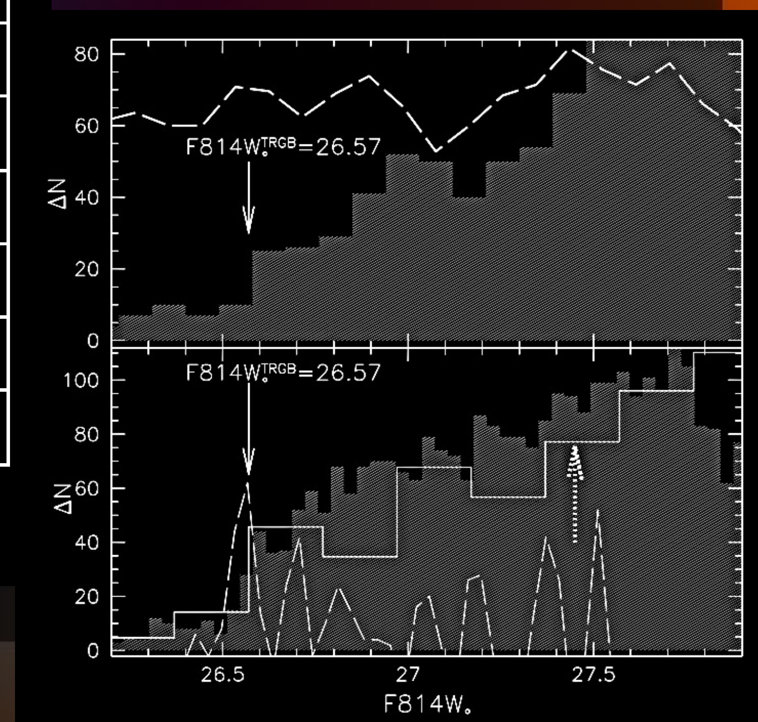
Saviane et al. (2008)



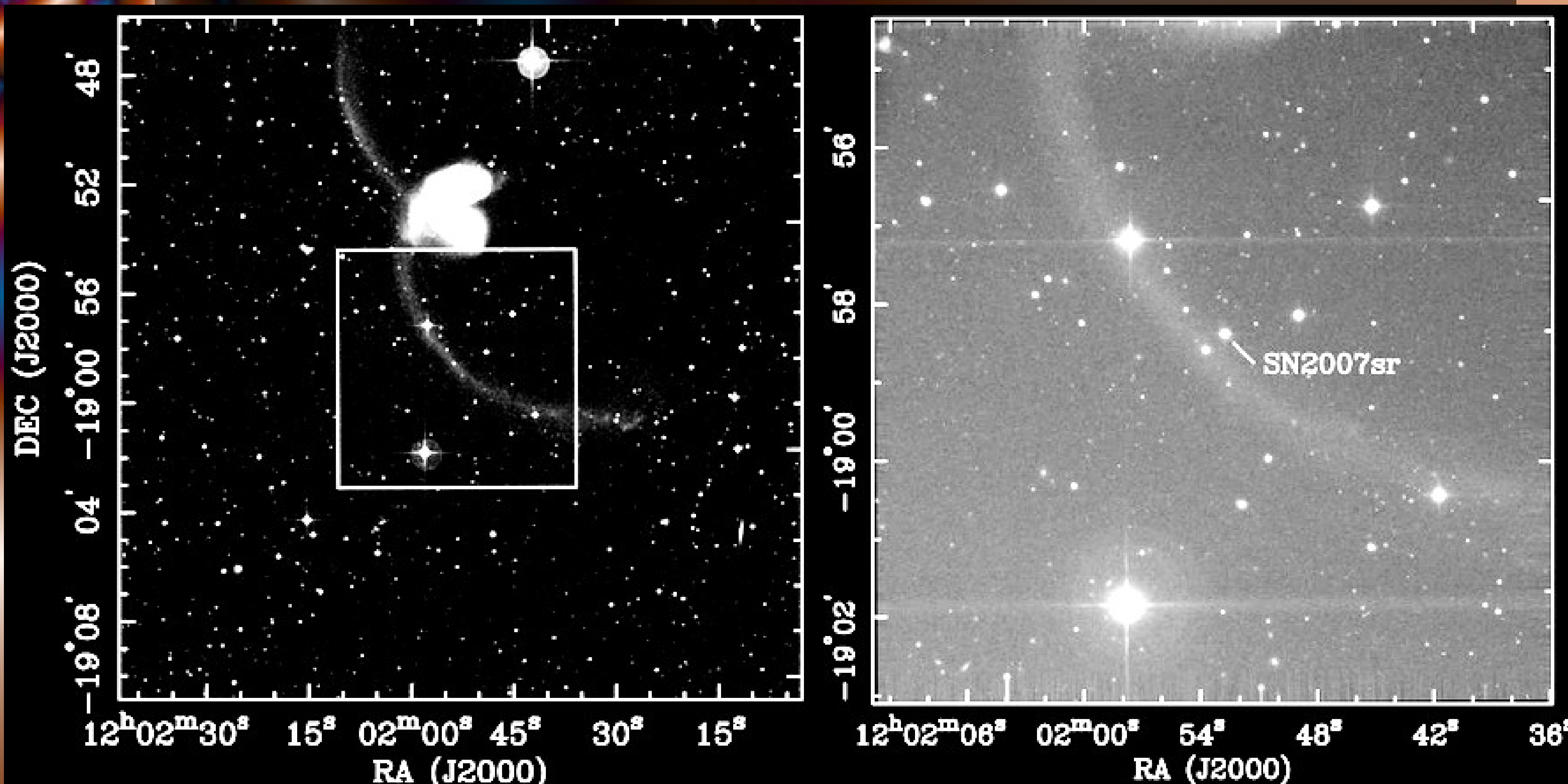
I_o^{TRGB} = 26.65 (0.09)

(m-M)o= 30.62 (0.17)
=>

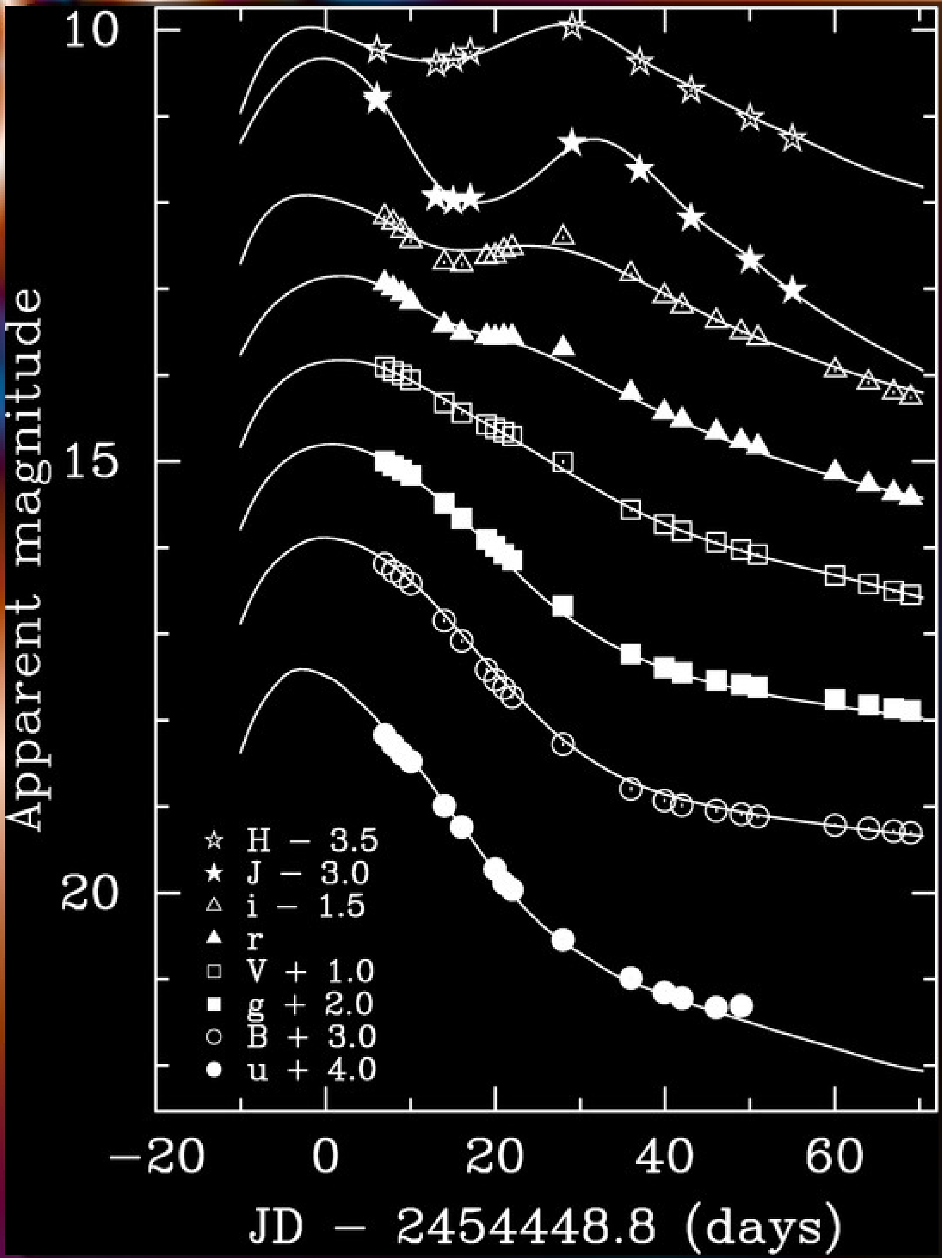
D = 13.3 (1.0) Mpc



Schweizer et al. (2008)



Schweizer et al. (2008)



As usual, have to correct for the decline-rate vs. lumin. using

Δm_{15}

change in B between max and 15 days later

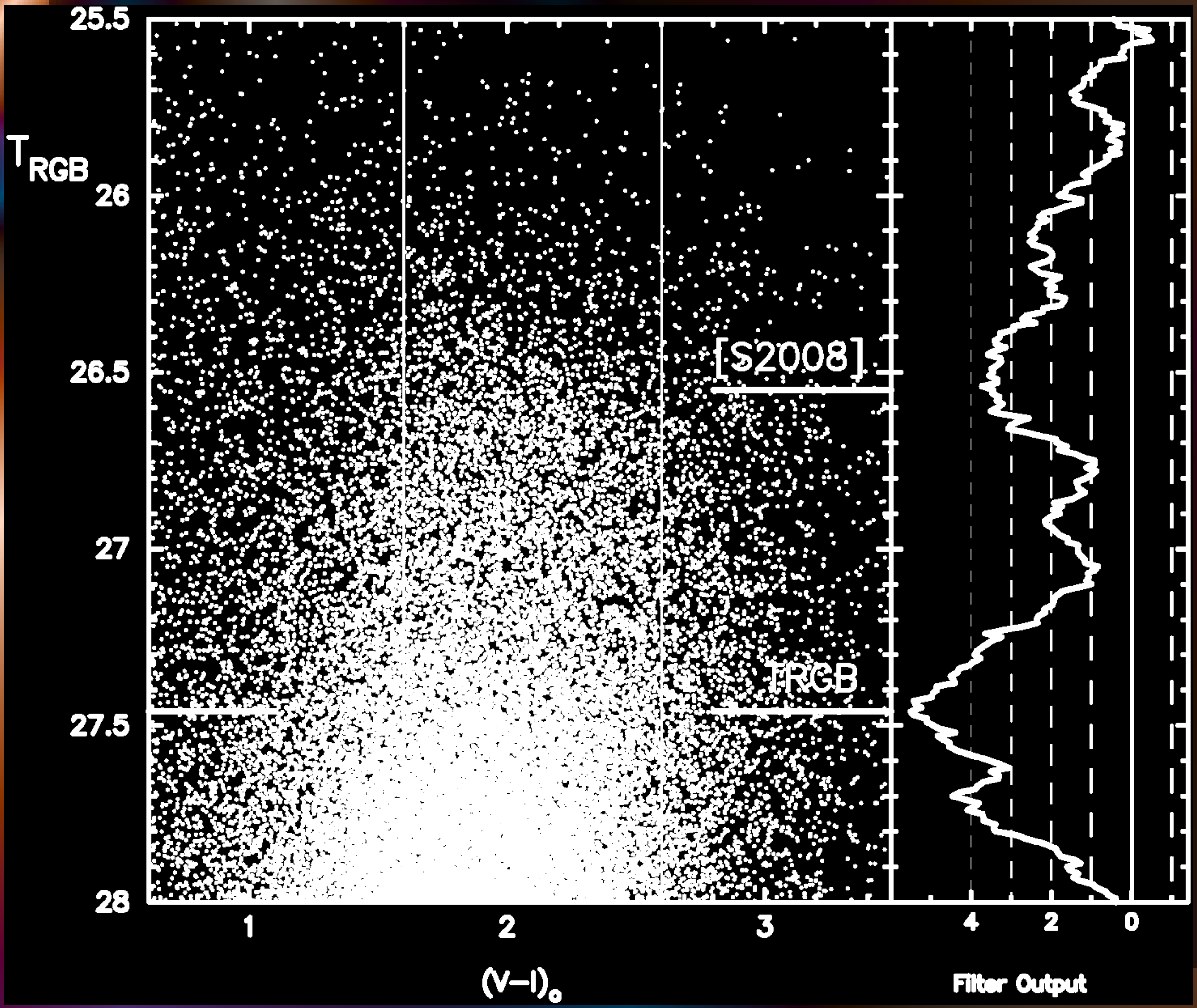
But lum. @ max extrapolated

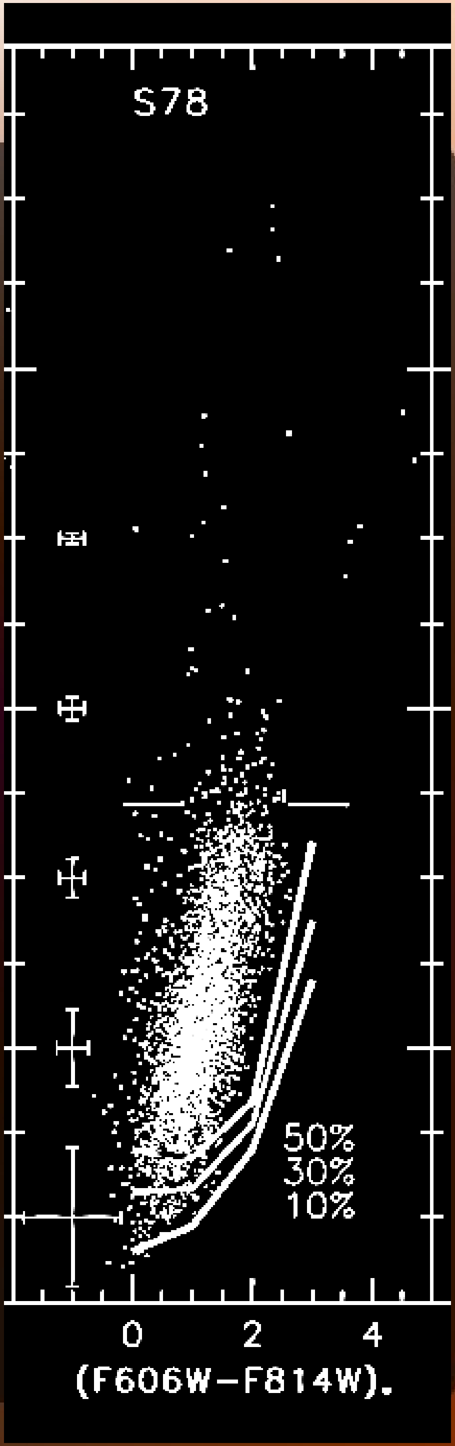
=> use templates to get
L_{max} and intrinsic colors
(and host galaxy extinction)

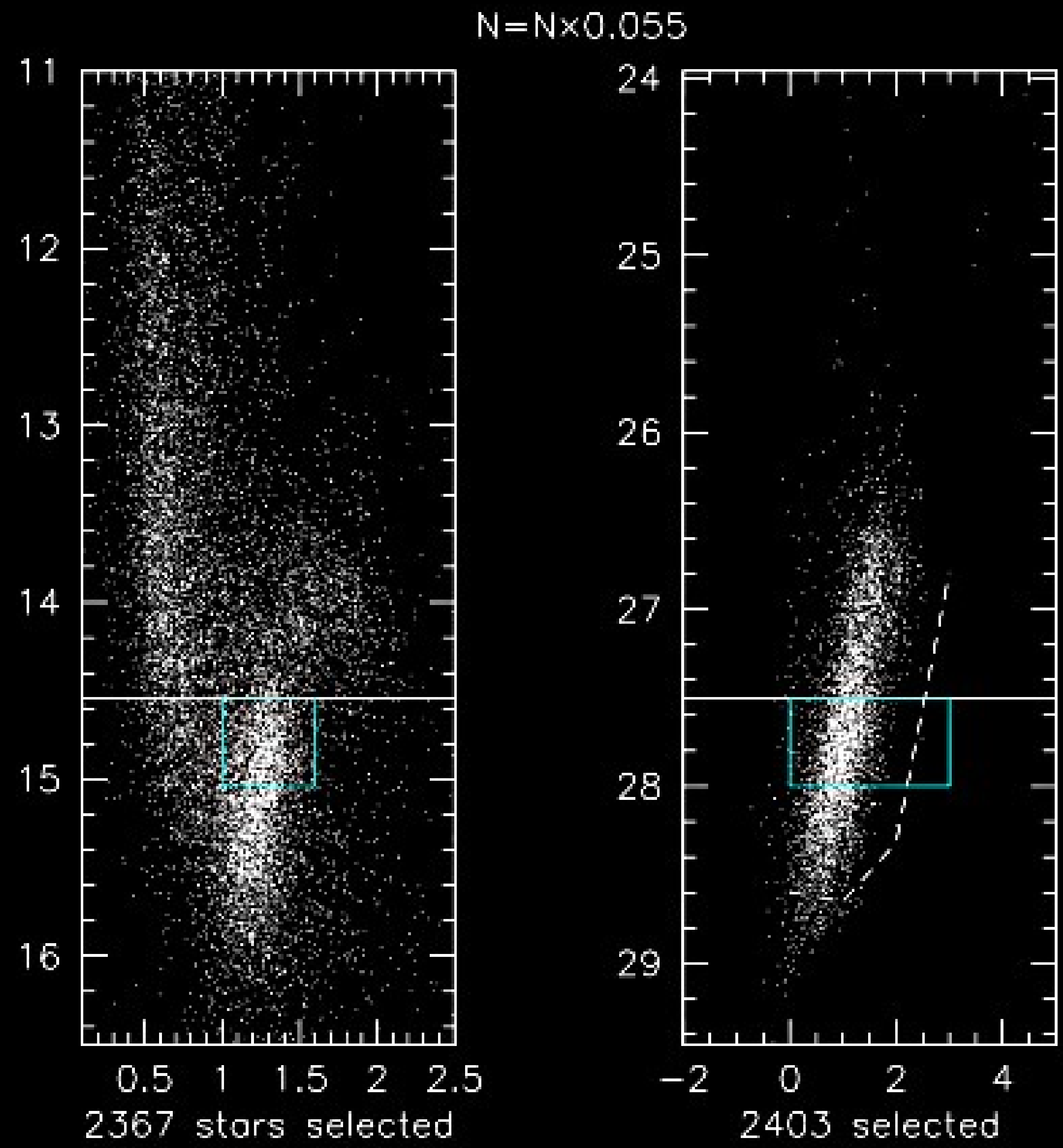
(m-M)o = 31.74 (0.27) opt.
= 31.80 (0.11) NIR

=> D = 22.3 – 23 Mpc
(err ~ 3 Mpc)

Using un-cleaned CMD
TRGB is found by Schweizer et al.
ca. 1 mag fainter






N=N×0.055
11
12
13
14
15
16
0.5 1 1.5 2 2.5
2367 stars selected
24
25
26
27
28
29
−2 0 2 4
2403 selected

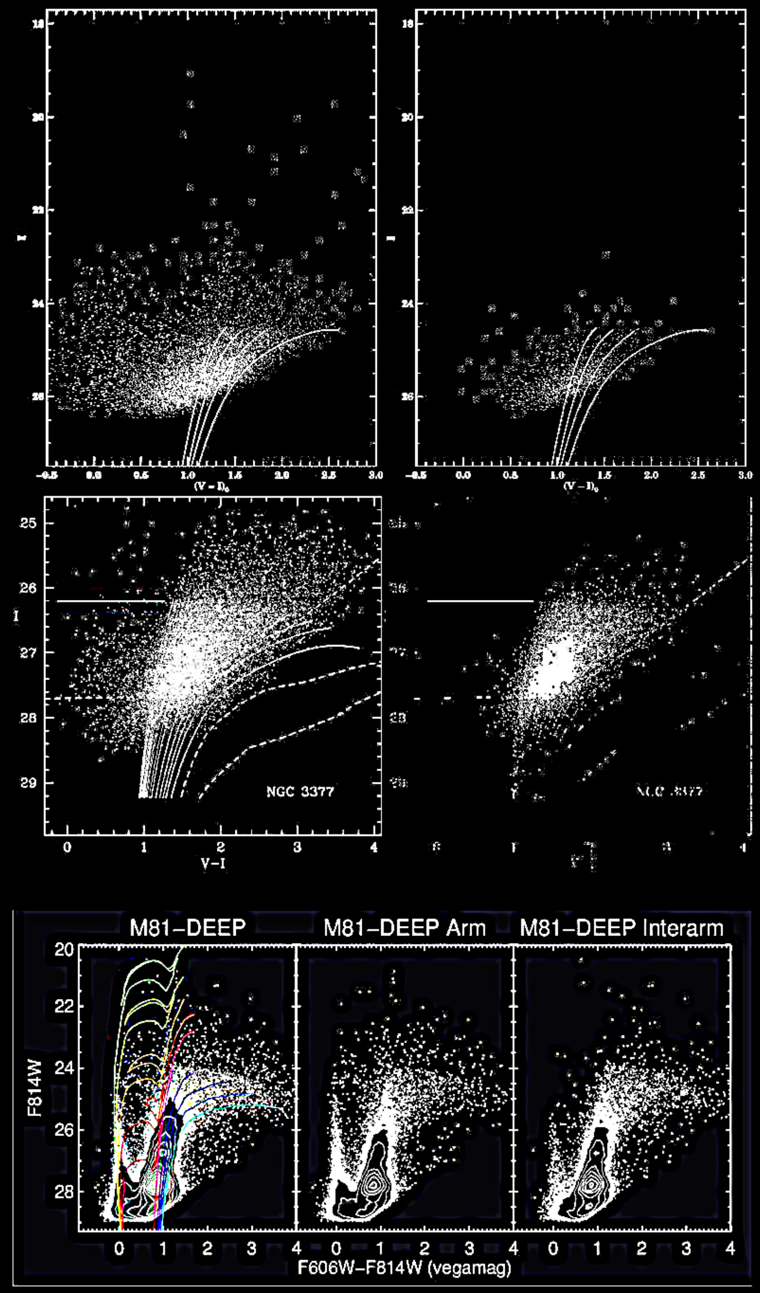


Figure 3: Examples of RGBs that show features. The top two panels show UGC 3755, from Mendez et al. (2002). The left panel shows the original CMD, while in the right panel the same CMD is shown after applying a threshold in the black color. The central two panels show NGC 3377 from Harris et al. (2007) with the same threshold processing applied. And M81 from Williams et al. (2008) is shown in the bottom three panels.

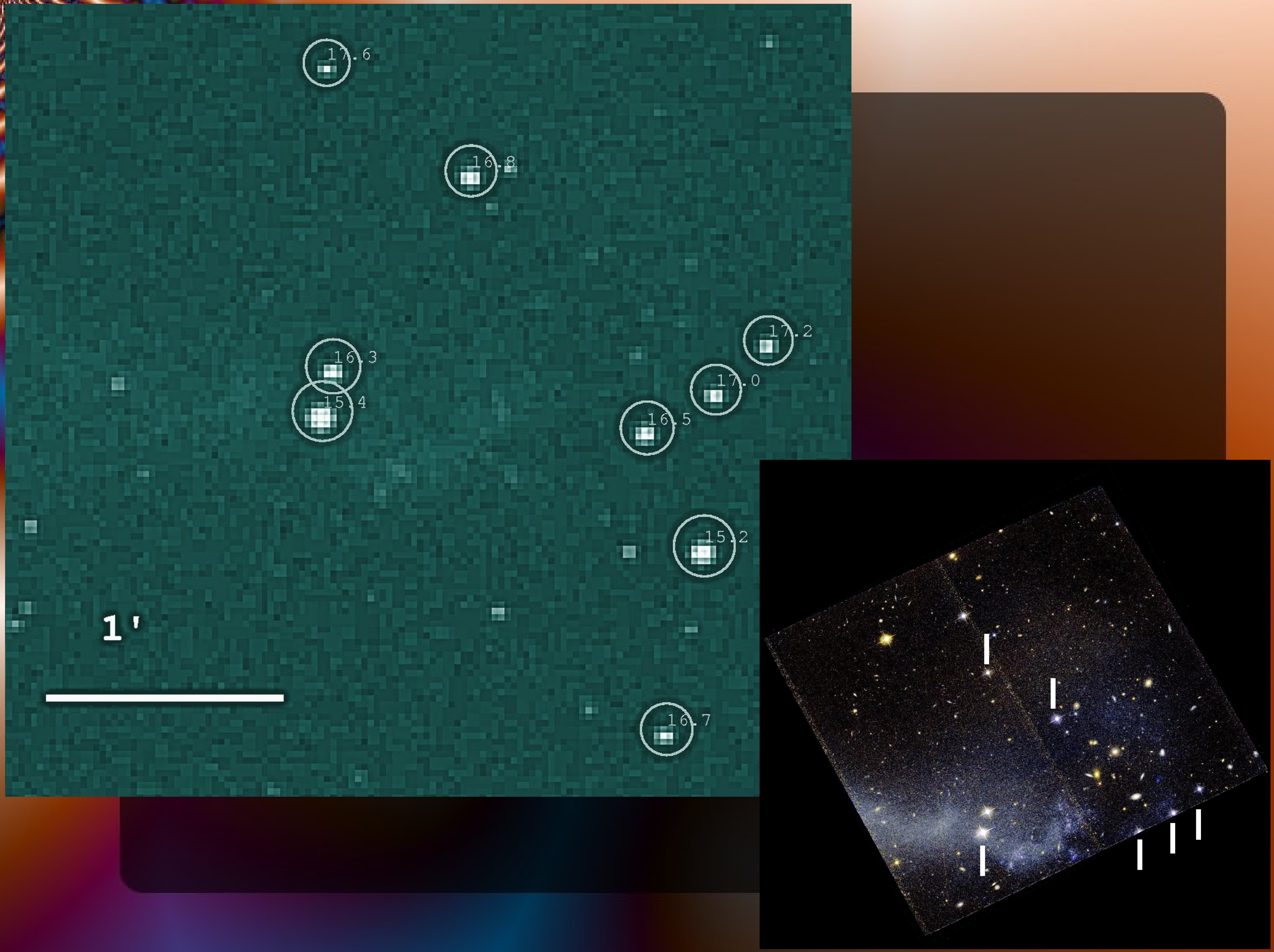
Solving the controversy using Cepheids

Solving the controversy using Cepheids

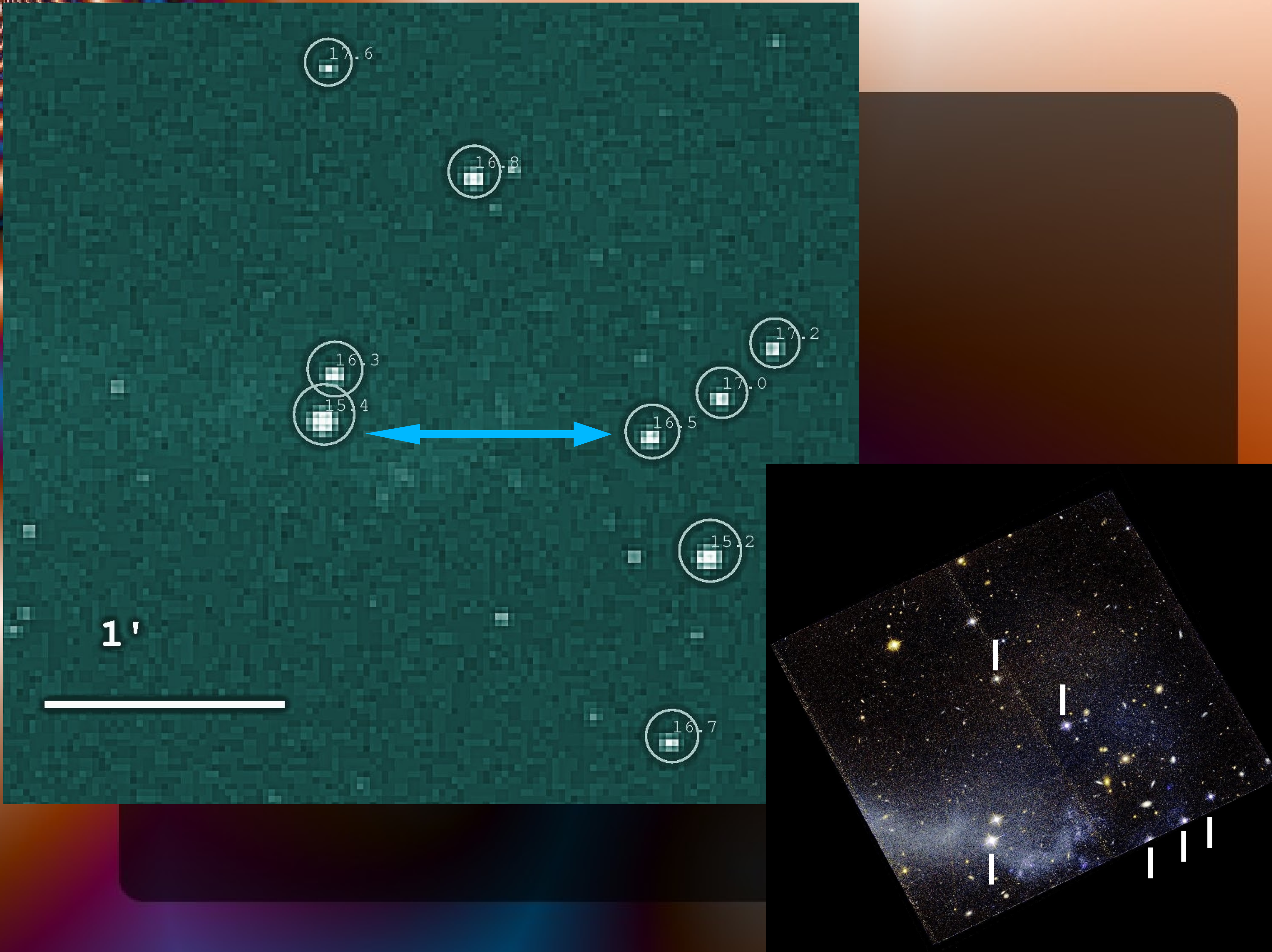
Feasible with MAD v2? Yes if:

1. Useful NGS
2. Spatial resolution
3. Candidate variable stars
4. Sensitivity
5. Useful Period coverage

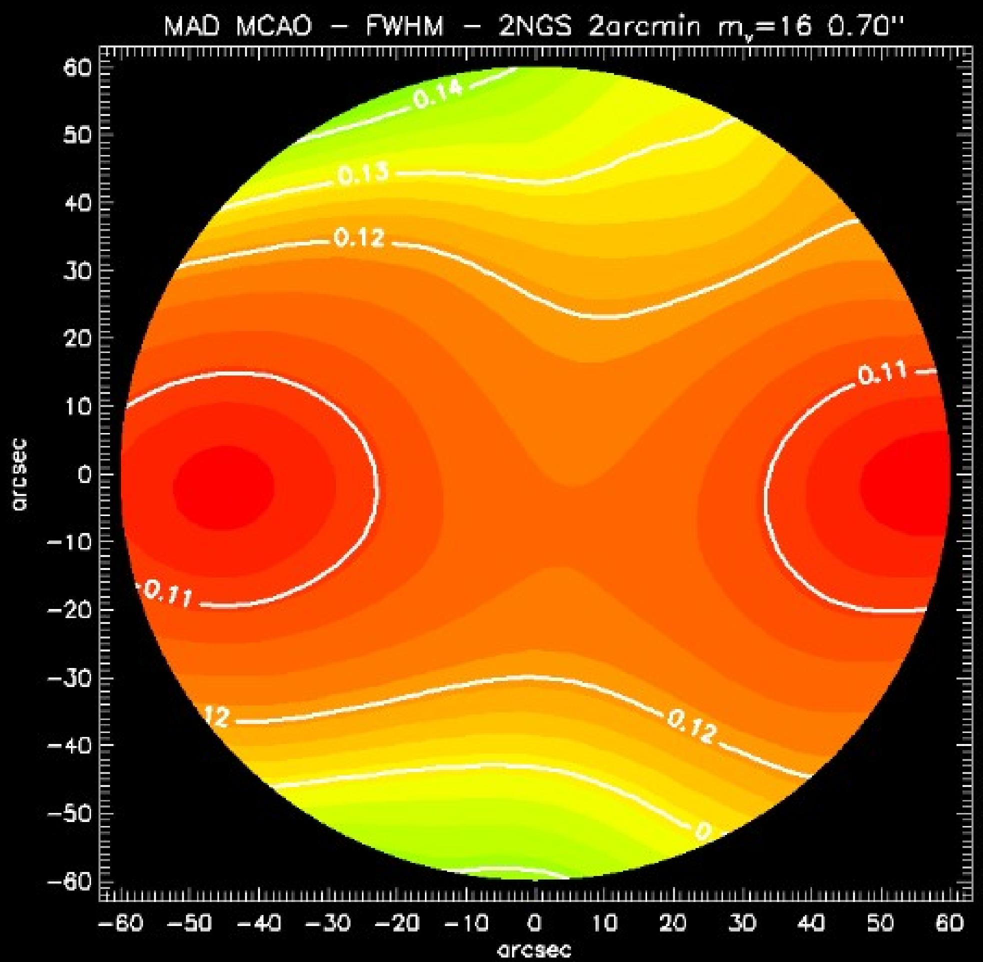
1. Natural Guide Stars

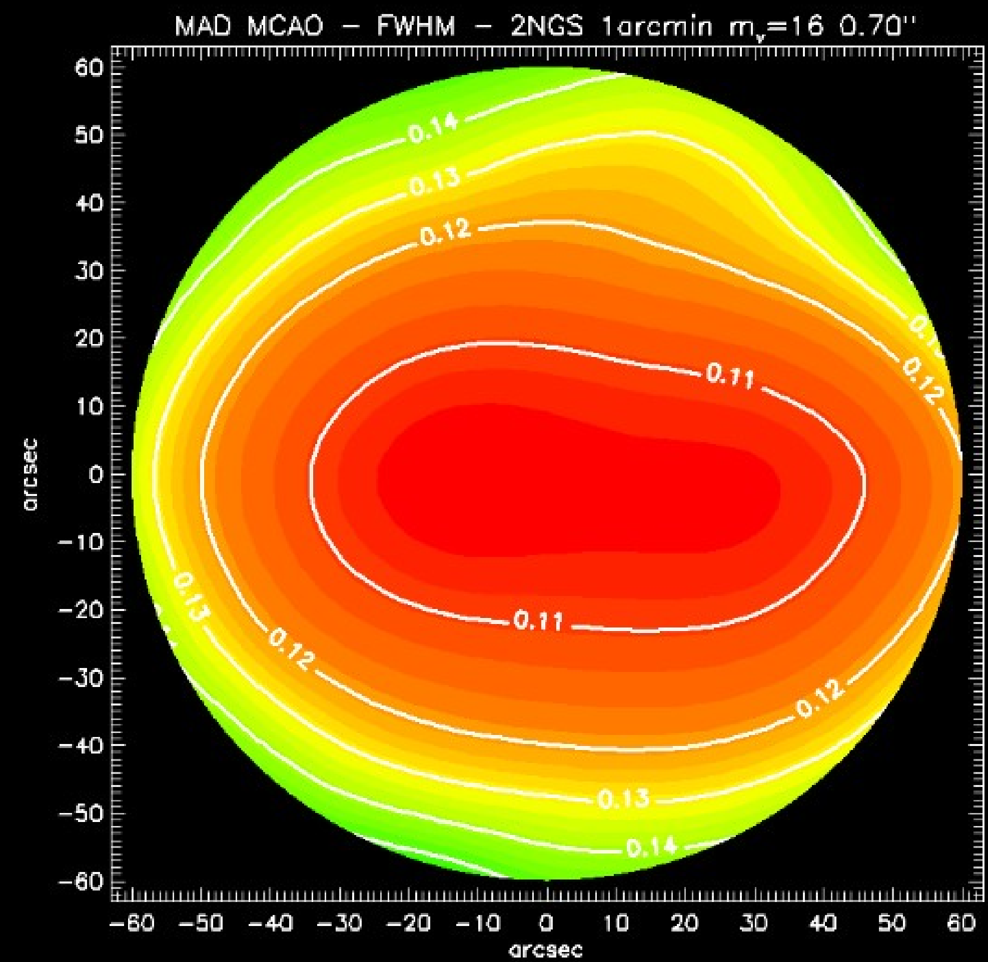

17.6
16.8
17.2
16.3
17.0
15.4
16.5
15.2
1'
16.7

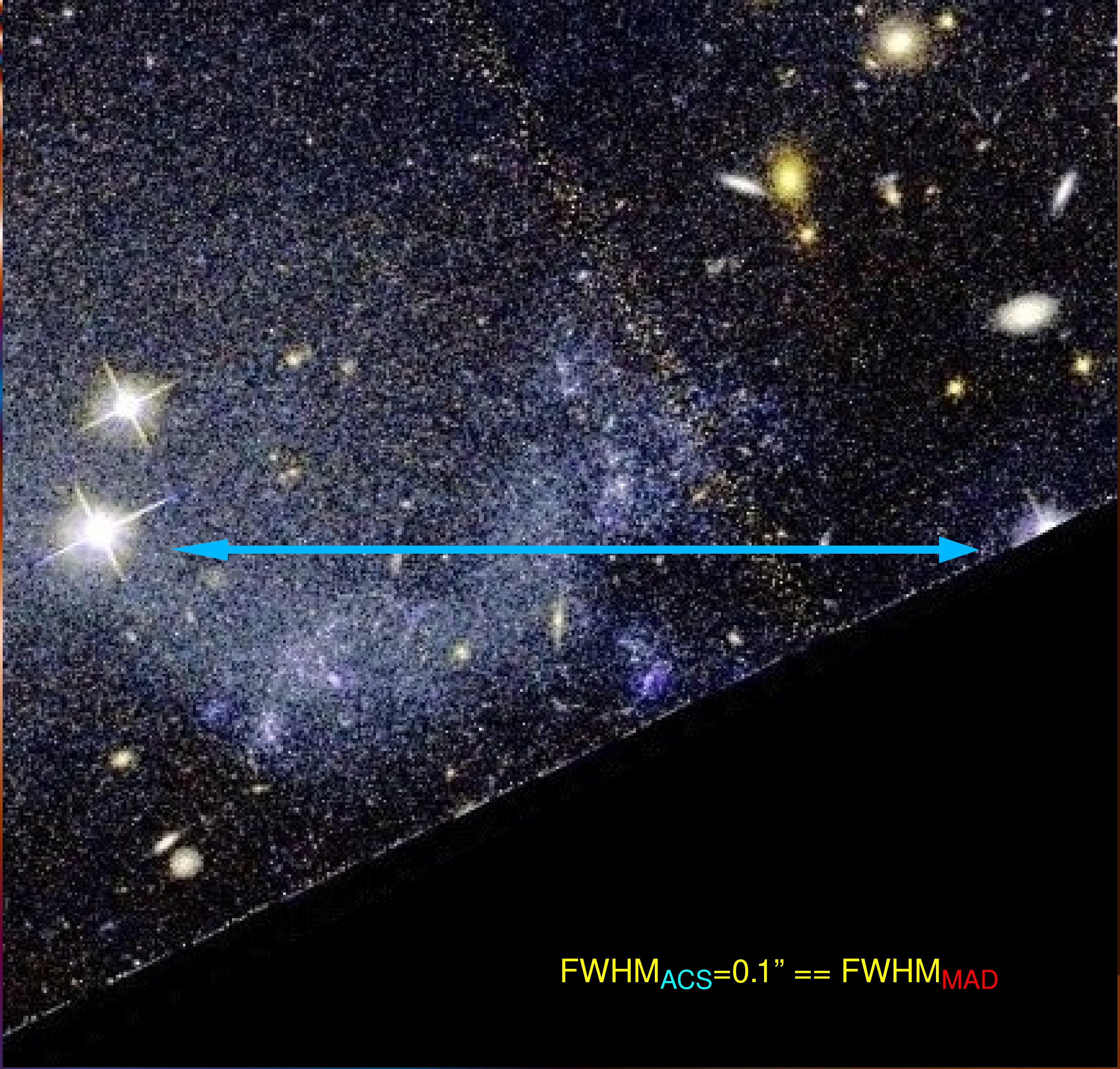
2. Spatial resolution

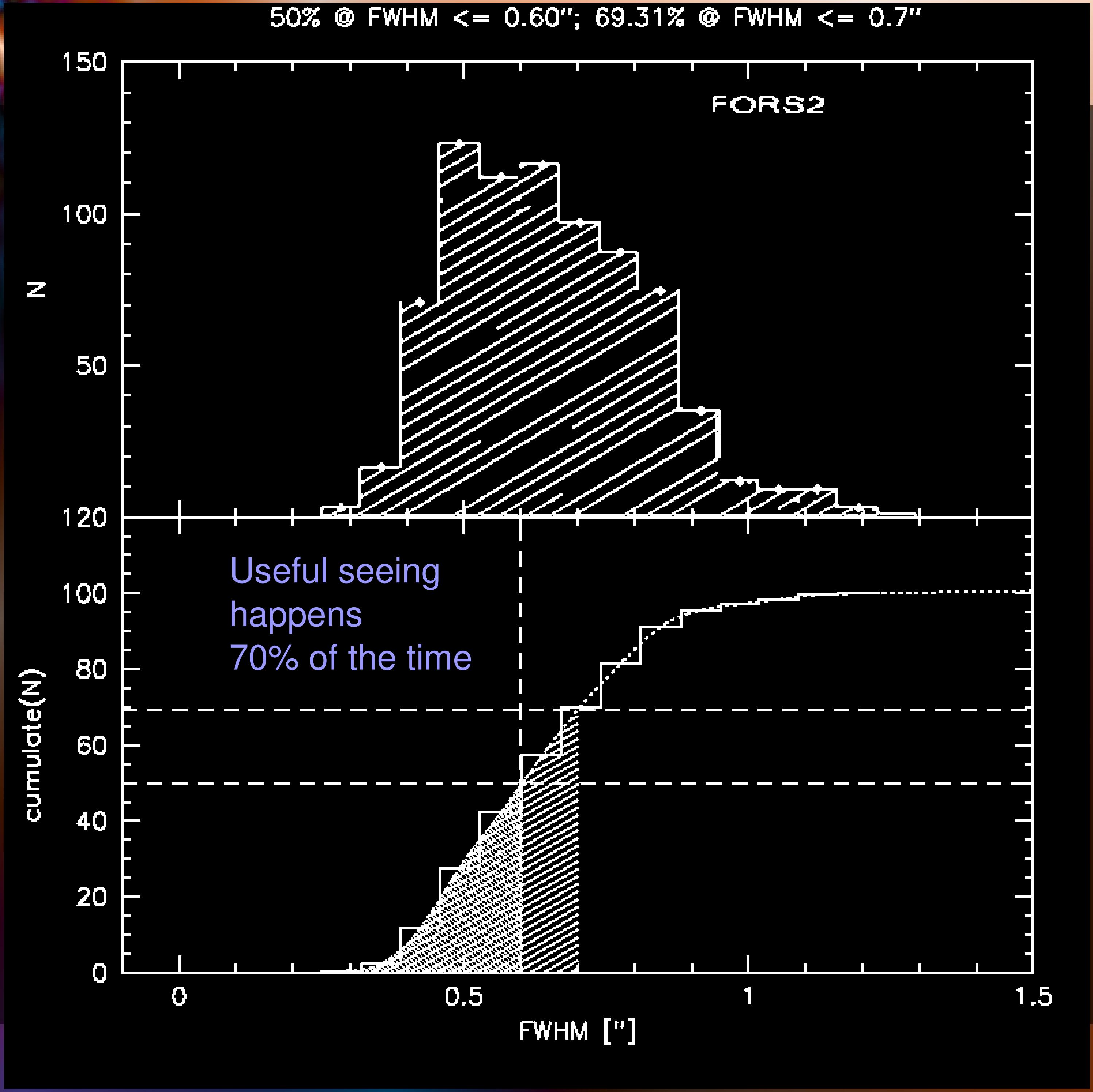

17.6
16.8
17.2
16.3
17.0
15.4
16.5
15.2
1'
16.7

FWHM [arcsec] @ 2.166 μm ***V magnitude: 16 - Seeing: 0.70”***





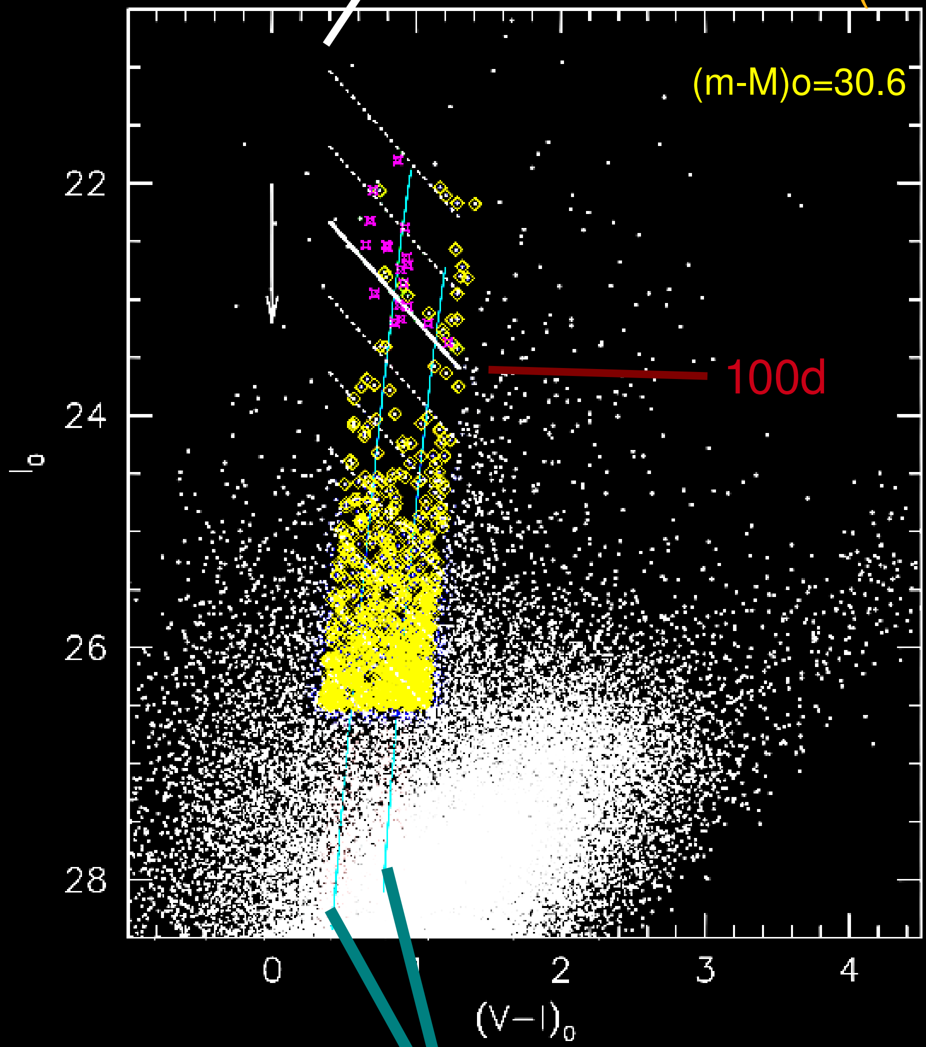

FWHM$_{ACS}$=0.1” == FWHM$_{MAD}$


50% @ FWHM <= 0.60"; 69.31% @ FWHM <= 0.7"
FORS2
N
150
100
50
120
100
80
60
40
20
0
cumulate(N)
Useful seeing
happens
70% of the time
0
0.5
1
1.5
FWHM ["]

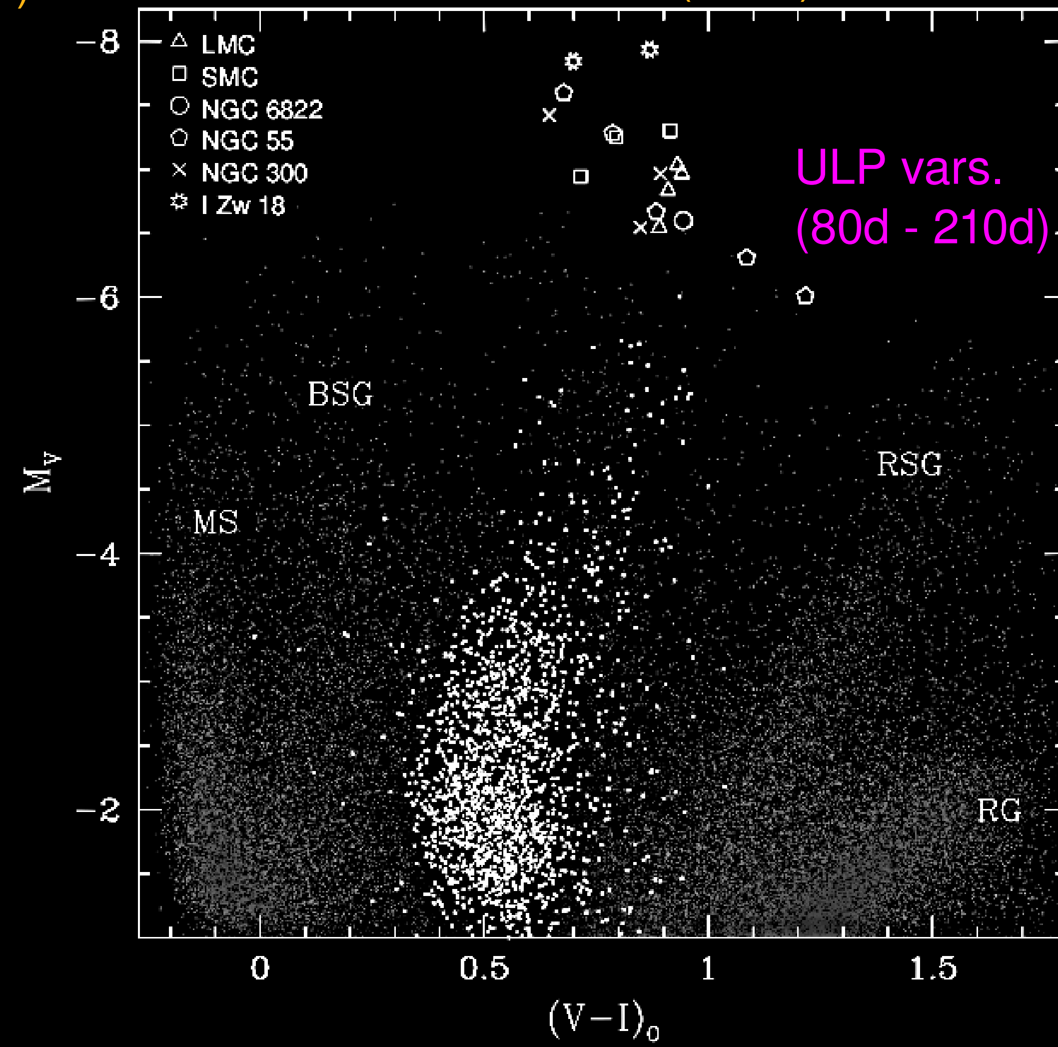
3. Candidate variable stars

PLC relation of Udalski et al. (1999)

From Saviane et al. (2008)



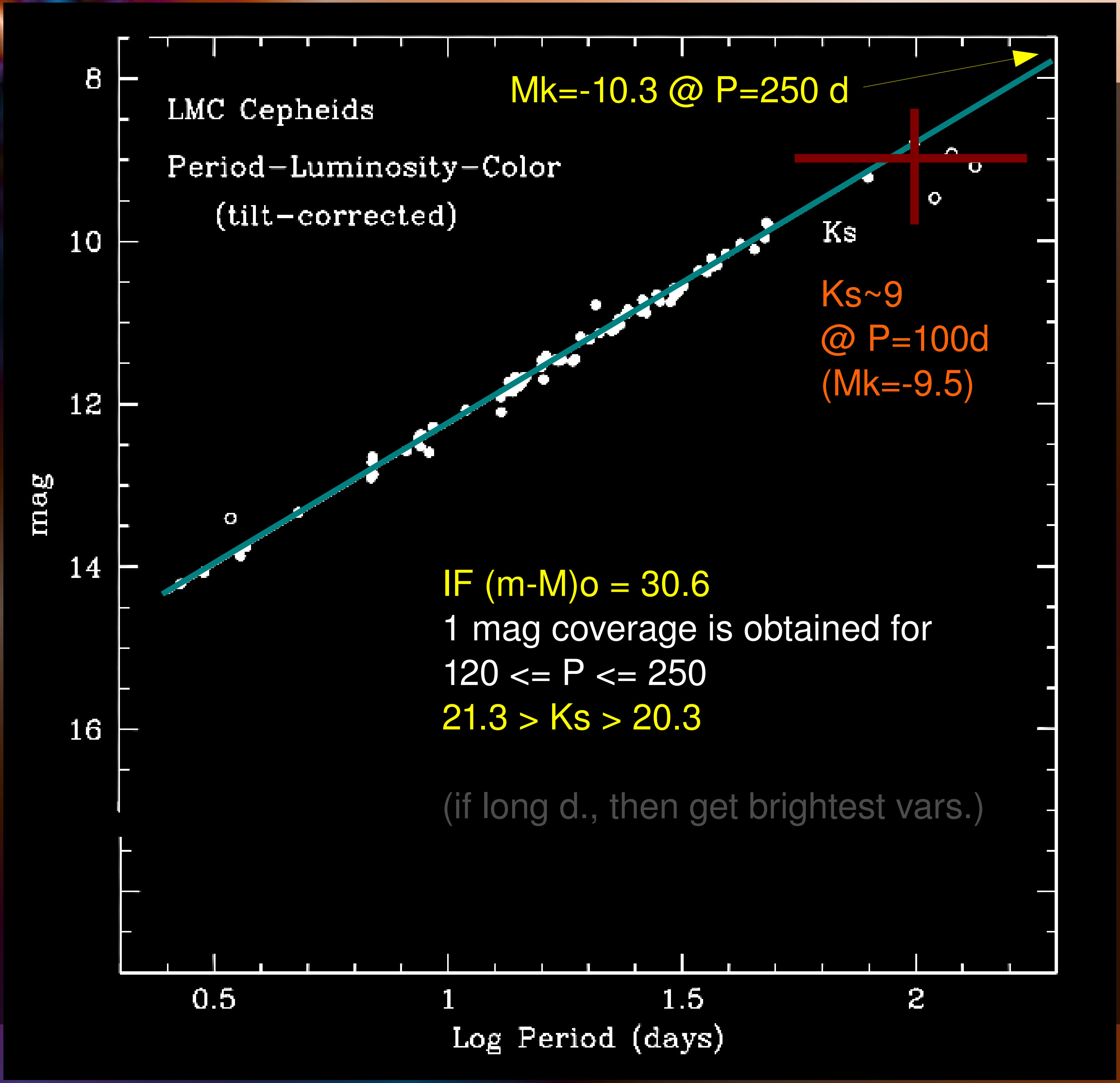
From Bird et al. (2009)



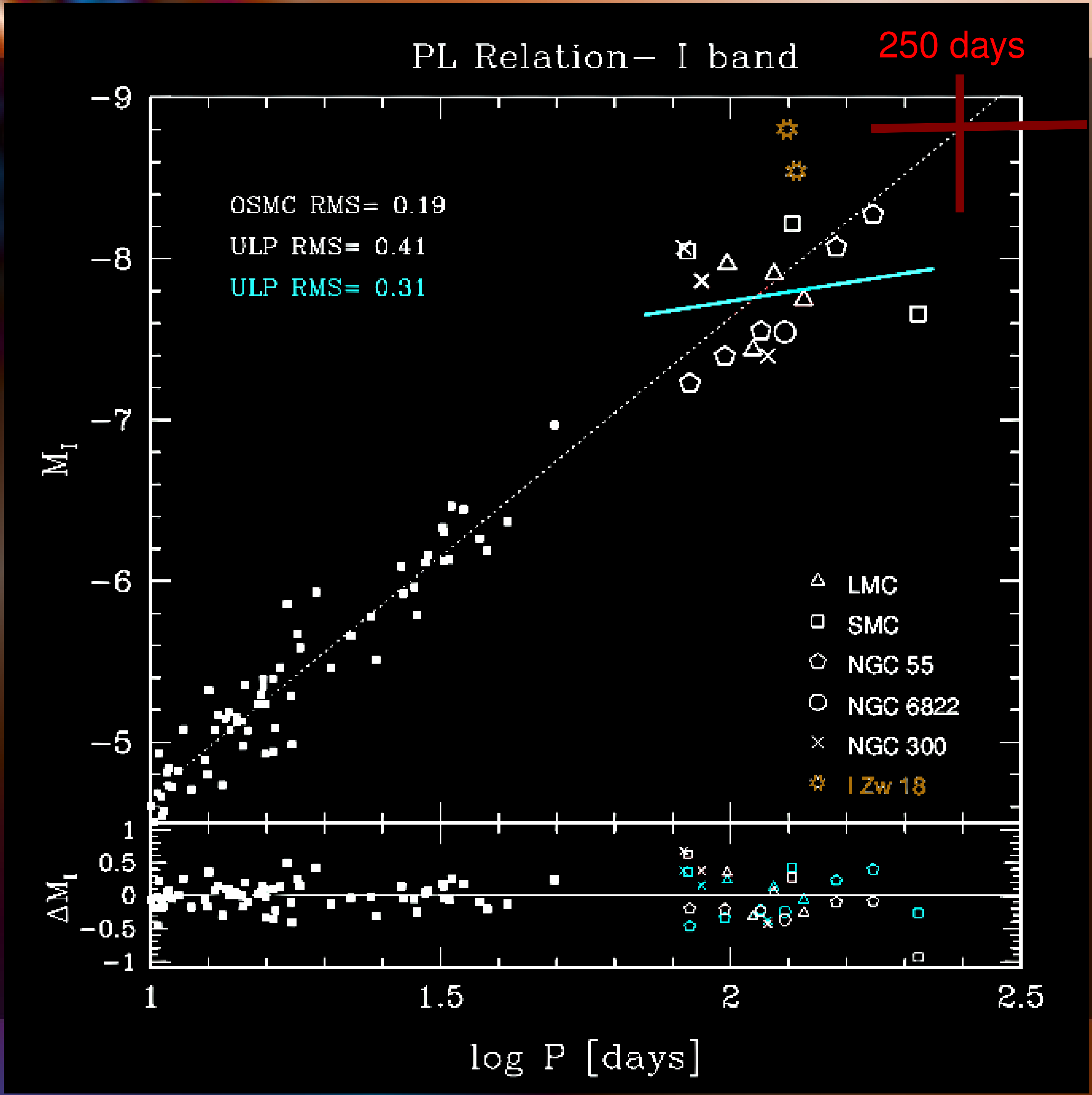
IS from Sandage, Bell, & Tripicco (1999, ApJ, 522, 250)

4. Sensitivity

From Persson et al. (2004)



From Bird et al. (2009)



An useful parallel project:

- add Ks photometry of ULPs in galaxies of the Bird et al. sample:
- LMC
- SMC
- NGC 55
- NGC 300
- NGC 6822
- I Zw 18

1.

Momany et al. (2008, MNRAS, 391, 1650)

K~20.5 at SNR= 3 needs 600 s (if FWHM~0. 1)

2.

σ_K = 0.2 mag is sufficient to obtain a sufficiently well-defined light curve

3.

K~20.5 at SNR=5 needs 1600 s

$(5/3)^2 \times 600 \simeq 1600$ s

4.

K = 21.3 at SNR=5 needs 2.8 hours

5. Scheduling

- The current idea is to schedule 2 MAD runs per semester

- Each run would be about one week

- Antennae can be observed at the VLT, at a reasonable airmass, from the end of December 2009 to the beginning of July 2010

Observability of Antennae

Date	(eve)		☾	eve			cent			morn			night	hrs@sec.z:	
				HA		sec.z	HA		sec.z	HA		sec.z	<3	<2	<1.5
2009	Oct	3	F	8	6	down	-11	22	down	-6	49	down	0	0	0
2009	Oct	17	N	9	9	down	-10	30	down	-6	10	10.1	0	0	0
2009	Nov	2	F	10	24	down	-9	29	down	-5	22	3.6	0	0	0
2009	Nov	16	N	11	32	down	-8	32	down	-4	36	2.3	0.5	0	0
2009	Dec	1	F	-11	15	down	-7	28	down	-3	42	1.6	1.4	0.6	0
2009	Dec	15	N	-10	9	down	-6	27	29.4	-2	45	1.3	2.4	1.6	0.7
2009	Dec	31	F	-8	59	down	-5	16	3.3	-1	33	1.1	3.6	2.8	1.9
2010	Jan	14	N	-8	4	down	-4	15	1.9	0	25	1	4.7	3.9	3
2010	Jan	29	F	-7	12	down	-3	12	1.4	0	48	1	5.9	5.1	4.2
2010	Feb	13	N	-6	24	22.1	-2	12	1.2	2	1	1.1	7.1	6.3	5.5
2010	Feb	27	F	-5	42	5	-1	18	1.1	3	6	1.4	8.2	7.4	6.5
2010	Mar	15	N	-4	56	2.7	0	19	1	4	19	2	9.2	8.6	6.9
2010	Mar	29	F	-4	16	2	0	32	1	5	20	3.5	9.4	8.6	6.9
2010	Apr	13	N	-3	31	1.5	1	27	1.1	6	25	25.2	8.6	7.8	6.9
2010	Apr	27	F	-2	47	1.3	2	19	1.2	7	26	down	7.9	7.1	6.2
2010	May	13	N	-1	52	1.1	3	21	1.5	8	35	down	7	6.2	5.3
2010	May	27	F	-1	1	1	4	17	2	9	36	down	6.1	5.3	4.5
2010	Jun	11	N	0	2	1	5	19	3.5	10	40	down	5.1	4.3	3.5
2010	Jun	25	F	0	56	1	6	17	14.2	11	38	down	4.2	3.4	2.5
2010	Jul	11	N	2	4	1.1	7	23	down	-11	18	down	3	2.3	1.4
2010	Jul	25	F	3	4	1.4	8	19	down	-10	26	down	2	1.3	0.4
2010	Aug	9	N	4	8	1.9	9	17	down	-9	34	down	1	0.2	0
2010	Aug	24	F	5	12	3.2	10	13	down	-8	46	down	0	0	0
2010	Sep	7	N	6	12	11	11	4	down	-8	4	down	0	0	0
2010	Sep	22	F	7	16	down	11	58	down	-7	21	down	0	0	0
2010	Oct	7	N	8	23	down	-11	8	down	-6	39	down	0	0	0

- The current idea is to schedule 2 MAD runs per semester

- Each run would be about one week

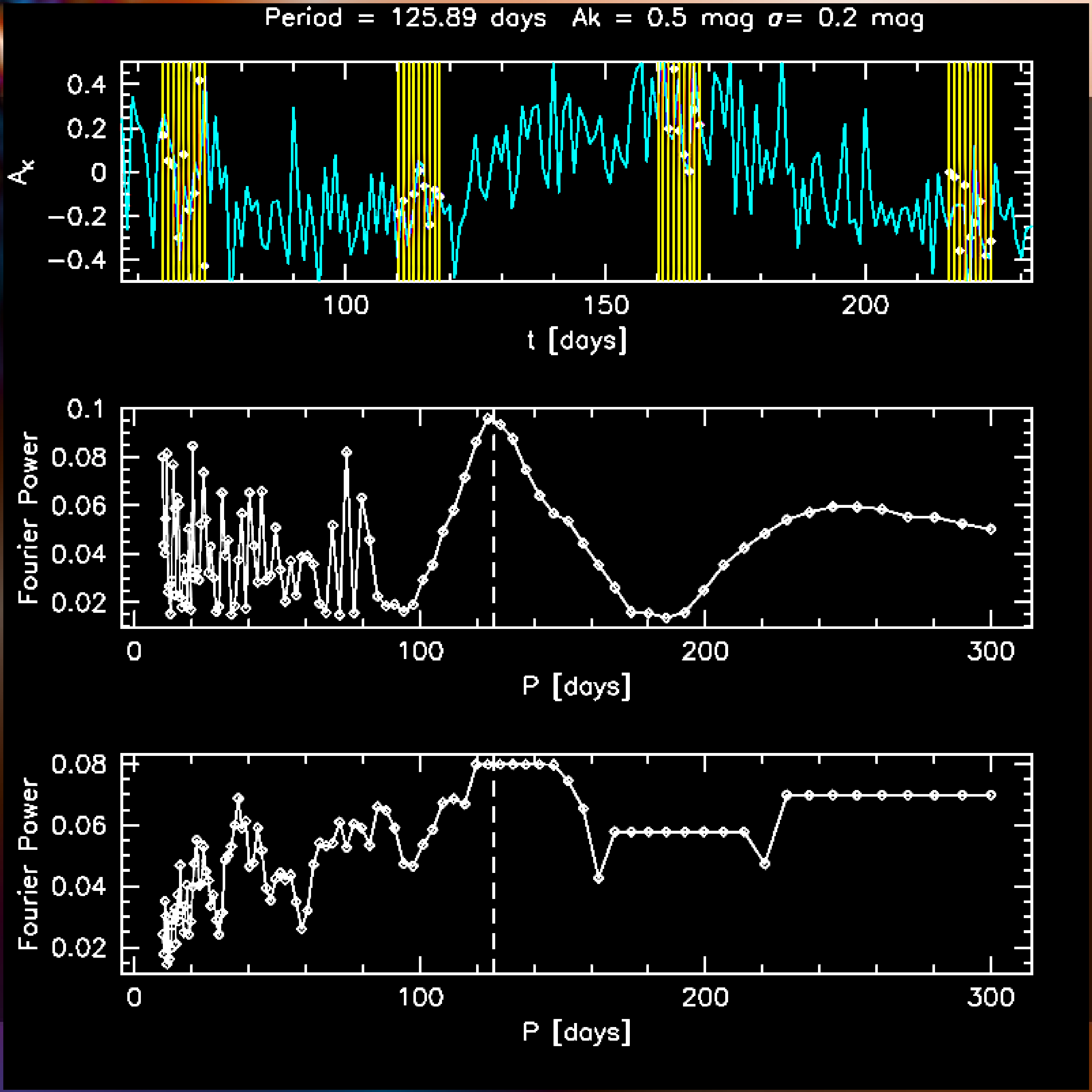
- Antennae can be observed at the VLT, at a reasonable airmass, from the end of December 2009 to the beginning of July 2010

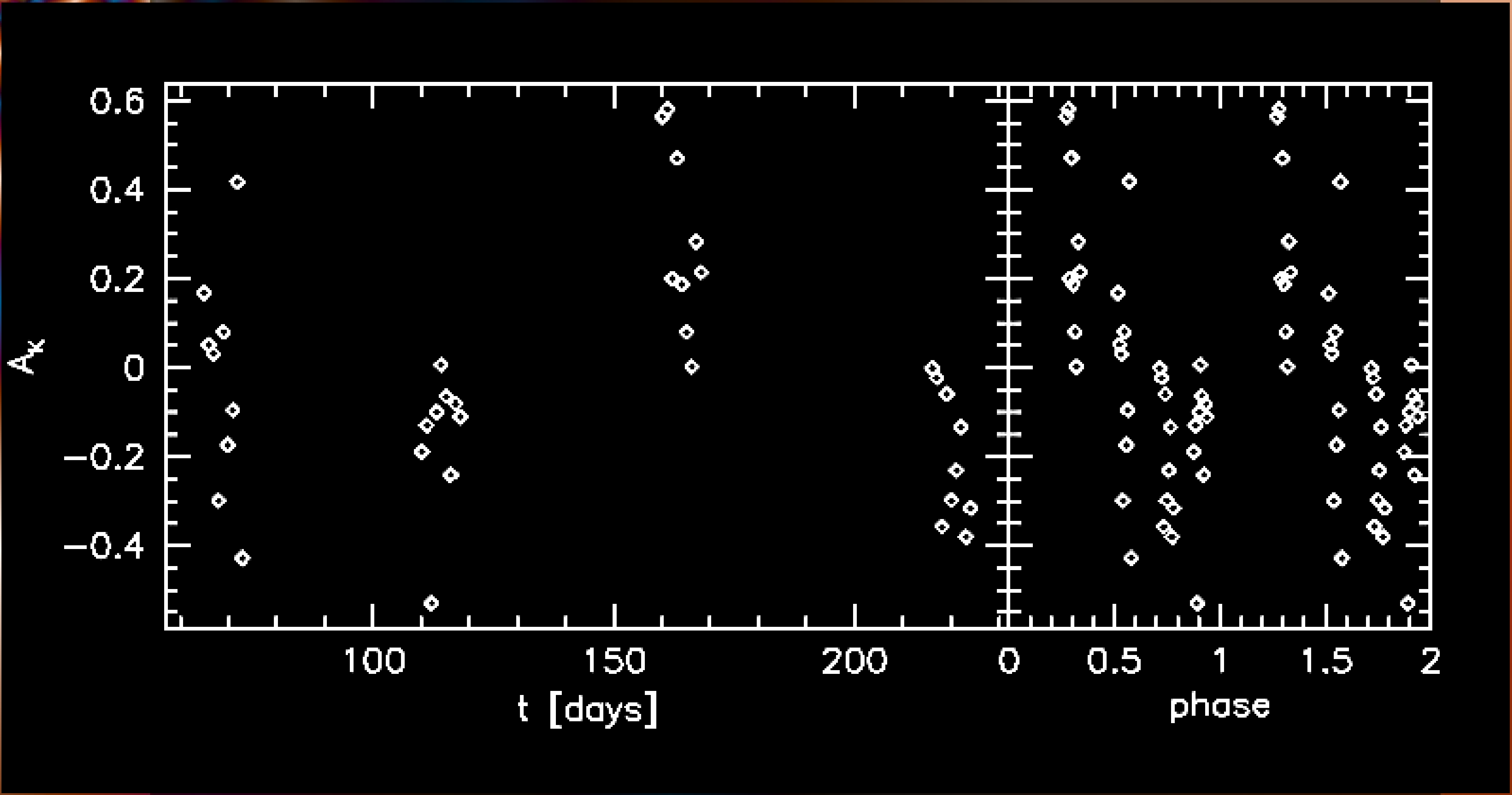
- Is this enough?

=> $A_K = A_0 \sin(t)$ curve generated
A0 = 0.5 mag, period = 120 days
+ Gaussian noise with $\sigma_K = 0.2$ mag

Light curve sampled in four 8-day periods chosen at random during one year.

(For the longest period variables a coverage of two years would be better)


Period = 125.89 days Ak = 0.5 mag σ= 0.2 mag
Ak
0.4
0.2
0
−0.2
−0.4
100
150
200
t [days]
Fourier Power
0.1
0.08
0.06
0.04
0.02
0
100
200
300
P [days]
Fourier Power
0.08
0.06
0.04
0.02
0
100
200
300
P [days]


0.6
0.4
0.2
0
−0.2
−0.4
A_k
100
150
200
t [days]
0
0.5
1
1.5
2
phase