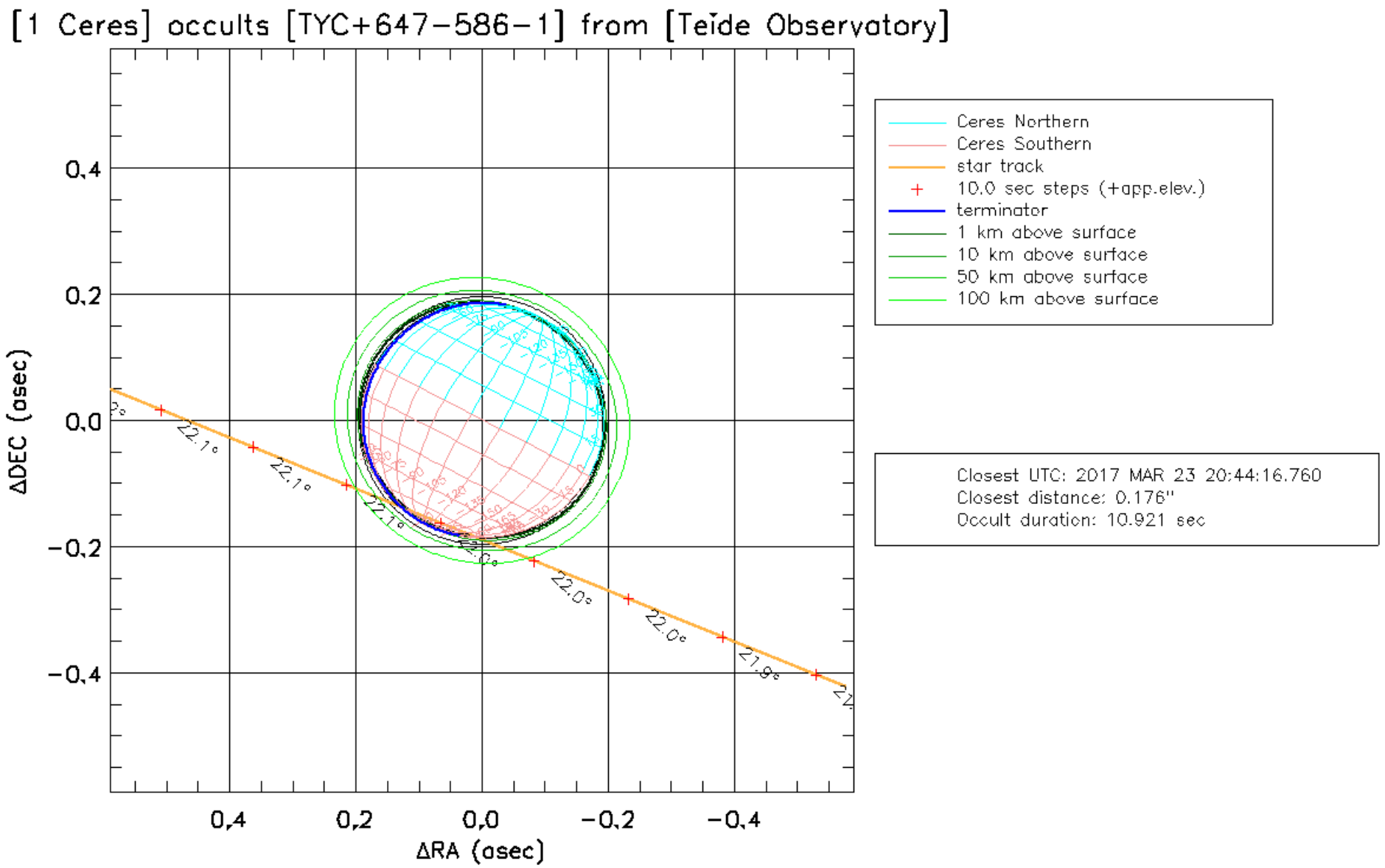

[1 Ceres] occults [TYC+647-586-1] from [Teide Observatory]
ΔDEC (asec)
ΔRA (asec)
0,4
0,2
0,0
−0,2
−0,4
Ceres Northern
Ceres Southern
star track
10.0 sec steps (+app.elev.)
terminator
1 km above surface
10 km above surface
50 km above surface
100 km above surface
Closest UTC: 2017 MAR 23 20:44:16.760
Closest distance: 0.176"
Occult duration: 10.921 sec

Stjernehobe: de ældste stjerner og laboratorier for stjernernes fysik

Frank Grundahl

STELLAR ASTROPHYSICS CENTRE

Aarhus Universitet

Astronomidag, 24/3 - 2017

Hvad vil vi (jeg!) gerne vide om stjerner ??

Alder – kendes kun for Solen !! (via meteoritter! og Jordens alder)

Masse – kun for binær-stjerner (stort set)

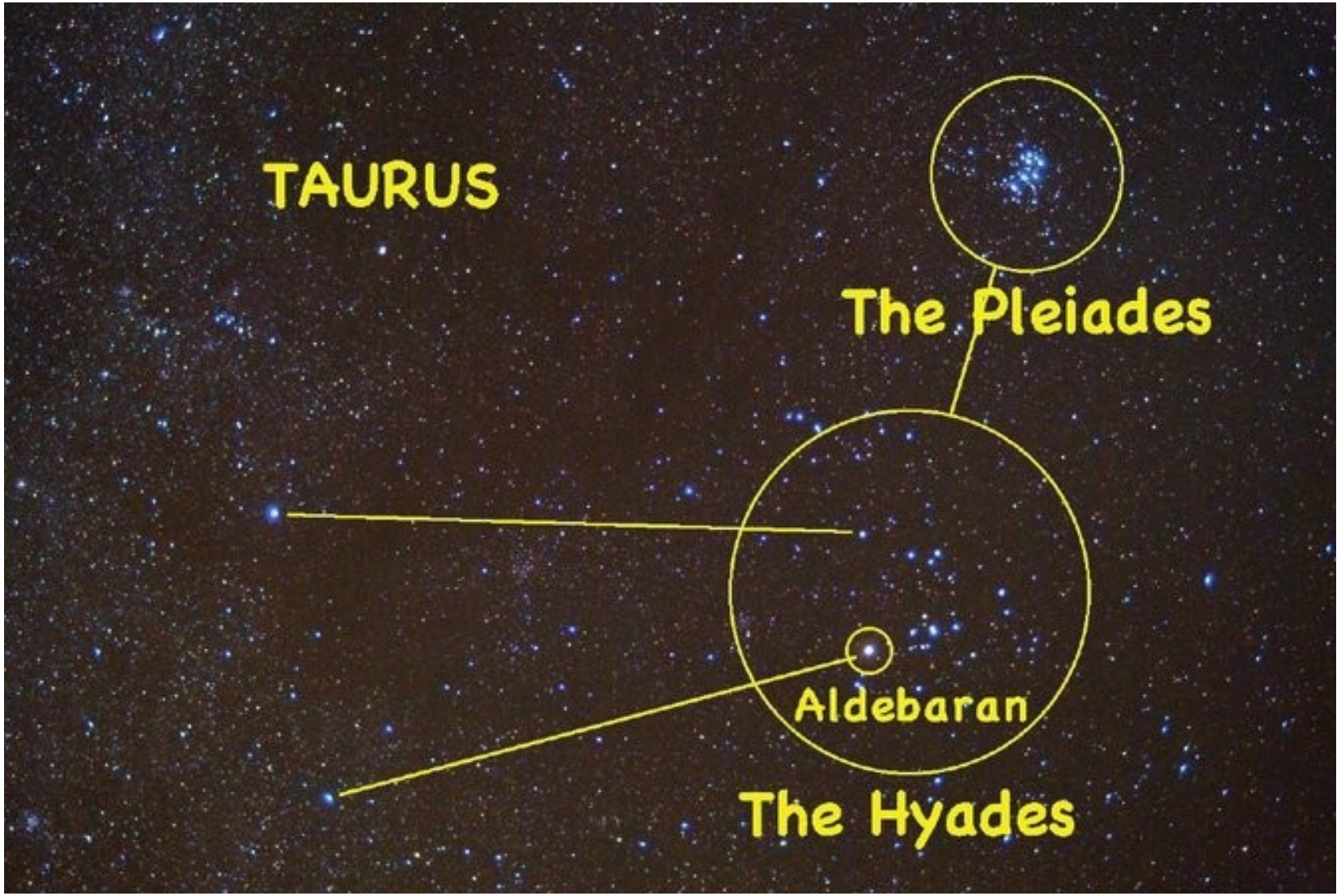
Radius – via interferometri

Grundstoffer – kendes kun via modeller (og lidt fra meteoritter)

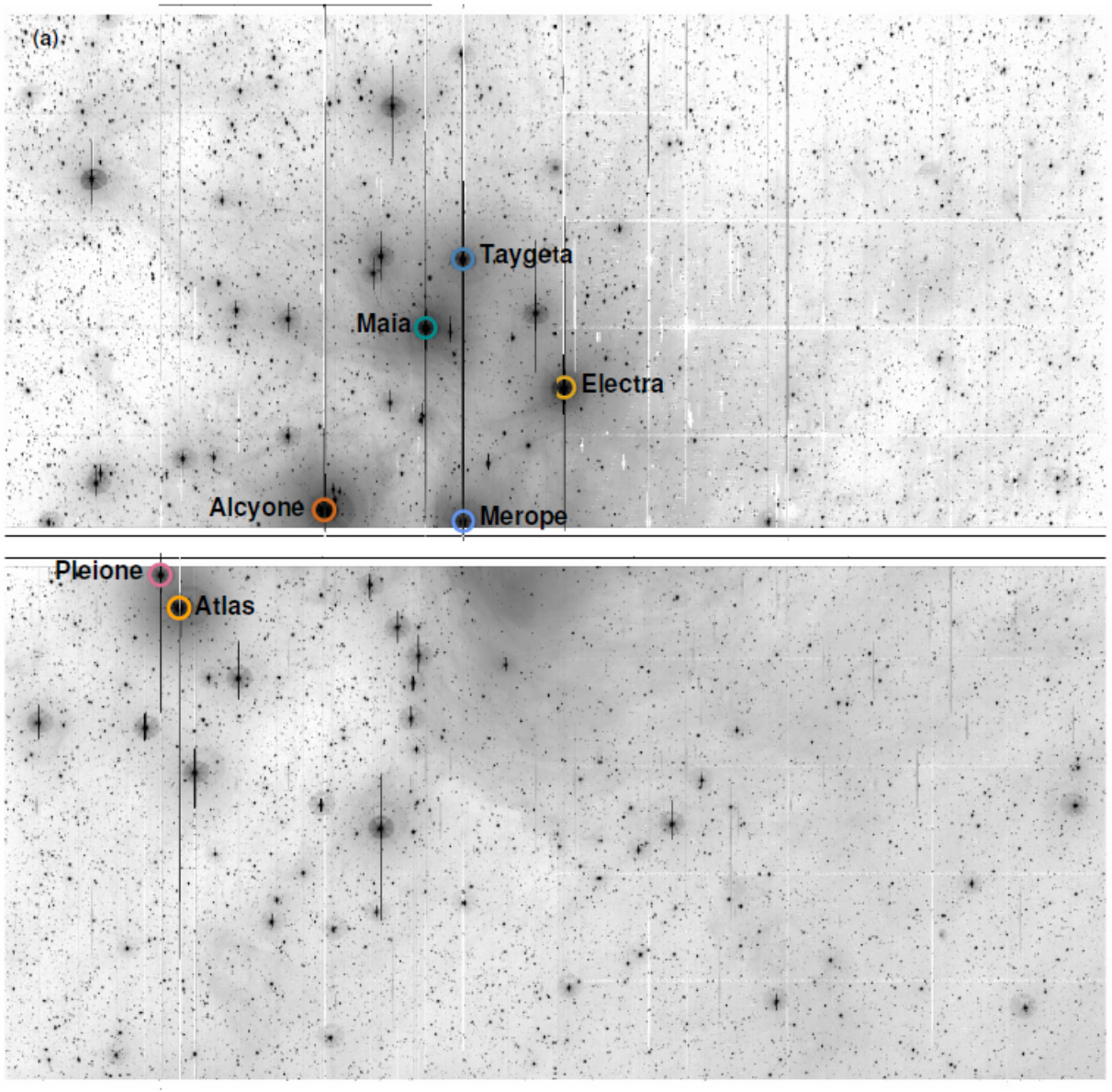
så vi er dybt afhængige af at stjerne-udviklings-modellerne er **rigtige**, og det skal verificeres og testes

– stjernehobene kan hjælpe os….

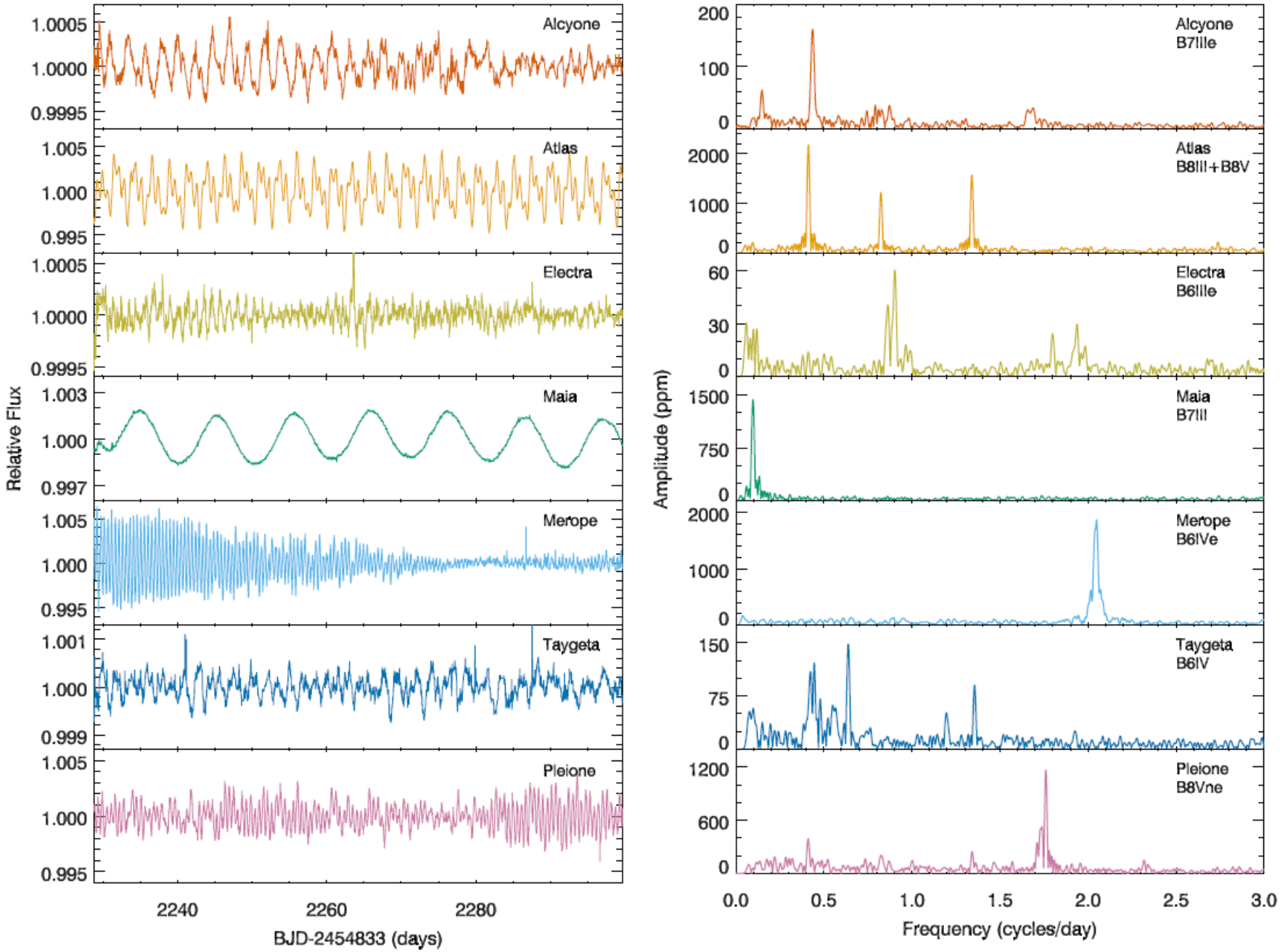
Kun to hobe kan (let) ses med det blotte øje..



Plejaderne observeret med K2 / Kepler



T. White et al. (2017, submitted)


Alcyone
Atlas
Electra
Maia
Merope
Taygeta
Pleione
Relative Flux
BJD-2454833 (days)
Alcyone B7IIIe
Atlas B8III+B8V
Electra B6IIIe
Maia B7III
Merope B6IVe
Taygeta B6IV
Pleione B8Vne
Amplitude (ppm)
Frequency (cycles/day)

Hvorfor skal vi studere stjernehobe ?

- 'homogene' stjerne-populationer (samme afstand, alder, grundstofsammensætning)

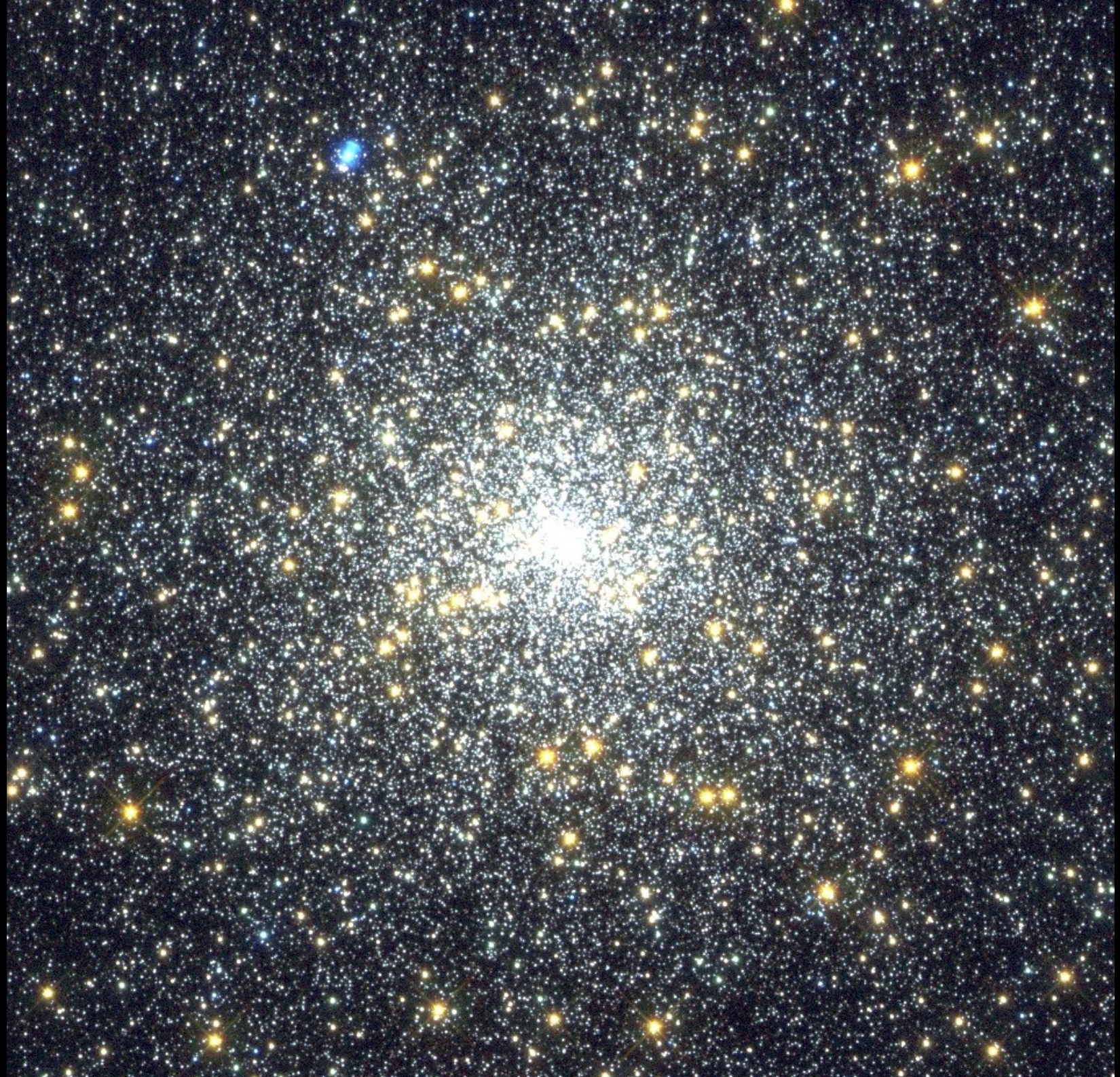
- de mest nøjagtige aldre kan bestemmes i hobe.

- kan bruges til at studere stjerne-udvikling i stor detalje, da en given hob indeholder stjerner i mange udviklings-trin

- hjælper til forståelse af galakse-dannelse

- afstandsskalaen afhænger af hobene

- hobe findes overalt i universet

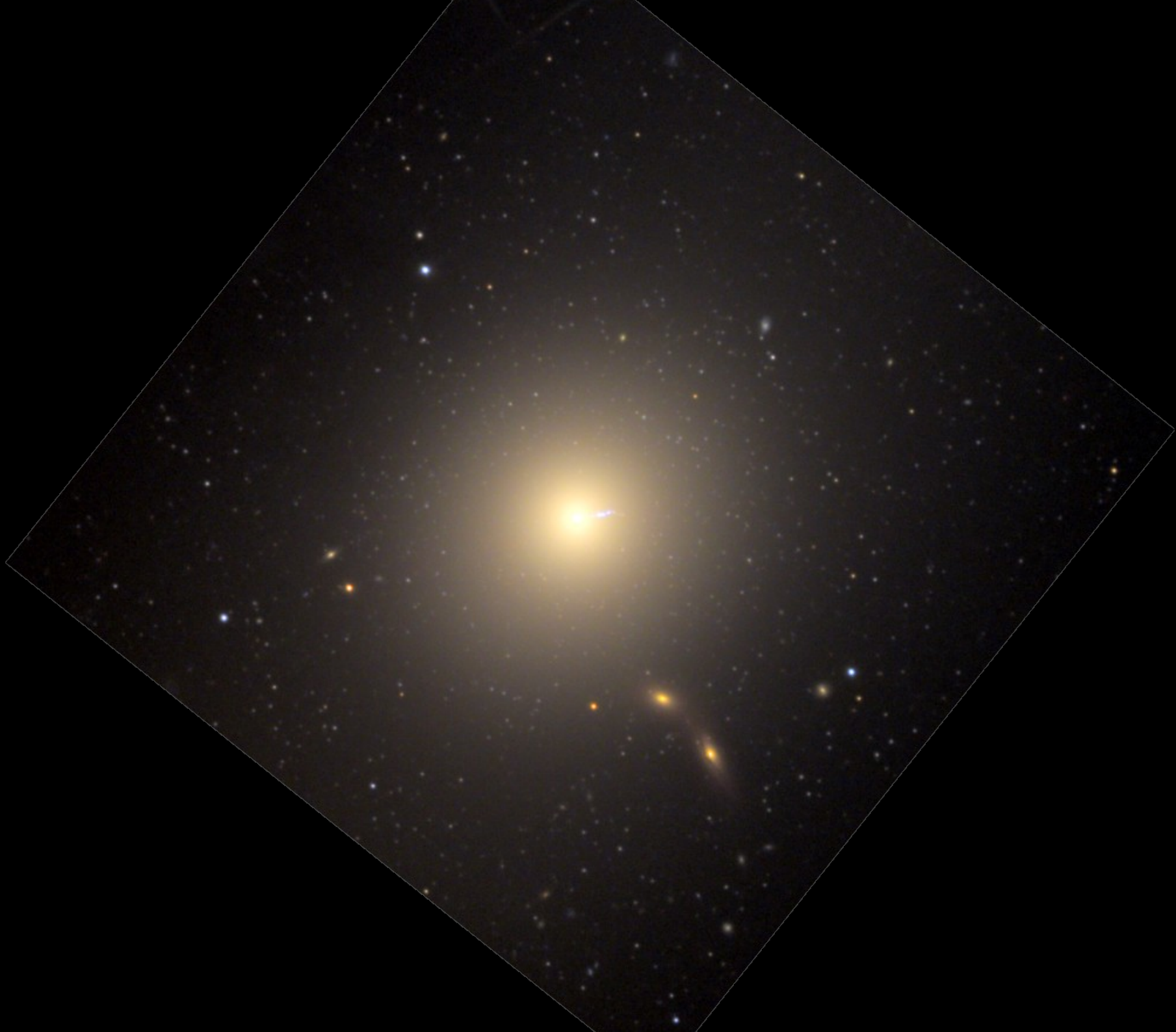


NGC 5139 = ω Centauri

Fra APOD, 2013 May 1 – Copyright:Joaquin Polleri & Ezequiel Etcheverry (Observatorio Panameño en San Pedro de Atacama)

Globular clusters are everywhere in the universe.....

M87 – giant elliptical galaxy in Virgo. Image from Gemini Observatory (GMOS)



Mælkevejen indeholder to typer af stjernehobe

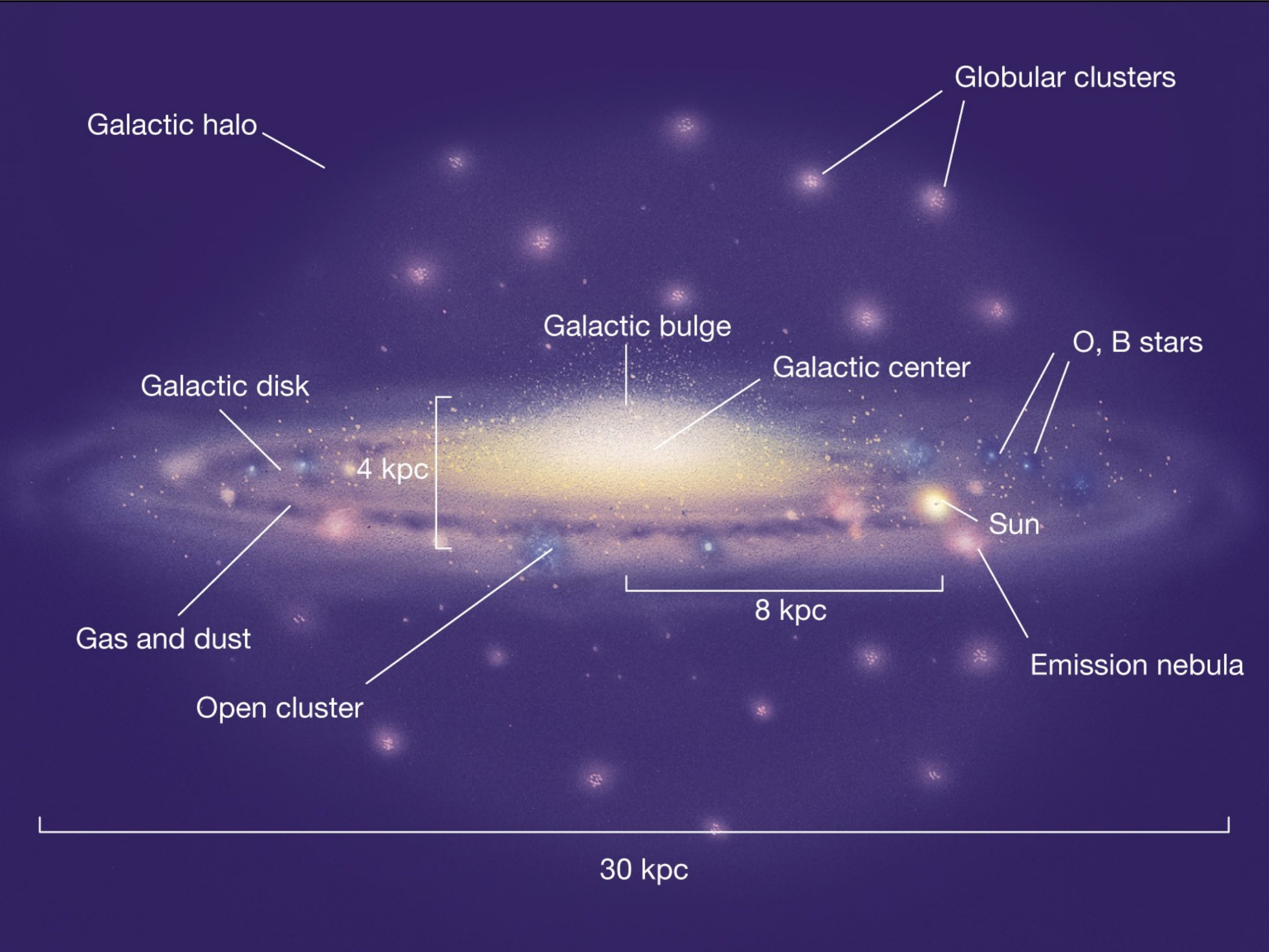
åbne hobe:

unge, fortrinsvis i Mælkevejens skive, 'metal-rige'.
ung → indeholder stjerner med høj(ere) masse

kan ikke overleve mødet med de store molekyle-skyer i galaksens skive og overlever kun i ~få Giga-år.

kugleformede hobe:

gamle, findes overalt i galaksen og udviser stor variation i indhold af tunge grundstoffer. Typically only low-mass (~1M_o) stars.


Globular clusters
Galactic halo
Galactic bulge
O, B stars
Galactic center
Galactic disk
4 kpc
Sun
8 kpc
Gas and dust
Emission nebula
Open cluster
30 kpc

Characteristics for Milky Way star clusters

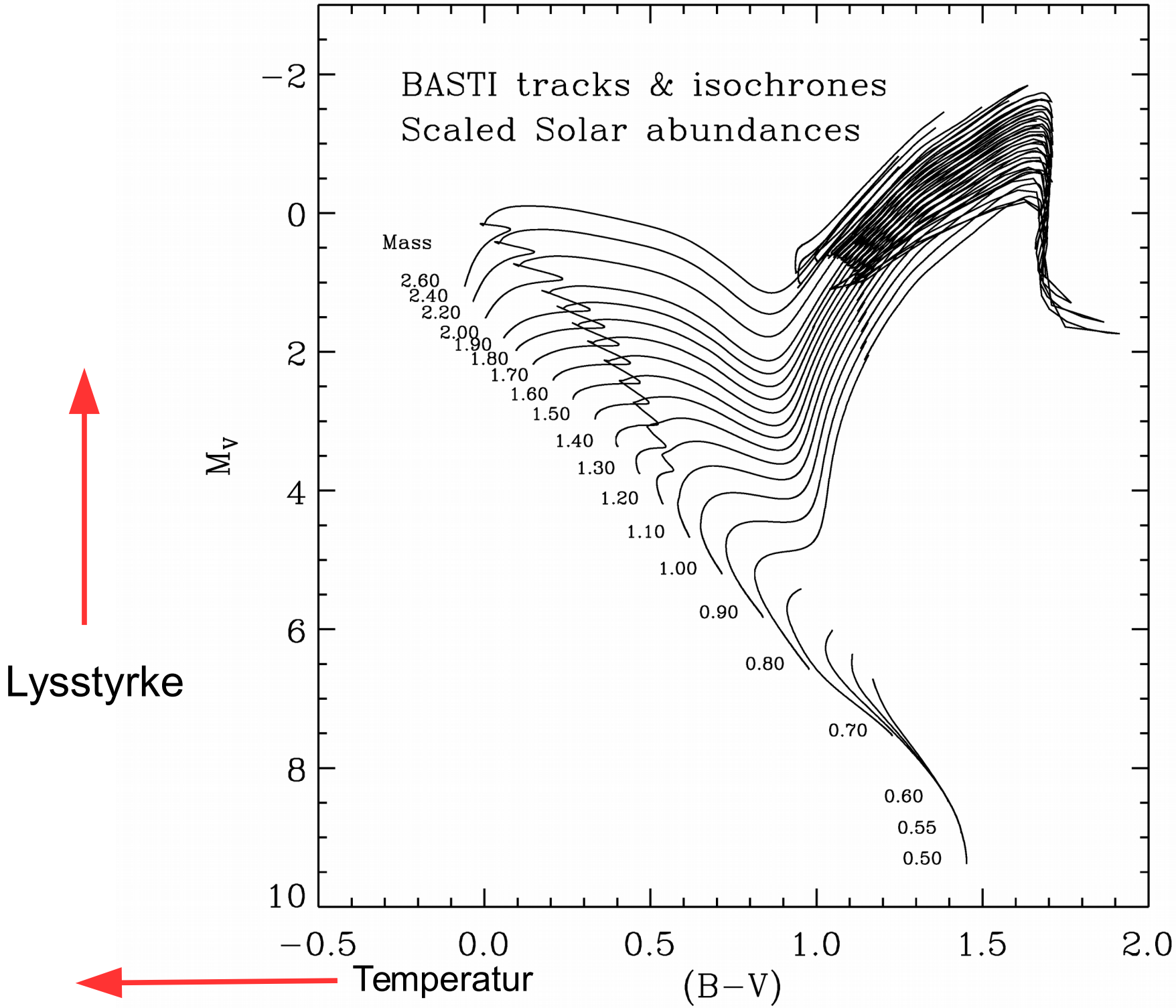
	Open	**Globular**
Where	Disc	Halo, disc, bulge
Age	$<10^{10}$ yr	$>10^{10}$ yr
Mass	$< 10^4$ M_{Sun}	op til 10^7 M_{Sun}
Size	few pc	5-50 pc (r_h)
Z (heavy elements)	$> 0.1xZ_{Sun}$	$10^{-3} < Z_{Sun} < 0.5\ Z_{Sun}$
No. clusters in MW	>1000	~150
No. stars in a cluster	~100 - 10^4	10^5 typically but large variation

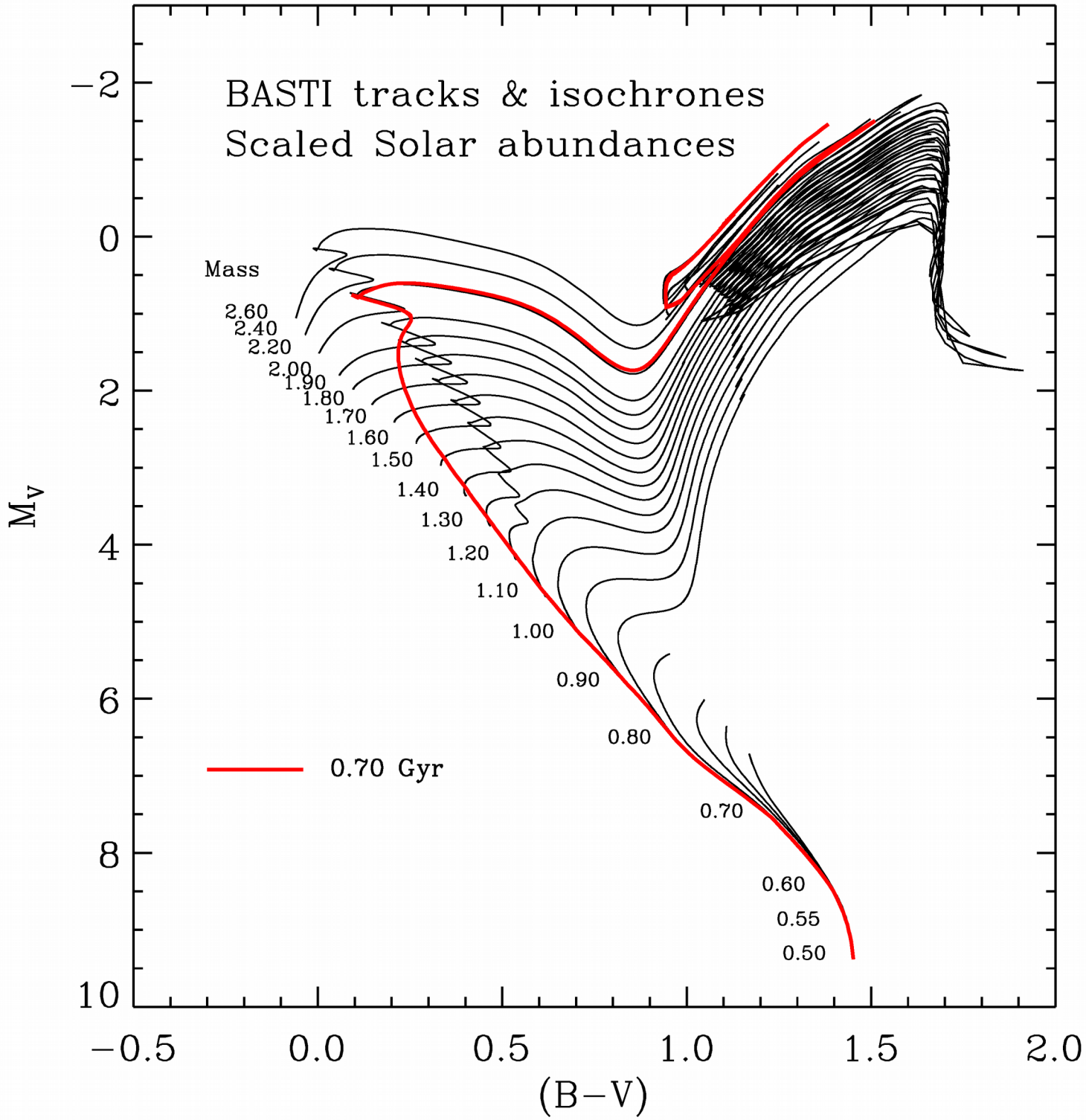
Z: masse-brøkdel af grundstoffer tungere end H og He (X+Y+Z = 1)

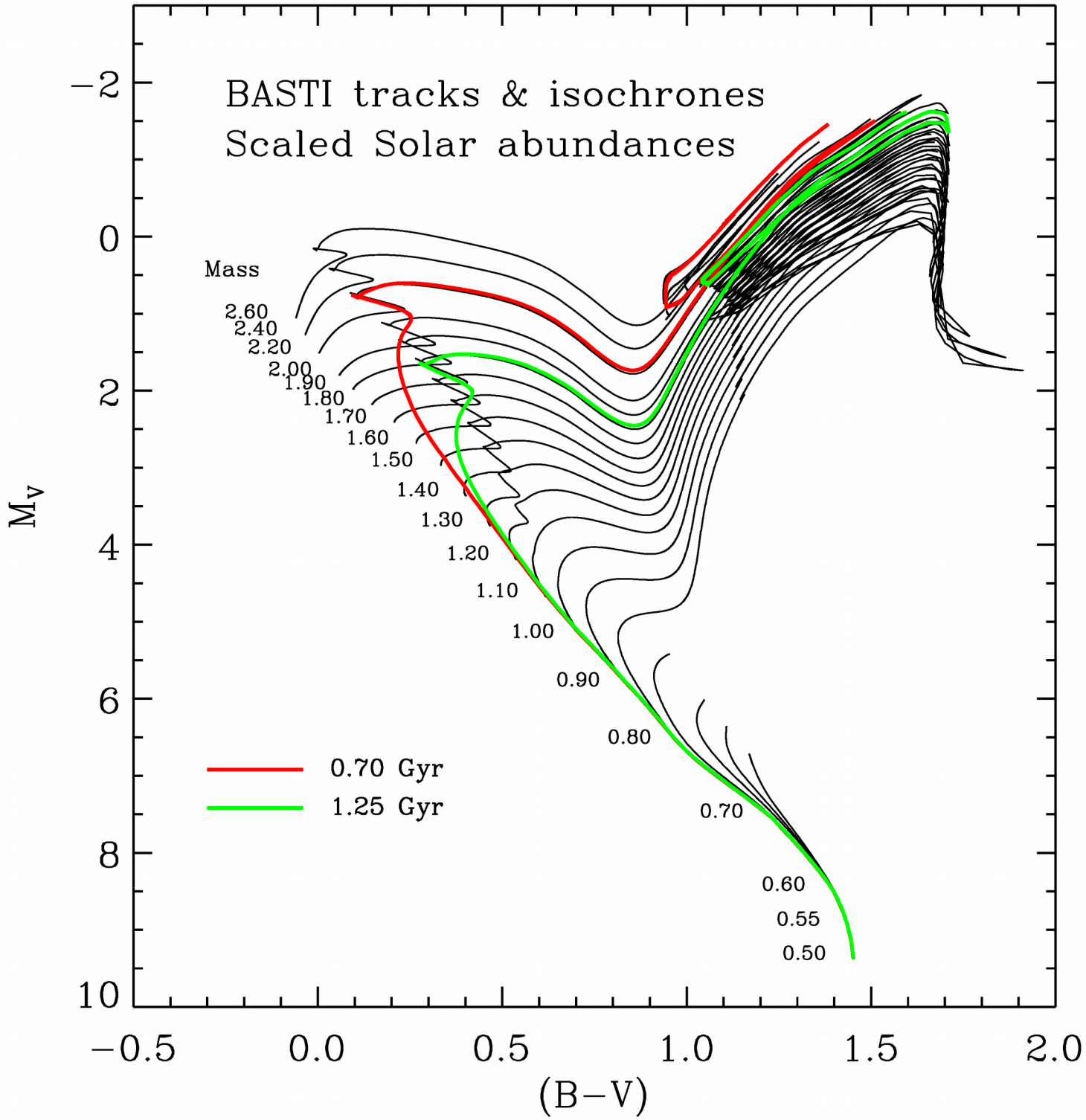
Den tungeste af kuglehobene, ω Centauri, indeholder ~8% af massen af alle kuglehobe i Mælkevejen.

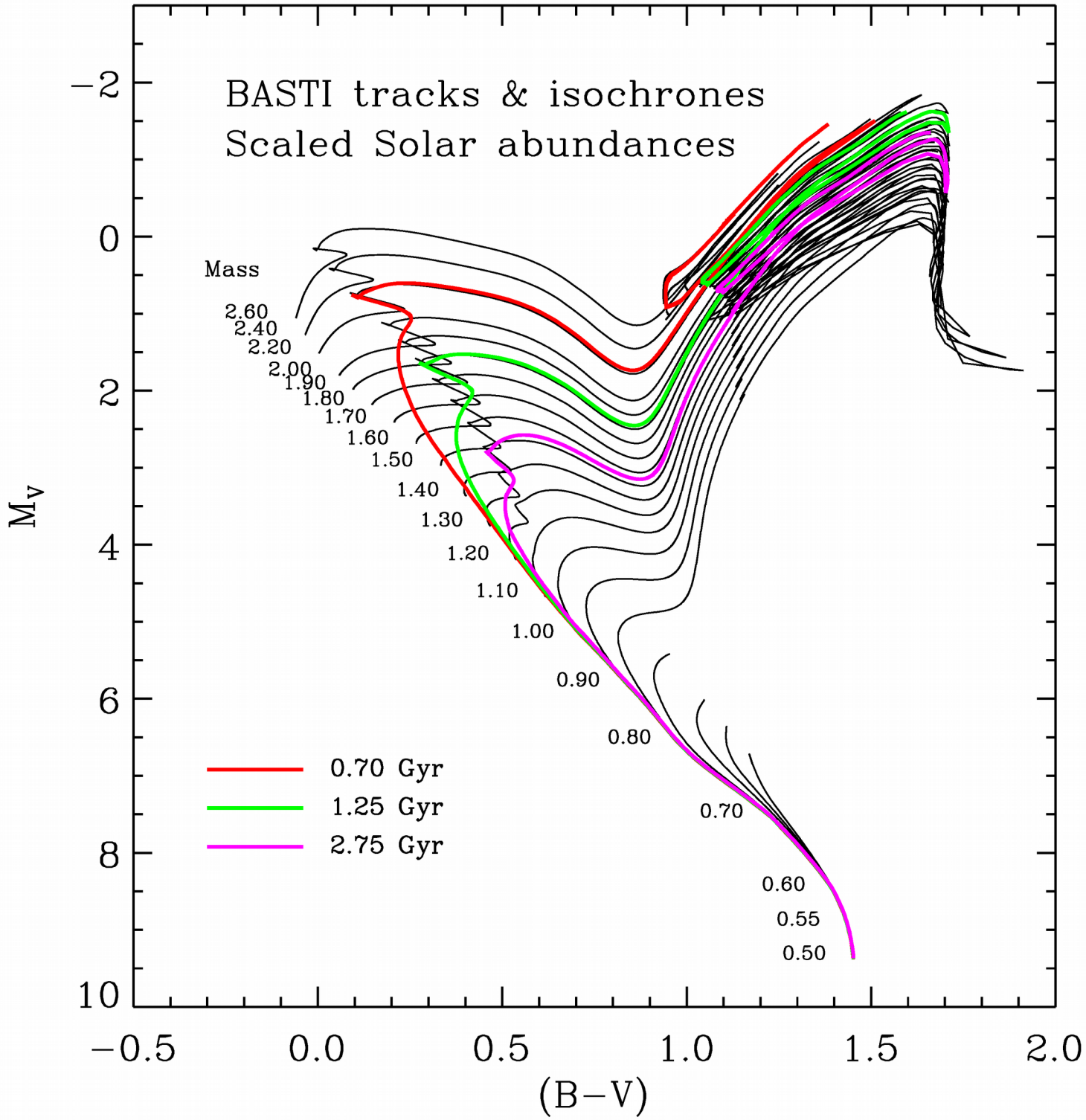
så hvordan kan vi bruge hobene som laboratorier

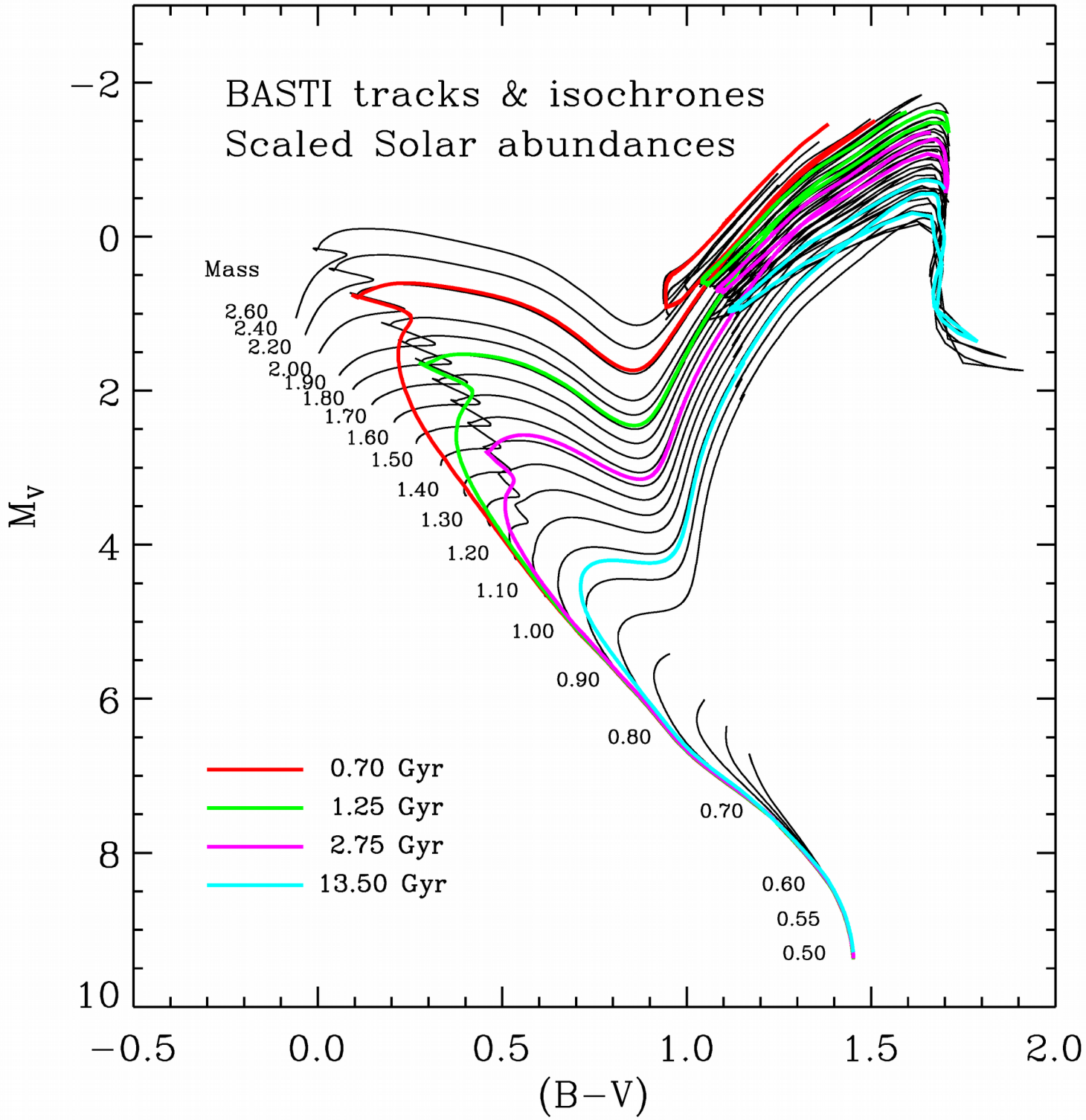
til at studere stjerneudvikling ?


BASTI tracks & isochrones
Scaled Solar abundances
Mass
2.60
2.40
2.20
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.55
0.50
M_V
−2
0
2
4
6
8
10
−0.5
0.0
0.5
1.0
1.5
2.0
(B−V)
Lysstyrke
Temperatur


BASTI tracks & isochrones
Scaled Solar abundances
Mass
2.60
2.40
2.20
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.55
0.50
0.70 Gyr
M_V
(B−V)
−2
0
2
4
6
8
10
−0.5
0.0
0.5
1.0
1.5
2.0


BASTI tracks & isochrones
Scaled Solar abundances
Mass
2.60
2.40
2.20
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.55
0.50
0.70 Gyr
1.25 Gyr
M_V
(B−V)
−2
0
2
4
6
8
10
−0.5
0.0
0.5
1.0
1.5
2.0


BASTI tracks & isochrones
Scaled Solar abundances
Mass
2.60
2.40
2.20
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.55
0.50
0.70 Gyr
1.25 Gyr
2.75 Gyr
M_V
(B−V)
−2
0
2
4
6
8
10
−0.5
0.0
0.5
1.0
1.5
2.0


BASTI tracks & isochrones
Scaled Solar abundances
Mass
2.60
2.40
2.20
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.55
0.50
0.70 Gyr
1.25 Gyr
2.75 Gyr
13.50 Gyr
M_V
(B−V)
−2
0
2
4
6
8
10
−0.5
0.0
0.5
1.0
1.5
2.0


NGC 6791

Vi skal udnytte at for formørkelses-variable er det muligt at bestemme:

- Masse (fra bane-bevægelsen, radial-hastighed og perioden)

- Radius (fra formørkelserne, også inklinationen)…..

Vi skal udnytte at for formørkelses-variable er det muligt at bestemme:

- Masse (fra bane-bevægelsen, radial-hastighed og perioden)

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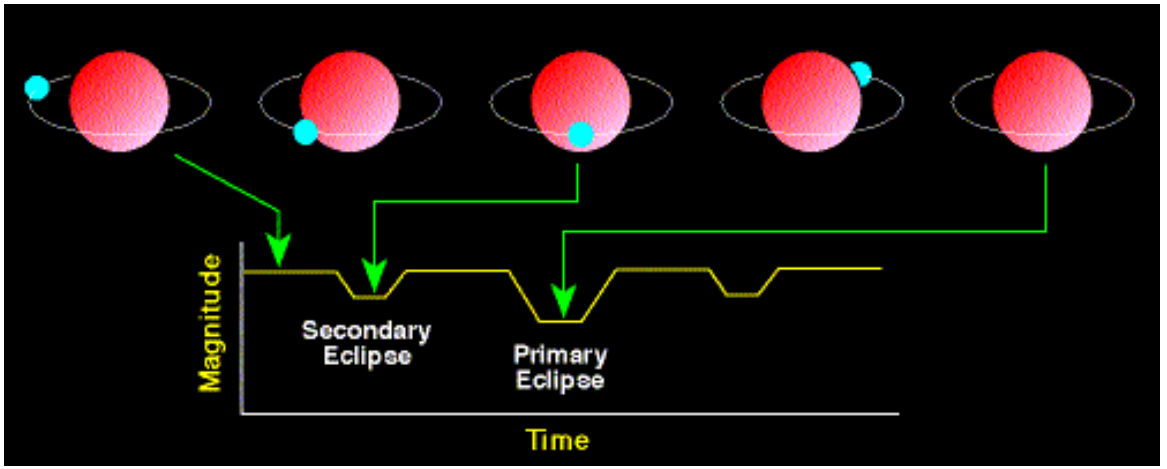
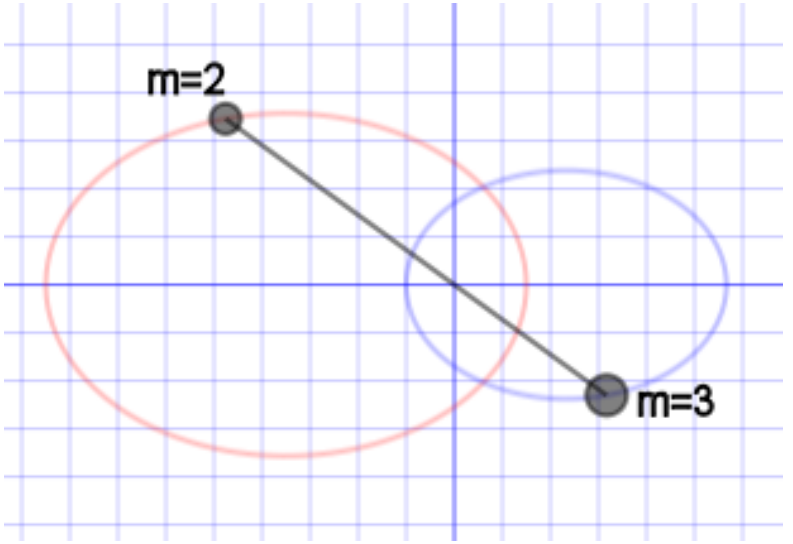
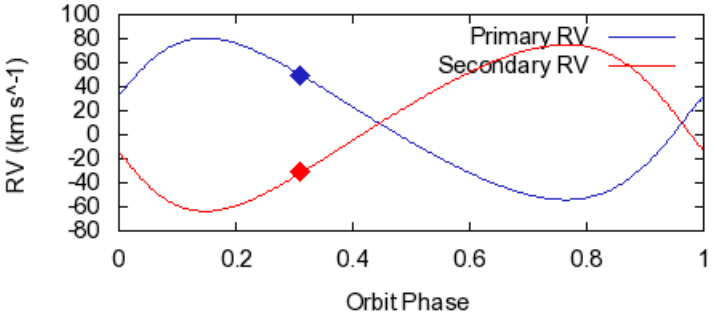




Lad os se på V20 i NGC 6791



Farve-lysstyrke diagram

NGC 6791

Ældste(?) åbne hob

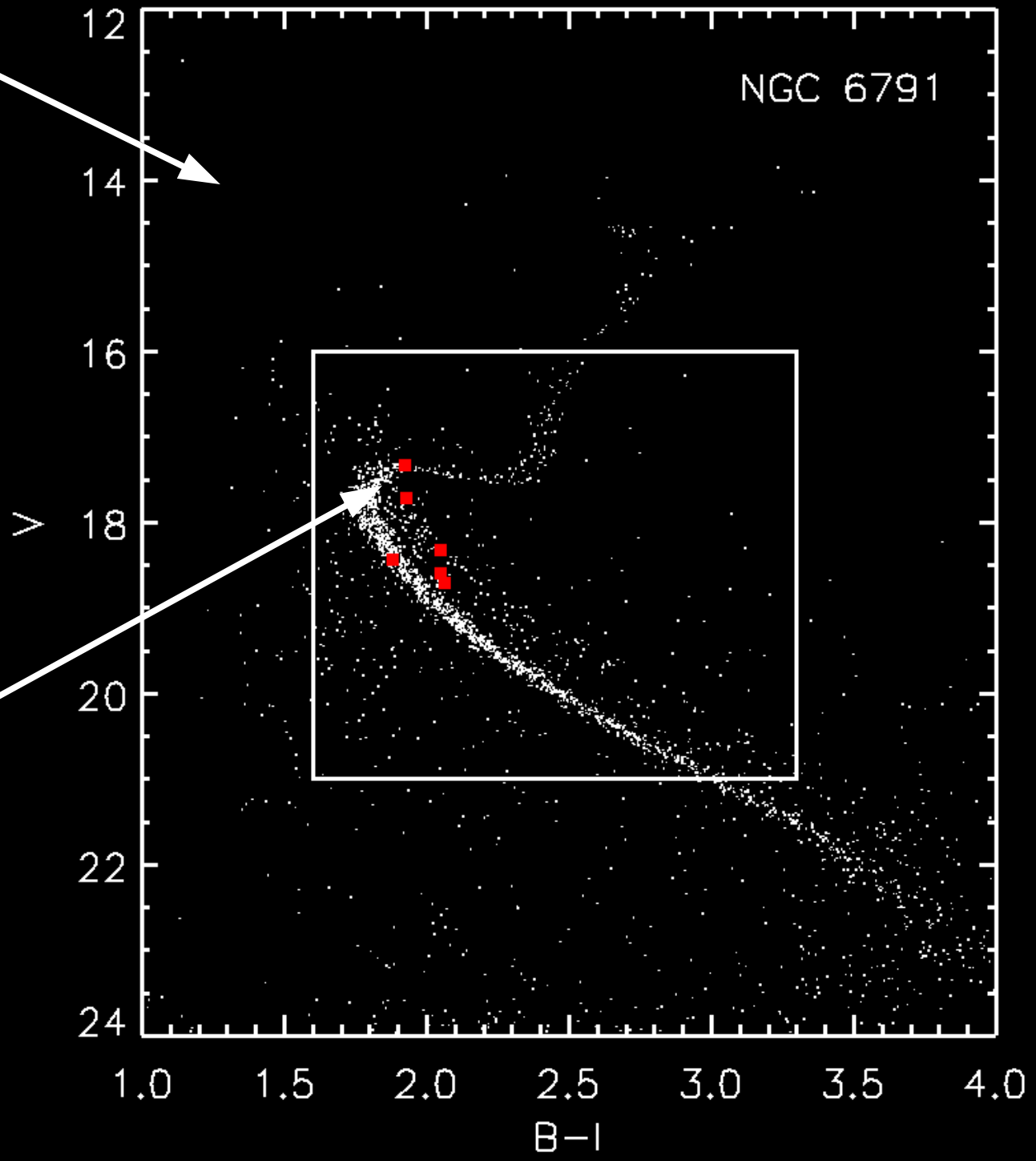
Alder: ~8 Gyr

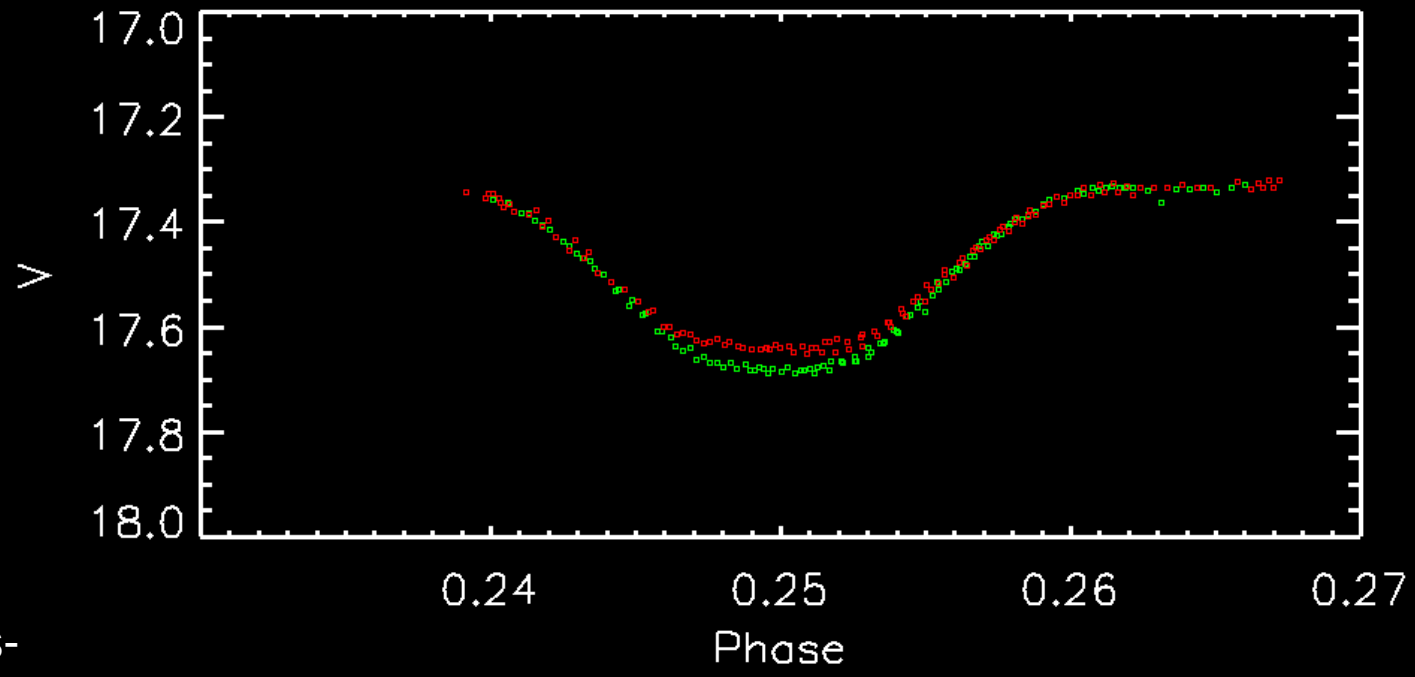
[Fe/H] = +0.4

Indeholder formørkelses-variable

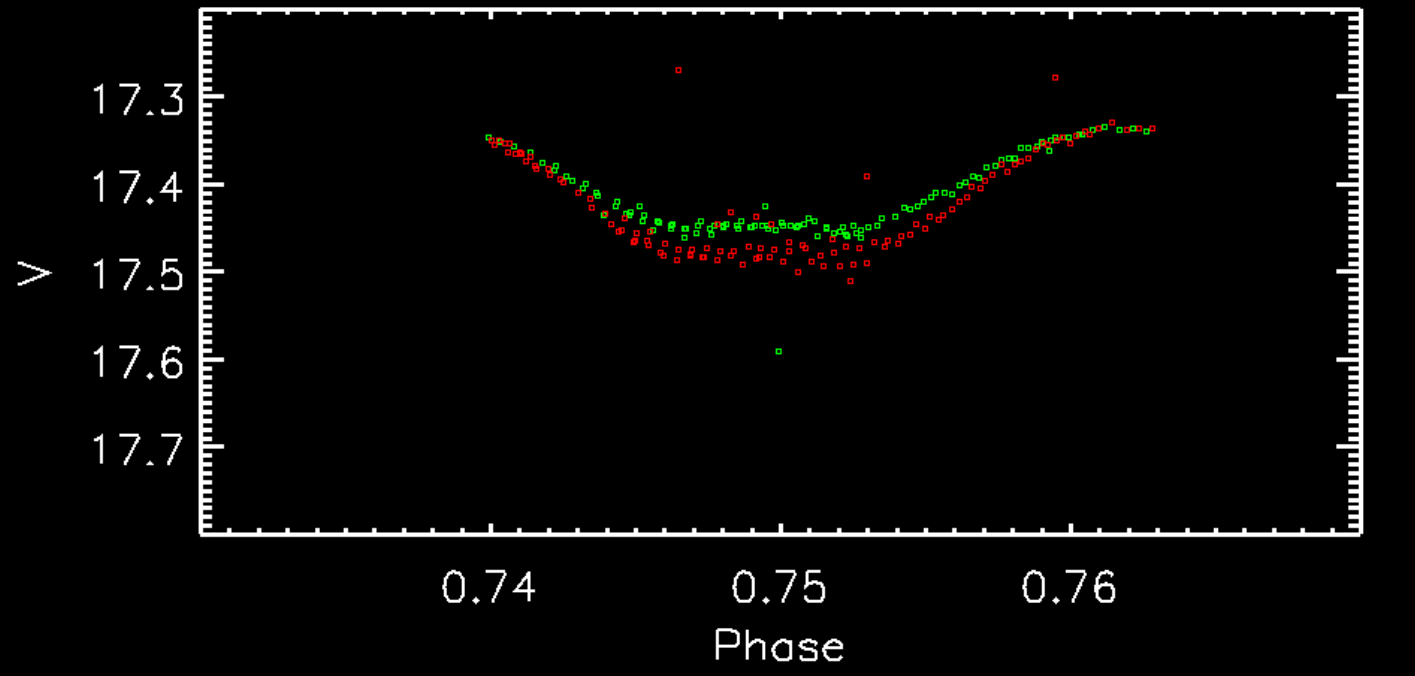
Fotometri fra Nordisk Optisk Teleskop på La Palma

17 VLT/UVES spektre for V20





Lyskyrve for formørkelses-variablen V20



V20 – NGC 6791

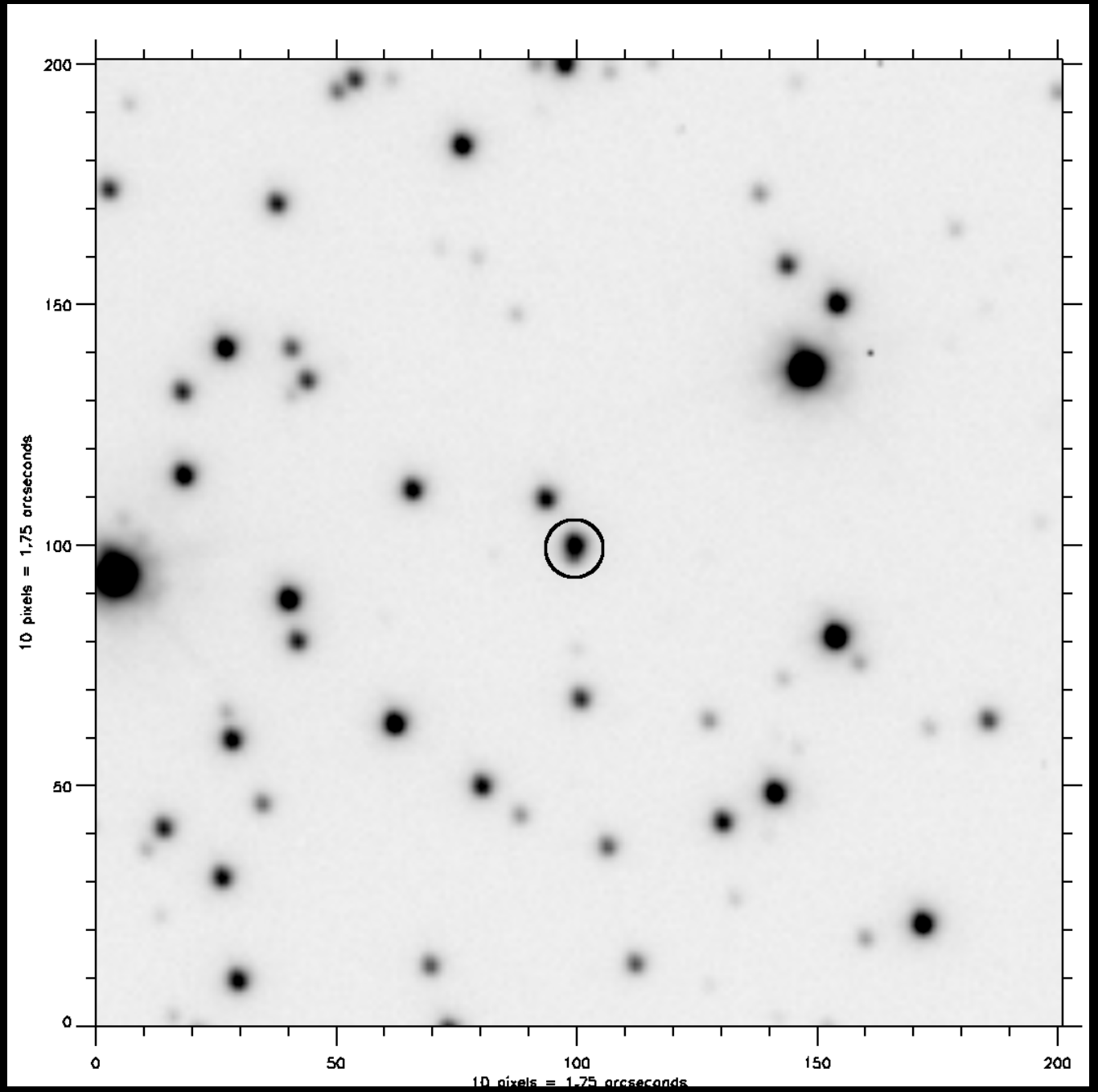
I – band (180s)

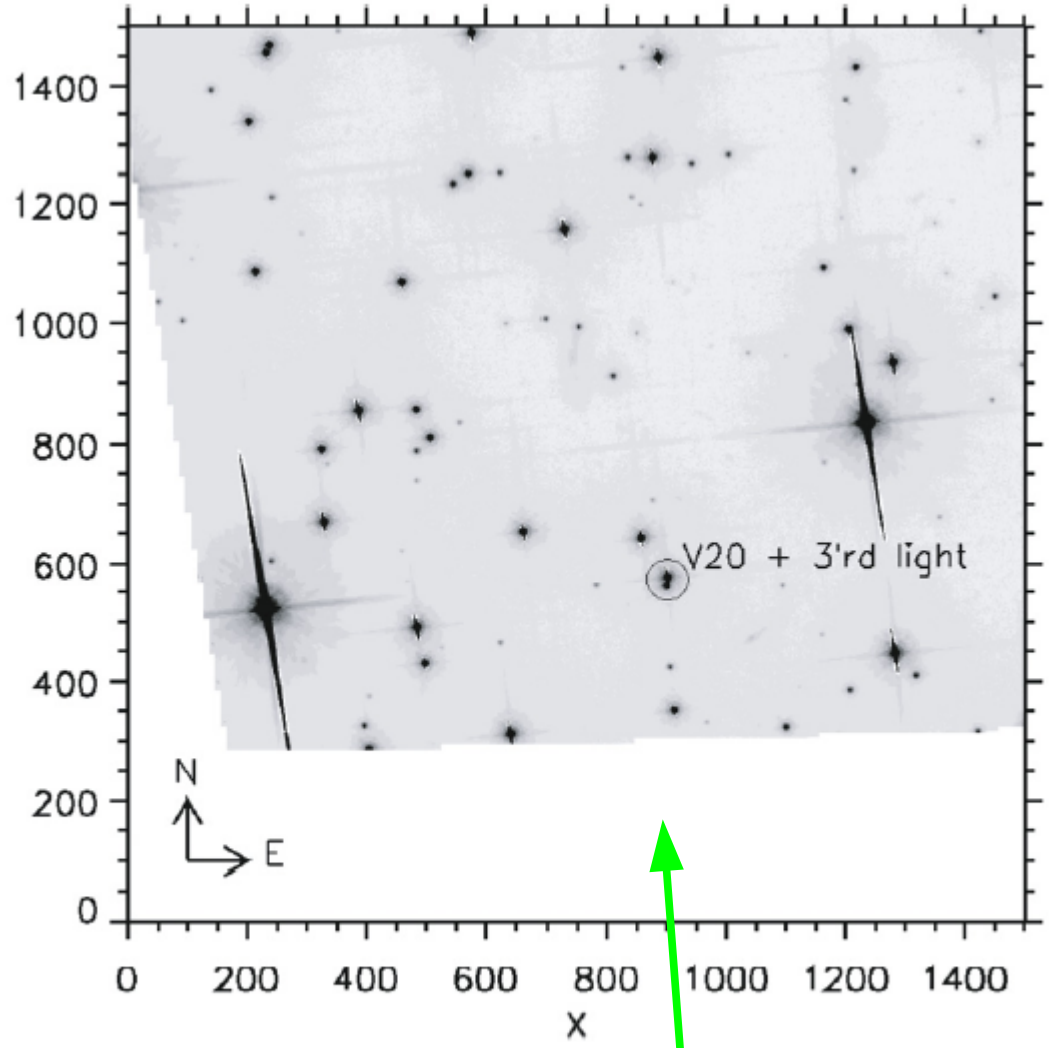
FWHM = 0.”47

Nordic Optical Telescope

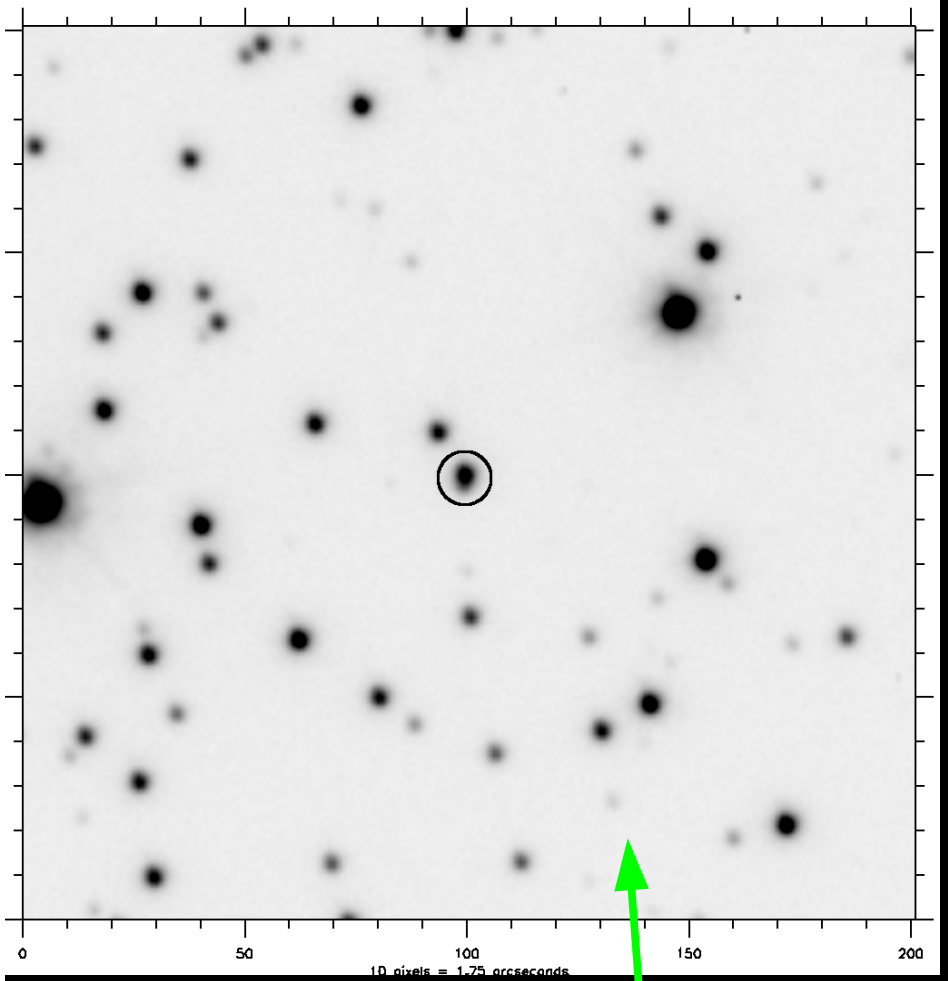
Separation ~0.”5 between primary and 3'rd light.

Søge-kort (finding chart) til identifikation af objektet når man er ved teleskopet.





.2. Finding chart for V20. Plate scale is 0.05″ per pixel. Image
ACS on *HST*.



Fra Hubble Space Telescope (HST)

Fra Nordisk Optisk Teleskop (NOT)

Placering af komponenterne i V20

Grøn: totale lys, primær + sekundær og tredie-lys.

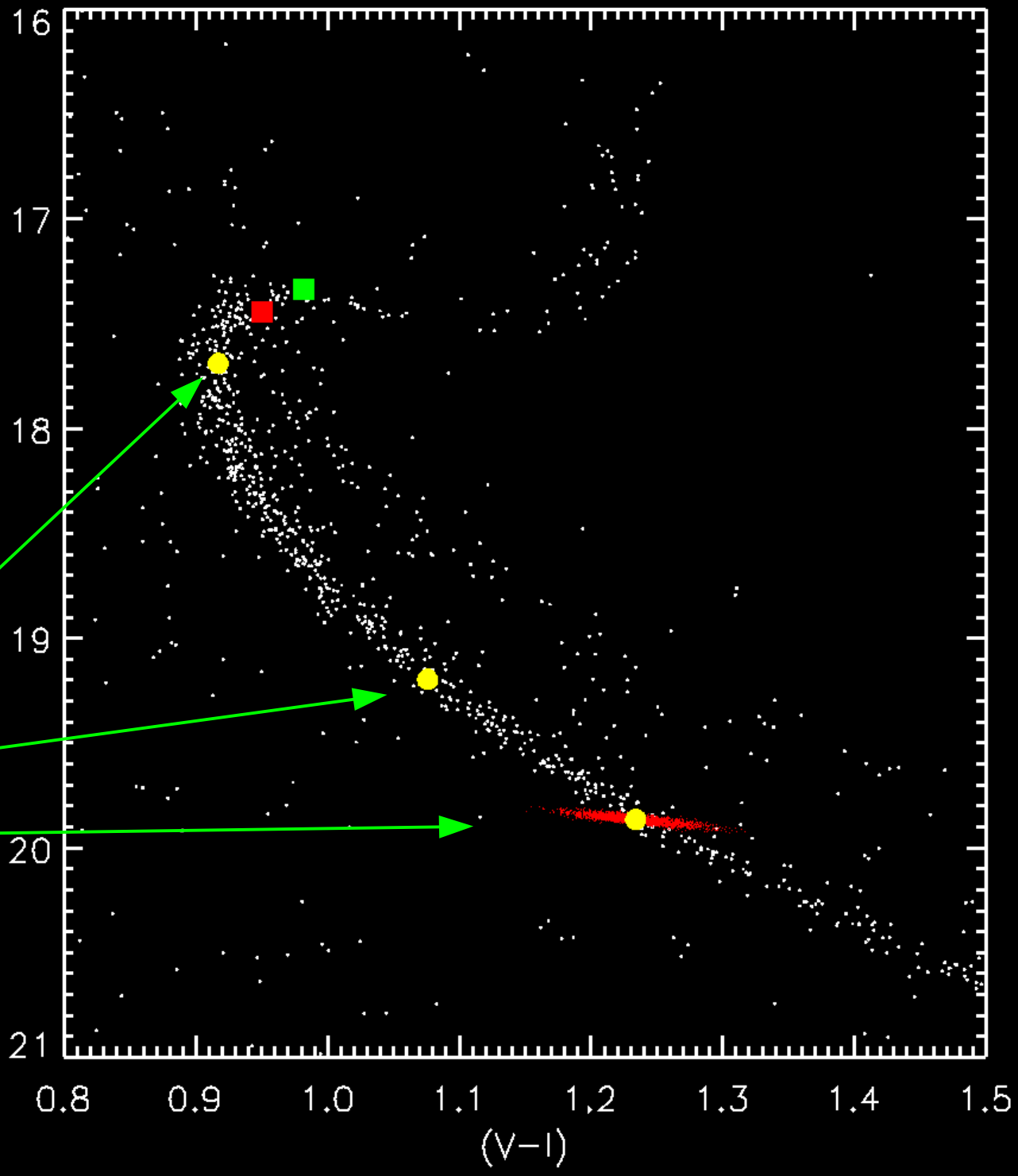
Rød: Position under formørkelsen (sekundær er bag ved primær).

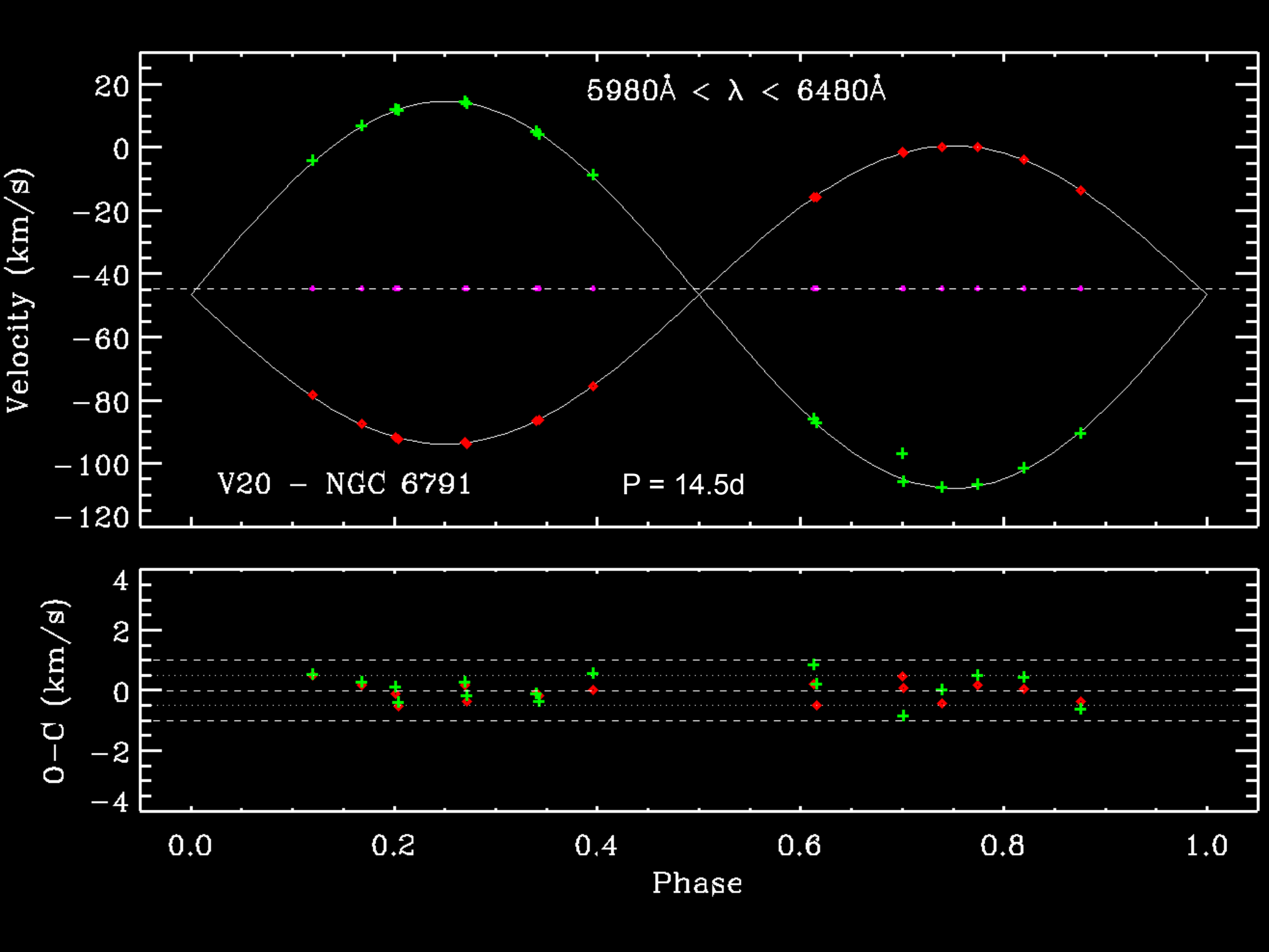
Gule:

Primær stjerne alene

Tredje lys

Sekundær




5980Å < λ < 6480Å
V20 – NGC 6791
P = 14.5d
Velocity (km/s)
O–C (km/s)
Phase
20
0
−20
−40
−60
−80
−100
−120
4
2
0
−2
−4
0.0
0.2
0.4
0.6
0.8
1.0

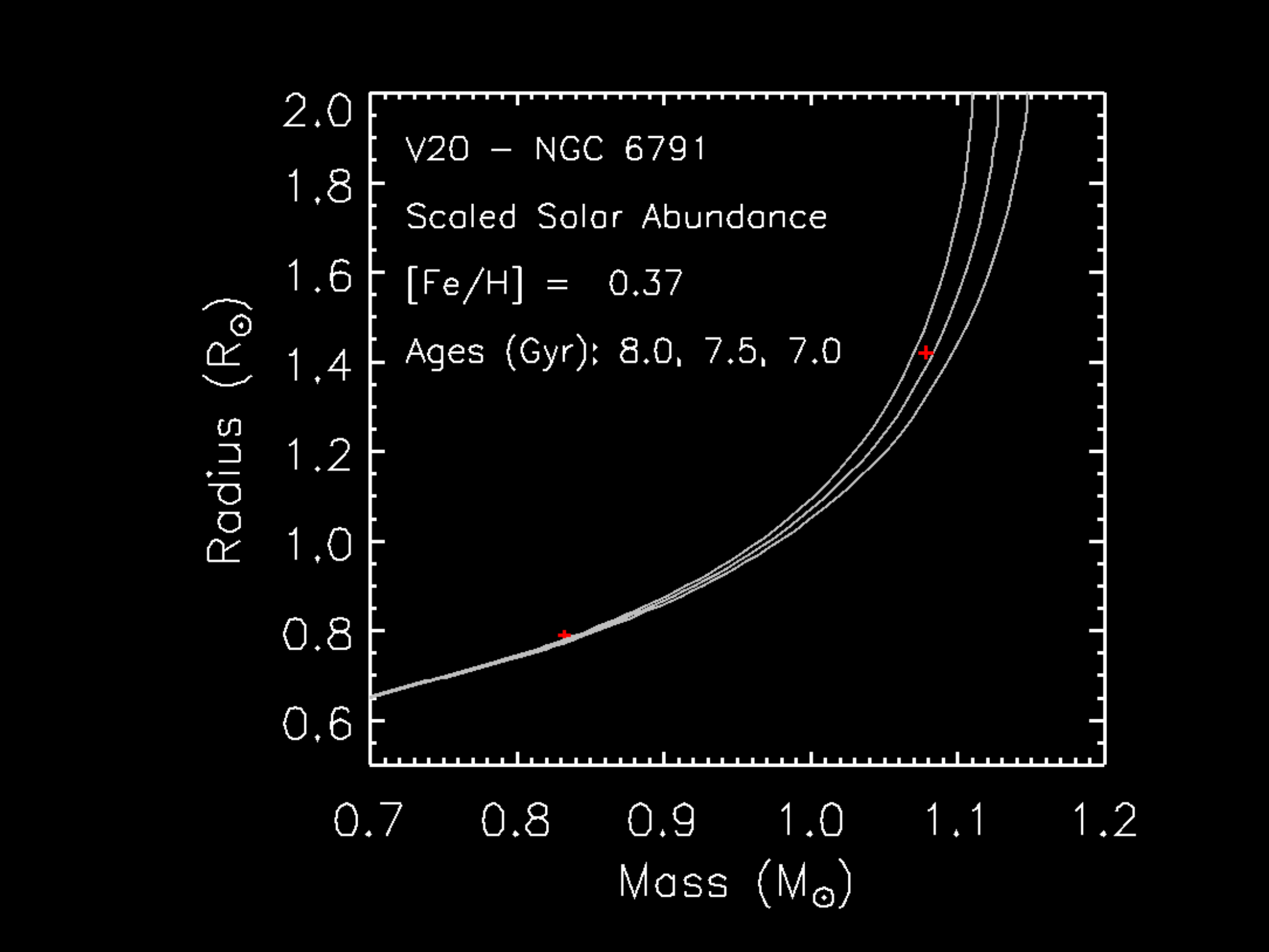
V20 – NGC 6791

“Easy to get better data for METALLICITY, PHOTOMETRY, SPECTROSCOPY”

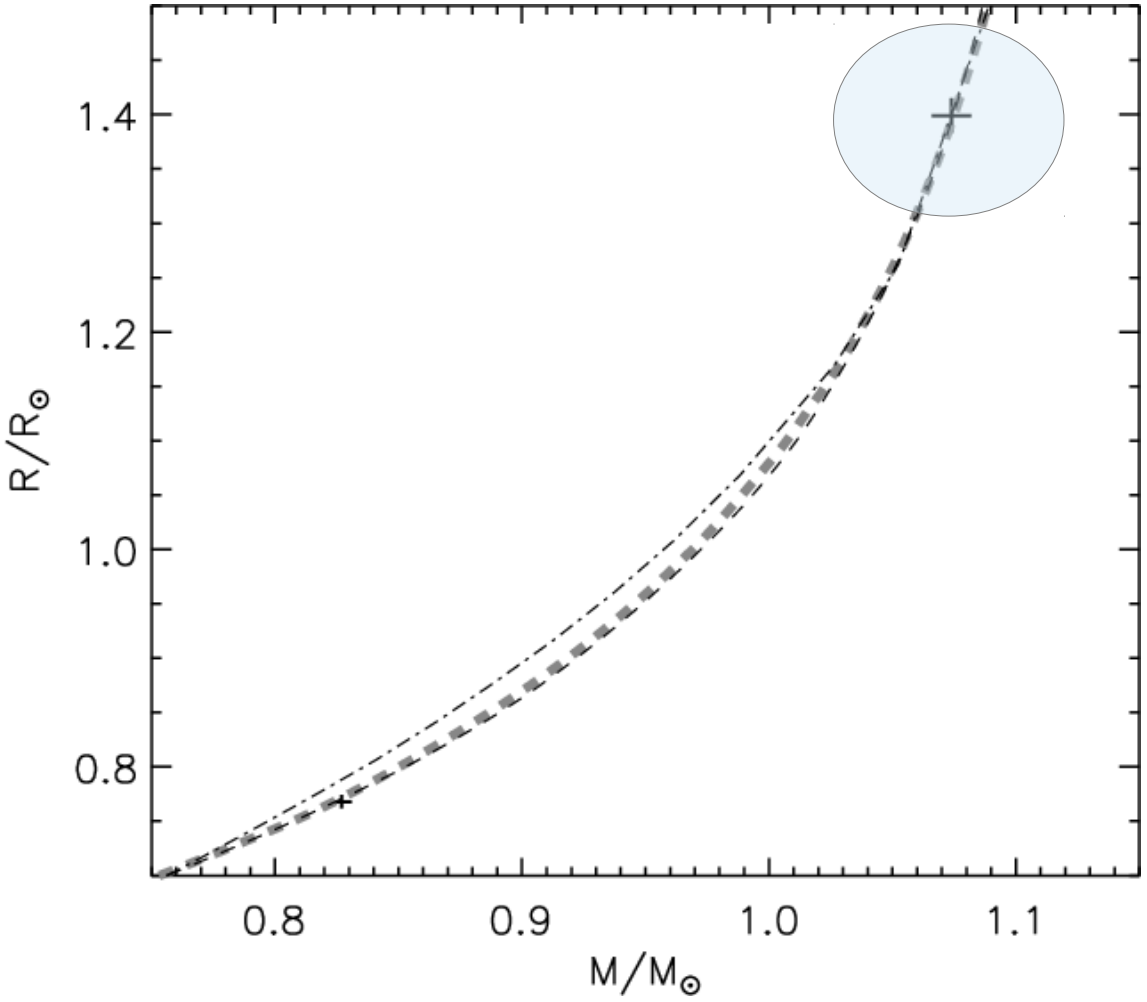
Improve estimate of 3'rd light component (AO or Lucky Imaging).

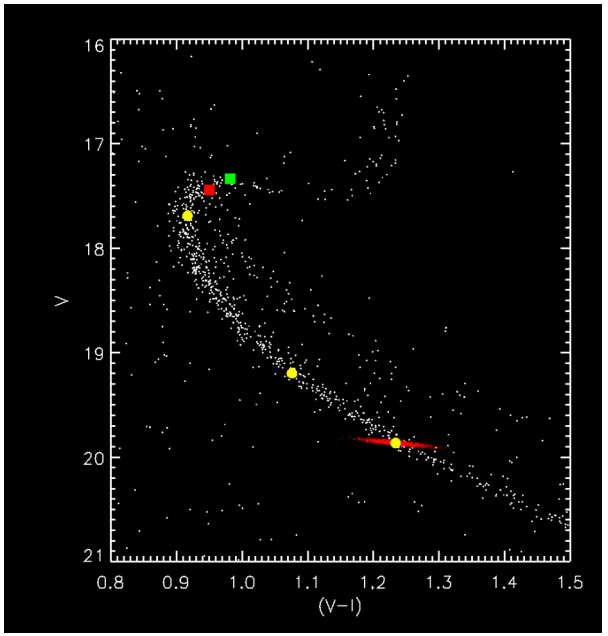
Depth of eclipses

	Primary	Secondary
Mass	**1.079 ± 0.006**	**0.832 ± 0.005**
Radius	**1.420 ± 0.016**	**0.790 ± 0.010**
Log g	**4.167 ± 0.010**	**4.563 ± 0.011**

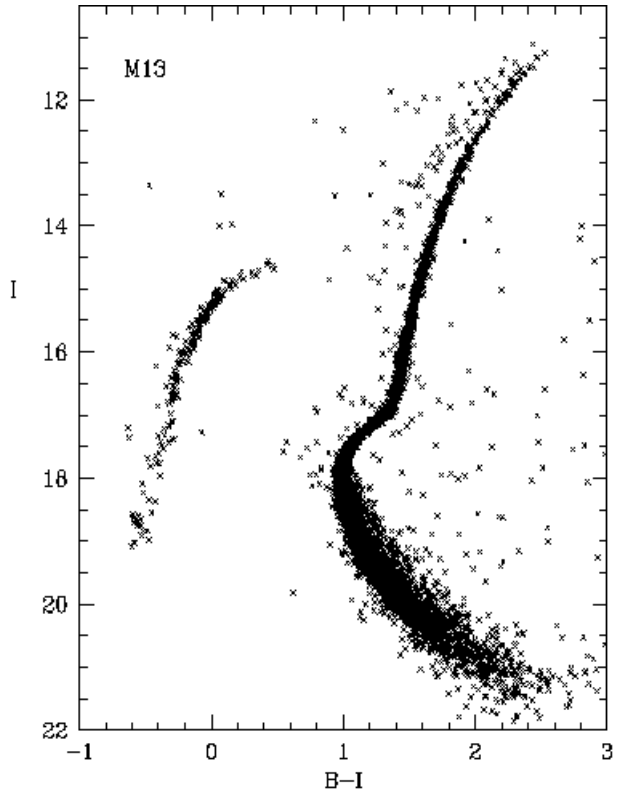

V20 – NGC 6791
Scaled Solar Abundance
[Fe/H] = 0.37
Ages (Gyr): 8.0, 7.5, 7.0
Radius (R⊙)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Mass (M⊙)

3 isokroner, 7.7, 8.2 og 9.0 milliarder år … så samme data, men vidt forskellige aldre!



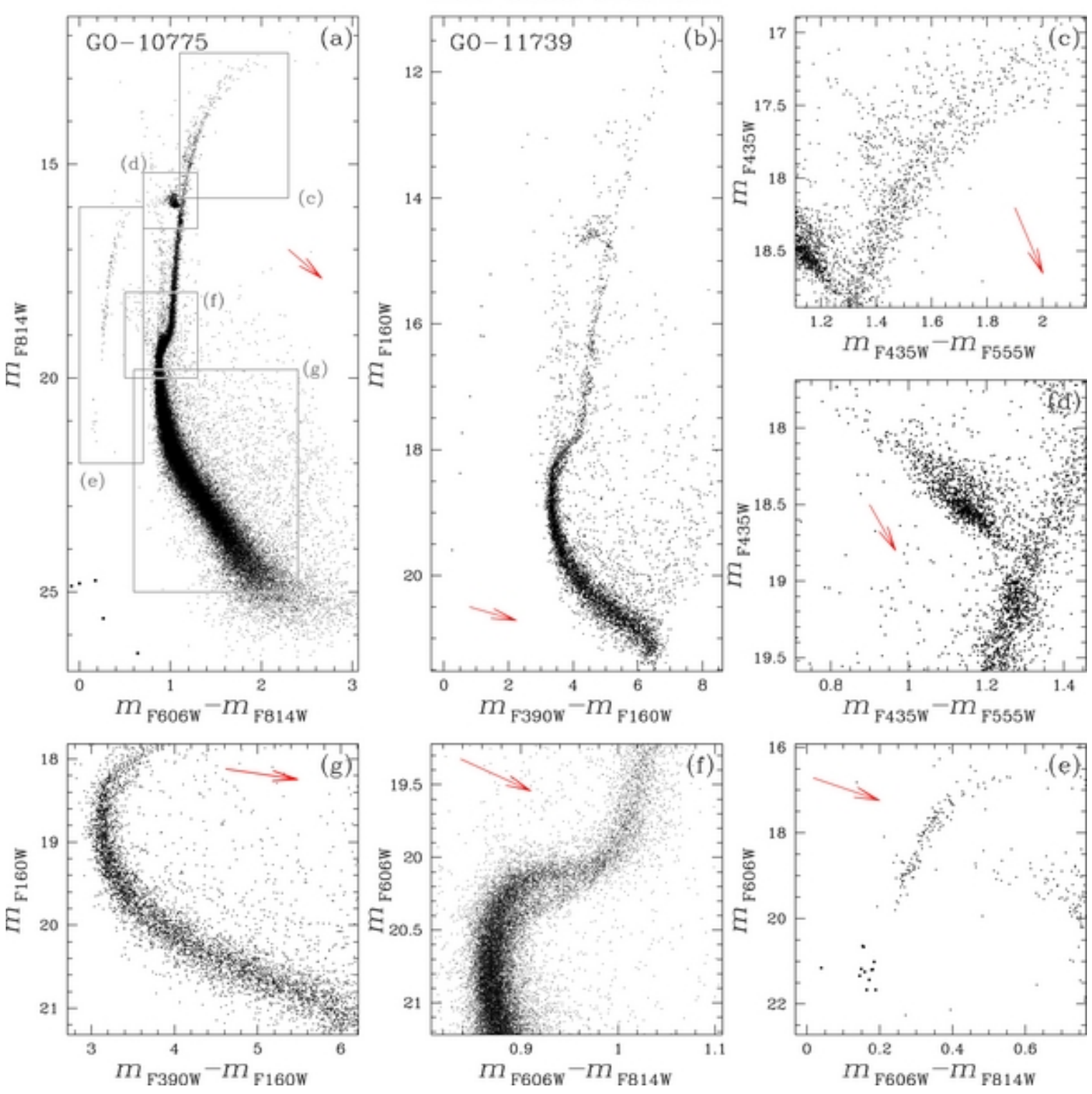


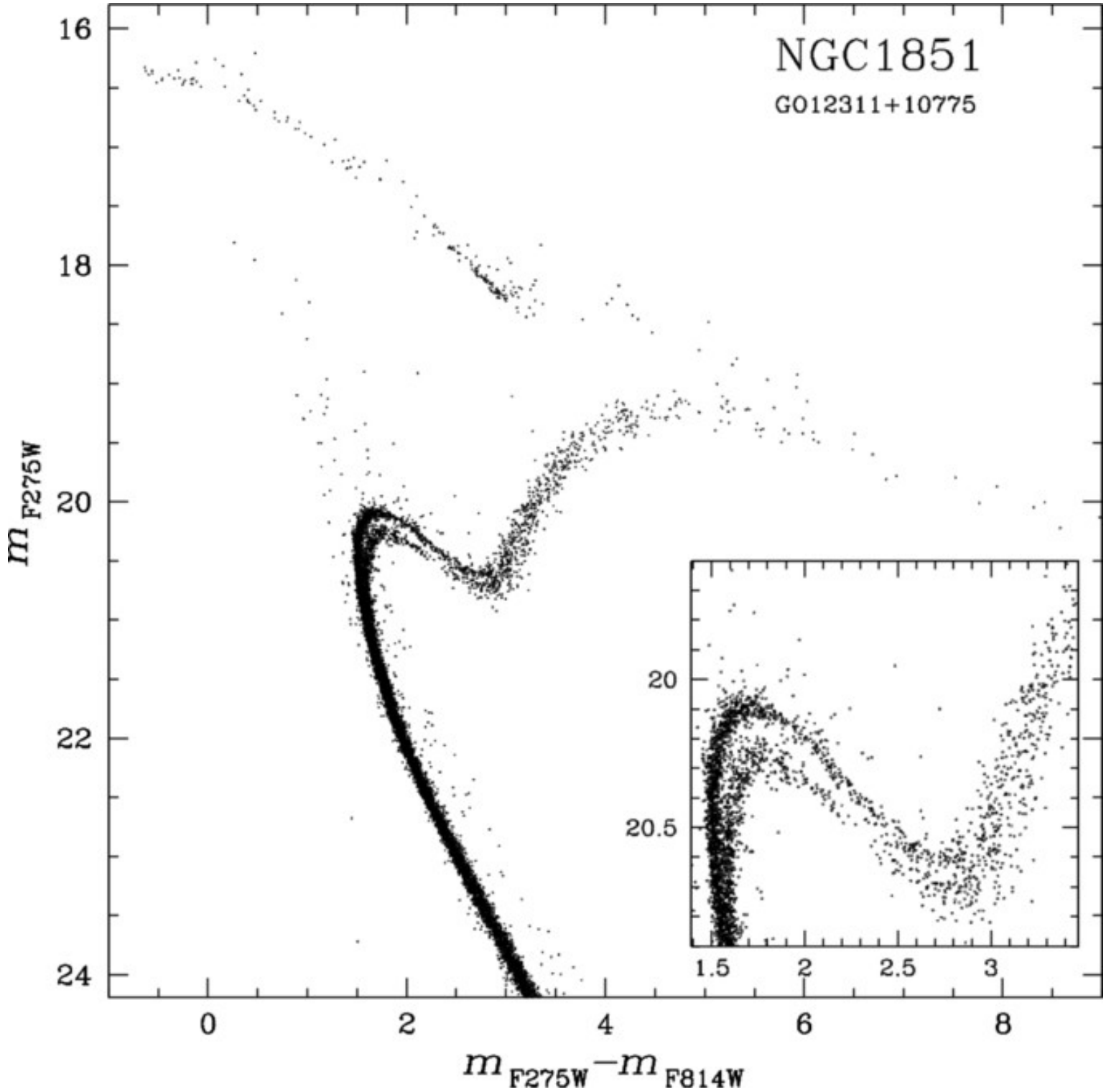
De ældste stjerner brug kuglehobene!



Color-magnitude diagram for 6,624 minimally crowded stars in the field of M13.

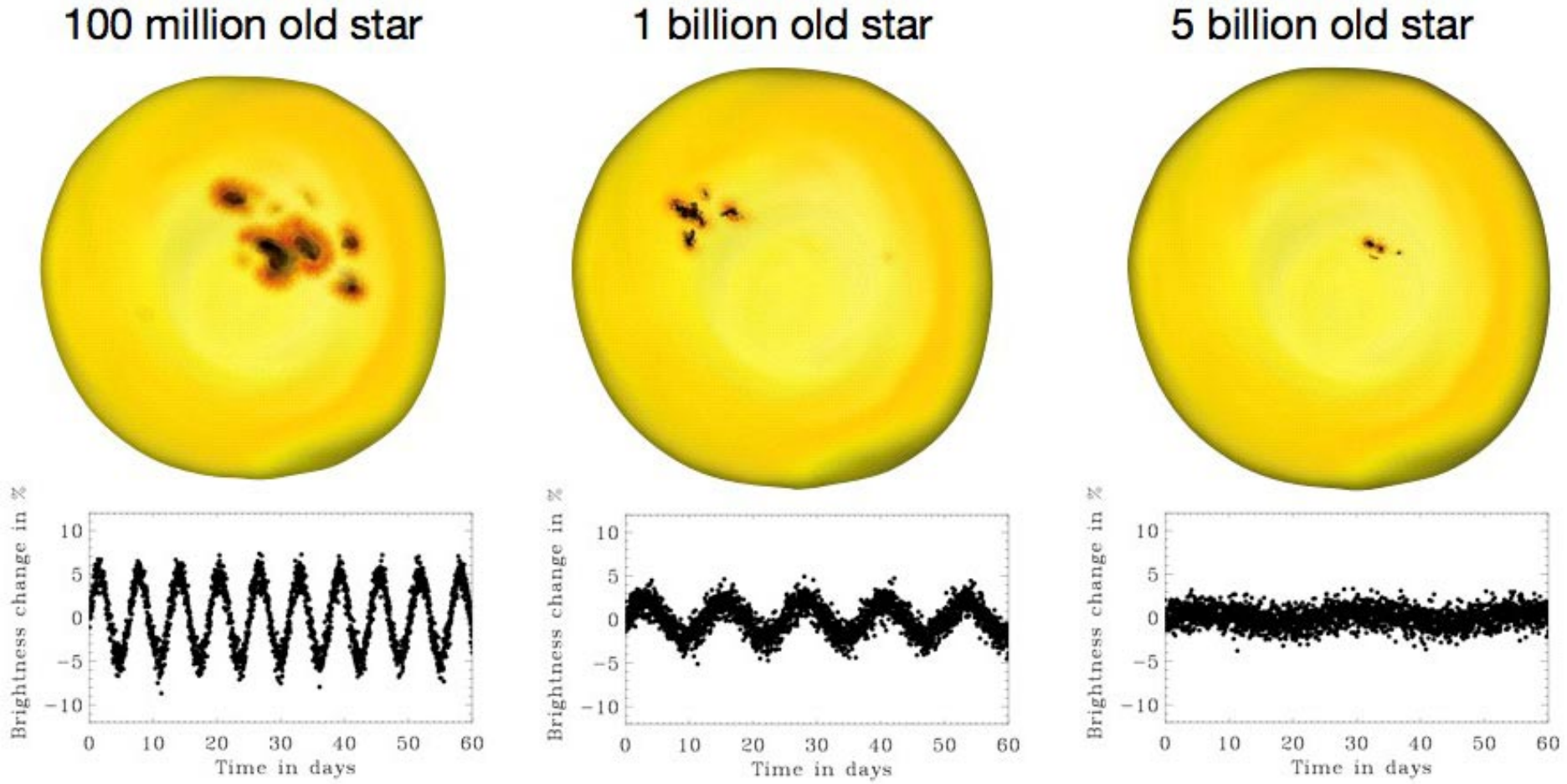
kompliceret … for tingene ændrer sig kun langsomt for gamle stjerner….

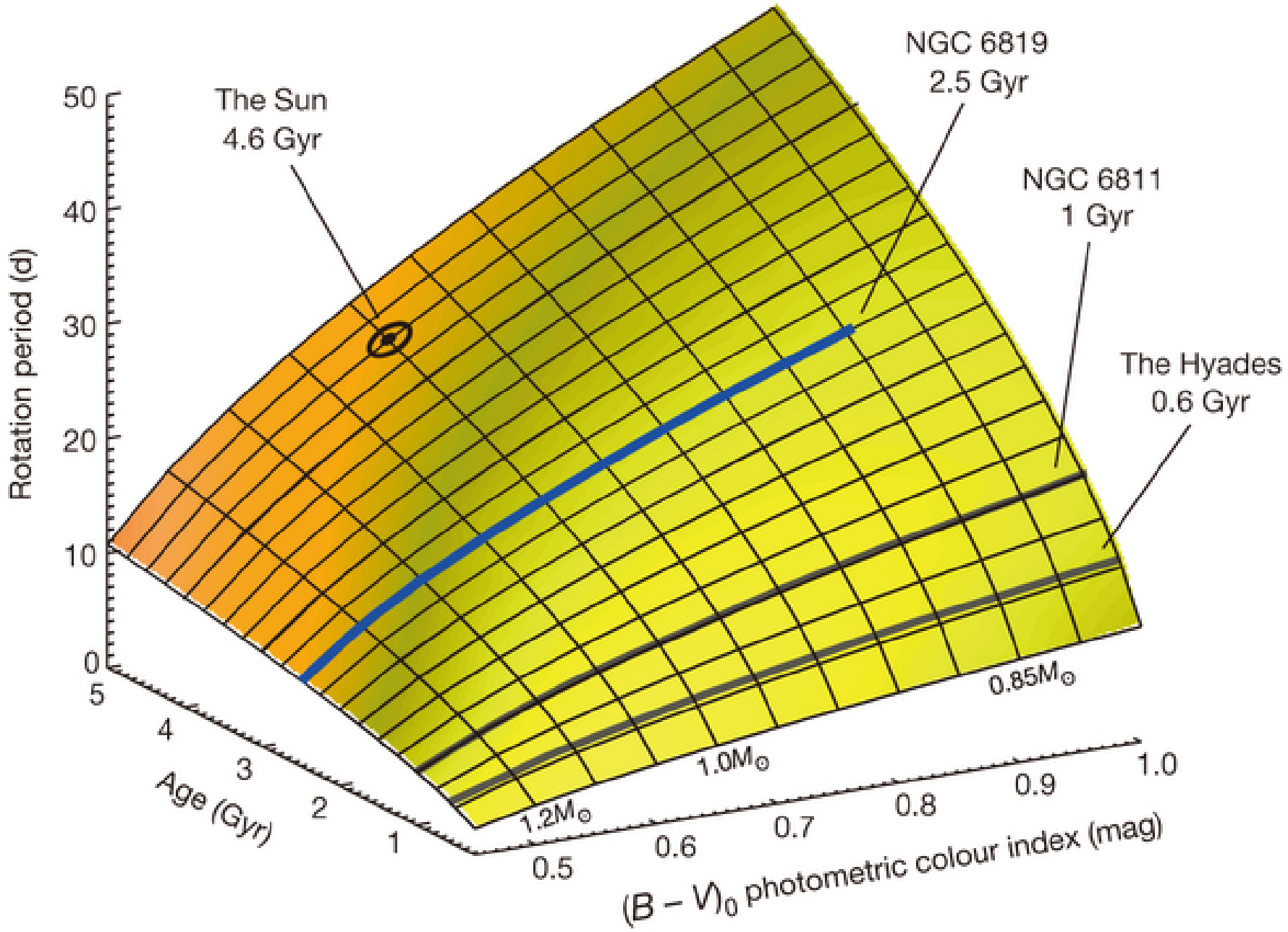

NGC 6388 overview
GO−10775
(a)
(b)
GO−11739
(c)
(d)
(e)
(f)
(g)
m_{F814W}
$m_{F606W}-m_{F814W}$
m_{F160W}
$m_{F390W}-m_{F160W}$
m_{F435W}
$m_{F435W}-m_{F555W}$
m_{F606W}
$m_{F606W}-m_{F814W}$
$m_{F390W}-m_{F160W}$

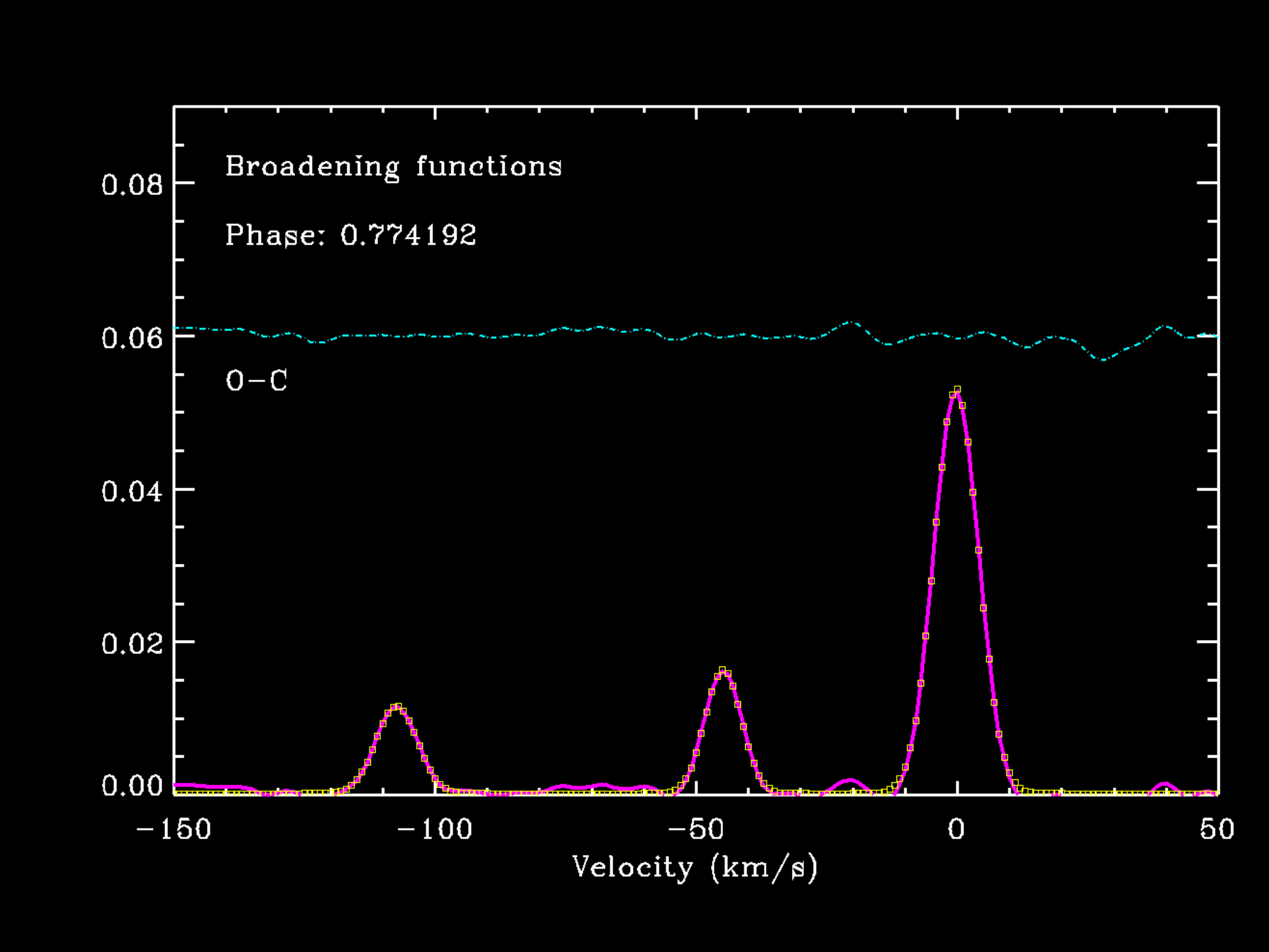

NGC1851
G012311+10775
16
18
20
22
24
m_{F275W}
0
2
4
6
8
$m_{F275W} - m_{F814W}$
20
20.5
1.5
2
2.5
3

Stjerner roterer langsommere når de bliver ældre

Rotations-periode kan måles vha. pletter på overfladen,
som får lysstyrken til at variere.




The Sun
4.6 Gyr
NGC 6819
2.5 Gyr
NGC 6811
1 Gyr
The Hyades
0.6 Gyr
Rotation period (d)
50
40
30
20
10
0
5
4
3
2
1
Age (Gyr)
1.2M⊙
1.0M⊙
0.85M⊙
0.5
0.6
0.7
0.8
0.9
1.0
(B – V)0 photometric colour index (mag)


Broadening functions
Phase: 0.774192
O−C
0.08
0.06
0.04
0.02
0.00
−150
−100
−50
0
50
Velocity (km/s)