Rotating stars in the young open cluster M11

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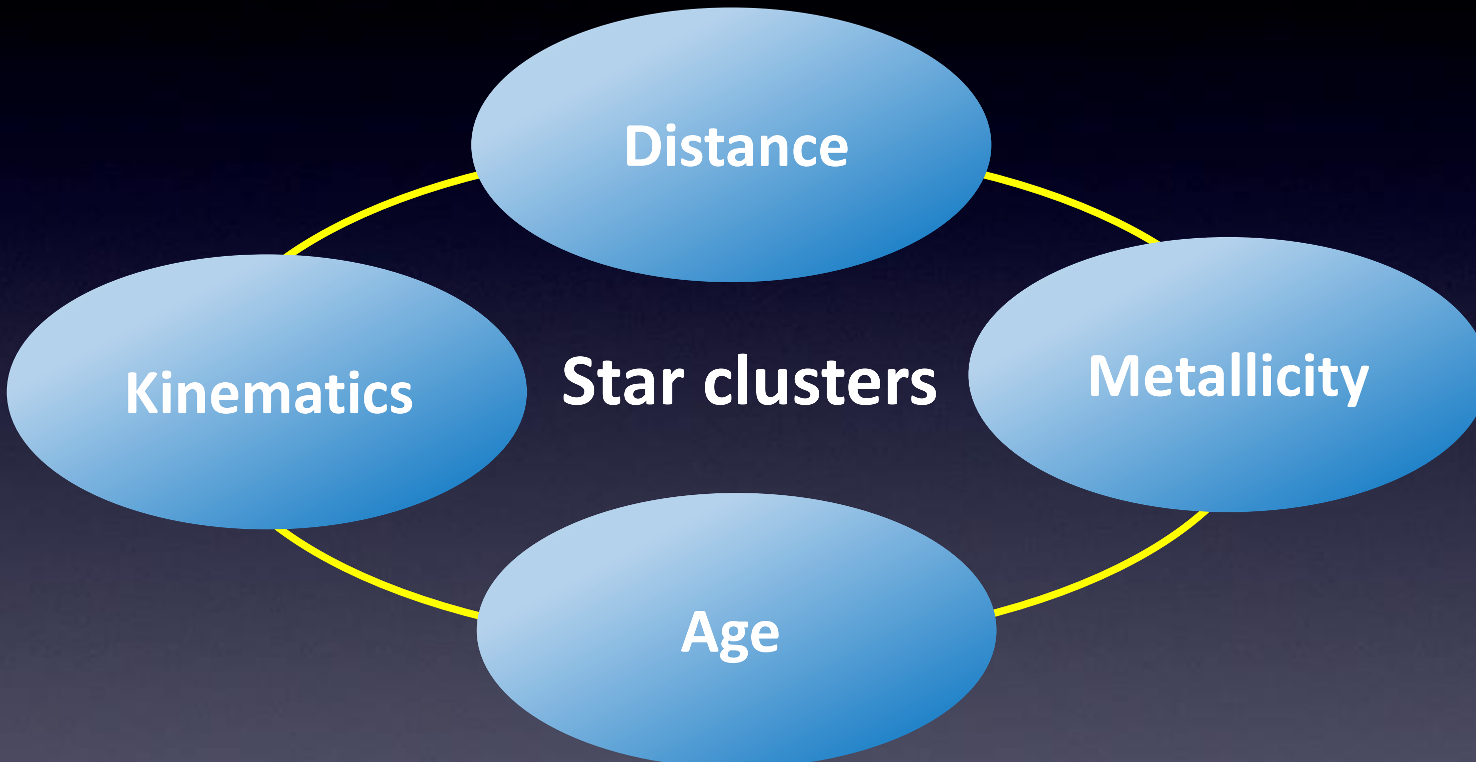
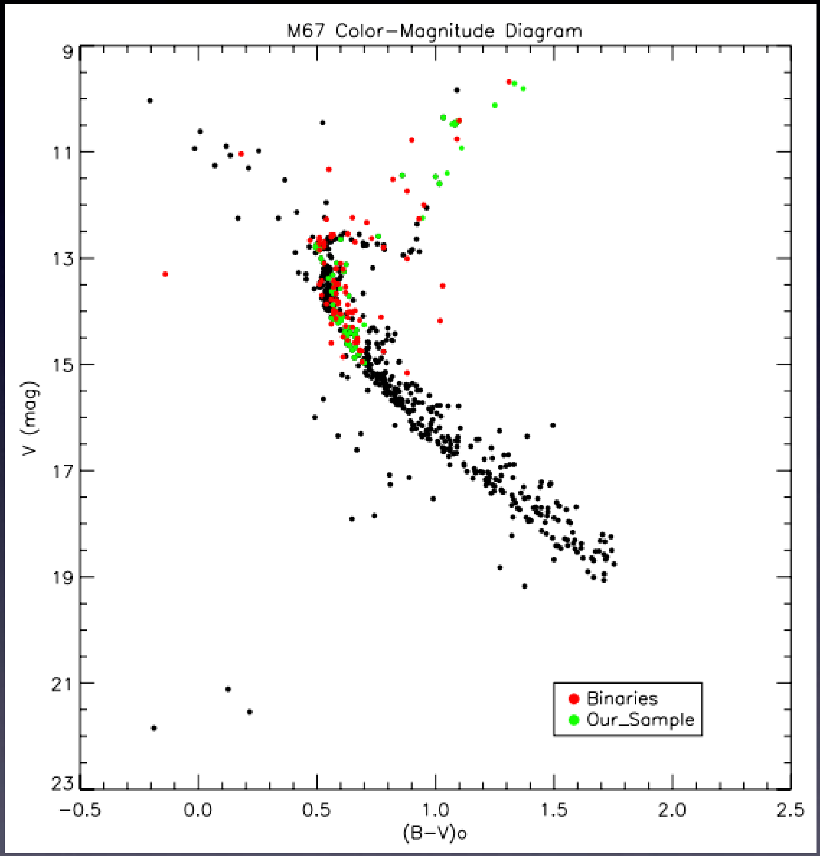
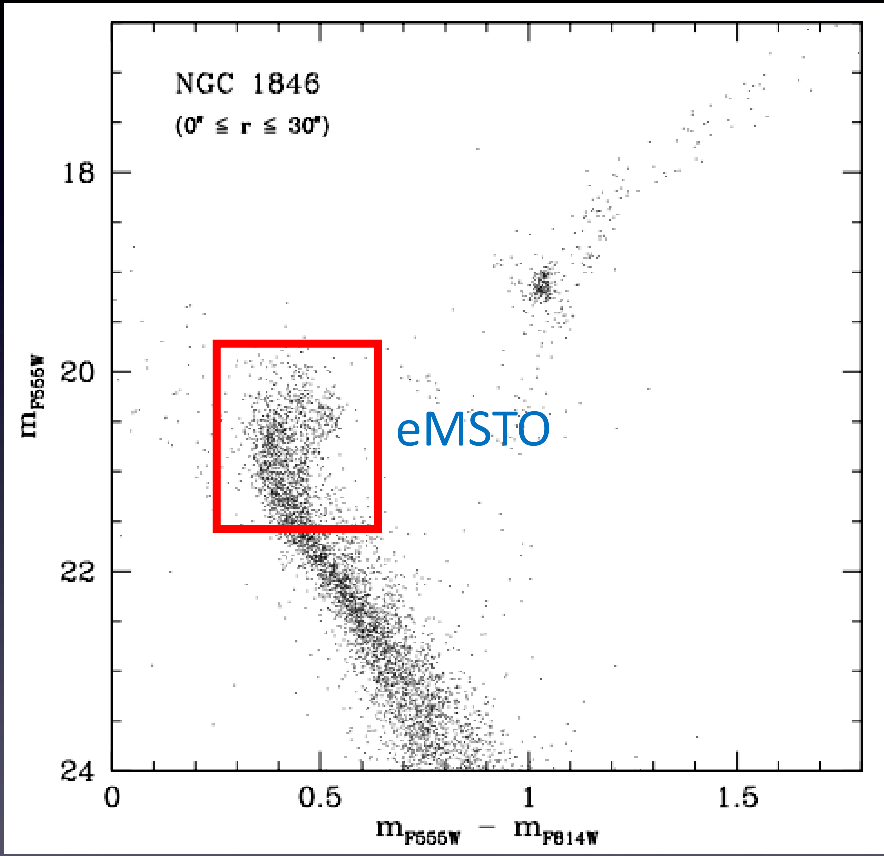

Distance
Kinematics
Star clusters
Metallicity
Age



Pasquini et al. (2012)



Mackey & Nielsen (2007)

Age spread

1st generation

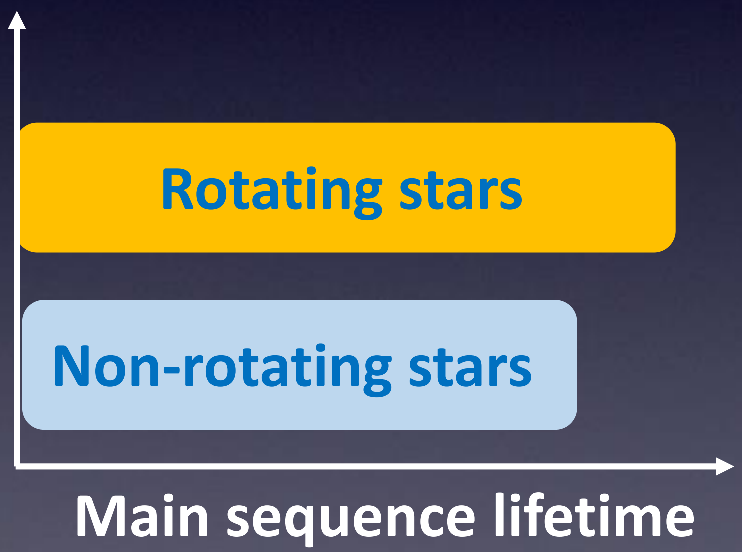
Gas retention

1st + 2nd generations

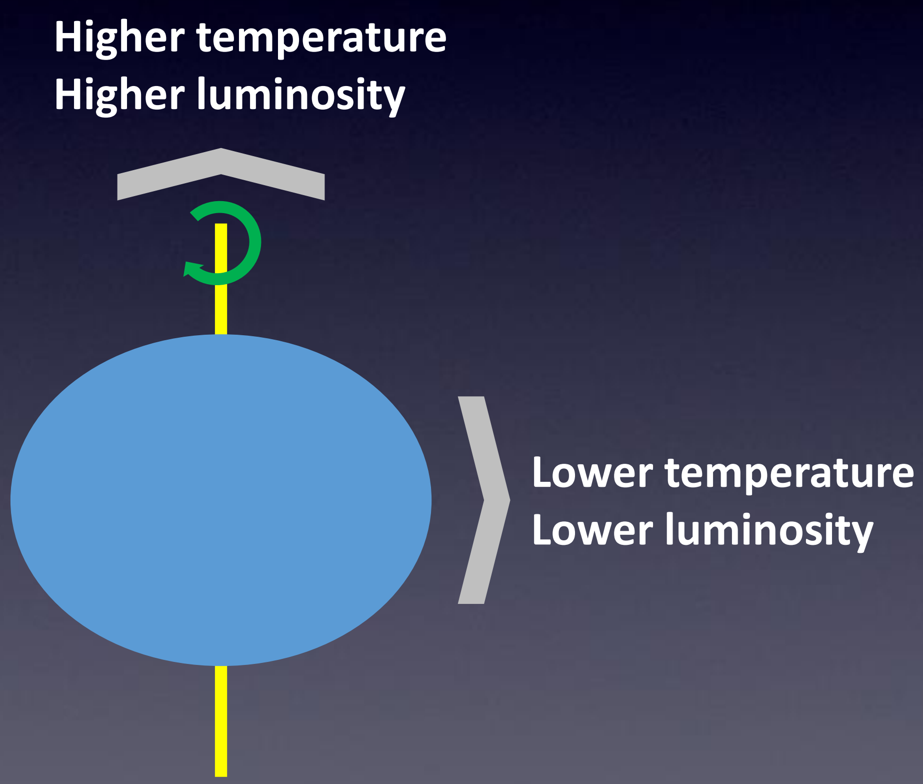
Donors,
Asymptotic Giant Branch stars?

Stellar rotation

I. Rotational mixing



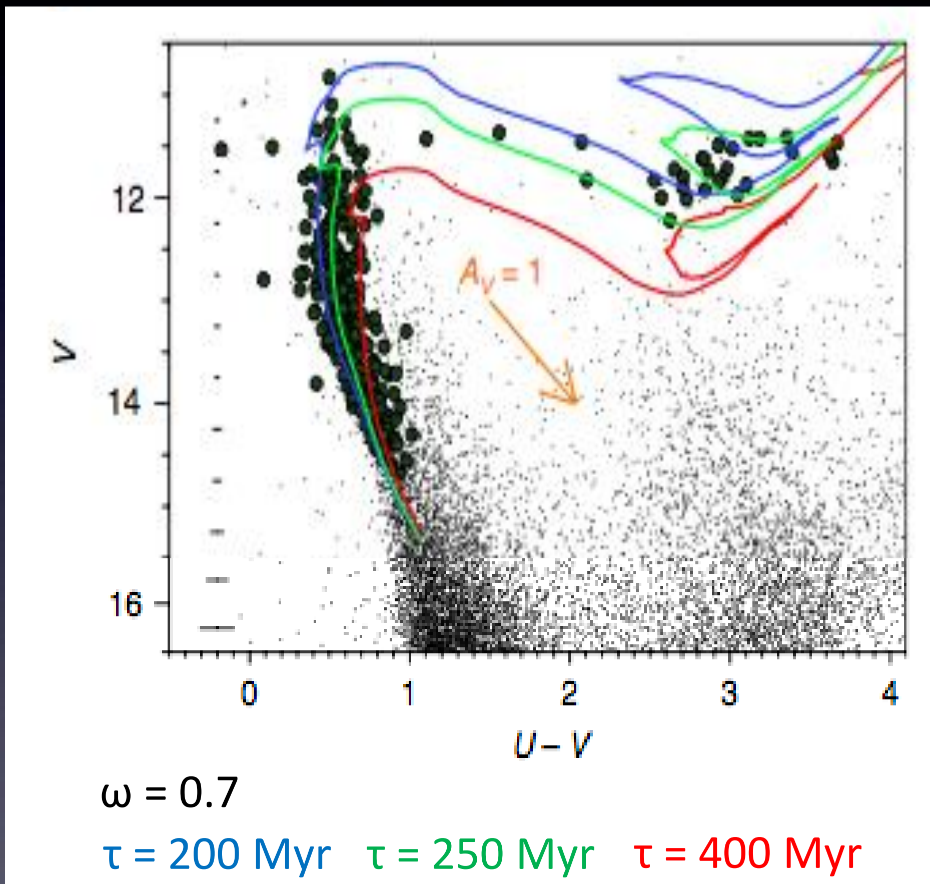
II. Gravity darkening



Distance

Underlying distributions

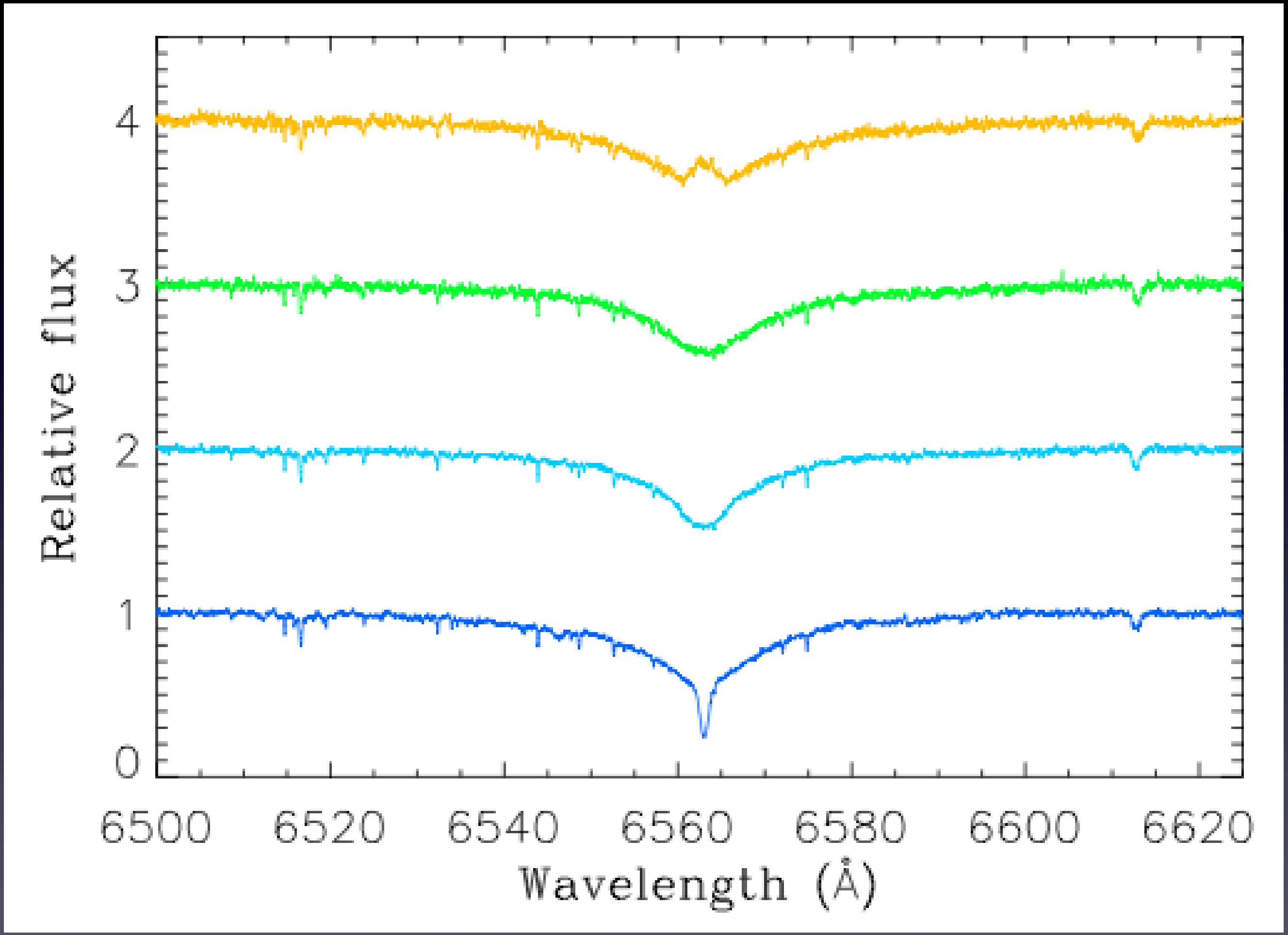
Discovery of eMSTO in Messier 11



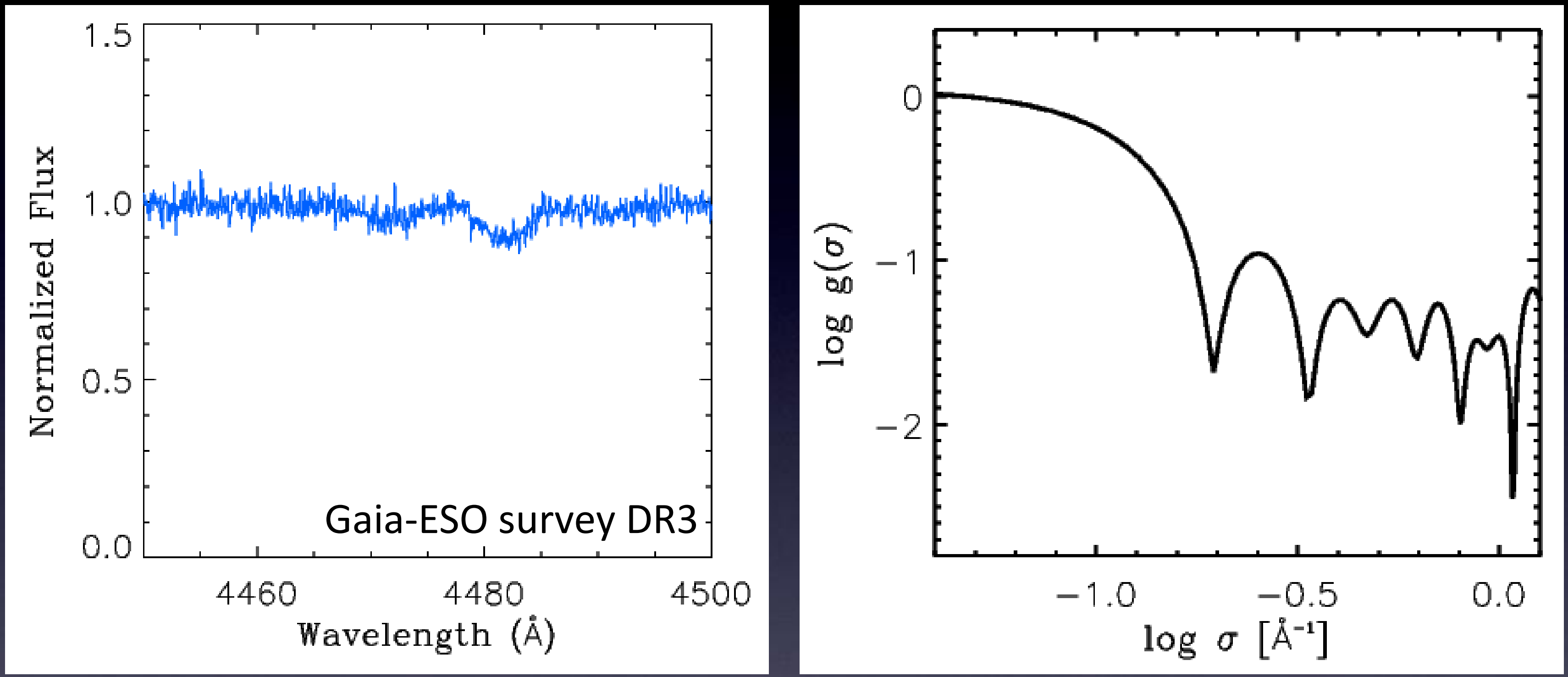
Possible factors

- **Photometric errors** ✗
- **Binary star population** ✗
- **Differential reddening** △

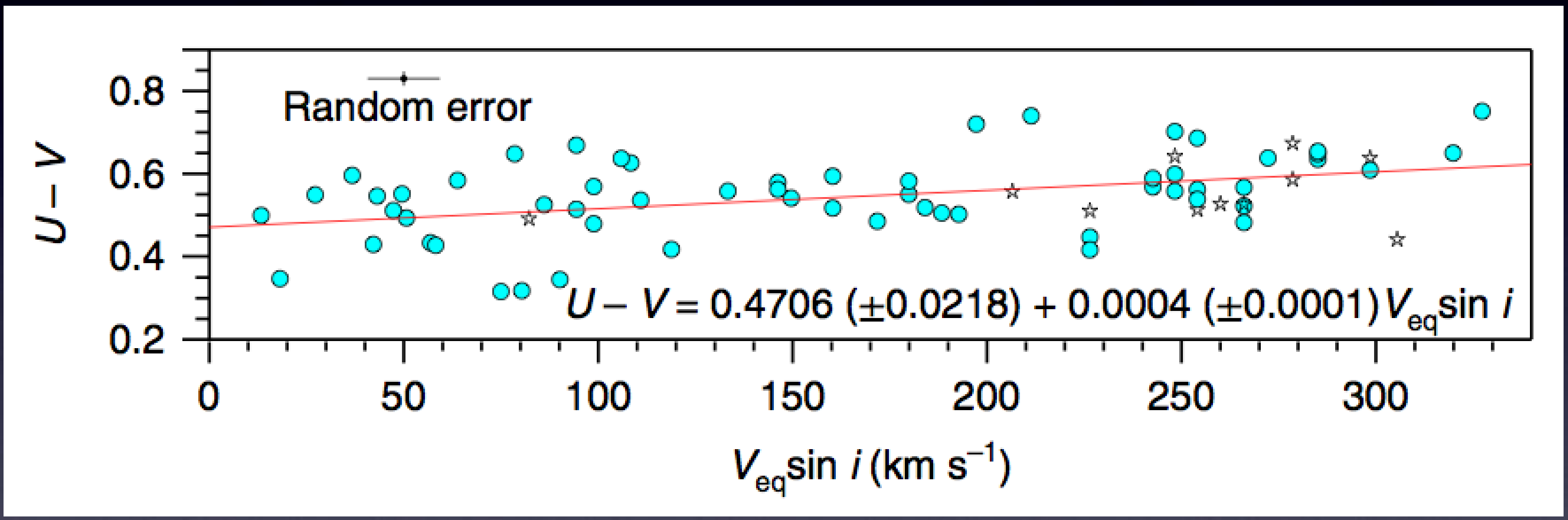
The observed eMSTO is a genuine feature!

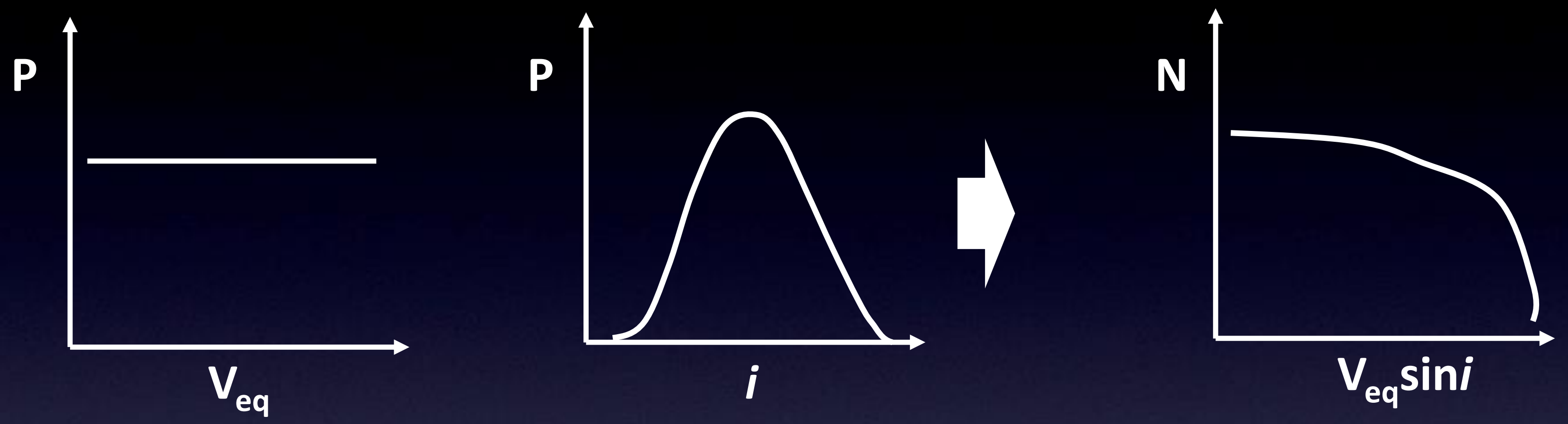


MMT/Hectochelle (2017A)



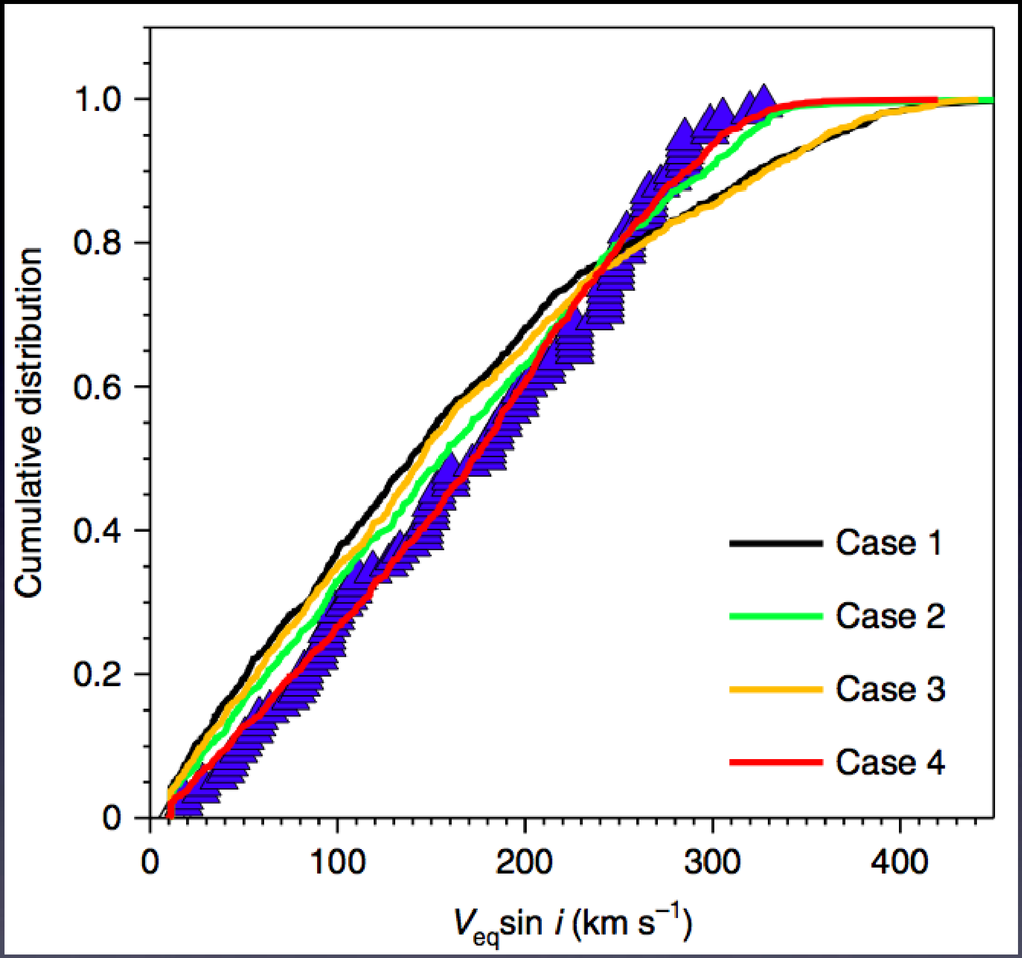
$$\frac{\lambda}{c}\sigma_1 V sin\ i = 0.66, \text{ Gray (2005)}$$


Random error
U − V = 0.4706 (±0.0218) + 0.0004 (±0.0001) V_eq sin i
U − V
0.8
0.6
0.4
0.2
0
50
100
150
200
250
300
V_eq sin i (km s^−1)



Underlying distributions

- Case 1 : uniform dist. of V_{eq} and uniform dist. of i
- Case 2 : uniform dist. of V_{eq} and Gaussian dist. of i
- Case 3 : skewed dist. of V_{eq} and uniform dist. of i
- Case 4 : skewed dist. of V_{eq} and Gaussian dist. of i



Case 1 : 6.2 ± 4.0 %

Case 2 : 42.1 ± 13.2 %
(Best-fit i_{peak} = 54 ± 1°)

Case 3 : 10.7 ± 4.6 %

Case 4 : 74.1 ± 12.8 %
(Best-fit i_{peak} = 50 ± 2°)

Simple stellar population model

V_{eq} i mass

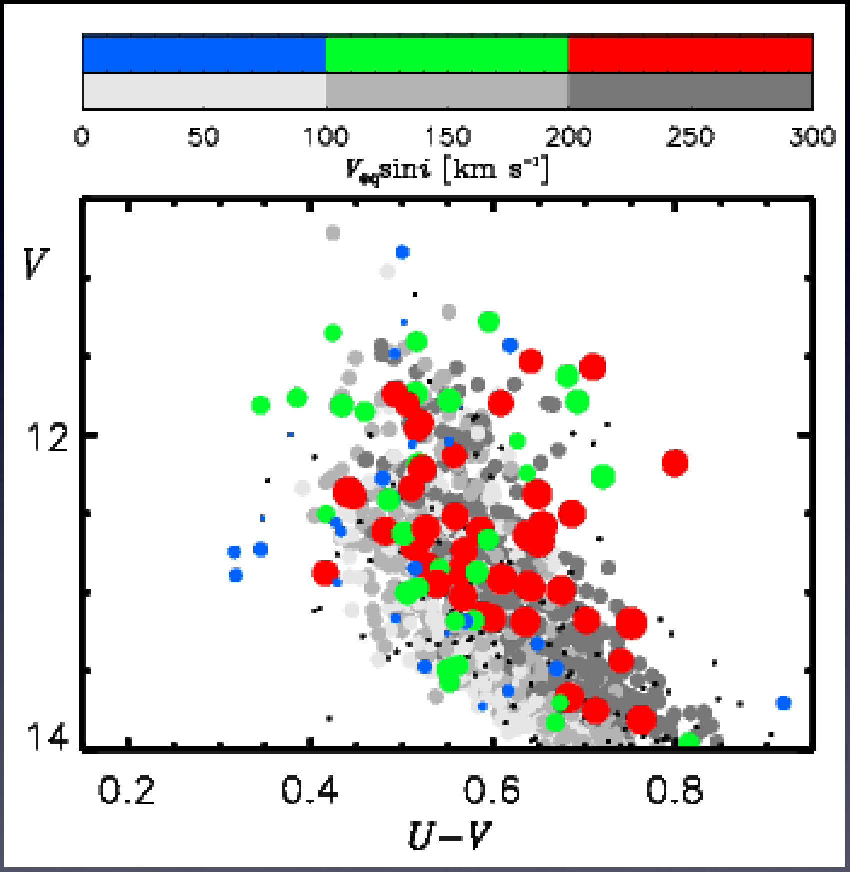
Stellar evolution model

Gravity darkening

T_{eff} and L_{bol}

Differential reddening

Color and V mag




A simple stellar population
Stellar rotation

LETTERS
https://doi.org/10.1038/s41550-018-0619-5

nature astronomy

Extended main sequence turn-off originating from a broad range of stellar rotational velocities

Beomdu Lim[1,2,3]*, Gregor Rauw[1], Yaël Nazé[1], Hwankyung Sung[2], Narae Hwang[4] and Byeong-Gon Park[4,5]

Star clusters have long been considered to comprise a simple stellar population, but this paradigm is being challenged, since in addition to multiple populations in Galactic globular clusters[1], a number of younger star clusters exhibit a significant colour spread at the main sequence turn-off[2–9]. A sequential evolution of multiple generations of stars formed over 100–200 Myr is a natural explanation of this colour spread[10]. Another approach to explain this feature is to introduce the effect of stellar rotation[11]. However, its effectiveness has not yet been proven due to the lack of direct measurements of rotational velocities. Here, we report the distribution of projected rotational velocities ($V_{eq}\sin i$) of stars in the Galactic open cluster M11, measured by Fourier transform analysis. Cluster members display a broad $V_{eq}\sin i$ distribution, and fast rotators, including Be stars, have redder colours than slow rotators. Monte Carlo simulations infer that cluster members have highly aligned spin axes and a broad distribution of equatorial velocities biased towards high velocities. Our synthetic cluster simulation further demonstrates how stellar rotation affects the colours of cluster members, suggesting that the colour spread observed in populous clusters can be understood in the context of stellar evolution without introducing multiple stellar populations.

STAR CLUSTERS

Stars in M11 Hide Their True Colors

THE WILD DUCK CLUSTER — or Messier 11 (M11) — is one of the most enticing telescopic sights in the summer. There are some 2,900 stars here, a rich assemblage of suns that for some resembles a flock of ducks in flight. Astronomers have long believed that all the stars in an open cluster such as M11 were born in a single generation and therefore should be close in age. But the Wild Duck presents a mystery. Stars of similar brightness (and presumably similar mass and, thus, evolutionary stage) display different colors, which are generally a good indicator of age.

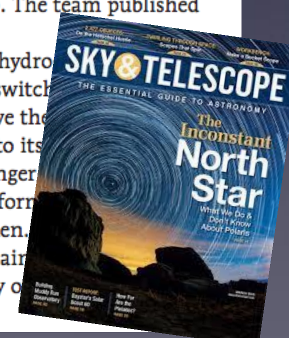
To get to the bottom of this mystery, Beomdu Lim (Kyung Hee University, South Korea) and colleagues examined the spectra of stars in M11. To their surprise, it isn't the stars' ages that cause the spectral variety but their rotation. Spectra revealed that the stars are spinning at different rates. This range of spins leads to differences in star color and ultimately stellar lifetimes.

"The effects of rotation on stellar evolution were often neglected in the past," says study co-author Yaël Nazé (University of Liège, Belgium). The team published their findings November 5th in *Nature Astronomy*.

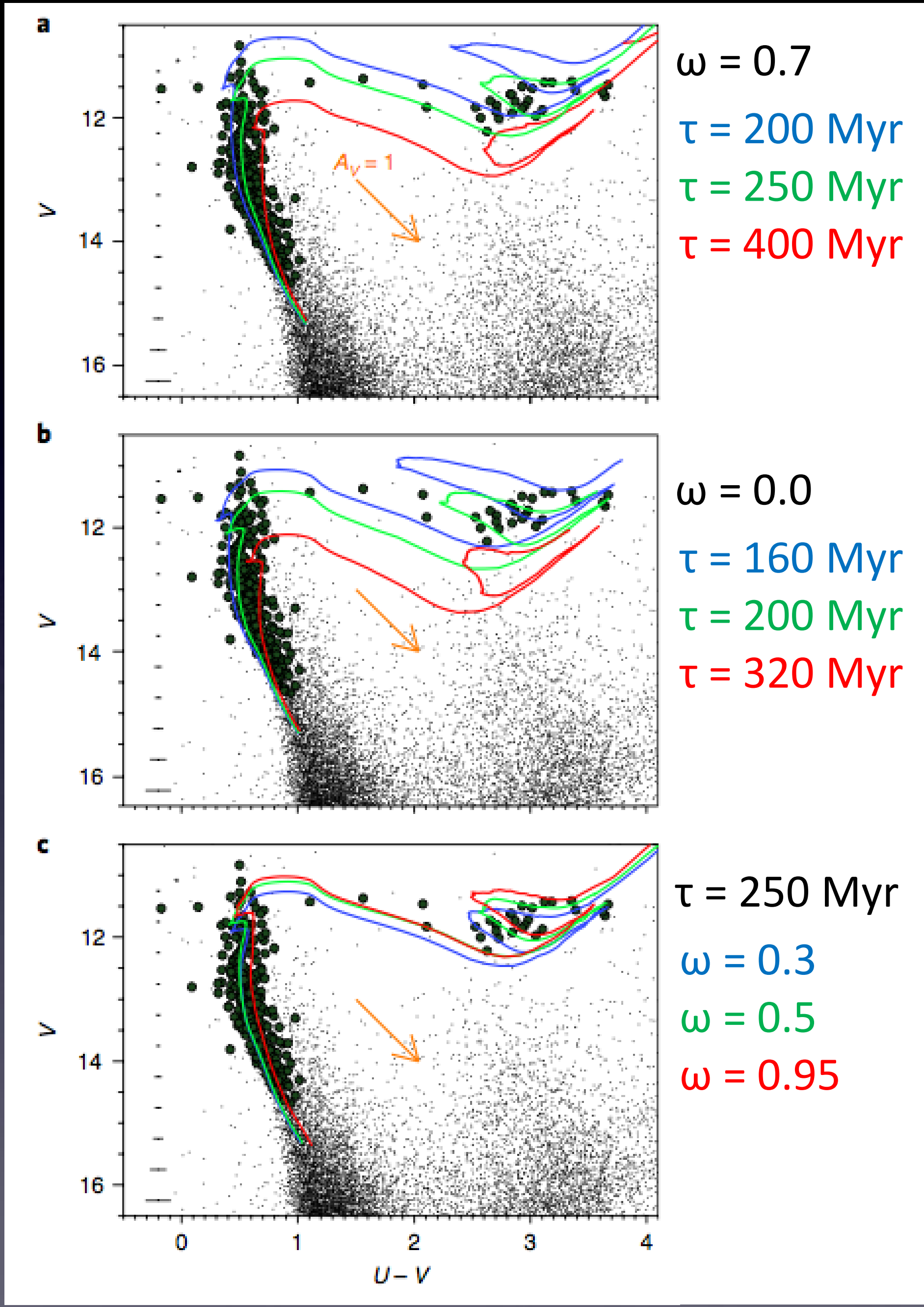
Most of a star's life is spent on the *main sequence* burning hydro (see page 14). When its core hydrogen is exhausted, the star switch and burning strategies, causing it to expand, redden, and leave th

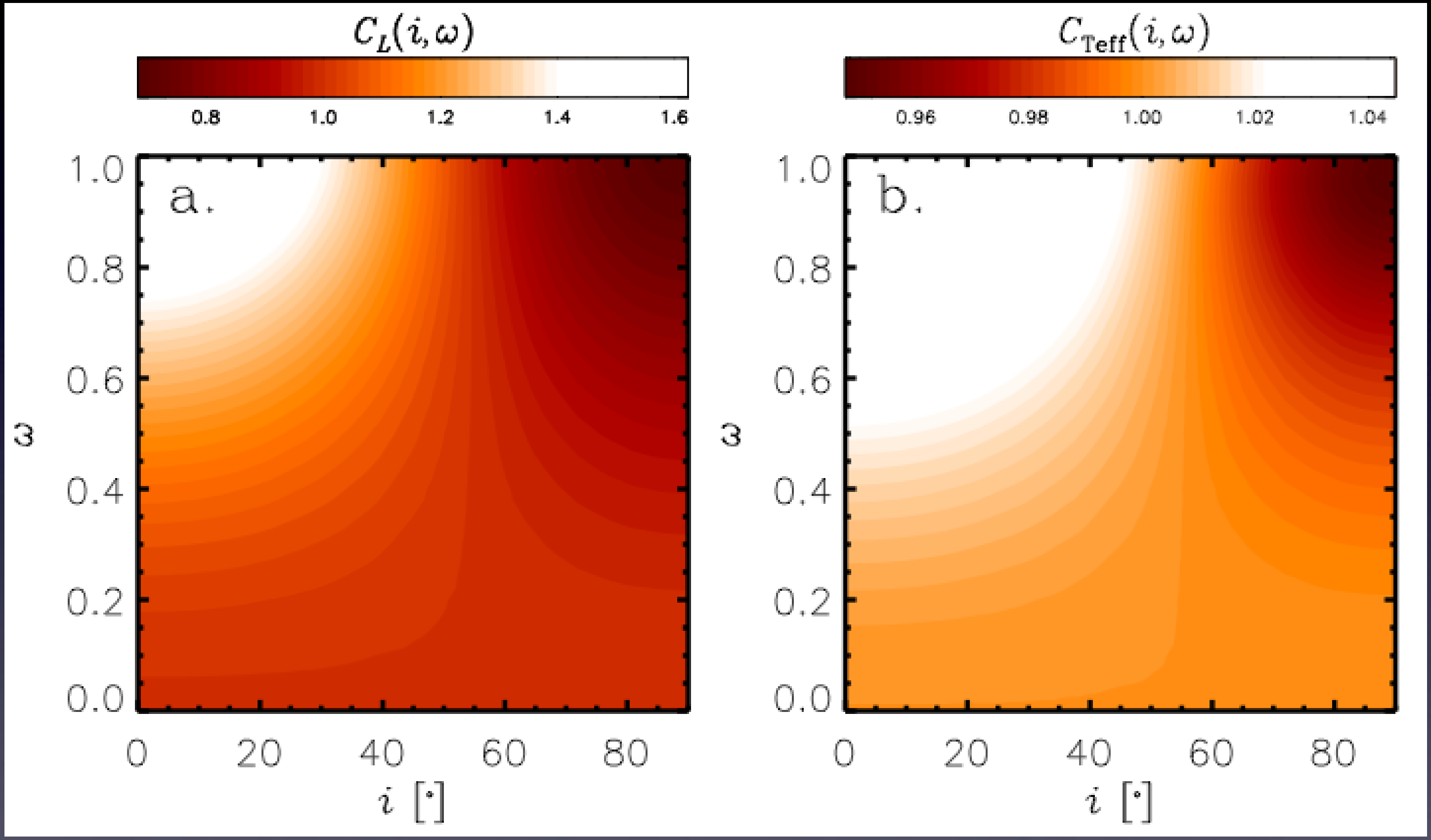
But the faster a star spins, the better it mixes hydrogen into its longer it can remain on the main sequence — 15% to 62% longer slower-rotating cousins of similar mass. Fast rotation also defor As its diameter expands, the equatorial regions cool and redden. appear redder than slow rotators while still basking on the mair Wild Duck Cluster mimics two stellar populations when only o

■ BOB KING

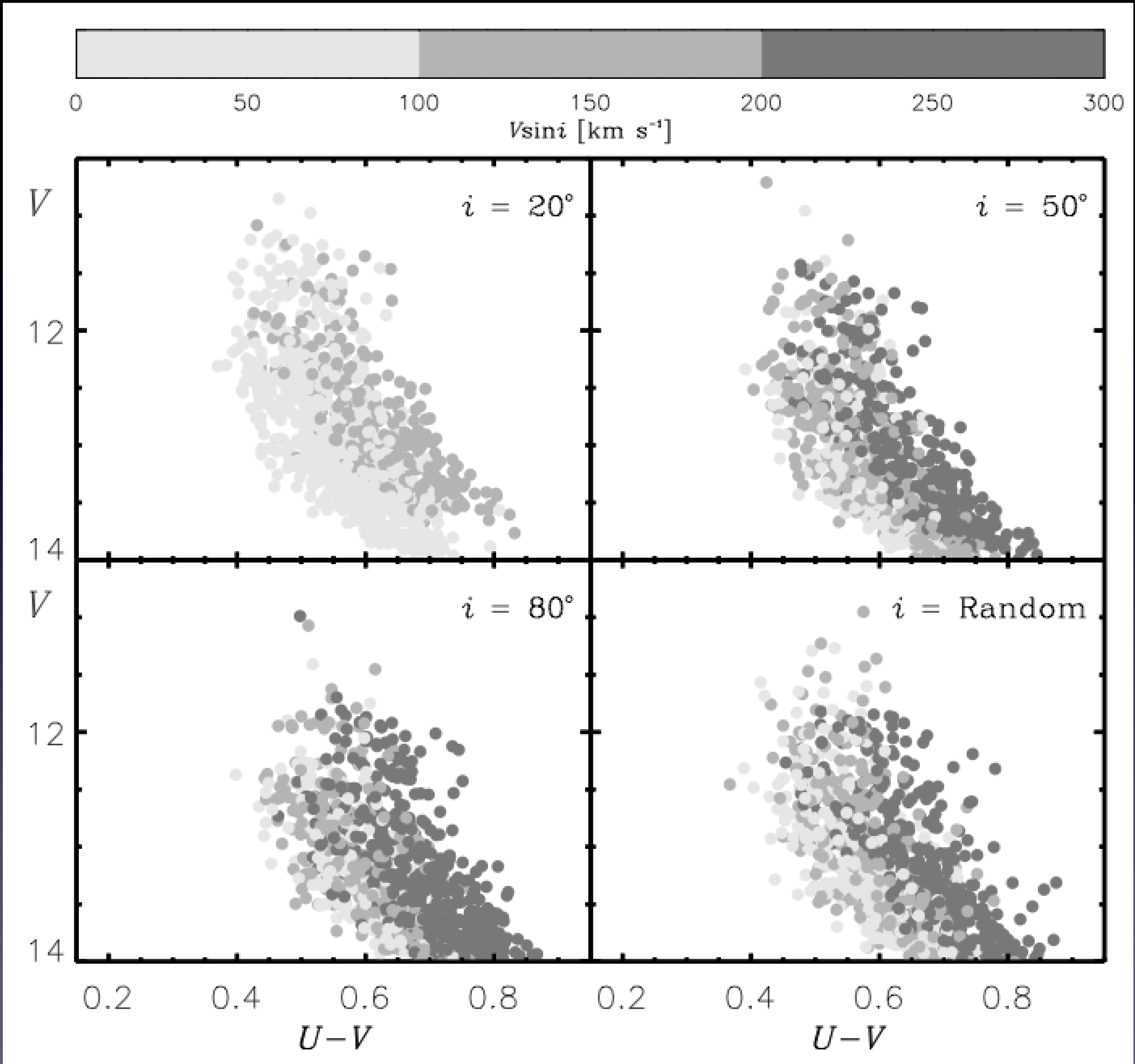


Thank you!


a
b
c
V
U − V
$A_V = 1$
ω = 0.7
τ = 200 Myr
τ = 250 Myr
τ = 400 Myr
ω = 0.0
τ = 160 Myr
τ = 200 Myr
τ = 320 Myr
τ = 250 Myr
ω = 0.3
ω = 0.5
ω = 0.95



$C_L(i,\omega)$
0.8
1.0
1.2
1.4
1.6
a.
1.0
0.8
0.6
0.4
0.2
0.0
ω
0
20
40
60
80
i [°]
$C_{\rm Teff}(i,\omega)$
0.96
0.98
1.00
1.02
1.04
b.
1.0
0.8
0.6
0.4
0.2
0.0
ω
0
20
40
60
80
i [°]


0
50
100
150
200
250
300
Vsini [km s⁻¹]
i = 20°
i = 50°
i = 80°
i = Random
V
12
14
0.2
0.4
0.6
0.8
U−V