Red Clump Stars, Stellar Twins, and the Prospects of Chemical Cartography with Gaia

Ignace Gaston Pardies, Star Map Plate 2: Cetus, Aquarius, Andromeda. etc, Paris, 1693

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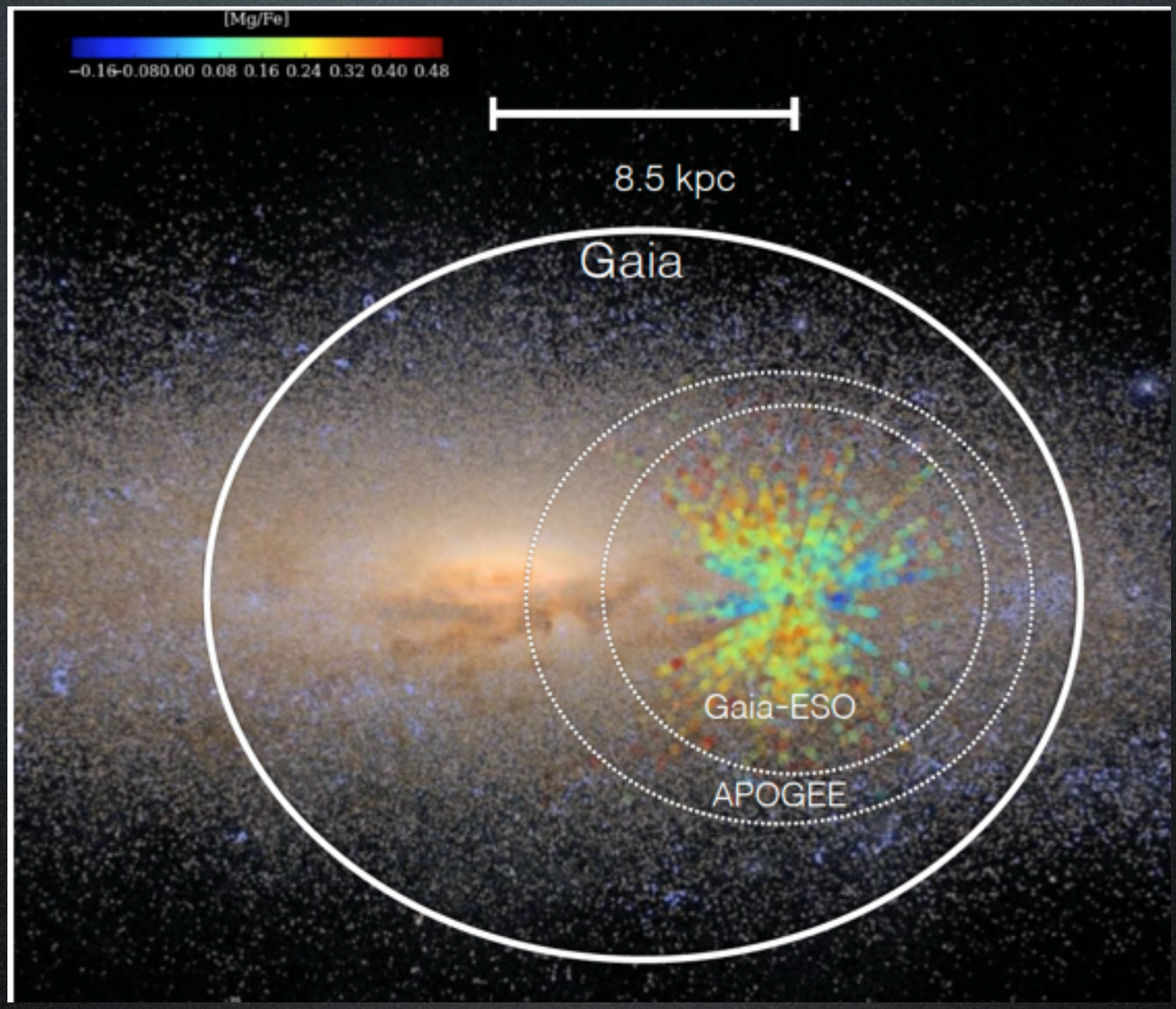
A Vision of Chemical Cartography



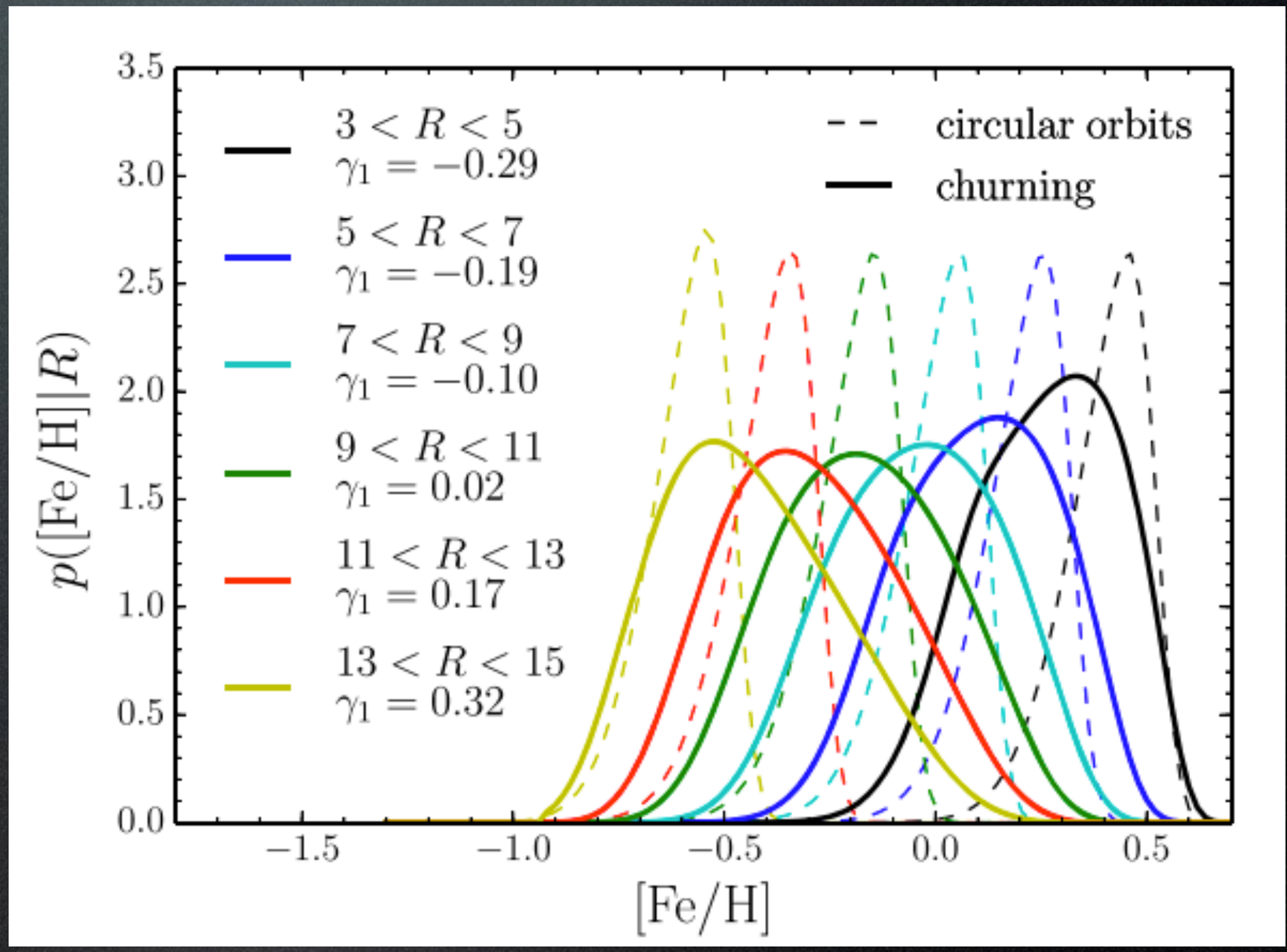
[Mg/Fe] as a function of spatial position in Gaia-ESO

Adapted from Greg Stinson and Maria Bergemann.

Ingredients : chemical abundances, Distances, sky positions, ages?

What can cartography tell us

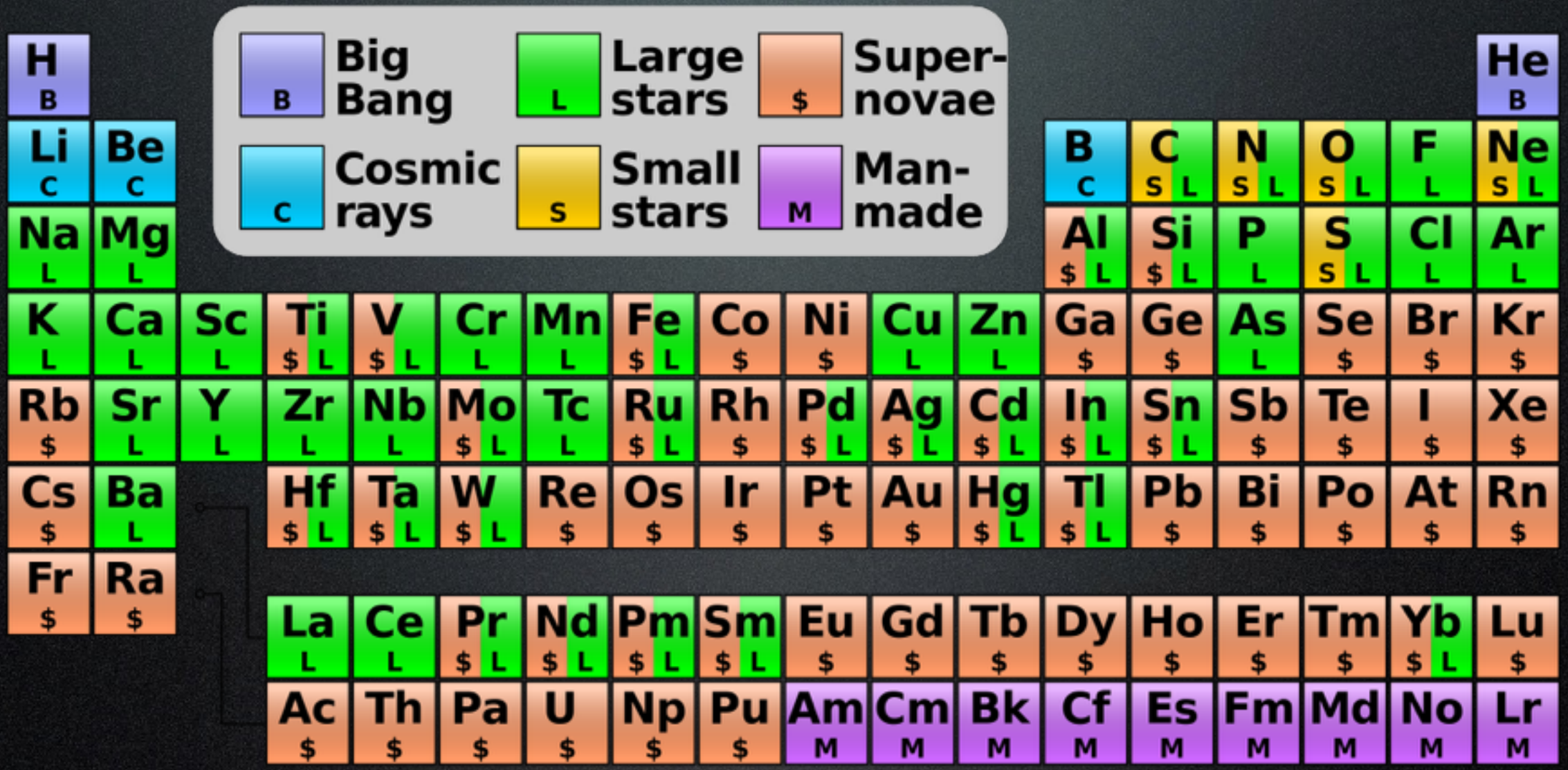
- chemical history across the galaxy
- chemical substructure
- Radial migration



Hayden+2015

Note: This (and many Galactic structure) work(s) made use of Red Clump Stars

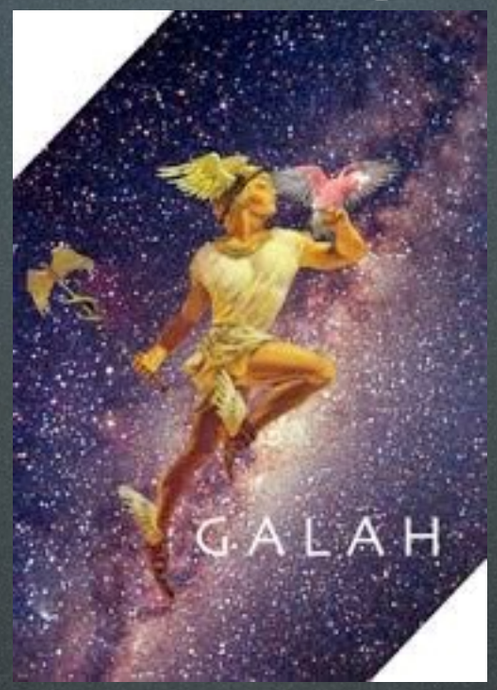
Ingredient 1: chemical abundances



credit: commons.wikimedia.org

The Era of Large Surveys

N ~ 100,000
25+ elements
2012—



N ~ 1,000,000
15+ elements
2014—

N ~ 10,000,000
18+? elements
2021-2026?

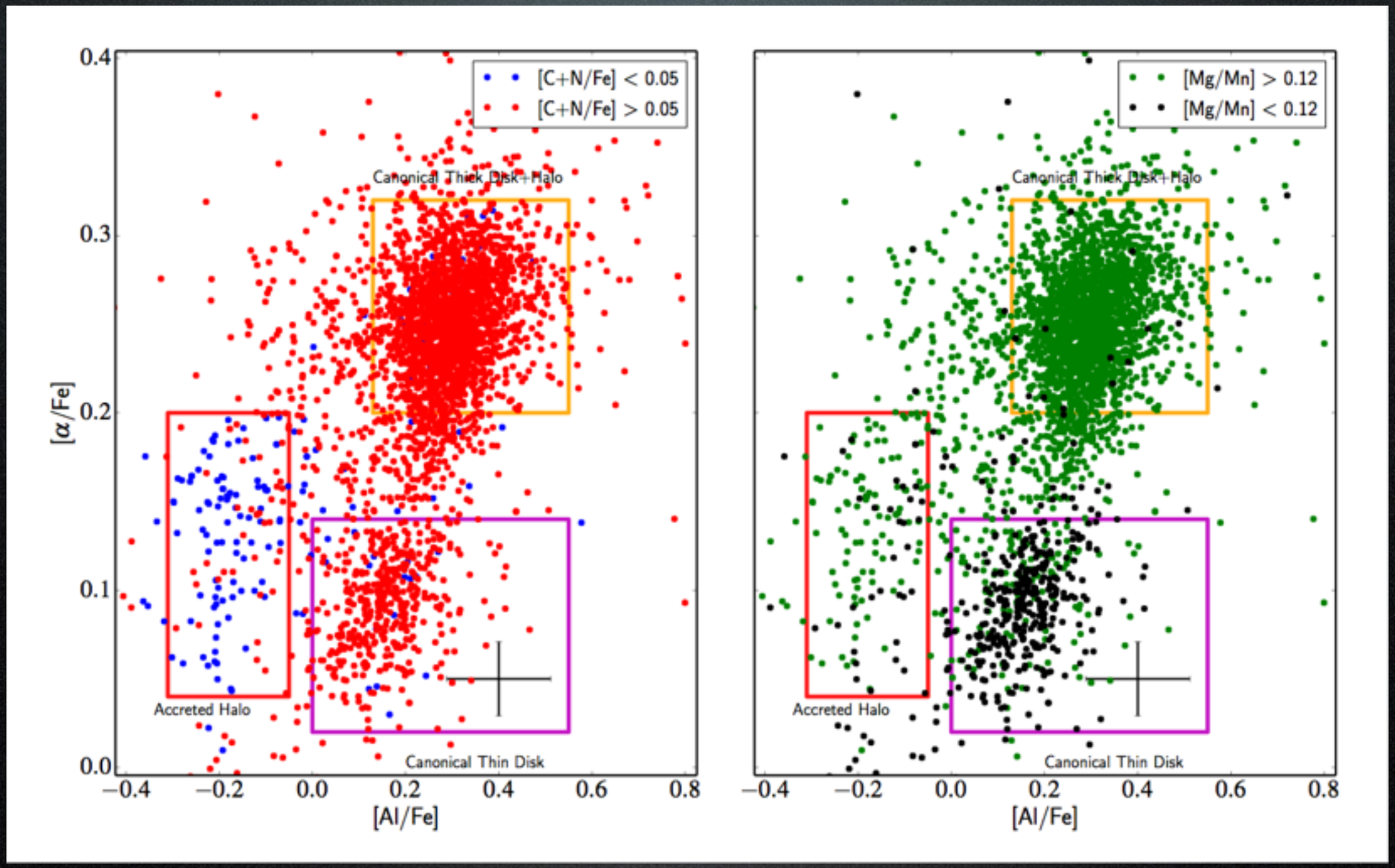
N ~ 100,000
15 (20*+) elements
2008—

N ~ 483,000
8+ elements
2003-2013

Chemical ‘Labeling’

Galactic components ‘cluster’ in chemical space!

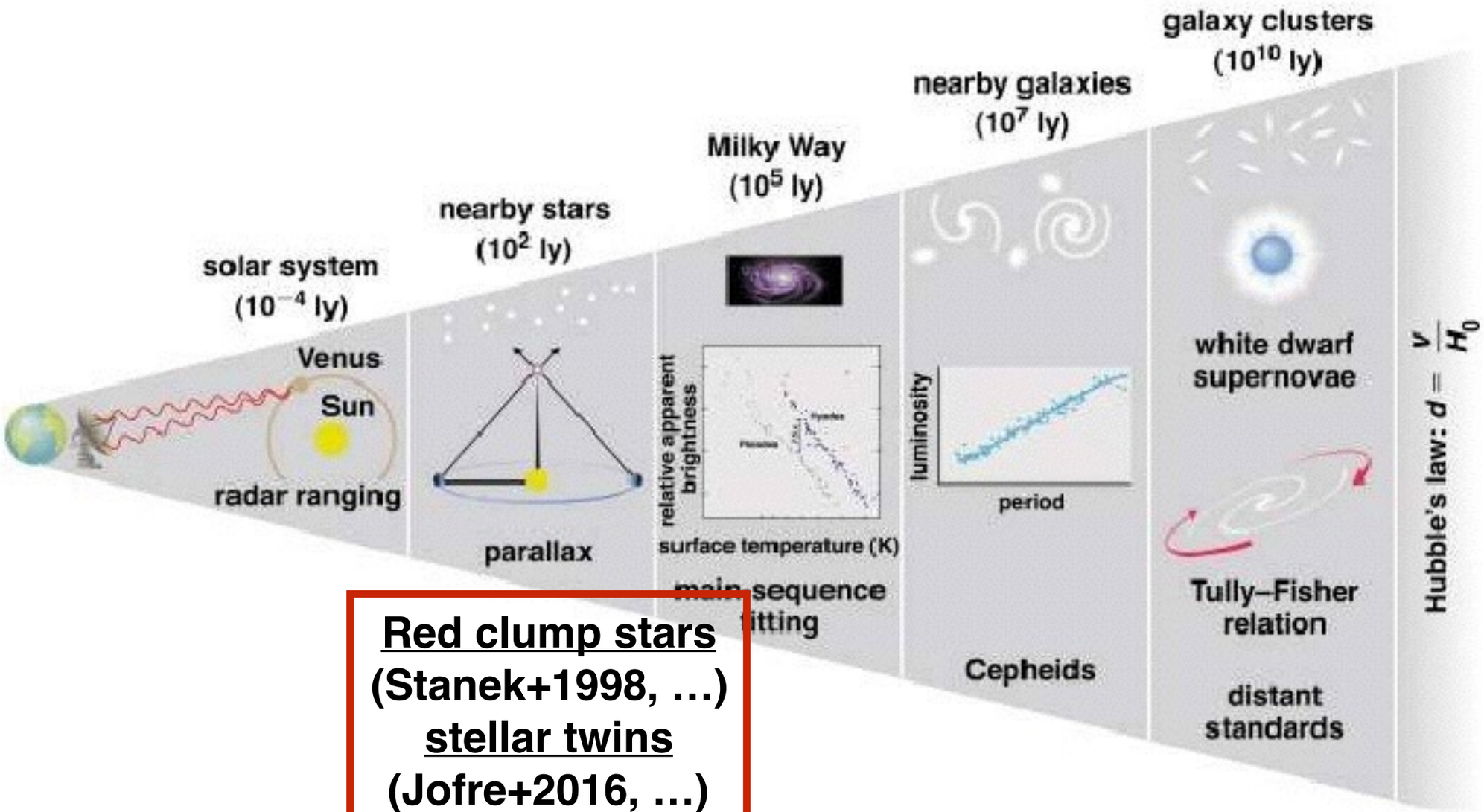
(cartography is the next step —> need distances)



R. Wyse Talk, Hawkins+ 2015b; see also Hogg+2016, Blanco-Carisma +2016, Lambert+2017, Ness+2017; and many others

Ingredient 2: Distances

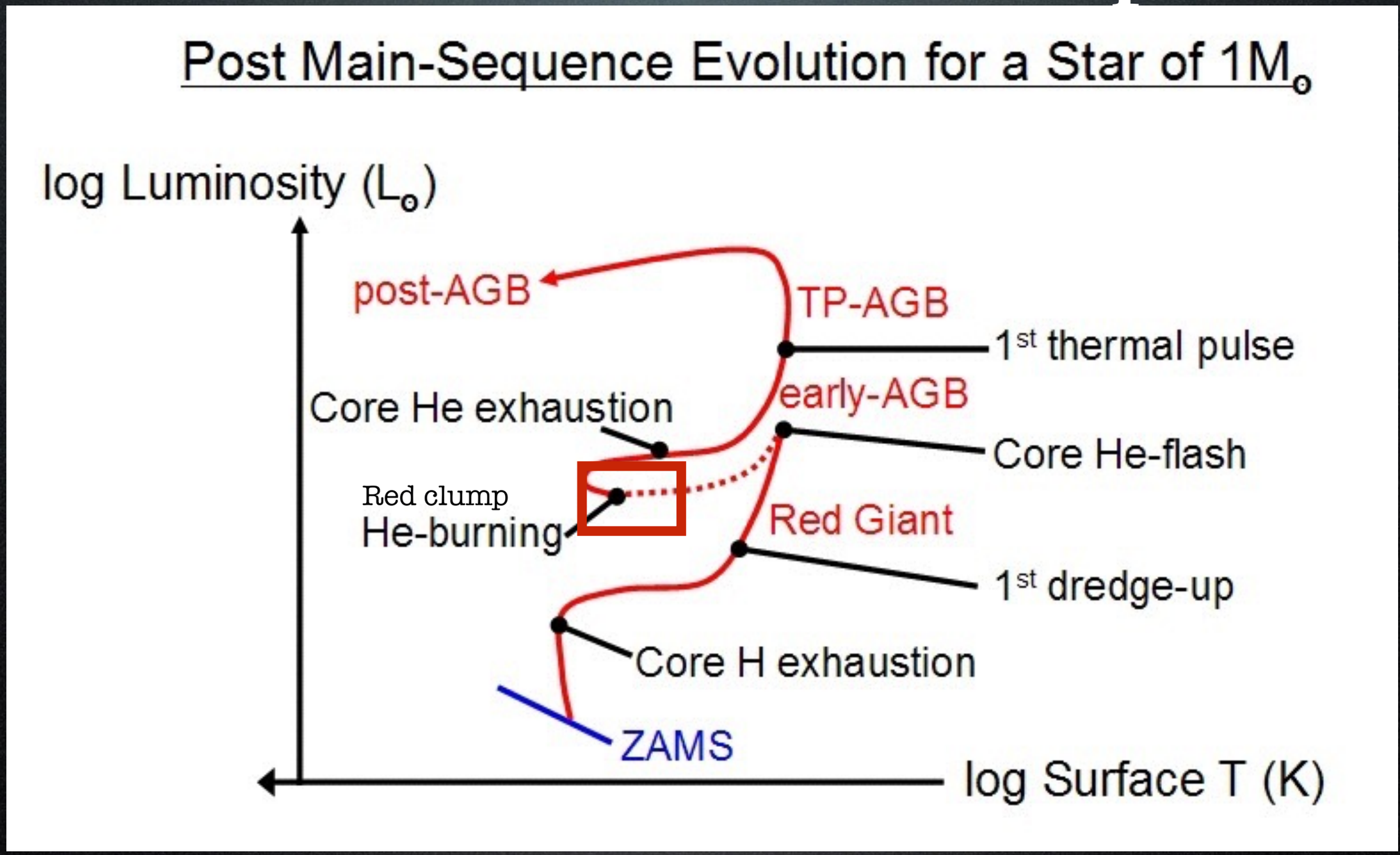
This is the cosmic distance ladder.



Red clump stars
(Stanek+1998, …)
stellar twins
(Jofre+2016, …)

From "The Essential Cosmic Perspective", Bennett et al.

Distances: Red Clump

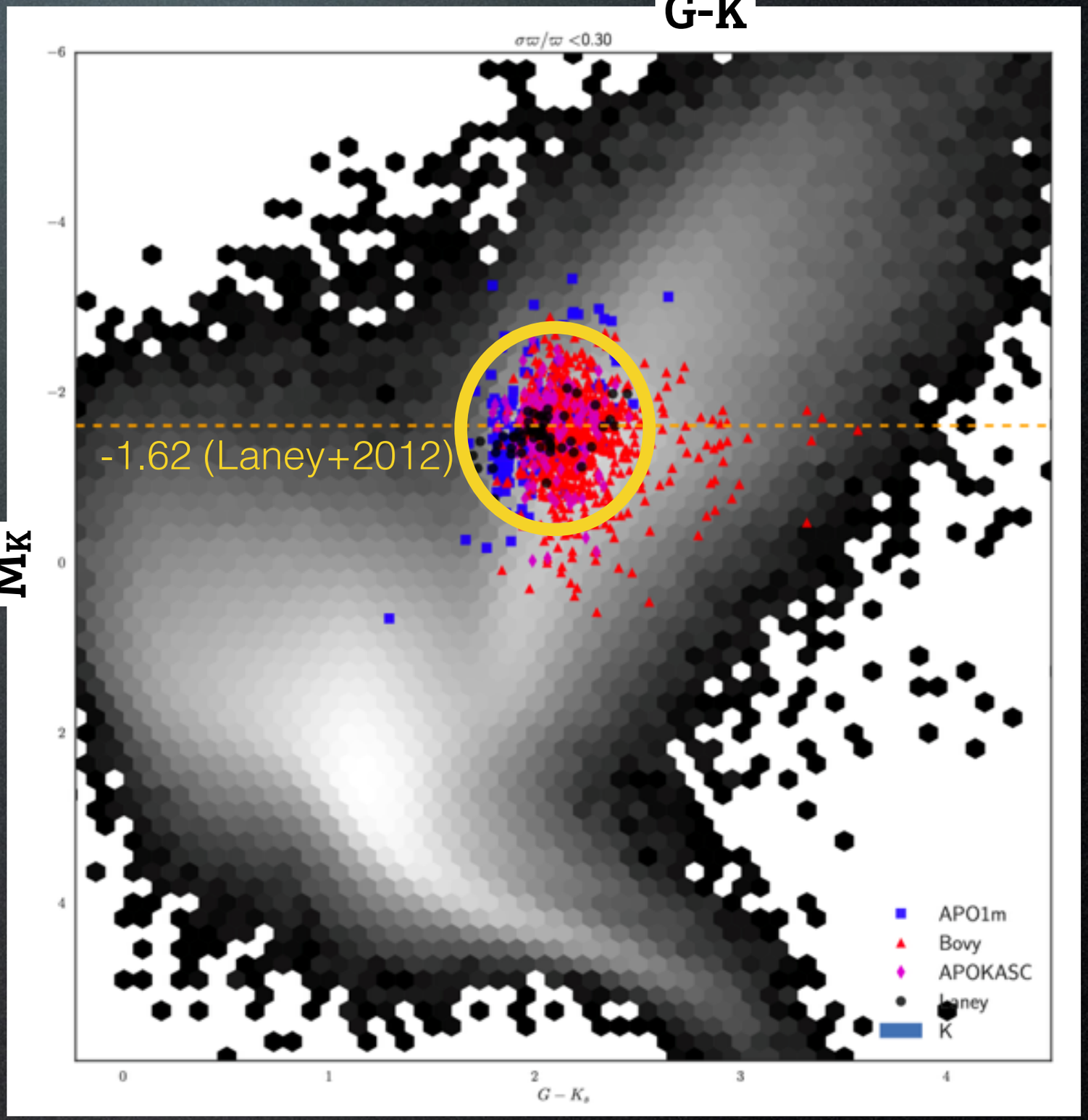


Use Gaia parallaxes to assess:

(1) How good of a standard candle is the RC? (2) Update magnitude of RC in J, H, Ks, W1, W2, W3, W4, G, NUV*

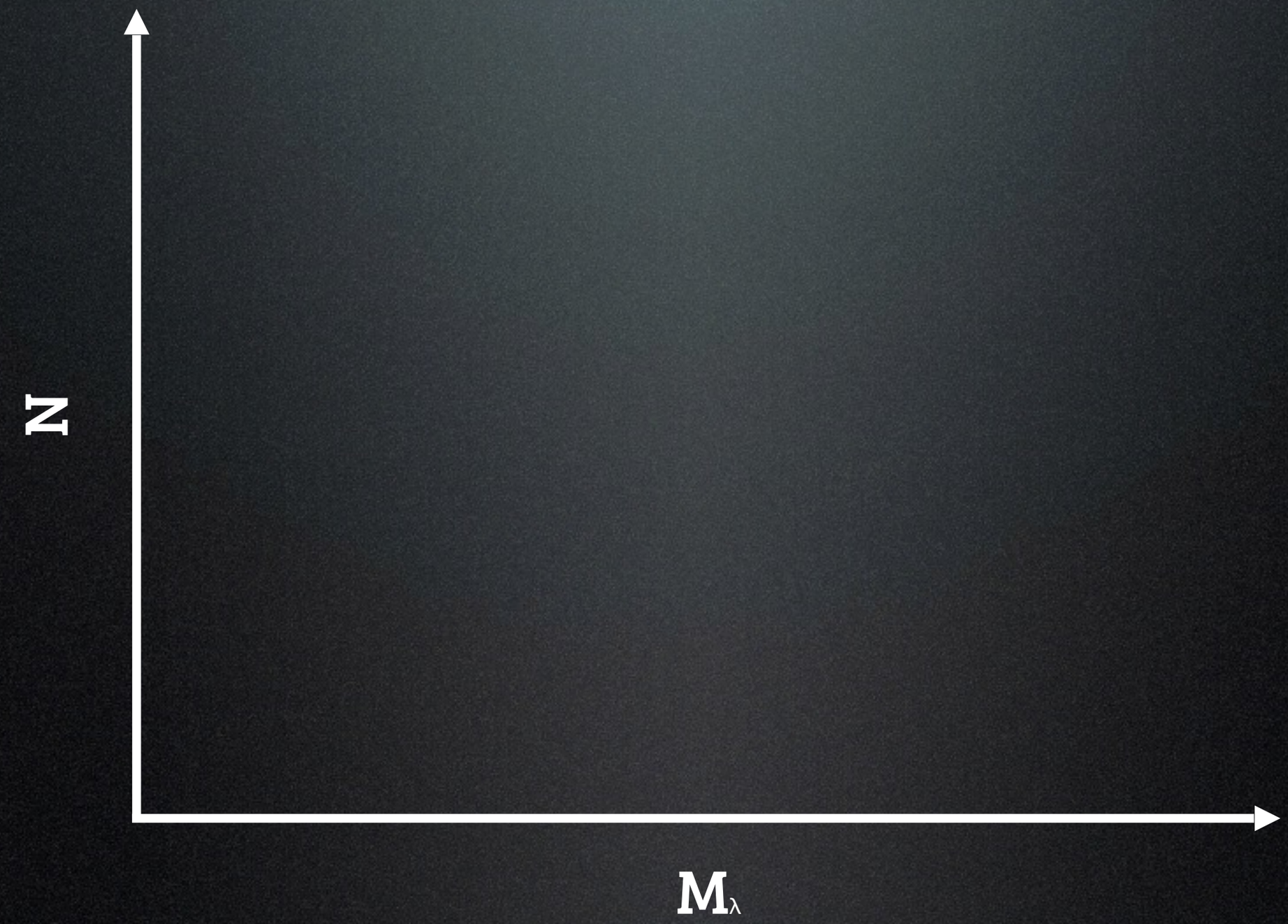
Red Clump Datasets

- Parallax cut at 30% (prior v.s. data dominated posterior)
- N ~ 970 (30%)
- N ~ 180 (10%)



APOKASC (Elsworth+2016), APOGEE-RC (Bovy +2014), Laney+2012, APO1m (Feuillet+2016)

Distances: Red Clump The Model



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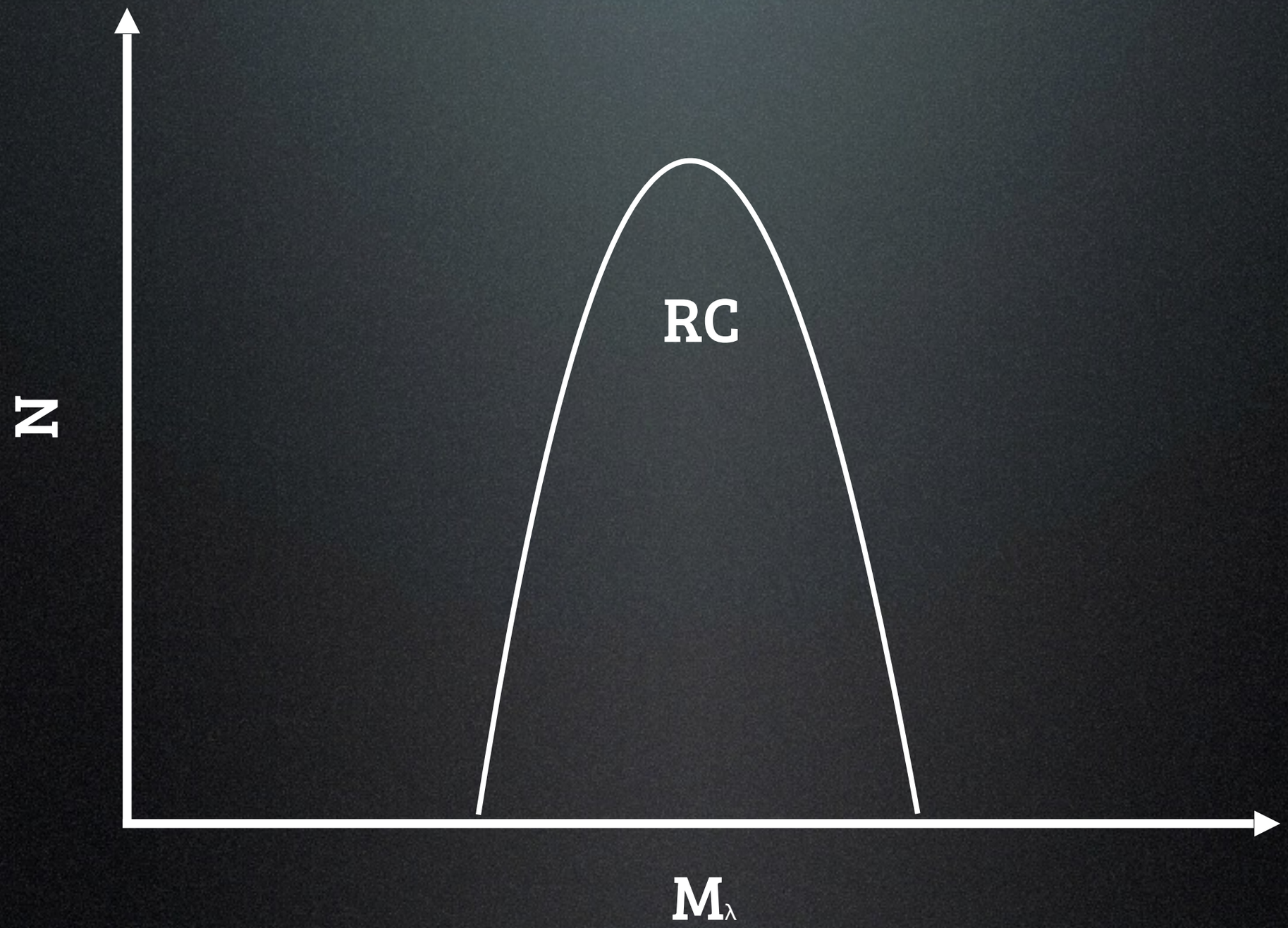
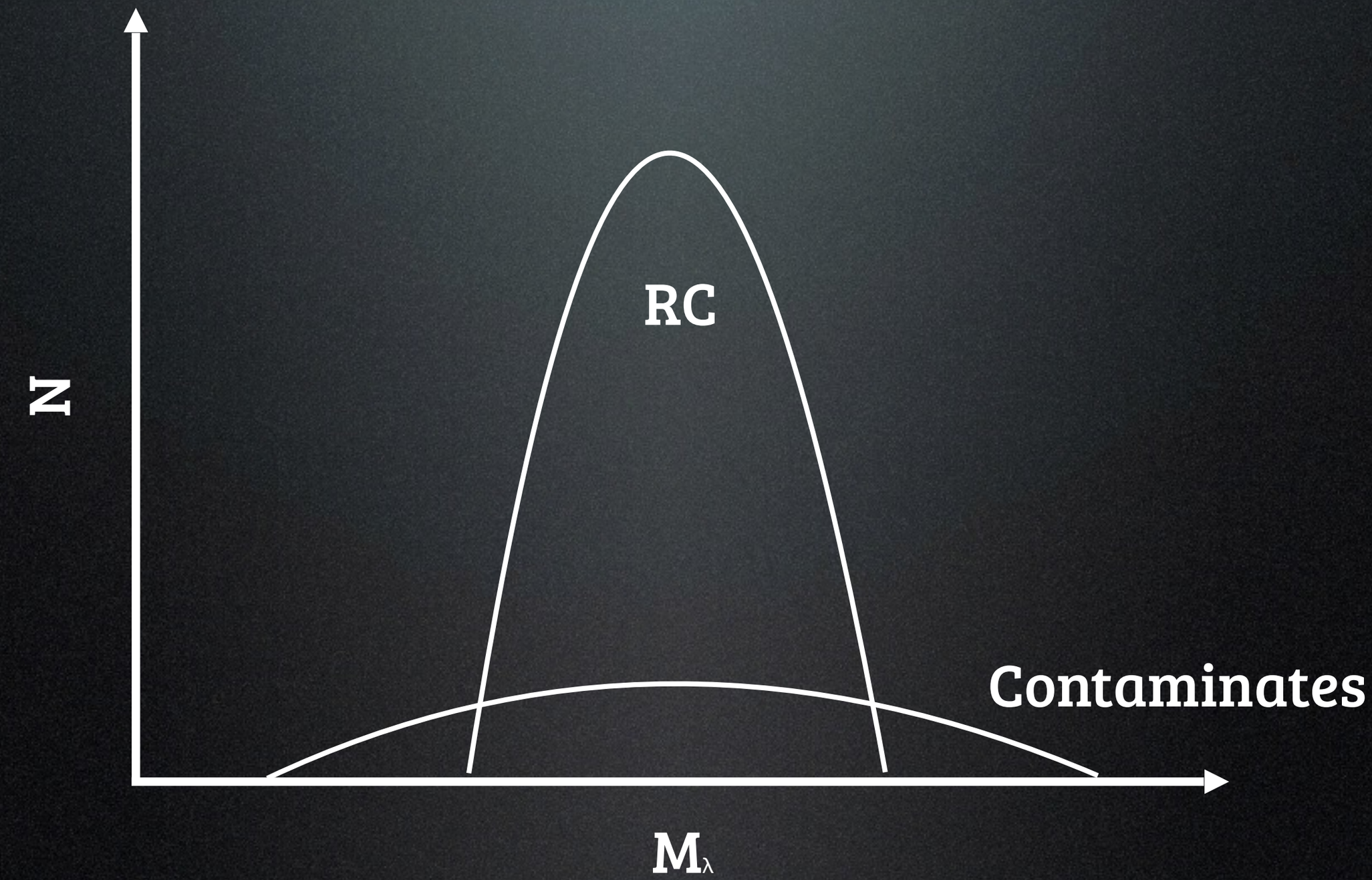


Distances: Red Clump

The Model



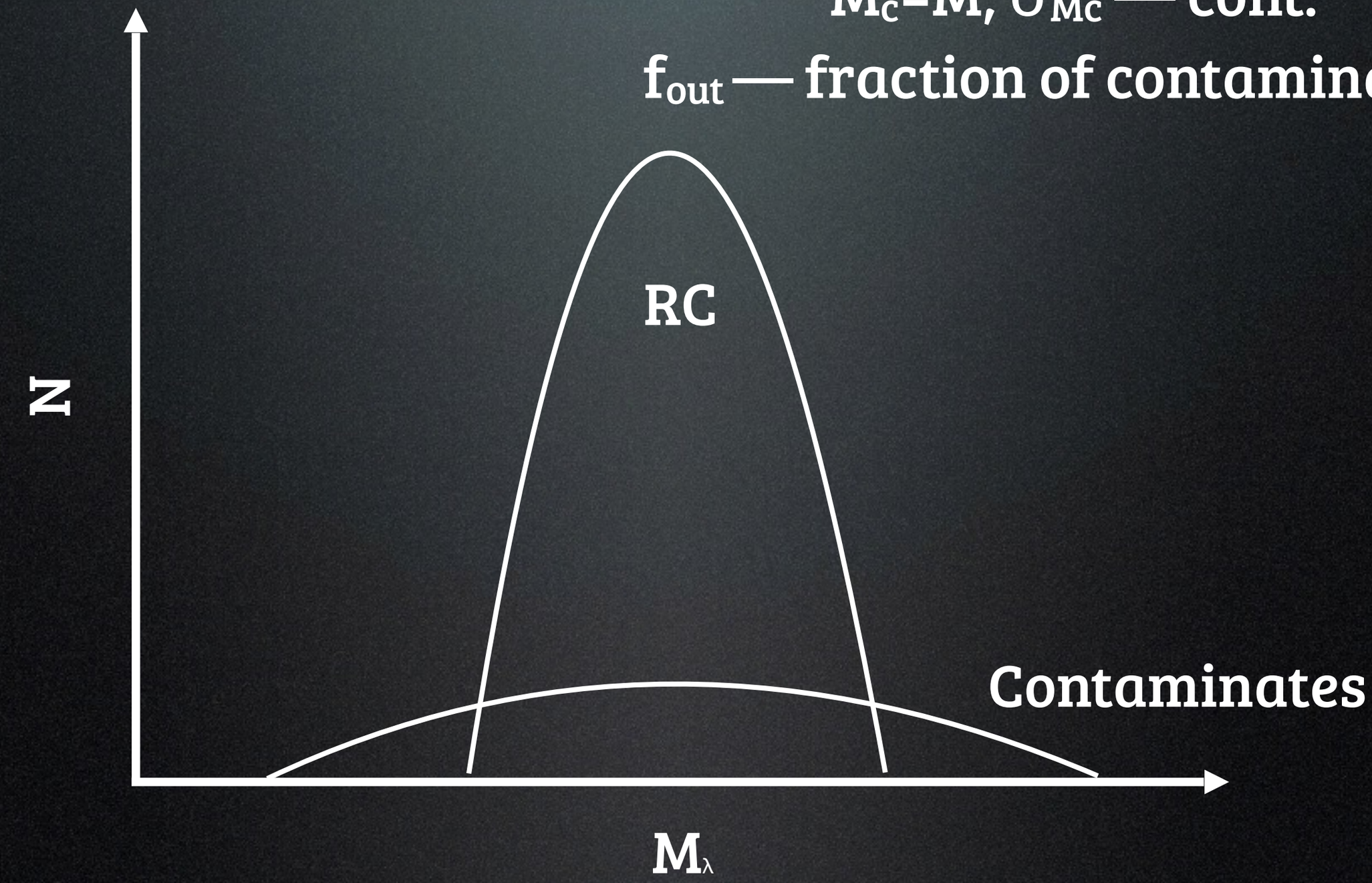
Distances: Red Clump

The Model

M, σ_M — RC

$M_c=M$, σ_{Mc} — cont.

f_{out} — fraction of contamination



Distances: Red Clump

The Model

M, σ_M — RC

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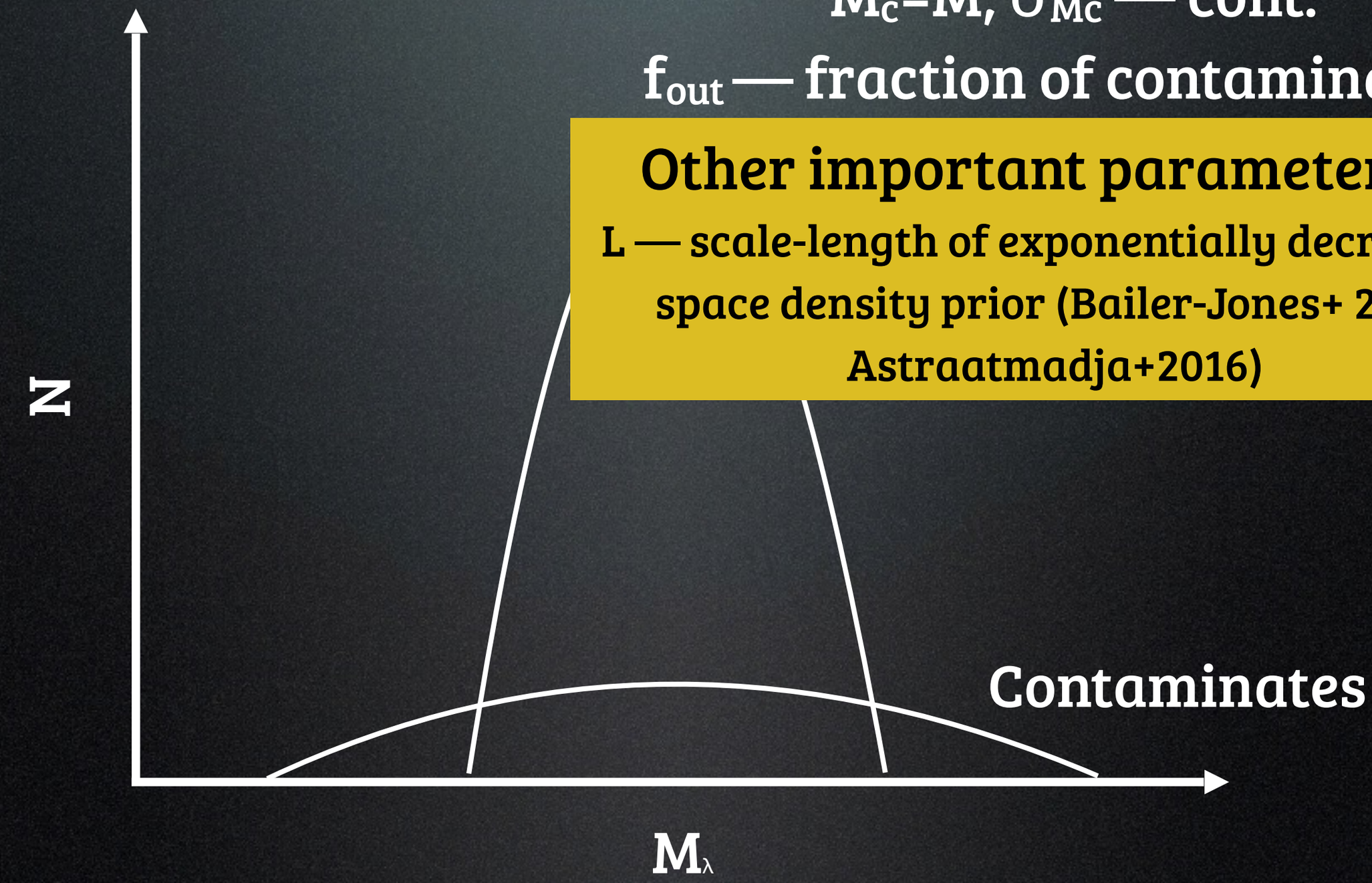
f_{out} — fraction of contamination

Other important parameter(s):

L — scale-length of exponentially decreasing space density prior (Bailer-Jones+ 2015; Astraatmadja+2016)



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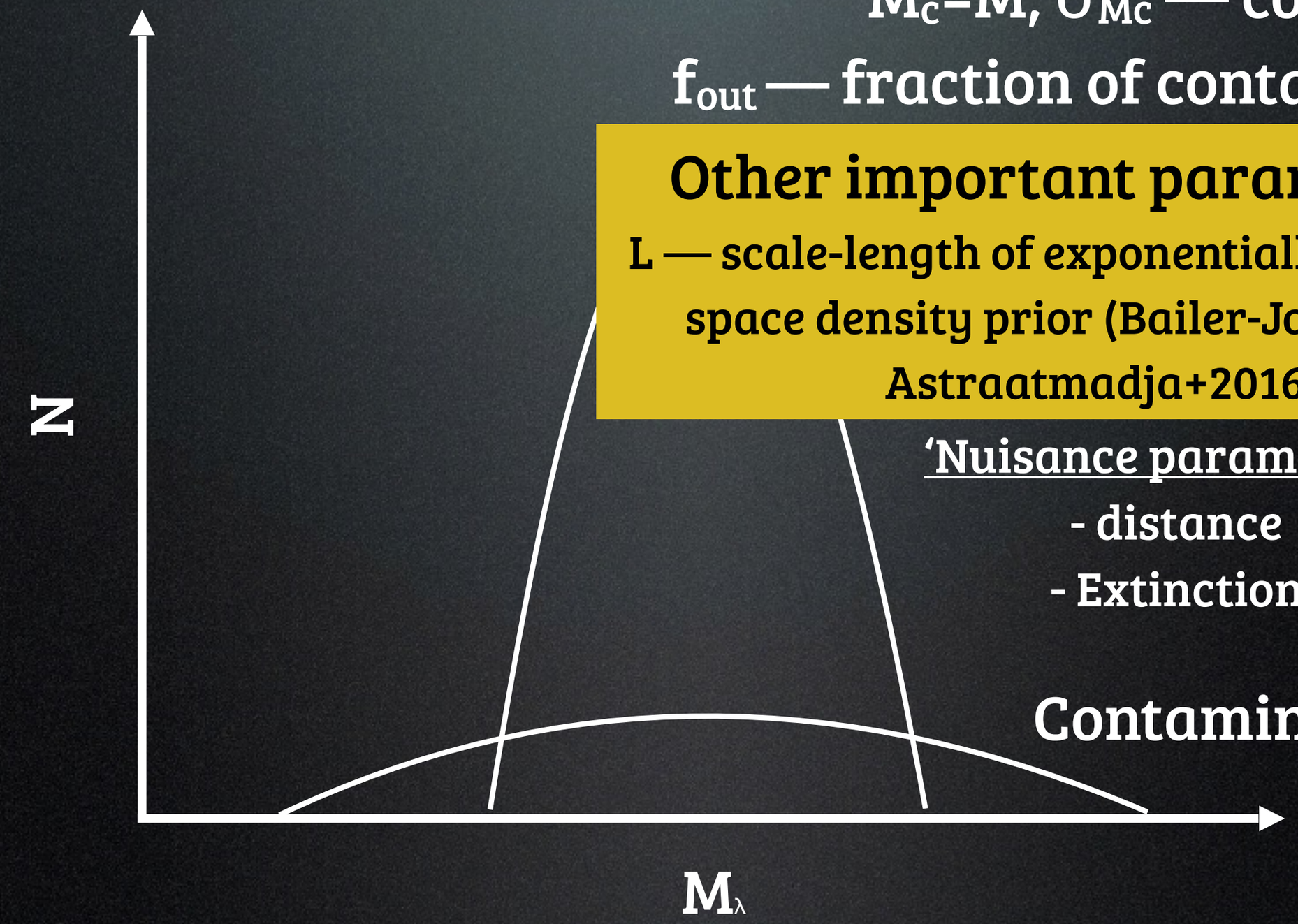

‘Nuisance parameters’:

- distance
- Extinction

Contaminates

Distances: Red Clump

The Model

M, σ_M — RC

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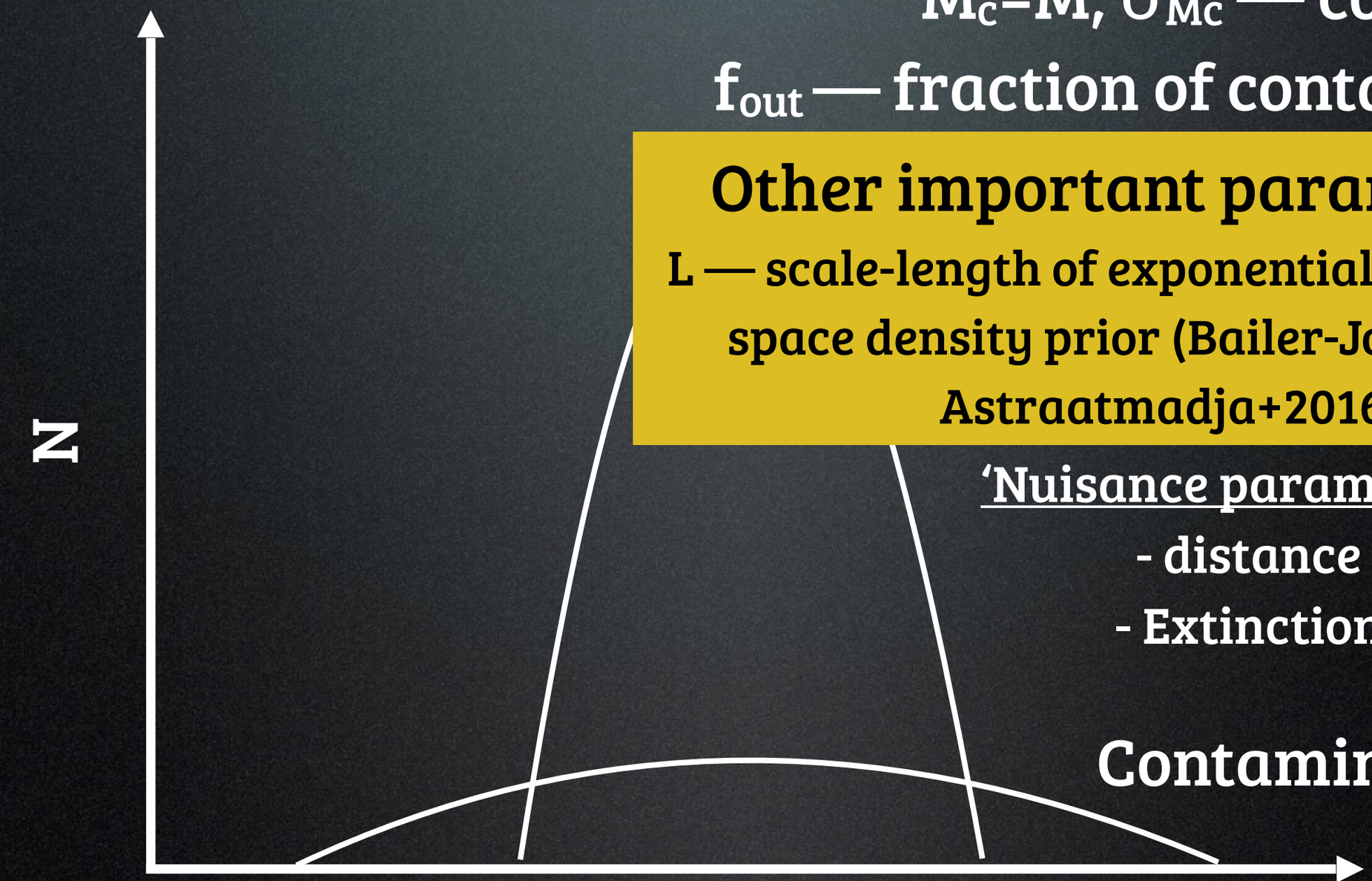


‘Nuisance parameters’:

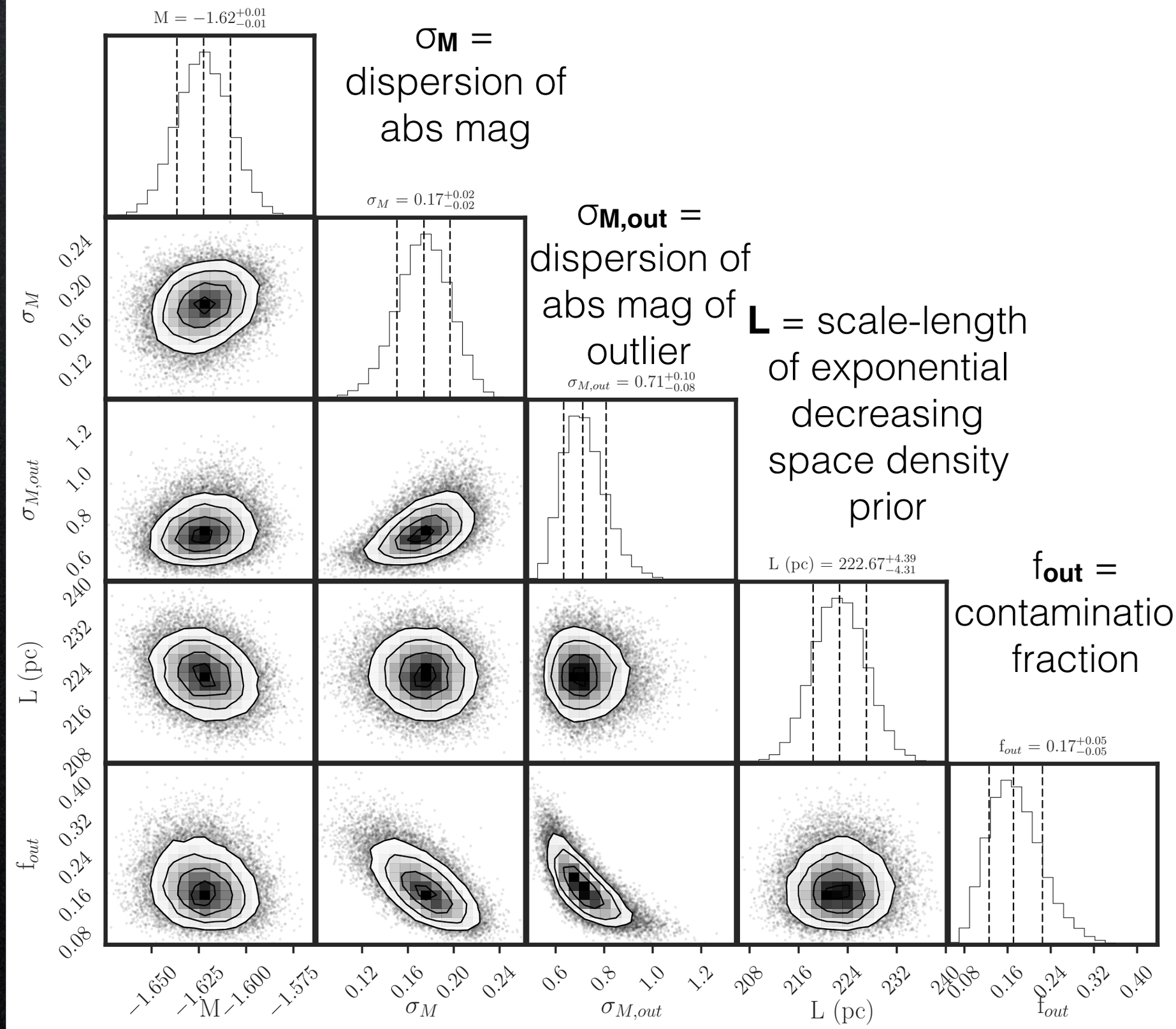
- distance
- Extinction

Use STAN statistical software to sample posterior in parameters

Red Clump K(JHG+)-Magnitude

M_k = -1.62 +/- 0.013 ; σ_{MK} = 0.17+/- 0.02; f_{out} ~ 17%

M = abs mag



σ_M = dispersion of abs mag

$\sigma_{M,out}$ = dispersion of abs mag of outlier

L = scale-length of exponential decreasing space density prior

f_{out} = contamination fraction

Hawkins+ 2017 in prep

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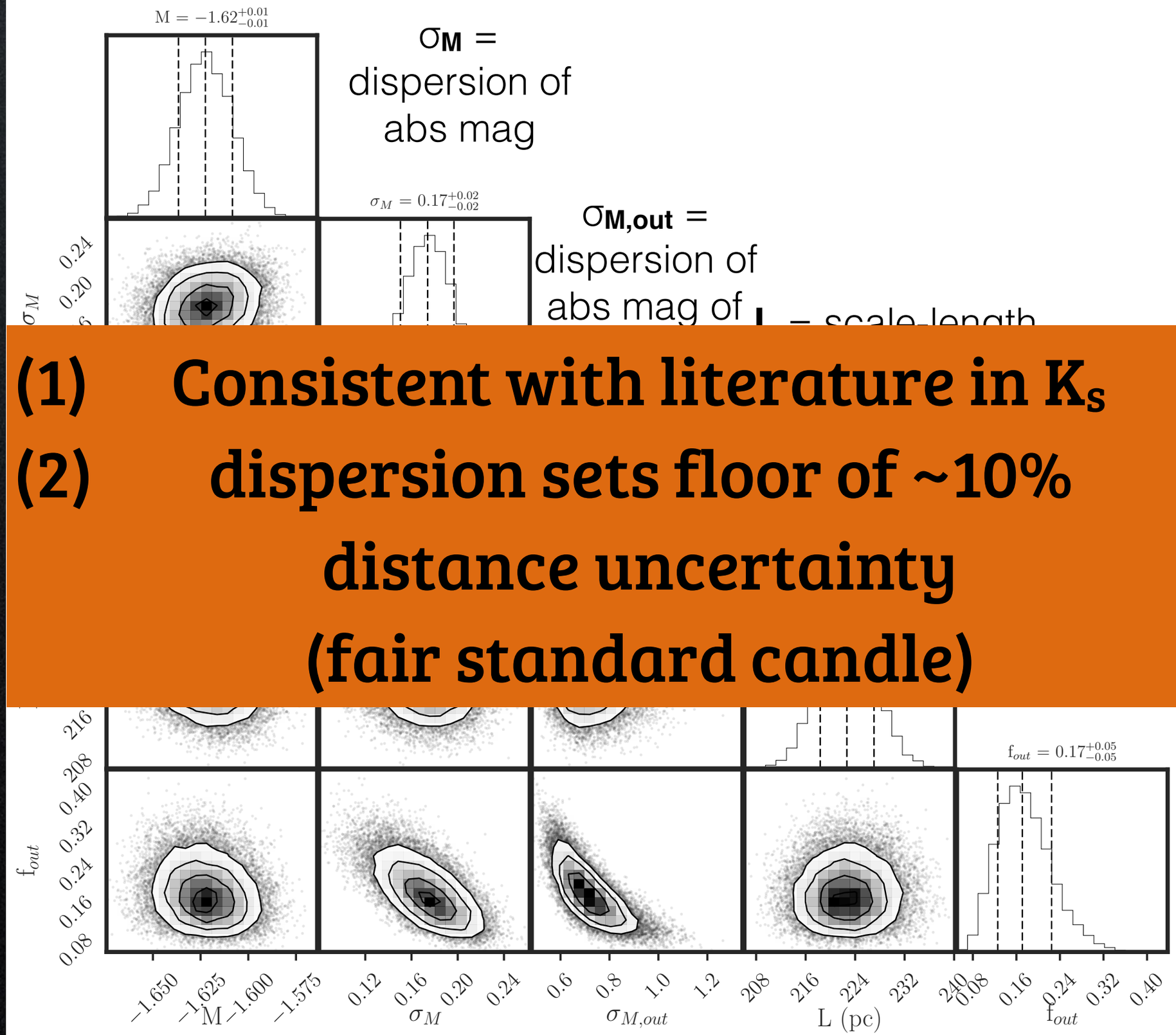


σ_M = dispersion of abs mag

$\sigma_{M,out}$ = dispersion of abs mag of

L = scale-length

(1) Consistent with literature in K_s

(2) dispersion sets floor of ~10% distance uncertainty (fair standard candle)

Hawkins+ 2017 in prep

Red Clump K(JHG+)-Magnitude

Band	M_λ (mag)	σM_λ (mag)	$\sigma M_{\lambda,out}$ (mag)	L (pc)	f_{out}	N	$\frac{A_\lambda}{E(B-V)}$
G	+0.44±0.01	0.20 ±0.02	0.75±0.08	215.6±4.2	0.18±0.04	972	2.85
J	–0.93±0.01	0.20 ±0.02	0.72±0.09	213.5±4.0	0.13±0.05	972	0.72
H	–1.46±0.01	0.17 ±0.02	0.71±0.09	$213.3^{+4.1}_{-3.9}$	0.18±0.05	972	0.46
K_s	–1.62±0.01	0.17 ±0.02	$0.71^{+0.10}_{-0.08}$	222.6±4.3	0.17±0.05	972	0.30
W1	–1.68±0.02	0.10 ±0.04	$0.73^{+0.12}_{-0.09}$	231.5±4.8	0.15±0.04	936	0.18
W2	–1.69±0.02	0.20 ±0.03	0.84±0.10	237.8±4.8	0.15±0.04	934	0.16
W3	–1.68±0.01	0.16 ±0.02	0.74±0.08	228.3±4.6	0.18±0.05	936	0.16
W4	–1.76±0.01	0.16 ±0.02	$0.73^{+0.09}_{-0.07}$	221.1±4.5	0.18±0.05	910	0.11

Agreement with literature:

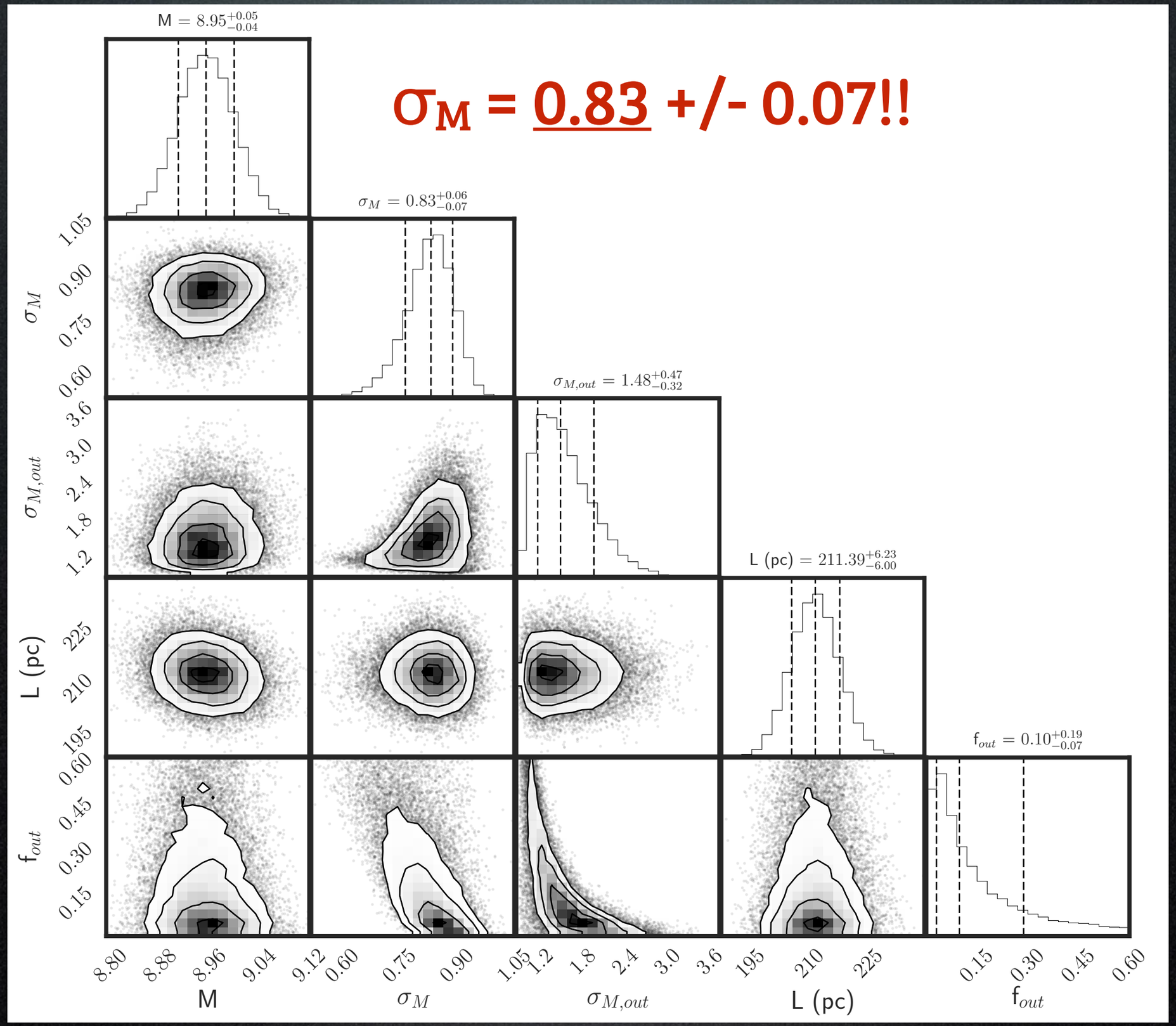
Good **New** **Fair** **Poor**

Hawkins+ 2017, in prep

RC in Galex NUV

New

$\sigma_M = \underline{0.83} \pm 0.07$!!



RC in Galex NUV

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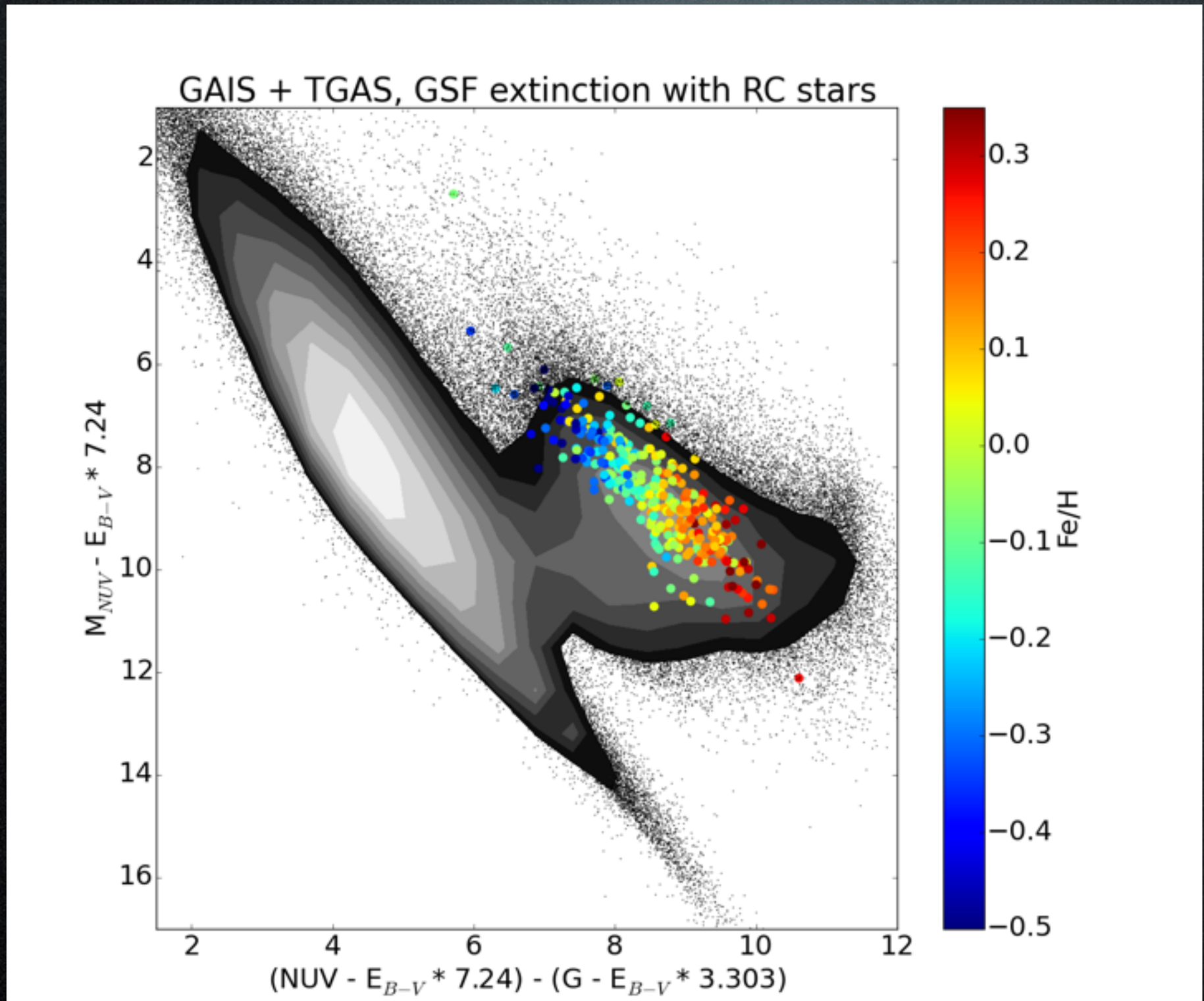
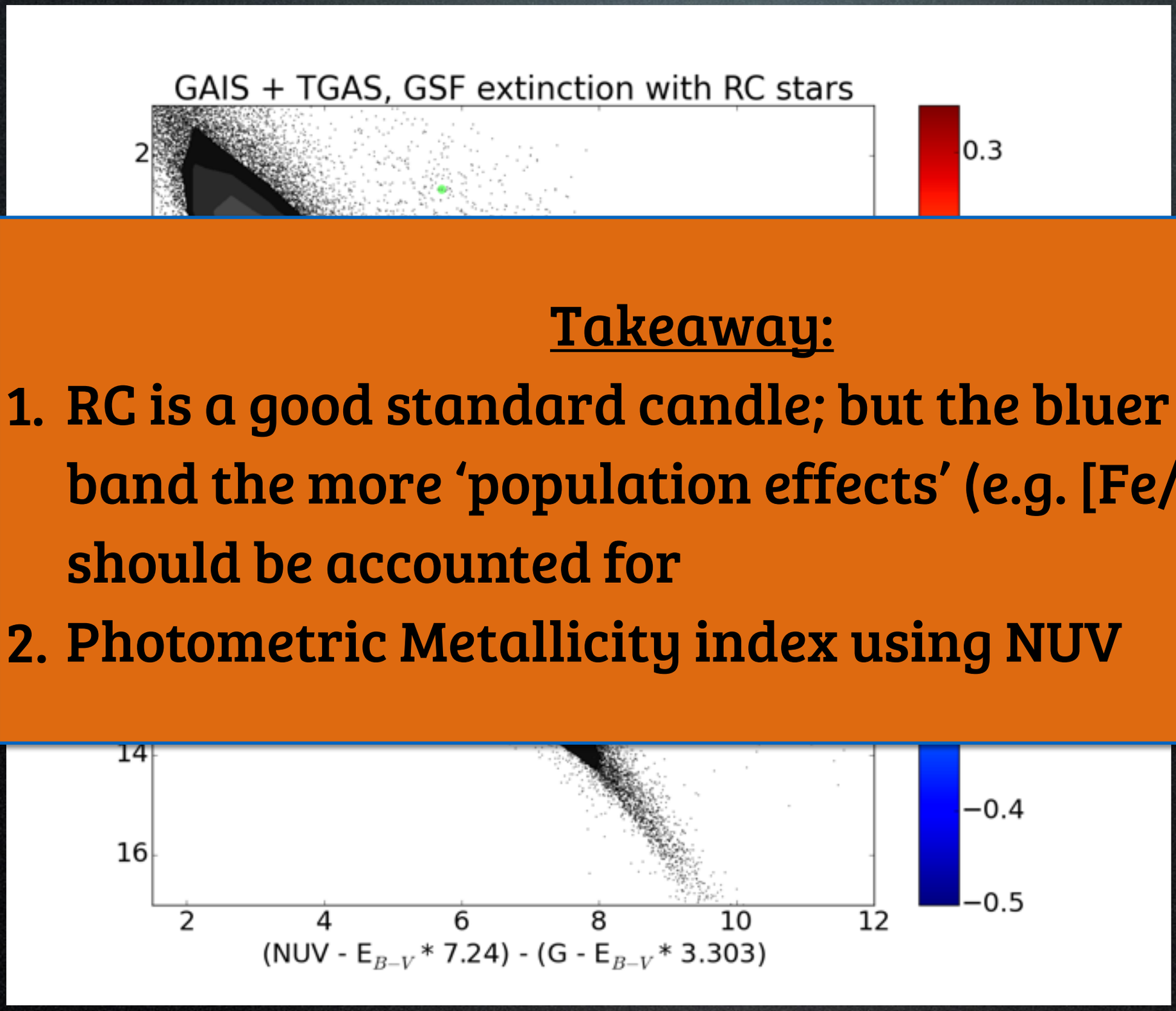


Mohammed+ (with KH), 2017 in prep

RC in Galex NUV

New

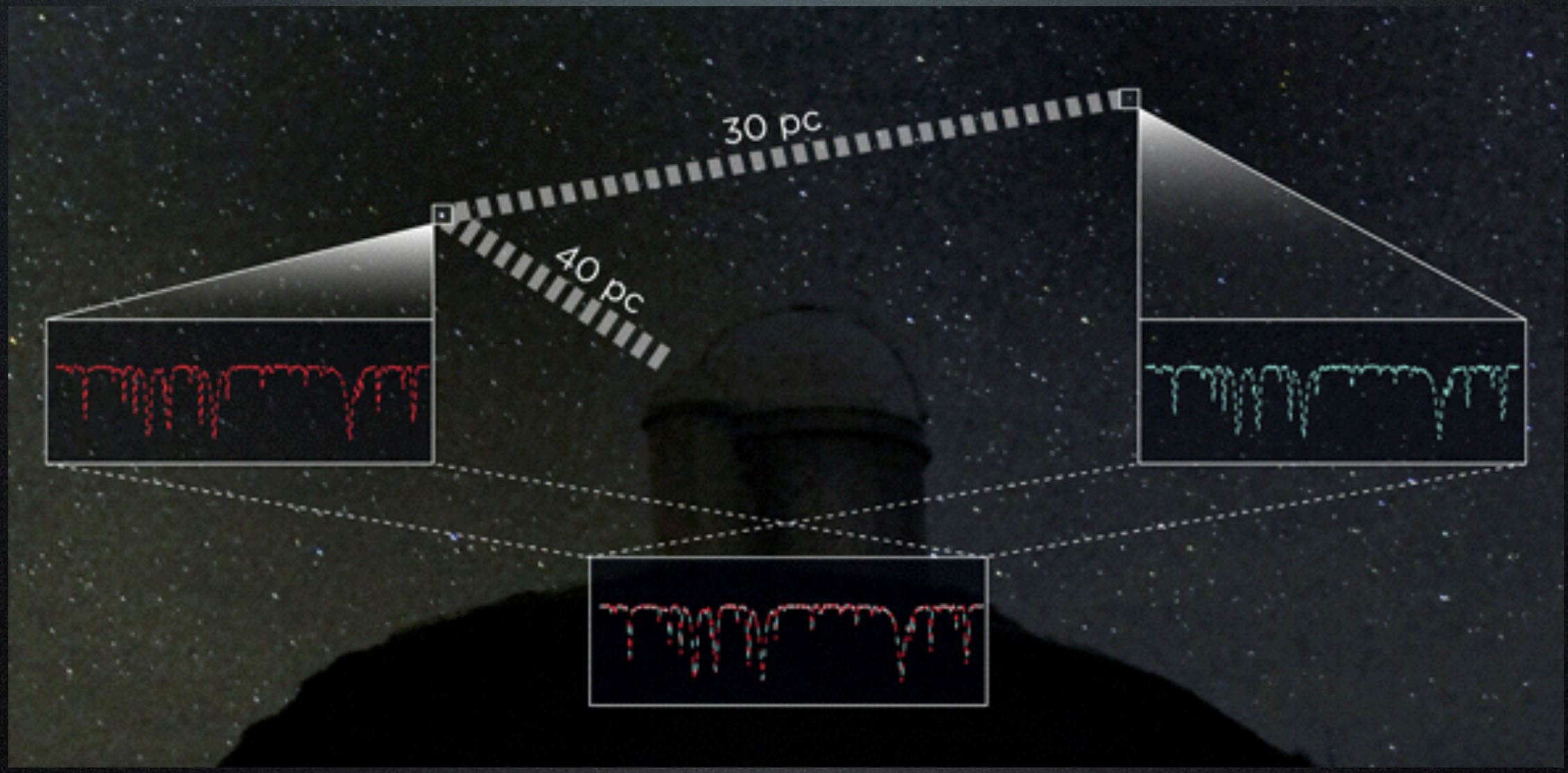


Takeaway:

1. **RC is a good standard candle; but the bluer the band the more 'population effects' (e.g. [Fe/H]) should be accounted for**
2. **Photometric Metallicity index using NUV**

Mohammed+ (with KH), 2017 in prep

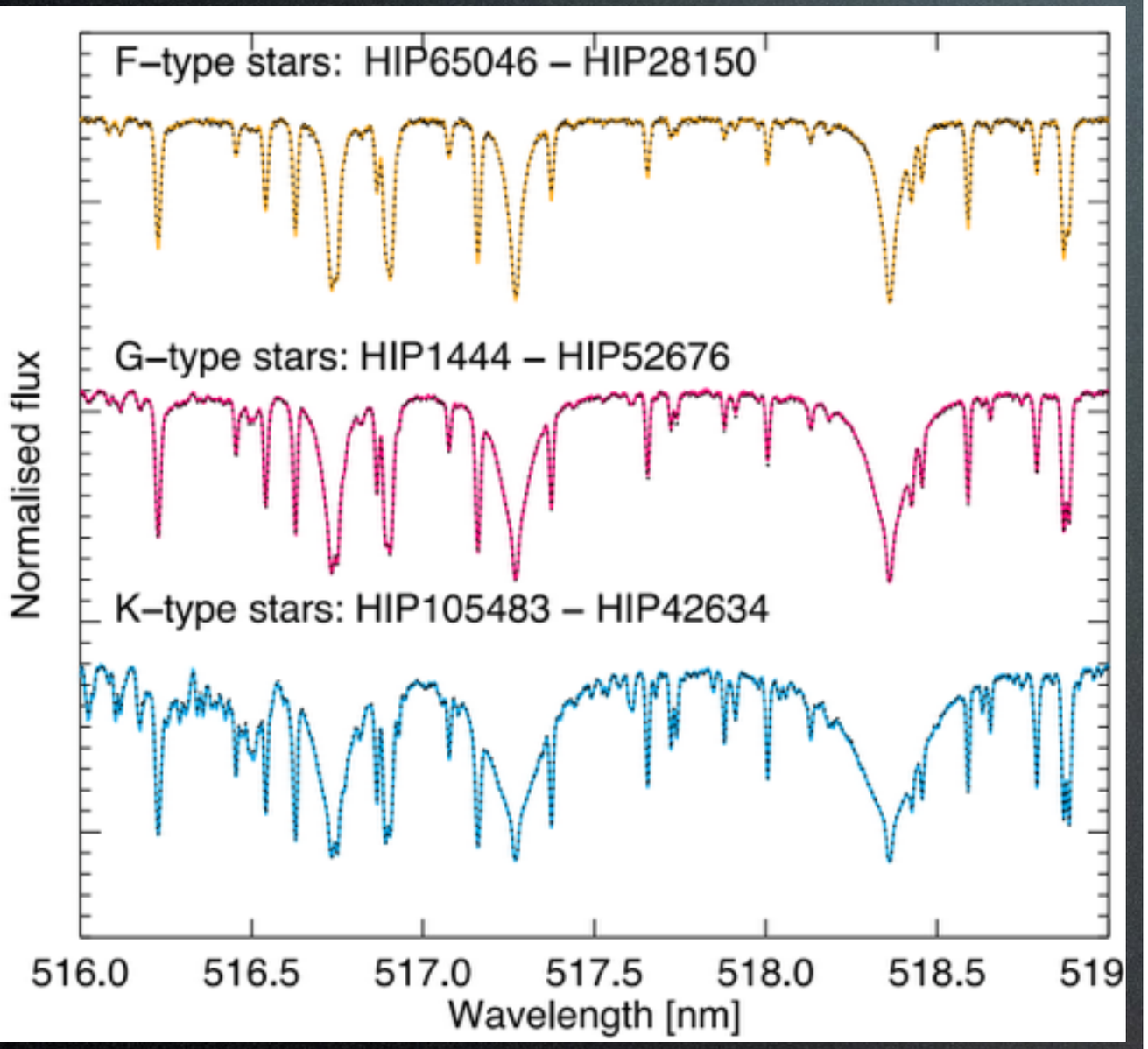
Stellar Twins

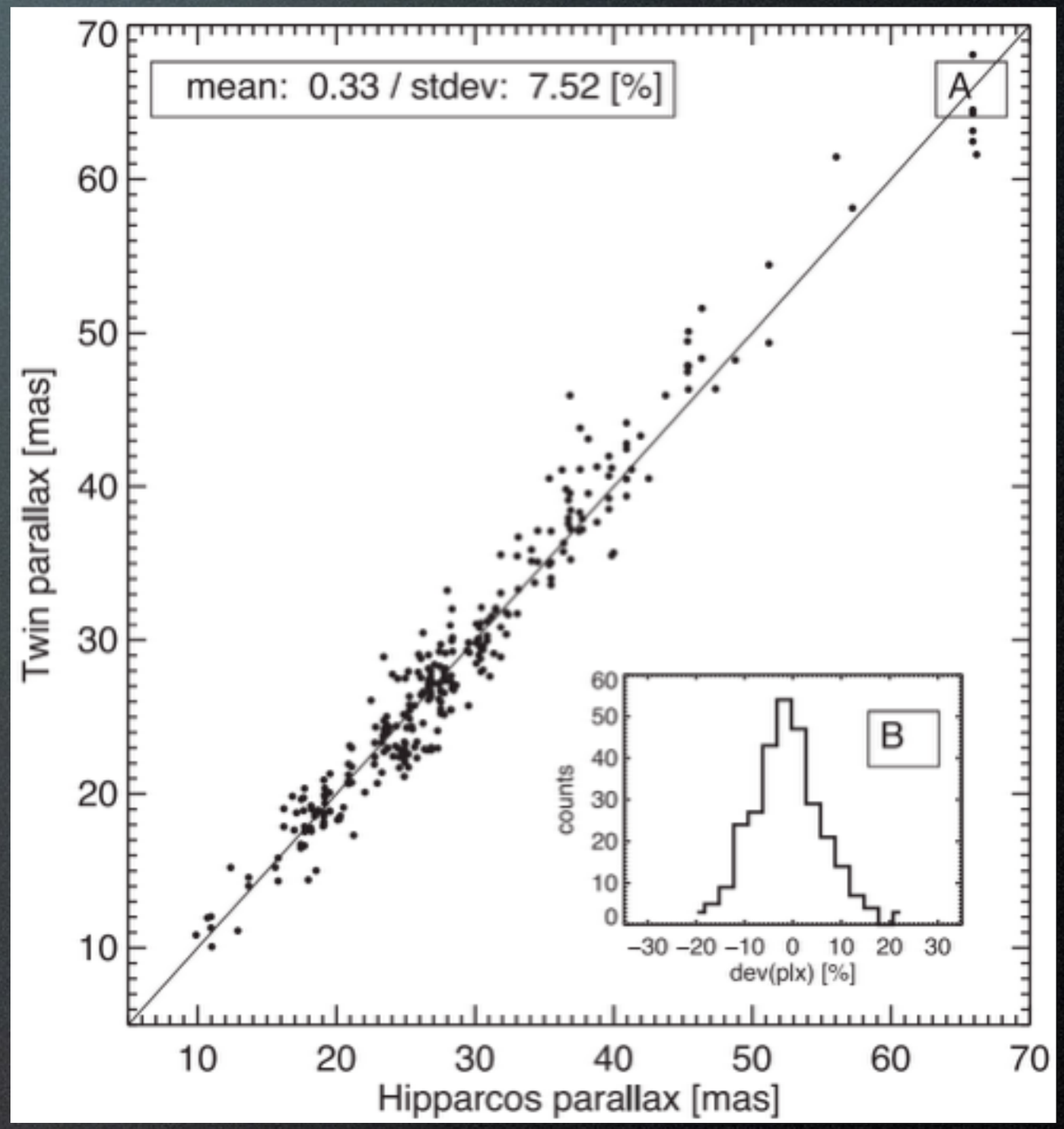


Interests: Use twins to map the bulge, obtain distances to stars at larger distances than Gaia can reach

credit: IoA, Cambridge

Distances: Stellar Twins

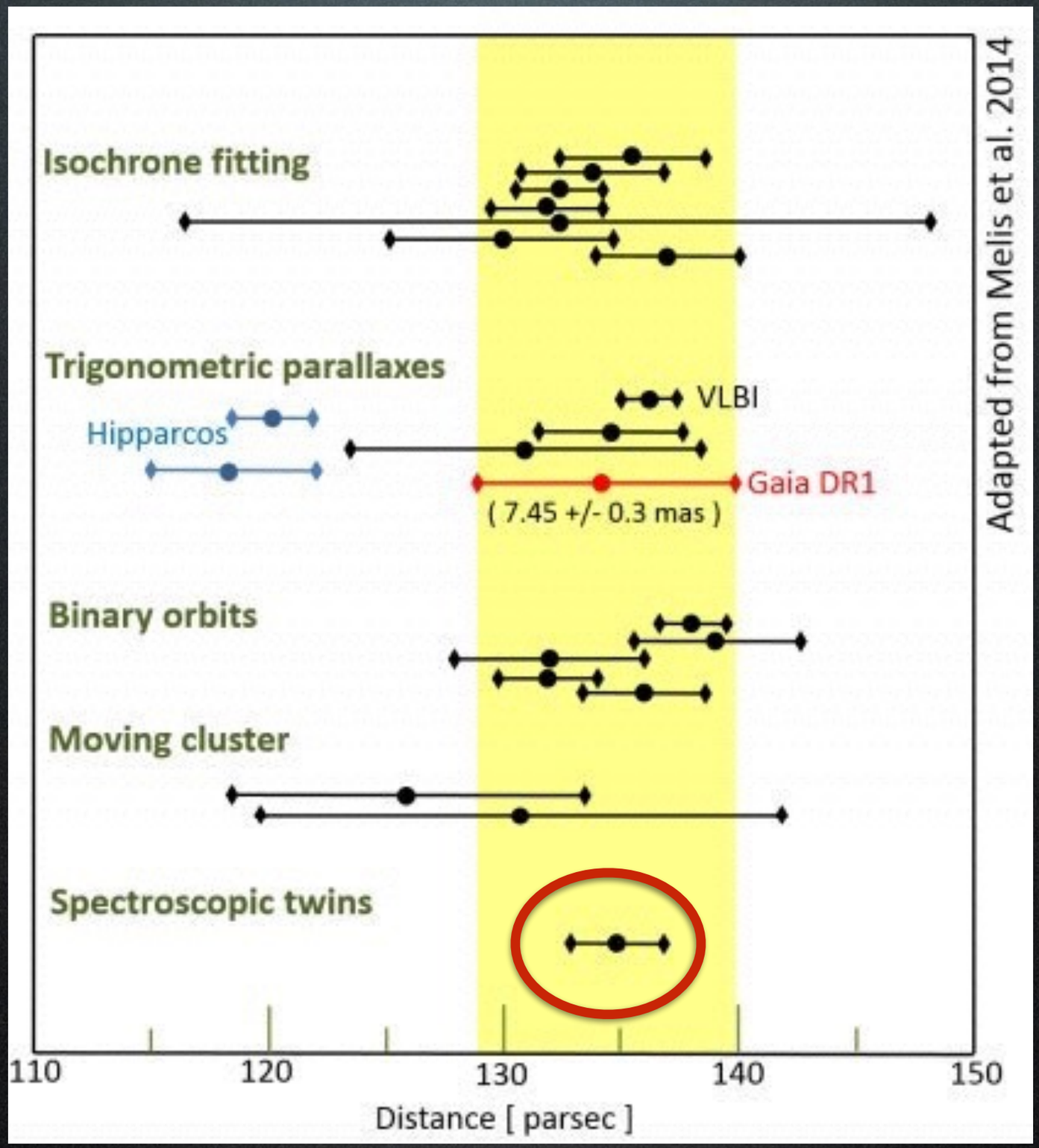




$$\varpi_2 = \varpi_1 \times 10^{\frac{1}{5}\left(H_1 - H_2 - R_{K_s}[(H-K_s)_1 - (H-K_s)_2]\right)},$$

Jofre et al. 2016

Distances: Stellar Twins

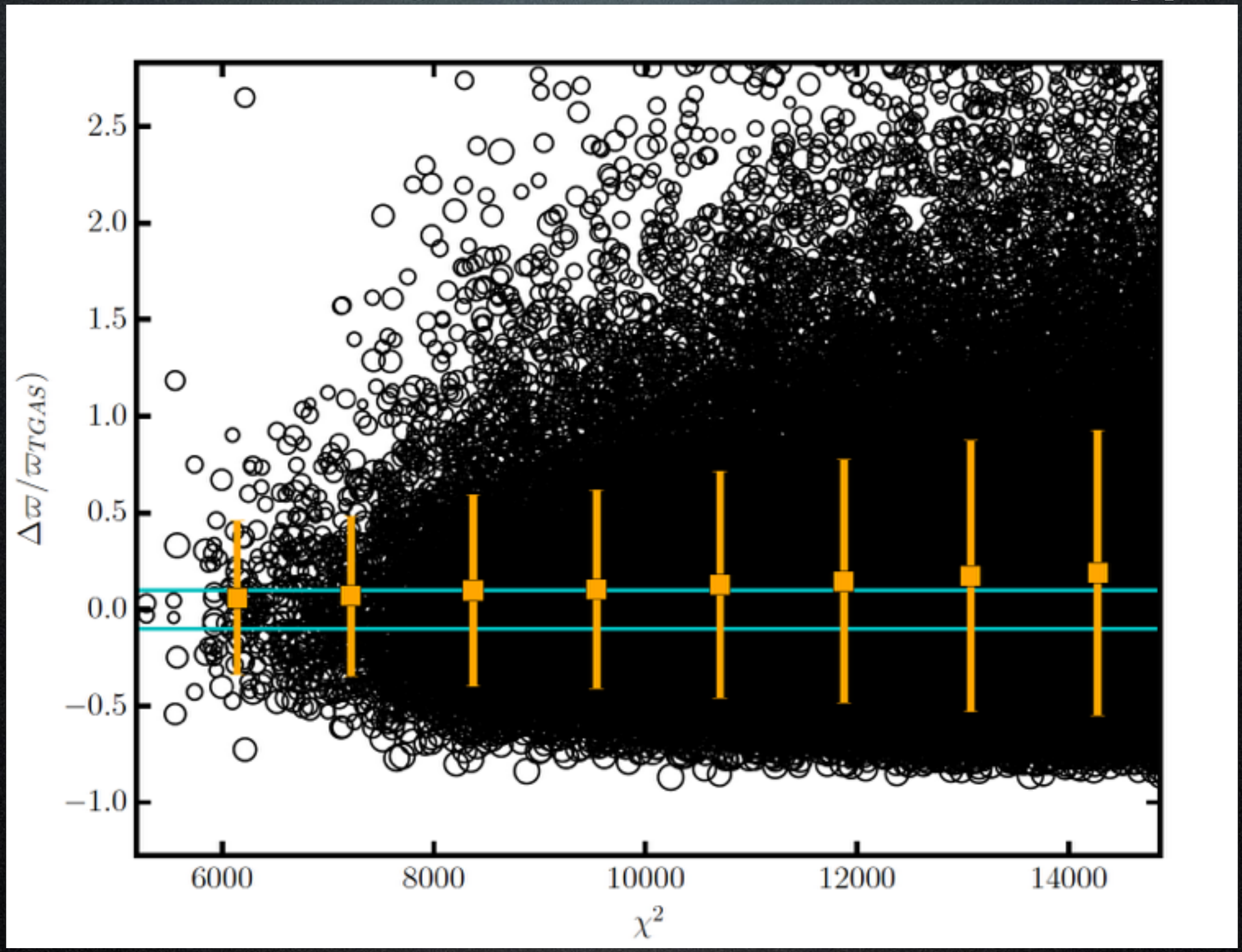


Twins used to help ‘settle’ Pleiades debate

Mädler et al. (incl. KH) 2016
Figure taken from Gaia collab. et al. 2016

Stellar Twins in APOGEE

Alternative ways to find stellar twins: χ^2



~600 APOGEE-TGAS stars with quality spectra+ASPCAP params

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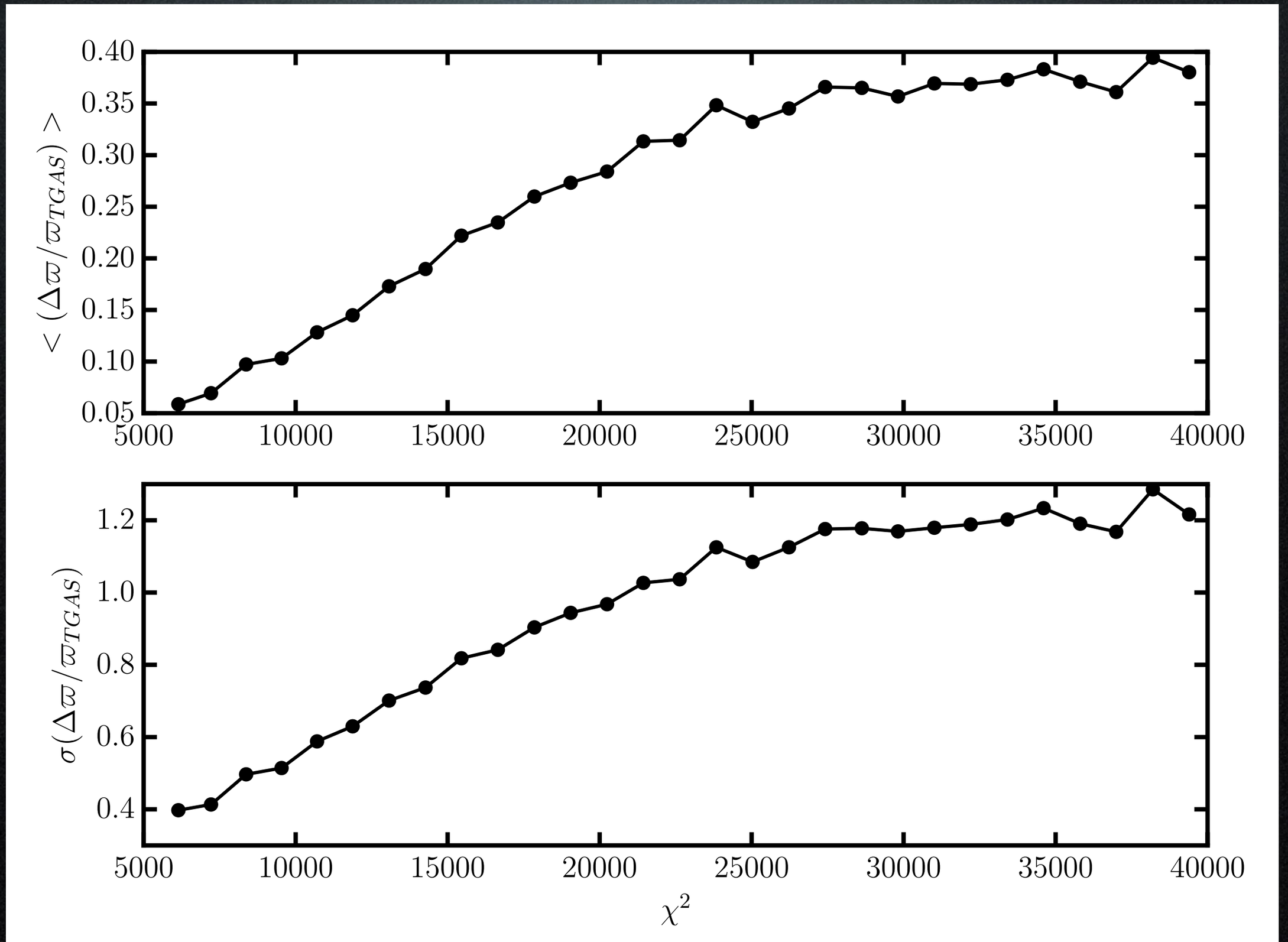

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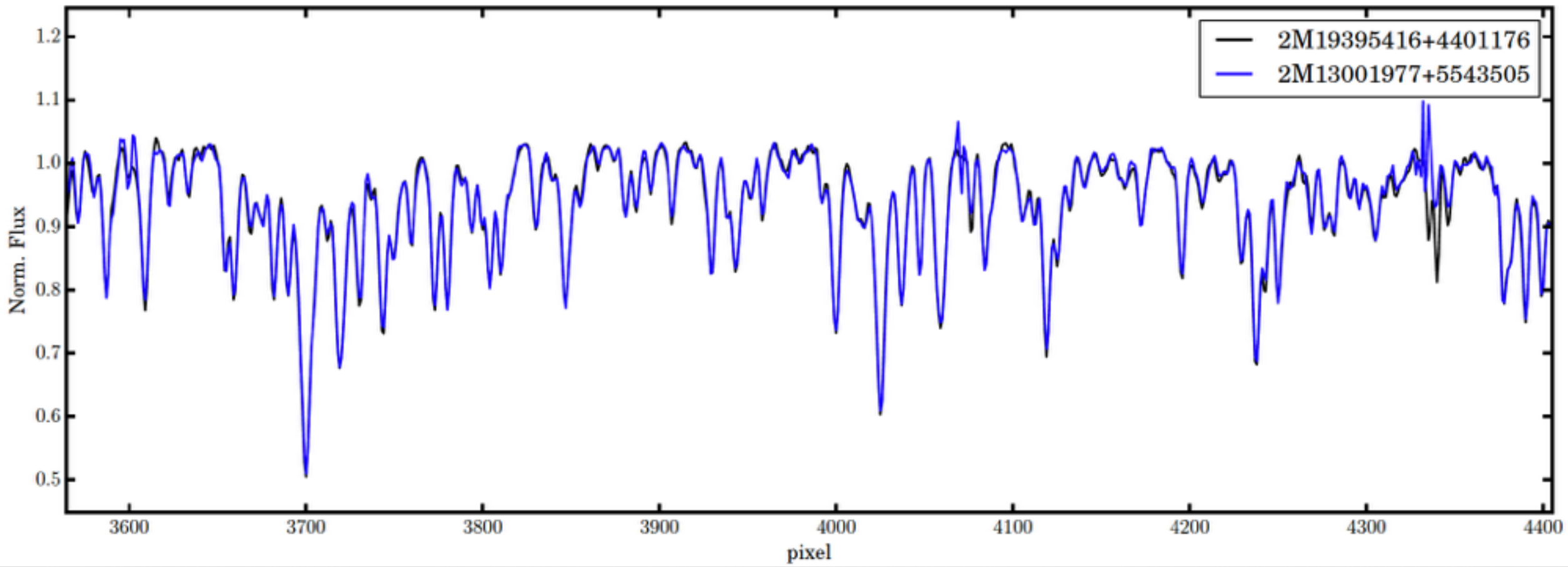

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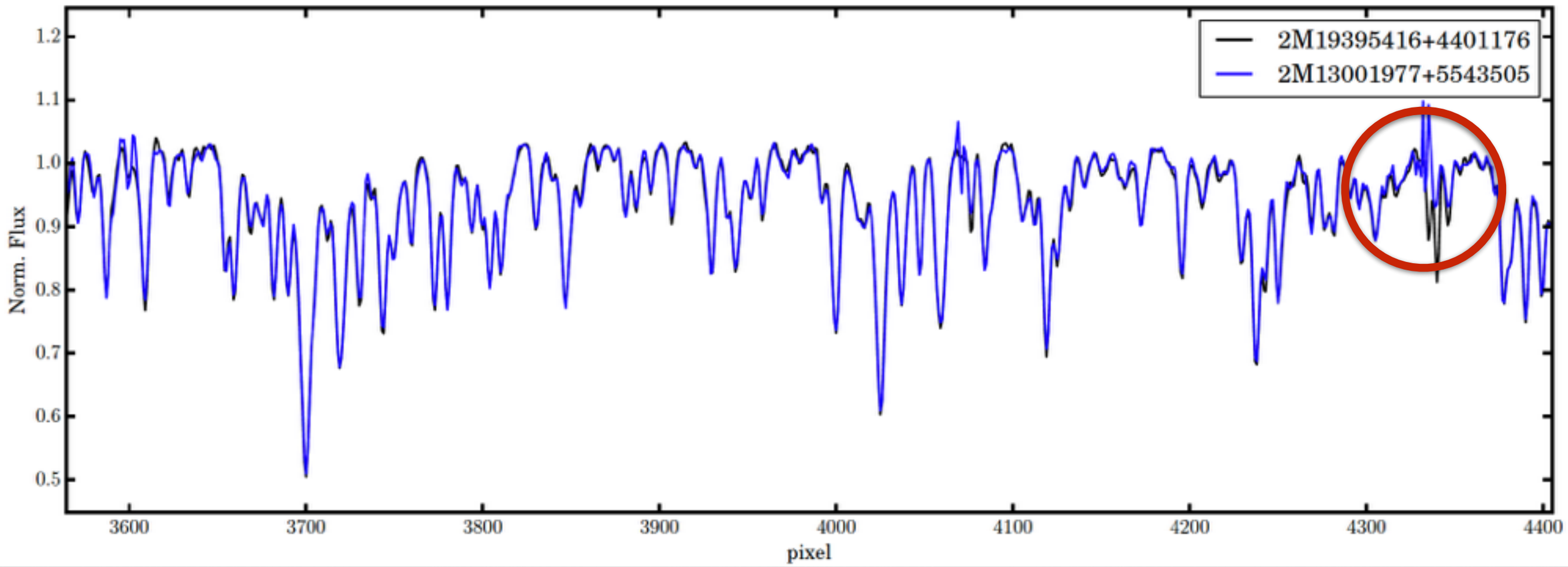
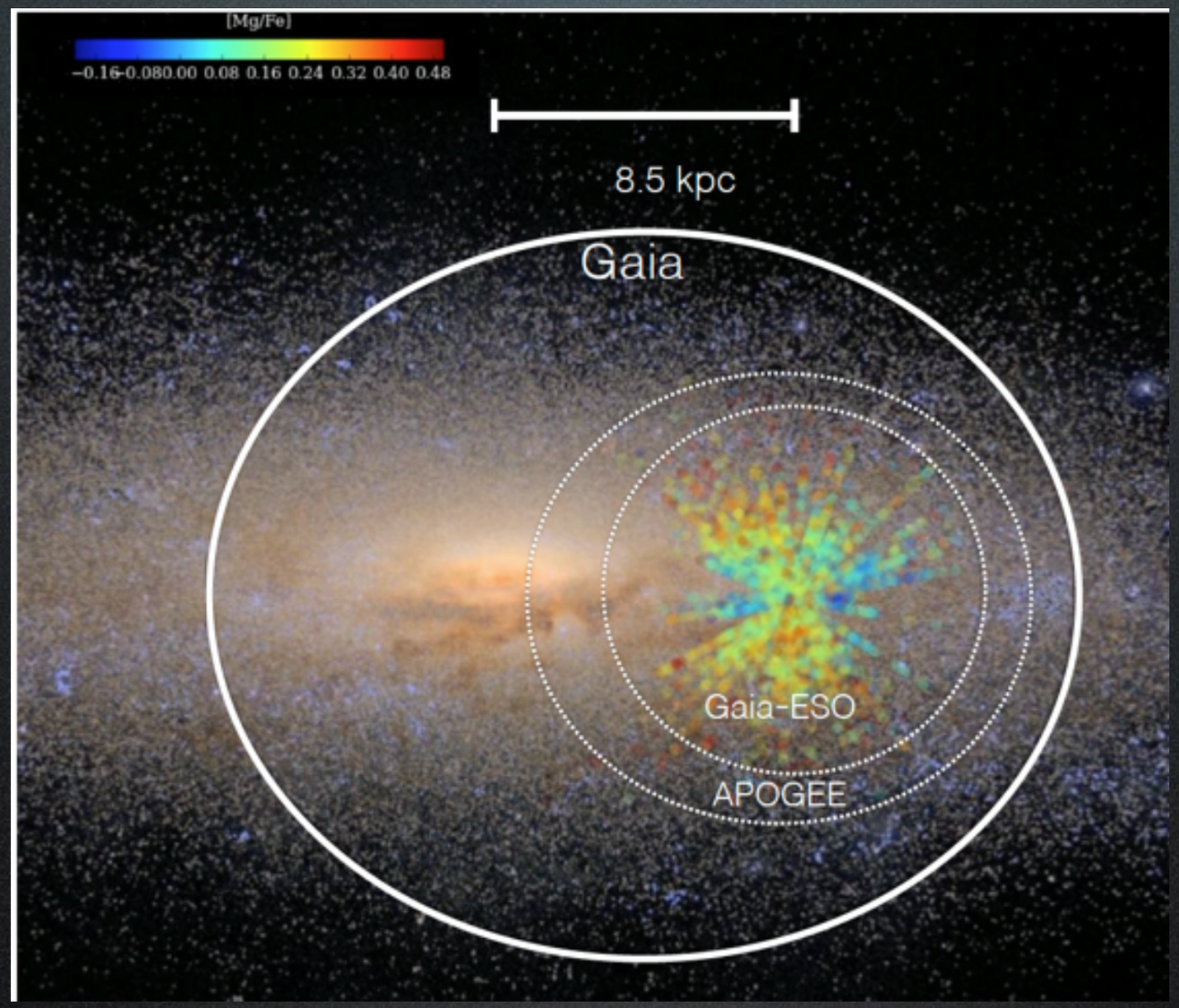


What are the Prospects for chemical cartography?



[Mg/Fe] as a function of spatial position in Gaia-ESO

Adapted from Greg Stinson and Maria Bergemann.

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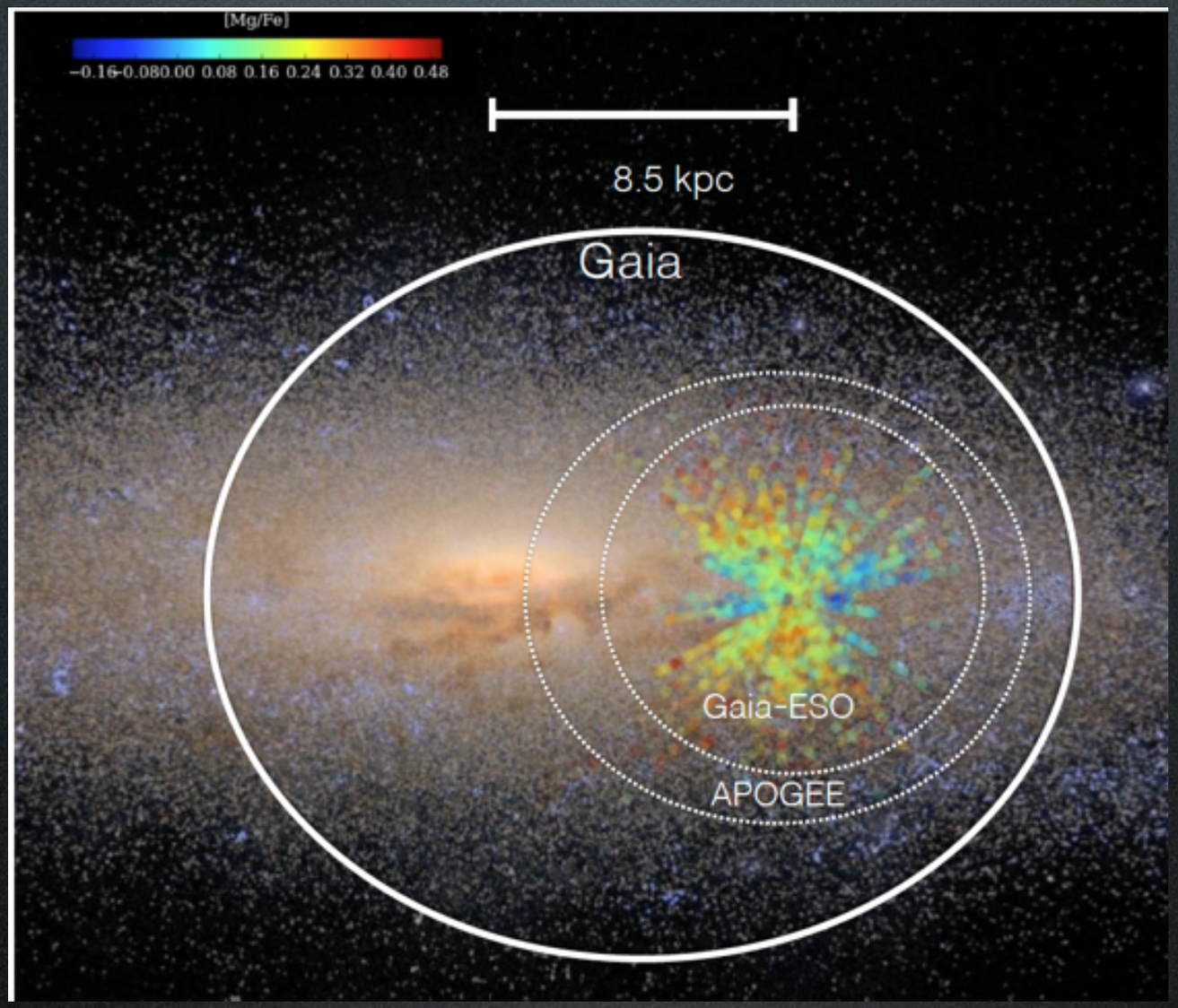

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Great! with RC stars, Gaia, stellar twins and a ton of large surveys for chemistry.