A three-dimensional map of the Milky Way using classical Cepheid variable stars

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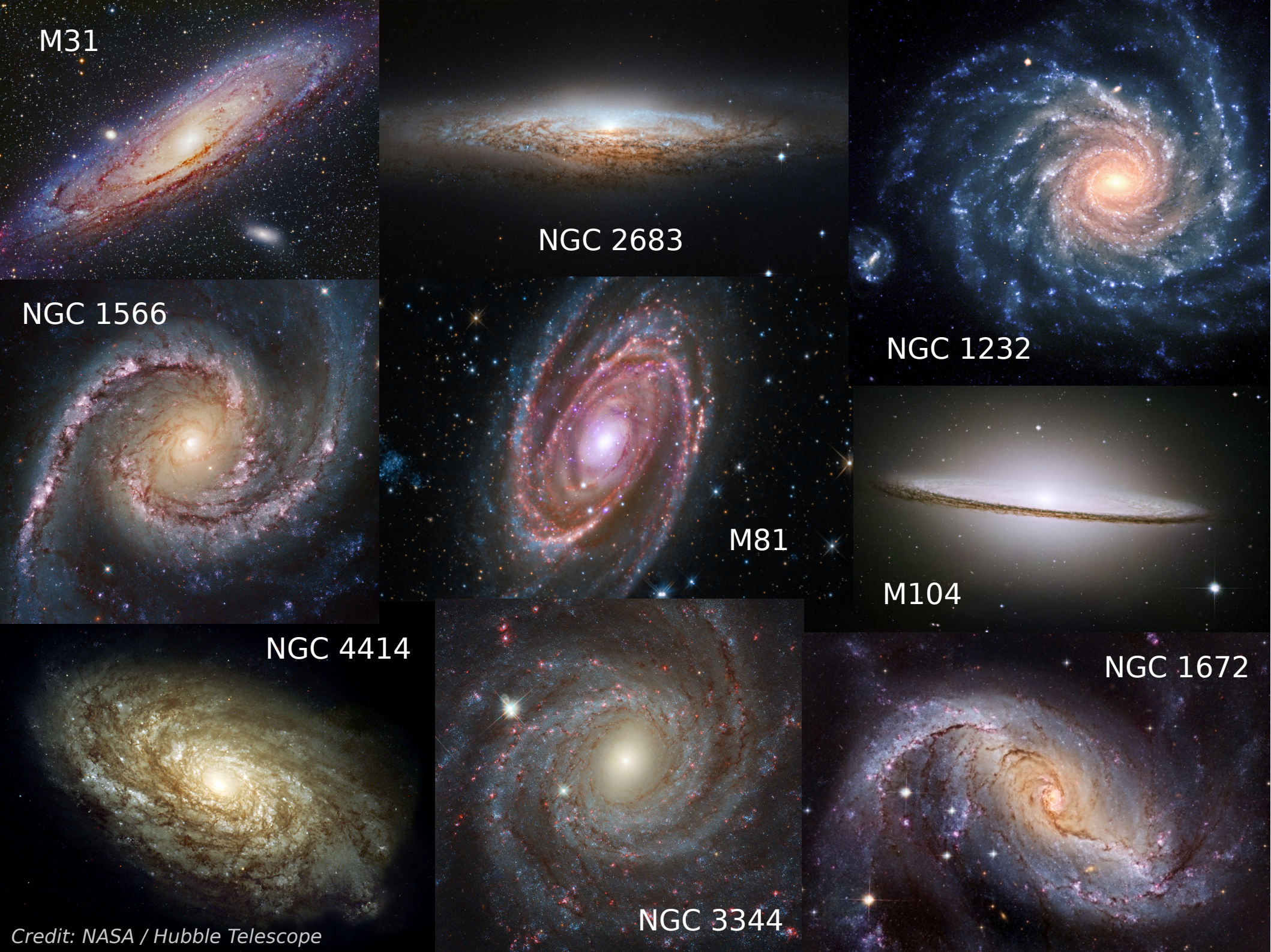
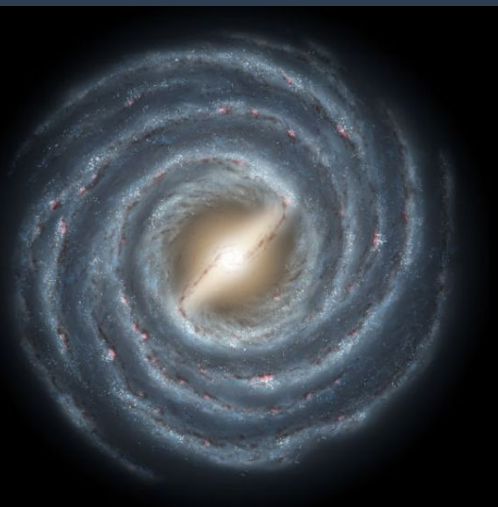
University of Warsaw

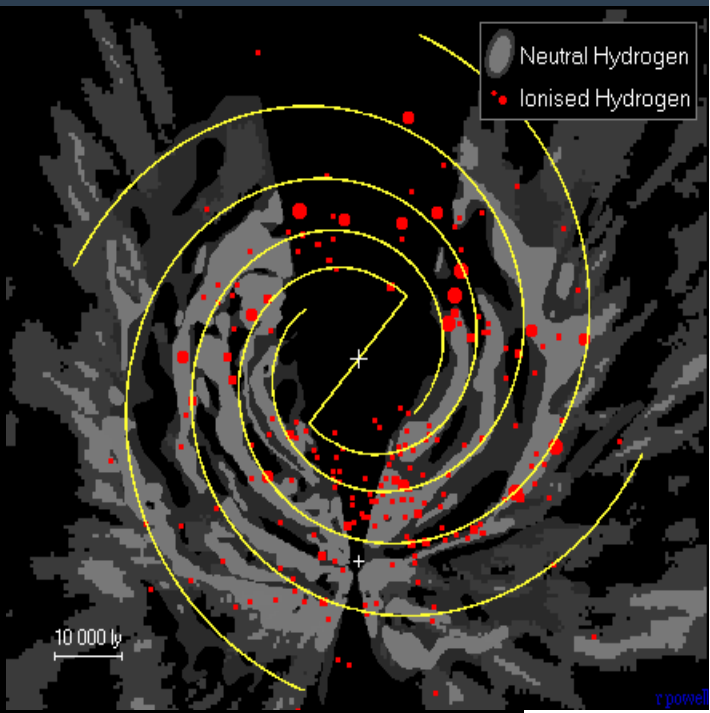
THE MILKY WAY

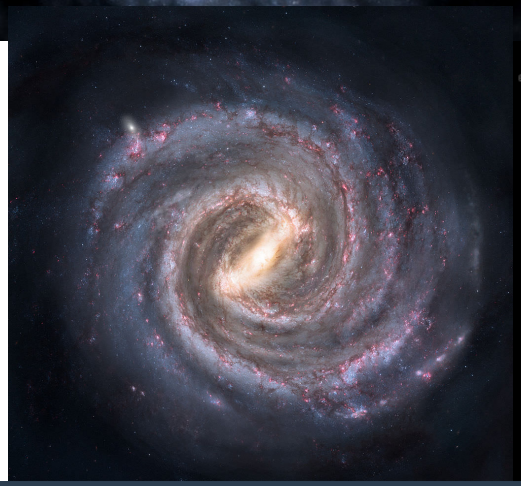
Credit: K. Ulaczyk / J. Skowron / OGLE

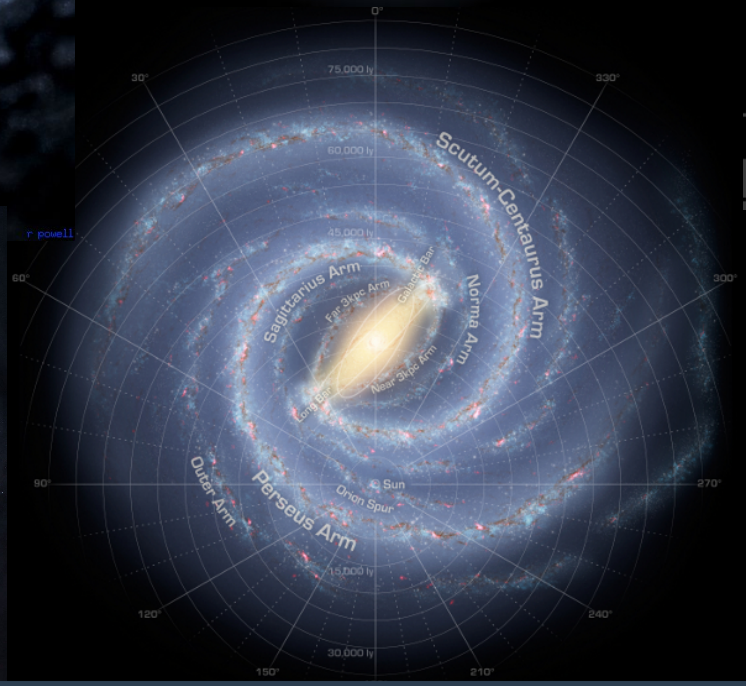

M31
NGC 2683
NGC 1232
NGC 1566
M81
M104
NGC 4414
NGC 3344
NGC 1672
Credit: NASA / Hubble Telescope

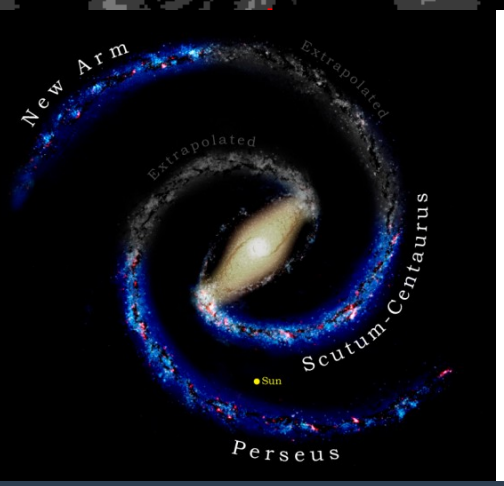
THE MILKY WAY





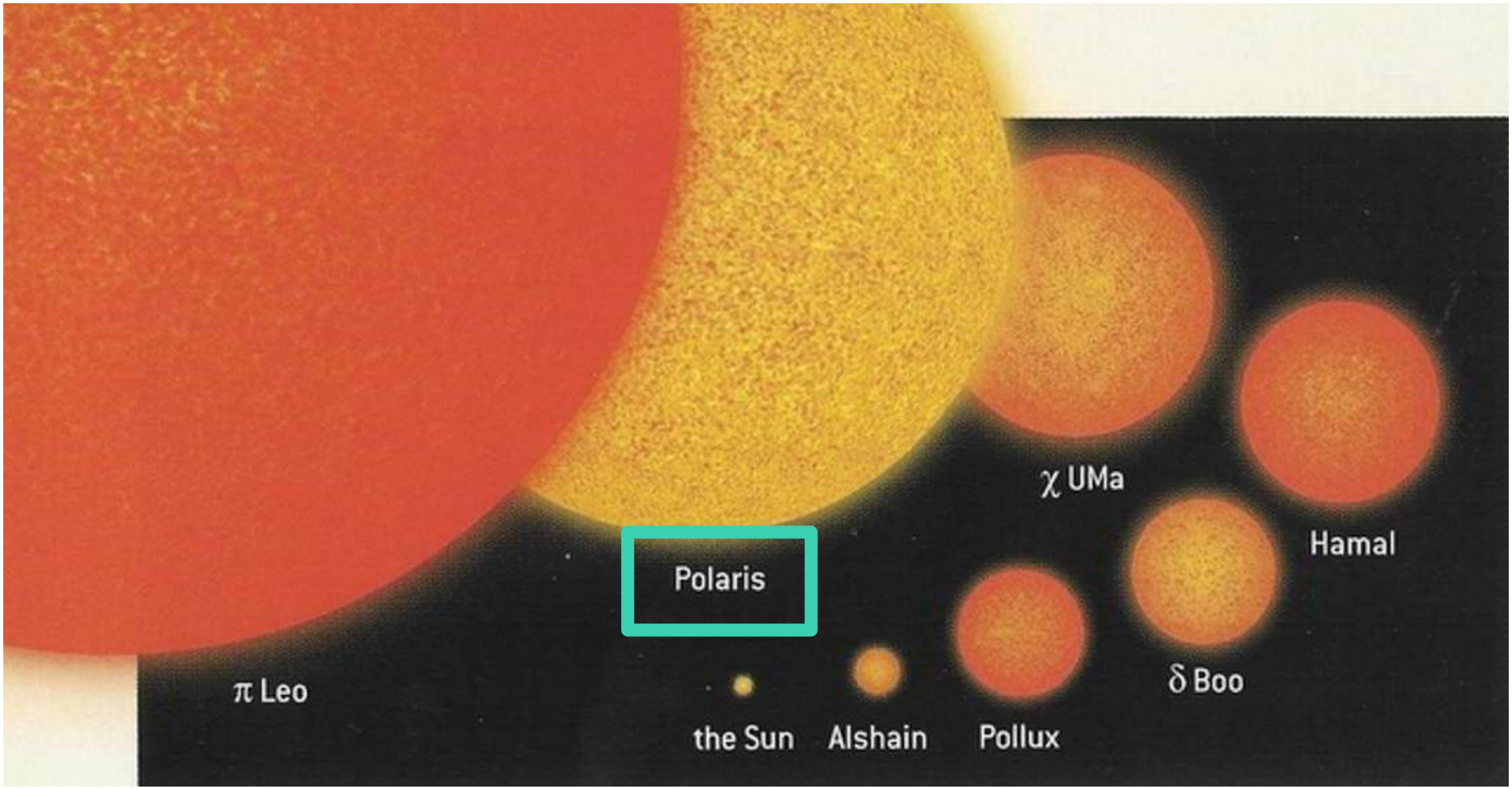






CLASSICAL CEPHEIDS

Bright young supergiants



Credit: wordlesstech.com

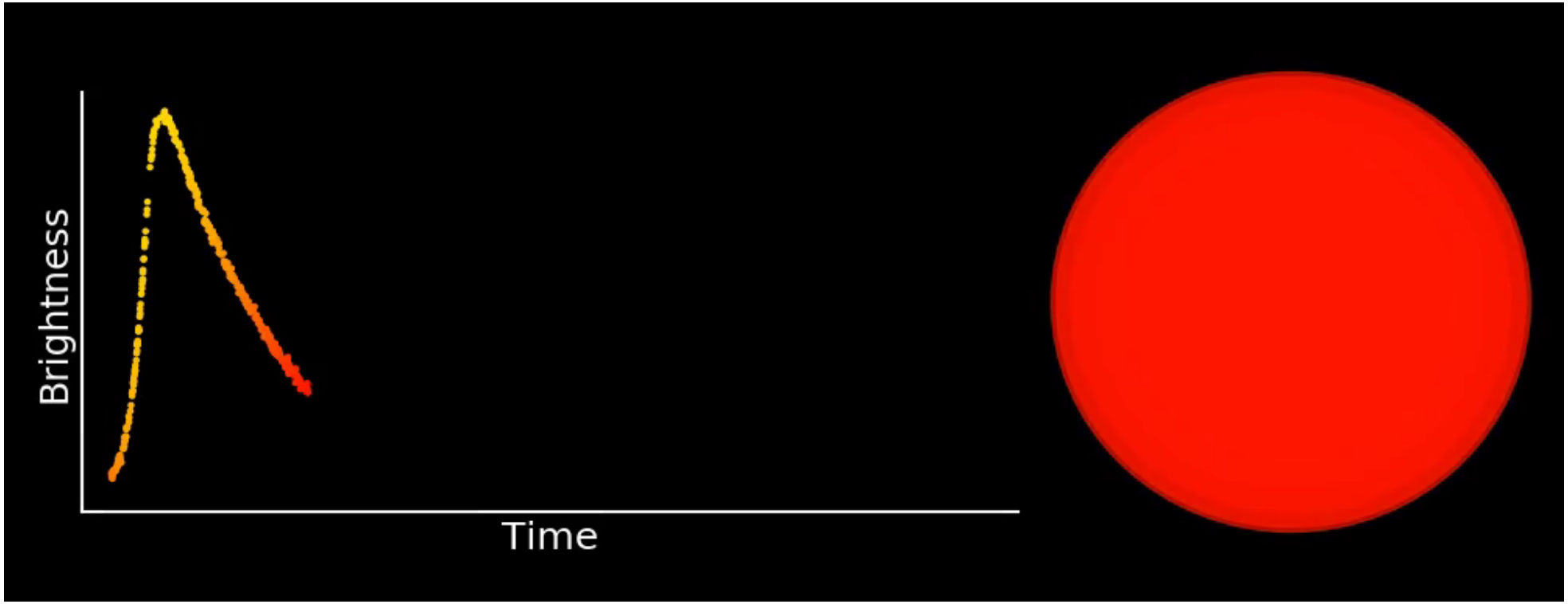
CLASSICAL CEPHEIDS

Bright young supergiants

Age:	**< 400 Myrs**
Mass:	**4 – 20 $M_\odot$**
Luminosity:	**10^2 – 10^4 $L_\odot$**
Pulsation period:	**1 – 100 days**

CLASSICAL CEPHEIDS

Stars pulsating radially



Credit: J. Skowron, P. Mróz / OGLE

CLASSICAL CEPHEIDS

Why are they good for mapping our Galaxy?

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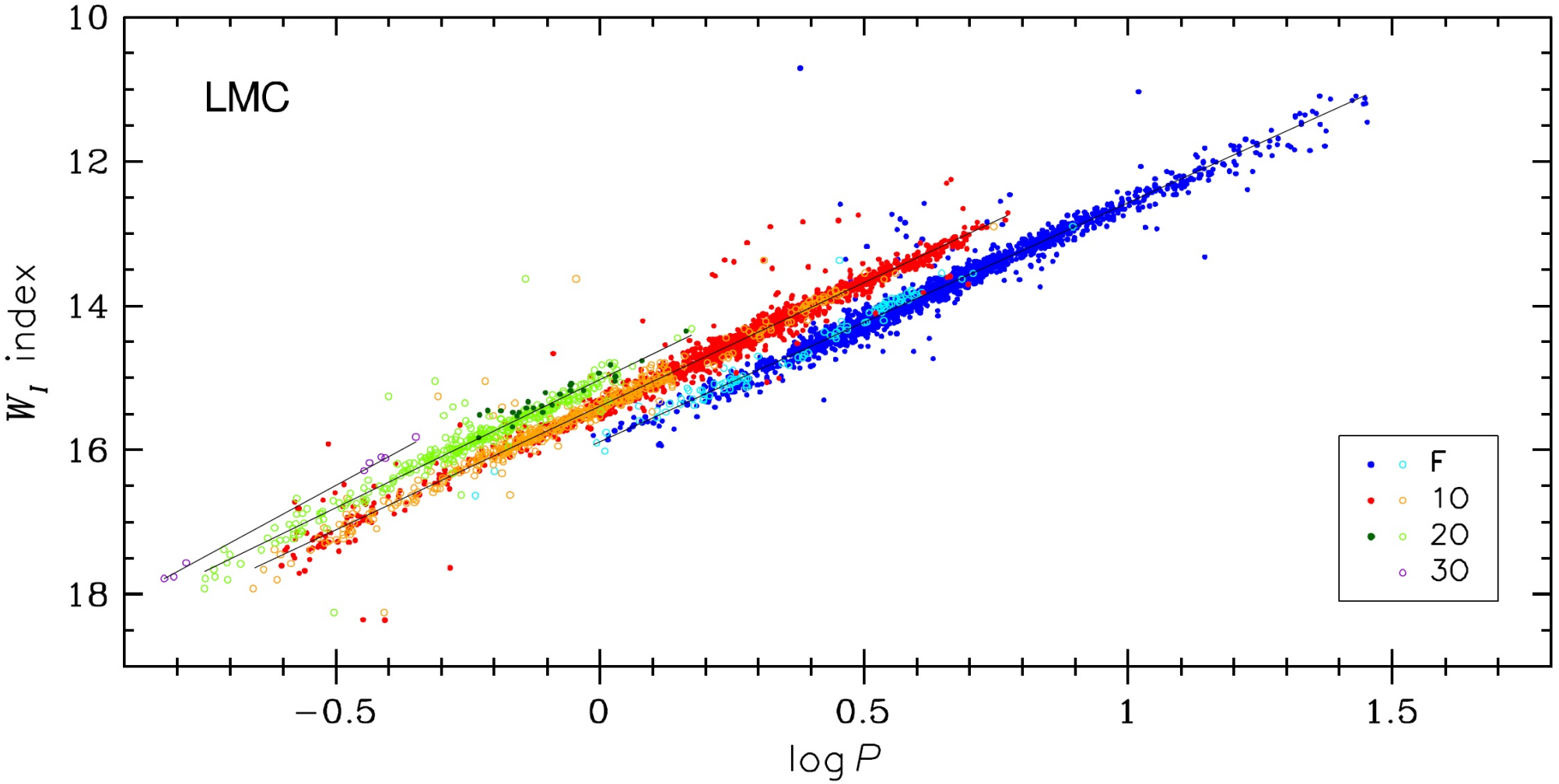
OBEY PERIOD-LUMINOSITY RELATION

→ allow for direct, model independent distance determination (standard candles)

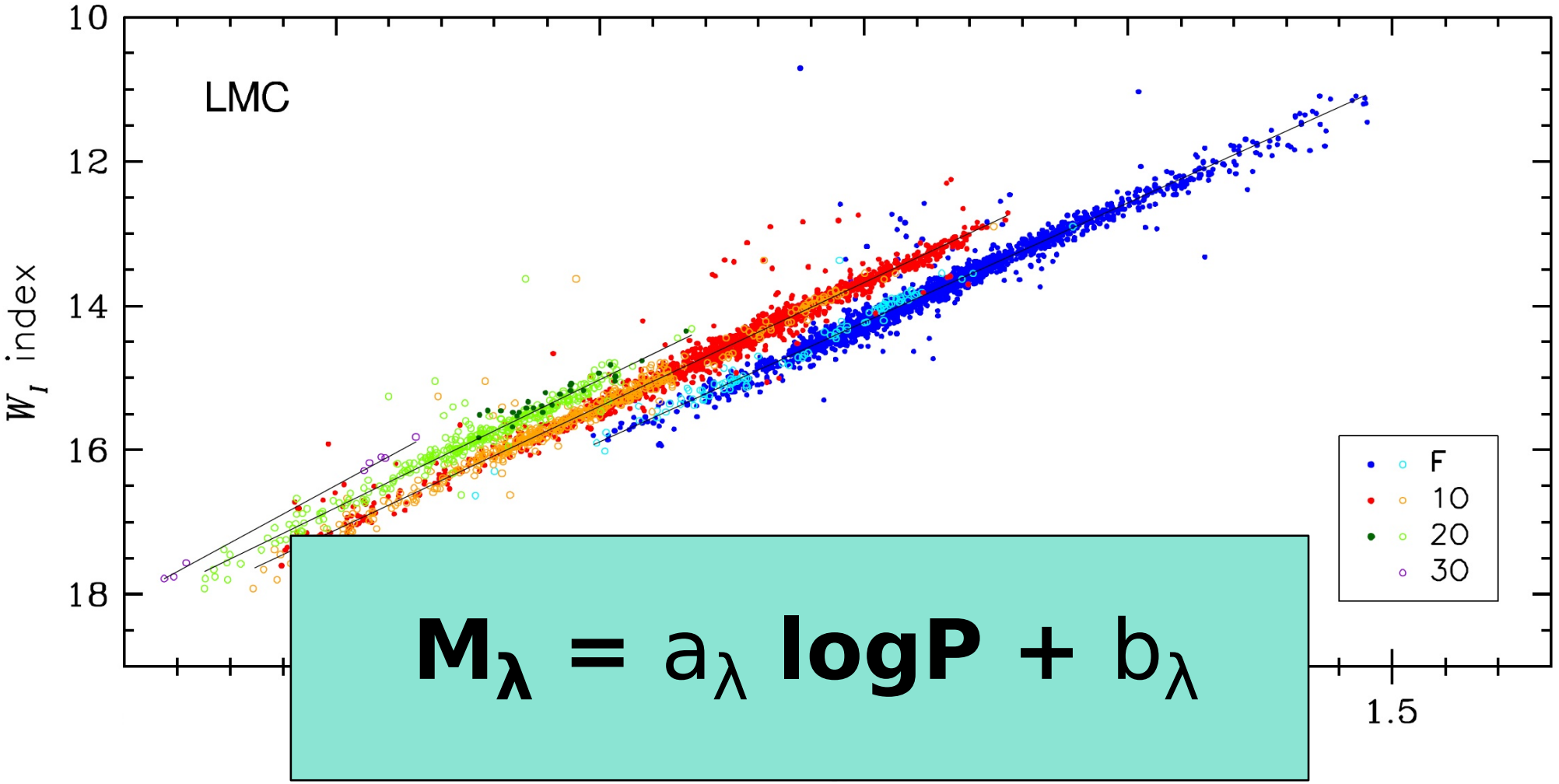
PERIOD – LUMINOSITY RELATION



Soszyński et al. 2015

$W_I = I-1.55(V-I)$

PERIOD – LUMINOSITY RELATION



$$M_\lambda = a_\lambda \log P + b_\lambda$$

Soszyński et al. 2015

$W_I = I-1.55(V-I)$

DISTANCE DETERMINATION

We have:

P – pulsation period

m_λ – observed magnitude

A_λ – interstellar extinction

- we then calculate absolute magnitude from **P** based on P-L relation:

$$\mathbf{M_\lambda} = a_\lambda \mathbf{logP} + b_\lambda$$

- and get the distance:

$$\mathbf{d_\lambda} = 10^{0.2(\mathbf{(m_\lambda - A_\lambda) - M_\lambda})+1} \text{ [parsecs]}$$

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VERY BRIGHT

→ can be detected at extragalactic distances, and through obscuring interstellar gas and dust within our Galaxy

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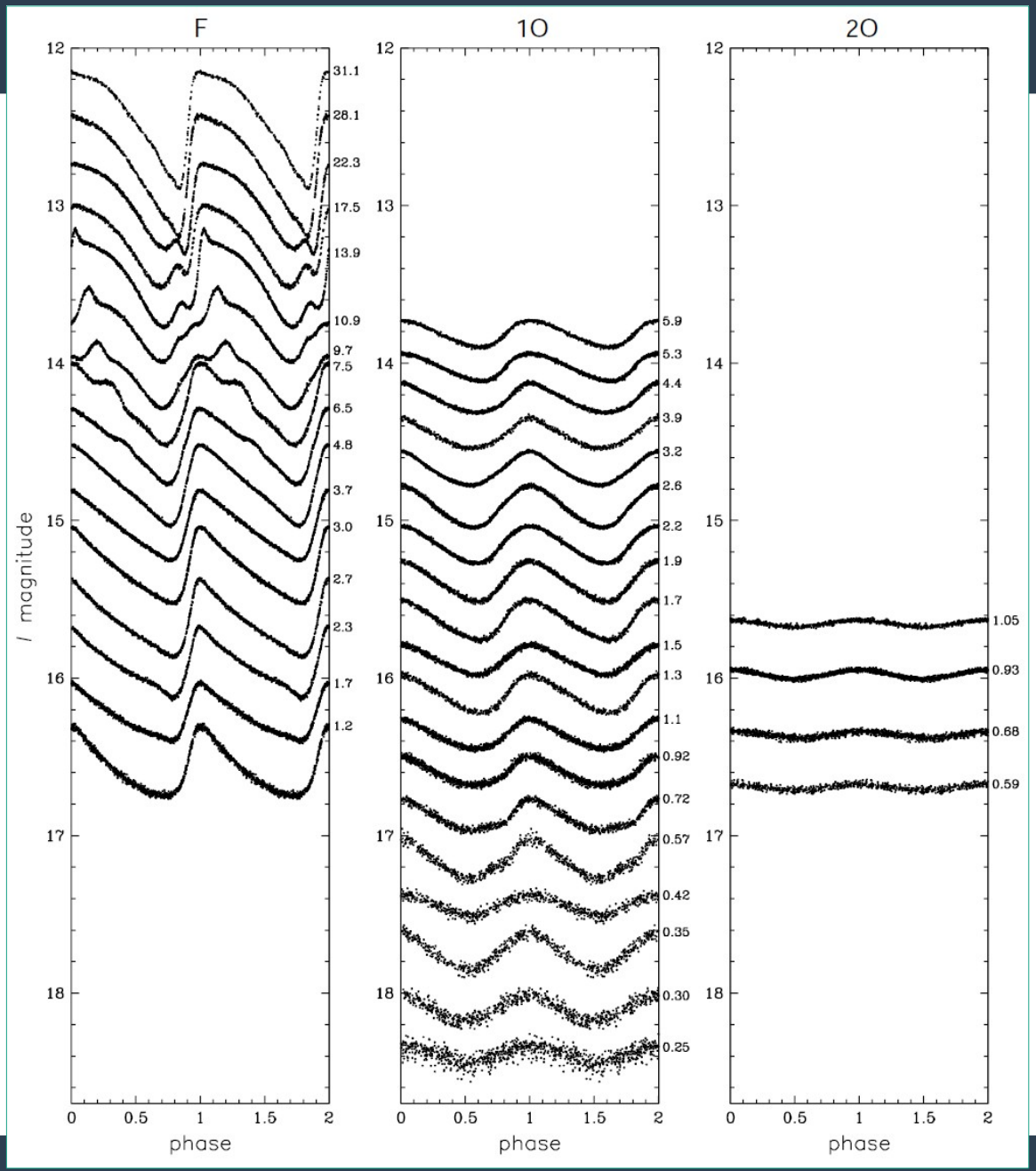
FAIRLY EASY TO SEPARATE FROM OTHER VARIABLES

→ given several years of observations and hundreds of data points

CLASSICAL CEPHEID LIGHT CURVES

Distinct shape for the given period (in optical bands)



Soszynski et al. 2008

DISTANCE DETERMINATION

A_λ – the biggest uncertainty

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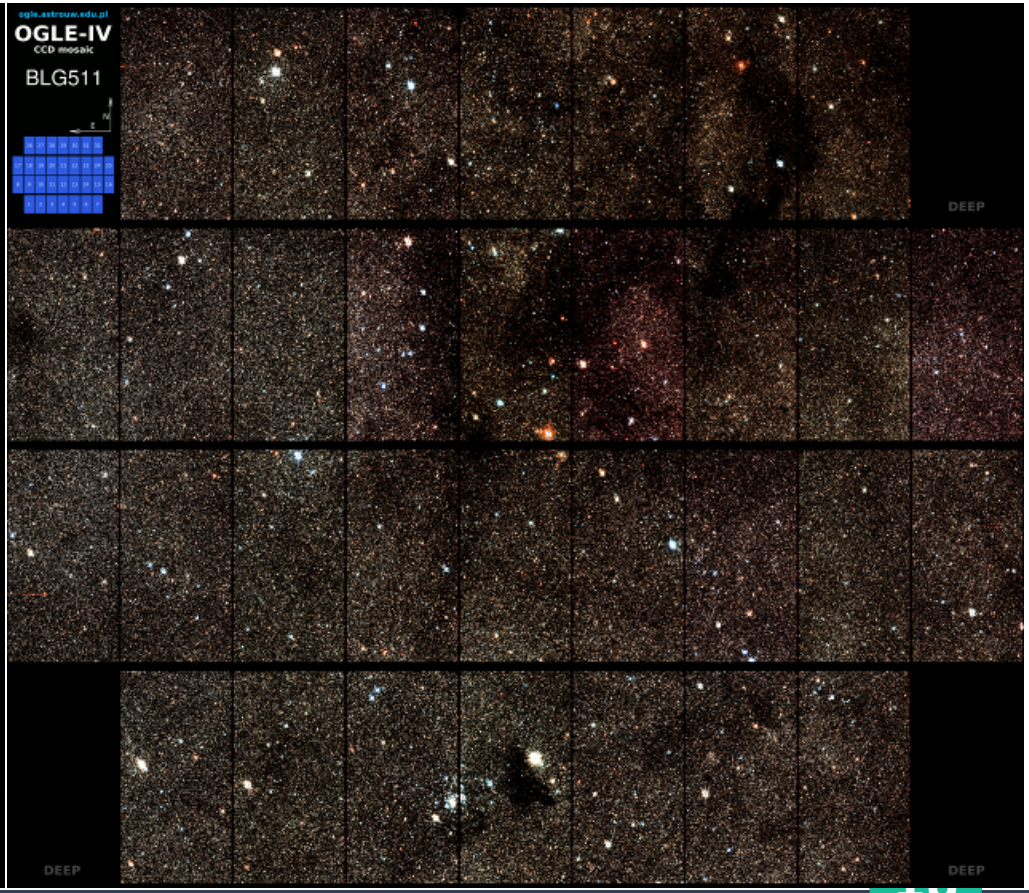
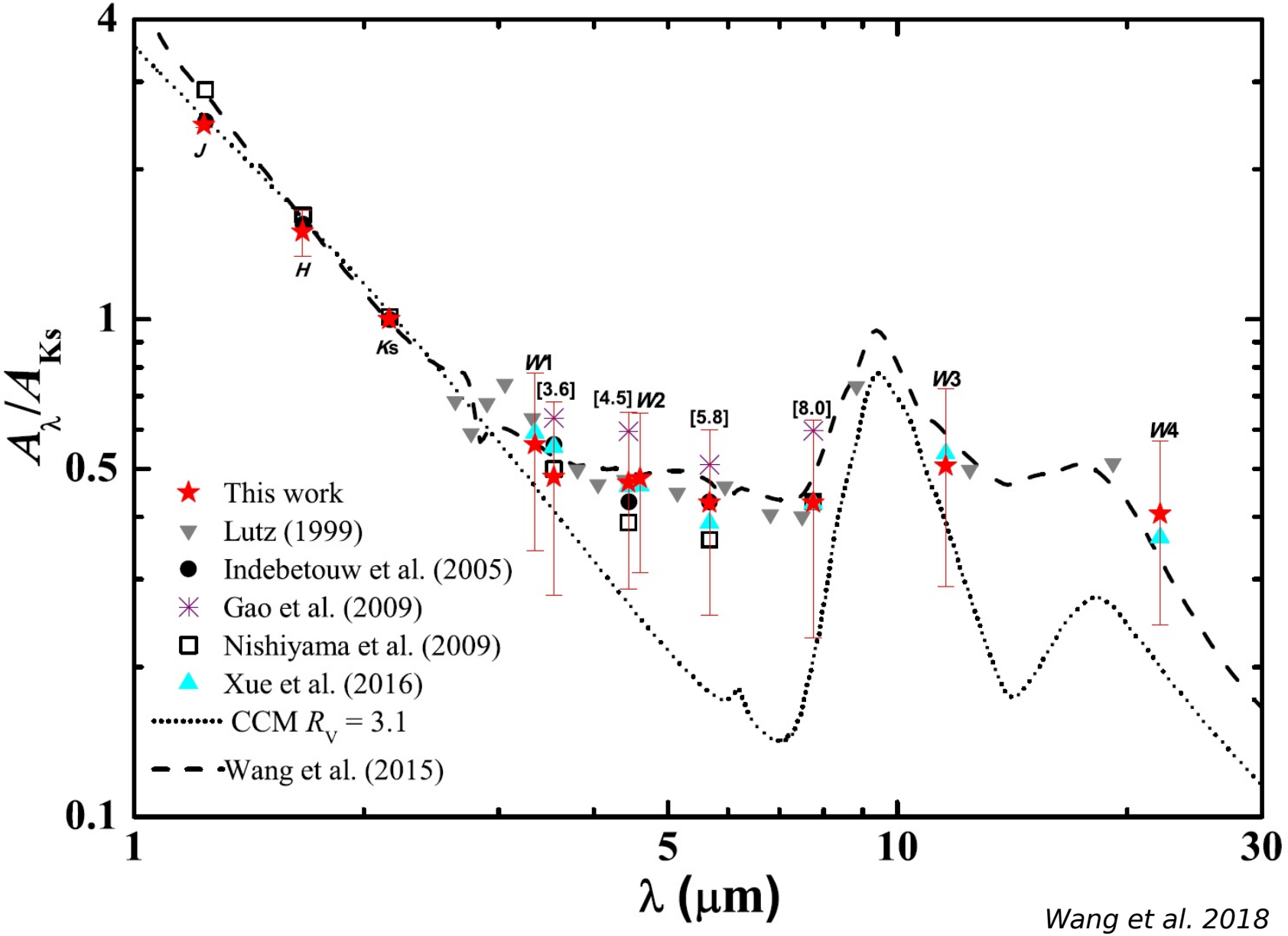


DISTANCE DETERMINATION

A_λ – the biggest uncertainty

- using **mid-infrared** data from space (*Spitzer, WISE*) and mid-infrared P-L relations minimizes extinction

THE EXTINCTION CURVE



Wang et al. 2018

DISTANCE DETERMINATION

A_λ – the biggest uncertainty

- using **mid-infrared** data from space (*Spitzer, WISE*) and mid-infrared P-L relations minimizes extinction
- available extinction maps provide distance-dependent extinction values in the infrared bands

DISTANCE DETERMINATION

distance and extinction are correlated → calculating distance is an iterative process

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- calculate distance to each object separately for every available Spitzer and WISE band ($\mathbf{d_\lambda}$, $\lambda \in$ [W1...W4,S1...S4]) (initially assuming no extinction)

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- extract $\mathbf{A_\lambda}$ from IR extinction map, for calculated distance **d**

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- extract $\mathbf{A_\lambda}$ from IR extinction map, for calculated distance **d**
- recalculate distances $\mathbf{d_\lambda}$ and their mean: **d**
- extract new value of $\mathbf{A_\lambda}$

...

THE CEPHEID SAMPLE

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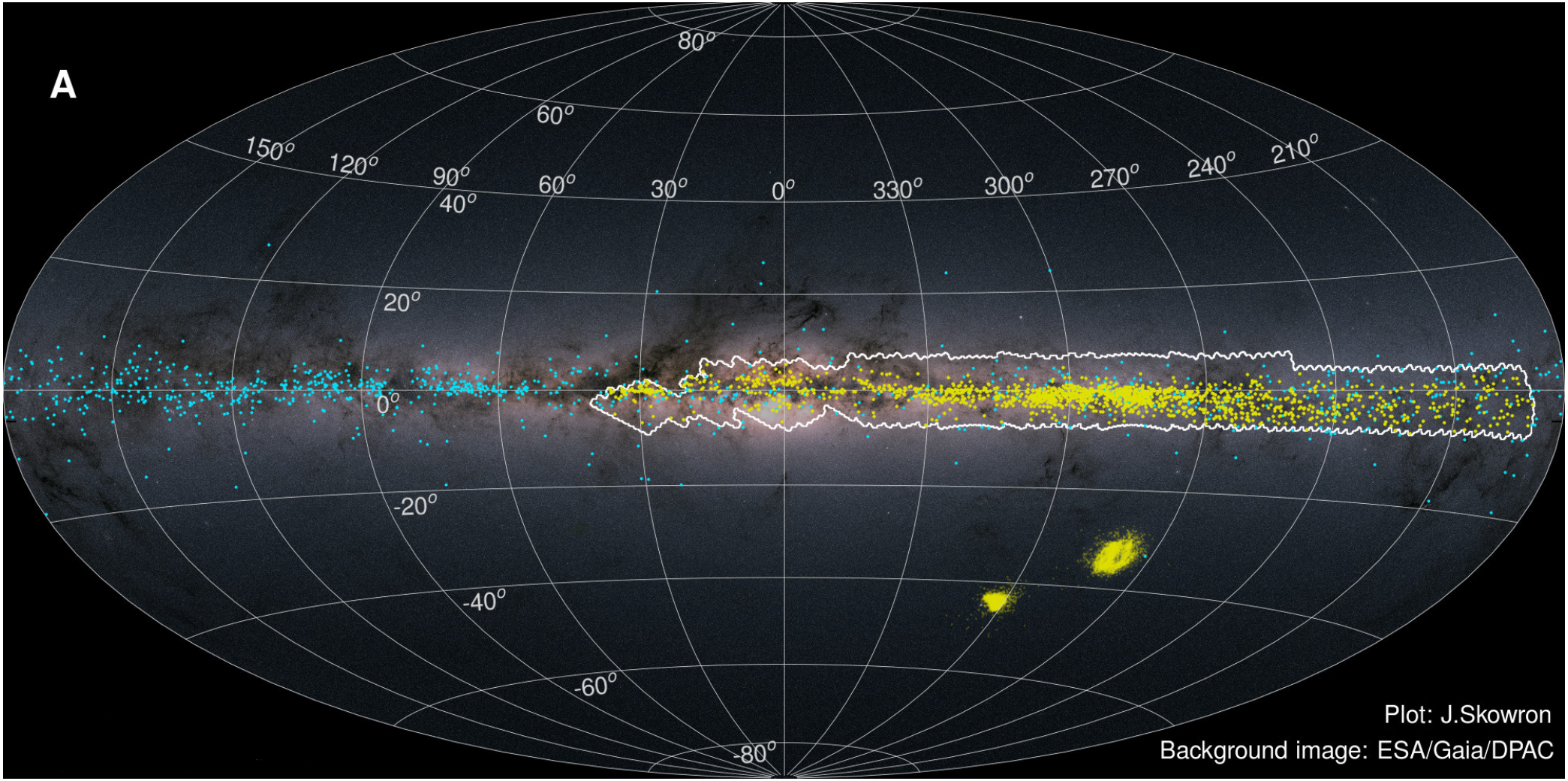

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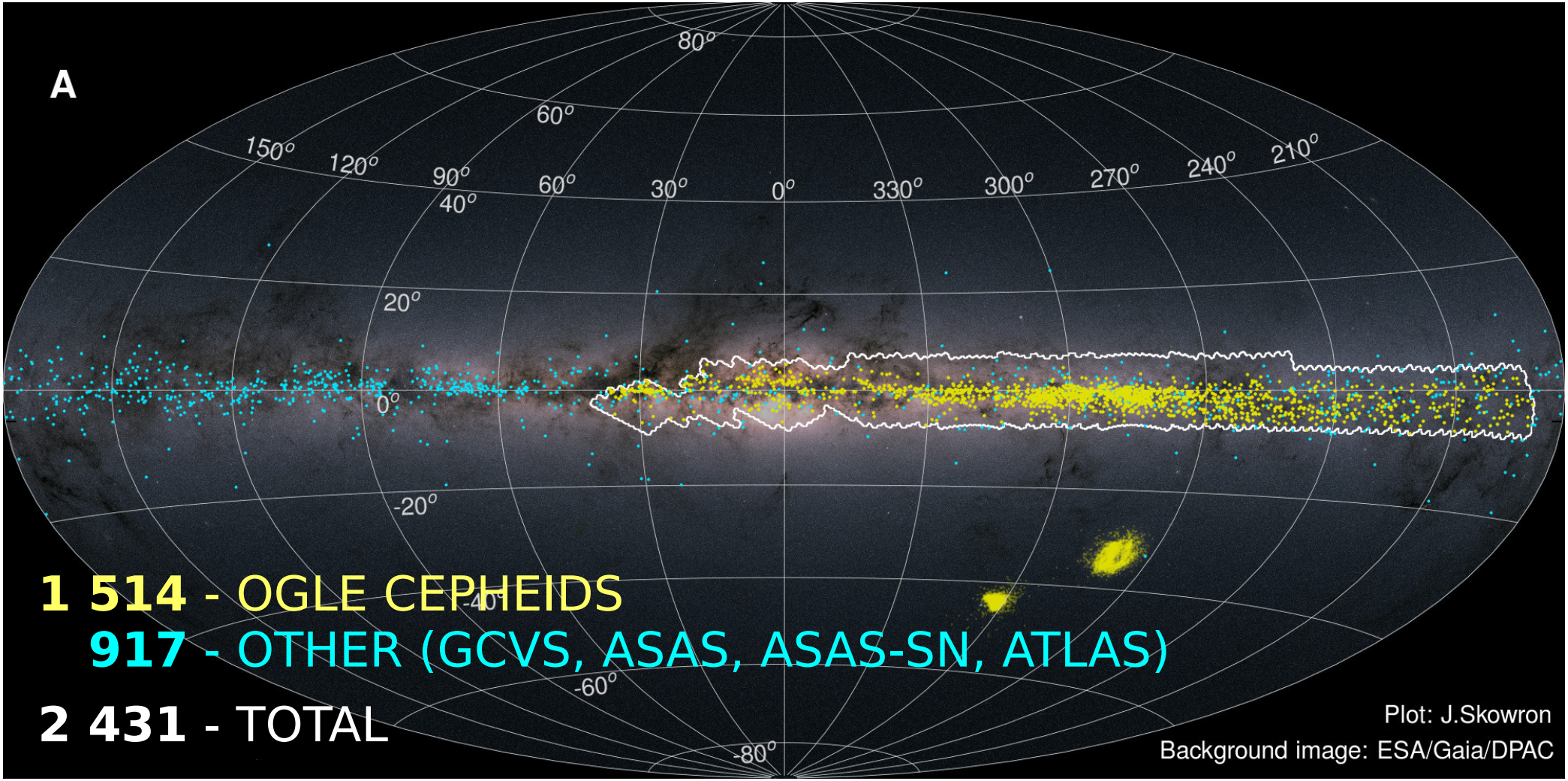

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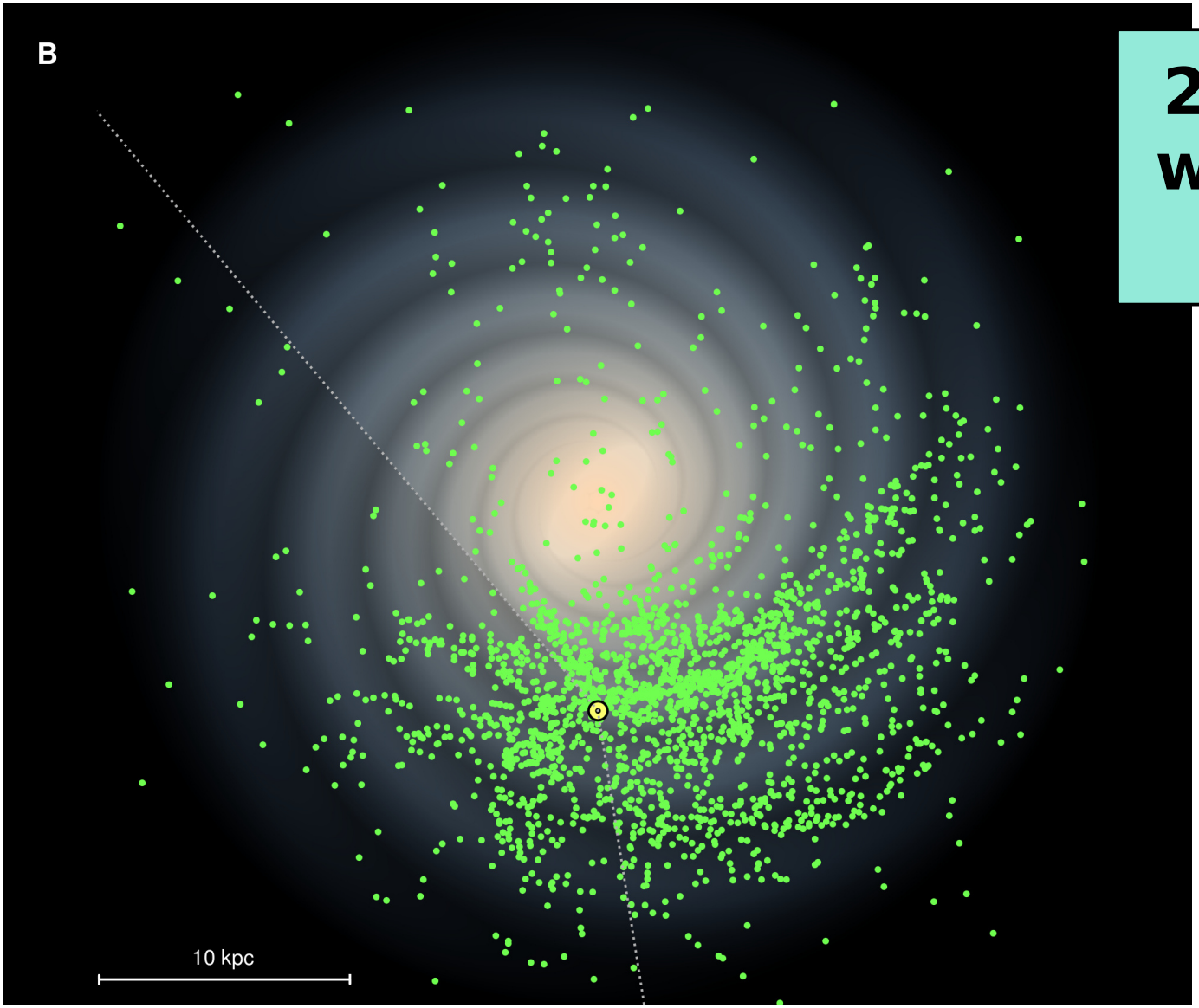
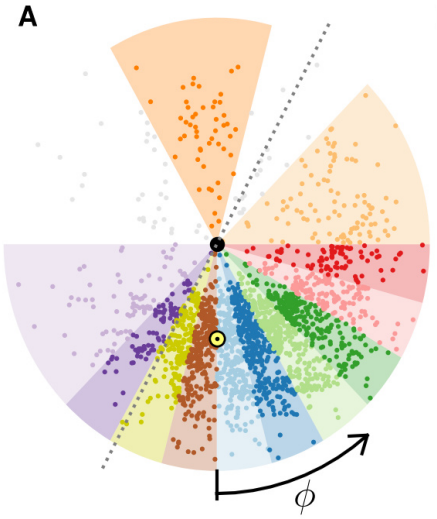


2222 cepheids with measured distances

Skowron et al. 2019

THE WARP



Skowron et al. 2019

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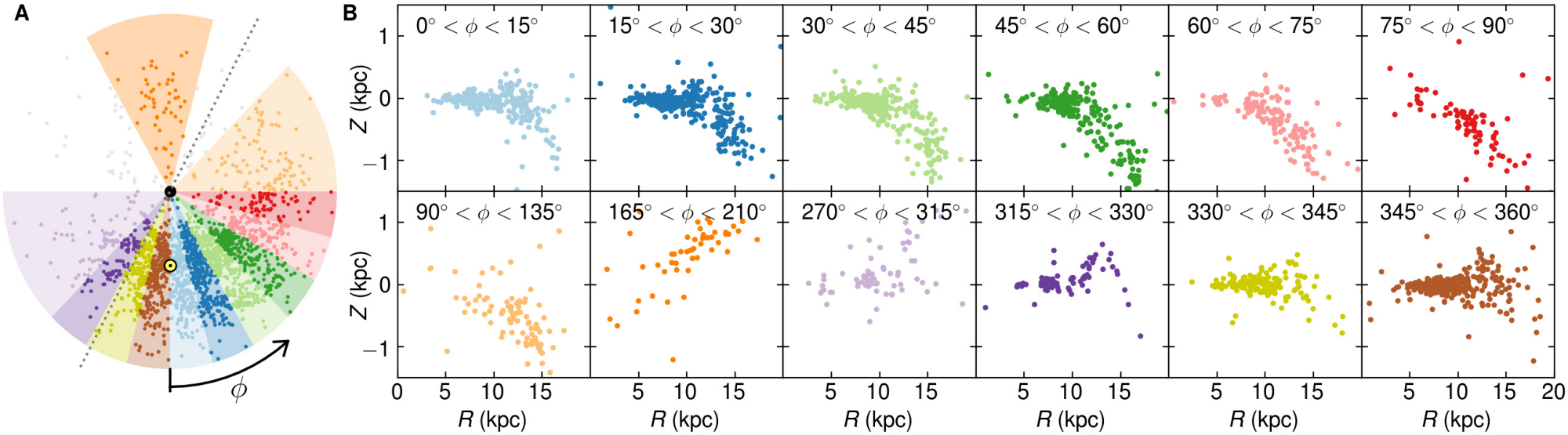

Skowron et al. 2019

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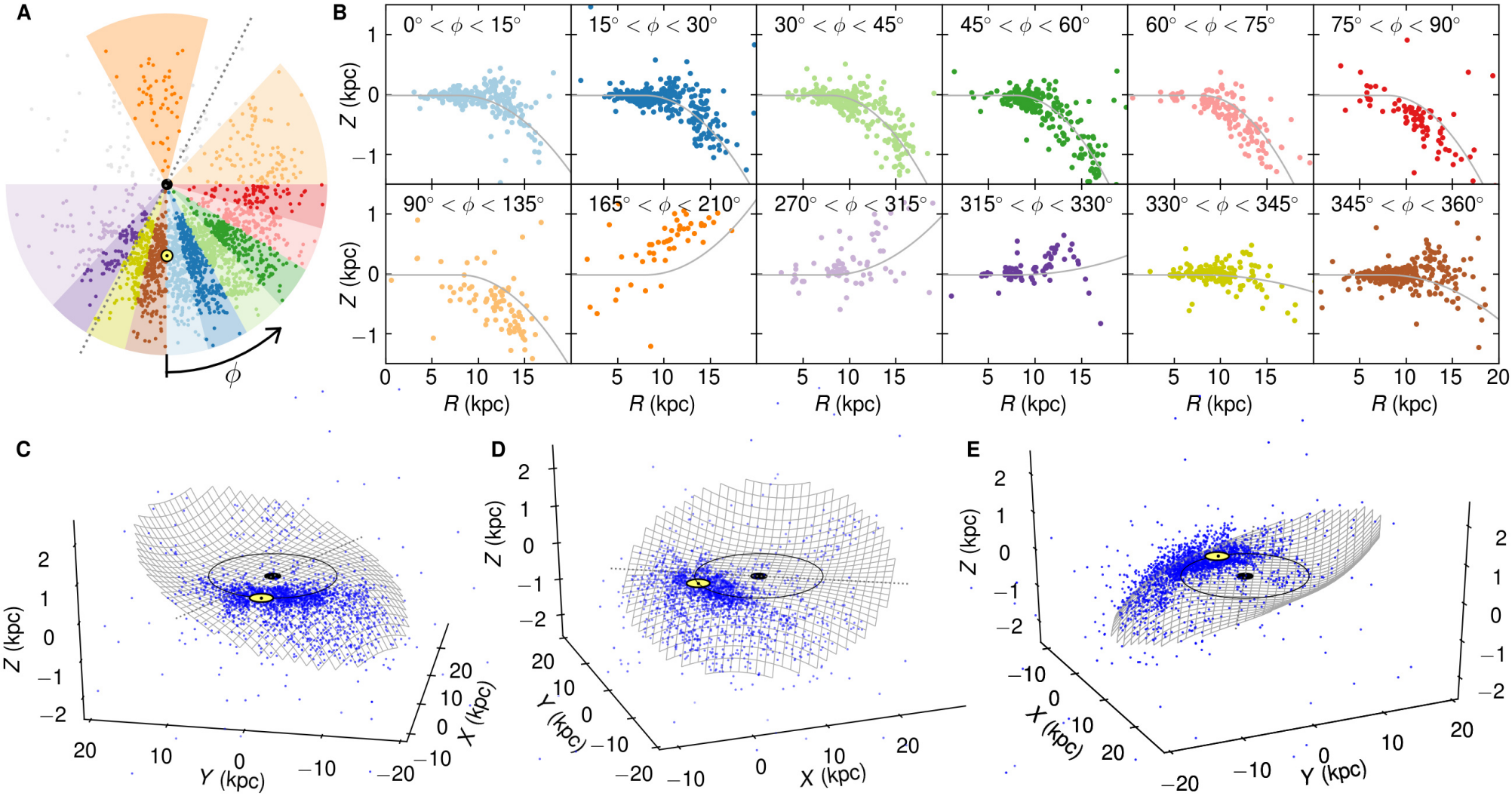

Skowron et al. 2019

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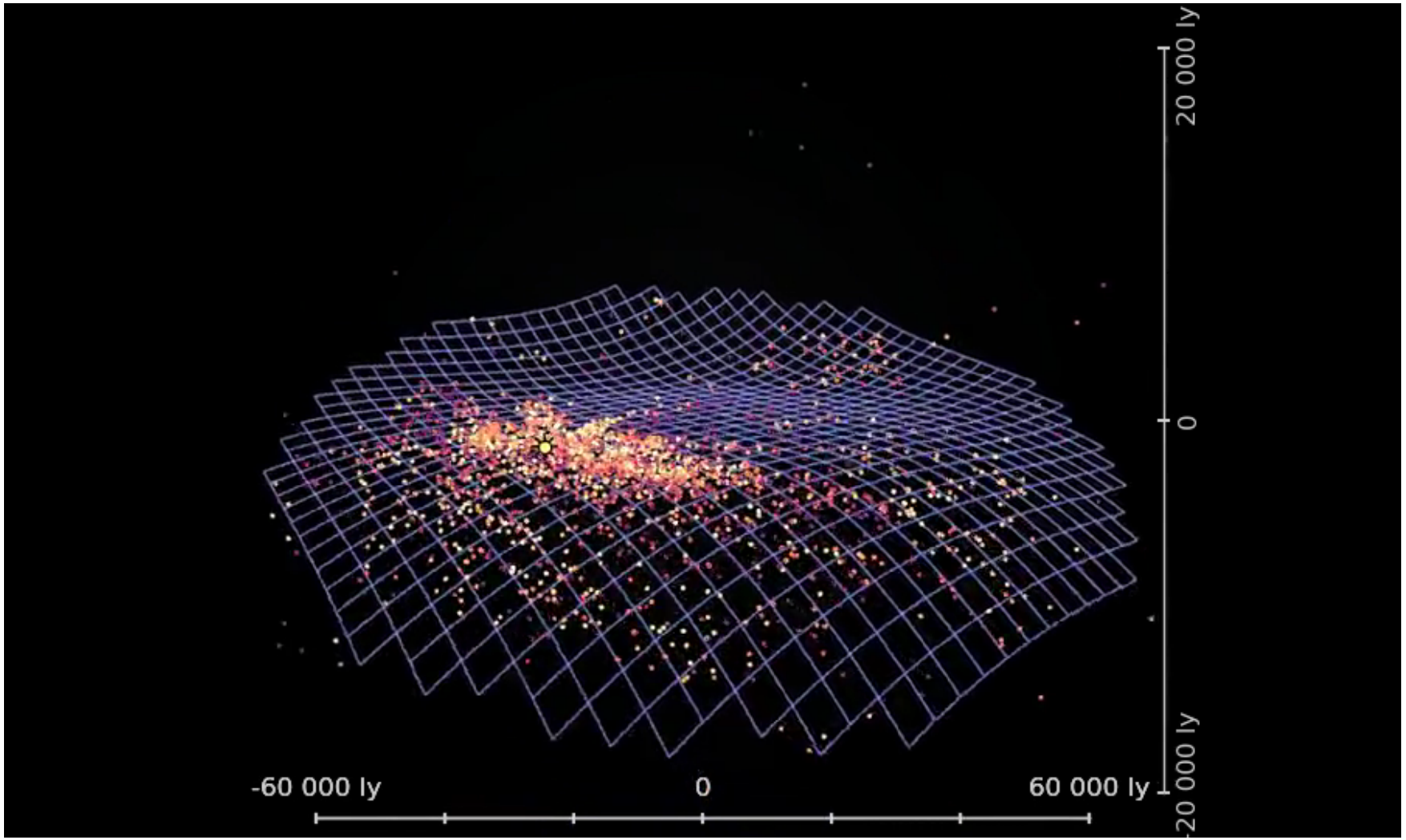

Credit:
J. Skowron / OGLE

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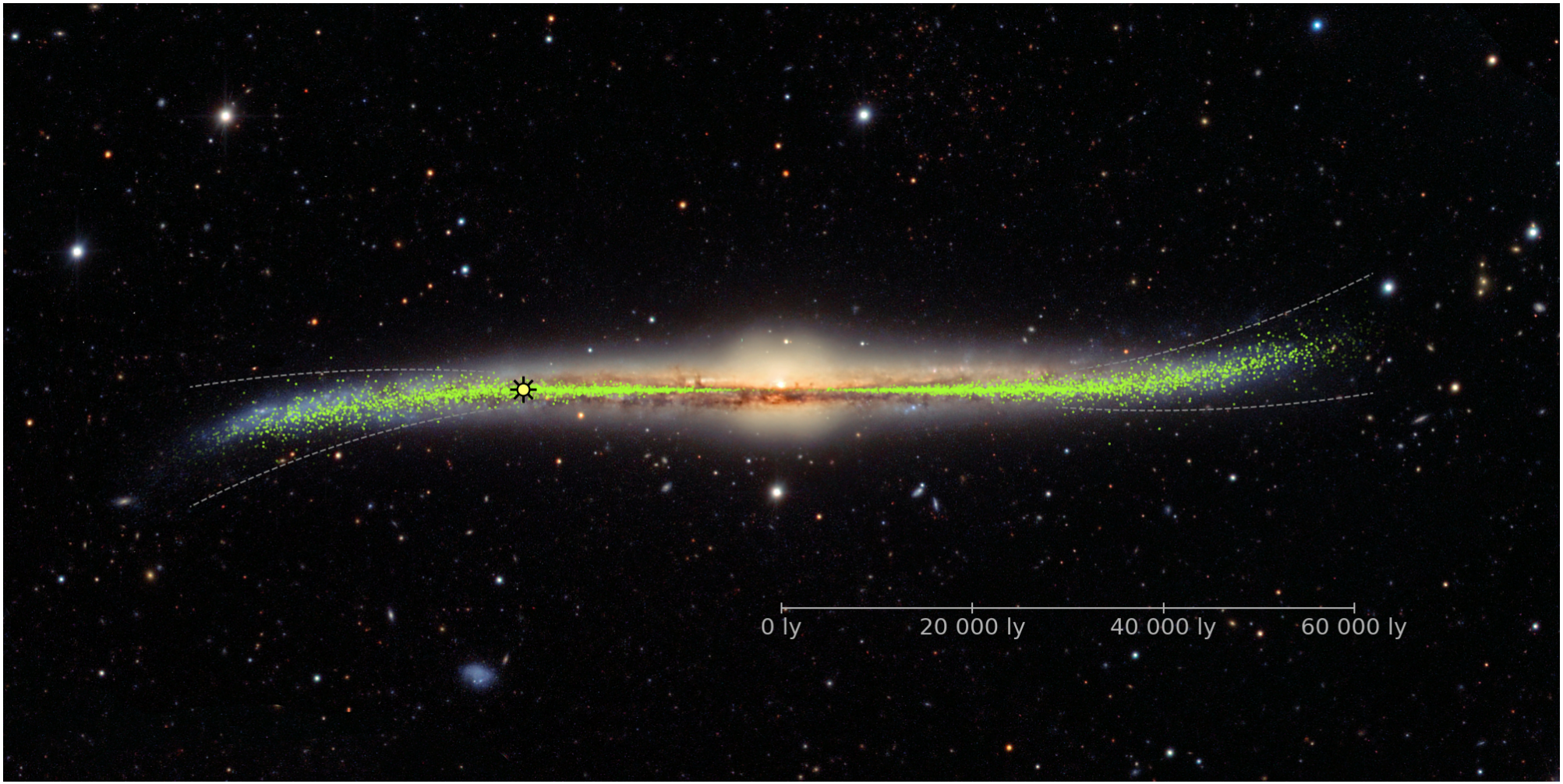
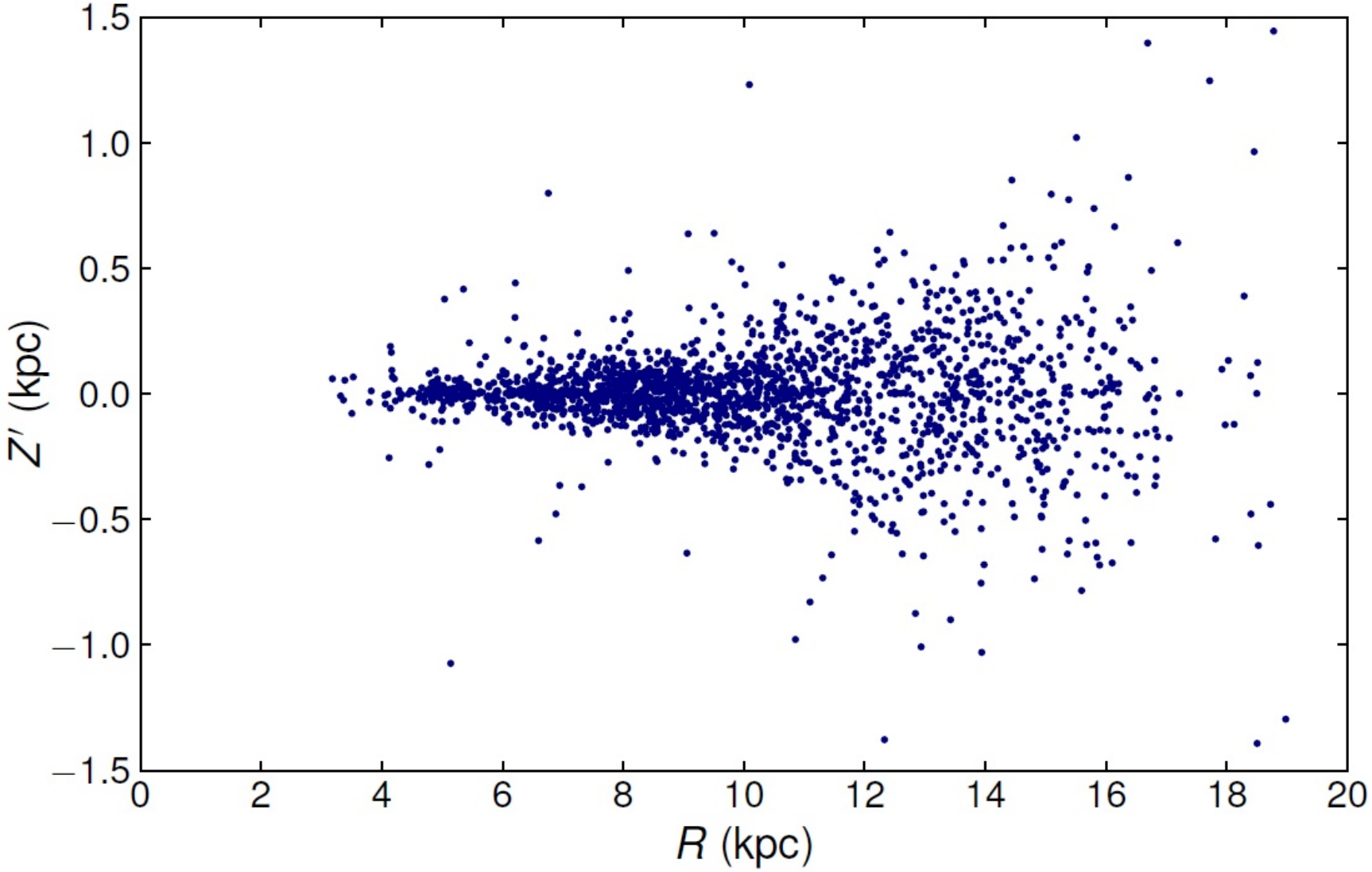


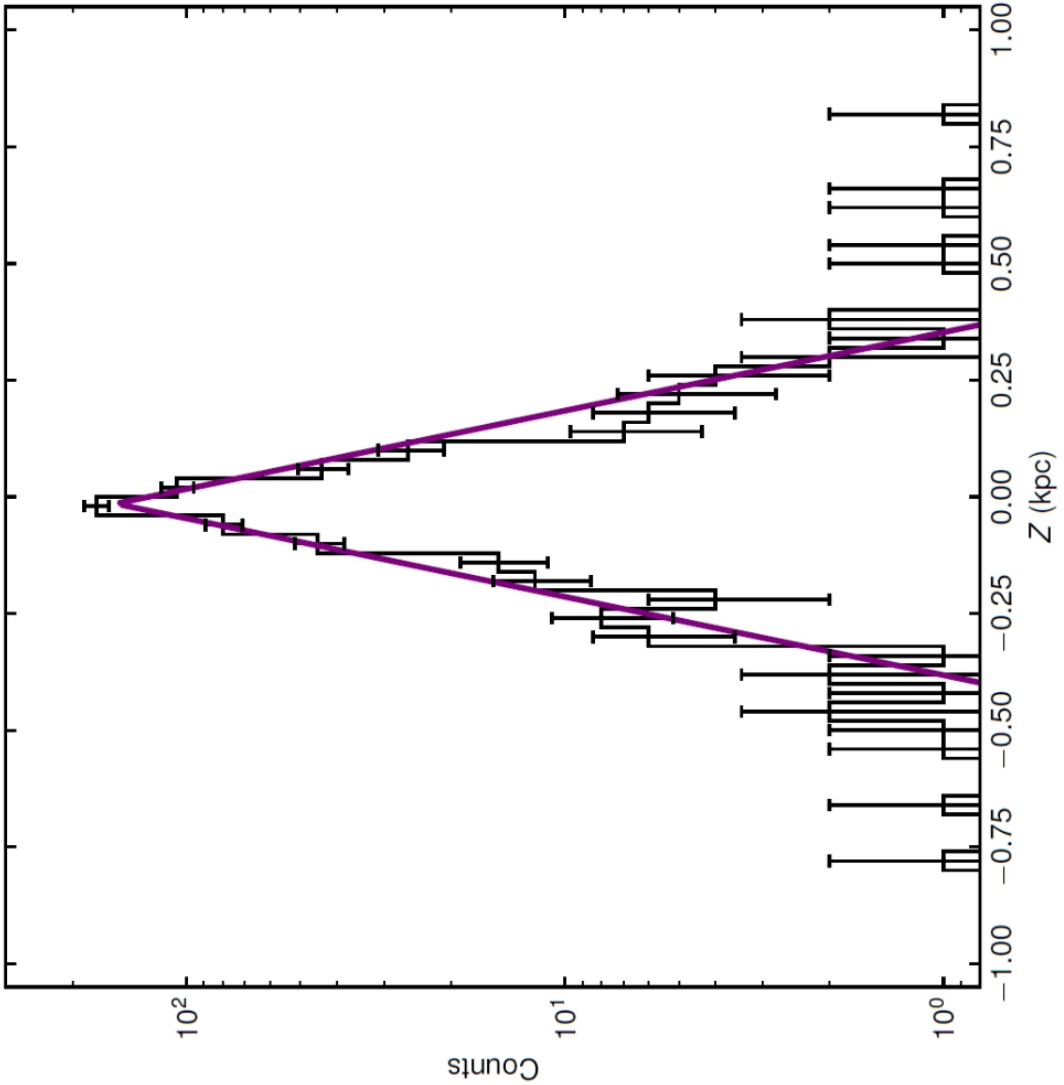
Credit: J. Skowron / OGLE

THE FLARING



Skowron et al. 2019

DISK SCALE HEIGHT



H = 73.5 ± 3.2 pc
z_0 = 14.5 ± 3.0 pc

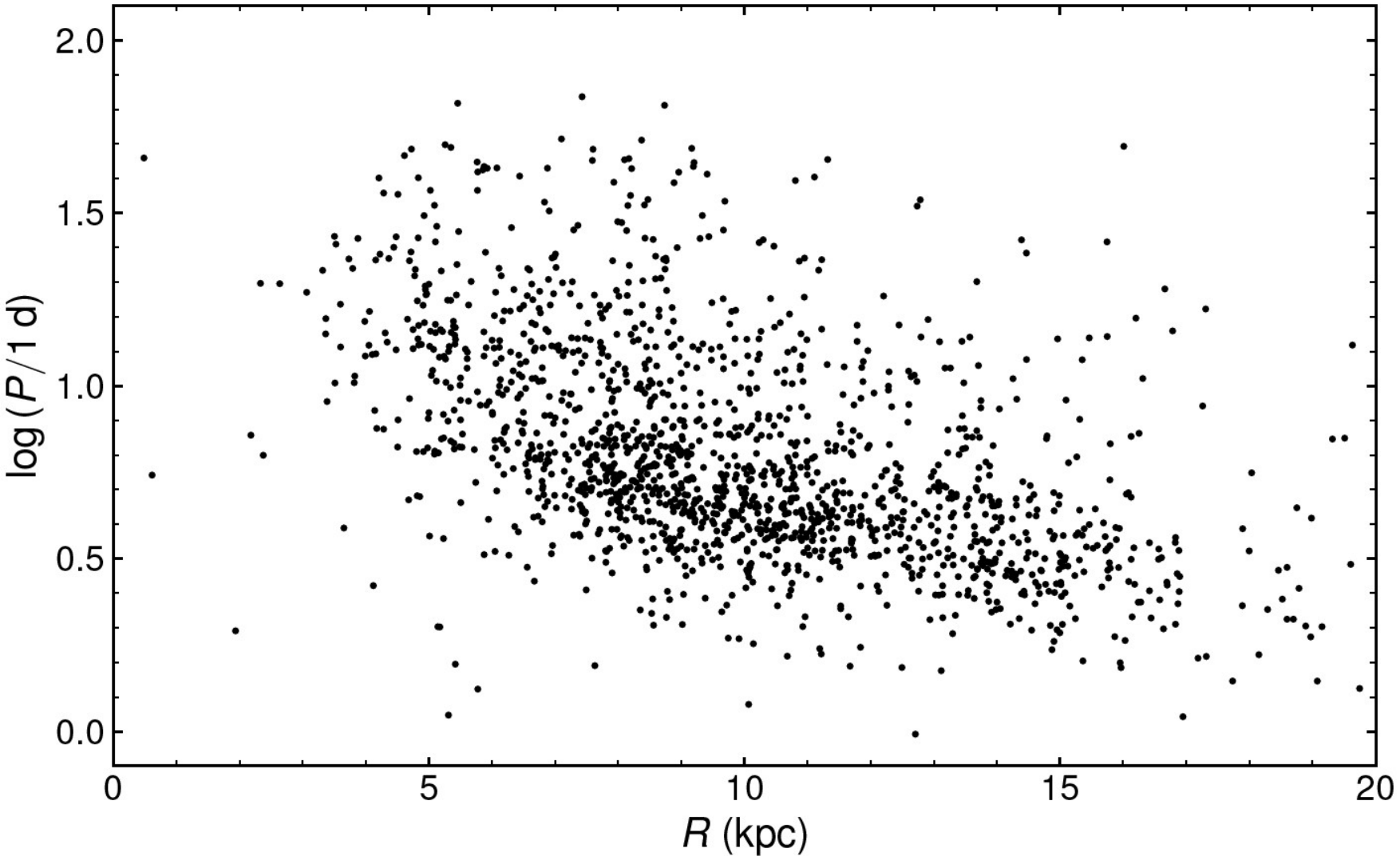
Skowron et al. 2019

THE MILKY WAY DISK IN NUMBERS

- warping starts at ~**25,000 ly** from the Galactic center
- stars in the outer disk are up to **4,500 ly** away from the Galactic plane
- the disk thickness is not constant – about **500 ly** near the Sun and over **3,000 ly** near the edges
- the Sun is displaced by ~**50 ly** from the plane

(1 pc = 3.26 ly = 31 x 10^{15} m)

PULSATION PERIODS



Skowron et al. 2019

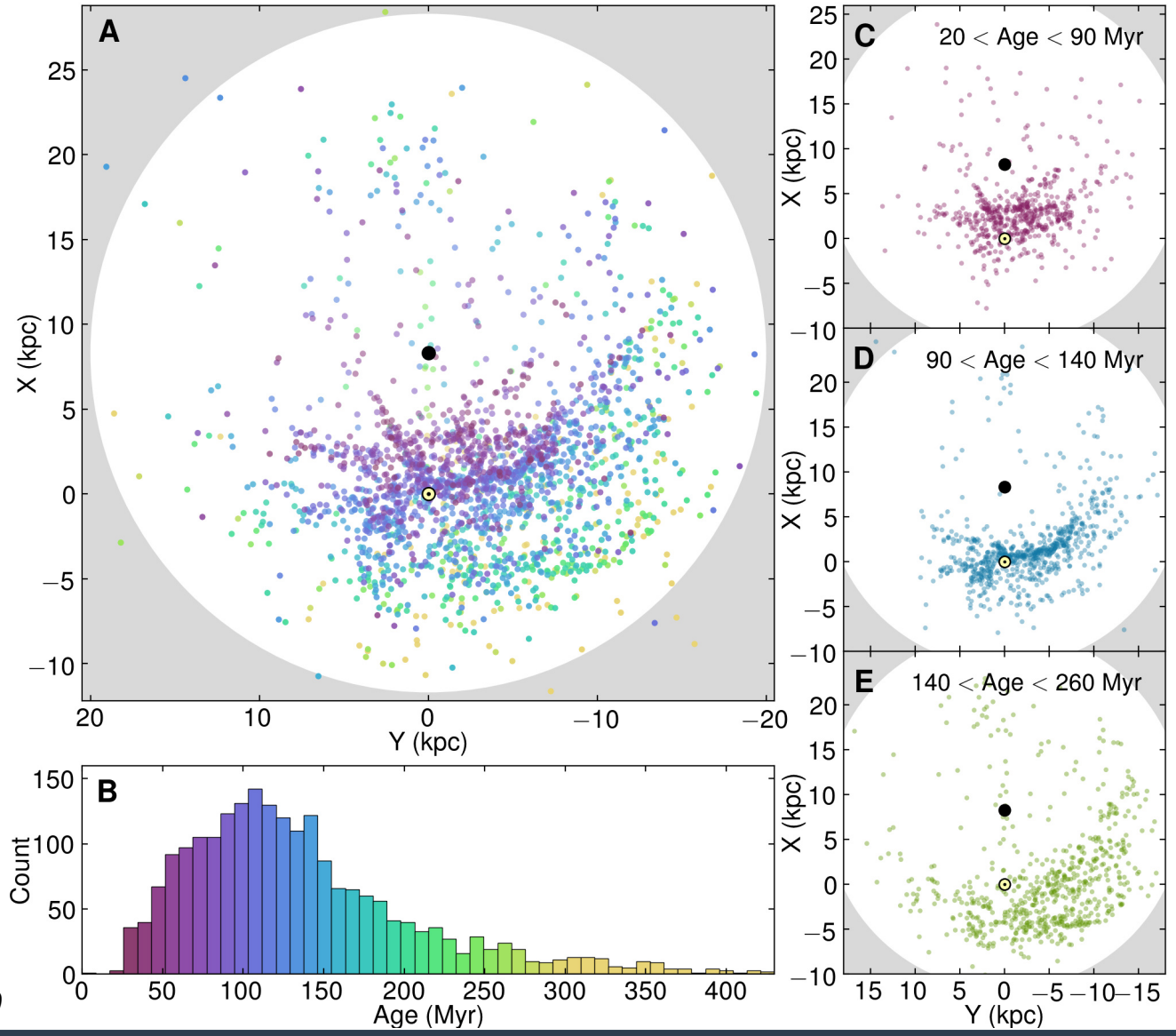
THE AGES

period–age relation: $\log(\mathbf{Age}) = a - b \log \mathbf{P}$

→ **older** cepheids pulsate **faster** than the younger

→ there might be an age distribution in the Galaxy

THE AGES



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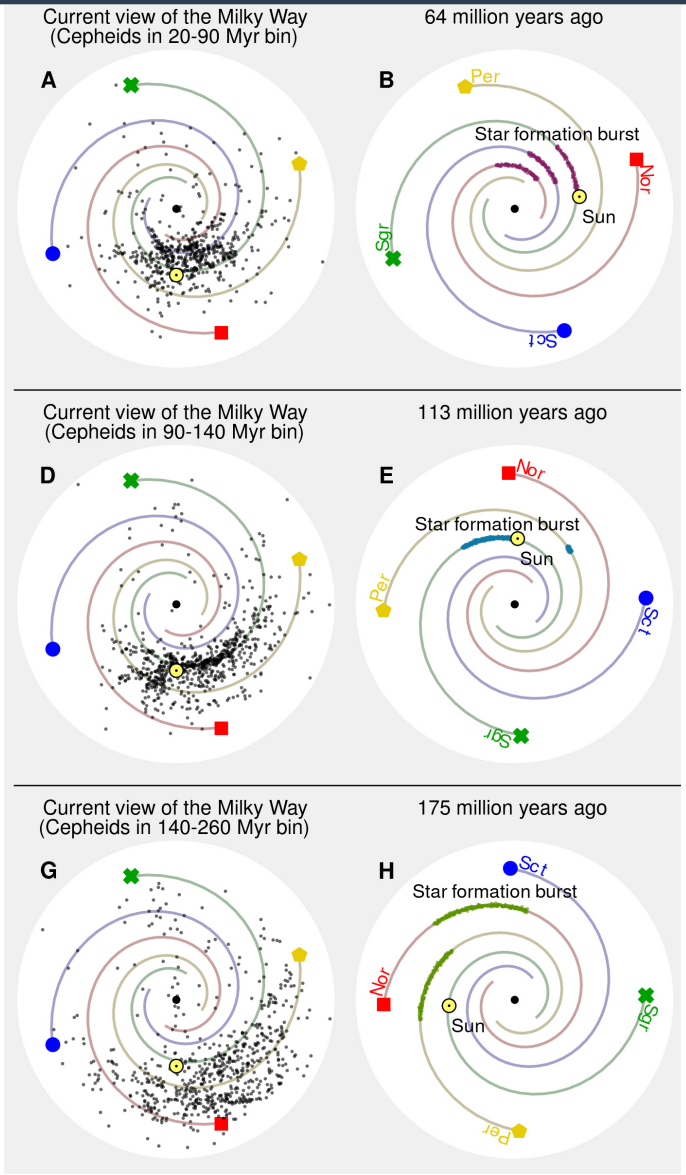
CEPHEID HISTORY



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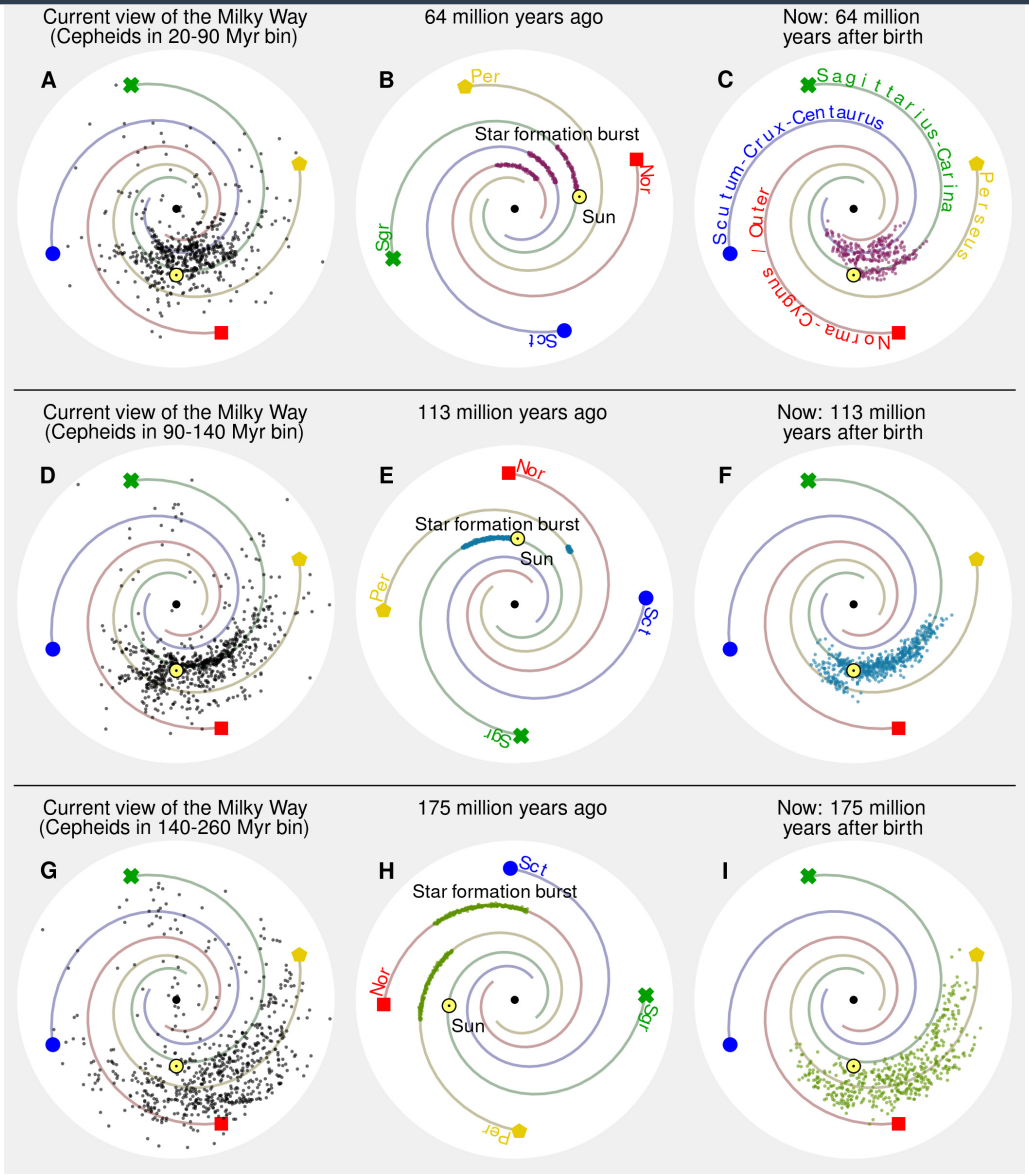

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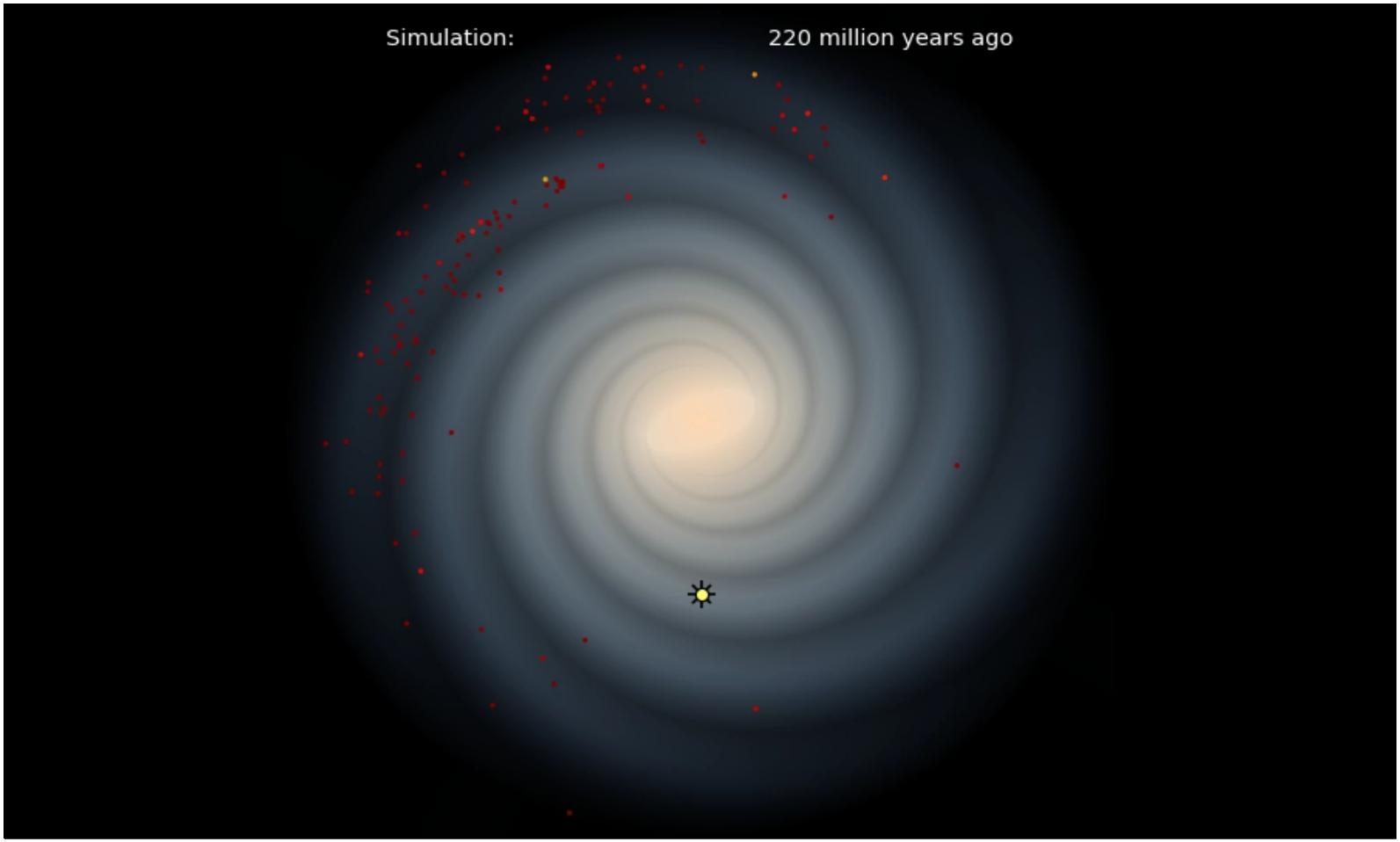

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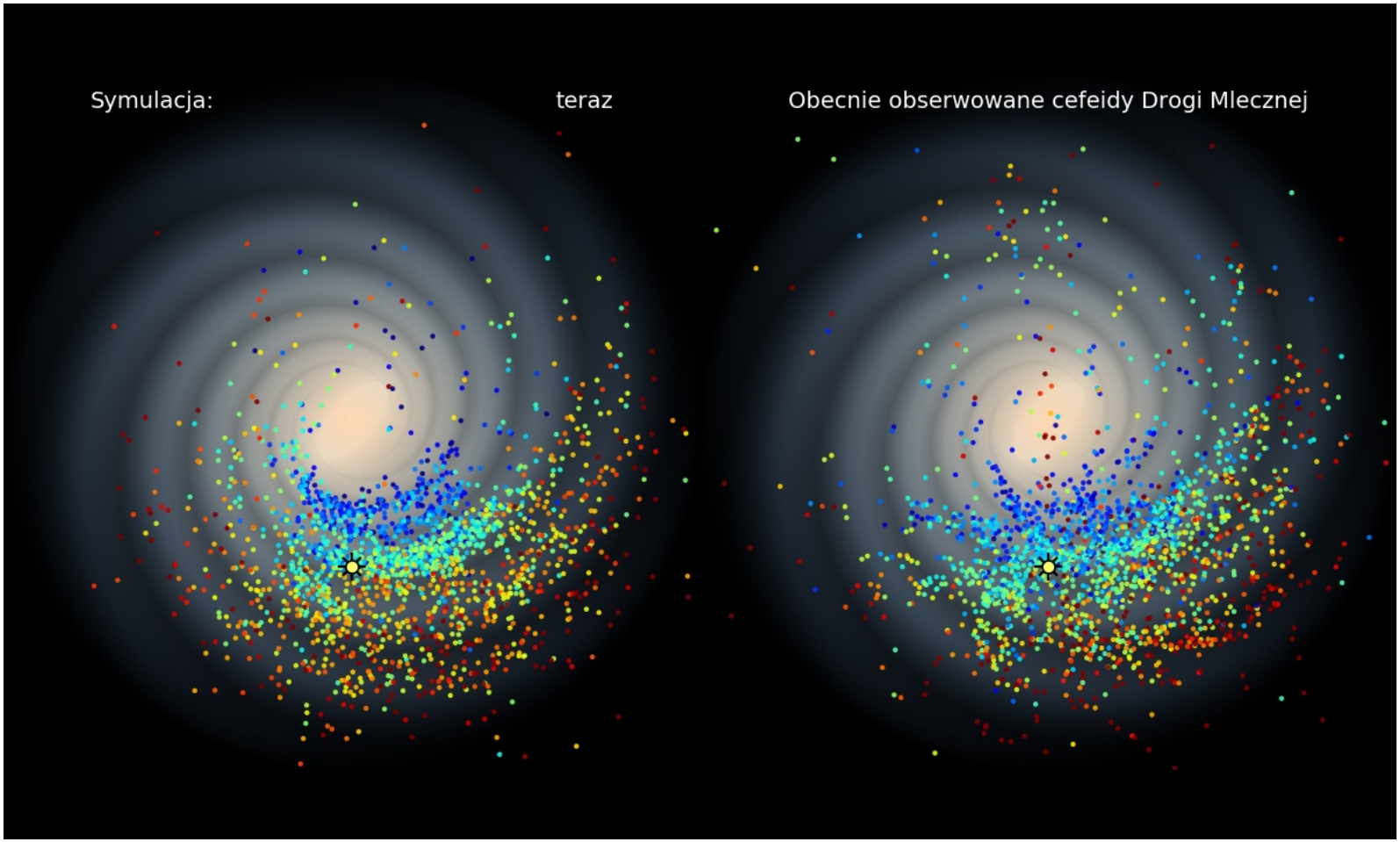

Credit: J. Skowron / OGLE

THANK YOU!

Credit: K. Ulaczyk / J. Skowron / OGLE