Morphology of the Large Magellanic Cloud using classical Cepheids

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SURC, April 10 2015

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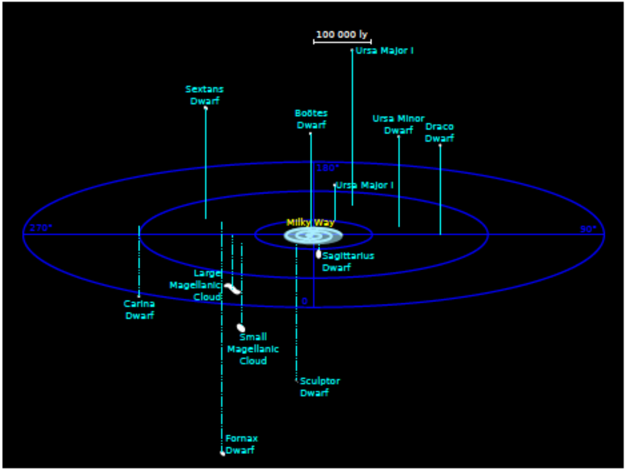
Large Magellanic Cloud

Summary

- a satellite galaxy of our Milky Way
- located $49.97 \pm 2.3\%$ kpc from Earth (Pietrzyński, 2013)
  - that's 958.1 quadrillion (10^{15}) miles
- useful as a calibrator for more distant targets

Photograph

Local Neighborhood



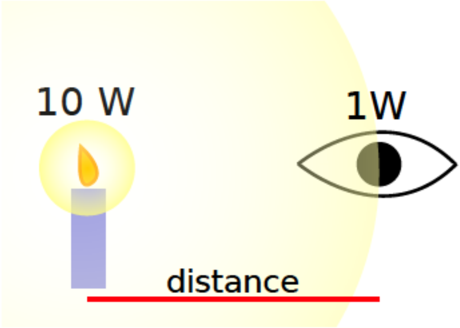
http://www.atlasoftheuniverse.com/sattelit.html

Standard Candles

Definition

- a standard candle is an object whose luminosity or absolute brightness can be determined, in order to compute distances
- the luminosity is compared to the observed brightness
    - the discrepancy is used to compute distance via the inverse square law of brightness

Example

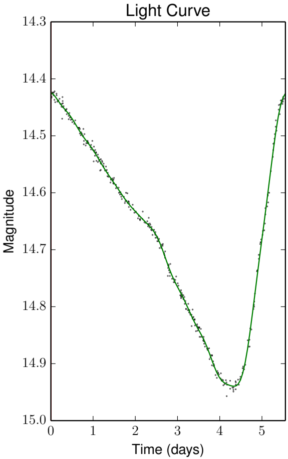


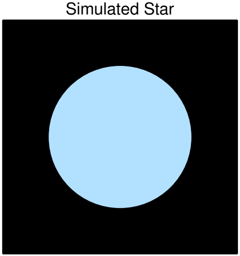
$$B = \frac{L}{4\pi d^2} \implies d = \frac{2.5\,\mathrm{m}}{\pi} \approx 0.8\,\mathrm{m}$$

Classical Cepheids

- a class of variable star
  - pulsate radially with a steady period
  - luminosity is a function of their radial velocity
- there is a strong correlation between a Cepheid's period of oscillation, and its mean luminosity
  - for this reason it is useful as a standard candle

Light Curve of a Cepheid Variable Star





Distance Modulus

- the brightness of a Cepheid, (aka its apparent magnitude, m), can be observed
- the luminosity (aka its absolute magnitude, M), can be computed
- apparent magnitude is corrected for the effects of interstellar gas and dust, using the maps of Zaritsky (1999)
- the distance to a Cepheid can be described by its distance modulus

$$\mu = m - M$$

Leavitt's Law

Discovery

Henrietta Swan Leavitt

- worked as a "computer" at Harvard in the early 20th century
- discovered a correlation between the period and brightness of variable stars
    - the brighter stars had longer periods

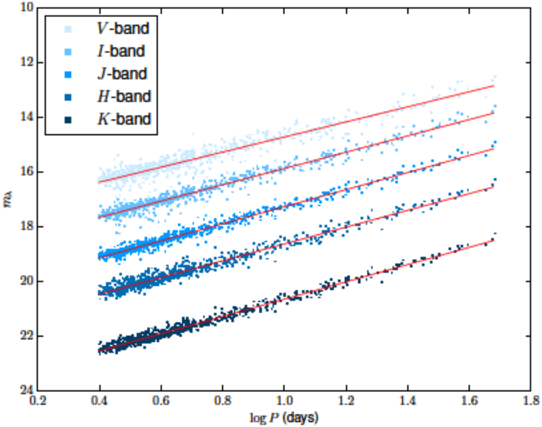
Period Luminosity Relation

- the period–luminosity relation can be described mathematically as

$$m = a + b \log P + (\text{error})$$

- it is an empirical formula, with coefficients a and b determined by the fit

Period Luminosity Relations



PL relations in 5 different bands

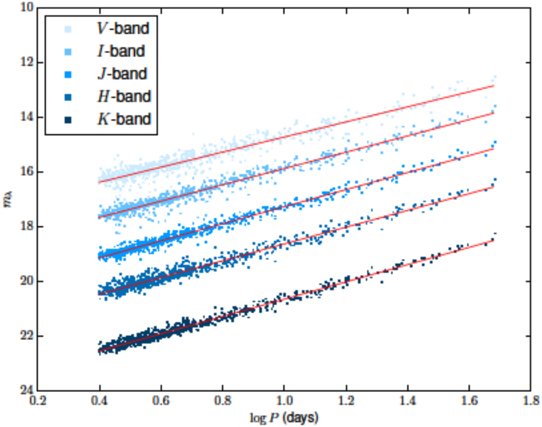
Cepheid Distances

- any individual differences from the fit can be attributed to several things
  - temperature, which we can approximate by color
  - observational error
  - metallicity
  - distances to individual stars
- all other things accounted for, we determine the individual distances by their difference from the fit

Data

- visible light observations made by the OGLE project (Soszynski et al. 2008) as well as Persson et al. (2004) in the V and I bands
- near-infrared observations made by the CPAPIR camera at the Cerro Tololo Interamerican Observatory (Macri et al. 2015) in the J, H, and K bands

Period Luminosity Relations



PL relations in 5 different bands

Coordinate Transformations

Equatorial Coordinates

- the position of any celestial object in the sky can be described by two values
  - right ascension (α)
    - projection of latitude onto the sky
  - declination (δ)
    - projection of longitude onto the sky
- after obtaining the distance of a given object, D, we can describe its position in 3D space

$$(\alpha, \delta, D)$$

Cartesian Coordinates

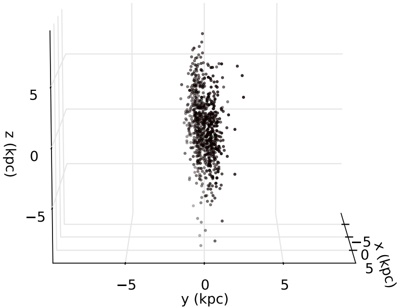
- we want to transform our coordinate system from equatorial to Cartesian

$$(\alpha, \delta, D) \to (x, y, z)$$

- this is done by the following equations, where a subscript 0 denotes the value of the LMC as a whole

$$\begin{aligned}
x &= -D \sin(\alpha - \alpha_0) \cos\delta, \\
y &= D \sin\delta \cos\delta_0 - D \sin\delta_0 \cos(\alpha - \alpha_0) \cos\delta, \\
z &= D_0 - D \sin\delta \sin\delta_0 - D \cos\delta_0 \cos\alpha - \alpha_0 \cos\delta.
\end{aligned}$$

Side-view of the LMC



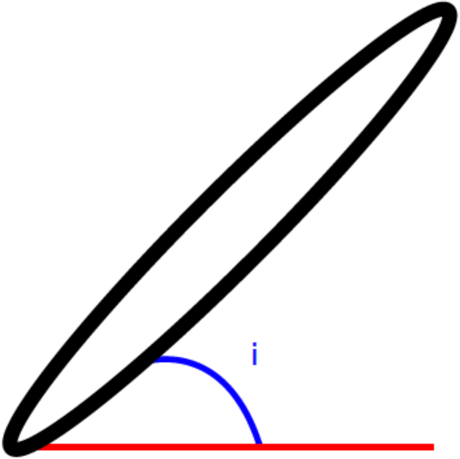
View of the unviewable side of the LMC

Galactic Morphology

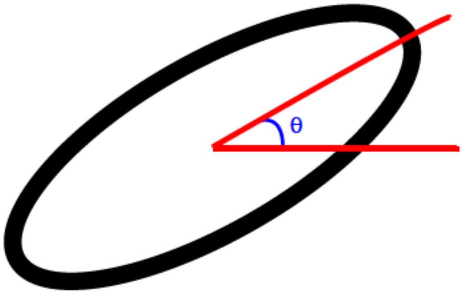
Galactic Orientation

- the orientation of a galaxy relative to Earth is an important parameter in galaxy interaction simulations
- can be described by two angles
  - inclination (i)
  - position angle (θ)
- there are different ways to obtain these angles, of which we explored two

Inclination



Position Angle



Plane Fitting

- we fit, to the Cartesian coordinates, a plane of the form

$$z = ax + by + c$$

- this is accomplished using ordinary linear regression
- the inclination and position angle are given by the coefficients of the plane

$$i = \arccos\left(\frac{1}{\sqrt{1 + a^2 + b^2}}\right)$$
$$\tan\theta = -\frac{a}{b}$$

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Ellipsoid Fitting

- we fit an ellipsoid (3D ellipse) to the stars using a principal axis transformation
- this gives us 3 perpendicular vectors which describe the ellipsoid of best fit
- the orientation of these vectors gives i and θ
    - $i = 175.13°$
    - $\theta = 24.85°$

Acknowledgments

Special thanks goes to Dr. Shashi Kanbur, Sukanta Deb, and Harinder P. Singh.

Questions?