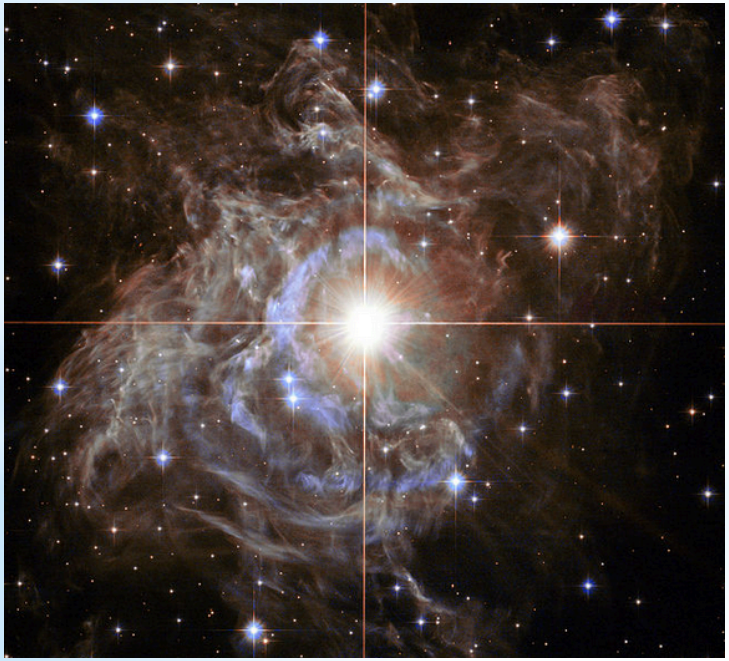
Cepheid P-L Relation

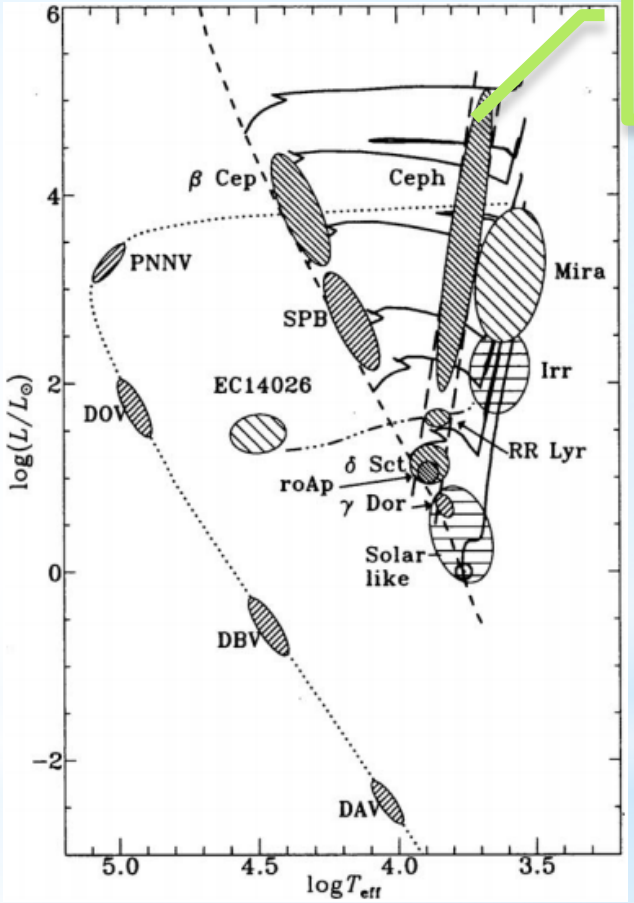
Wenlong Yuan

AstroStat Class / Sep 22, 2015

Classical Cepheid Properties

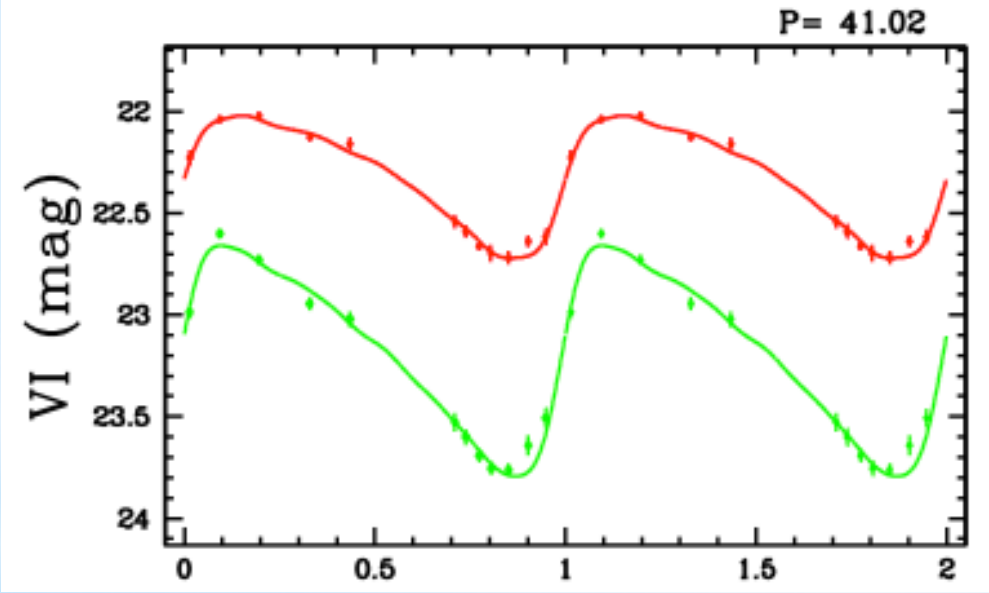
- Brightness: 1000~5000 L_{Sun}
- T_{eff} : ~ 6000K
- Radius: ~ 50 R_{Sun}

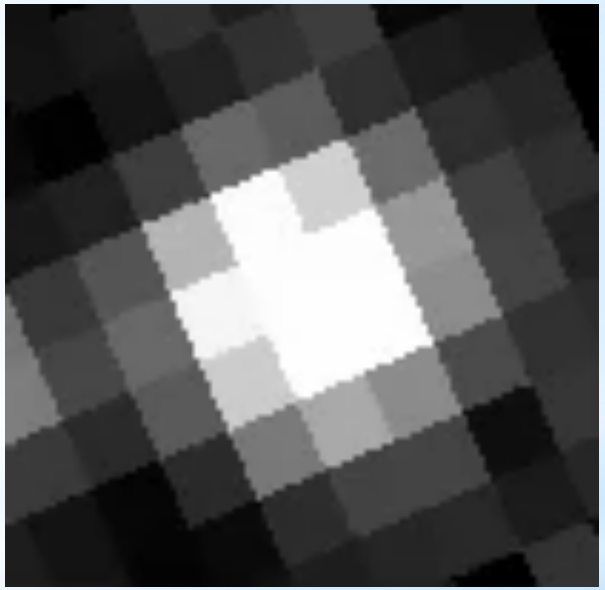




Percy, John. Understanding Variable Stars. Cambridge. 2007. Print.

Period-luminosity (P-L) relation





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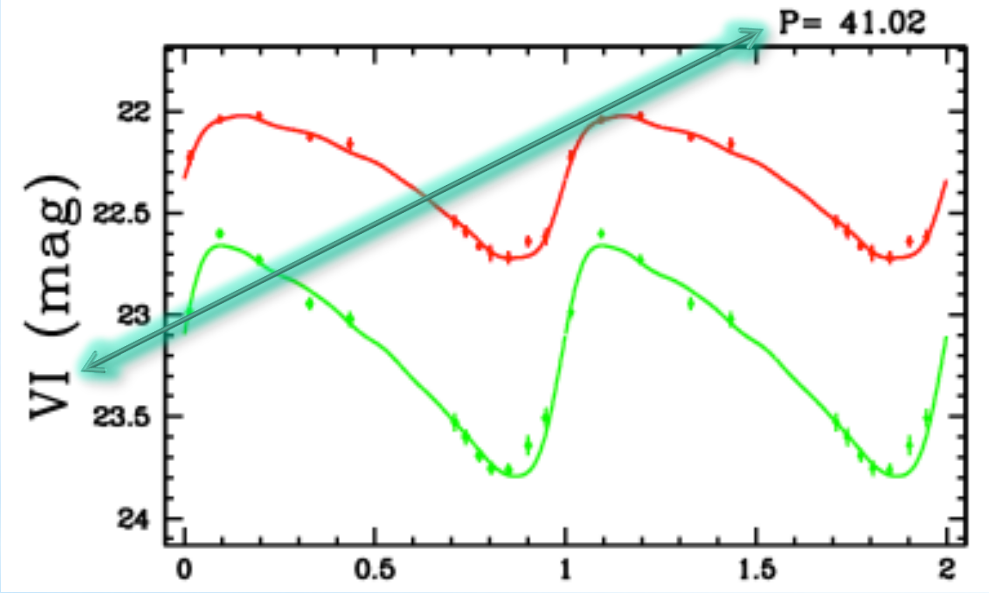

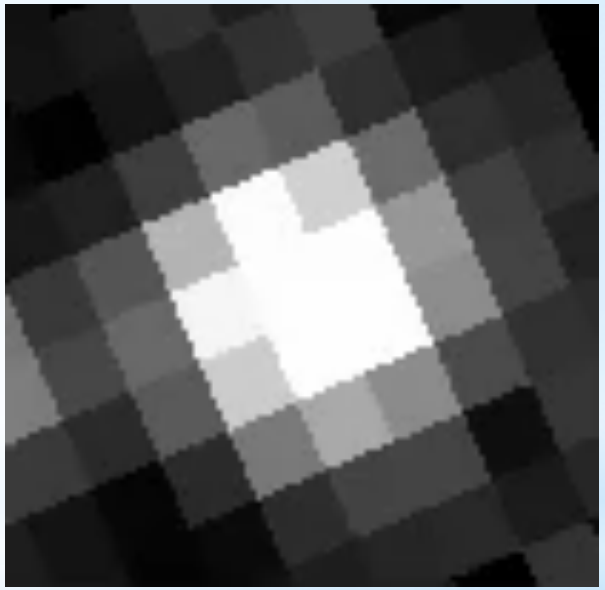

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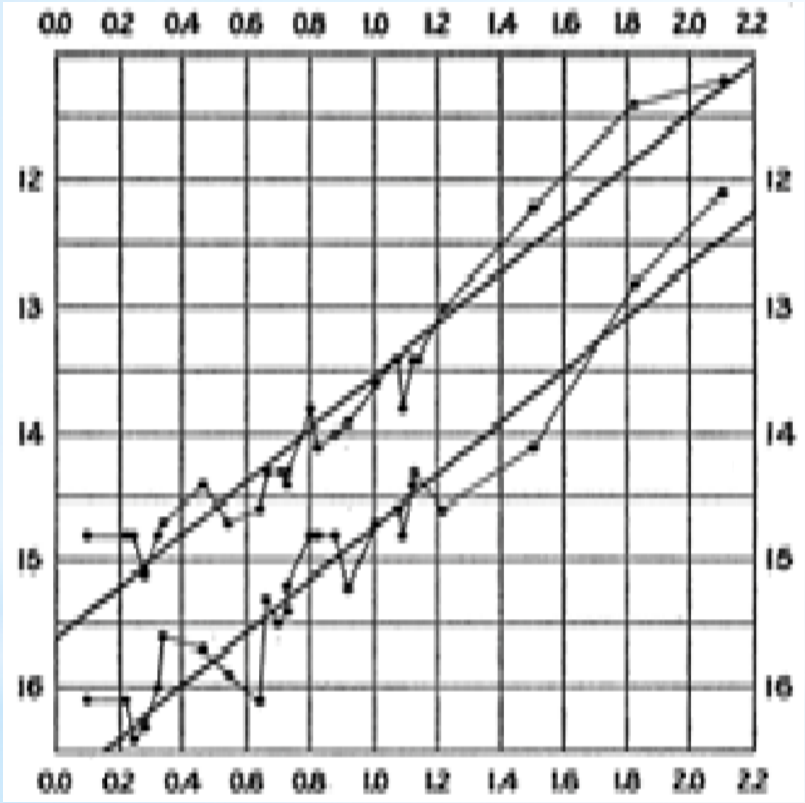
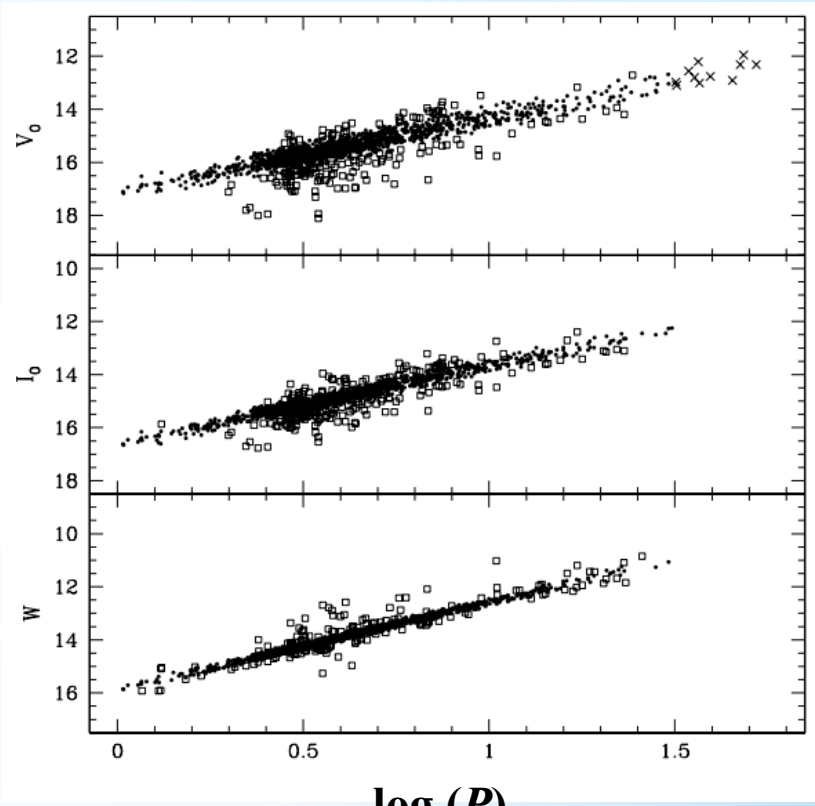
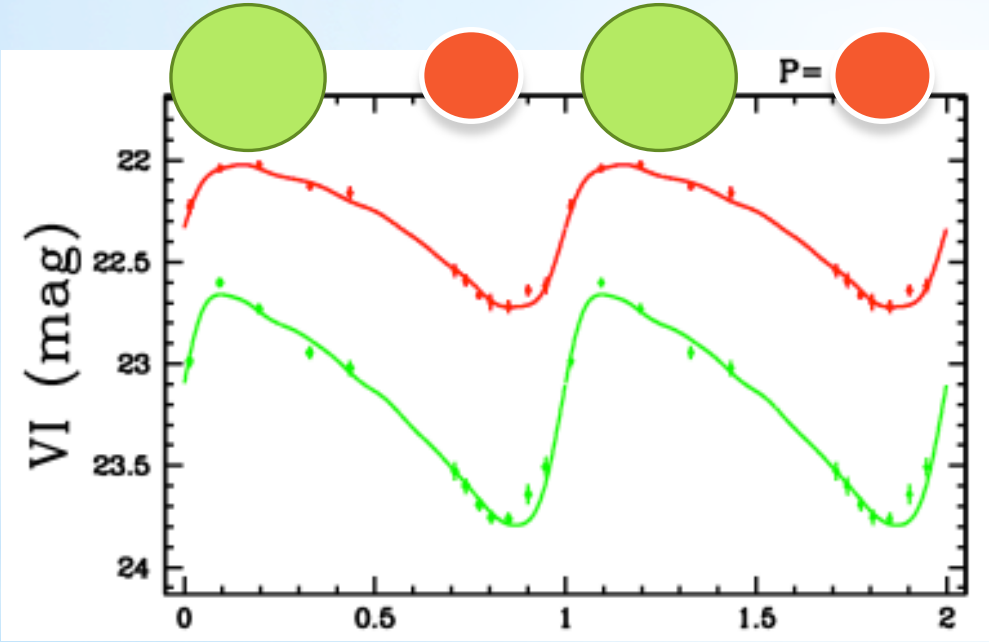


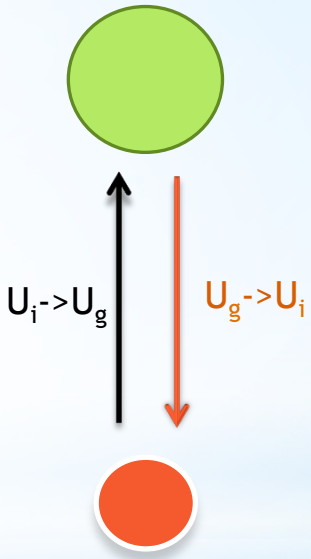
Leavitt, Henrietta S. & Pickering, Edward C. (1912)



Ngeow et al. (2009)

Why do they pulsates?





He^+, transparent, photons emit out, star getting cooler/ less pressure

He^{2+}, opaque, photons bounce back, star getting hotter/more pressure

Why does period relate to luminosity?

A smaller Cepheid

Why does period relate to luminosity?

A smaller Cepheid

- More massive
- Bigger in size
- More gravitational potential energy
- Nuclear fusion more efficient and hotter
- More luminous

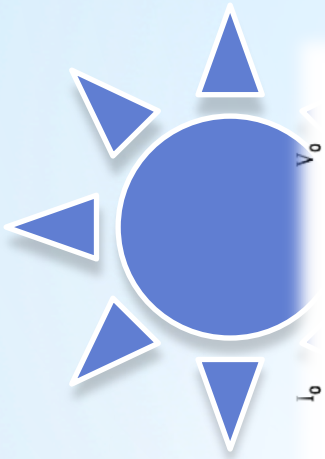
- Less massive
- Smaller in size
- Less gravitational potential energy
- Nuclear fusion less efficient and cooler
- Less luminous

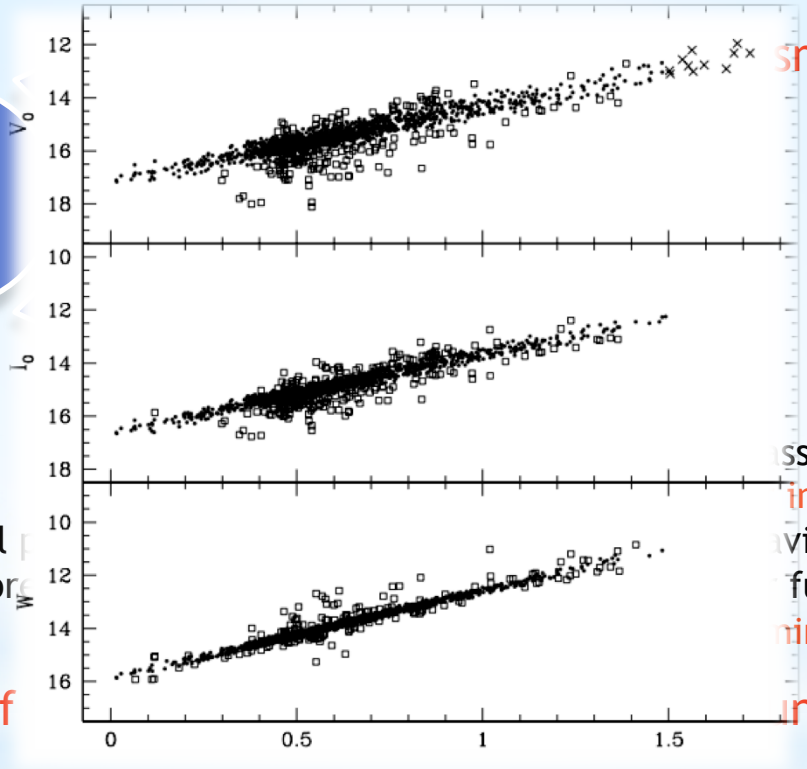
The speed of variation in size is the speed of sound in the star

- Takes longer time to finish a cycle

- Take shorter time to finish a cycle

Why does period relate to luminosity?





smaller Cepheid

- More massive
- Bigger in size
- More gravitational
- Nuclear fusion mor
- More luminous

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vitational potential energy
fusion less efficient and cooler
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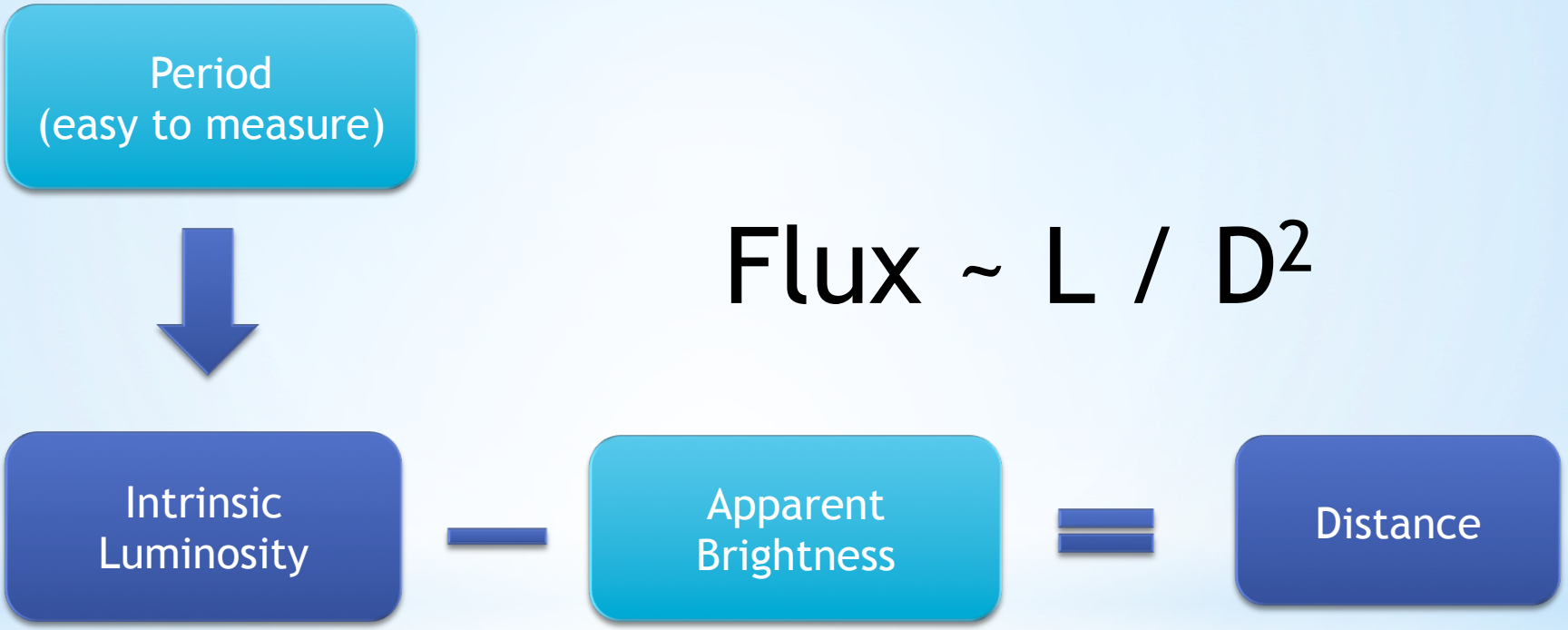
Ngeow et al. (2009)

Why do we care about P-L relation?



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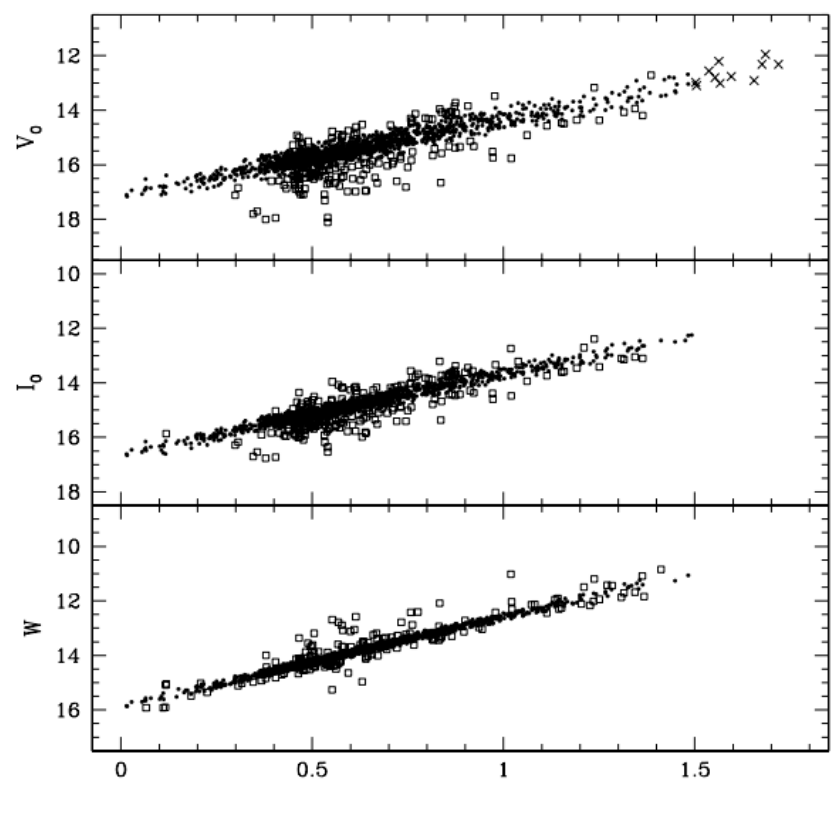

P-L relations for Large Magellanic Clouds (LMC)

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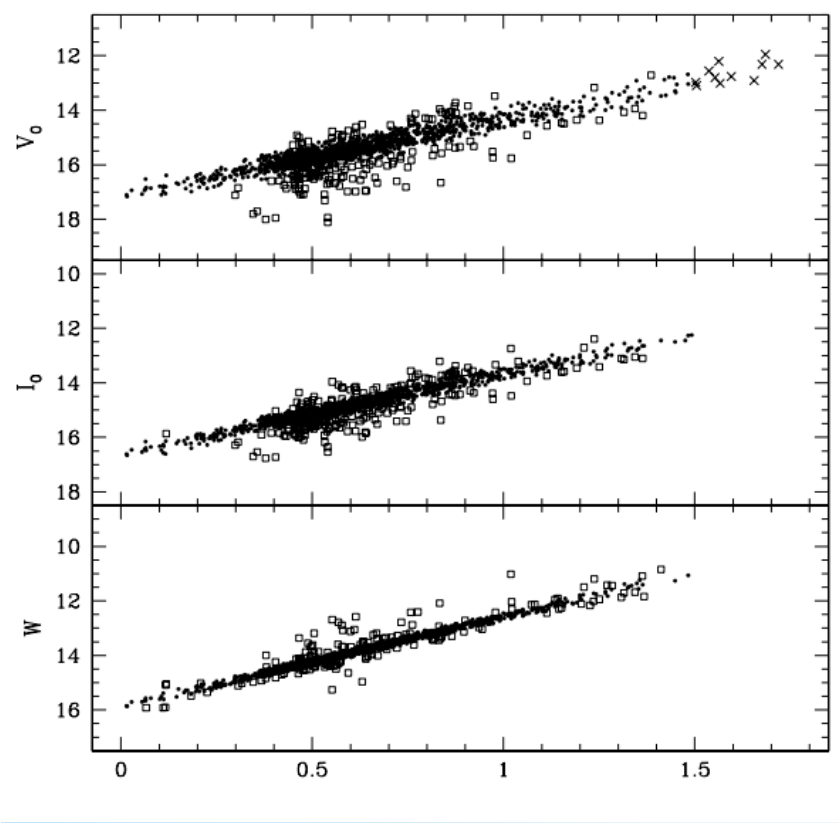

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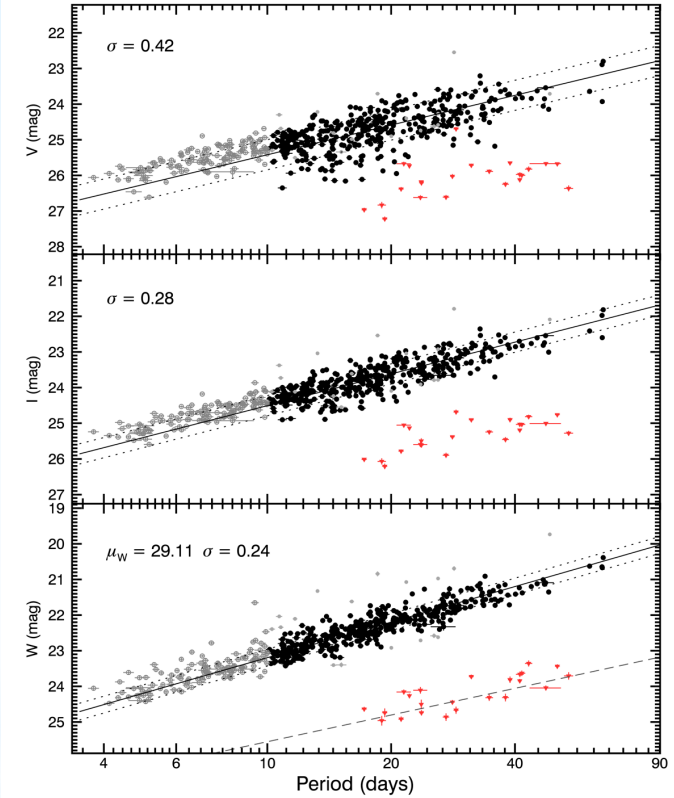

P-L relations for Pinwheel Galaxy (M101)

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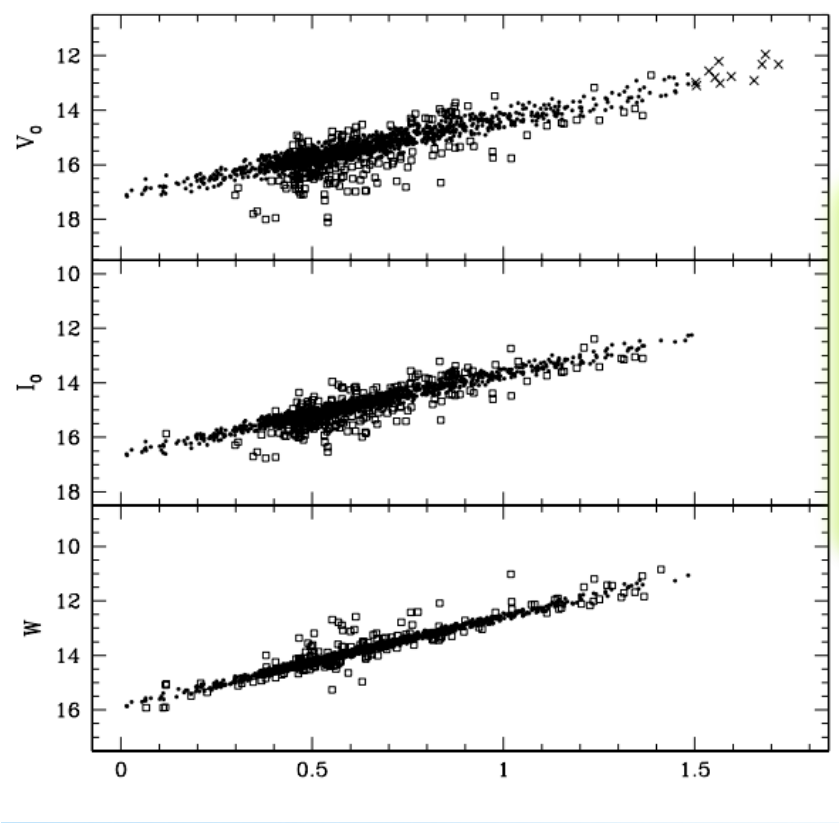
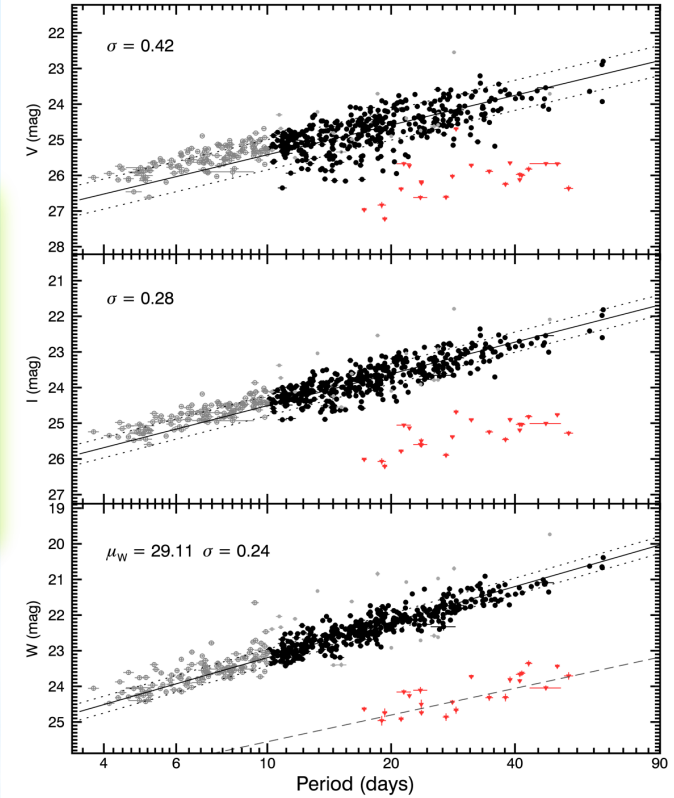


Distance difference between galaxies



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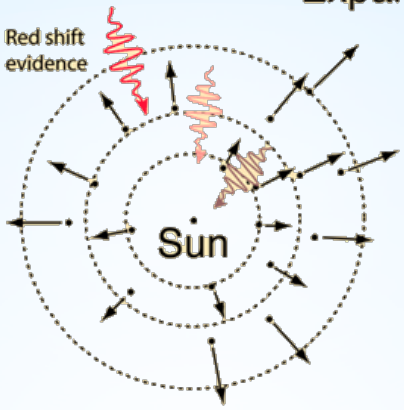

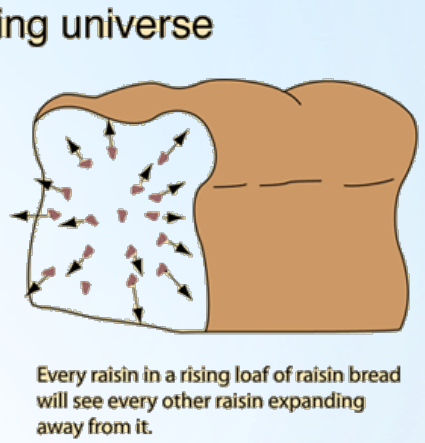

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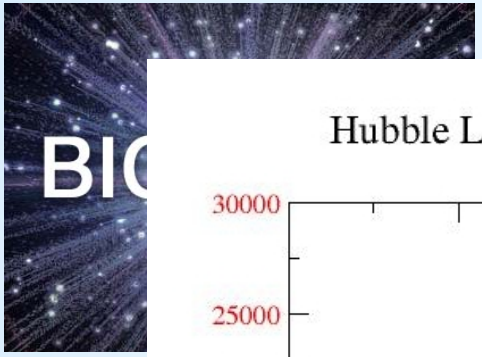
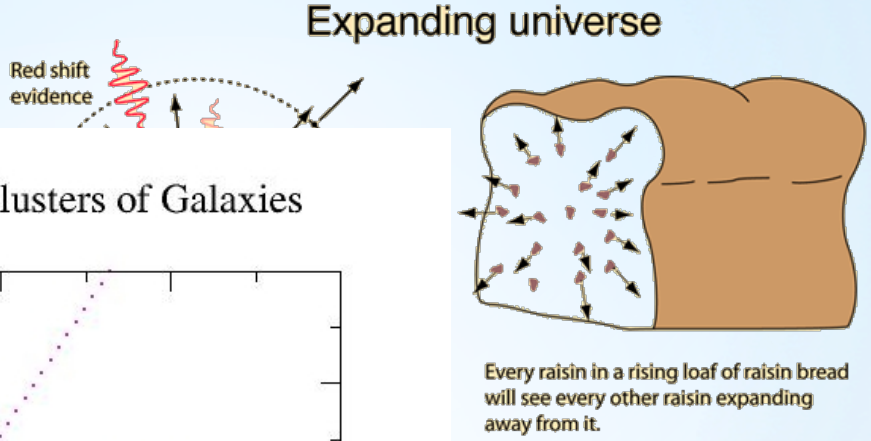
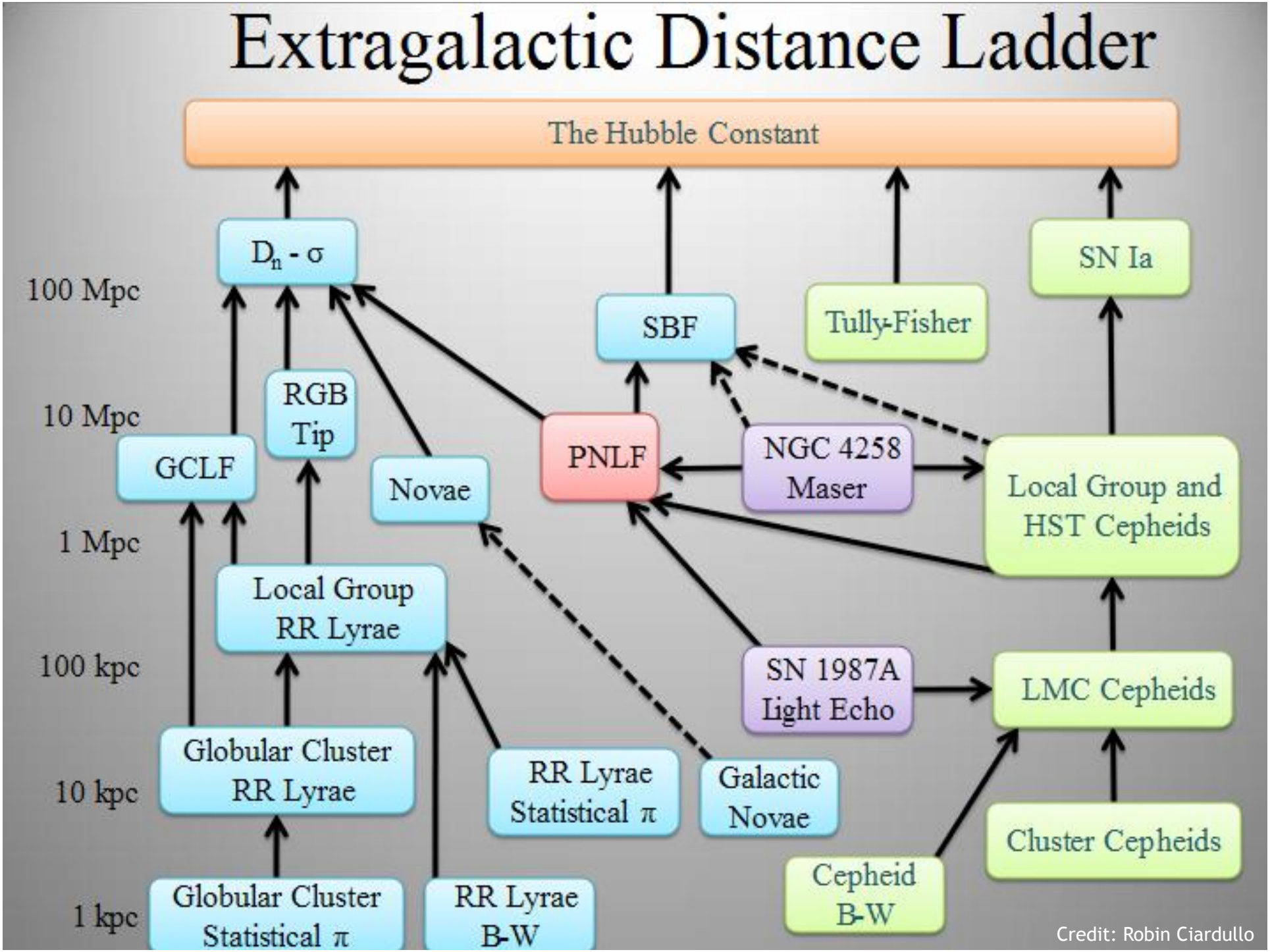




$$V = H_0 D$$


Extragalactic Distance Ladder
The Hubble Constant
D_n - σ
SBF
Tully-Fisher
SN Ia
100 Mpc
10 Mpc
1 Mpc
100 kpc
10 kpc
1 kpc
RGB Tip
GCLF
Novae
PNLF
NGC 4258 Maser
Local Group and HST Cepheids
Local Group RR Lyrae
SN 1987A Light Echo
LMC Cepheids
Globular Cluster RR Lyrae
RR Lyrae Statistical π
Galactic Novae
Cluster Cepheids
Cepheid B-W
Globular Cluster Statistical π
RR Lyrae B-W
Credit: Robin Ciardullo

How to measure?

1. Searching for Cepheids:

- Time series observation of one galaxy (usually 12 epochs)
- PSF Photometry on the images, extract the light curves
- Use Stetson's variability index to search Cepheid candidates

$$J=\frac{\sum_{k=1}^{n} w_k \operatorname{sgn}(P_k)\sqrt{|P_k|}}{\sum_{k=1}^{n} w_k}$$

$$P_k=\begin{cases}\delta_{i(k)}\delta_{j(k)}, & \text{if } i(k)\neq j(k)\\ \delta_{i(k)}^2-1, & \text{if } i(k)=j(k)\end{cases}$$

$$\delta=\sqrt{\frac{n}{n-1}}\frac{v-\bar{v}}{\sigma_v}$$

$$K=\frac{1/N\ \sum_{i=1}^{N}|\delta_i|}{\sqrt{1/N\ \sum_{i=1}^{N}\delta_i^2}}$$

$$L=\left(\frac{JK}{0.798}\right)\left(\frac{\Sigma w}{w_{\text{all}}}\right)$$

How to measure?

1. Searching for Cepheids:
- Time series observation of one galaxy (usually 12 epochs)
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2. Calculate the periods and magnitude:
- Fit light curves to Cepheid templates, which are functions of period (~Project 2)
- Calculate the mean magnitude of the best-fit template
- Check the P-L relation and remove outliers

How to measure?

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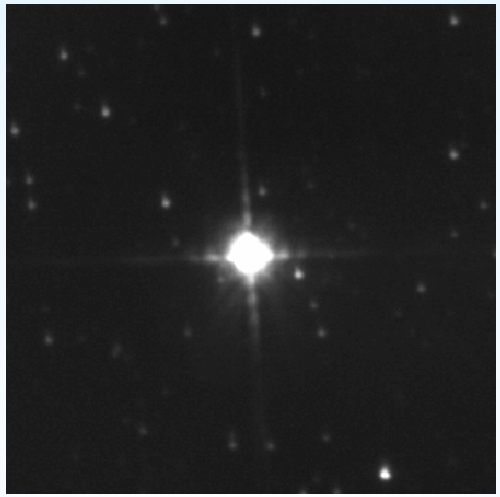
3. Calibrate the magnitude and derive distance:
- Transform the magnitude into the filter system of interest
- Correct for dust reddening
- Calculate the P-L zero point

Bootstrap

Permute the Residuals

Problem to Deal With:

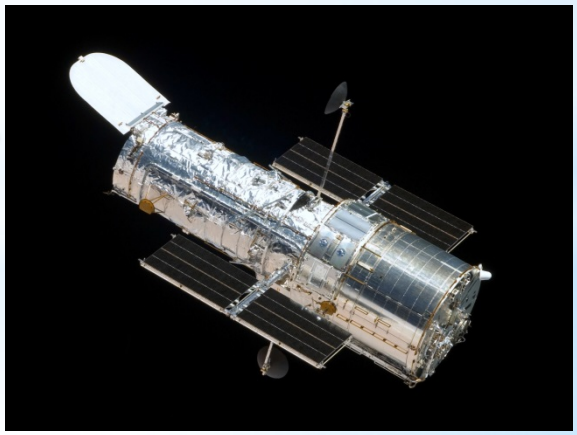
- Ground-based
  - Phase correction



- *HST*
  - Parallax
  - One-epoch photometry

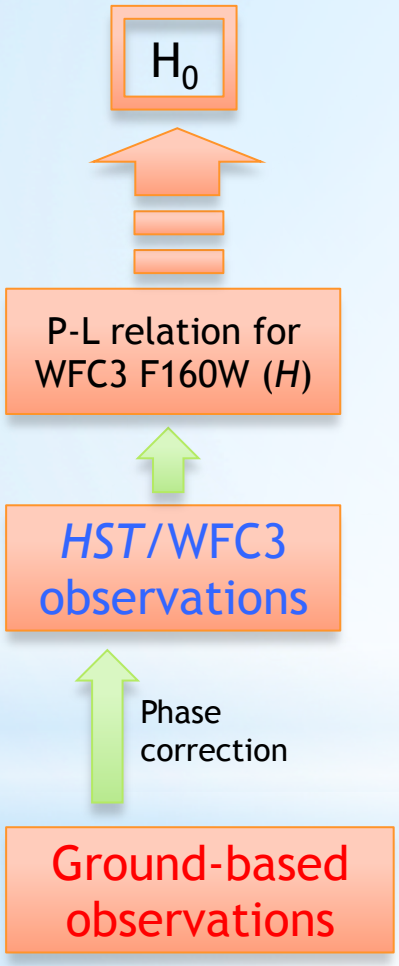
Credit: Frederick M. Walter

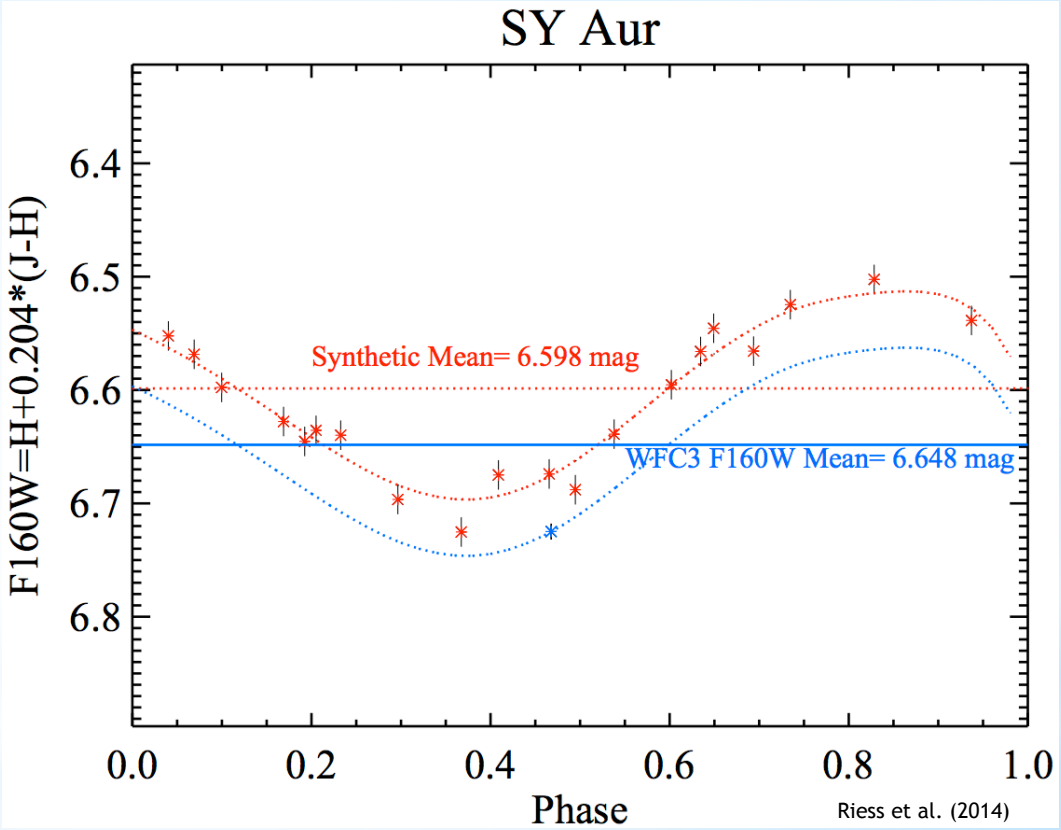
P-L relation



Credit: Ruffnax (Crew of STS-125)

Problem to Deal With:





Error Propaganda: We need the uncertainty of Period

Var(Period) → Var(Phase) → Var(Mean magnitude)

How to estimate Period?

THE ASTROPHYSICAL JOURNAL, 748:107 (29pp), 2012 April 1 doi:10.1088/0004-637X/748/2/107

A GLOBAL PHYSICAL MODEL FOR CEPHEIDS

ONDŘEJ PEJCHA[1] AND CHRISTOPHER S. KOCHANEK[1,2]
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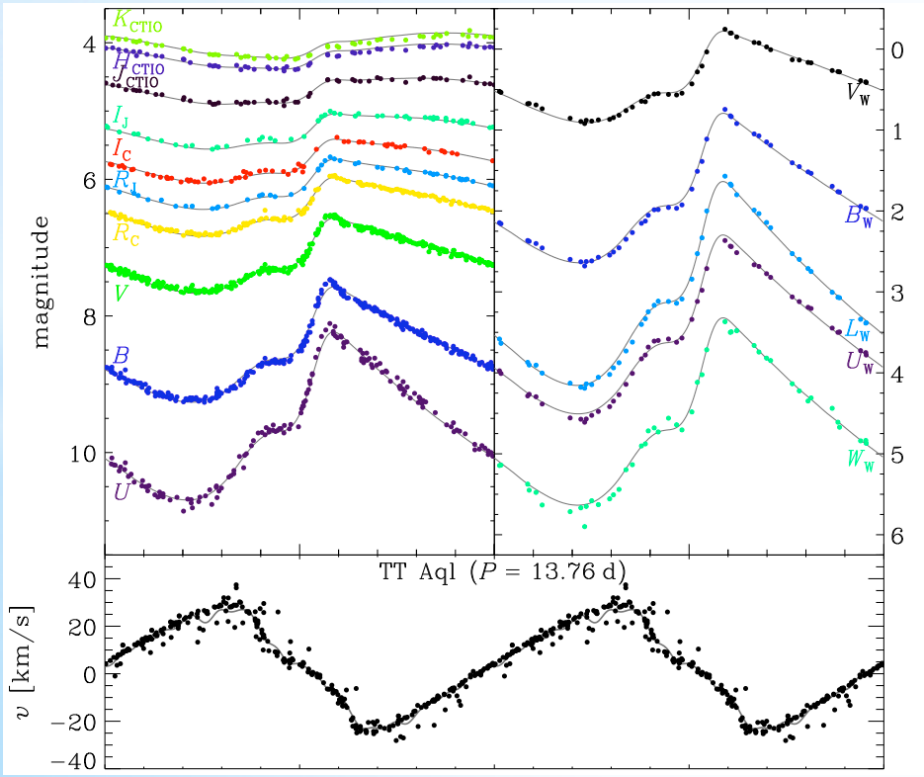
Received 2011 December 7; accepted 2012 January 23; published 2012 March 13



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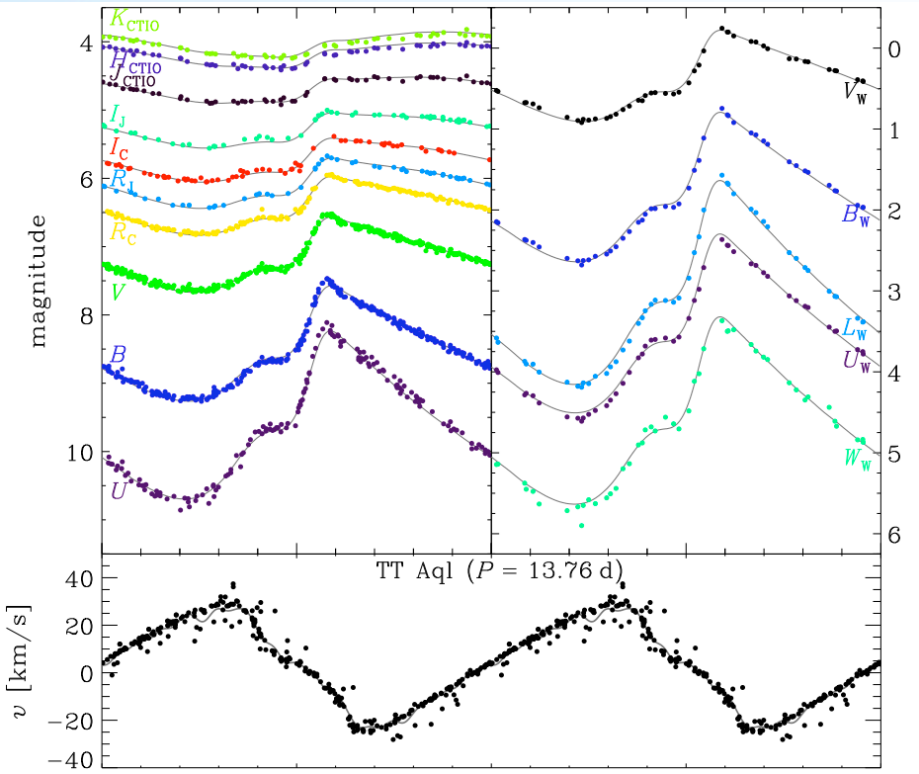

Collect literature data

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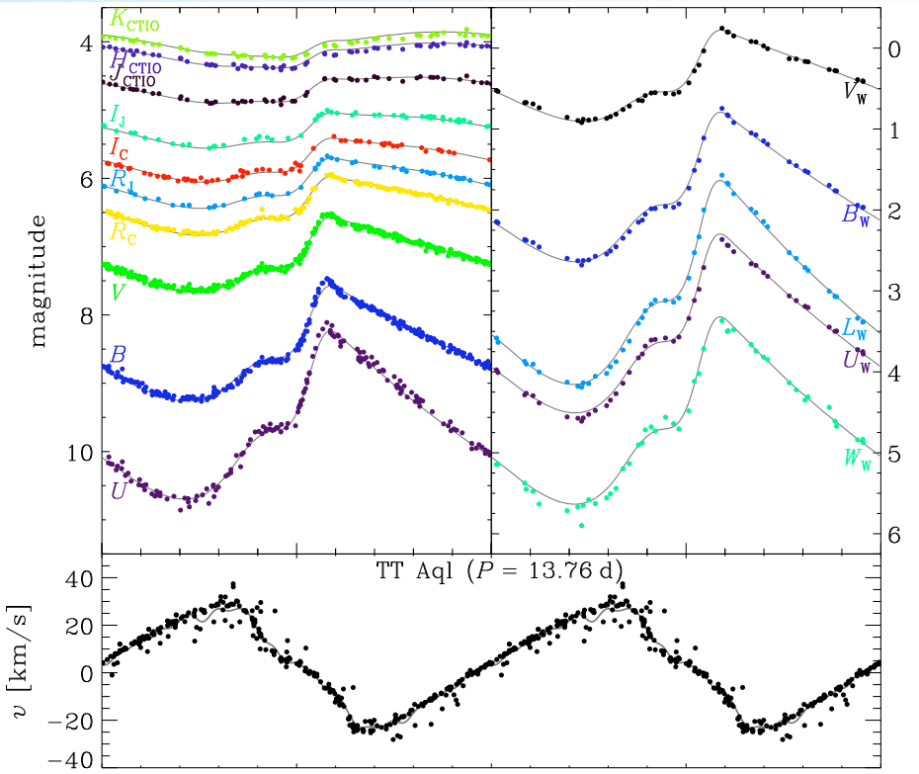

Collect literature data

Fit the model with many trial periods

How to estimate Period?

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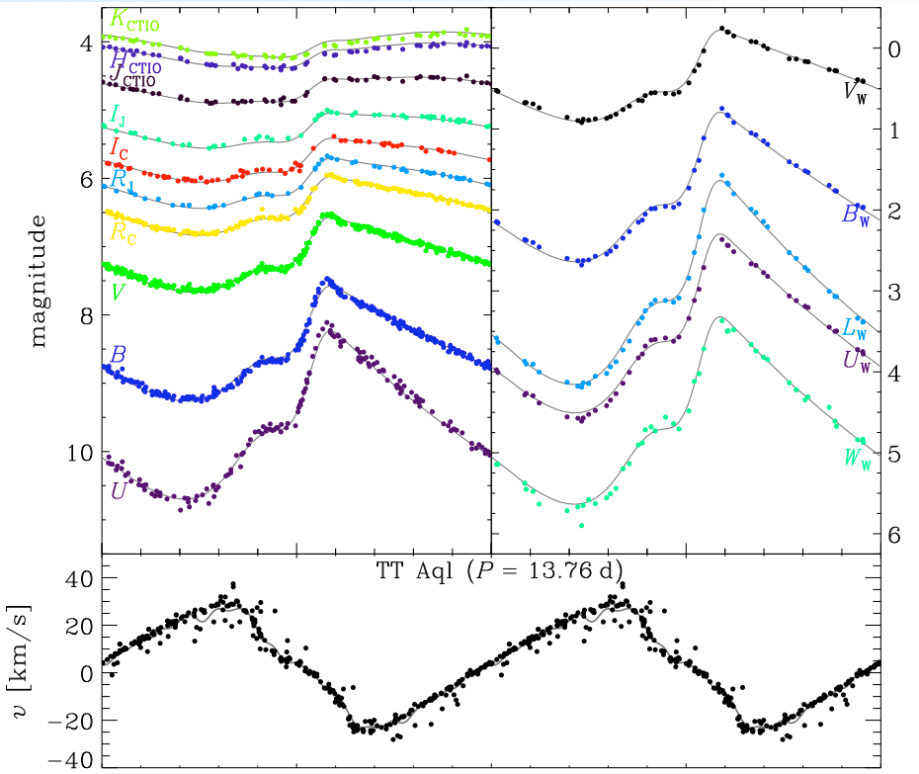

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Fit the model with many trial periods

Calculate χ^2

How to estimate Period?

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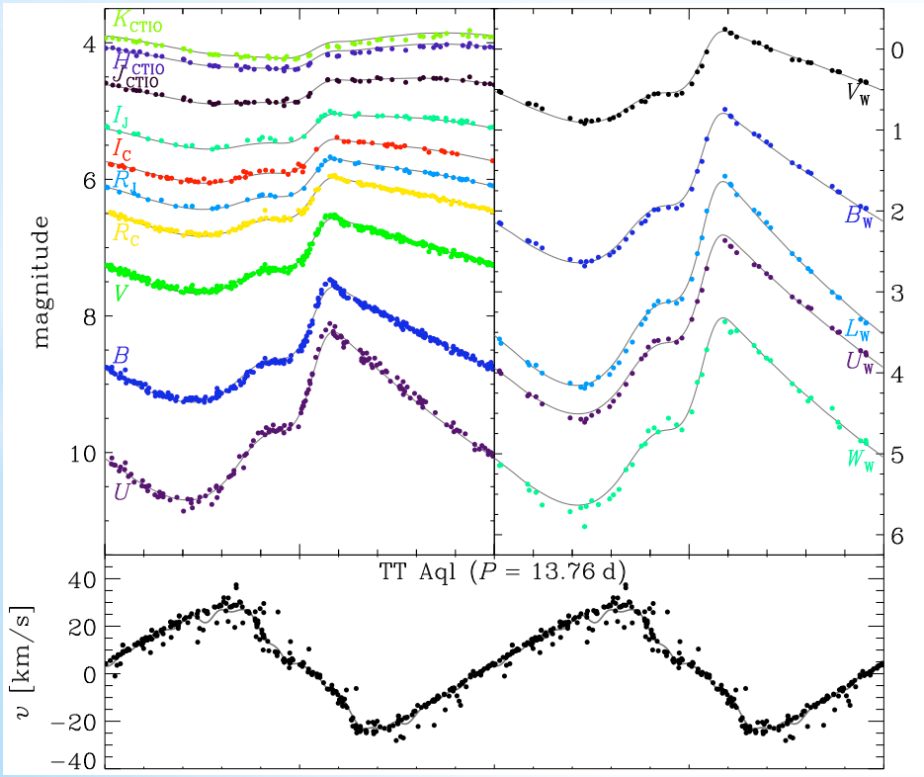


Collect literature data

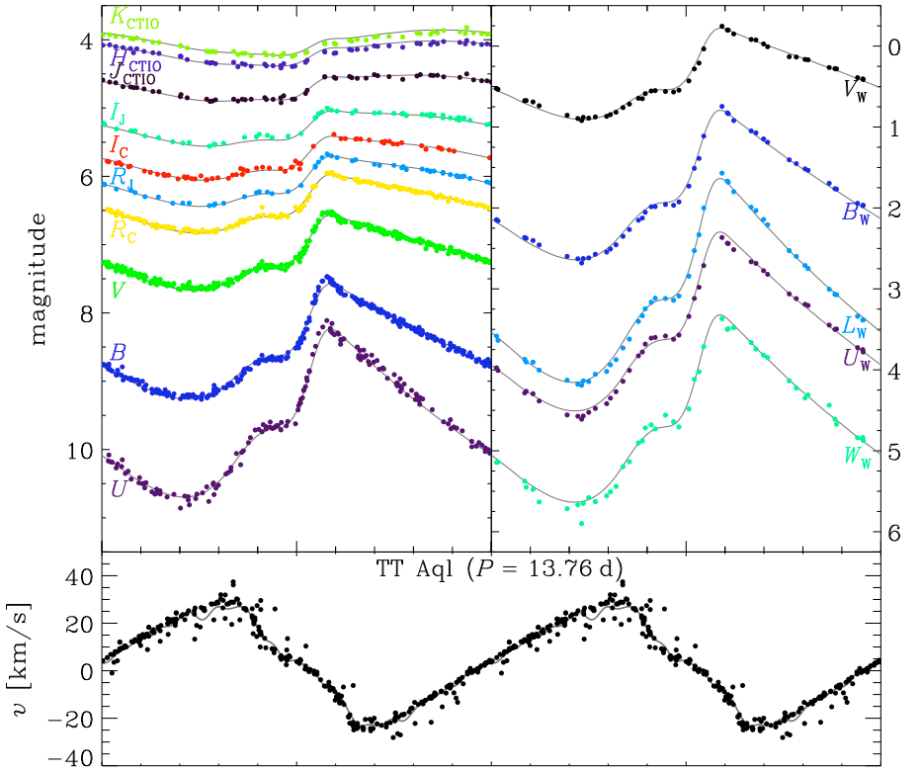
Fit the model with many trial periods

Calculate χ^2

Least χ^2 → Period

How to estimate Period Uncertainty?

Bootstrap by
permute residuals



Collect literature data

Fit the model with many trial periods

Calculate χ^2

Least χ^2 → Period

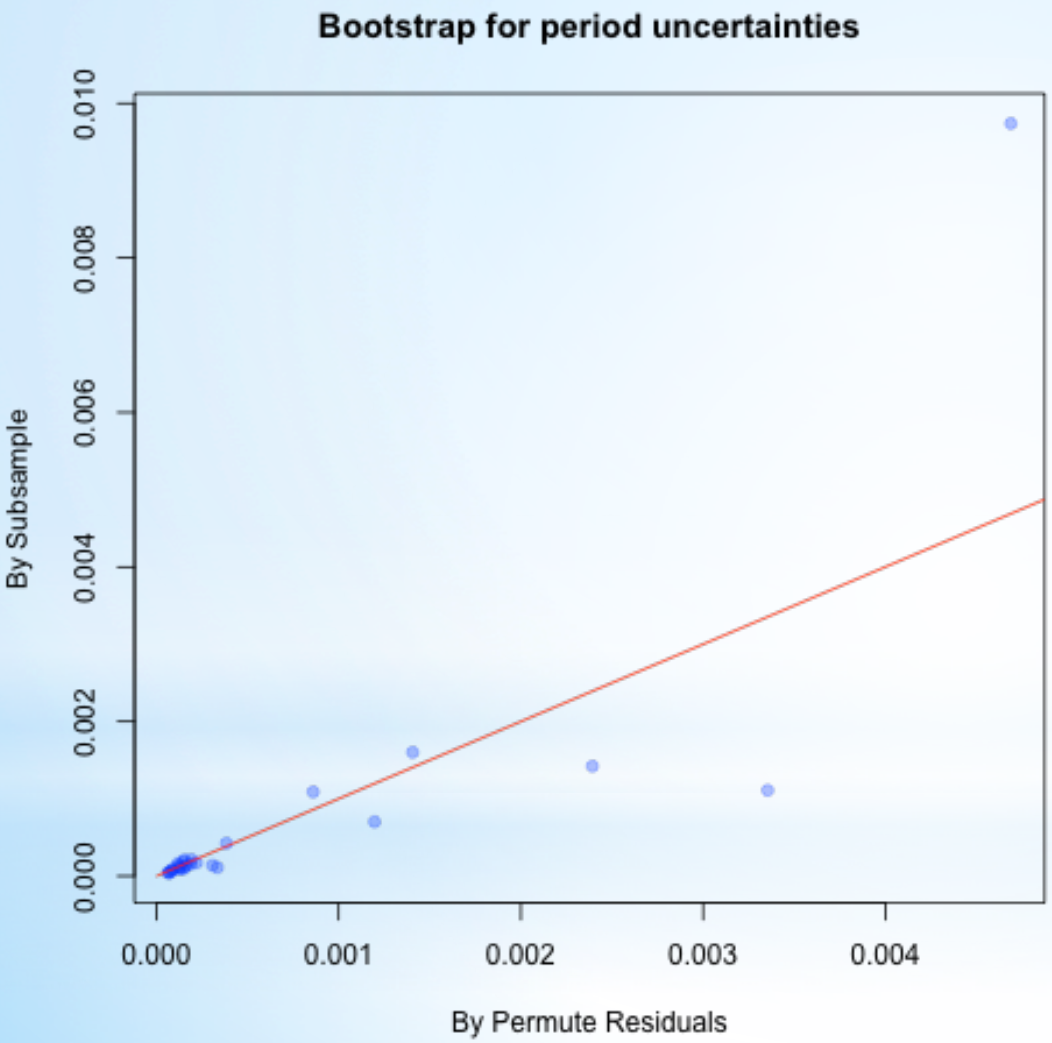
Residuals = observations - model

Make up 200 fake light curves:
Obs' = model + sample(residuals)

Least χ^2 → P's

Uncertainty ~ sd(P's)

How to estimate Period Uncertainty?



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Thank you!