The 3D structure of the Magellanic Clouds traced by Classical Cepheids

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W. Gieren (Concepcion)....

RASPUTIN
Resolved And unresolved Stellar PopUlaTIoNs

Outline

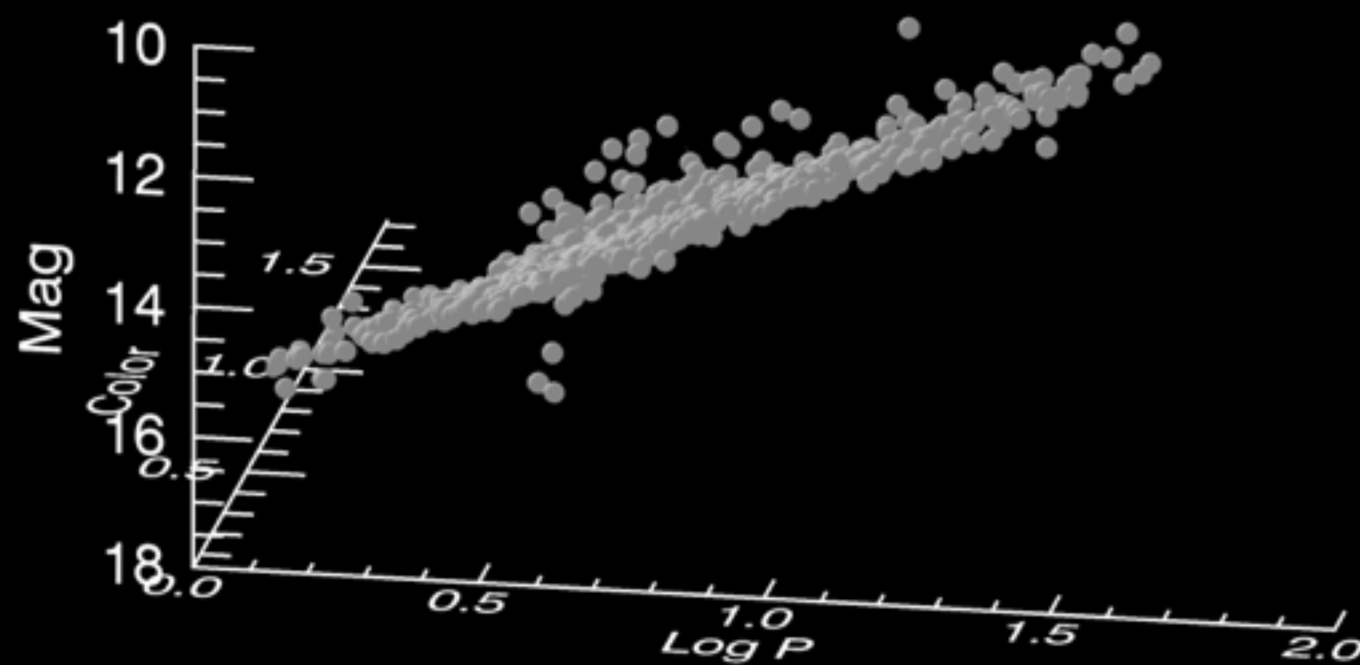
- Classical Cepheids in the Near Infrared (NIR)
- New NIR Light Curve Templates For Cepheids
- Application to Magellanic Clouds (MCs) Cepheids
- The 3D structure of MCs
- Conclusion

Classical Cepheids are primary distance indicators

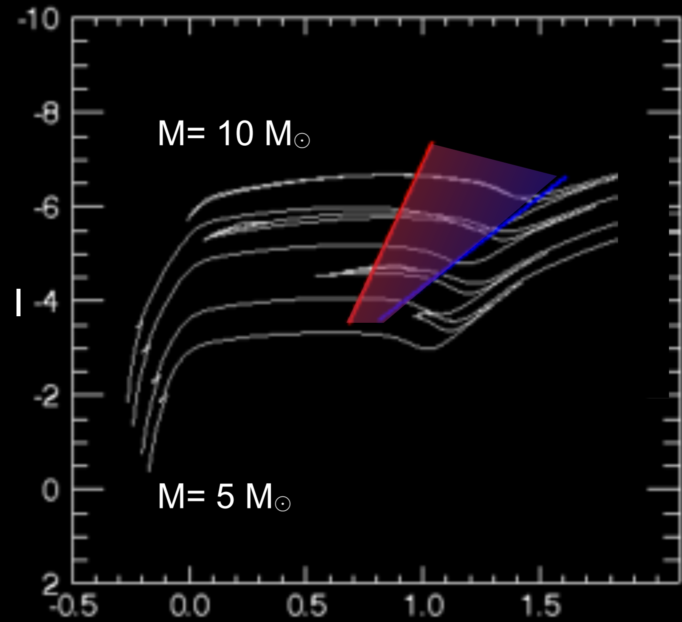
- radially pulsating variable stars
- obey to well-defined Period-Luminosity Relations

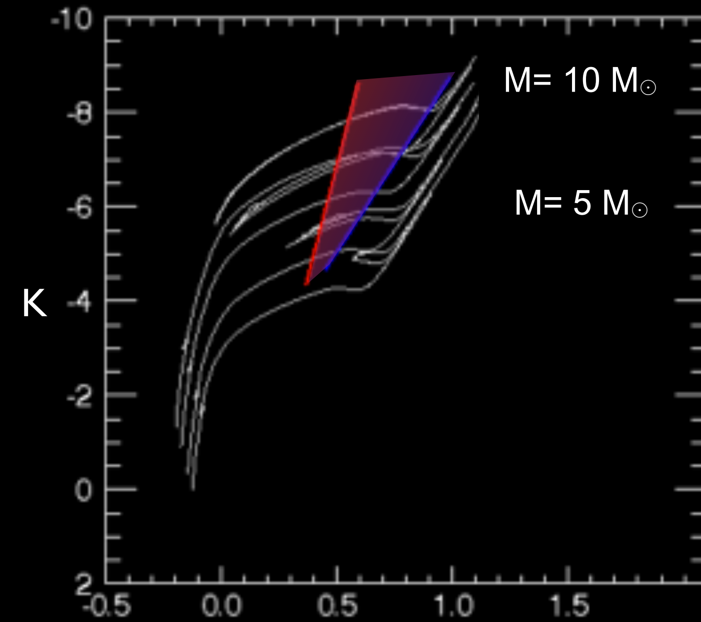
Classical Cepheids are primary distance indicators

- Period Luminosity relation bi-dimensional projection of Period-Luminosity-Color relation
- intrinsic dispersion due to the finite width in temperature of the Instability Strip



The dispersion on Period-Luminosity relations due to the finite width in temperature of the Instability Strip is lower





The dispersion on Period-Luminosity relations due to the finite width in temperature of the Instability Strip is lower

The amount of extinction in the NIR is much lower than in the optical bands (Av ~ 10 Ak)

The Wesenheit magnitudes are reddening free by construction *(Madore+1982)*

$$W(\lambda_2,\lambda_1) = m_{\lambda_1} - \left[\frac{A(\lambda_1)}{E(m_{\lambda_2} - m_{\lambda_1})}\right] \times (m_{\lambda_2} - m_{\lambda_1})$$

NIR Period-Wesenheit relations :

- minimally affected by uncertinity on the reddening law
- lower intrinsic dispersion

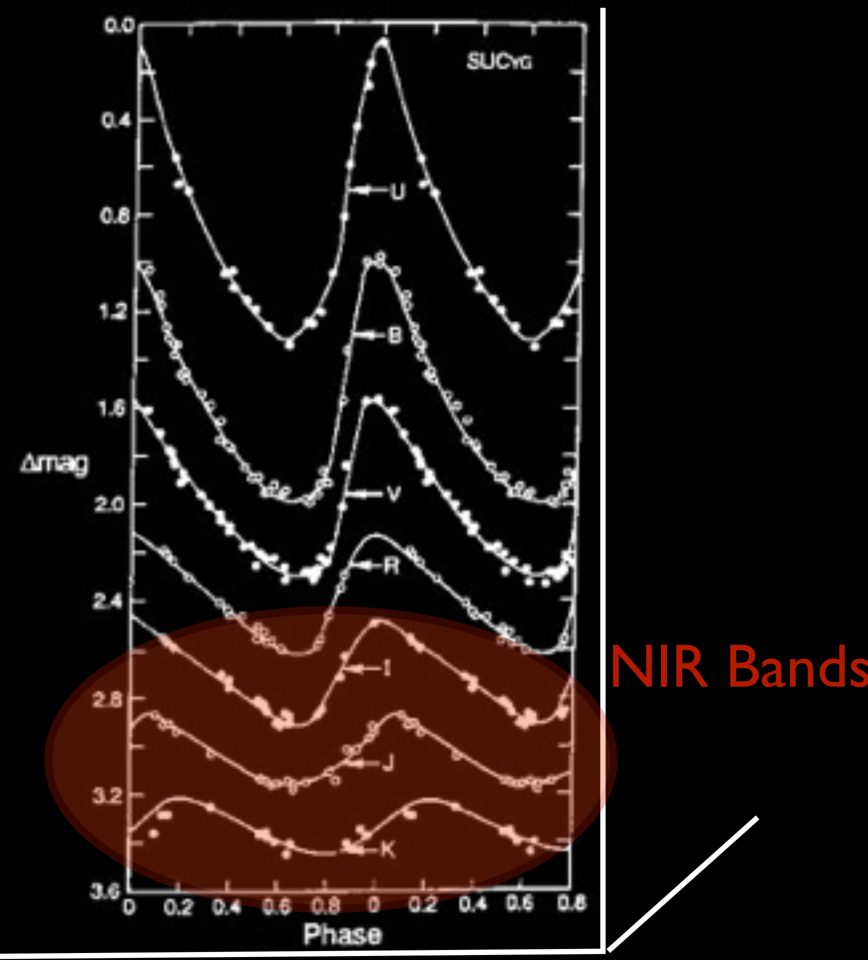
The amplitude decreases for increasing wavelength

Cepheids in the LMC

~ 90 (JHK)+170 VMC (YJK,FU)
Complete coverage of light curves in the JHKs bands (published data):

(Persson+2004, Ripepi+2012)

~1700 2MASS, IRSF/SIRIUS single epoch observations LMC

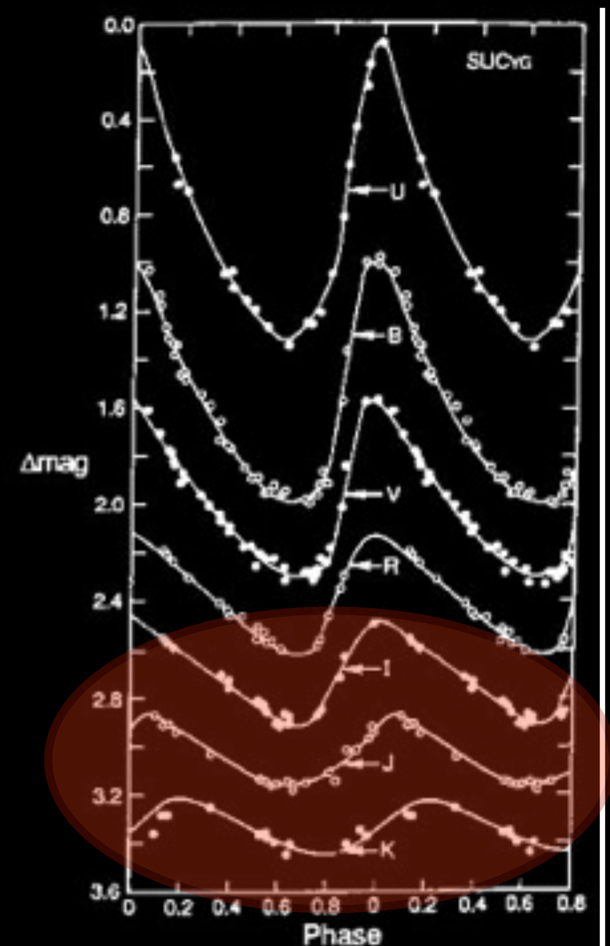


The amplitude decreases for increasing wavelength

single epoch observation

error = semi-amplitude

> 5% in distance



NIR Bands

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- Conclusion & Future Perspective

An empirical model to predict the shape of Cepheids NIR light curve:

$$< m_J >= m_{J,i}(\phi) - A_J \times Template(\phi)$$

- Correct phasing

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Epoch of the maximum light

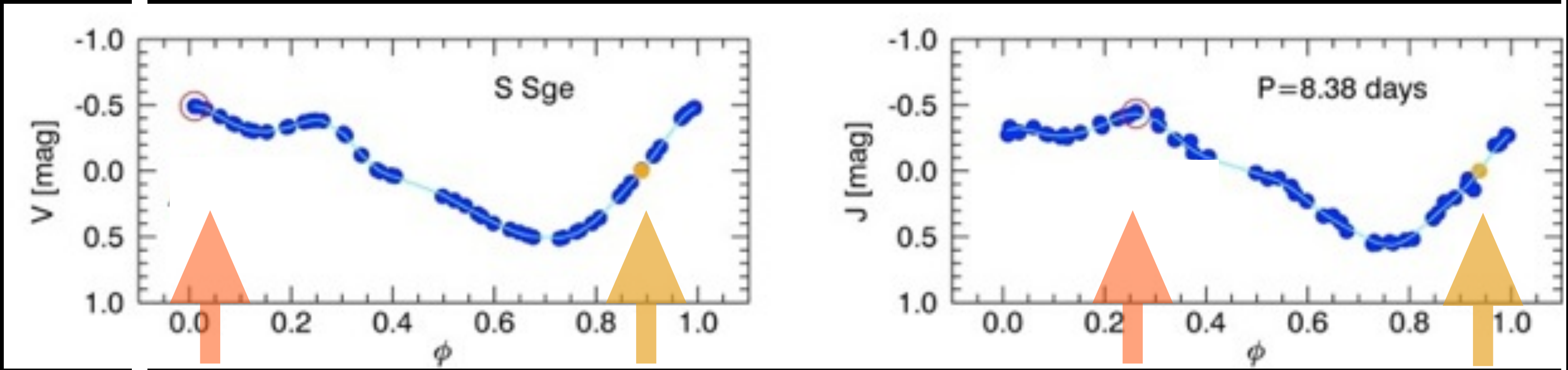

Fig 1 Red circles: phase of the maximum light for V and J bands. Orange dot: phase of the magntirude on the rising branch.

Inno+2014, A&A, in press

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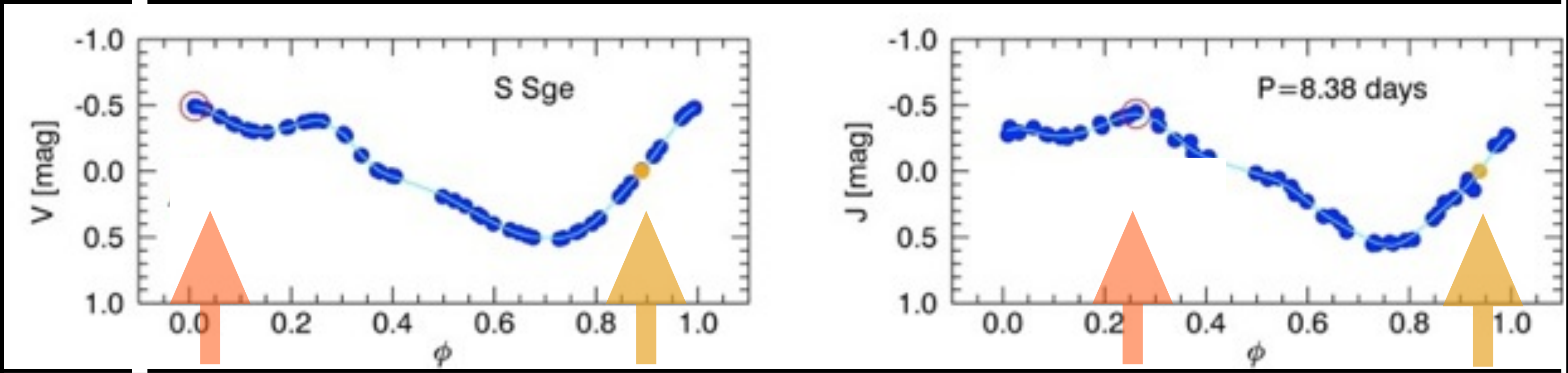
- Correct phasing

~~Epoch of the maximum light~~

Epoch of the mean along the rising branch



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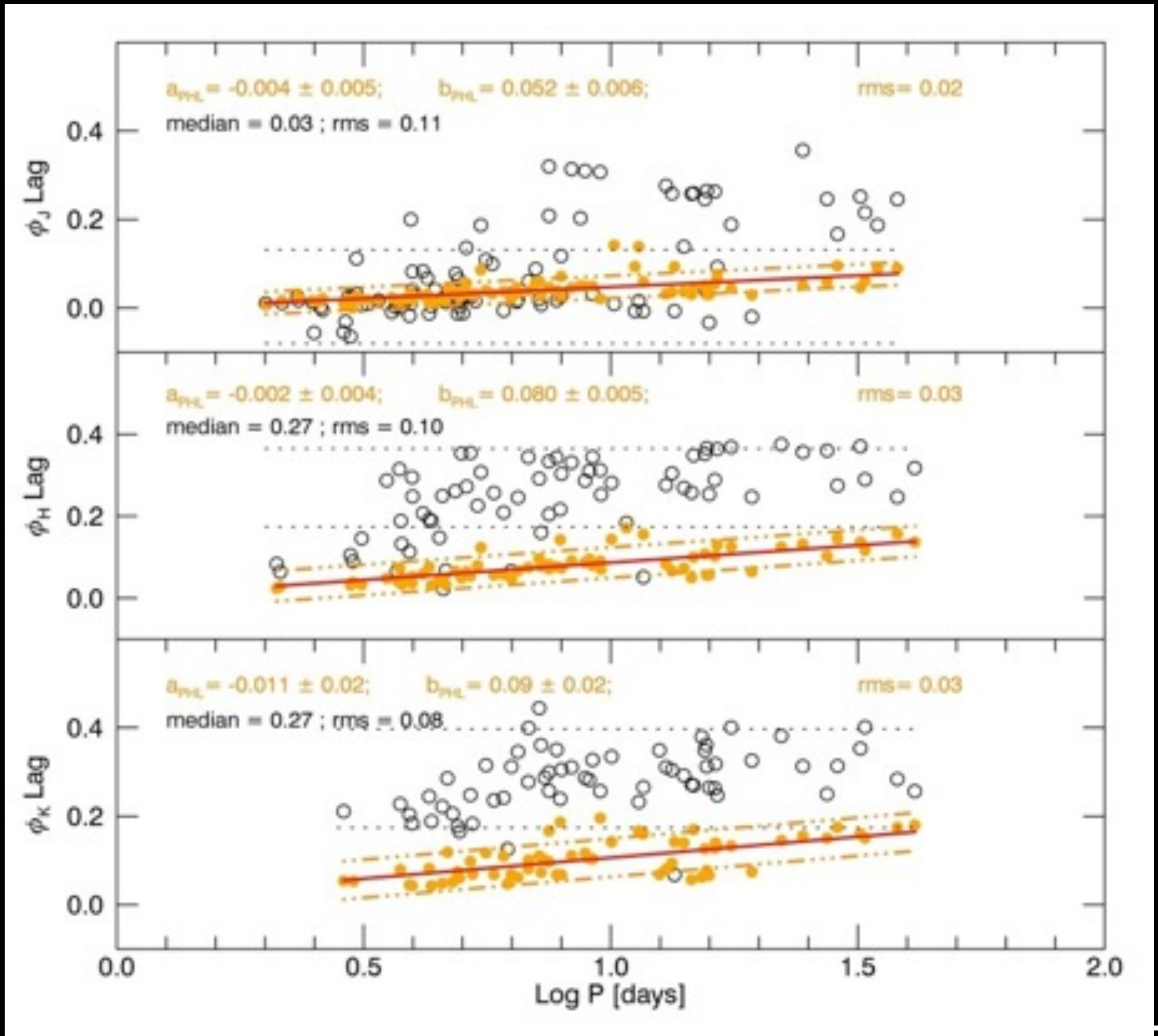

Fig 2 Phase lags in the J, H and Ks bands.

Inno+2014, A&A, in press

An empirical model to predict the shape of Cepheids NIR light curve:

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- Correct phasing: $JD_{mean}^{J,H,Ks} = JD_{mean}^{V} + P \times \phi_{Lag}^{J,H,Ks}$
- 10 bins in Period (bump, short period, FO)

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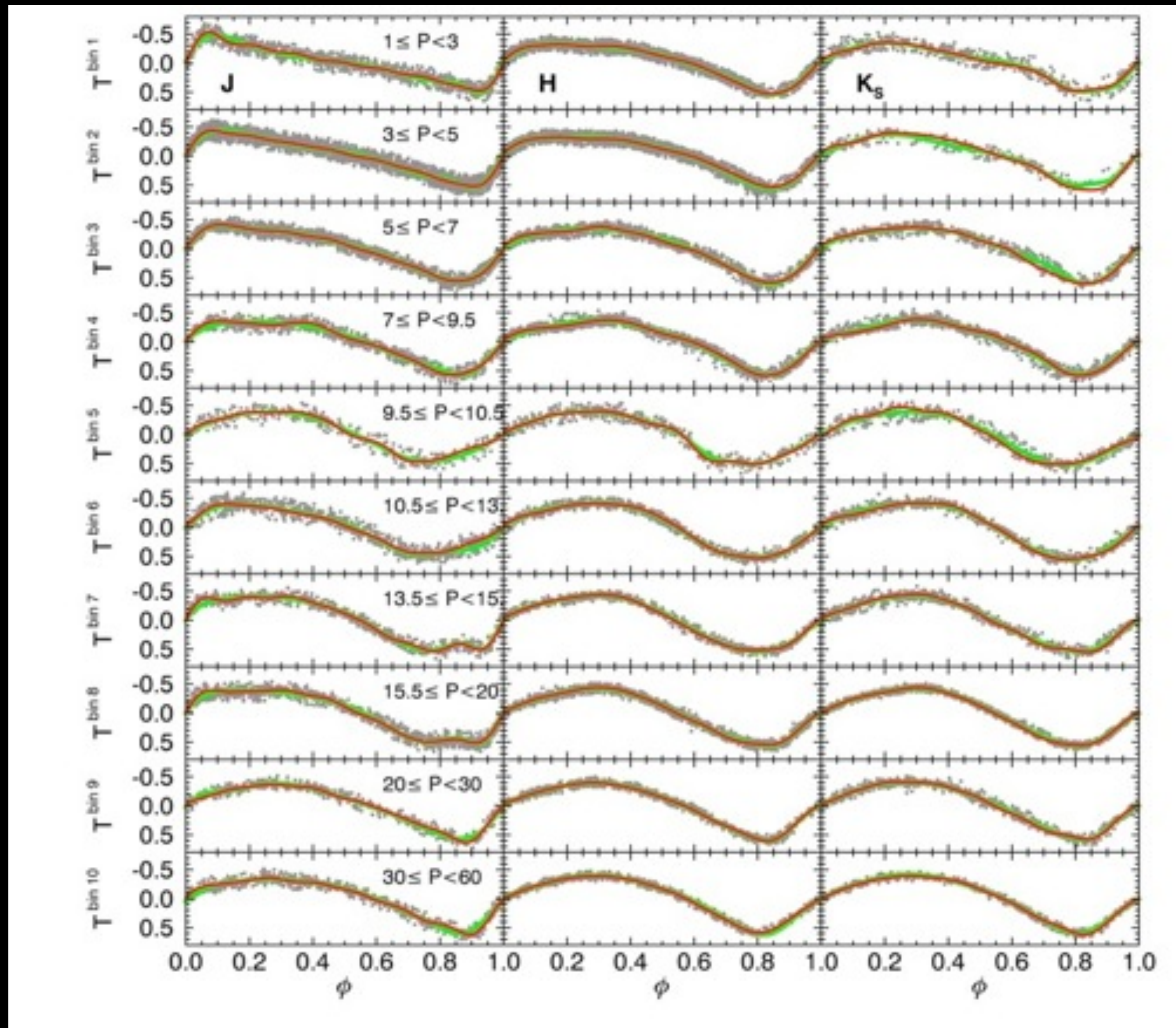

Fig 3 Templates for all the bins and all the bands.

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An empirical model to predict the shape of Cepheids NIR light curve:

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- Correct phasing: $\phi^V_{obs} = \mathrm{mod}\left(\frac{JD^V_{obs} - JD^V_{max}}{P}\right)$
- 10 bins in Period (bump, short period, FO)
- optical-NIR amplitude ratios for different bins of metallicity

An empirical model to predict the shape of Cepheids NIR light curve:

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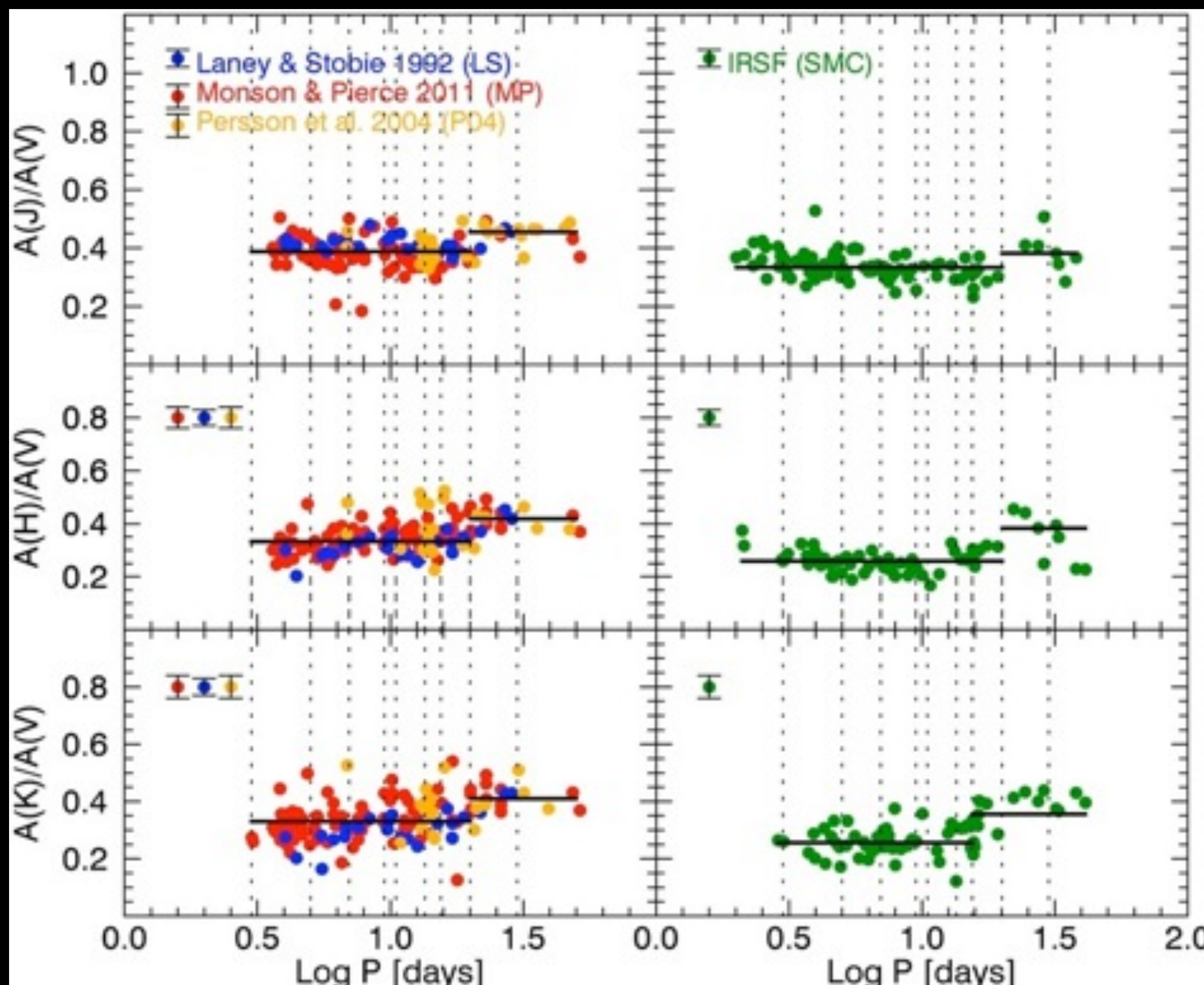

Fig 4 optical-NIR amplitude ratios for calibrating Cepheids

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An empirical model to predict the shape of Cepheids NIR light curve:

$$< m_J >= m_{J,i}(\phi) - A_J \times Template(\phi)$$

Error budget

Template: **0.015** mag (J) -- **0.019** mag (K)

$$\sigma_{TOT} = \sqrt{\sigma^2_{ph} + \sigma^2_{tmp} + \sigma^2_{ID}}$$

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1% Photometric accuracy

$\sigma_{phot} \sim 1\%$ $\sigma_{tmp} \lesssim 1\%$ $\sigma_{ID} \sim 3\%$

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Inno+2014, A&A, in press

<u>The Intrinsic Dispersion (ID) is the dominant term</u>

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Inno+2014, A&A, in press

The ultimate tool to derive precise distances from NIR single epoch observations

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Largest sample ever collected in the NIR bands:

Ita +, in prep

LMC Data Sample

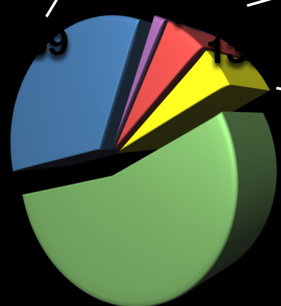
SMC Data Sample

FO single epoch (IRSF) + template

FU mean (Persson+04)

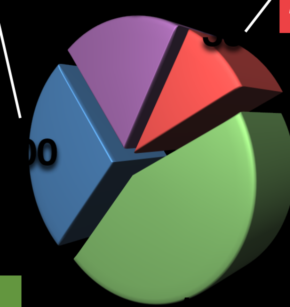
FU mean K + template J (VMC)

FO mean K + template J (VMC)



FU mean (IRSF)

FO mean (IRSF)



NEW

FU single epoch (IRSF) + template

Total ~ 2,700 (90 % of OGLE-III Cepheids)

Total ~ 4,000 (91 % of OGLE-III Cepheids)

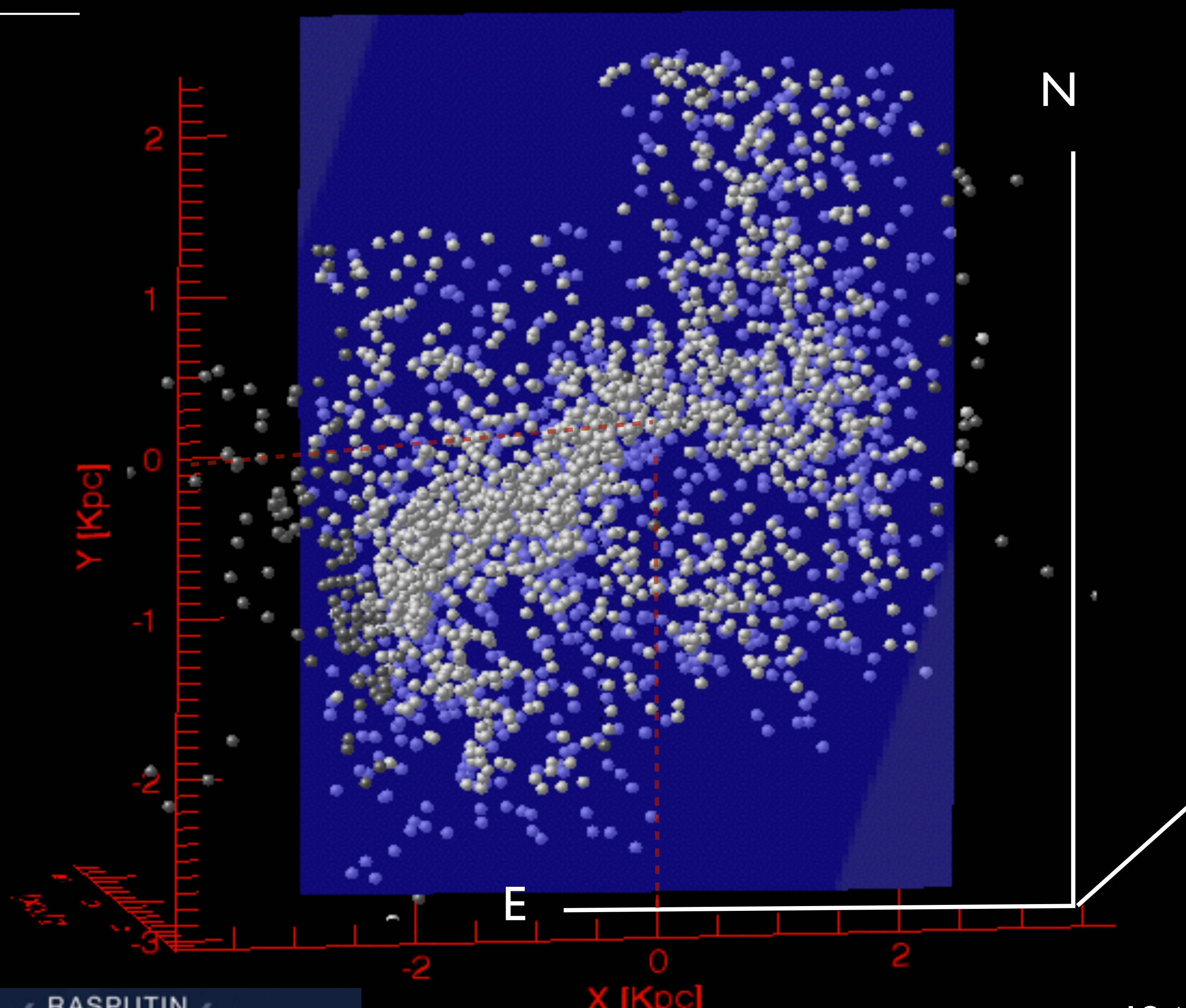
Largest sample ever collected in the NIR bands:

10 PW relations to estimate relative distances for ~ 7000 Cepheids

Cepheid relative distances to 1% precision

Preliminary!

The LMC Structure



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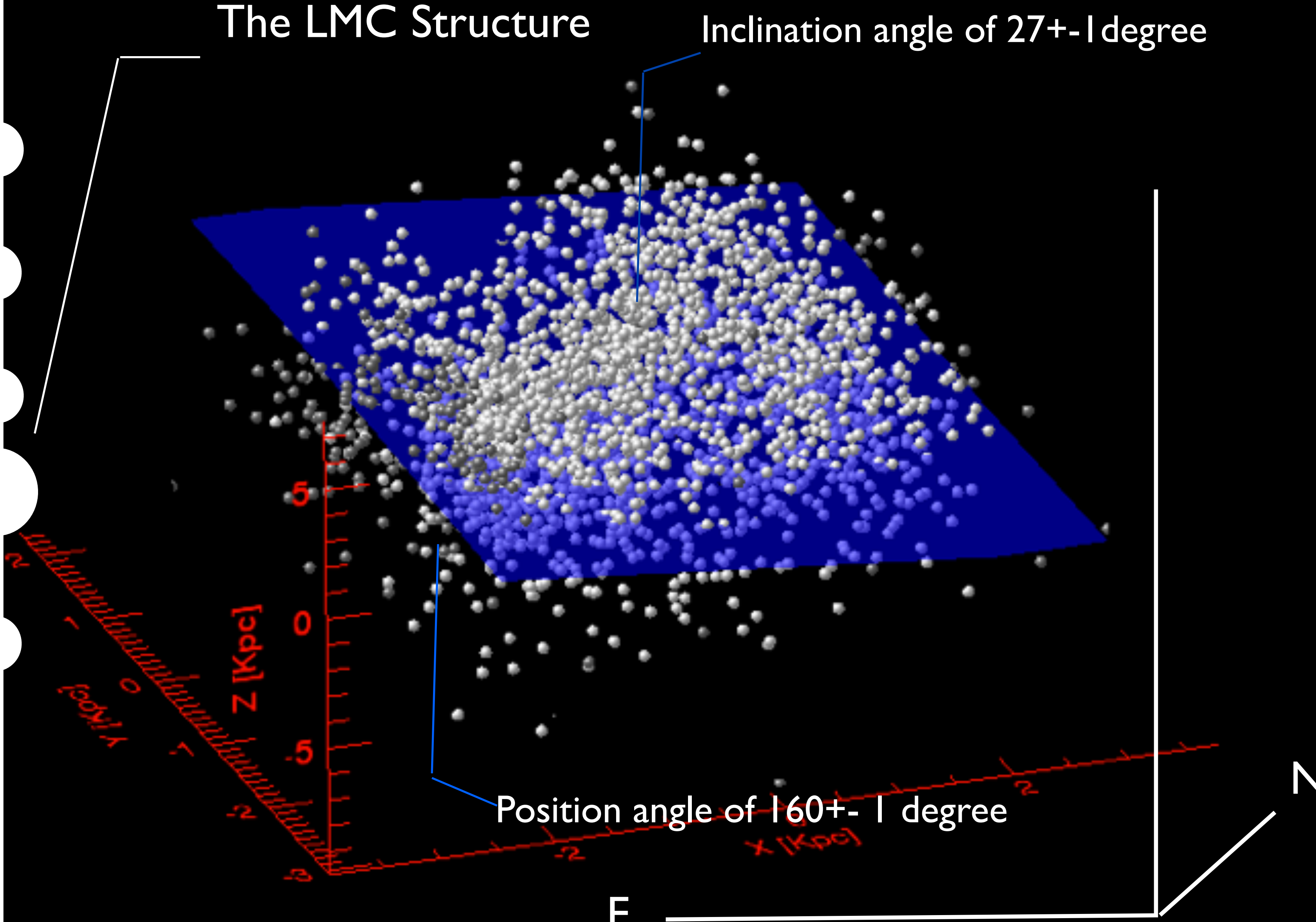

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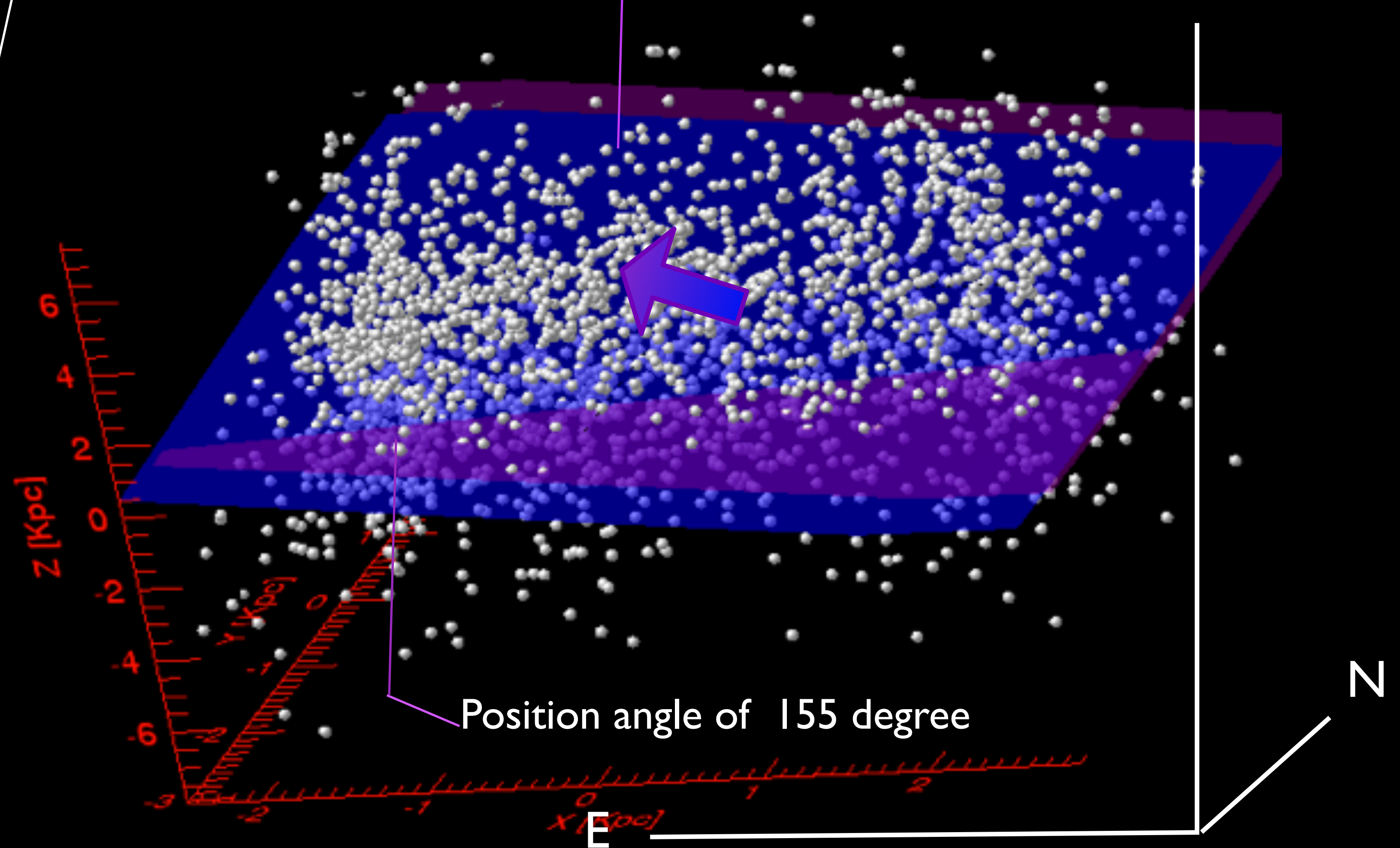

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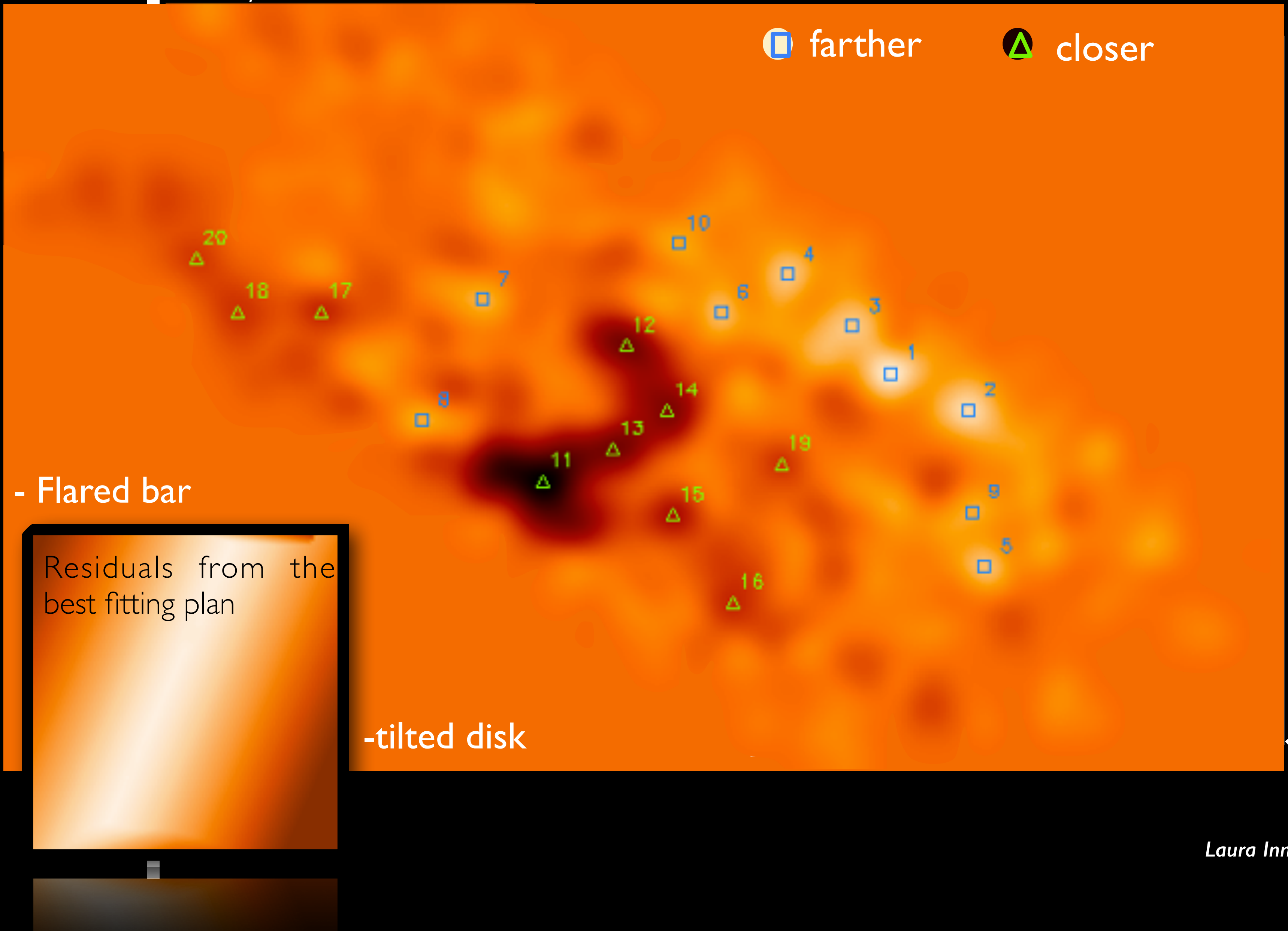


Fig 5 Map of the distance-density distribution for Cepheids in the LMC

The LMC Structure

Preliminary!

N

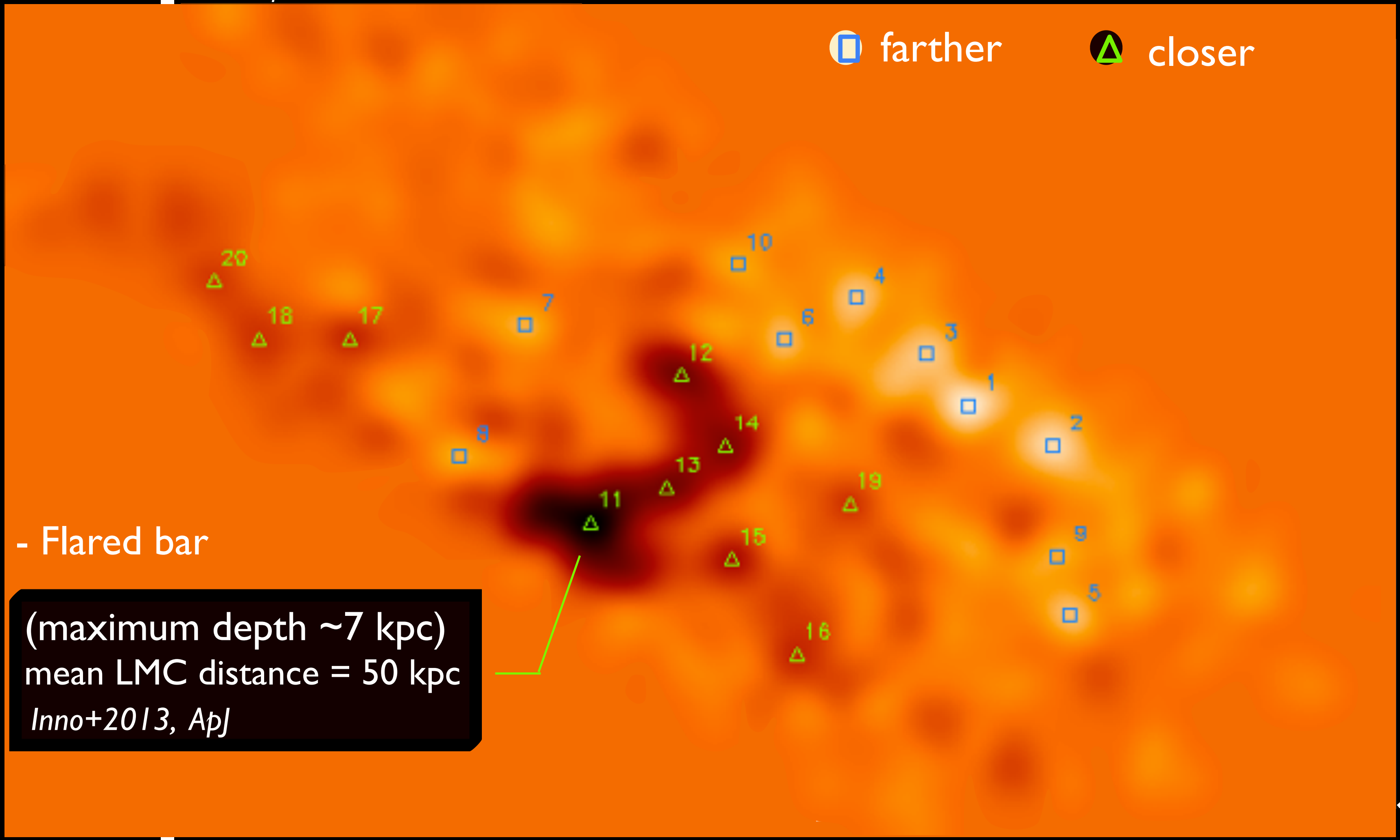


Fig 5 Map of the distance-density distribution for Cepheids in the LMC

The SMC Structure

Preliminary!

N

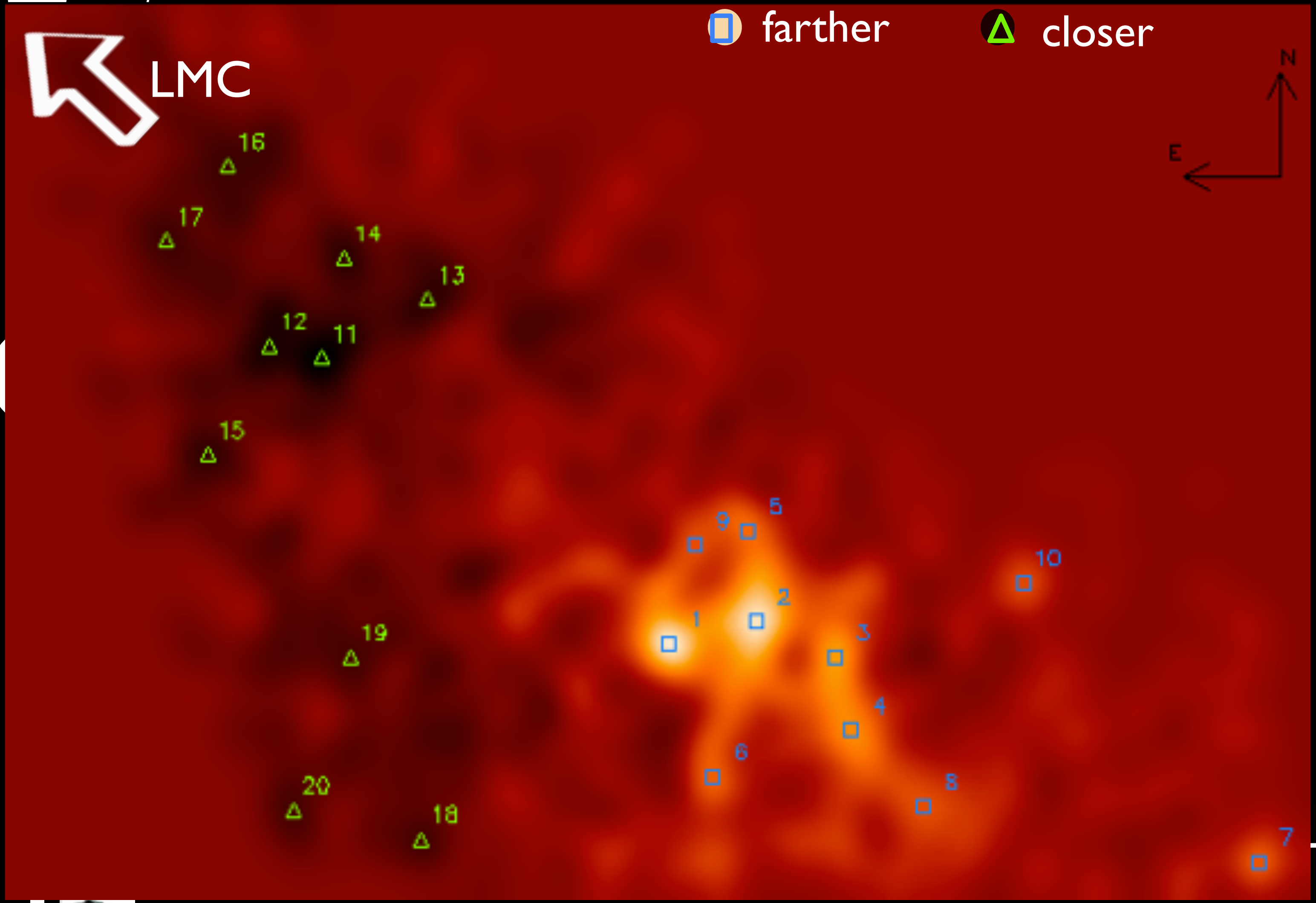


Fig 6 Map of the distance-density distribution for Cepheids in the SMC

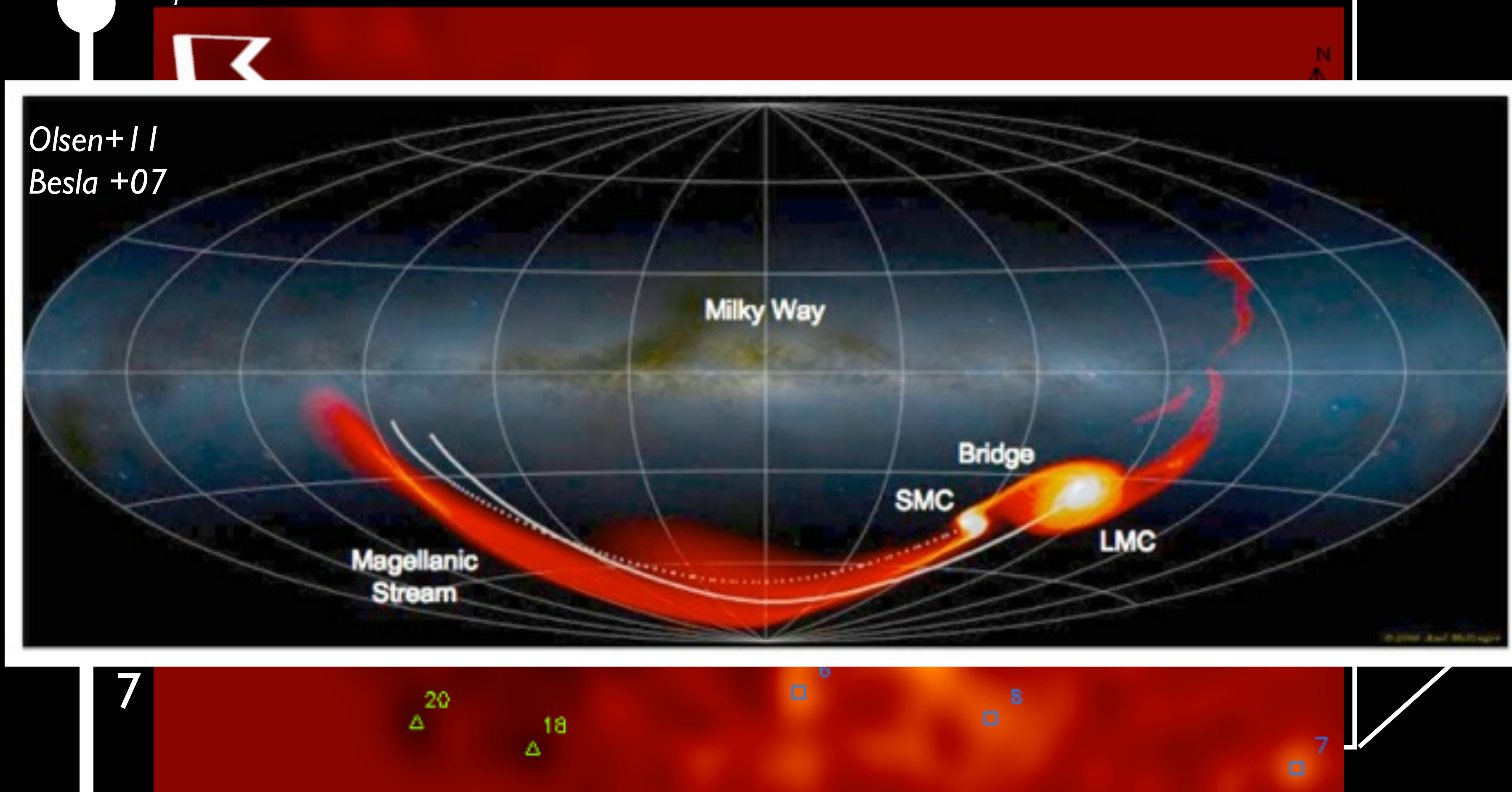
Preliminary!

The SMC Structure

LMC

N

Olsen+11
Besla +07



7

VIMOS spectra

Preliminary!

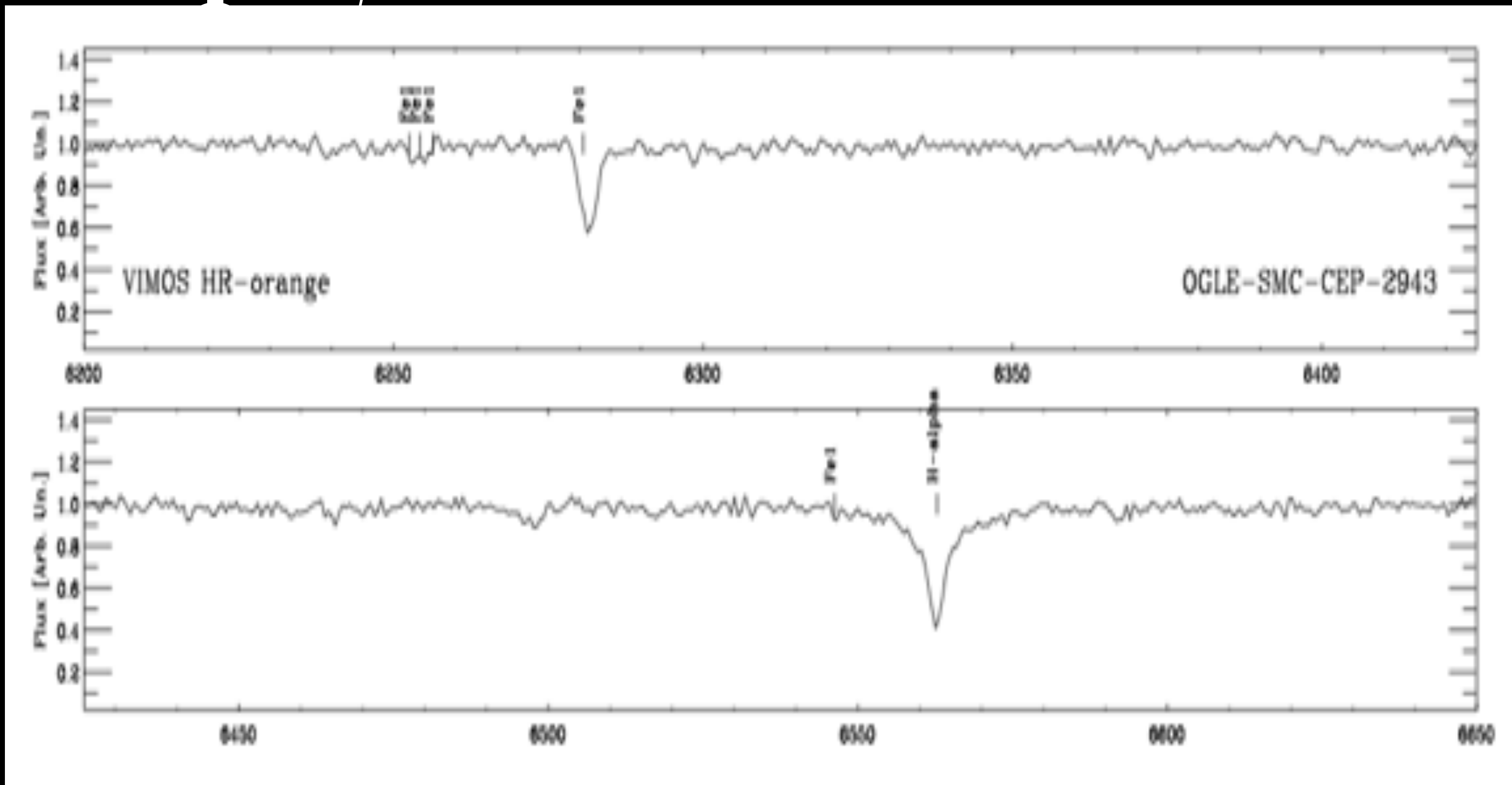
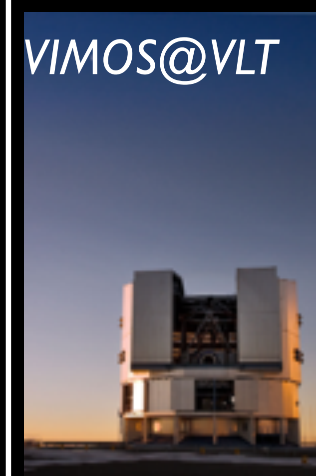


Fig 7 VIMOS spectrum for 1 of our target Cepheids in the LMC



Kinematics & Chemical tagging of Cepheids in the MCs

- Low-Resolution Chemical abundances: Iron (and alpha elements?) for ~700 Cepheids in the MCs

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- Radial Velocities with a few km/s precision

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New NIR templates

Mean magnitude estimates

80(J)%-70(K)%

more accurate than single epochs.

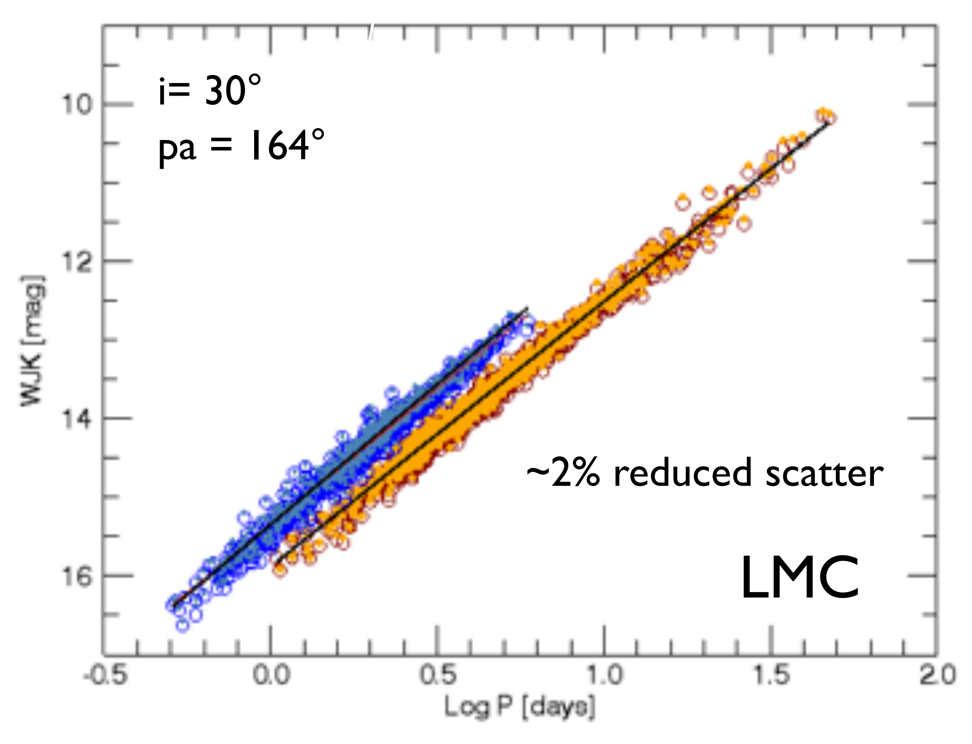
50%(J)-30 (K)%

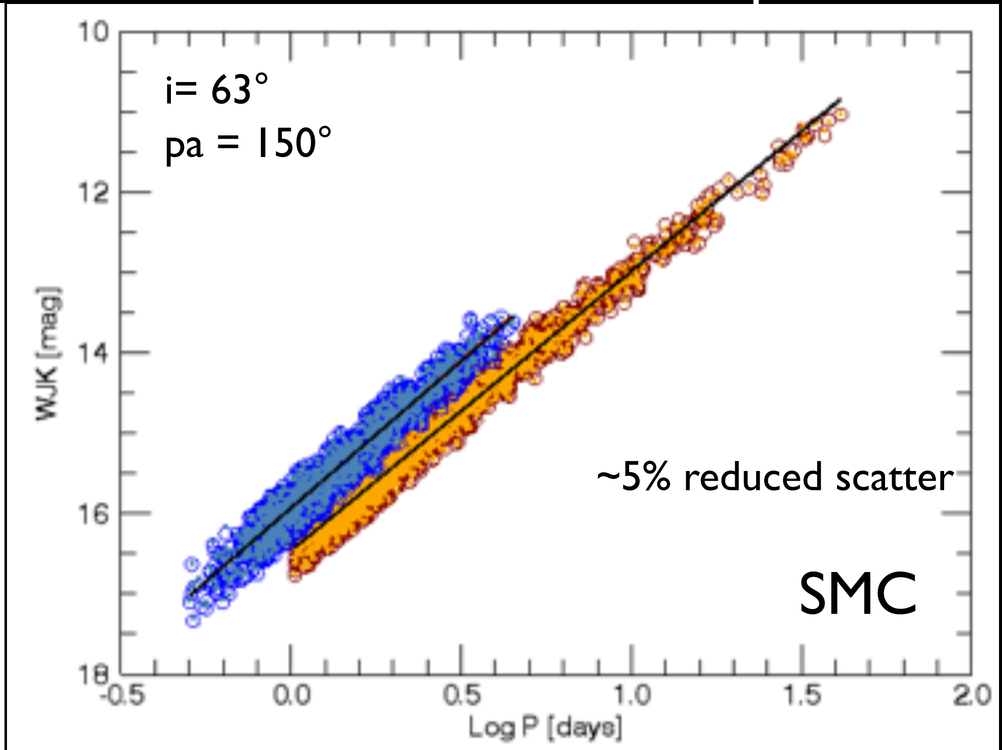
more accurate than previous templates.

PW relation total dispersion reduced up to 30% (PWVJ) compared to single epoch. observations and up to 5% compared to previous templates *(Soszynski+2005)*

Preliminary!

Geomertry: Inclination Corrections





Preliminary!

3D

Complex vertical structure, especially in the inner 3 degrees

Cepheids line of sight depth 20% of the distance to SMC

off center bar?
Alves +2004, van der Marel +2002

flared bar?
Olsen & Salyk 2002

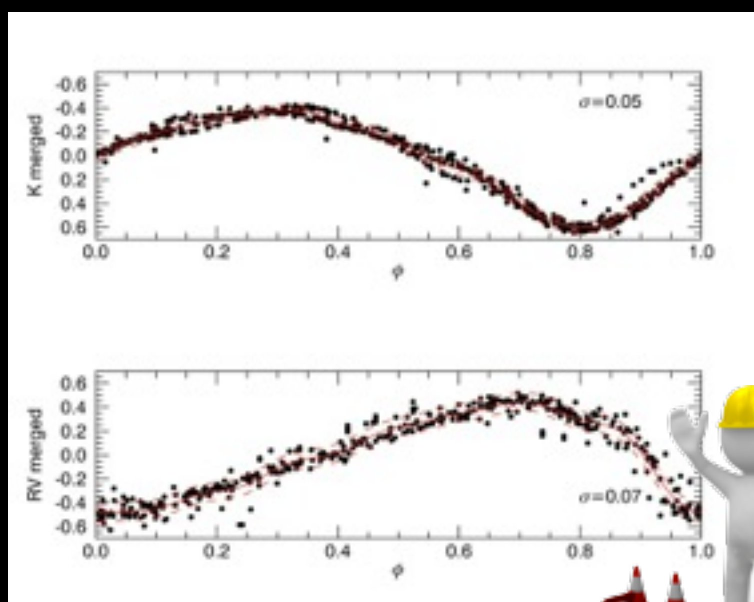
secondary bar?
Subramanian 2003, 2004.

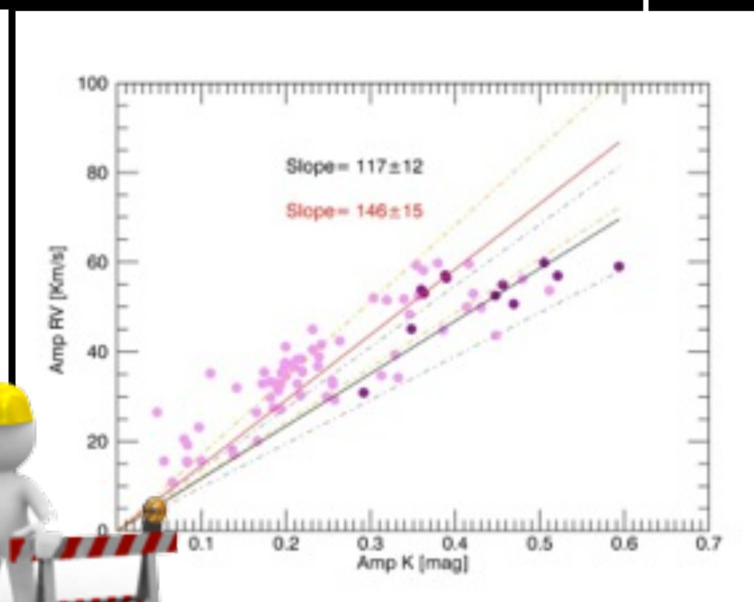
tilt in the disk

flared bar with line of sight depth 10% of the distance to LMC

Kinematics of the MCs

- Radial Velocities with a few km/s precision
- New radial velocity curves templates to estimate Cepheid γ-velocities





Cepheids

- NIR photometry & LR spectroscopy
- Light curve & Radial velocity curve Templates

characterization of the spatial distribution, kinematics and chemical composition of young stellar populations

Cepheids in the MCs

- Precise absolute and relative distances: NIR PW relations+ NIR templates
- Geometry and 3D structure
- Kinematics: radial velocity from LR spectra + light curve templates
- Chemical tagging
- Pioneering approach to the E-ELT era

The LMC Structure