GCDS Survey Science

Cepheid distance scale in the era of spectroscopic surveys

Nice, 03/11/2010

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Cepheids in astrophysics

- F-G supergiants
- Core He-burning phase
- Pulsating variable stars (P = 1-~100d)

- **Cosmological distance scale**
- Evolutionary & Pulsation models
- Chemo-dynamical evolution of galaxies (abundance gradients)

The cosmological distance scale

- Secondary distance indicators (distant galaxies) :
  - Tully Fisher (spiral galaxies)
  - Dn-σ a.k.a. Faber-Jackson (elliptical galaxies)
  - **SN Ia lightcurves**
  - …
- Calibrated on Primary indicators :
  - **Mostly Cepheid distance scale**

    Period –Luminosity (PL) relation : $M = \alpha + \beta \log P$
  - + TRGB, masers …
- Implies the **universality** of the Cepheid PL relation

The universality of the PL relation in question

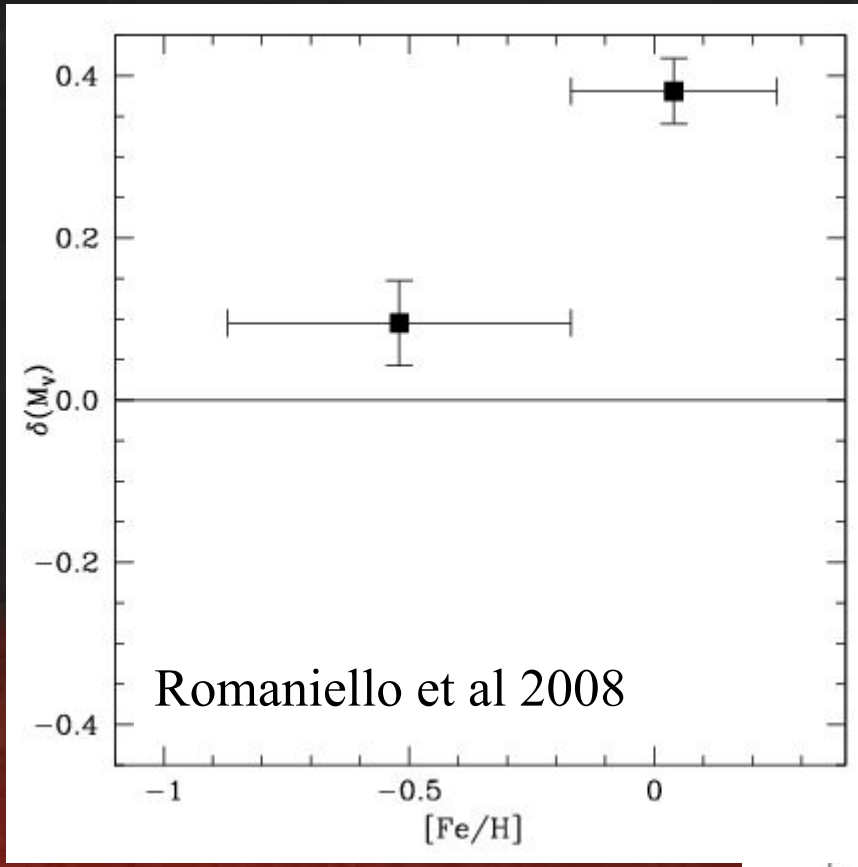
- Slope and/or zero-point may depend on the **Metallicity** (details next slide)
- Possible non-linearity of the PL relation (break at P ≈10d) (Tammann 2003, Ngeow et al 2003, 2006, Caputo 2008)

- Ho from the HST Key Project : 72 ± 8 km s^{-1} Mpc^{-1} (Freedman et al 2001)
- Ho from the SNe Project : 62.3 ±1.3(r) ±5.0(s) km s^{-1} Mpc^{-1} (Sandage et al 2006)
- Difference mainly due to the adopted Cepheid distance scale

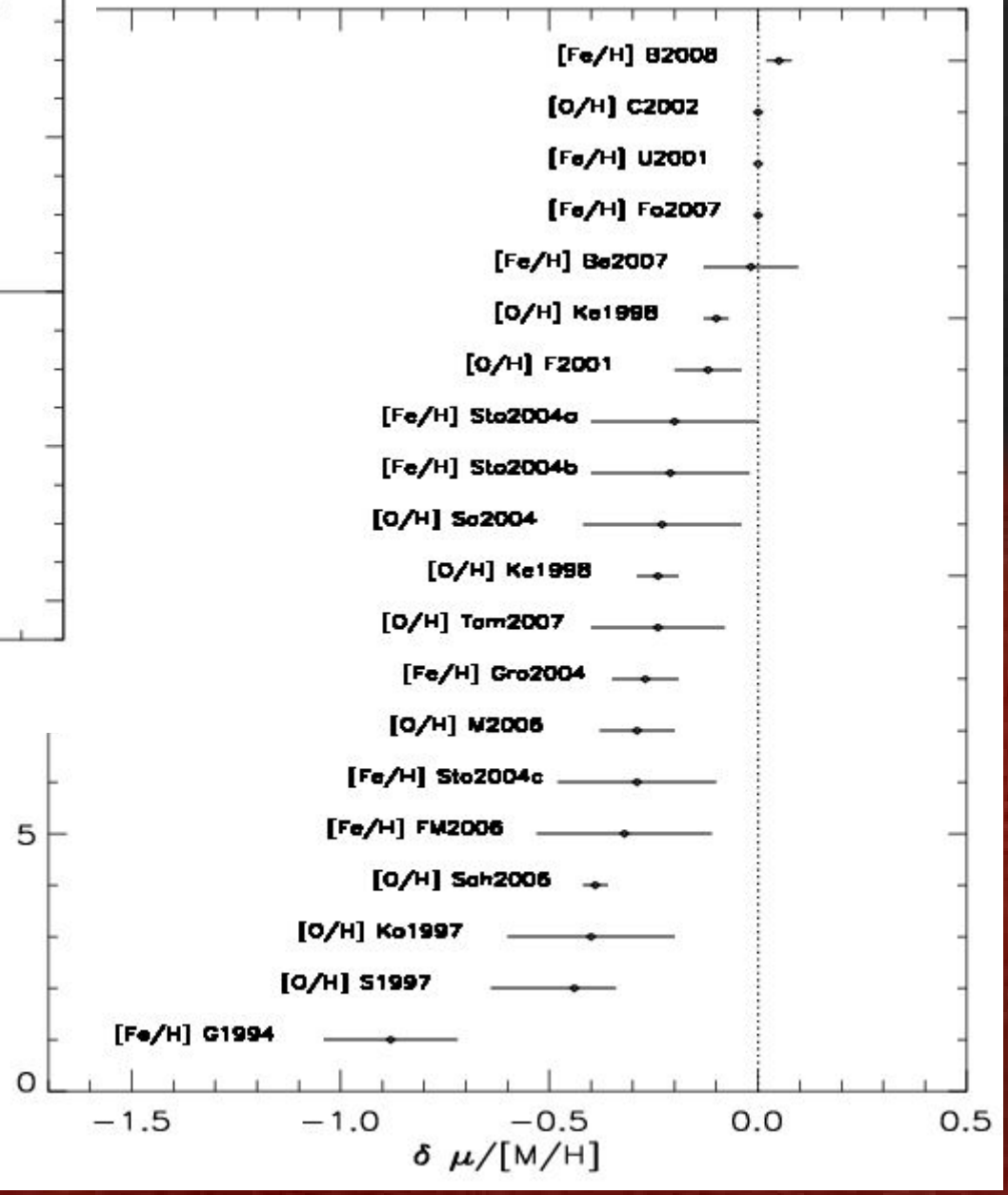
No consensus reached so far !

- Current model predictions and observations suggest <u>different trends with the metallicity</u>
- In particular, observations show a disappointing large range of values

  Negative ⇒ true distance > distance obtained with no metallicity effect
- Bono et al 2010 : slopes of the PL_K and $PW_{V,I}$ marginally affected (Models)
- Fouqué et al 2007 : slopes universal in all bands (Observations)



Romaniello et al 2008



Variation of the distance modulus μ per metallicity dex

Concerns on metallicity constraints

- Most of them : **indirect** measurements :

  Emission lines in HII regions and PNe of external galaxies ($\Rightarrow$ mainly [O/H])
- Concerns on the underlying assumptions:
  - Nebular abundances are still affected by uncertainties of $\approx$0.2 dex
  - Do extragalactic Cepheids/HII regions have the same metallicity for a given galactocentric distance ?
  - Linear correlation between [O/H] and [Fe/H] in external galaxies ?

Lack of direct measurements

- **~250** Galactic Cepheids with direct, accurate abundance measurements

  Andrievsky, Luck, Kovtyukh et al 2002-2006; Lemasle et al 2008, 2009
- Magellanic clouds :
  - 5 LMC + 5 SMC Luck et al 1992
  - 10 LMC + 6 SMC Luck et al 1998
  - 22 LMC + 14 SMC Romaniello et al 2008
  - Stars in common $\Rightarrow$ only **34+18** stars
- Other galaxies : **No** direct measurement
- Lack of **metal-rich** and **metal-poor** stars

Our best tools

- PL relation in the K band
  - Reddening reduced in the near-IR
  - Smaller intrinsic spread
  - Less dependent on metallicity

  } than in optical bands
  - (Persson et al 2004 : slope : ±0.04 mag; zero-point ±0.05 mag)
- Period-Wesenheit relation
  - Reddening-free by construction $W = V - R_I \times (V-I)$
  - Models predict a slope independent on metallicity
  - Current observational uncertainties : zero-point : 0.29 mag; slope : 0.20 mag (Bono et al 2010)
  - Monte Carlo simulations : uncertainties reduced to 0.07/0.05 with a sample of 600 Cepheids

Census of Cepheids :

- The Milky Way : **Only 676** Cepheids in the GCVS
  - Bright but located in the thin disk ⇒ dust
  - Larger zone to be surveyed → lightcurve

- Magellanic Clouds : nearly complete sample (thanks to microlensing surveys).

  OGLE III : **3361 LMC, 4630 SMC** Cepheids

  (Soszynski et al 2008, 2010)

- External Galaxies : Cepheids found in 74 external Galaxies, mostly from HST in V, I bands

What do we need : photometry

- Discover **new targets**
  - GAIA (2000 to 8000, Eyer & Cuypers 2000)
  - Other surveys
- **Near IR magnitudes** from public surveys
  - **VMC**: Vista Magellanic Clouds (PI: M. R. Cioni)
  - **VVV**: VISTA Variables in the Via Lactea, covers only a small part of the disk (PIs: D. Minniti, P. Lucas)
- **Long period cepheids** enter the calibration
- To be completed in the MW & external galaxies
- + FUTURE : mid-IR (Spitzer + JWST)

What do we need : distances

- GAIA : High precision **trigonometric parallax** including the brightest Cepheids of the LMC
  - HST FGS : 9 stars, accuracy of 8% (Benedict et al 2007)
  - Hipparcos data 250 stars, only 100 with $\sigma\pi < 100$ mas (Van Leeuwen et al 2007)
- Baade-Wesselink method :
  - surface-brightness relations to link variations in colour to variations in angular diameters
  - Projection (p-)factor that links radial velocity to pulsational velocity
  - Dependence of the p-factor on period (Nardetto et al 2009) and metallicity ?
  - **Vr curves** : need of several dozens of points/period, **survey for smaller telescopes ?**

What do we need : metallicities

- Metal-rich Cepheids : MW inner disk (abundance gradients)
- Metal-poor Cepheids : MW outer disk, LMC ($\rightarrow$ -0.6 dex), SMC ($\rightarrow$ -0.9 dex), external galaxies

- MC's : easy to find a GIRAFFE field with 60 to 100 targets
- MW, other galaxies : only small numbers

- **$\Rightarrow$ Borrow a few fibers to other surveys**

ESO spectroscopic surveys

- Simulations with the Besançon Model (Robin et al 2003) toward the Galactic center/anticenter
- Parameters corresponding to Cepheids

  (spectral types F6-K2, luminosity class I-II, -7<Mv<-2, age <130Myr)

- Would use **1-2 fibres** in a GIRAFFE f.o.v., 1h exposure, λ=500-700nm

- Depends on reddening and latitude **(-4°<b<–+4°)**
- Only currently known Cepheids

GYES@CFHT

- MOS (500 fibres) spectrograph, R=20000, f.o.v. > 1°
  (PI : P. Bonifacio, see talk this afternoon)
- Very accurate chemical abundances (≈0.1 dex),
  gain significant compared to GAIA

- For **V<16 mag**, spectra of **ALL** Cepheids in the GAIA catalogue with **S/N > 50** (Northern hemisphere)
- 1h exposure time, standard configuration
- Science case «variable stars» : **10-15** fibres over 500
  (Simulations with the Besançon model)

Summary

Whatever the loi(s) selected/merged…

Please consider the Cepheids !

(Not only for the distance scale,
also abundance gradients in the thin disk and models)



Table 2 Systematics error budget on H_o: past, present, and future

Known	Key Project	Revisions	Anticipated	Basis
Systematics	(2001)	(2007/2009)	*Spitzer*/JWST	
(1) Cepheid Zero Point	±0.12 mag	±0.06 mag	±0.03 mag	Galactic Parallaxes
(2) Metallicity	± 0.10 mag	±0.05 mag	±0.02 mag	IR + Models
(3) Reddening	±0.05 mag	±0.03 mag	±0.01 mag	IR 20–30× Reduced
(4) Transformations	±0.05 mag	±0.03 mag	±0.02 mag	Flight Magnitudes
Final Uncertainty	±0.20 mag	±0.09 mag	±0.04 mag	Added in Quadrature
Percentage Error on H_o	±10%	±5%	±2%	Distances

Revisions (Column 2) incorporating the recent work of Benedict et al. (2007) and Riess et al. (2009b).

Freedman et Madore 2010