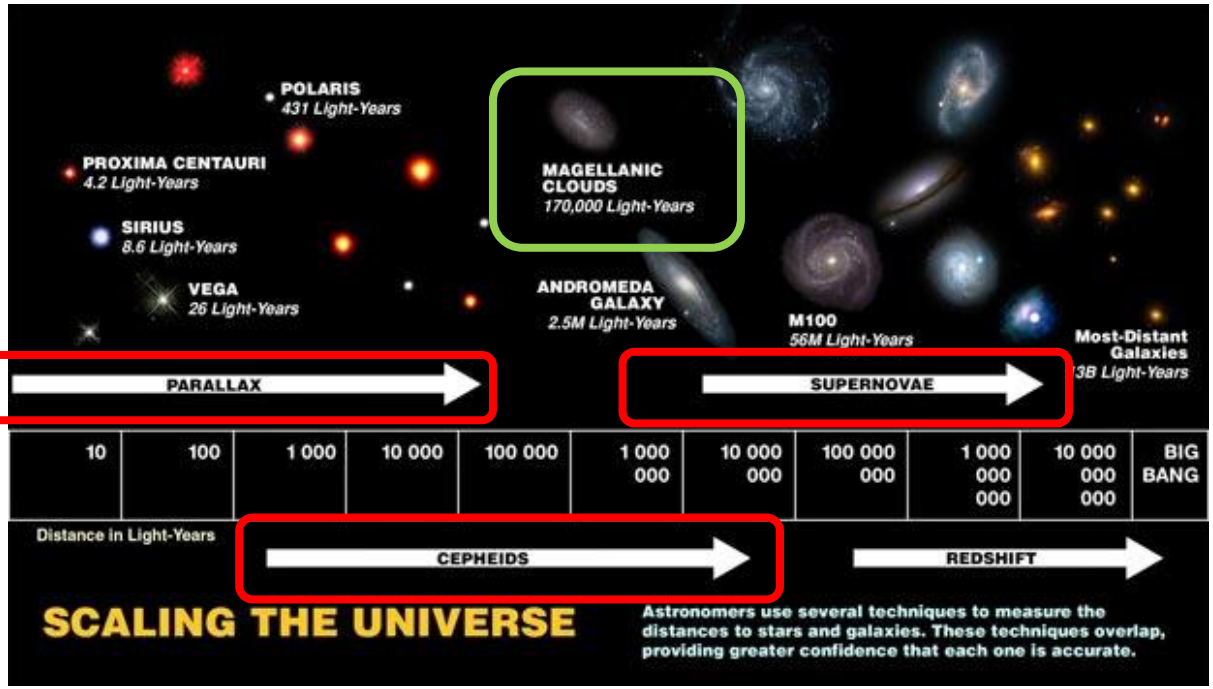
Data Analysis: D1

"Calibrating distance ladder to the LMC"

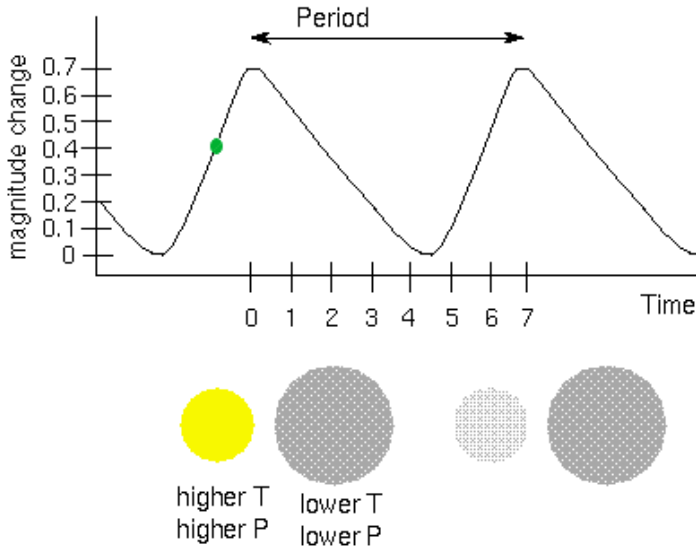
IBM, Monday Nov 13th, 2017

Introduction & Motivation

- **Cosmic Distance Ladder** has been successfully applied in extragalactic astronomy & observational cosmology
  - **Cepheid variables:** bridging the local parallax and distant SNIa methods
  - **Large Magellenic Cloud (LMC)**: very good for detailed studies and calibration work



Cepheid variable light curve

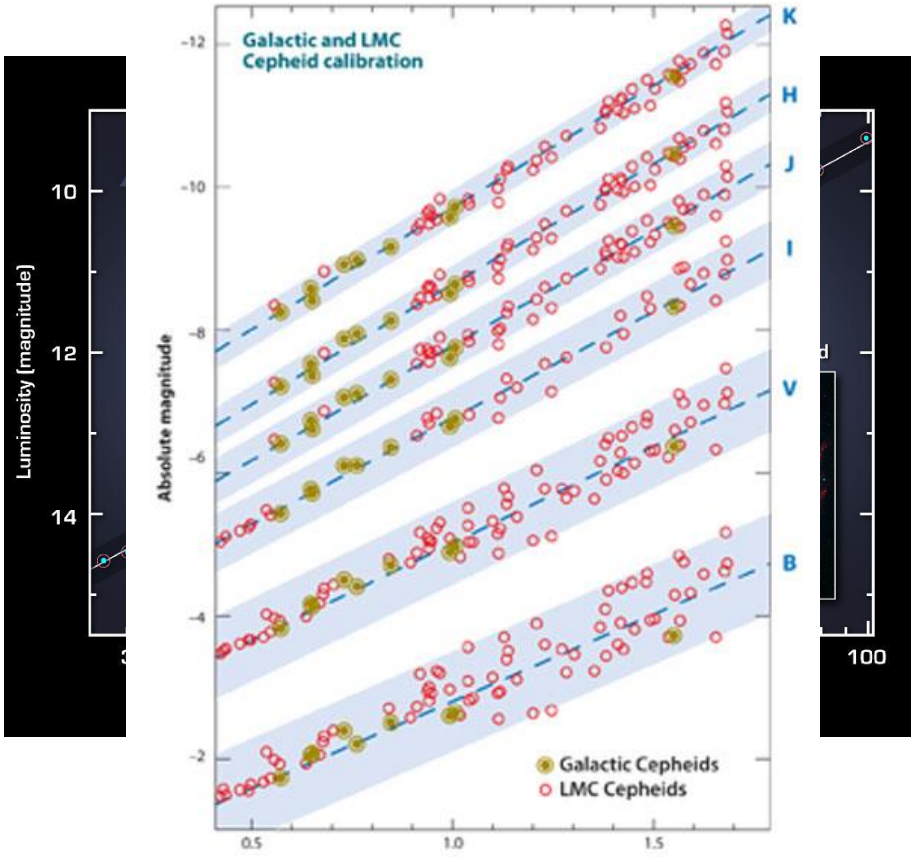


Cepheid variables: outward pressure (P) and inward grav
are out of sync, so star changes size and temperature: it

Objectives

To calibrate/derive **Cepheid Period-Luminosity (PL) relation** using well measured distances of **Galactic Cepheids** then use it to estimate **distance to LMC**

- **Dust extinction** in optical and NIR bands
- **Wavelength dependent PL relation** → Period-Luminosity-Colour (PLC) relation
- **Scatter of estimated distances** in different bands



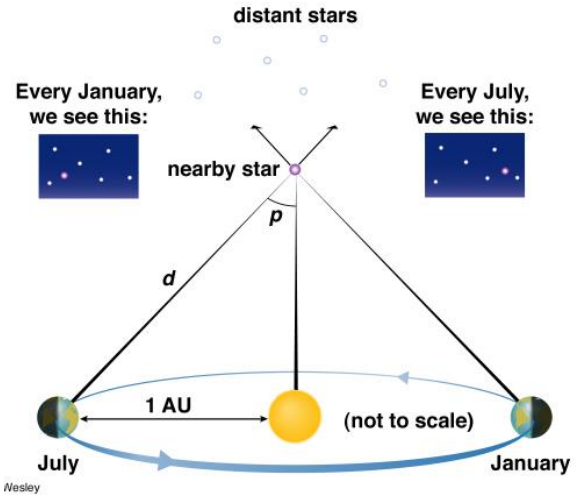
Knowledge and topics

- **Star & Stellar Properties**
  - Method of distance determination
  - Cepheid variable & PL relation
  - Luminosity & magnitude
- **Stellar System & Galaxy**
  - Interstellar medium and Galactic absorption
  - Luminosity & distance determination
- **Elementary Cosmology**
  - Cosmic distance ladder
- **Multi-wavelength & space astronomy**
- **Data and statistical analysis skill**

Task 1 (D1.1)

- **Derive PL relation** from Galactic Cepheids using data in V- and K-band (**36.5/75 marks**)
  - Using Accurate parallax measurements (~0.2mas) from **Hubble Space Telescope** → **distance to 10% acc.**

  - **Given Data** (Table 1), period, average apparent magnitude, extinction correction, parallaxes of **5 MW Cepheids**



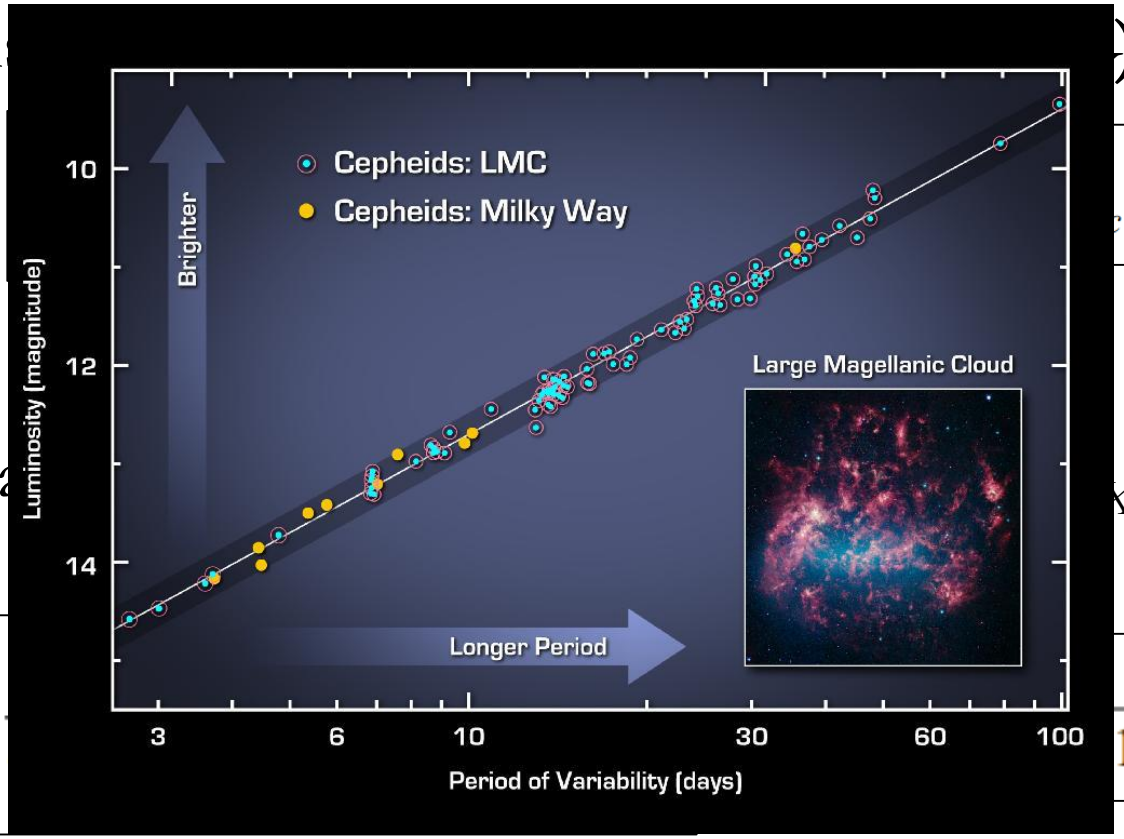
	P (day)	<V> (mag)	<K> (mag)	A_V (mag)	A_K (mag)	<I> (mag)	parallax (mas)	error (mas)
RT Aur	3.728	5.464	3.925	0.2	0.02	4.778	2.4	0.19
FF Aql	4.471	5.372	3.465	0.64	0.08	4.51	2.81	0.18
X Sgr	7.013	4.556	2.557	0.58	0.07	3.661	3.0	0.18
ζ Gem	10.151	3.911	2.097	0.06	0.01	3.085	2.78	0.18
l Car	35.551	3.732	1.071	0.52	0.06	2.557	2.01	0.2

Task 1 (D1.1) contd.

- **Cepheid PL relation**

$$P \propto L^{\alpha} \text{ or } L \propto P^{\beta}$$
$$\log L = \beta \log P + C$$

- log L i) via



- Calcula and its error

$$d_{pc}(\text{parsec}) \approx$$

$$\frac{}{10} \times \Delta d_{pc}$$

Task 1 (D1.1) contd.

	d_{pc}	Δd_{pc}	logP	M_V	ΔM_V	M_K	ΔM_K
RT Aur	416.6	32.	0.572	-2.83	0.17	-4.19	0.17
FF Aql	355.8	22.	0.65	-3.02	0.13	-4.37	0.13
X Sgr	333.3	20.	0.846	-3.63	0.13	-5.12	0.13
ζ Gem	359.7	23.	1.007	-3.92	0.14	-5.69	0.14
l Car	497.5	49.	1.551	-5.27	0.21	-7.47	0.21

- **Plot graphs (with error bars) of** log P vs. M_x for each band and estimate slopes with uncertainties

- **Compare** the values for V- and K-band

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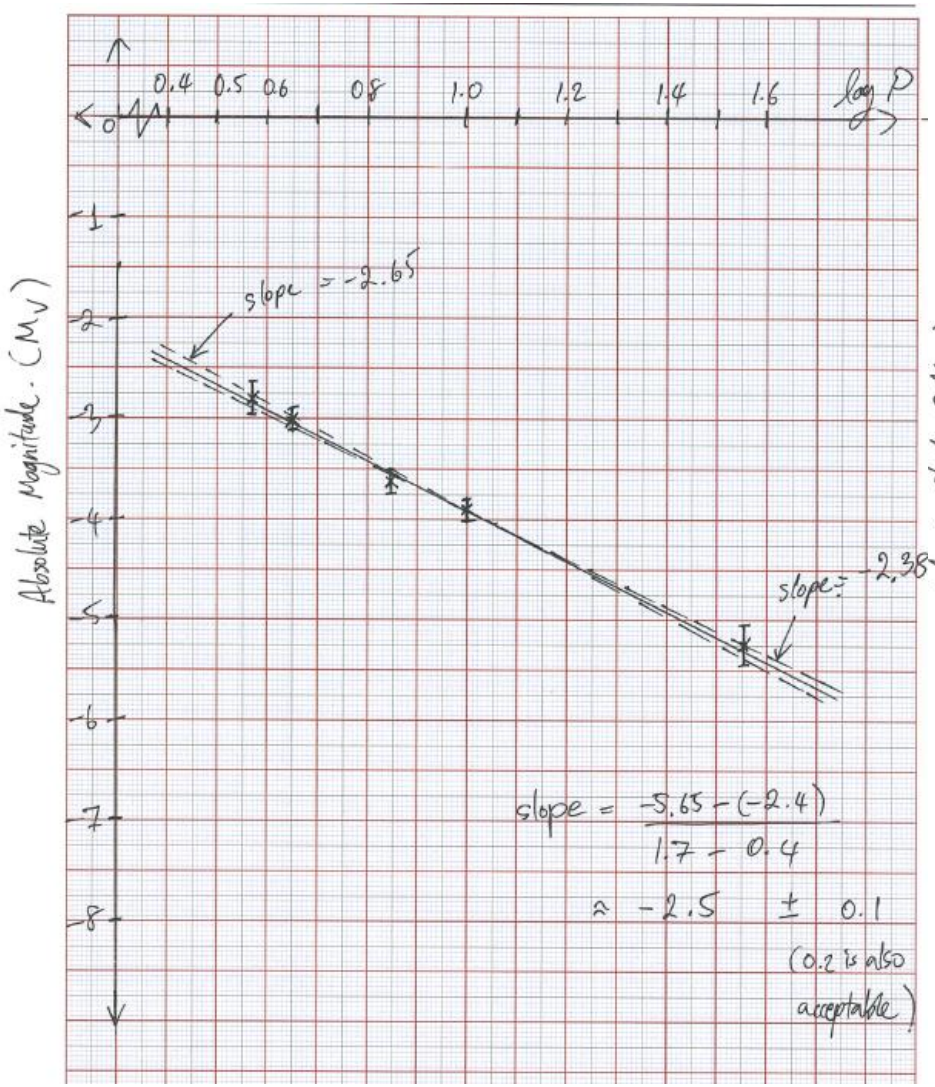
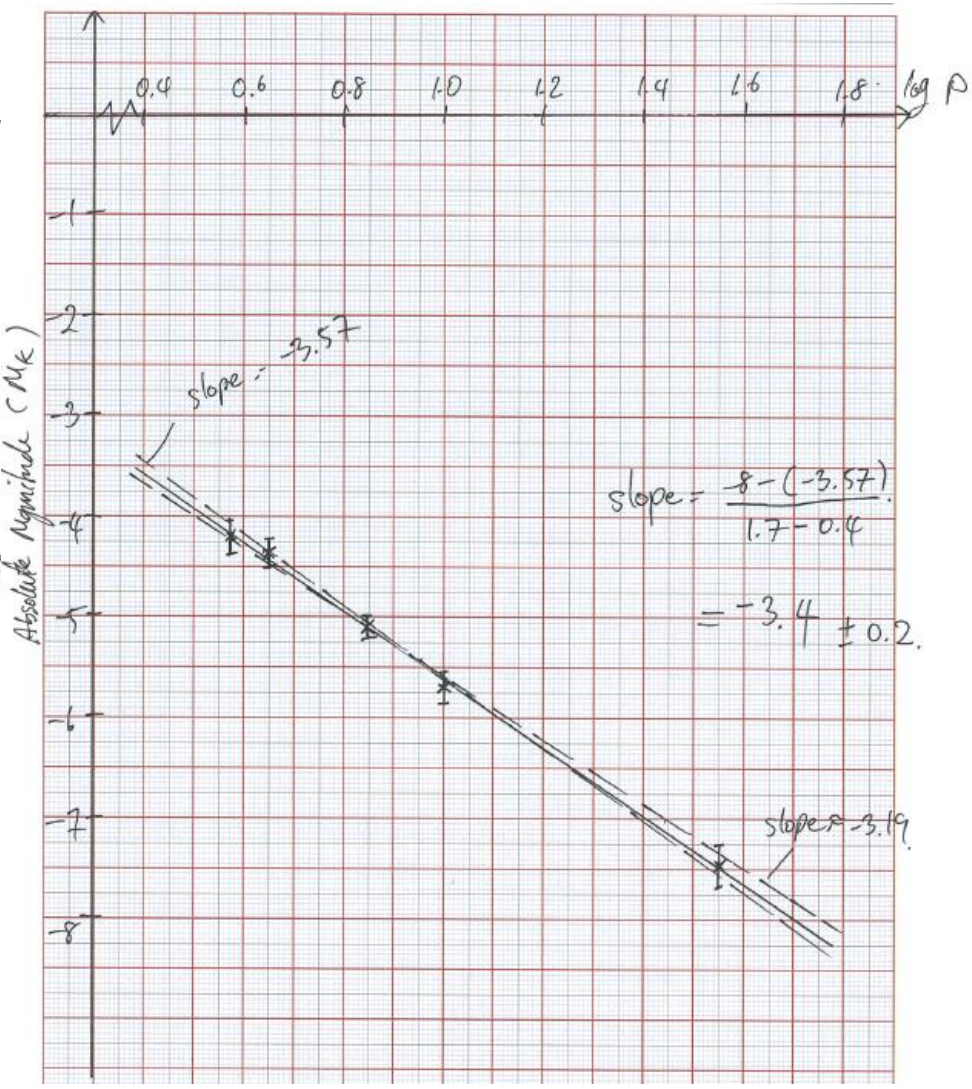
V-band

Slope = -2.5 +/- 0.2



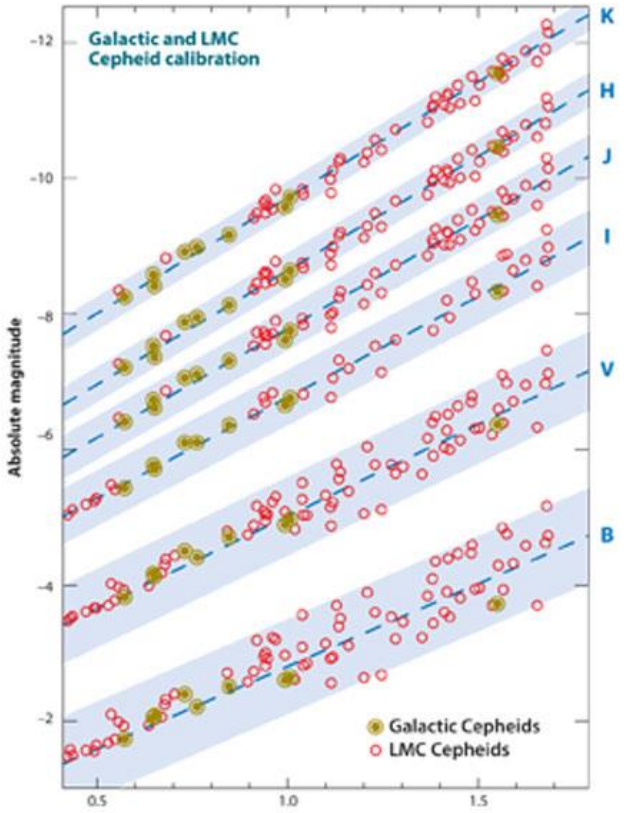
K-band

Slope = -3.4 +/- 0.2



Task 2 (D1.2)

- **Derive PL relation** of same dataset as (D1.1) but for Wesenheit magnitude
  - Introducing wavelength dependent PL, i.e. PLC relation, and **reddening-free bandpass**, **Wesenheit**, W_{VI}
  - **Calculate** W_{VI}, M_{WVI} and its uncertainties
  - **Plot graph** and draw the expected straight line similar to (D1.1) and estimated slope and uncertainty
  - **Compare and conclude** if the derived slope is more consistent with V- or K-band



$$W_{VI} = V - \left[\frac{A_V}{E(V-I)}\right](V-I),$$

$$= V - R_v(V-I)$$

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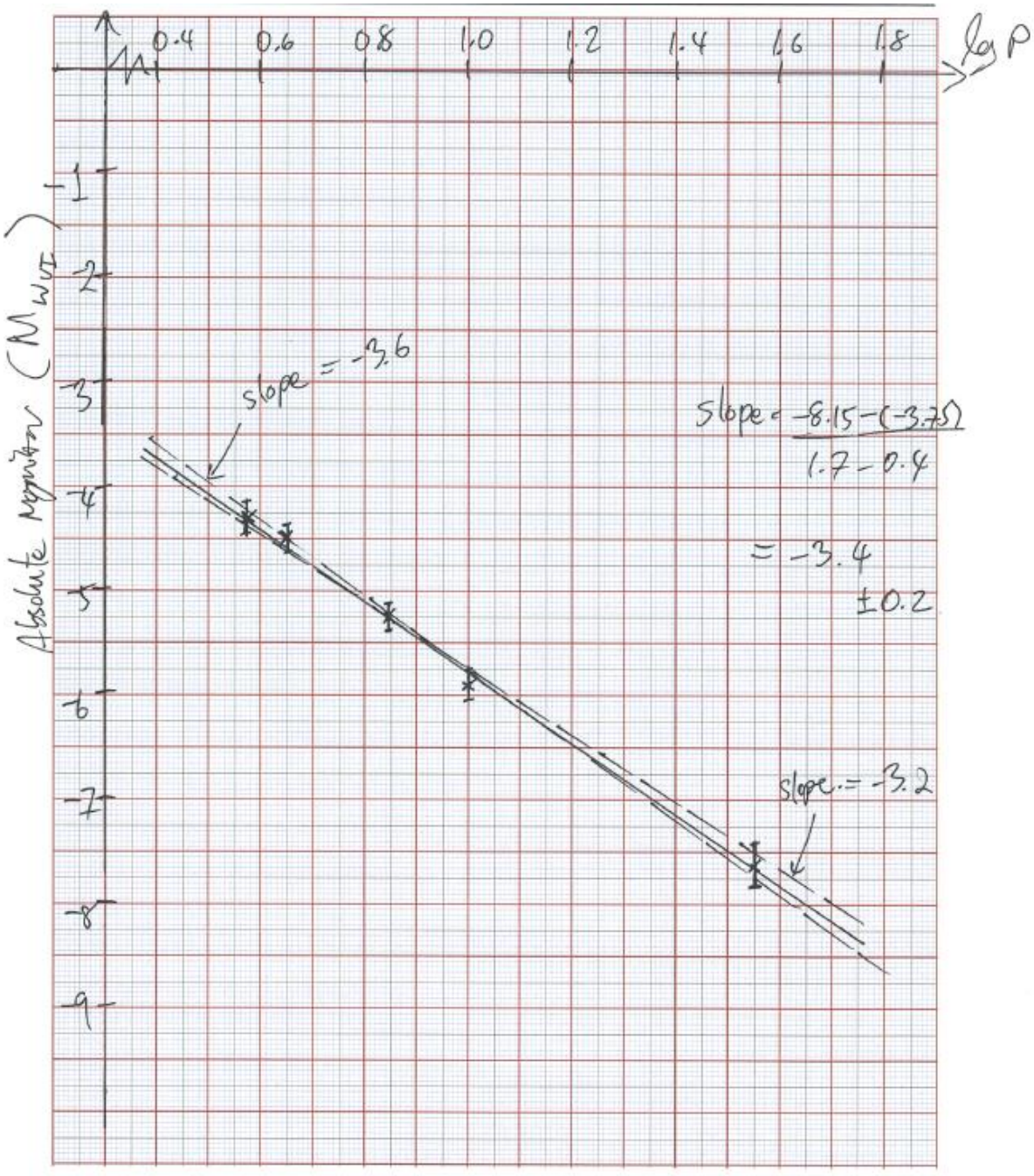
W_{VI}-band

Slope = -3.4 +/- 0.2

	W_{VI}	M_{WVI}
RT Aur	3.78	-4.31
FF Aql	3.26	-4.49
X Sgr	2.36	-5.25
ζ Gem	1.88	-5.89
l Car	0.85	-7.63

14.5 / 75 Marks



Task 3 (D1.3)

- Calculate distance to the LMC (**24/75 Marks**)
  - Using the PL relations for V- and W_{VI}-band **derived in D1.1 & D1.2** to calculate distance moduli and distances to LMC

$$\mu_x = m_x - M_x$$

$$M_x = \beta_x \log P + C'_x$$

Need to go back to estimate this from plots in (D1.1) & (D1.2)

$$\mu = m_x - (\beta_x \log P + C'_x) = 5 \log_{10} d_{pc} - 5$$

Task 3 (D1.3)

- **The intercepts** estimated using plots and "Best-fit" lines in previous sections

V-band: $C'_V = -1.4$ (**1 mark** if within +/-0.2, half if within +/-0.3)

W_{VI} band: $C'_{WVI} = -2.4$ (**1 mark** if within +/-0.2, half if within +/-0.3)

- **Given data:** 5 LMC Cepheids (Periods, average extinction corrected apparent mag., V- and W_{VI}-band)

	P (day)	<V> mag	<W_{VI}> mag
HV12199	2.63	16.08	14.56
HV12203	2.95	15.93	14.4
HV12816	9.1	14.3	12.8
HV899	30.9	13.07	10.97
HV2257	39.36	12.86	10.54

Task 3 (D1.3)

- **Calculate mean** distance (accurate to the nearest 100pc) and **scatter** (RMS) in each band

Star	LogP	μ_V	μ_{WVI}	V distance (pc)	W_{VI} distance (pc)
HV12199	0.42	18.53	18.39	50813	47596
HV12203	0.47	18.50	18.40	50223	47805
HV12816	0.96	18.10	18.46	41640	49221
HV899	1.49	18.19	18.43	43549	48660
HV2257	1.60	18.25	18.36	44620	47058
			Mean	46170	48068
			RMS	4116	865

- Make a few conclusions on **consistency of distance and accuracy estimated from different bands**

d_{LMC} = 49.97+/-0.2 kpc (Pietrzyński et al., Nature, 2013)

Thank You