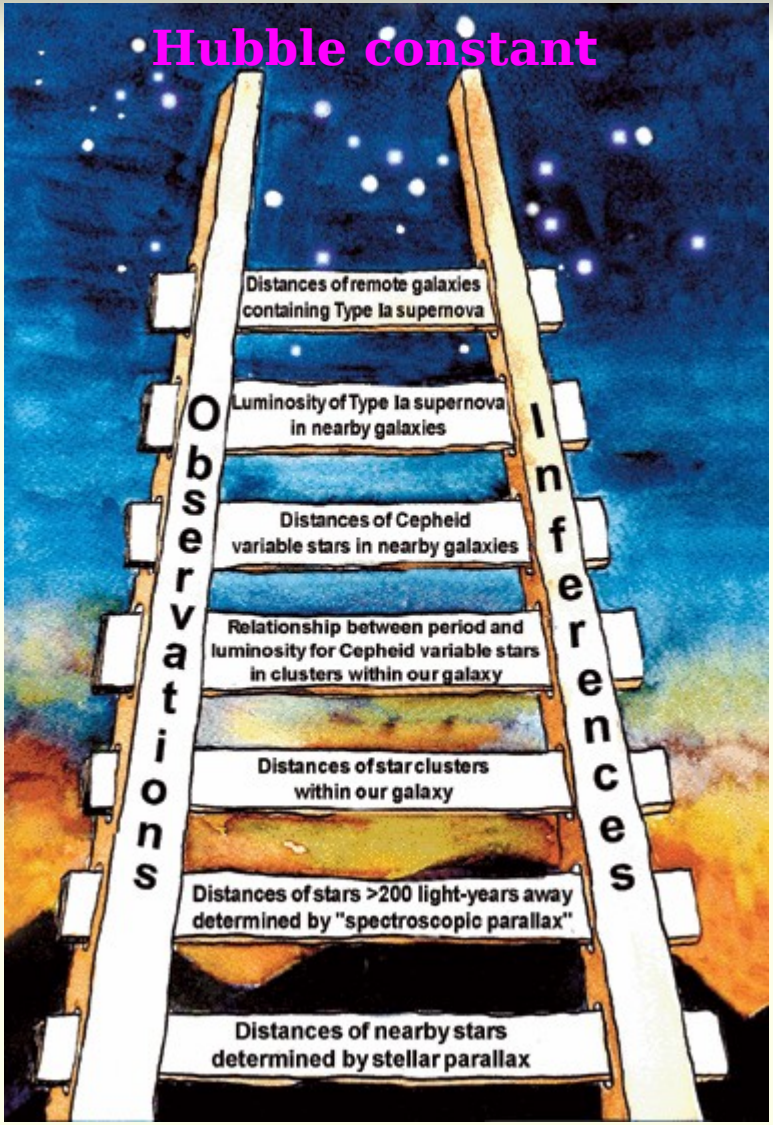
Graduate Institute of Astronomy, NCU
國立中央大學天文研究所

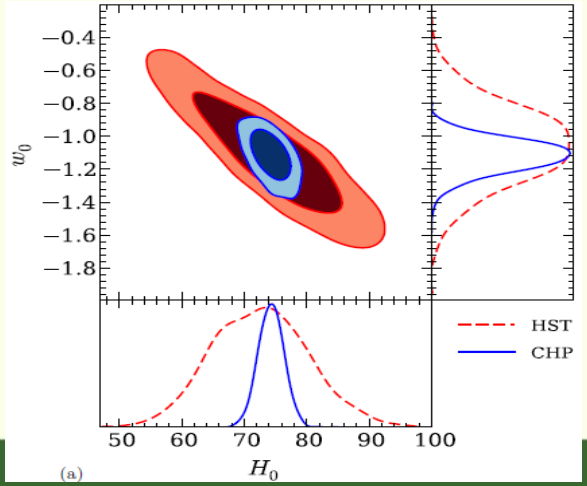
Distance Scale and Variable Stars Research at National Central University

Dr. Chow-Choong Ngeow / 饒兆聰
(National Central University, Taiwan)

Introduction: The Extragalactic Distance Scale

- Goal of extragalactic distance scale:
  - Independent measurement of Hubble constant accurate to ~few % level
- Local calibrators (Cepheids and RR Lyrae) to calibrate 2nd distance indicators (T-F, SNIa) in Hubble flow





Freedman et al (2012)

Part I:
Cepheids Period-Luminosity Relations in Mid-Infrared

Why Moving to Mid-IR?

- Extragalactic distance scale work mainly rely on Cepheids P-L relations in V and I band (e.g. HST H0 Key Project)
    - Issues of extinction and metallicity dependence/correction
- A way to improve distance scale measurement is moving to mid-IR band: extinction is negligible

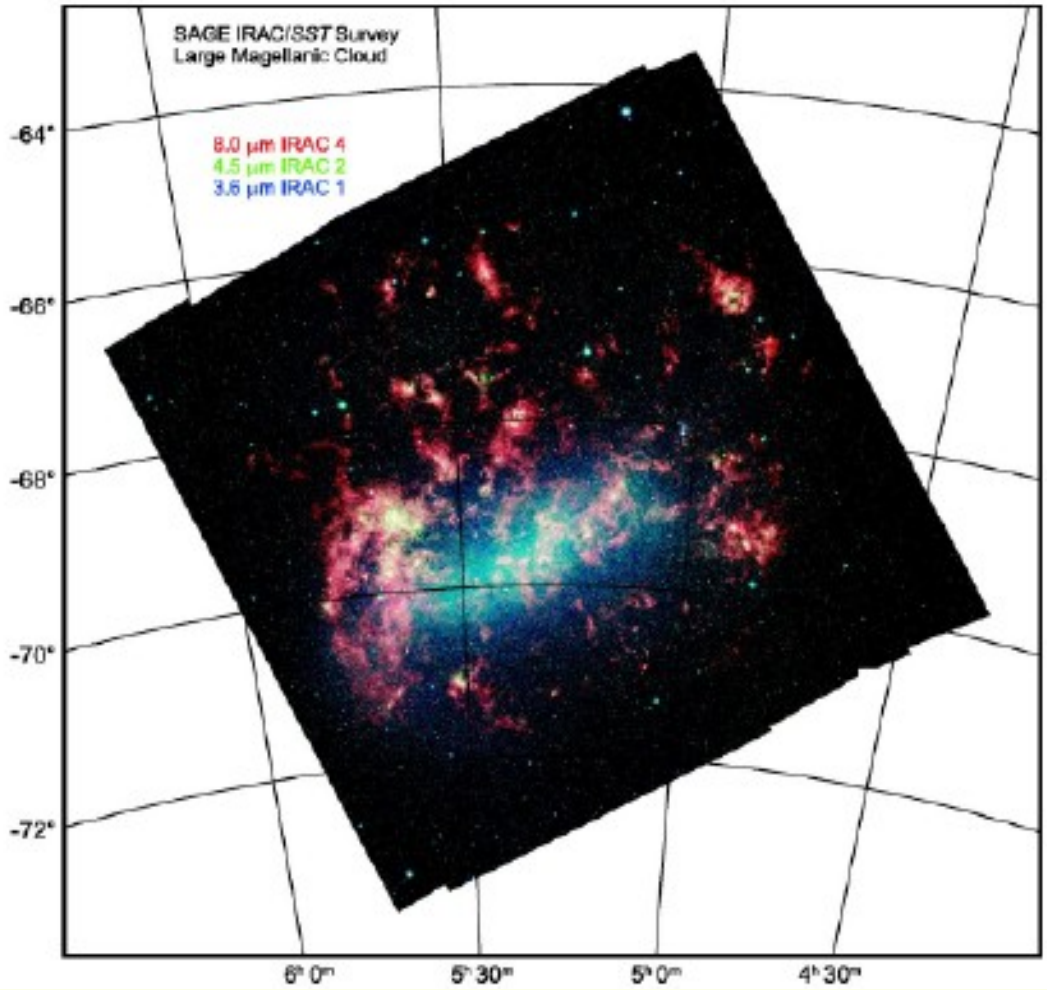
Table 2 Systematics error budget on H_0: past, present, and future — Freedman & Madore (2010)

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 20-30x 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_0	±10%	±5%	±2%	Distances

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

Mid-IR Cepheid P-L Relation from Spitzer SAGE Data

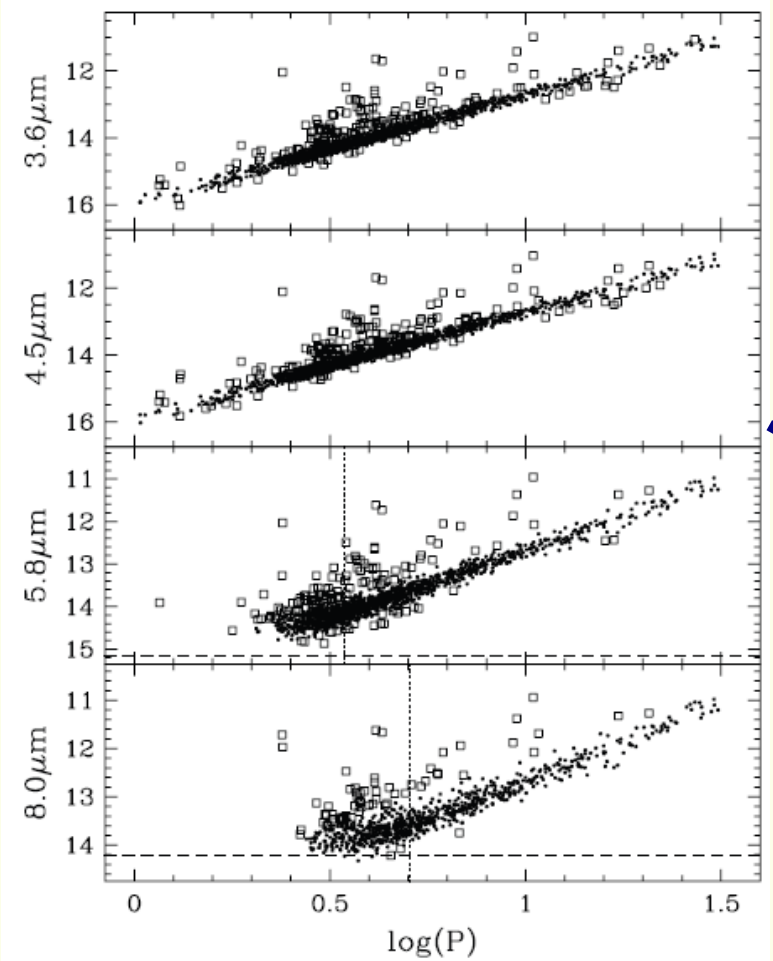
Matched known LMC Cepheids to public data from SAGE program



Meixner et al 2006

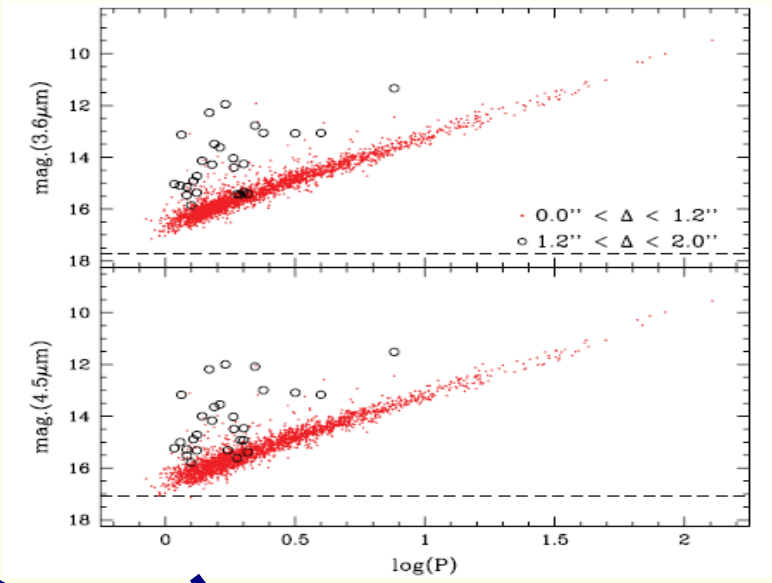
Mid-IR P-L Relations from MC Cepheids and Example of Application

LMC Cepheids + SAGE LMC

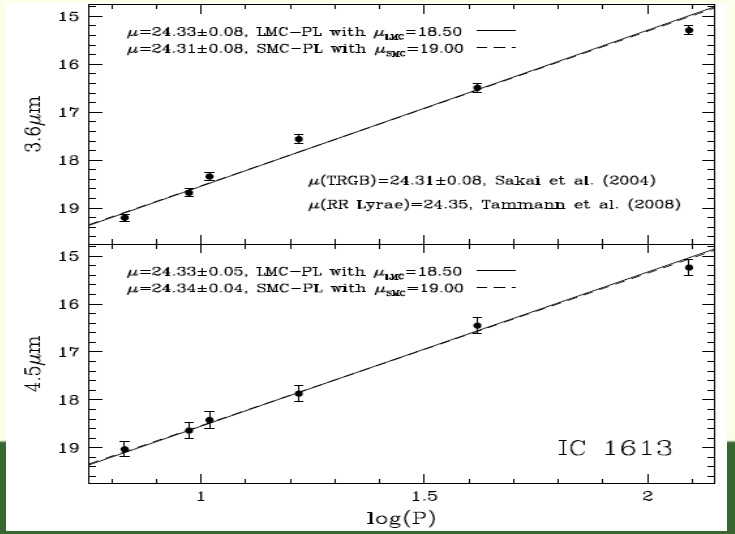


Ngeow et al (2009)

SMC Cepheids + SAGE SMC



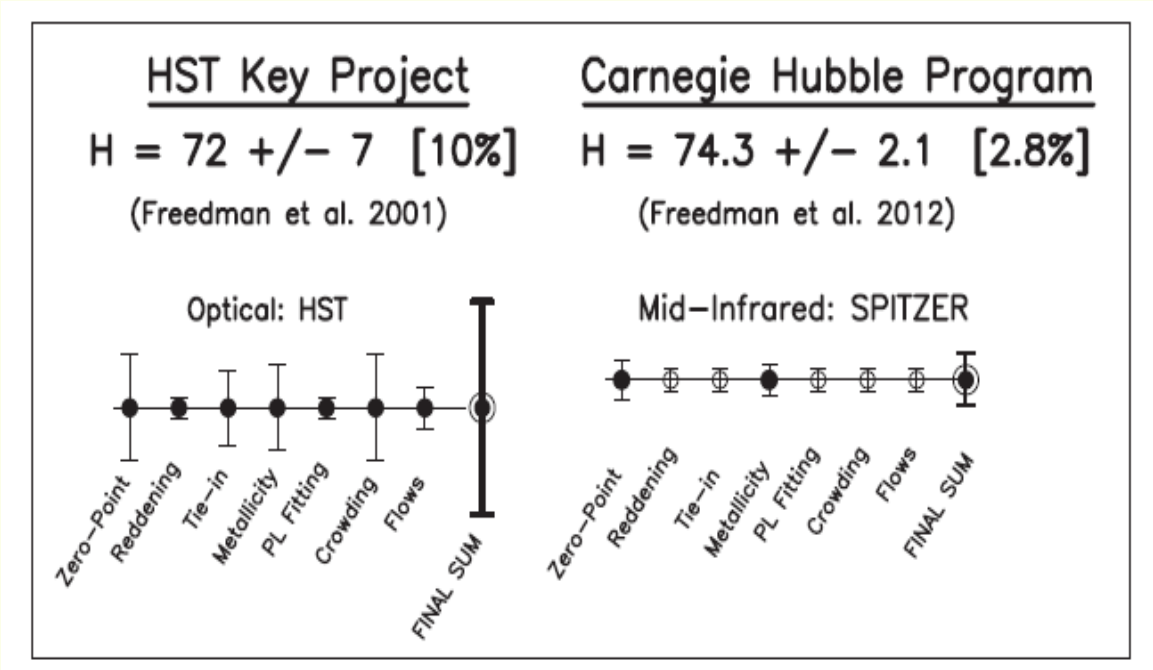
Ngeow & Kanbur (2010)



Ngeow et al (2012)

A Site Note: Carnegie Hubble Program
(P. I.: Wendy Freedman)

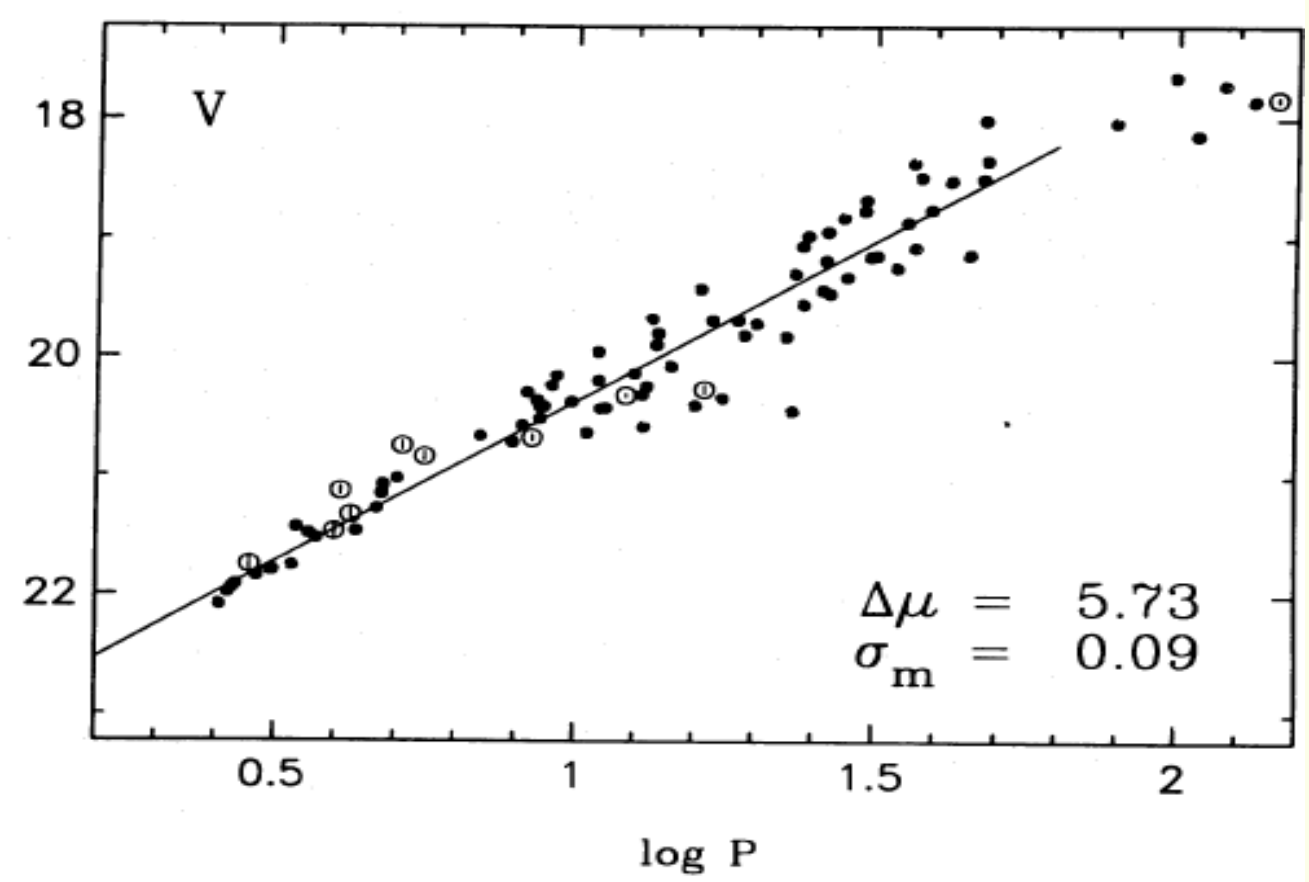
- Independently derived the Mid-IR Cepheid P-L relation using 85 LMC Cepheids with “full” light curves
- Single Spitzer instrument to minimize cross-instrumental calibration



Freedman et al (2012)

Part II:
Search For Ultra-Long Period Cepheids in M31

Cepheids with P>80days are Generally Ignored in Distance Scale Work



Freedman (1988, ApJ)

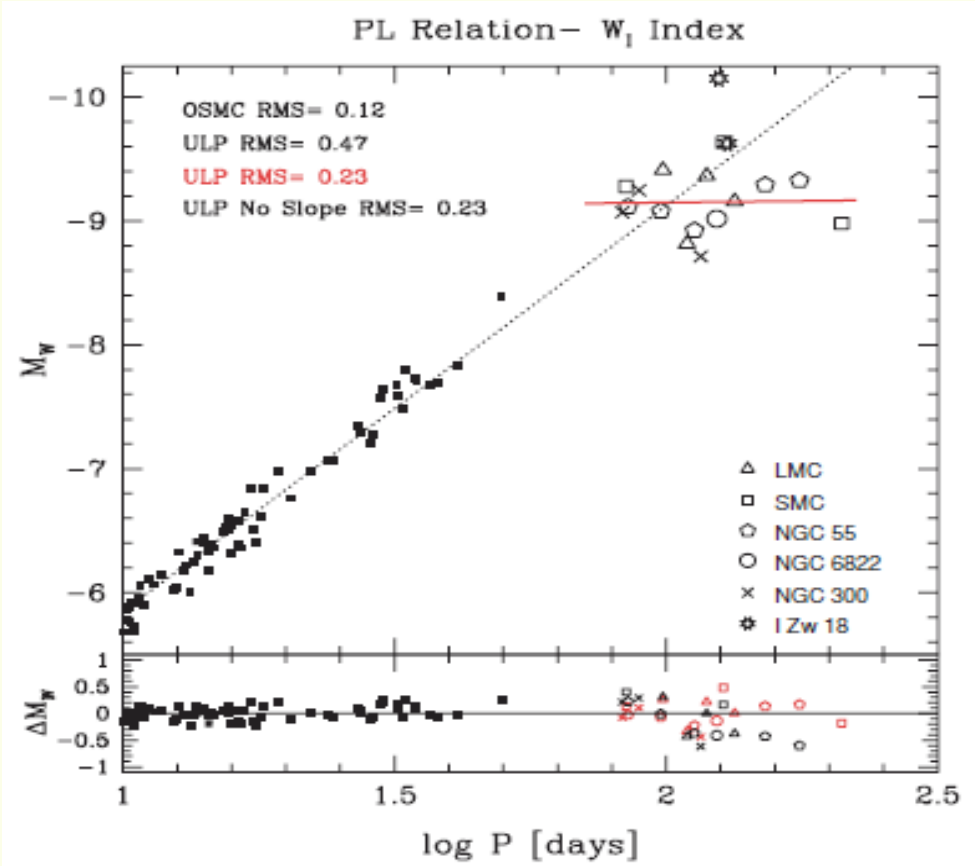
Outliers

HST (KP) observing strategy focused on Cepheids with period from 10 to ~60days

However ...

Bird et al (2009, ApJ) proposed Cepheids with periods > 80 days follow a different PL relation, and called them Ultra-Long Period Cepheids (ULPCs)

- Can be observed to ~100Mpc with future space telescopes (JWST) and 30m class ground based telescopes (E-ELT)
    - capable to derive Hubble constant in 'single step'
- Very long periods suggest long term monitoring
- Expect small numbers to be presented in host galaxies



$W_I = I - 1.96\,(V-I)$

ULPCs in M31?

- M31 is nearest spiral galaxy: potential to be anchoring galaxy in future distance scale work
- So far no ULPCs been identified in M31
- Need long term monitoring with large FOV CCD that cover entire M31
  - Past surveys/projects either cover small patches of M31 or observed in short period of times (<80 days)
  - Data from Palomar Transients Factory (**PTF**) is ideal for our purpose

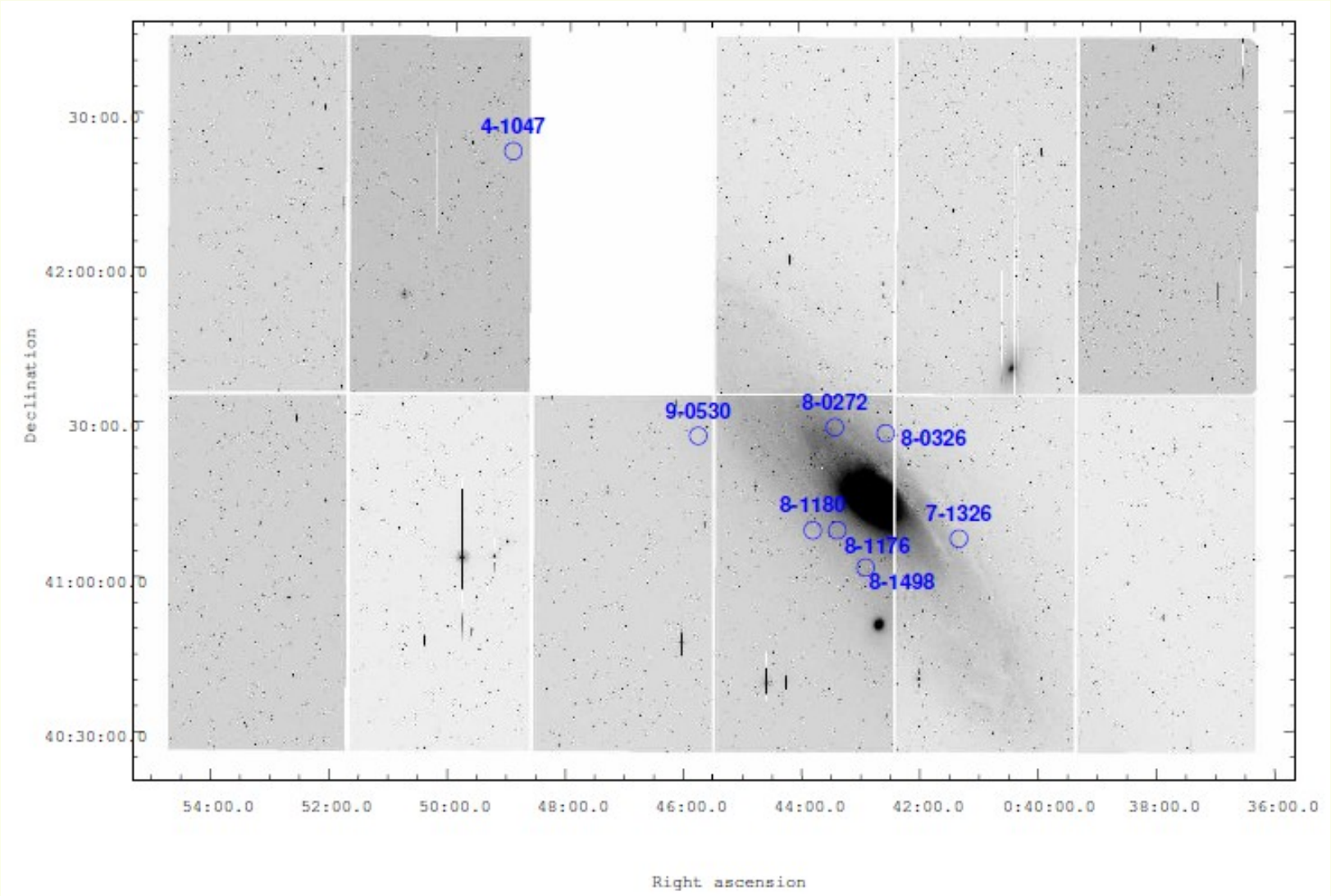
Search of M31's ULPCs with PTF

- PTF data from Jan 2010 to Jan 2012, total of 172 frames with cadence of 1 - few days
  - PTF data has been processed prior to download
  - Single R-band data from P48 only
- Image subtraction techniques to search for candidates
  - Initial candidates: 10^5
  - Various selection criteria + eye inspections: 8 candidates left

Criterion	CCD number										
	0	1	2	4	5	6	7	8	9	10	11
$17.5 \leq R \leq 19.5$	3059	2560	3244	3070	3101	2450	3792	5162	2555	2341	2639
$0.5 \leq \mathrm{Power}_{AoV} \leq 0.9$	1442	1494	551	141	178	48	73	155	1584	552	643
80 d $\leq$ Period $\leq$ 300 d	490	53	11	3	2	0	4	14	3	2	1
Eye inspection	0	0	0	1	0	0	1	5	1	0	0

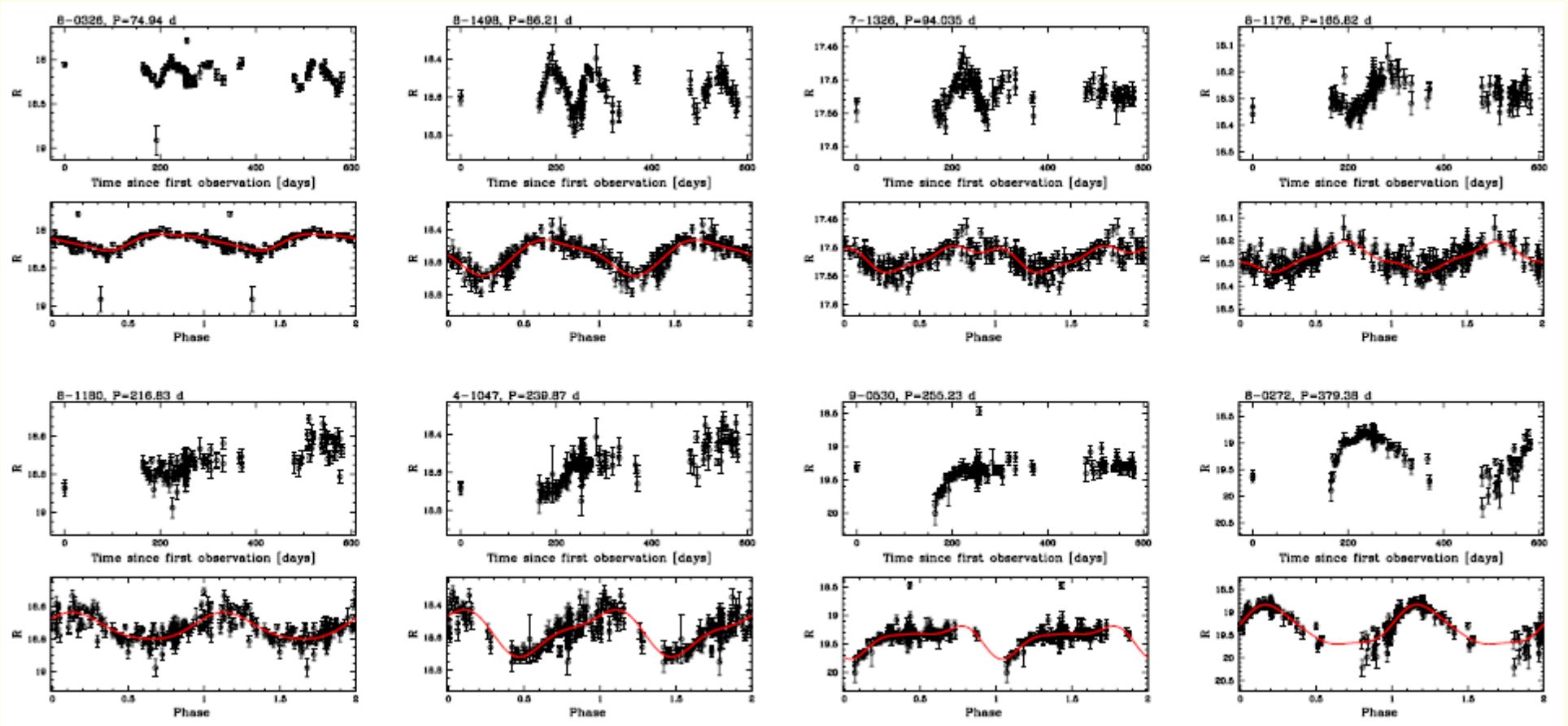
Lee, Ngeow et al. (2013)

ULPC Candidates in M31



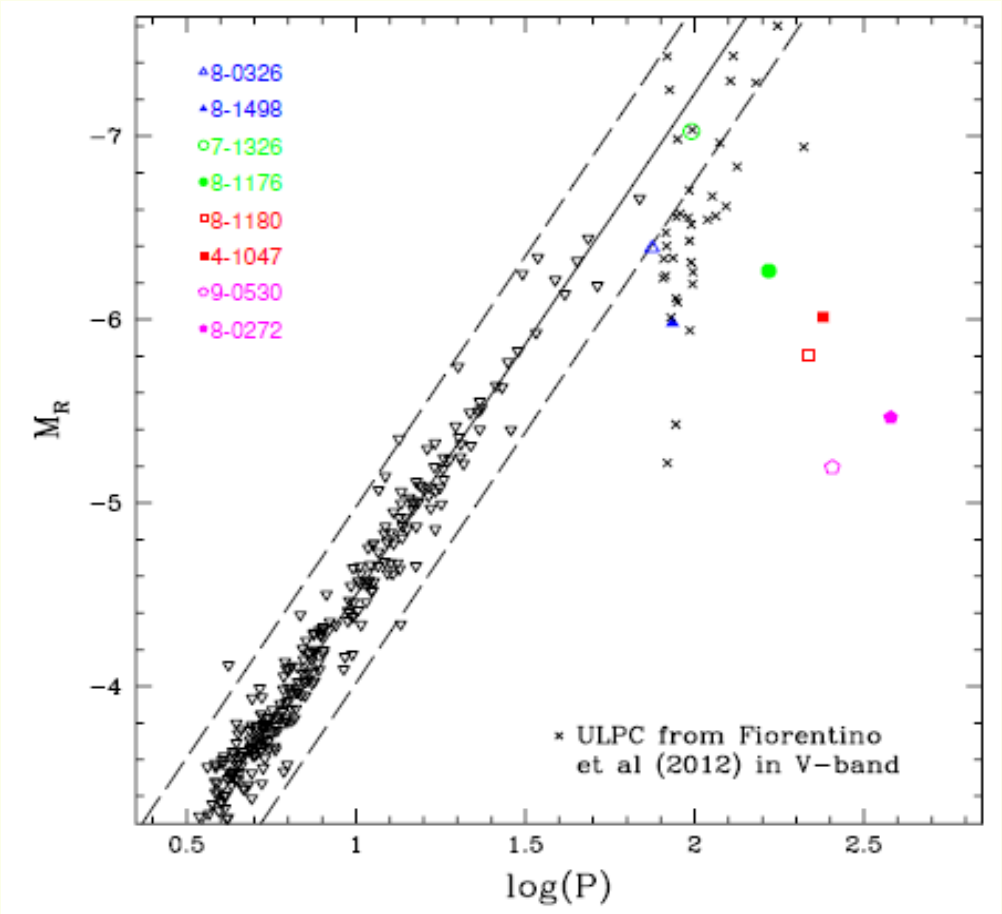
Lee, Ngeow et al. (2013)

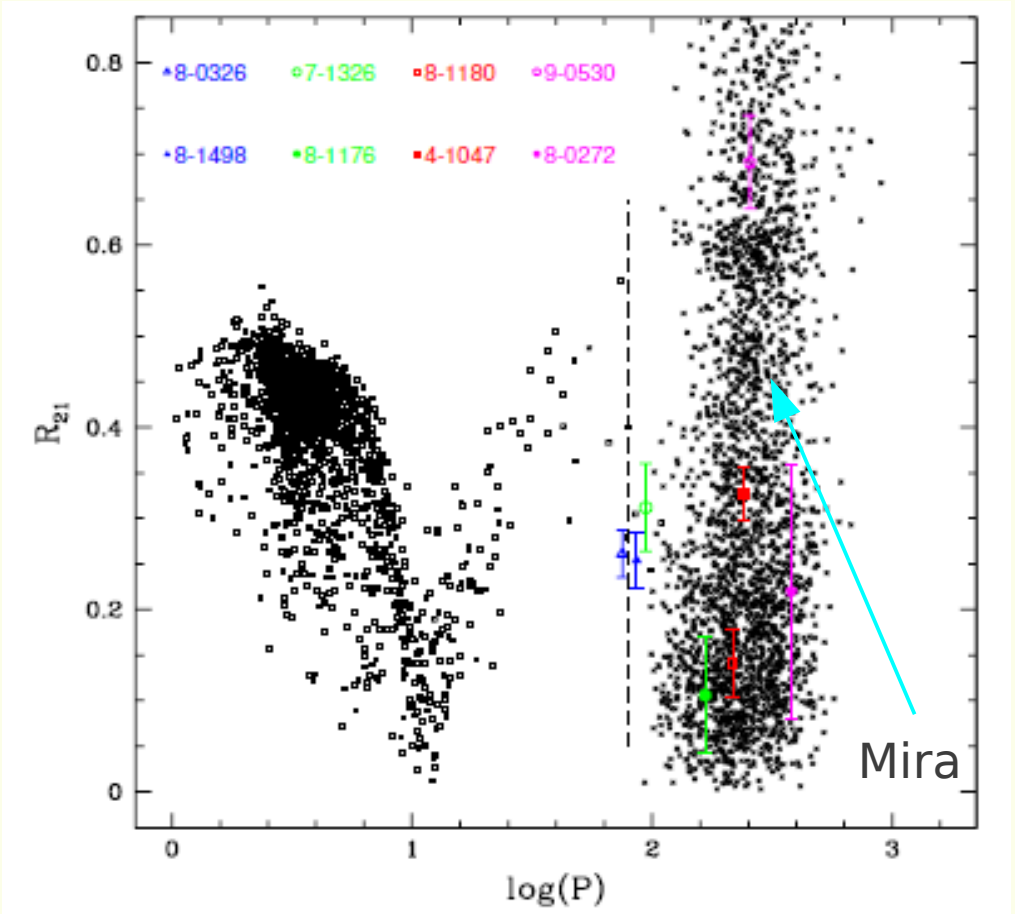
… and Their R-Band Light Curves



Lee, Ngeow et al. (2013)

But Only 2 or 3 Are ULPCs



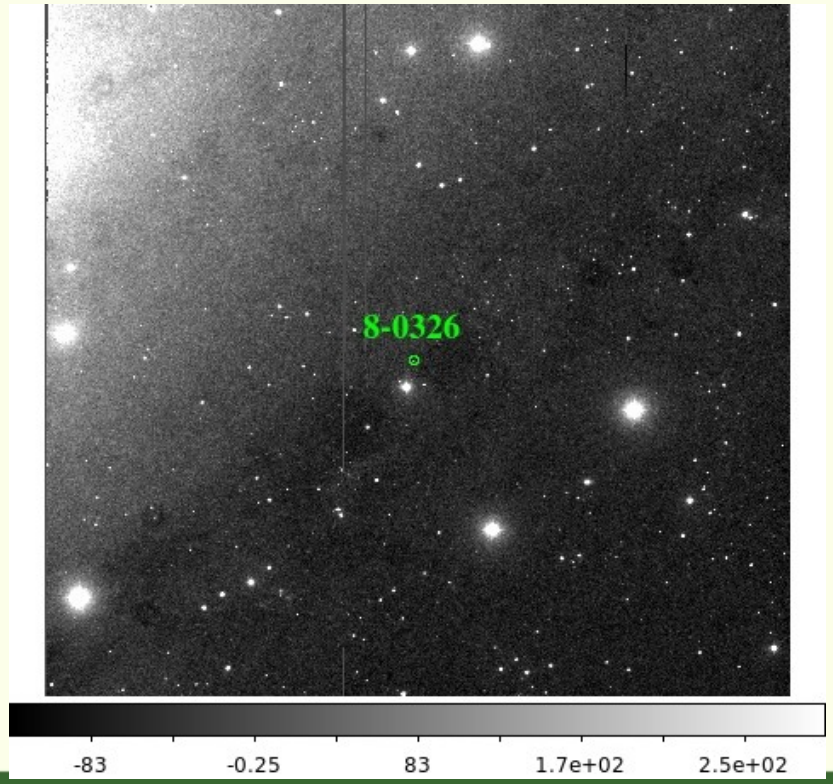


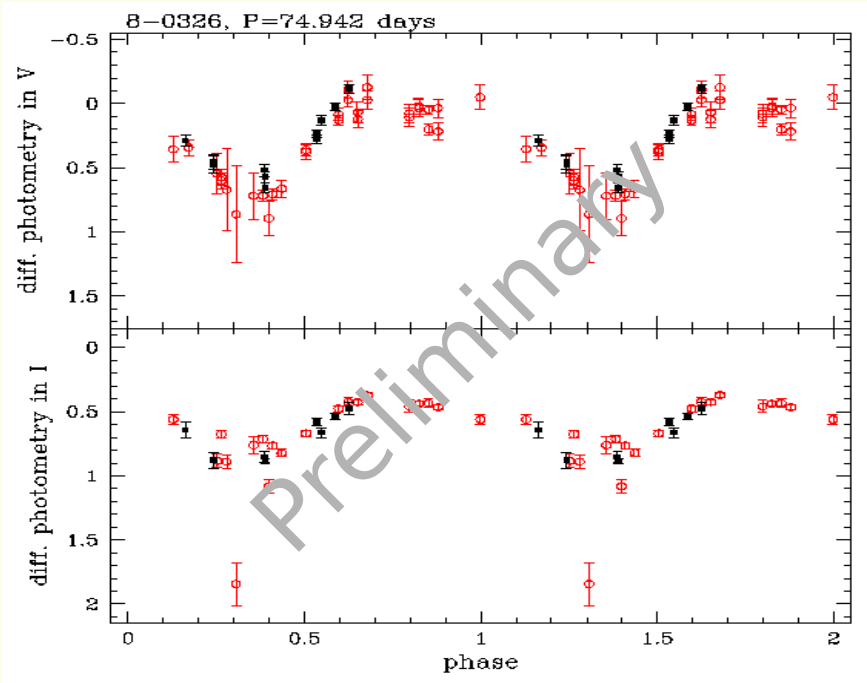
Need V and I band light curves

Lee, Ngeow et al. (2013)

VI Band Follow-Up with P60 and LOT

- Time-series follow-up observations carried out at LOT and robotic P60 telescope from October 2012 to **NOW** (on-going).
- Differential PSF photometry: calibration with catalogs from Local Group Survey (LGS, Massey et al. 2006, AJ).



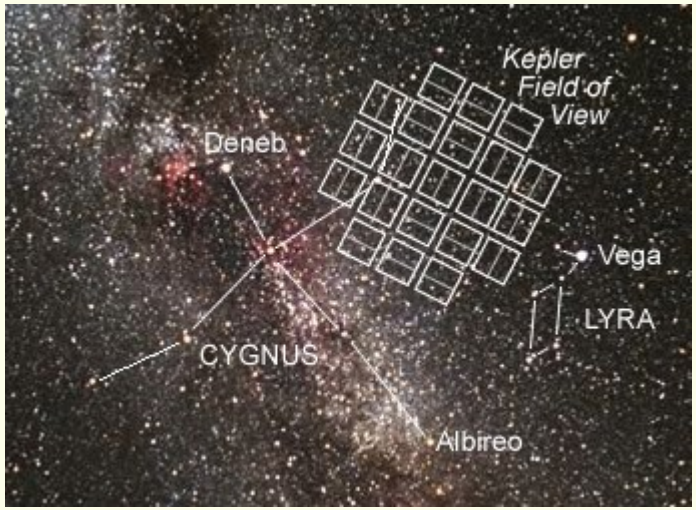


Ngeow et al. (2013, in-prep.)

Part III:
BVRI Band Follow-Up Observations of RR Lyrae in Kepler's Field

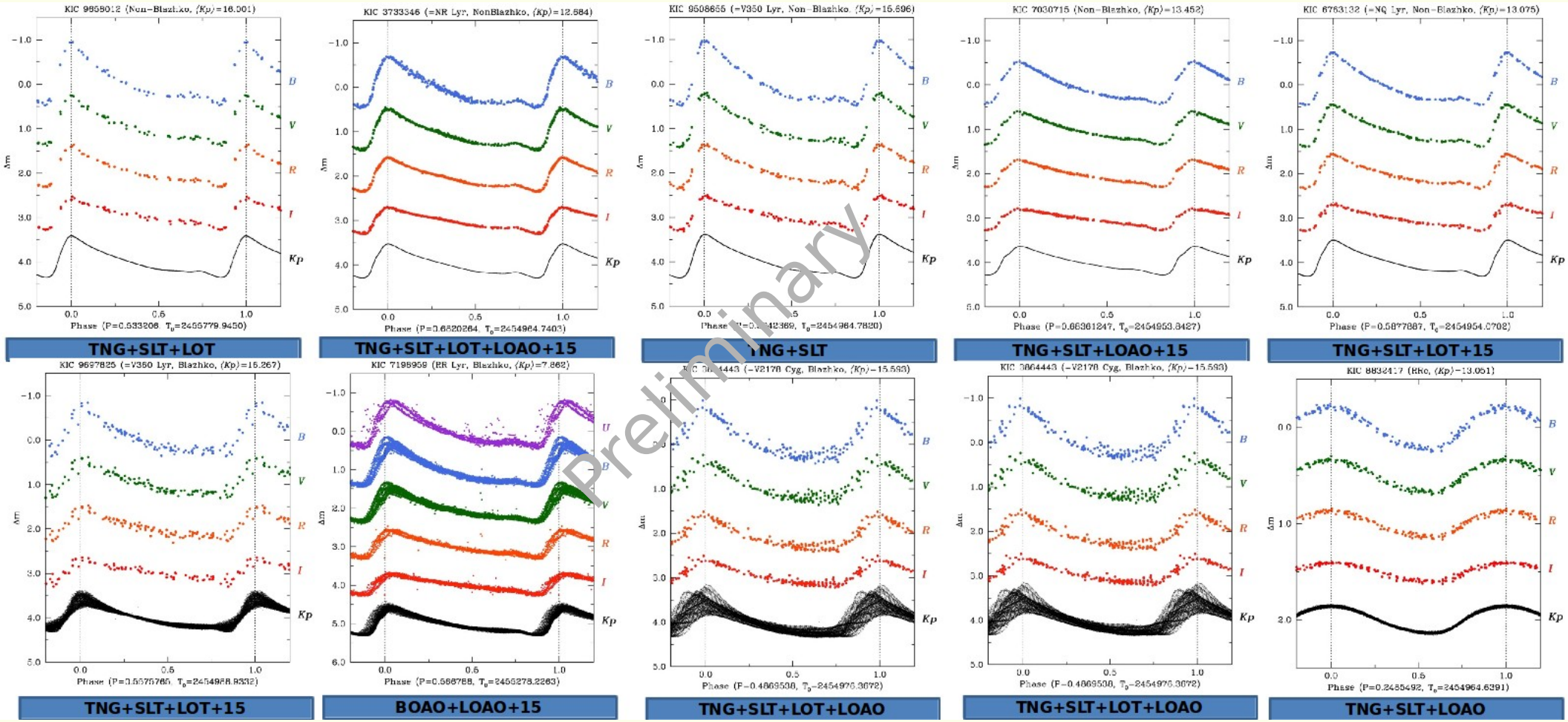
The BVRI F Follow-Up Program for RR Lyrae in Kepler's Field

- Unprecedented, almost continuous light curves from Kepler
  - Mode identification etc, but in single broad-band filter (Kp)
- Need BVRI follow-up observations
  - Color curves for extinction
  - V band light curves shape vs. [Fe/H]
  - Distance calibration with M_V-[Fe/H]



- Collaborate with Y.-B. Jeon (KASI)
  - Taiwan: 1m & 0.4m @ Lulin Obs.
  - Korea: 1.8m & 0.15m @ BOAO; 0.61m @ SOAO
  - Arizona: 0.81m @ Tenagra Obs.; 1m @ LOAO

Gallery of RR Lyrae BVRI Light Curves

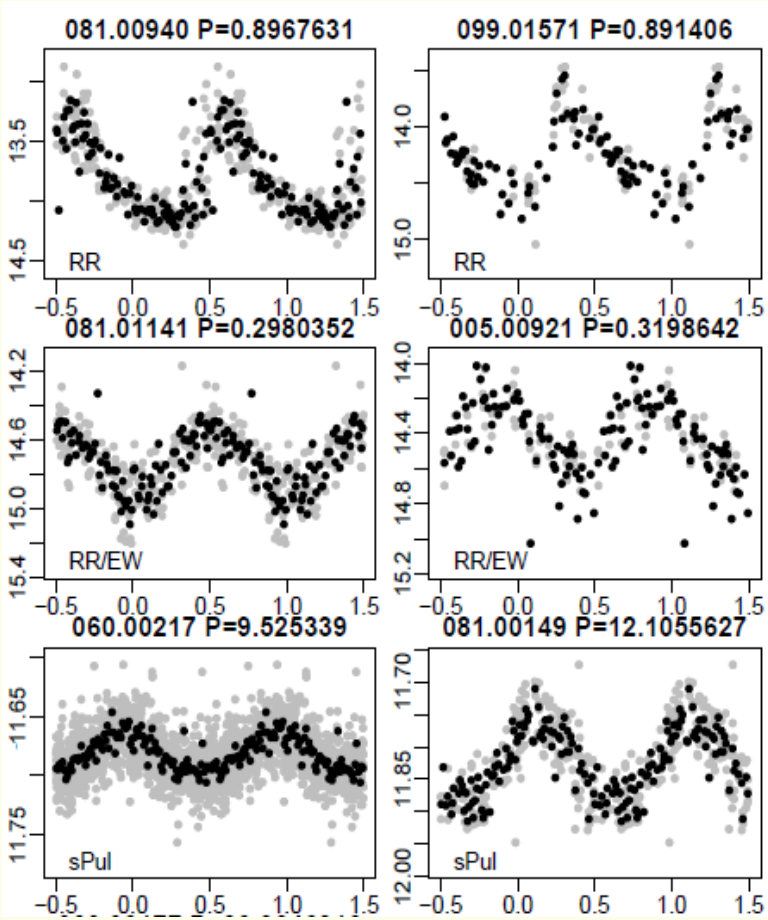


Jeon, Ngeow & Nemec (2013, in-preparation)

Part IV:
Variable Stars in TAOS Fields

Searching For New Variable Stars in TAOS Suitable for DS Calibration

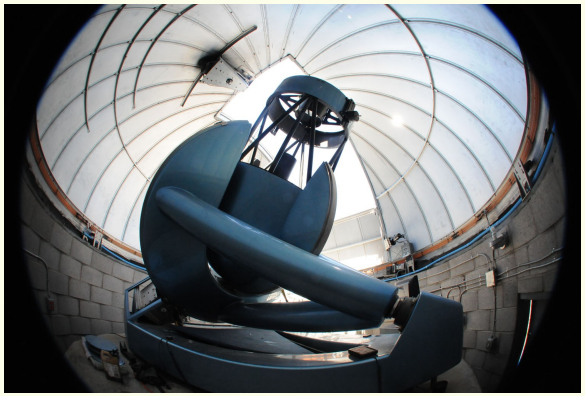
- TAOS: 4 x 0.5m telescopes at Lulin Obs. To search for stellar occultation by KBO
- Time series data from TAOS also suitable for finding variable stars
- My interest: expanding new variable stars (Cepheids & RR Lyrae) for distance scale (DS) calibration in era of Gaia
- Collaborate with TAOS team, esp. R. Ishioka (ASIAA)
- From 16 TAOS fields:
    - 84 known and 54 news variables
    - New: 12 RR Lyr + 4(?) Cepheids

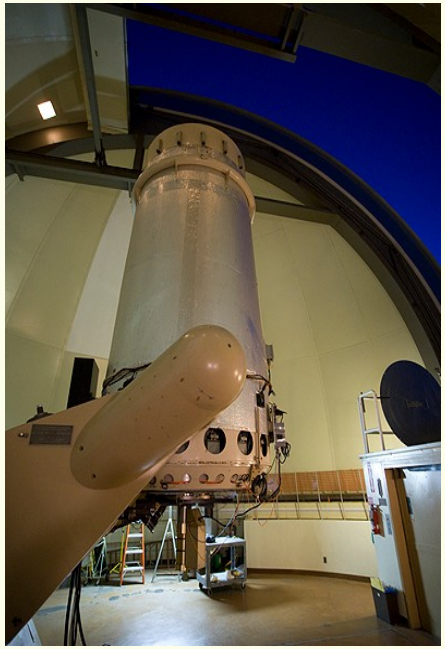


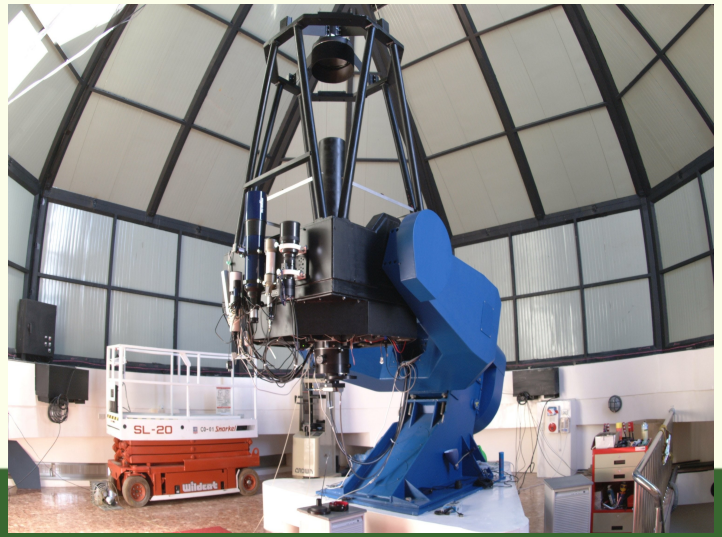
Ishioka et al. (2013, Submitted)

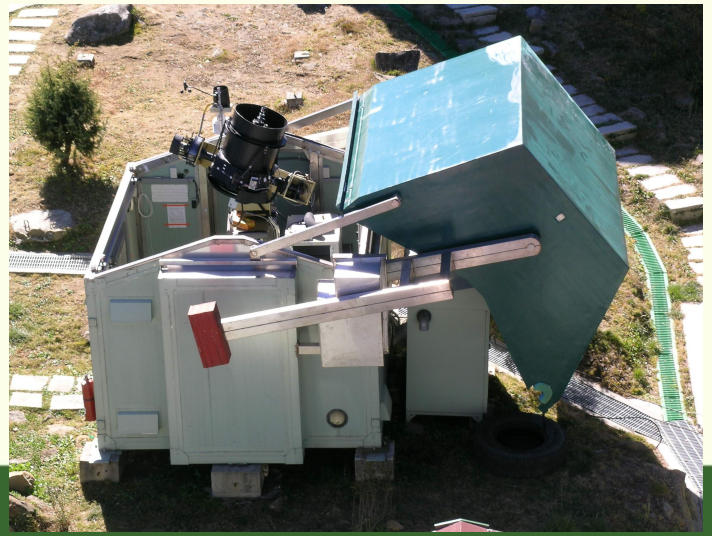
A Final Remark

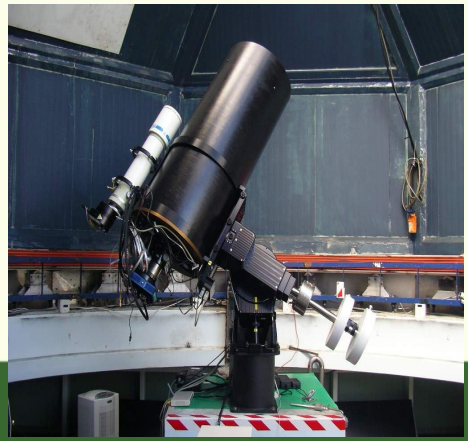
- Small-aperture (<2m) telescopes → "light curves machines"











A Final Remark

- Small-aperture (<2m) telescopes → "light curves machines"
  - Robotic/automatic/remote control
  - Queue observing mode + flexible scheduling
  - Simple imaging data, "standard" pipeline
  - Photometric calibration can be tricky

In the era of big (>2m) telescopes:
Small aperture telescopes still valuable/ suitable for astrophysical research

(in my case, it is distance scale & variable stars)

~ Thank You ~