# Spectroscopy of Cepheid variable stars using IRCS+AO188

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## Abstract

Cepheid variable stars are useful tracers of the distance scale and stellar populations within the Galaxy. Our photometric survey found these objects in the inner part of the Galaxy (the Galactic nuclear bulge and the inner disk), which are highly obscured that they can be observed only in the infrared wavelength. We are carrying out spectroscopic project to measure radial velocities and chemical abundances of these objects. Here we report a preliminary result on the H-band spectra of three Cepheids in the nuclear bulge which we obtained in July 2012.

## 1. Background

Cepheids are pulsating giants or supergiants and have pulsation periods roughly between 2 and 50 days. It is well known that they follow period-luminosity relation, and this allows estimating their distances (Sandage and Tammann, 2006). Another important characteristics of Cepheids is their period-age relation (Bono et al. 2005), i.e. the younger Cepheids have the longer pulsation periods. We can also estimate their ages from their periods. One of the advantages of Cepheids is that individual Cepheids can be used as a tracer with a known distance and age (and the space motion, the radial velocity and proper motion, if measured).

## 2. Targets and scientific goal

In spite of the usefulness of Cepheids, survey of these objects in the Milky Way is far from complete. As shown in Figure1, Cepheids only on the near side of the Sun were found due mainly to large foreground extinction. Thus we have been carrying out photometric survey in the infrared to search for Cepheids and other variable stars in the inner Galaxy. Using the IRSF/SIRIUS, a near-IR imager attached to a 1.4-m telescope in South Africa, we discovered three Cepheids in the Galactic nuclear bulge (within 200 pc of the Galactic center) (Matsunaga et al. 2011). In addition, there are a few Cepheids in the inner disk, at 4—5 kpc away from the Galactic Center, discovered in our survey.

In order to study kinematics and chemical evolution of the inner Galaxy, we proposed and carried out spectroscopic observations for these new Cepheids. The abundances like [Fe/H] and [α/Fe] of the Cepheids would give the first measurement of the interstellar matter chemistry in the Nuclear Bulge a few tens of Myr ago. Comparing their abundances with those of the inner-disk Cepheids and young stars (a few Myr old) in the Nuclear Bulge, it becomes possible to trace temporal evolution in and around the Nuclear Bulge (see Figure 2).

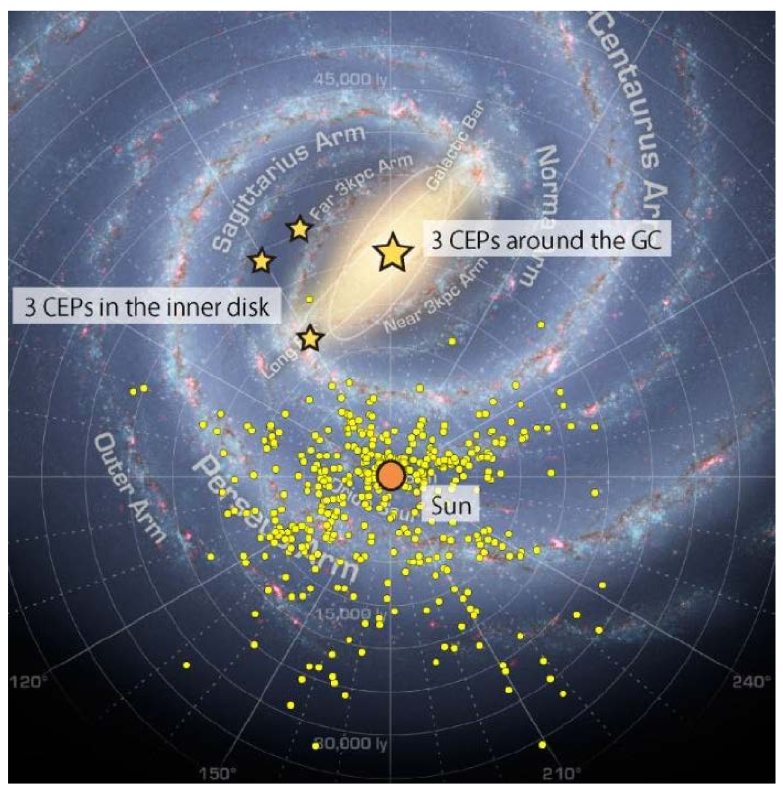



**Fig. 1 | Locations of our targets in the Galactic disk.** The background is an artist's illustration of the Milky Way). Star symbols indicate our targets, while small yellow points for other known CEPs (Fernie et al. 1995).
† http://www.astro.wisc.edu/sirtf/

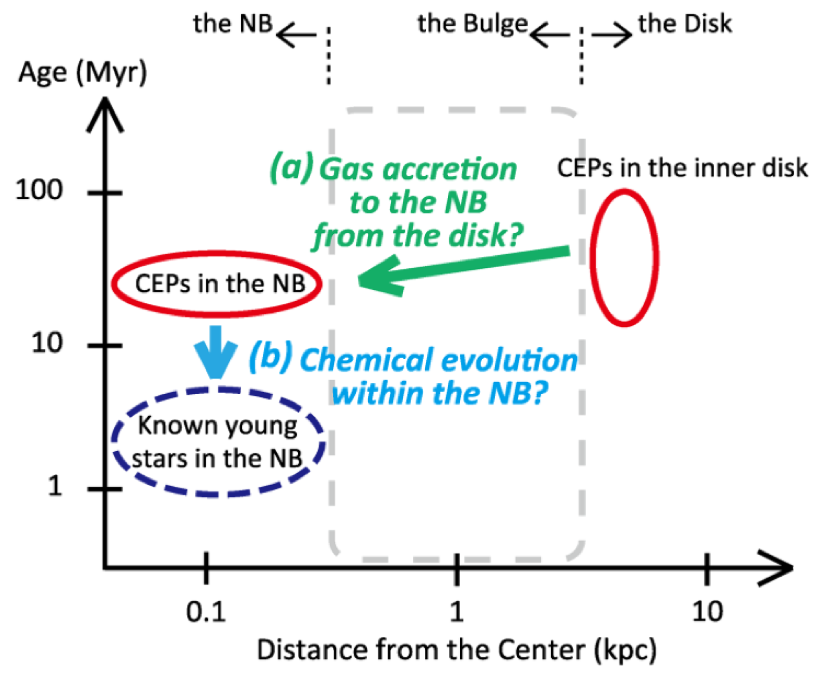



**Fig. 2 | Distribution of some stellar populations in the Galaxy.** Various populations are illustrated according to their ages and distances from the Galactic Centre, and their typical tracers are indicated. CEP and NB stands for Cepheid and the nuclear bulge. Comparisons between the populations would trace how they are co-related.

## 3. Observations and analysis

With SUBARU/IRCS, we have collected H-band spectra for 7 target Cepheids (four in the nuclear bulge and three in the inner disk) in 2012 (S12A-563 in May and S12A-053 in July; PI. N. Matsuaga). Only the spectra taken in the 2012 July run were obtained with the reasonable gain of the AO188 system (FWHM=0.2—0.3 arcsec at airmass between 1.5 and 1.8). We here discuss the data taken in the 2012 July run (Table 1). In addition, several spectra for well-known Cepheids were observed for the calibrating purpose.

**Table 1 | Spectra for 4 target Cepheids towards the Galactic Center** taken in the 2012 July run. All of them are taken with the resolving power of λ/Δλ~20,000.

| Object | Date | Integration time [sec] | FWHM [sec] | S/N |
|---|---|---|---|---|
| GCen_a | 2012/07/26 | 300 × 14 | 0.30 | 40—50 |
| GCen_b | 2012/07/26 | 300 × 12 | 0.20 | 50—60 |
| GCen_c | 2012/07/27 | 300 × 12 | 0.24 | 40—50 |
| GCen_d† | 2012/07/27 | 300 × 8 | 0.34 | 30—40 |

† The fourth target (GCen_d) was recently found by us roughly one degree away from our original survey region, while the other three are reported in Matsunaga et al. (2011).

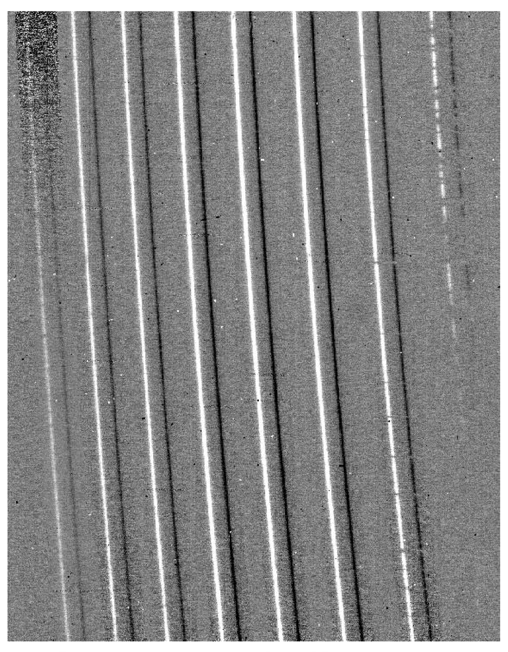


**Fig. 3 | Image of an IRCS echelle spectra** obtained by subtracting a pair of data at two sky positions (AB).

Data analysis is still on progress. Analysis is being done with IRAF (echelle and onedspec packages) as well as some software being developed by us. Our own software includes *cl* scripts for semi-automating the IRAF analysis procedures and *C* codes with PGPLOT for making various plots (eg. Fig. 4). Wavelength calibration is done with use of ThAr lamp calibration spectra as well as telluric absorption lines within spectra of science targets. We are investigating accuracy and robustness of the calibration, but an accuracy corresponding to ~0.1 pix (0.8 km/s) seems to be achieved. After the wavelength calibration and the correction of telluric absorptions are done, the constructed spectra are compared with line lists compiled by Kurucz and synthesized spectra using *sptool* by Y. Takeda.

## 4. A preliminary result

The IRCS H-band spectra of Cepheids show dozens of strong absorption lines (many metallic lines as well as some molecular bands). At first we are investigating kinematics of the Cepheids (radial velocities), whereas chemical abundances will investigated then. Fig. 4 compares a small part of the spectra of the target Cepheids and illustrates that the four objects have clearly different radial velocities. Although pulsation of Cepheids gives periodic shifts in redshift of absorption lines (±30 km/s), but the difference is larger than this effect. The trend of the different velocities seems to agree with the rotation of the Galactic nuclear disk, but further analysis and discussions remain to be done.

**Fig. 4 | A part of the Cepheids' spectra** where several metallic lines are included. Differences of the velocities are clearly seen.

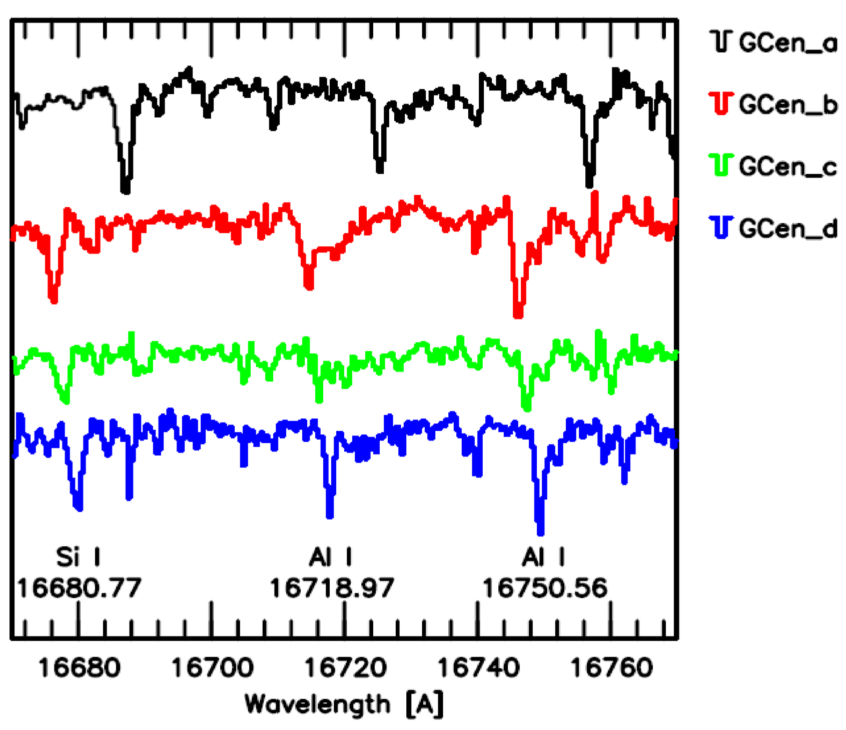
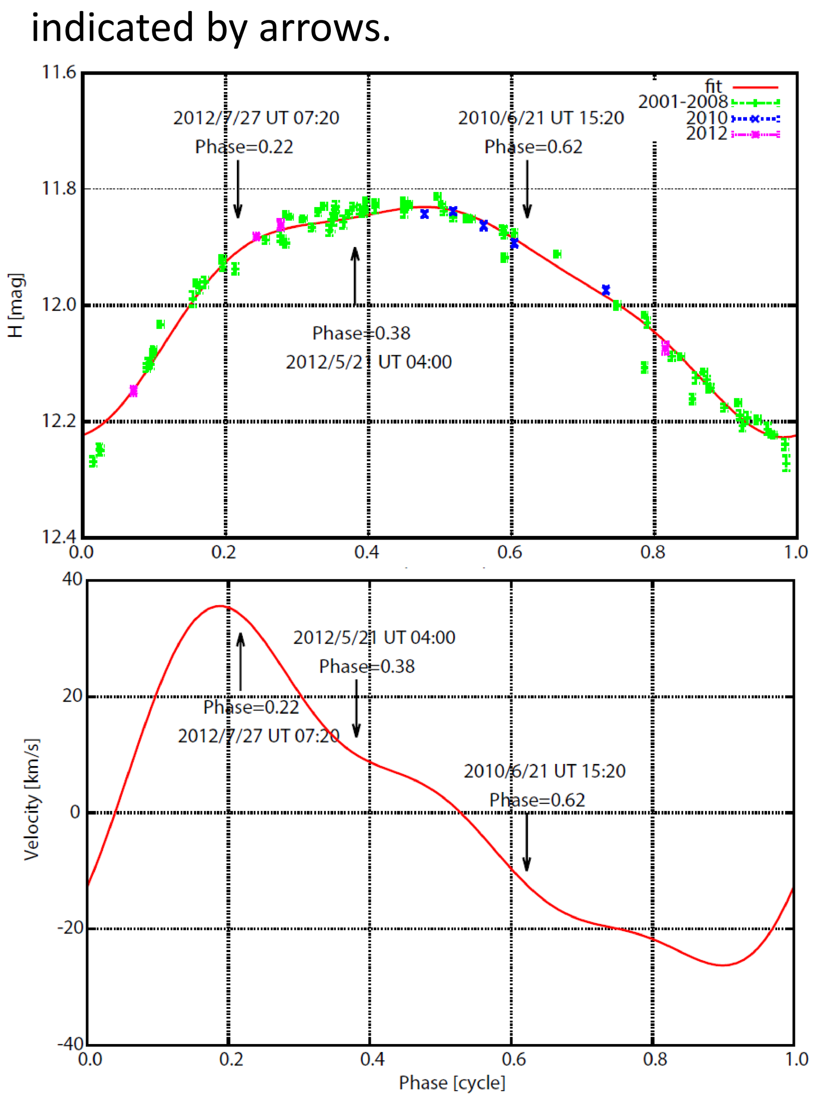



**Fig. 5 |** H-band light curve (*left*) and predicted variation of velocity curve due to Cepheid pulsation (right) for one of our targets. Phases of the IRCS spectra are indicated by arrows.




## References

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