Probe the Stellar Population of Milky Way and Nearby Galaxies using Photometry and Spectroscopy of Variable Stars

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special thanks to:
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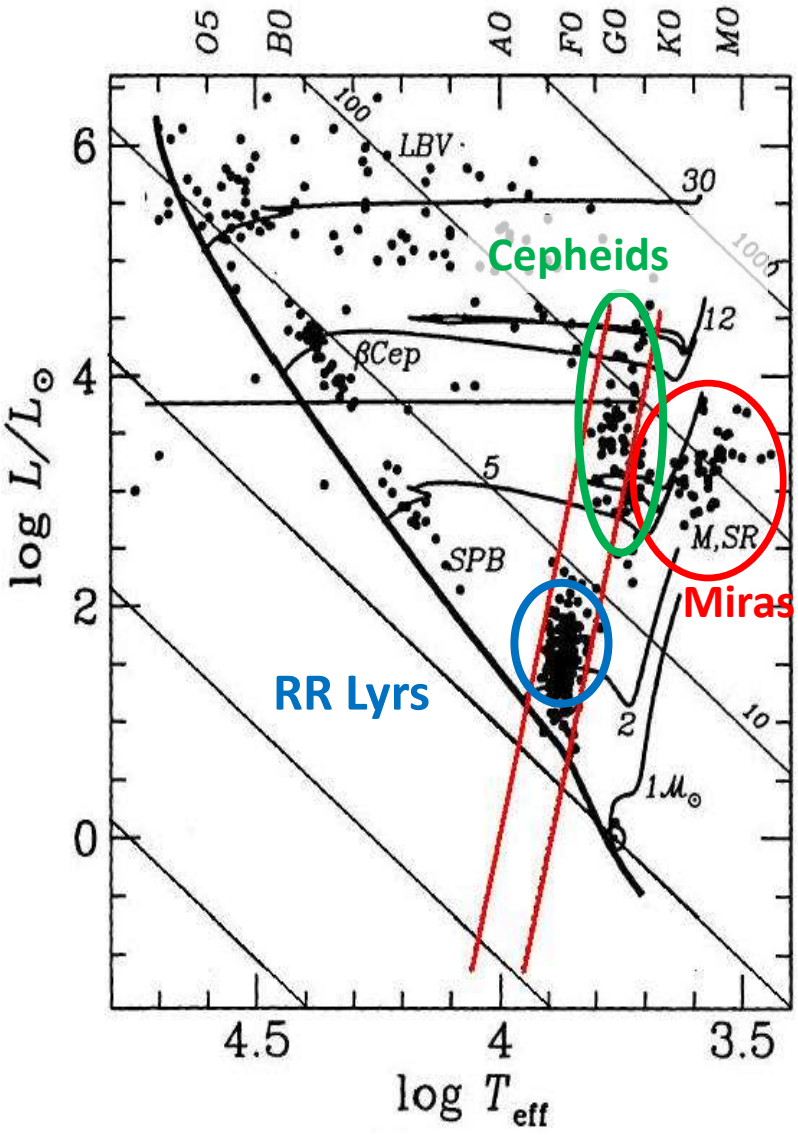
Pulsating Variable Stars

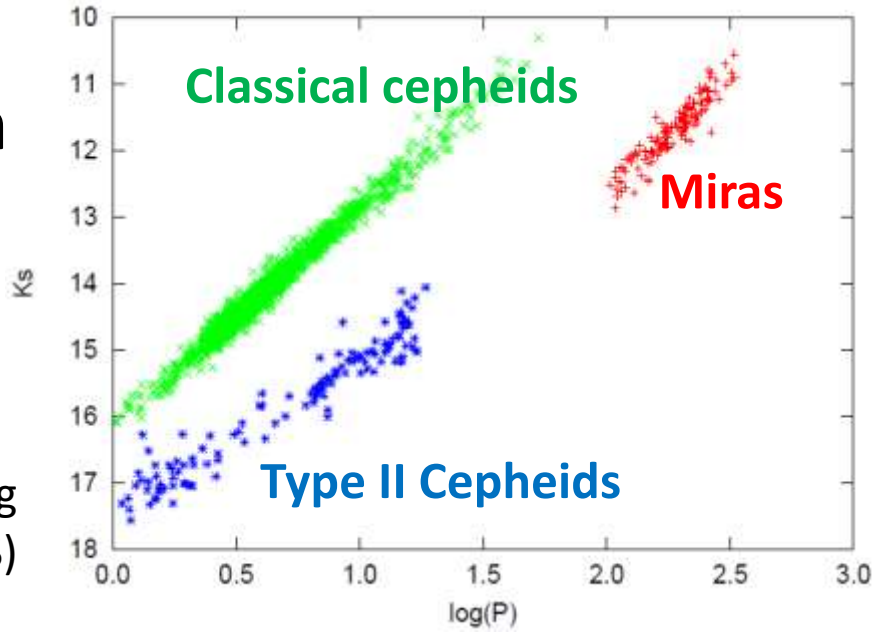
- Classical Cepheids
  - Blue loop (4—10 M_{sun})
  - P : 3—50 days
- Miras
  - AGB (1—6 M_{sun})
  - P : 100—1000 days
- RR Lyrs
  - HB (~1 M_{sun})
  - P : 0.3—1 days
- Type II Cepheids
  - post-HB（~1 M_{sun}）
  - P : 1—40 days



Gautchy & Saio (2005)

As Tracers of Stellar Population

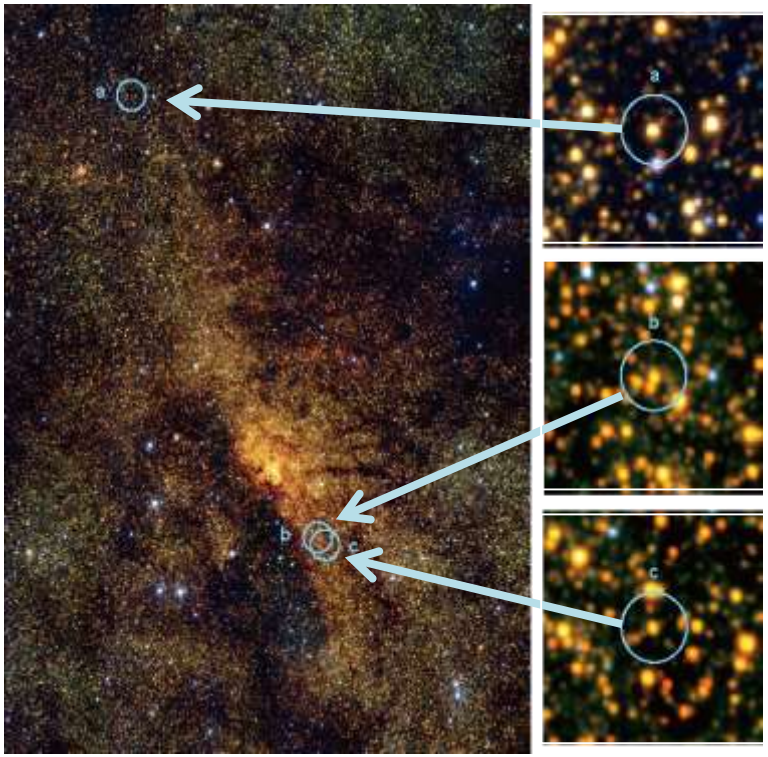
- Pulsating stars can be used to study stellar population in detail tracing individual stars.
- 4 major points which pulsating stars can reveal in studying stellar populations
  - Galactic structure
  - Age distribution
  - Metallicity distribution
  - Kinematic structure

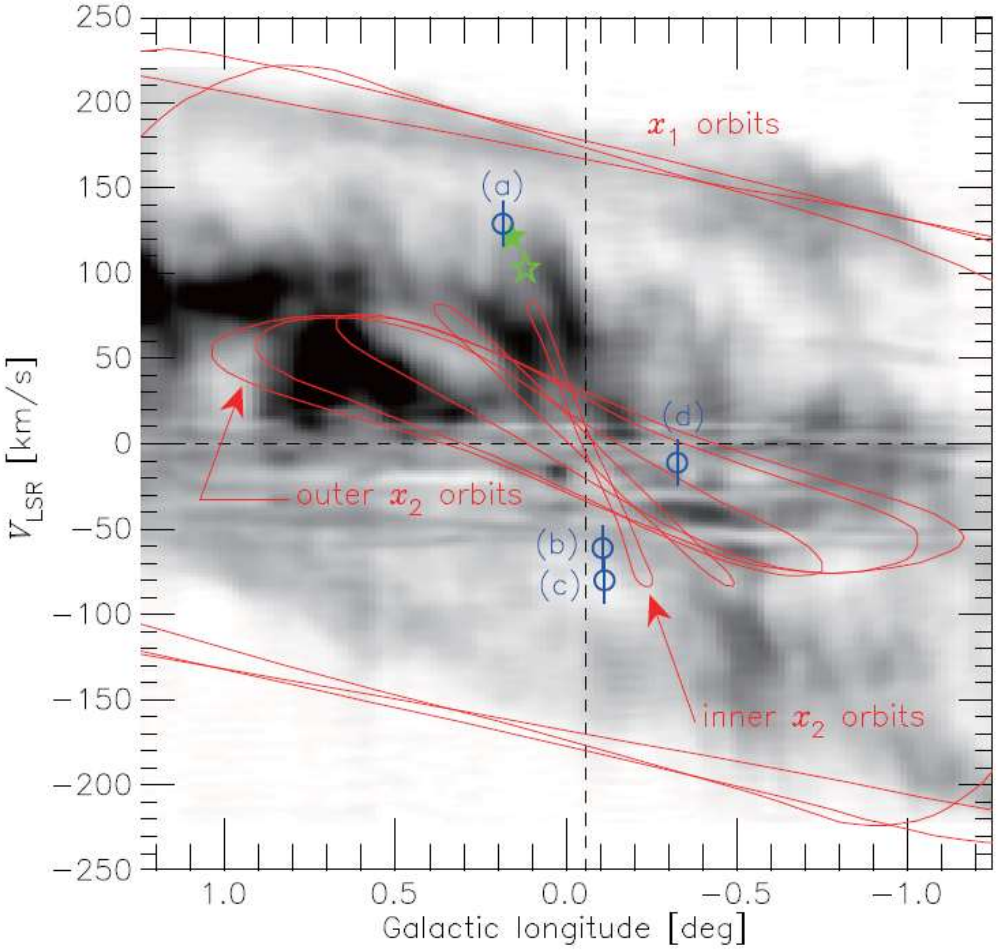


Period-luminosity relations of pulsating stars in the LMC (results from IRSF/SIRIUS)

Cepheids in the Nuclear Stellar Disk

- ~20 Myr population within 200 pc of the Galactic Center
  - Tracing Star formation history/kinematics/chemistry





(Matsunaga et al., 2011, Nature, 477, 188; Matsunaga et al. 2015, ApJ, 799, 46)

Cepheids in the disk flare

- The first stars (not gas) identified in the flared part of the Galactic disk

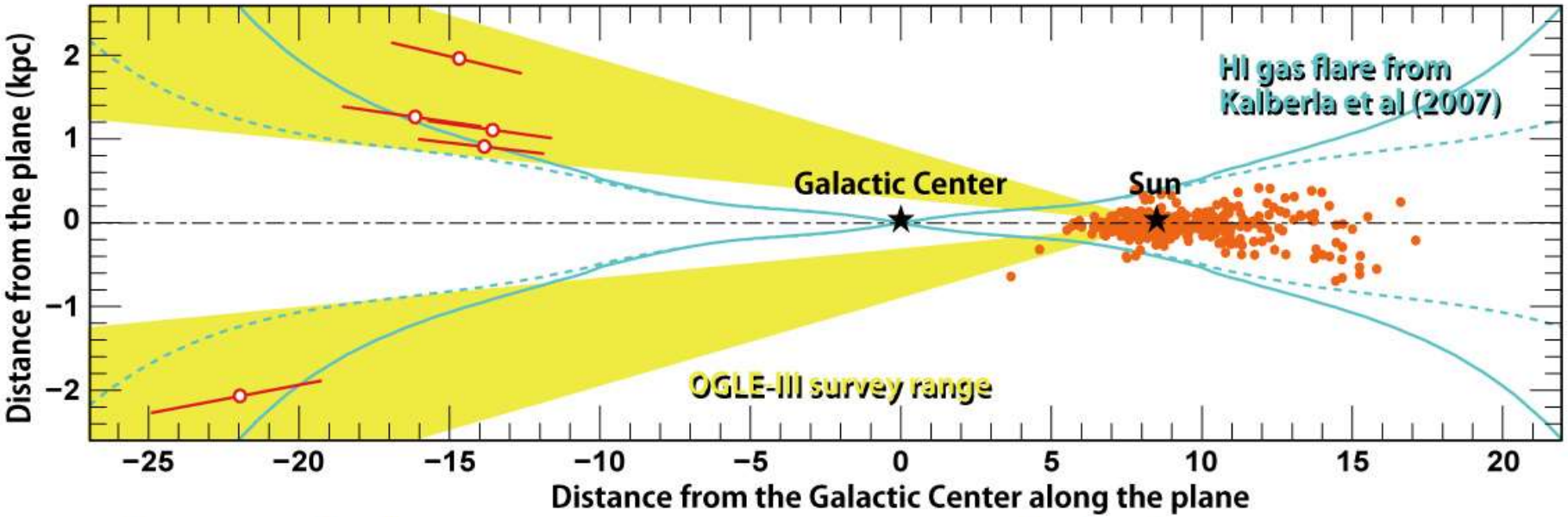


Figure 1 | Schematic of the Galaxy. The positions of the Cepheids (open circles with assumed maximum uncertainties of ±0.2 mag) are compared to the location of the H I gas. The solid and dashed curves are model fits, S and N1, respectively, from ref. 1 at three times the HWHM above and below the Galactic plane. We note that figures 1 and 2 of ref. 2 show the H I flare in the relevant region extending up to about 2 kpc. The dark grey points are previously known Galactic Cepheids[10] and the approximate regions surveyed by OGLE ($2 < |b| < 6$) are shown in light grey on either side of the plane. The positions of the Sun and Galactic centre are indicated by the star symbols.

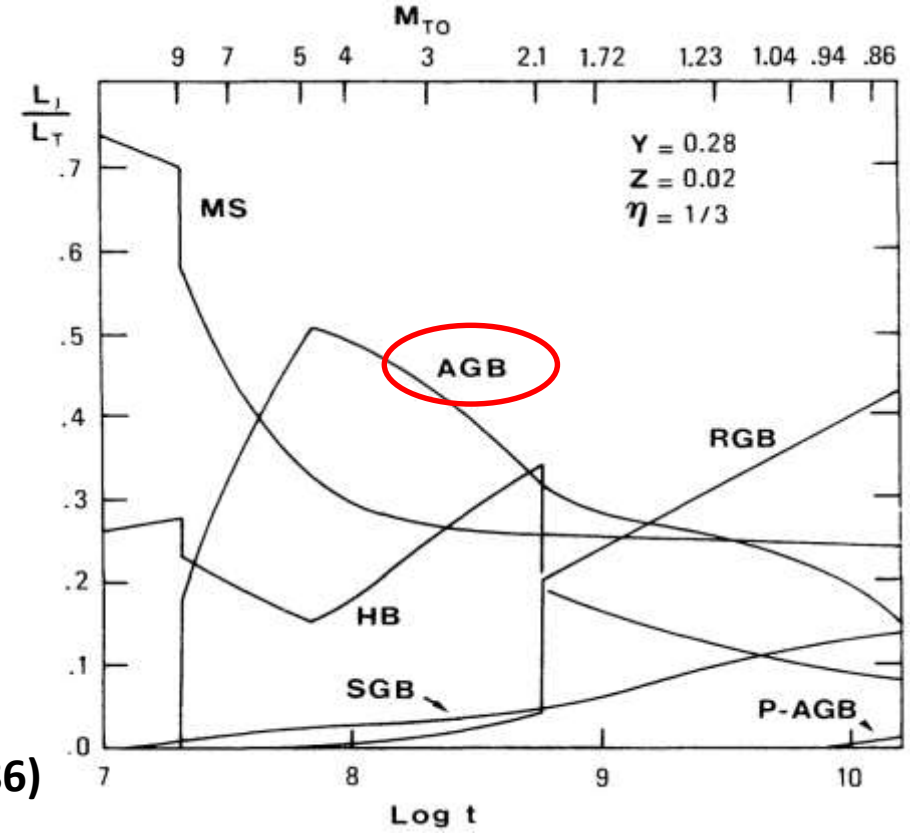
(Feast et al. 2014, Nature, 509, 342)

Characteristics of Miras

- A broad age distribution (100 Myr to 10 Gyr).
  - Present even in galaxies with only old populations.
  - Age can be roughly determined, typically ±30 % (not so accurate as the case of Cepheids).
- Can trace various galaxy components:
  - intrim- and old-components of disk, halo.
- Period-luminosity relations only in the IR bands are useful for distance determination.

AGB's role in galaxies

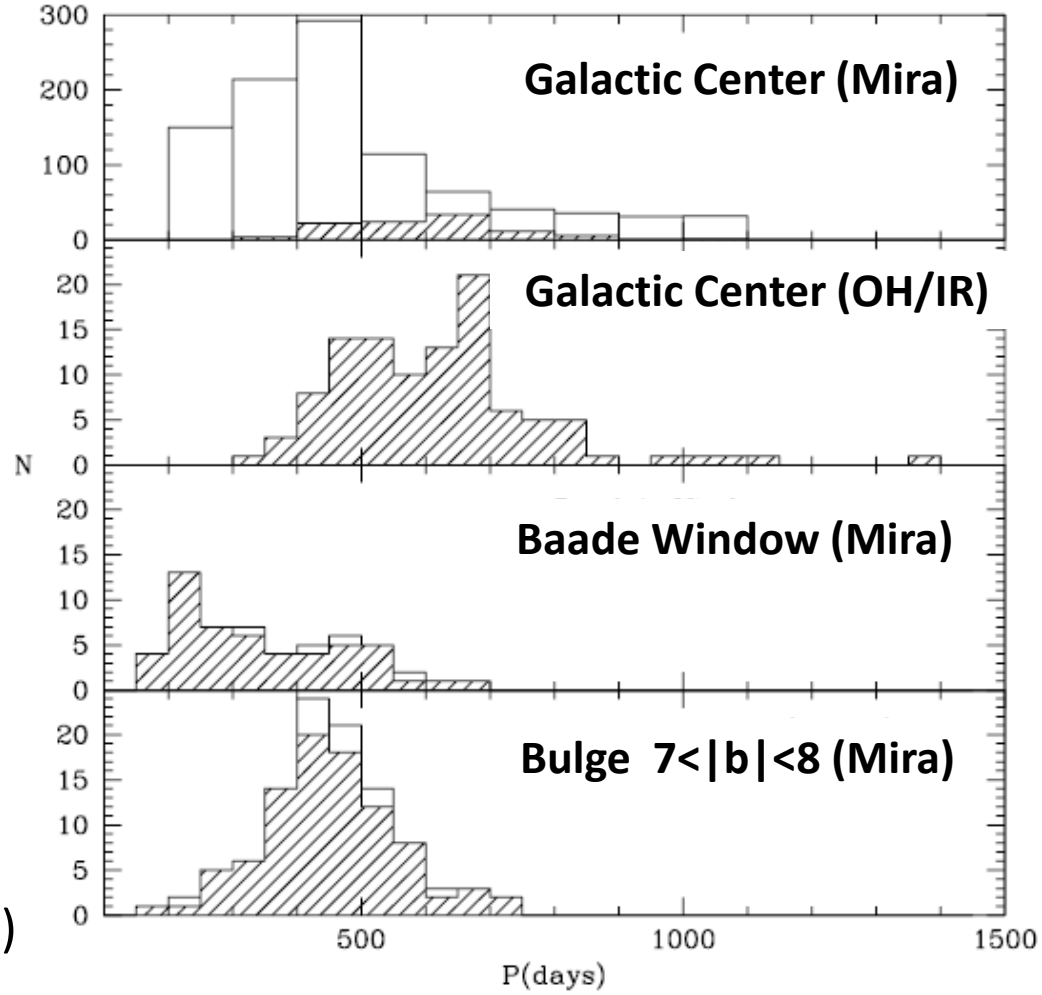
- Dominant emission sources of intermediate-age populations (50 Myr—1 Gyr)
- Contributing (chemically enhanced) gas and dust



Renzini & Buzzoni (1986)

Period distribution

- Correlated with age distribution of stellar population.
  - The longer-P Miras indicate the presence of the younger population (up to 100 Myr).

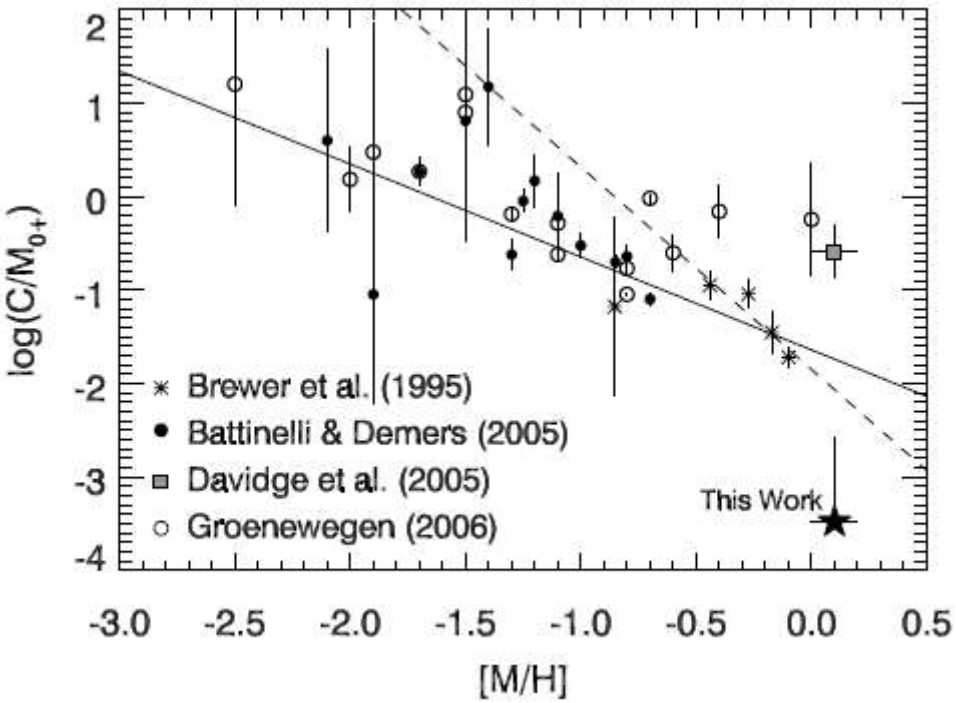


Wood et al. (1998)

C-rich and O-rich AGB stars

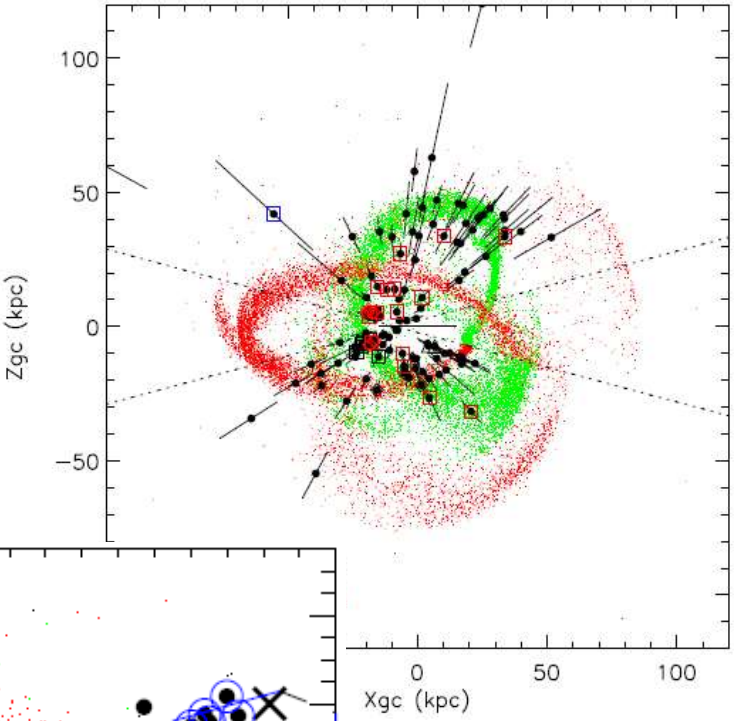
- Dredge-up of carbon leads to 2 (almost distinct) groups of AGB stars: C-rich/O-rich.
  - Initial metallicity and mass affects whether an AGB star evolves into a C-rich AGB star or not.

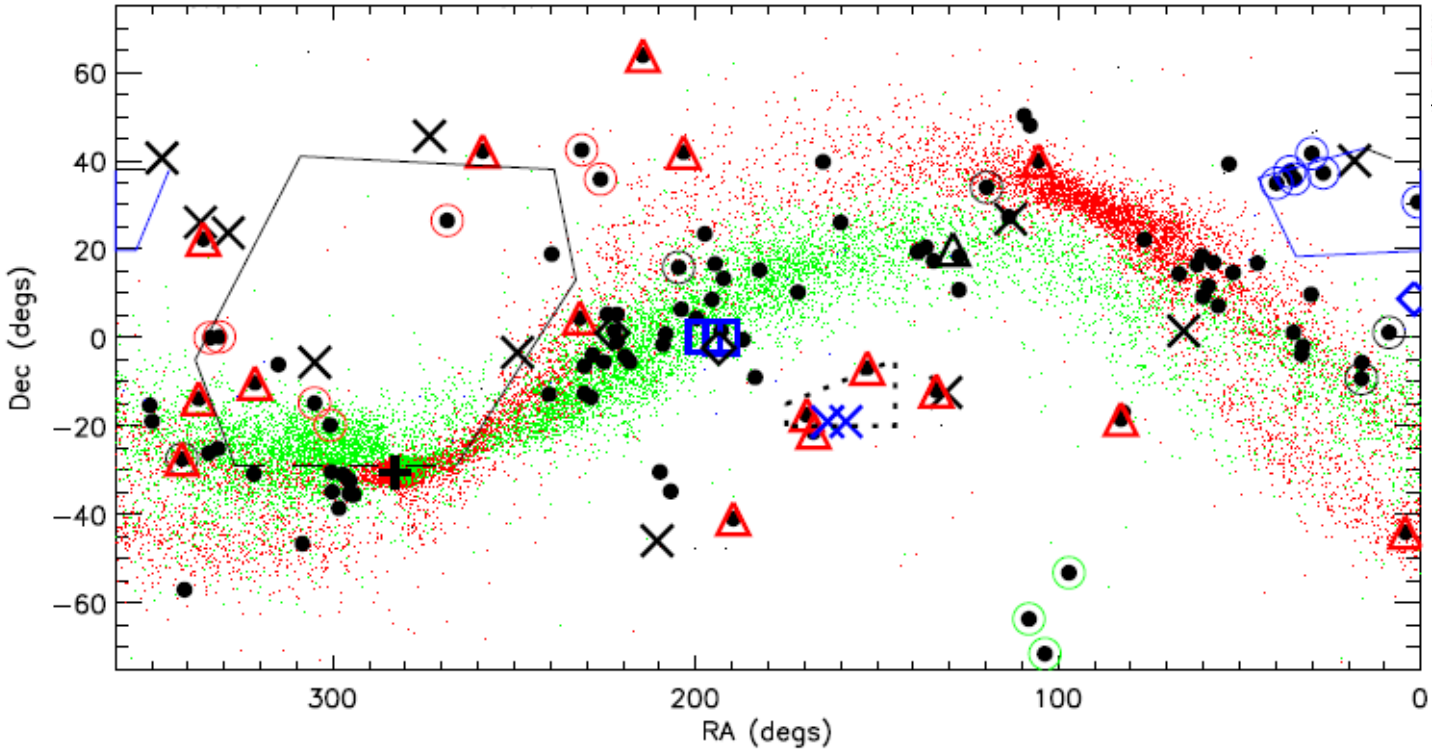
Mean metallicities of nearby galaxies and ratios between C-rich and O-rich stars (Boyer et al. 2013)



Miras in Sgr streams

- Most of carbon-rich Miras (a few Gyrs) in the Milky Way halo seem to exist in Sgr streams (Huxor & Grebel, 2015).



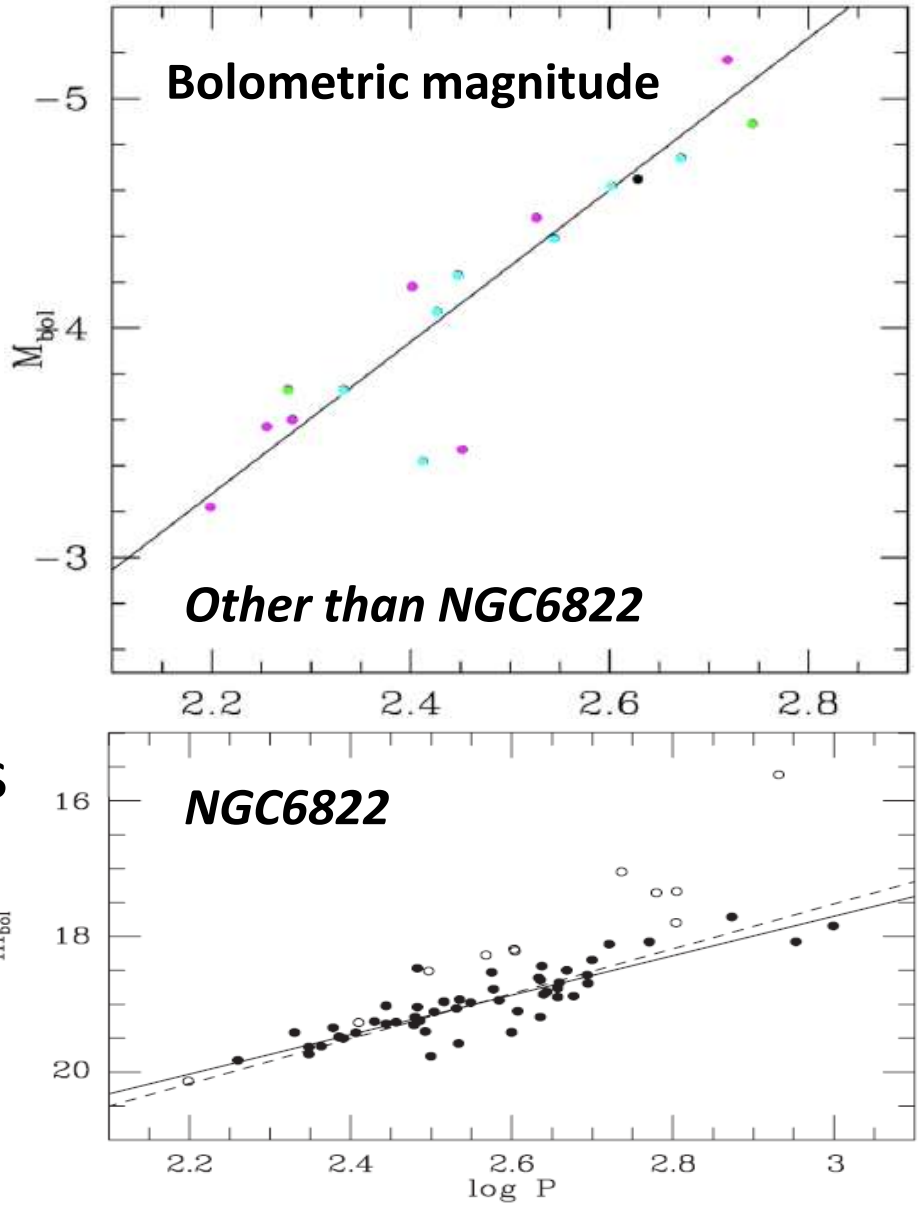


Previous observations of Miras in nearby galaxies

- LMC、SMC
  - Many observations in various wavelengths
- Dwarf galaxies in the Local Group
  - Our collaboration with South African astronomers
- M31, M33
  - Incomplete at all→CFHT、Pan-STARRS (PS1)
  - Almost no observations in the IR
- Beyond the Local Group
  - Only a work on Cen A with VLT (Rejkuba 2004)

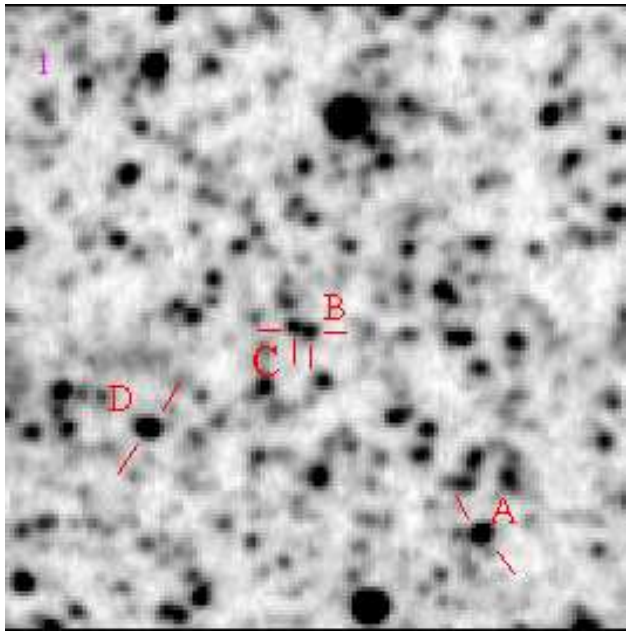
Dwarf galaxies in the Local Group

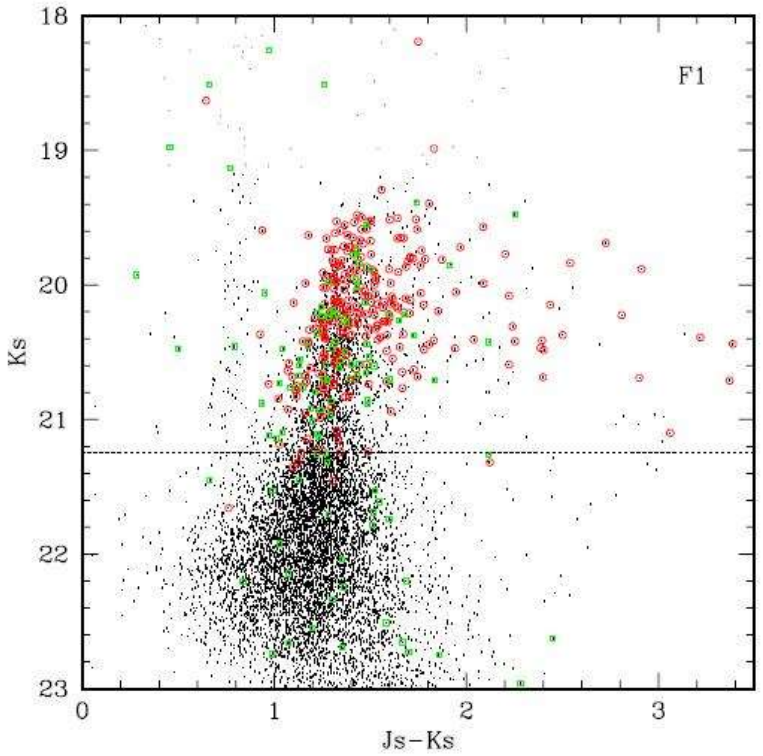
- Collaboration using IRSF
  - Whitelock, Menzies, Feast, Matsunaga, Tanabé, Ita …
  - Fornax, Leo I, NGC6822, Sculptor, Phoenix
  - 1 to dozens in each galaxy
  - Mainly carbon-rich Miras



Cen A: Rejkuba (2002-2004)

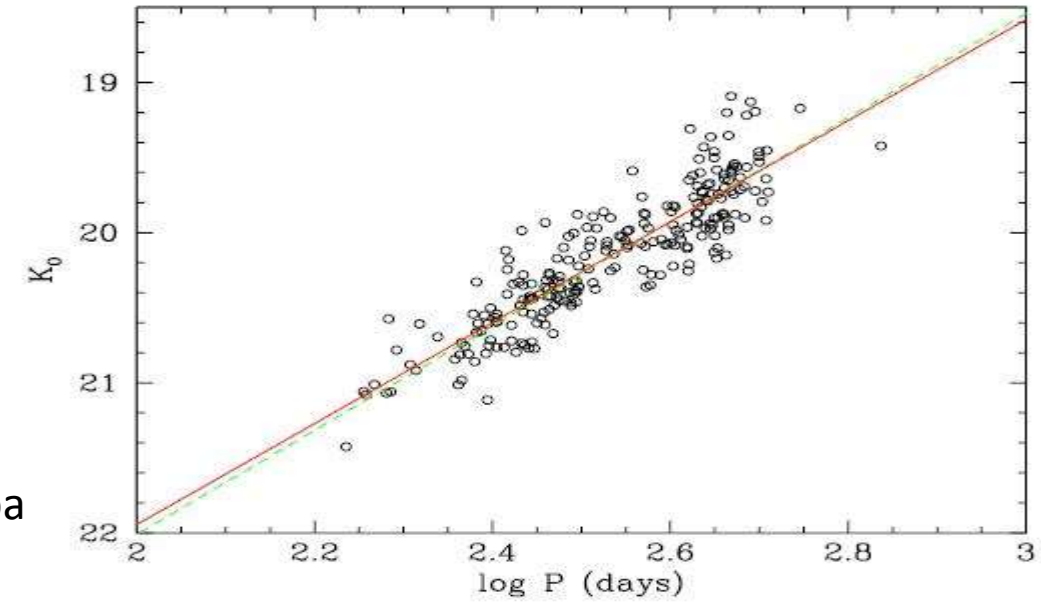
- Cen A (NGC 5128)　S0-type galaxy at 4 Mpc
- VLT-8.2m / ISAAC
  - 20 epoch observations in 1999~2002
  - FWHM ~ 0.4—0.5”、0.148”/pix Exposure ~ 60 min





P-L relation of Miras in Cen A

- >1000 Miras were discovered.
- The first and the only galaxy beyond the Local Group in which Miras have been found.
- The slope of P-L is consistent with that of LMC.
- Distance measurement by the P-L
  - μ_0(Cen A) = 27.96 ± 0.11 mag, 3.9 Mpc
  - Consistent with the result from RGB tip 27.87±0.16 mag



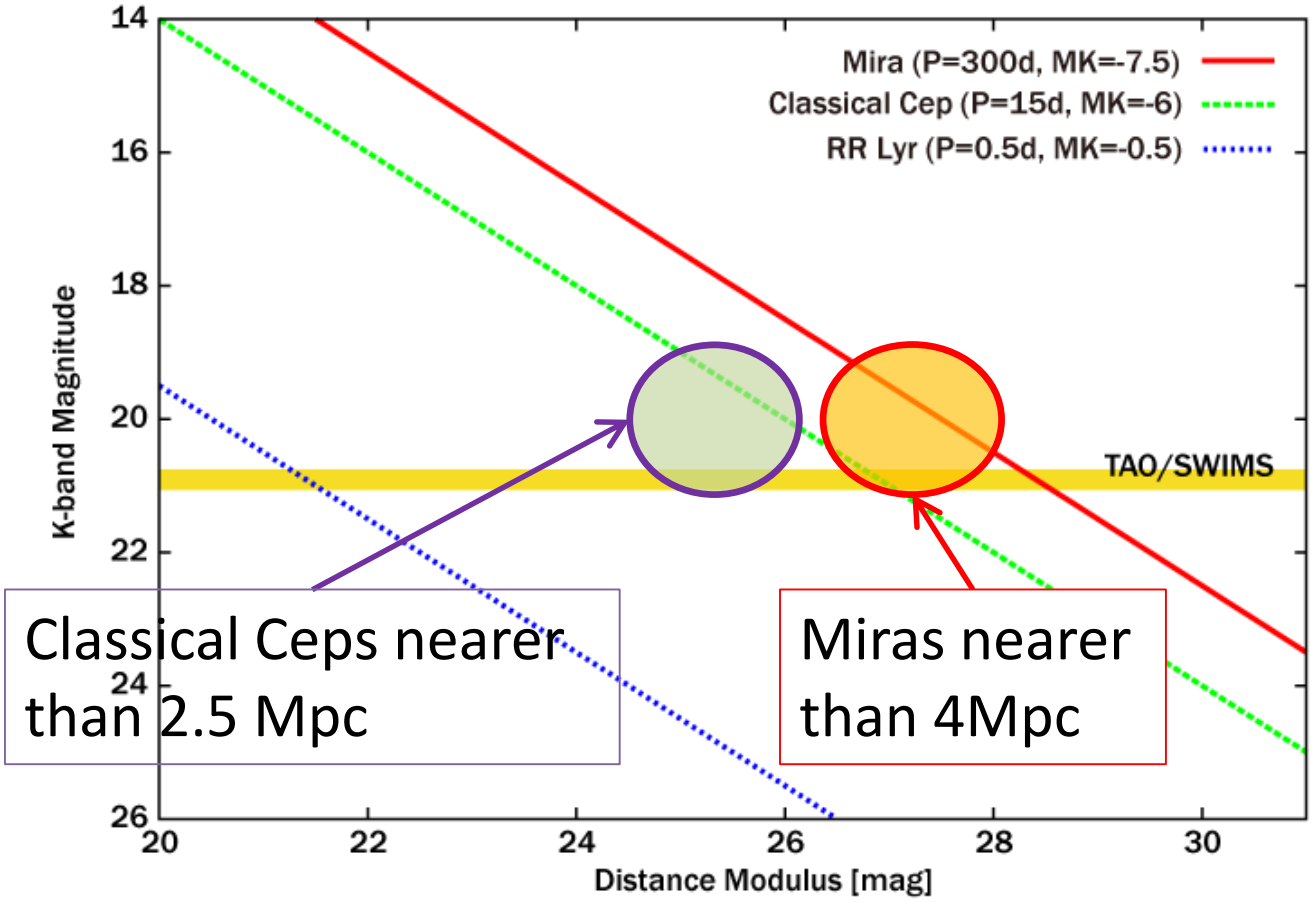
Rejkuba (2004)

Observations of Miras with TAO/SWIMS

- Goals:
  - Distance measurements by the P-L relation of Miras
  - Period distribution of Miras gives an insight of age distribution of stellar population (100Myr~10Gyr)
  - Structures of disks and halos
- A regular access to the 6.5 m telescope would be highly advantageous.

TAO/SWIMS limiting mags in the K band

- 1hr on-source integration→ K=22.5 Vega mag (S/N～5)
  - **K=20.8 Vega mag (S/N～25)**
- Miras are bright in the IR and can be reached to ~4 Mpc.



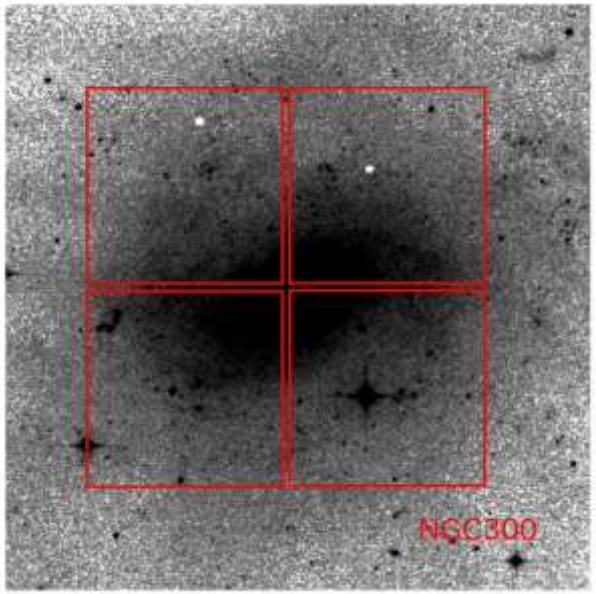
Necessary observational time（survey）

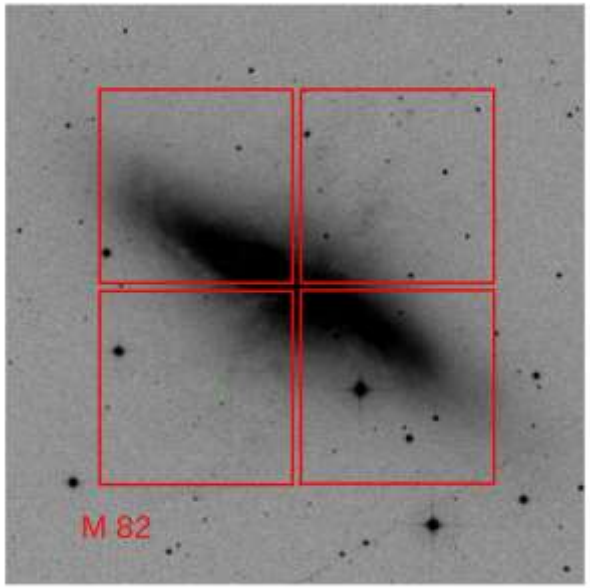
- ~1 hr integration per epoch.
- First 3—5 deep imaging to construct CMDs and to check if Miras can be detected.
- If Miras candidates are found (K>0.4 mag). ~20 epoch repeat observations in ~3 years.
- Including overheads (~1 hr per epoch), 40 hours are necessary for each galaxy (~6 nights, including the weather factor, x1.5).
- 7 galaxies → 1.5 months in 3 years (~4%)

Some targets

- NGC 300 : SA, 2.2 Mpc
- NGC 55 : SB, 2.2 Mpc
- M82 : I0 (starburst), 3.5 Mpc

Previous observations of stars in these galaxies are mainly by HST (mainly Cepheids) and/or Subaru. Difficult to make wide-field surveys of long-period variables.



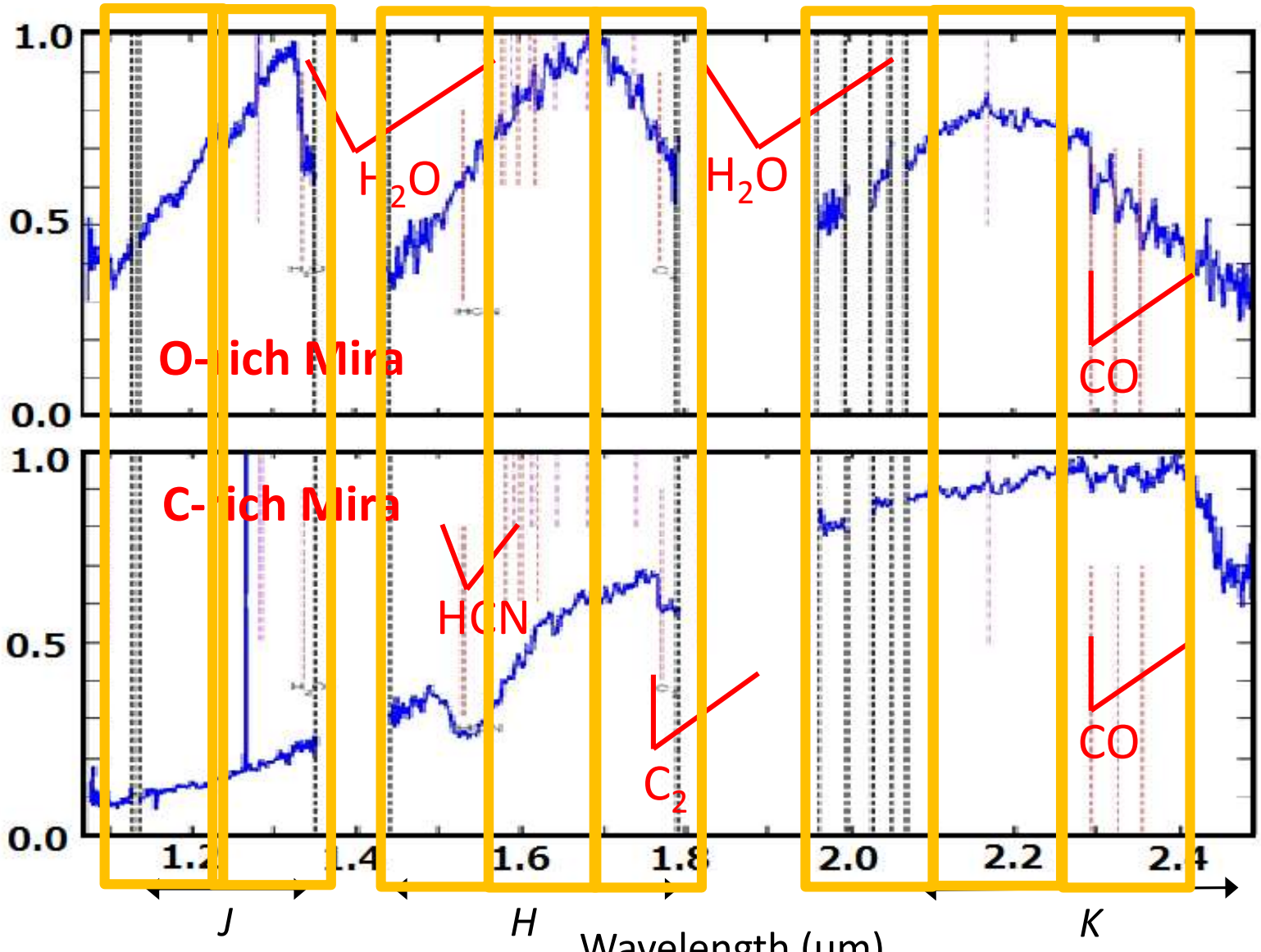


Necessary observational time (classification)

- Multi-object spectroscopy (~20 objects)
  - K~18.5 Vega mag (Miras@1.5 Mpc)→ ~1 hr
  - K~19.2 Vega mag (Miras@2.0 Mpc) → ~4 hr
- Need to check how medium- and narrow-band filters are useful to classify C-rich/O-rich.

Classification between O-rich/C-rich

NIR spectra of KISOGP Miras from ISLE@Okayama 74 inch



Summary

- Pulsating variable stars as population tracers
- TAO/SWIMS can reach Miras at ~4 Mpc
  - Would be the first systematic survey of Miras beyond the Local Group
  - A program using ~4% of observational time during 3 years for surveying Miras in ~7 galaxies.