Near-IR spectroscopic observations of stellar tracers in the inner Galaxy

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Main collaborators

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- South Africa
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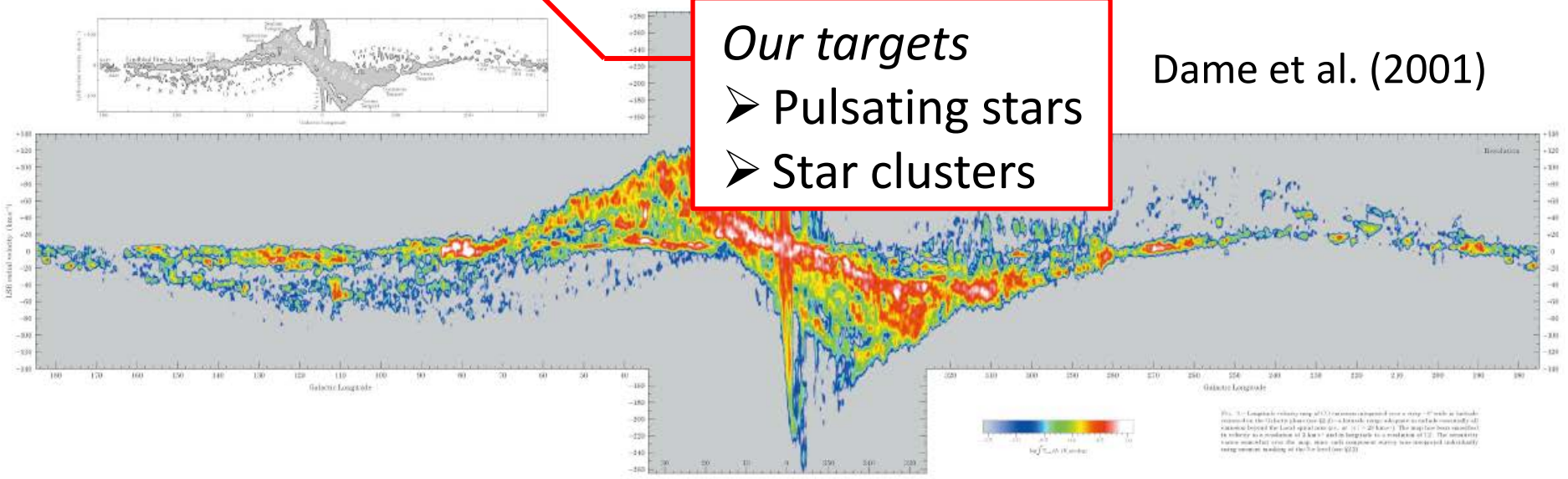
  - Kinematics of classical Cepheids in the Nuclear Disk around the Galactic Center

- Posters concerned with chemical abundances
  - Fukue et al. – K-type metal standard stars
  - Yamamoto et al. – M-type supergiants in a young cluster

The Galaxy: the nearest spiral

- Detailed information within reach.
  - A lot of the information needs to be collected yet.
- Details are necessary for the comprehensive understanding of the galactic evolution.
  - Bridging individual stars, clouds, and the whole galaxy



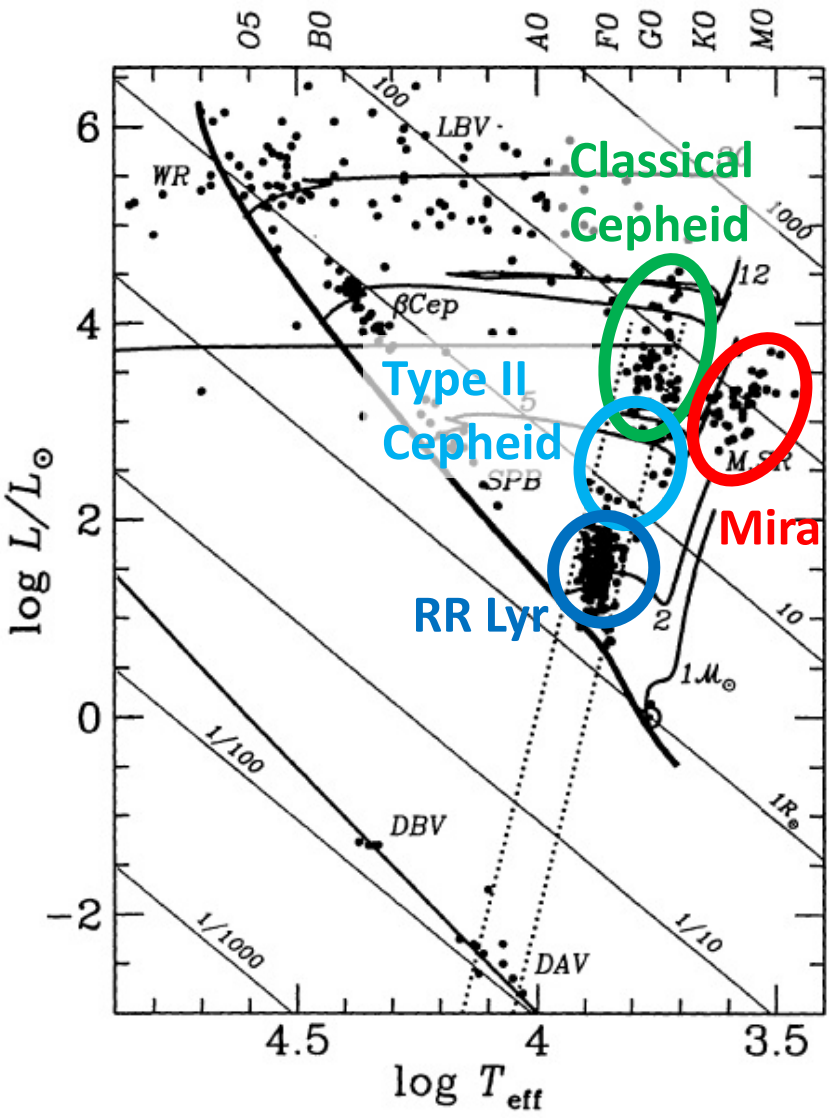
Our targets
- ➢ Pulsating stars
- ➢ Star clusters

Dame et al. (2001)

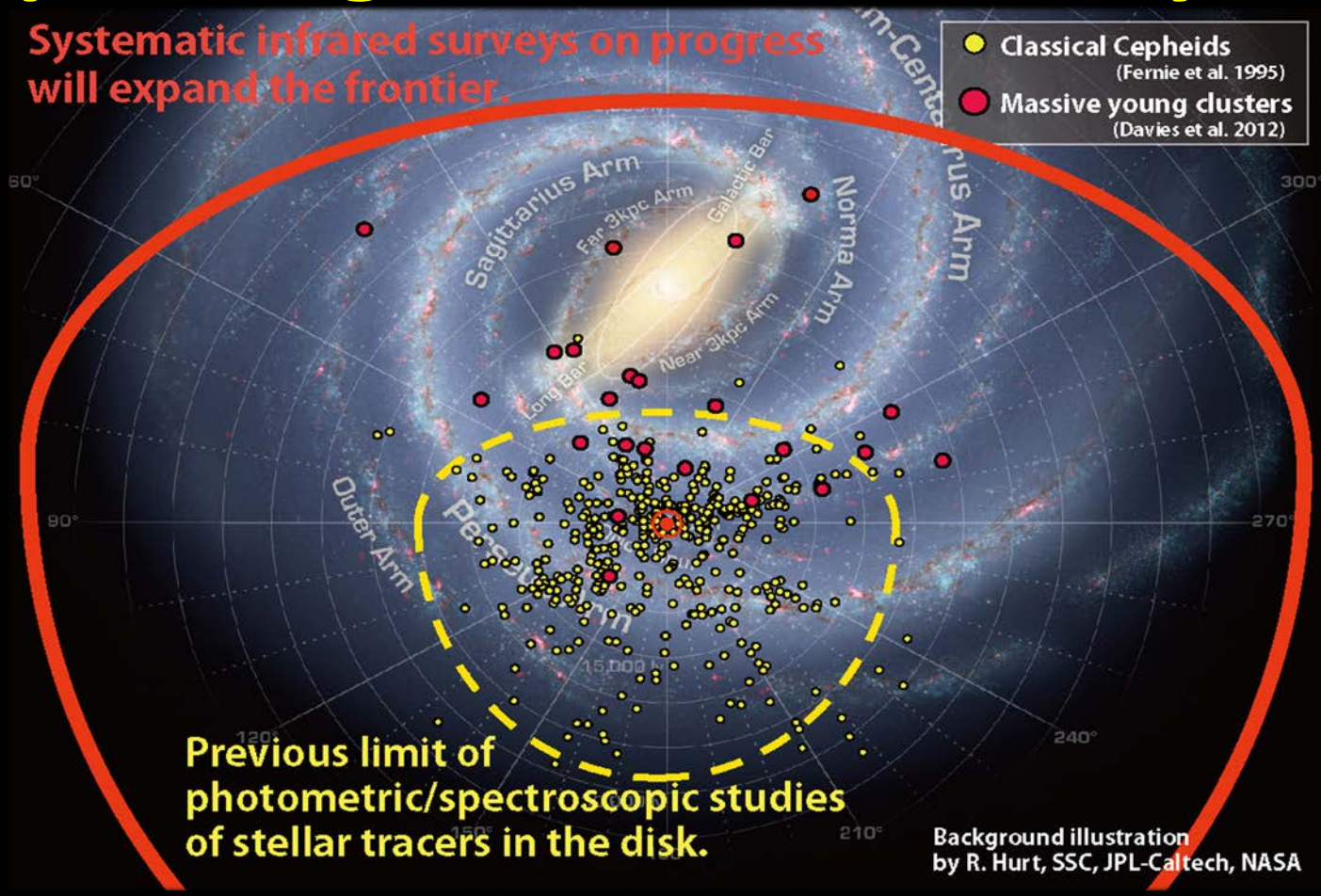
Pulsating stars and star clusters

- Pulsating stars
  - Period-luminosity relation
    →Distance
  - Evolutionary model
    →Age, Population
- Star clusters
  - Distances and ages can be determined by the CMD.
- Good tracers of
  - Galactic structure
  - Kinamatics
  - Chemical evolution

Locations of pulsating stars on the HR diagram (Gautchy & Saio 1995)



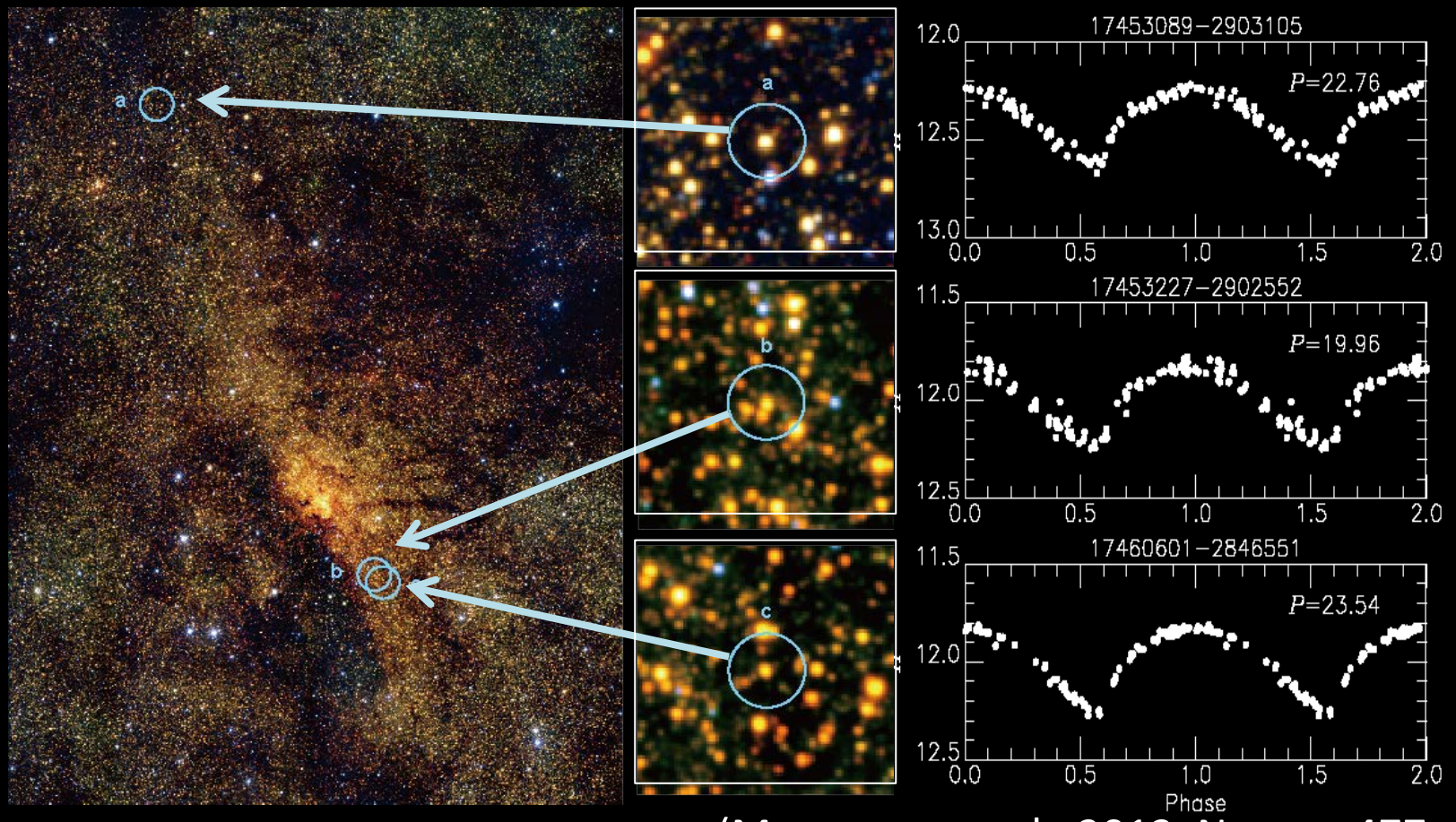
Expanding the frontier in 5 years



- Illustrating a rough idea on how much we can expand the frontier of the Galactic disk with ongoing survey projects like IRSF, OGLE-IV, VISTA/VVV.
- Gaia cannot reach such a wide range of the disk.

Our discovery of classical Cepheids

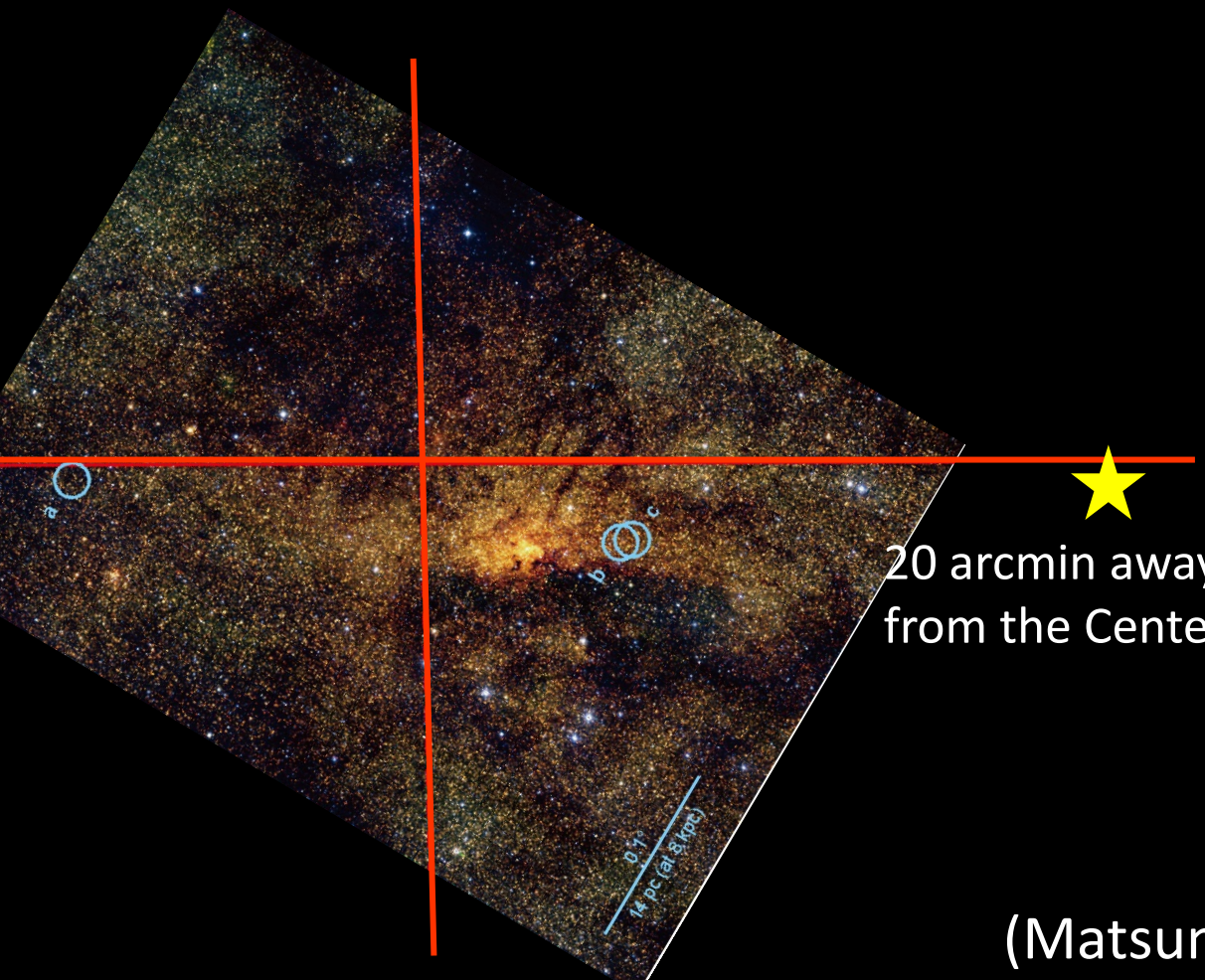
- 3 Cepheids found near the GC (μ_0=14.5^{mag}, D~8kpc).
- Similar light curves, all with P~20 days which indicates their ages being 25(±5) Myr.



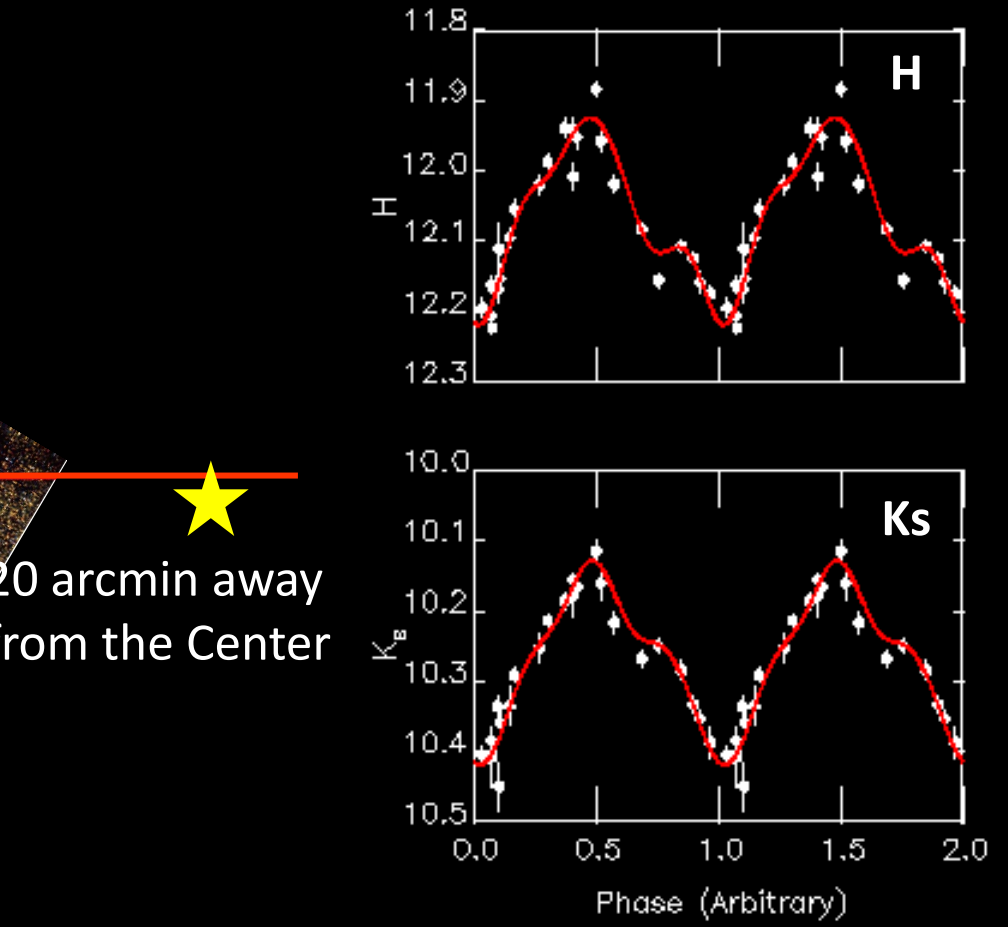
(Matsunaga et al., 2013, Nature, 477, 188)

And a new classical Cepheid

- P=18.84^{d} !! (close to the pervious three)
- μ_0=14.57^{mag} (belonging to the nuclear bulge)



20 arcmin away
from the Center



(Matsunaga et al., in preparation)

Our objectives

- To trace the Galactic structure and evolution using pulsating stars (especially Cepheids) and star clusters.
- *Photometric surveys of pulsating stars hidden in the disk/bulge (IRSF, KISOGP; not with Subaru).*
- Spectroscopic observations (with Subaru) to measure ***kinematics*** and ***chemical abundances*** of newly discovered objects in the disk/bulge.

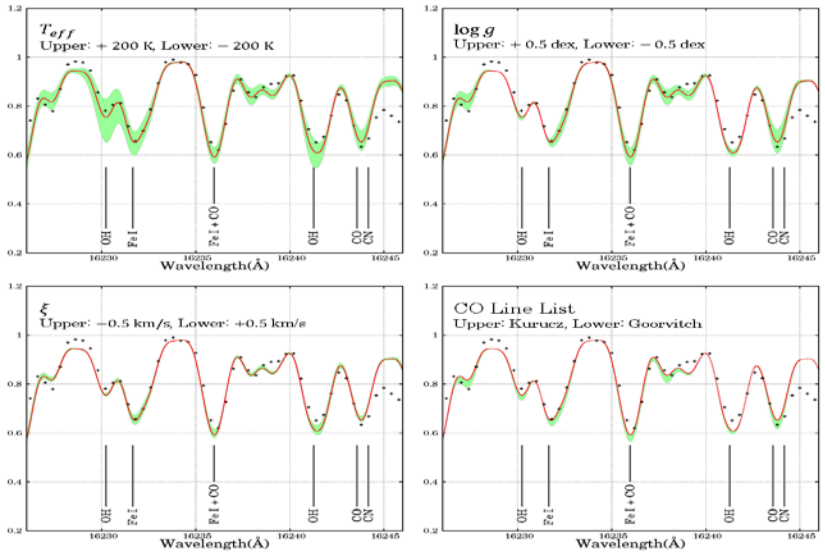
Chemical abundances

- No work has been done to get the metallicities of Cepheids based on IR spectra.
- At first, we need to establish a list of lines in the IR using spectra of calibrating Cepheids (with [Fe/H] measured on optical spectra).
  - We have collected IRCS spectra of several calibrating stars (both Cepheids and normal stars).

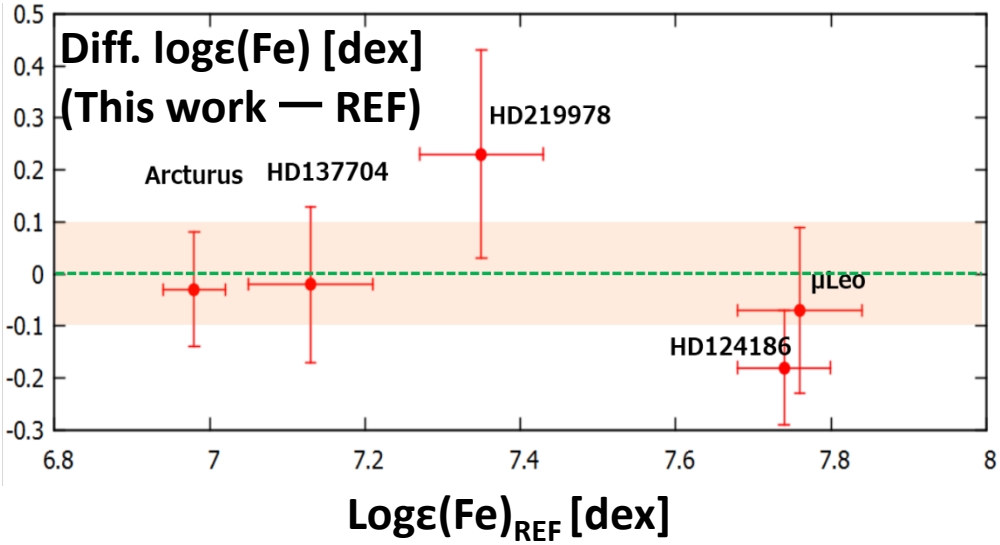
On progress…

- Not trivial tasks to establish the method to derive abundances based on infrared spectra.
  - list of lines in IR, spectroscopic estimation of parameters of heavily obscured stars
- Posters by Fukue et al., Yamamoto et al.

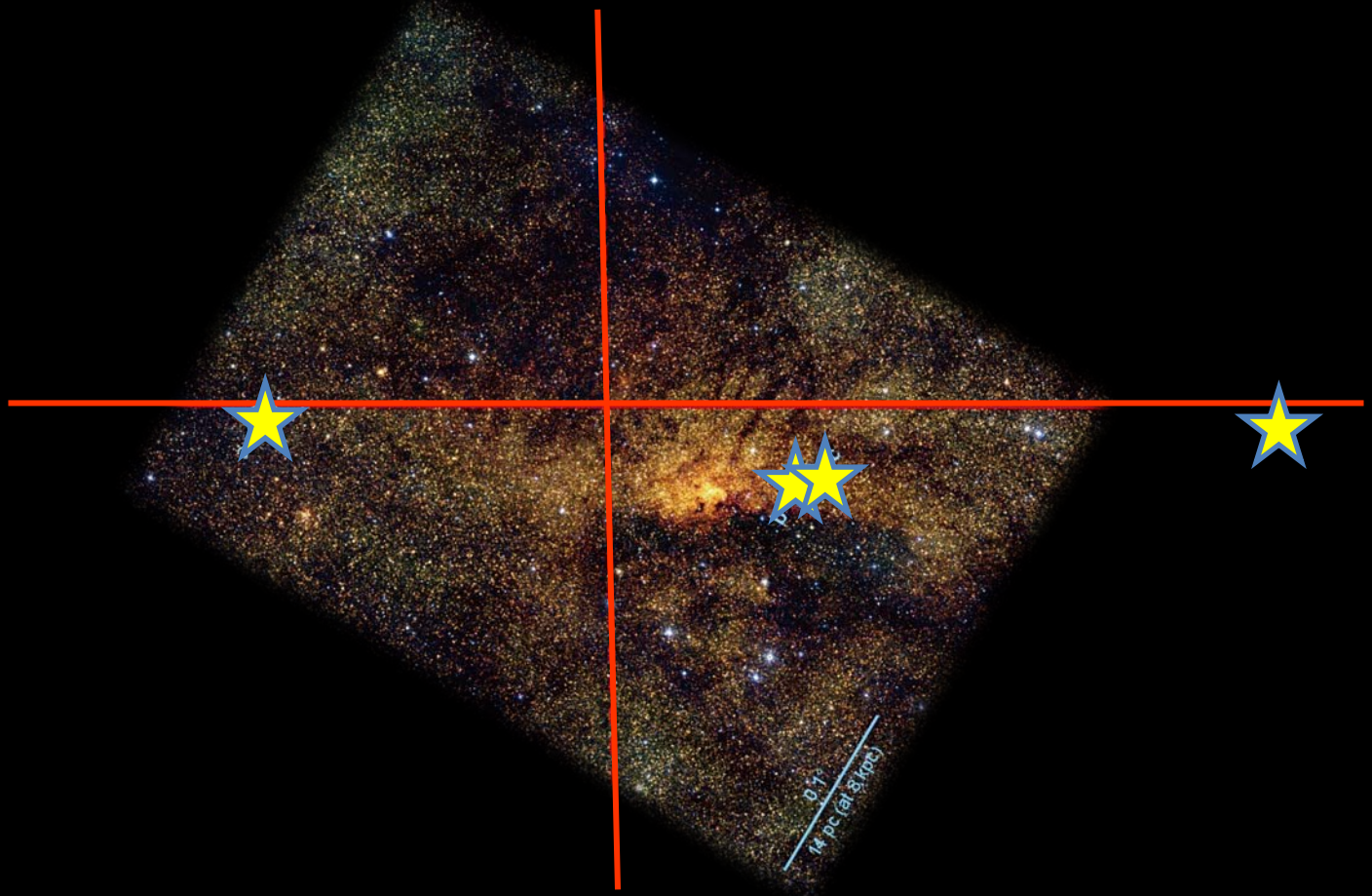
Determining stellar parameters (Teff, logg, microturbulence).



Check the analysis procedures with calibrating stars



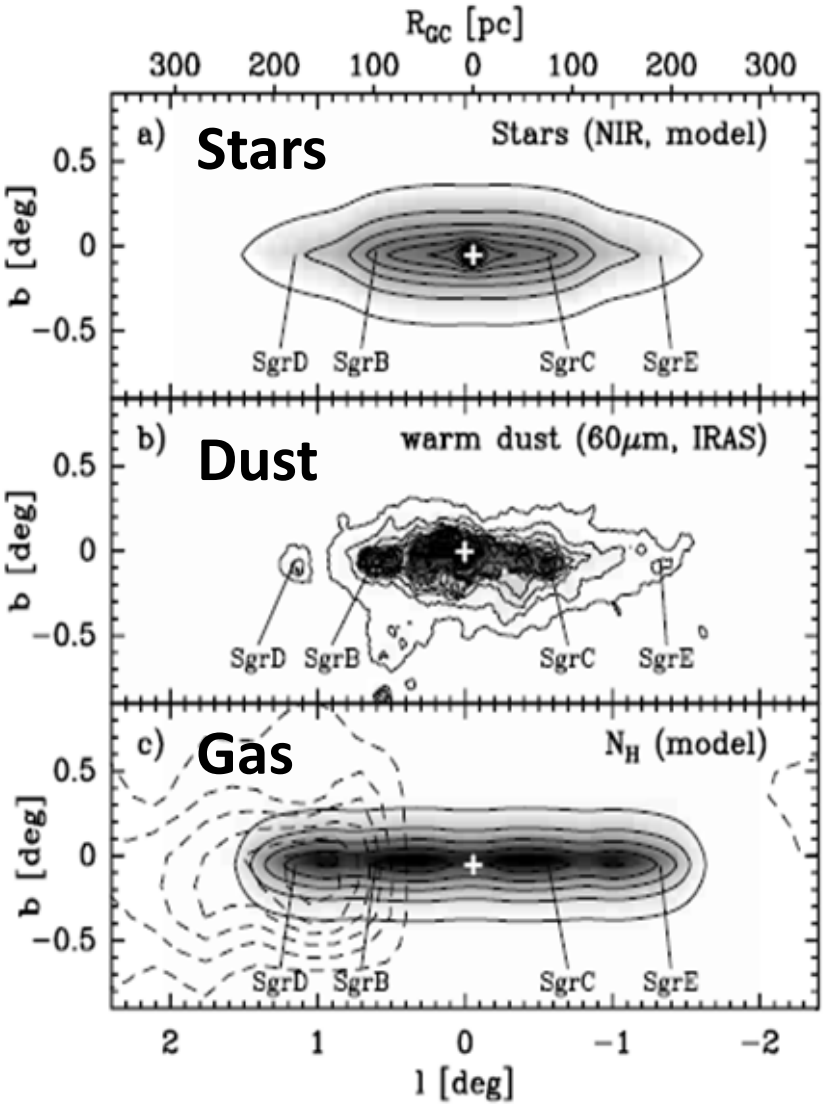
Kinematics of Cepheids in the Nuclear Disk



The Galactic Nuclear Disk

- Infrared observations in 1990s revealed:
  - a much smaller and more concentrated system (~200 pc in radius)
  - a disk-like system where gas and dust coexist (Central Molecular Zone)
  - a rather distinct system from the extended bulge
  - including young stars

Launhardt et al. 2002

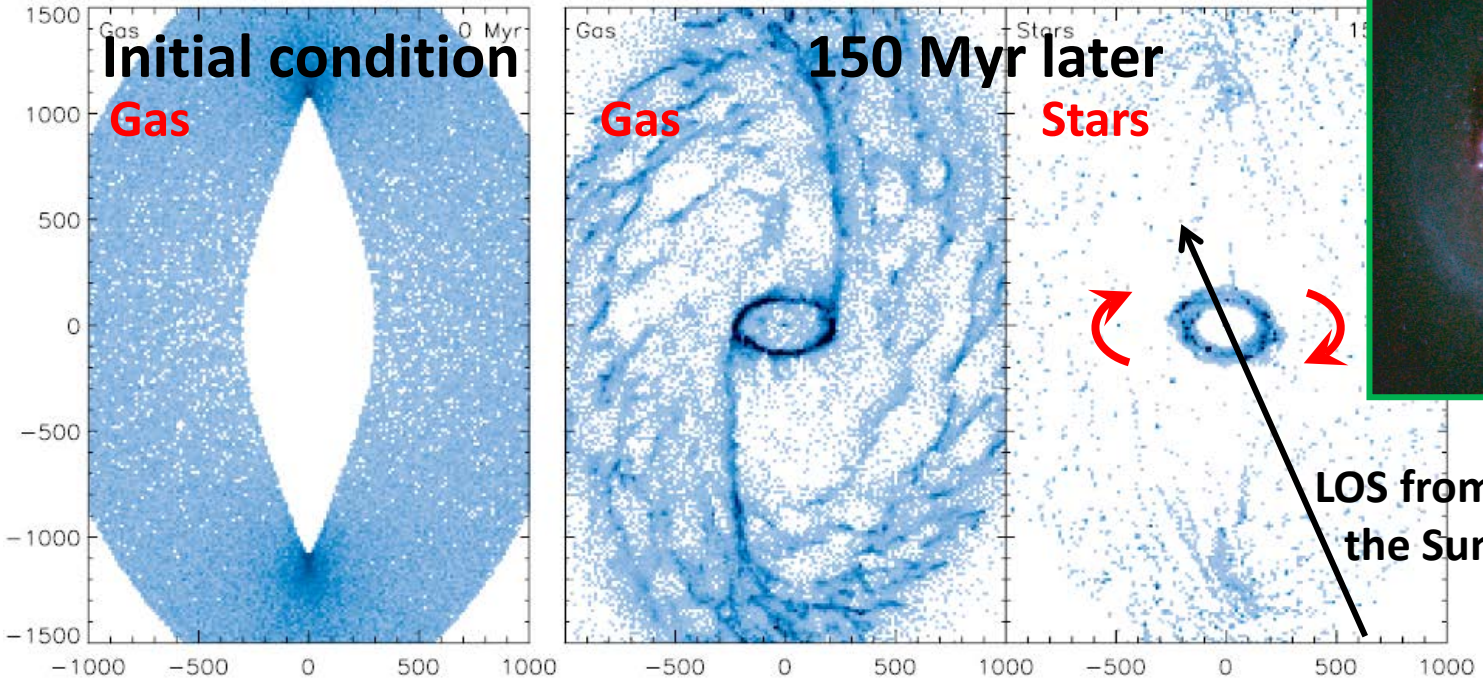


A probable scenario of the ND formation

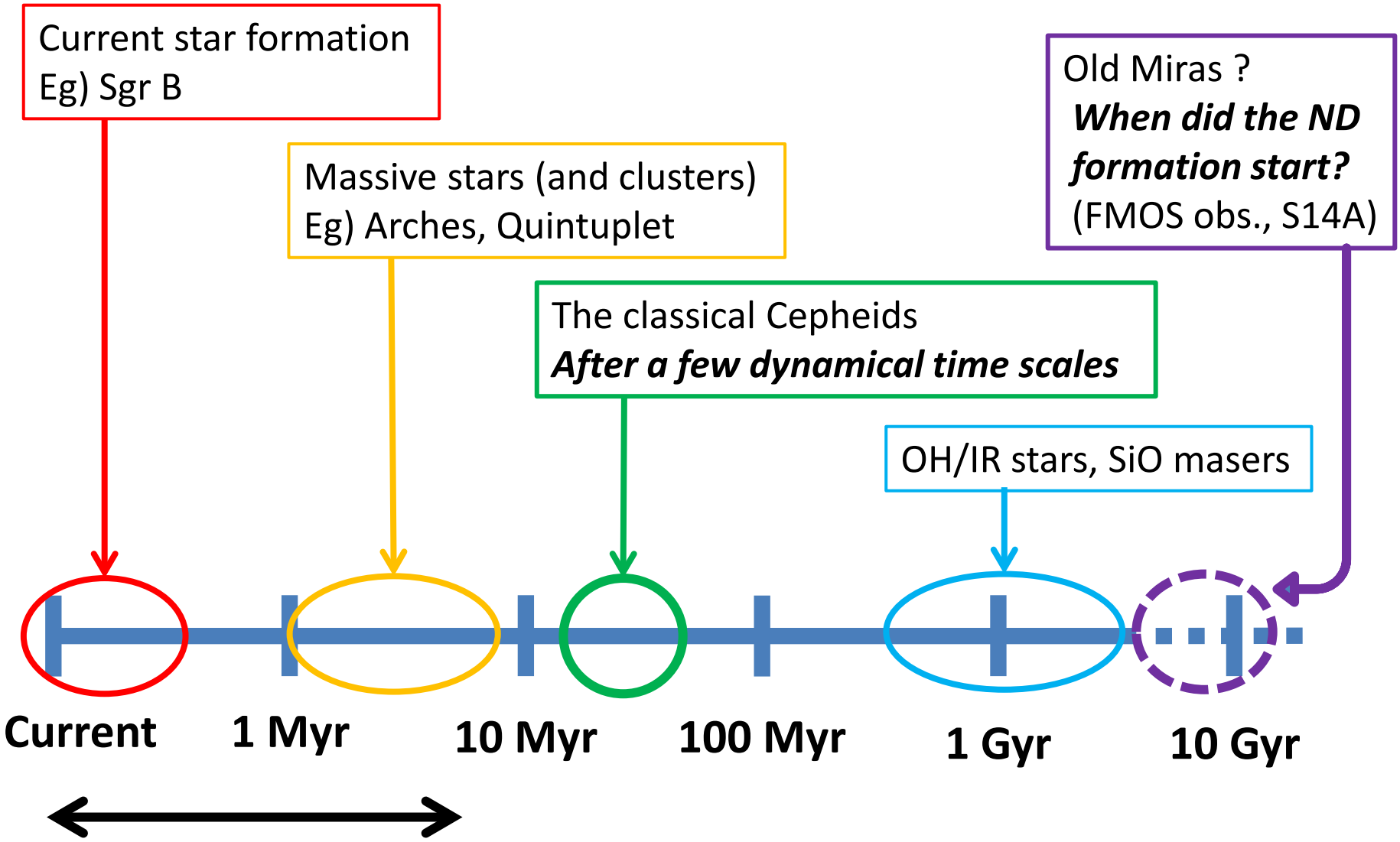
- Gas through the bar fuels the star formation in the Nuclear Disk (with a ring structure).
- Secular evolution of the Galactic central part, which may be related to nuclear star-forming rings in external galaxies.

Nuclear Ring in NGC 4314
(Benedict et al. 2002)

N-body/SPH simulation by Kim et al. (2011)



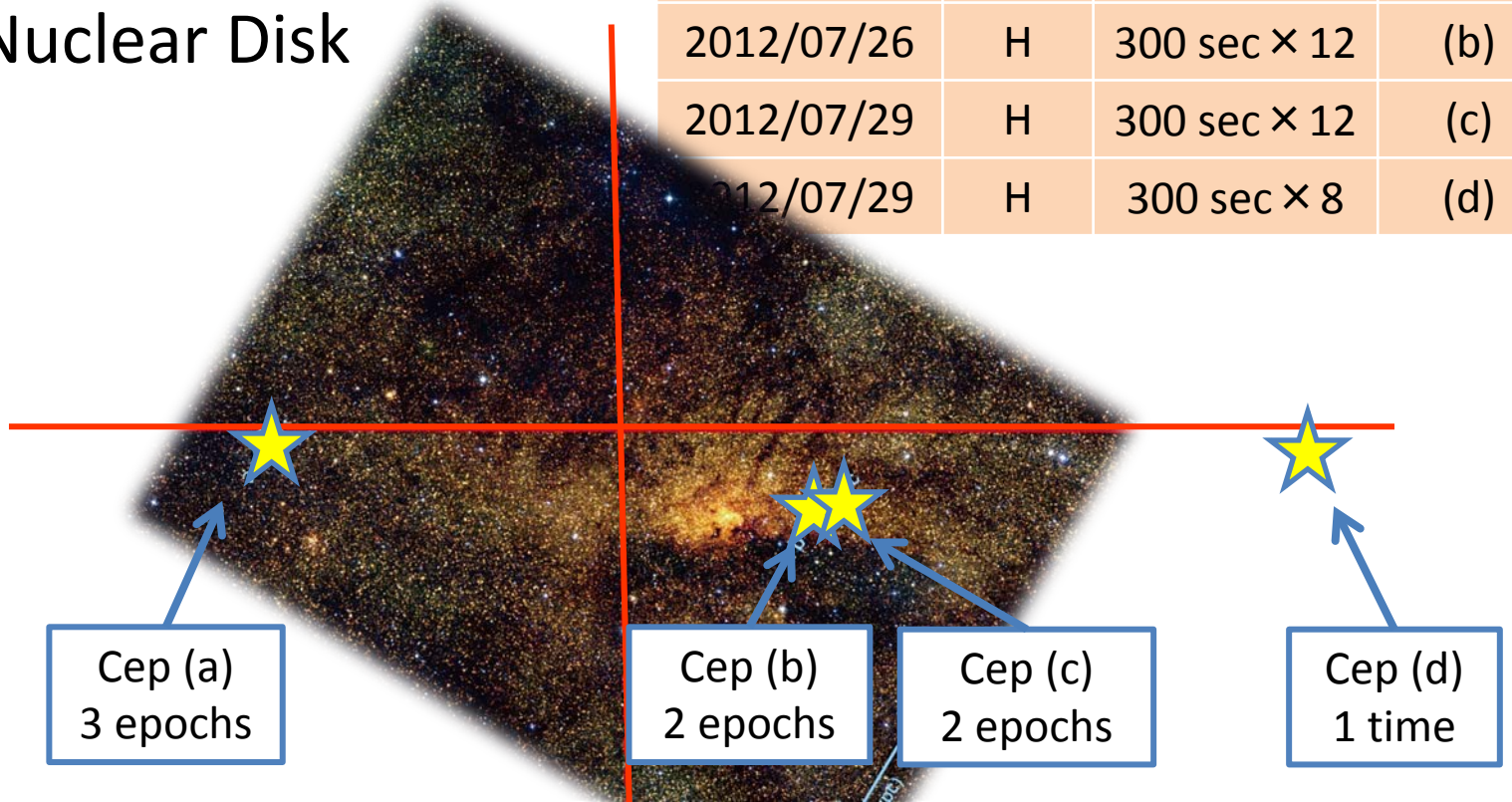
Stellar populations in the Nuclear Disk



Observation

- SUBARU/IRCS + AO188
  - S12A-053, S12A-563, S10A-123
- H- (or K-) band spectra (R~20,000) for 4 Cepheids in the Nuclear Disk

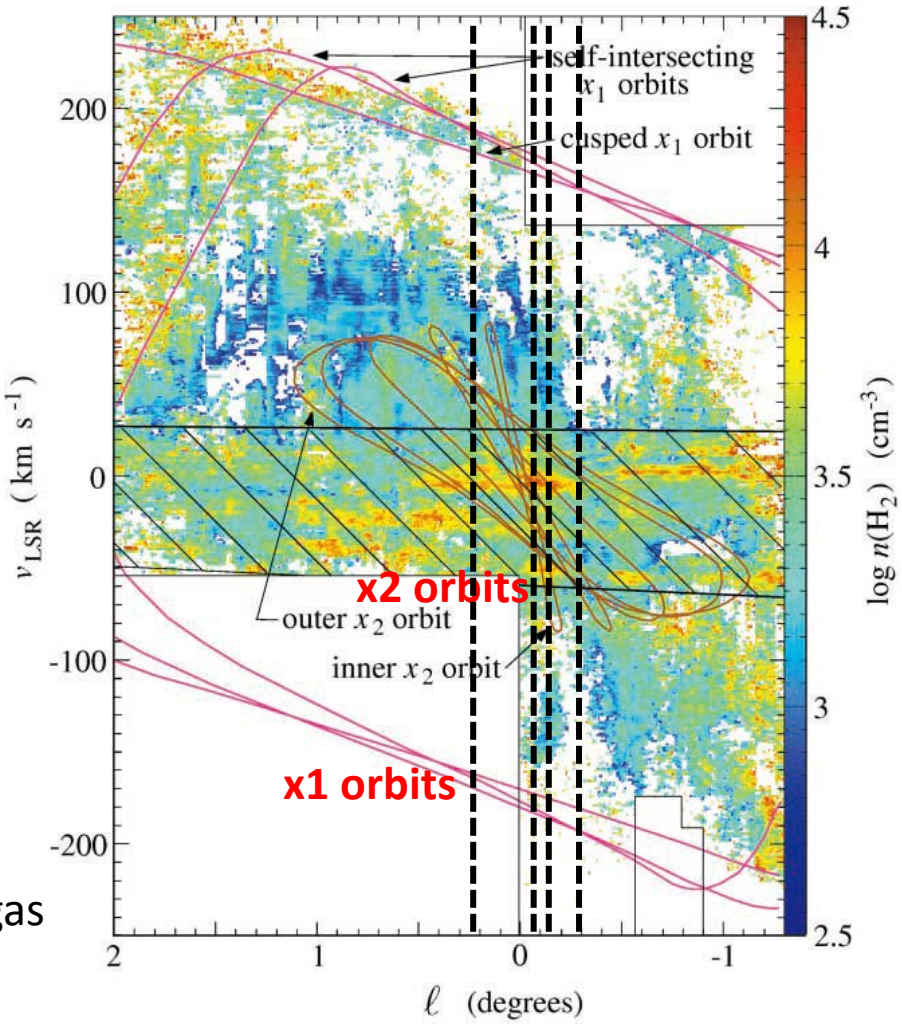
Date	Band	Integration	Object
2010/06/20	K	300 sec × 8	(a)
2012/05/25	H	300 sec × 12	(a)
2012/05/25	H	300 sec × 10	(b)
2012/05/25	H	300 sec × 12	(c)
2012/07/26	H	300 sec × 14	(a)
2012/07/26	H	300 sec × 12	(b)
2012/07/29	H	300 sec × 12	(c)
212/07/29	H	300 sec × 8	(d)



The first goal of our observations

- Comparing kinematics of the Cepheids with that of interstellar gas and other young stars

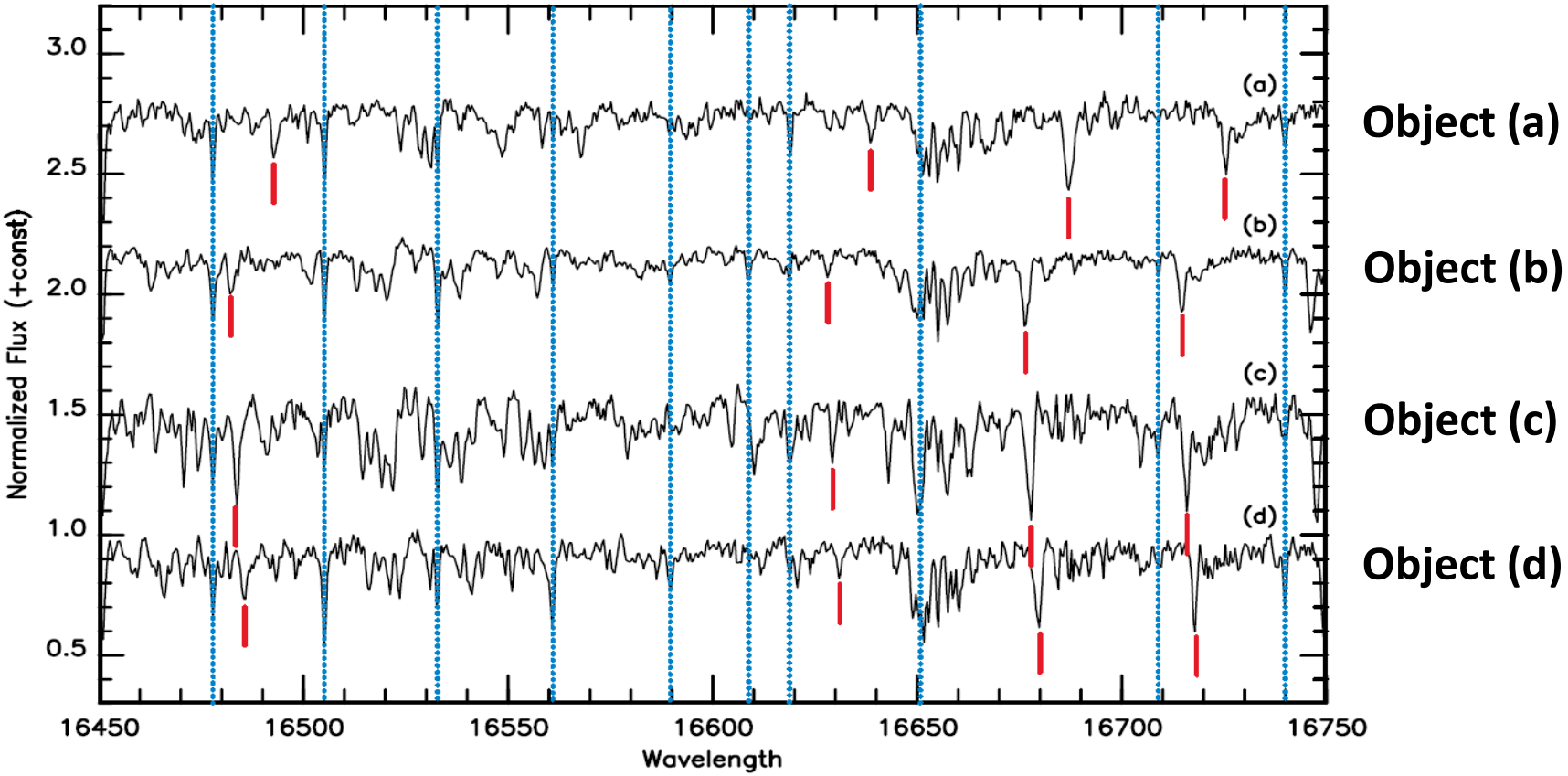
Positions of the 4 Cepheids



An l-v diagram of CO gas (Stark et al. 2004).

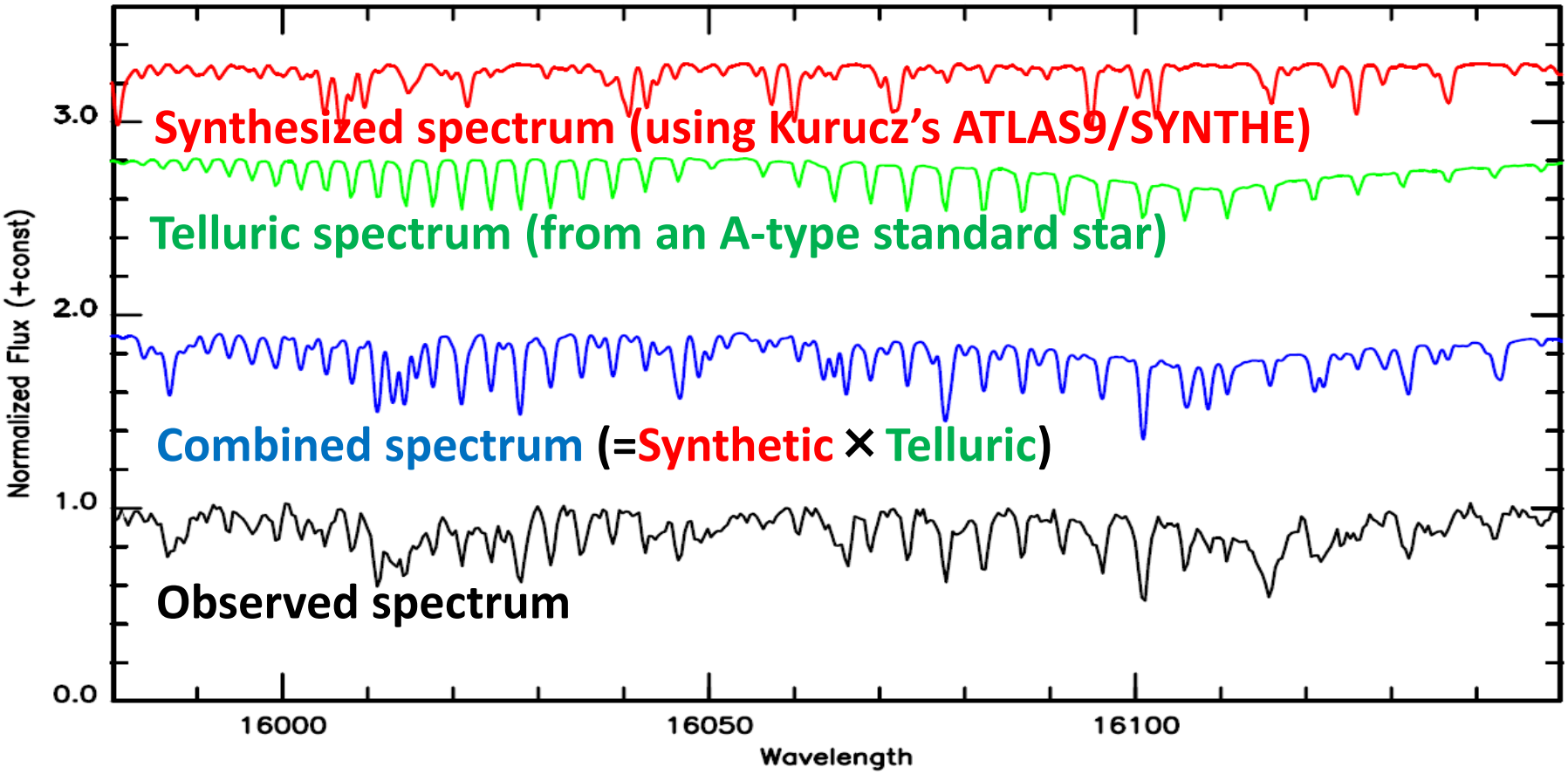
IRCS Spectra of the Cepheids

- H-band spectra (R~20,000)
- Dozens of metallic absorption lines exist.
- Significantly different radial velocities found.



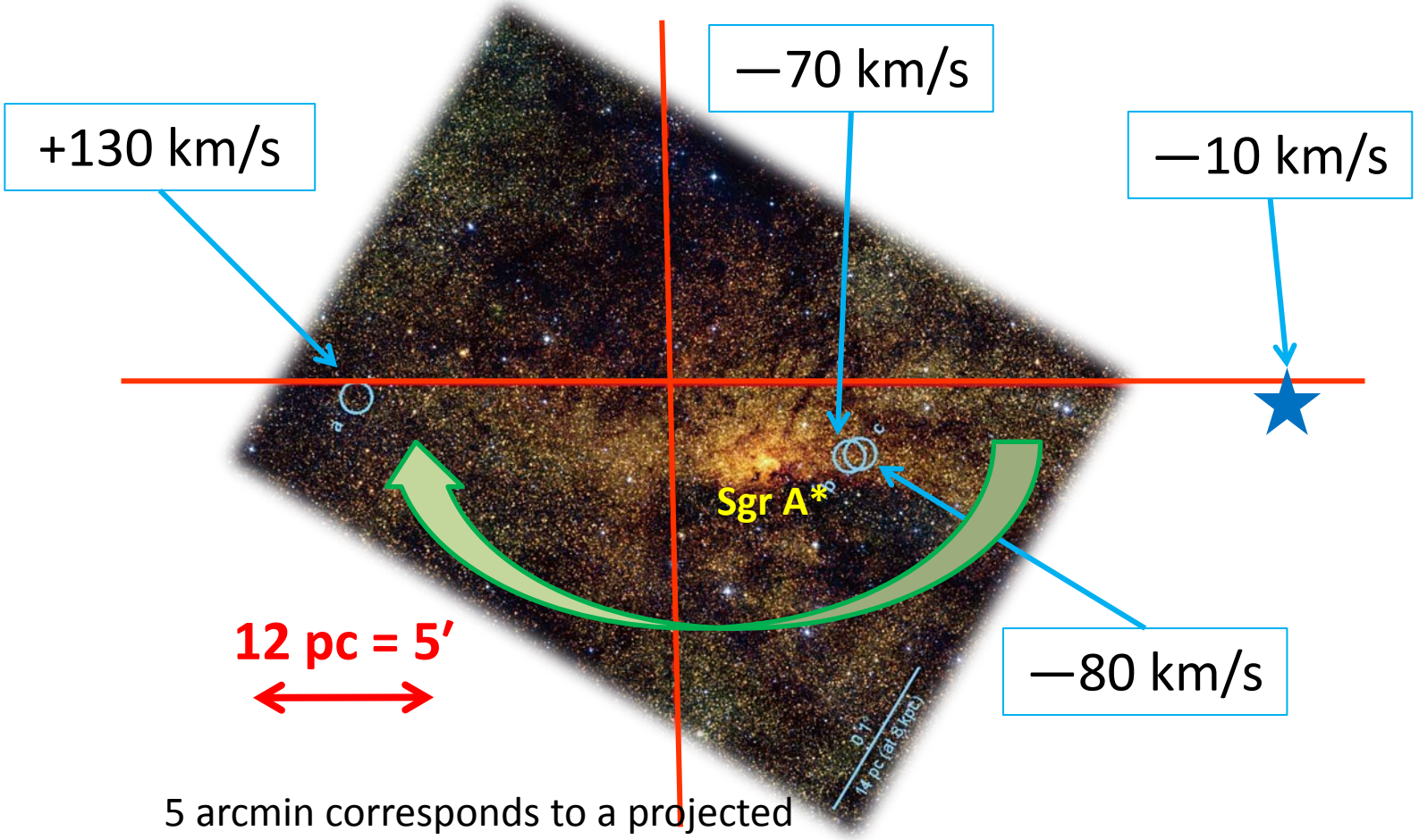
Estimating radial velocities

- Comparing **Observed** spectra are with **Combined** spectra (=**Synthesized** × **Telluric**)
- Finding velocities which give the best matches between the Observed and Combined spectra



Velocities (V_{LSR}) of the Cepheids

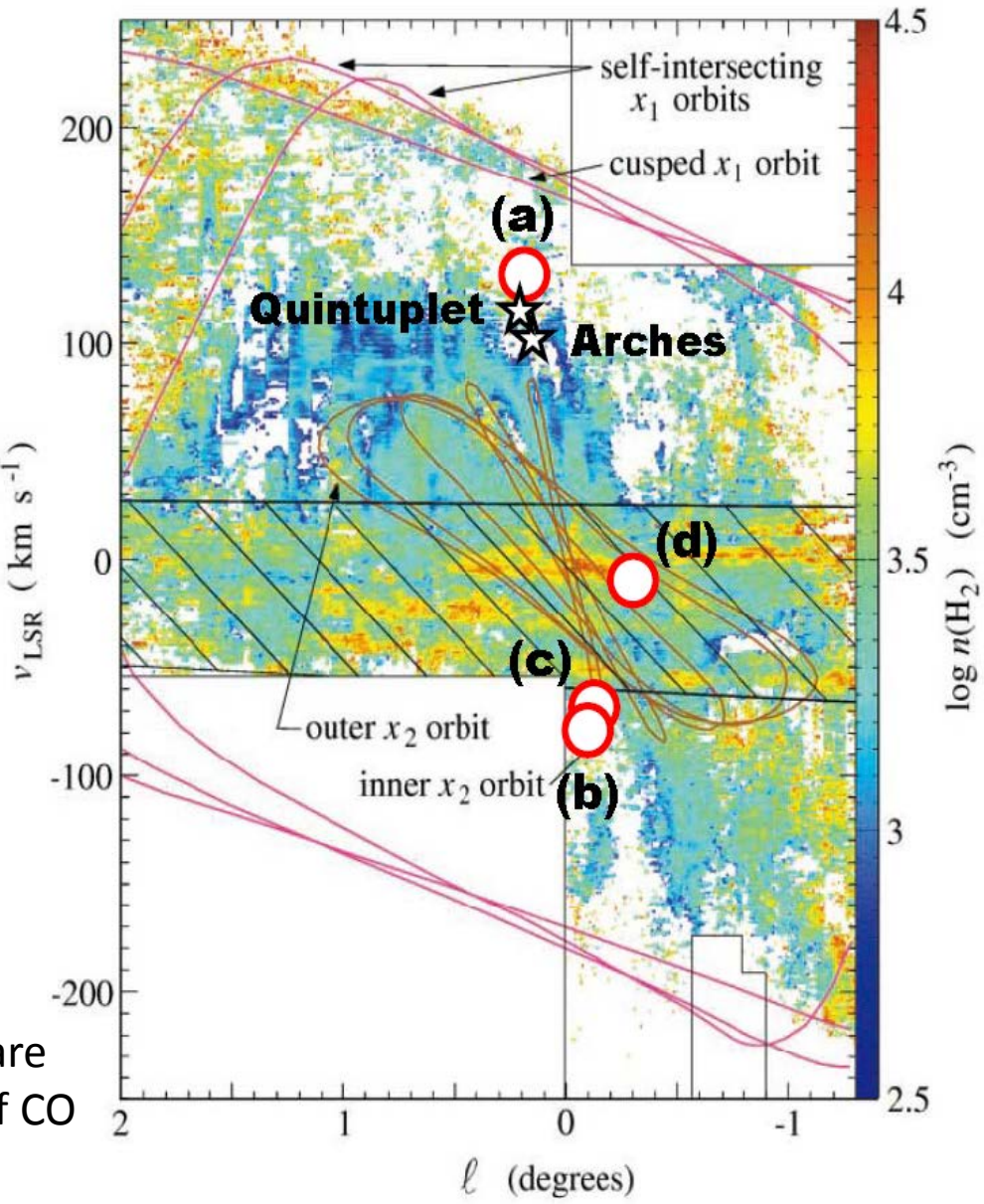
- Consistent with the rotation of the Nuclear Disk.



5 arcmin corresponds to a projected distance of 12 pc at 8 kpc.

Discussion

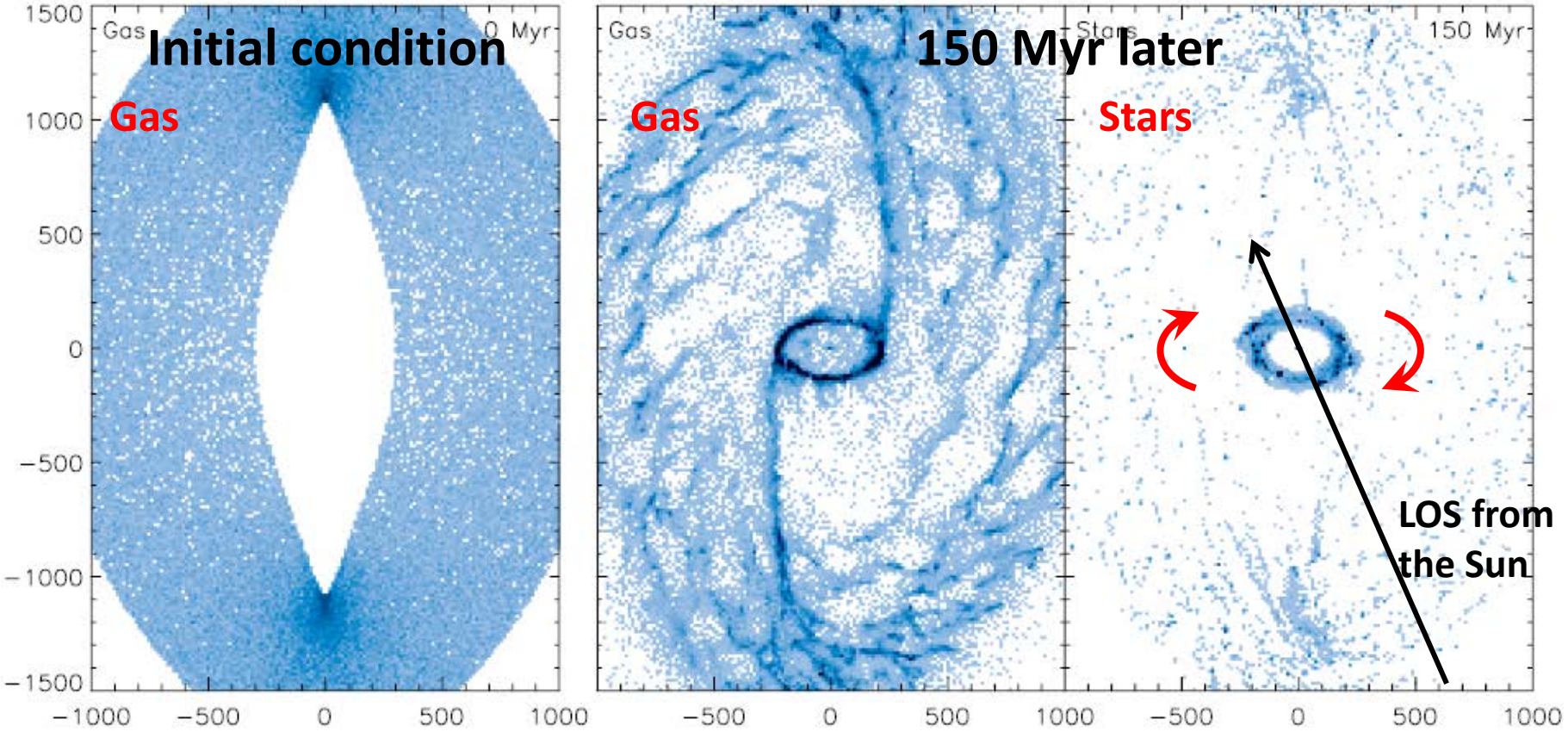
- Consistent with the rotation of the nuclear stellar disk.
- Proper motions should be measured in the future. (possibly in a comparison w. our 2012 images with AO).



V(LSR) of Cepehids and clusters are overplotted on the l-v diagram of CO gas (Stark et al. 2004).

The Nuclear Disk (Ring?) in a simulation

- Gas through the bar fuels the star formation.
- Our Cepheids could have been formed in such a ring 20 Myr ago (~a few dynamical time-scale).



N-body/SPH simulation by Kim et al. (2011, ApJ, 735, L11)

Summary

- The Cepheids in the GC have radial velocities consistent with the rotation of the Nuclear Disk.
  - Supporting the scenario of gas accretion from the inner Galactic disk along the Galactic bar.
  - Proper motion measurements need to be done in the near future before we discuss detailed scenarios.
- Chemical abundance measurements being on progress.


End