

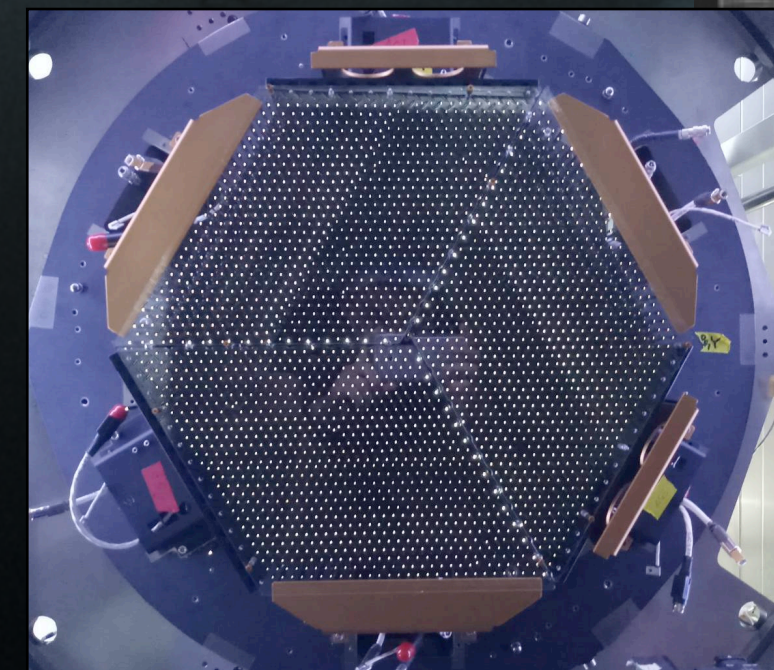
PFS Galactic Archaeology survey

- With deep gratitude to Hitoshi -

Miho N. Ishigaki (Subaru Telescope/NAOJ)

Hitoshi-Fest @ Kavli IPMU

December 16 - 20, 2024



Lamp spectra with Subaru/
Prime Focus Spectrograph
(PFS) under construction



<https://pfs.ipmu.jp/blog/2021/10/p1924>

When I was a PhD student...

The concept design document by one of the teams

- One of my first international conferences:
Cosmology Near & Far: Science with WFMOS,
May 19-21, 2008, Waikoloa (Hawaii)
- Two independent designs have been seriously considered for a wide-field spectrograph @ 8m telescope (“WFMOS”, the precursor of PFS) by two teams (“Team A” and “Team B”), and ultimately, one of them is adopted.

😲 I was impressed that a large project was initiated with such tremendous effort.



PFS-SSP Galactic Archaeology survey planning

- The biggest observational proposal, with a big research team and with the longest preparation time in my (short) research carrier
- The field of Galactic Archaeology has been advancing rapidly over the years during the preparation of the proposal



I have been fortunate to have the opportunity to seriously consider the most important challenges at each point in time.

PFS-Subaru Strategic program survey proposal

COSMIC EVOLUTION AND THE DARK SECTOR: A PFS SSP FOR THE SUBARU TELESCOPE

THE SUBARU PRIME FOCUS SPECTROGRAPH (PFS) COLLABORATION
The full list of members can be found in the Appendix

ABSTRACT

We propose a large-scale survey with PFS to address fundamental and important questions in the dark sector (dark matter and dark energy) with significant implications for cosmology, galaxy evolution and the origin of the Milky Way Galaxy. The unique wide-field and massively-multiplexed spectroscopic capability of PFS will maintain and strengthen Subaru's world-leading role in cosmology and astronomy for the next decade. Our experienced team of Japanese and international astronomers has developed an ambitious 360 night survey to be undertaken over 5 years which fully exploits the unique capabilities of PFS to address outstanding questions relating to the history and fate of the Universe as well as the physical processes and role of dark matter in governing the assembly of galaxies including our Milky Way. We commit to fully reducing the data from this landmark survey and making it available to the global astronomical community in a timely manner.

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PFS SSP TEAM

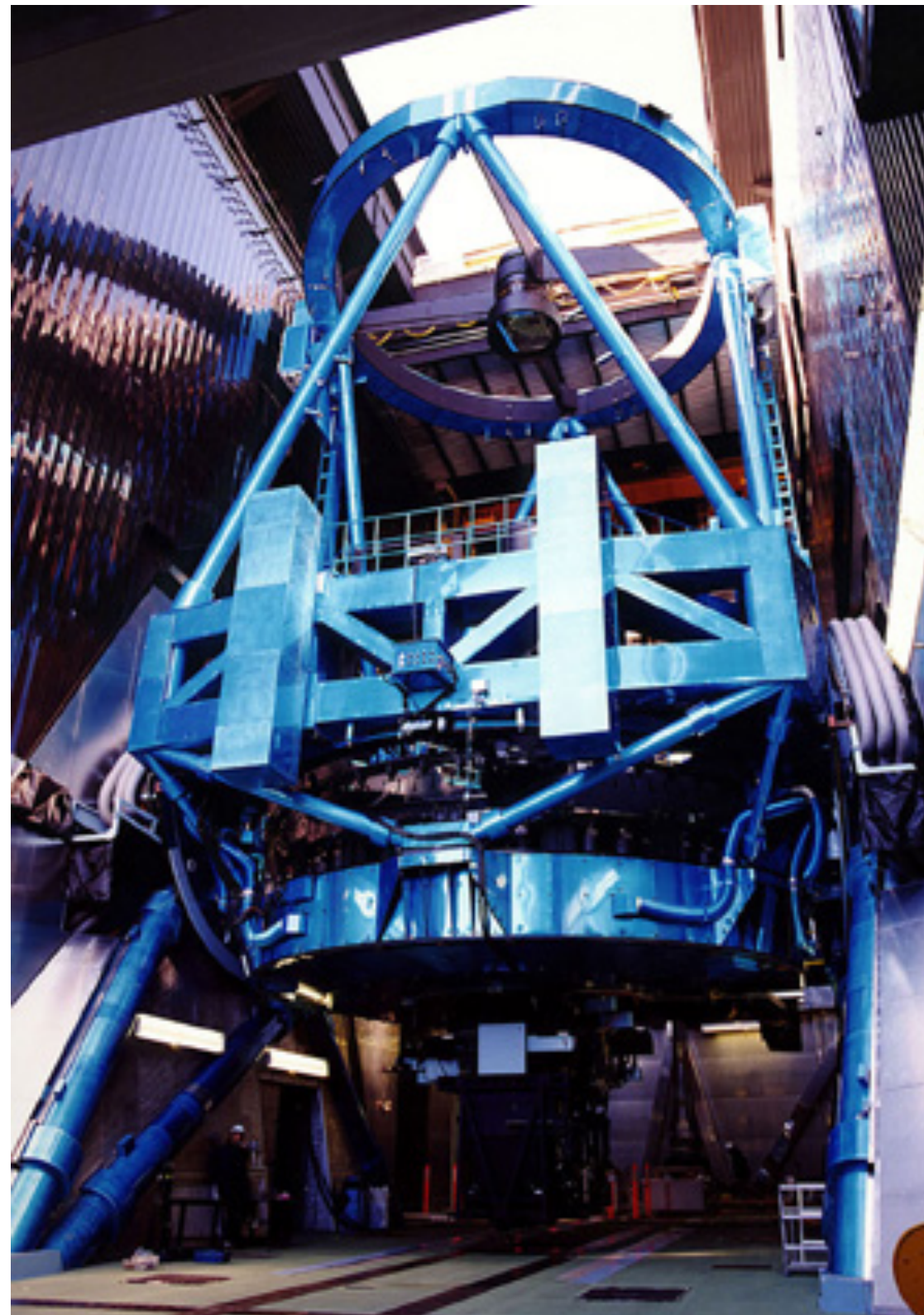
	Testing Λ CDM	Assembly history of galaxies	Importance of IGM
CO	<ul style="list-style-type: none"> • Nature & role of neutrinos • Expansion rate via BAO up to $z=2.4$ • PFS+HSC tests of GR 	<ul style="list-style-type: none"> • PFS+HSC synergy • Absorption probes with PFS/SDSS QSOs around PFS/HSC host galaxies 	<ul style="list-style-type: none"> • Search for emission from stacked spectra
GA	<ul style="list-style-type: none"> • Curvature of space: Ω_K • Primordial power spectrum 	<ul style="list-style-type: none"> • Stellar kinematics and chemical abundances – MW & M31 assembly history 	<ul style="list-style-type: none"> • dSphs as relic probe of reionization feedback • Past massive star IMF from element abundances
GE	<ul style="list-style-type: none"> • Nature of DM (dSphs) • Structure of MW dark halo • Small-scale tests of structure growth 	<ul style="list-style-type: none"> • Galaxy-halo connection: M_*/M_{halo} • Outflows & inflows of gas • Environment-dependent evolution 	<ul style="list-style-type: none"> • Physics of cosmic reionization via LAEs & 21cm studies • Tomography of gas & DM

Accepted in October this year!

PFS operation at Subaru Telescope


Being involved in the open-use operation of PFS as a member of the observatory staff

Subaru Telescope operation



PFS call for proposals

(Page 1)

	Subaru Telescope National Astronomical Observatory of Japan	Semester <u>S23X</u> Proposal ID <u>PROPIDTMP</u> Received <u>RECEIVETMP</u>
	Application Form for Telescope Time (PFS Classical Programs)	
1. Title of Proposal PFS Normal Test 2023/11/17 a		
2. Principal Investigator Name: <u>kobayakawa</u> <u>naoki</u> Institute: <u>NAOJ</u> Mailing Address: <u>2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan</u> E-mail Address: <u>naoki.kobayakawa@nac.ac.jp</u> Phone: <u>+81-422-34-3512</u>		
3. Scientific Category <u>Nearby Galaxies</u>		
4. Abstract <i>(approximately 200 words)</i>		



Early next year, all the efforts of so many people will finally come to fruition with the start of the science operation!

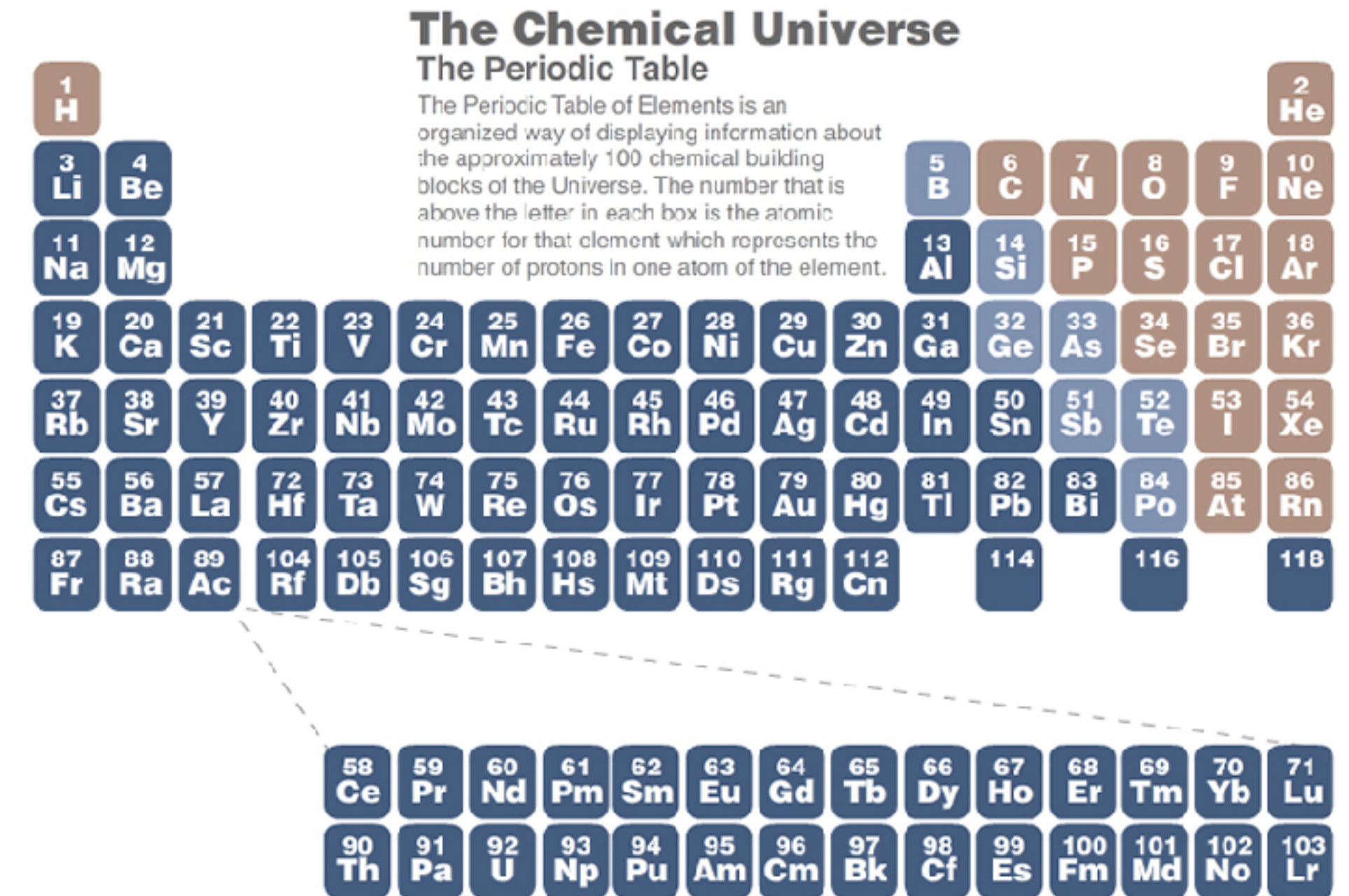
Science with PFS at IPMU

Credit: Chandra X-ray observatory

- 2013: I joined IPMU as a postdoc to do research on nucleosynthesis and chemical evolution of the universe

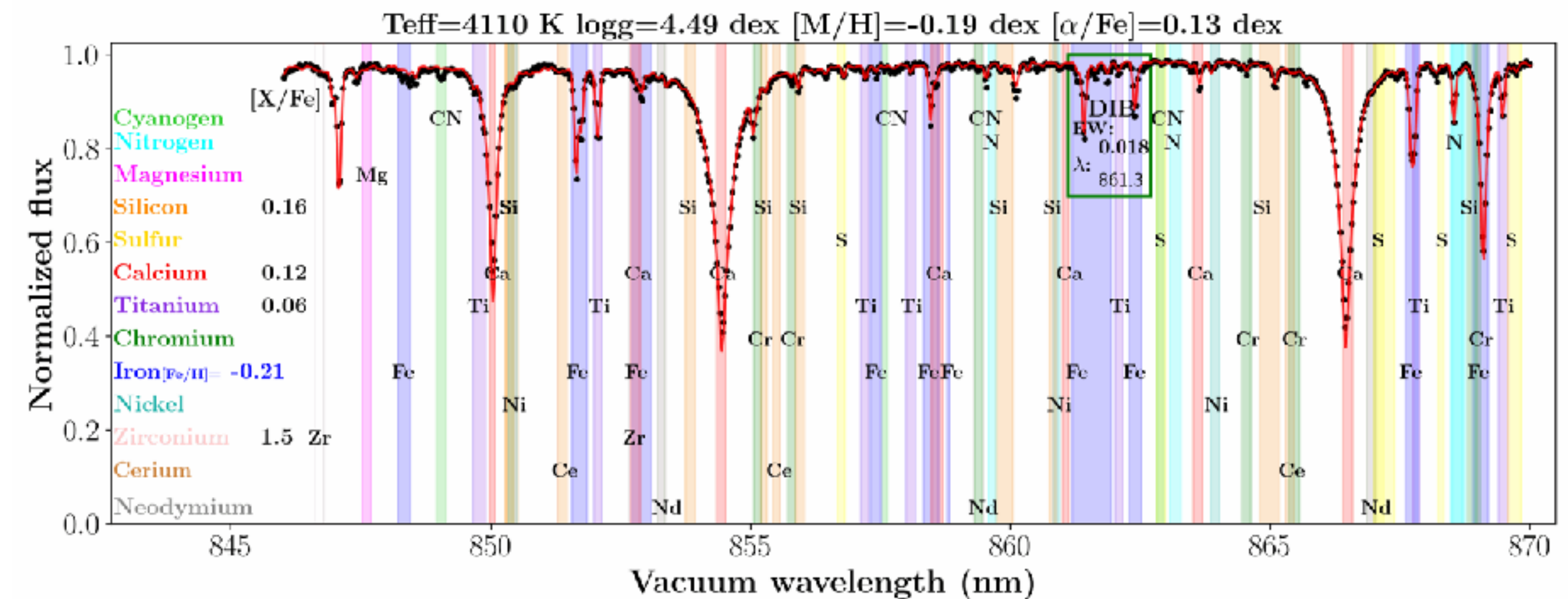


IPMU



It was decided that the PFS will not host a high-spectral resolution mode but only low and medium-resolution mode

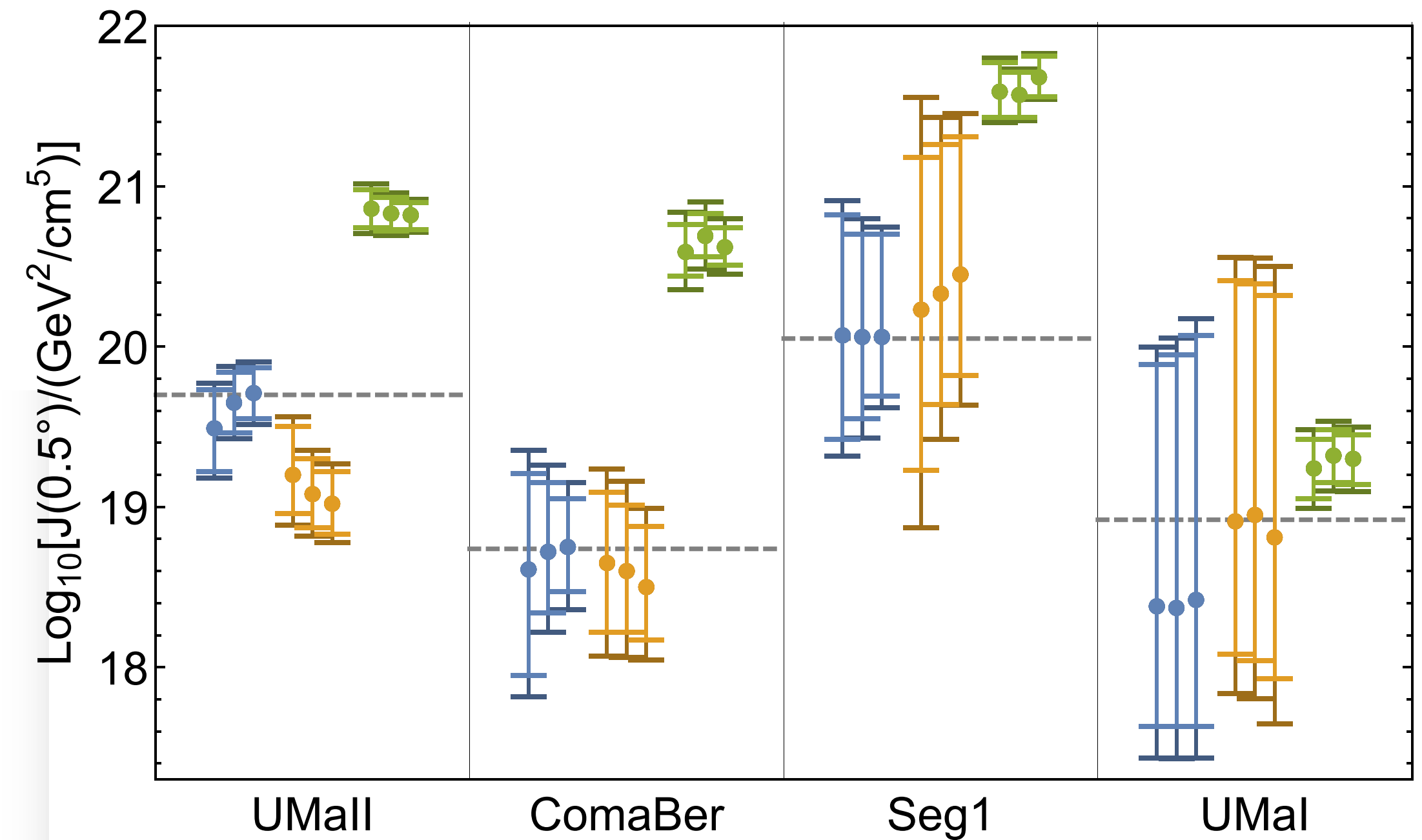
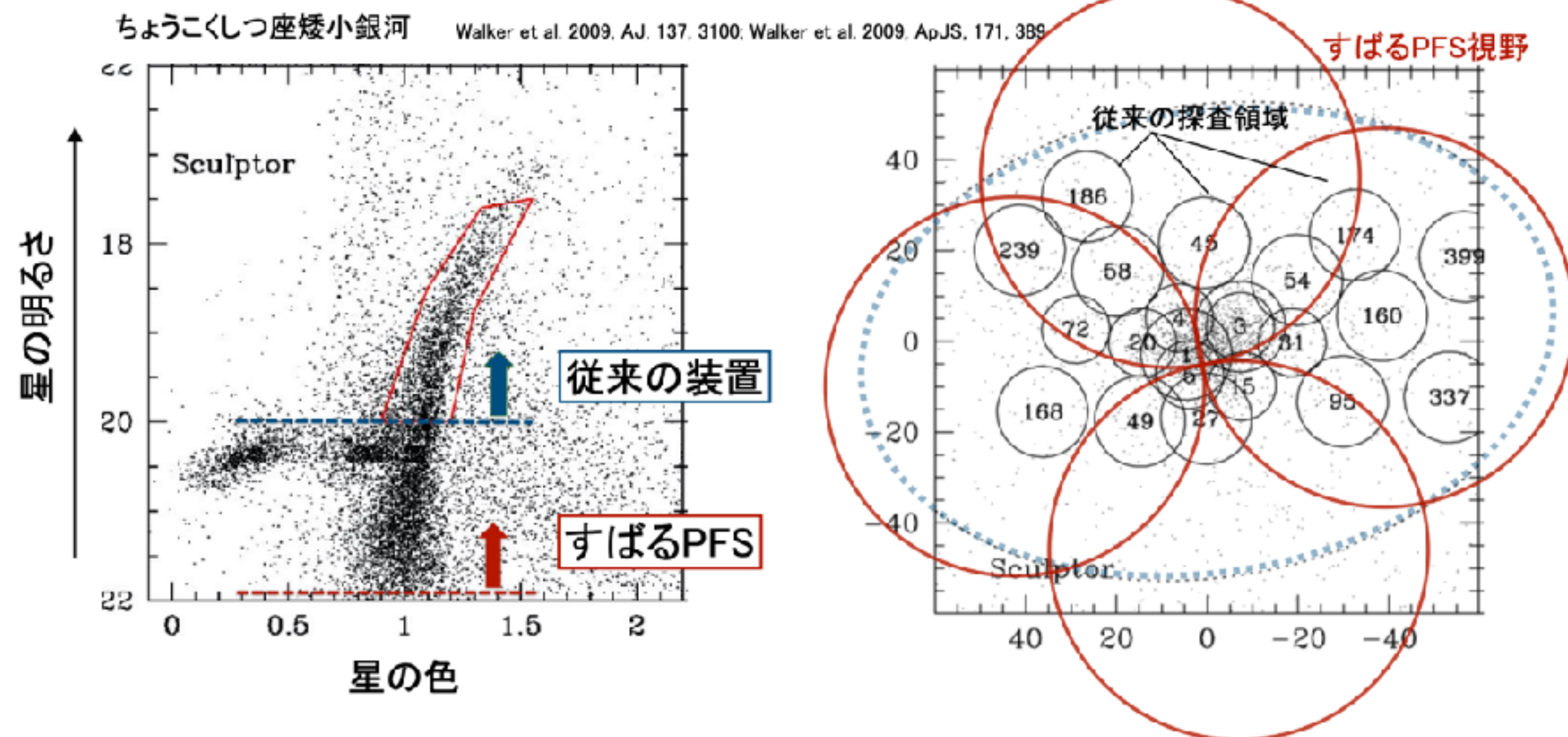
But....



Particle nature of dark matter with PFS medium-resolution mode

😊 Stellar observations with PFS is highly demanded by particle physics

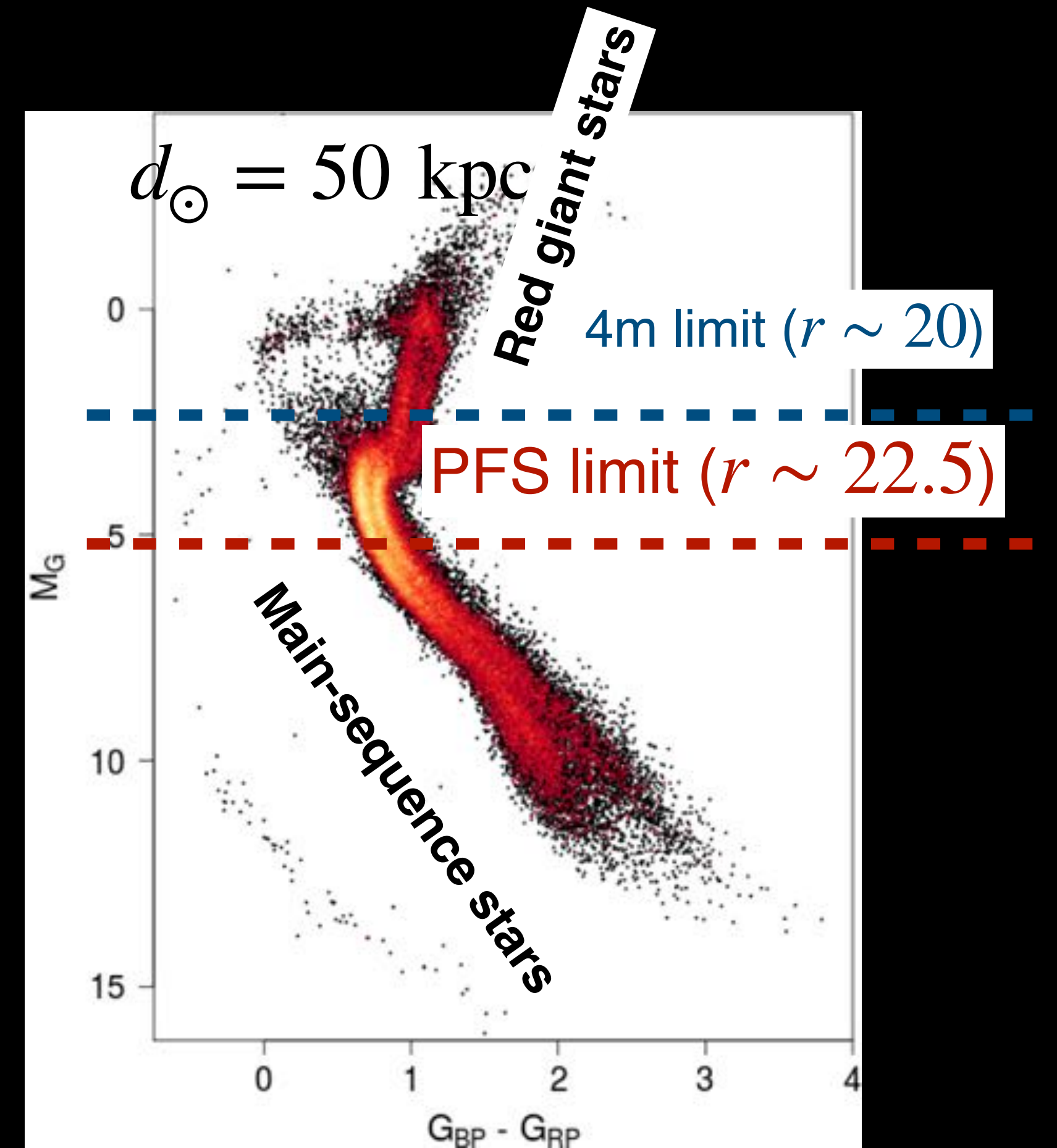
Ichikawa-san, Horigome-san (U-Tokyo grad students) together with Matsumoto-san, Ibe-san and Suga-san



A careful statistical treatment and detailed dynamical modeling of stellar measurements help improve the inference on the dark matter distribution in dwarf galaxies

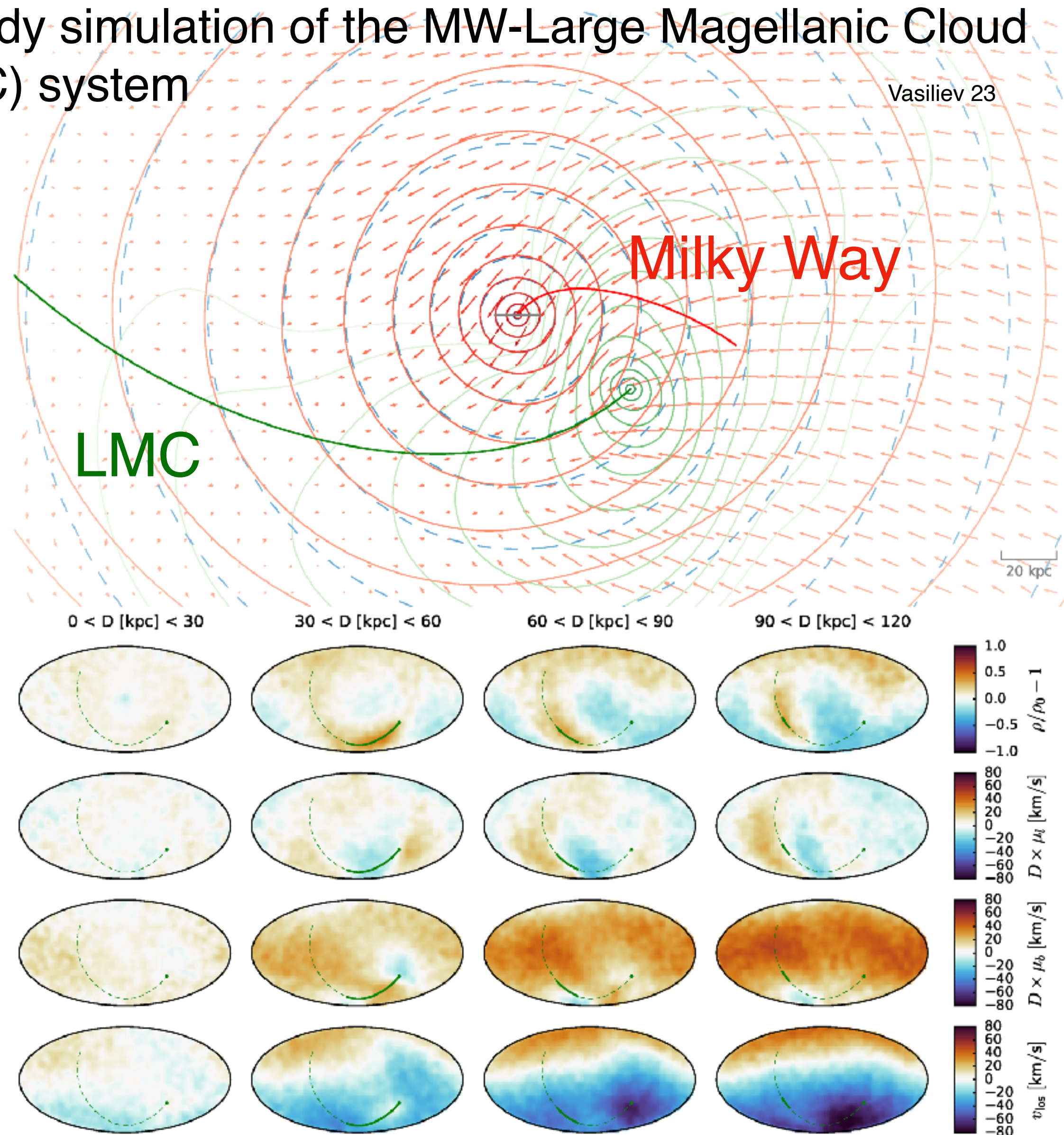
The strength of PFS to study the origin of elements and the formation of our Galaxy

NASA, ESA, and A. Feild (STScI)



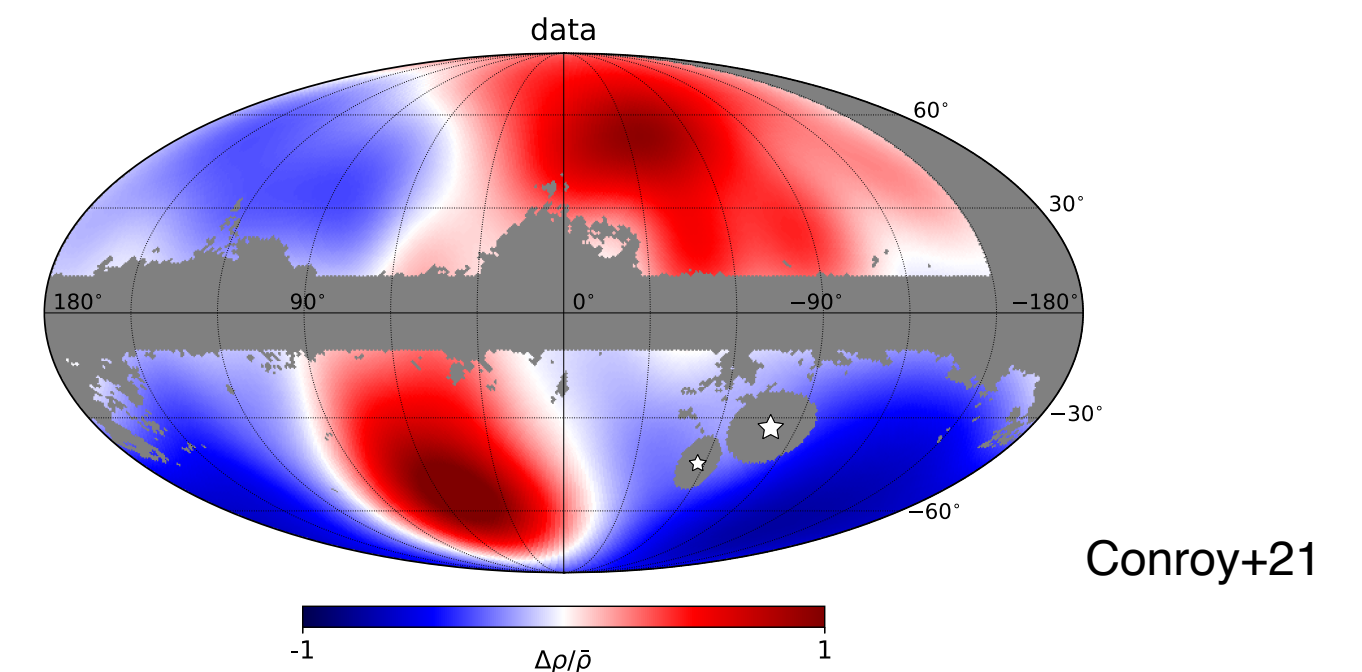
The Galactic dark matter halo in disequilibrium

N-body simulation of the MW-Large Magellanic Cloud (LMC) system



Main findings

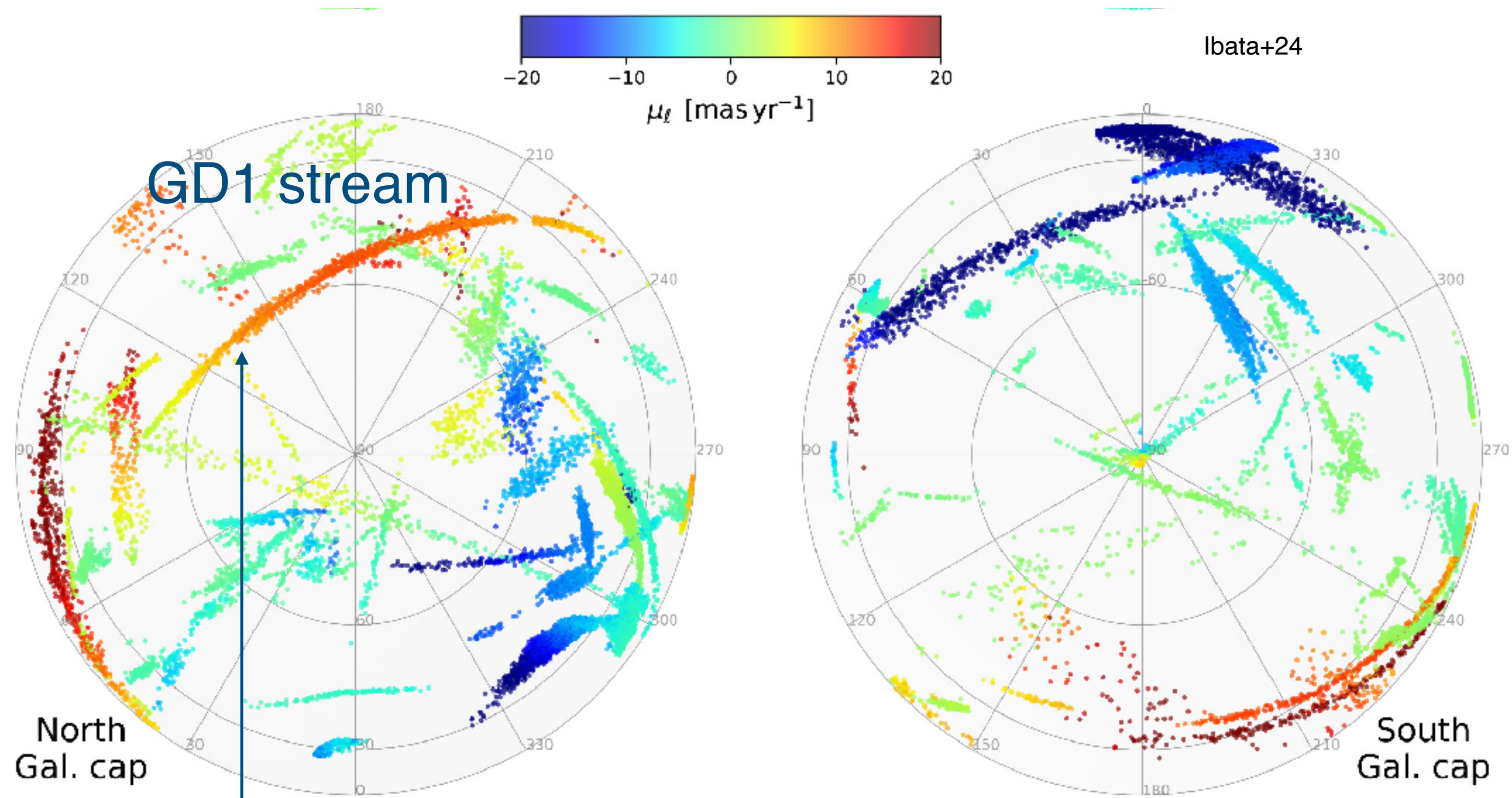
- LMC mass $\sim 1 - 2 \times 10^{11} M_{\odot}$ ($\lesssim 30\%$ of the mass of the Milky Way halo within ~ 50 [kpc]) e.g. Erkal+19
- Possible signatures of the dynamical interactions with LMC



Open questions

- Only small samples of stellar kinematics in the outer halo through luminous stars are available
- Not clear the reported signature is due to the LMC or other substructures

Many stellar streams, some show gap / over-density

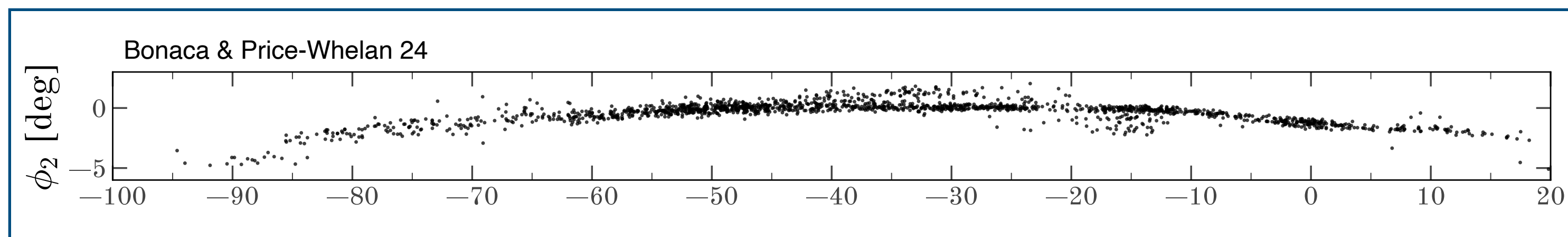


Main findings

- Stream members robustly identified by Gaia proper motion and parallax combined with wide-field photometry
- Detailed structures (over-/under-density, “spur”) revealed

Open questions

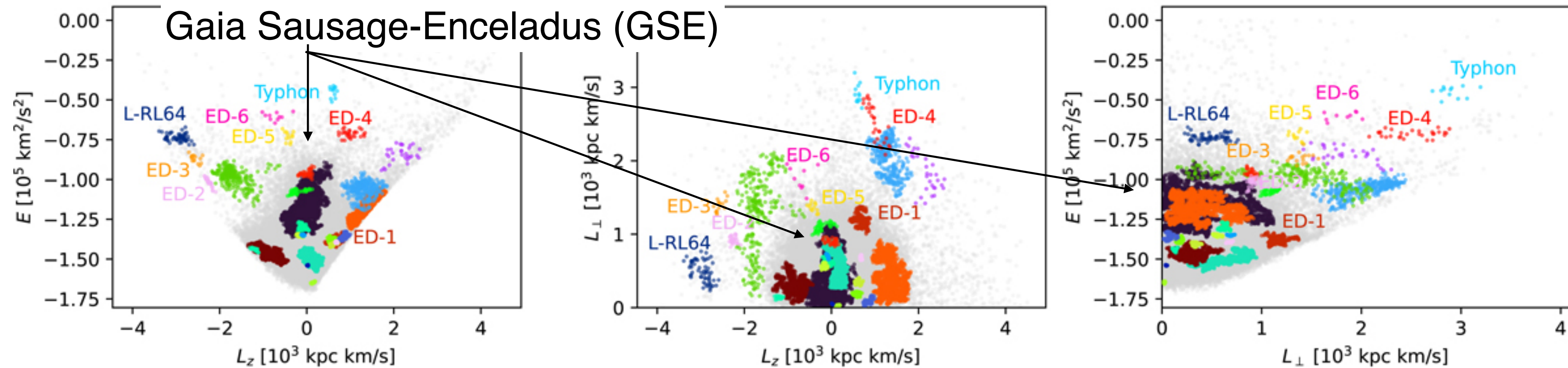
- The origins of each structure remain unclear
 - Dark matter subhalo interaction
 - Time-varying ejection of stars



Clustering in phase space + chemical abundance

Dodd+23

Detecting stars with common origins that are not spatially coherent

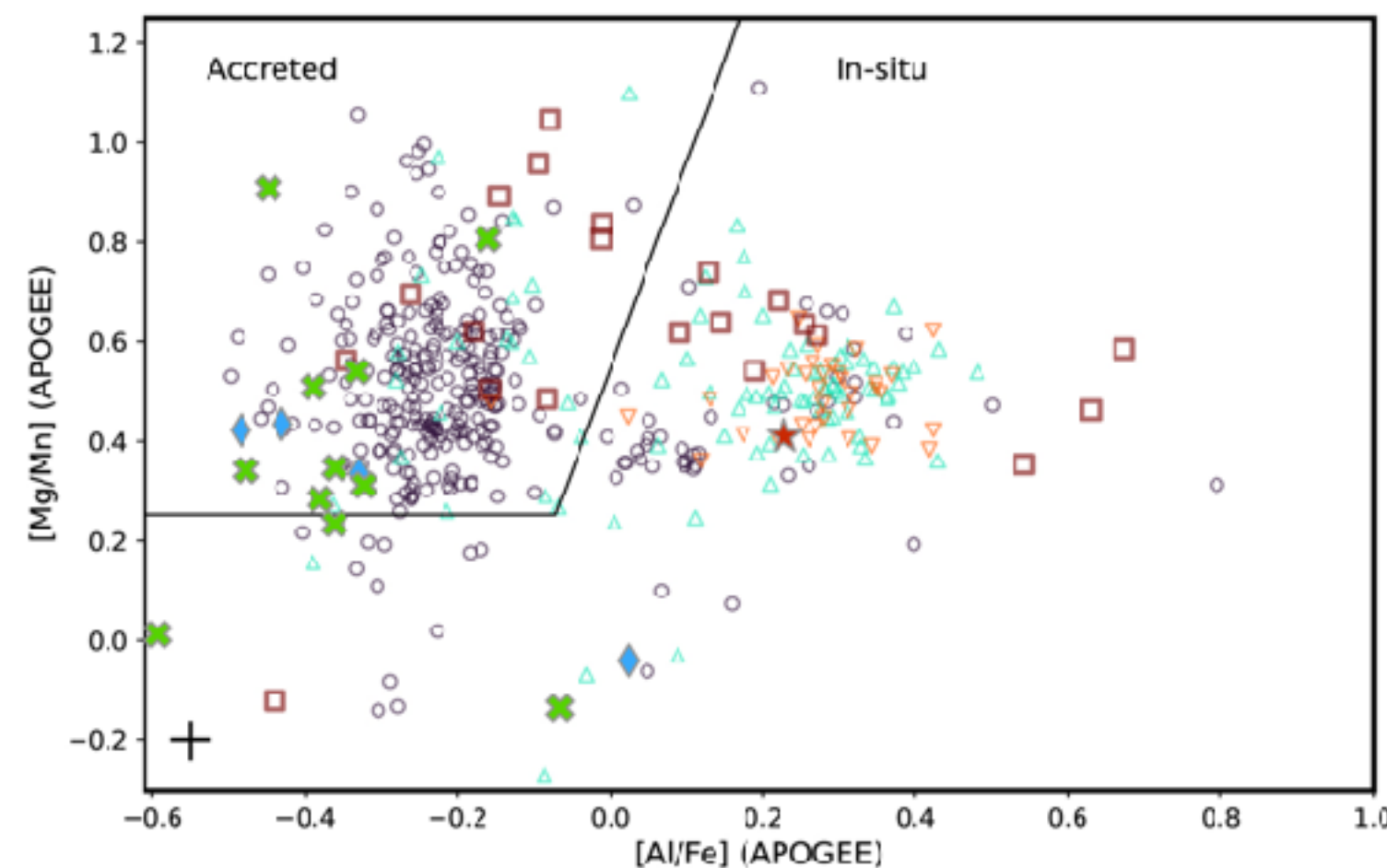


Main findings

- Inner halo is almost dominated by the debris of a single massive dwarf galaxy accreted ~ 10 billion years ago (GSE)

Open questions

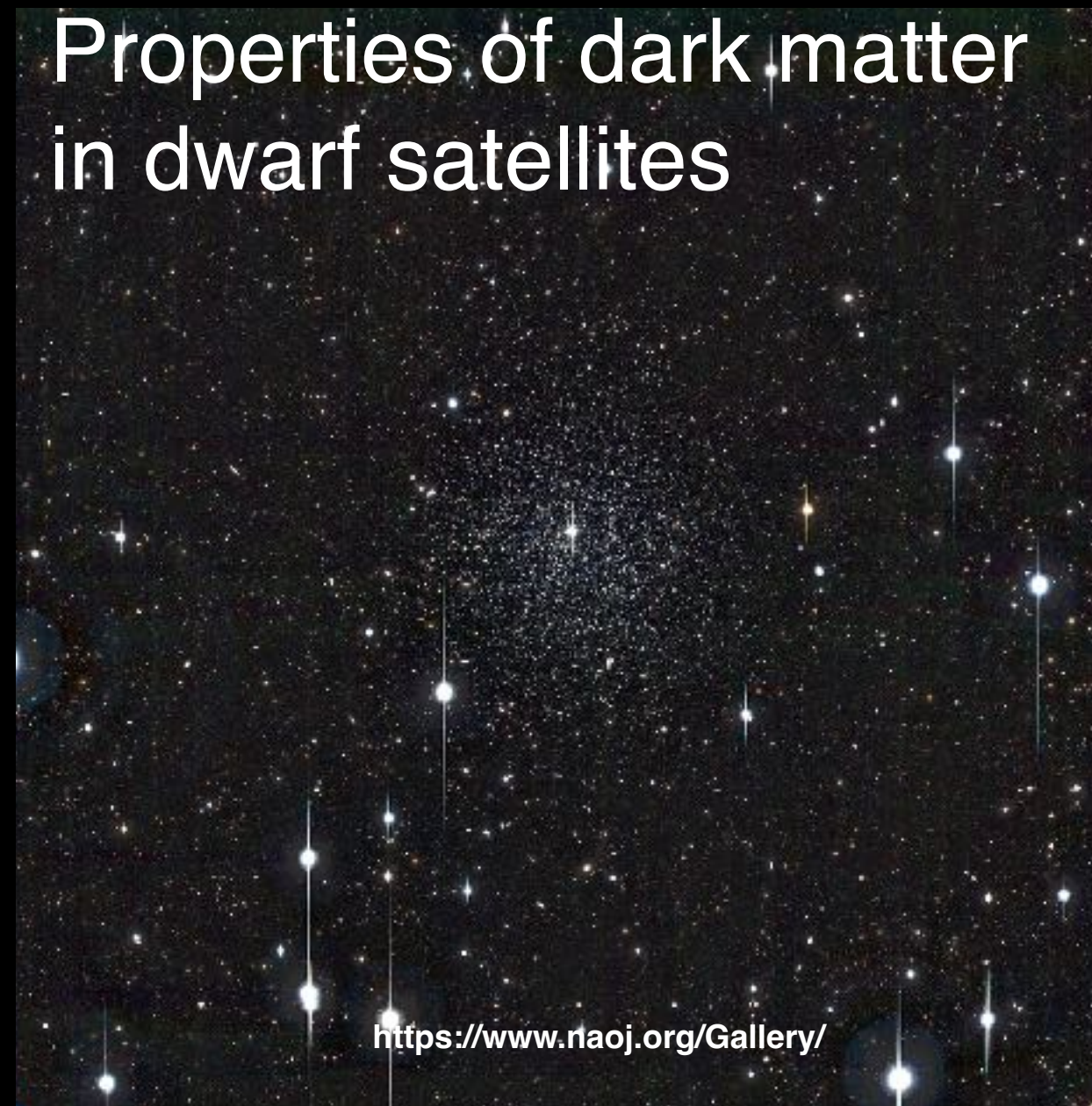
- Can we reconstruct the mass spectrum of accreted dwarf galaxies?
- Are the abundant substructures also seen beyond the inner halo?



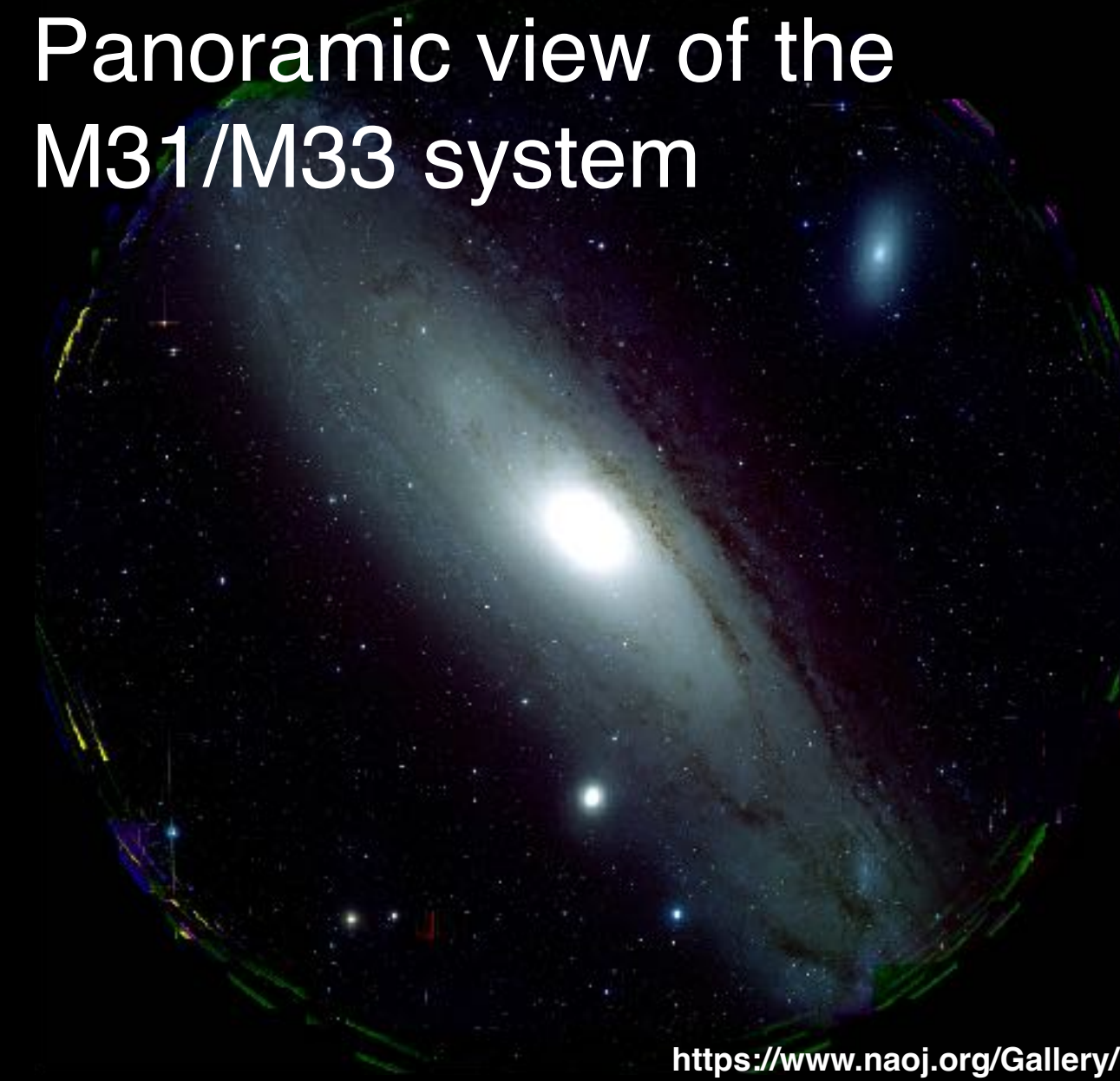
PFS Galactic Archaeology survey will start early next year!

M. Chiba, R. Wyse, E. Kirby, PFS GA science working group

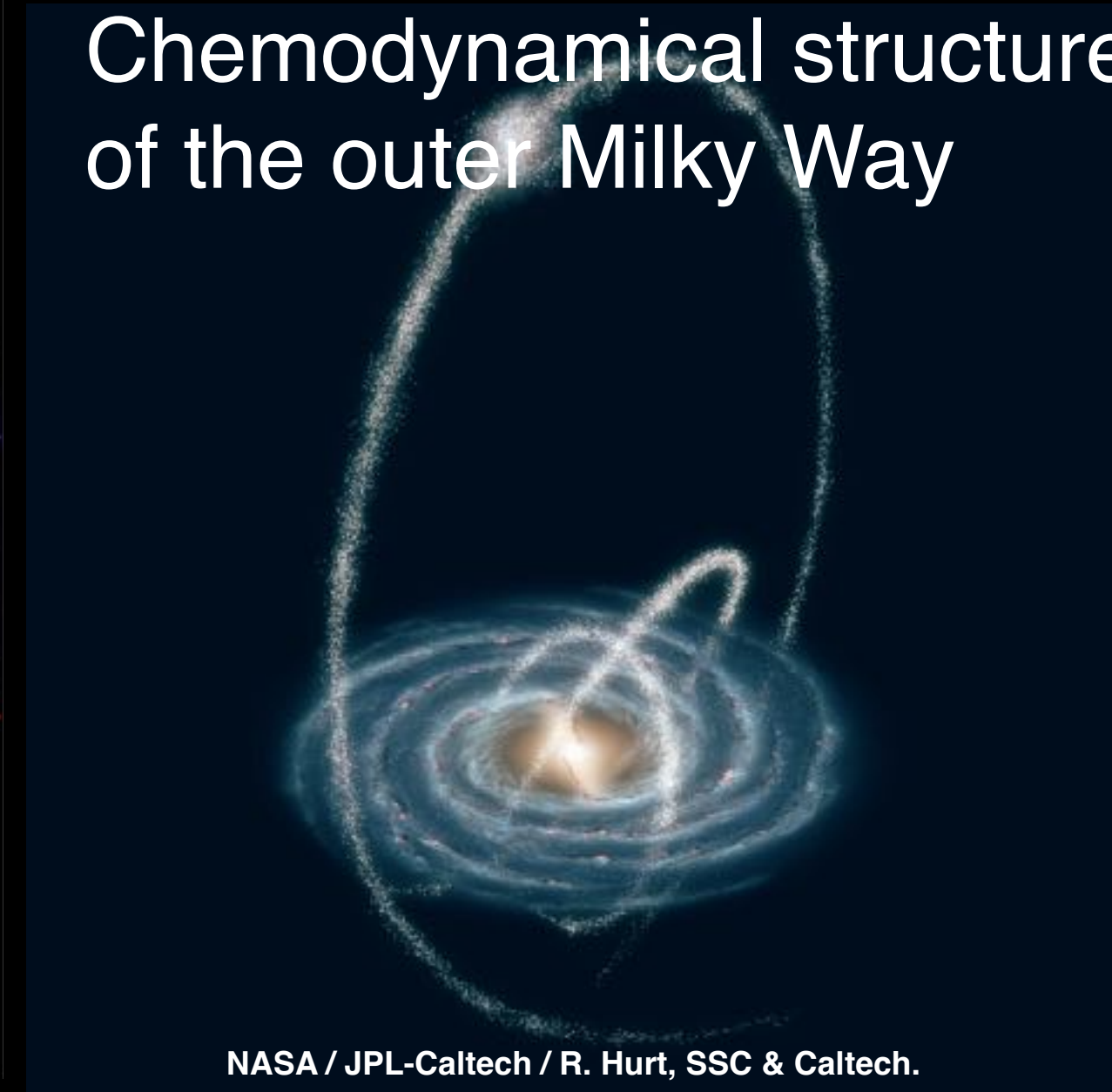
Properties of dark matter
in dwarf satellites



Panoramic view of the
M31/M33 system



Chemodynamical structure
of the outer Milky Way



The PFS SSP (すばる戦略枠) proposal (360 nights over 5 years) accepted

➔ ~120 nights will be used for observations of stars

Conclusion

👍 The PFS is one of **the most powerful instruments** to better understand the nature of dark matter and the origin of elements through stellar observations.

🌸 *I deeply appreciate Hitoshi's efforts in initiating and leading the PFS project, as well as providing an ideal research environment and opportunities for young researchers.*