Spectroscopic Study of Stars and Exoplanets using the Future Korean Large Spectroscopic Survey

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01.22.2025
우주탐사워크숍 / 정선

PRESENTATOR: SOUNG-CHUL YANG
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Where we start?
We, Astronomers always start from a question.

Q. Why do we need our own large survey telescope?
Q. What kind telescope?
Q. What we can do with this?

“

Motivation

Why we need KLST?

Telescope Spec

What kind of telescope?

Key Science

What can be done?

“ To find our motivation we need to look back …

The Most Successful Large Spectroscopic Survey Programs Past & Current

- Works achieved & still missing

The Most Successful Large Spectroscopic Survey Programs for Stellar Astrophysics

- **APOGEE** (**A**pache **P**oint **O**bservatory **G**alactic **E**volution **E**xperiment) under SDSS III/IV
- **Gaia**-ESO Survey
- **LAMOST** (**L**arge Sky **A**rea **M**ulti-**O**bject Fiber **S**pectroscopic **T**elescope) Experiment
- **RAVE** (**RA**dial **V**elocity **E**xperiment)
- **GALAH** (**Gal**actic **A**rchaeology with **H**ERMES) Survey
- **H3** (**H**ectochelle in the **H**alo at **H**igh Resolution) Stellar Spectroscopic Survey
- **S**outhern **S**tellar **S**tream **S**pectroscopic **S**urvey (S^5)

Survey Name	Main Mirror Size	Field of View	Spectral Resolution	Wavelength Coverage	Operation Period
SDSS / APOGEE	2.5 m	7 sq. deg	High (R ~ 22,500)	1.5–1.7 µm (NIR)	2000–present (APOGEE: 2011–present)
Gaia-ESO Survey	8.2 m (VLT)	~0.16 sq. deg	Medium-High (R ~ 20,000/47,000)	480–680 nm (optical)	2012–2018
LAMOST	4 m	20 sq. deg	Low-Medium (R ~ 1,800/5,000)	370–900 nm (optical)	2012–present
RAVE	1.2 m (AAO UKST)	6 sq. deg	Medium (R ~ 7,500)	840–880 nm (NIR)	2003–2013
GALAH	3.9 m (AAT)	~2 sq. deg	High (R ~ 28,000)	470–790 nm (optical)	2013–present
H3 Survey	6.5 m (MMT)	1 sq. deg	Medium-High (R ~ 32,000)	515–675 nm (optical)	2017–present
S^5 Survey	4 m (AAO UKST)	~3 sq. deg	Medium (R ~ 7,500)	370–880 nm (optical)	2018–present

Short Descriptions and Key Sciences of the Listed Survey Programs

Survey Name	Key Sciences	Number of Targets Observed	Limiting Magnitude
SDSS / APOGEE	Galactic archaeology, chemical abundances, and kinematics of Milky Way stars	Over 500,000 stars	$H \sim 12.2$ (bright stars)
Gaia-ESO Survey	Galactic structure, star formation history, and stellar populations	~115,000 stars	$V \sim 19$
LAMOST	Stellar astrophysics, Galactic evolution, and star cluster studies	Over 10 million stars	$r \sim 18.5$
RAVE	Galactic kinematics, radial velocities, and chemical abundances	~500,000 stars	$I \sim 12$
GALAH	Chemical tagging, Galactic archaeology, and stellar abundances	Over 500,000 stars	$V \sim 14$
H3 Survey	Milky Way halo structure, stellar streams, and dwarf galaxy kinematics	~200,000 stars	$r \sim 18$
S^5 Survey	Stellar streams, Galactic halo dynamics, and dark matter studies	~100,000 stars	$g \sim 20.5$

Further Descriptions for a Couple of Survey Programs …

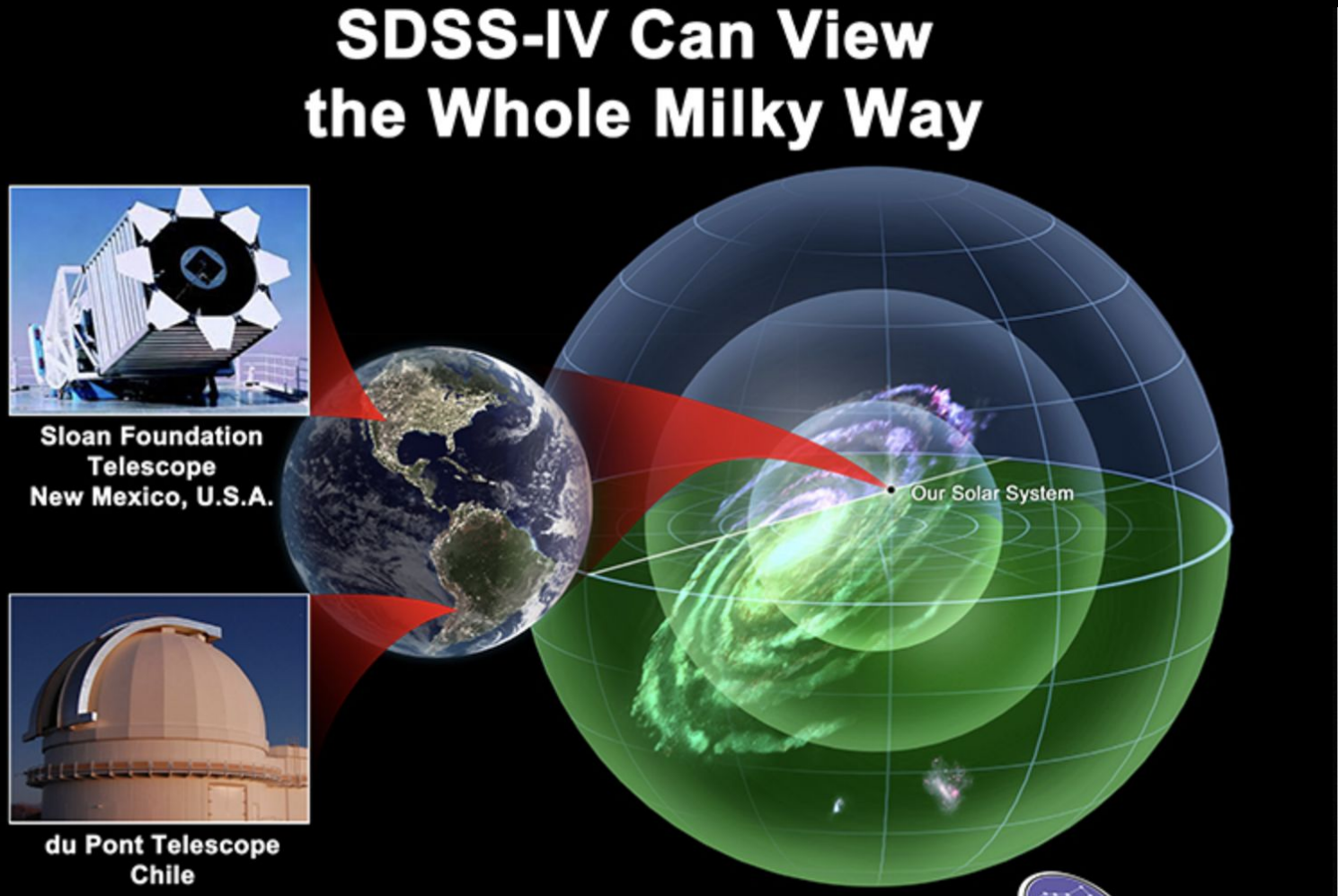
- **A**pache **P**oint **O**bservatory **G**alactic **E**volution **E**xperiment (**APOGEE**) under SDSS III/IV

- **Gal**actic **A**rchaeology with **H**ERMES (**GALAH**)

APOGEE under SDSS III & IV







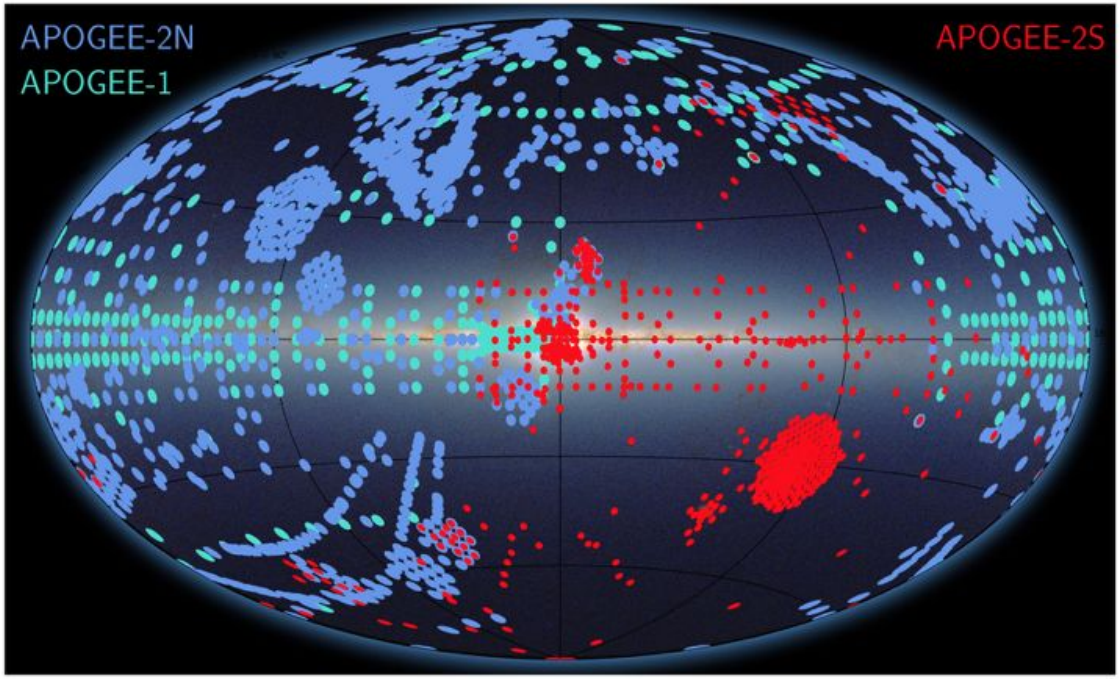
2.5m Telescopes @North/South

APOGEE under SDSS III & IV

⇨ Under SDSS III **APOGEE 1** observed ~ 180,000 RGBs in the MW disk within a few kpc

⇨ In SDSS IV **APOGEE 2** published atmospheric parameters and abundances of ~ 800,000 stars across the entire sky

Apache Point Observatory Galactic Evolution Experiment (APOGEE)

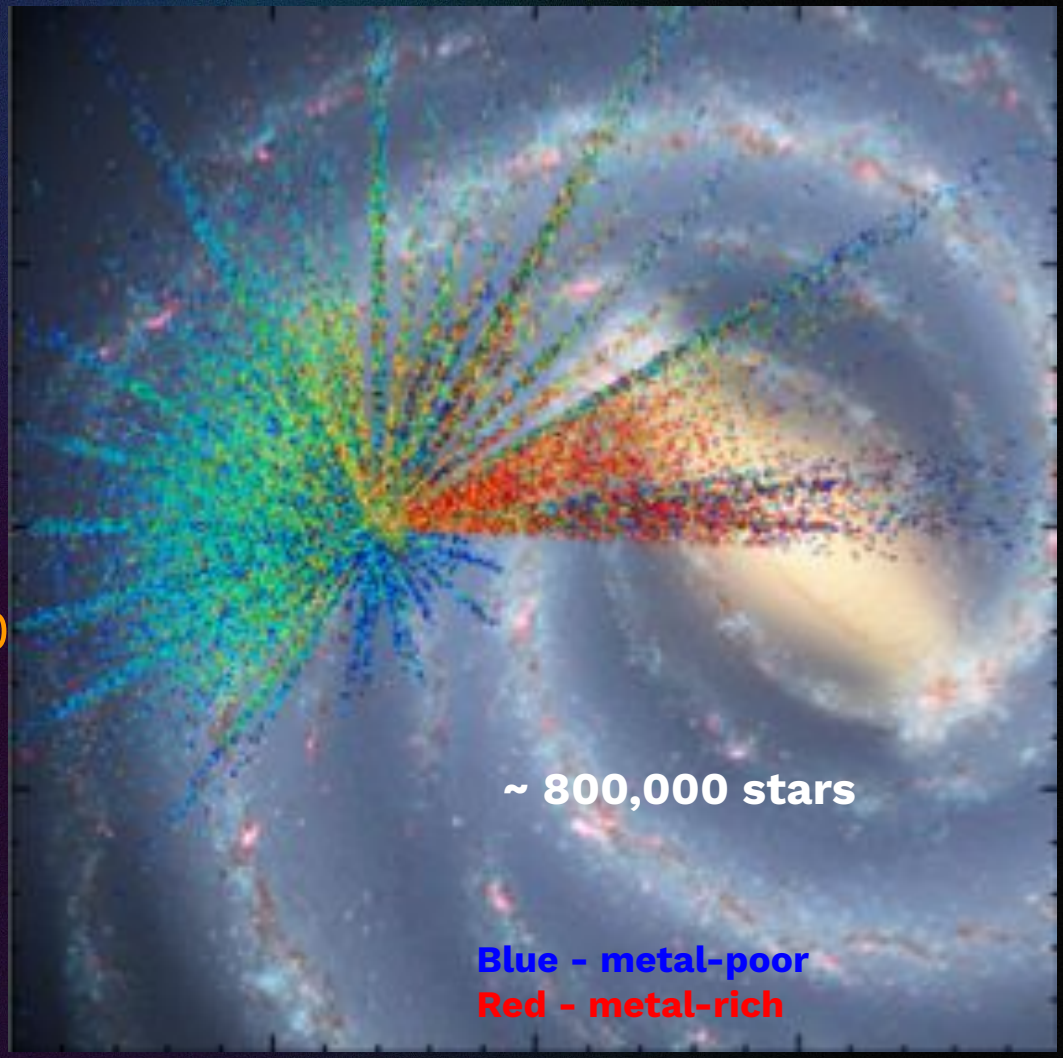


Facillity/Instruments	SDSS
Aperture	2.5 m
Multiplex	300
Survey Period	2014~2021
Resolution	22,500
FOV	7 deg^2, 2.8 deg^2

Wavelength Range : 1.51 - 1.76 um

APOGEE under SDSS III & IV

APOGEE is unique among the large spectroscopic surveys because it observes stars in the near-infrared, specifically from 1.5 to 1.7 micron with the resolving power of R ~ 22 50 which allows it to reach the dust-obscured regions of the Milky Way in the disk, center, and bulge.



APOGEE Key Sciences

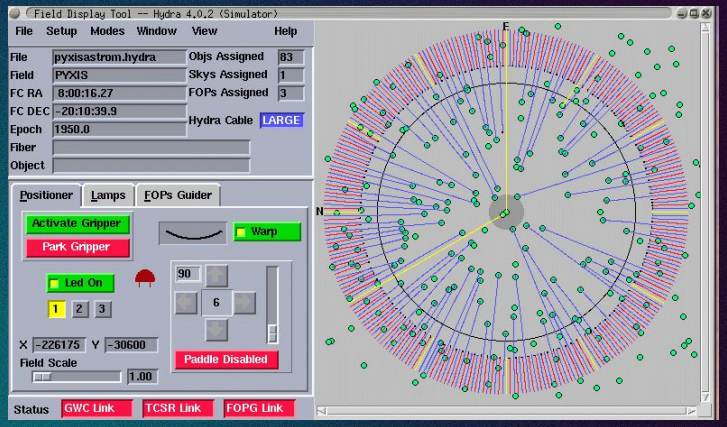
- The SDSS/APOGEE reveals a galaxy criss-crossed by long **streams of stars**, each associated with a former satellite galaxy that has since been absorbed into the Milky Way

- APOGEE measures the **abundance of multiple elements** in each of hundreds thousands of stars across the Galaxy. The chemistry of stars encodes information about the gas from which they formed, and this gas is enriched in different elements in a variety of astrophysical environments

Galactic Archaeology with HERMES (GALAH)

2dF fiber positioner at the 3.9m Anglo-Australian Telescope

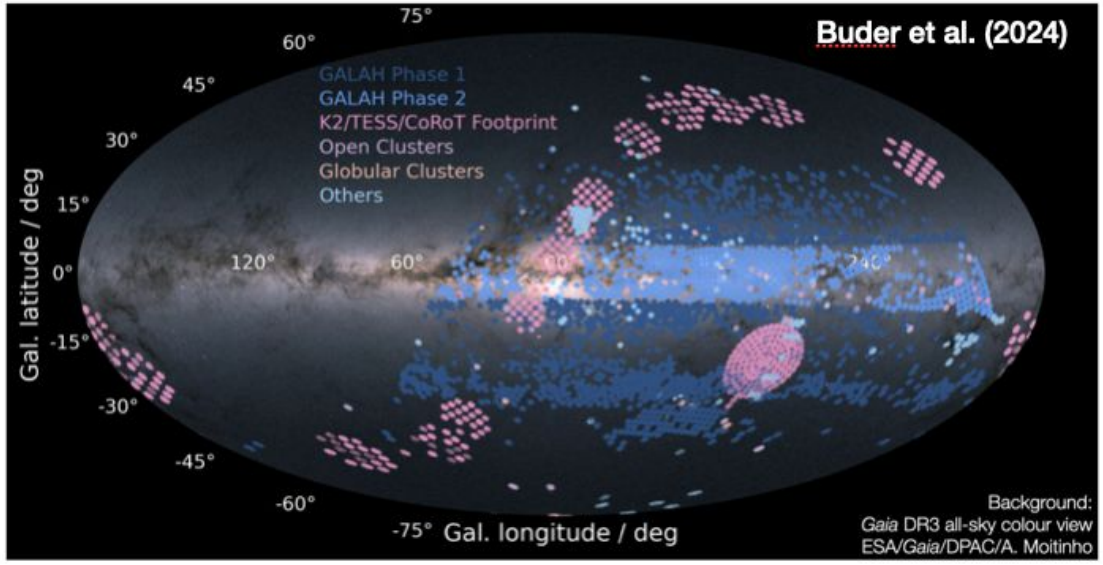


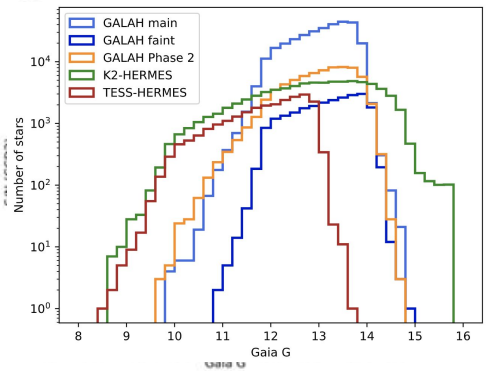




Galactic Archaeology with HERMES (GALAH)

GALactic Archaeology with HERMES (GALAH survey)





Facillity/Instruments	AAT/Galah
Aperture	4m
Multiplex	~390
Survey Period	2013~2023
Resolution	28,000
FOV	2 degree

Band	λ_{min} (nm)	λ_{max} (nm)
Blue	471.8	490.3
Green	564.9	587.3
Red	648.1	673.9
IR	759.0	789.0

GALAH Key Sciences

- **Dissection of the stellar discs**
  GALAH has found evidence for **differing abundance trends between the thin and thick disc** as well as with metallicity and age (Buder *et al.* 2018, Duong *et al.* 2018).
  Nearly 40% of stars in the solar vicinity have metallicities higher than the local ISM. This has an implication that **radial migration** is an important process in the evolution of disk galaxies.

- **Lithium**
  The ability to measure the **lithium abundance** of stars is a **key capability of the GALAH** survey.Many researchers have used GALAH to investigate too long-standing problems related to lithium: dwarf stars with too little lithium; and giant stars with too much lithium.

Most Frequently Mentioned Key Words in the Key Sciences of these survey programs

Chemical Abundance (or Chemical Tagging)

Star Formation History

Stellar Kinematics

Galactic Structures & Stellar Streams

Mapping the Sky

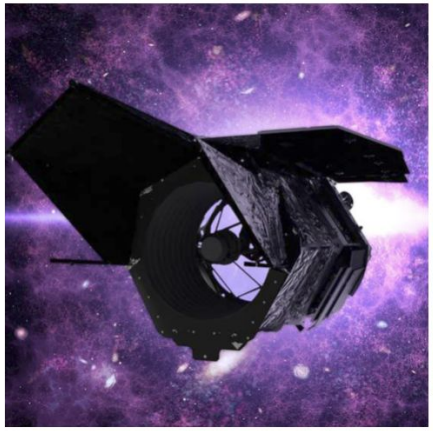
“ To find our motivation

Landscape of Survey Telescopes in the Near Future

What is waiting for us ...



LSST



Roman Space Telescope



SKA project

1.5 billion stars down to the Gaia magnitude G~ 21 from Gaia

17 billion stars down to R~ 27.5 from the Rubin LSST

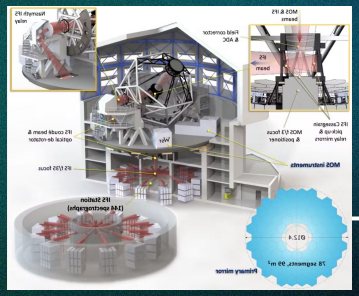
Existing facilities with spectroscopic capability cannot follow up on faint o bjects (G > 17) from Gaia or upcoming surveys like LSST, RST, and SKA.

Spectroscopic measurements will be limited to much brighter stars (G < ~17 mag).

For IGRINS (R~45,000) @ Gemini Telescope (8m)
2400~3600s exposure time is required/one source with G_{Gaia}=17 mag to get S/N~100

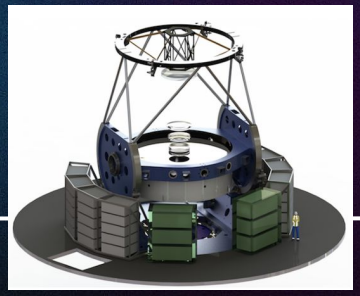
The demand for a wide-field MOS on larger telescopes

Relevant Future Telescopes for Spectroscopic Surveys



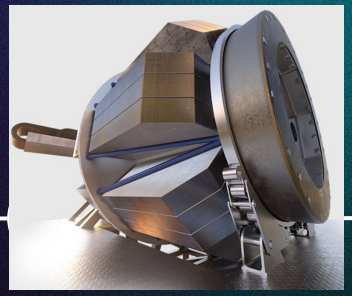
WST

12m Wide-field Spectroscopic Telescope



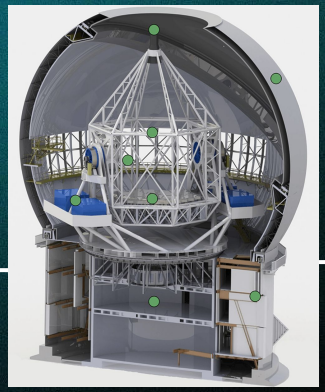
MegaMapper

6.5m Magellan-like Telescope



ELT/MOSAIC

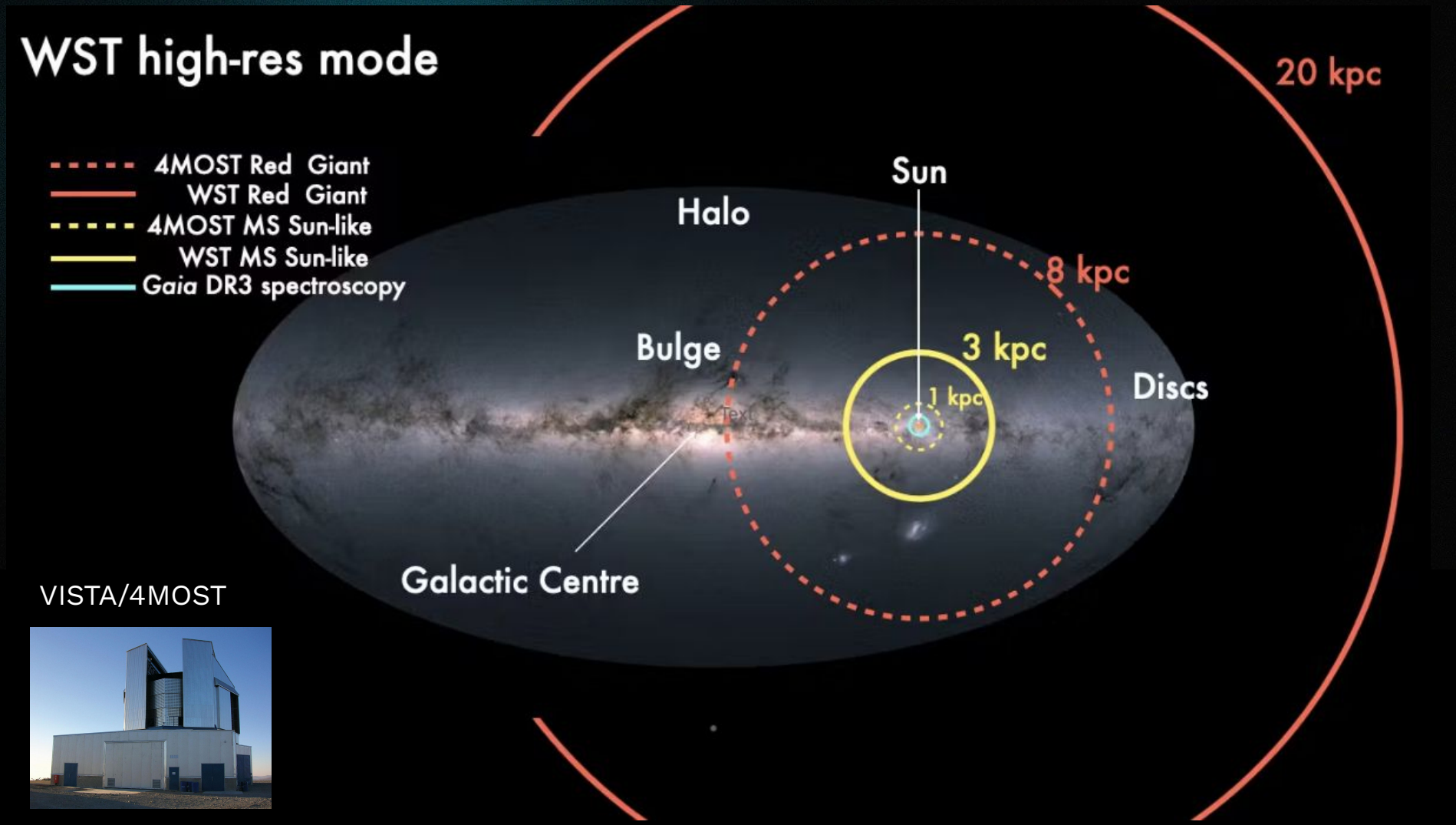
39m Primary mirror Telescope with



MSE

10m Maunakea Spectroscopic Explorer Telescope

Volume Coverage Comparison



VISTA/4MOST

Facility/Instrument	First light	Aperture (M1 in m)	Field of View (sq. deg)	Etendue	Multiplexing	Wavelength coverage (μm)	Spectral resolution	Dedicated facility
TMT/WFOS	2030+	30	0.007	4.9	80	0.30-1.0	1500-3500	No
VLT/FLAMES-GIRAFFE	2002	8.2	0.14	7.4	132	0.37-0.95	5000-38000	No
VLT/MOONS	2024	8.2	0.14	7.4	1000	0.65-1.8	4000-6000	No
						3 windows	9000-18000	
ELT/MOSAIC	2030+	39	0.009	10.7	200	0.39-1.80	5000	No
					100	windows	20000	
WHT/WEAVE	2022	4	3.14	39.5	1000	0.37-1.00	5000	Yes
						3 windows	20000	
GMT/MANIFEST	2030+	25.4	0,09	45.5	250	0.35-0.95	2000-6000	No
VISTA/4MOST	2024	4	4.2	52.8	1600	0.37-0.95	4000-8000	Yes
					800	3 windows	18000-20000	
Subaru/PFS	2024	8.2	1.25	65.9	2400	0.38-1.26	2000-5000	No
Mayall/DESI	2019	4	7.1	89.2	5000	0.36-0.98	4000	Yes
MSE-QM	2030+	11.25	1.5	149	20000	0.36-1.8	3000	Yes
						0.36-0.95	6500	
						3 windows	30000	
MUST	2030+	6.5	5	166	10000	0.36-1.0	2000-4000	Yes
MegaMapper	2030+	6.5	7.1	235	20000	0.36-0.98	4000	Yes
WST	2030+	12	3.1	350	20000	0.37-0.97	4000	Yes
					2000	windows	40000	

Mainieri et al. (2024) - WST White Paper

Preliminary Requirements For KLST Spec

Telescope Preference	1 x 10m
Magnitude Limit	-
Survey Area	Southern Sky
Field of View	3 deg x 3 deg (MOS) 5 arcmin x 5 arcmin (IFU)
Multiplex	10,000 (0.31 / arcmin^2), 2000
Spectral Range	3,400-8,000 A, 11,000-16,500 A
Spectral Resolution	4000 (low), 40,000-50,000 (High)
Signal-to-Noise Ratio	30, 100
Others	Commissioning camera for imaging MOS (main) + IFU (switchable)

Q. How competitive is the KLST compared to other future survey telescopes?

* **NIR coverage** is important

* **High-resolution MOS** would be essential to measure abundances and infer stellar activity in large samples of planet-hosting stars, thus unveiling the role of host-star chemical composition.

* **Low-resolution MOS** is ideal to investigate the properties of dispersed populations and faint objects

Where are the gaps we can squeeze in?

Telescope	NIR Coverage	High Resolution	M1 size	Multiplex
WST	C	A	A	A
MegaMapper	C	C	C	A++
ELT/MOSAIC	A	A	A++	B
MSE	A	A	A	A++
4MOST	C	C	C	BB
KLST	A	A	A	A++

“

Key Science in Stellar Astrophysic using KLST

Key Science 1 : Rubin/LSST/Gaia follow-up

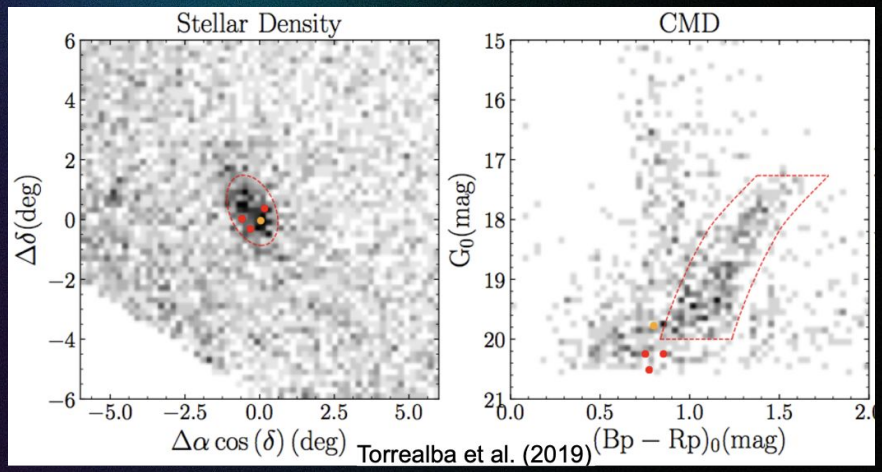
- Spectroscopic observation for isolated/newly discovered dwarf galaxies
- Newly discovered transients/peculiar transients



The Rubin/LSST will observe the entire southern sky every three nights and it will identify about 10 million transients in the southern sky every night.

>> Supernovae, Binaries, Flares, Neutron star mergers, stars being torn by black holes, etc.

Chemical abundances of stellar populations of newly discovered dwarf galaxies is crucial for understanding the MW formation & evolution.



Key Science 2 : Origin of Elements

We do not know the exact stellar sources of all the chemical elements and the timescales these elements are formed.

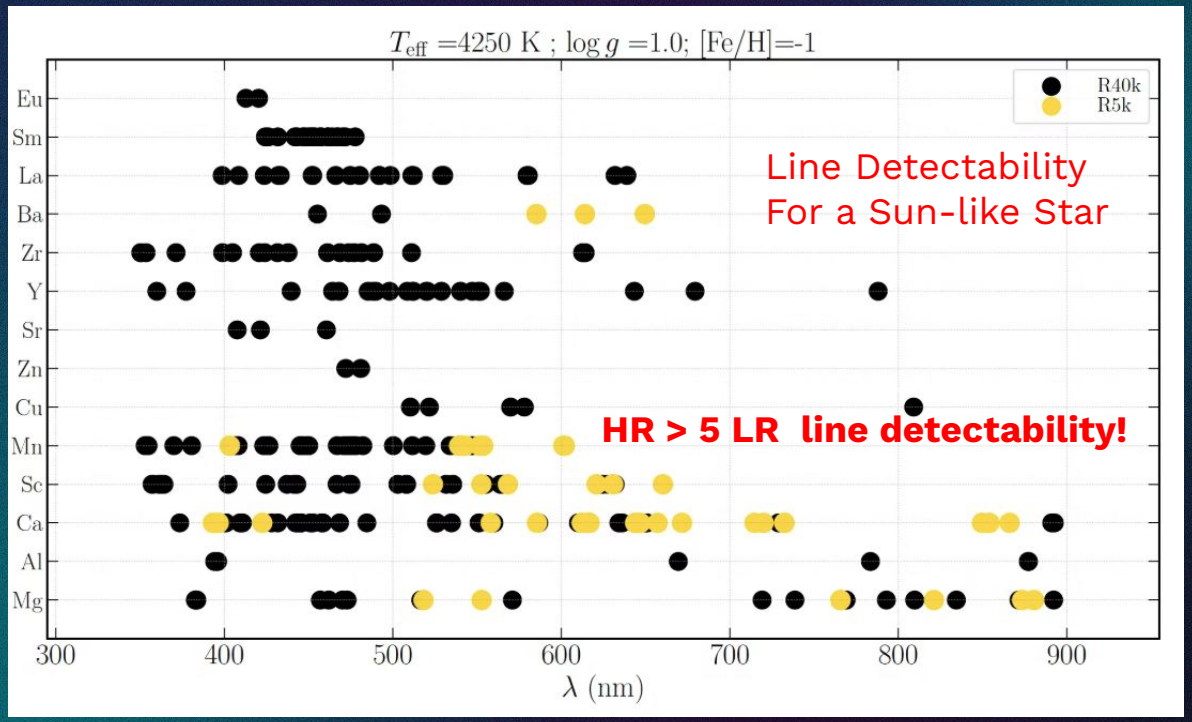
From light to heavy elements

Li : primordial, mainly novae, AGB, massive stars

S-process elements: low mass AGB, rotating massive star, r-process contribution

Europium: mainly NSM, CC SNe

High Resolution is essential to detect elements of all kind!

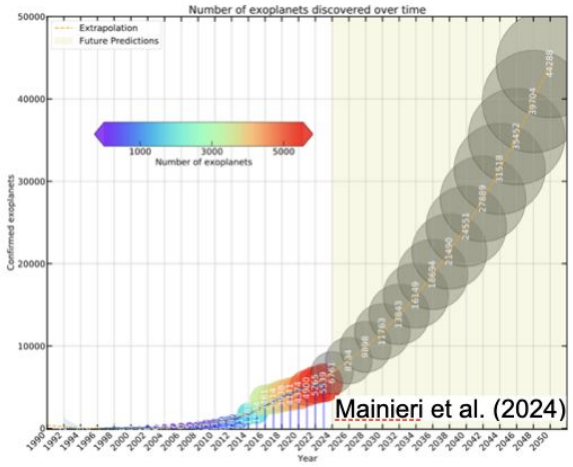


Abundance ratios are sensitive to **age** thus can be used **"chemical clocks"** for significant samples of stars. This ultimately helps us to produce extensive age maps of the Galactic disk.

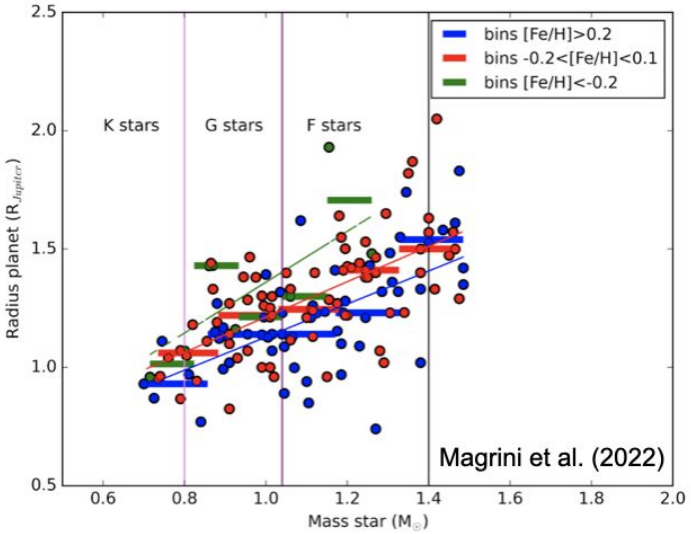
Kordopatis et al. (2023) A&A 674,104

Key Science 3 : Exoplanet hosting stars and nearby exoplanet

- High-resolution spectroscopic survey for nearby stars (M-dwarf) with planets



We do not know what exoplanets are made of, how they form, and how they evolve.



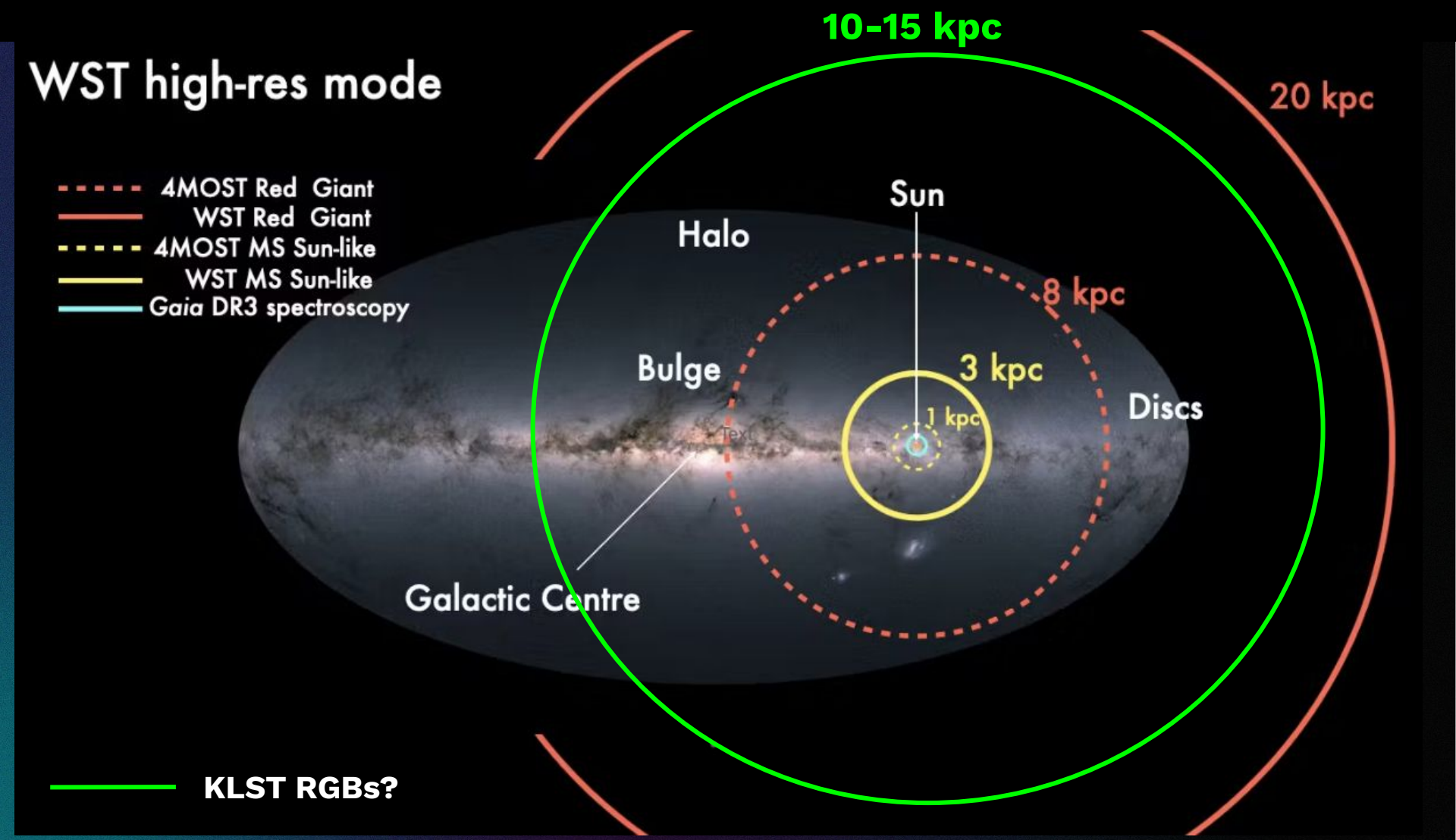
A detailed classical stellar parameters (e.g. Teff, metallicity, …) of host stars are needed to know the properties of exoplanets.

Star Type	Temperature Bounds	Planet Type
M	$T_s \leq 3890$ K	Earth/Super-Earth
K	3890 K $< T_s \leq$5330 K	Sub-Neptune
G	5330 K $< T_s \leq$ 5960 K	Neptune
F	5960 K $< T_s \leq$7300 K	Jupiter
A	7300 K $< T_s$	Inflated Jupiter

EDWARDS & TINETTI (2022)

A relationship between the chemical and physical properties of planets and planet-hosting stars

What can be done using KLST?



Remaining Issues…

Main Science Issue…

Specific top science oriented telescope	VS	Flagship & Multi-purposed telescope

Now : The survey on the science required by the Korean astronomical community has been completed based on Flagship & Multi-purpose telescope

Instruments

Low Resolution (cosmology/galaxy)

High Resolution (star)

Higher Resolution (exoplanet)

Develop

Three different instruments !!!

Need for Roadmap of Next-Gen spectroscopic Survey Telescope

THANK YOU

01.22.2025
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