A-SPEC: The All-sky SPECtroscopic survey of nearby galaxies with K-SPEC

Complete 3D Mapping of the Local Accelerating Universe

Hwang, Ho Seong[1,2], Kim, Jae-Woo[1],
Hyeonguk Bahk[2],Young-Man Choi[3], Moo Young Chun[1], Sang-Hyun Chun[2], Haeun Chung[4], Sungwook E. Hong[1], Minhee Hyun[1], Donghui Jeong[5,6], Ueejeong Jeong[2], Kang-Min Kim[2], Dongkok Kim[2], Yunjong Kim[1], Jongwan Ko[1], Chung-Uk Lee[1], Ho-Gyu Lee[1], Jong Chul Lee[1], Sungho Lee[1], Yongseok Lee[1], Hyun-Ho Lim[3], Heeyoung Oh[1], Chan Park[1], Changbom Park[6], Junsup Shim[8], Hyunmi Song[7],
Mingyeong Yang[1], Yongmin Yoon[1]

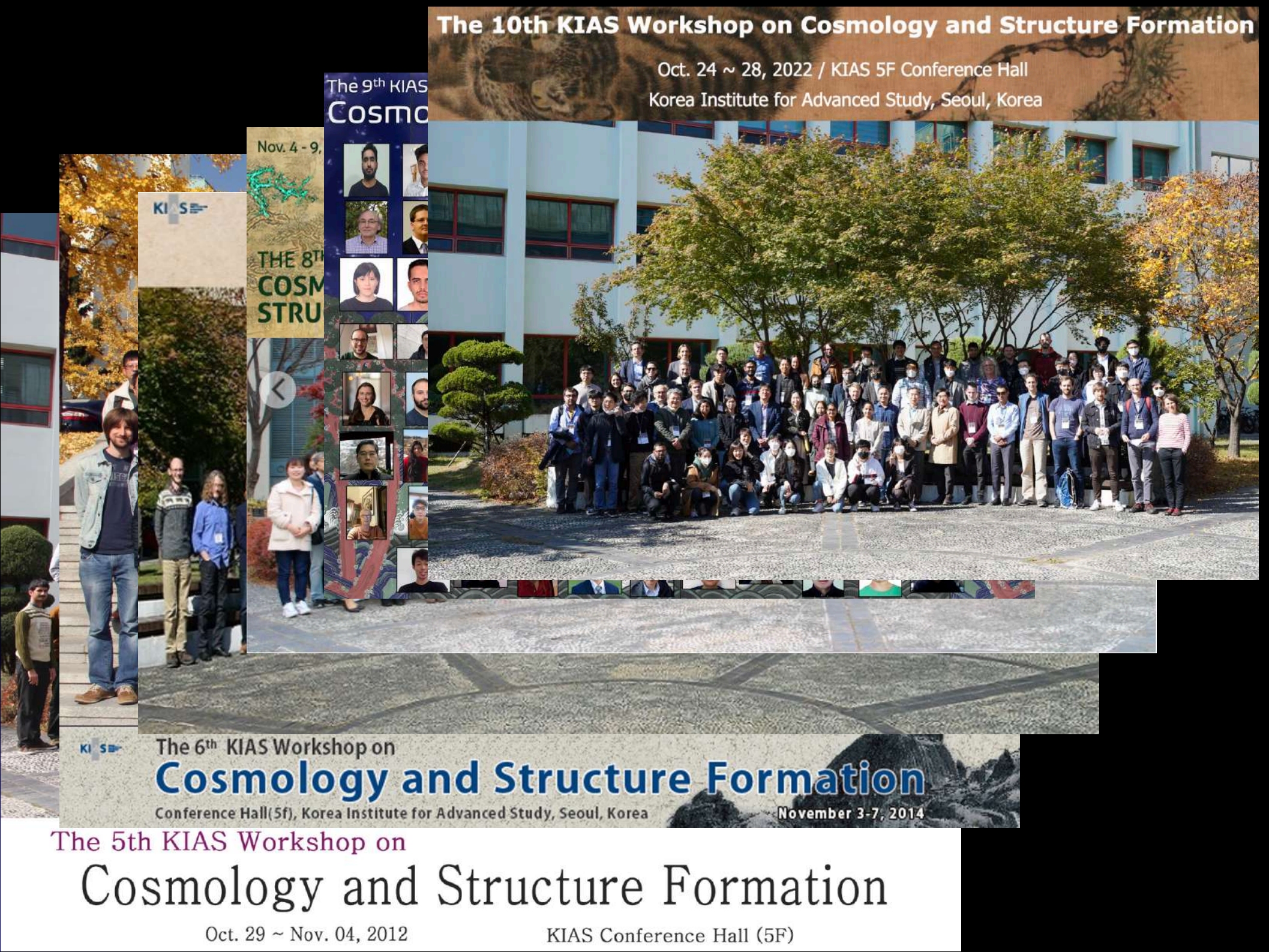
[1]KASI, [2]SNU, [3]Ajou, [4]UoA, [5]PSU, [6]KIAS, [7]CNU, [8]ASIAA

Nov. 1, 2024
The 11th KIAS Workshop on Cosmology and Structure Formation

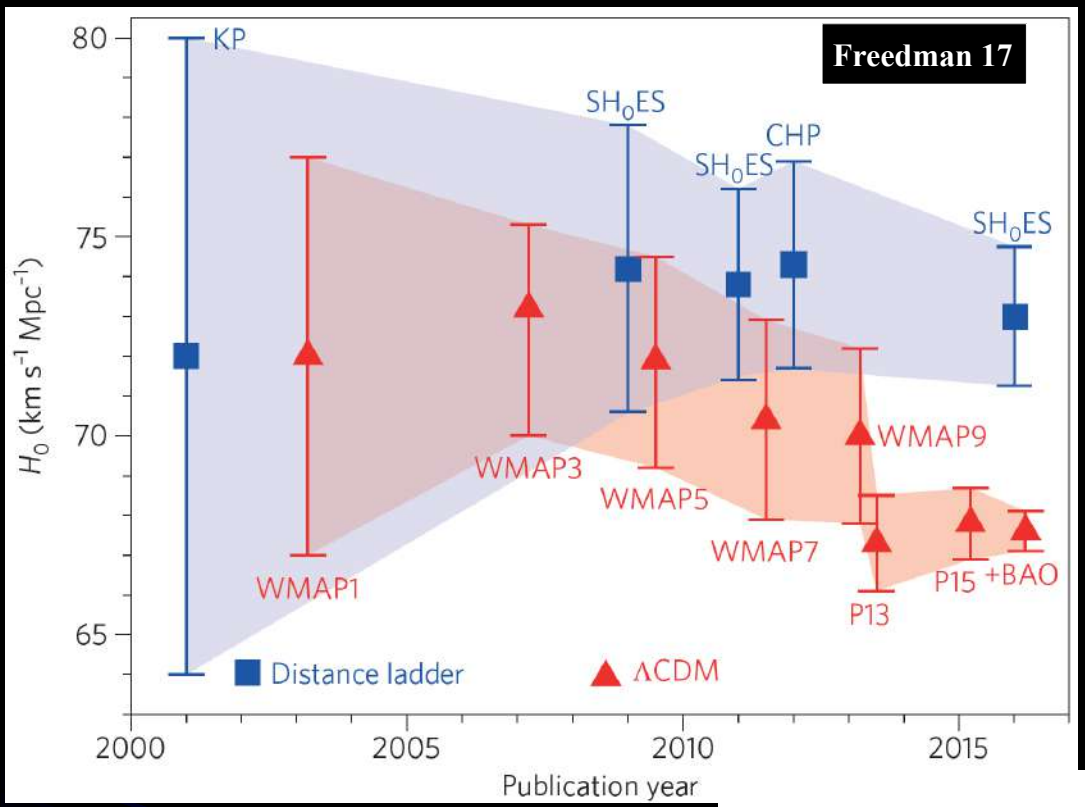
ASPEC All Sky Spectroscopic Survey with Korea Multi-Object Spectrograph(K SPEC)
K-SPEC Korea Multi-object Spectrograph
KASI 한국천문연구원 Korea Astronomy & Space Science Institute
KIAS Korea Institute for Advanced Study
in S.N.U. Astronomy



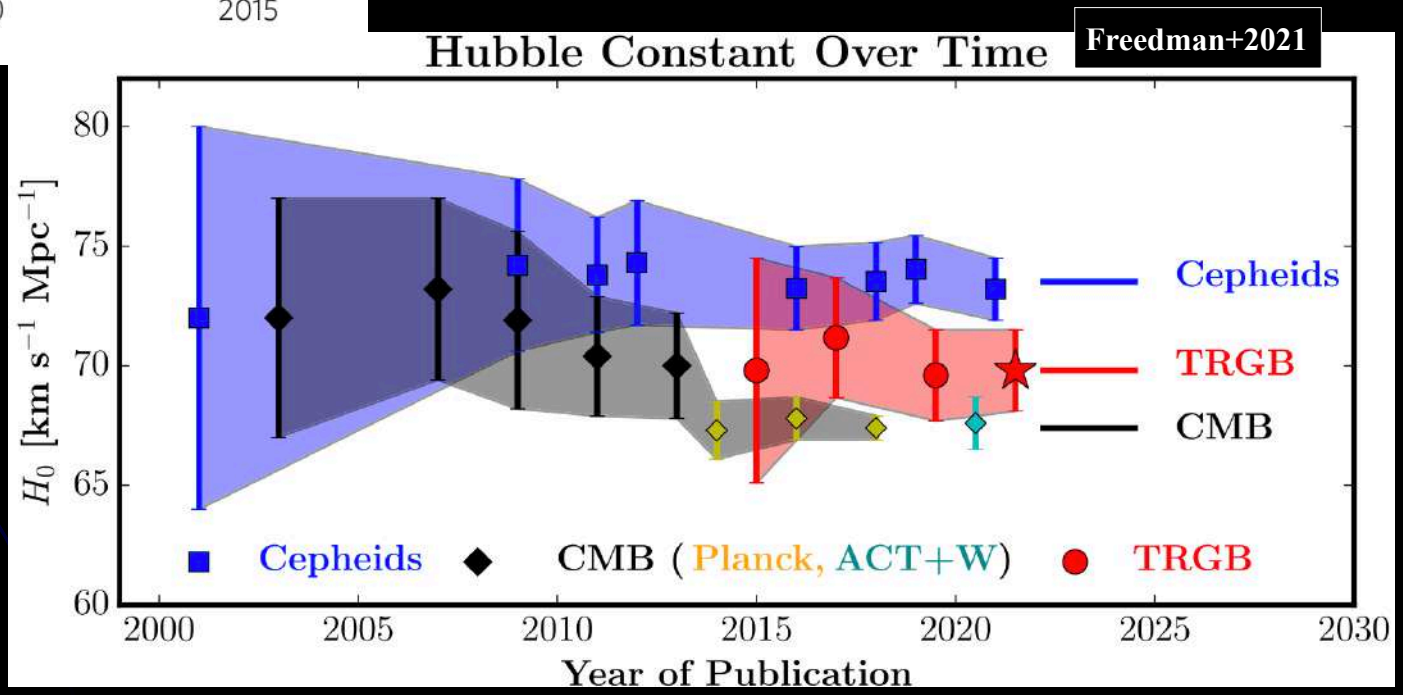
The 4th KIAS Workshop on
COSMOLOGY AND STRUCTURE FORMATION
"Photos"


The 10th KIAS Workshop on Cosmology and Structure Formation
Oct. 24 ~ 28, 2022 / KIAS 5F Conference Hall
Korea Institute for Advanced Study, Seoul, Korea
The 9th KIAS
Cosmo
Nov. 4 - 9,
THE 8TH
COSM
STRU
KIAS
The 6th KIAS Workshop on
Cosmology and Structure Formation
Conference Hall(5f), Korea Institute for Advanced Study, Seoul, Korea
November 3-7, 2014
The 5th KIAS Workshop on
Cosmology and Structure Formation
Oct. 29 ~ Nov. 04, 2012
KIAS Conference Hall (5F)

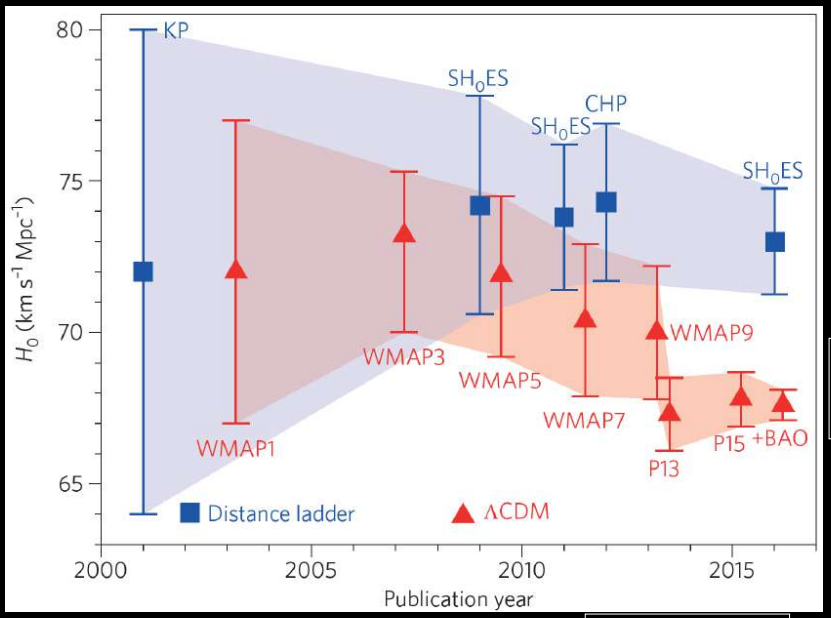
Issues in the Standard Cosmological Model: H_0 Tension



As reviewed by Prof. Myung Gyoon Lee, The difference is more than 4 sigma!

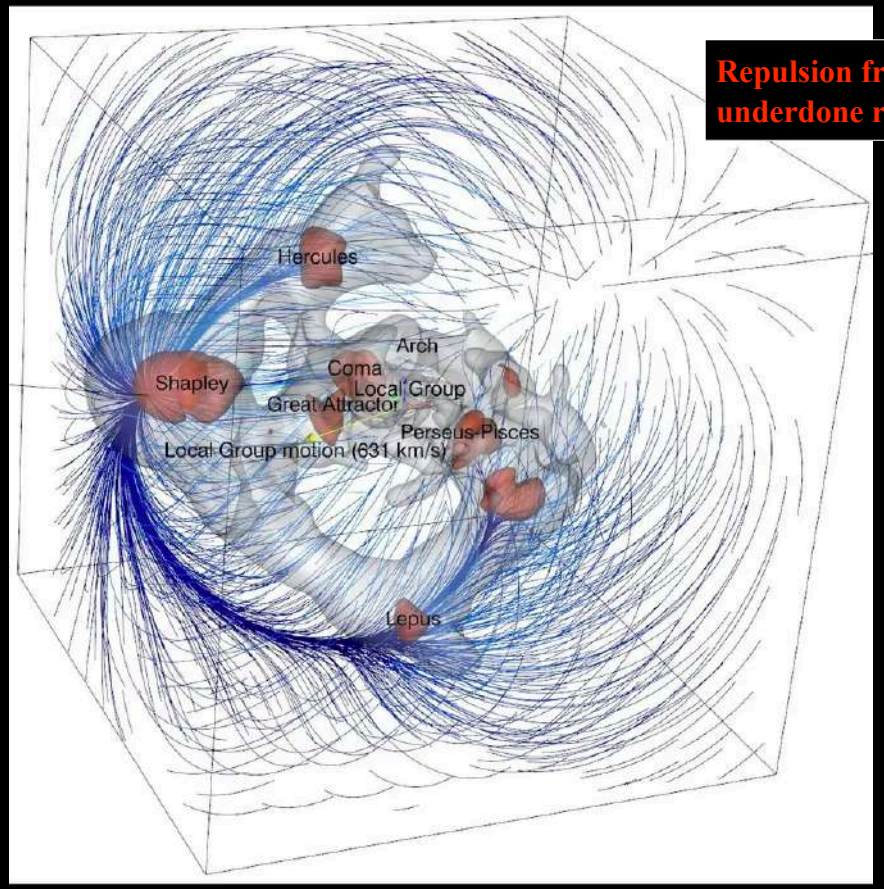


z=0: Hubble Parameter Discrepancy

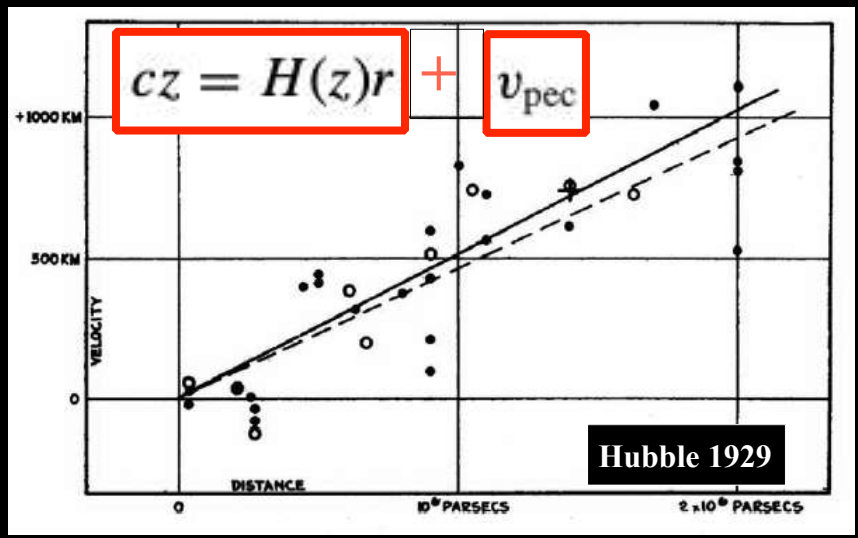


Freedman 17

Attraction by overdose regions



Repulsion from underdone regions



Hubble 1929

- One Solution to the Problem
  - If we live in an underdense region! (e.g. LeeJ 2014; Haslbauer+2020)
  - We need to know an accurate density contrast of the local universe

How underdense with the current data?

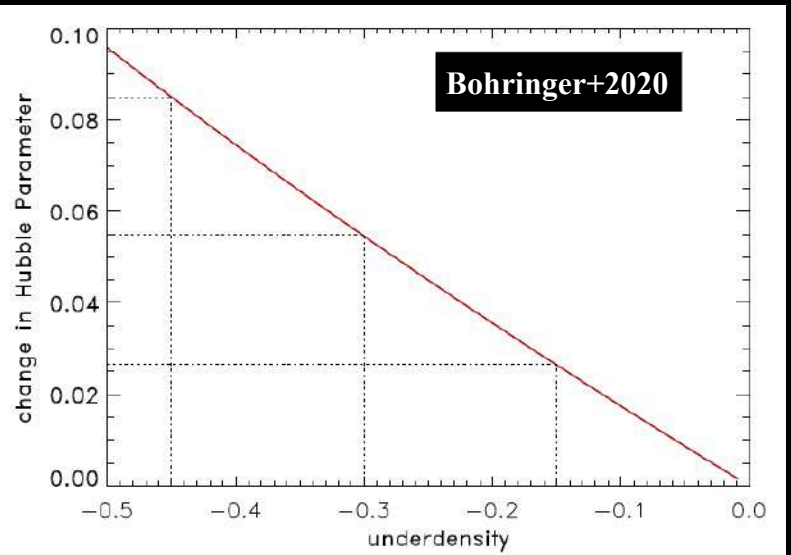


Fig. C.1. Change of the Hubble parameter as a function of the underdensity of the region studied. The dotted lines mark the underdensity values of 30 ± 15%.

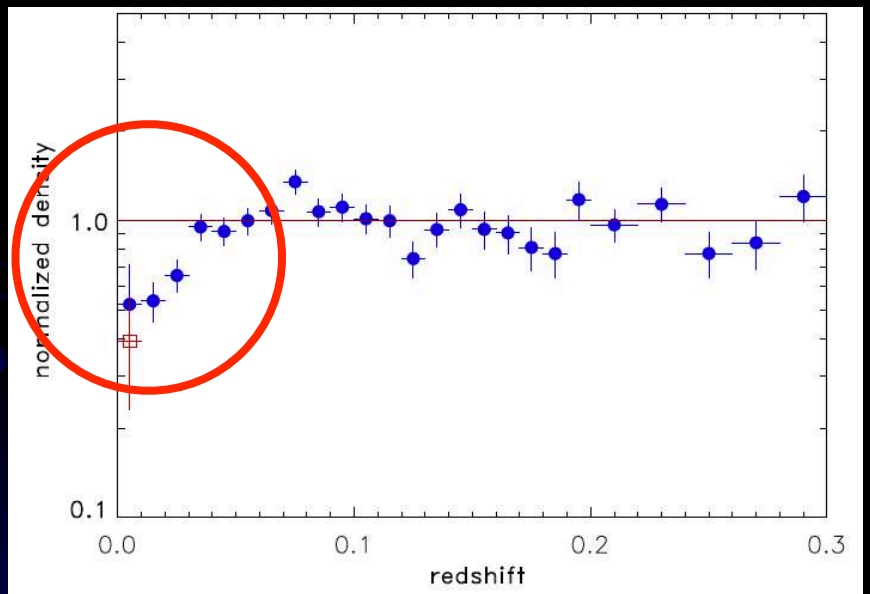
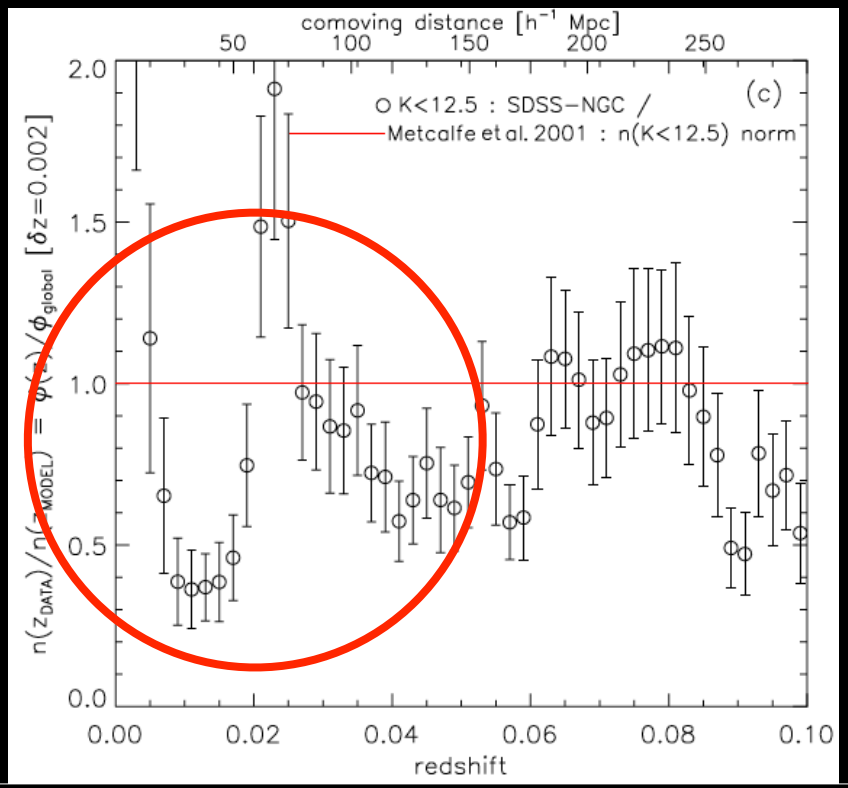


Fig. 1. Cluster density distribution as a function of redshift for the CLASSIX galaxy clusters covering the sky at $|b_{II}| \geq 20^{o}$ for a minimum luminosity of 10^{42} erg s^{-1} (0.1 - 2.4 keV). The density distribution has been normalised by the predicted redshift distribution as explained in the text. The open square shows the result if the region of the Virgo cluster is excluded from the analysis.

Galaxy Clusters (Bohringer+2020)



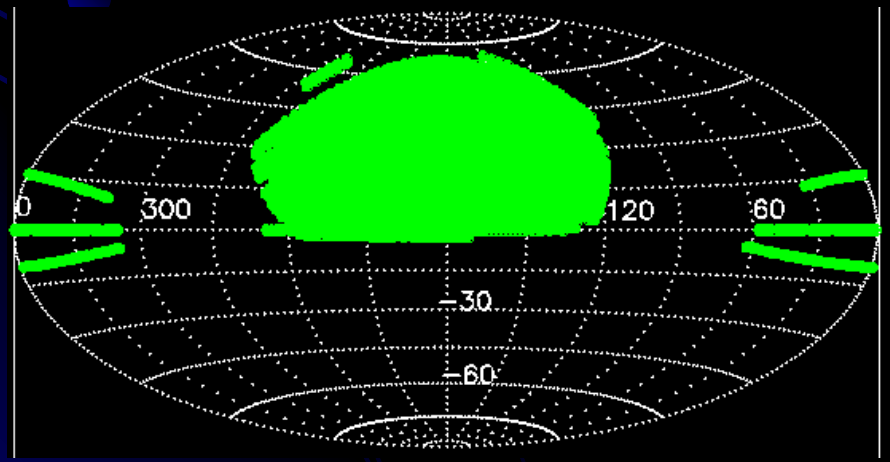
Galaxies (Whitbourn & Shanks 2014; see also Keenan+2013 for the KBC void with underdensity=-0.54 with 40-300 Mpc size)

- Previous Redshift Surveys
  - Some very nearby, bright galaxies (z<0.05) were excluded because of various observational selection effects (e.g. saturation; not in the phot. cat.)
  - Few all-sky surveys

- New Redshift Surveys
  - Need a complete sample of nearly galaxies
  - All-sky Survey: Need a Sufficient Volume for the study of z=0 Universe

Q: Why do we need an all-sky survey?

1. **Not only to decrease the uncertainties of physical parameters we would like to measure**
   1. **Need a Sufficient Volume for the study of z=0 Universe (larger is better)**



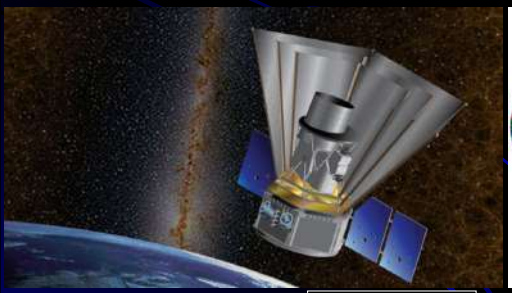


e.g. SDSS - not all sky!

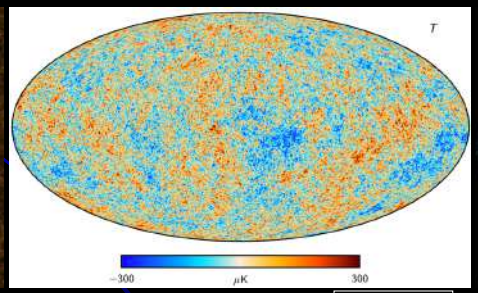
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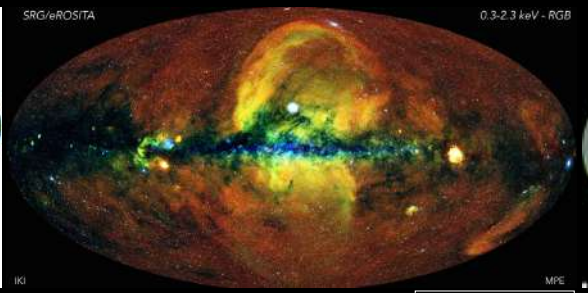
2. But also to secure scientific competitive power (cf. SDSS/DESI/4MOST): Blue Ocean Strategy!
   - ➢ Science Cases that can be done only with all-sky data
     - ➢ Combination with all-sky survey data (e.g. SPHEREx/Planck/eROSITA/WISE+)



SPHEREx



Planck

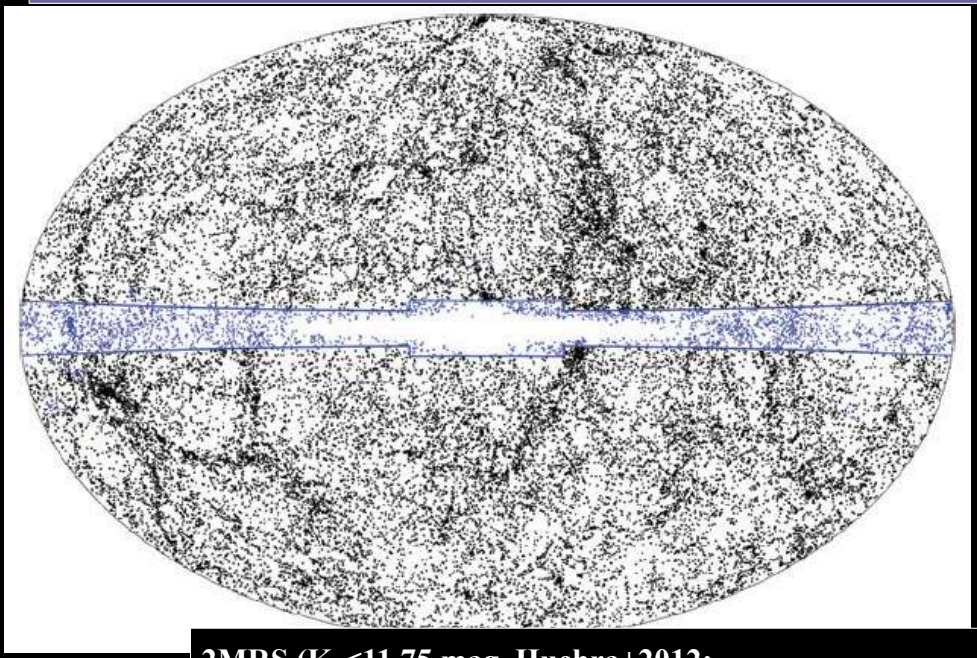


eROSITA

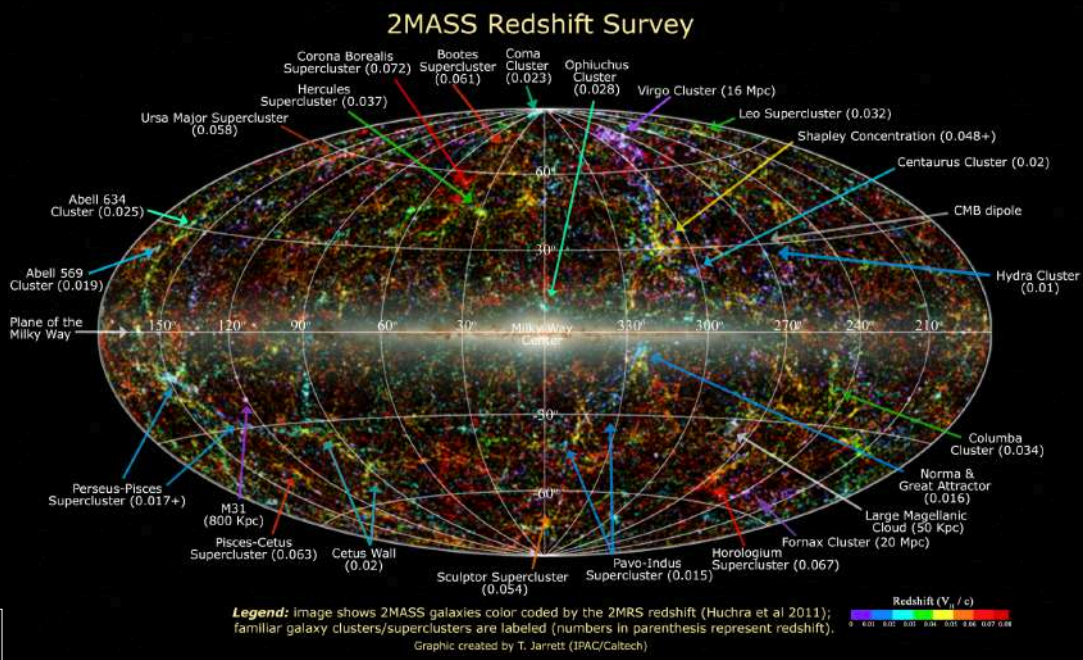


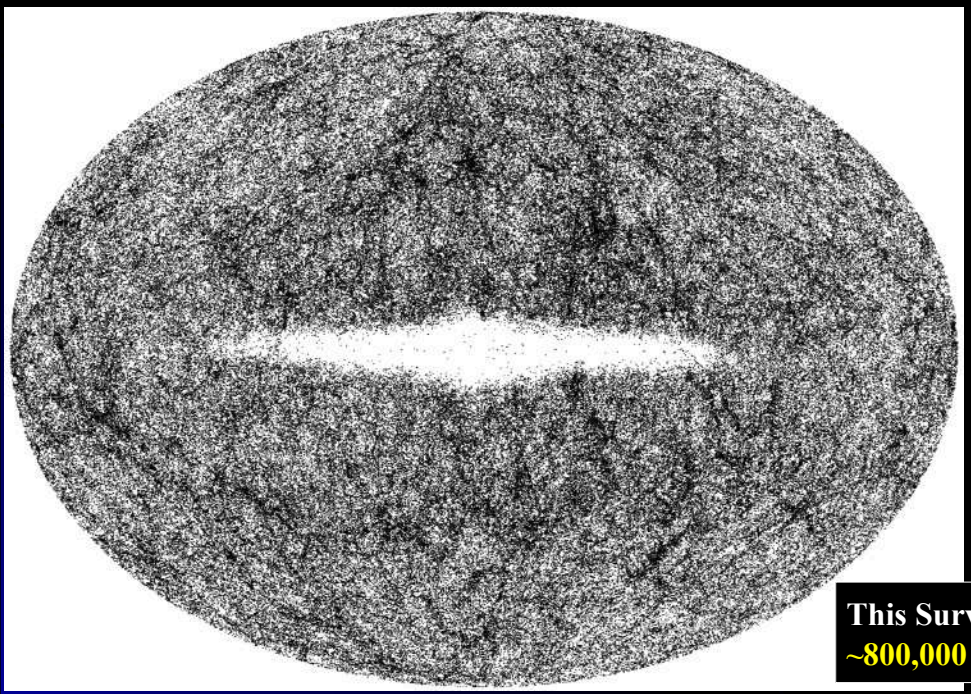
WISE

All-sky Survey: Upgraded 2MRS (K_S<11.75 => 13.75)



2MRS (K_S<11.75 mag, Huchra+2012;
~50,000 sources including those near the Galactic plane)





This Survey (K_S<13.75 mag, only 50% ploted for clarity;
~800,000 sources including those near the Galactic plane)

Multi-Object Spectrograph System (K-SPEC) Development + Spectroscopic Survey (A-SPEC): 1 page Summary

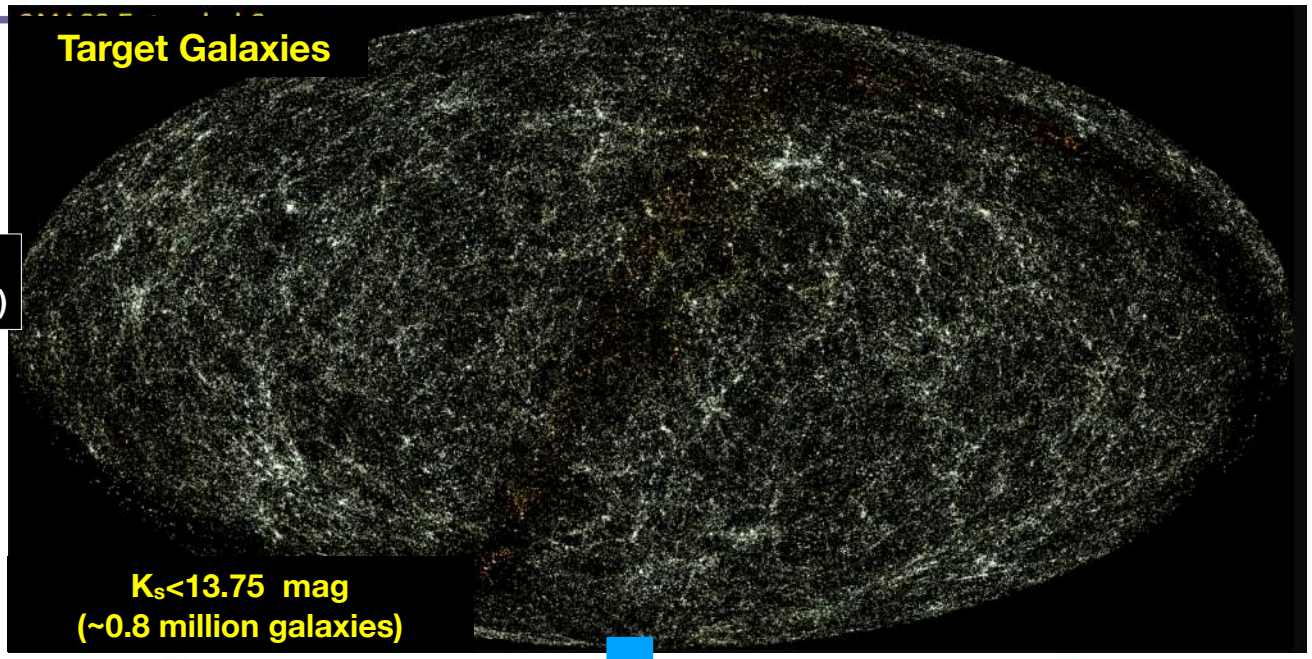
2. [2025-27]
All-sky Spectroscopic Survey

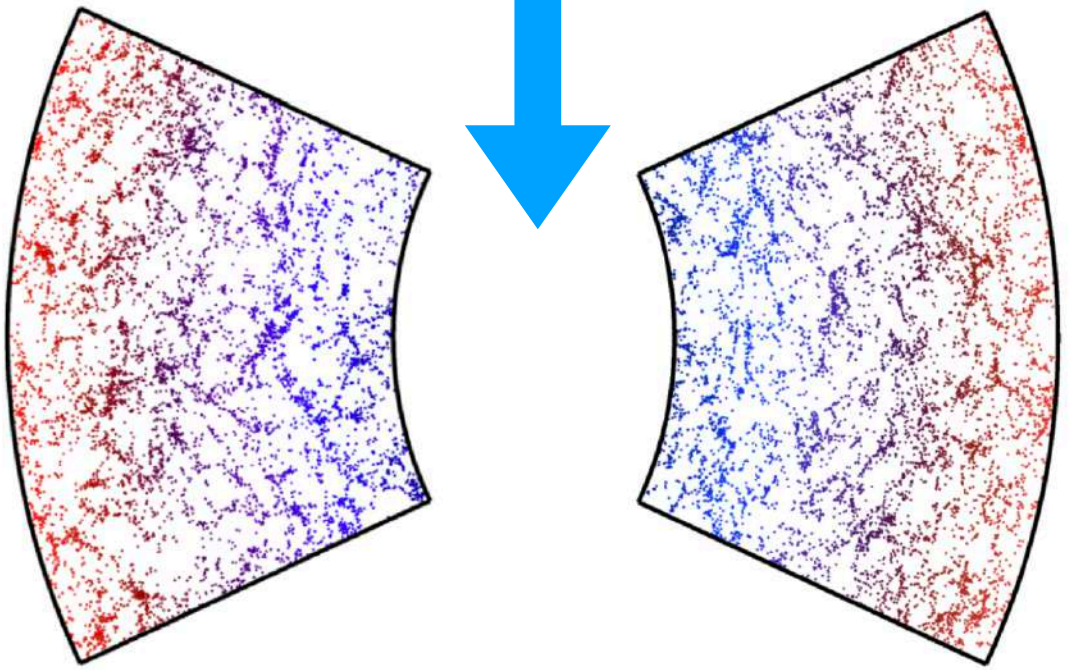
Northern Hemi.: 1-2 m class Tel.
Southern Hemi.: KMTNet 1.6 m Tel. (Australia)



1. [2021-25]
Development of MOS







3. [2027-29] Study of Cosmology and Galaxy Formation by comparing Observations (Left) and Simulations (Right)

➢ Team Members (29 in total: 23 professors/staffs, 3 postdocs, 4 grad students)

➢ KASI (Project management: Planning, Manufacture, Science)

- ➢ Galaxy Evolution/Cosmology Group
  (Sang-Hyun Chun, Sungwook Hong, Minhee Hyun, Jongwan Ko, Jong Chul Lee, Jae-Woo Kim, Yongmin Yoon, Mingyung Lee)
- ➢ GMT Science/Instrumentation Group
  (Kang-Min Kim, Moo Young Chun, Chan Park, Heeyoung Oh, Ho-Gyu Lee, UeeJeong Jeong)
- ➢ Technology Center for Astronomy and Space Science (Sungho Lee, Yunjong Kim)
- ➢ KMTNet Operation Group (Chung-Uk Lee, Yongseok Lee)



Kim, Dongkok

Lim, Hyun-Ho

Kwon, Minseong

Bahk, Hyeonguk

Kim, Dachan

➢ Domestic Collaboration

- ➢ KIAS (Planning, Science: Changbom Park)
- ➢ SNU (Management, Manufacture: Ho Seong Hwang, Dongkok Kim, Hyeonguk Bahk, Minseong Kwon)
- ➢ CNU (Science: Hyunmi Song, Dachan Kim)
- ➢ Ajou (Fiber Positioner: Young-Man Choi, Hyun-Ho Lim)



➢ International Collaboration

- ➢ University of Arizona (MOS design: Haeun Chung)
- ➢ Penn State University (Science: Donghui Jeong)
- ➢ Macquarie University (Spectrograph: Jon Lawrence)
- ➢ Australian National University (Science: Matthew Colless, Chris Kidman)



Q: What do we need?

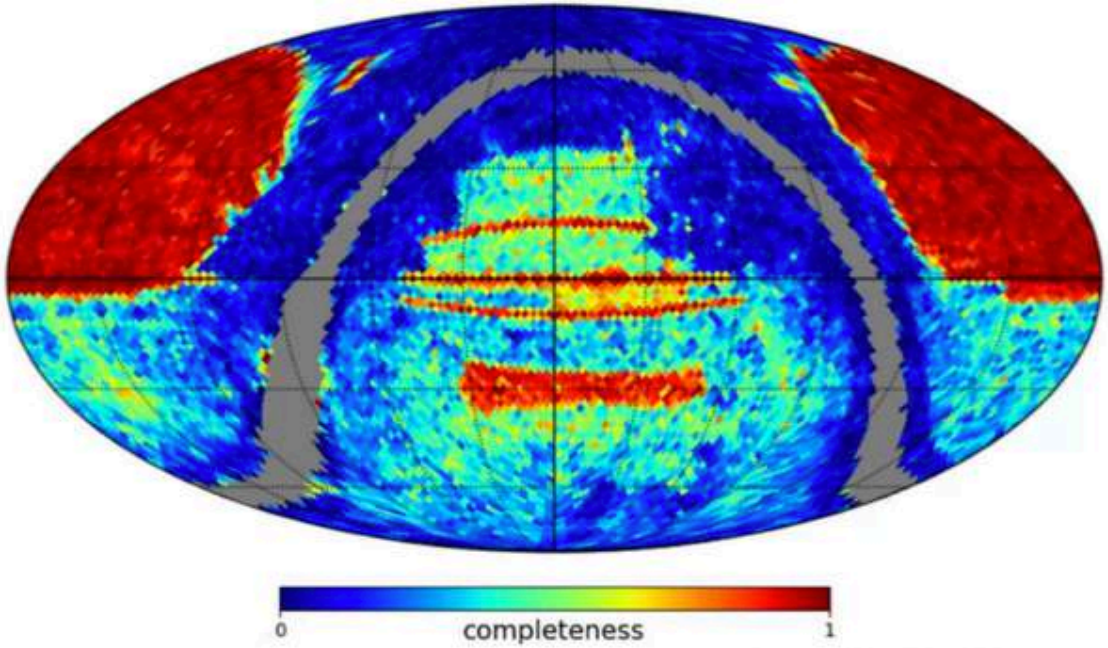
1. Survey

Spectra of sources
- redshift, spectral lines, etc

Large Volume
- wide sky coverage

Complete

All-sky Spectroscopic Survey (A-SPEC)
- Few all-sky surveys
- Ks<13.75 galaxies



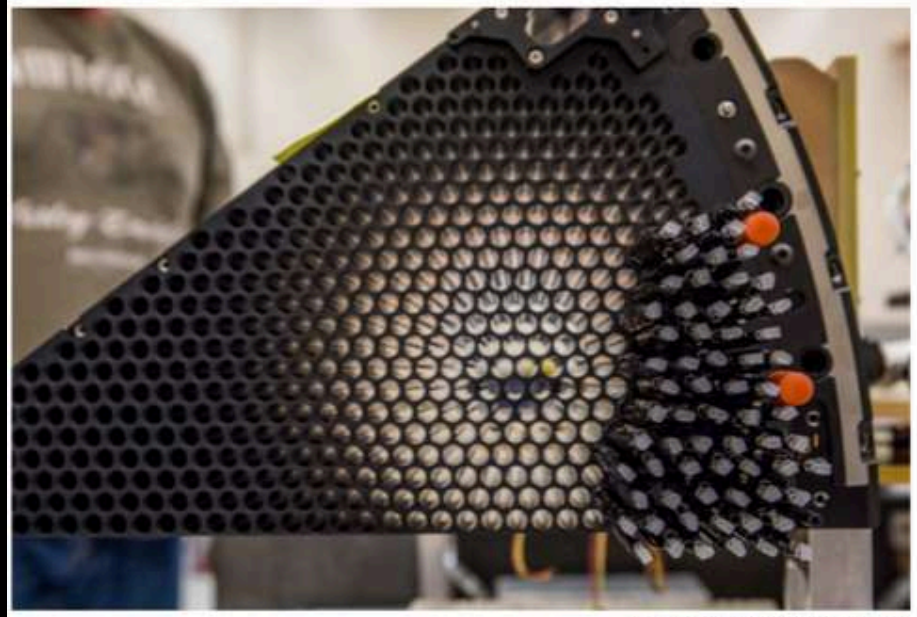
Jong Chul's slide

2. Multi-object Spectrograph

Multi-object spectroscopy
- Fibre fed spectrograph

Wide Field of View
- at least a few deg^2

New Instrument (K-SPEC)
- Our own one for the survey

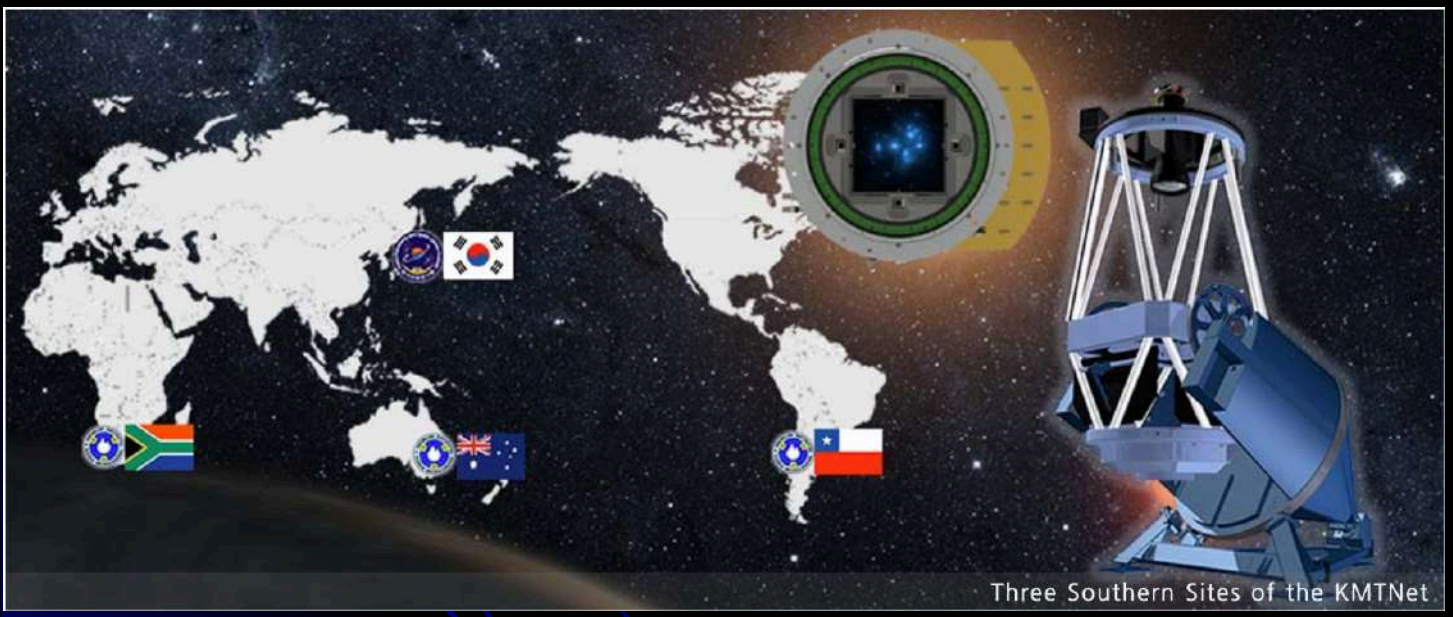


www.desi.lbl.gov

Slide from Jae-Woo

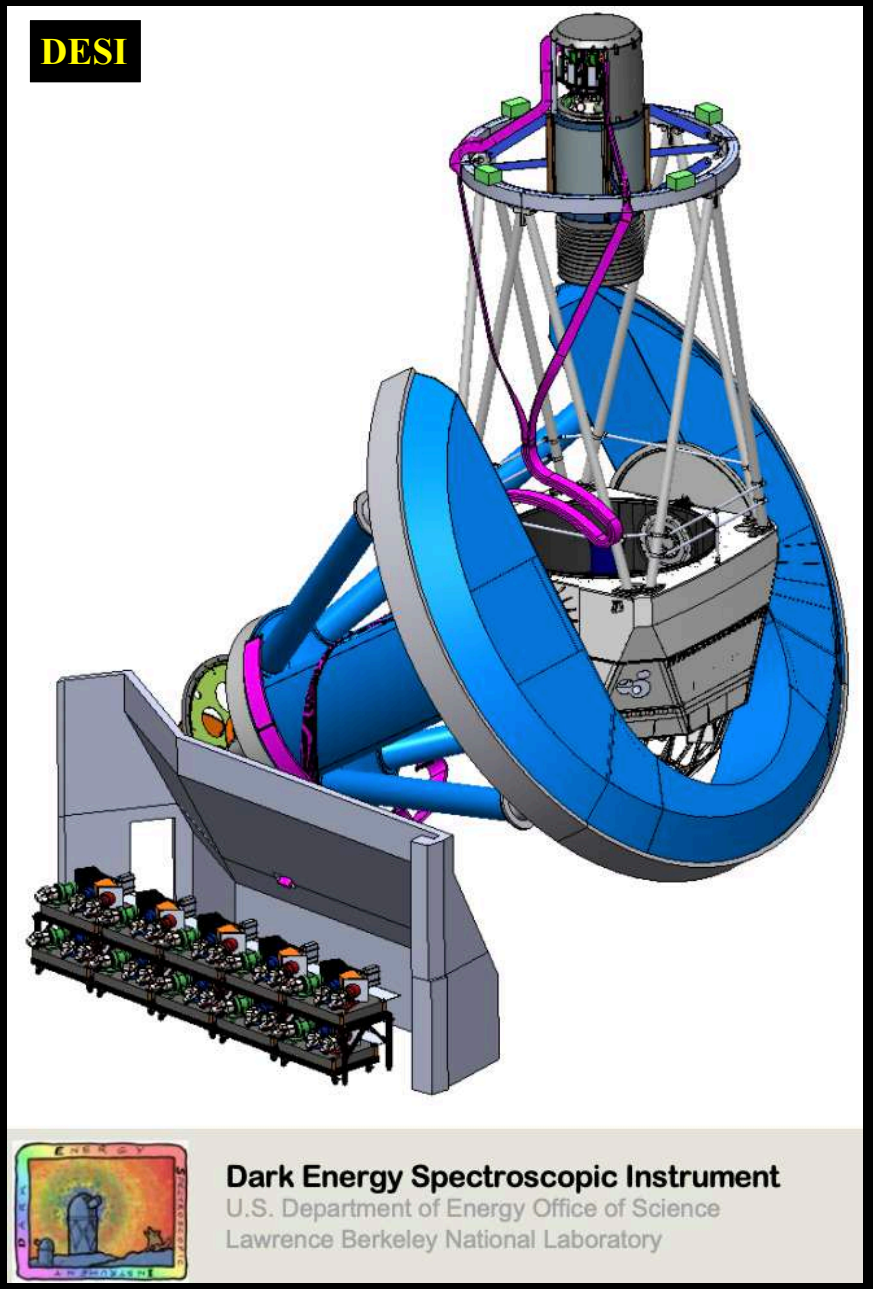
Q: Which Telescope?

1. Southern Hemi.: KMTNet 1.6m telescope at SSO (Prime Focus)
2. Northern Hemi.: TBD



Plan for KMTNet: DESI-like MOS (prime focus + theta/phi positioner, but with a small number of fibers)



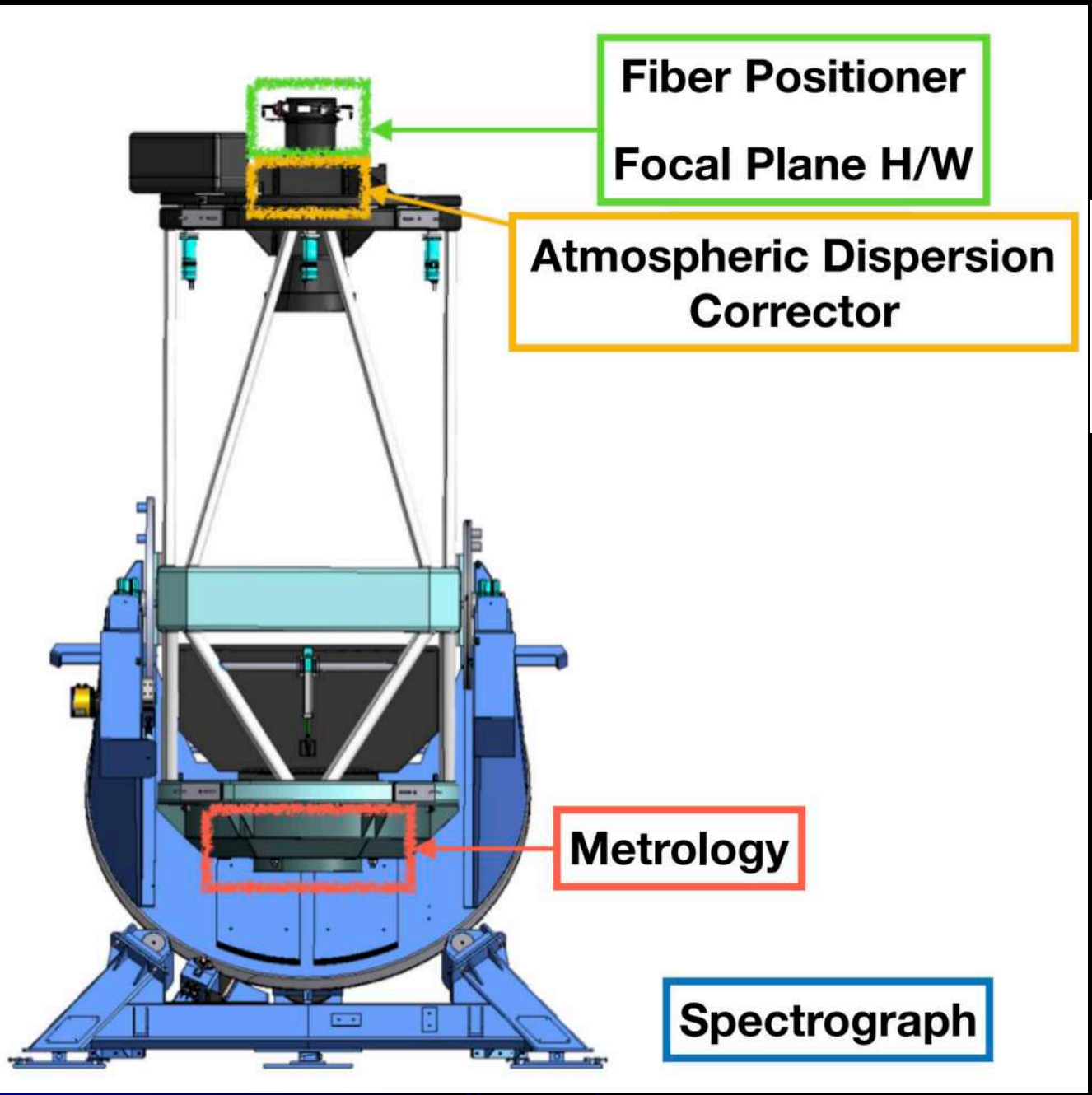


New Redshift Survey: Spectrograph Requirement

Specification	Requirement (Spec…) - KMTNet
Field of View	> 6 deg^2
Number of Fibers per field	~150 (130 targets + 20 cal/sky)
Fiber FoV (Diameter)	~3” (75 μm)
Spectral Resolution	R~1400-2500 (=> v(err)=30-50 km s^{-1})
Wavelength Coverage	3700 - 8700 Å
Exposure per field	<15 min (10 min on source + 5 min overhead)

	Fiber Diameter	Resolution	Wavelengths
SDSS/main	3”	1300-1900	3800-9200 Å
SDSS/BOSS	2”	1200-2400	3650-10,400 Å
DESI	1.5”	2200-5500	3600-9800 Å

KMTNet for Spectroscopy



Commissioning with KMTNet
Dec., 2023 - Feb., 2024 +1 year

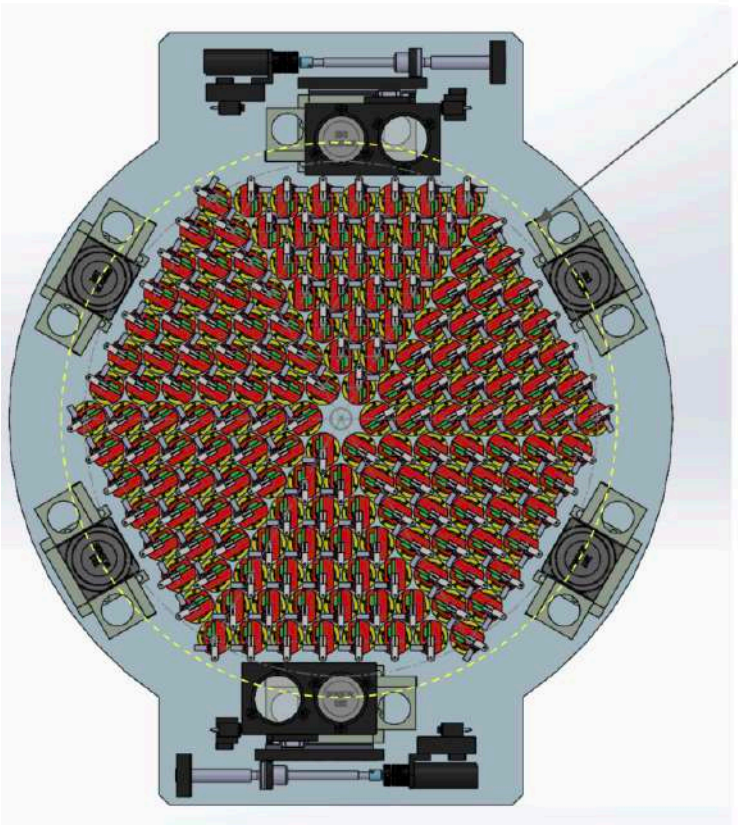
Full operation with KMTNet
Nov., 2024 +1 year

Work for KMTNet

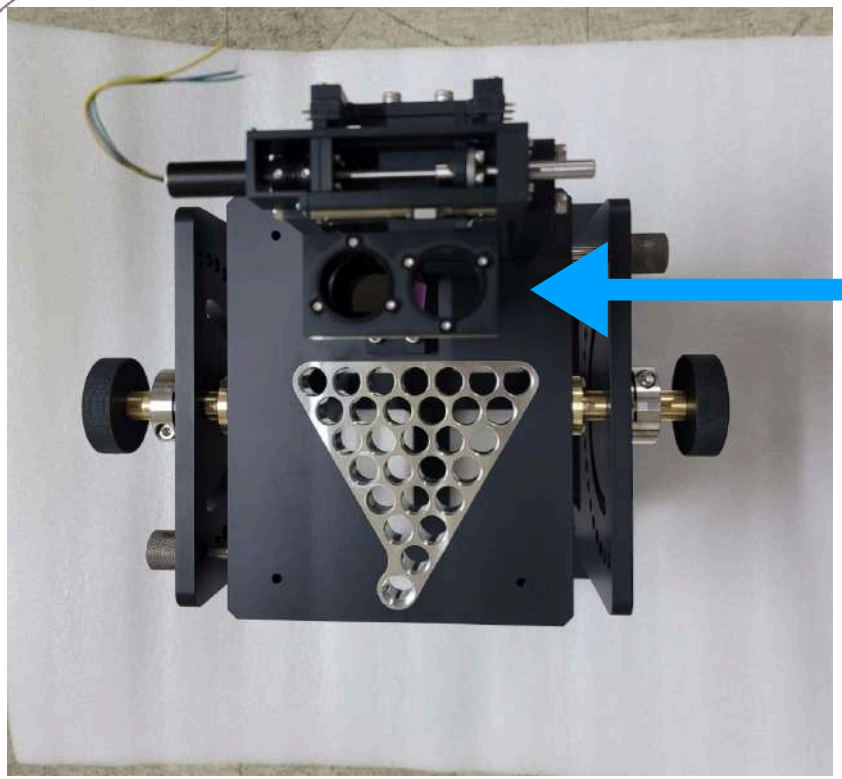
1. Fiber Positioner
2. Fiber Cable Management
3. Wide Field Corrector
4. Spectrograph
5. Focal Plane H/W
6. Plate & Cage for Focal Plane H/W
7. Electronics, Power & Thermal
8. Metrology system
9. Interface Control System
10. Data Management
11. Instrument Storage
12. Delivery & Installation
13. Survey Plan
14. Science Cases

Slide from Jae-Woo Kim

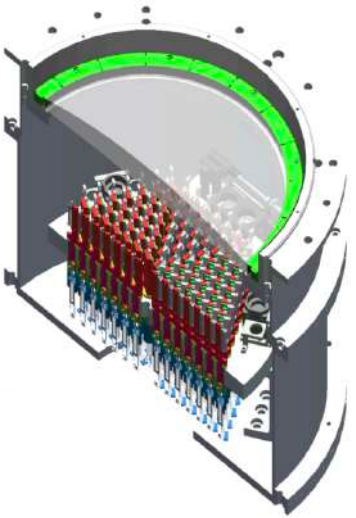
Focal Plane



Φ 260 -- diameter of guide camera center







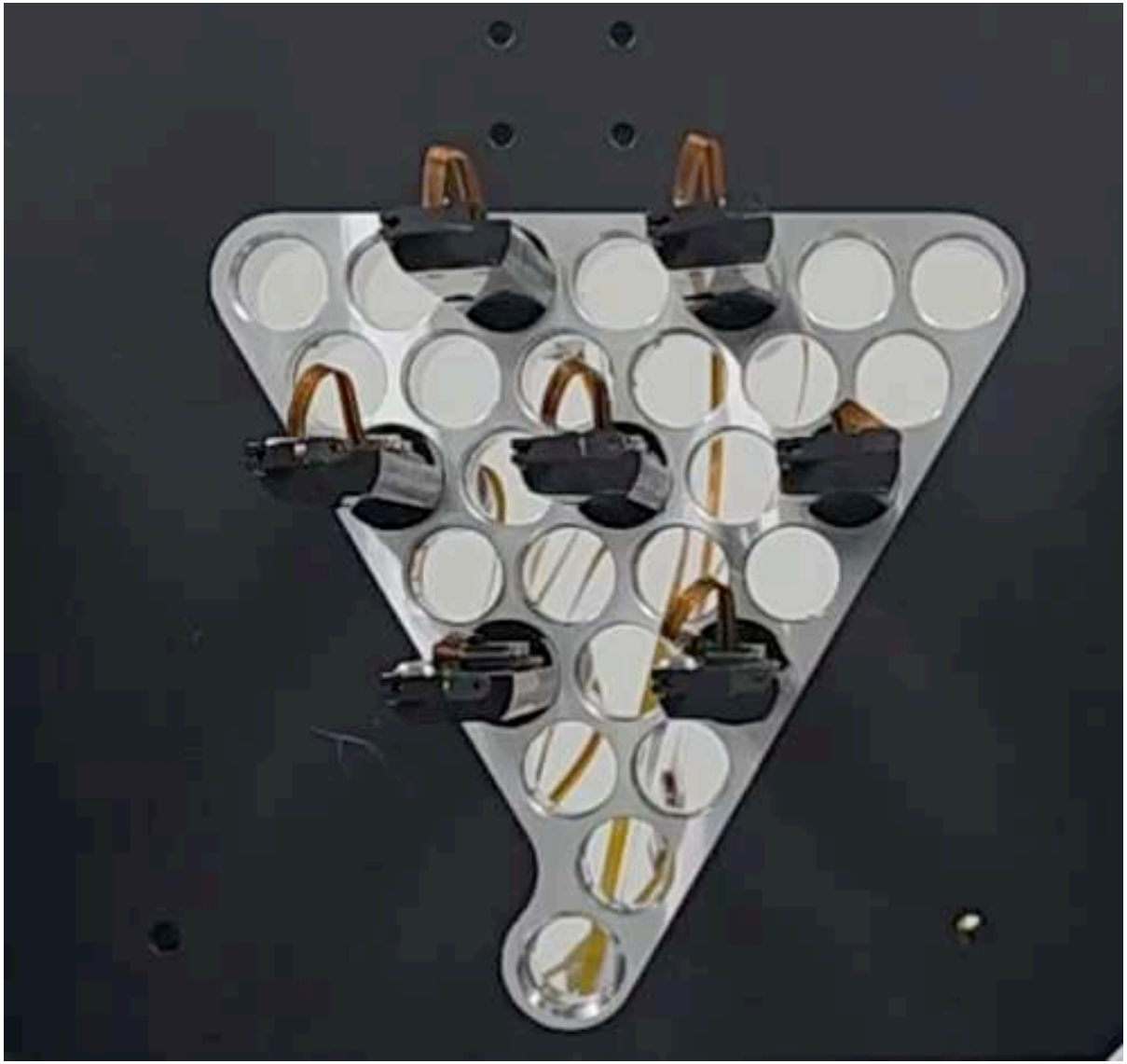
Replacing the current imaging camera

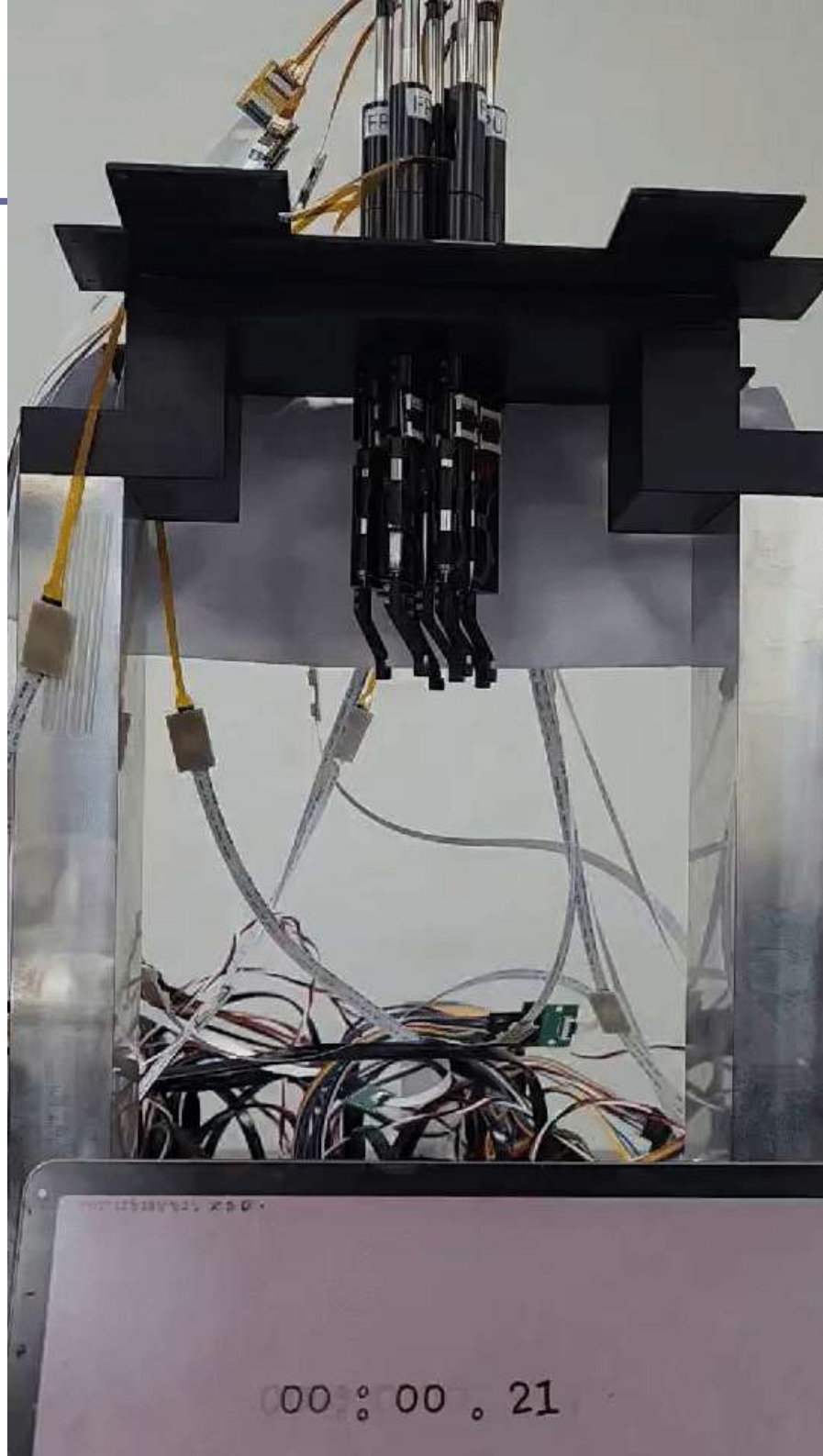
Focal Plane hosts

- **150 fiber positioners** in 256mm (= 2.8 degree) diameter
- **7 CMOS cameras** with SDSS r filters for guiding, focusing & Alignment
- **26 fiducials** as a reference for the metrology

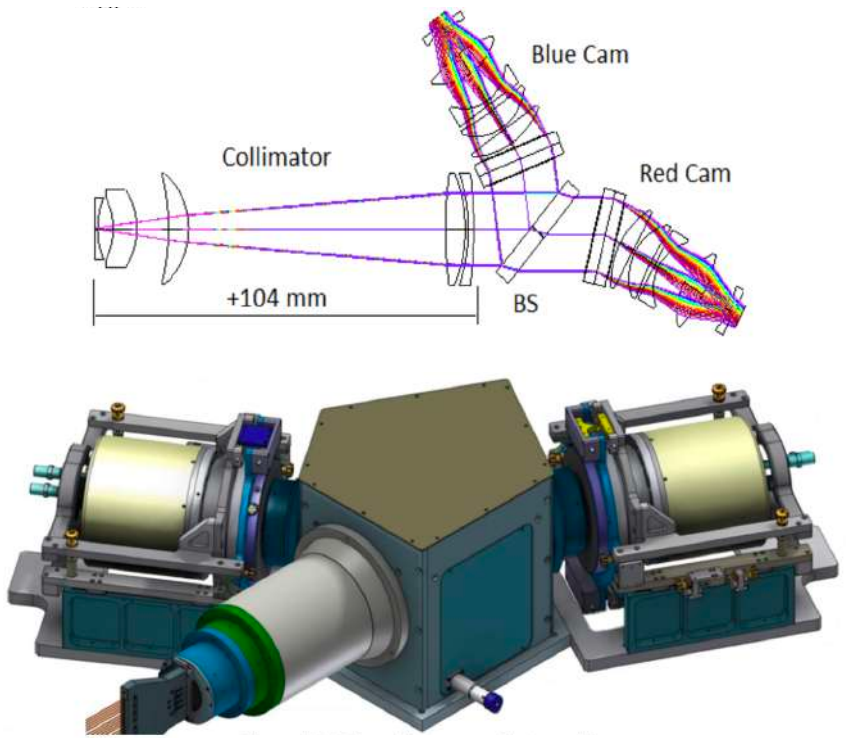
The final one will be manufactured in the late this year.

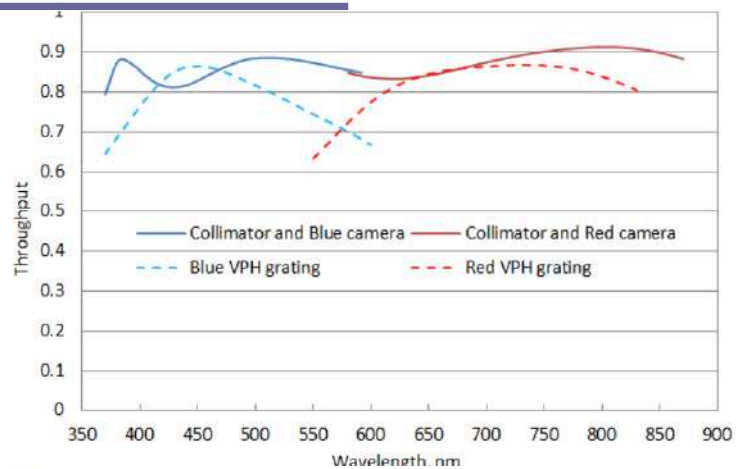
Fiber Positioner + Focal Plane

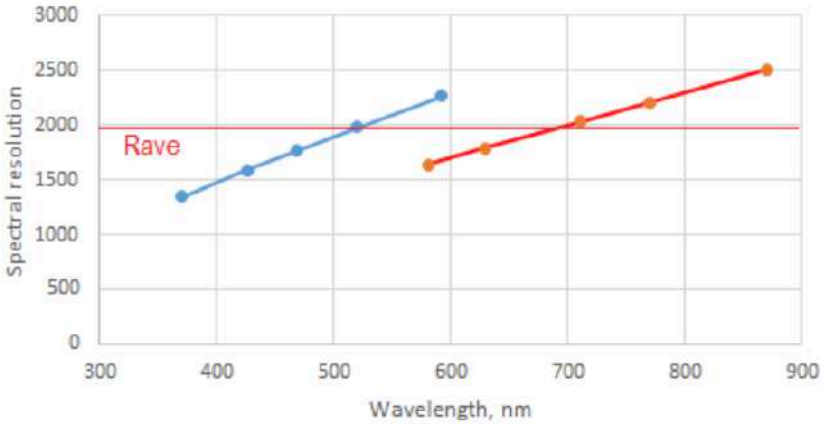




Spectrograph





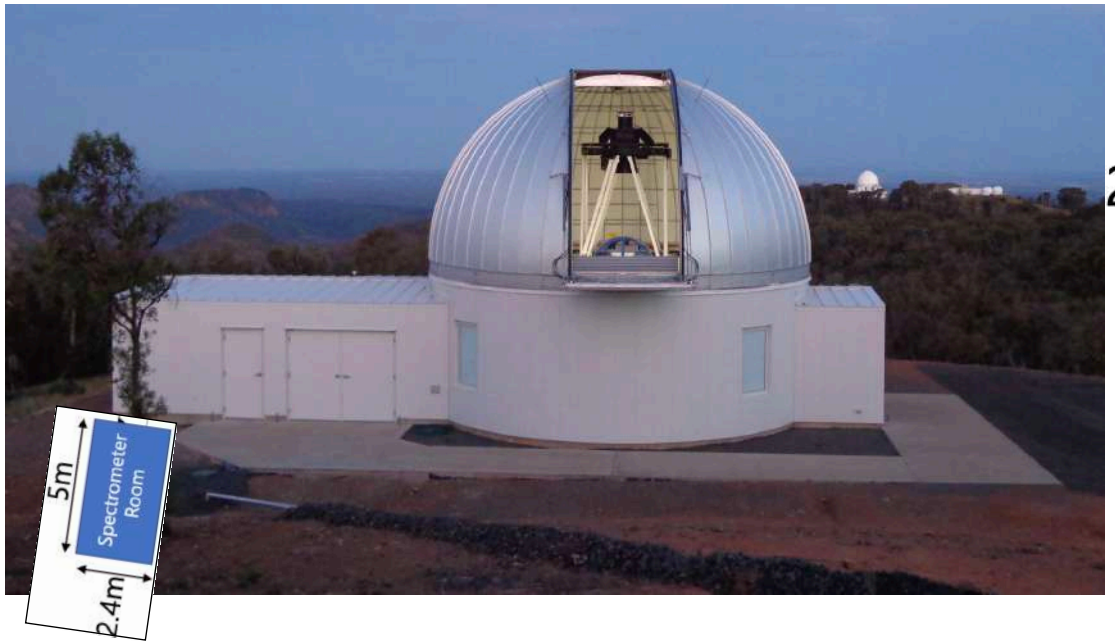


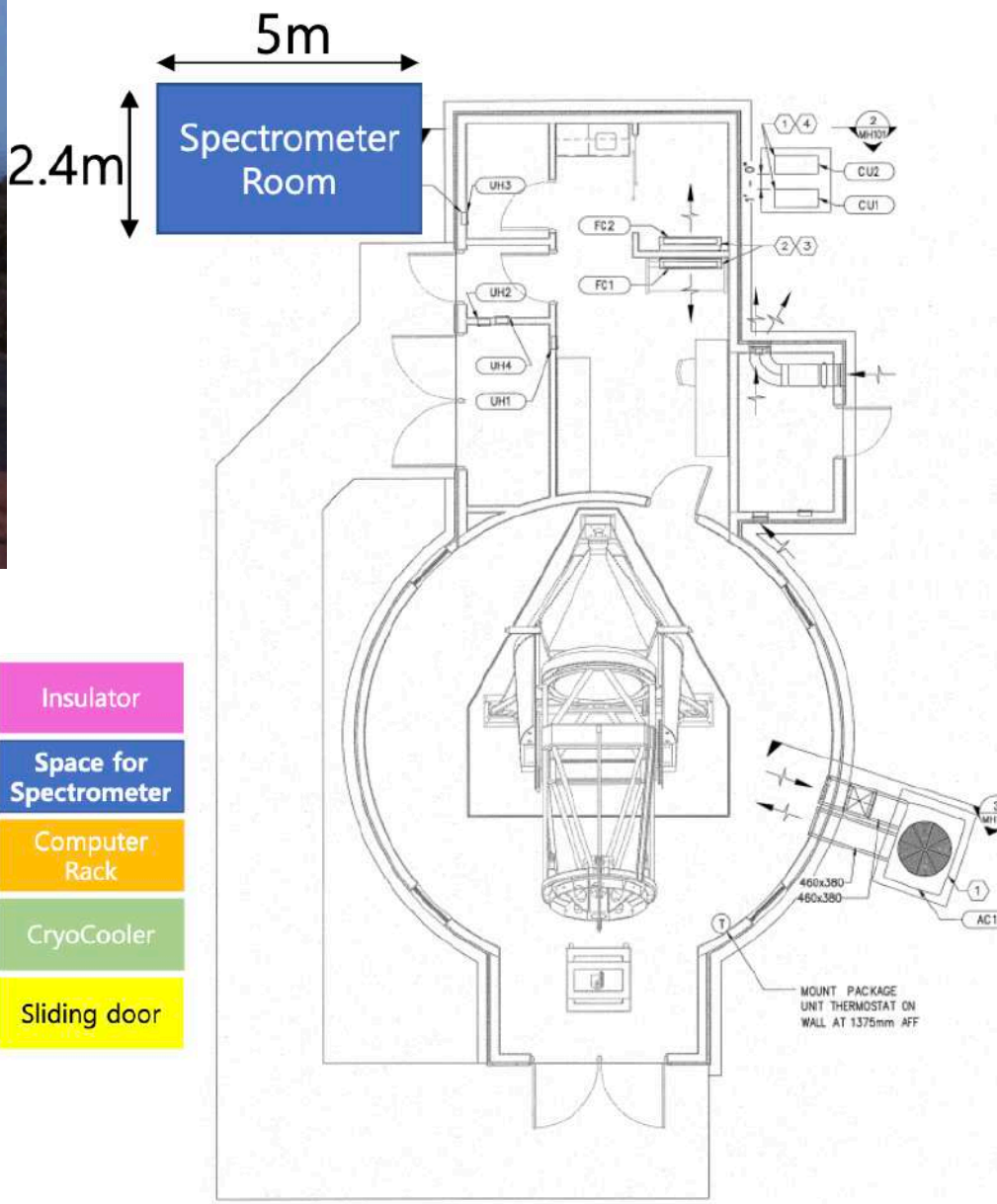
Collaboration with AAO in Macquarie University, Australia
Supported by the Korean Spectroscopic Survey Consortium (KASI, KIAS and SNU)
Nearly identical to the TAIPAN spectrograph
Optimized spectrograph for KMTNet
- Optics for KMTNet f/3.2
- Wavelength coverage of **370-870nm**
- Mean Spectral Resolution of **R>1600 for blue & R>1800 for red**
- **150 fibers** with a back-illumination system

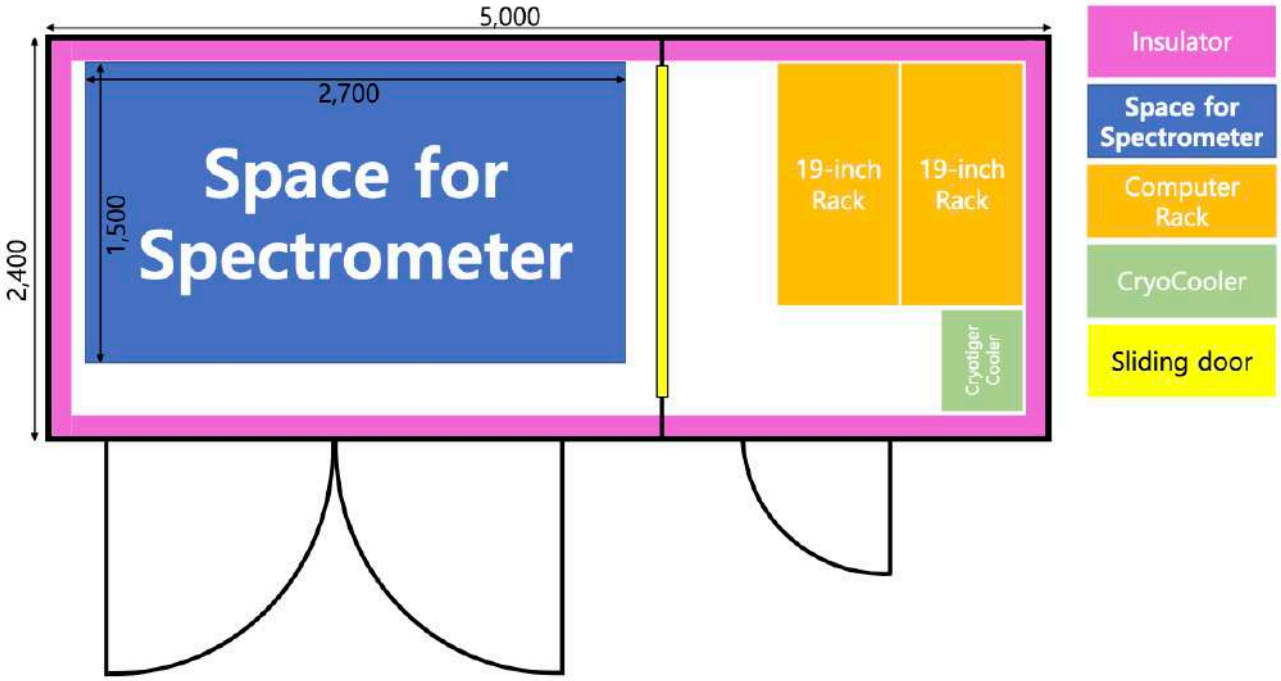
Planned to be delivered by the early Feb. 2025

This is the reason why I spent my sabbatical year now at AAO.

Spectrograph Room

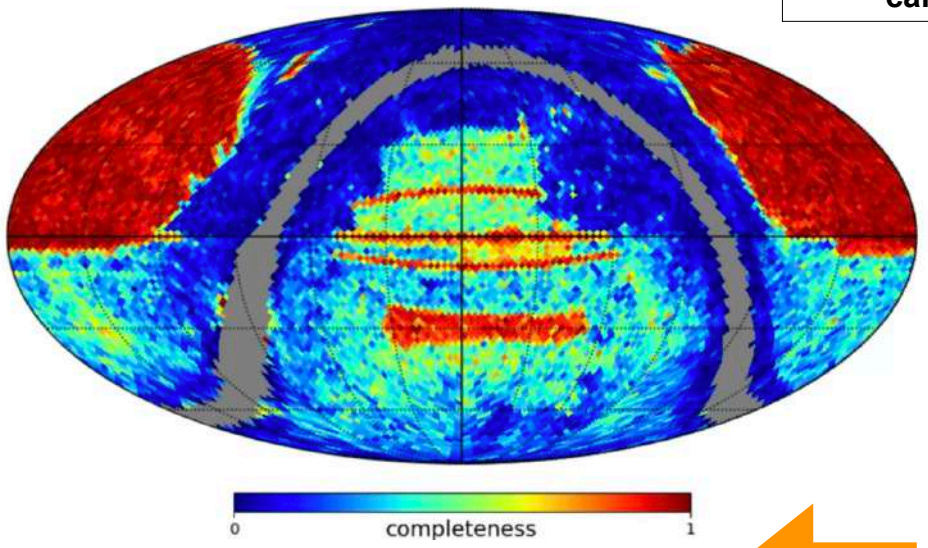




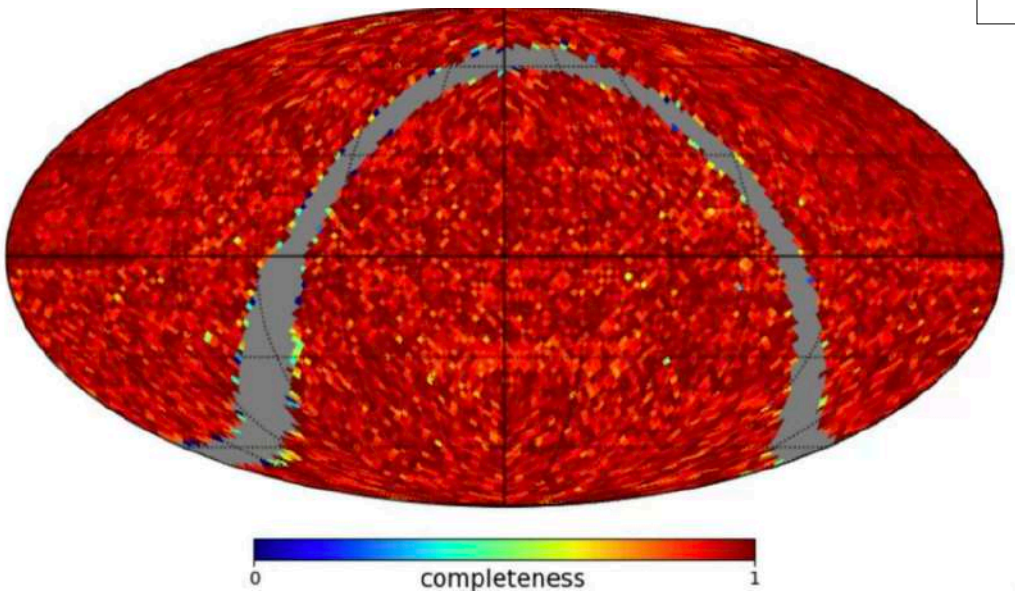


Survey Plan

- **Targets**
  - **Primary: ~165,000 nearby galaxies with K_S < 13.75 (Vega) & −84º.8 < Declination < −21º.4**
  - **Secondary (filler, bright time): metal-poor star candidates, bright quasar candidates, mid-infrared excess galaxies, etc.**

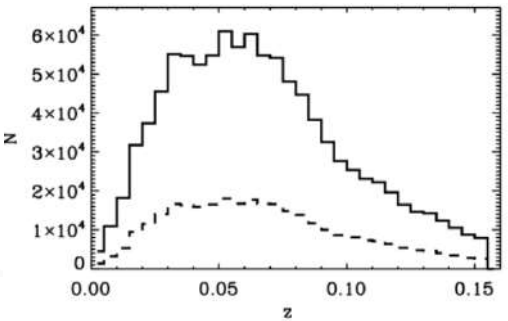


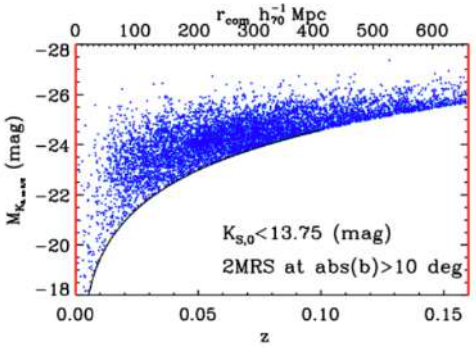
- **209 nights with three blocks of non-bulge season from February 2025**
  - **19 nights in February of 2025 (Commissioning with 15 fibers)**
  - **120 nights from 2025 Oct. to 2026 Feb.**
  - **70 nights from 2026 Oct. to Dec.**



Aiming >90% completeness

- For Ks<13.75 galaxies (~782,000 sources)
- On the nearly entire sky





A-SPEC Mock Data

Limitations of cosmological simulations

1. Hydrodynamical simulations

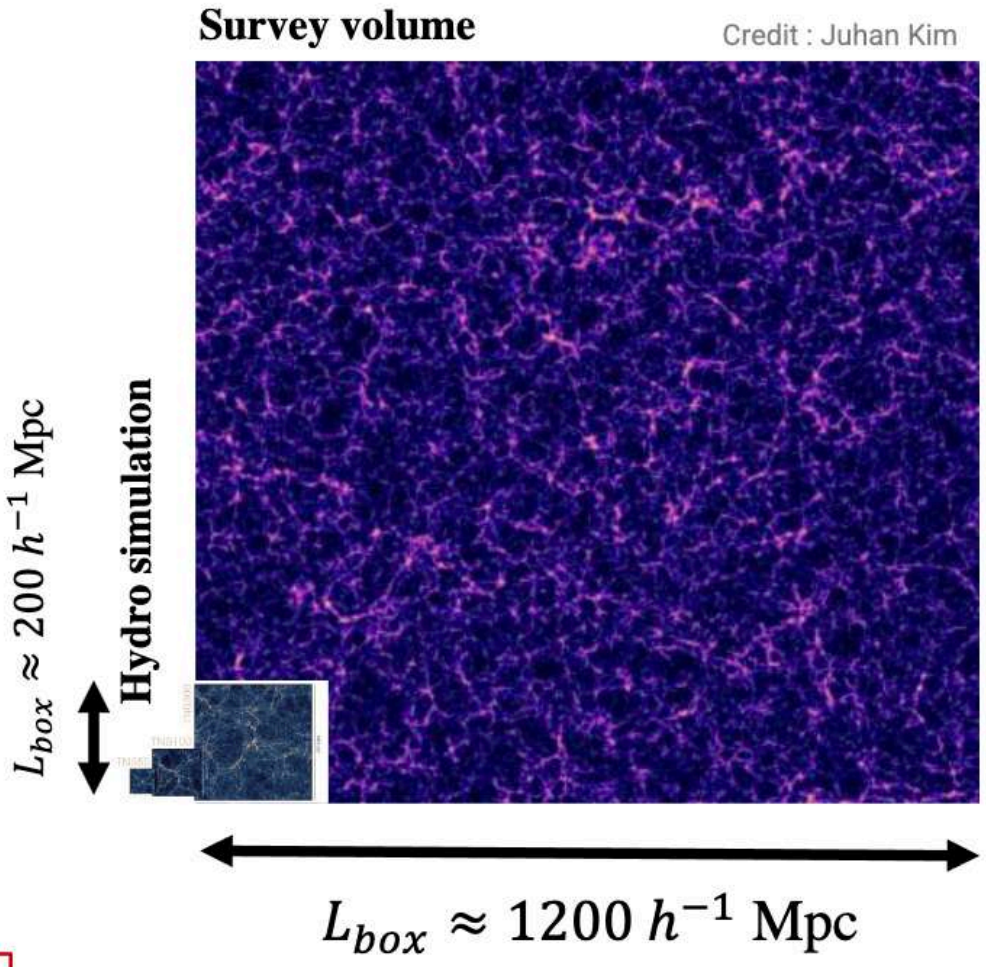
- Much smaller than the survey volume $\left(<\sim \frac{1}{200}\right)$

2. N-body simulations

- No baryonic properties (stellar mass, magnitudes, etc.)
- Various methods(Abundance matching, SAM, etc.) are used to connect dark matter halos identified in N-body simulations to galaxy properties.

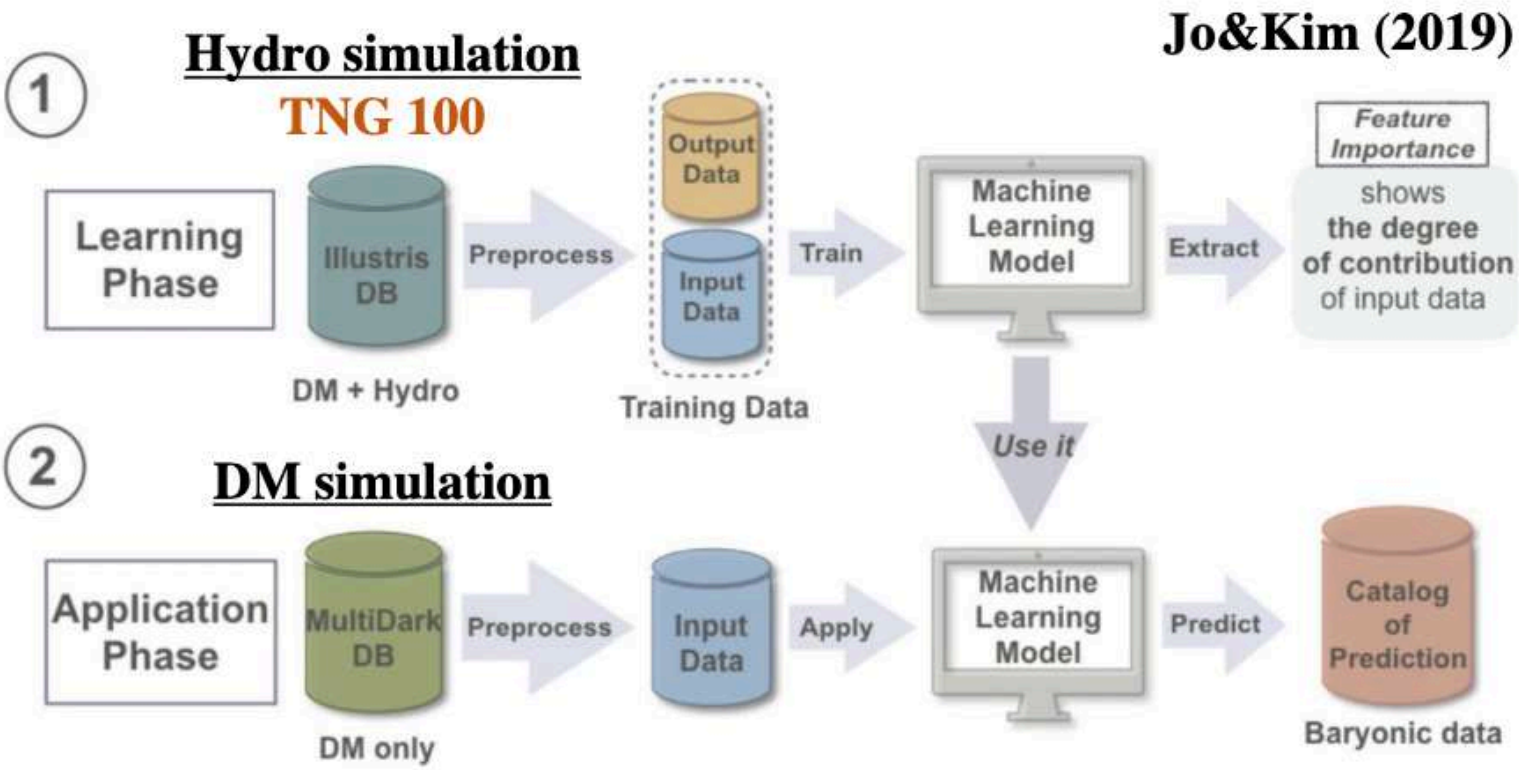
→ Require many tunable parameters

We decided to adopt MSSM (Machine-assisted semi-simulation model)



A-SPEC Mock Data

Halo painting with MSSM



Input parameters : DM halo mass, Velocity, Merger tree, Local information, etc.

Output parameters : Stellar mass, Magnitudes(K, r, etc.), SFR, Metallicity

A-SPEC Mock Data

MSSM applied to N-body simulations

You can ask Dongkok Kim (SNU) for more details.

1. A-SIM (KIAS)

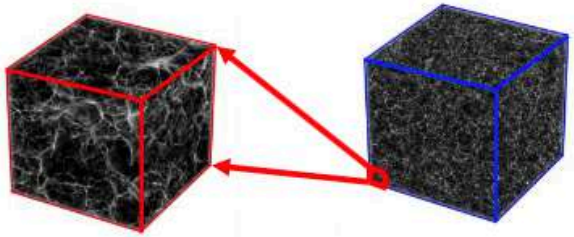
$L_{box} = 1228.8\ h^{-1}$ Mpc

WMAP5 cosmology

$N_p = 4096^3$

$m_p \approx 1.95 \times 10^9\ M_\odot$

Subfind subhalo catalog



2. Uchuu (Ishiyama 2021)

$L_{box} = 2000\ h^{-1}$ Mpc

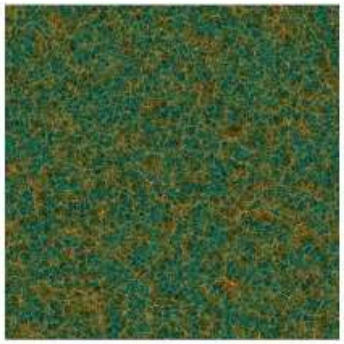
Planck cosmology

$N_p = 12800^3$

$m_p \approx 3.27 \times 10^8\ M_\odot$

Rockstar subhalo catalog





In Summary

1. A development of MOS (K-SPEC)
   for an all-sky spectroscopic survey of
   nearby galaxies at K_s<13.75 (A-SPEC) is going well as planed
   1. Southern Hemi. with KMTNet 1.6m telescope at SSO
      1. Key components
         1. Fiber Positioners
         2. Mounting plates
         3. Cage for the Fiber Positioner System
         4. Wide-field corrector
         5. Fiber view camera
         6. Guiding/Focusing modules
         7. …

2. There are lots of opportunities for you in this direction!

Thank you!

Backup Slides

How underdense with the current data?

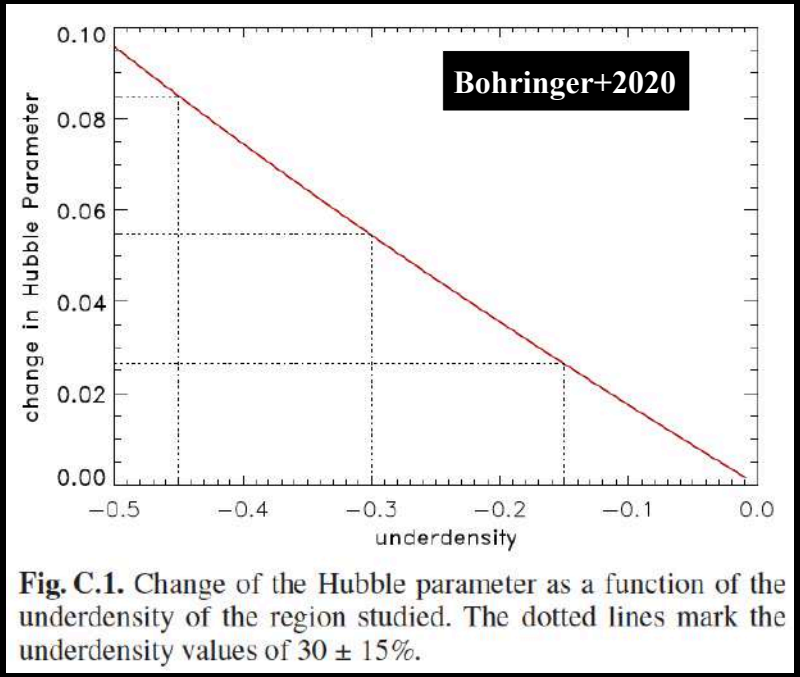
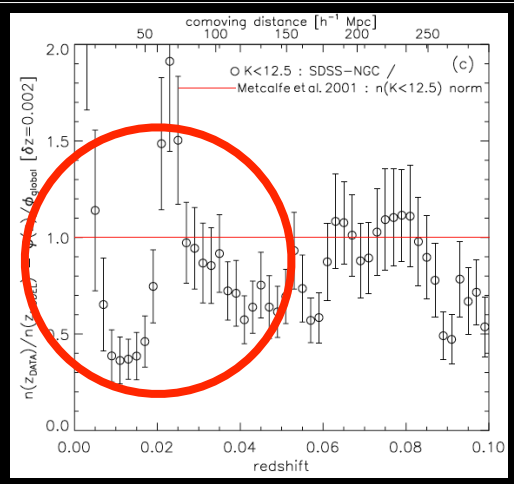
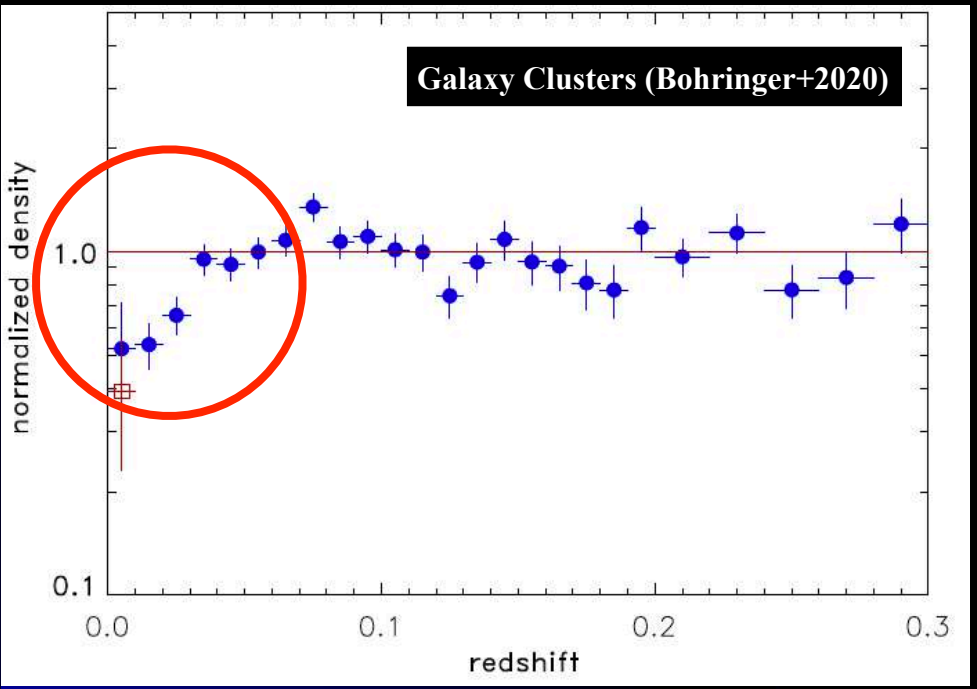


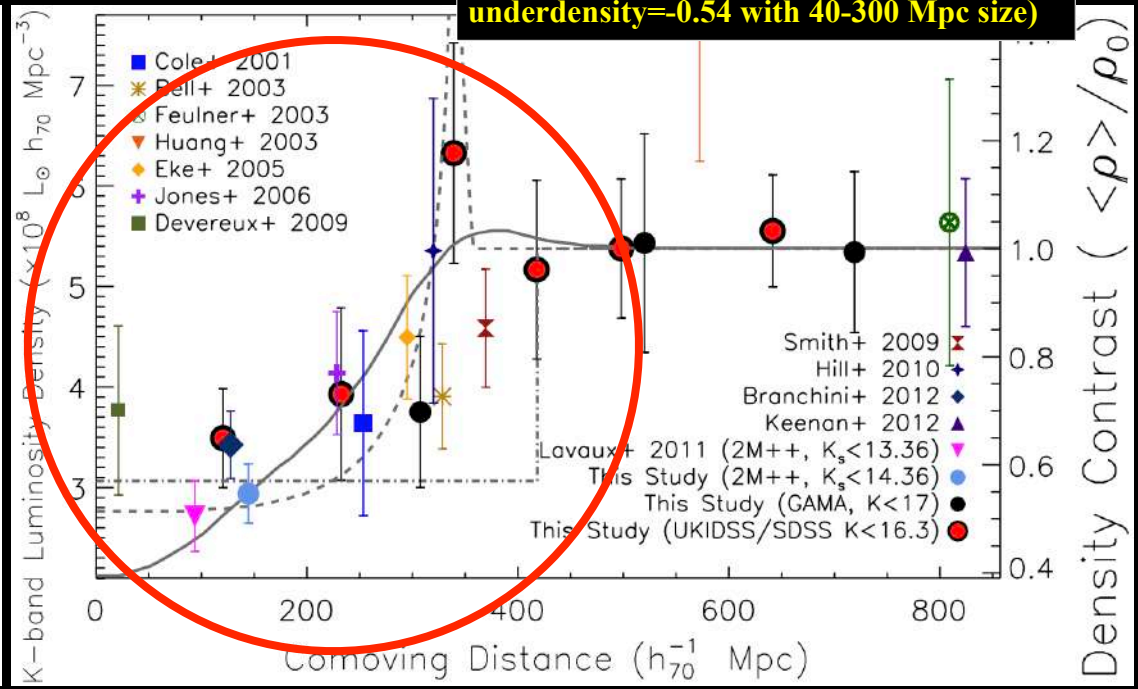
Fig. C.1. Change of the Hubble parameter as a function of the underdensity of the region studied. The dotted lines mark the underdensity values of 30 ± 15%.

Galaxies (Whitbourn & Shanks 2014)





Galaxies (Keenan+2013; KBC void, underdensity=-0.54 with 40-300 Mpc size)



How underdense with the current data?

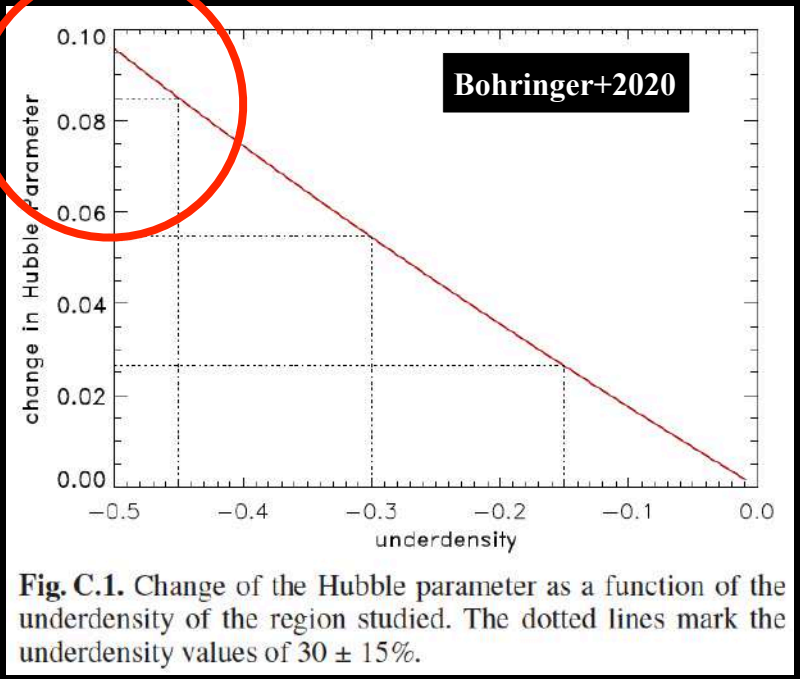
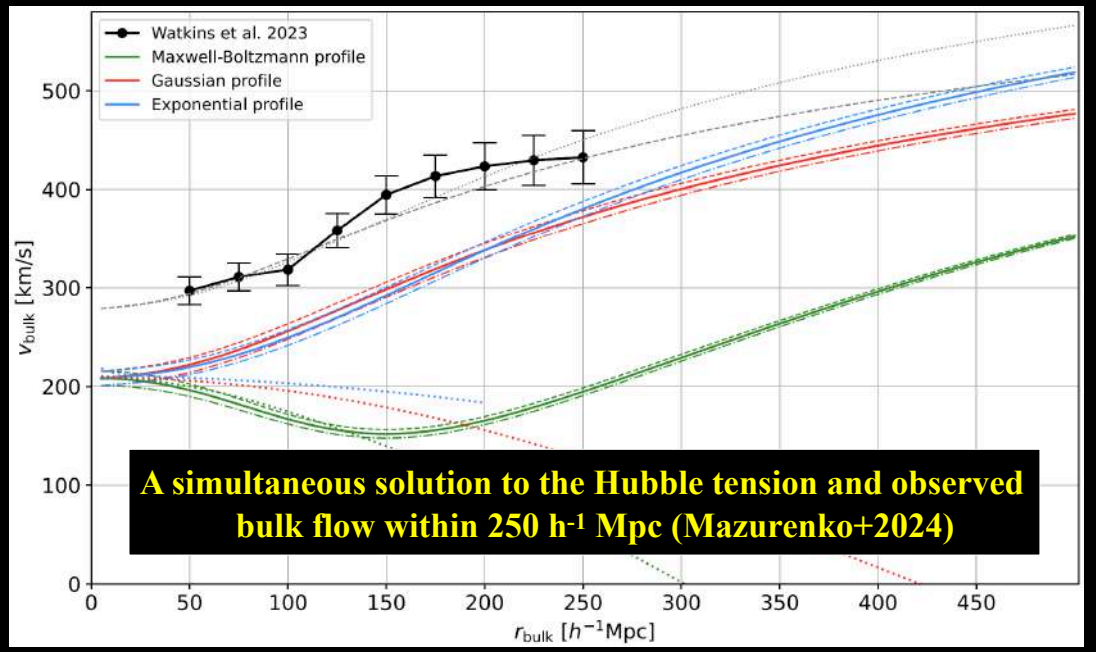
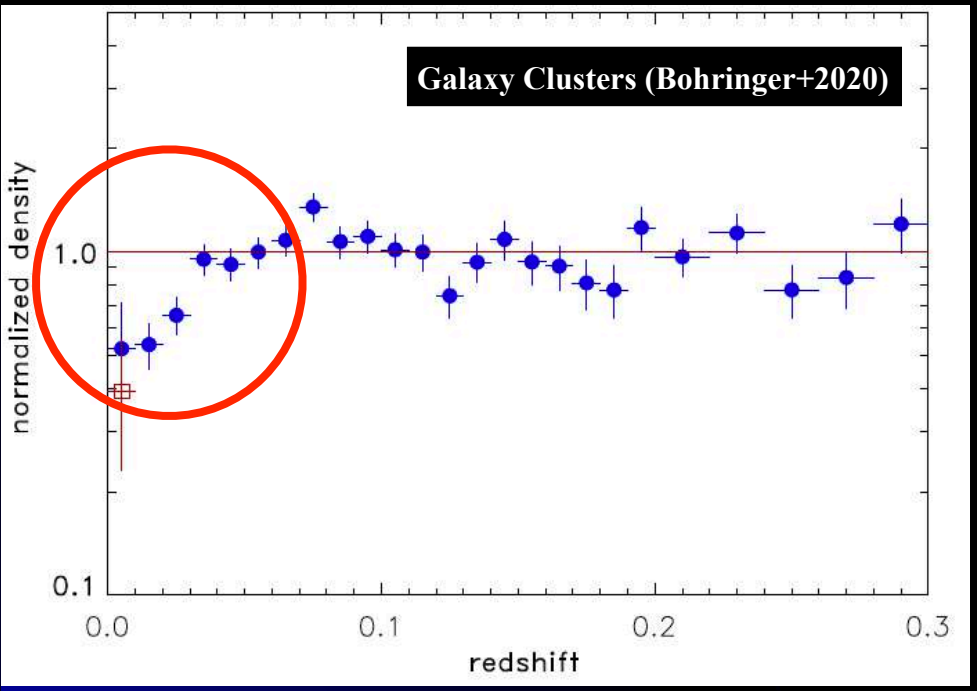
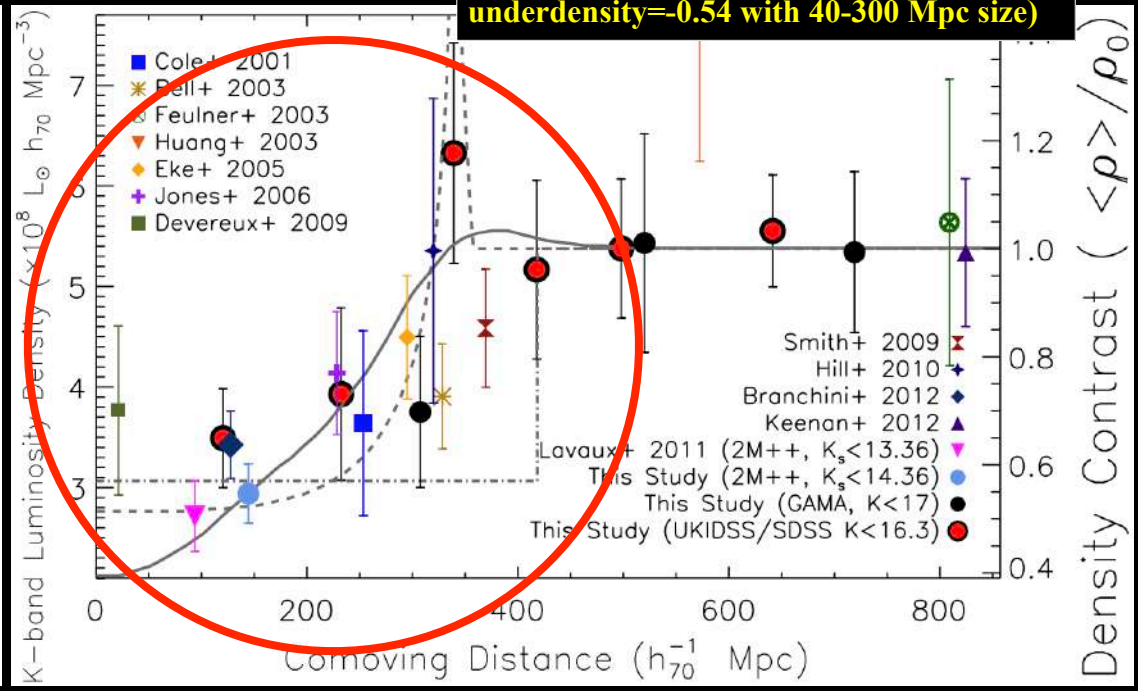


Fig. C.1. Change of the Hubble parameter as a function of the underdensity of the region studied. The dotted lines mark the underdensity values of 30 ± 15%.







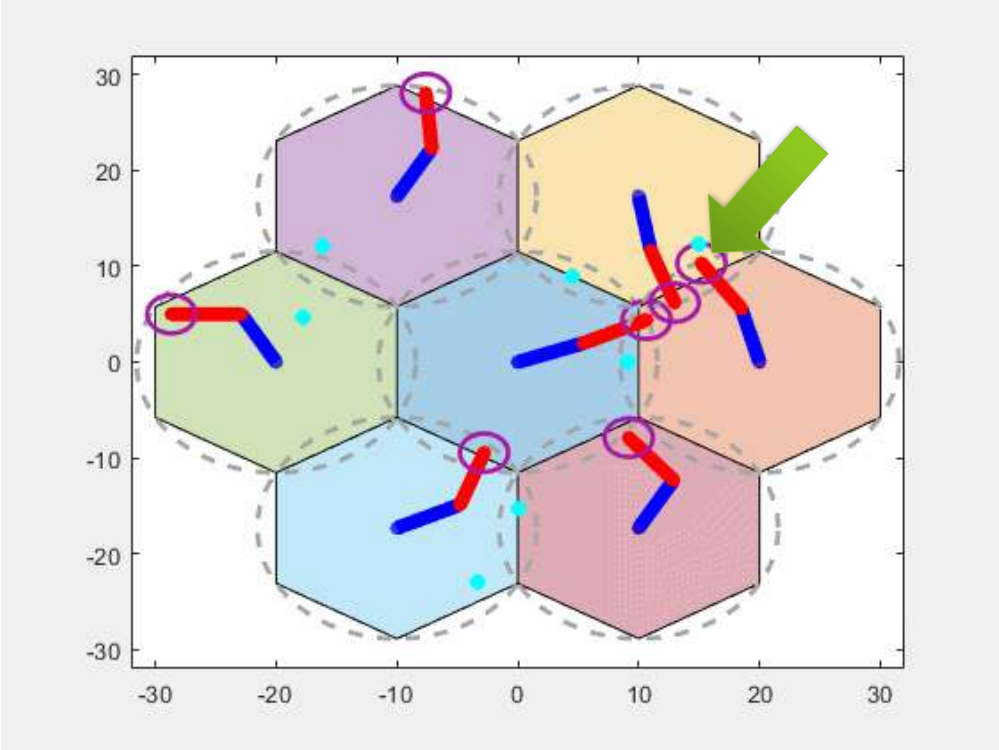
Expected Data Products

1. Target Selection Criterion: ~782,000 sources
    1. Any sources with K_S<13.75 mag (r~16.8) in the 2MASS Extended Source Catalog
        1. To construct a good(?) sample of galaxies at z<0.15
    2. Masked region:
        1. l<30 or l>330 (Galactic bulge): |b|<8 deg
        2. l>30 or l<330: |b|<5 deg

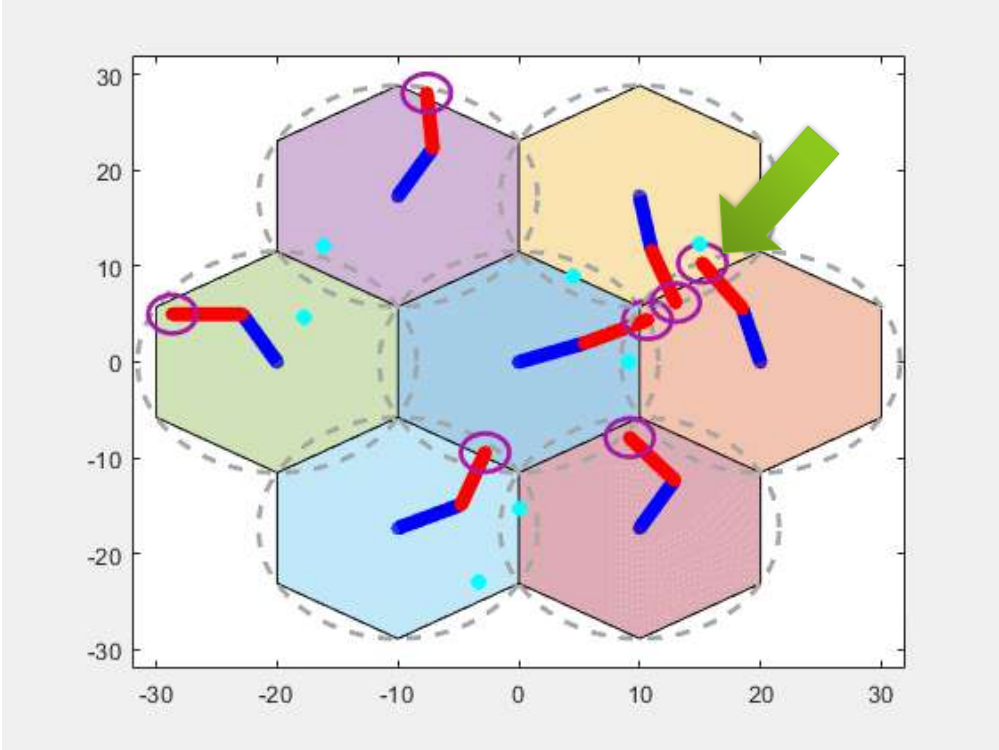
2. Already in our hands
    1. Photometric data
        1. SuperCOSMOS Sky Survey B/R/I bands
        2. 2MASS J/H/K_S bands
        3. WISE 3.4,4.6,12,22 μm
        4. IRAS 12, 25, 60, 100 μm
        5. AKARI 9, 18, 65, 90, 140, 160 μm
    2. Photometric Redshifts
        1. SuperCOSMOS+2MASS+WISE: Bilicki+2014
    3. Spectroscopic Redshifts
        1. Our compilation from the literature for our targets: ~42% (~332,000 sources)

3. To be available when the survey is done
    1. Spectroscopic Redshifts
        1. South (by 2025/26?): ~470,000 sources (90% completeness)
        2. North (by 2027/28?): ~230,000 sources (90% completeness)
    2. (Flux-Calibrated) 1D Spectra
    3. Galaxy properties: K_S absolute magnitude, Stellar mass, Star Formation Rate, etc

Motion Plan : Collision Avoidance Simulation



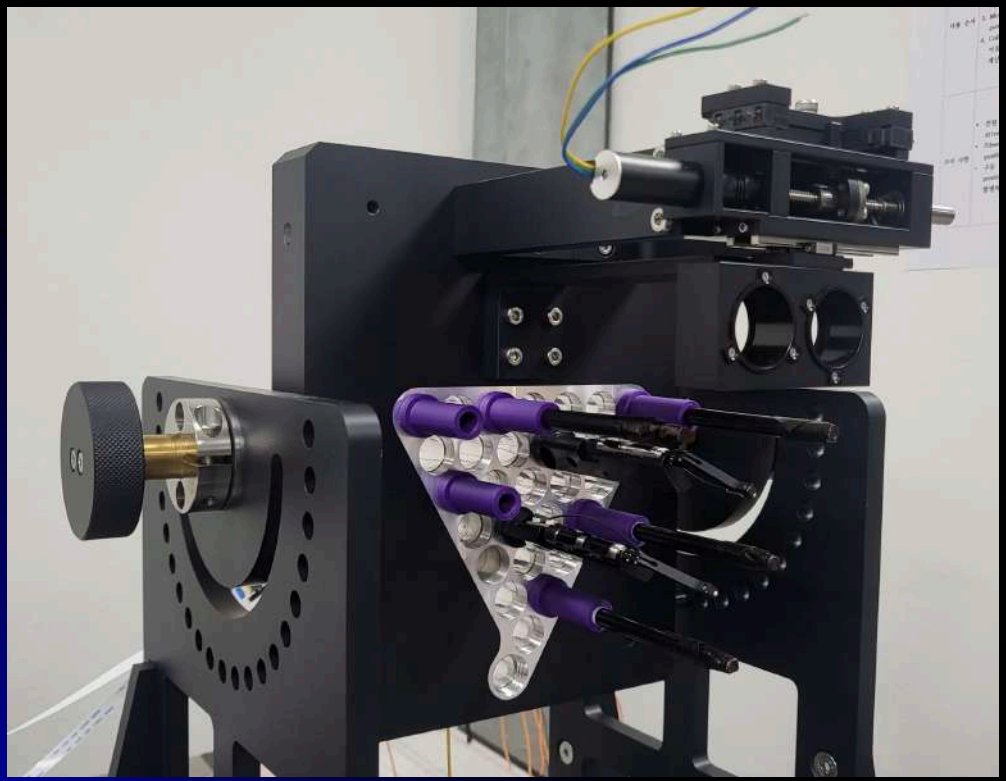
Without Collision avoidance algorithm



With Collision avoidance algorithm

8. Fibers in Real World





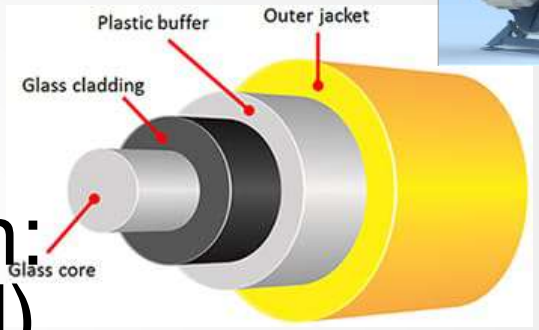


Dec. 20, 2023 [Credit: Dongkok Kim (SNU)]

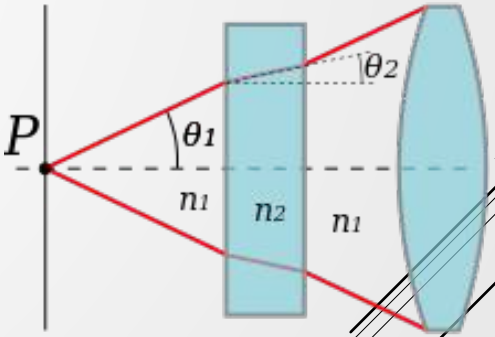
FIBER REQUIREMENTS



- Core diameter: 75 μm
  - Suitable angular size: 3”
  - Suitable spectral resolution: $R > 1{,}900/2{,}100$ (blue/red)



- Numerical aperture (NA): ~0.22
  - Similar to the input beam from KMTNet WFC
  - Minimizing the focal ratio degradation (FRD)



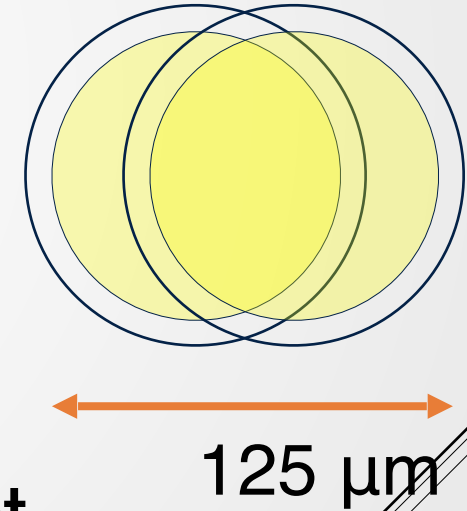
$$\mathrm{NA} = n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Slide from Sungwook Hong

Fiber Requirements - 2

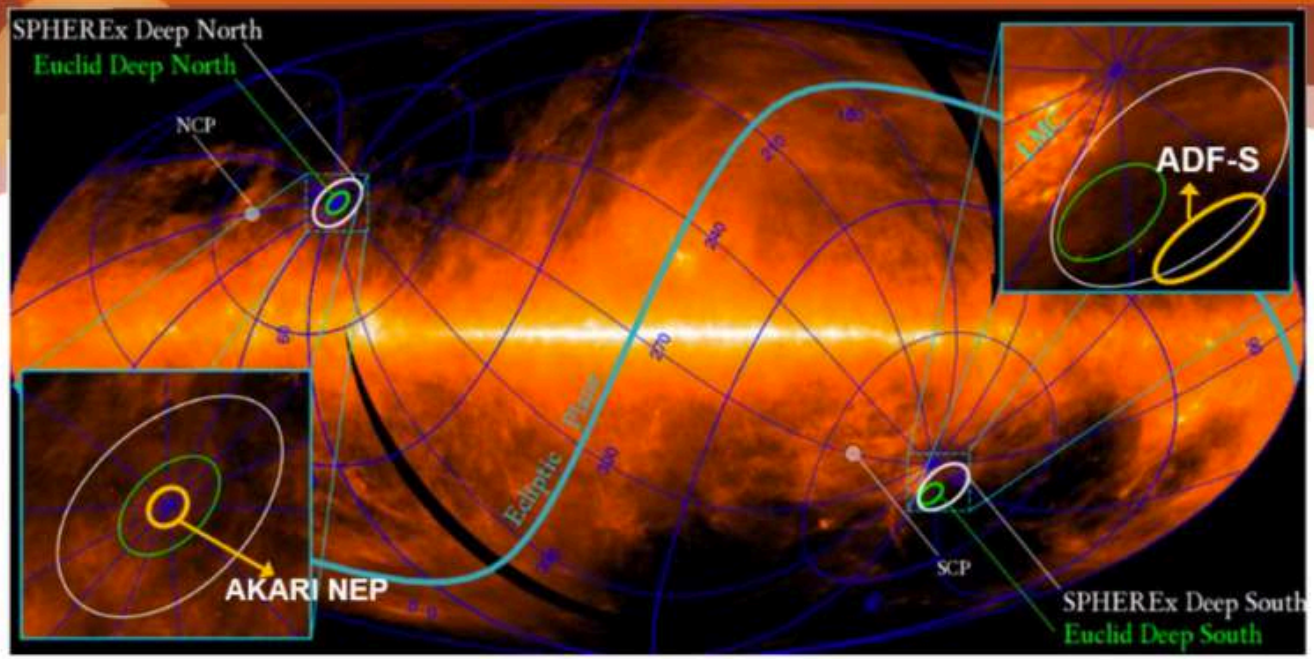
- Cladding diameter: 125 μm
  - Most fiber connectors use 125um-diameter holes
  - Smaller cladding diameter will change the alignment within the connector, which leads the light loss when two fiber cores contact.

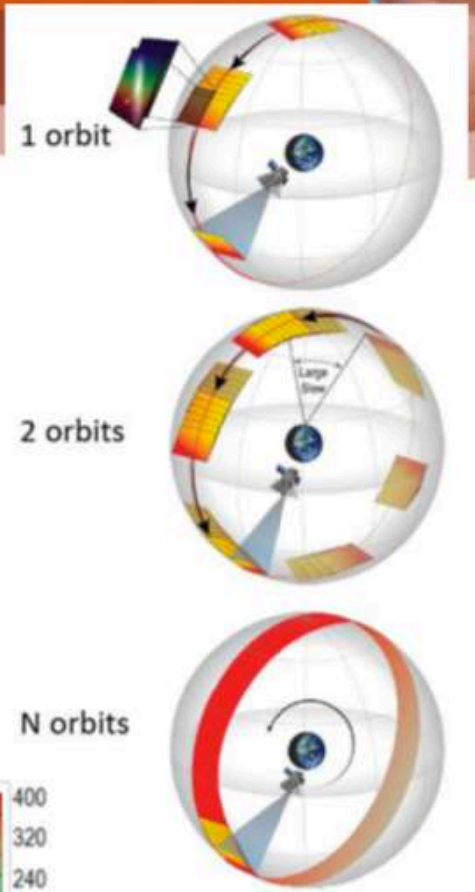


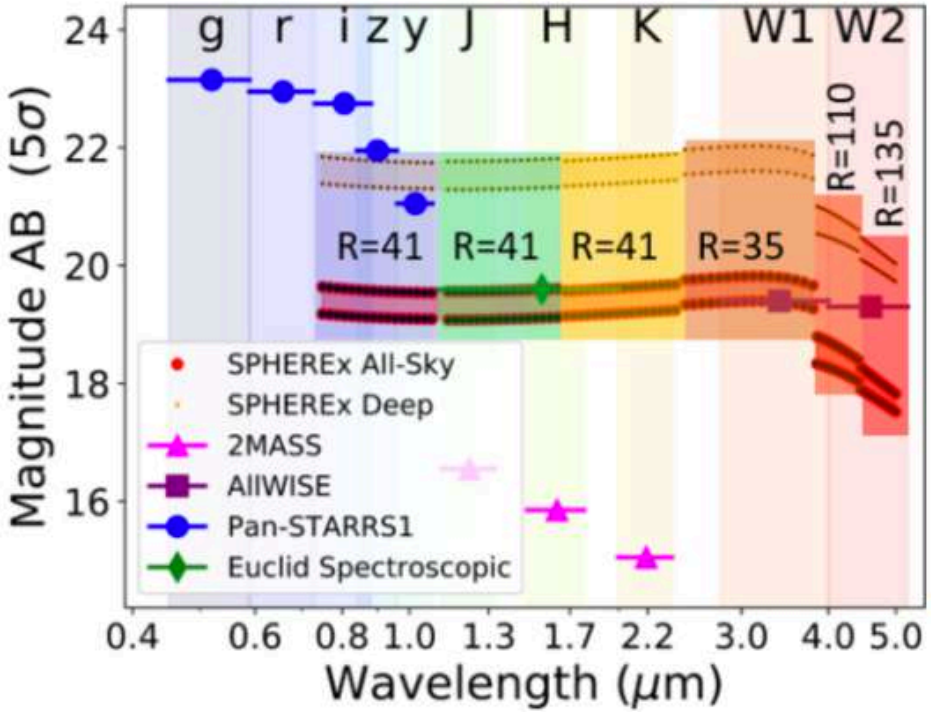


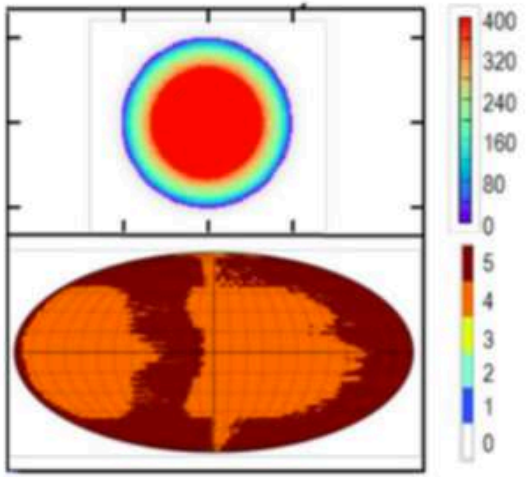
Slide from Sungwook Hong

SPHEREx Mapping & Deep Fields







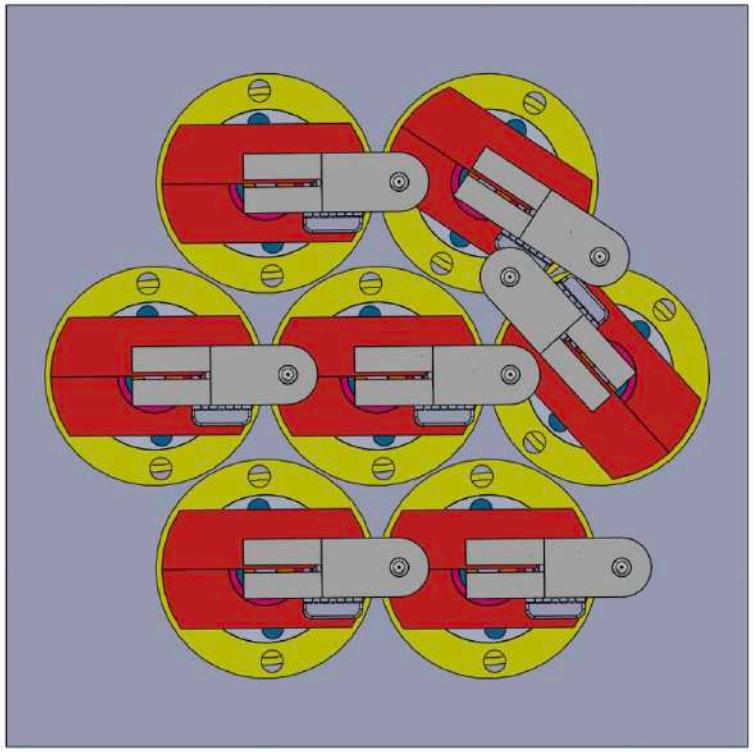


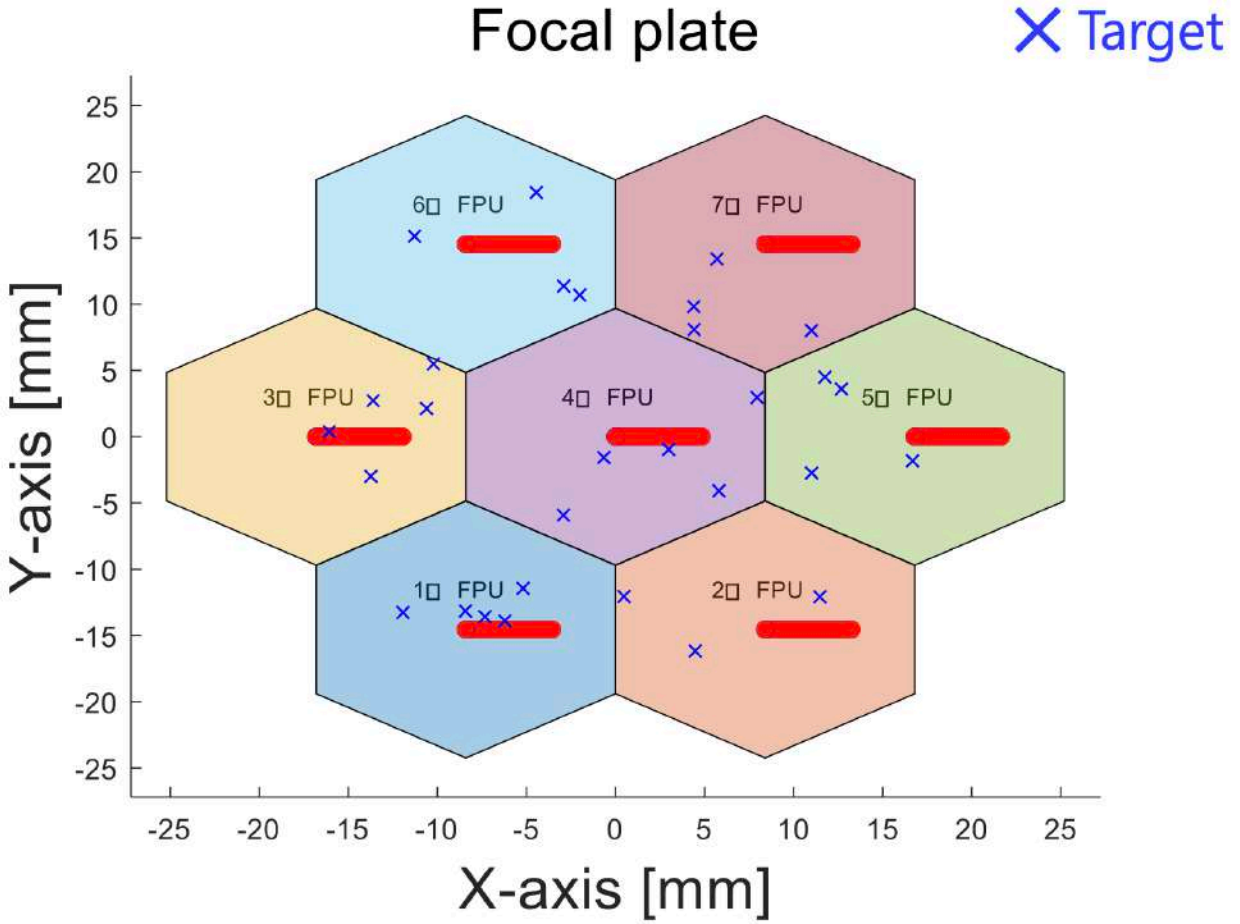
Deep fields @ NEP/SEP: 100 + 100 sq. deg.

Spatially not uniform, but includes Euclid DFs

Adopted from Woong-Seob Jeong's Slides

Motion Plan

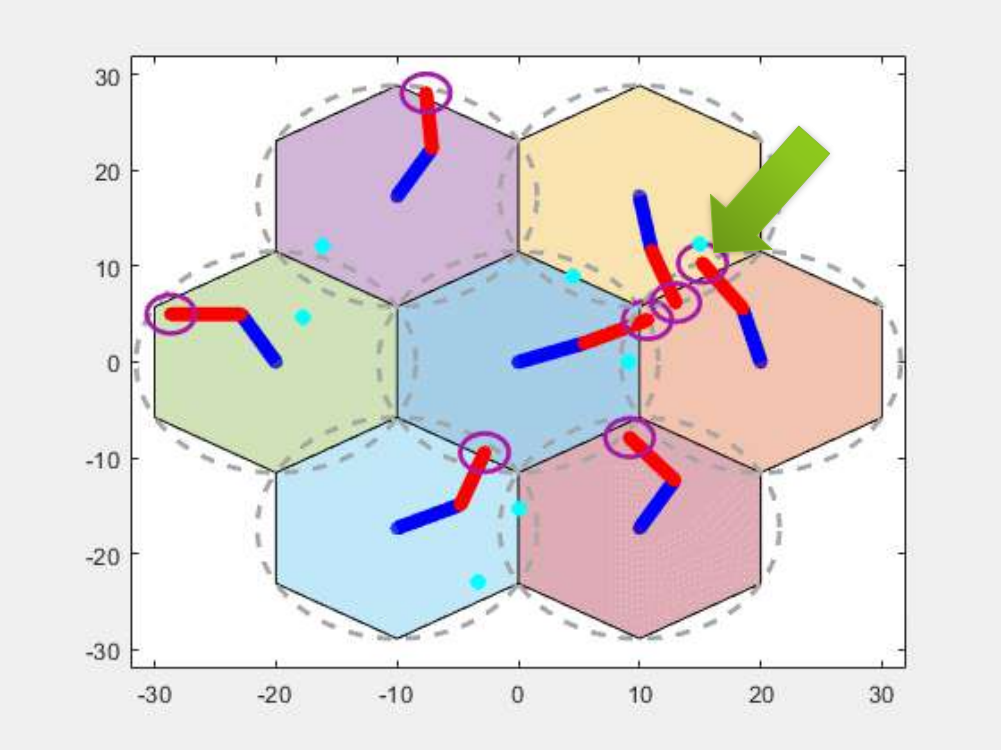




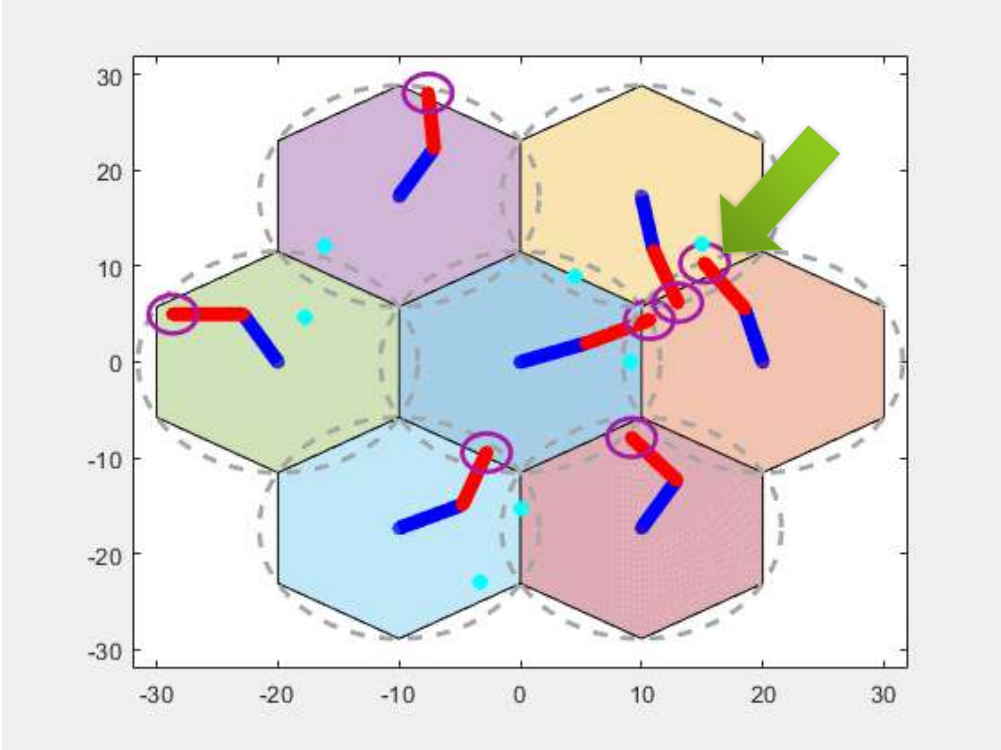
- 7개의 FPU와 30개의 Target을 통해 Simulation 진행
- Target assignment는 측정 가능 영역에서 랜덤하게 선택
- Collision avoidance algorithm은 기존 연구*를 적용함

*Collision Avoidance in Next-generation Fiber Positioner Robotic System for Large Survey Spectrograph, A&A 566, (2014)

Motion Plan : Collision Avoidance Simulation

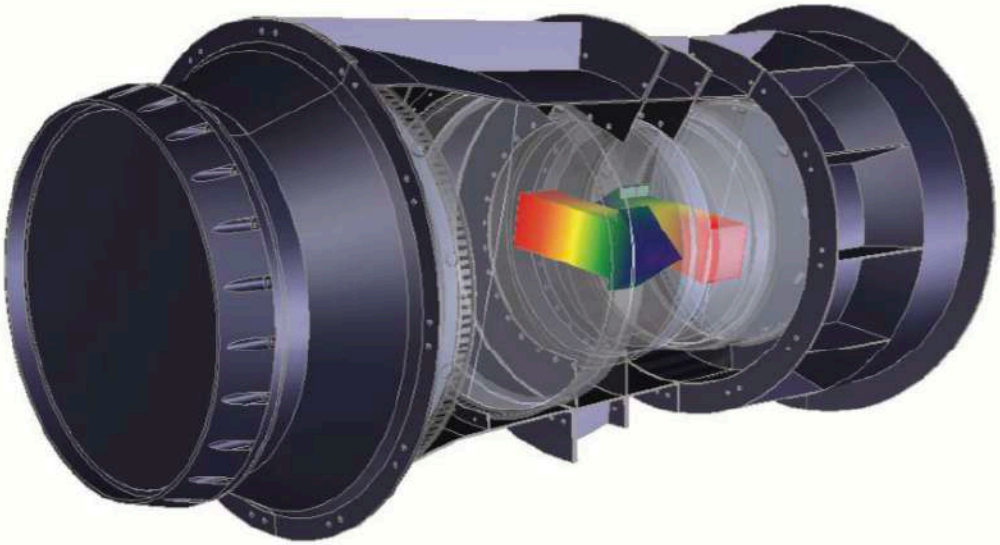


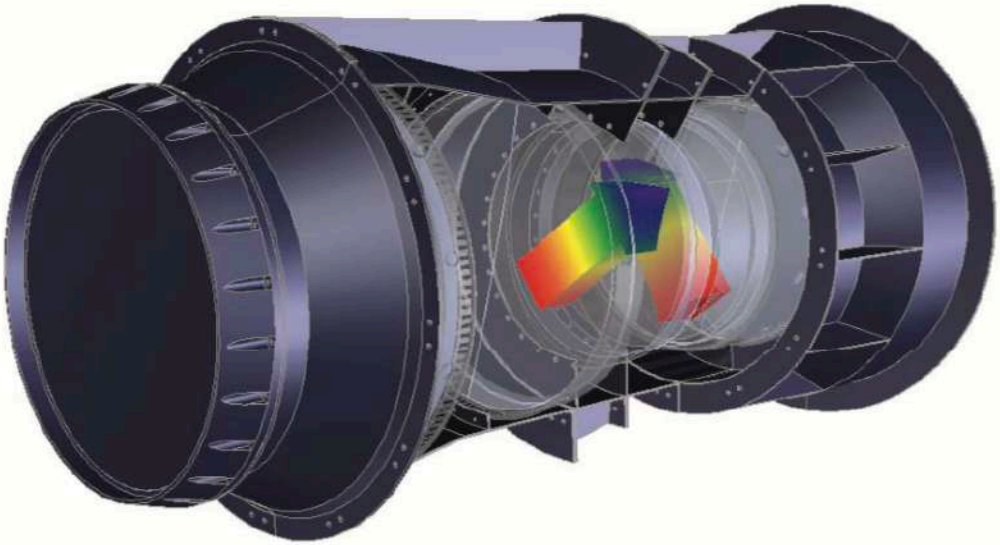
Collision avoidance 미적용

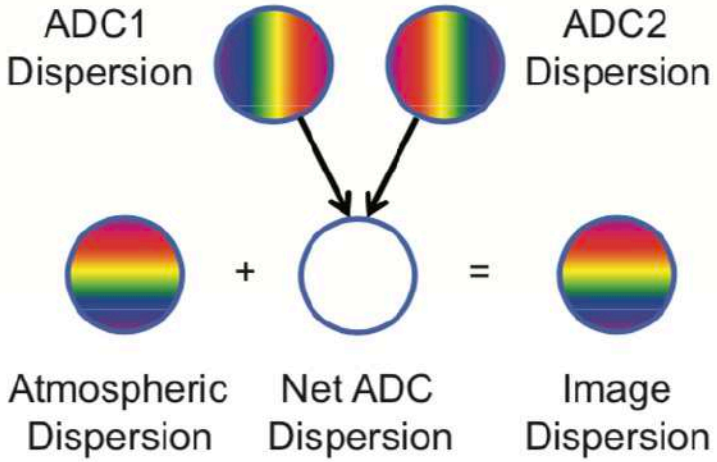


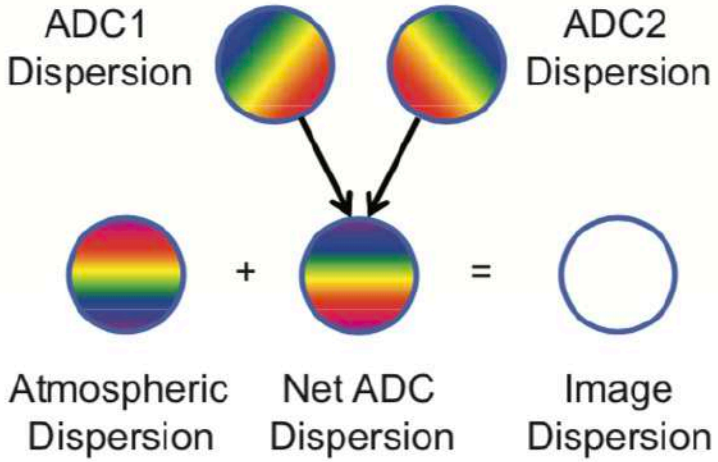
Collision avoidance 적용

4. Wide-Field Corrector (e.g. DESI)





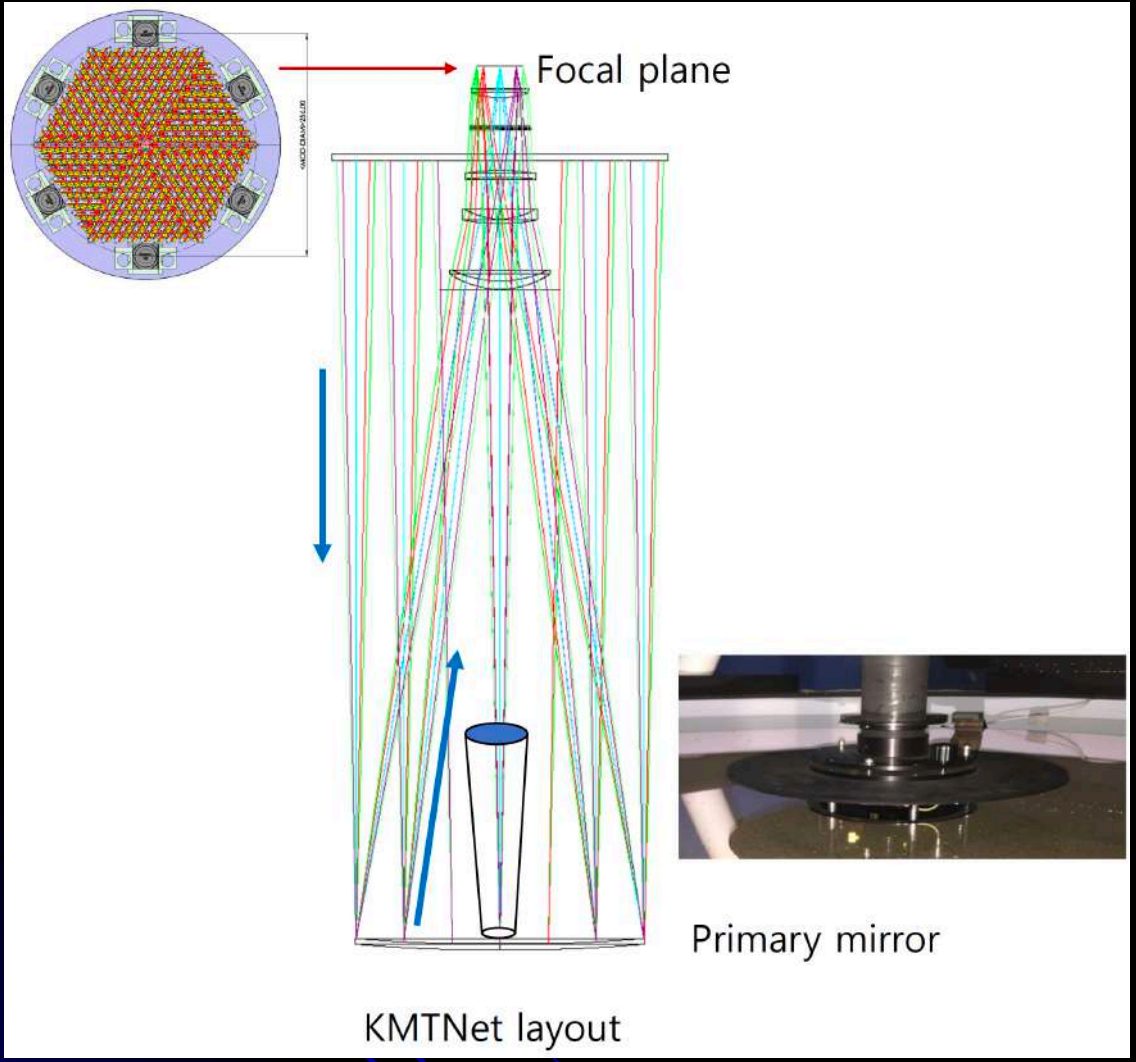




준비: 김윤종/오희영 (천문연)

5. Fiber View Camera (Metrology System)

Credit: Dongkok Kim (SNU)

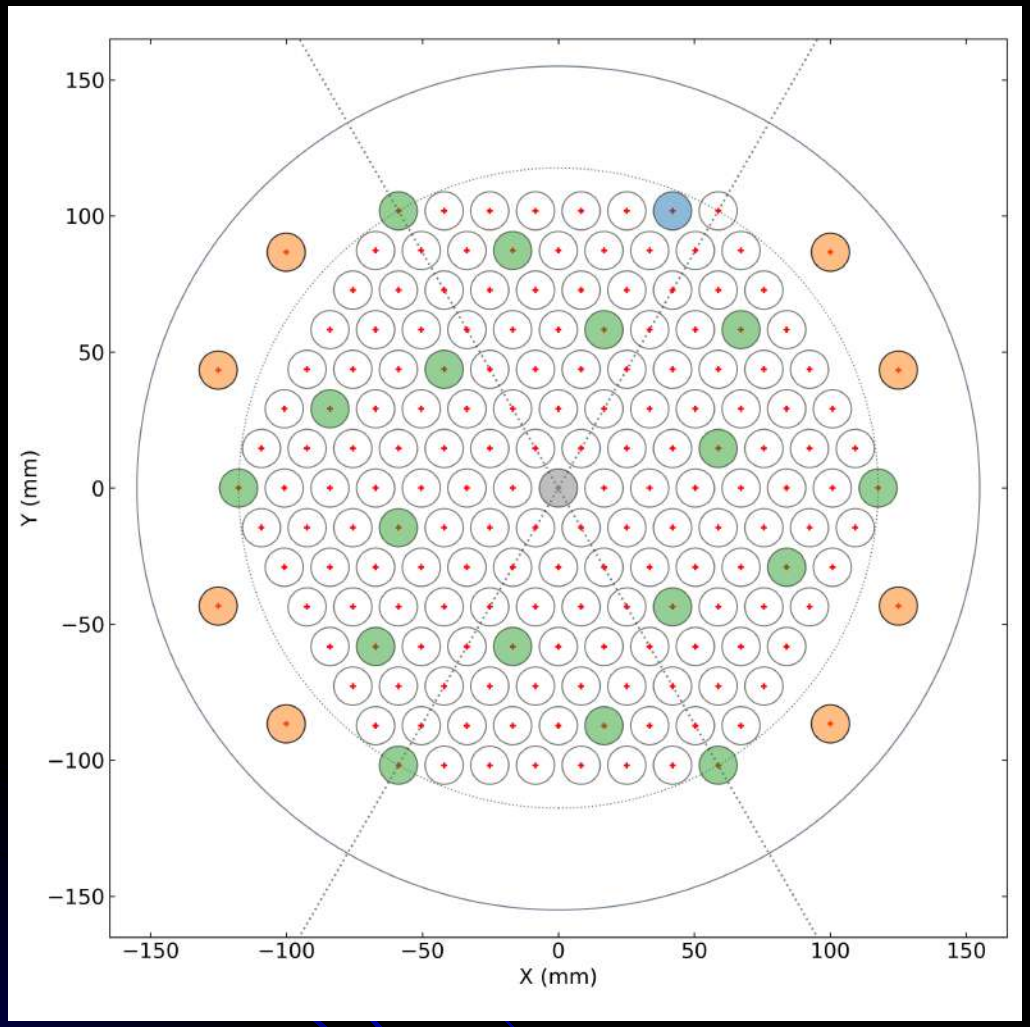


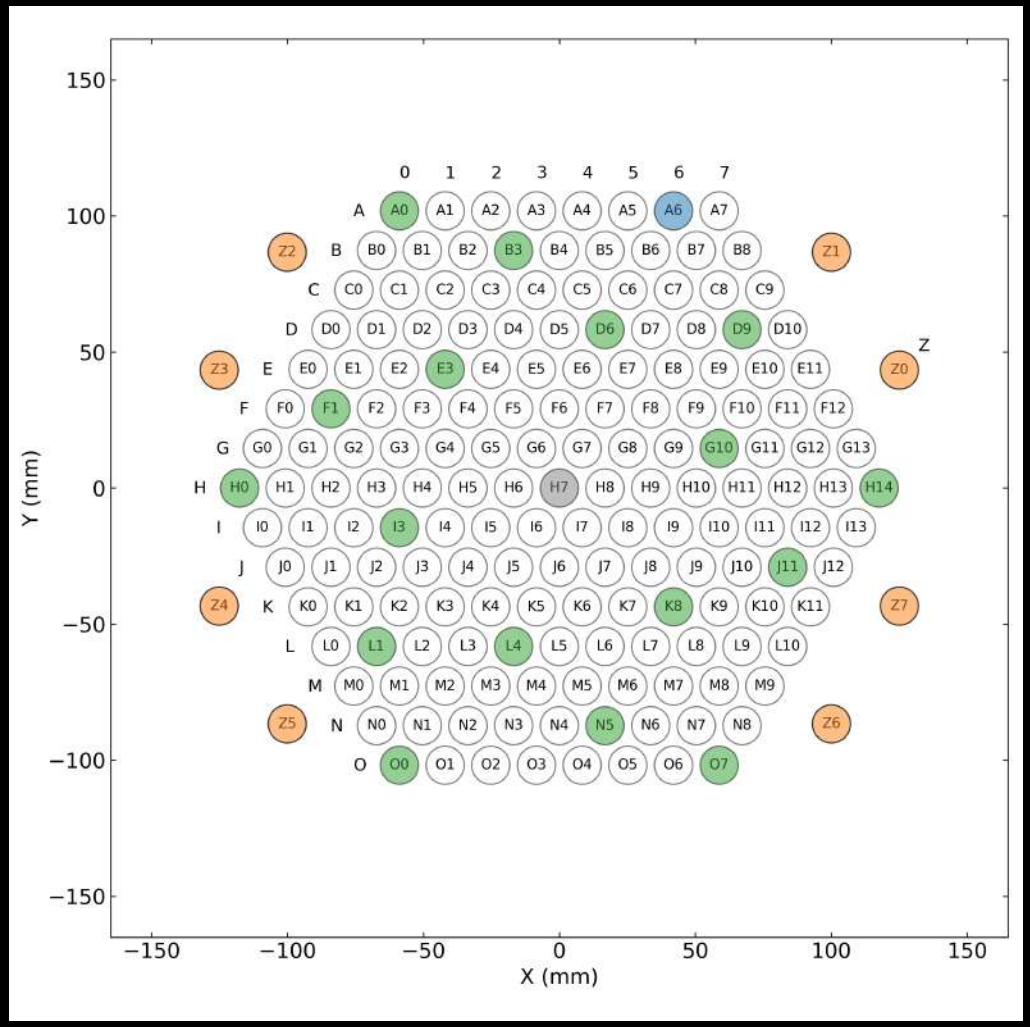


Goal 1: To monitor the exact positions of the fiber positioners and to provide the offset between the target positions and the fiber positioners

*** We need a light source from the spectrograph for back illumination**

5. Fiber View Camera (Metrology System)





Goal 2: Fiducial - To provide the reference positions (e.g. field distortion) for the fiber positioners

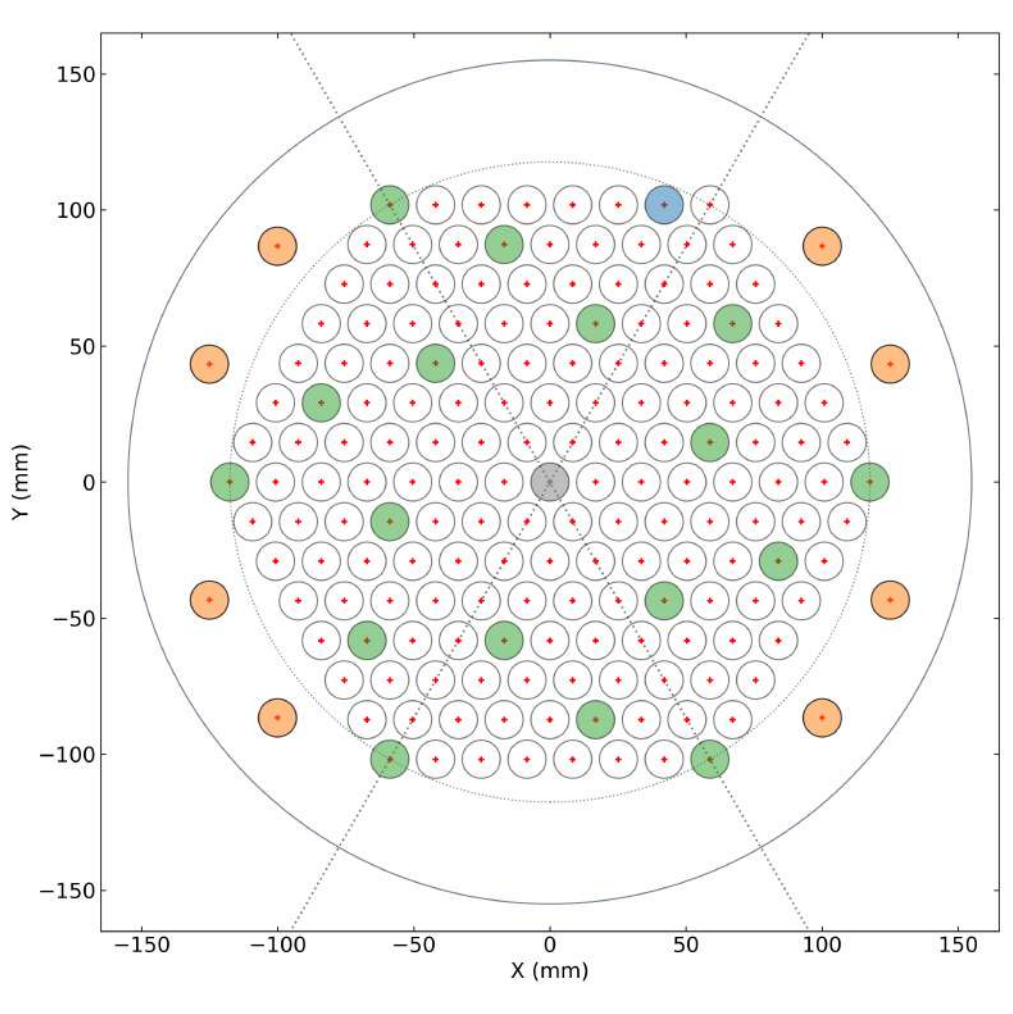
Credit: Dongkok Kim (SNU)

Q: Why KMTNet (large FoV, 24/7 monitoring)?

1. Right telescope for this survey!
    1. Wide-Field of View: survey efficiency
    2. Southern Hemisphere: LSST follow-up, GMT preparation

2. Should we give up the unique feature of KMTNet? (24/7 continuous monitoring of a target)
    1. 24/7 monitoring is mainly for the observation of Galactic bulge. We will use non-bulge time (4 months) for our survey (with 1 telescope)
    2. Eventually, we can think about 24/7 spectroscopic monitoring with 3 telescopes! (e.g. any bright variables from LSST?, AGN)

Fibres in Summary



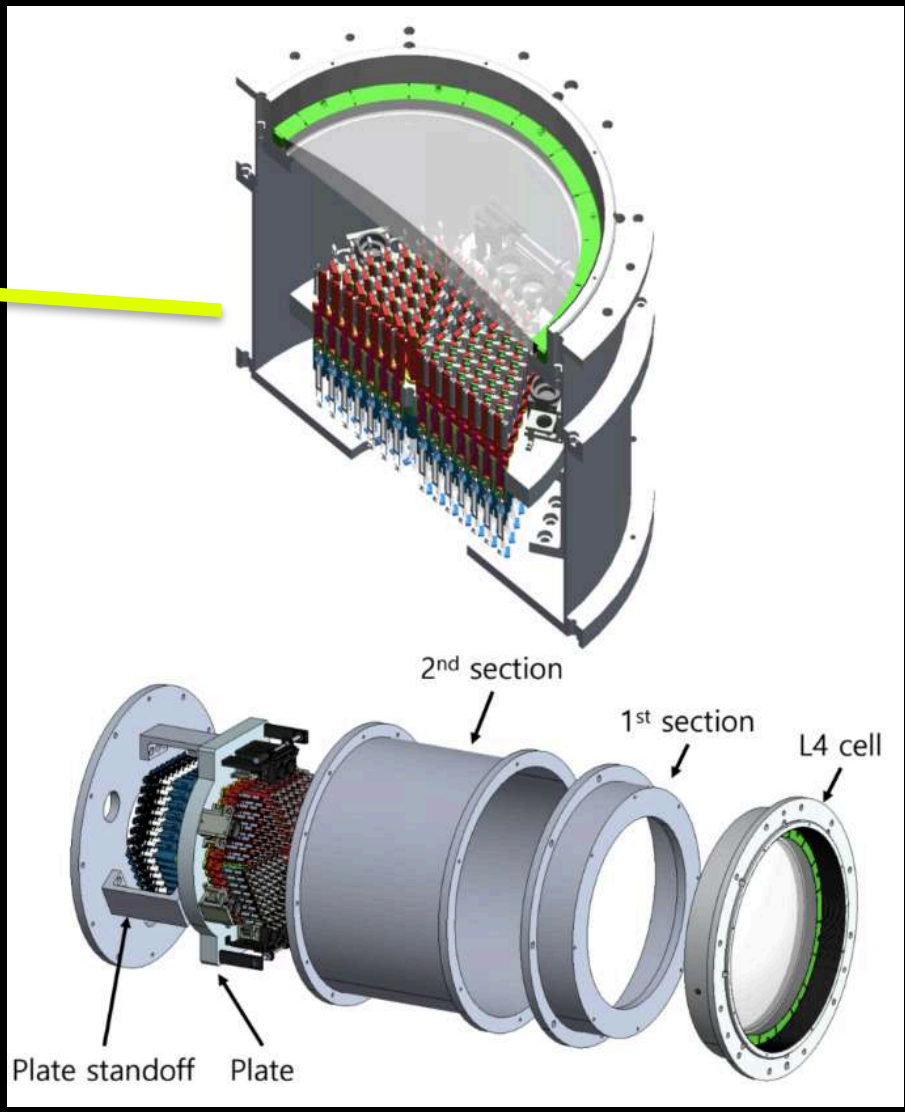
* Total number of holes: 177 (= 169 + 8)
  * Number of Fiducials: 26 (= 8 orange + 18 green/blue)
  * Number of hole for a guiding camera in the center: 1 (gray)
  * Number of fibers for scientific observation: 150
    * For Targets: ~130
    * For Skys: ~20

Credit: Dongkok Kim (SNU)

3. Focal Plane Hardware

A new system will replace the current imaging camera!!!





Slide from Jae-Woo Kim

Q: With this Survey?

➢ **Immediate Goal: Construction of a complete sample of galaxies at z<0.1**

Galaxy Evolution & Galaxy Cluster

- Local superclusters and their members (with K-DRIFT)
- Construction of a complete catalog of galaxy clusters/groups
- Connection between BCG and host clusters
- Evolutionary stage of galaxy clusters from their environment
- Effect of cluster-cluster interaction on galaxy properties
- All-sky bright quasar survey

Cosmology

- Cosmic expansion history and dark energy
- Accurate measurement of local density for the Hubble parameter discrepancy
- Cosmological study with local galaxies
- Reconstruction of the local dark matter distribution
- Testing isotropy in the local universe

Stellar

- Nearby stars & halo stars
- Chemical linking of dynamical substructures and stellar stream in the MW
- Red supergiant stars in LMC & SMC

Slide from Jae-Woo

KMTNet

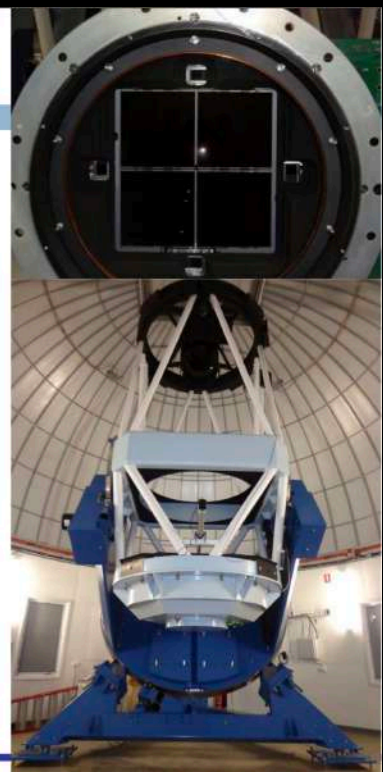
1. Right telescope for this survey!
    1. Wide-Field of View: survey efficiency
    2. Southern Hemisphere: LSST follow-up, GMT preparation



KMTNet Observation System

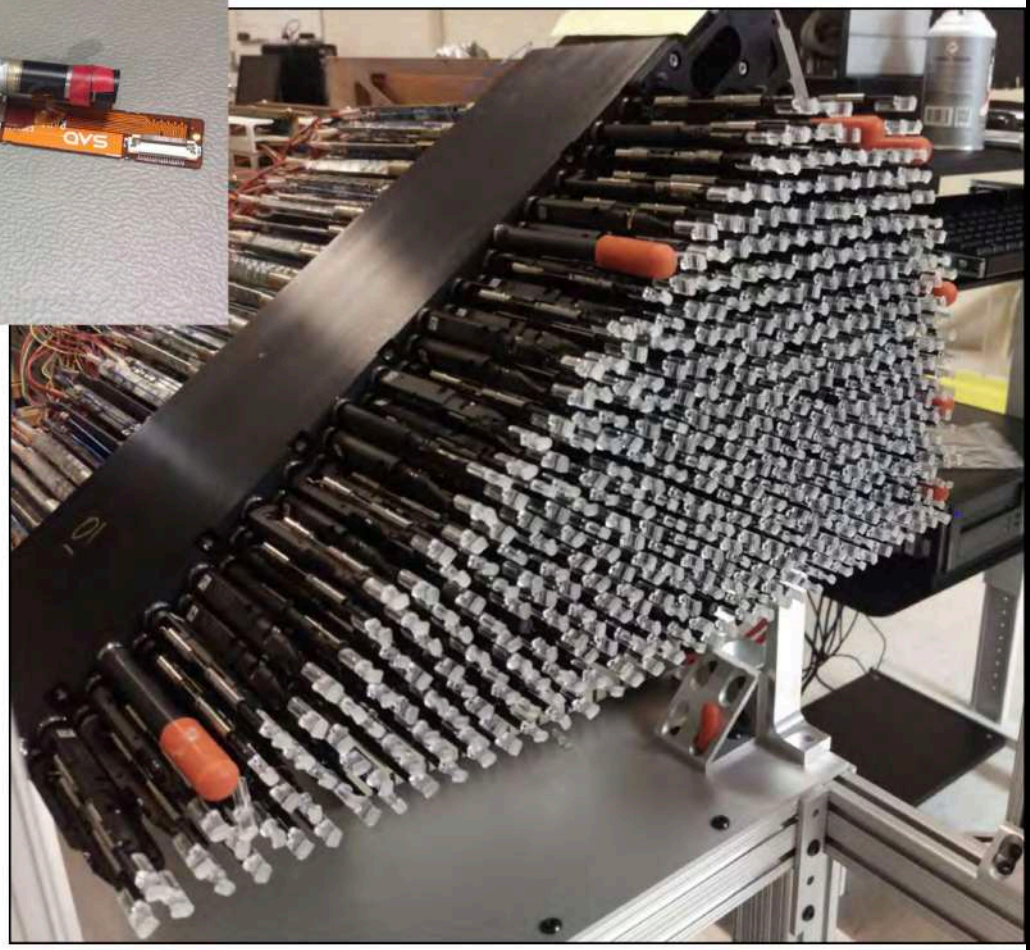
3

- **K**orea **M**icrolensing **T**elescope **Net**work
- Three Identical Observing Systems: CTIO in Chile, SAAO in South Africa, SSO in Australia
- **24-hours Monitoring** of night sky at Southern Hemisphere
- Primary Mirror with 1.6m Diameter
- 4 Chips with 9K x 9K pixels
- 0.4 arcsec/pixel,
- **2°x2° wide-field of view** (FOV)



1. Fiber Positioners

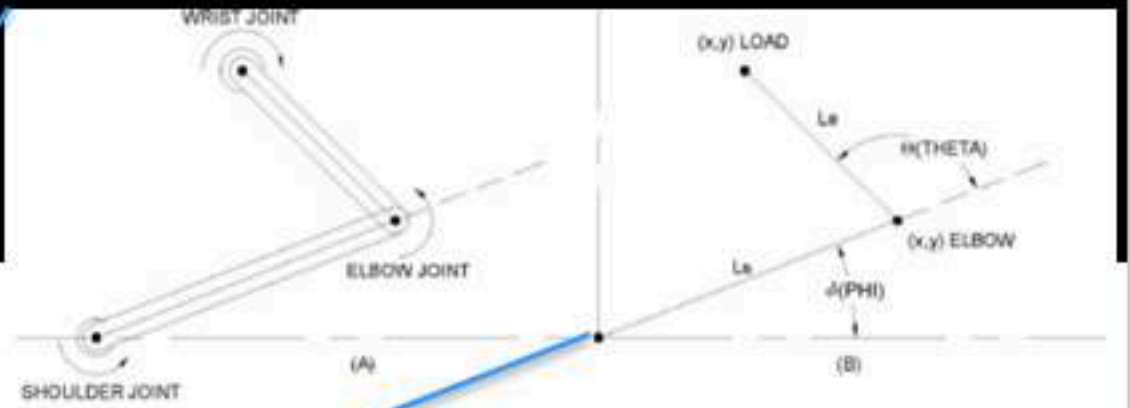


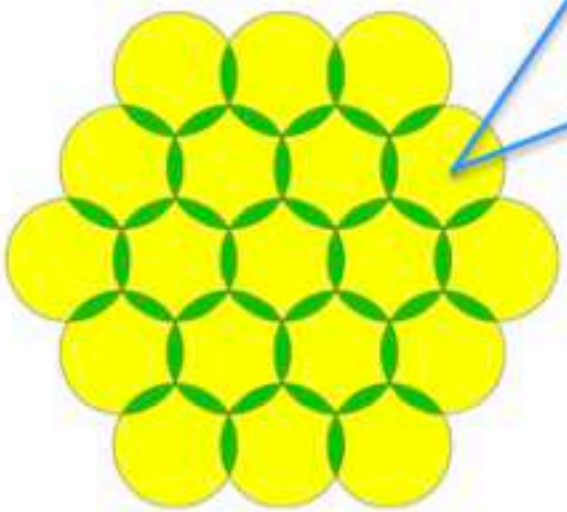


DESI

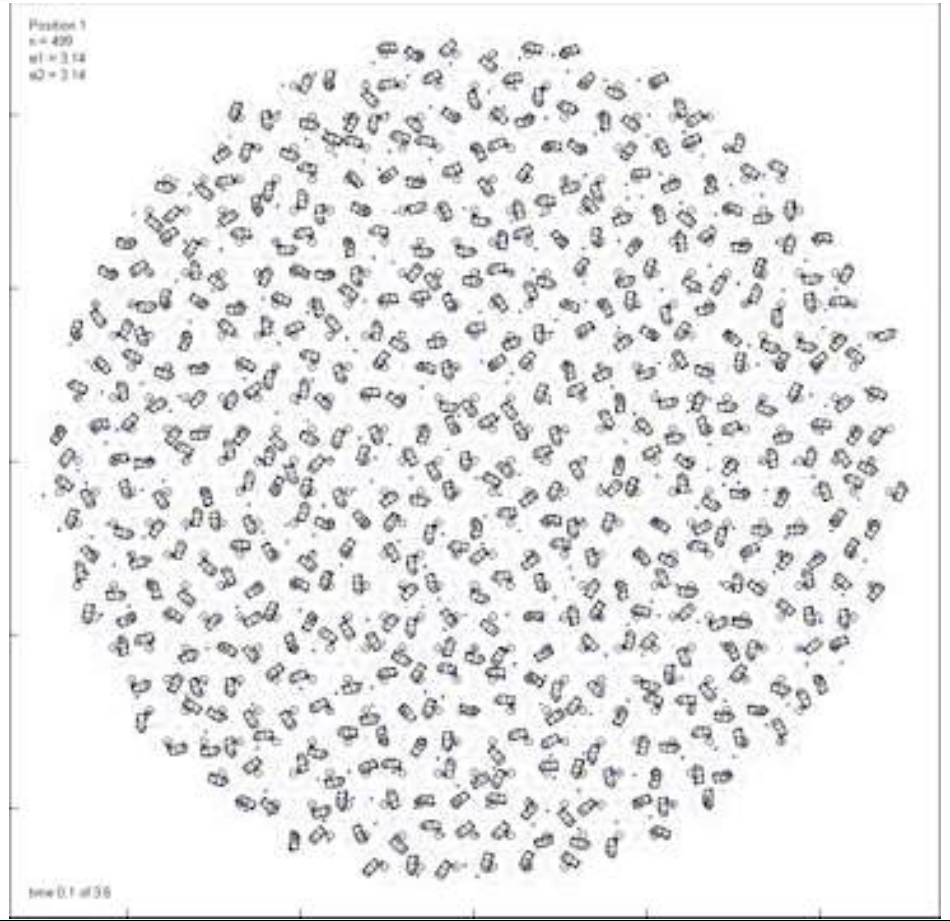
1. Fiber Positioners

Focal plane integration





Positioners reaching their center



DESI

Fiber Positioners

	Cobra[1,2]	MOONS[3]	SDSS-V[4-6]	DESI[7,8]	K-SPEC
Figure					
Range	Φ 9.5 mm	Φ 50 mm	Φ 30 mm	Φ 10.4 mm	**Φ 33.2 mm**
XY Error	≤ 5 μm	≤ 20 μm	10.36 μm (bef. correc.) 1.12 μm (after correc.)	10-13 μm (bef. correc.) 1-2 μm (after correc.)	**≤ 5 μm**
Housing Dimensions	Φ 7.7 mm	-	<Φ 25 mm	Φ 8 mm	**Φ 16 mm**
Actuation Principle	Piezo motor	Stepper motor (MPS Faulhaber)	BLDC motor (MPS Faulhaber)	BLDC motor (Namiki Precision Jewel Co.)	**BLDC motor (Maxon, Swiss)**
Feedback	NO	YES(IEM3-1024)	Hall sensor	Digital hall sensor	**Magnetic encoder (256 pulse/rev)**
Telescope / Instrument	Subaru / PFS	VLT / MOONS	Apache Point / SDSS-V	Mayall 4m / DESI	**KMTNet /K-SPEC**
Research group	Caltech/ New Scale Technologies	United Kingdom Astronom y Technology Center	École Polytechnique Fédérale de Lausanne	LBNL	**Ajou Univ,/KASI**

1. Fisher C., Braun D., Kaluzny J., Haran T., 2009, IEEE Aerospace Conference
2. Status Report, New Scale Technologies, 2016
3. Proc.SPIE 9908, Ground-based and Airborne Instrumentation for Astronomy VI, 990895 (9 August 2016)
4. High density fiber positioner system for massive spectroscopic surveys, MNRAS 481, 3070–3082 (2018)
5. INTERNATIONAL JOURNAL OF OPTOMECHATRONICS, 2020, VOL. 14, NO. 1, 53–77
6. An 8-mm diameter Fiber Robot Positioner for Massive Spectroscopy Surveys, MNRAS 450, 794–806 (2015)
7. The DESI experiment part II: Instrument design (2016)

Credit: Y. Choi/H. Lim (Ajou)

Design of Fiber Positioner

