The SDSS-V Local Volume Mapper

A 1-sterad IFU survey

Niv Drory (PI; UT Austin)
for the LVM team

Curtis Bartosz, Matt Bershady, Dmitry Bizayev, **Guillermo Blanc (PS)**, Mike Blanton, Brian Cherinka, Julianne Dalcanton, Eric Emsellem, Eric Hooper, Amy Jones, **Kathryn Kreckel (PS)**, **Nick Konidaris (IL)** David Law, **Nick MacDonald (IS)**, Kristy McQuinn, Mark Seibert, **Eric Pellegrini (PS)**, José Sánchez-Gallego, Eva Schinnerer, Josh Simon, Conor Syres, Anne-Marie Weijmans, Vivienne Wild, Marsha Wolf, Renbin Yan

What is LVM?

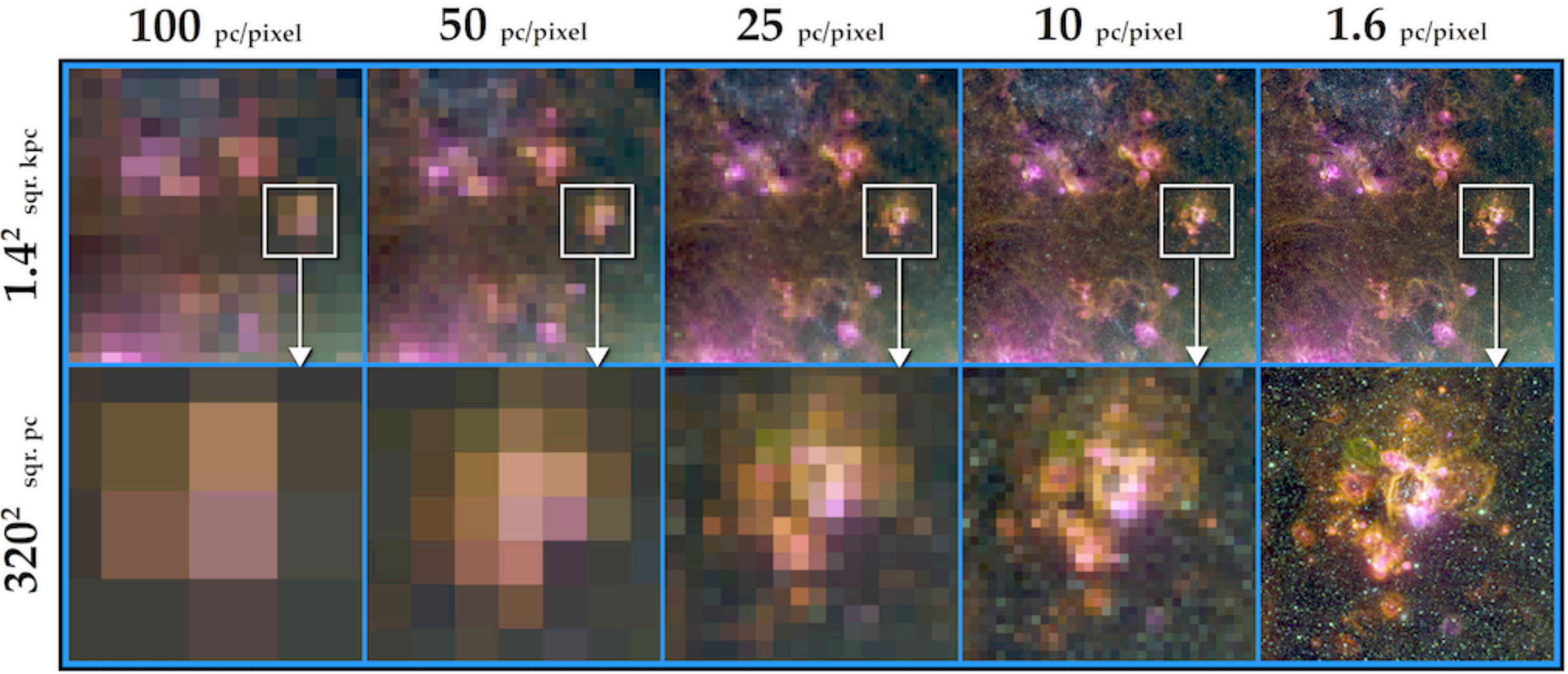
- LVM is an optical **integral-field spectroscopic** survey of the **Milky Way** and the **Local Group**
- The LVM is the first IFU survey of complete galactic systems to isolate and resolve distinct environments within galaxies
- LVM is the first IFU survey to cover significant fractions of the night sky, **~1 sterad**

Why LVM?

- The ISM is what stars are made of and the medium they feedback into
- We'd like to resolve these multi-scale processes on galactic scales
- Resolve Jeans Mass on all targets, down to individual sources of feedback in LG
- This requires data spanning a large dynamic range in size:
    - < 1 pc scale of individual sources
    - to clusters and clouds (10-50 pc)
    - to kpc scales of in/outflows, galactic fountains, winds, and disk dynamics

Spatially sampling the ISM

At resolutions of better than 25 pc, the filamentary structure of the ISM is starting to be resolved

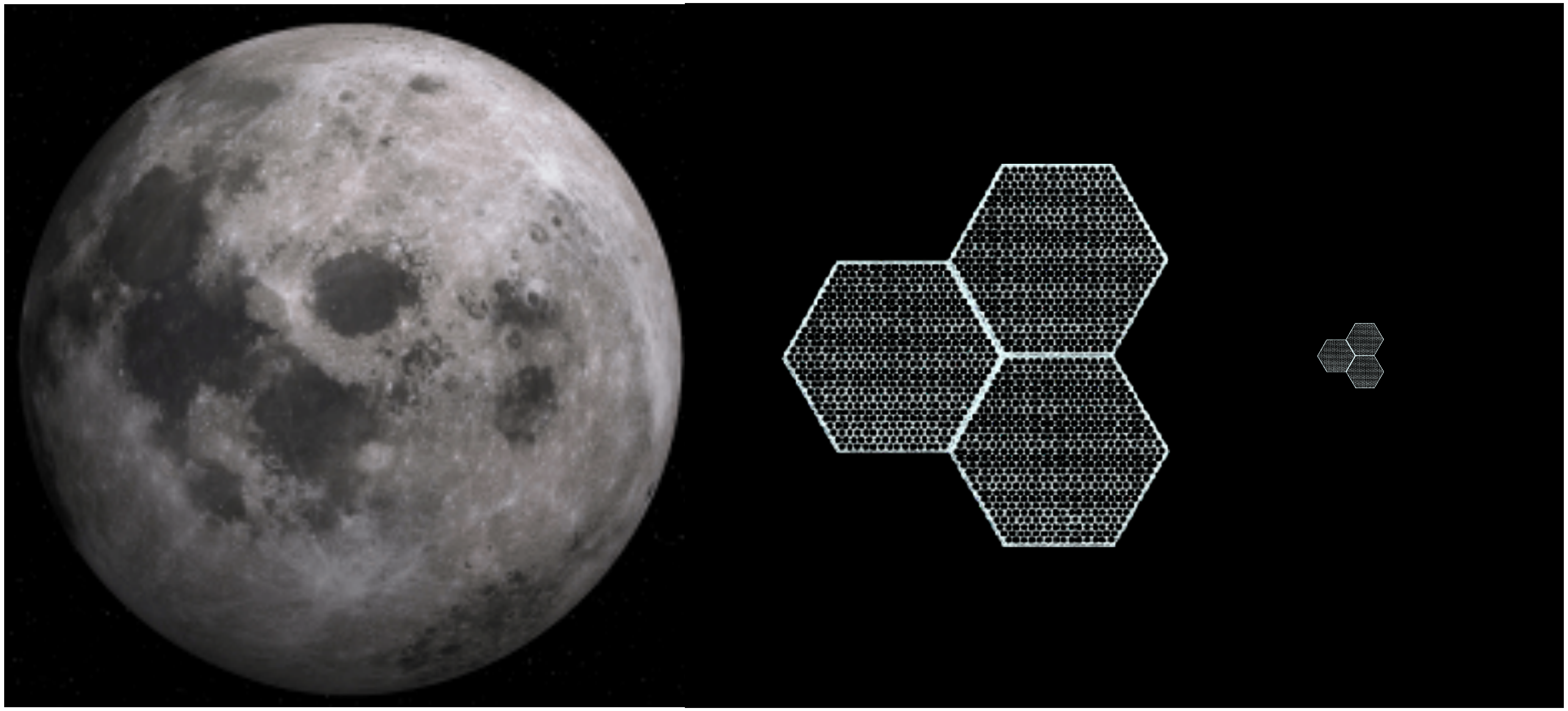


How LVM?

- At fixed f-ratio (fibers!), conservation of AΩ implies that the telescope aperture sets nothing but the plate scale
- Choose **telescope aperture** to give **desired spatial sampling** at a given target **distance**
  - 1 pc in Milky Way requires ~30” spaxels
  - 10 pc in LMC, SMC require ~6” spaxels
  - ~20 pc in M31/M33 require ~6” spaxels
  - (10 pc in M31 requires 2.5” spaxels)

Big IFUs

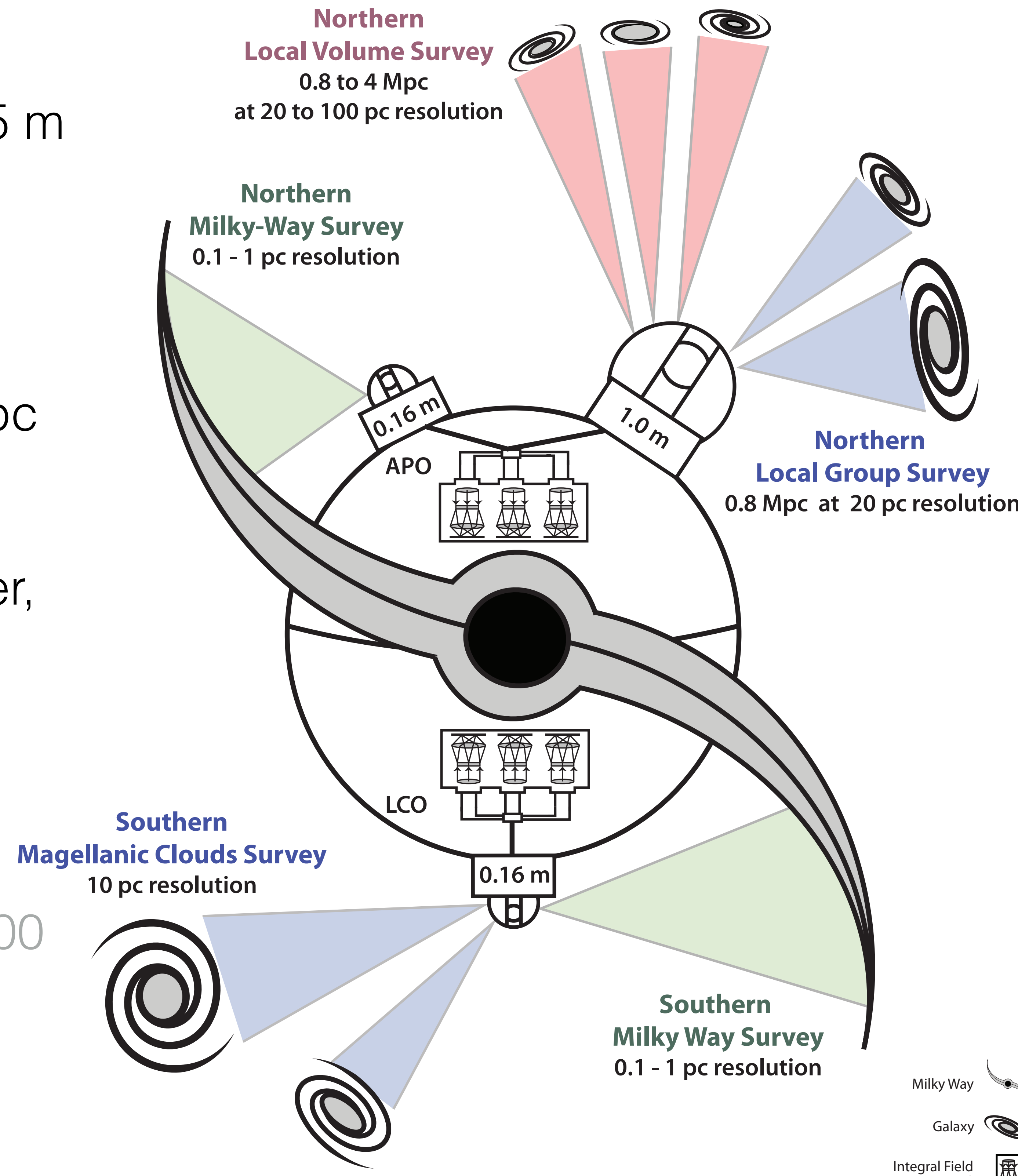
- 490 arcmin^2 @ 0.16 m,
- 12 arcmin^2 @ 1 m, and
- (2 arcmin^2 @ 2.5 m)



LVM Overview

Using 3 telescope sizes of 0.16, 1, 2.5 m and an array of IFU-coupled spectrographs at *R*~4000 and 3600-10000Å, we survey

- ~3000 sq. deg. in the MW @ 0.1-1 pc resolution,
- ~300 sq. deg. in the MW 10x deeper,
- LMC & SMC @ 10 pc resolution,
- M31 & M33 @ 20 pc resolution, and
- nearby galaxies (D≲8 Mpc) @ 50–100 pc resolution — likely on the 1m



Now is the time to join the team and influence what LVM will be!

LVM Spectroscopy

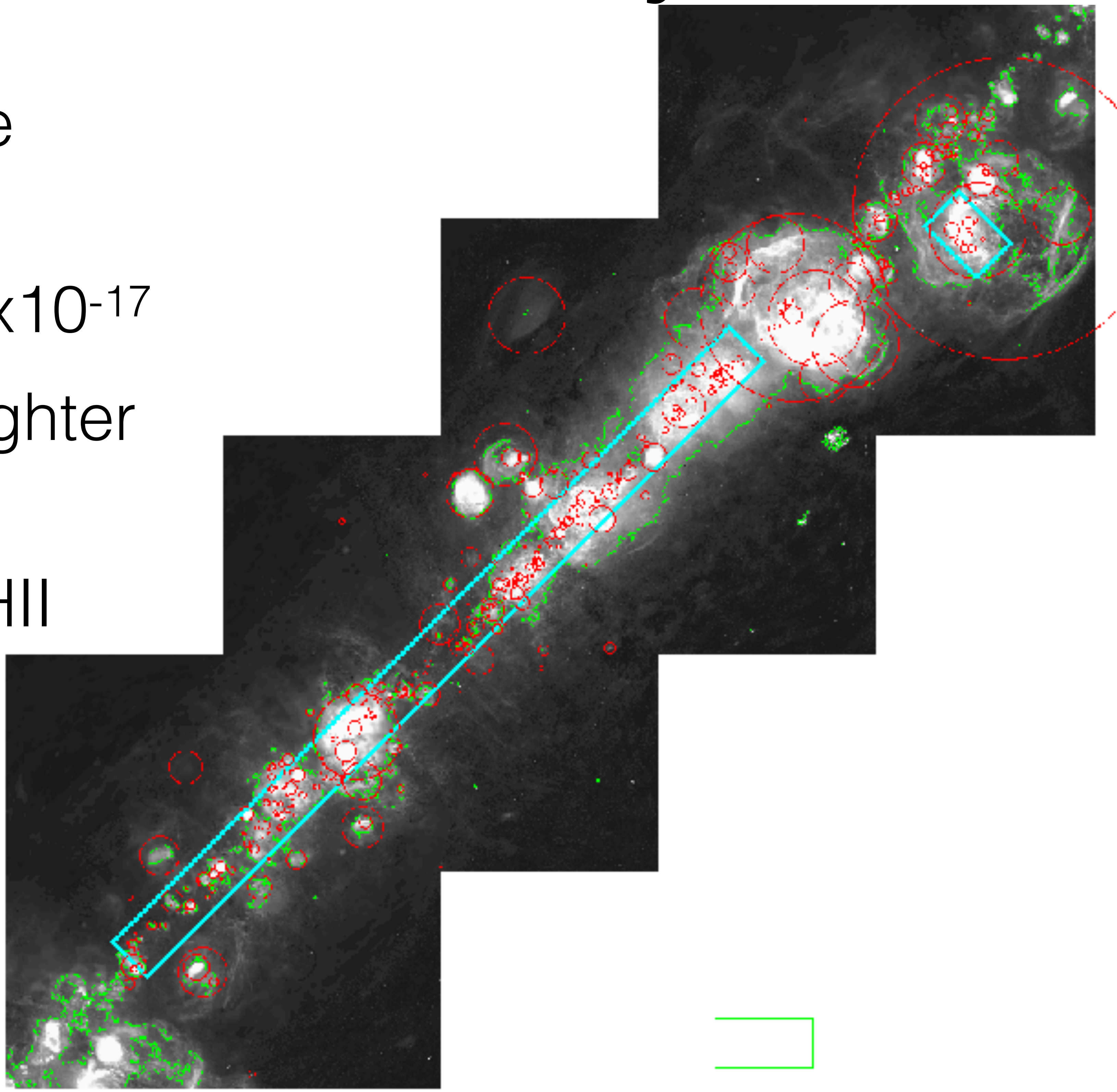
- LVM spectroscopy spans 3600–10000Å at R~4000 (~2500 blue – 5000 red)
- Cover both strong and weak auroral lines
  - [O II]3727,3729, [Ne III]3869, Hß, [O II]4960,5008, [NII]6549,6585, Hα, [S II]6718,6732
  - [S II]4068,4076, **[O III]4363**, [N II]5755, [S III]6312, [OII]7320,7330, [S III]9069, [S III]9532
- Stable, bench-mounted and environmentally controlled instrument
- High-quality ~5% flux calibration (see MaNGA; Yan+2016)
- Uniform data with maximum coverage
- Wide applicability to gas and stars

LVM & ancillary data

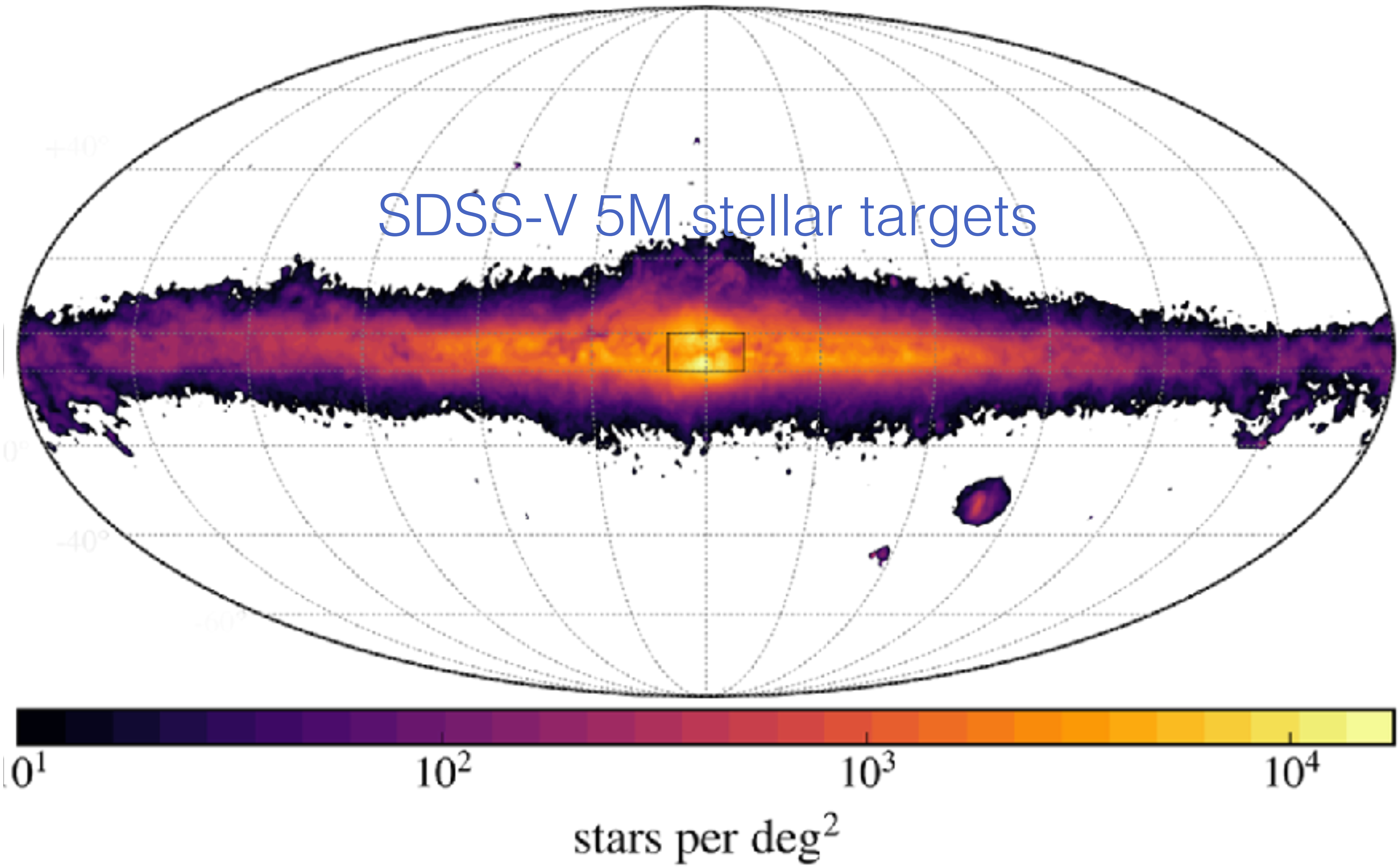
- LVM will tie into and make use of wide range of ancillary data from the X-ray to the radio. A few examples:
  - The Galactic Plane: **atomic** (e.g. THOR, Beuther+2016), **molecular** (e.g. Dame+2001) dust (GLIMPSE, Churchwell+2009; Hi-GAL, Molinari+2016; ATLASGAL, Schuller+2009) angular resolutions similar to LVM or better
  - M31 & M33 have been covered in the **NIR–IR** by Spitzer, Hershel SAGE (Meixner+2006; Gordon+2011), HERITAGE (Meixner+2010) and HELGA (Fritz+2012)
  - M31 CARMA (**CO**) at 20 pc (Shruba+), 10 pc by Leroy+; VLA (**HI**) Koch+, Rosolowsky+
  - eROSITA will reveal ALL **X-ray** binaries in the LMC, SMC
  - PHAT, APOGEE, GAIA, … stellar spectroscopy and imaging
- The combination of stellar, cold & warm gas and dust data offers a unique window into star-ISM interactions (SF + feedback)

LVM MW Survey

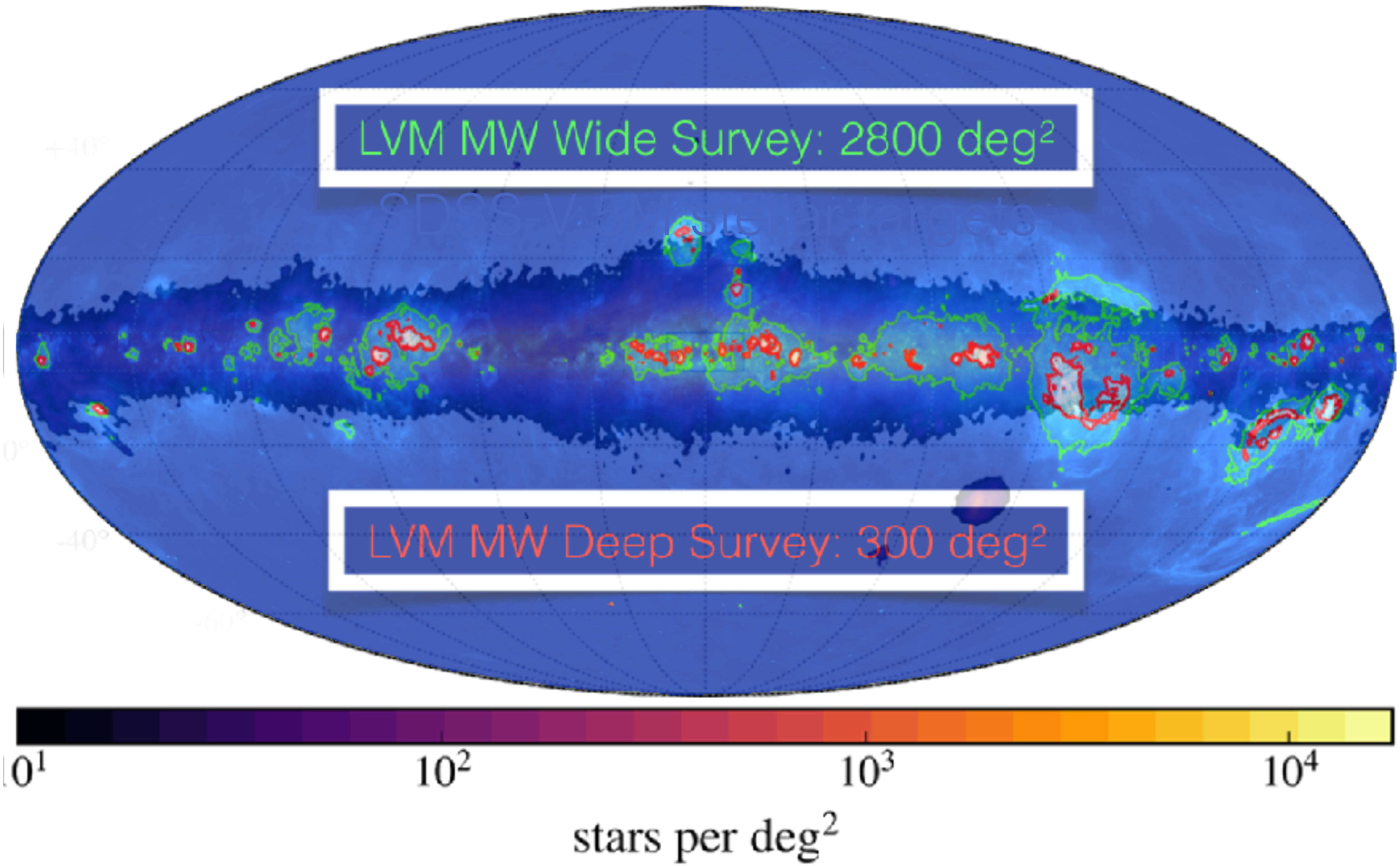
- MW: ~3000 square degrees
- All strong lines >6x10^{-17}
- Auroral lines in brighter regions
- All known optical HII regions D<3 kpc



LVM MW Survey



LVM MW Survey



Orion

- M42 0.07 pc / spaxel
- APOGEE stars (yellow)
- Combine information from gas and stars to map the interaction between stars and ISM
- Have Teff, L, Z, [X/H], f_{uv}, (age) for each star
- Gas: temperature, density, kinematics, abundances

Images: ESO 2.2m

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Images: ESO 2.2m

NGC 3576

- NGC 3576 in Carina
- 0.5 pc / spaxel

Images: ESO 2.2m

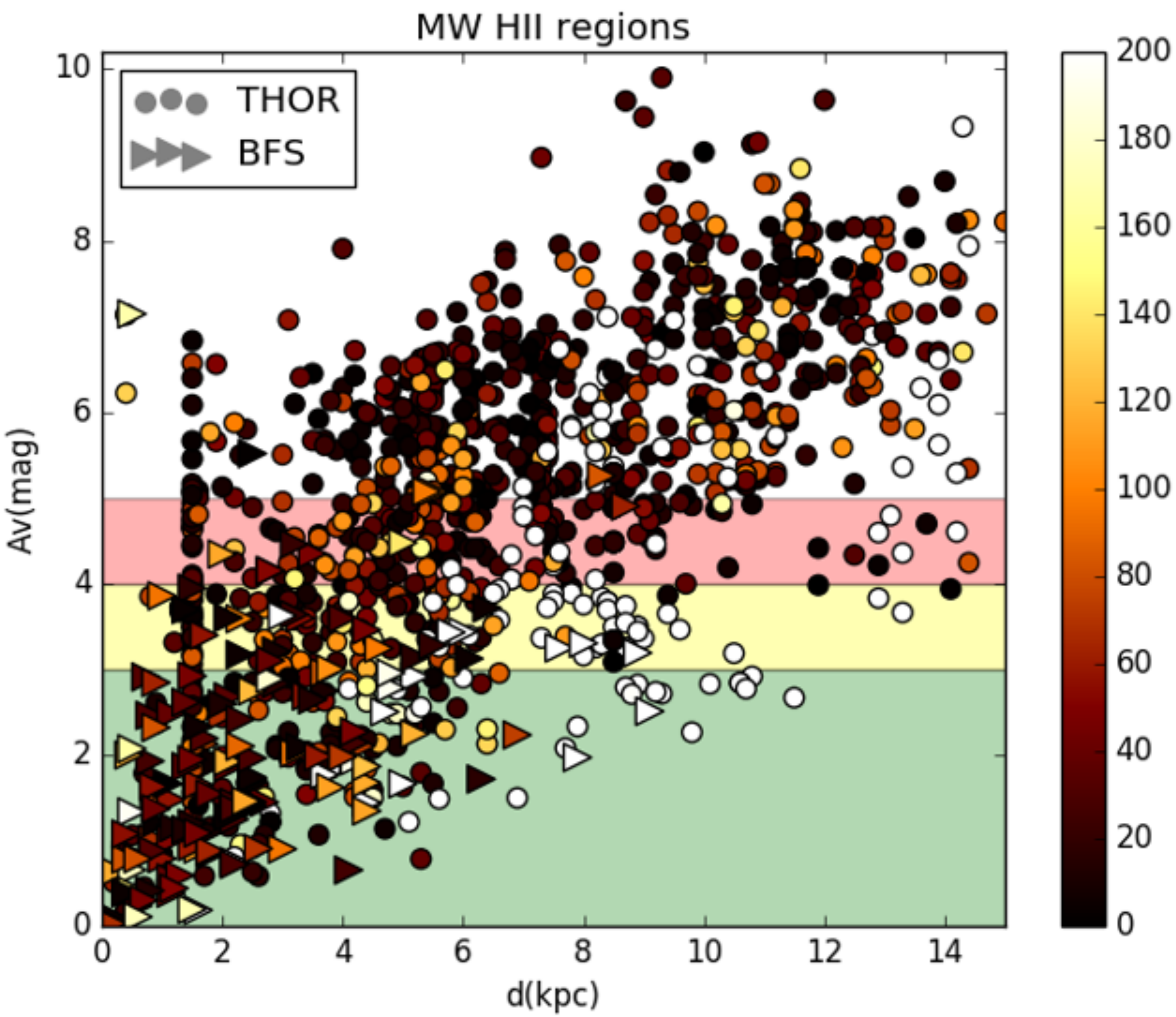
NGC 3576

- NGC 3576 in Carina
- 0.5 pc / spaxel

Images: ESO 2.2m

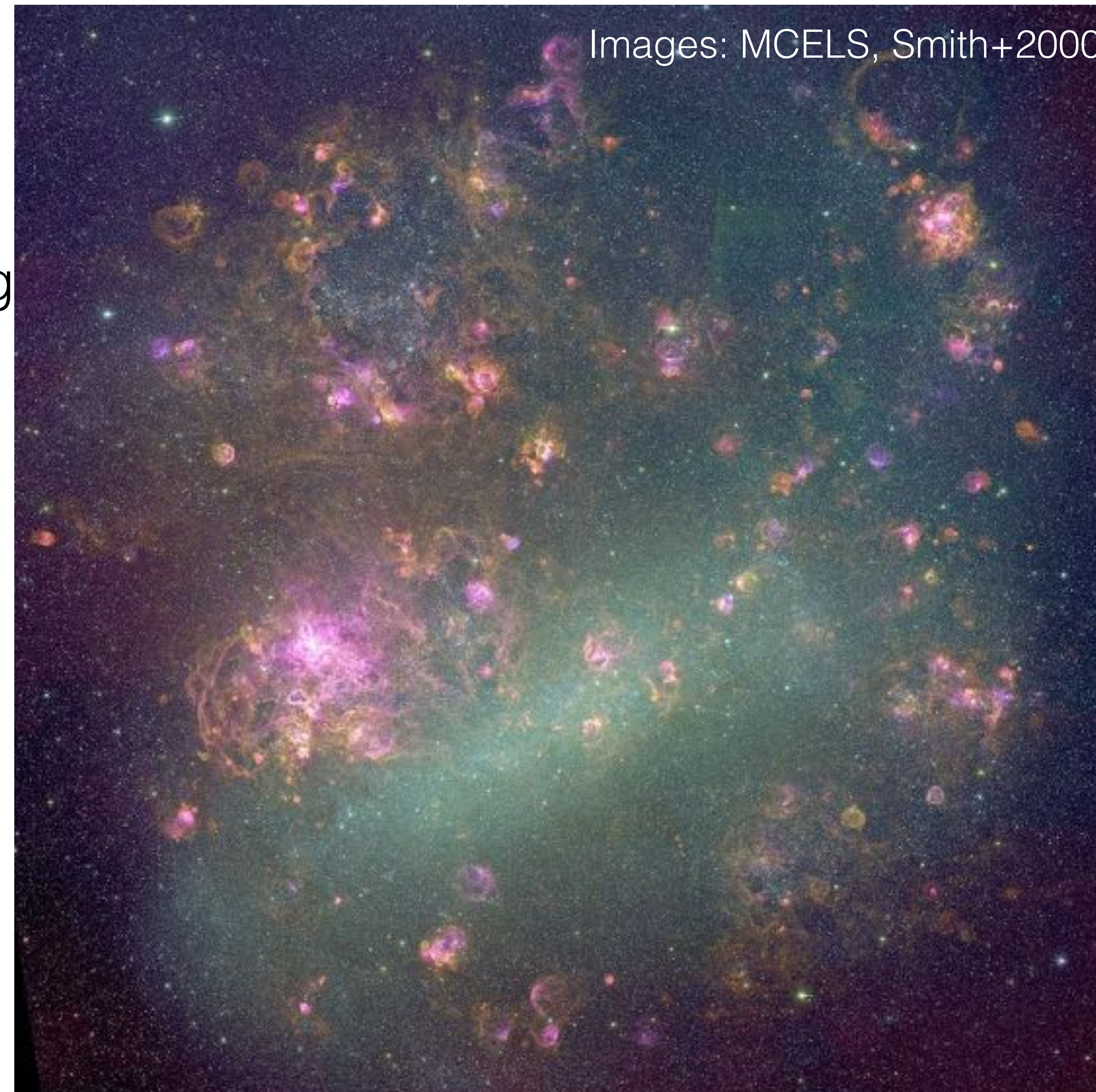
LVM MW Survey

- Effectively dust-limited in distance to about ≤ 3kpc in the MW disk
- Median extinction is about A_V~2.3
- Limit is ≤ A_V~5



LVM LMC/SMC Survey

- LMC @ 10 pc / spaxel
- 10^6 resolution elements
- Every pixel in image will have a spectrum!
- < 2×10^{-18} erg/s/cm^2, 23 mag



Images: MCELS, Smith+2000

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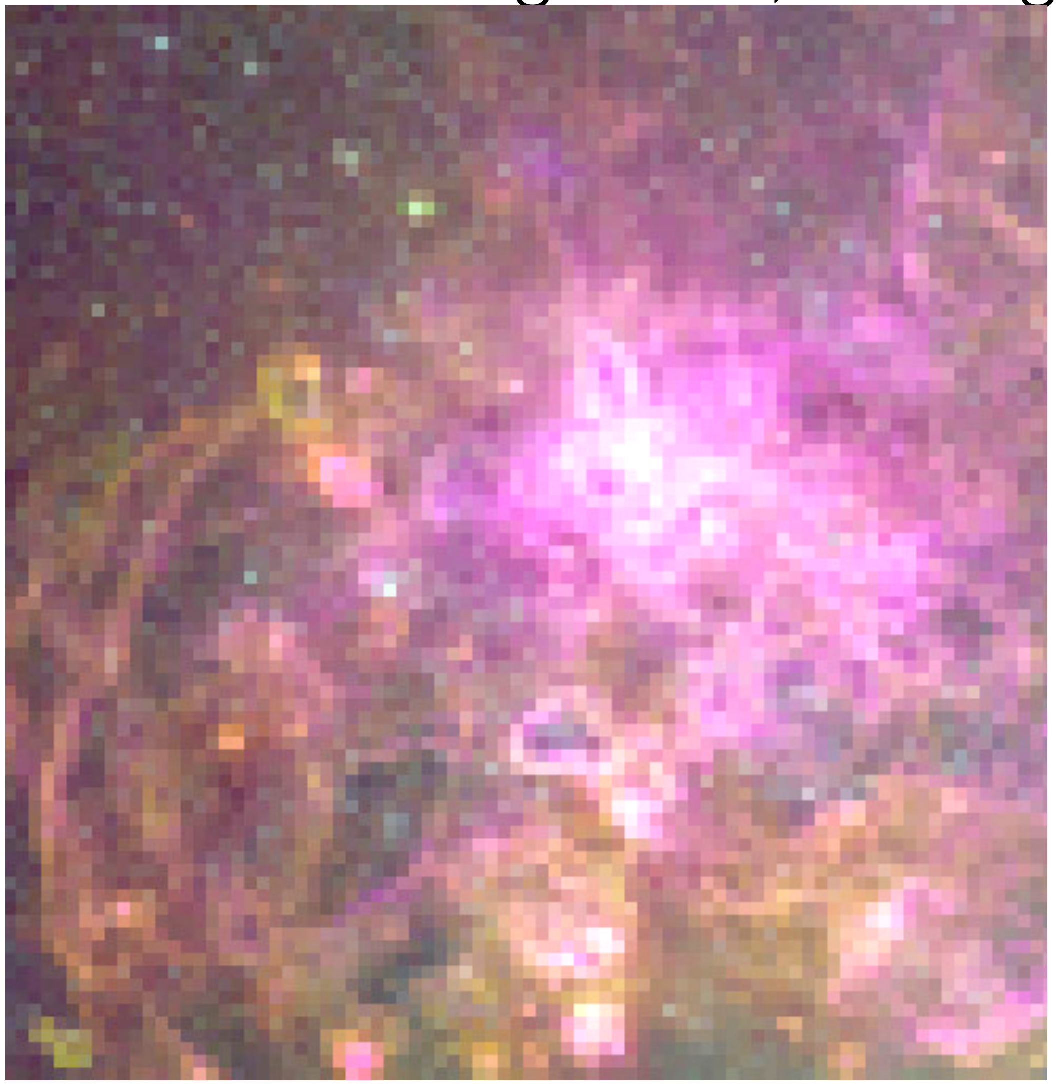
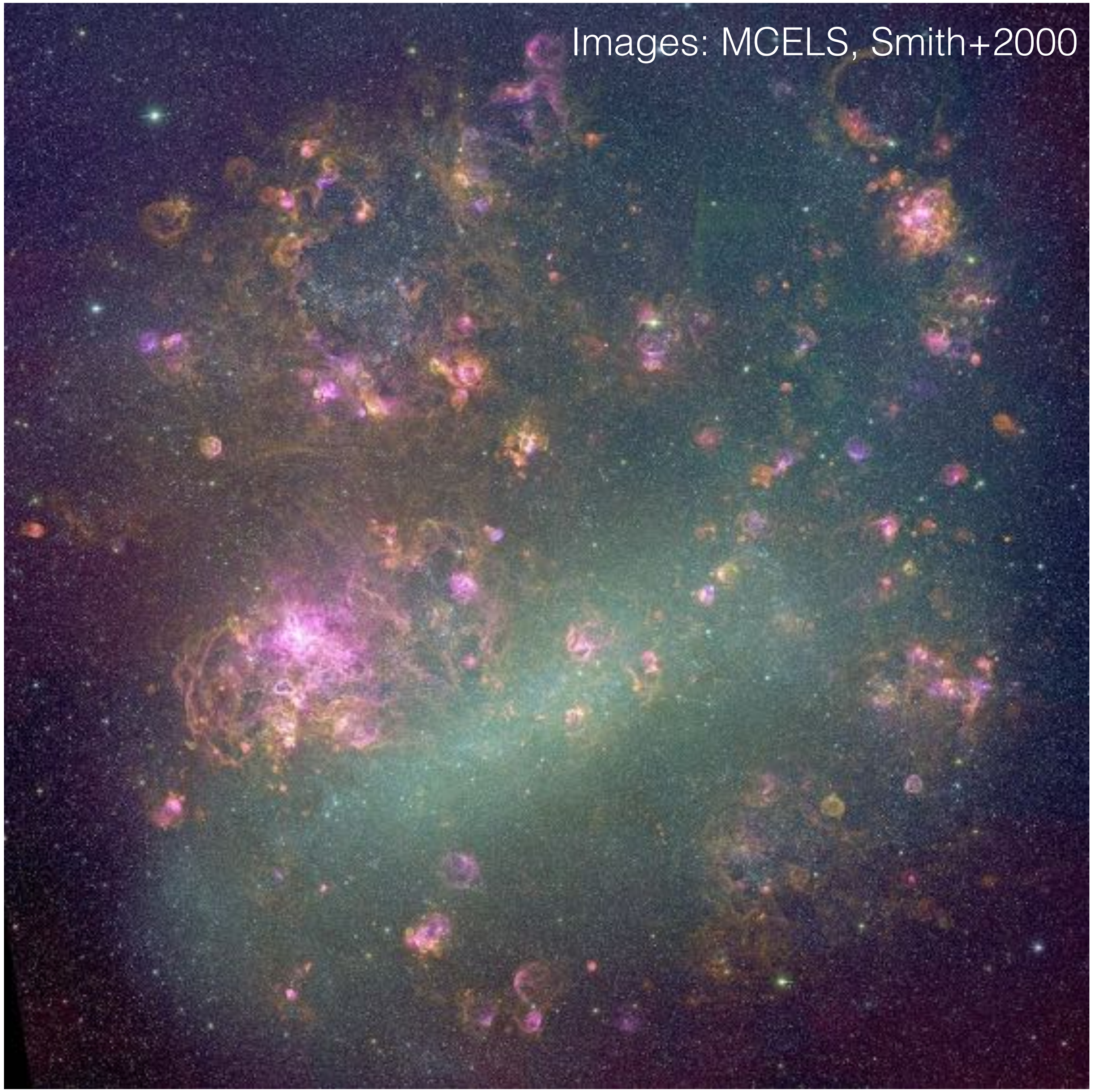
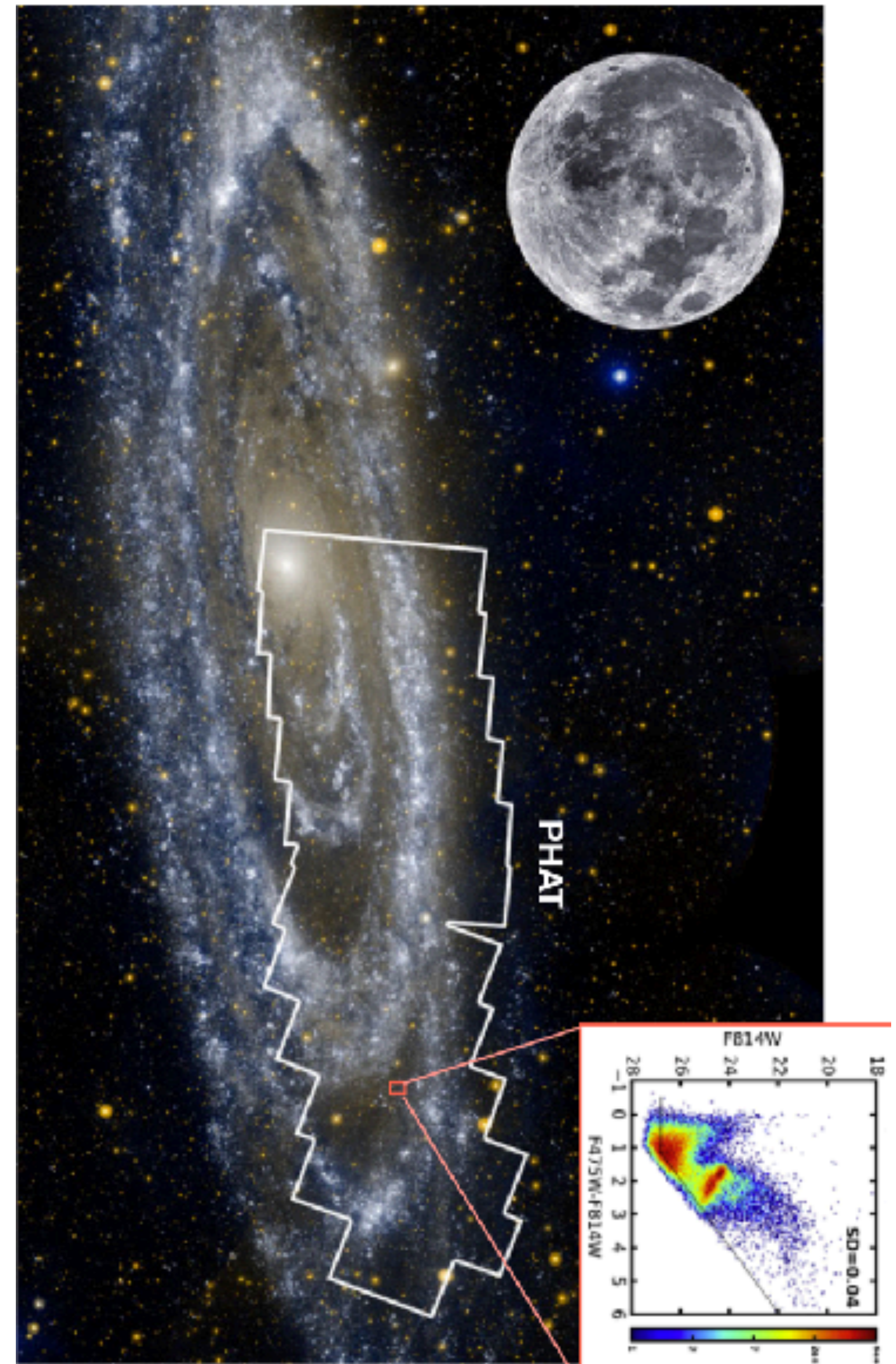




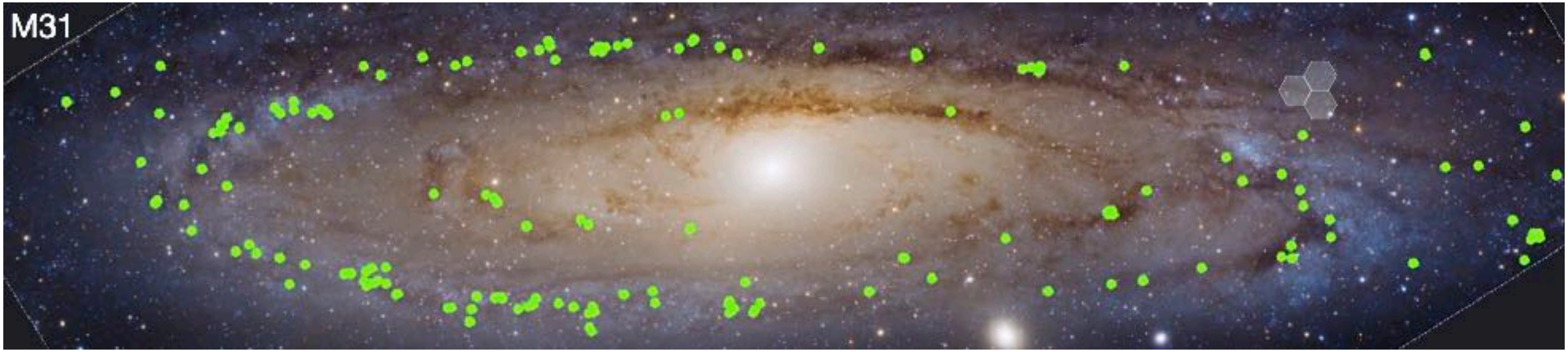
Images: MCELS, Smith+2000

LVM M31/M33 Survey

- M31/M33: At least the regions coverd by HST/PHAT, likely more
- All strong lines
- Auroral lines in brighter regions
- $< 2x10^{-18}$ erg/s/cm^2
- Continuum to 23 mag/arcsec^2
- HST CMDs



LVM M31 Survey



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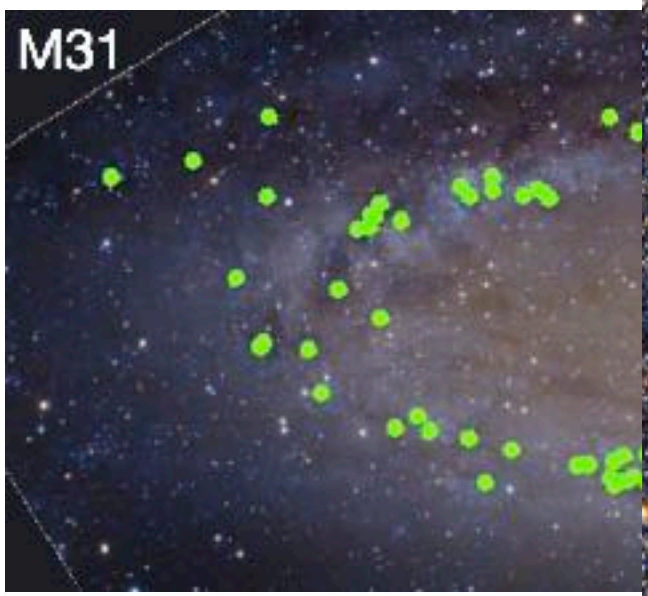

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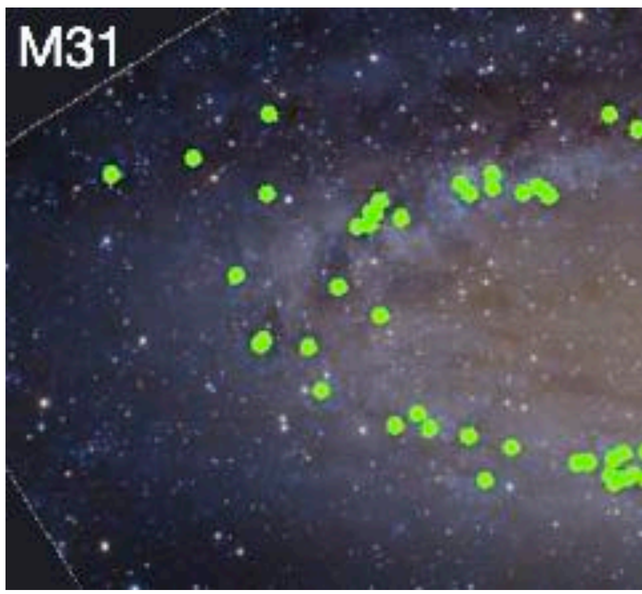
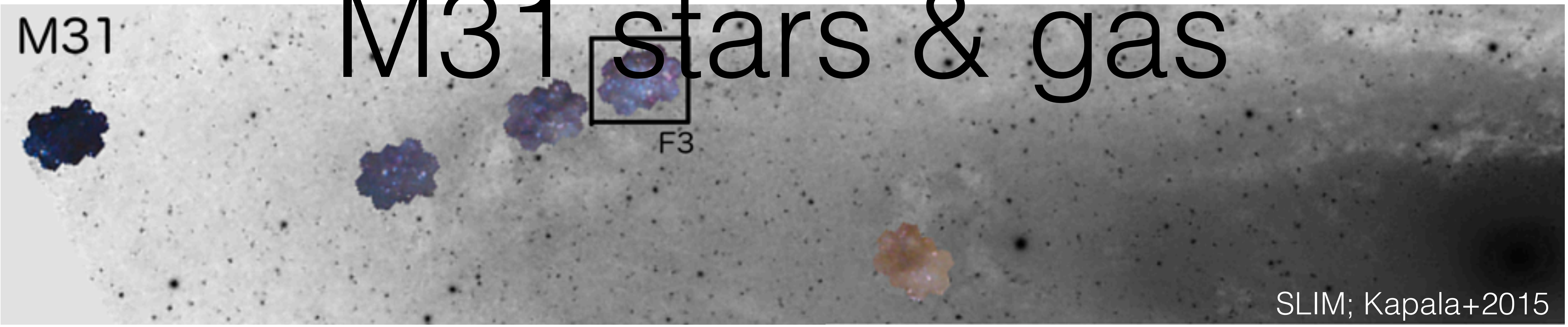
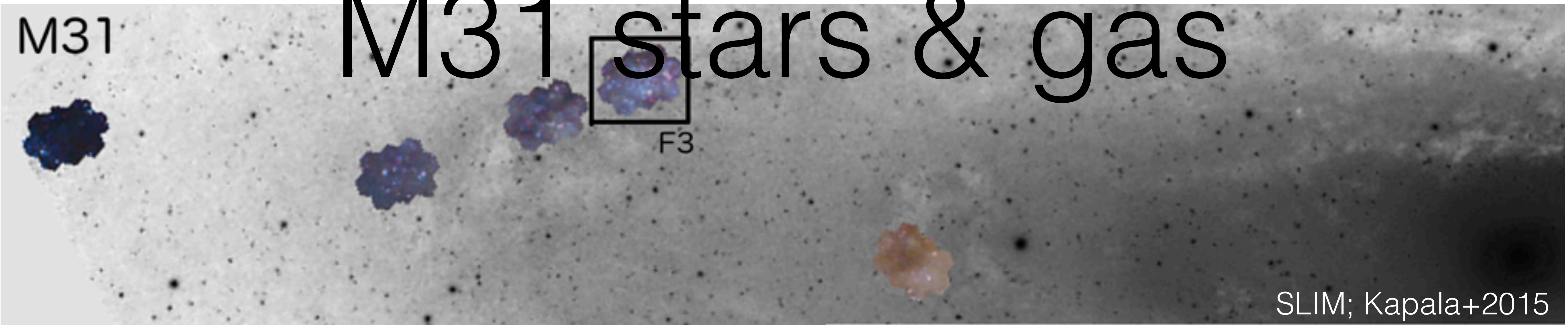


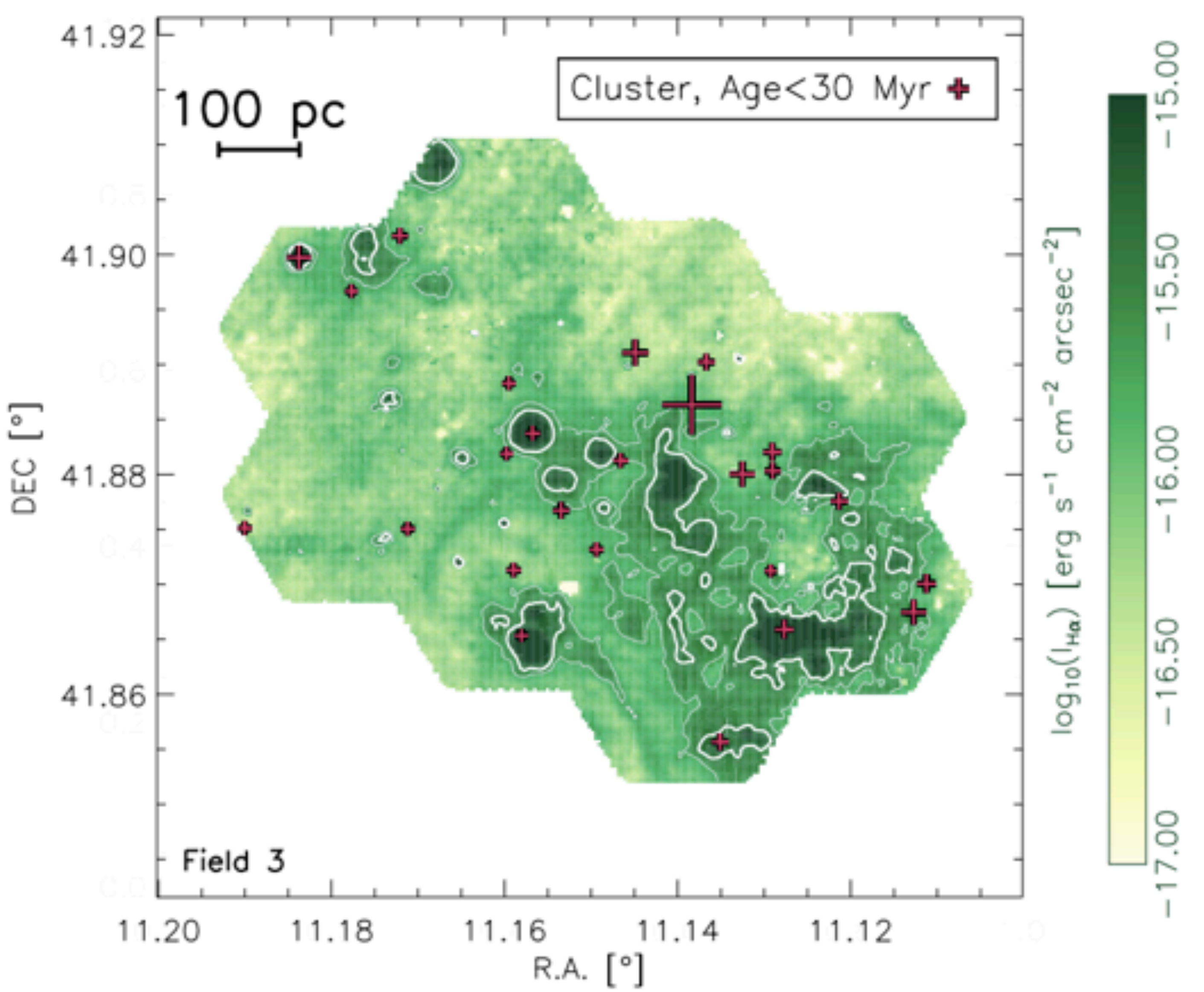
M31 stars & gas

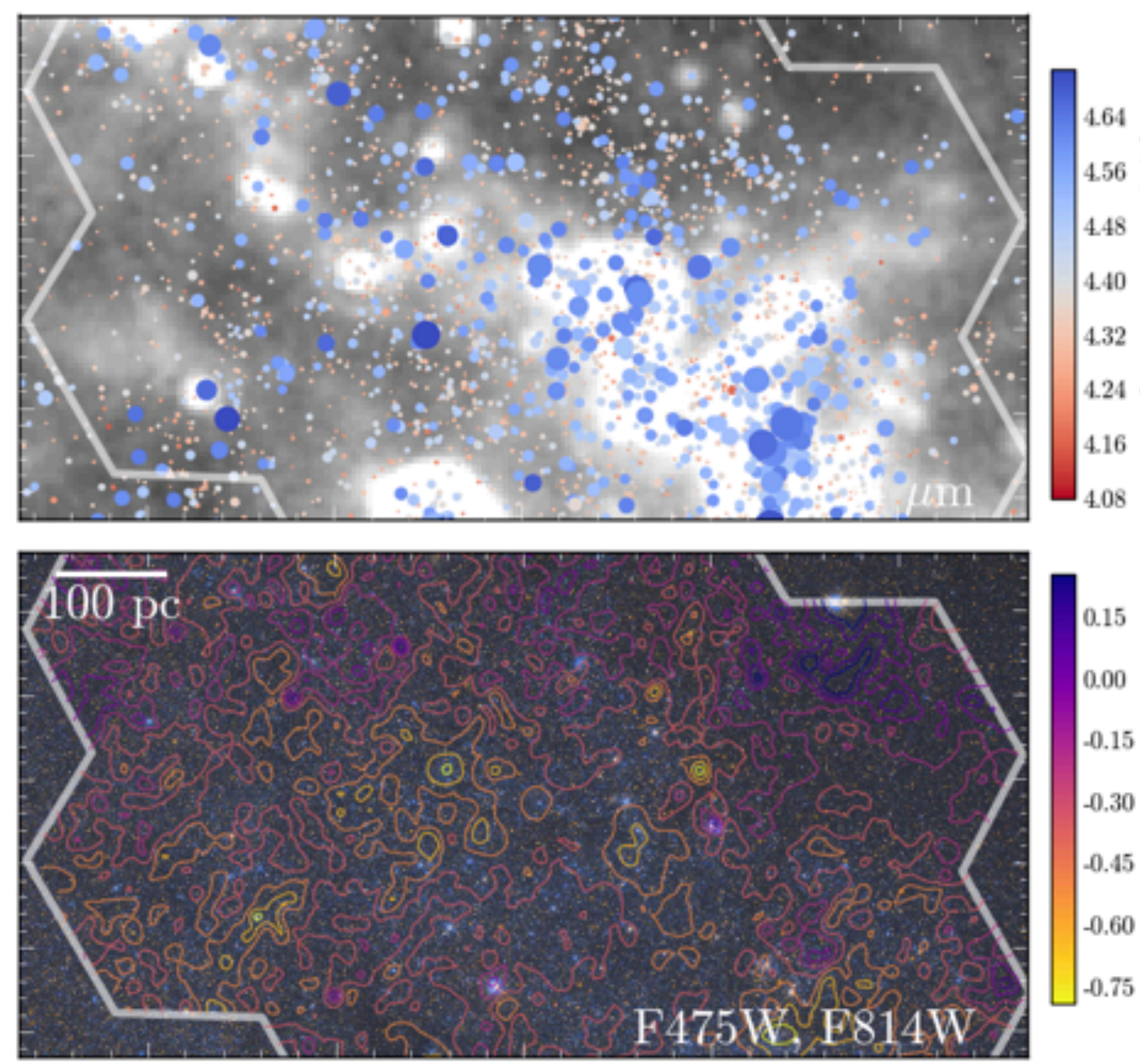


- LVM spectra provide gas properties and kinematics
- Resolved stars (APOGEE, PHAT, …) provide Type, Teff, L, Z, [X/H], fuv, (age)
- The combination allows direct observations of feedback: correlating stellar radiation field and winds with impact on surrounding gas
- Example: SLIM observations of 5 HII regions in PHAT – M31

M31 stars & gas







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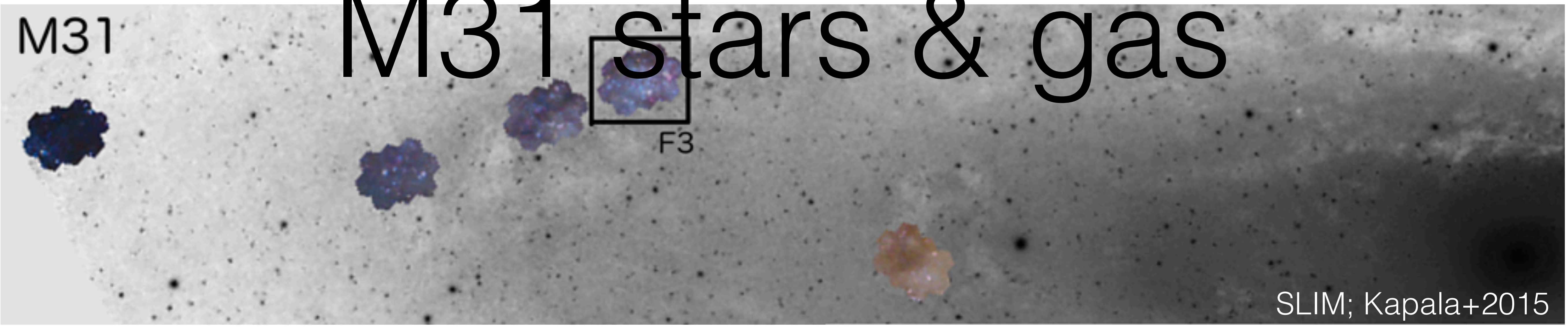
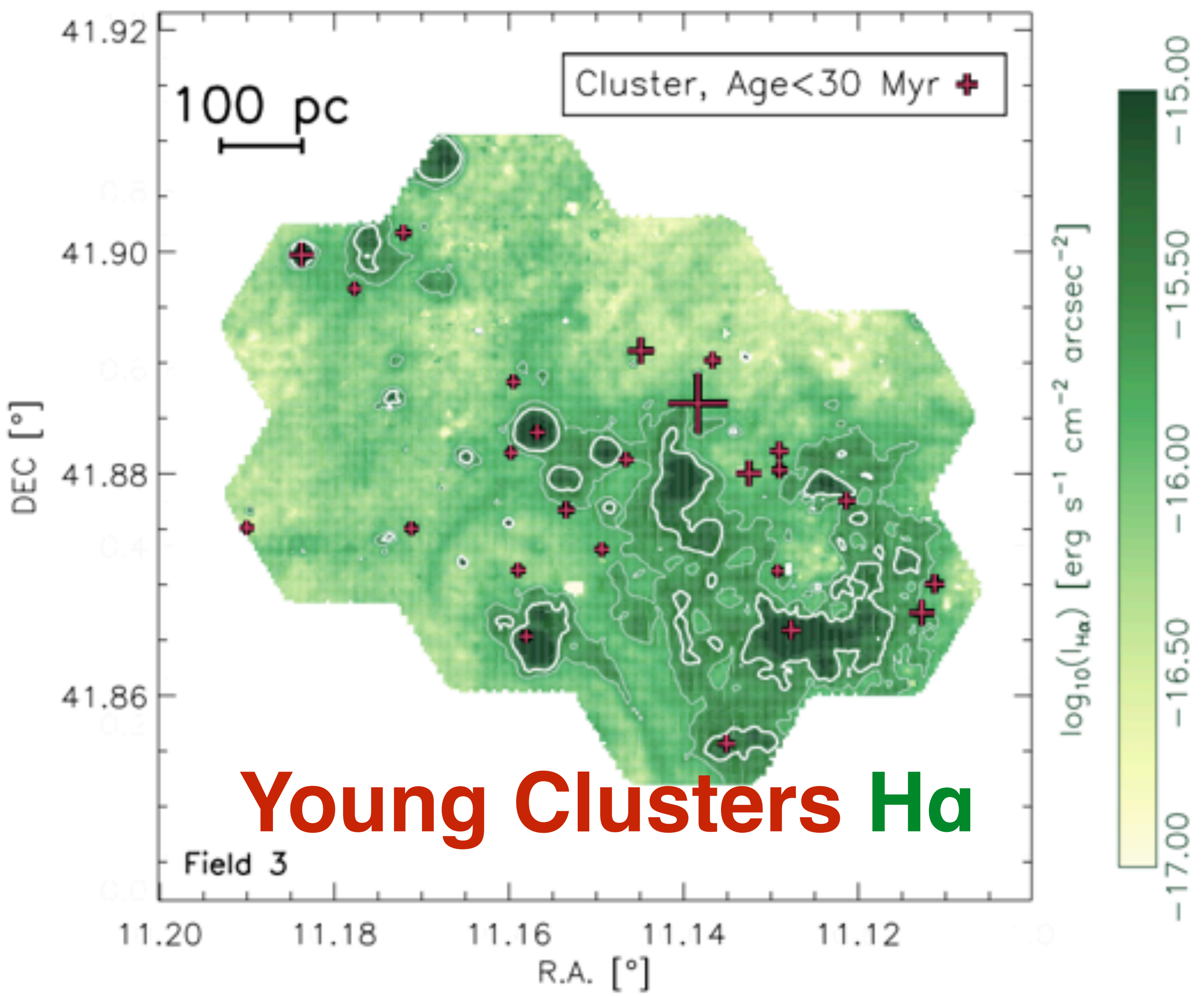
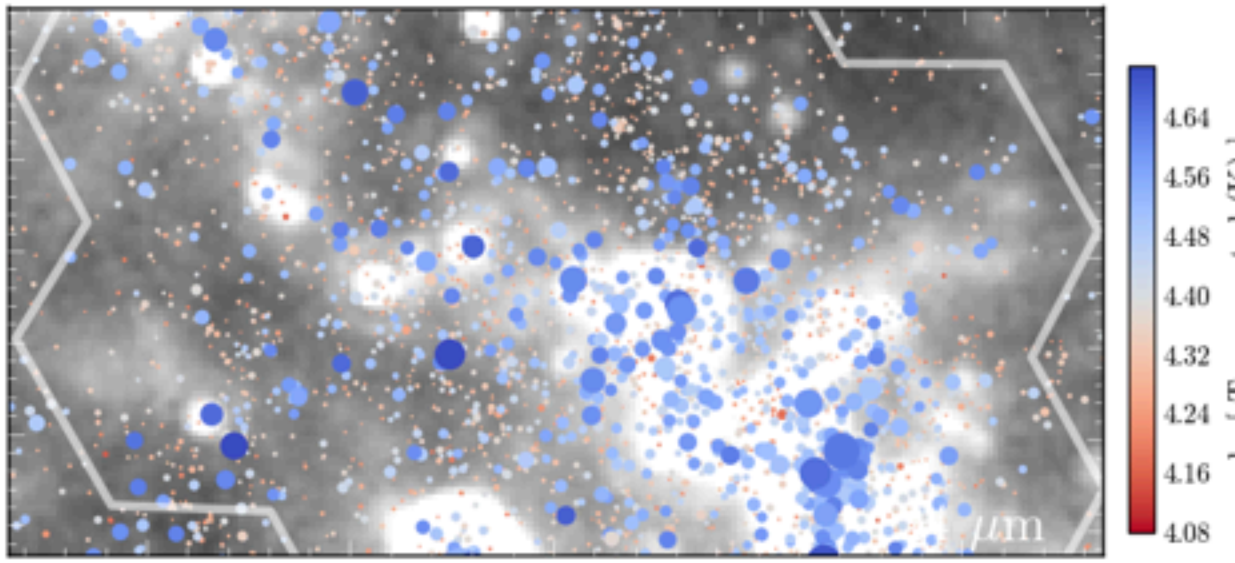
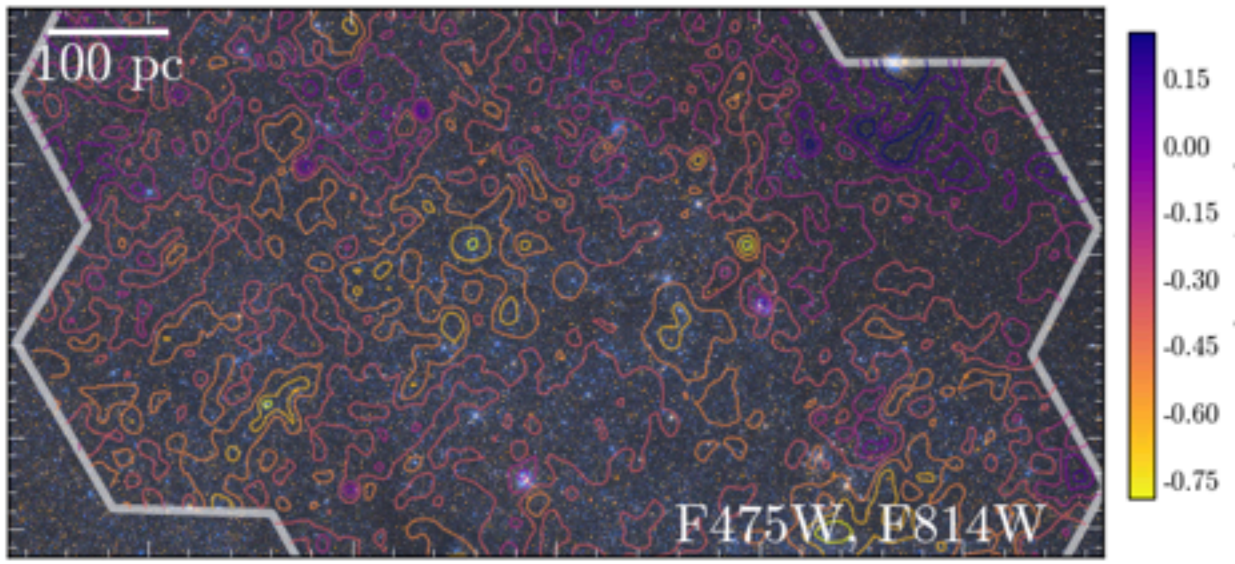




Young Clusters Ha





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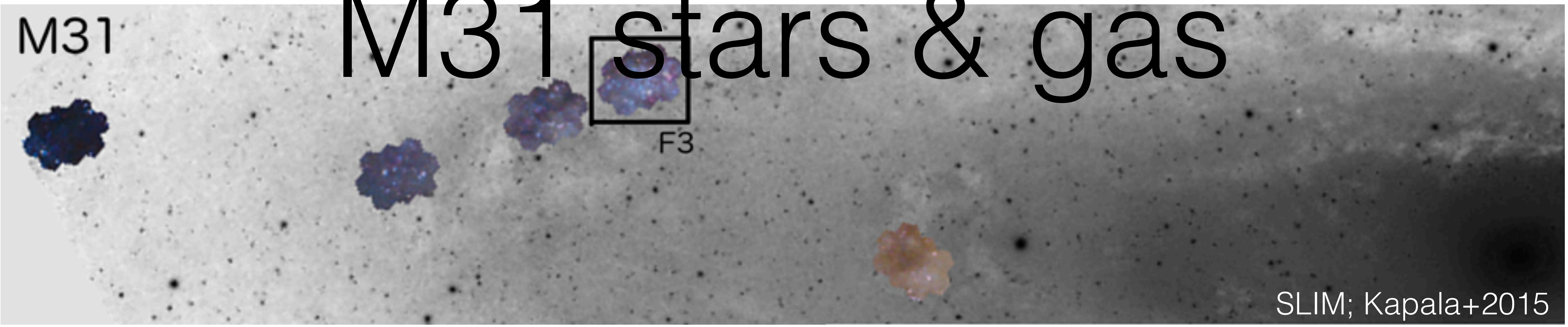

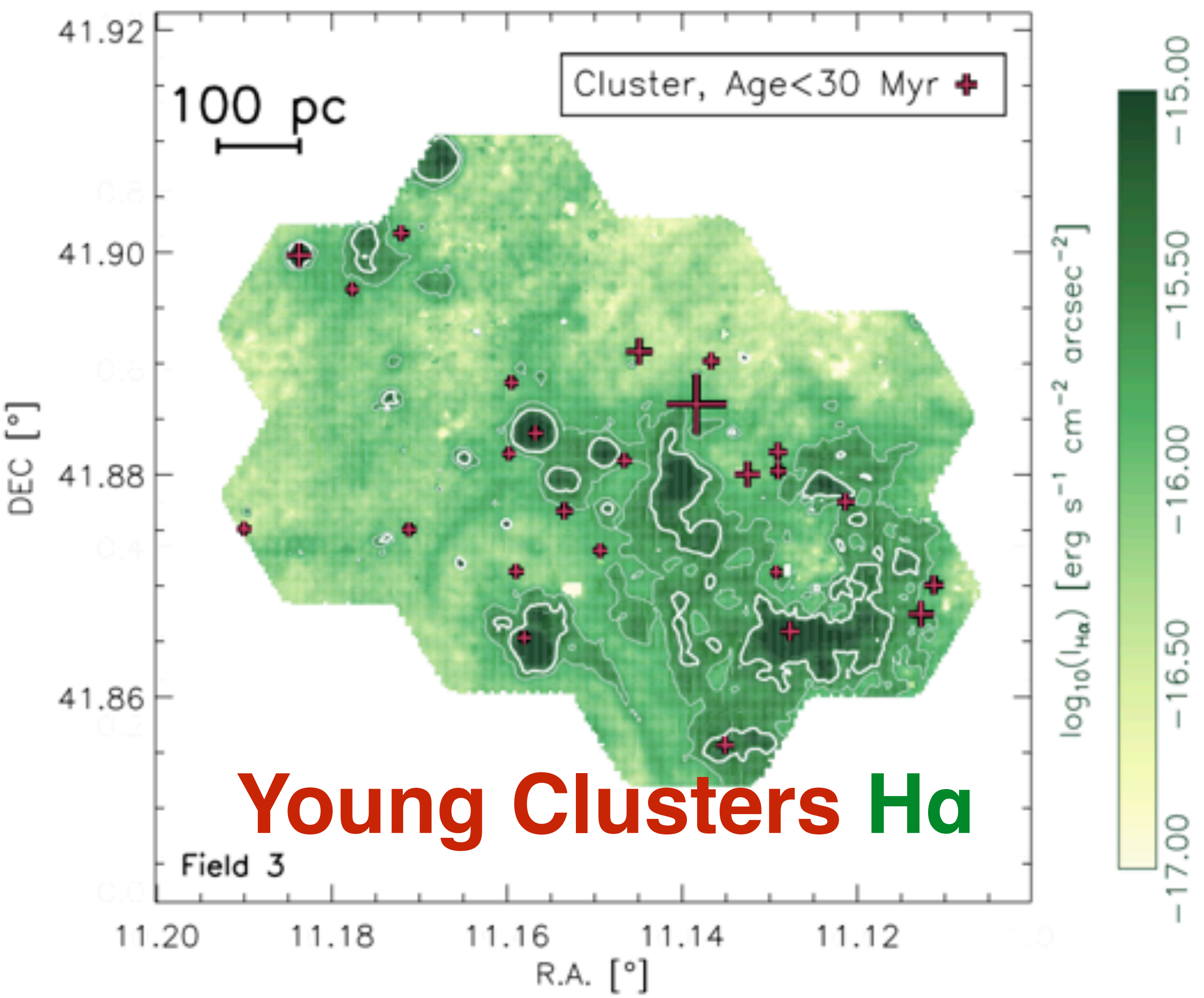

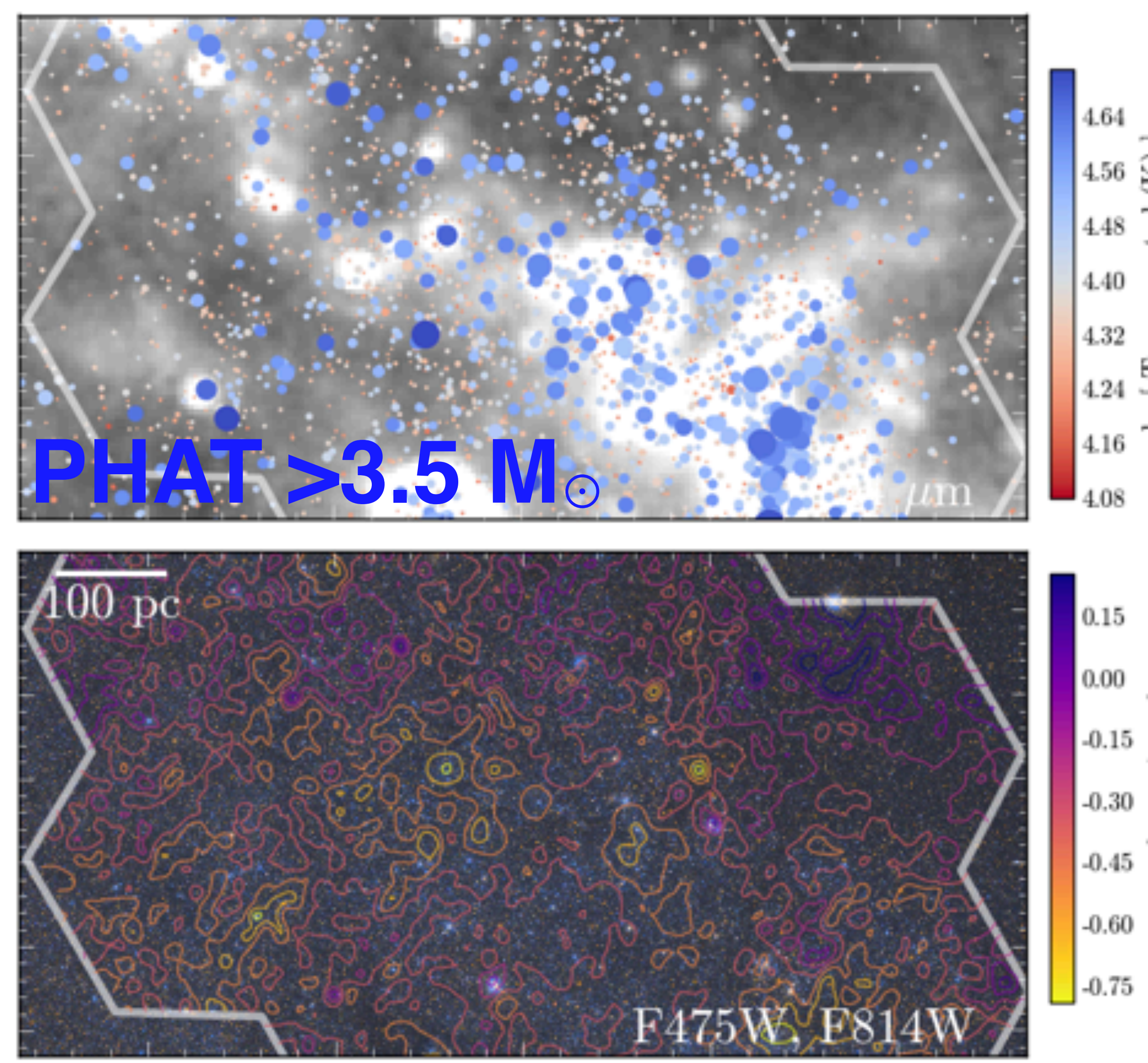

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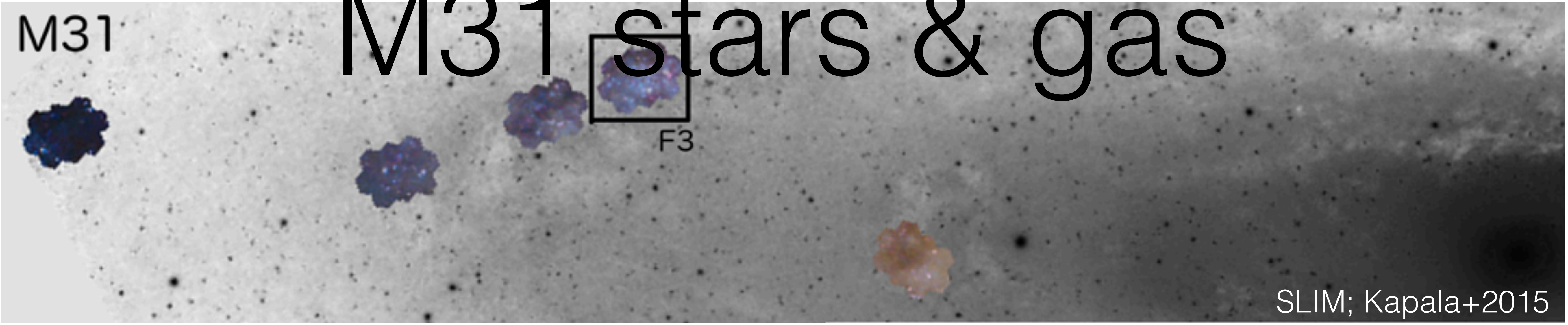
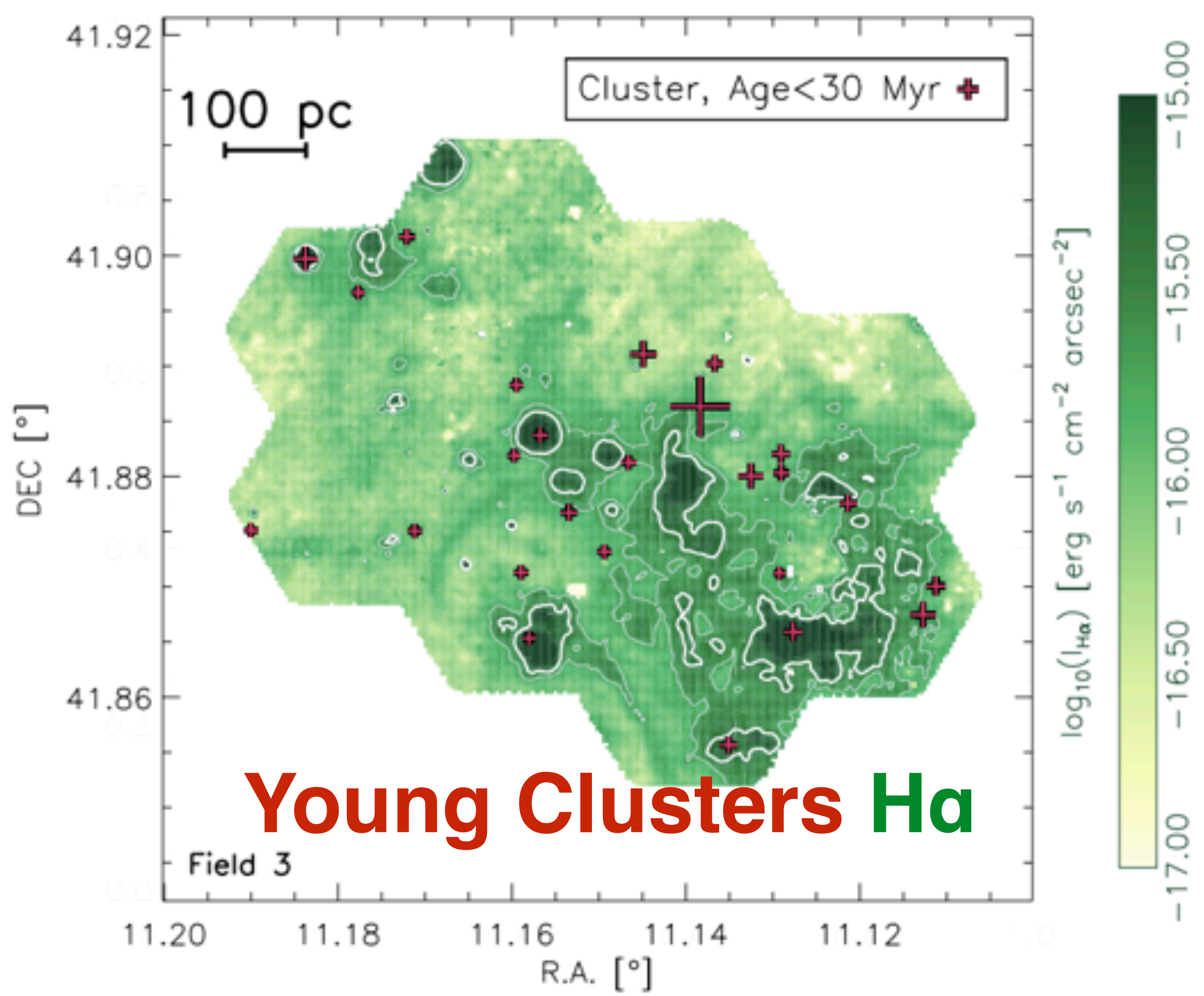
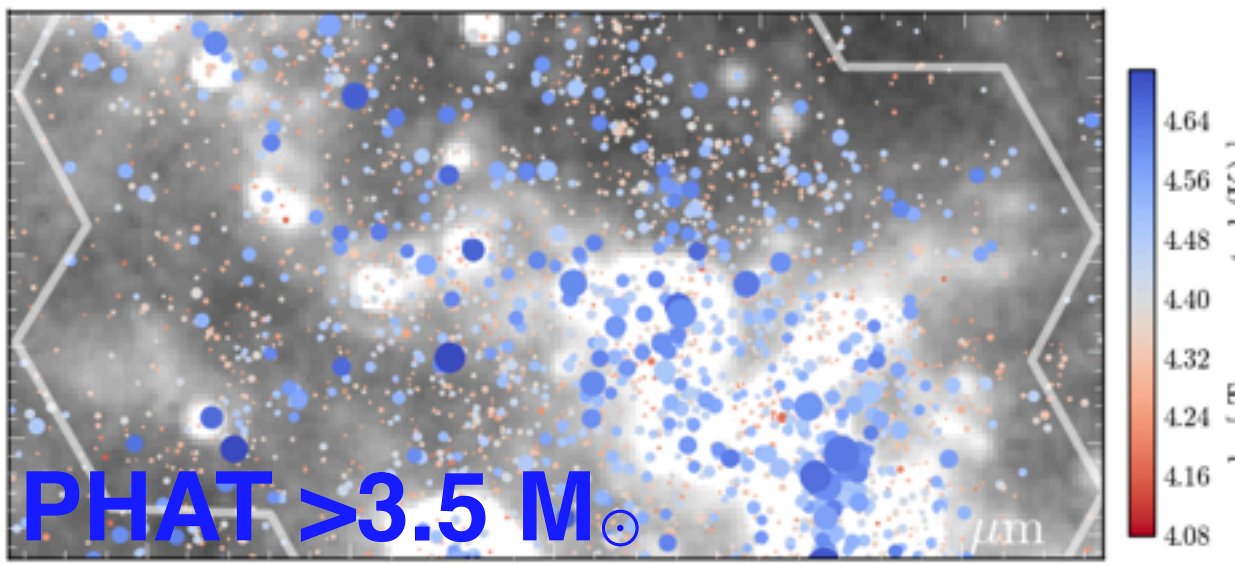
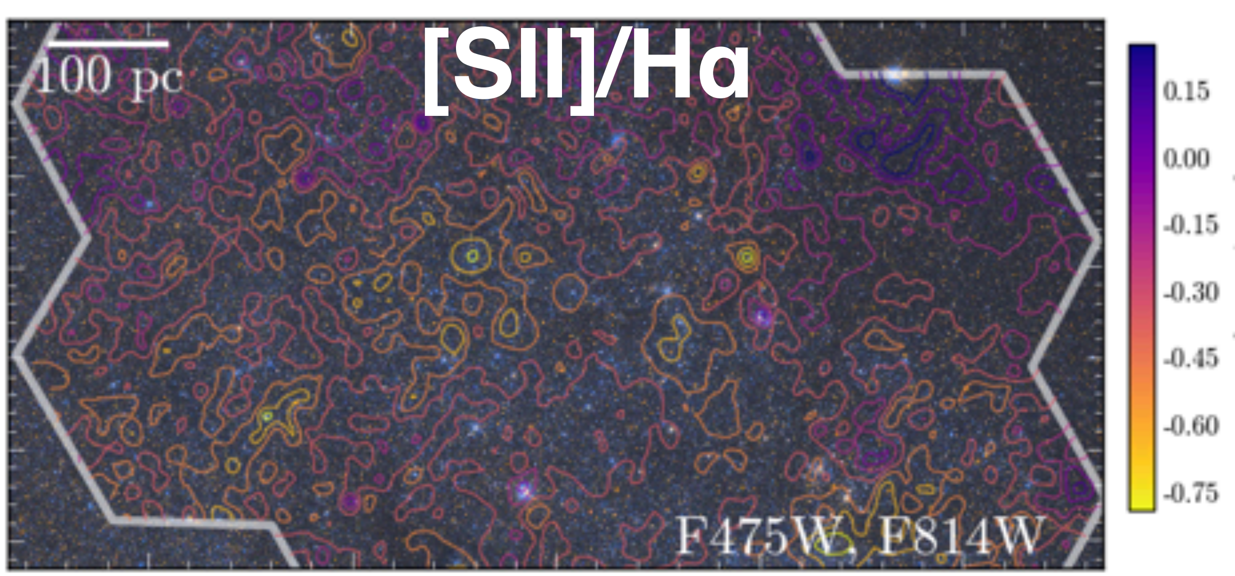


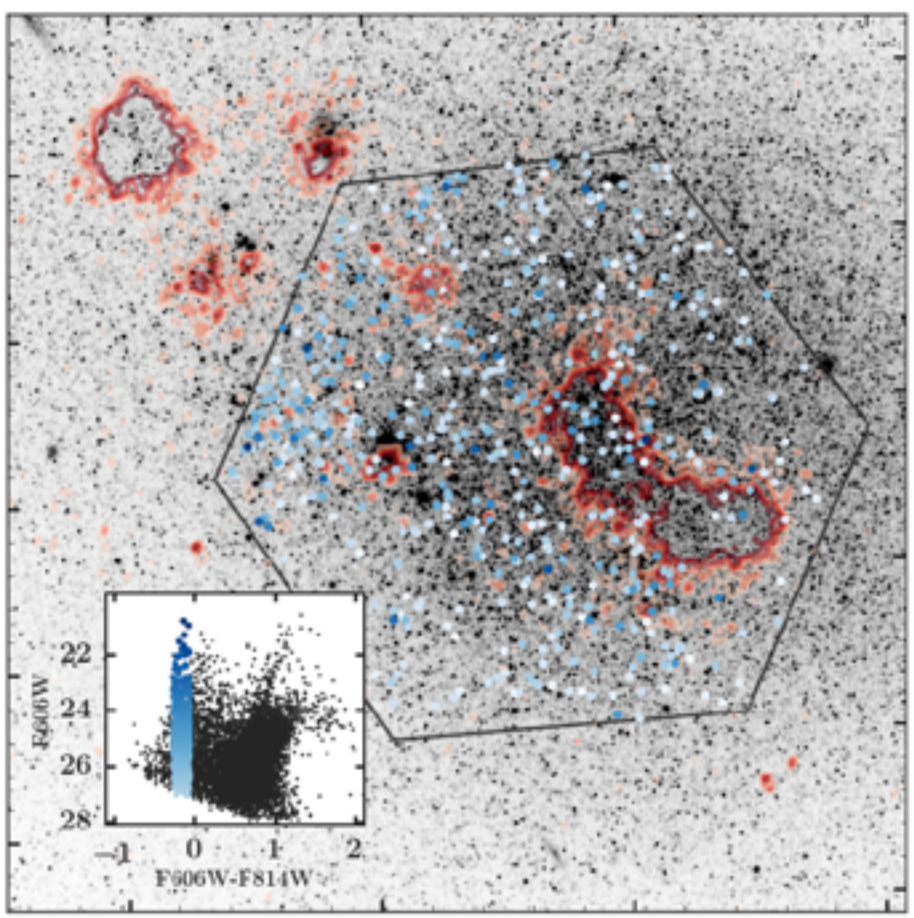


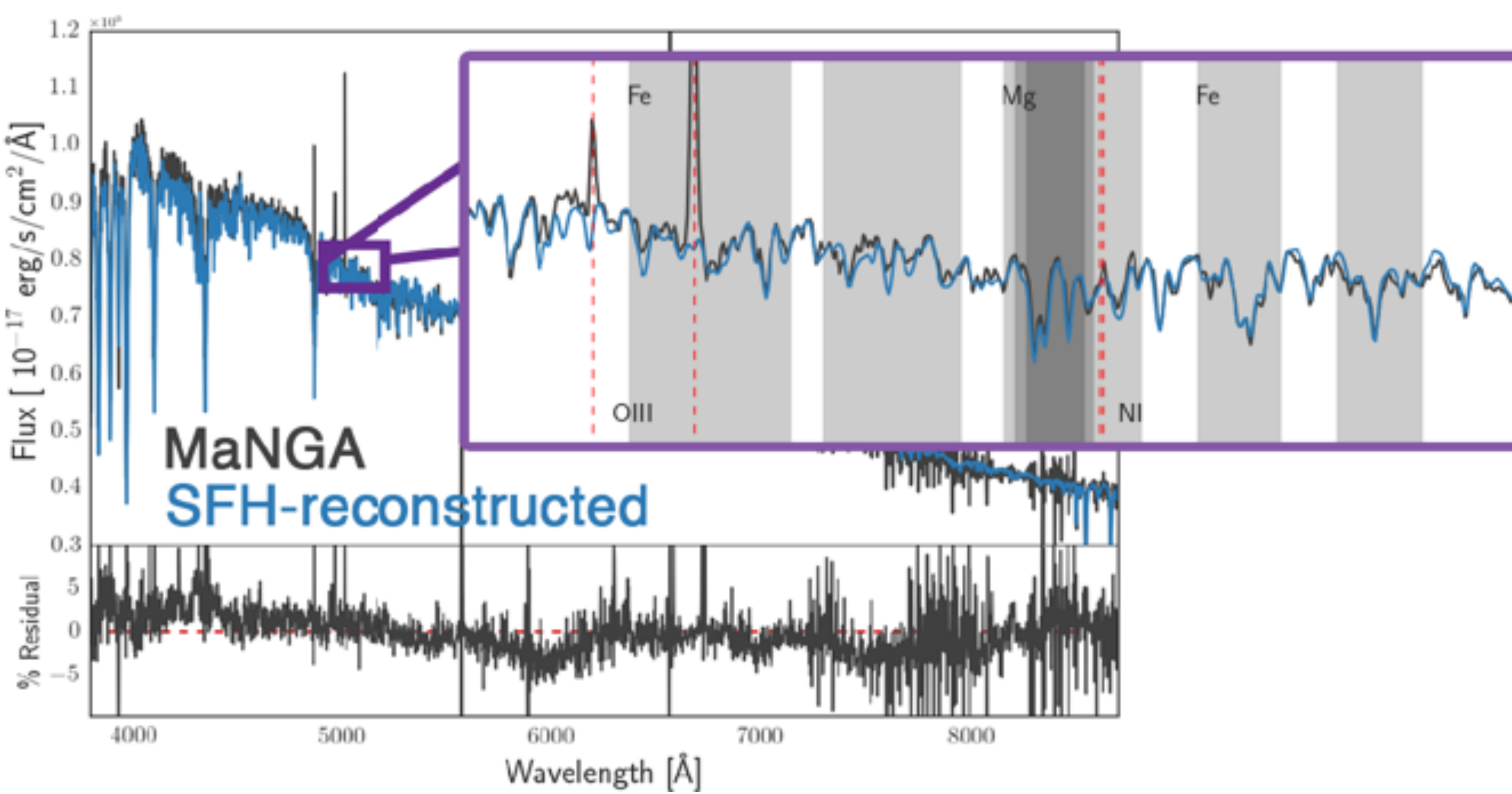




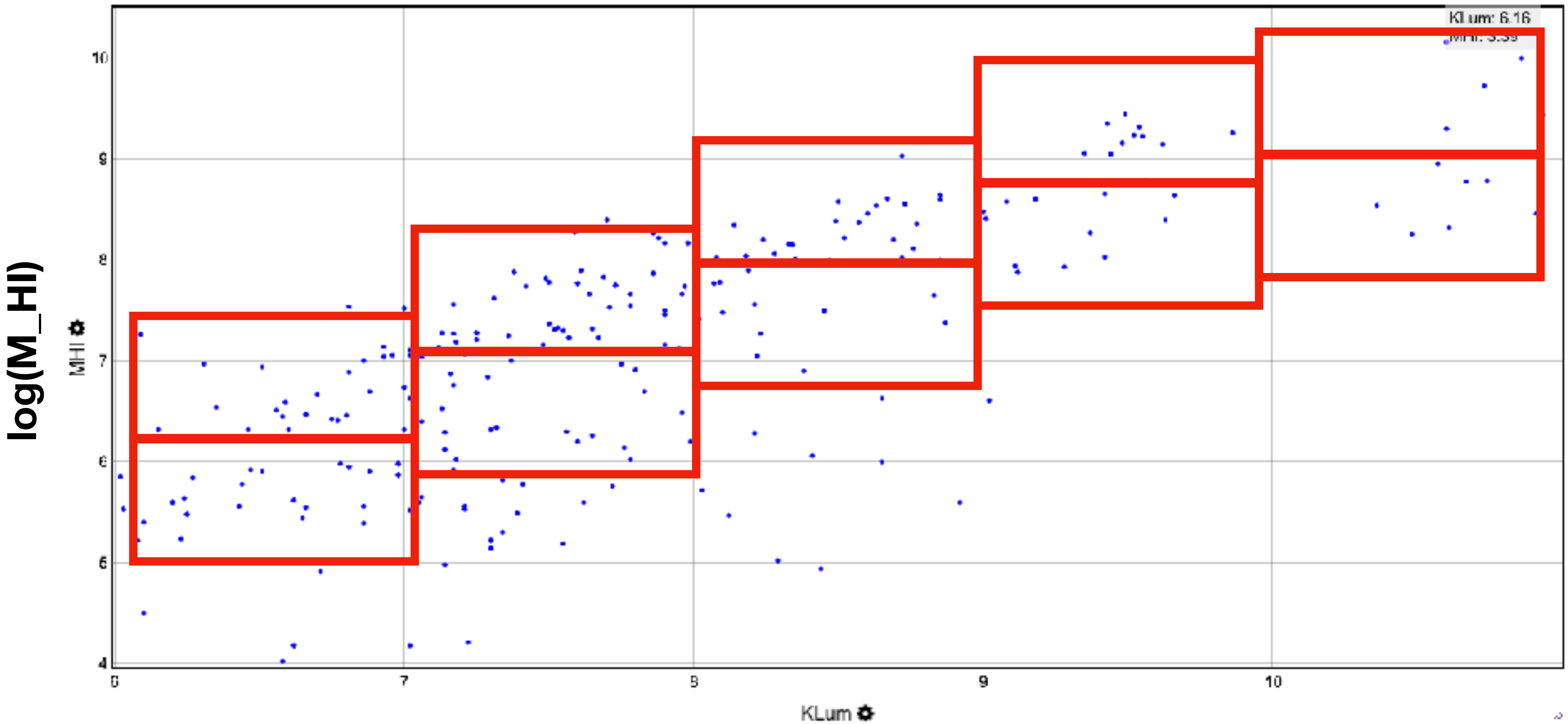
Stellar Populations

- SFH reconstructed from CMD (the best we can ever hope to do!)
- Stellar population synthesis (SPS) of spectrum
- Comparison with the IFU observations – fundamental calibration of SPS
- MaNGA has demonstrated this in NGC 4163 and M31 (in prep; Byler+2017)





LVM beyond the LG



log(M*)

Karachentsev et al. 2013

In 600 hr with LVM 1m we can map 40 D<2 Mpc galaxies at <50 pc resolution.

Now is the time to join the team and influence what LVM will be!

Science Highlights

- **The energetics of feedback; energy sources and sinks**
  - LVM nebular emission morphology, line ratios and kinematics will probe the dynamics, density, temperature, ionization, and shock structure of the gas
  - Directly observe how energy and momentum from known sources is deposited into the ISM, and how the balance between thermalization, the driving of turbulence, and the buildup of coherent bulk motions of gas (fountains and outflows) proceeds from small cloud scales up to kpc and galactic scales
  - Trace energy deposited into the gas from scales of single sources (hot stars, young clusters) to galactic scales

Science Highlights

- **The life cycle of GMCs**
  - Observations of SF as a function of galactic environment
  - Resolve the Jeans scale (<100pc) of GMCs
  - Combination of CO (cold) and ionized warm gas with resolved stellar populations to map the interactions between SF regions and the GMCs
  - How are clouds affected by proximate SF? How long until they are disrupted? How does it depend on galactic environment?
  - How does it correlate with stellar content, ages, local and global SFH?

Science Highlights

- **Precision abundances**
  - Resolving the structure of HII regions enables more realistic photoionization models
  - Strong and weak lines enable measurement of hardness, temperatures, and densities within HII regions (at least 4363 accessible in the LMC,SMC)
  - Stellar data allow constraining the ionizing radiation field
  - Separation of local and diffuse ISM emission
  - Precision calibration of abundance indicators
  - Abundance gradients around HII regions allow observations of enrichment and mixing in action

Science Highlights

- **Calibrating Sub-grid Physics**
    - Resolving the structure of HII regions and SF regions in a statistical sample across a wide range of galactic environments
    - High-quality data on feedback sources and sinks
    - Correlation with other phases of ISM
    - Allow calibration of sub-grid physics in simulations of galaxy formation which are now reaching similar scales of few pc in a cosmological context

Science Highlights

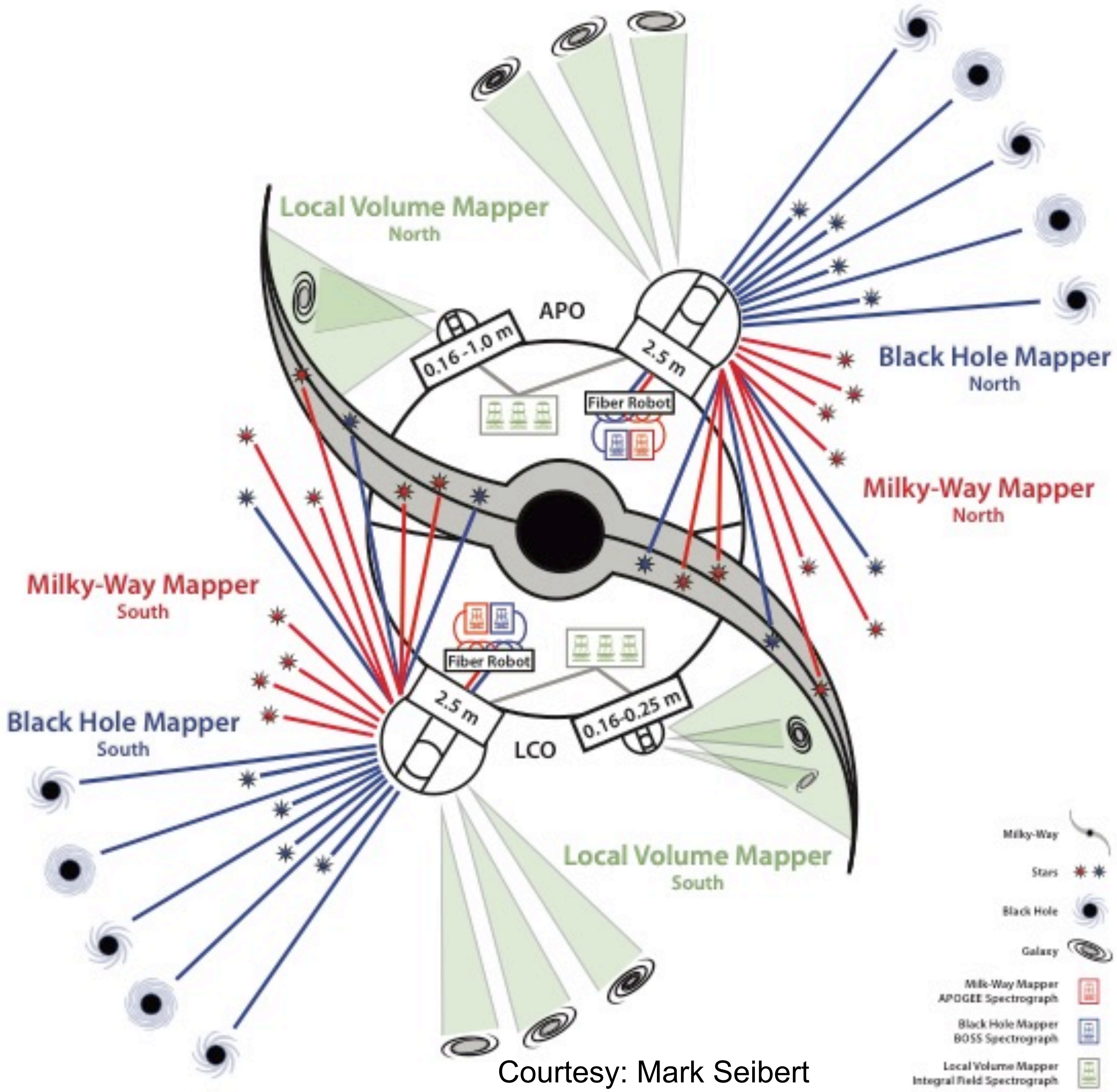
- **The co-evolution of stars and the ISM**
- **Next-generation SPS modeling**
- **Radiative transfer modeling the ionized ISM**
- **Small and large-scale distribution of metals in gas and stars**
- **…**

SDSS-V

- SDSS-V is (astro-ph/1711.03234; Pioneering Panoptic Spectroscopy)
    - Milky Way Mapper,
    - Black Hole Mapper, and
    - Local Volume Mapper
- Single fiber programs are full sky and synoptic using new robot fiber positioner
- Time domain spectroscopy of 100,000 quasars
- 5M stars with H<11 and G-H>3.5 at S/N>40
- Synergy with astroseismology & transits with TESS & PLATO
- RVs across the HR diagram for binary studies at all masses
- YSO targets in SF regions, IR spectroscopy
- **MWM + LVM: unique stellar and ISM census of the MW**

SDSS-V

- an observing facility:
  telescopes, hardware, software
- a science survey program:
  panoptic spectroscopy
- a consortium and collaboration
- in definition, implementation and fund-raising phase
  to start 2020 (…5 years



Courtesy: Mark Seibert

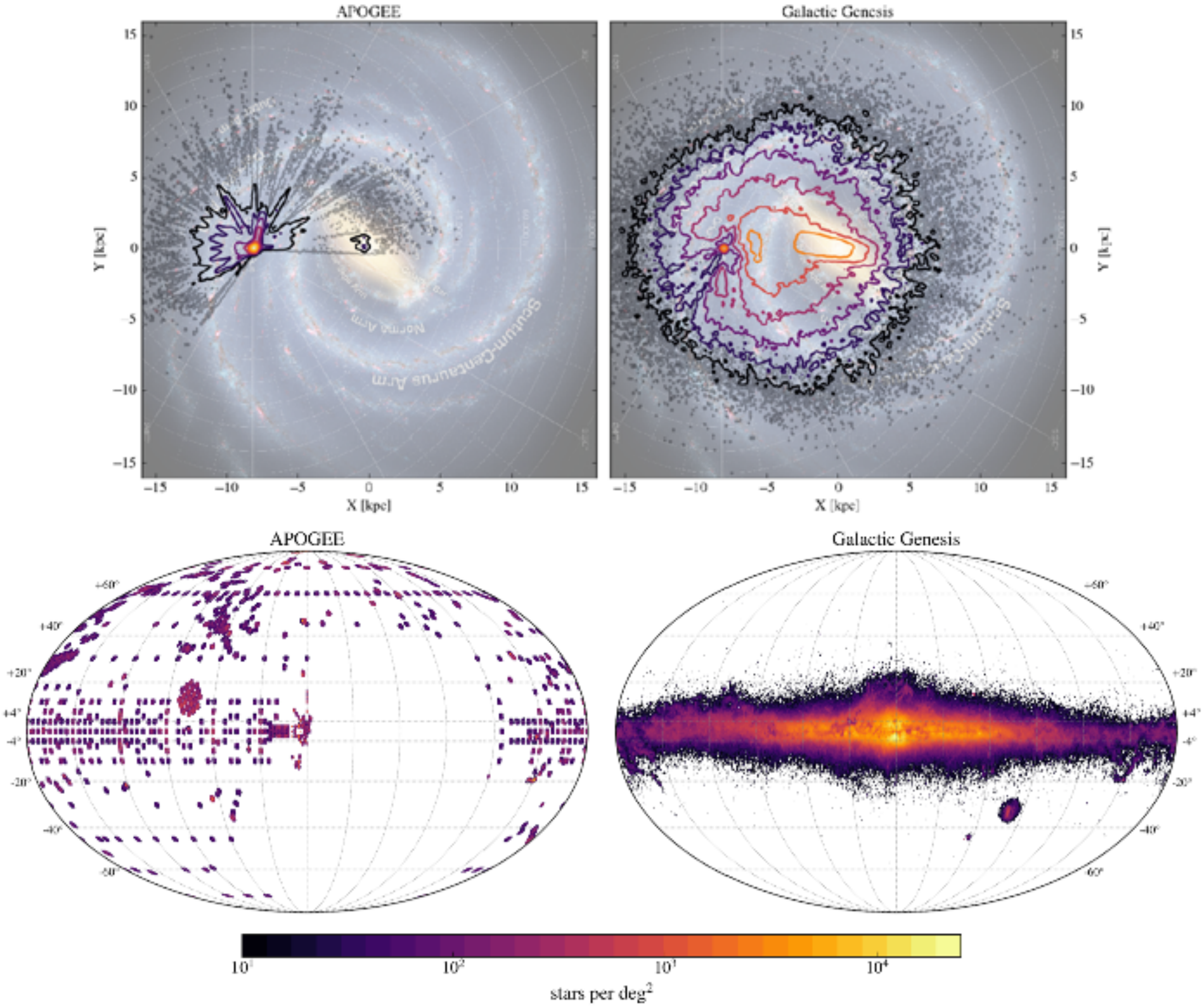
What are SDSS-V's Unique Capabilities

- (Near-)identical set-ups in ***two*** hemispheres → all-sky
  - MW is all around us
  - Gaia, (Kepler), Tess, eROSITA are all-sky missions
  - Data homogeneity!
- Rapid robotic fiber configuration (300 nearIR/ 500 opt) over ≈5sqdeg
  - enables short exposure time (13min) H<11
  - can cover the whole sky once a year (and in parts much more often)
- Wide-field, multi-object, high-res. Spectroscopy (APOGEE)
  - No other near-IR spectroscopy comes close to all-sky & 5M targets
- Push (optical) IFU spectroscopy to unprecedented regime
  - from 0.05deg^2 → 3000deg^2 (huge pixels, small telescope)

SDSS-V Panoptic Spectroscopy Surveys

- Milky Way Mapper (>6,000,000 targets & multi-epoch)
  - Galactic genesis
  - Stellar Astrophysics
  - Spectral complement to Kepler, Gaia, TESS
- *Black Hole Mapper* (>400,000 targets & monitoring)
  - QSO reverberation & changing-look QSOs
  - eRosita (X-ray survey) follow-up
- Local Volume Mapper (>25,000,000 spectra & >3000 sqdeg)
  - Ultra-wide field IFU spectroscopy, focus on the ISM

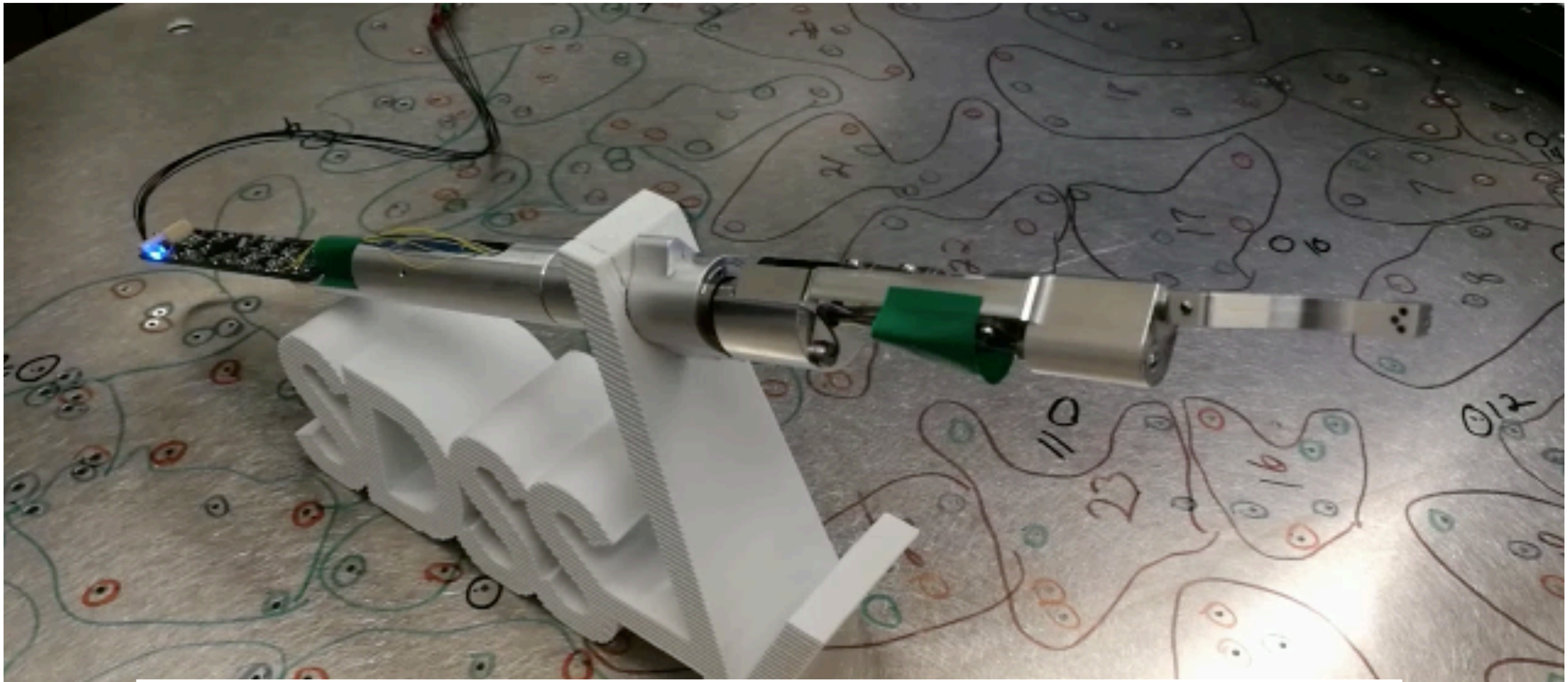
Milky Way Mapper



MWM Details ...

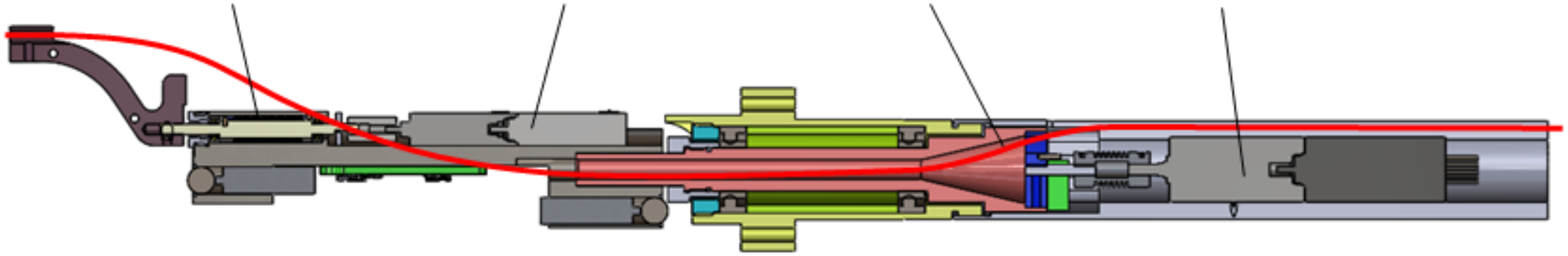
Galactic Genesis & Stellar Astrophysics Targeting Classes					
Name	**Instrument**	**Selection**	$\mathbf{N}_{\text{Targets}}$	$\mathbf{N}_{\text{Epoch}}$	Comment
Galactic Genesis	APOGEE	H<11, $G-H>3.5$	4,800,000	1	dust-extincted disk
	APOGEE	$\|z\|<200$ pc, H< 11, distance <5 kpc	125,000	1	to complete hi-res dust map
Binaries with Compact Objects	BOSS	PTF, ZTF, Gaia photo variability	30,000	3	binaries w/WD, NS & BH
	BOSS	Gaia parallaxes	30,000	1	wide WD+MS/RGB binaries
Solar Neighborhood Census	APOGEE *and* BOSS	d <100 pc, $G<20$, $H<12$	400,000	2	1000x increase in volume & stars
White Dwarf Chronicle	BOSS	$G<20$	300,000	3	15x increase in sample size
TESS Exoplanet Host Candidates	APOGEE	H<= 13.3	300,000	1-8	All short-cadence targets & planet hosts
Binaries Across the Galaxy	APOGEE	H< 13.4 & $N_{visit}>=6$ by start of SDSS-V	60,000	6-18	Gives orbits with 24-40 epochs for all targets with long baseline
Gaia Astrometric Binaries	APOGEE, BOSS	d <3 kpc	200,000	1	rare types of systems
TESS Red Giant Variability	APOGEE	H <12.5	250,000	1	only stars with at least 80 days of observation
Convective Core Sample	APOGEE	H <12	200,000	2	Detection of single vs. binary systems
	APOGEE	H<12	500	25	current samples <10
Young Stellar Objects	APOGEE	H< 12, d<1 kpc	20,000	12	nearby SF regions
	APOGEE	H< 12	3,500	8	high-mass star-formation regions
	APOGEE	H<12, $\|b\|<2$	10,000	2	Galactic Plane massive young stars
	APOGEE	H< 13	10,000	2	Central Molecular Zone

Fiber Robot

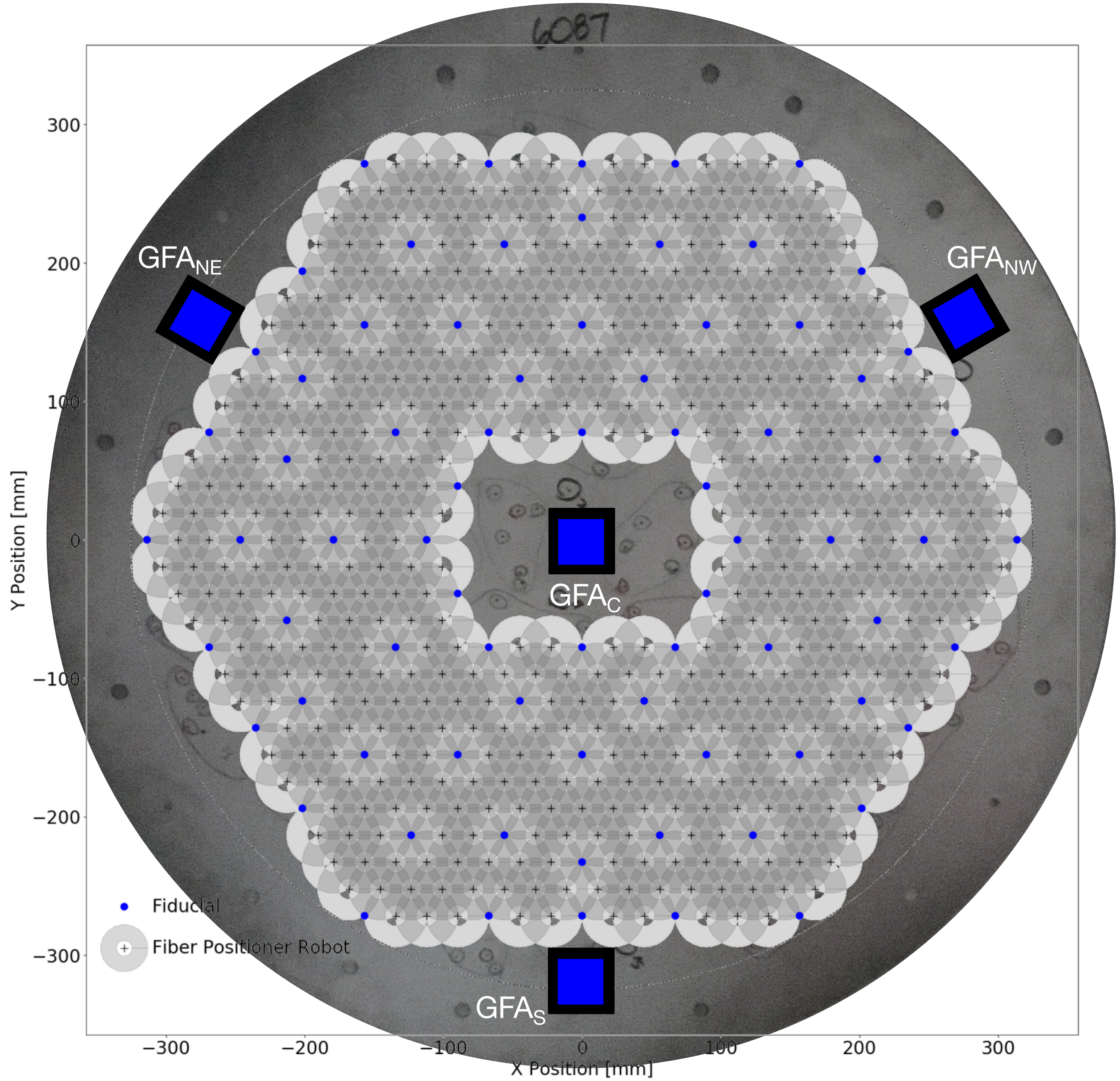


SDSS-V Prototype Design

Rick Pogge,OSU



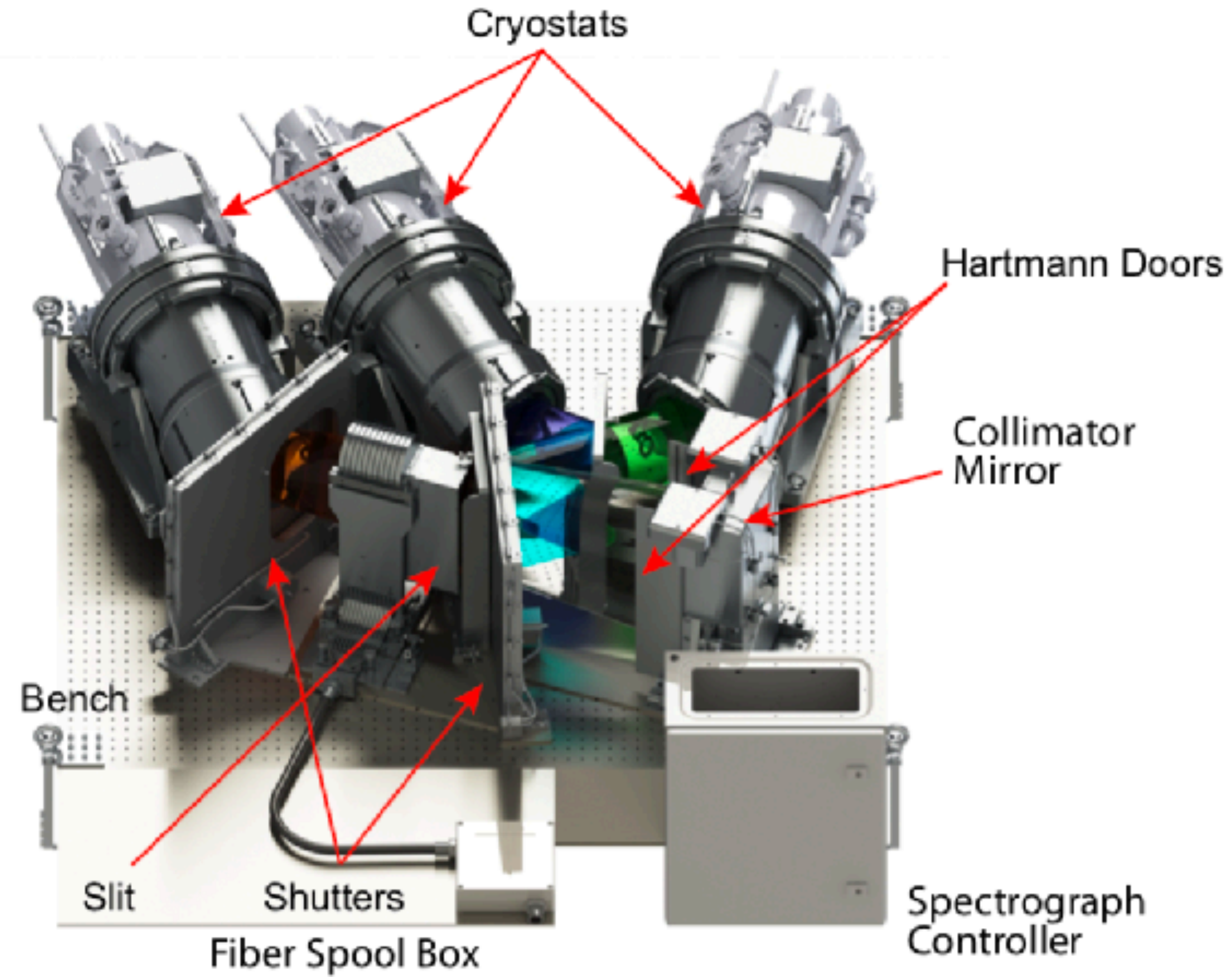
Focal Plane



6087
GFA$_{NE}$
GFA$_{NW}$
GFA$_{C}$
GFA$_{S}$
Fiducial
Fiber Positioner Robot
Y Position [mm]
X Position [mm]
300
200
100
0
−100
−200
−300

LVM Spectrograph

- DESI 3-channel design 3600-9800 Å, 2000 < R <5100
- 3 4k CCDs

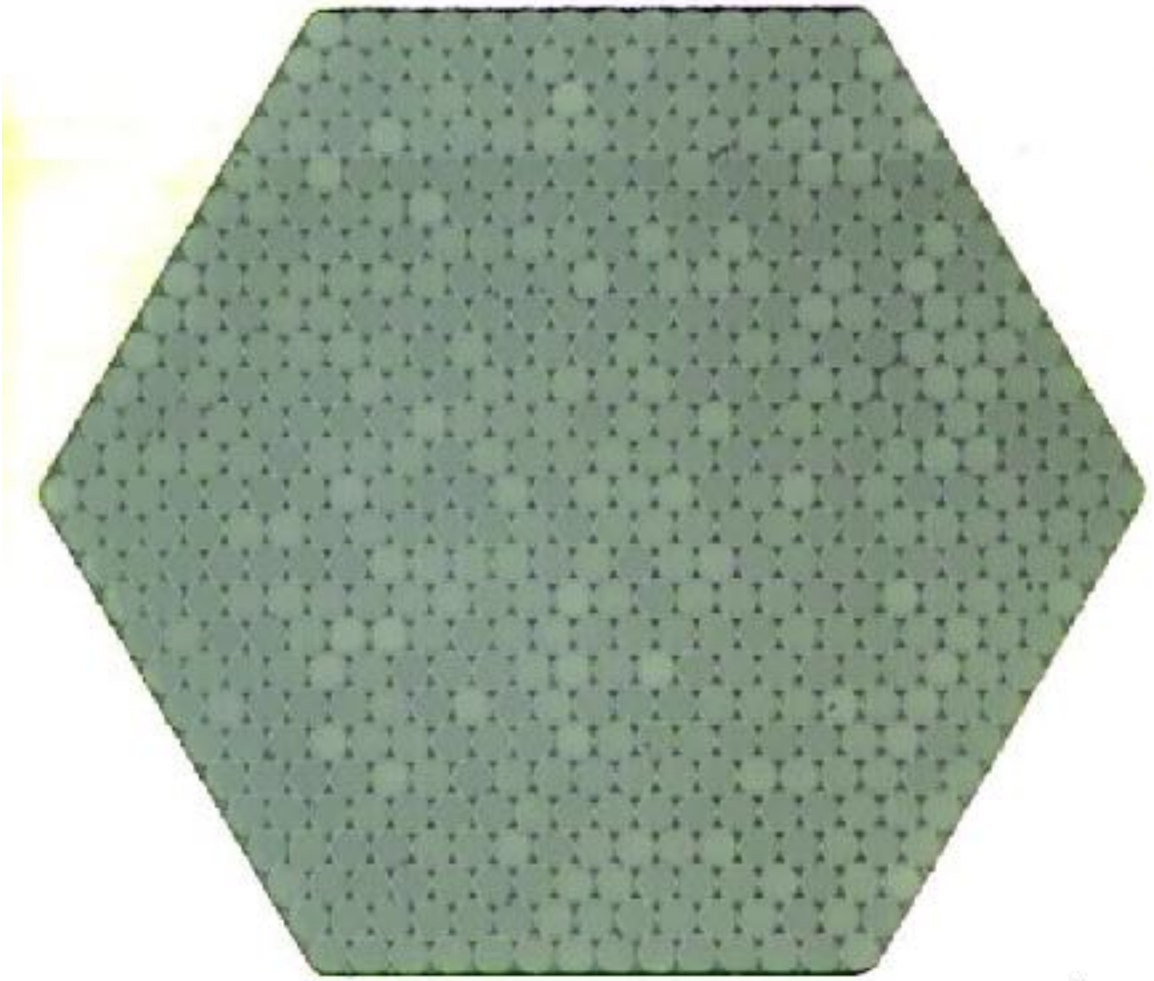


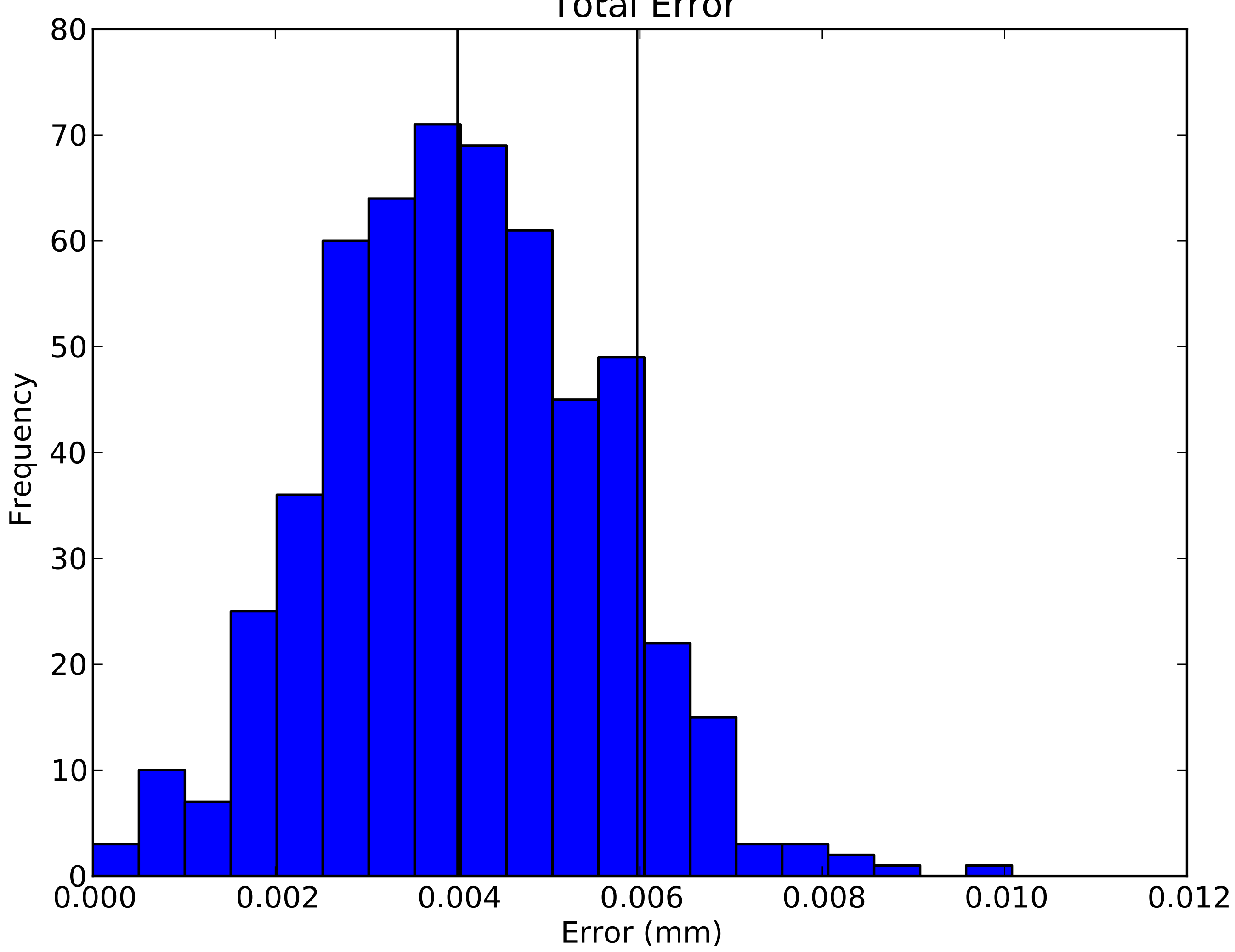
360 – 980 nm, 3 channels
Resolution average = ~3,500
- Blue 360–555 nm, R~2,000–3,200
- Green 555–656 nm, R~3,200–4,100
- Red 656–980 nm, R~4,100–5,100

Throughput max = 56% at 650 nm
Throughput min = 21% at 360 nm
Collimator f-ratio = 3.57
Pixel samplings = 3.4
Detectors = 4k x 4k w/ 15 um pixels
Slit length = 120.9 mm
Mass = ~500 kg
Size = 1.8 x 1.4 x 0.6 m

LVM IFU Tech

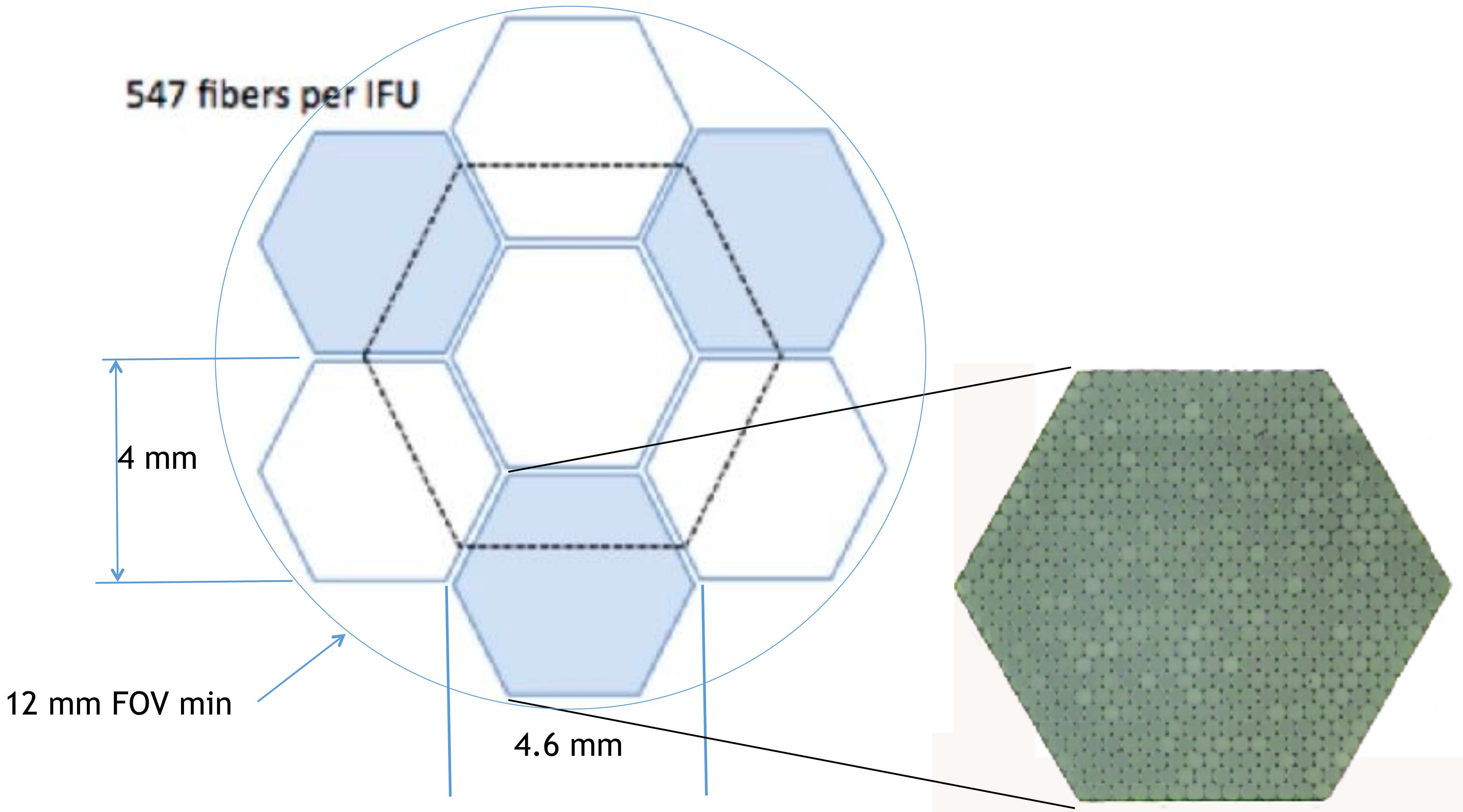
- IFUs based on MaNGA hexagonal insertion ferrule technology
- Lenslet coupling
- 547-fiber unit feeding one spectrograph
- 547 fiber ferrule made at UW shows scalability of the tech





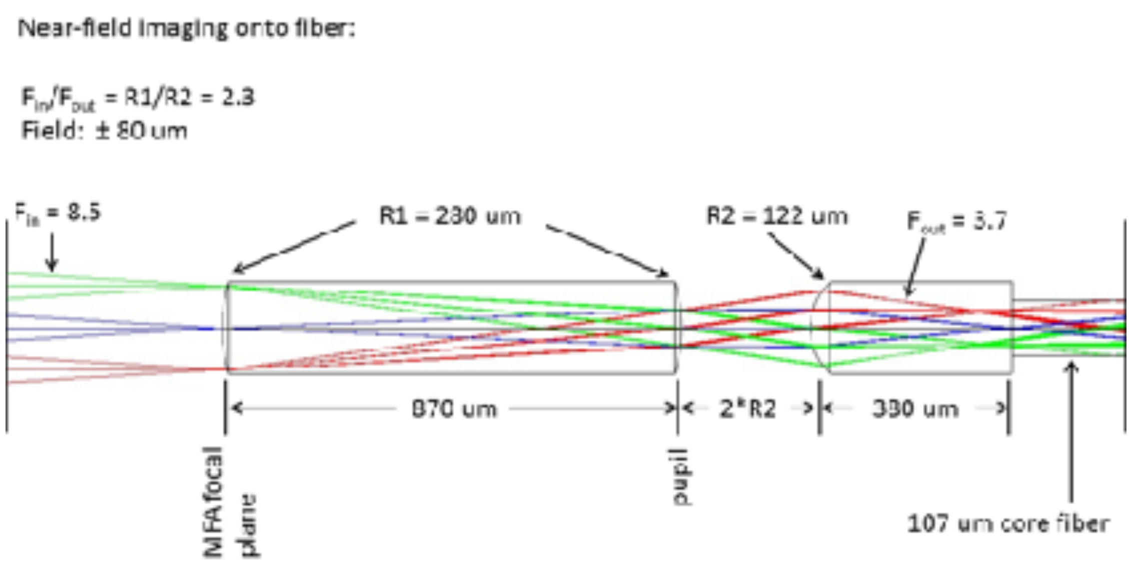
LVM Focal Plane

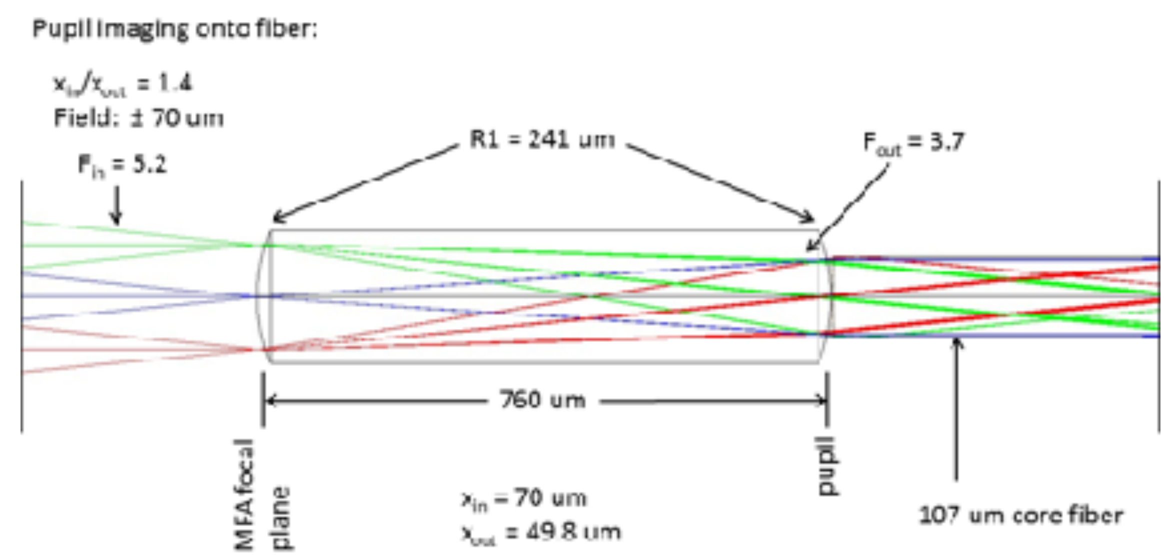
- IFUs are spaced by one 547 fiber group.
- Tiling is then interlaced to provide full coverage.
- Registration between IFUs must be good to the ~1/10 of a fiber size or 10 microns.



LVM Lenslets

- Lenslet designs under investigation
- Pupil/near-field imaging onto fiber
- Further scrambling options being considered





Project Status

- SDSS-V received a $16M grant from the Sloan Foundation in October 2017. First payment expected end of 2017
- SDSS-V to take over operations from SDSS-IV mid 2020
- We have 2.5 yr to build the LVM hardware!
- Minimize R&D (fiber system only), use pre-developed or commercial solutions wherever possible
- We have signed an MOU with US DoE for licensing the DESI designs and IP, and access to the DESI vendors (in particular Winlight)
- **We need more people to take on work! Please join us.**
- SRD close to completion; CoDR Jan 13-14, 2018

Join SDSS-V and be part of it!