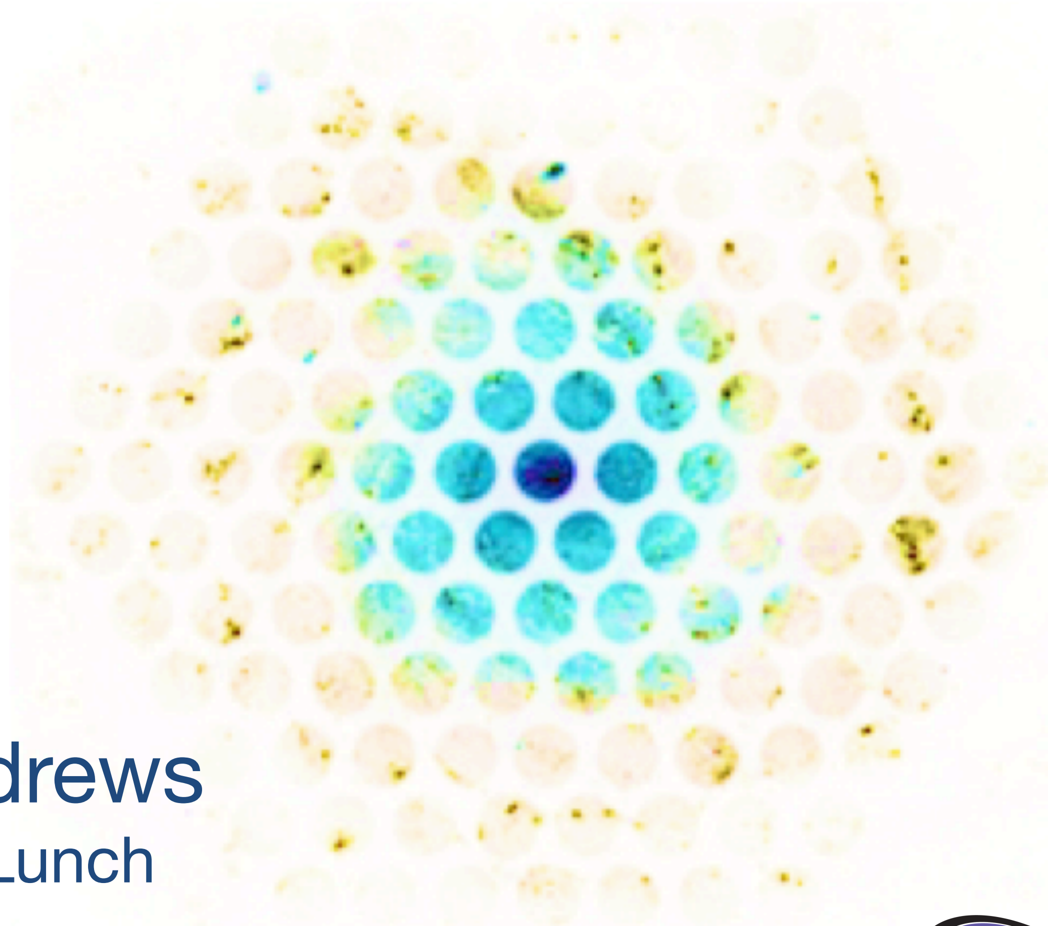
The SDSS-IV MaNGA Survey:

Galaxy Dissection on an Industrial Scale



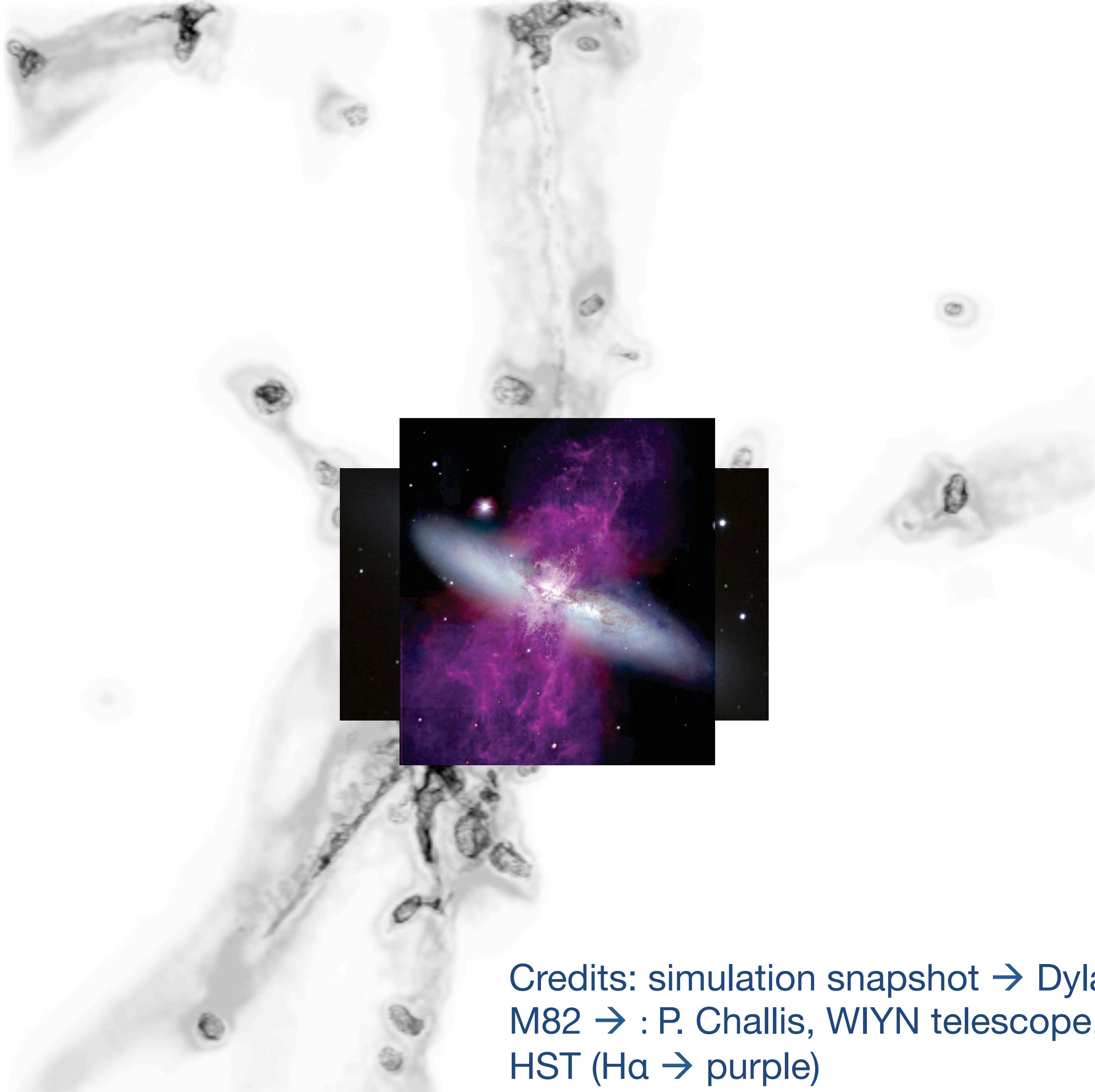
Brett Andrews

CMU AstroLunch

9.15.2017

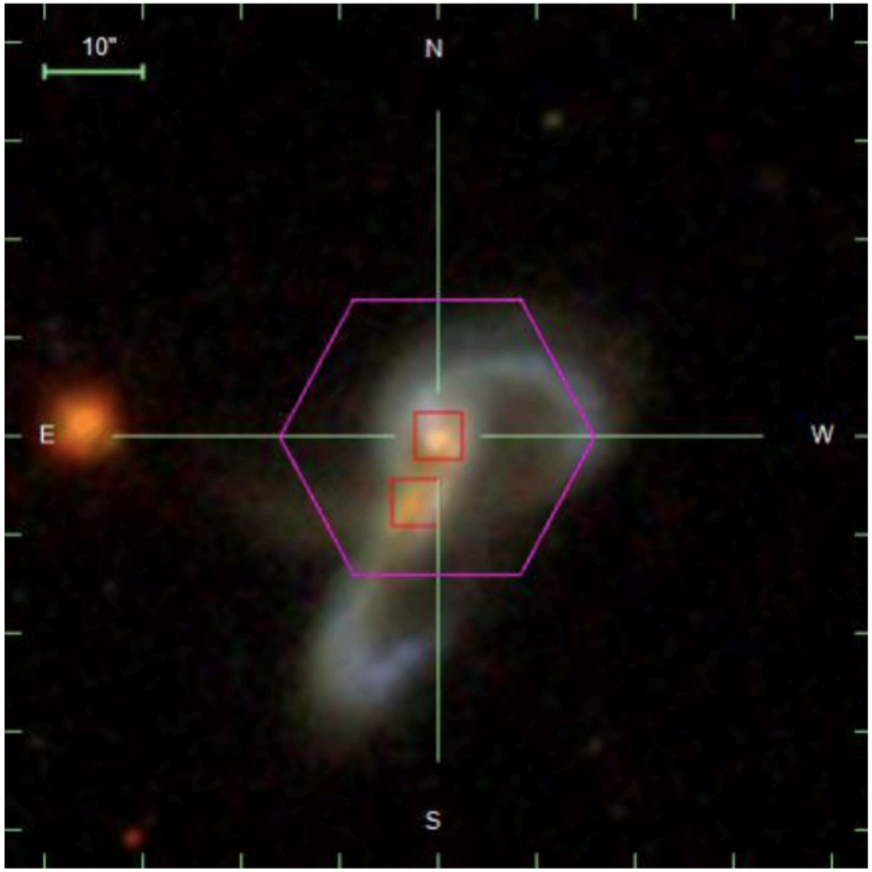
University of Pittsburgh

SDSS

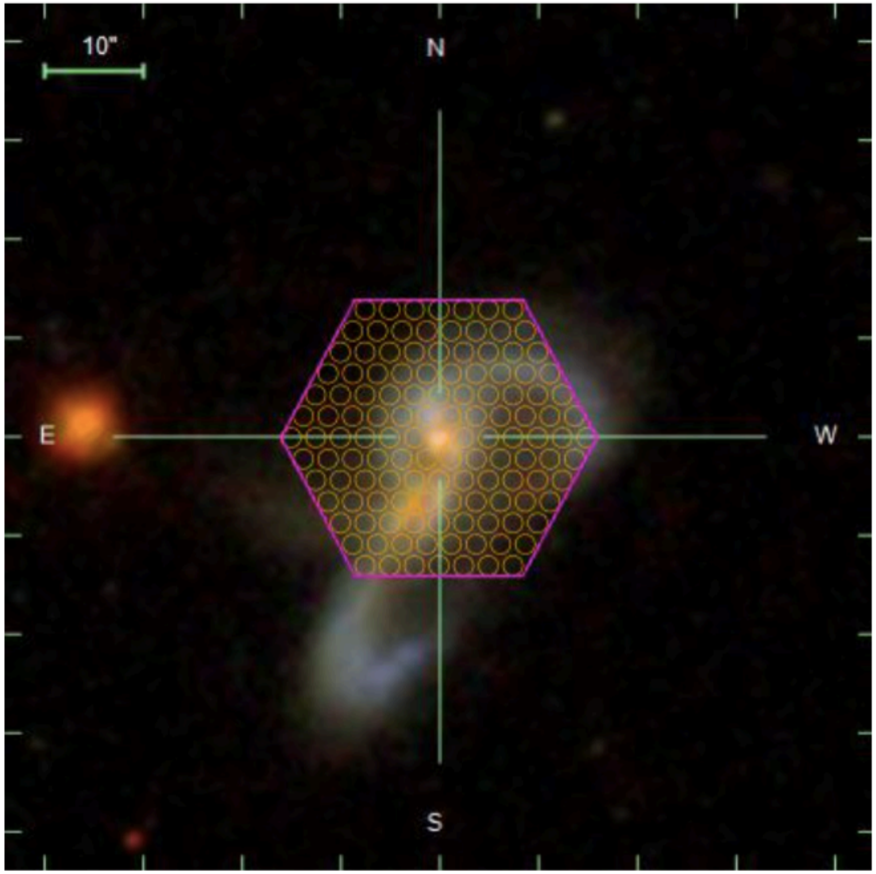


Credits: simulation snapshot → Dylan Nelson
M82 → : P. Challis, WIYN telescope, &
HST (Hα → purple)

Previous SDSS Surveys



MaNGA



Credit: Mike Blanton

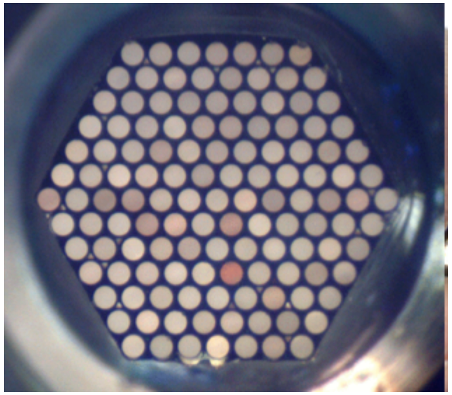
MaNGA Science Drivers

1. How does gas accretion drive growth?
2. How do mergers, stellar accretion, and instabilities build spheroidals?
3. What quenches star formation? Does is it depend on environment?
4. How is angular momentum distributed and transferred during formation?
5. How do various mass components assemble and influence one another?

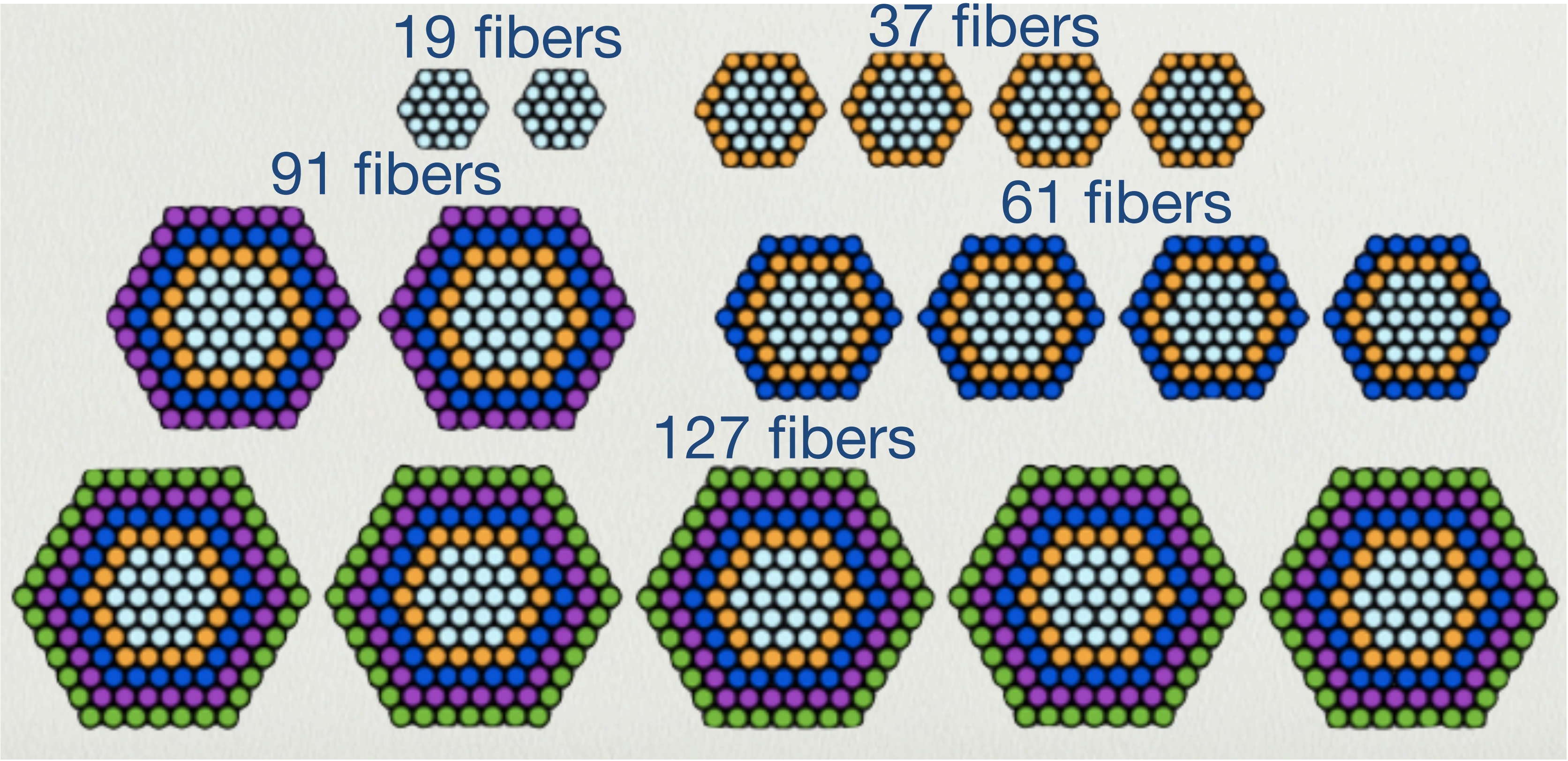
MaNGA Overview

- **MaNGA**: Mapping Nearby Galaxies at Apache Point Observatory
- One of three main sub-surveys of SDSS-IV (2014-2020)
- PI: **Kevin Bundy**. Over 160 members at 50+ institutions.

- Integral Field Unit (IFU) observations of 10,000 nearby galaxies
- z = 0.01 — 0.15
- λ ~ 3,600 — 10,300 Å
- R ~ 1400 — 2600 (115 — 215 km/s)
- Spatial resolution: 1.3 — 5.1 kpc

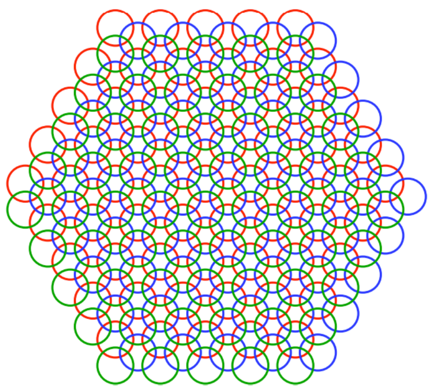


IFU Sizes

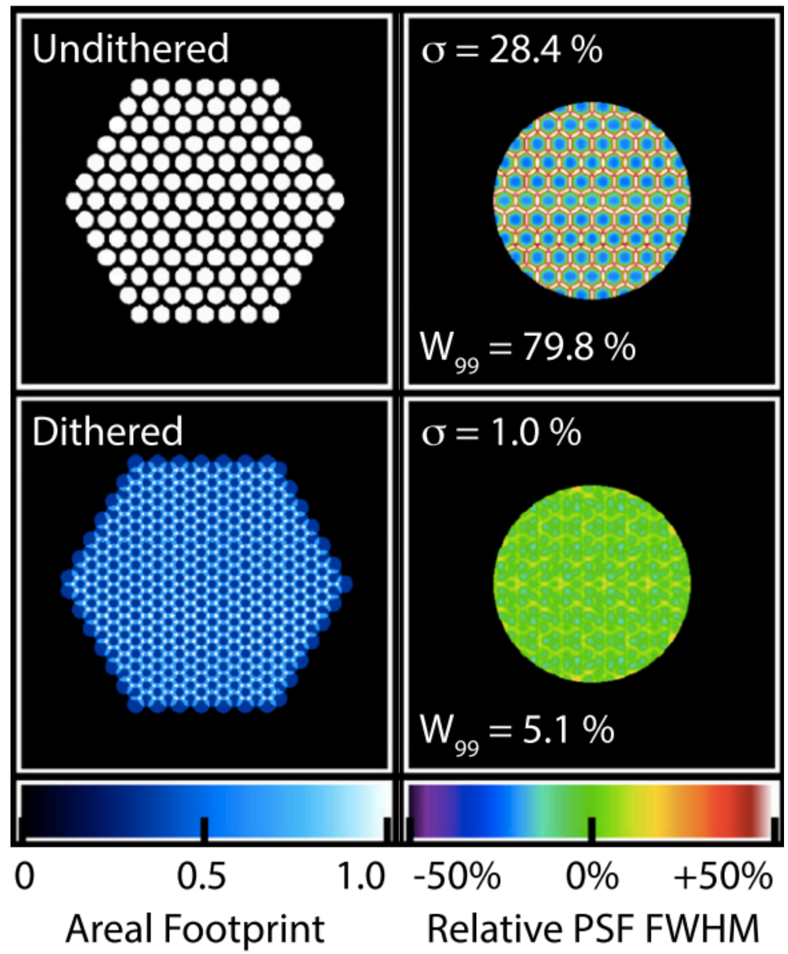


Credit: Kevin Bundy

Dithering



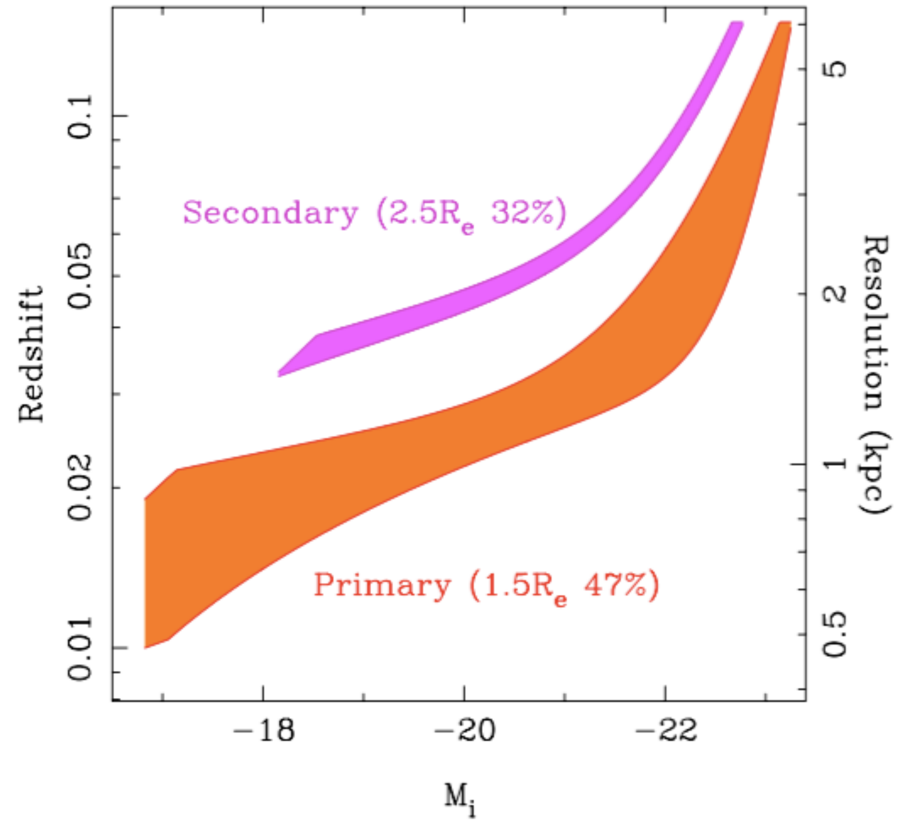
Law et al. (2015)



MaNGA Sample Design

- $M_\star > 10^9\ M_\odot$
- Flat distribution in $M_\star$
- Two main subsamples: 1.5 and 2.5 $R_{effective}$

- Ancillary programs:
  – 5-10% of bundles



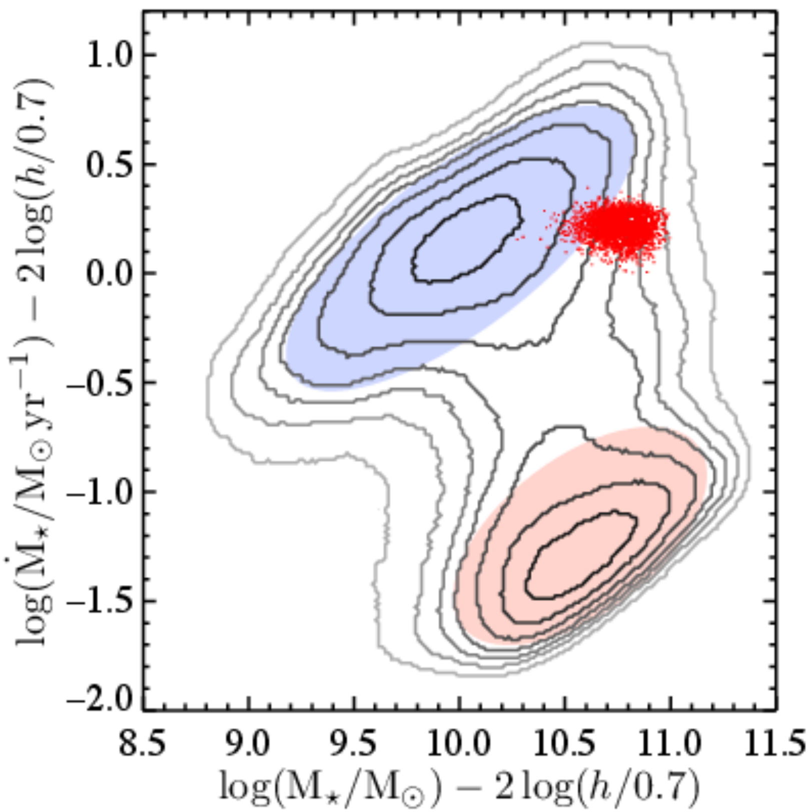
Bundy et al. (2015)

Milky Way Analogs

Jeff Newman, **Cat Fielder**, **Tim Licquia**, **BHA**, Matt Bershady, Jon Bird, Karen Masters

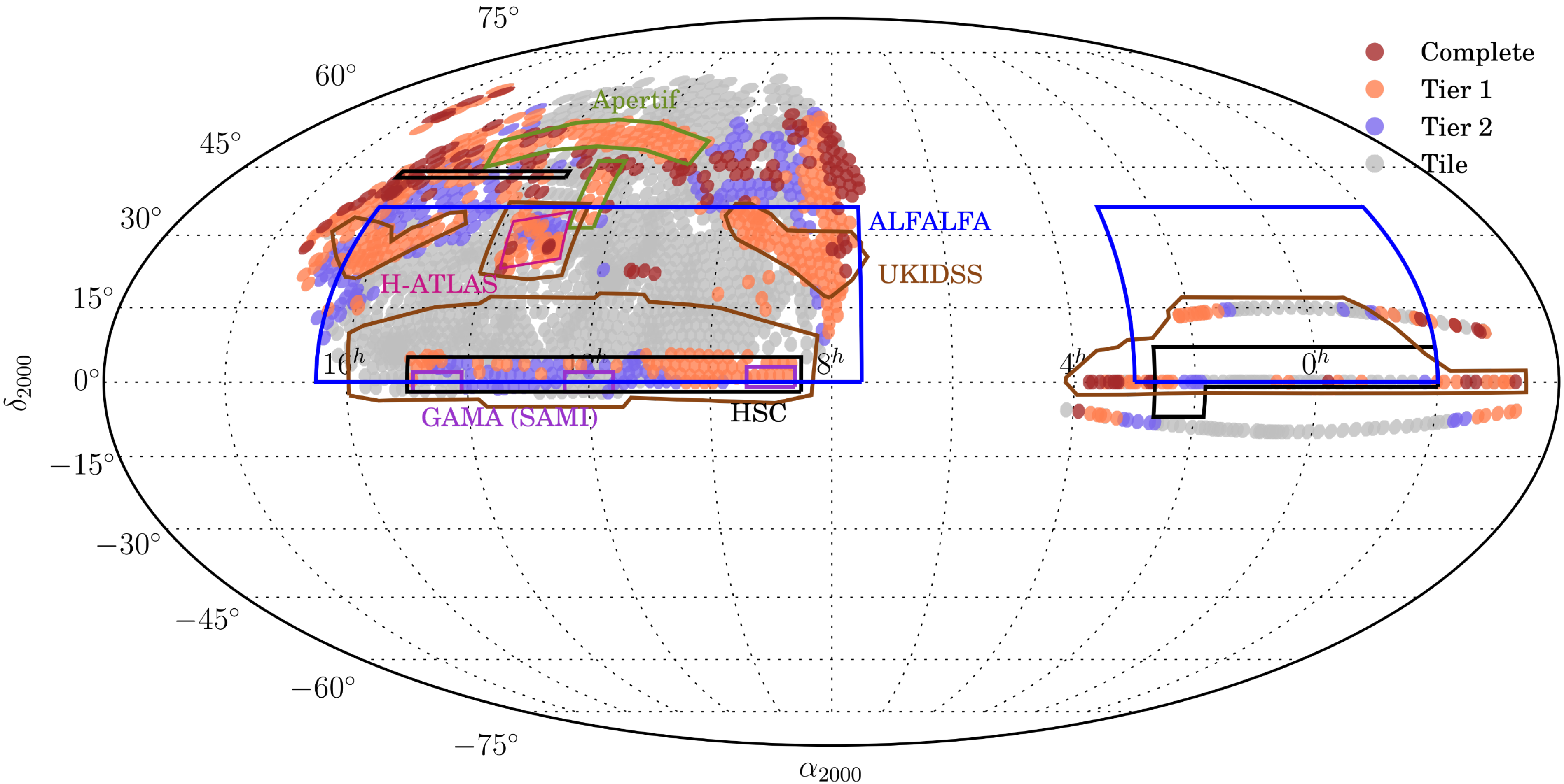
1. $M_\star$ and star formation rate
2. $M_\star$ and bulge-to-total mass ratio

- Measure global properties of MW (e.g., color and luminosity)
- How typical is the MW?
- Ancillary Data (HI)



Licquia, Newman, & Brinchmann (2015)

MaNGA Fields



Yan et al. (2015)

IFU Survey Comparison

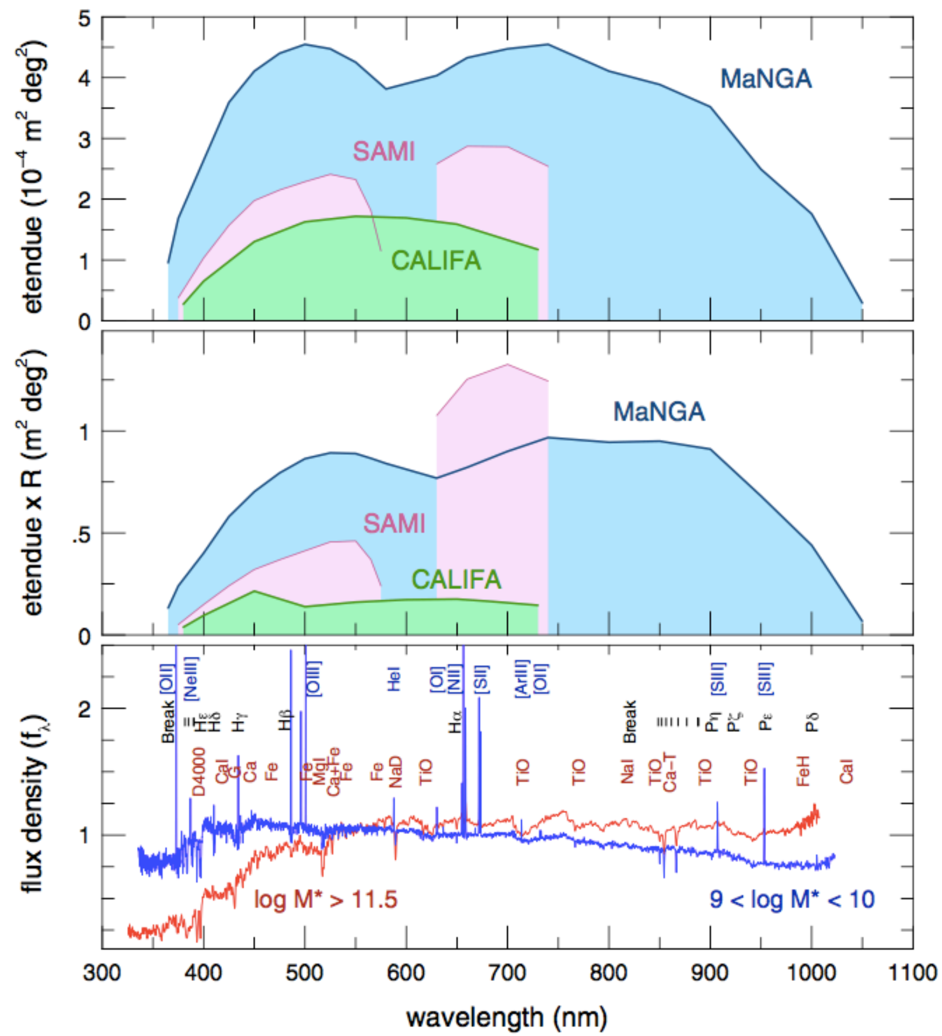
Survey	Year(s)	Galaxies	Science Focus
DiskMass	2001-2005	192	kinematics
ATLAS-3D	2011	260	kinematics
CALIFA	2010-2016	667	kin., em. lines, stellar pops
SAMI	2013-2016	3,400	kin., em. lines, stellar pops
MaNGA	2014-2020	10,000	kin., em. lines, stellar pops

IFU Survey Comparison

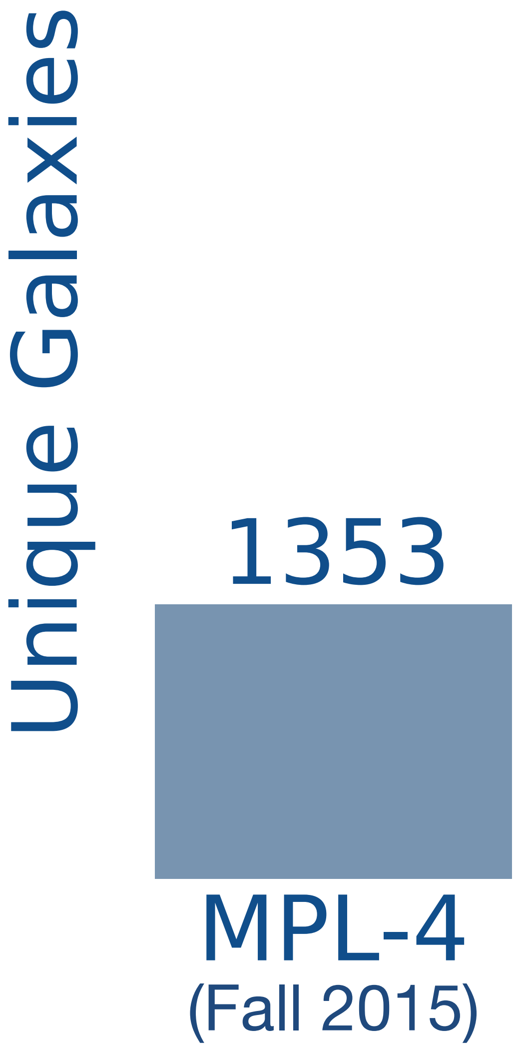
étendue: a measure of how quickly one can map the sky to a given S/N at a given spectral resolution.

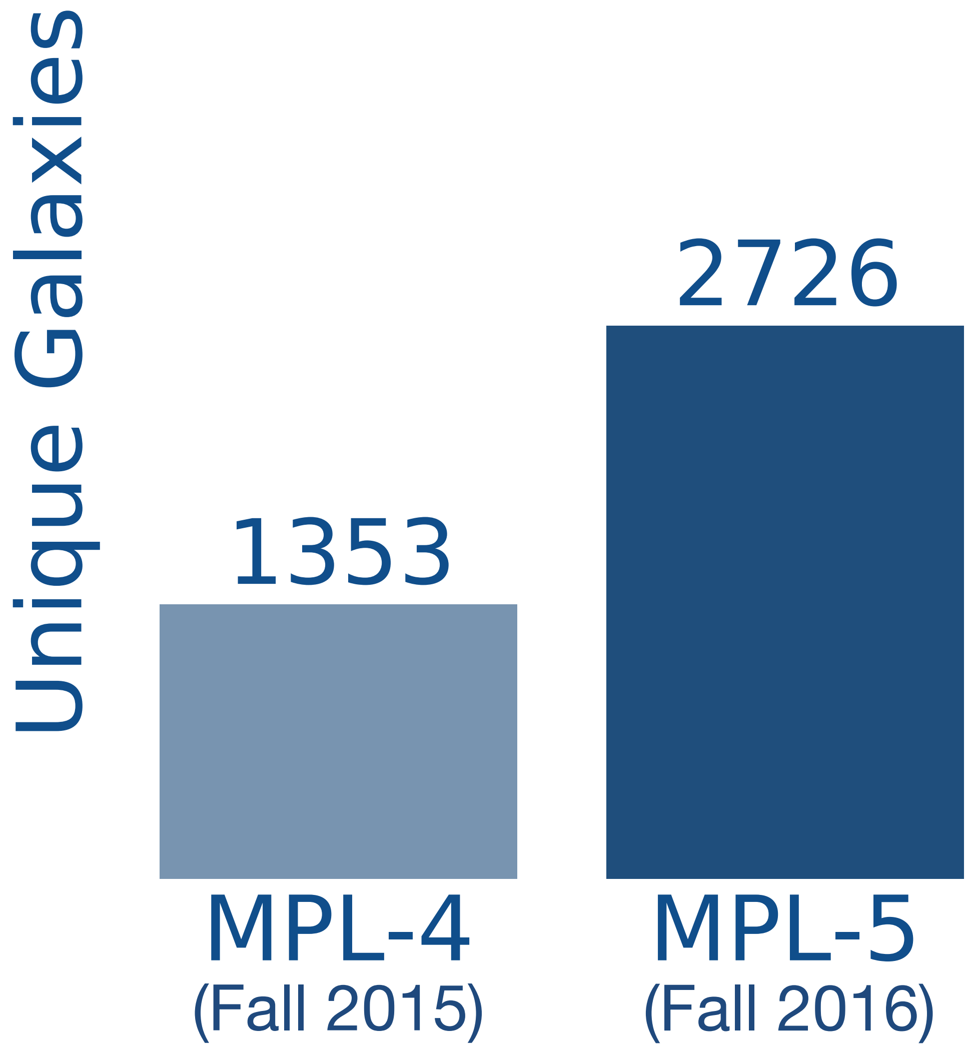
étendue = collecting area × solid angle covered by fibers × efficiency

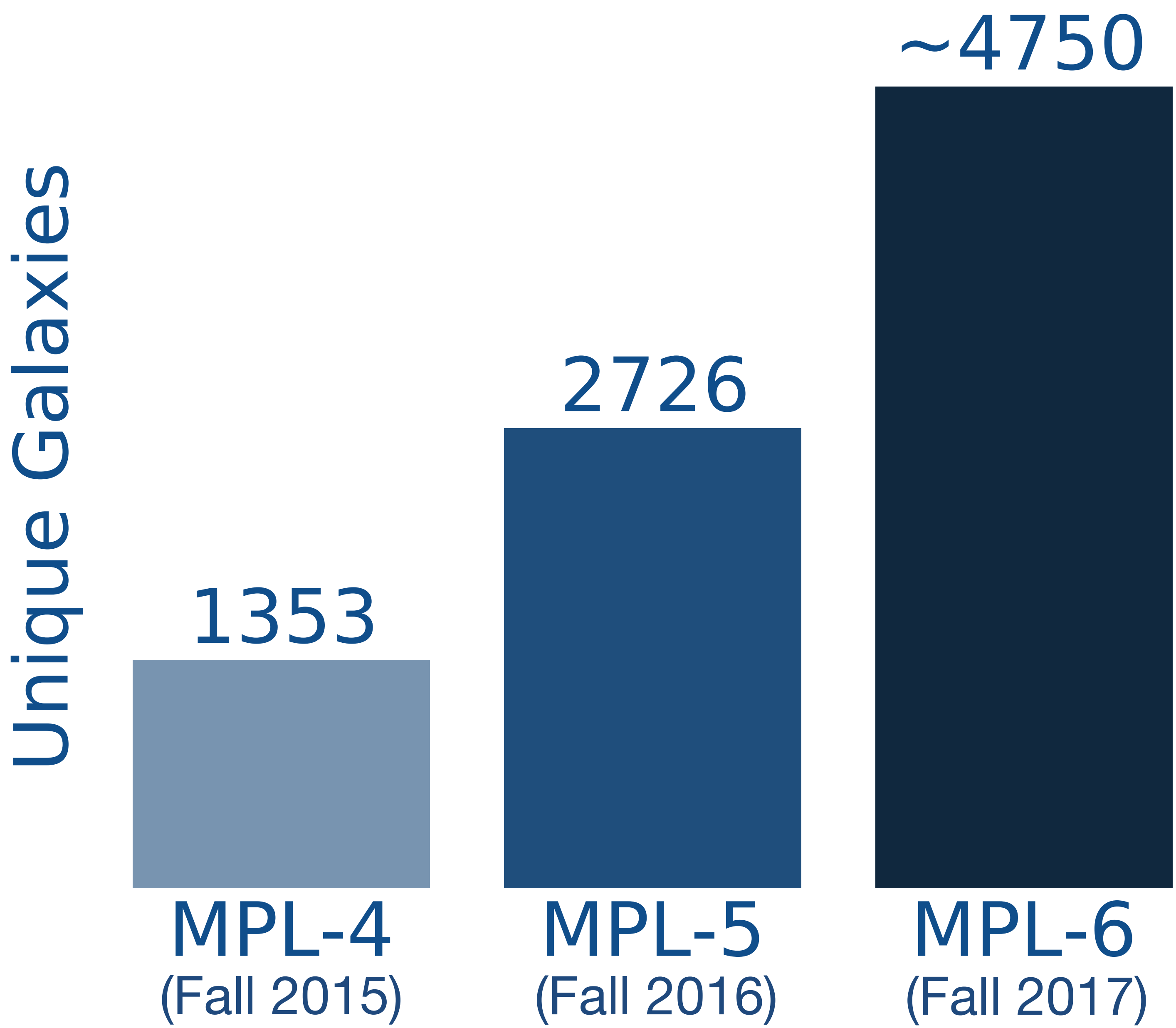
éntendue × *R* (resolving power): metric of simultaneous survey information gathering power.



Bundy et al. (2015)


Unique Galaxies
1353
MPL-4
(Fall 2015)

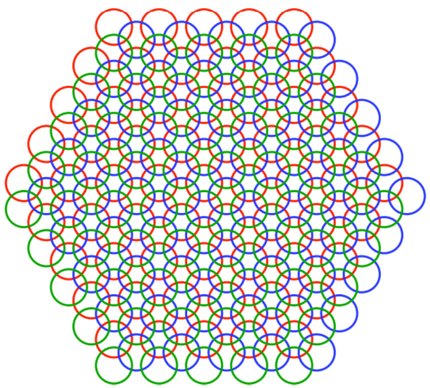

Unique Galaxies
1353
2726
MPL-4
(Fall 2015)
MPL-5
(Fall 2016)


Unique Galaxies
1353
2726
~4750
MPL-4
(Fall 2015)
MPL-5
(Fall 2016)
MPL-6
(Fall 2017)

MaNGA Data Reduction

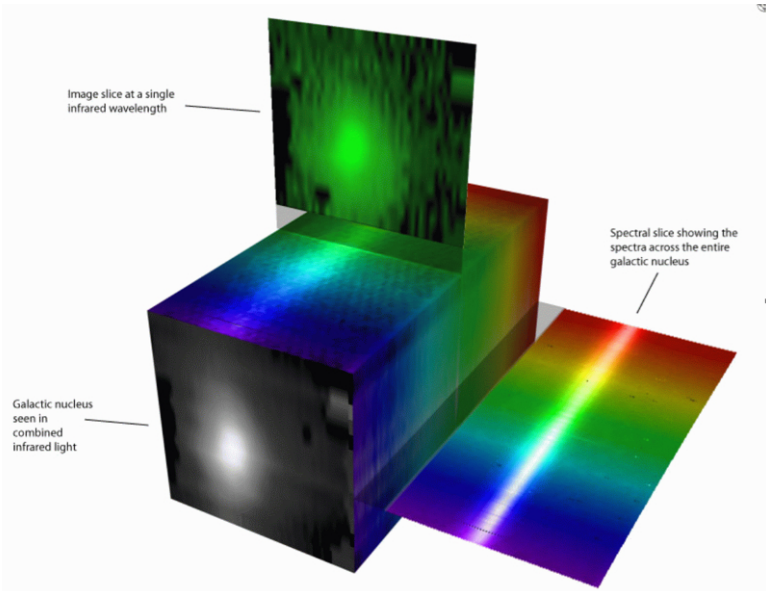
Row-Stacked Spectra

(spectrum from each fiber at each dither position)



Law et al. (2015)

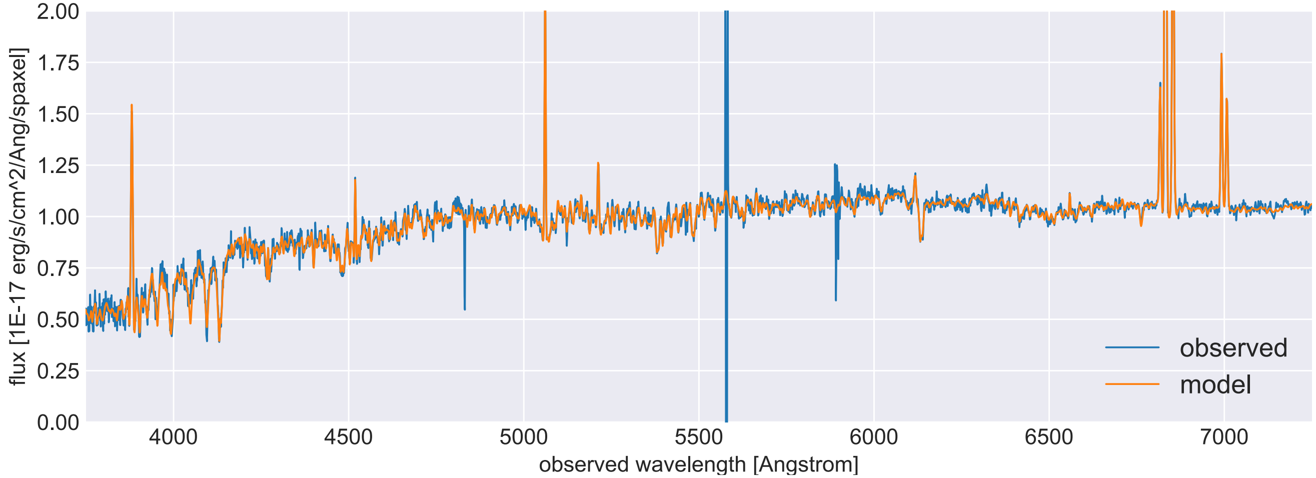
Cubes



Credit: Stephen Todd (ROE) & Douglas Pierce-Price (JAC)

MaNGA Data Analysis

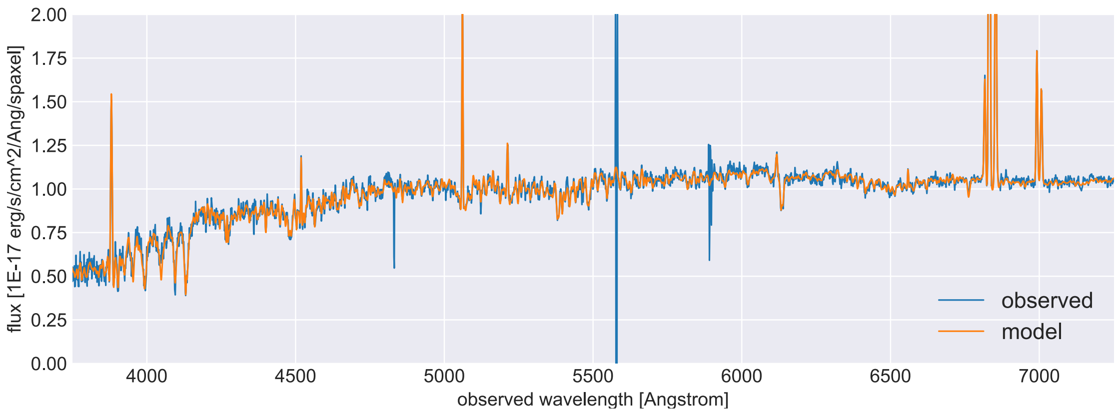
1. Fit stellar continuum
2. Fit emission lines
3. Measure spectral indices



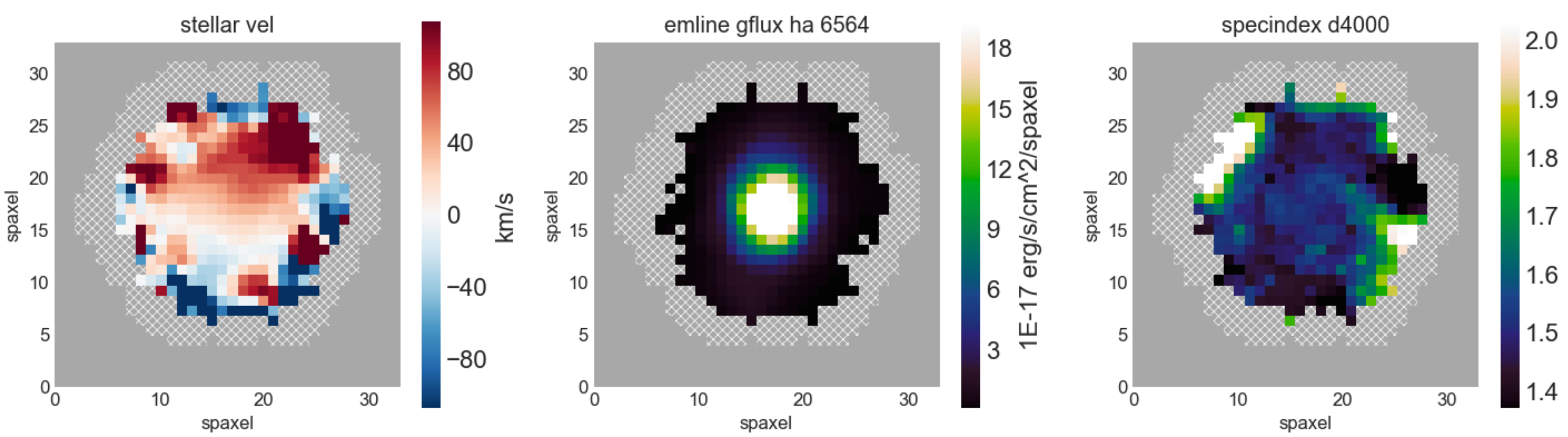
Westfall et al. (in prep.)

MaNGA Analysis Products

Model Cubes

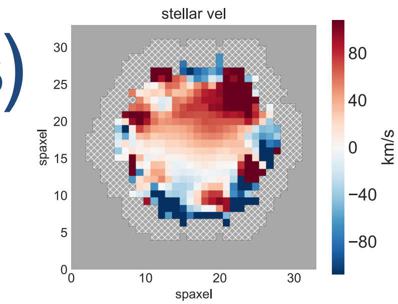


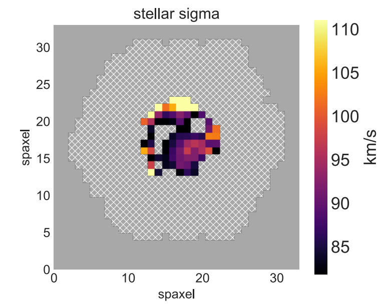
Maps



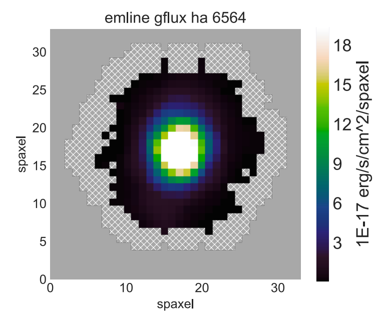
Analysis Properties

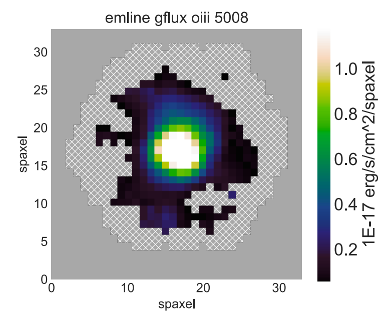
- Kinematics (stellar & gas)
  - velocity & sigma



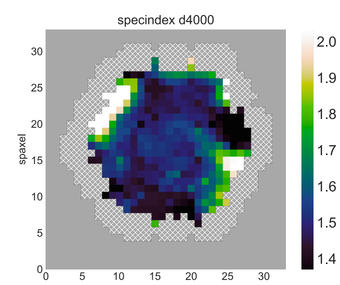


- Emission line fluxes
  - Hα–Hε, HeI, HeII, [OI], [OII], [OIII], [NII], [SII], [SIII]



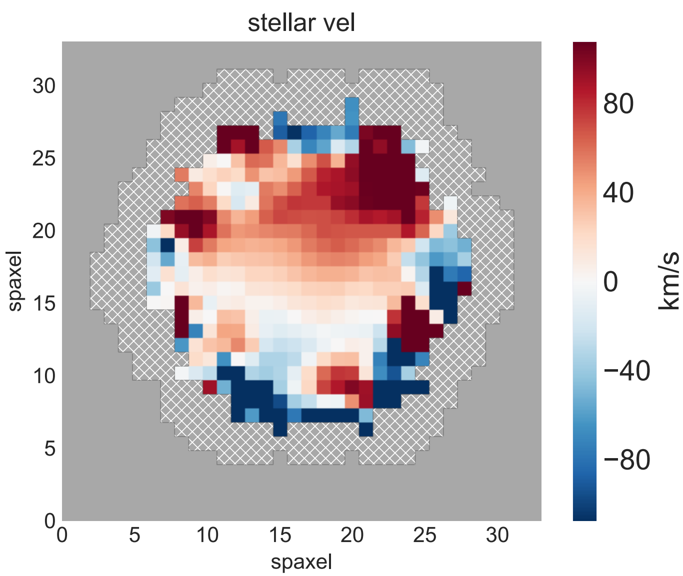


- Spectral Indices
  - D4000

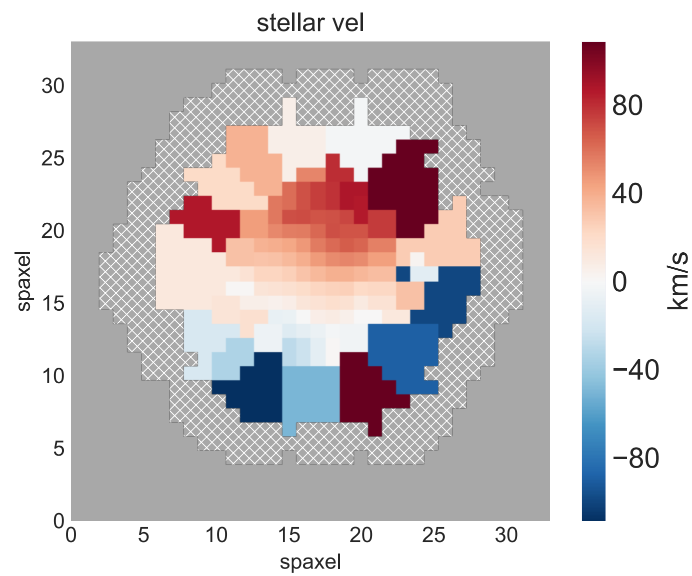


Bin Types

SPX (unbinned)



VOR10 (Voronoi binning to S/N = 10)



NRE (0–1 and 1–2 R_{eff})

ALL (global)

MaNGA Early Science Results

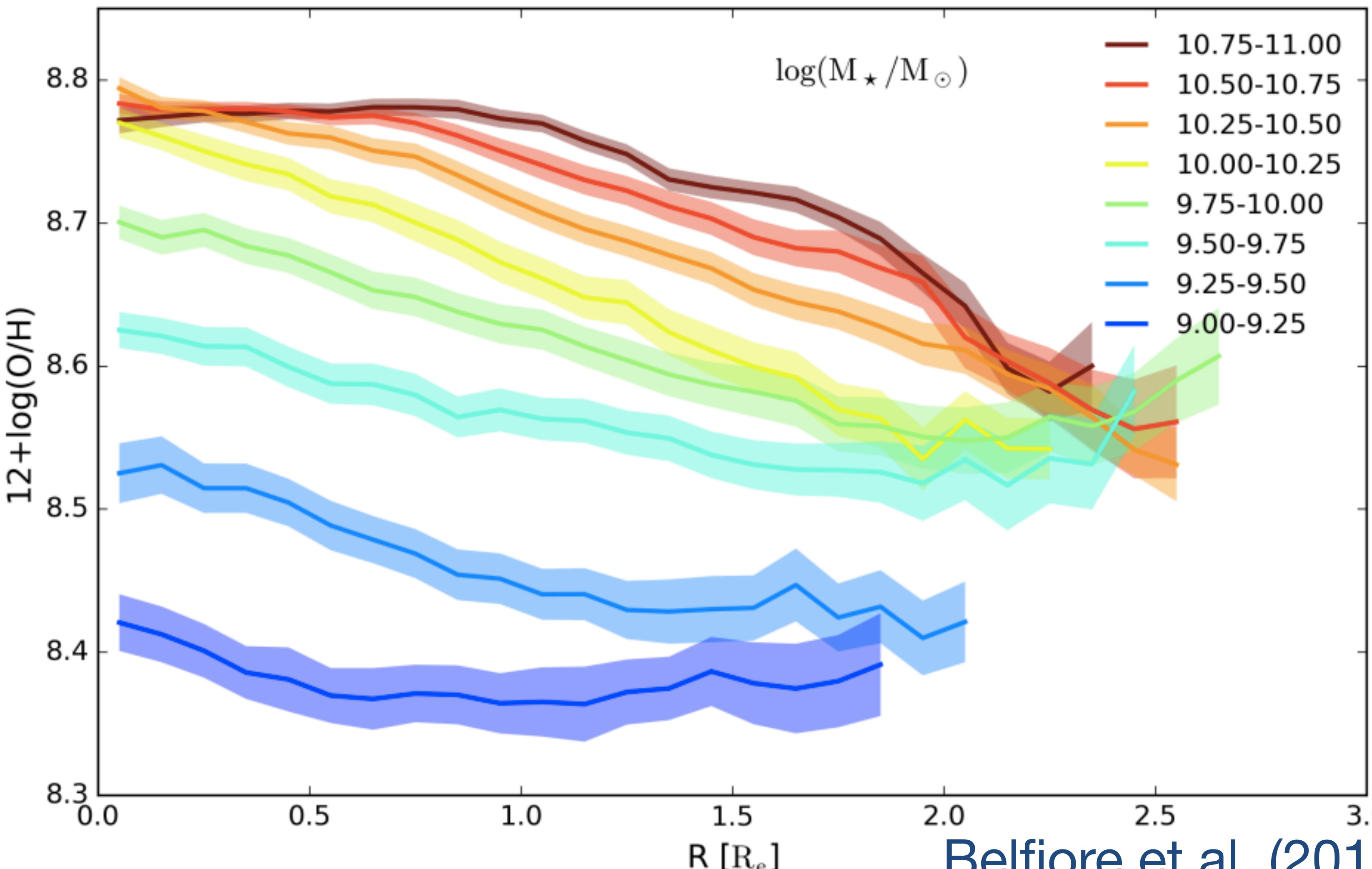
- Already 35 accepted publications

- Abundances (Belfiore)
- Mass—Metallicity[—SFR] Relation (Barrera-Ballesteros, Zhu)
- DIG (Zhang, Belfiore)
- Extraplanar DIG (Jones)

- AGN identification (Wylezalek)
- Red Geysers (Cheung)

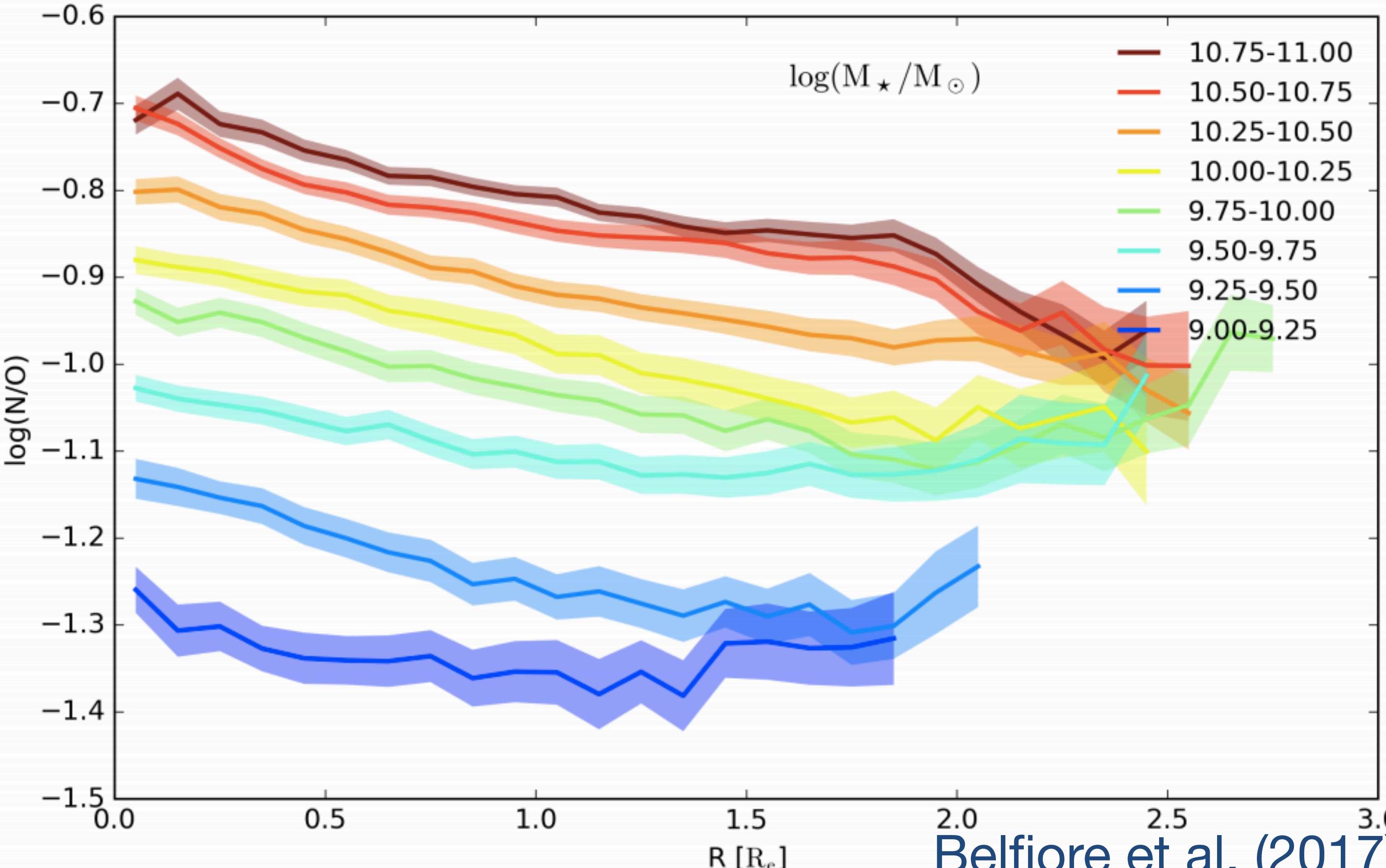
- Quenching in dwarf galaxies (Penny)
- SFH and stellar pop gradients (Goddard)

Early Science: Oxygen and Nitrogen Abundance Gradients



Belfiore et al. (2017)

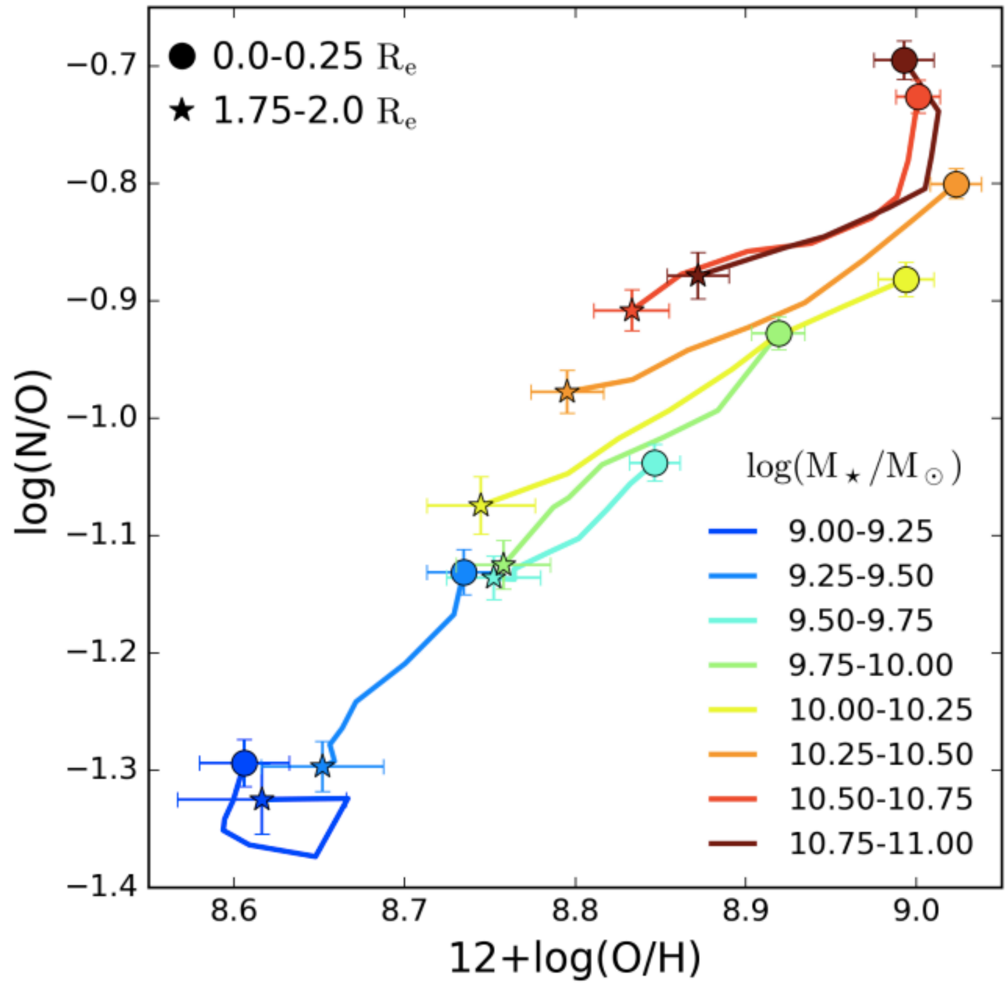
Early Science: Oxygen and Nitrogen Abundance Gradients



Belfiore et al. (2017)

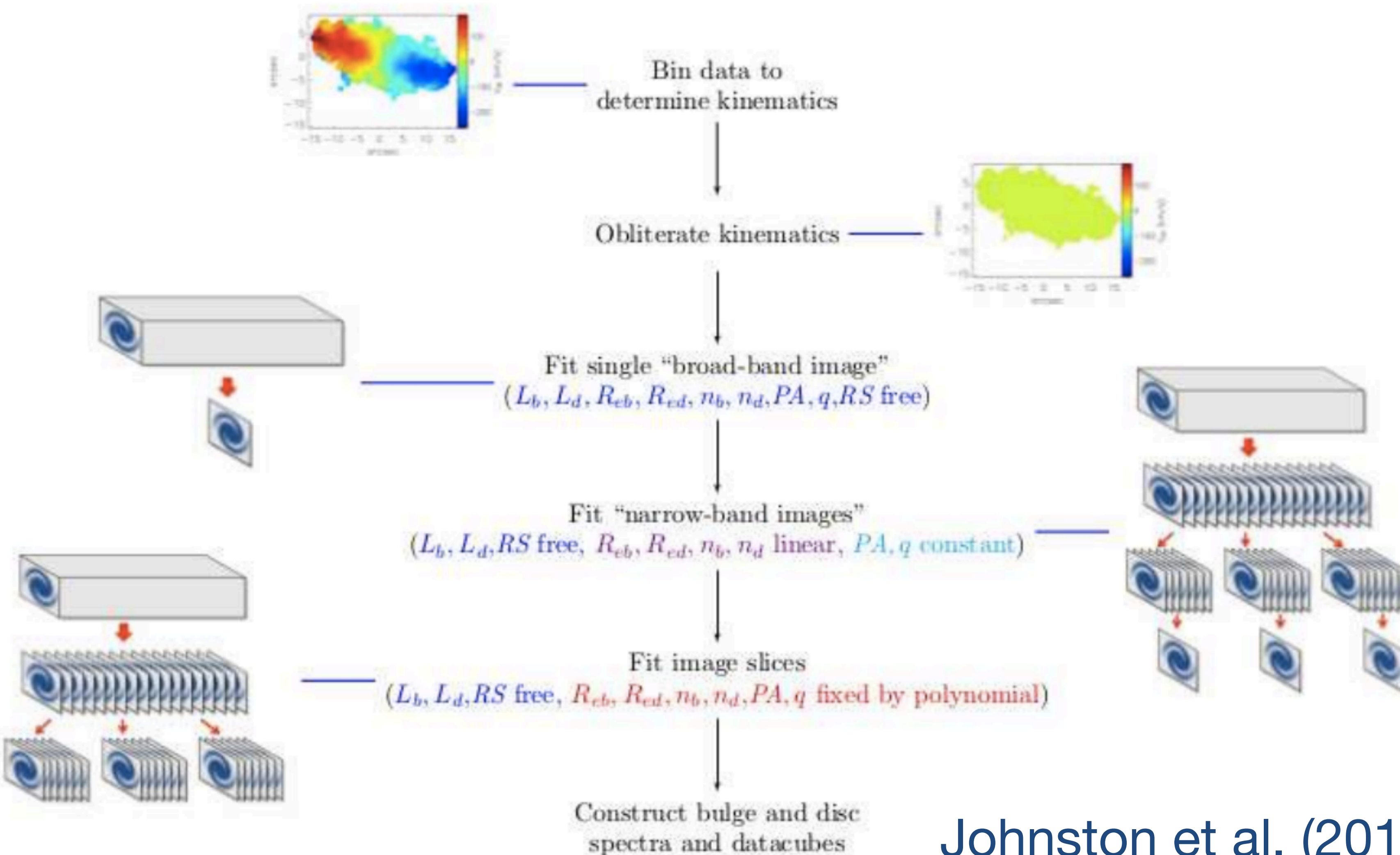
Early Science: Oxygen and Nitrogen Abundance Gradients

- Spatially resolved regions follow unresolved N/O—O/H relation…
- …but outer regions of massive disks have higher N/O than inner regions of low mass disks (at fixed O/H).
- Different SFE?
- Wind recycling?



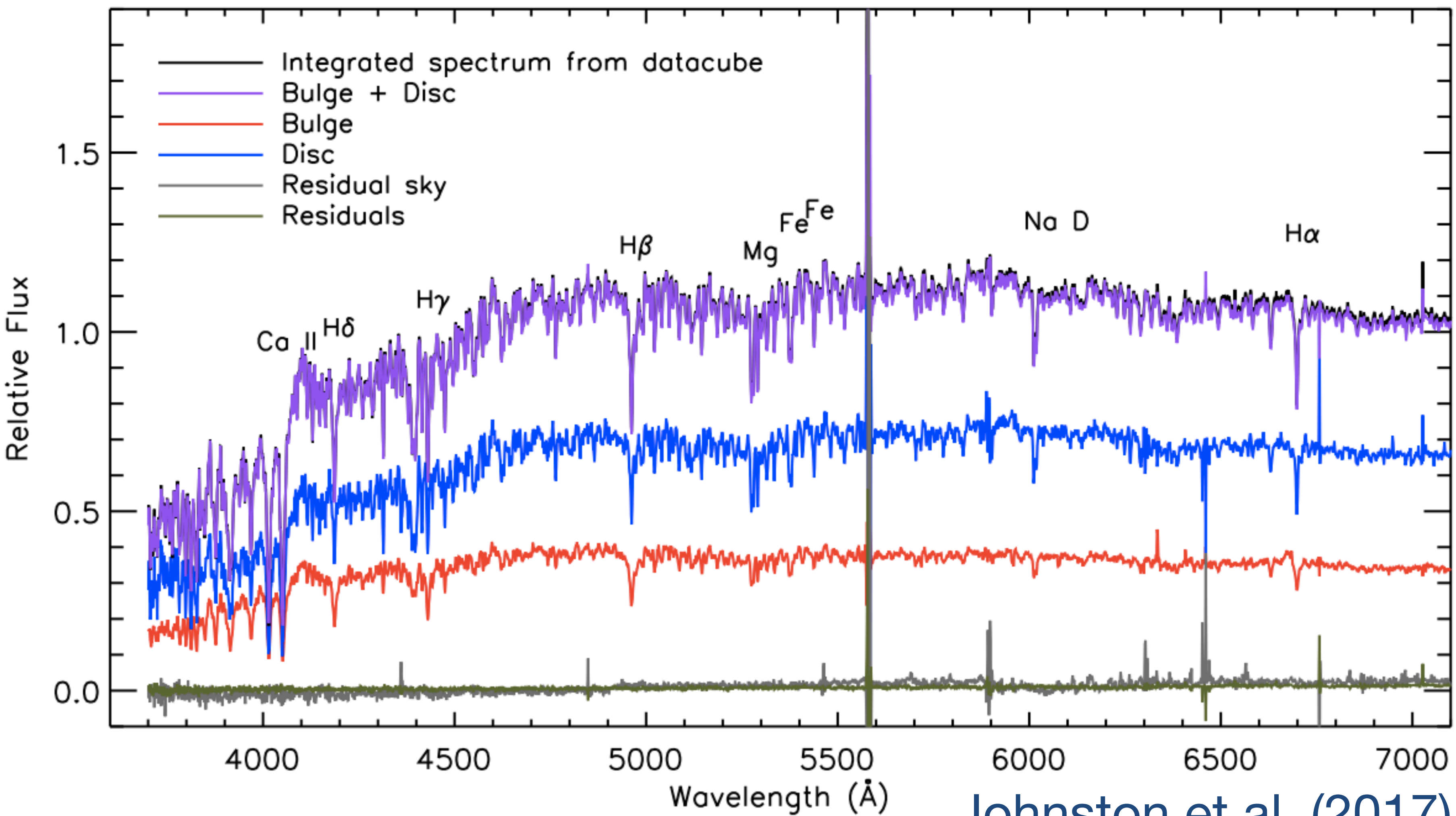
Belfiore et al. (2017)

Early Science: Spectral Bulge—Disk Decomposition



Johnston et al. (2017)

Early Science: Spectral Bulge—Disk Decomposition



Johnston et al. (2017)

MaNGA Total Data Volume

At the end of the survey (rough numbers):

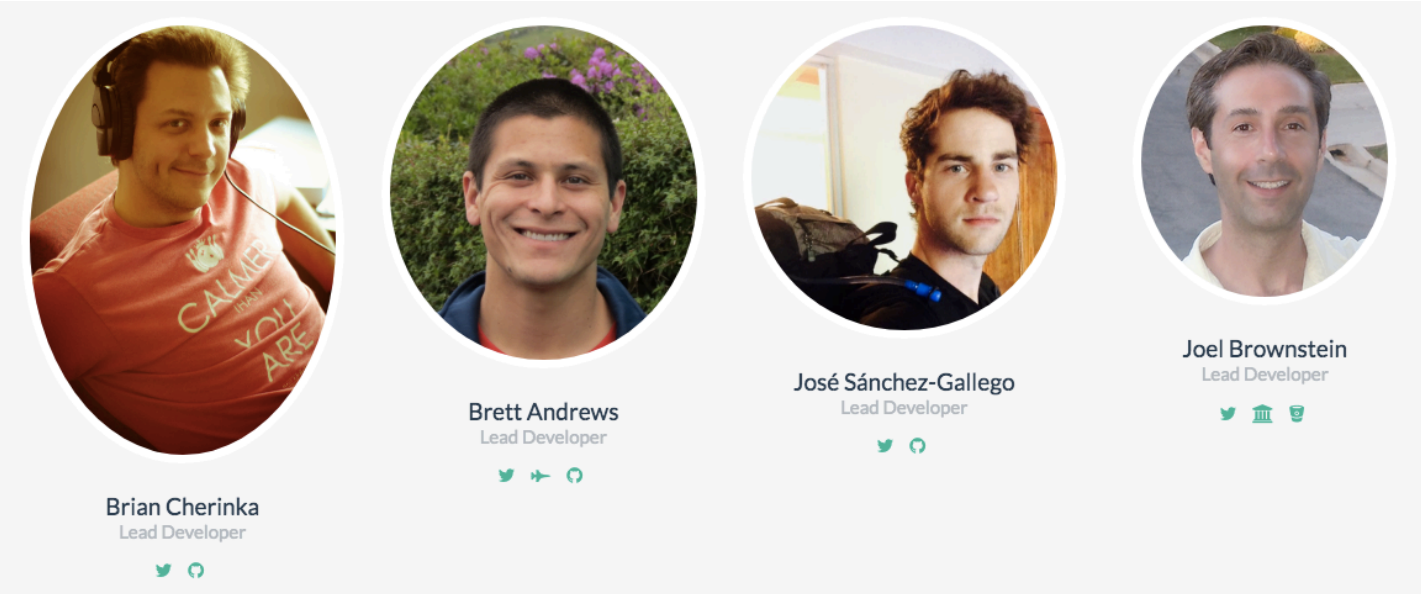
- 10,000 gal × 3,000 spax/gal
  = **30 million spaxels**

- 3e7 spax × 100 analysis prop./spax
  = **3 billion analysis properties**

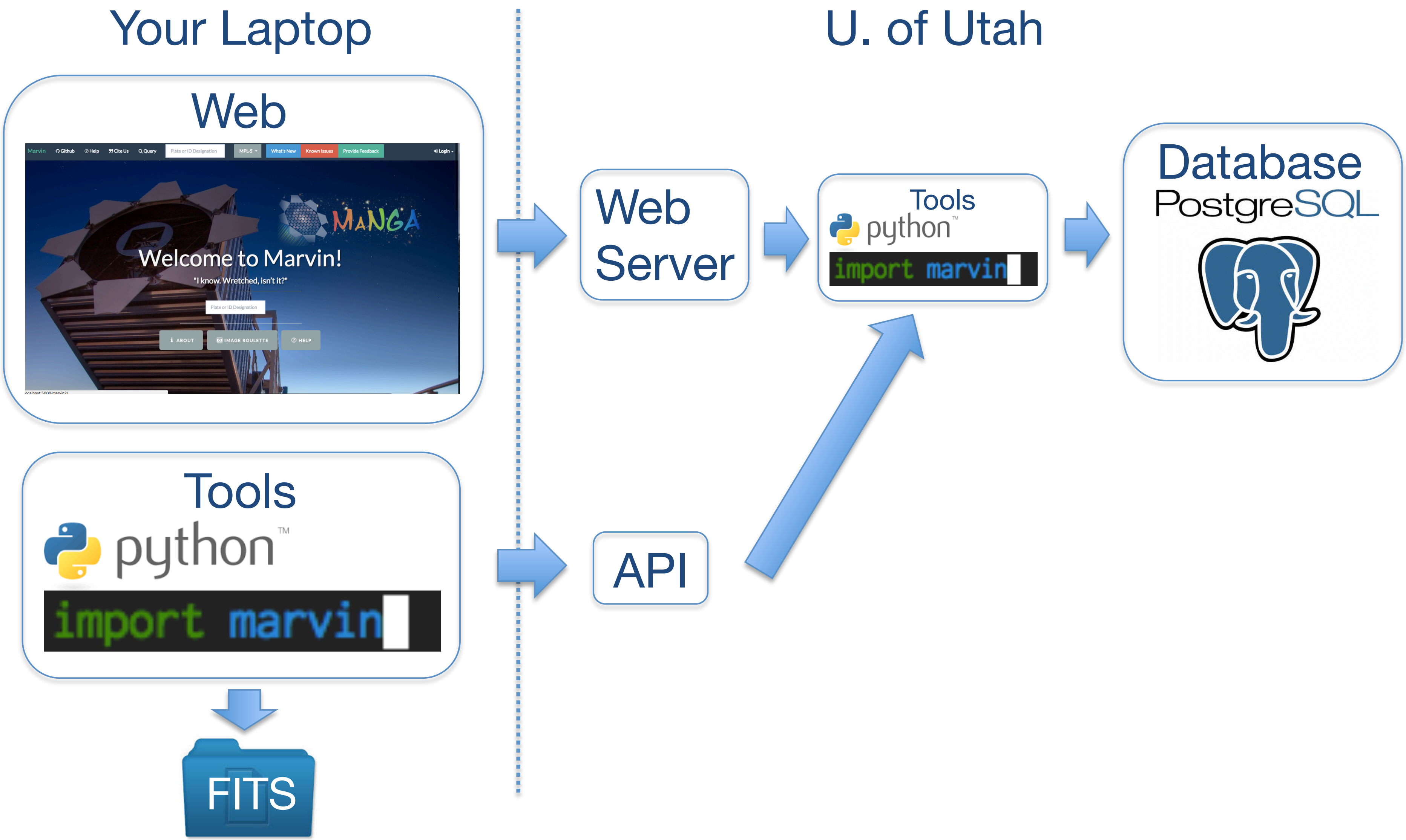
- 3e7 spax × 10,000 spectral elements/spax
  = **300 billion spectral elements**

Marvin

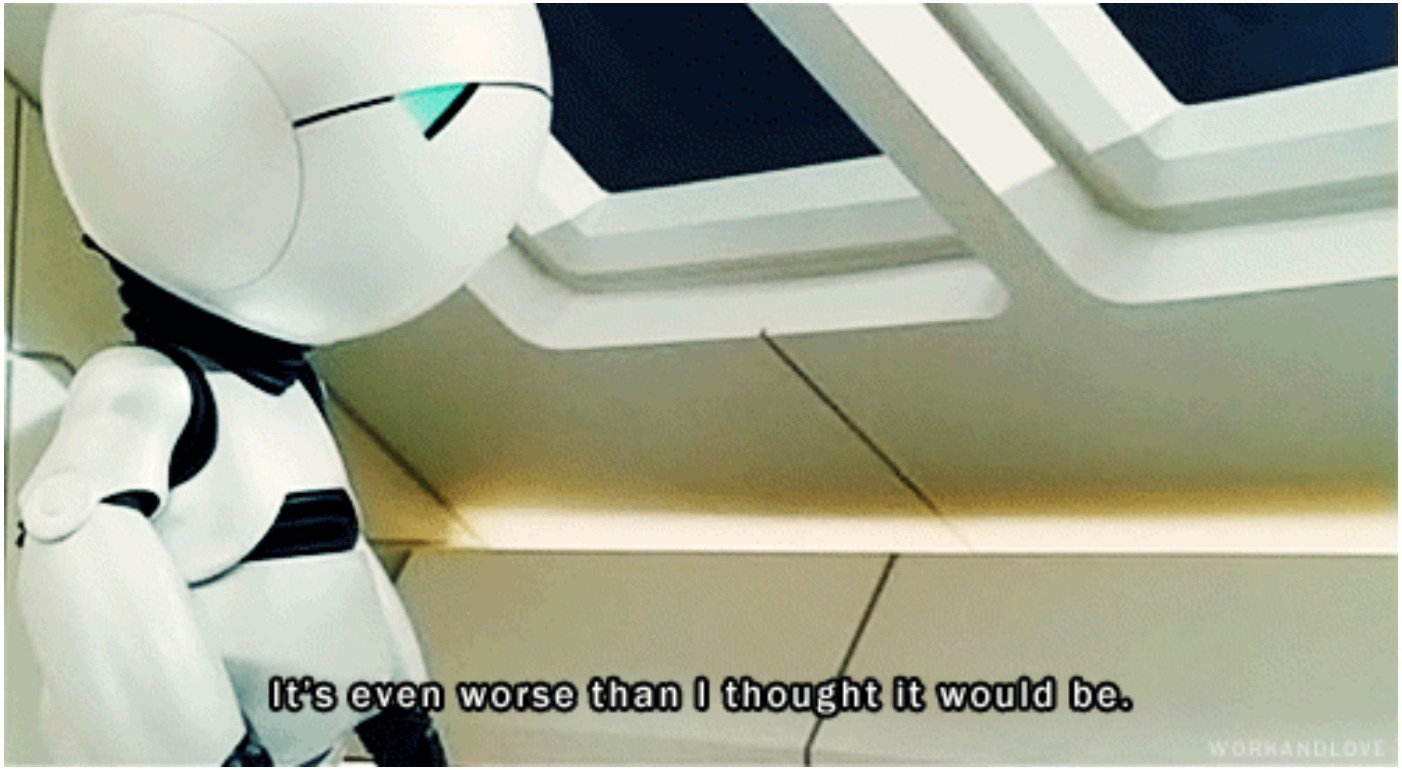
- Ecosystem for MaNGA
  - data access
  - exploration
  - visualization
  - analysis



Marvin Ecosystem

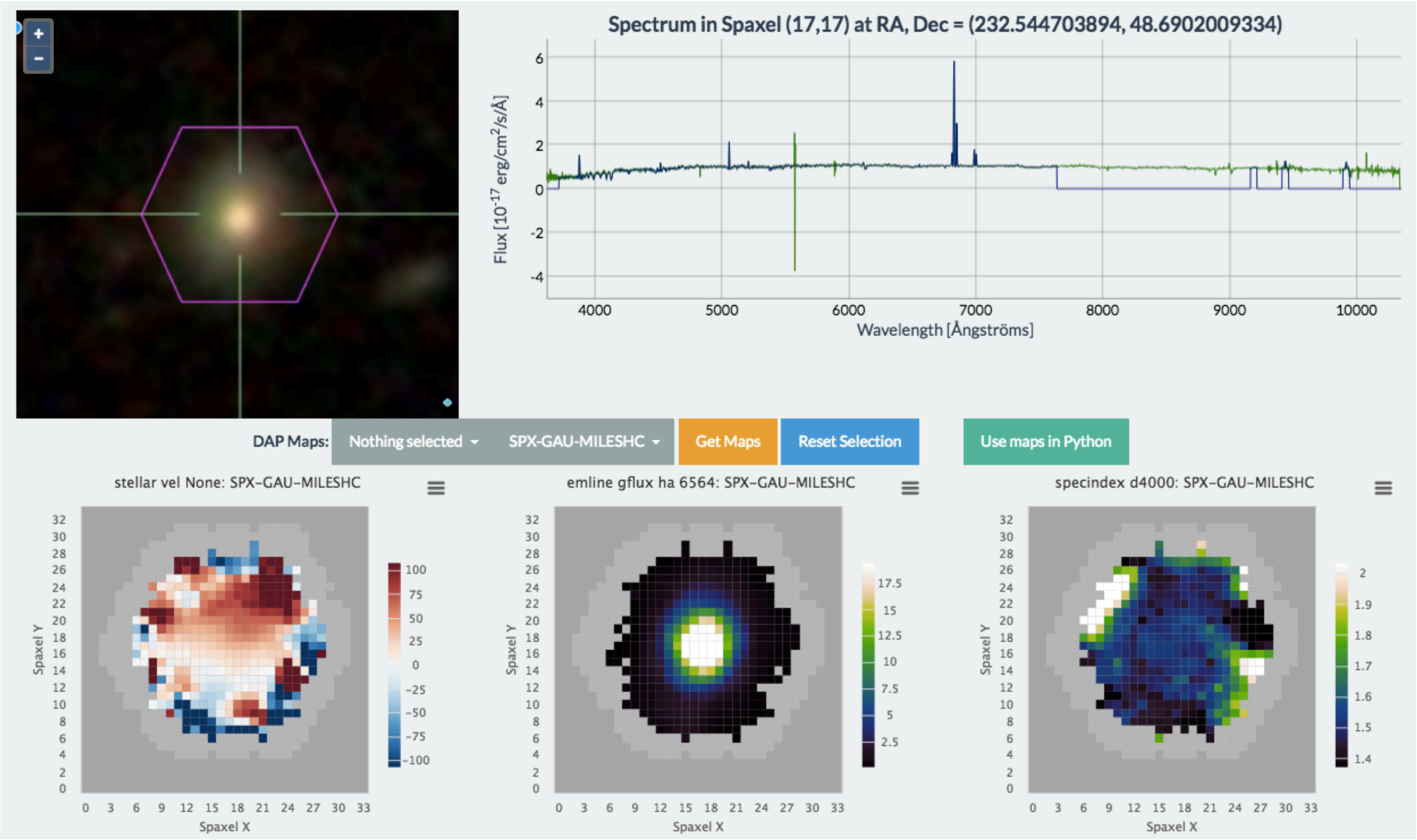


Marvin Demo

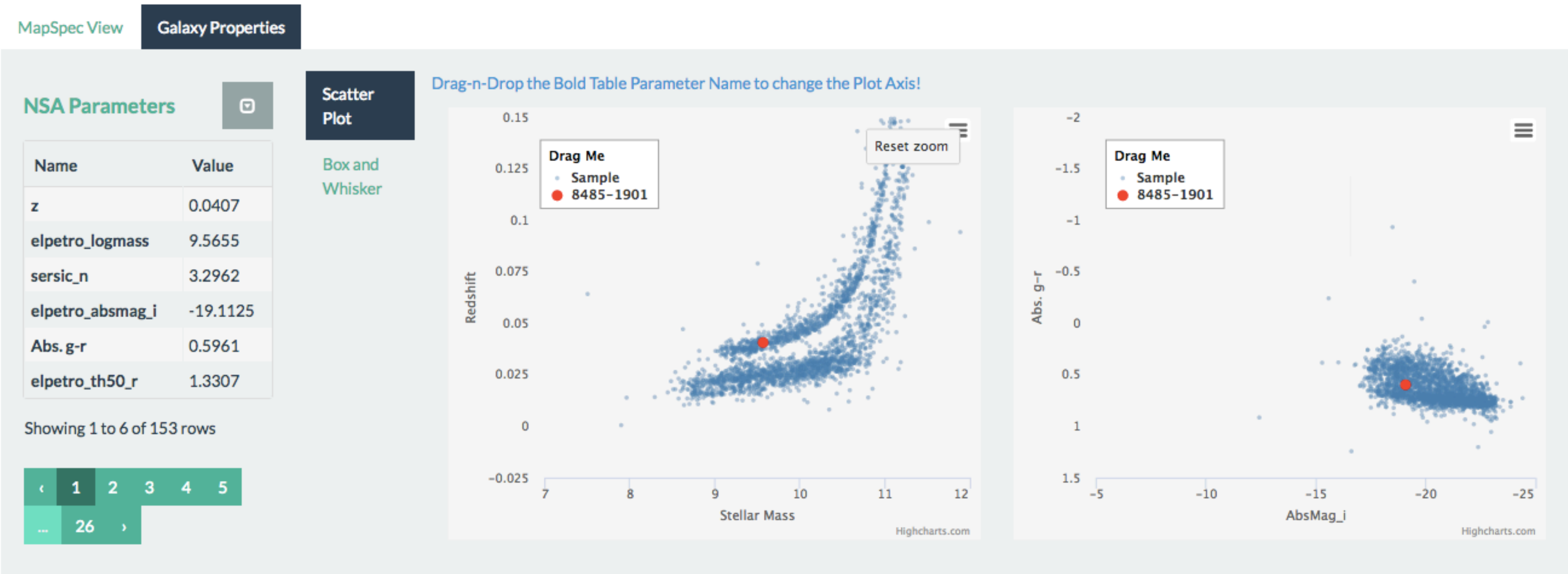


#whatcouldgowrong

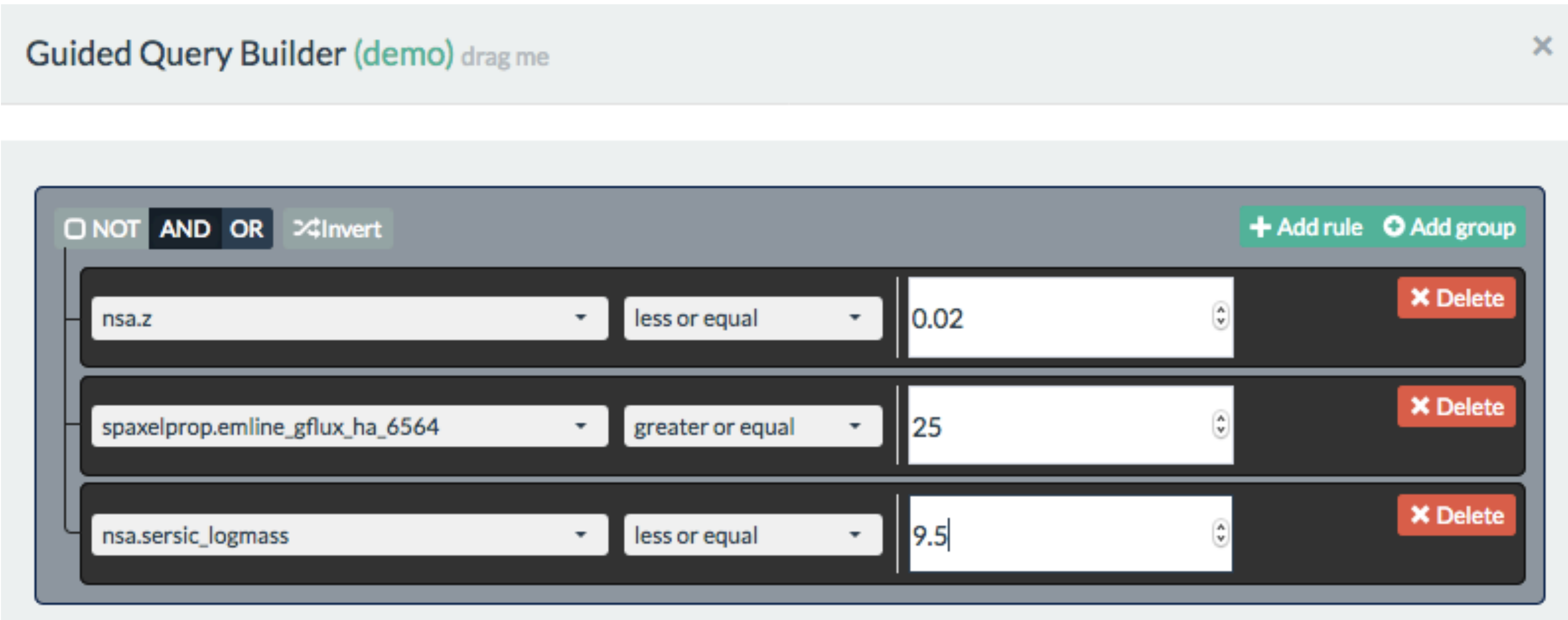
Point-and-click Maps



Galaxy Properties



Queries



nsa.z <= 0.02 AND
spaxelprop.emline_gflux_ha_6564 >= 25 AND
nsa.sersic_logmass <= 9.5

Queries

View Galaxies

cube.mangaid	cube.plate	cube.plateifu	ifu.name	nsa.sersic_logmass	spaxelprop.emline_gflux_ha_6564	nsa.z	spaxelprop.x	spaxelprop.y	bintype.name	template.name
1-113698	8618	8618-1901	1901	8.72179330901551	64648.578125	0.0167445	10	25	SPX	GAU-MILESHC
1-134004	8486	8486-1901	1901	9.23737531584658	25.2606716156	0.0185601	18	17	SPX	GAU-MILESHC
1-134004	8486	8486-1901	1901	9.23737531584658	25.9463405609	0.0185601	17	18	SPX	GAU-MILESHC
1-134004	8486	8486-1901	1901	9.23737531584658	27.0823745728	0.0185601	17	17	VOR10	GAU-MILESHC
1-134004	8486	8486-1901	1901	9.23737531584658	25.9476146698	0.0185601	17	18	VOR10	GAU-MILESHC
1-134004	8486	8486-1901	1901	9.23737531584658	25.2623615265	0.0185601	18	17	VOR10	GAU-MILESHC
1-134004	8486	8486-1901	1901	9.23737531584658	27.0845966339	0.0185601	17	17	SPX	GAU-MILESHC
1-137912	8250	8250-12703	12703	9.10949417692221	1111.30187988	0.014213	51	26	SPX	GAU-MILESHC
1-145894	8147	8147-9102	9102	8.85028897447965	3062.51074219	0.0152357	6	28	SPX	GAU-MILESHC
1-147394	8250	8250-12705	12705	8.82383403586861	25.430606842	0.0160493	25	47	SPX	GAU-MILESHC

Showing 1 to 10 of 4550 rows 10 rows per page

‹ 1 2 3 4 5 ... 455 ›

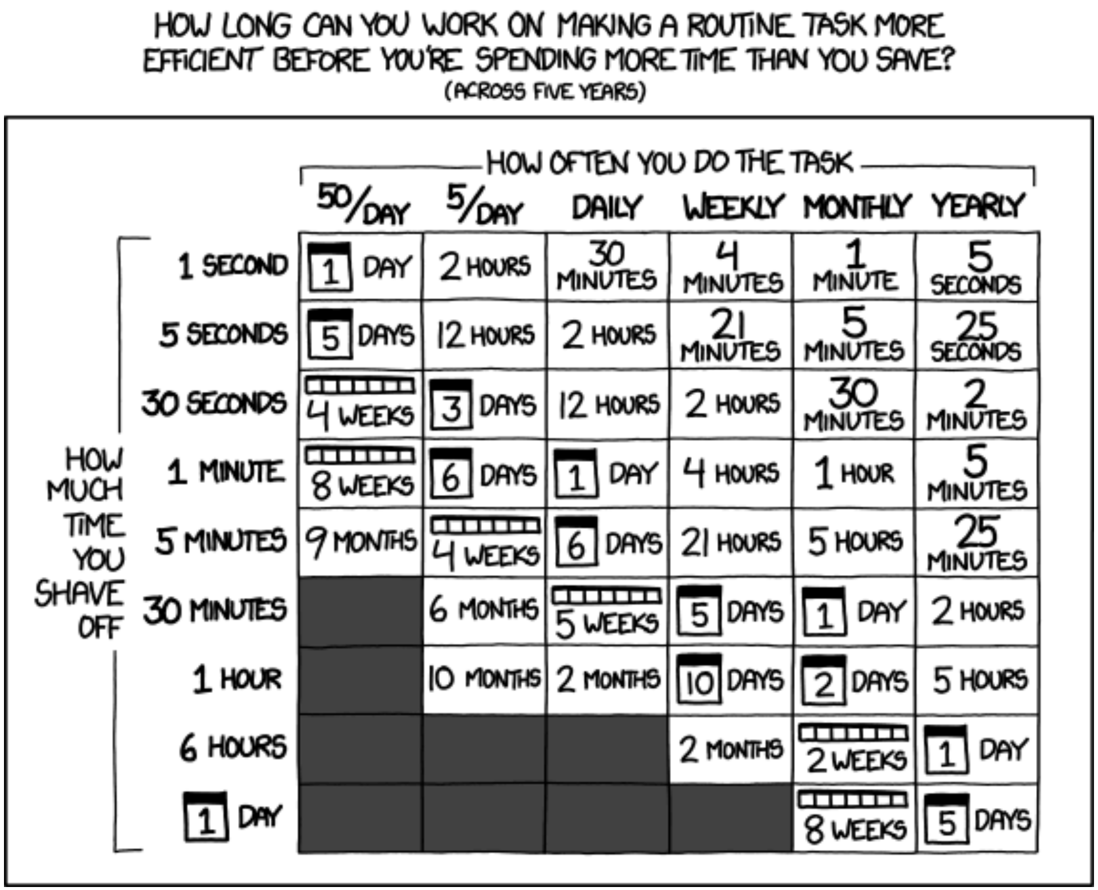
nsa.z <= 0.02 AND
spaxelprop.emline_gflux_ha_6564 >= 25 AND
nsa.sersic_logmass <= 9.5

From Exploration to Analysis

- `Marvin` python package powers `Marvin` web app
- `pip install sdss-marvin`
- code snippets in web
- Multi-modal access

Convenience Functions

- Everyone has the same problems.
- Solve them once. Solve them correctly.

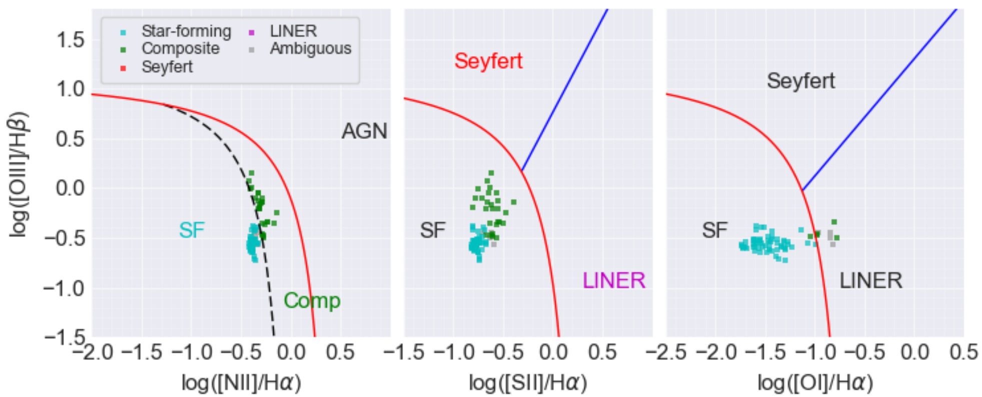


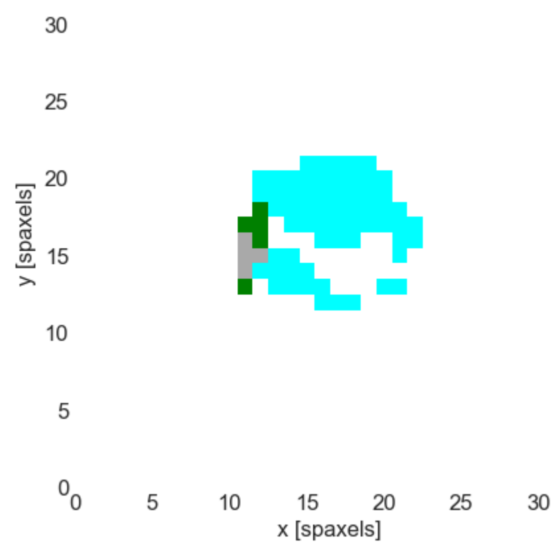
Convenience Functions

- Map Arithmetic (+, –, ×, ÷ , ^)
  - handle error propagation and mask combination

- Correction Functions
  - correct velocity dispersions for the instrumental resolution

BPT Diagram





Baldwin, Phillips, & Terlevich (1981)

`mglearn`: Deep Learning MaNGA

- `Marvin` enables human exploration/analysis
- `mglearn` enables machine exploration/analysis

- **Barnabas Poczos**, **Siamak Ravanbakhsh**, **Eric Ma**, **Ananth Tenneti**, **BHA**, **Jeff Newman**, Brian Cherinka, Jose Sánchez-Gállego, Joel Brownstein

`mglearn`: Deep Learning MaNGA

1. Exploratory analysis
   – clustering & visualization of cubes
2. Anomaly Detection
   – density estimation of cubes
3. Super-Resolution
   – increase effective spatial resolution of maps

Take Aways

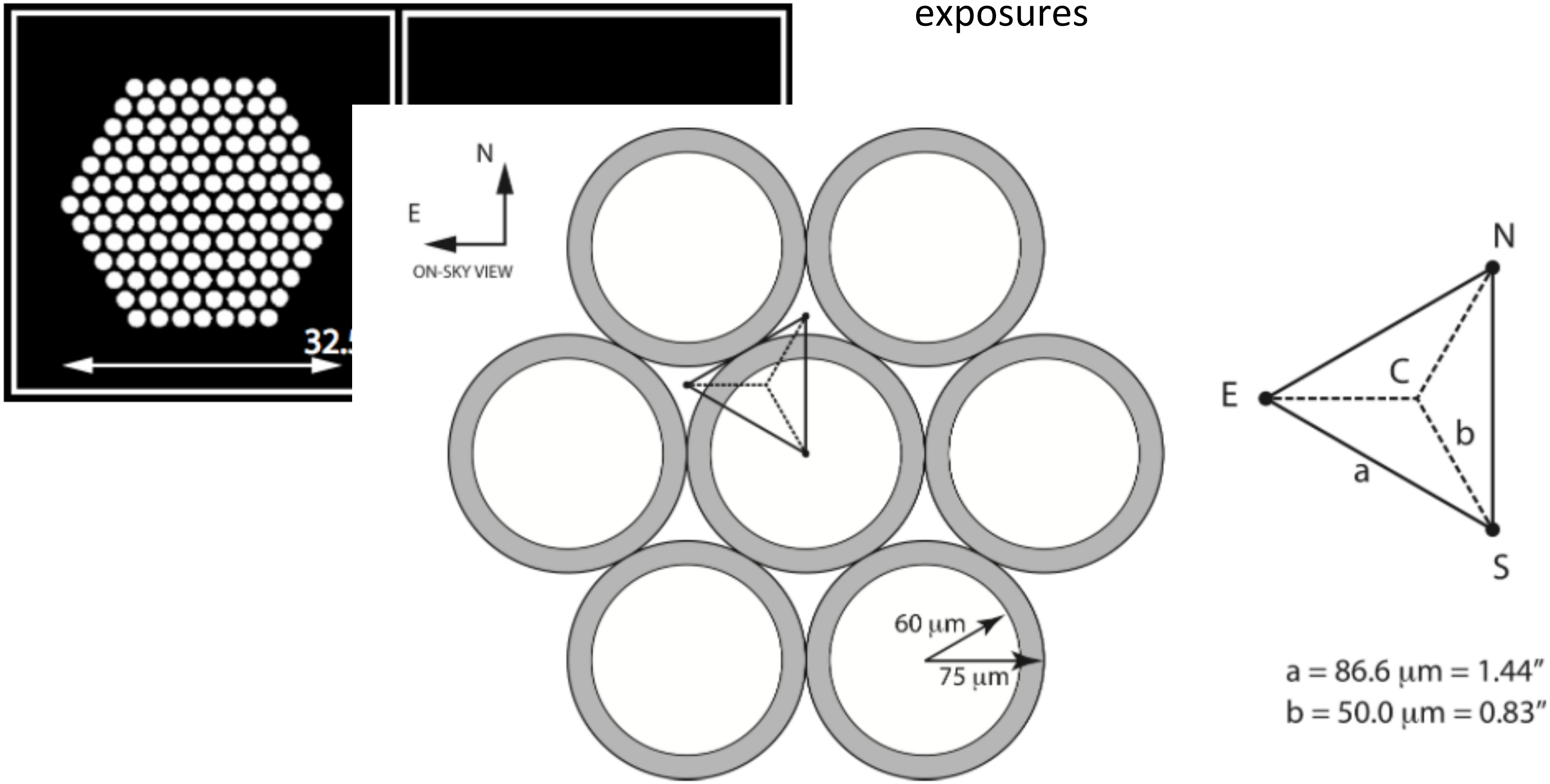
- MaNGA: statistically powerful spatially-resolved galaxy survey
  - 2700 galaxies now
  - 4750 galaxies soon
- `Marvin`
  - Web: sas.sdss.org/marvin
  - Tools: `pip install sdss-marvin`
- `mglearn`: clustering, anomaly detection, and super-resolution using deep learning

MaNGA overview

Dithering

MaNGA SAMI

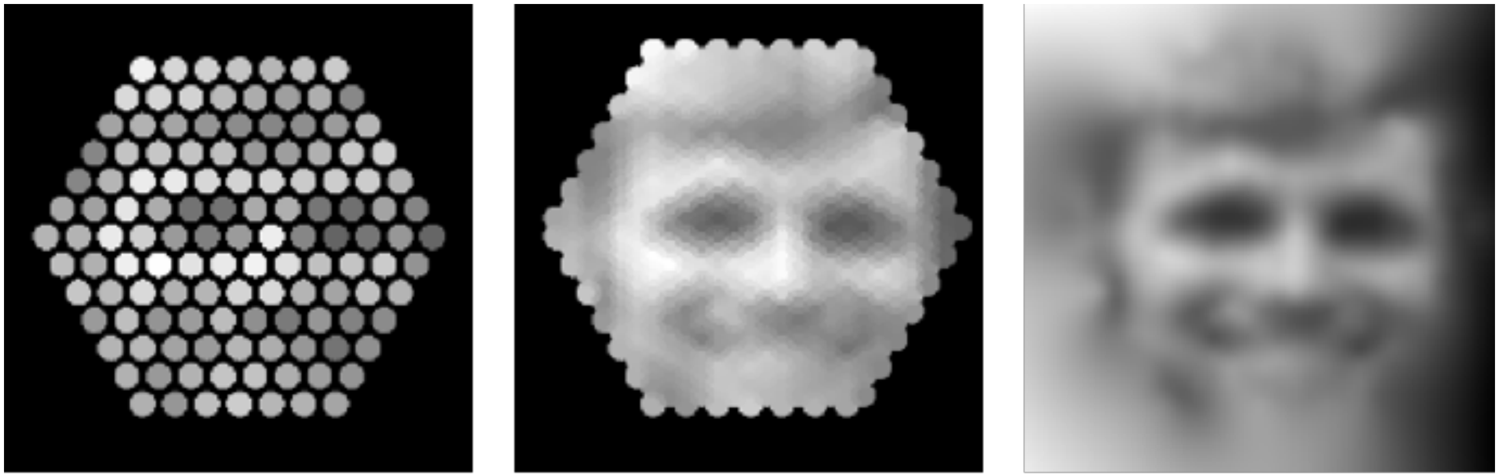
Set: combination of N+S+E exposures



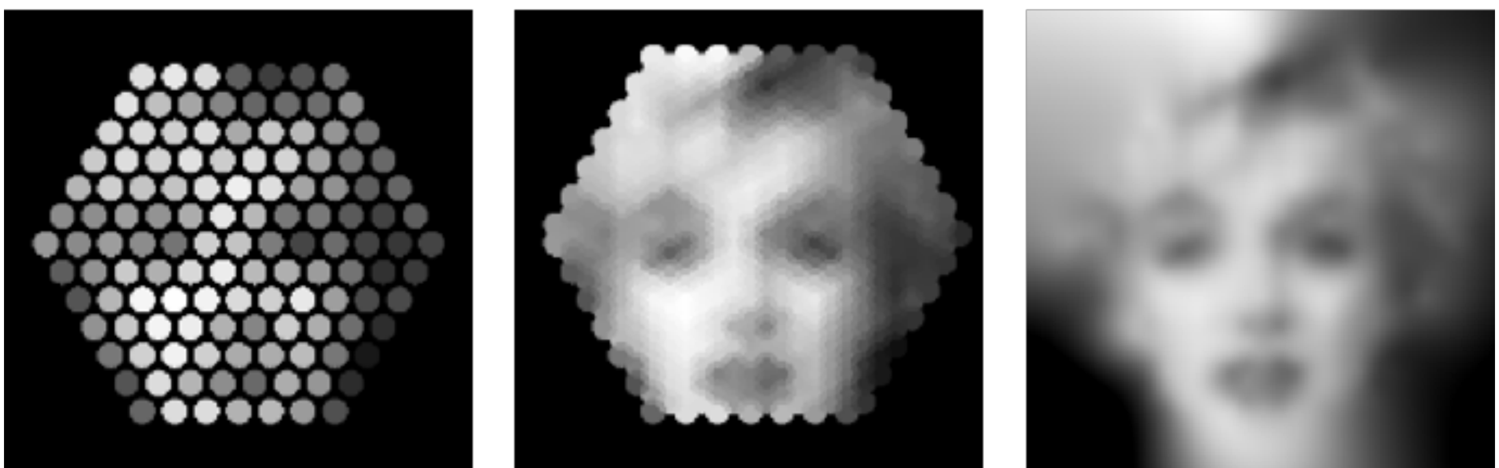
Law et al. (2015)

MaNGA overview

Dithering



Kevin ≠ Marilyn



MPL-6

- **~4750 galaxies**
- Extensive testing of the stellar kinematics
- Improved emission-line fitting
  - tied kinematics and tied fluxes of doublets
- Hybrid binning scheme
  - S/N > 10 for stellar kinematics and individual spaxels for emission lines
- Extended set of spectral index measurements

MaNGA overview

MaNGA vs the World

TABLE 3
COMPARISON OF IFU SURVEYS

Specification	MaNGA	SAMI	CALIFA	DiskMass (Hα)	DiskMass (stellar)	ATLAS^{3D}
Sample size	10,000	3,400	600	146	46	260
Selection	$M_* > 10^9 M_\odot$	$M_* > 10^{8.2} M_\odot$	$45'' < D_{25} < 80''$	S/SAab-cd, b/a>0.75 $10'' < h_R < 20''$		$M_* \gtrsim 10^{9.8} M_\odot$[e] E/S0
Redshift	0.01–0.15	0.004–0.095	0.005–0.03	0.001–0.047	0.003-0.042	$z \lesssim 0.01$
Radial coverage	1.5 R_e(P+) 2.5 R_e(S)	1.1–2.9 R_e	1.8–3.7 R_e	1.4–3 R_e	1.1–2.3 R_e	0.6–1.5 R_e
S/N[a] at 1R_e (per spatial sample)	14–35	12–28	10–50	6	9–16	15
λ range (nm)	360–1030	370–570 (580V) 625–735 (1000R)	375–750 (V500) 370–475 (V1200)	648–689	498–538	480–538
$\sigma_{instrument}$ (km s^{-1})	50–80	75 28	85 150	13	16	98
Angular sampling[b] (diameter)	2″	1.″6	2.″7	4.″7	2.″7	0.″8
Angular FWHM (reconstructed)	2.″5	2.″1[c]	2.″5	6″	3.″5	1.″5
Spatial FWHM (physical)	1.3–4.5 kpc (P+) 2.2–5.1 kpc (S)	1.1–2.3 kpc	0.8–1.0 kpc	0.4–4.2 kpc	0.3–3.0 kpc	0.15 kpc
Spatial FWHM (in R_e)	0.2–0.6 (P+) 0.3–0.9 (S)	0.3–0.8	0.2	0.2–0.4	0.1–0.2	0.09
IFU fill factor	56%	73%	53%	25%	53%	100%
With gradients measurable[d] to						
1.0 R_e:	4070	720	580	128	39	112
1.5 R_e:	6050	790	521	122	20	47
2.0 R_e:	2570	680	462	80	5	26
2.5 R_e:	2340	460	340	26	0	13
3.0 R_e:	670	350	111	3	0	1