Early Type Galaxies

Studying Velocity dispersion profiles

Ravi Shankar Chaurasia
Masters in astrophysics
Supervisor: Dr. Davor Krajnović

Scope of Presentation

- Motivation
- Classification of Galaxies
- Formation of Galaxies
- Distribution function and moments
- Pixel fitting
- Velocity dispersion
- Data & Sample Selection
- Kinemetry
- Results
- Future work

Understanding Galaxy Evolution Through Early-Types and Their Dynamics

Most massive galaxies = Most evolved systems

Excellent probes of galaxy evolution at all stages

Reveal complex internal dynamics

End products of hierarchical assembly processes

Galaxy kinematics → formation and evolution

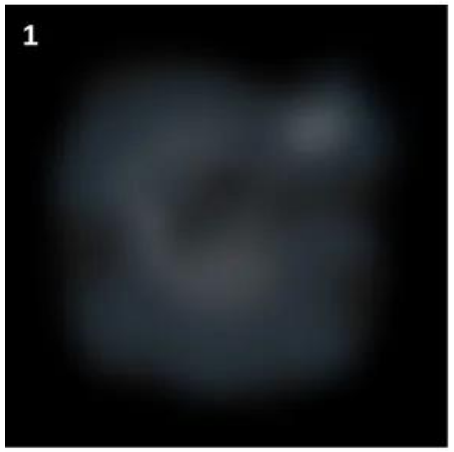
Velocity profiles → past assembly and evolution histories

Physical processes → shaping velocity dispersion

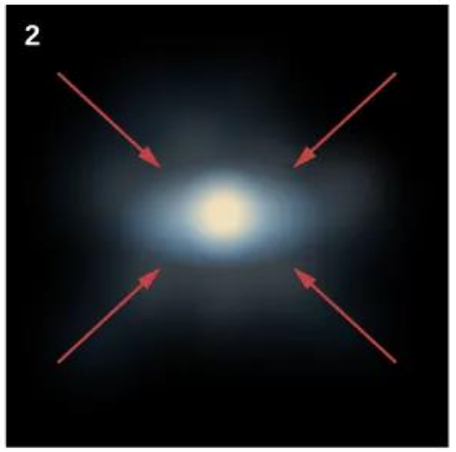
Reconstruct galaxy assembly histories from kinematics

Formation of Galaxies

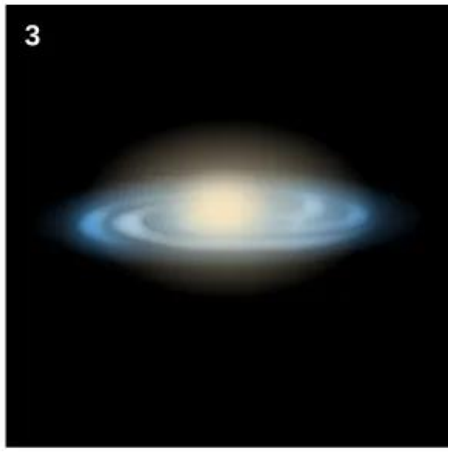
Rapid Collapse



Primordial hydrogen cloud.

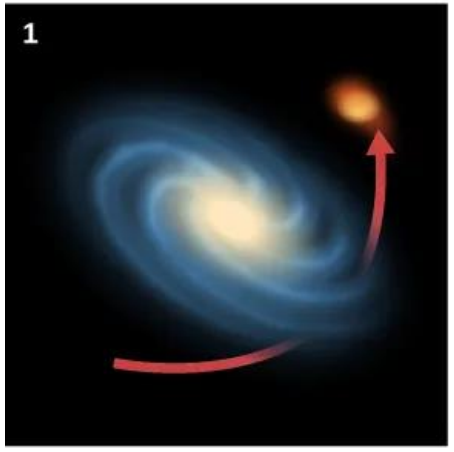


Cloud collapses under gravity.

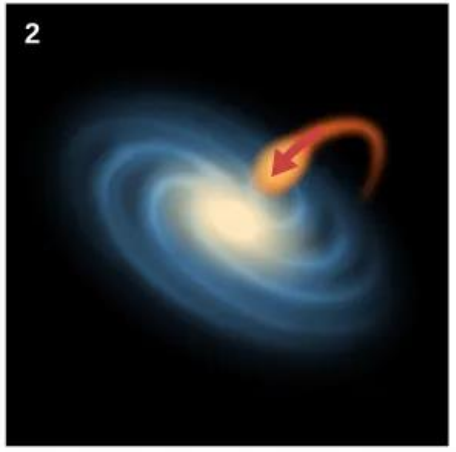


Large bulge of ancient stars dominates galaxy.

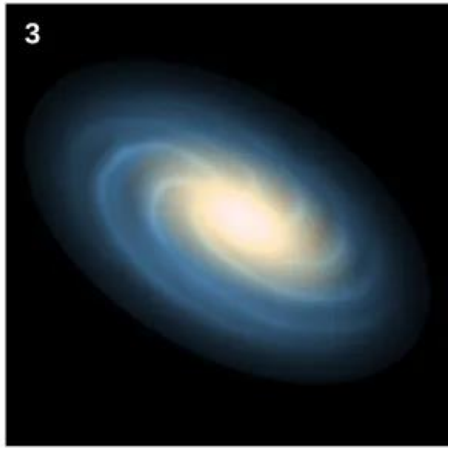
Environmental Effects



Disk galaxy and companion.



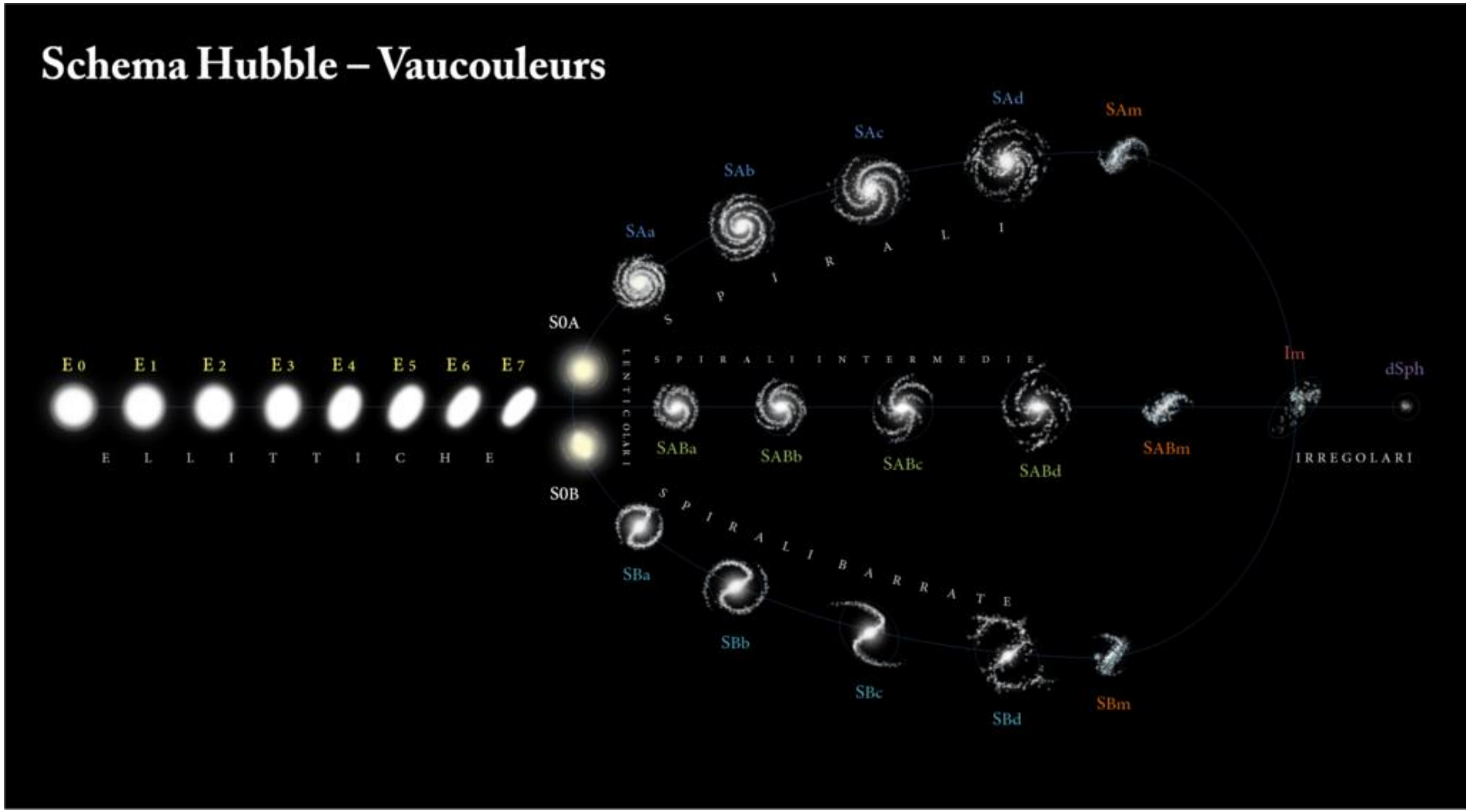
Smaller galaxy falls into disk galaxy.



Bulge inflates with addition of young stars and gas.

Astronomy 2e

Classification of Galaxies



Wikipedia

Distribution function and Moments

Davor Krajnovic et. al

$$\mu(x, y) = \int_{\mathrm{LOS}} \mathrm{d}z \int\int\int \mathrm{d}\boldsymbol{v}\, f(\boldsymbol{r}, \boldsymbol{v}).$$

$$\mathcal{L}(v; x, y) = \int_{\mathrm{LOS}} \mathrm{d}z \int\int \mathrm{d}v_x\, \mathrm{d}v_y\, f(\boldsymbol{r}, \boldsymbol{v}),$$

- The LOSVD is a projection of the distribution function.
- Distribution of stars as a function of line-of-sight velocity

$$\langle v \rangle = \frac{1}{\mu(x,y)} \int v\, L(v; x, y)\, dv$$

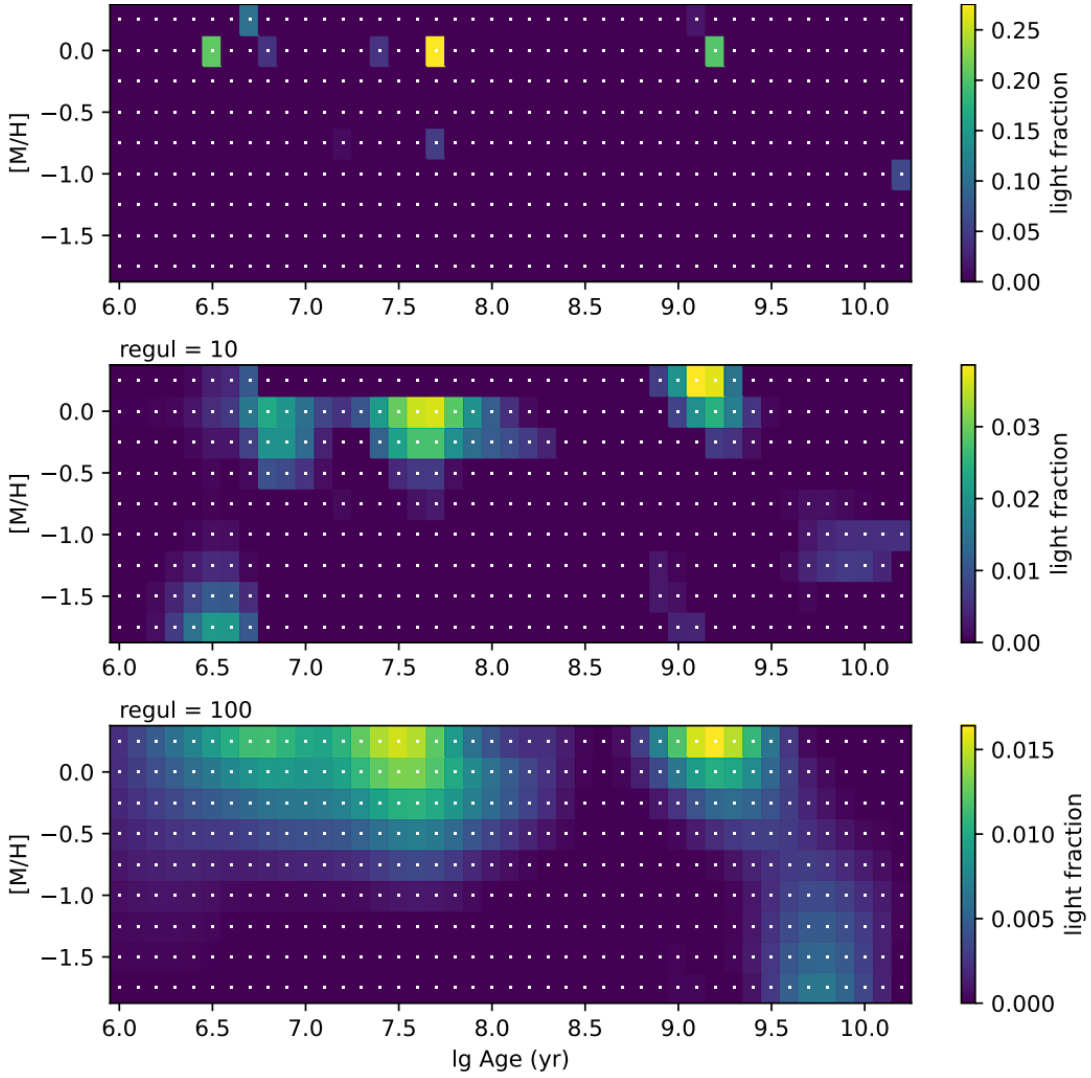
$$\sigma^2(x,y) = \frac{1}{\mu(x,y)} \int (v - \langle v \rangle)^2\, L(v; x, y)\, dv$$

$$L(v; x, y) = \frac{\mu(x,y)}{\sigma(x,y)\sqrt{2\pi}}\, e^{-\frac{(v-\langle v \rangle)^2}{2\sigma^2}} \left[1 + h_3 H_3(w) + h_4 H_4(w) + \ldots\right]$$

Penalized-PiXel Fitting

- Full-spectrum fitting technique
- Generates a model spectrum by convolving weighted templates with parametric LOSVD

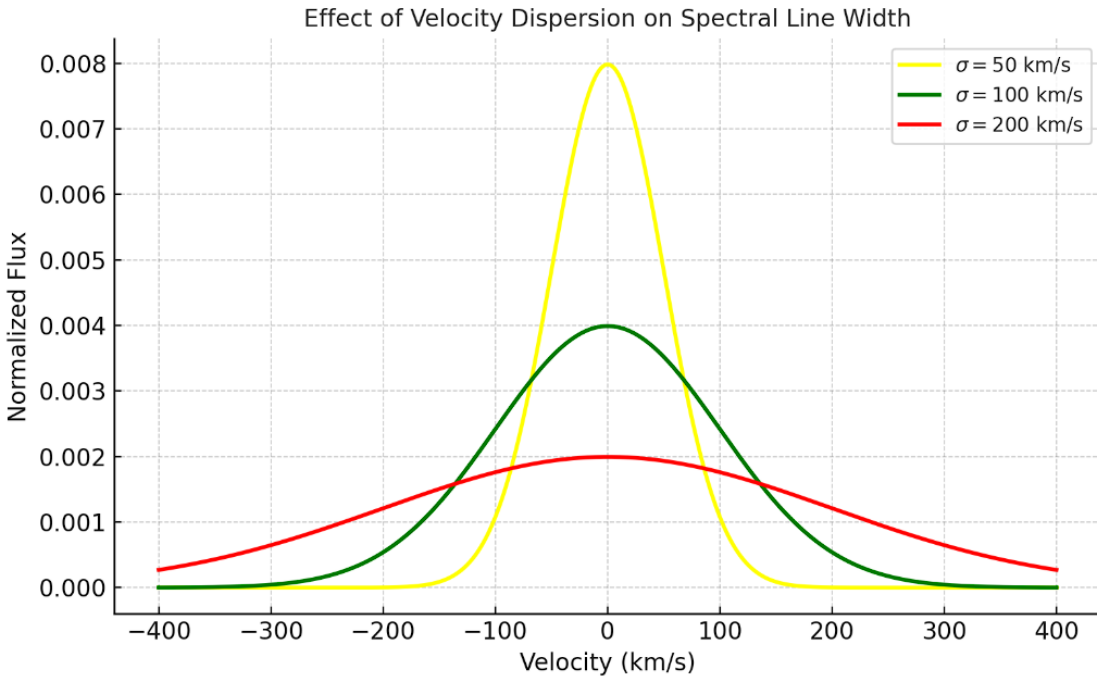
$$G_{mod} = \sum_{n=1}^{N} w_n \{T_n * L_n(x)\}$$



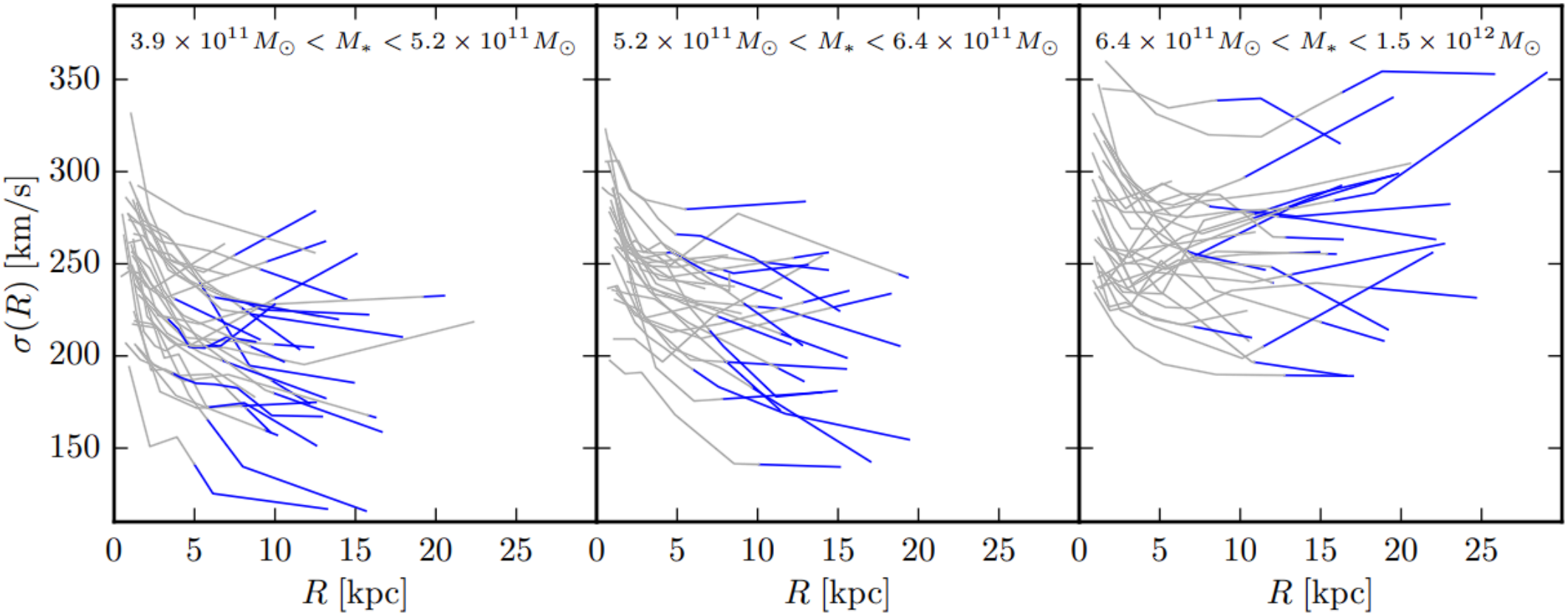
Michele Cappellari et. al

Velocity Dispersion

- Velocity dispersion → spread in velocities
- Galaxy spectrum → the absorption lines → broadened
- Fitting templates → observed galaxy spectrum → width of the best fit template
- High velocity dispersion implies a dynamically hot system → stars are moving in many directions, and there is no dominant rotation.
- Spiral disks → low dispersion and are rotation-dominated.



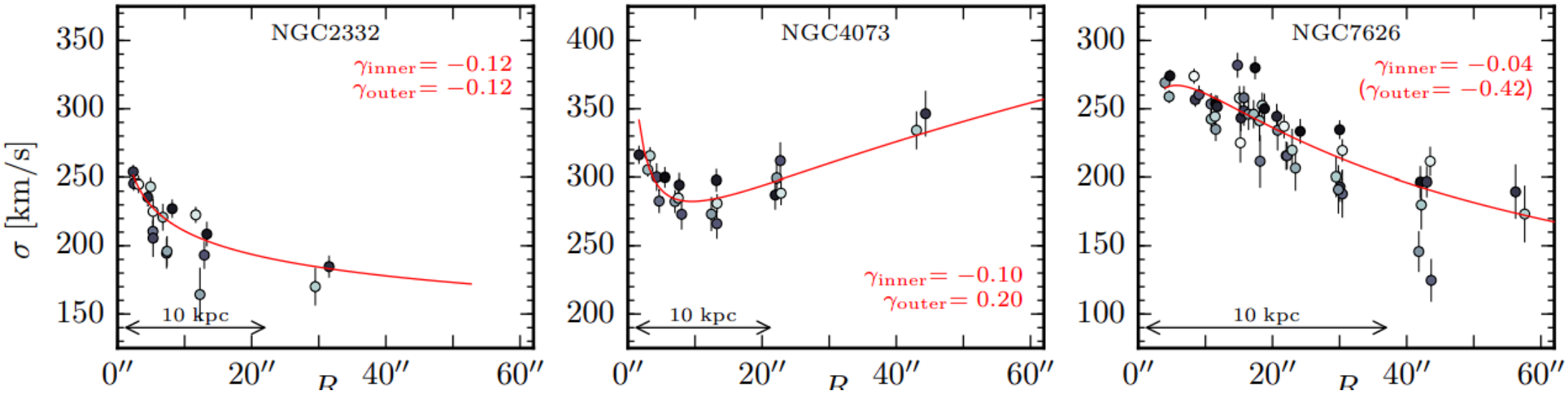
Massive Data



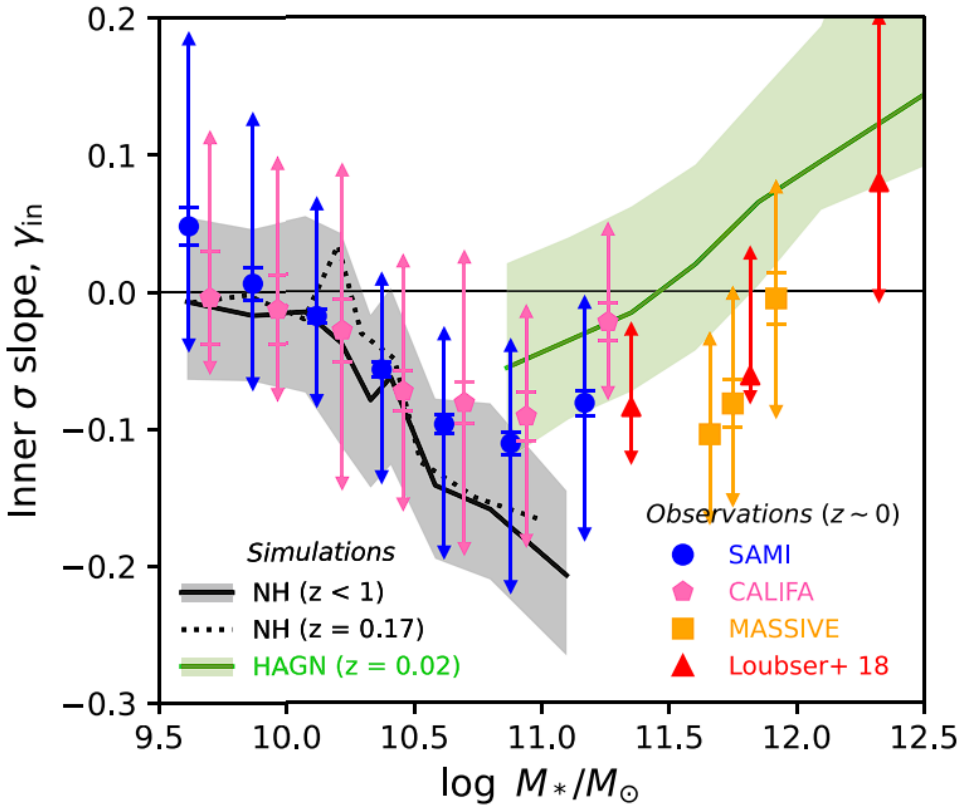
Veale et al.2017

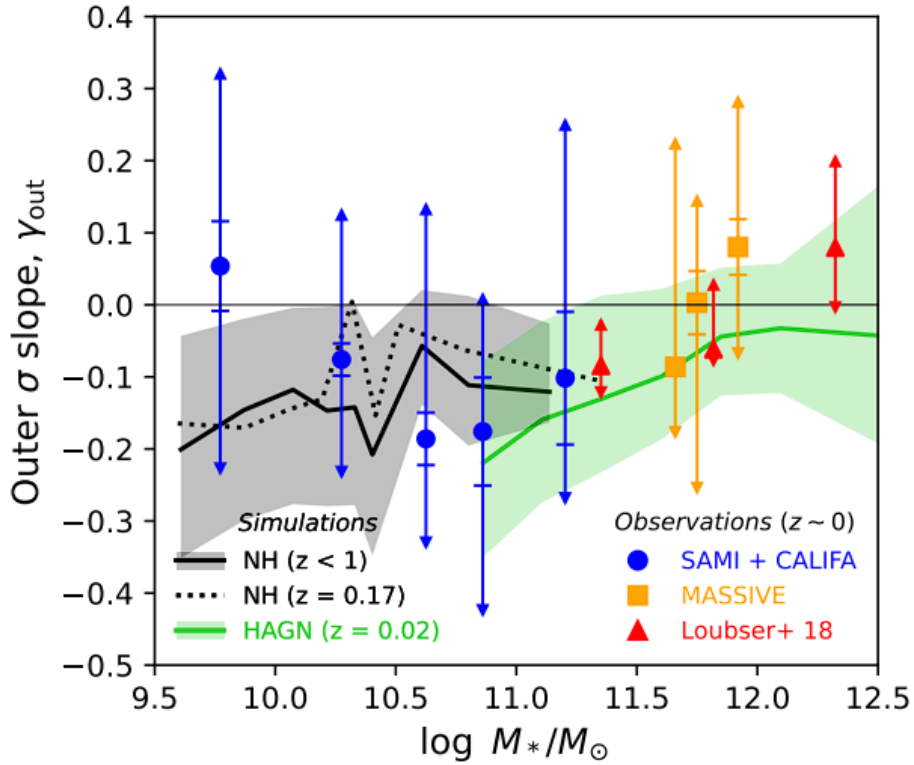
Parametrization

$$\sigma(R) = \sigma_0 2^{\gamma_1 - \gamma_2} \left(\frac{R}{R_b}\right)^{\gamma_1} \left(1 + \frac{R}{R_b}\right)^{\gamma_2 - \gamma_1},$$



Veale et al.2017

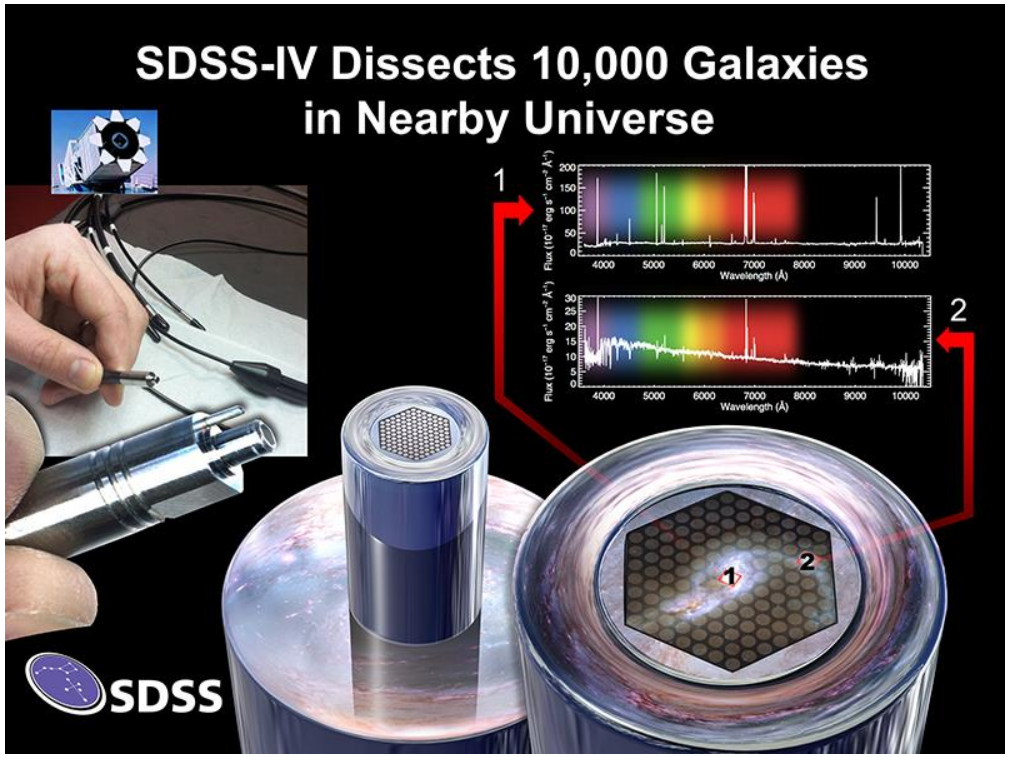

Inner σ slope, γ_{in}
log $M_*/M_\odot$
Simulations
NH (z < 1)
NH (z = 0.17)
HAGN (z = 0.02)
Observations (z ~ 0)
SAMI
CALIFA
MASSIVE
Loubser+ 18


Outer σ slope, γ_{out}
log $M_*/M_\odot$
Simulations
NH (z < 1)
NH (z = 0.17)
HAGN (z = 0.02)
Observations (z ~ 0)
SAMI + CALIFA
MASSIVE
Loubser+ 18

Han et al.

Data

- MaNGA (Mapping Nearby Galaxies at Apache Point Observatory)
- 0.5 arcsec/pixel in MaNGA
- 10000 nearby galaxies in the redshift range $0.01 < z < 0.15$
- The spectra cover a simultaneous wavelength range from 3600 Å to 10300 Å, with a spectral resolution $R \sim 2000$
- The observation covers a spatial range from $1.5Re$ to $2.5Re$



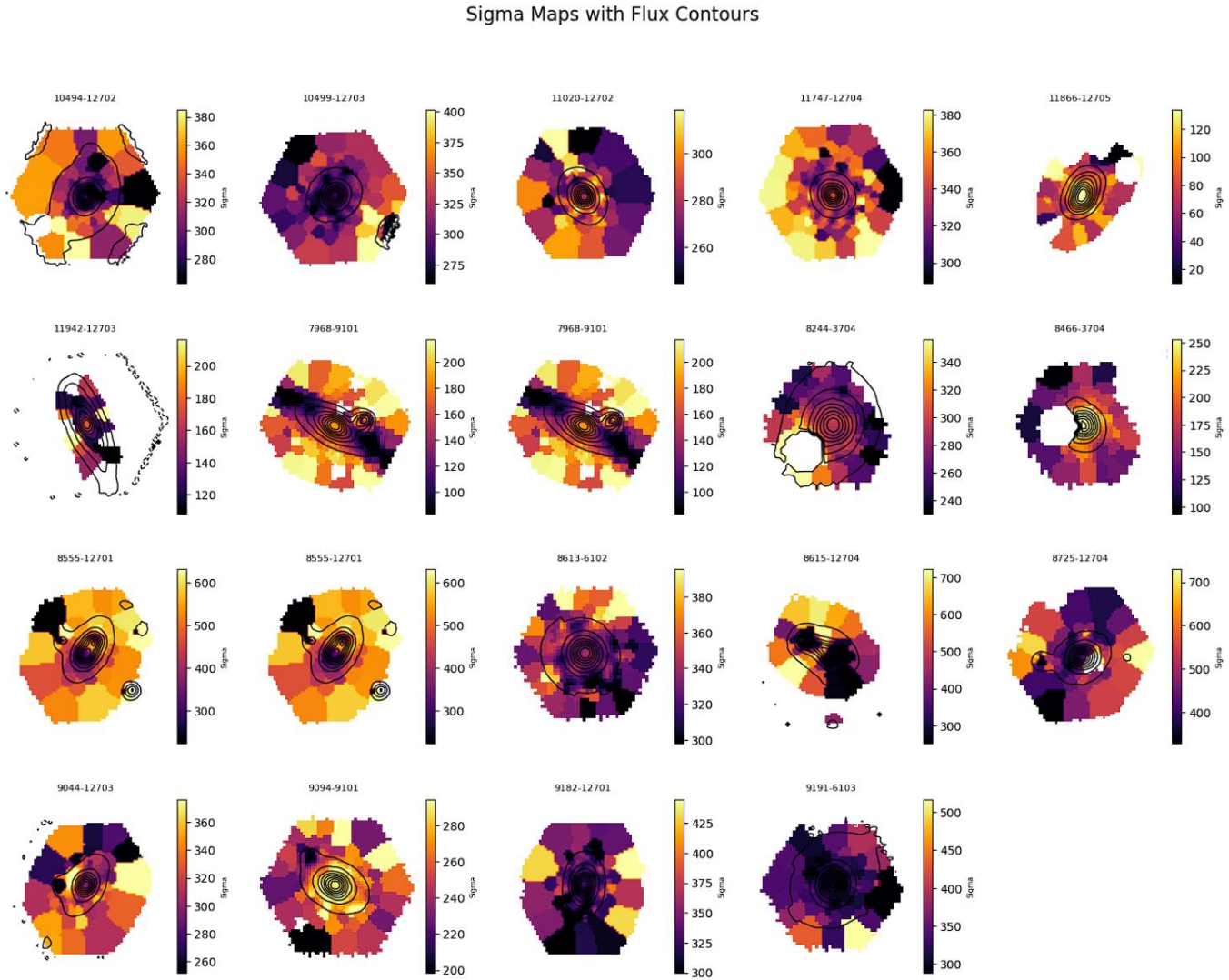
Credits: SDSS

Sample selection

- The final data release SDSS DR17 includes 10296 galaxies.
- Quality flag = −1 to 3
- 6,065 galaxies have Qual ≥ 1
- The TType follows standard morphological classification:
- TType < 0 → Early-type galaxies (E, S0)
- TType ≥ 0 → Late-type galaxies (Sa and later)
- Total galaxies with Qual >= 1 and TType available: 6054.
- Early-type galaxies: 1942 Late-type galaxies: 4112

Morphological Type	T-Type
Elliptical (E)	-5
E/S0	-4
Lenticular (S0)	-2 to 0
Sa	1
Sab	2
Sb	3
Sbc	4
Sc	5
Scd	6
Sd	7
Sdm	8
Sm	9
Irregular (Irr)	10
Unclassified / Merger	11

Contour plots

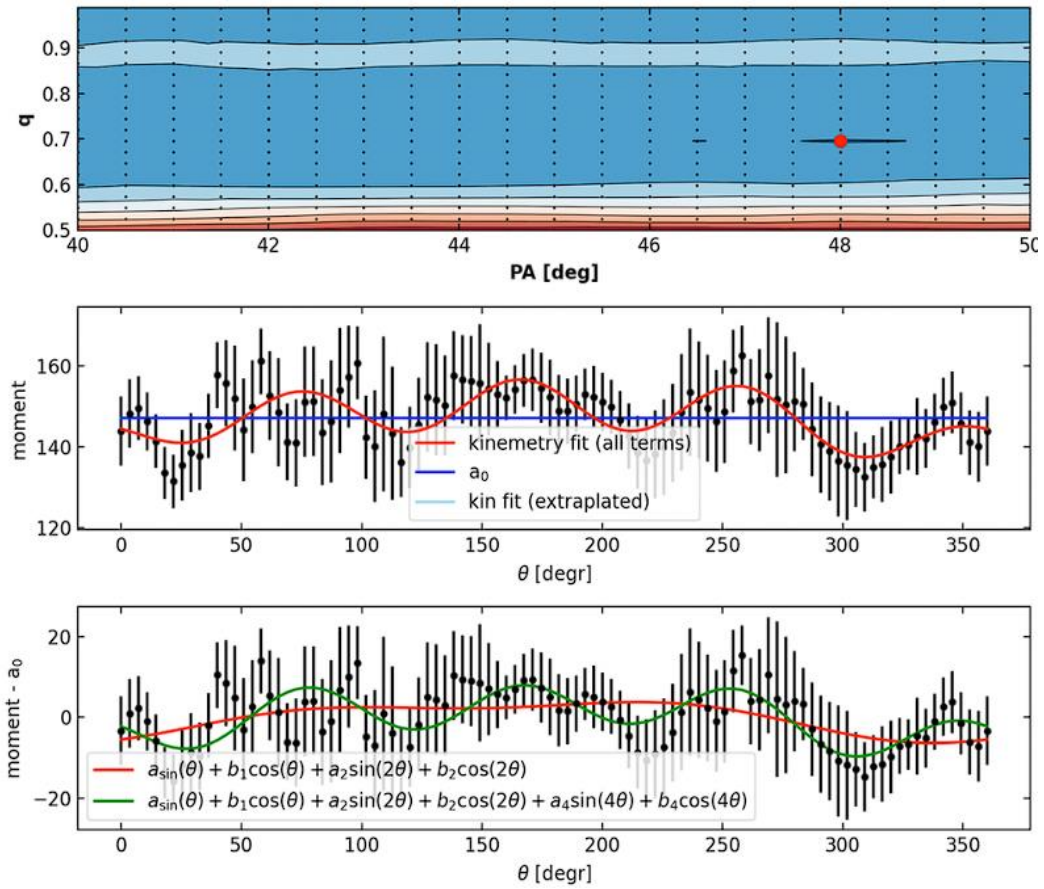


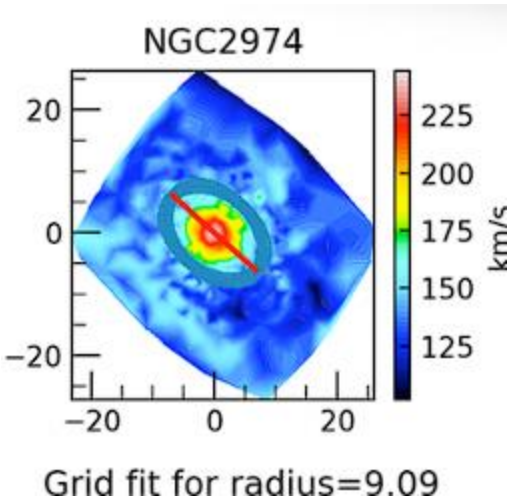
Kinemetry

- Kinemetry → **kinematic analogue of photometry**,
- Analyzes the **2D distribution** of kinematic quantities in galaxies.
- **Kinemetry** operates on a 2D spatial maps
- Ellipse fitting → Kinematic quantity → function of angle ψ
- It applies **Fourier decomposition** to extract how the observed kinematics vary with azimuthal angle ψ
- On each elliptical ring, a general kinematic field K(ψ) is modeled as:

$$K(\psi) = A_0 + \sum_{n=1}^{N} [A_n \sin(n\psi) + B_n \cos(n\psi)]$$

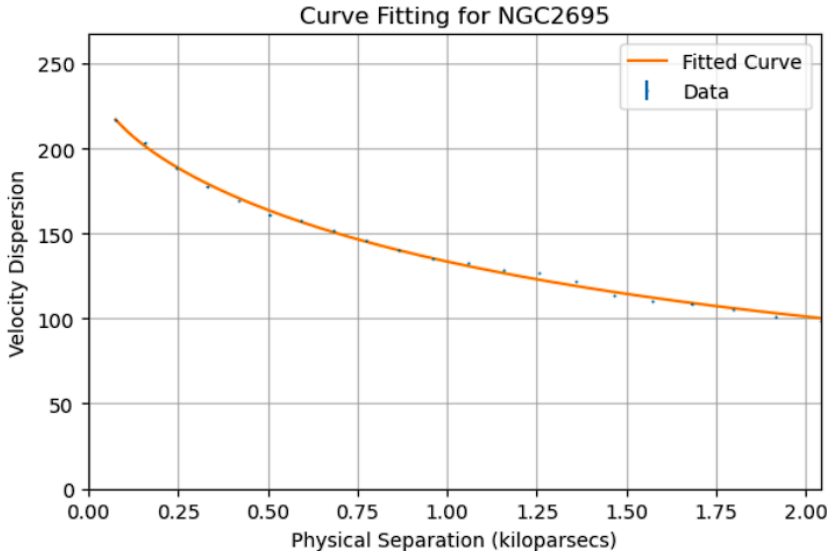
- Repeat for each ellipse to construct **radial profiles** of each harmonic coefficient.

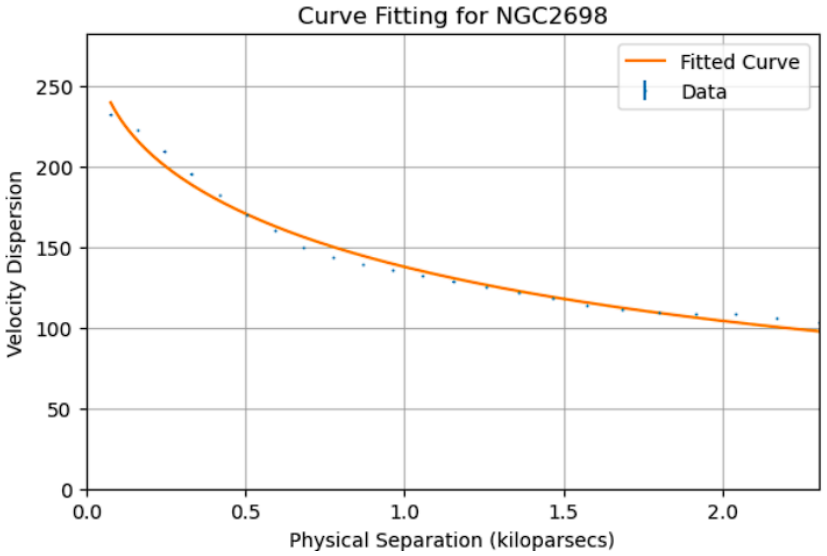


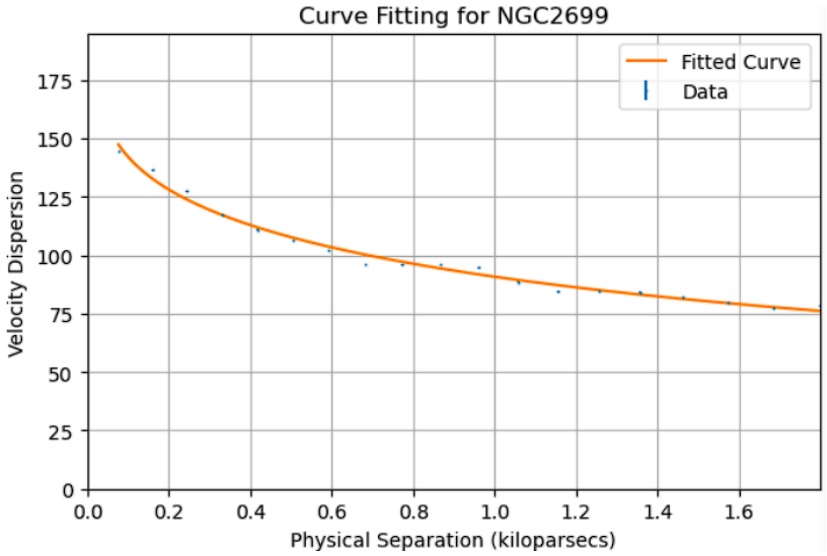


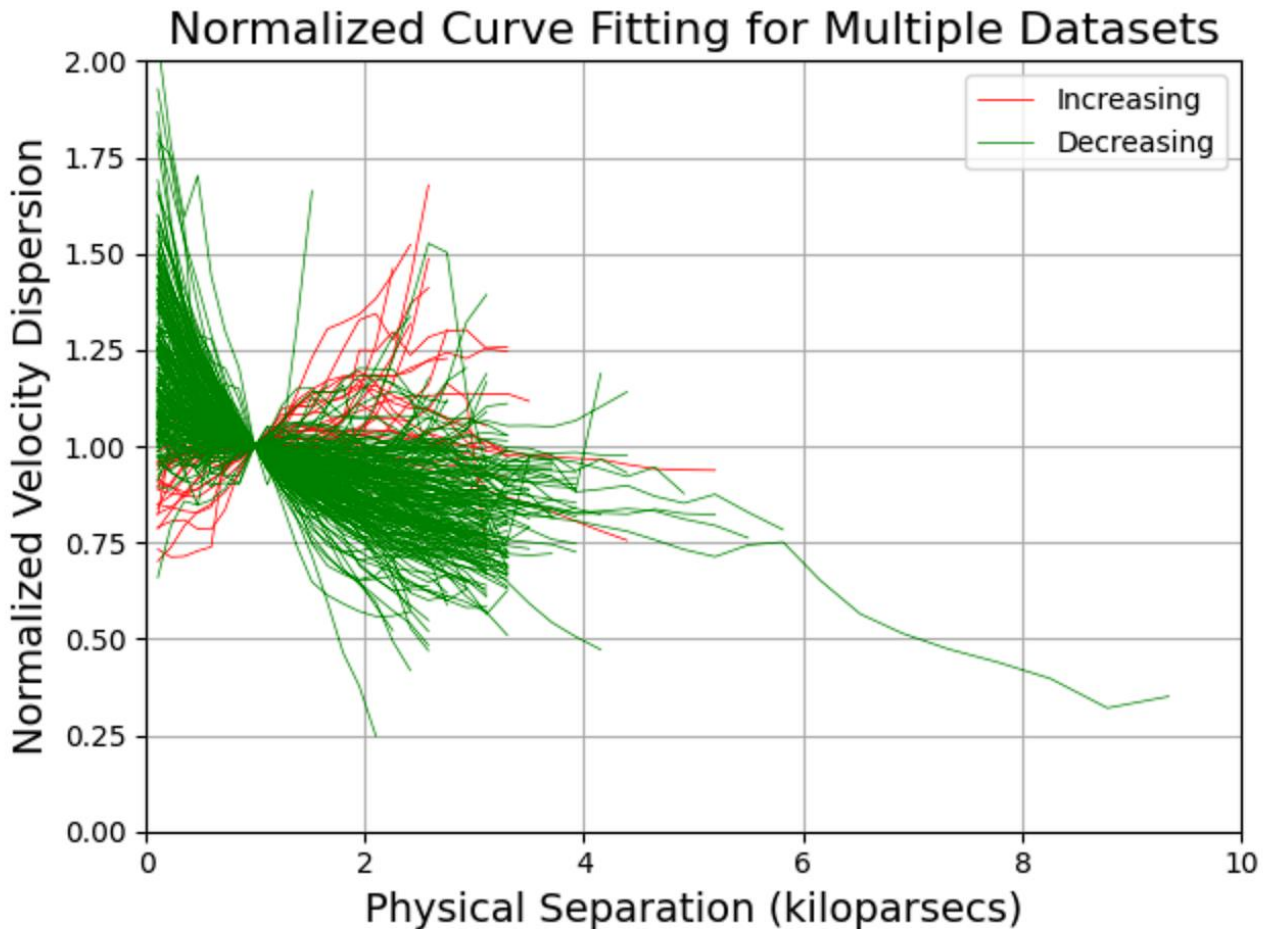
Davor Krajnovic et. al

Sauron Data

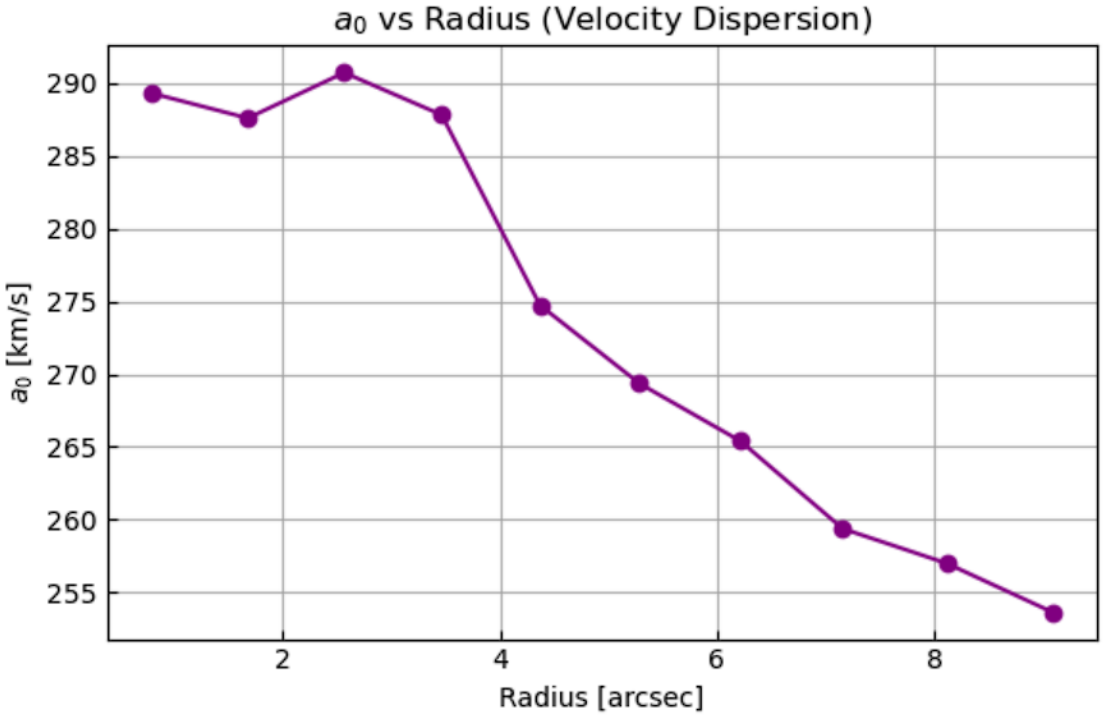

Curve Fitting for NGC2695
Fitted Curve
Data
Velocity Dispersion
Physical Separation (kiloparsecs)
0
50
100
150
200
250
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

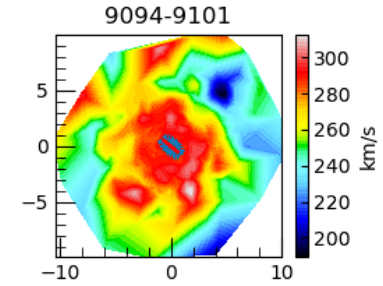

Curve Fitting for NGC2698
Fitted Curve
Data
Velocity Dispersion
Physical Separation (kiloparsecs)
0
50
100
150
200
250
0.0
0.5
1.0
1.5
2.0

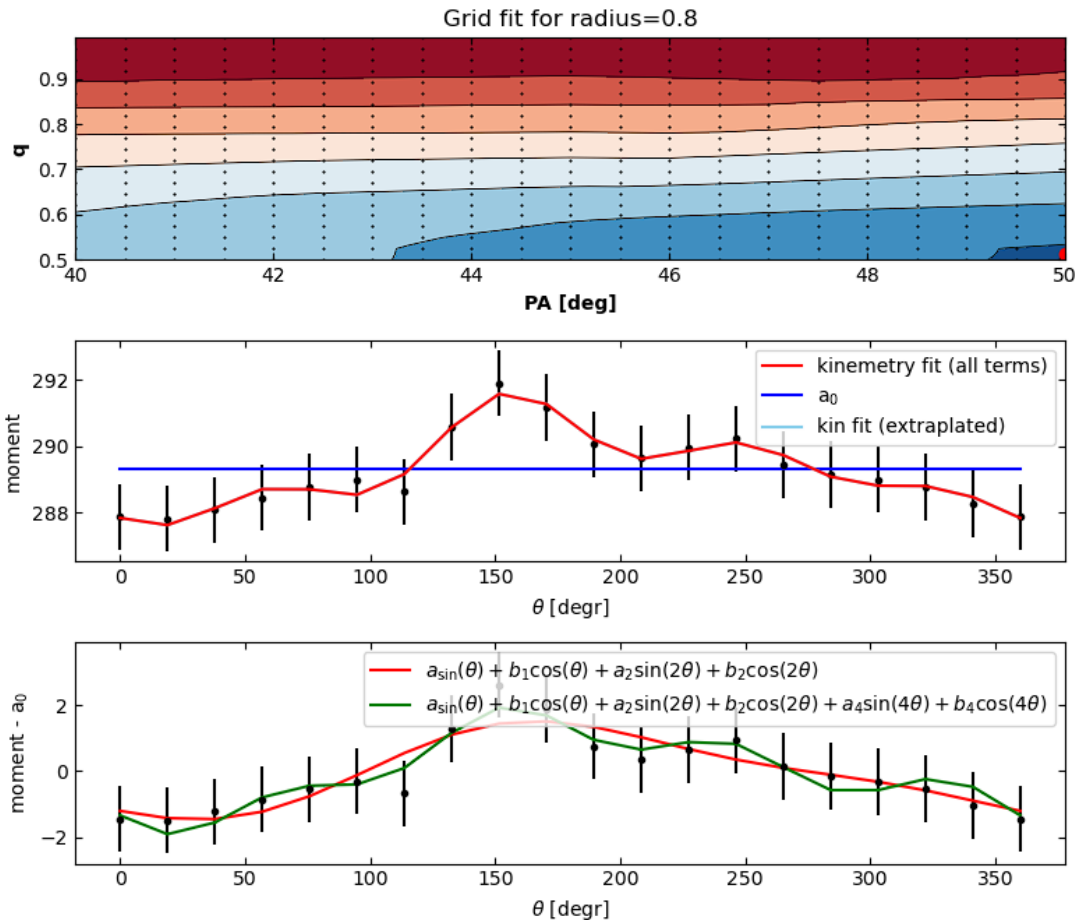

Curve Fitting for NGC2699
Fitted Curve
Data
Velocity Dispersion
Physical Separation (kiloparsecs)
0
25
50
75
100
125
150
175
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6


Normalized Curve Fitting for Multiple Datasets
Increasing
Decreasing
Normalized Velocity Dispersion
Physical Separation (kiloparsecs)
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
2
4
6
8
10

MaNGA data


a_0 vs Radius (Velocity Dispersion)
a_0 [km/s]
Radius [arcsec]


9094-9101
km/s


Grid fit for radius=0.8
q
PA [deg]
kinemetry fit (all terms)
a_0
kin fit (extraplated)
moment
θ [degr]
$a_{sin}(\theta) + b_1\cos(\theta) + a_2\sin(2\theta) + b_2\cos(2\theta)$
$a_{sin}(\theta) + b_1\cos(\theta) + a_2\sin(2\theta) + b_2\cos(2\theta) + a_4\sin(4\theta) + b_4\cos(4\theta)$
moment - a_0
θ [degr]

Future Work

- Measure inner and outer gradients of σ(R)
- Quantify correlations
- **Use kinemetry** to extract spatially resolved higher-order moments (h_3, h_4)
- Analyze K_5/K_1 ratio

Thank you