Chemo-dynamical Structure of ETG Halos

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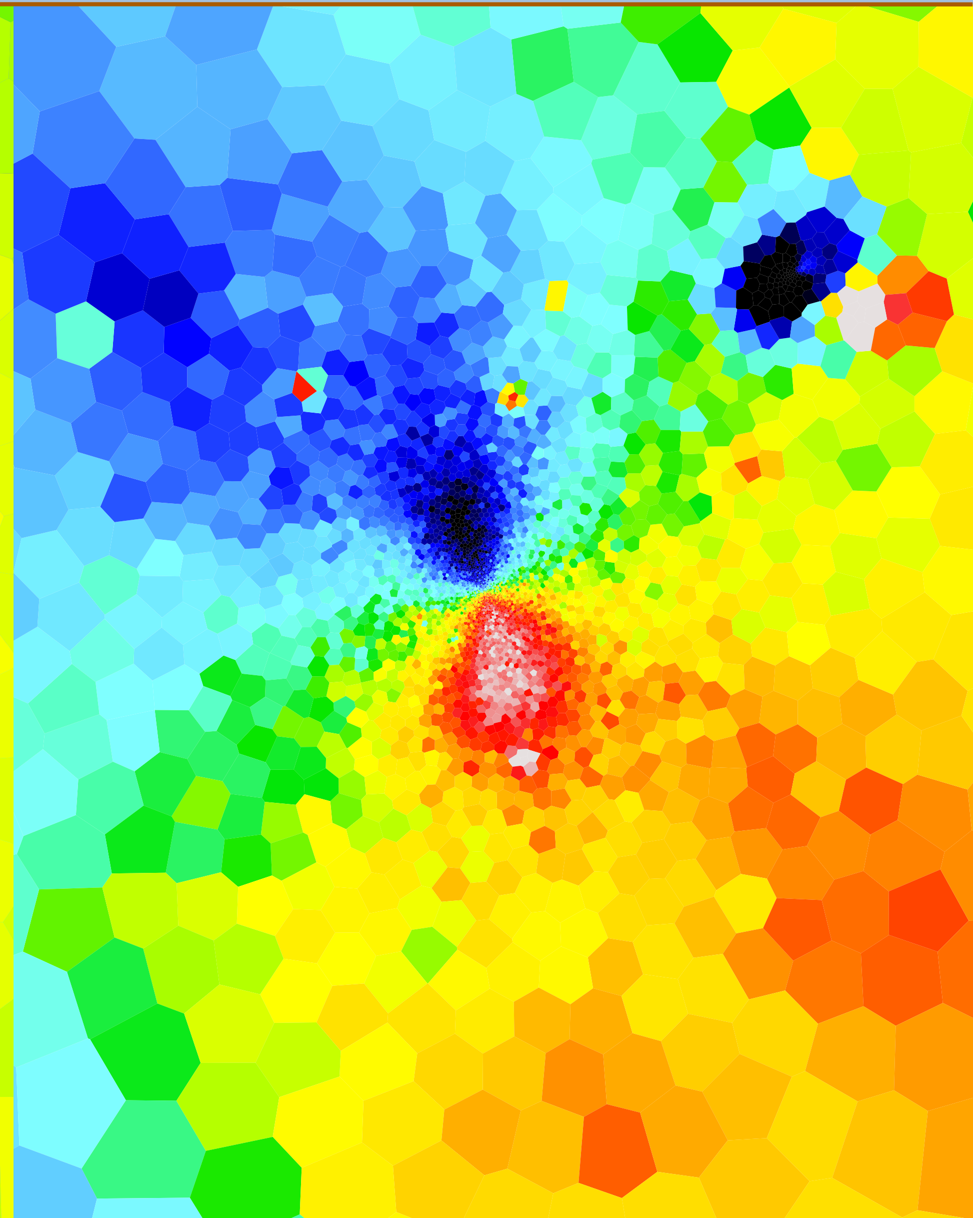
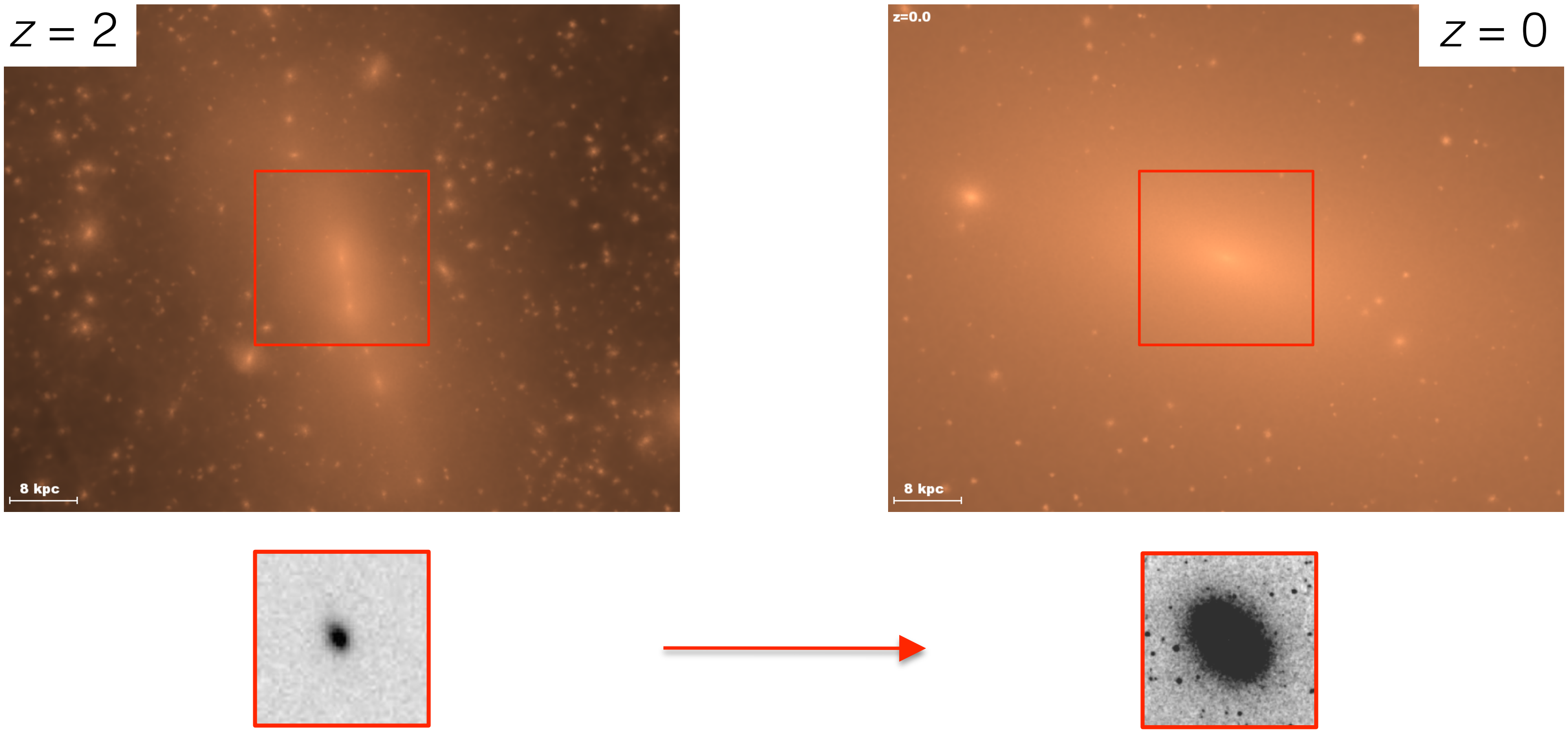


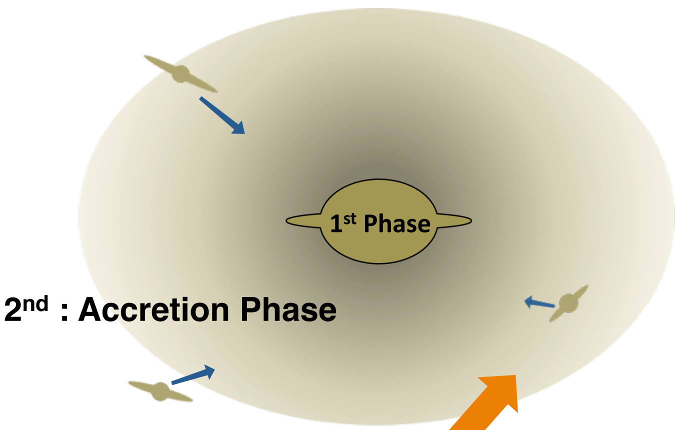
Inside-Out / Two-Phase Galaxy Formation



- ETG half-light radius grows by a factor of a few between z = 2 and today.

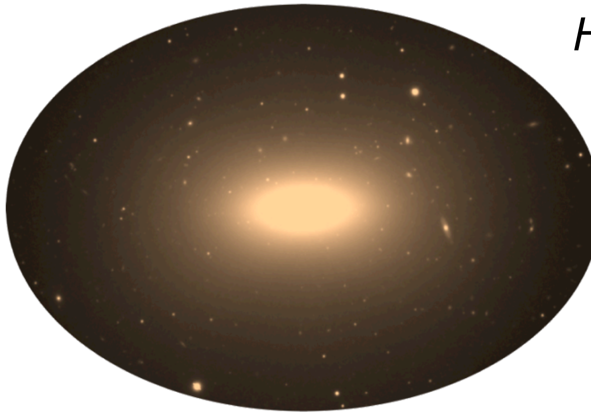
e.g., Daddi+2005, van Dokkum+2008, ...

Growth of Stellar Halos



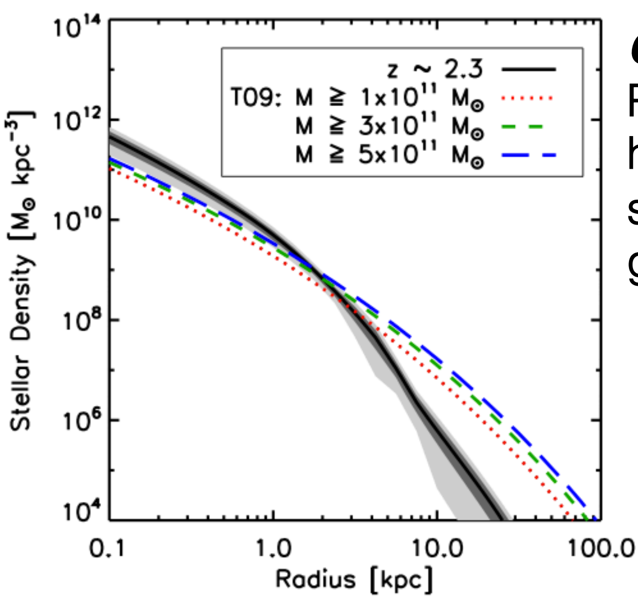
aka "the trash pile"

? =



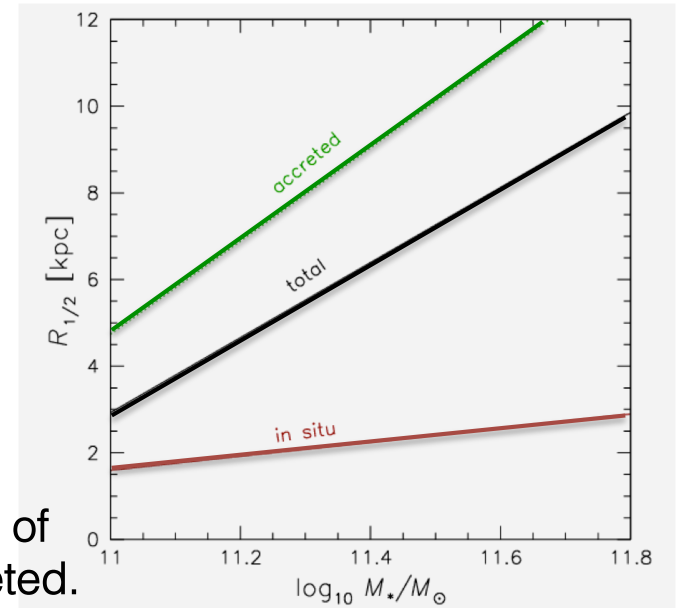
Halo Observables:

- *metallicity*
- *substructure*
- *angular momentum*
- *. . .*



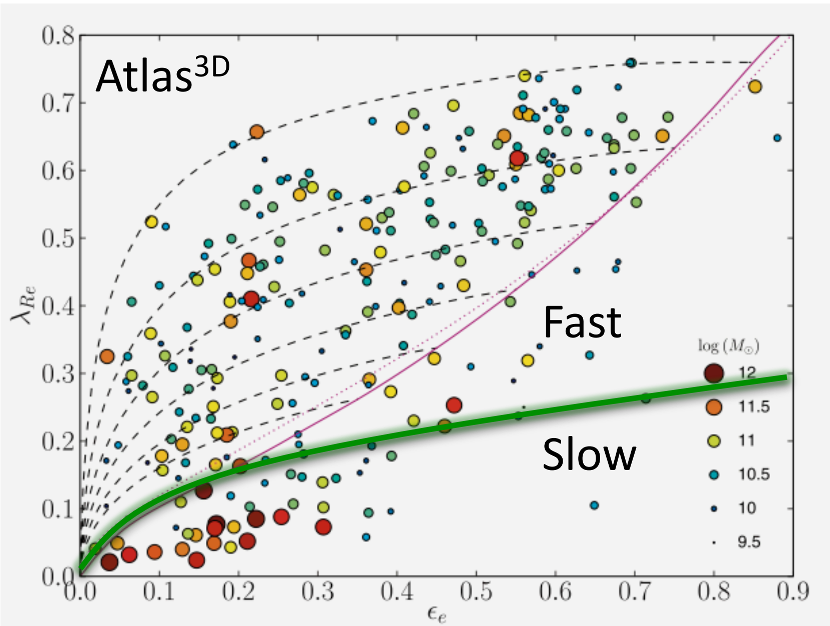
Observations: Present day galaxies have more extended stellar halos than z=2 galaxies.

Theory: A significant fraction of this material is accreted.

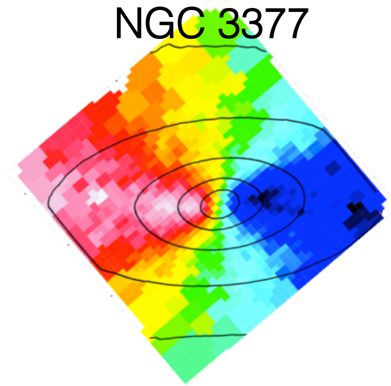


Angular Momentum at $< 1\ R_e$

$\lambda_R \equiv \frac{\langle R\,|V|\rangle}{\langle R\,\sqrt{V^2+\sigma^2}\rangle}$ = specific angular momentum with 1 R_e



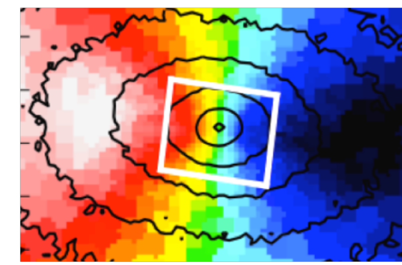
Emsellem+2011



Emsellem+2004

? =

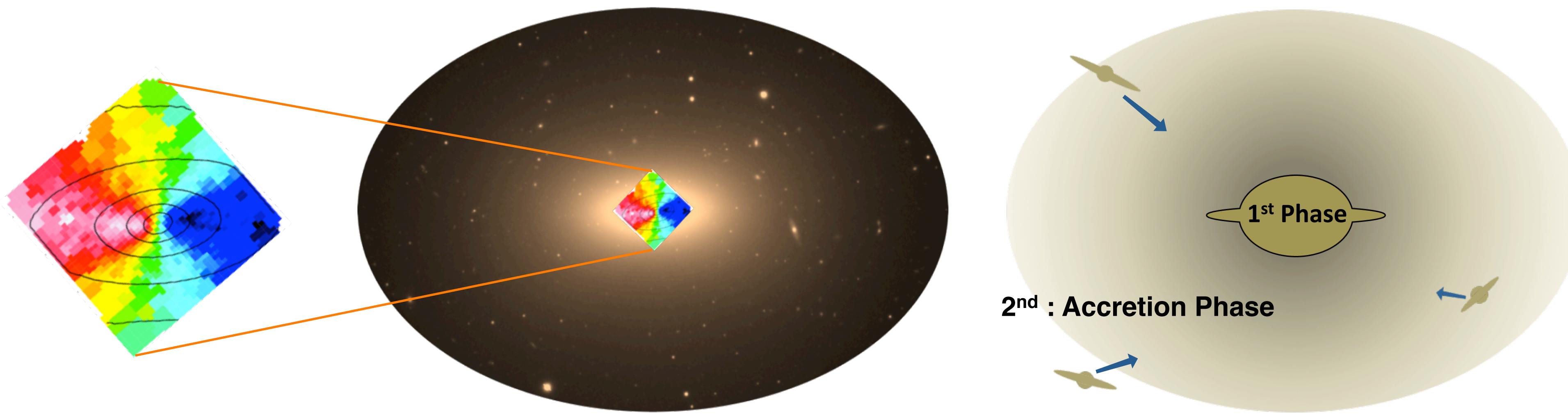
3:1 Merger



Bois+2011

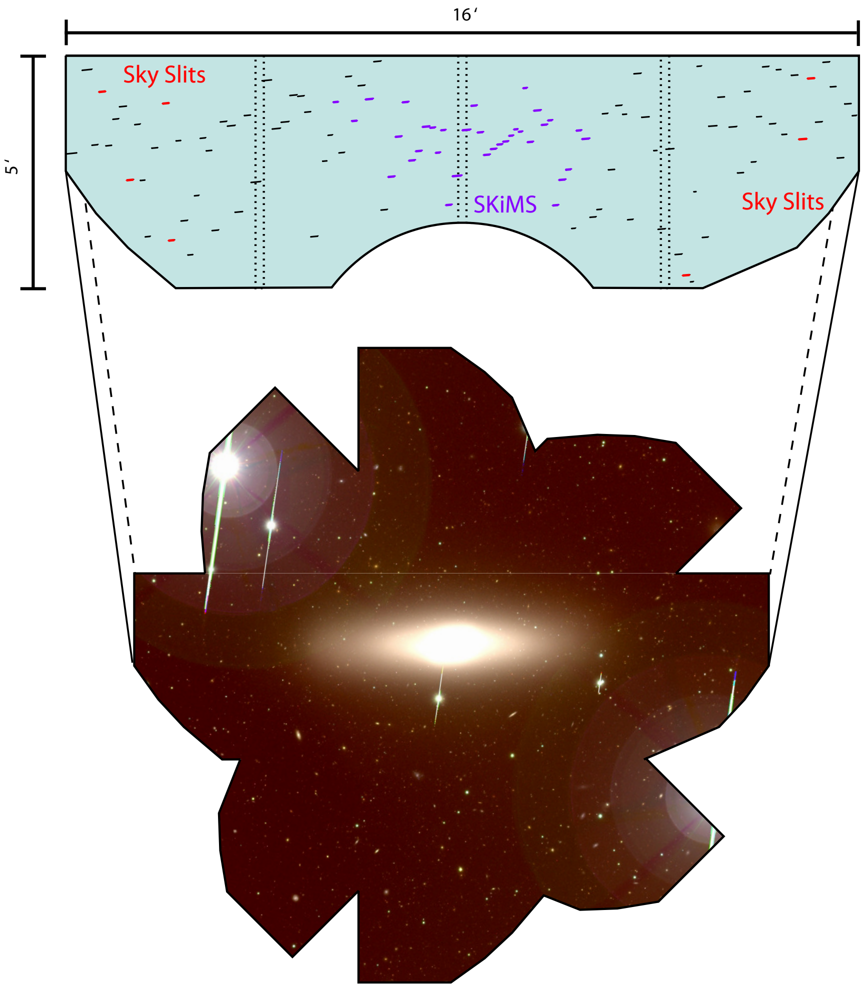
- 86 % of sampled ETGs are "fast rotators" with well-aligned photometric/kinematic axes
- Consistent with being oblate axisymmetric major-merger remnants

The Bigger Picture

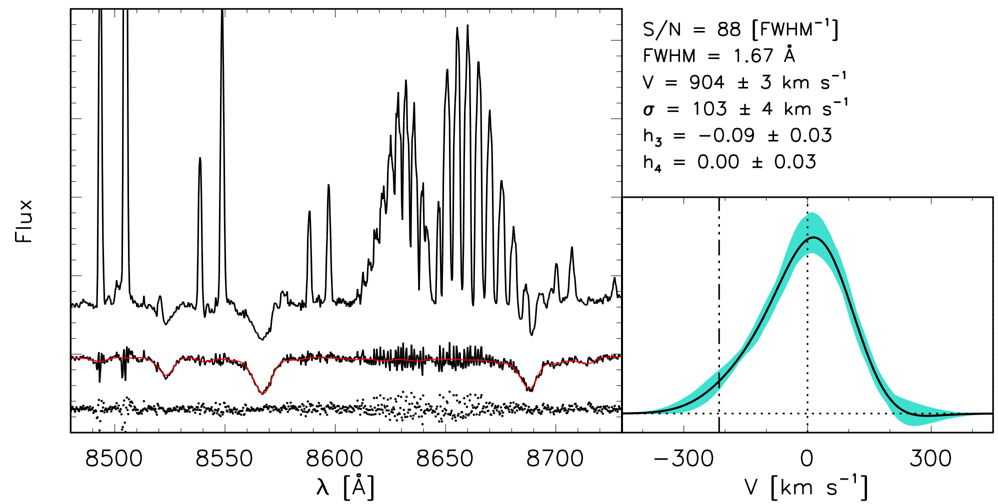


- Most of what we know about L* ETG kinematics is restricted to either < 1 R_e, or along the major/minor-axes.
- These data are telling us more about the 1st phase of growth (and very recent events)
- To study the 2nd accretionary phase, we need to extend our kinematic studies to the *halo*

*SKiMS (**S**tellar **Ki**nematics from **M**ultiple **S**lits)*

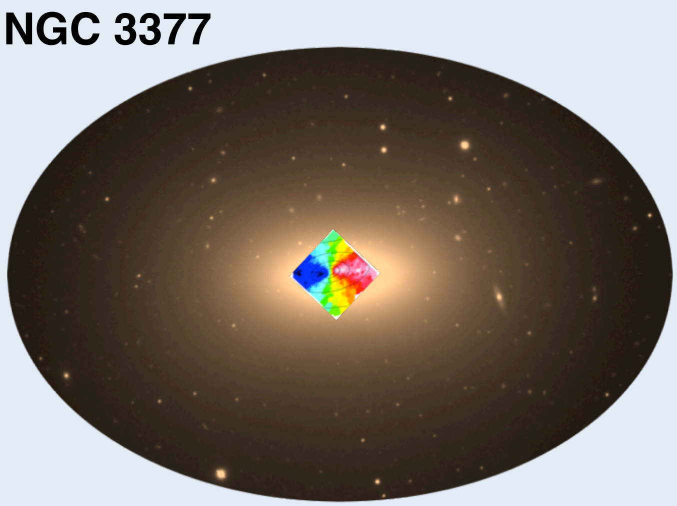


- We use the wide-field capabilities of the Keck/DEIMOS spectrograph to obtain stellar spectra at 3 – 5 R_e.
- Multiple pointings achieve sparse, but well sampled two-dimensional coverage of a galaxy.



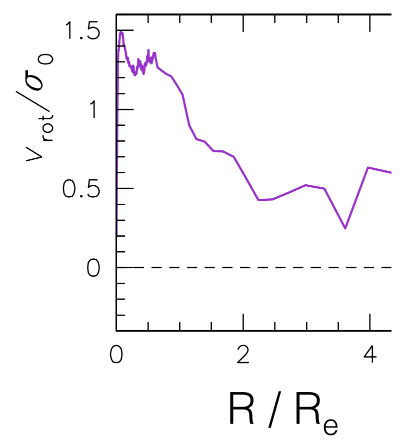
- Extract line-of-sight-velocity distributions from the NIR CaT absorption features
- Kinematic measurements (V, σ, h_3, h_4) provide clues to the internal dynamical structure and assembly history

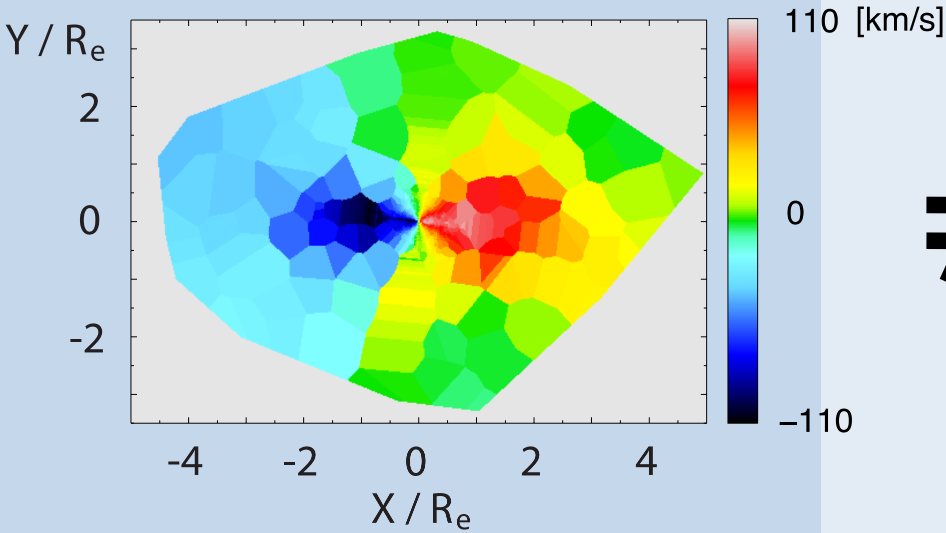
The Big Picture Revealed



Fast rotation at < 1 R_e

Slow rotation at > 2 R_e





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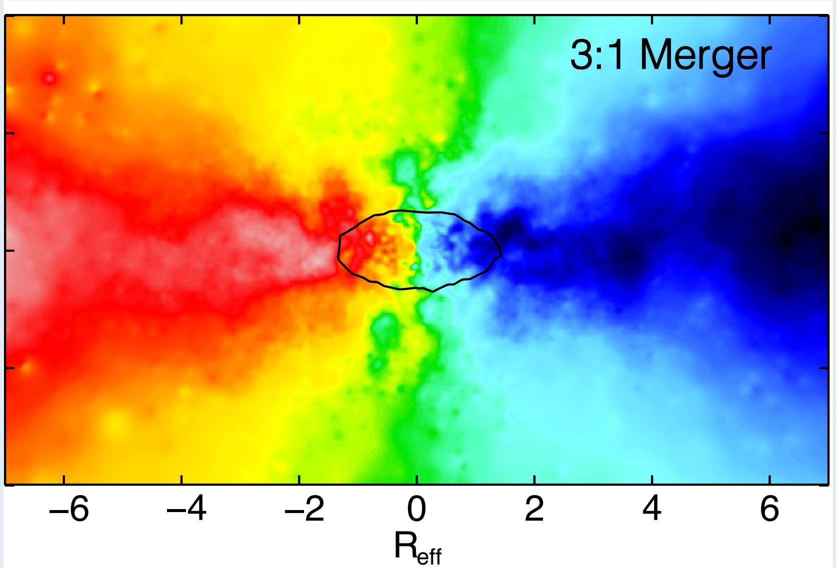
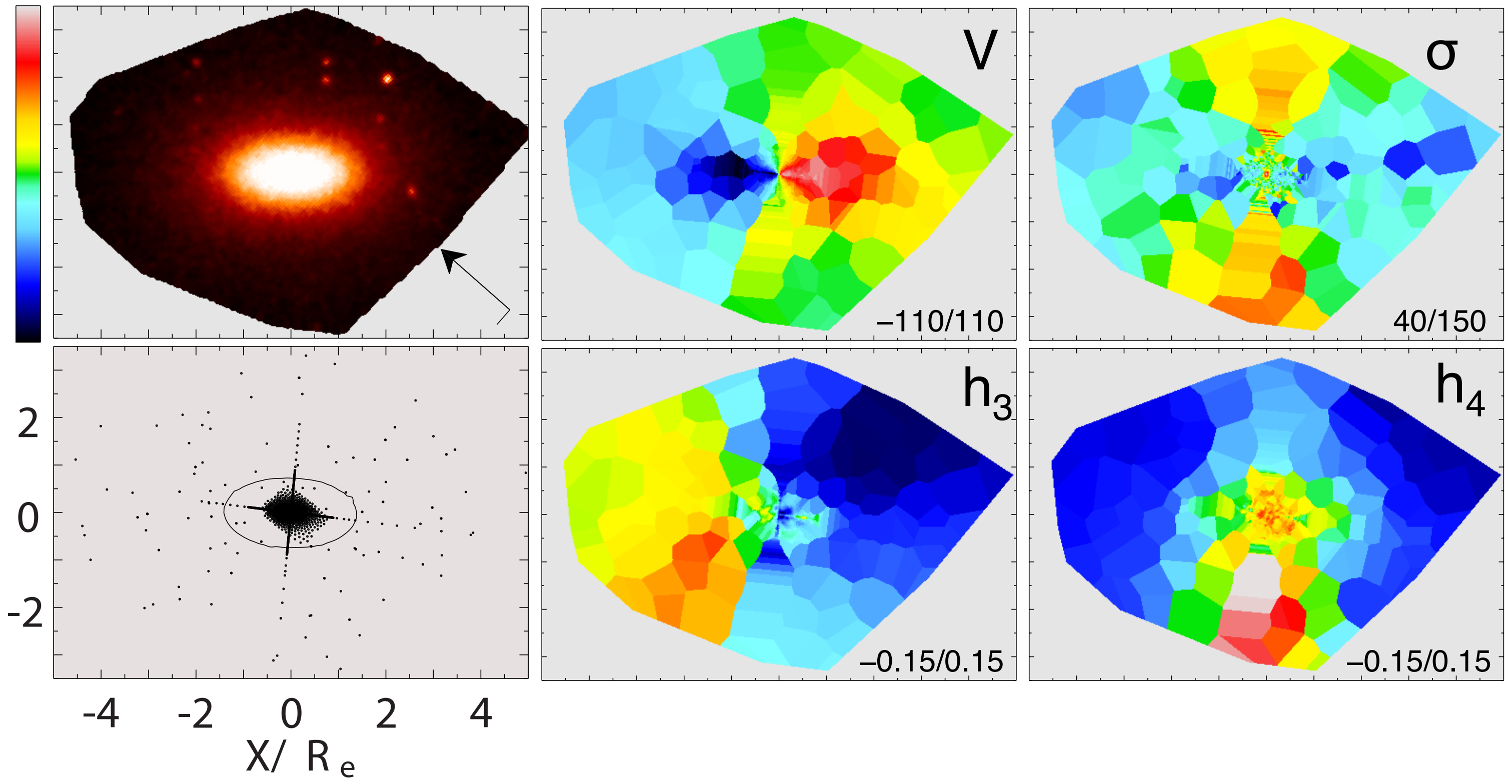
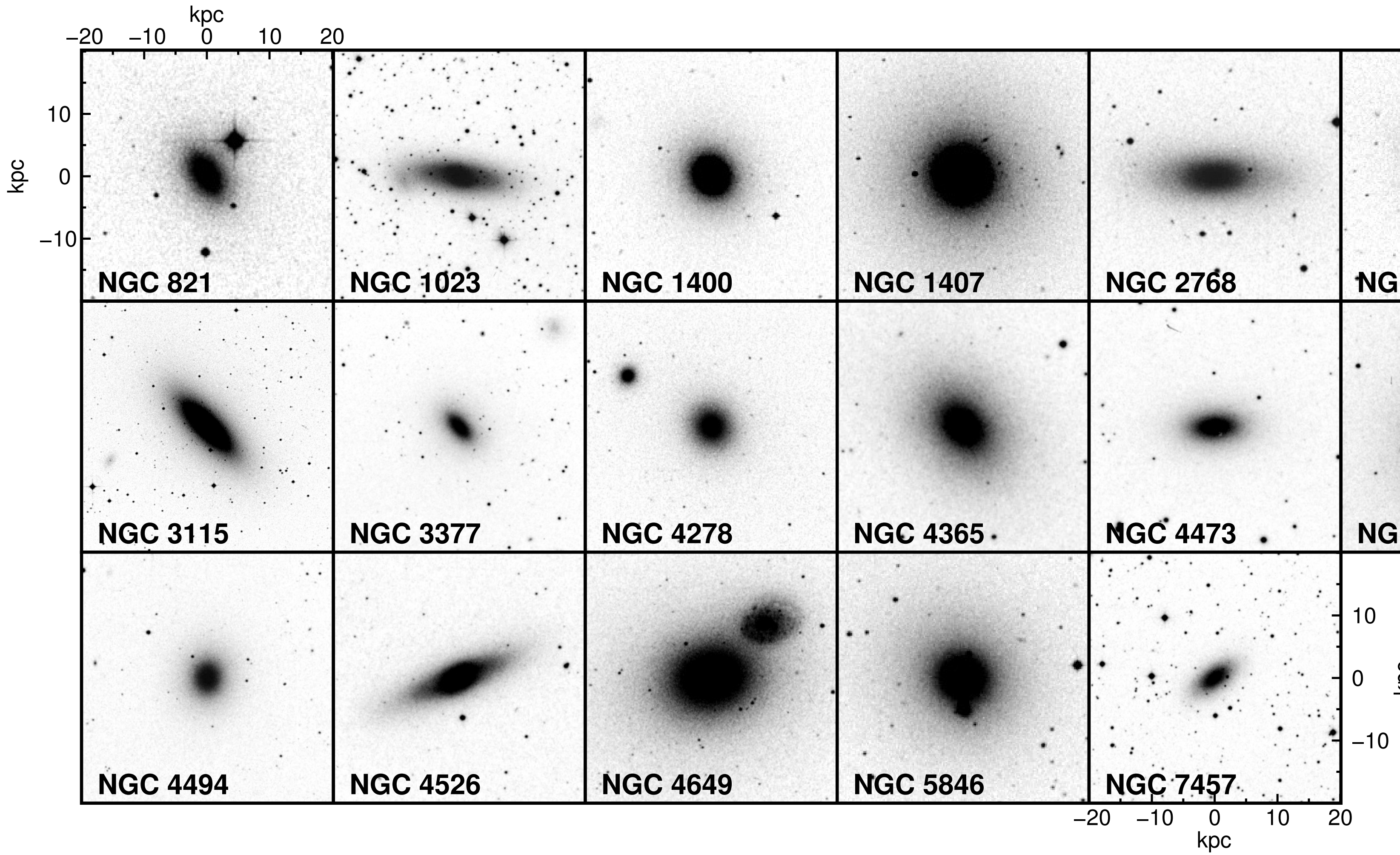


The Big Picture Revealed

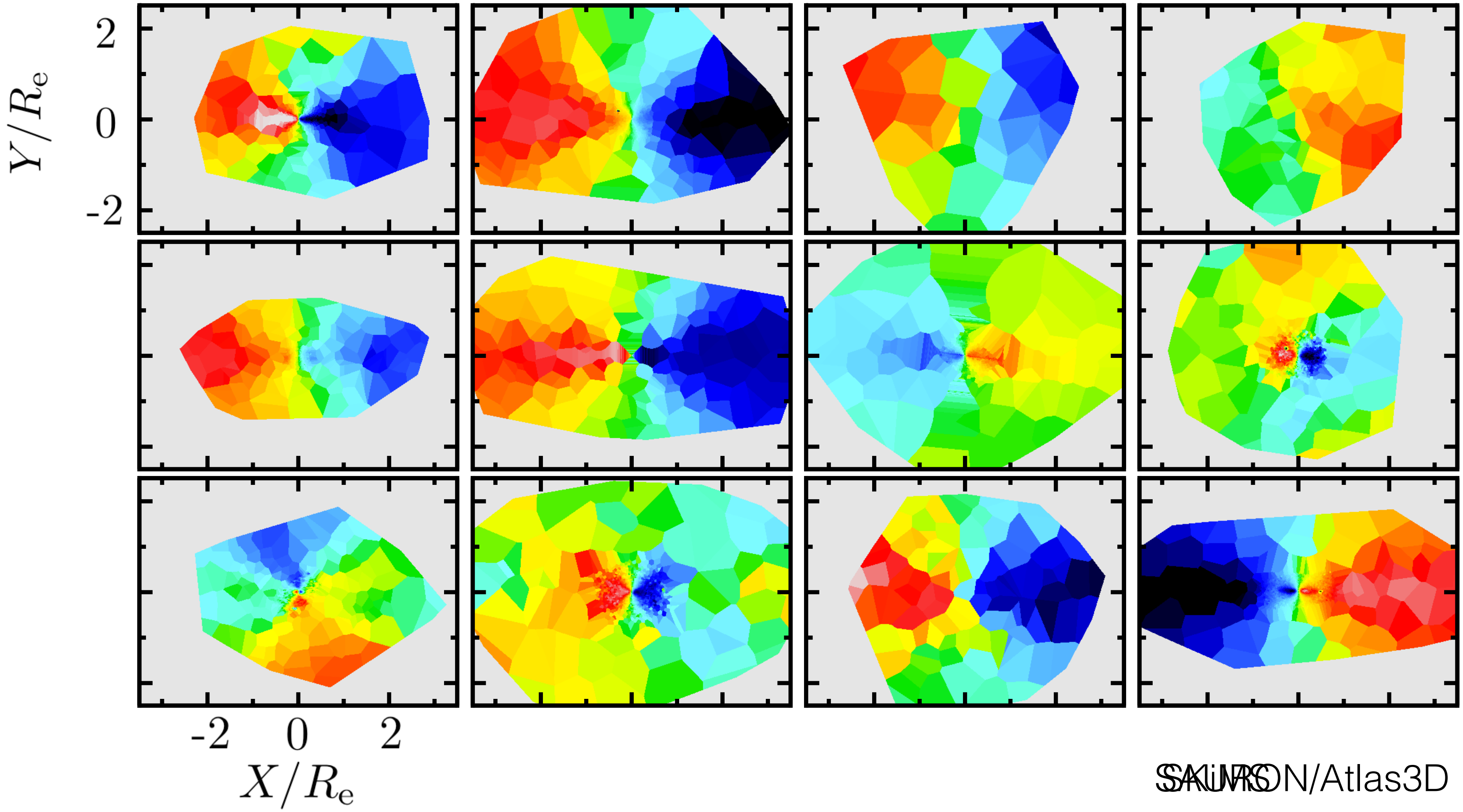


Wide-Field Kinematics for 17 ETGs



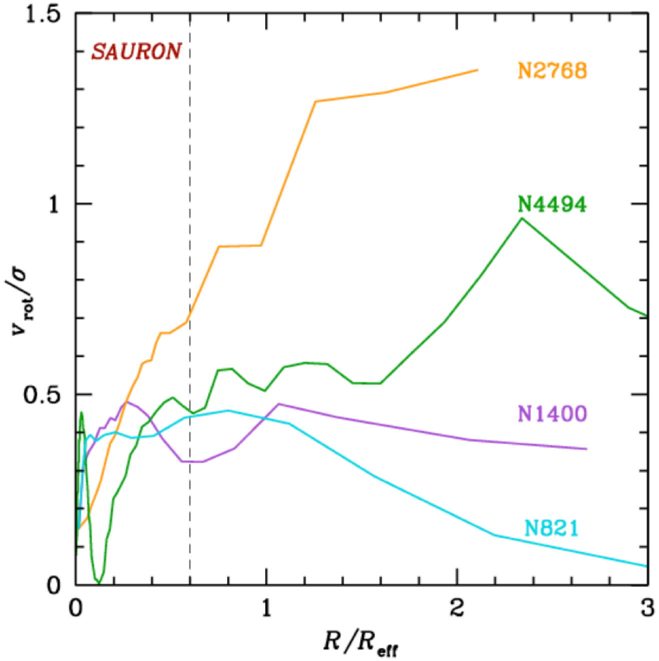
Stellar kinematics on 3 – 5 R_e for a representative sample of galaxies.
Morphology ranges from small S0s to massive BCGs

Velocity Maps



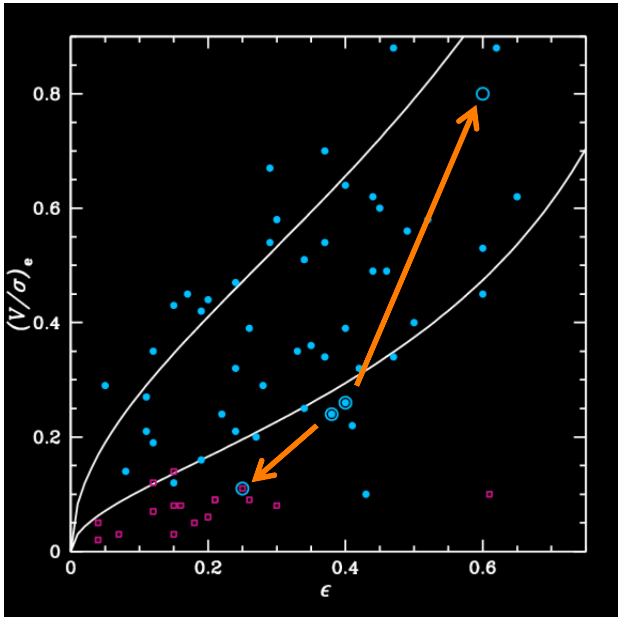
SAURON/Atlas3D

Angular momentum of the stellar halo



Stellar angular momentum within 1 R_e is a poor predictor of stellar angular momentum at 3 Re.

after Proctor+2009



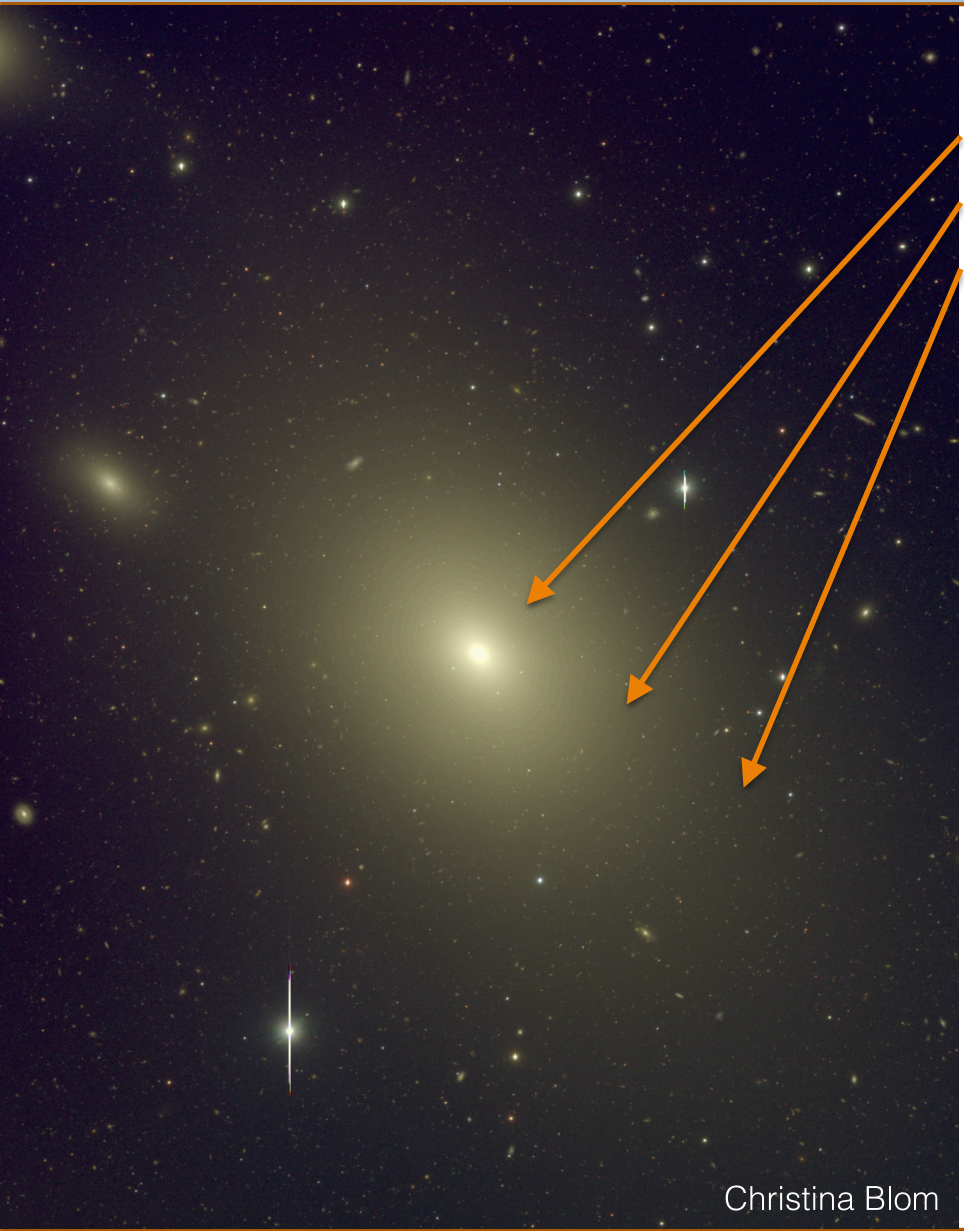
Classic results depend on the adopted spatial scale.

Next Steps:

Restrict study to ~ edge-on galaxies for simplicity

Obtain kinematics at even larger radius

Getting to 6 – 10 R_e



~1 R_e : SAURON IFU + Long-slit

3 – 5 R_e : DEIMOS SKiMS

6 –10 R_e : Globular Clusters & Planetary Nebulae

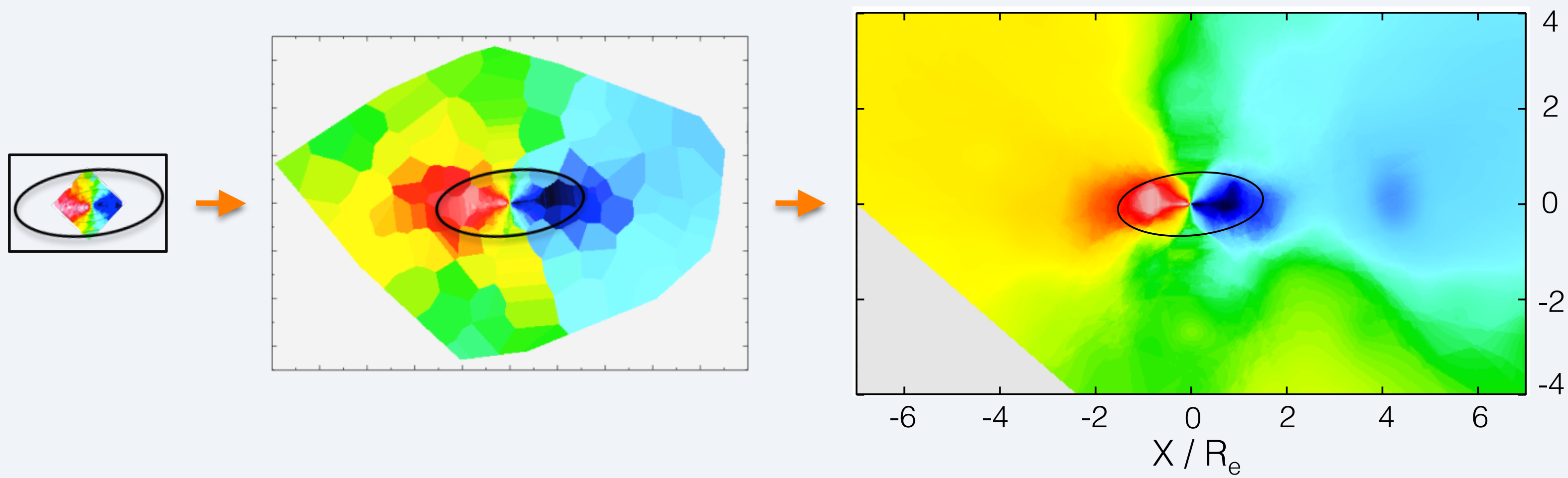
SLUGGS.ucolick.org

Literature Data:

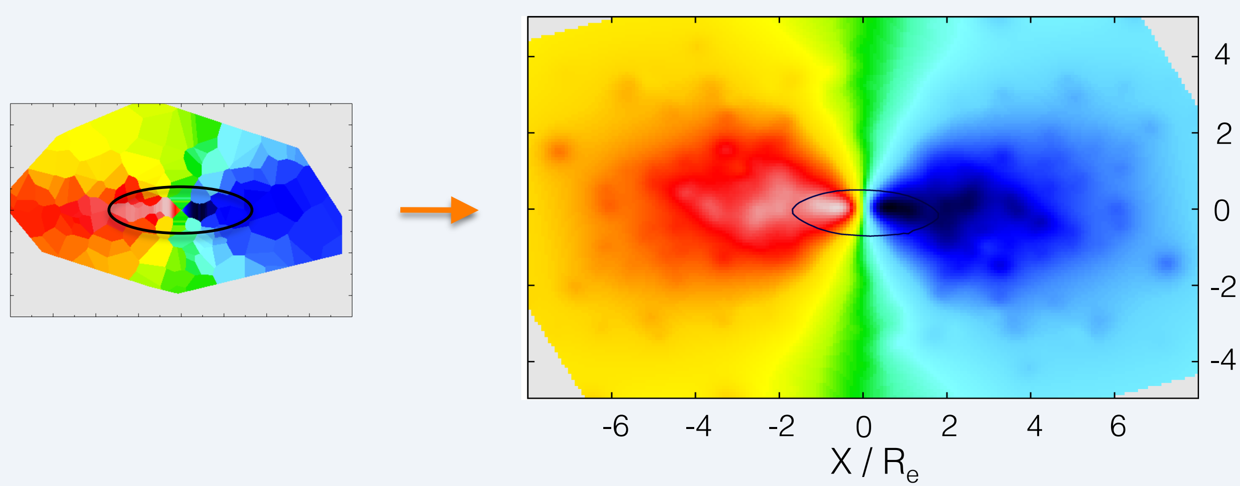
- Halliday et al. 2001
- Emsellem et al. 2004
- Peng et al. 2004
- Noordermeer et al. 2008
- Coccato et al. 2009
- Proctor et al. 2009
- Woodley et al. 2010
- Arnold et al. 2011
- Pota et al. 2012

Examples

Scale: 1 R_e 3 R_e 7 R_e

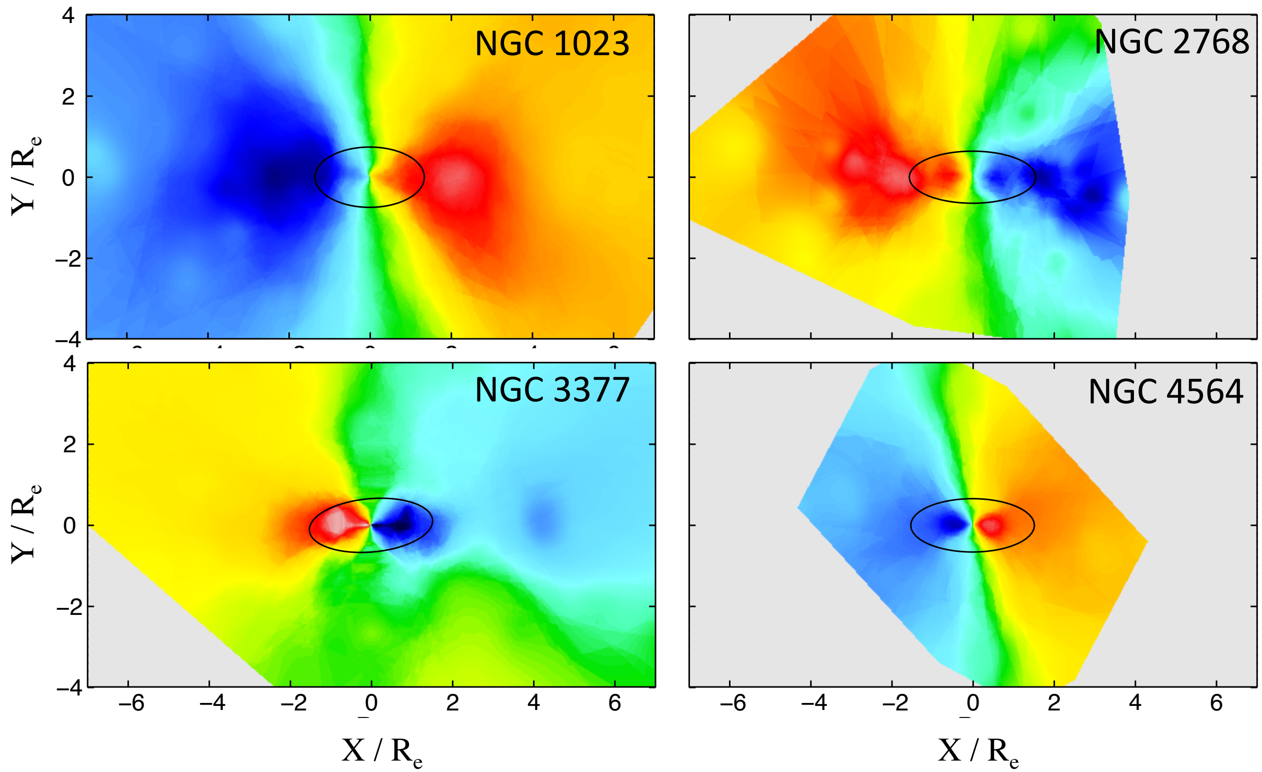


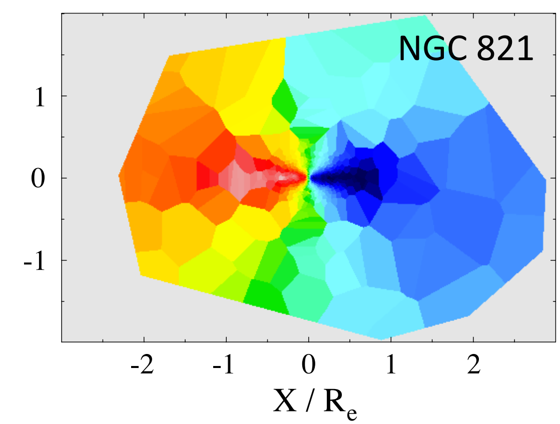
Fast rotator designation only applies to inner bulge.



Coccato+2009, Emsellem+2004, Proctor+2009,Arnold+2011

Two-Zone Kinematics



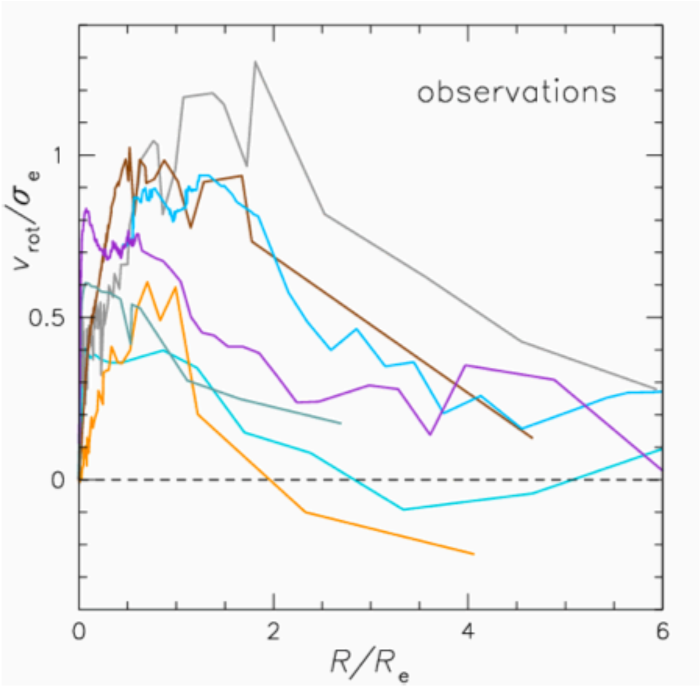


Edge-on Sample

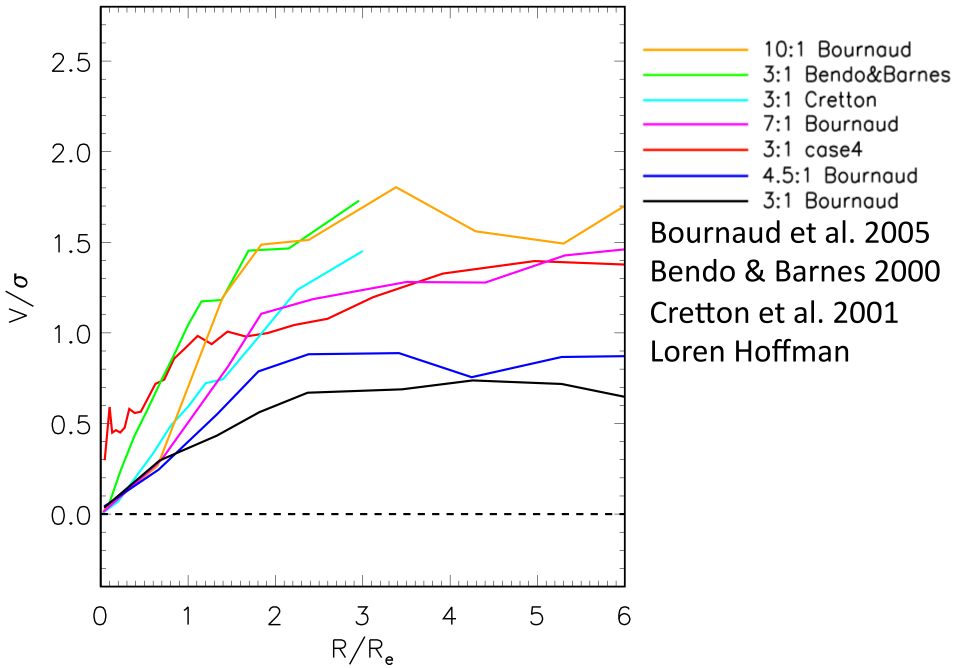
- All show aligned but declining rotation
- Size of inner “fast rotator” is variable

Major-Mergers (3:1 – 10:1) ?

Sample of 8 near to edge-on galaxies
All show an outer decline in v/σ

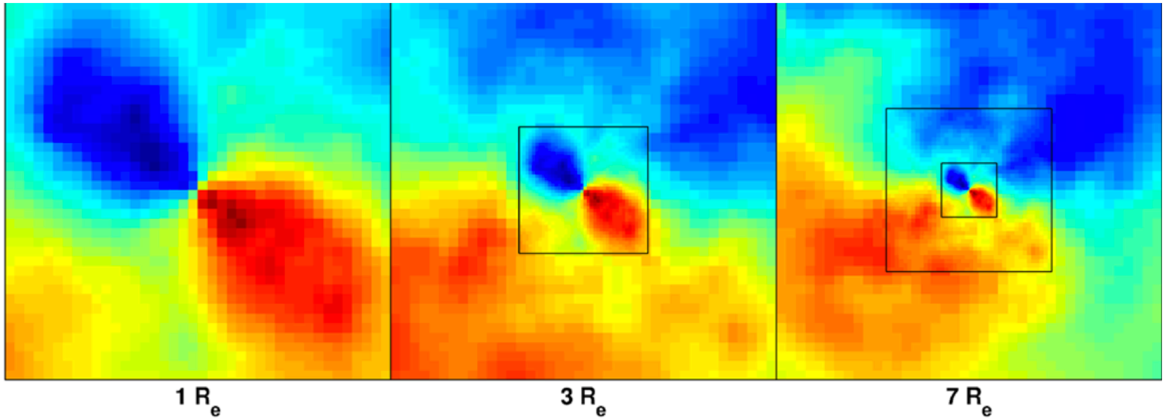


Representative major-merger remnants
All show rising to flat v/σ profiles



The generic major-merger prediction is for flat or rising v/σ profiles resulting from residual progenitor disk spin and the conversion of orbital into internal angular momentum
(Hernquist 1992, Bendo & Barnes 2000, Cretton et al. 2001, etc.)

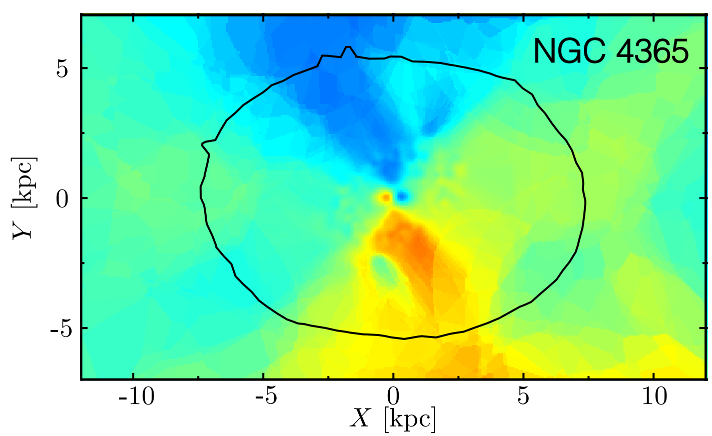
1:1 Mergers?



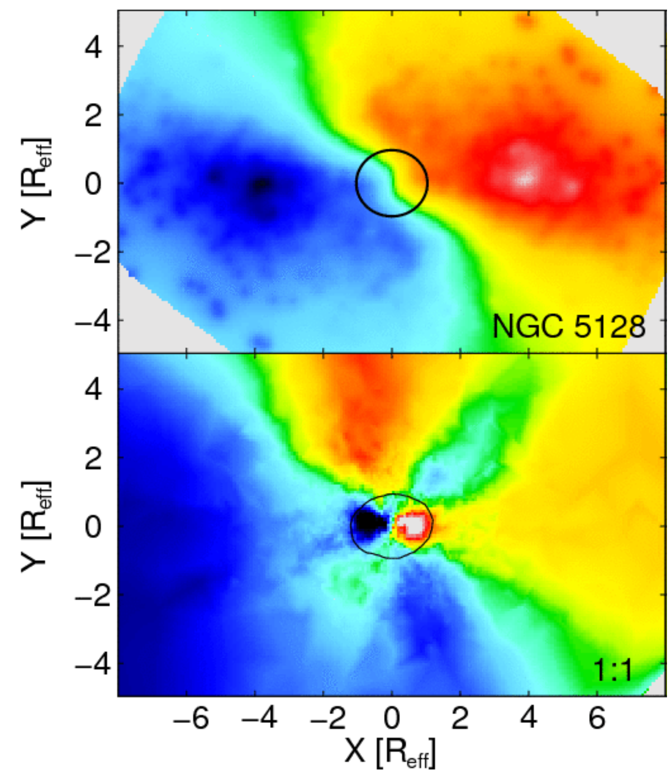
Simulated 1:1 major-merger
Hoffman+2010

Decoupled inner/outer components through low-angular-momentum, gas-rich, 1:1 major-mergers.

Frequently accompanied by KDCs or kinematic twists.



Explains a few specific examples, but probably not the general phenomenon of falling V/σ

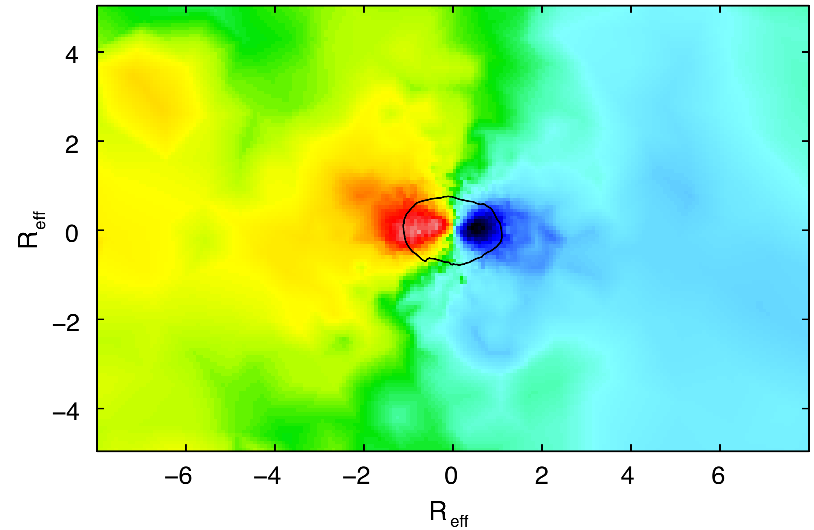


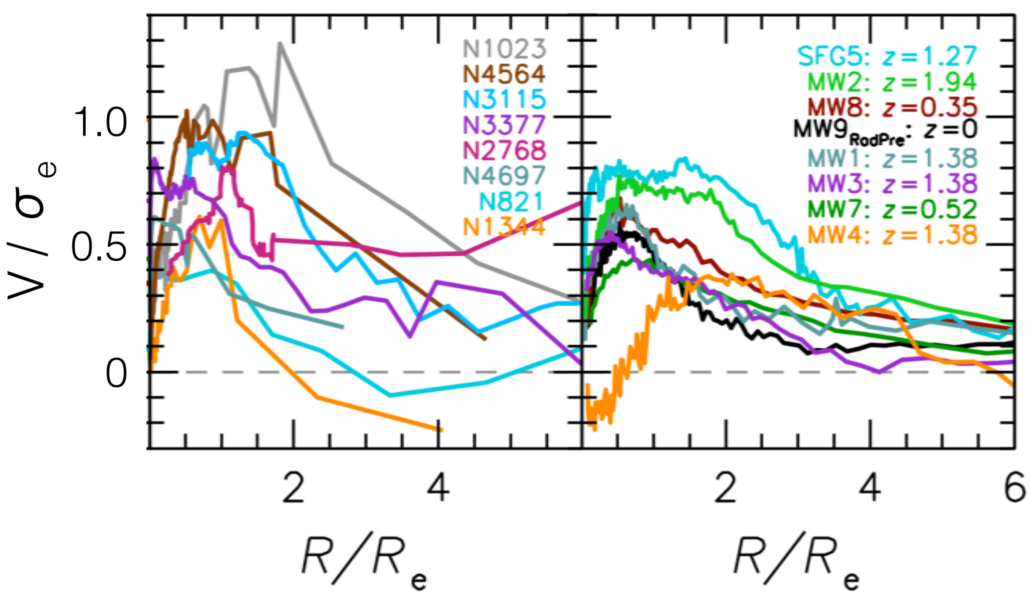
Two-zone Kinematics

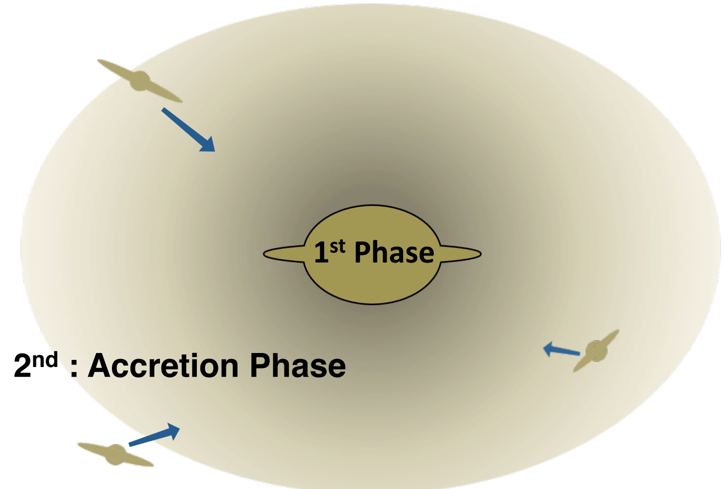
Cosmological Simulations
Daniel Ceverino, Avishai Dekel

In-situ, inner, rotating bulge the result of an unstable disk (VDI) fed by cold flows.

Numerous accretion events help build the slowly rotating outer spheroid
Vitvitska+2002, Abadi+06





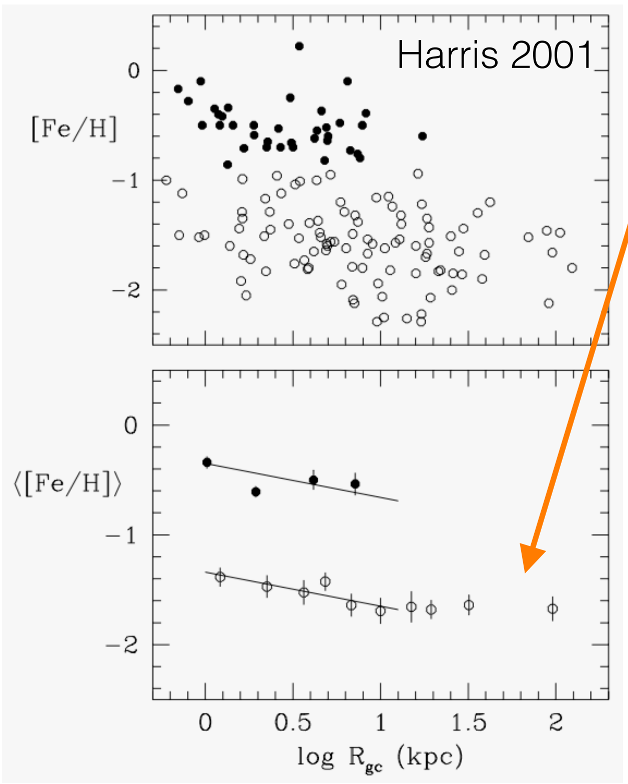


Two-phase formation naturally produces **two-zone** kinematics.

Chemical Structure of ETG Halos

Searle & Zinn 1978

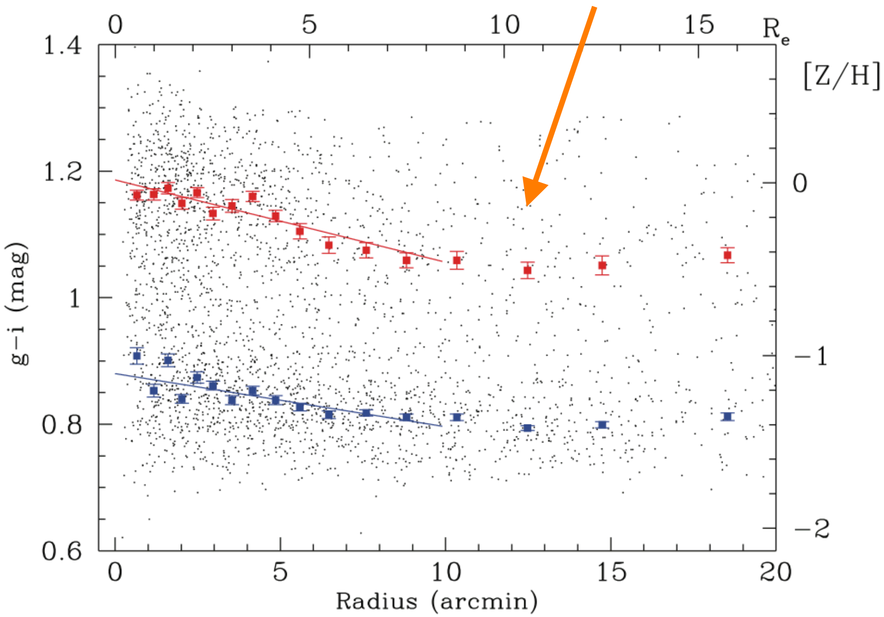
Key result: halo built via accretion exhibits a flattened metallicity gradient



Wide-field imaging/spectroscopy is now revealing this behavior in ETGs.

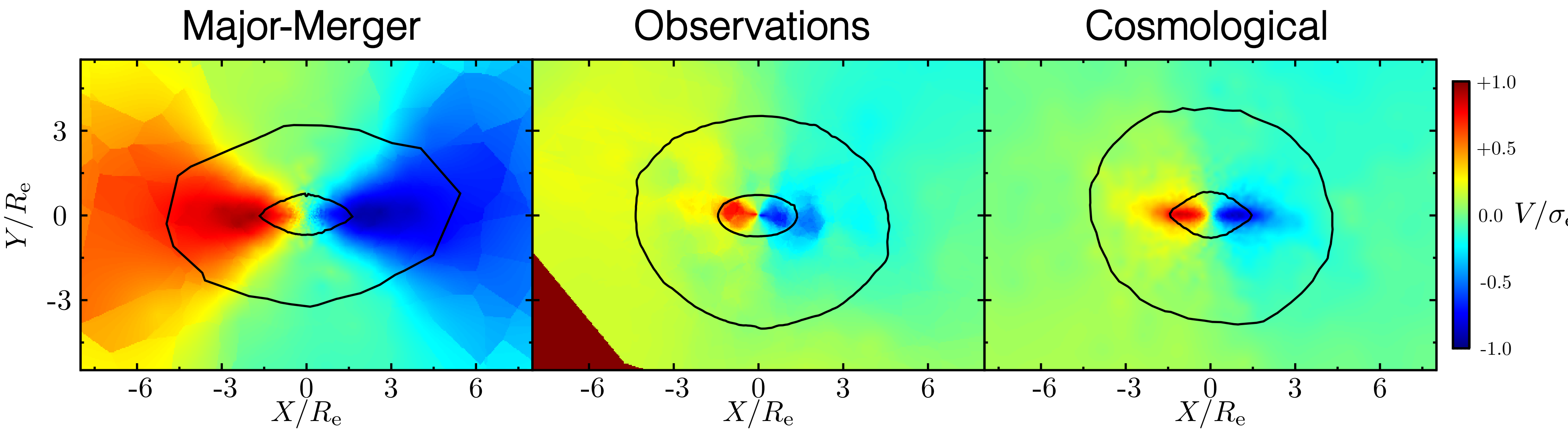
(Harris 2009, Alves-Brito+2009, Strader+2011, Coccato+2010, Arnold+2011)

Flat GC metallicity gradient beyond ~7 R_e



NGC 1407: Forbes et al. 2011

Summary



Two-Zone Kinematics:

Our sample of 8 edge-on galaxies all exhibit slowly rotating halos (> 2 – 5 R_e)

Two-phase assembly produces this kinematic structure via the accretion and subsequent disruption of infalling satellites.

Our comparisons with simulated galaxies highlight the importance of including a cosmological accretion history in simulating realistic ETGs