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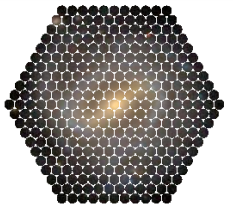
CALIFA Survey

The spins of galaxies in CALIFA

CALIFA team

C. Jakob Walcher
Leibniz Institut für Astrophysik Potsdam (AIP)

CALIFA primer



A survey to provide a benchmark of the local galaxy population

- IFS: 900 independent spectra per galaxy, good S/N
- Full optical wavelength coverage, from [OII] to [SII]
- 600 galaxies of **all** Hubble types out to 3 effective radii
- Diameter selected sample ➜ distribution functions

Data Release 3: Apr 2016
>600 objects (all)

Sanchez, et al. (2016)

http://califa.caha.es/

CALIFA as a project

http://califa.caha.es/

A&A 538, A8 (2012)
DOI: 10.1051/0004-6361/201117353

Astronomy & Astrophysics CALIFA Survey

3.5m telescope at CAHA (MPIA/CSIC)
Observing time: ~2 Million Euro

CALIFA, the Calar Alto Legacy Integral Field Area survey

I. Survey presentation*

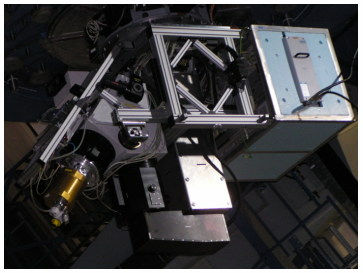
S. F. Sánchez[1], R. C. Kennicutt[2], A. Gil de Paz[3], G. van de Ven[4], J. M. Vílchez[5], L. Wisotzki[6], C. J. Walcher[6], D. Mast[5,1], J. A. L. Aguerri[9,28], S. Albiol-Pérez[20], A. Alonso-Herrero[12], J. Alves[22], J. Bakos[9,28], T. Bartáková[34], J. Bland-Hawthorn[7], A. Boselli[19], D. J. Bomans[25], A. Castillo-Morales[3], C. Cortijo-Ferrero[5], A. de Lorenzo-Cáceres[9,28], A. del Olmo[5], R.-J. Dettmar[25], A. Díaz[10], S. Ellis[8,7], J. Falcón-Barroso[9,28], H. Flores[31], A. Gallazzi[14], B. García-Lorenzo[9,28], R. González Delgado[5], N. Gruel[24], T. Haines[26], C. Hao[32], B. Husemann[6], J. Iglésias-Páramo[5,1], K. Jahnke[4], B. Johnson[30], B. Jungwiert[16,33], V. Kalinova[4], C. Kehrig[6], D. Kupko[6], Á. R. López-Sánchez[8,23], M. Lyubenova[4], R. A. Marino[1,3], E. Mármol-Queraltó[1,3], I. Márquez[5], J. Masegosa[5], S. Meidt[4], J. Mendez-Abreu[9,28], A. Monreal-Ibero[5], C. Montijo[5], A. M. Mourão[17], G. Palacios-Navarro[21], P. Papaderos[15], A. Pasquali[29], R. Peletier[11], E. Pérez[5], I. Pérez[27], A. Quirrenbach[13], M. Relaño[27], F. F. Rosales-Ortega[10,1], M. M. Roth[6], T. Ruiz-Lara[27], P. Sánchez-Blázquez[10], C. Sengupta[1,5], R. Singh[4], V. Stanishev[17], S. C. Trager[11], A. Vazdekis[9,28], K. Viironen[1,24], V. Wild[18], S. Zibetti[14], and B. Ziegler[22]

(Affiliations can be found after the references)

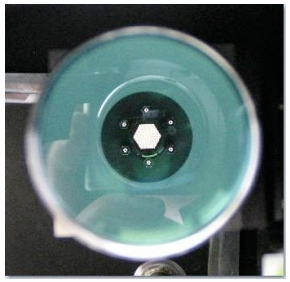
Received 27 May 2011 / Accepted 3 November 2011

48 refereed papers, ongoing

Observed: 237 clear equivalent dark/grey nights



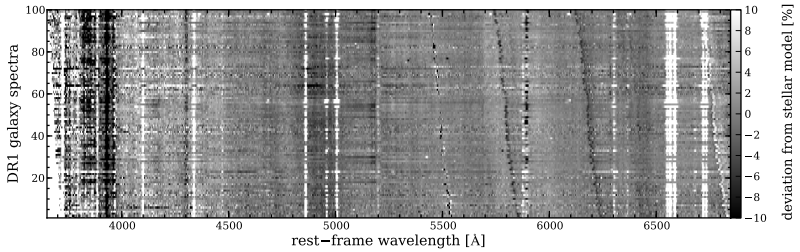
PMAS (Roth, Kelz, Verheijen)



PPaK

80 scientists from 20 institutions in 7 countries (mostly Spain, Germany)

PI: S. Sanchez (UNAM)
PS: C.J. Walcher (AIP)



Automatic data reduction pipeline (Husemann, Sanchez)

CALIFA sample is NOT biased!

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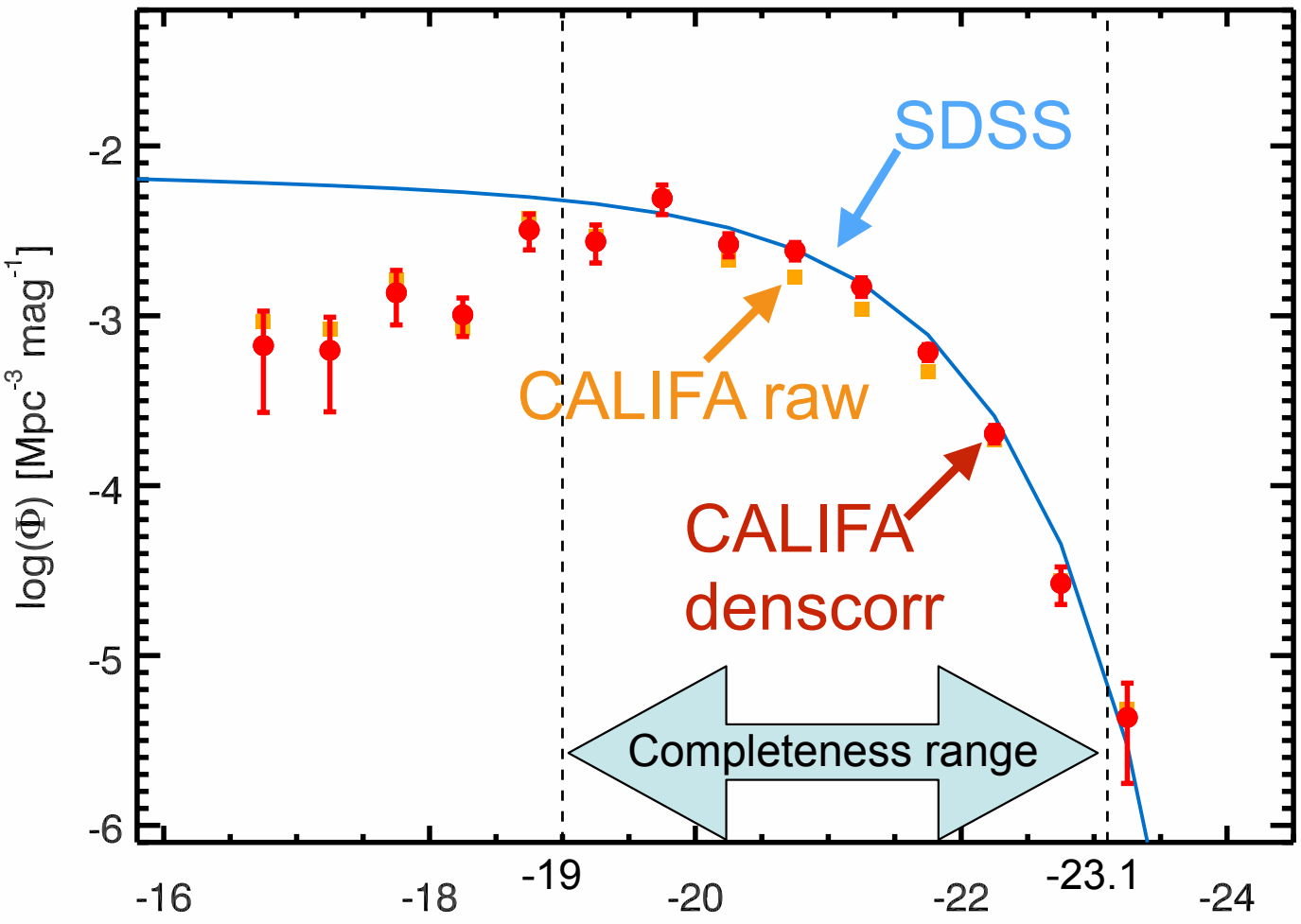
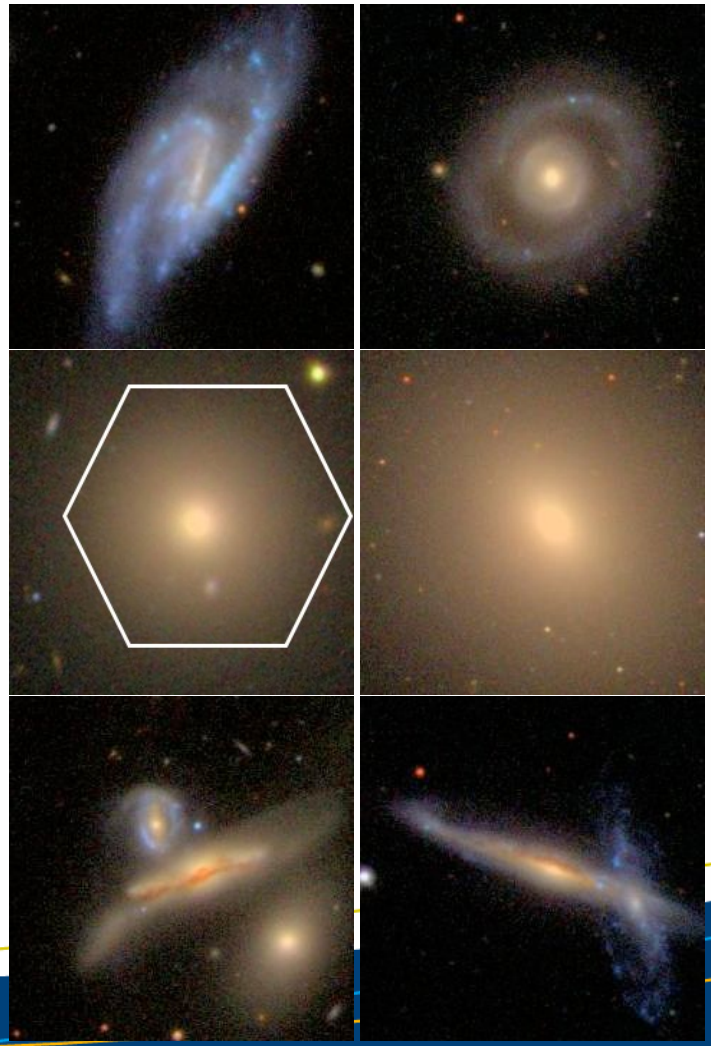
CALIFA Survey

Luminosity function

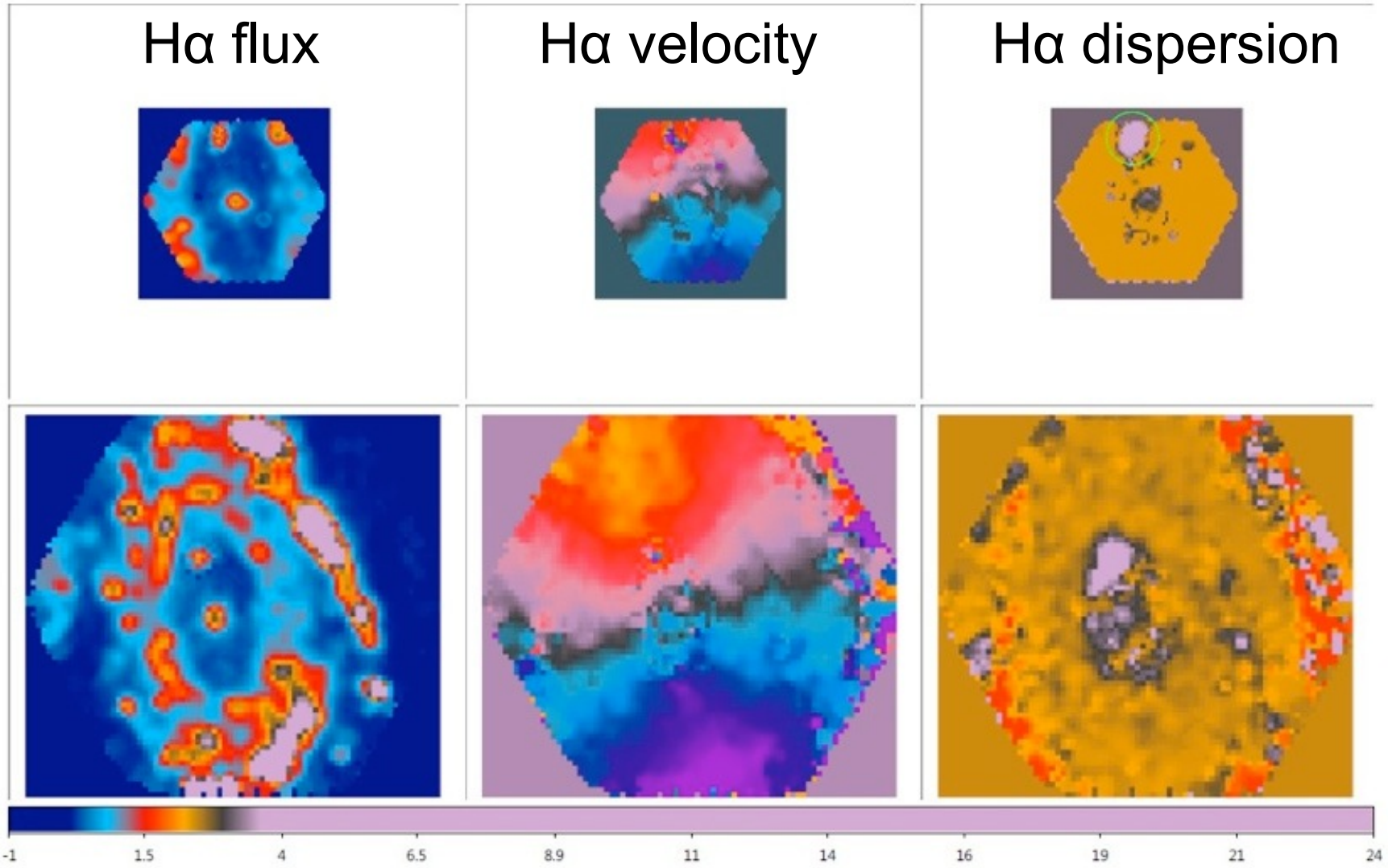


Walcher, et al., 2014

Diameter selected
(Trager, Wisotzki)



CALIFA uniqueness: total signal per galaxy



Coverage + spatial resolution + S/N!

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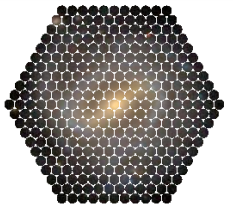


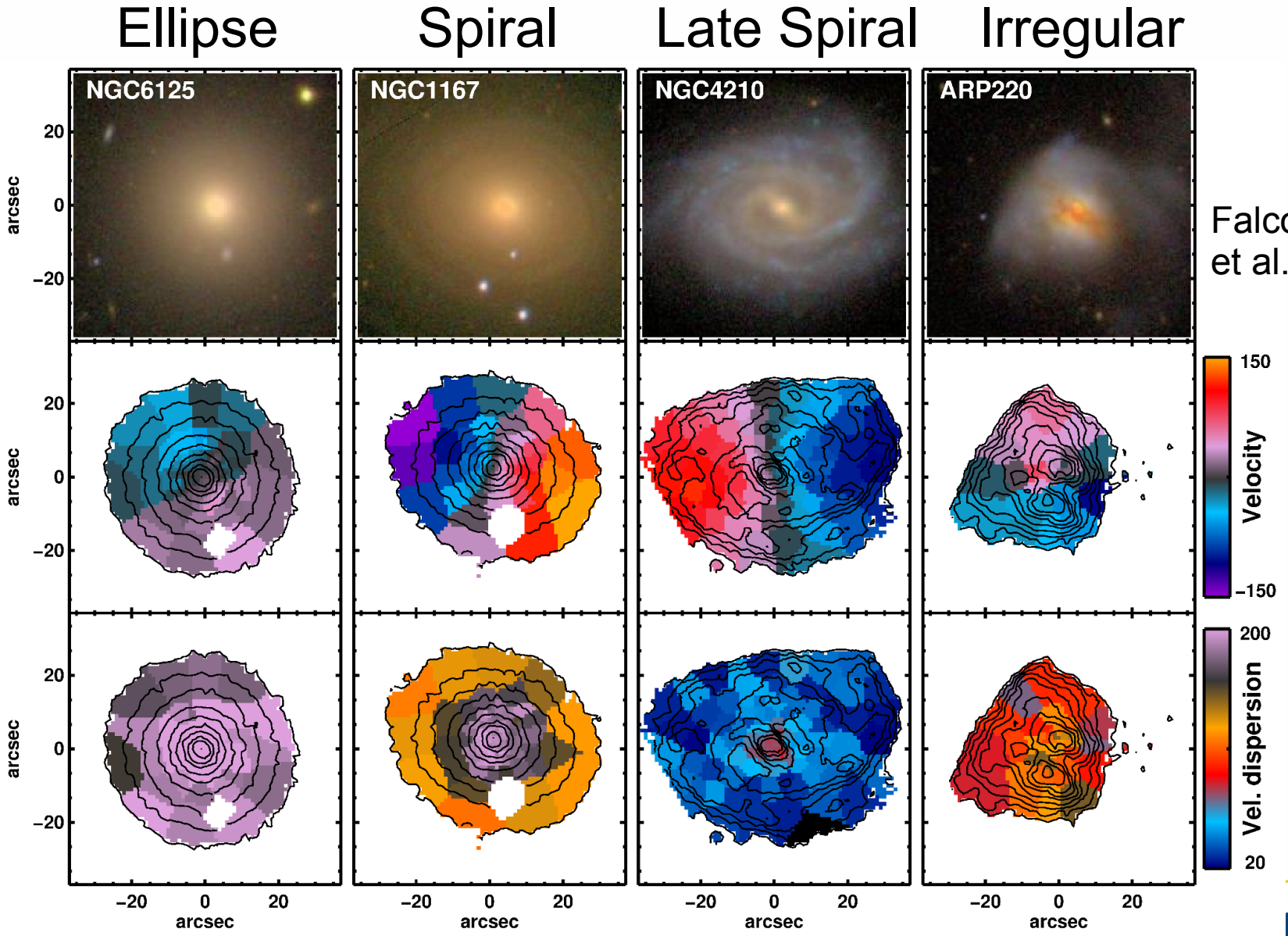
CALIFA Survey

Kinematic classification

Kinematics and morphology

AYKALI

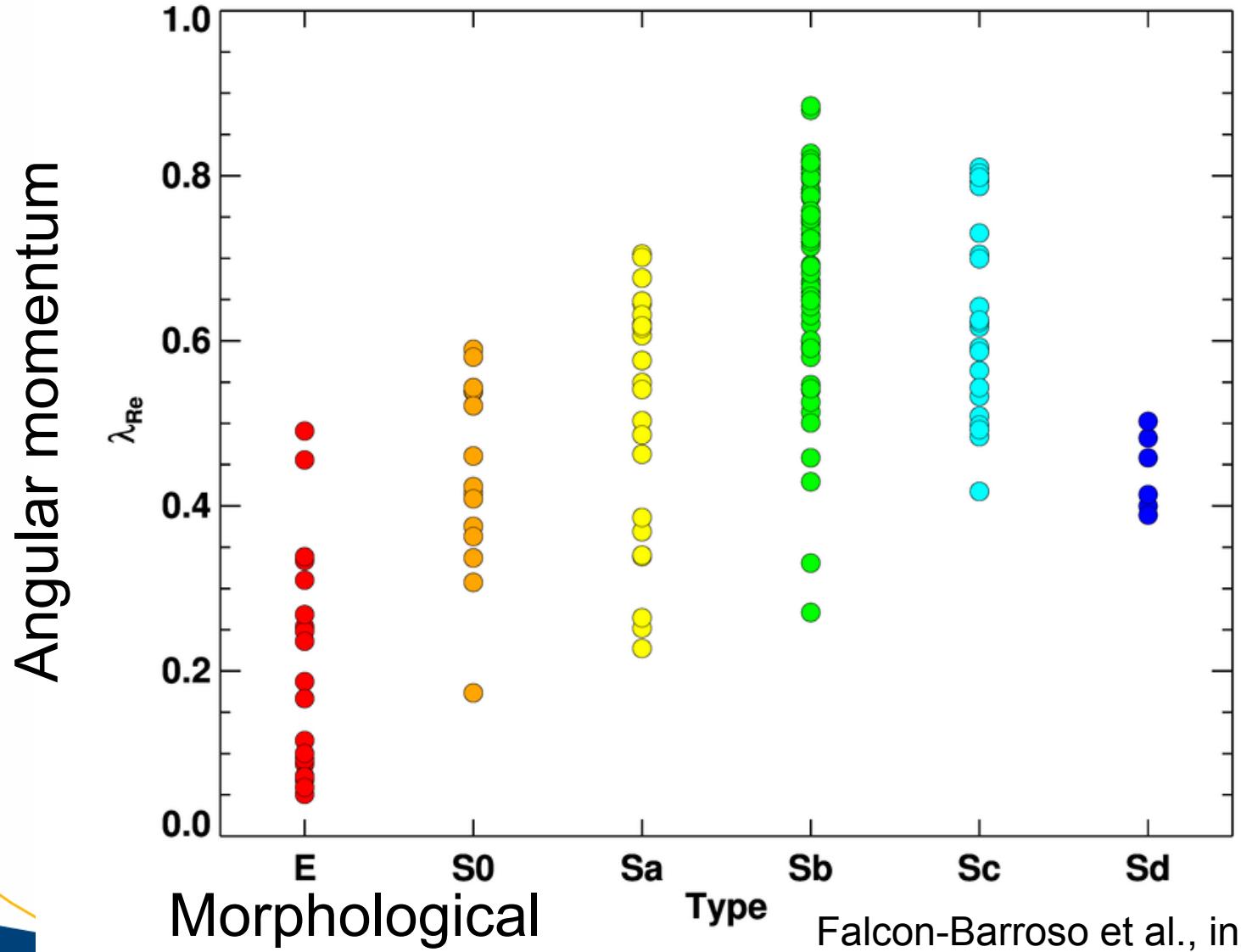
CALIFA Survey



Falcon-Barroso et al., subm.

Kinematics and morphology

CALIFA Survey



Falcon-Barroso et al., in prep.

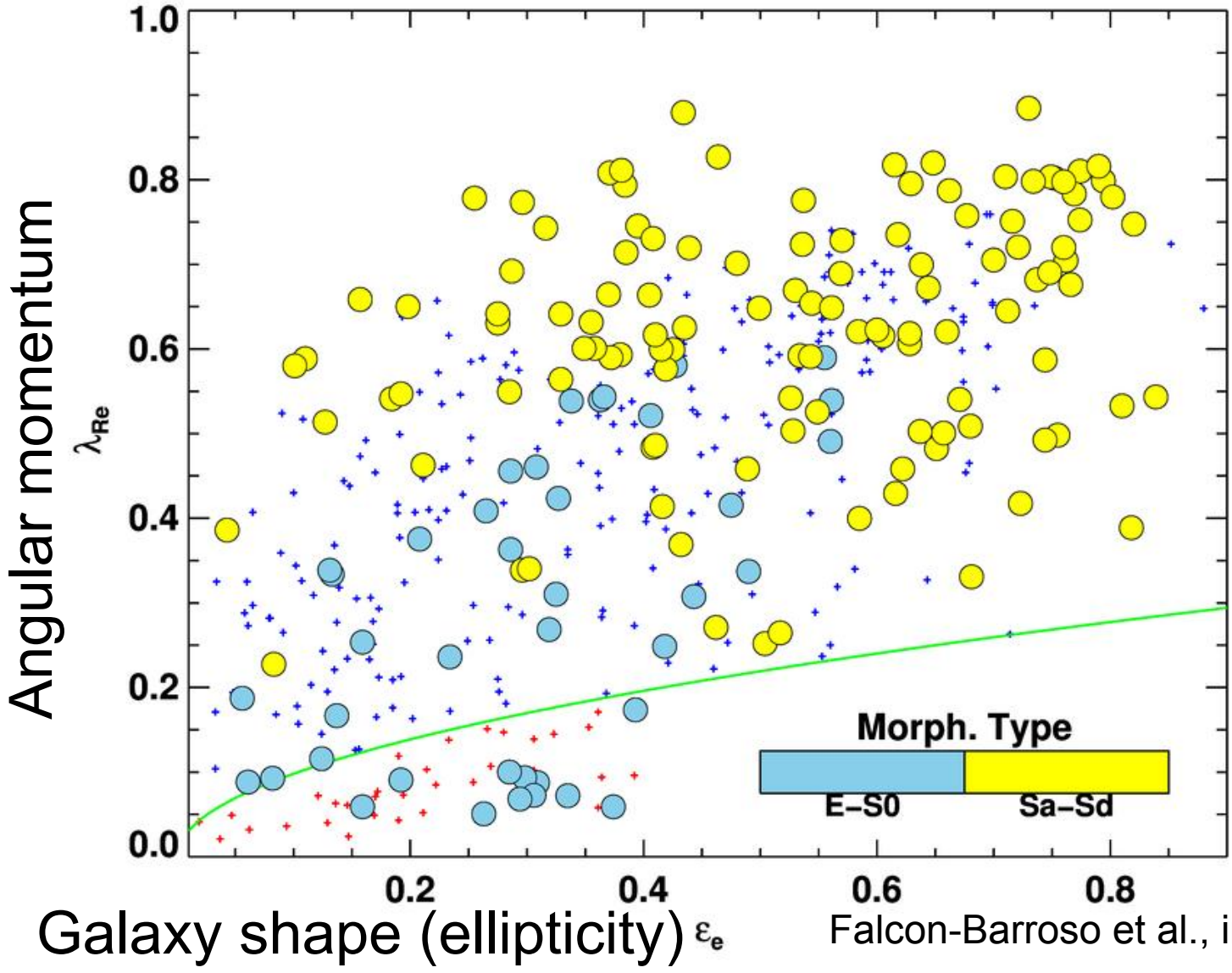
Morphology and angular momentum: no one to one relation!

➜ Cortese et al. 2016

$$\lambda_R = \frac{\sum_{i=1}^{N_p} F_i R_i |V_i|}{\sum_{i=1}^{N_p} F_i R_i \sqrt{V_i^2 + \sigma_i^2}},$$

Kinematic classification

CALIFA Survey



Following up on Emsellem et al., SAURON & ATLAS3D

➜ Fogarty et al. 2016

Falcon-Barroso et al., in prep.

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Tully-Fisher relation

Stellar velocity fields ➜ v_{circ}

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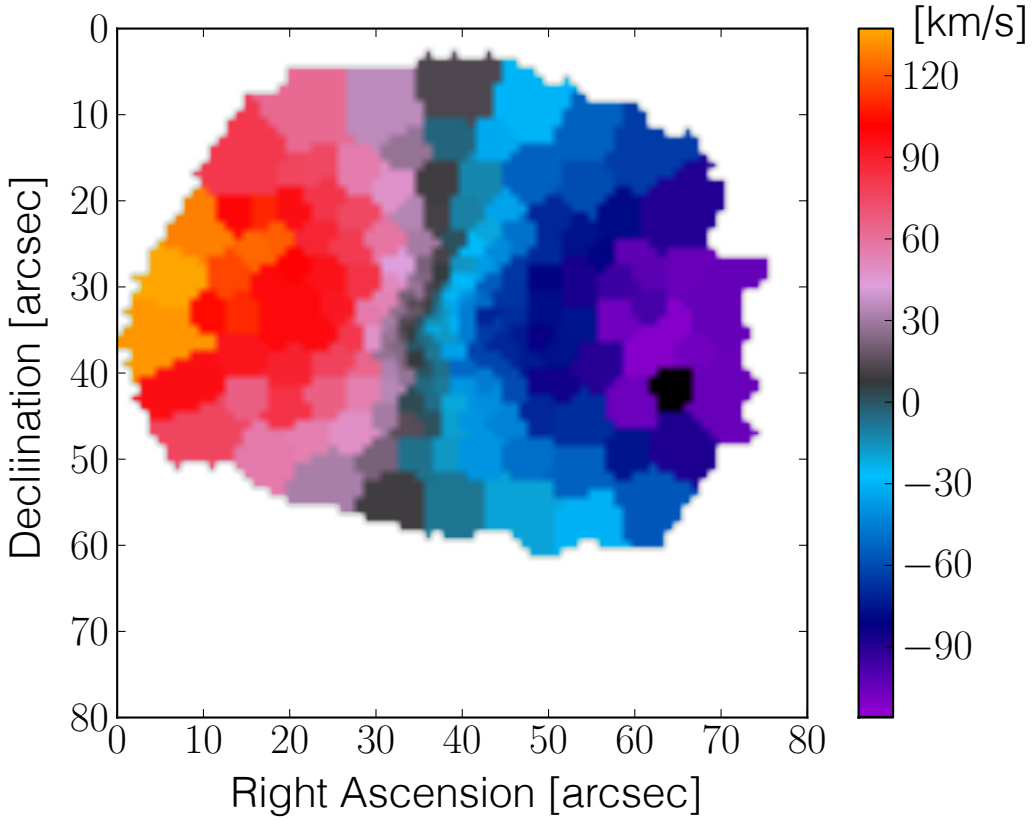
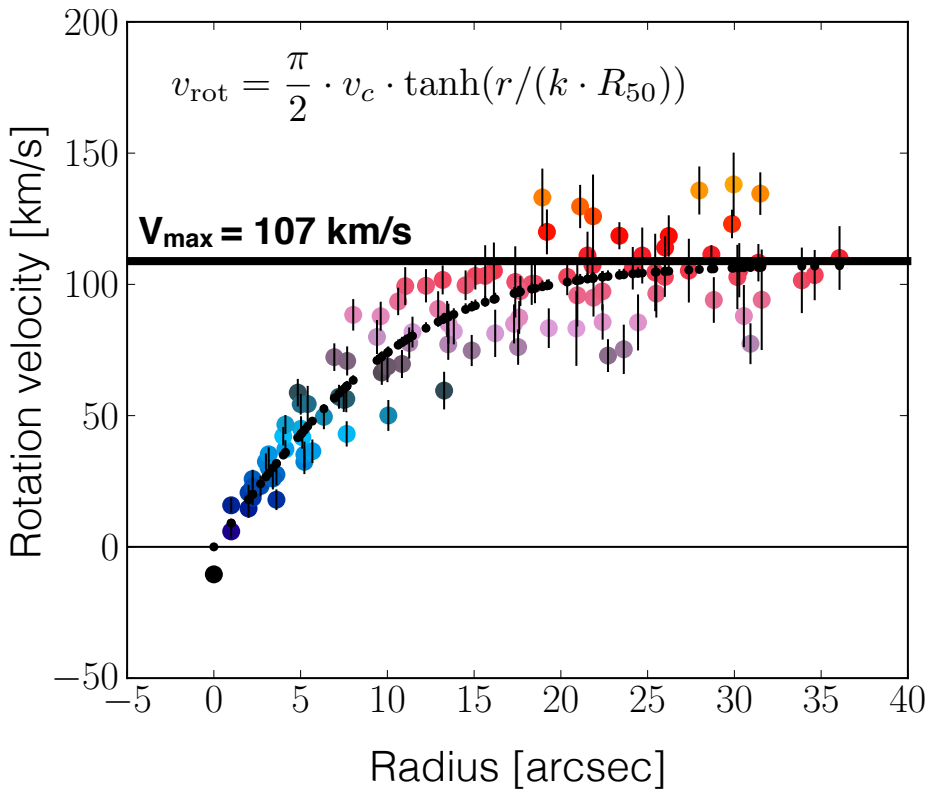




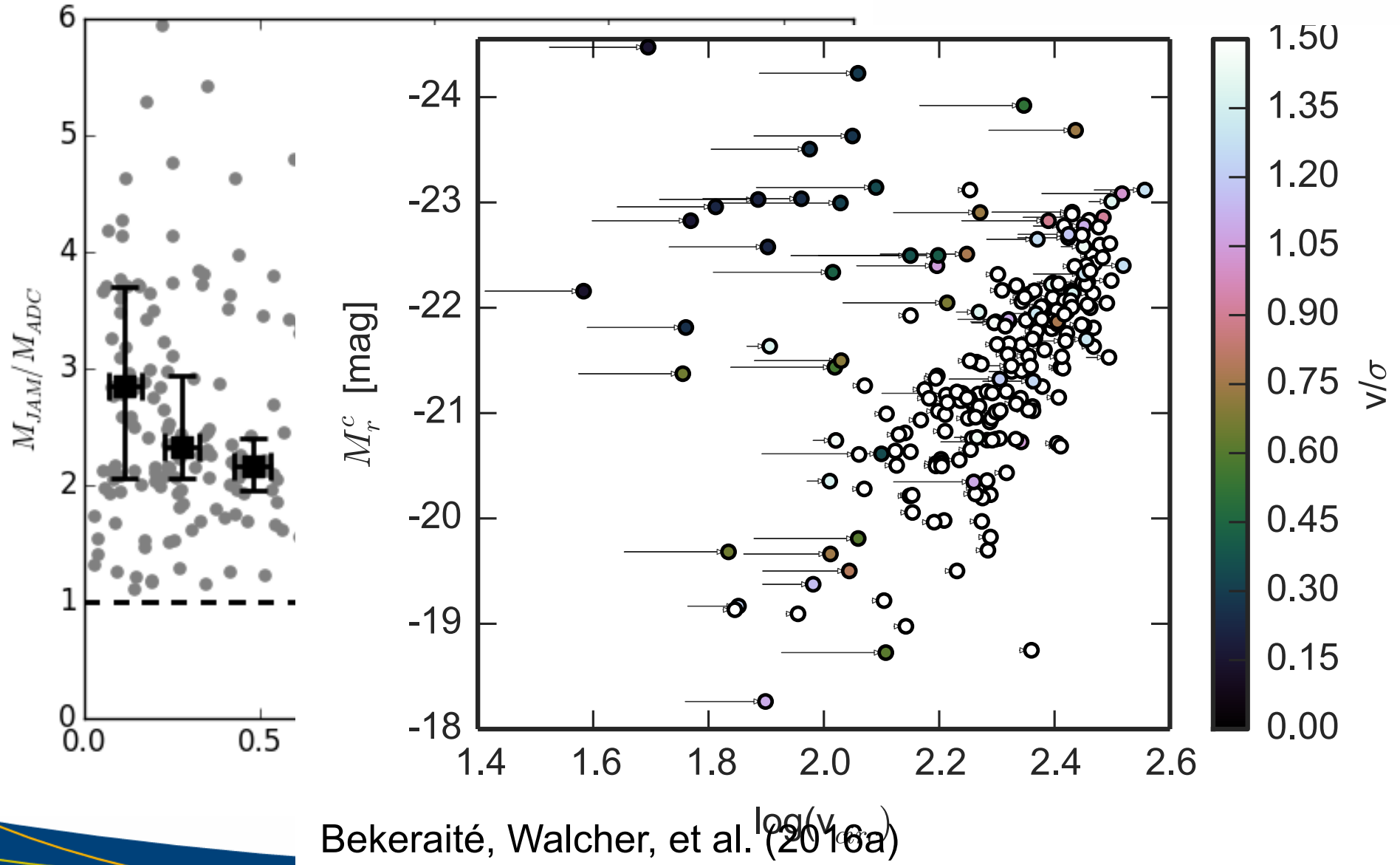
Bekeraité, Walcher, et al. (2016)

For early type galaxies correction for dispersion support is applied

We use velocity at radius with 80% of light - r_{opt} and v_{circ}

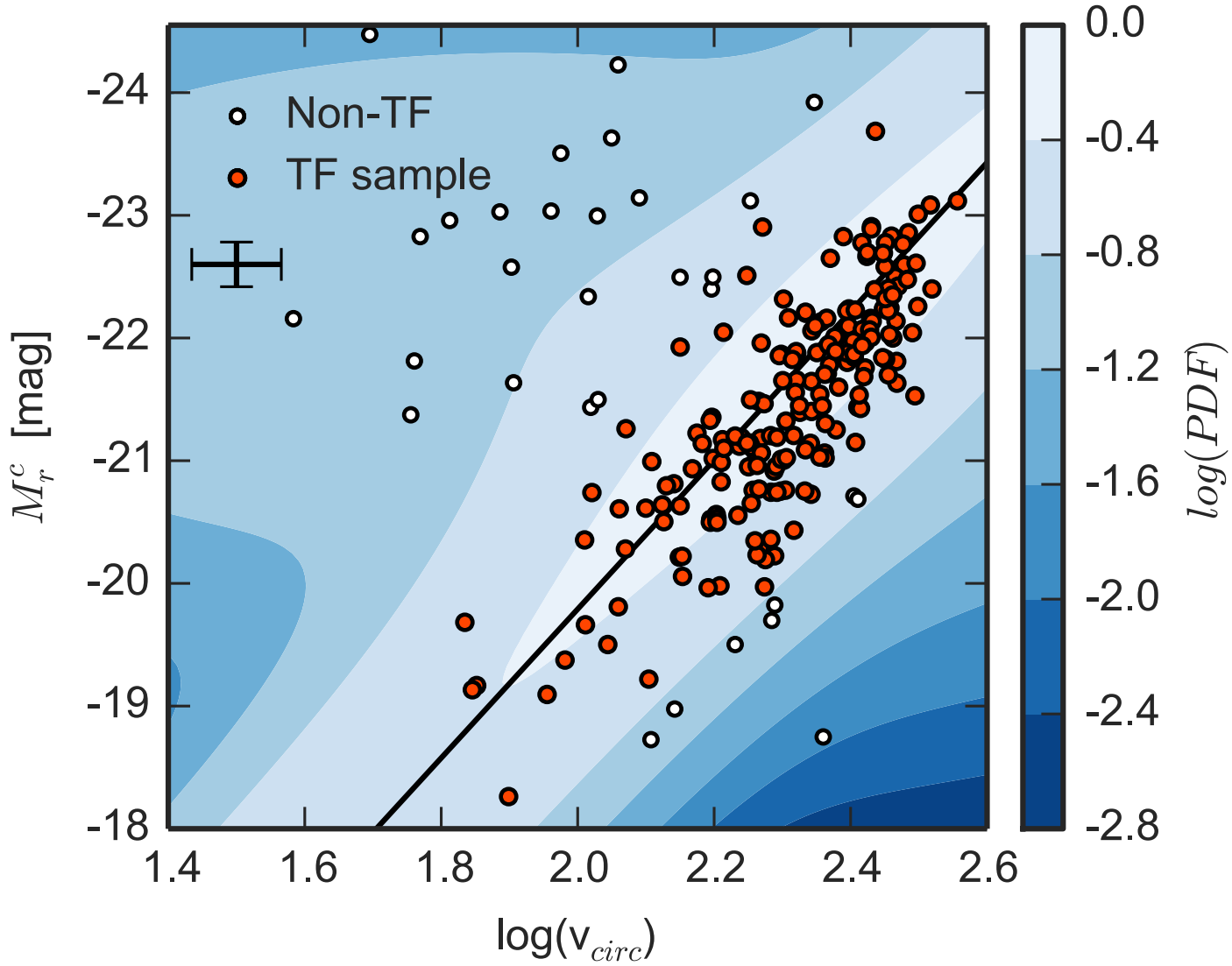
Bekeraité, Walcher, et al. (2016a)

Dispersion support correction



Bekeraité, Walcher, et al. (2016a)

Outlier rejection



TF sample:
Linear TFR

Non-TF:
2D Gaussian

Bekeraité, Walcher, et al. (2016a)

Bi-variate distribution function in Tully-Fisher space (M_r vs. V_{circ})

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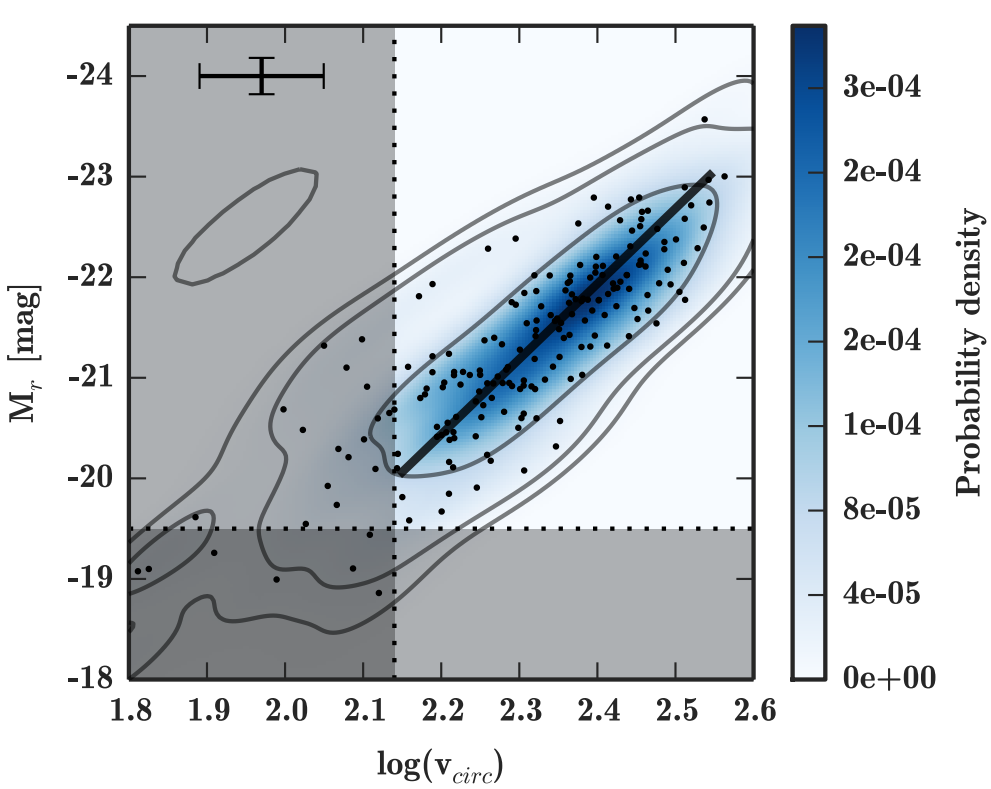
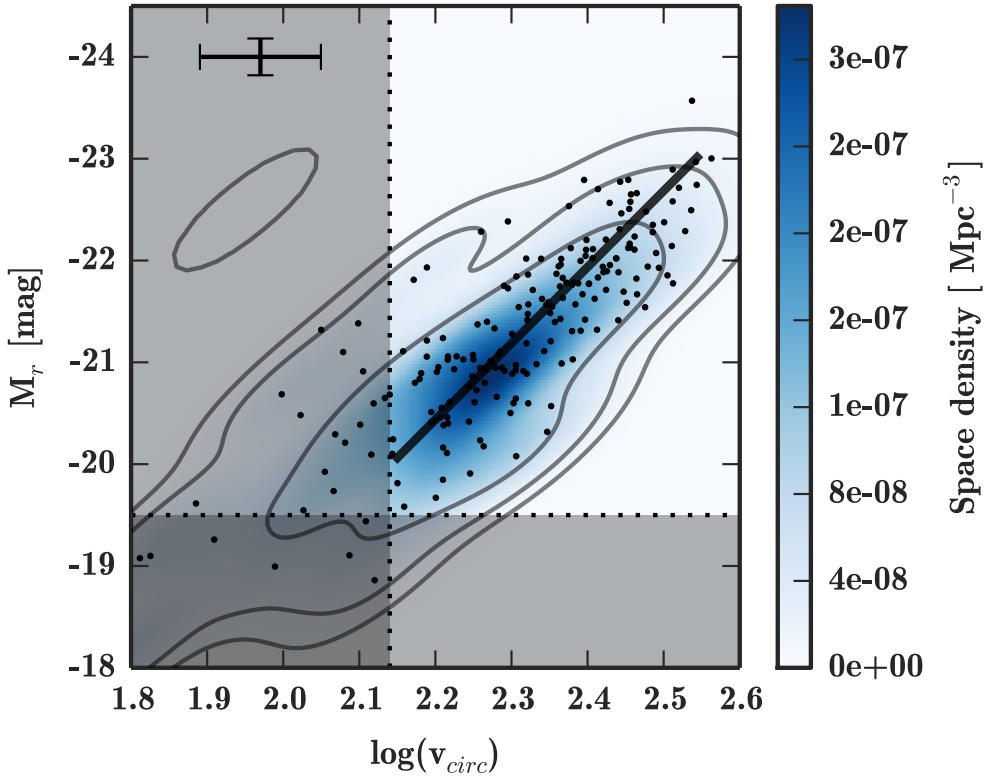
TF sample number densities

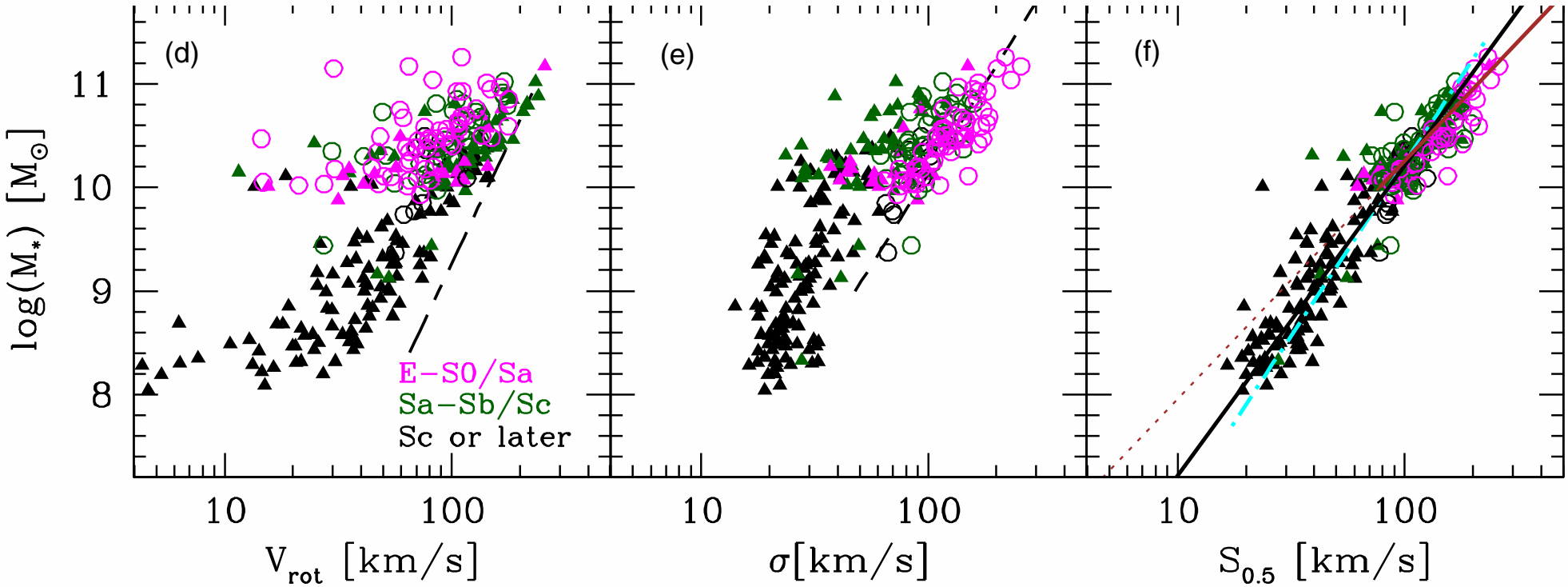


Space densities



Bekeraité, Walcher, et al. (2016a)

SAMI: it's all $S_{0.5}$



Cortese et al., 2015

$$S_K = \sqrt{K V_{\rm rot}^2 + \sigma^2}.$$

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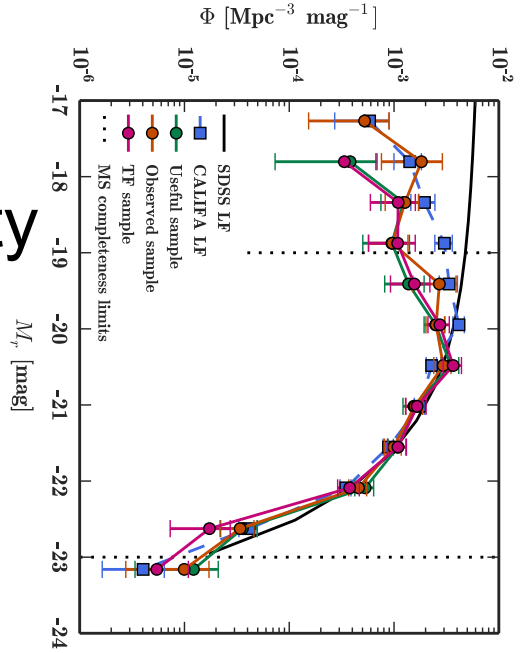
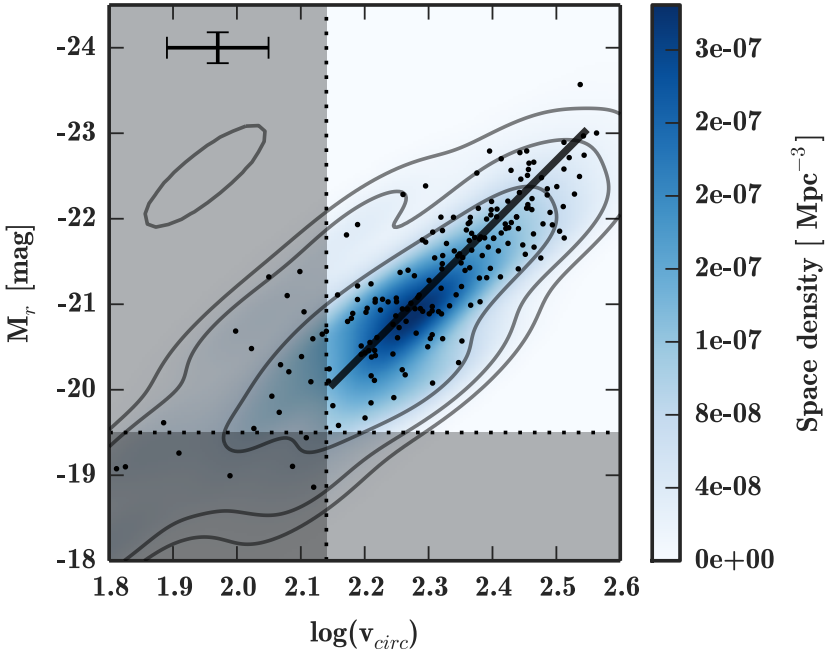
Velocity function

The marginal distributions of TF

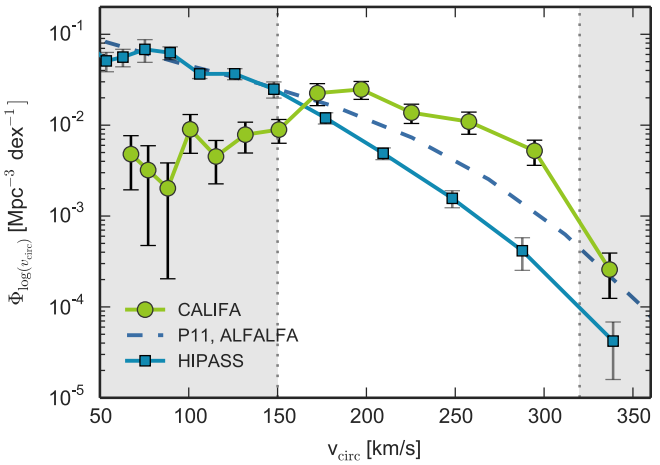
CALIFA Survey

Luminosity function

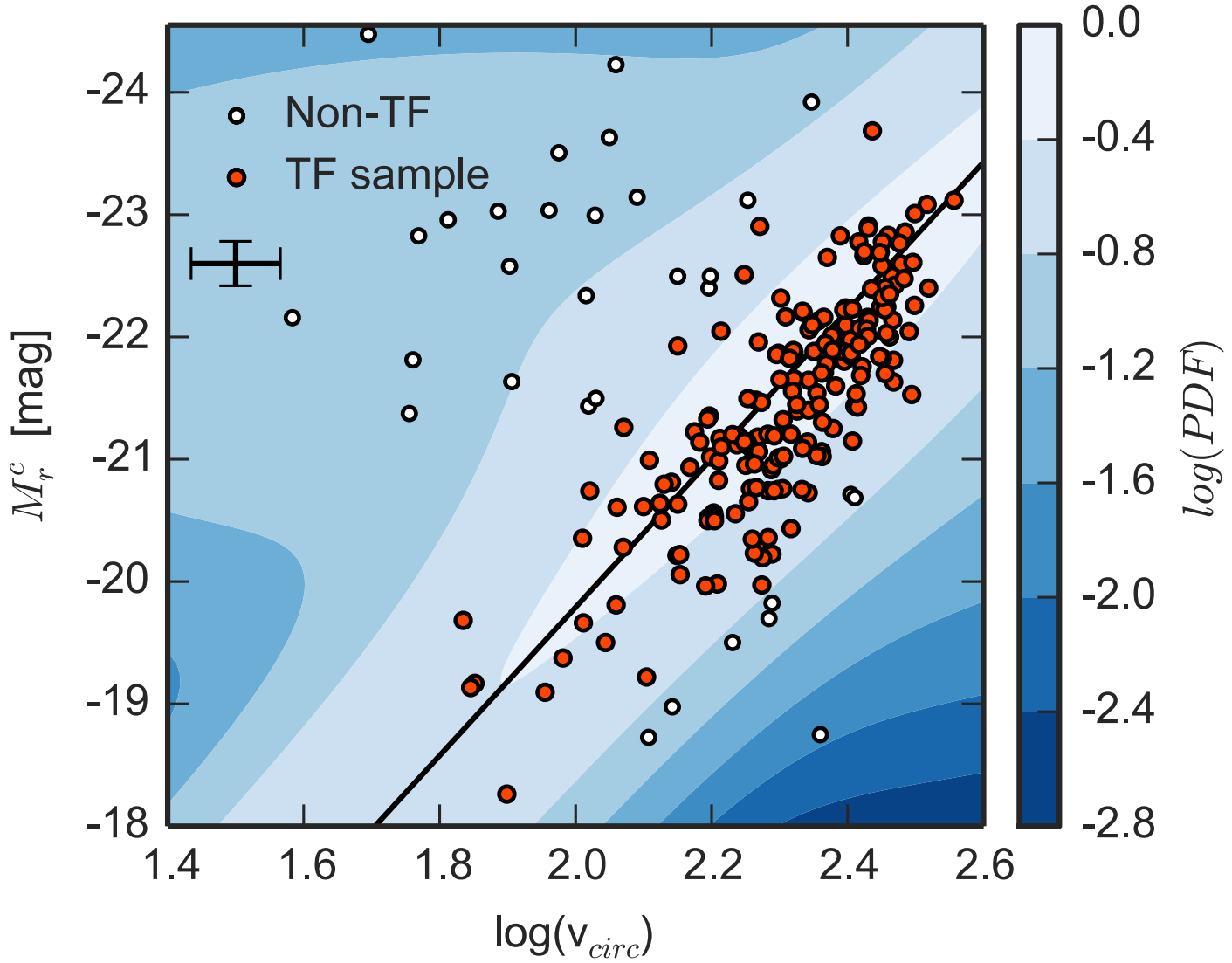




Velocity function



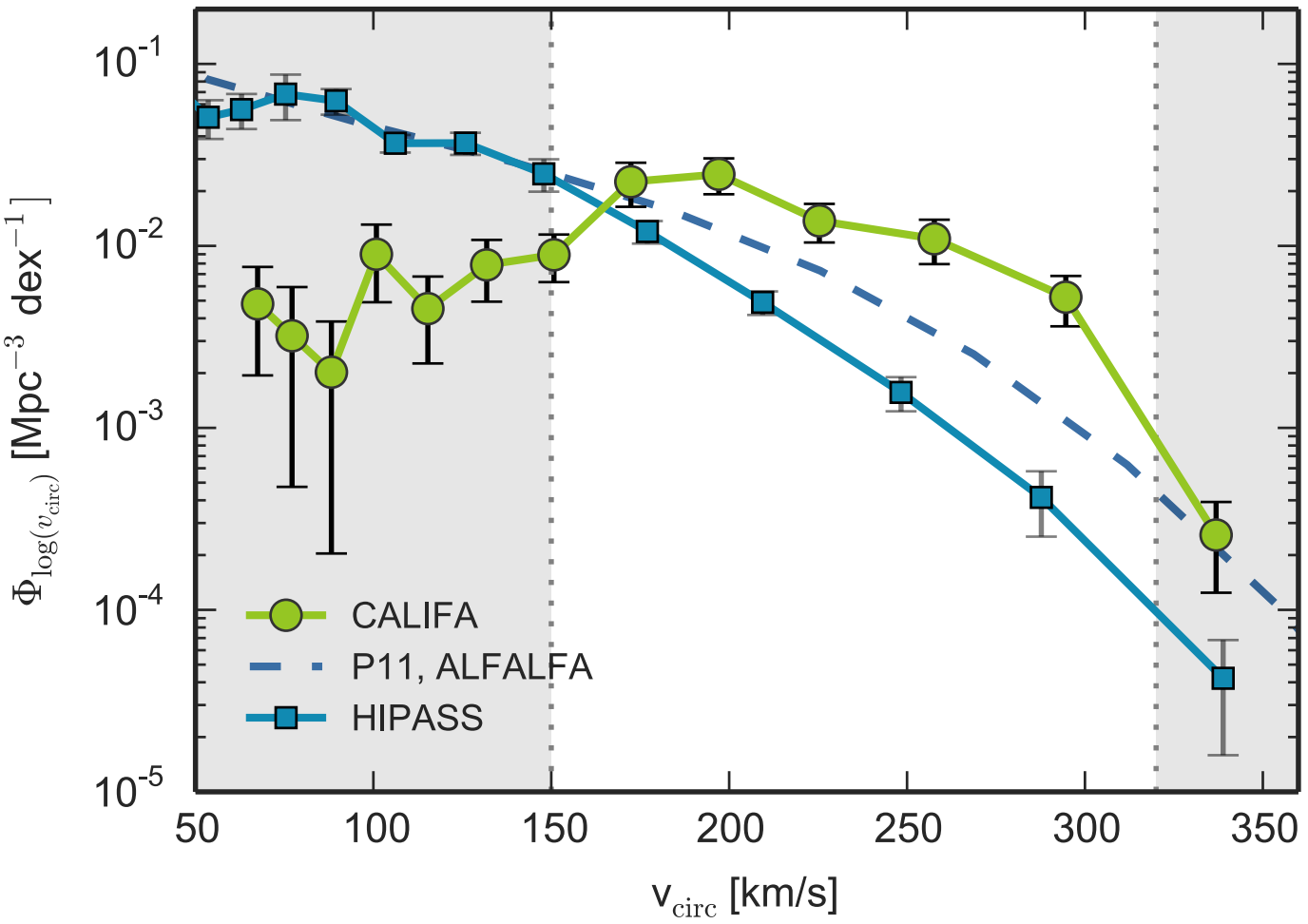
Outlier inclusion



For the velocity function we added the outliers back in!

Bekeraité, Walcher, et al. (2016a)

The CALIFA velocity function

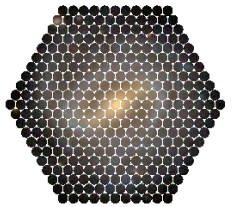


CALIFA is good for high mass, low gas galaxies, validity range in km/s:
$150 < v_{circ} < 320$

HIPASS (Zwaan et al., 2010) is good for low mass, gas rich galaxies
Combined:
$60 < v_{circ} < 320$

Bekeraité, Walcher, et al. (2016b)

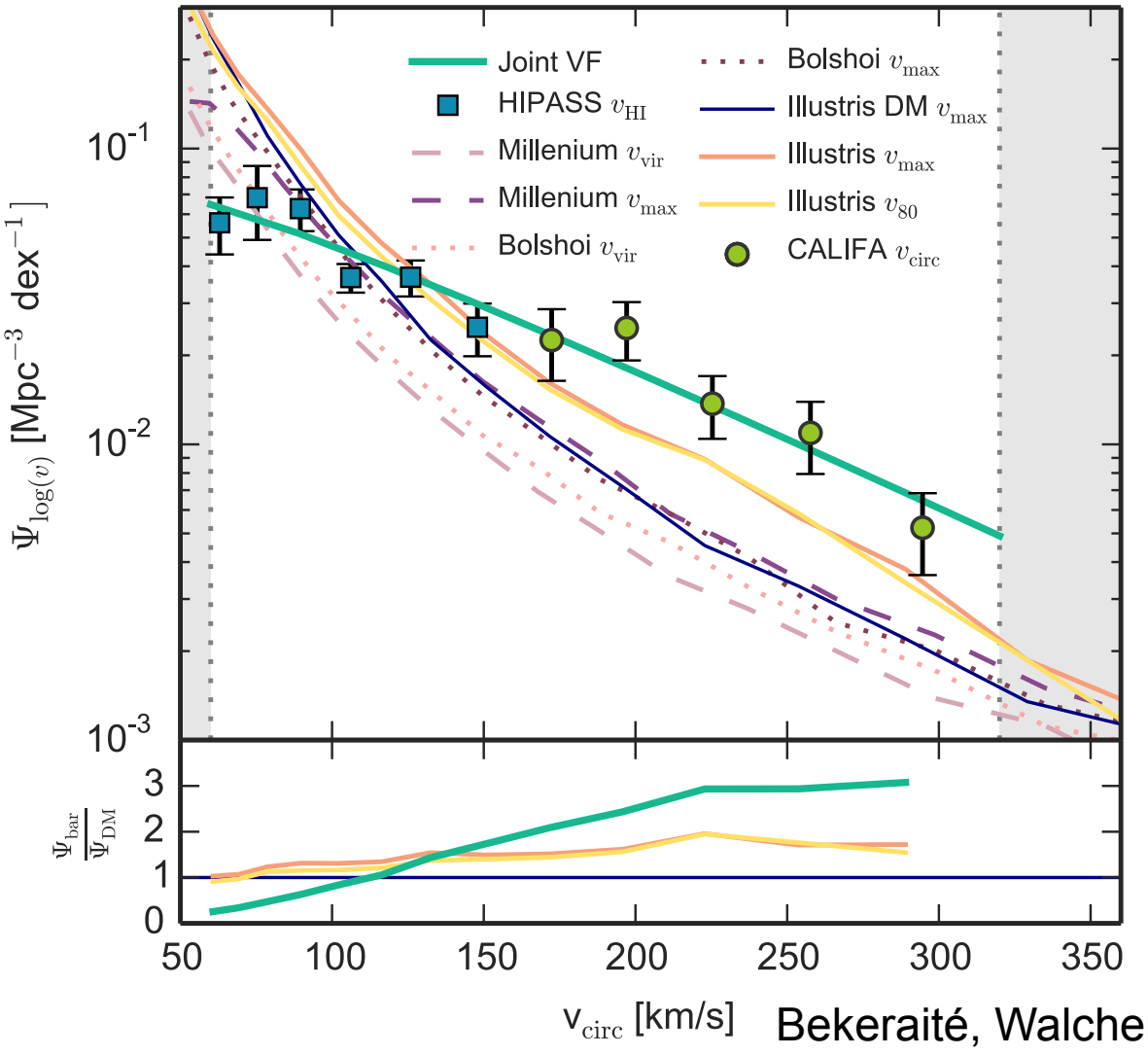
How do galaxies acquire their angular momentum?



- Torque theory: torques by other galaxies and large scale structure set initial angular momentum
  ➜ this would predict alignment with LSS.
- Mergers: growth of spin in galaxies is a random walk, triggered by minor and major mergers
  ➜ this conference.
- Additionally, V_{max} influenced by total mass, shape of potential and rotation vs. dispersion support.

Unlikely that an analytical model can capture all these constraints.
➜ Compare to simulations.

Velocity function: observations vs. simulations



Tension between observations and simulations robust to velocity definition

Influence of baryons on mass distribution important!

Bekeraité, Walcher, et al. (2016b)

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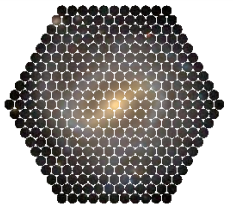


CALIFA Survey

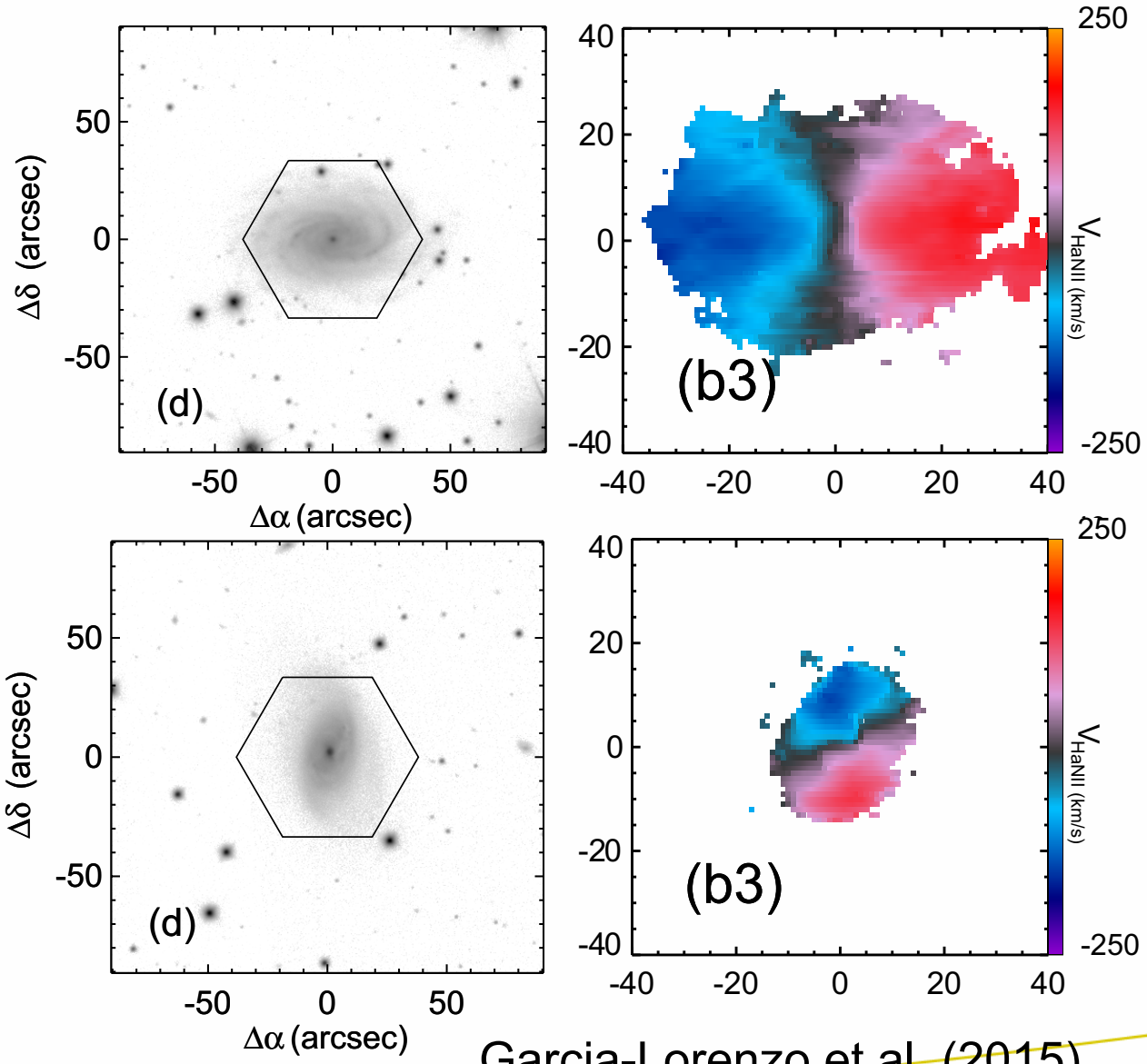
Kinematic disturbances and “multi-spin”

Kinematic disturbance

CALIFA Survey

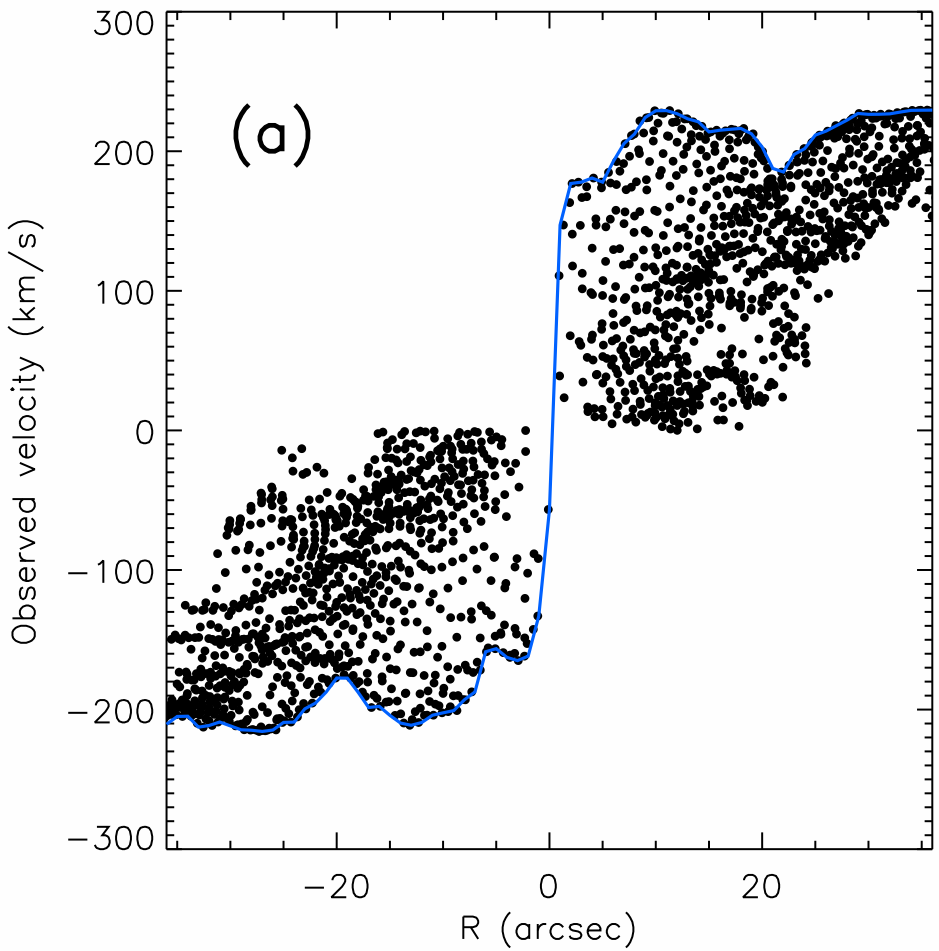
нет

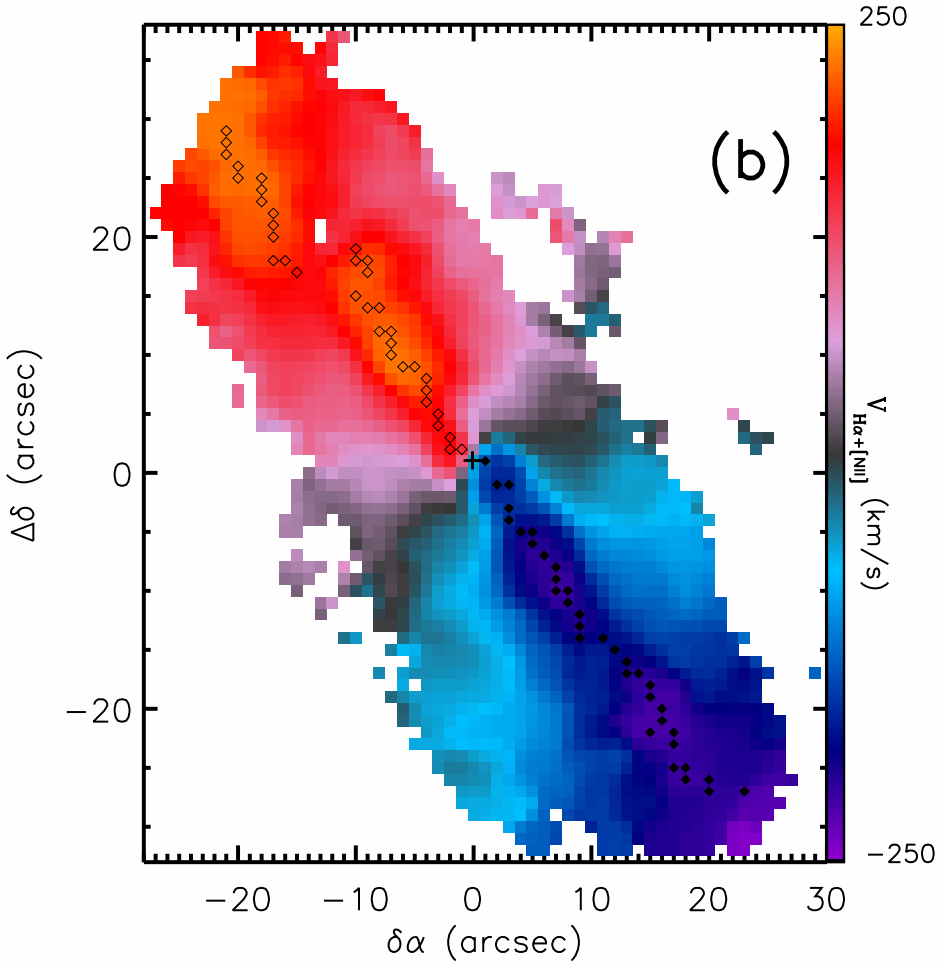
да



Garcia-Lorenzo et al. (2015)

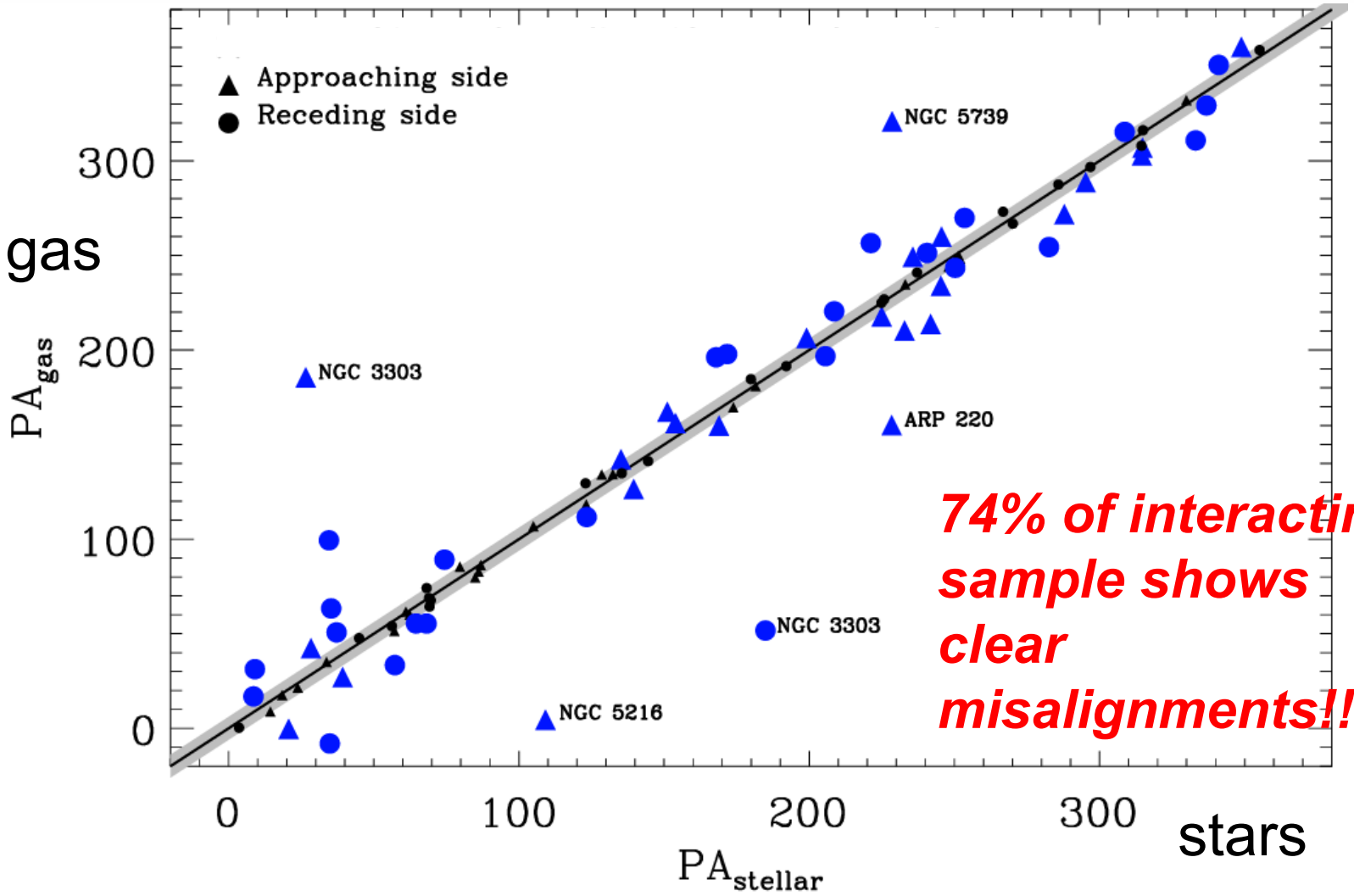
Measuring position angles





Garcia-Lorenzo et al. (2015)

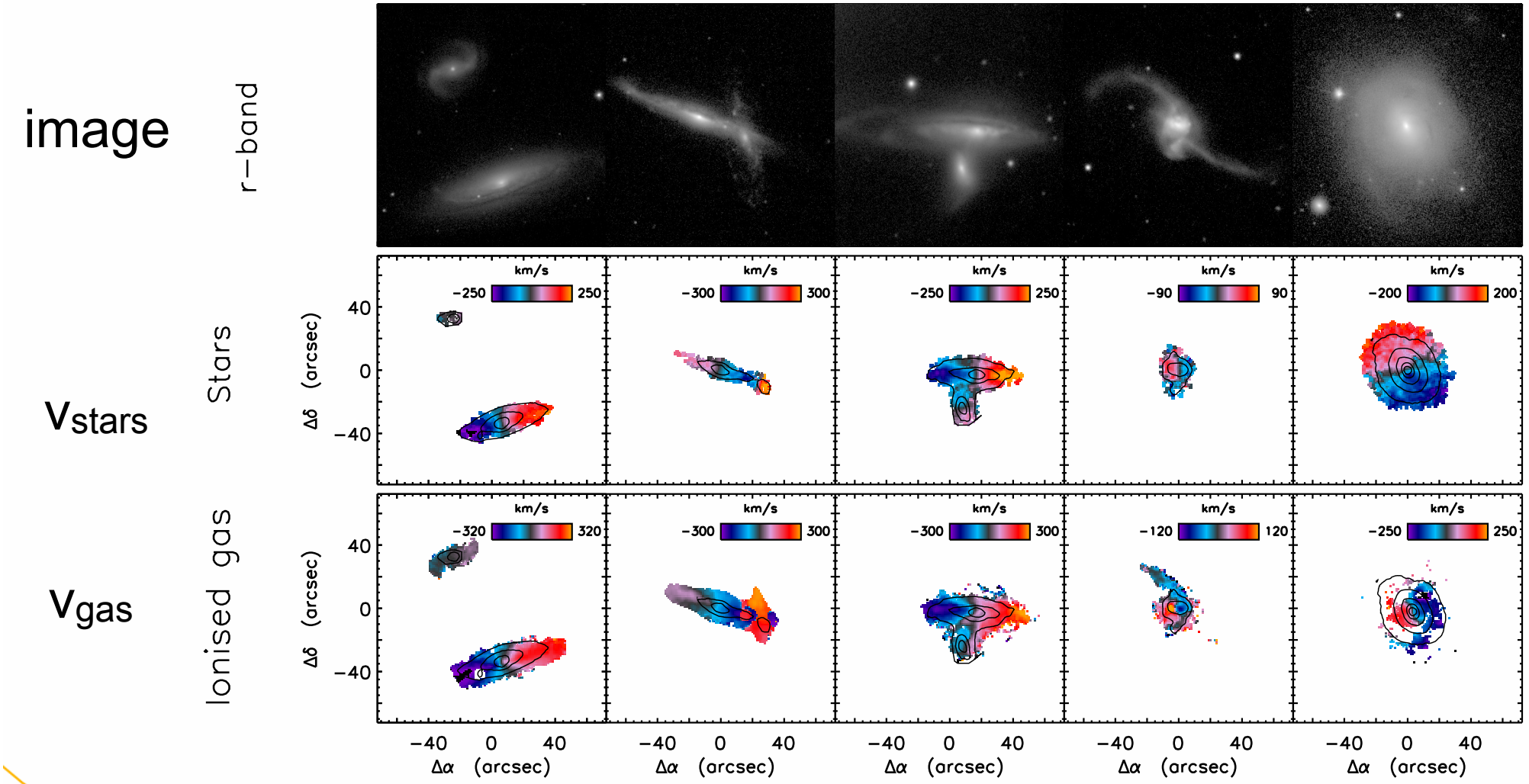
The systematics of kinematic disturbances



74% of interacting sample shows clear misalignments!!!

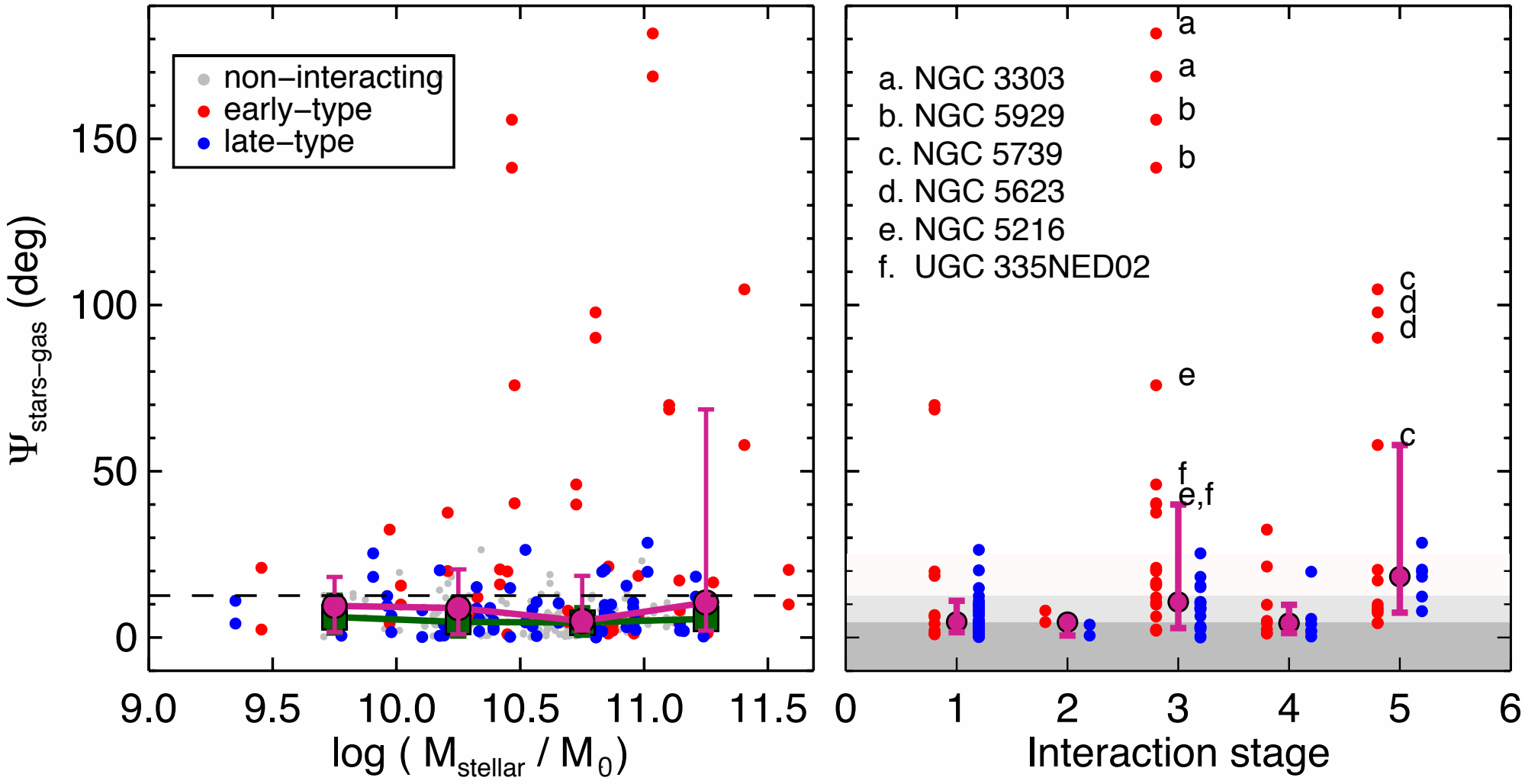
Barreras-Ballesteros et al. (2015)

Merger stages



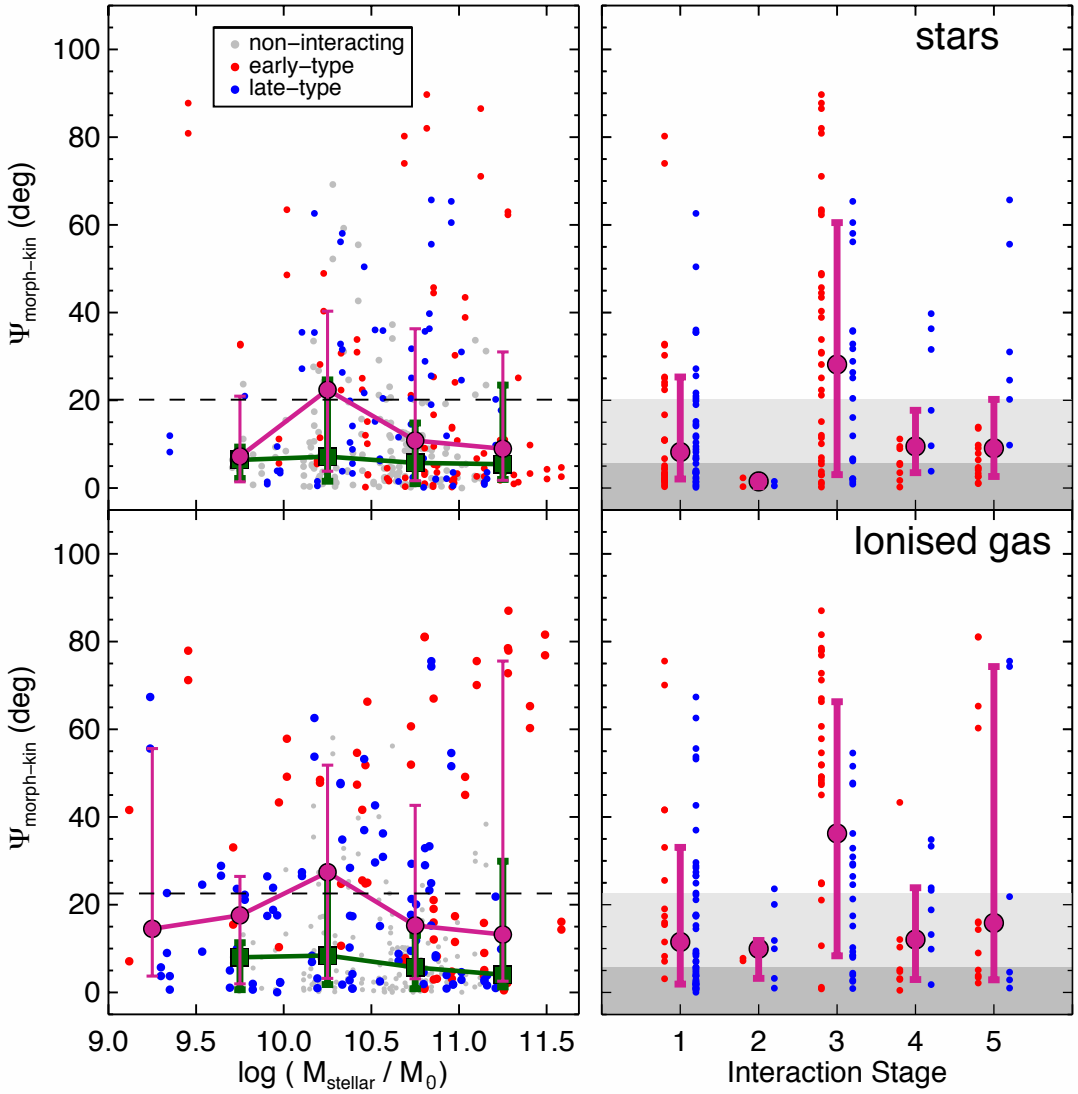
Barreras-Ballesteros et al. (2015)

Mis-alignment through merger stage



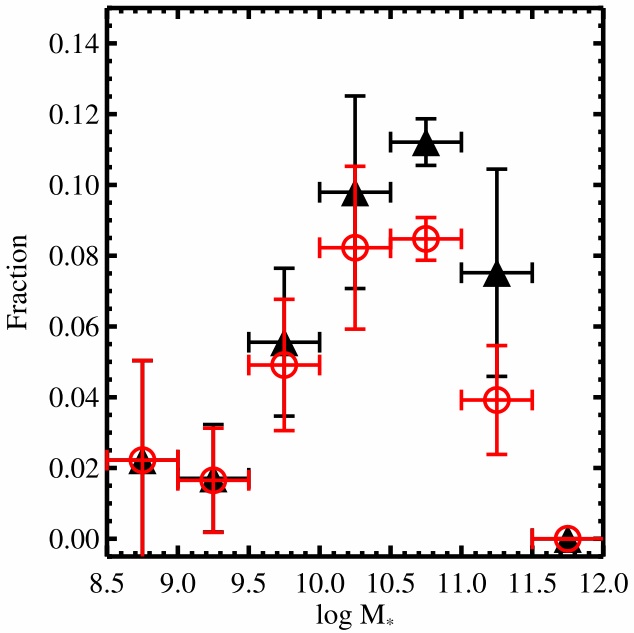
Barreras-Ballesteros et al. (2015)

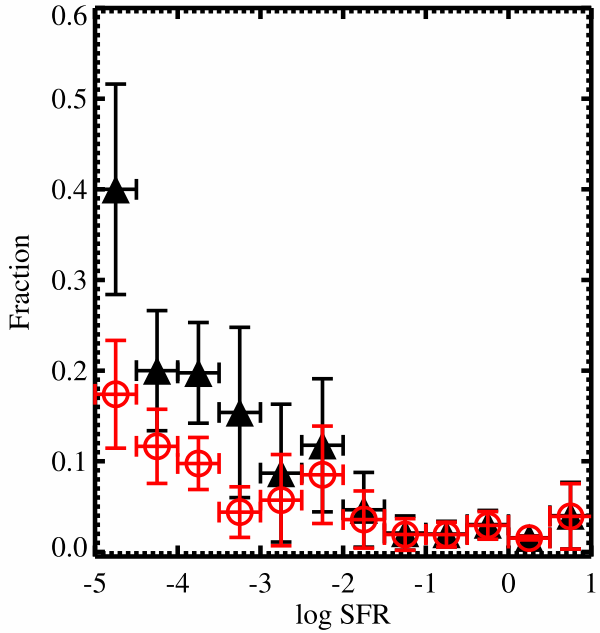
Misalignments morph vs. kin

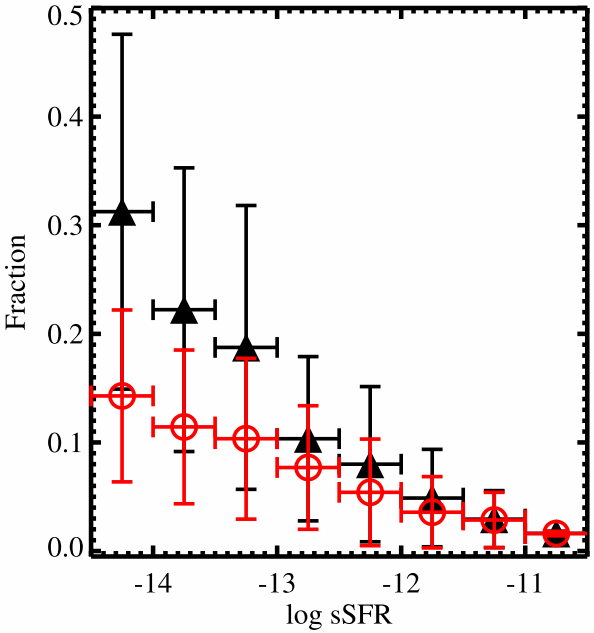


Barreras-Ballesteros et al. (2015)

Manga recent results







Jin et al. (2016)

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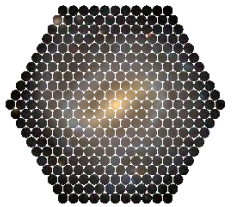

CALIFA Survey

Multi-spin???

Multi-spin???

- Multi-spin galaxies seem rare in CALIFA! (and 1/79 for SAMI, Fogarty+16)
- Still no one has systematically searched for them in the CALIFA sample.
- One could start from the maps in Falcon-Barroso et al. (subm.) and Garcia-Lorenzo et al. (2015).
- But much higher spatial resolution maps for the stars are possible if one accepts less quality for the velocity dispersion.

Multi-spin???

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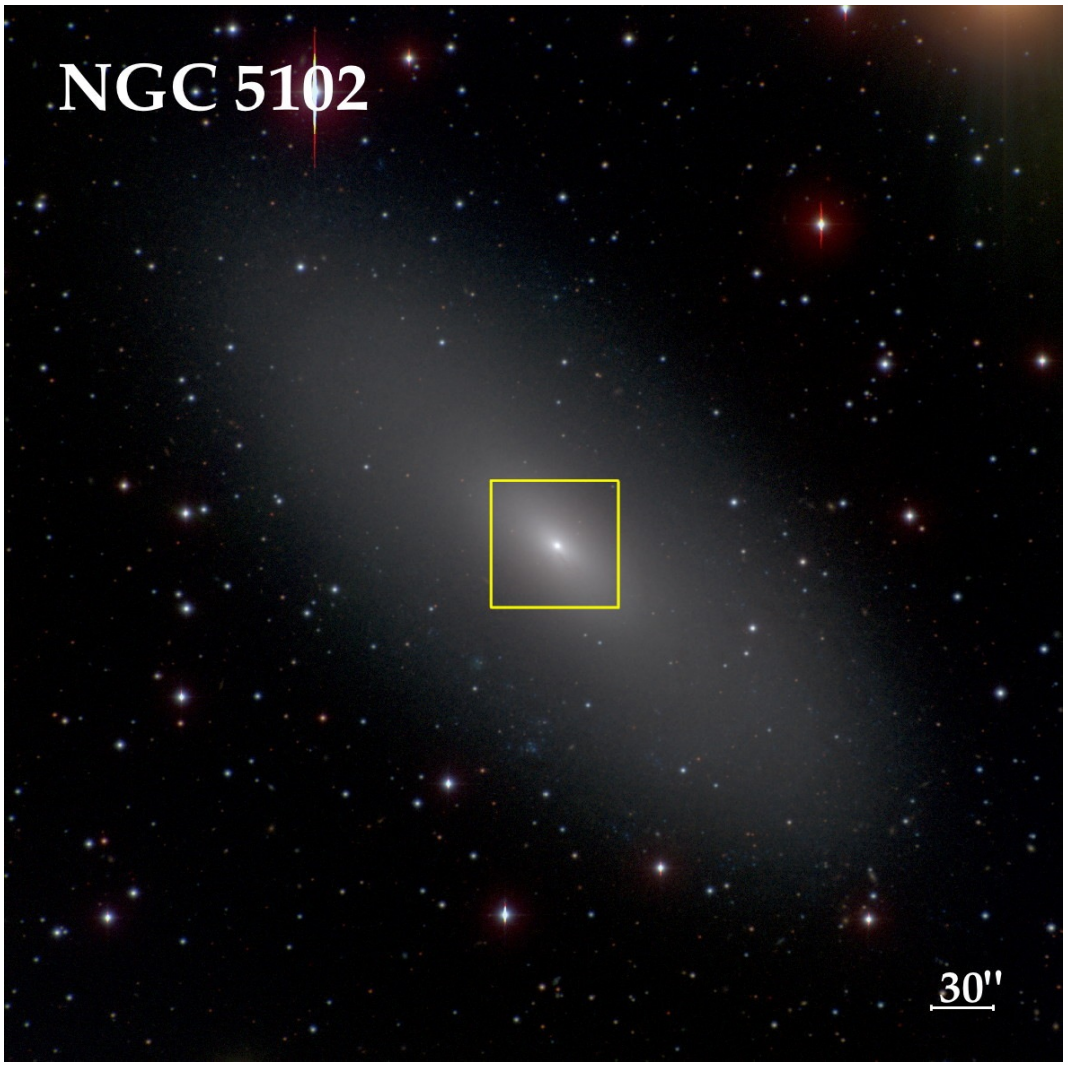
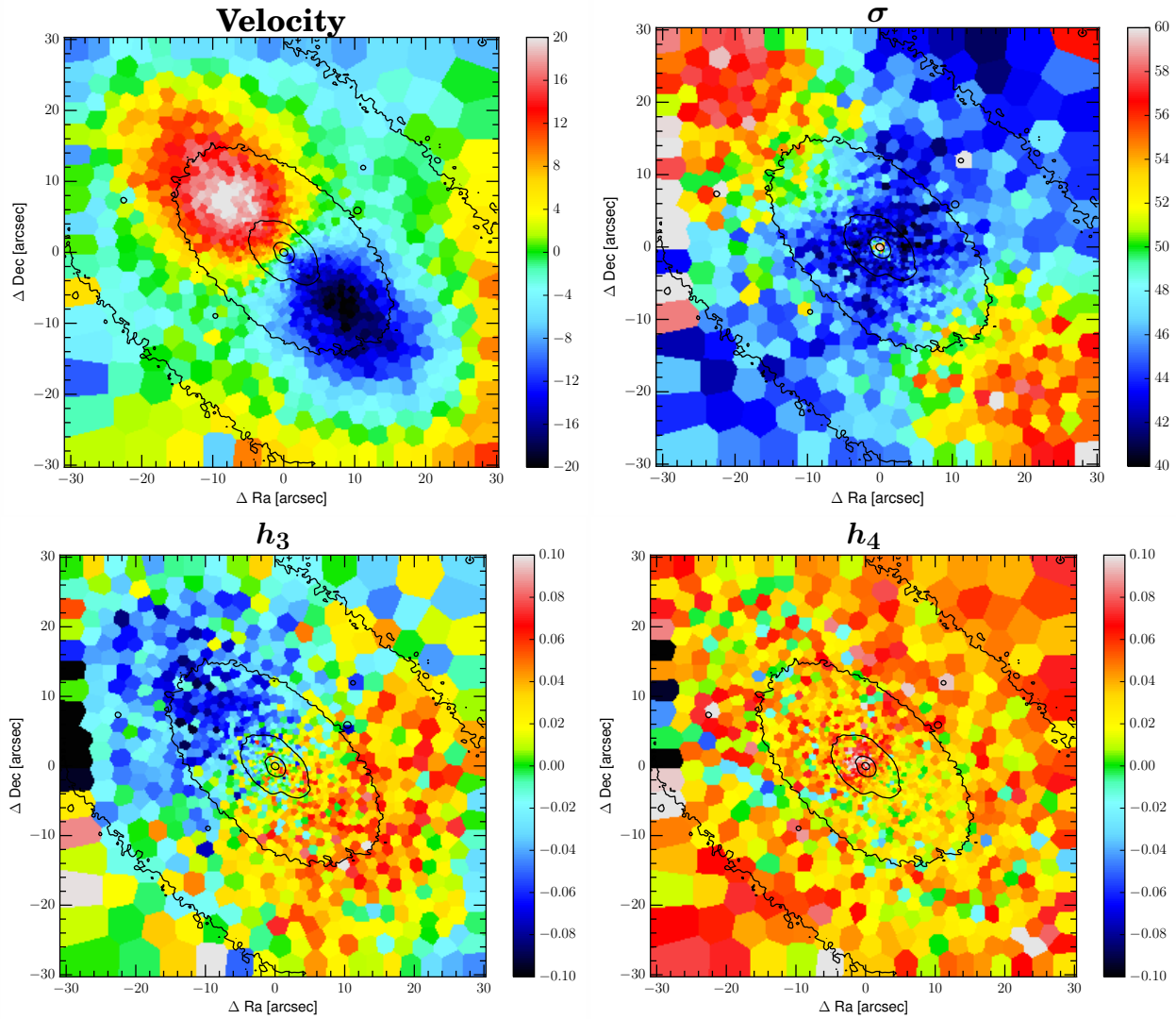
- Still no one has systematically searched for them in the CALIFA sample.
- One could start from the maps in Falcon-Barroso et al. (subm.) and Garcia-Lorenzo et al. (2015).
- But much higher spatial resolution maps for the stars are possible if one accepts less quality for the velocity dispersion.
- And I wanted to show some MUSE data as well …

NGC5102

- A MUSE-based multi-spin galaxy: NGC5102.
- Young nucleus, large HI content, central shock with line emission.
- Galaxy relatively old, with weak SF burst in the last 100 Myr.
- 5-10*10^9 M_{sun}



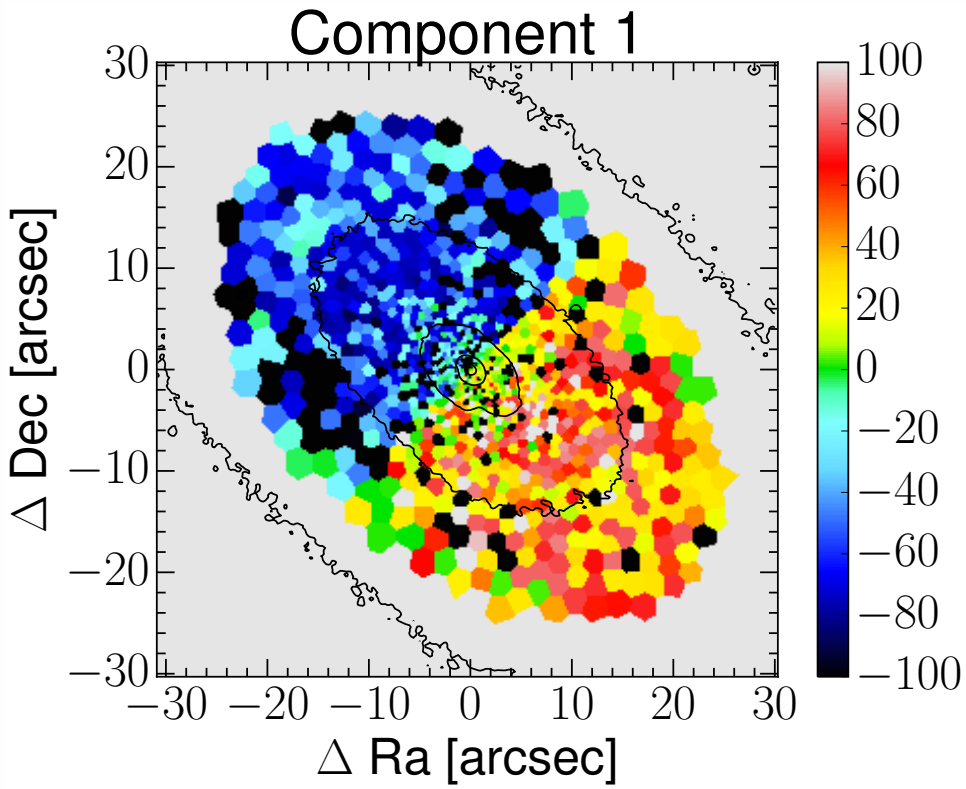
A classical 2σ-peak galaxy

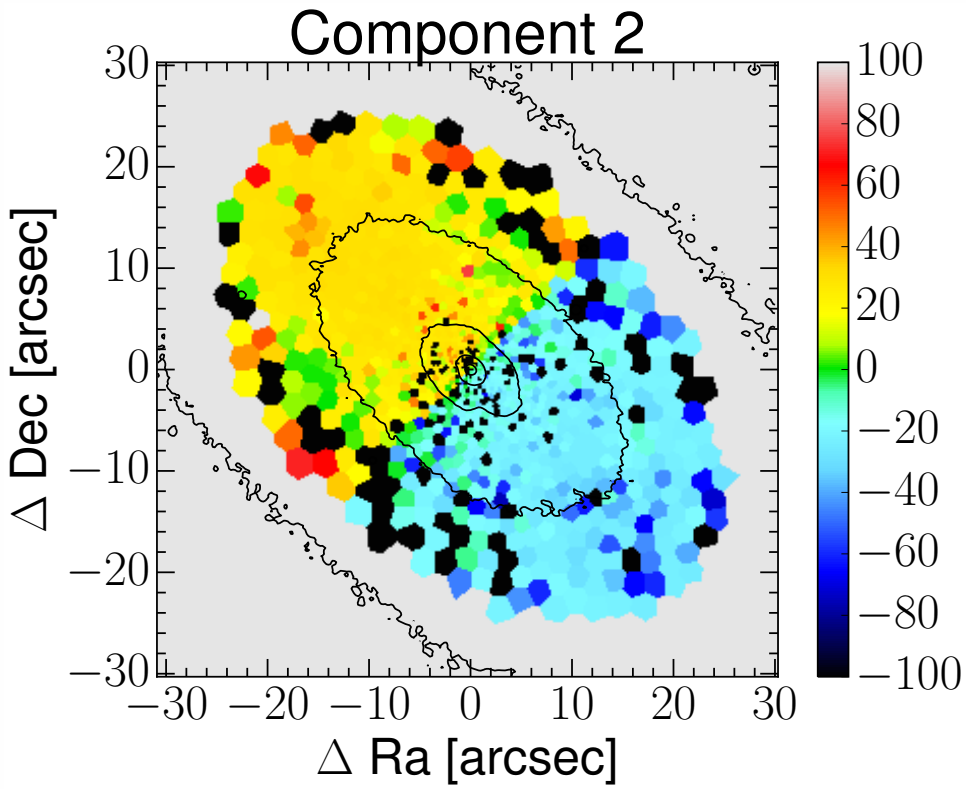


Mitzkus, Cappellari, Walcher (2016)

Kinematic separation of two components

CALIFA Survey

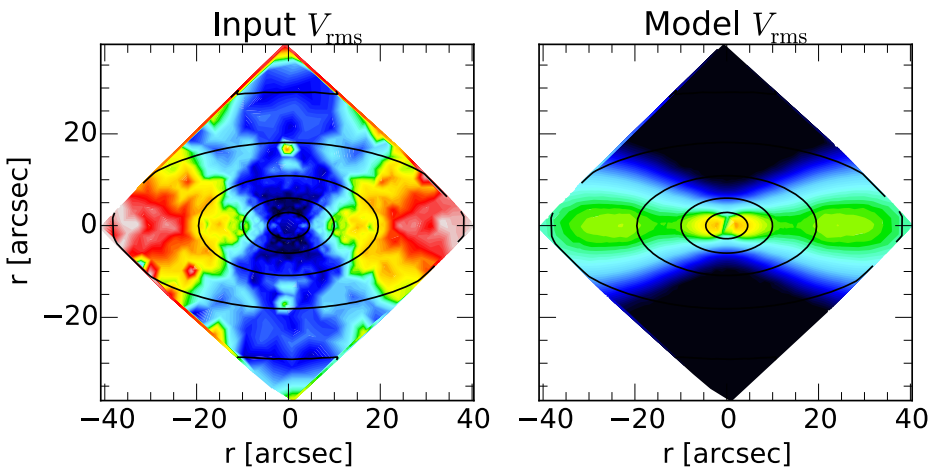




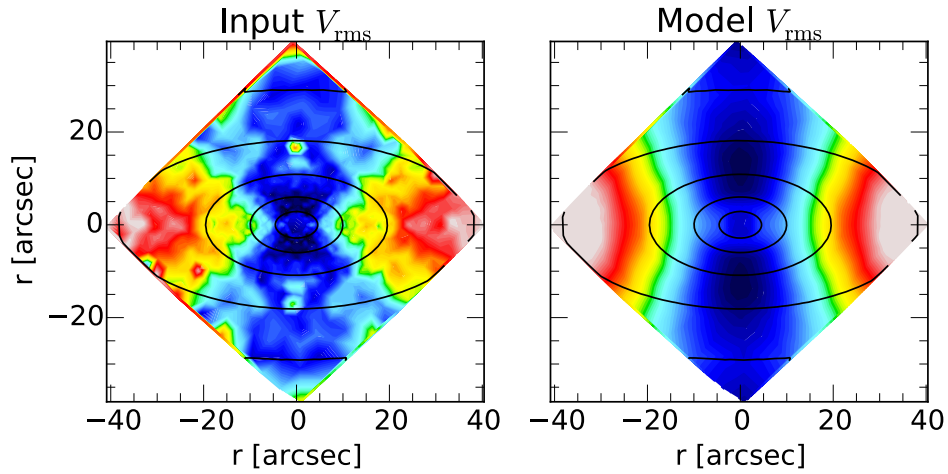
Mitzkus, Cappellari, Walcher (2016)

Relative ages are hard to get but may be 0.8 Gyr vs. 2 Gyr.

Mass models: require DM-dominated potential



Mass follows light, stellar mass based

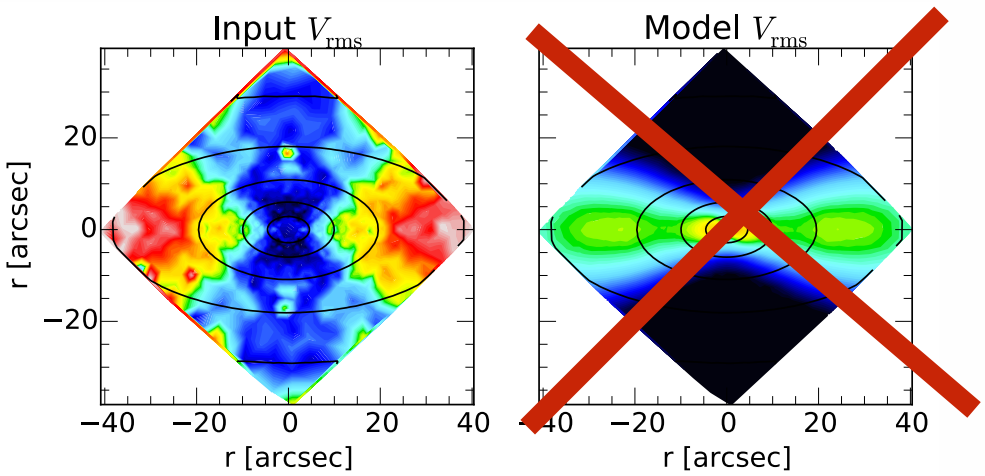


Stellar mass and NFW dark matter halo.

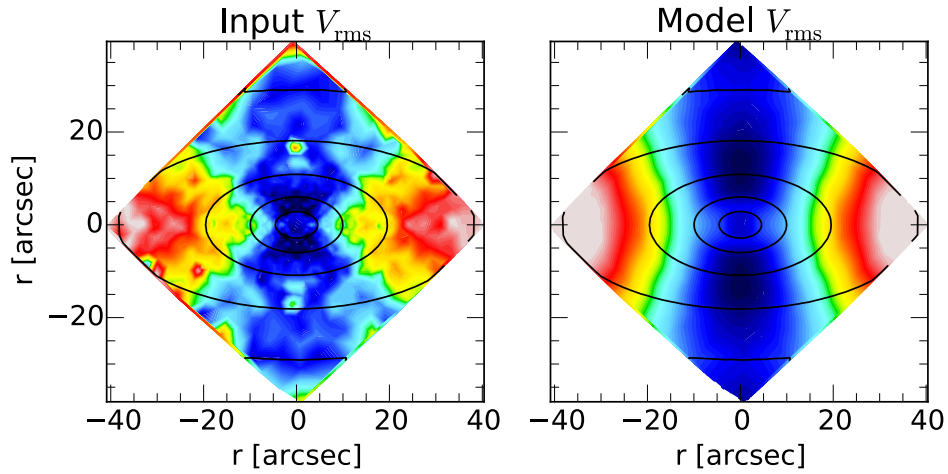
Mitzkus, Cappellari, Walcher (2016)

Footnote: We attempted a MOND model, which is **possibly** disfavoured.
But: how does one make a 2-D MOND dynamical model?

Mass models: require DM-dominated potential



Mass follows light, stellar mass based



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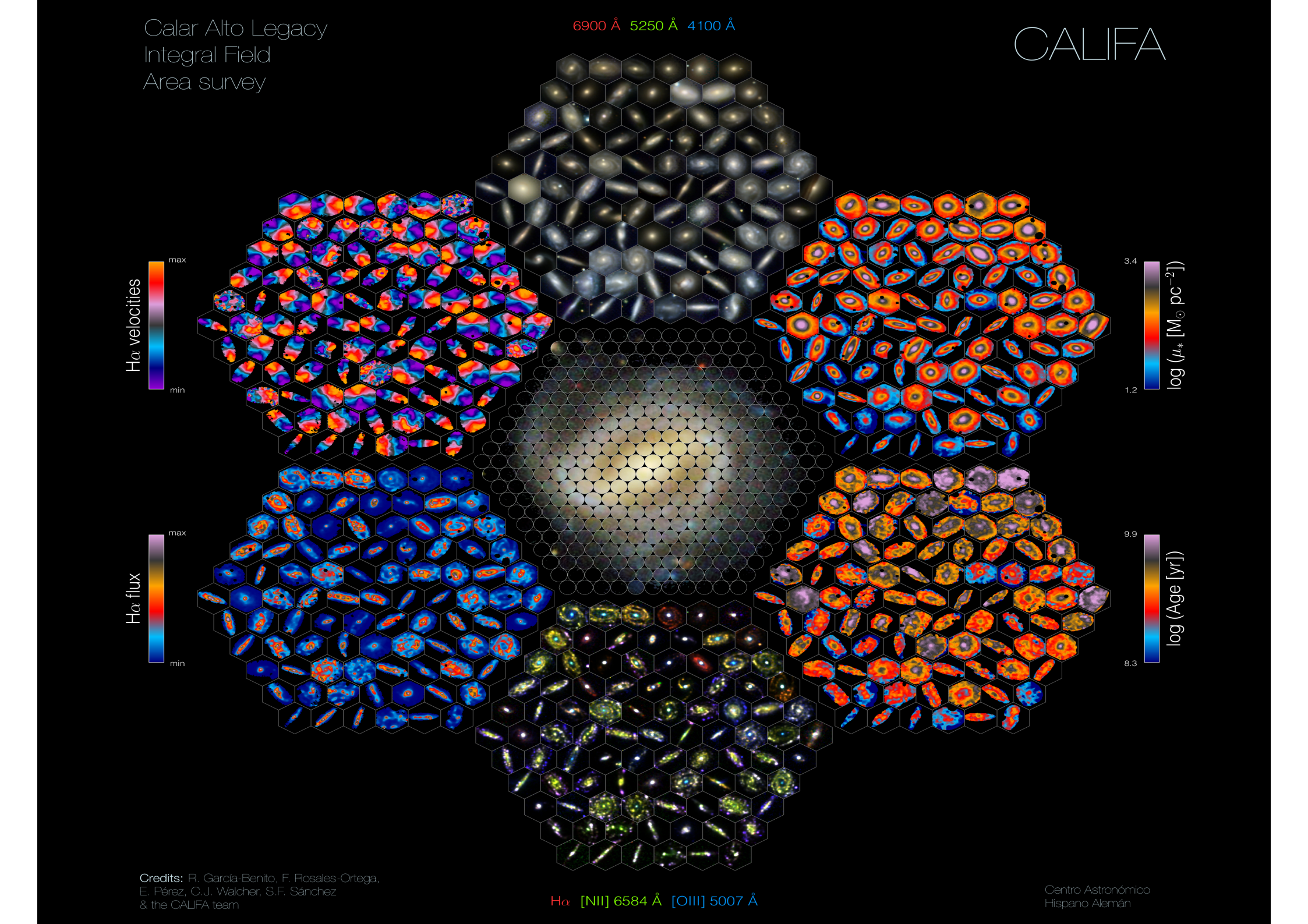
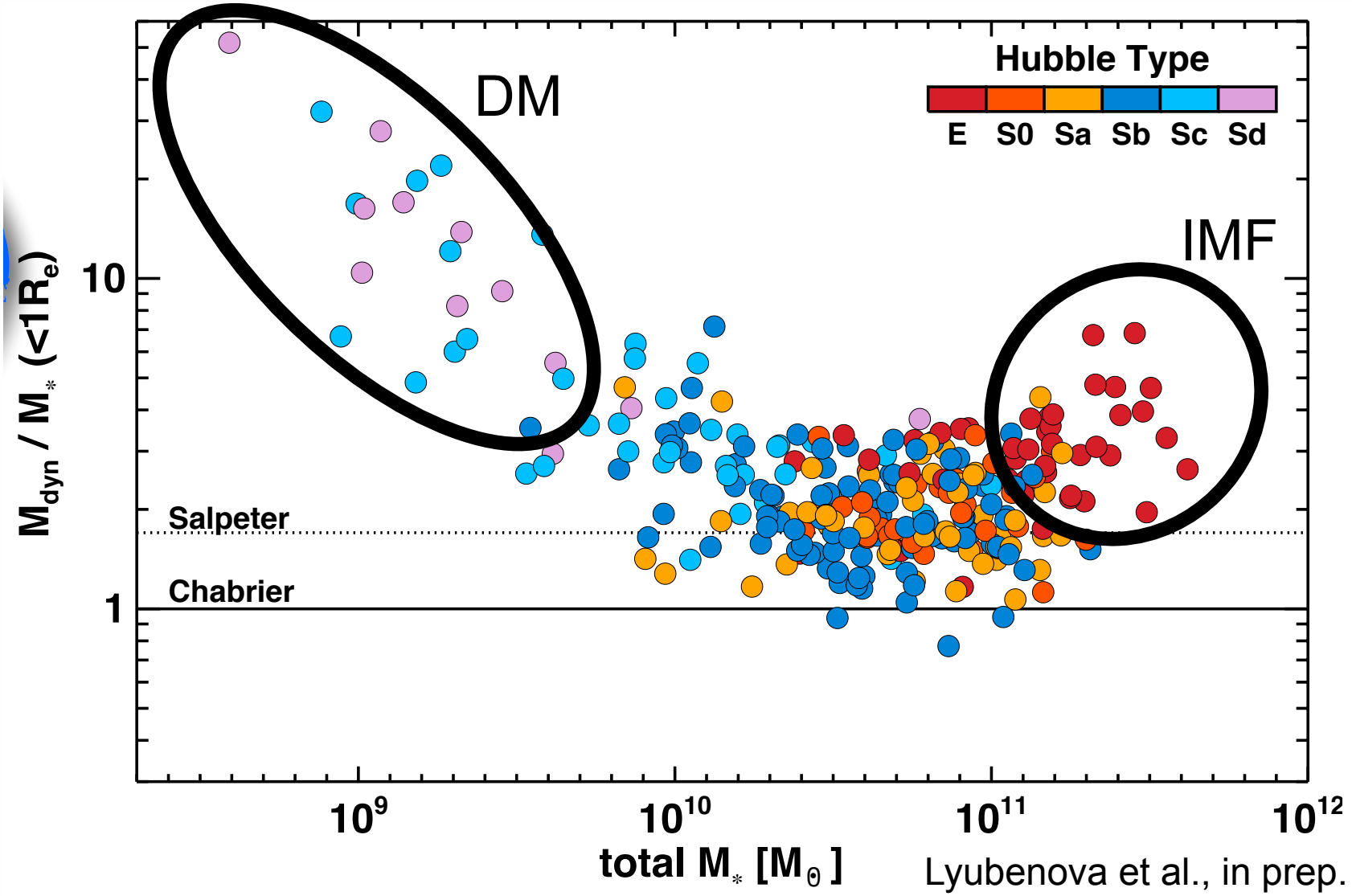
Conclusions

http://califa.caha.es/

- There is no direct correspondence between morphology and kinematics.
- We provide the bi-variate distribution function in luminosity - circular velocity space.
- Cosmological simulations cannot reproduce the CALIFA + HIPASS combined velocity function.
- Misalignment of stellar and ionized gas kinematics are tied to merger events, but are generally minor.
- Low mass early type galaxies likely require larger amounts of dark matter than do late types.
- Overall, multi-spin galaxies may be quite rare!


Calar Alto Legacy
Integral Field
Area survey
6900 Å 5250 Å 4100 Å
CALIFA
Hα velocities
max
min
Hα flux
max
min
3.4
1.2
log (μ_* [$M_\odot$ pc^{-2}])
9.9
8.3
log (Age [yr])
Hα [NII] 6584 Å [OIII] 5007 Å
Credits: R. García-Benito, F. Rosales-Ortega,
E. Pérez, C.J. Walcher, S.F. Sánchez
& the CALIFA team
Centro Astronómico
Hispano Alemán

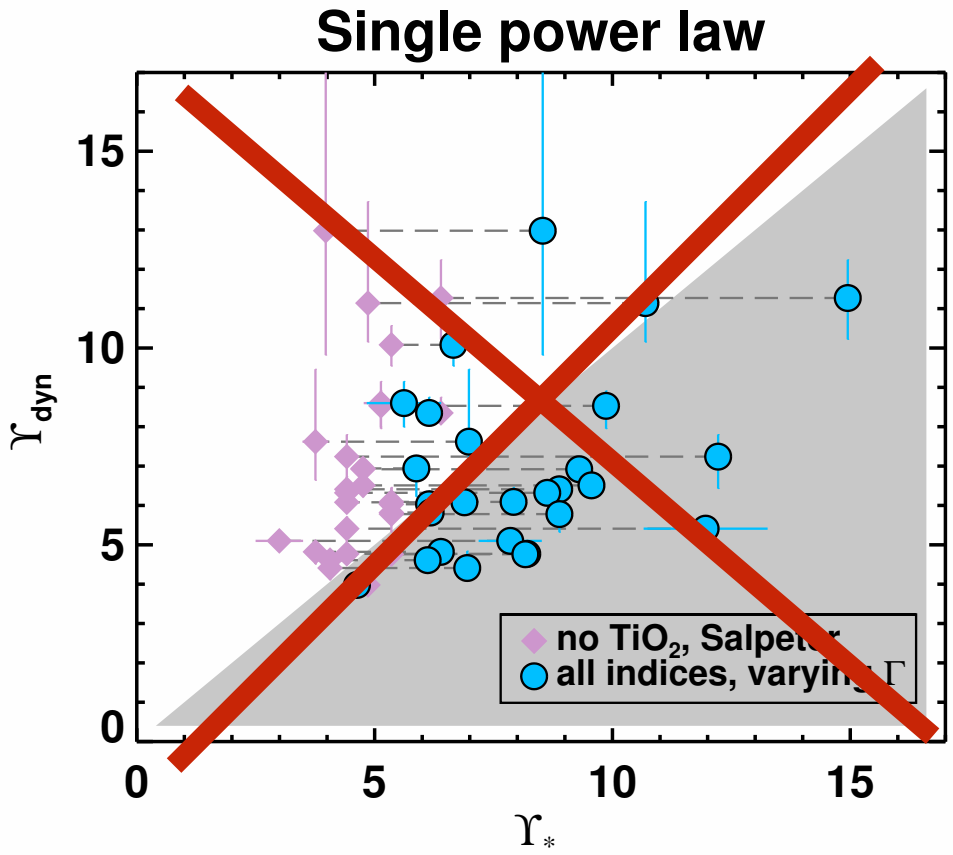
Stellar velocity fields ➜ M_{dyn}

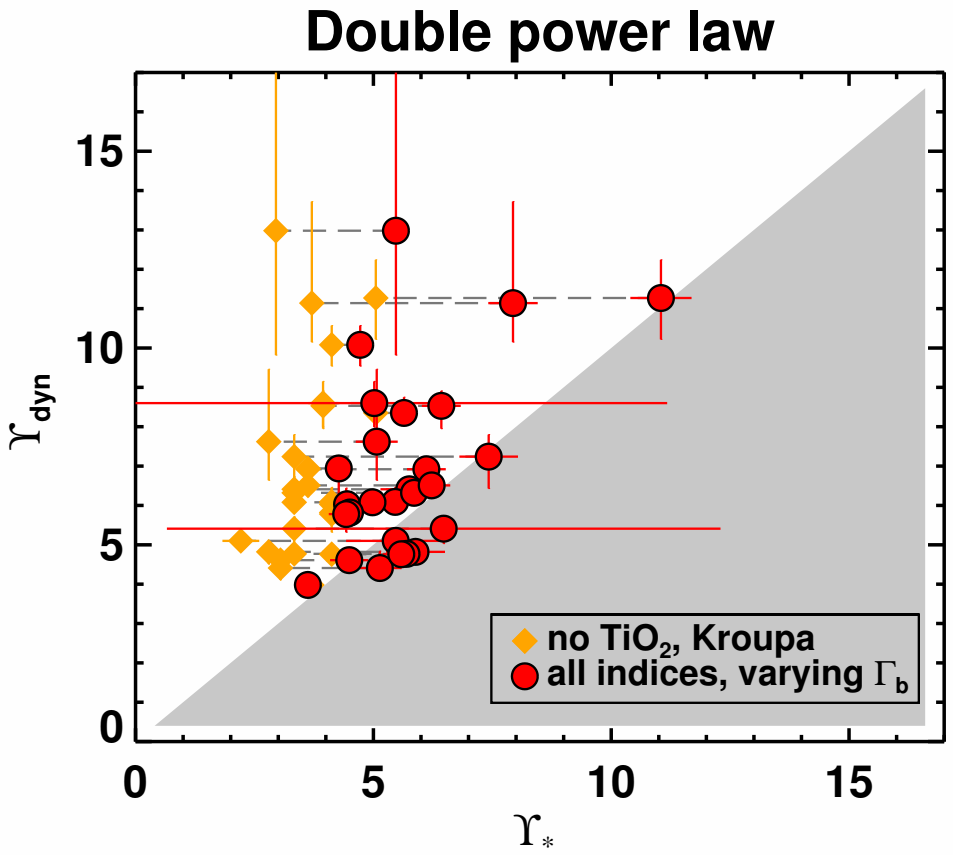


Lyubenova et al., in prep.

Constraining the stellar Initial Mass Function

CALIFA Survey





Lyubenova et al. (2016)

Dynamics and stellar populations give consistent results.
Single power law IMF ruled out ➜ **star formation at high z**