RESULTS FROM A JOINT IFU-INTERFEROMETRIC SURVEY OF THE NEARBY UNIVERSE: *MOLECULAR GAS IN GALAXIES THROUGH THE EDGE-CALIFA SURVEY*

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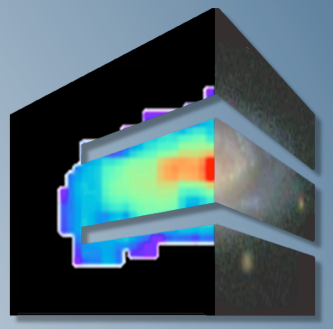
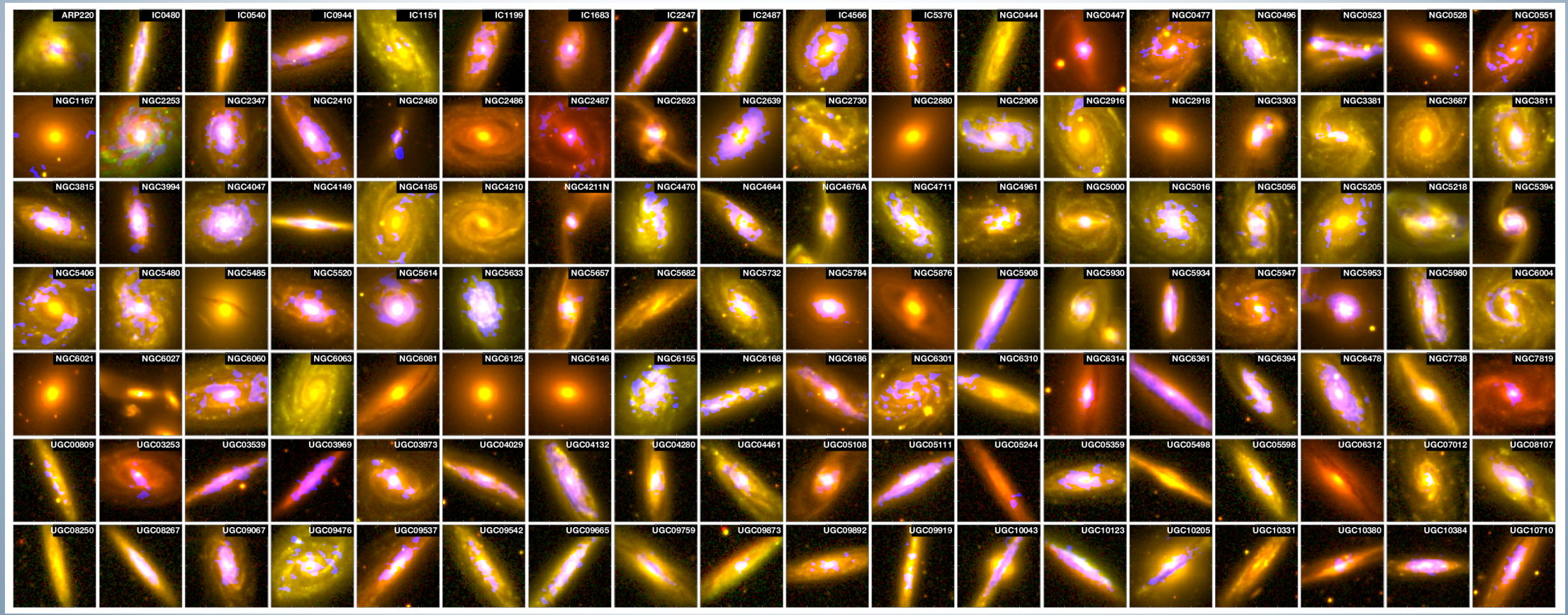
THE SURVEY



- Large dedicated project by CARMA, 800 hours of D+E observations
- Based on CALIFA (Sánchez+ 2012), selecting for “likelihood of CO emission” plus visibility
- 126 cubes, but several have more than one galaxy: 2-3 times larger than other resolved CO surveys

SDSS i SDSS g CO



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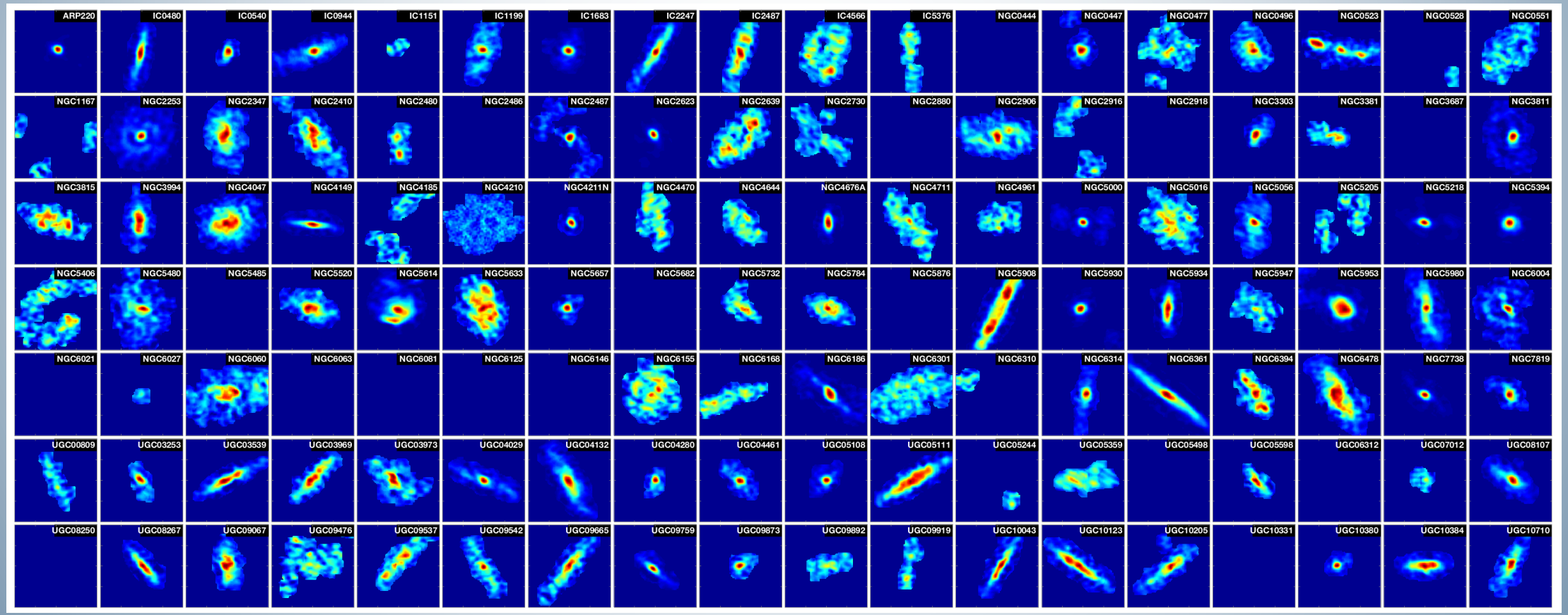

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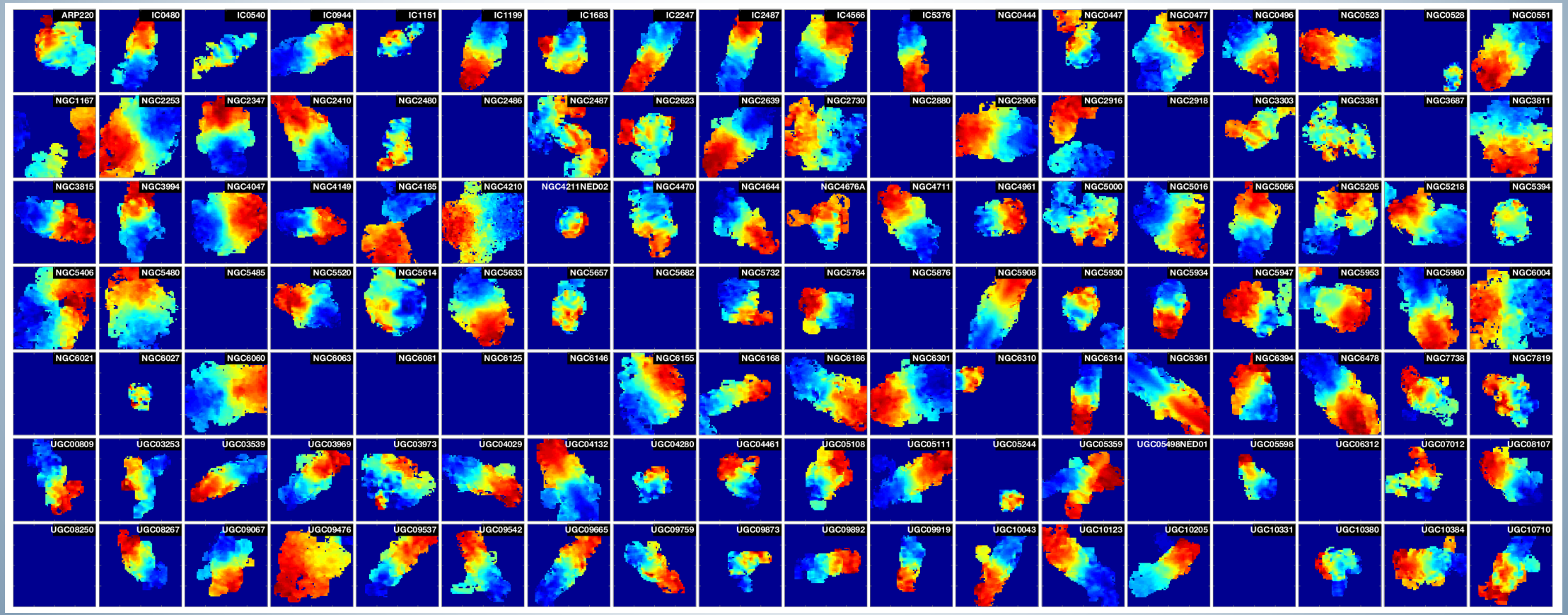
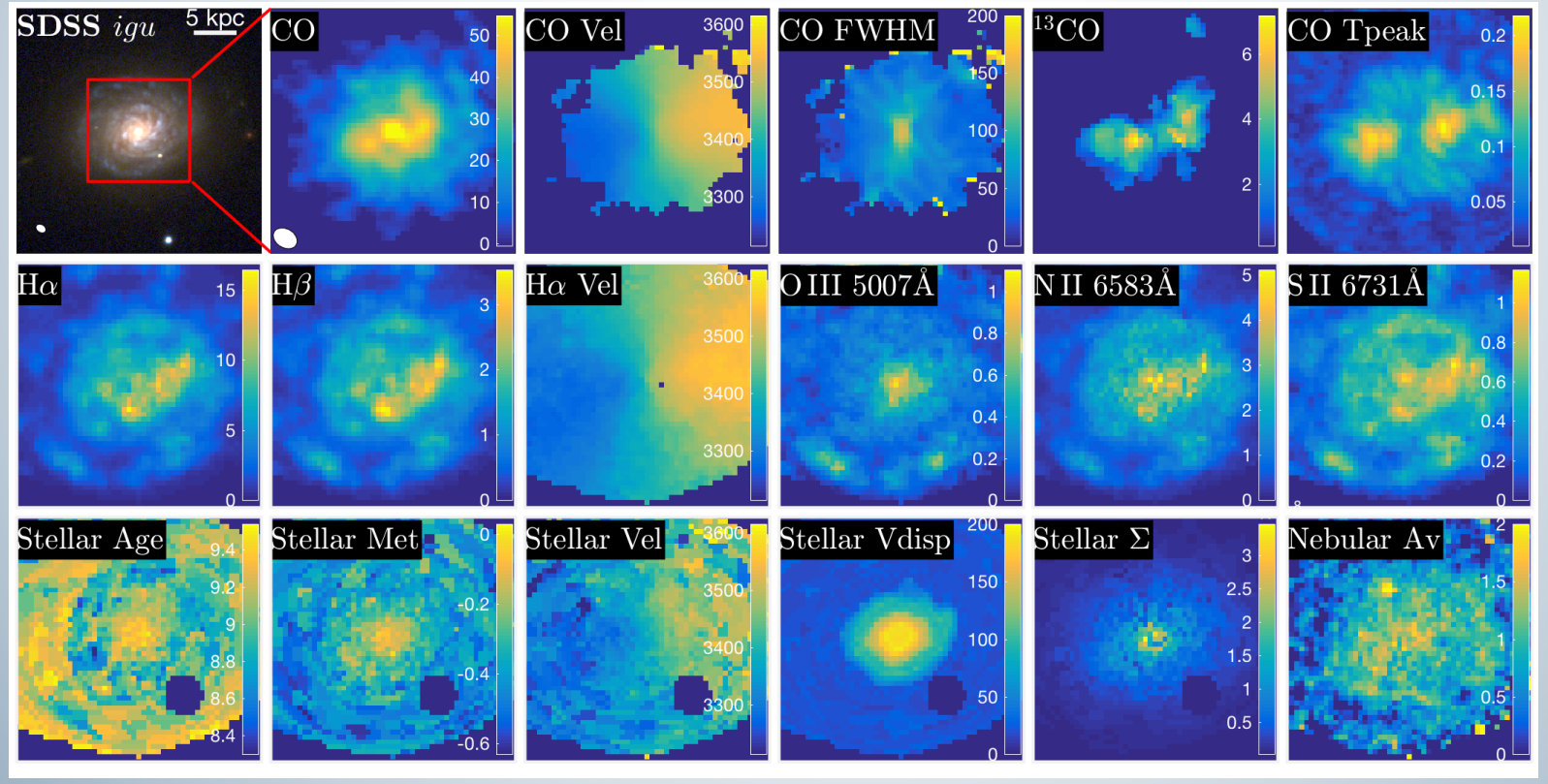
CO integrated intensity



CALIFA OBSERVATIONS

- The power of the survey comes not just from the number of galaxies. CALIFA:
  - Provides complete optical spectroscopic coverage with sizes matched to interferometer FOV
  - Is designed to provide representative local galaxy sample with known volume corrections
  - Has much better spatial resolution than SAMI or MaNGA, with angular resolution 2.7”

CALIFA and Pipe3D are described in Sánchez+ 2012, Walcher+ 2014, García-Benito+ 2015, Sánchez+ 2016

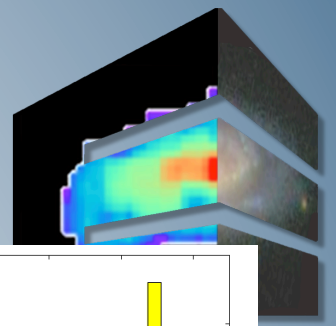


Data example:

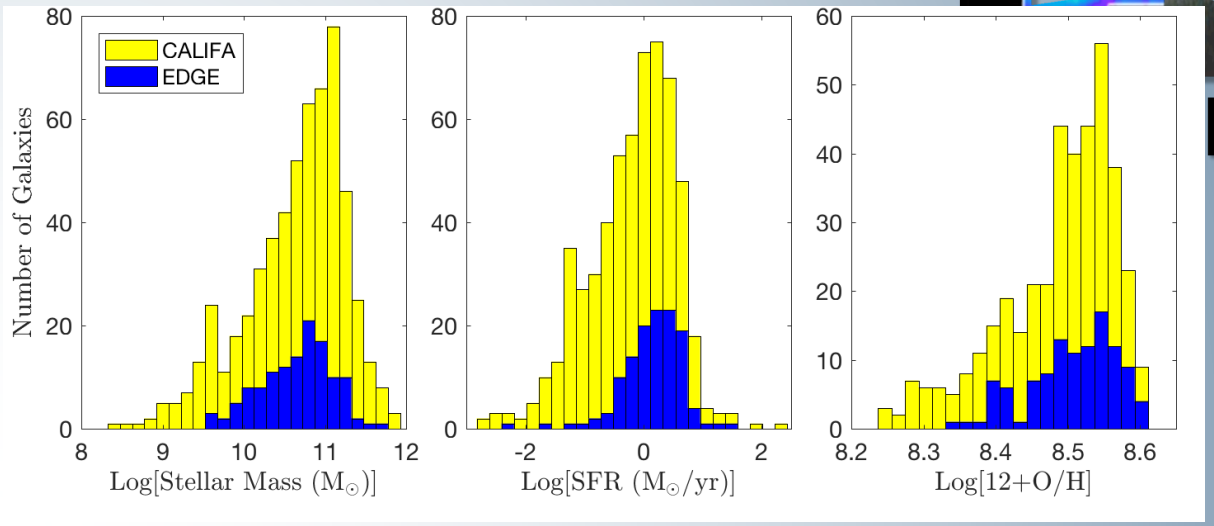
- Top row – ^{12}CO and ^{13}CO moments
- Middle – representative line intensities and velocities (Pipe3D)
- Bottom – stellar and ISM derived quantities

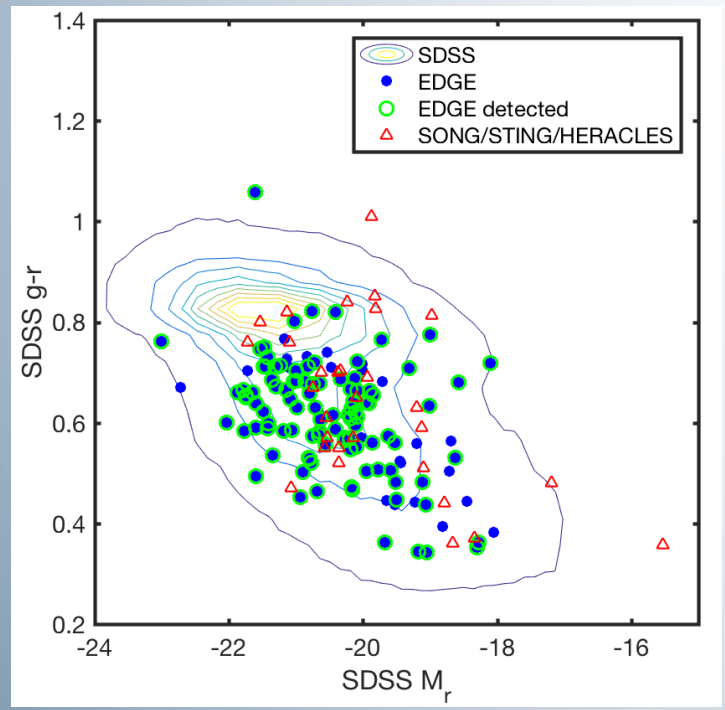
Bolatto et al. (ApJ, 2017)

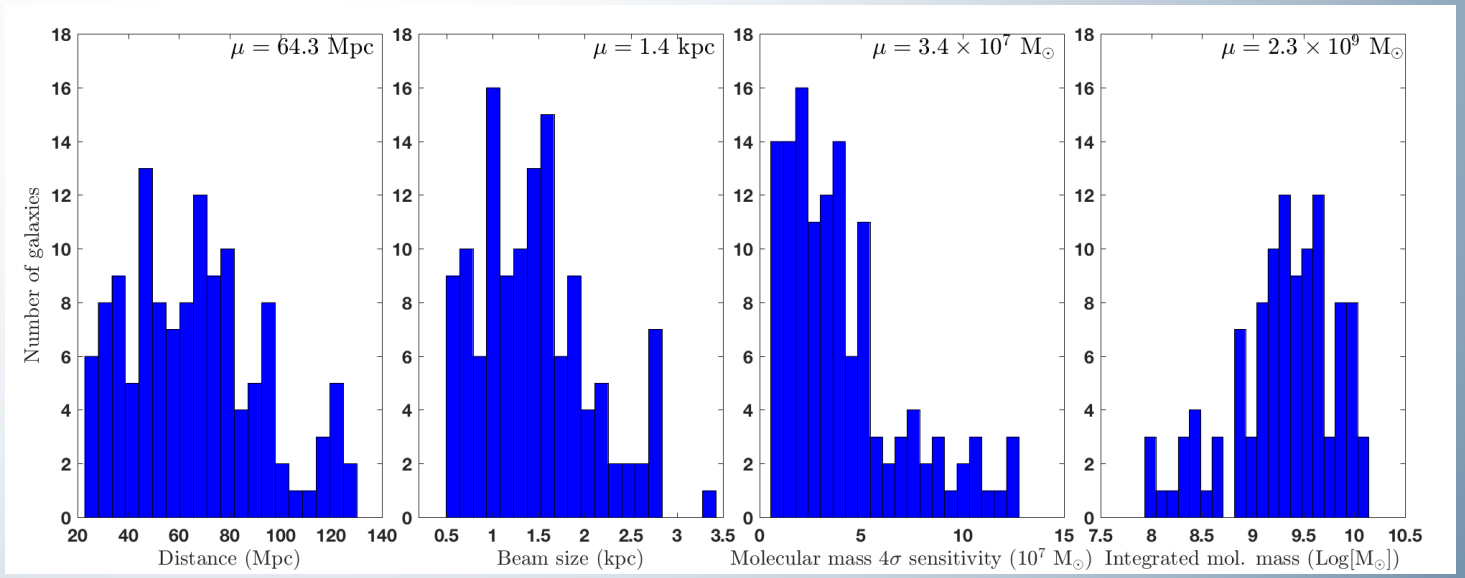
EDGE IS A REPRESENTATIVE SUBSAMPLE



- The EDGE subsample preserves many of the properties of the CALIFA sample, although it is biased toward high SFR/metallicity and late galaxy types
- Typical distance ~65 Mpc, typical resolution ~1.4 kpc (4.5")



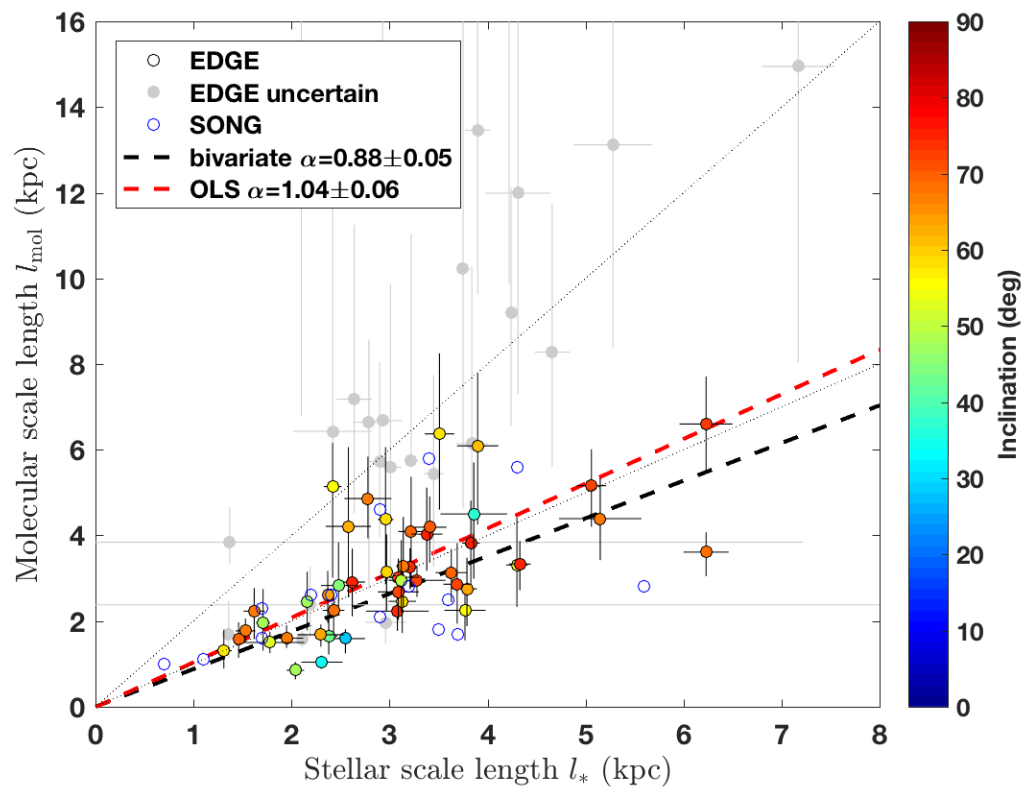


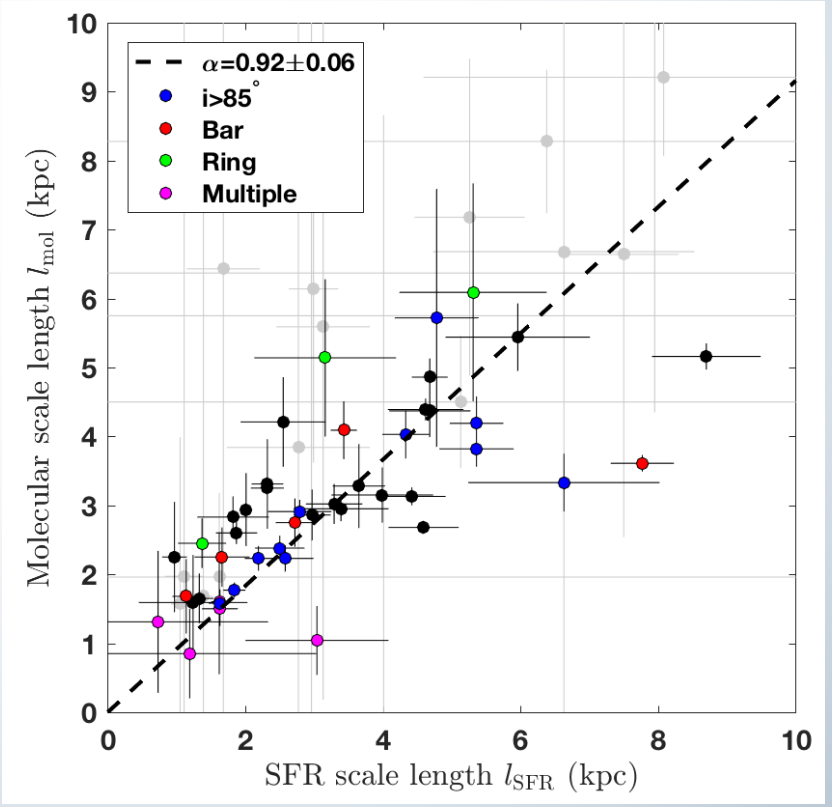


Bolatto et al. (ApJ, 2017)

DISKS REGULATE TO HAVE $R_* \cong R_{MOL} \cong R_{SFR}$

- Resolved data allows direct comparison of CO, stellar surface density (from SP modeling) and extinction-corrected SFR (from Hα)
  - Good match (see also e.g. Regan et al. 2001). Much better stats than previously possible
  - Deviant (e.g. CO-compact) galaxies show some evidence for interaction





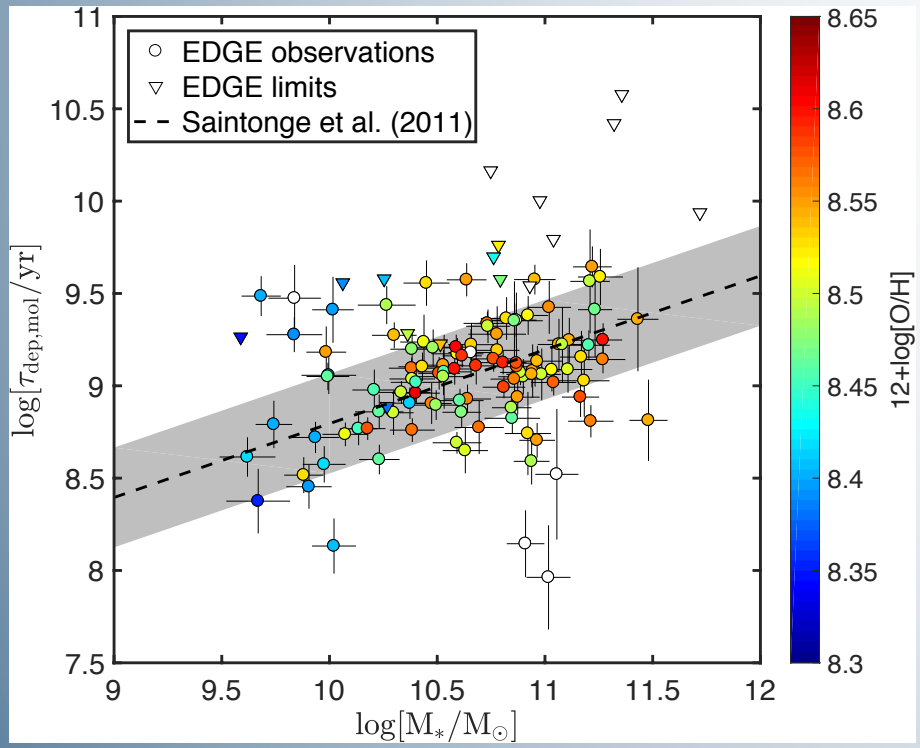
- Exponential molecular, stellar, and SFR scale lengths match 1:1 for good quality fits
- Same for half light radii
- Worst deviations associated with dustiness, multiplicity

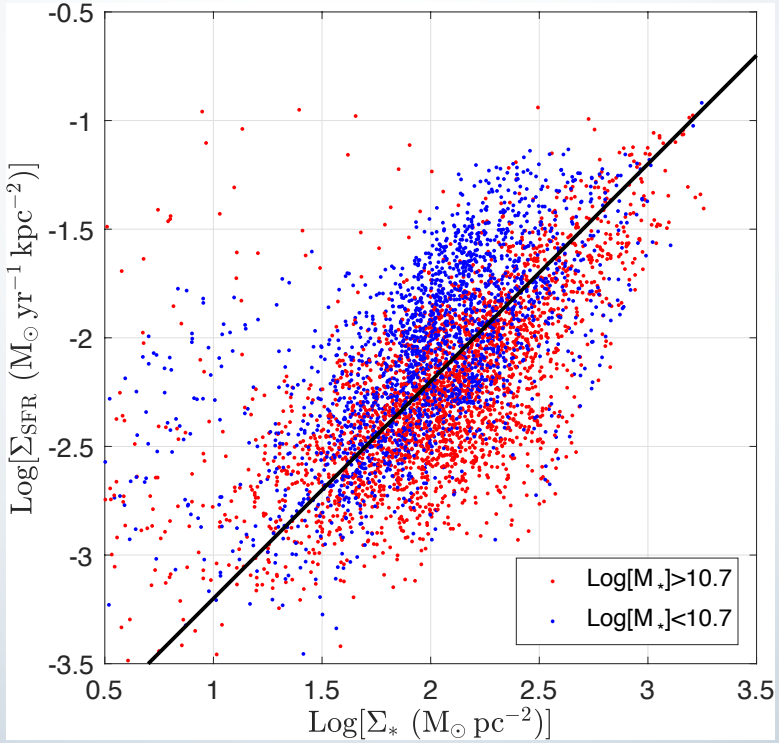
Bolatto et al. (ApJ, 2017)

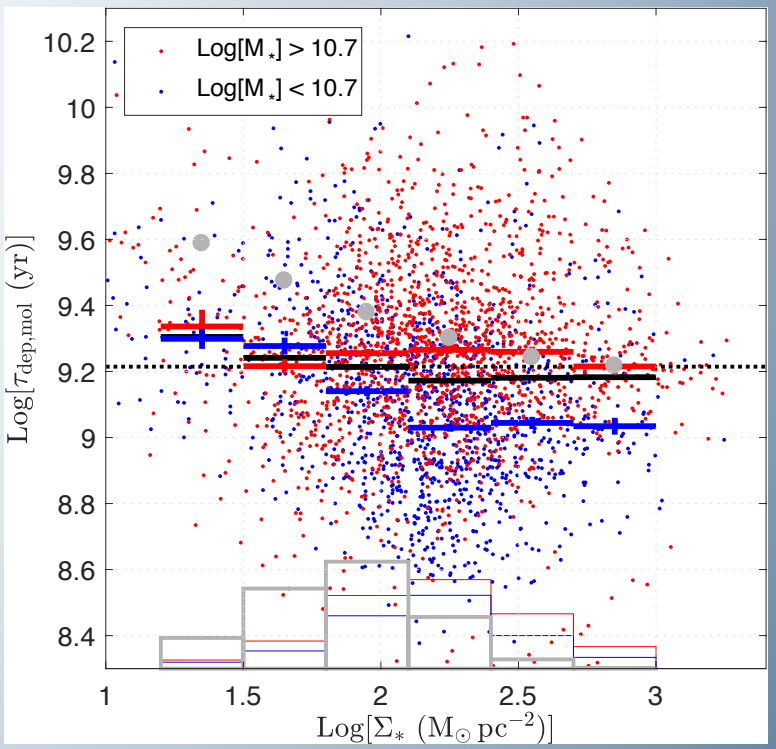
SCALING RELATIONS SEGREGATE BY MASS

- We recover integral relation for $\tau_{dep} = \frac{M_{mol}}{SFR}$ that depends on stellar mass (Saintonge+ 2011)
  - Origin? Is it controlled by a local or a global parameter?
- We see it in the resolved data, but not controlled by Σ_*
  - Hints for extinction and perhaps metallicity correlations, but this deserves further investigation

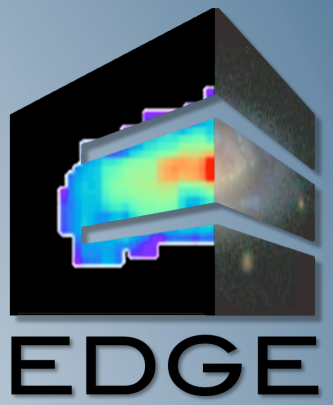
Bolatto et al. (ApJ 2017)





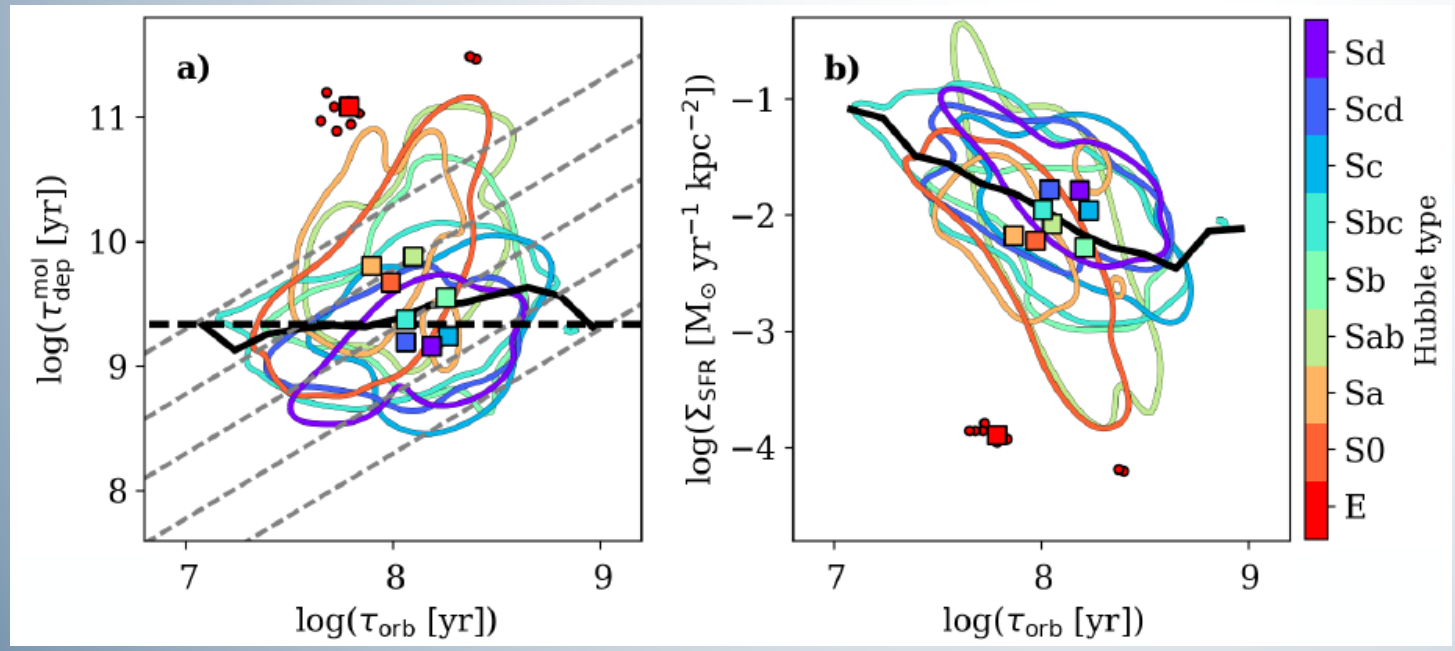


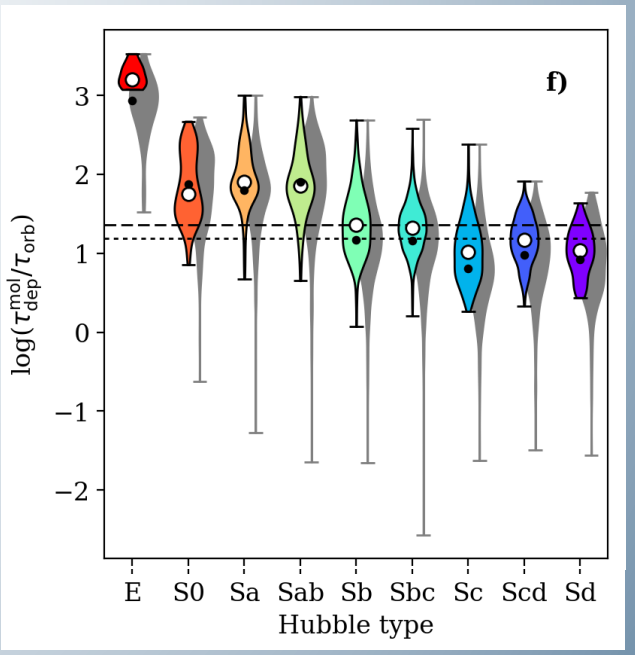
THEY ALSO SEGREGATE IN THE HUBBLE SEQUENCE



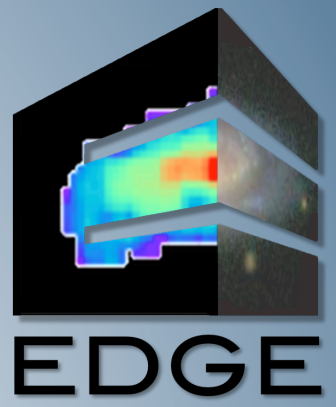
- Is there a fixed "efficiency" of star formation per orbital time in galaxies?
  - Computing τ_{orb} using stellar circular velocities from dynamical models for CALIFA (Kalinova+ 2017) derived using JAM (Capellari+ 2008)
- Large scatter for Silk-Elmegreen type relation (±0.5 dex around $\tau_{dep}=20\tau_{orb}$)
  - Systematic with Hubble type, driven by fall of Σ_{SFR} for earlier types: morphological stabilization?
  - Keep in mind that early types in EDGE were selected to be gas/molecule rich

Colombo et al. (MNRAS, submitted)



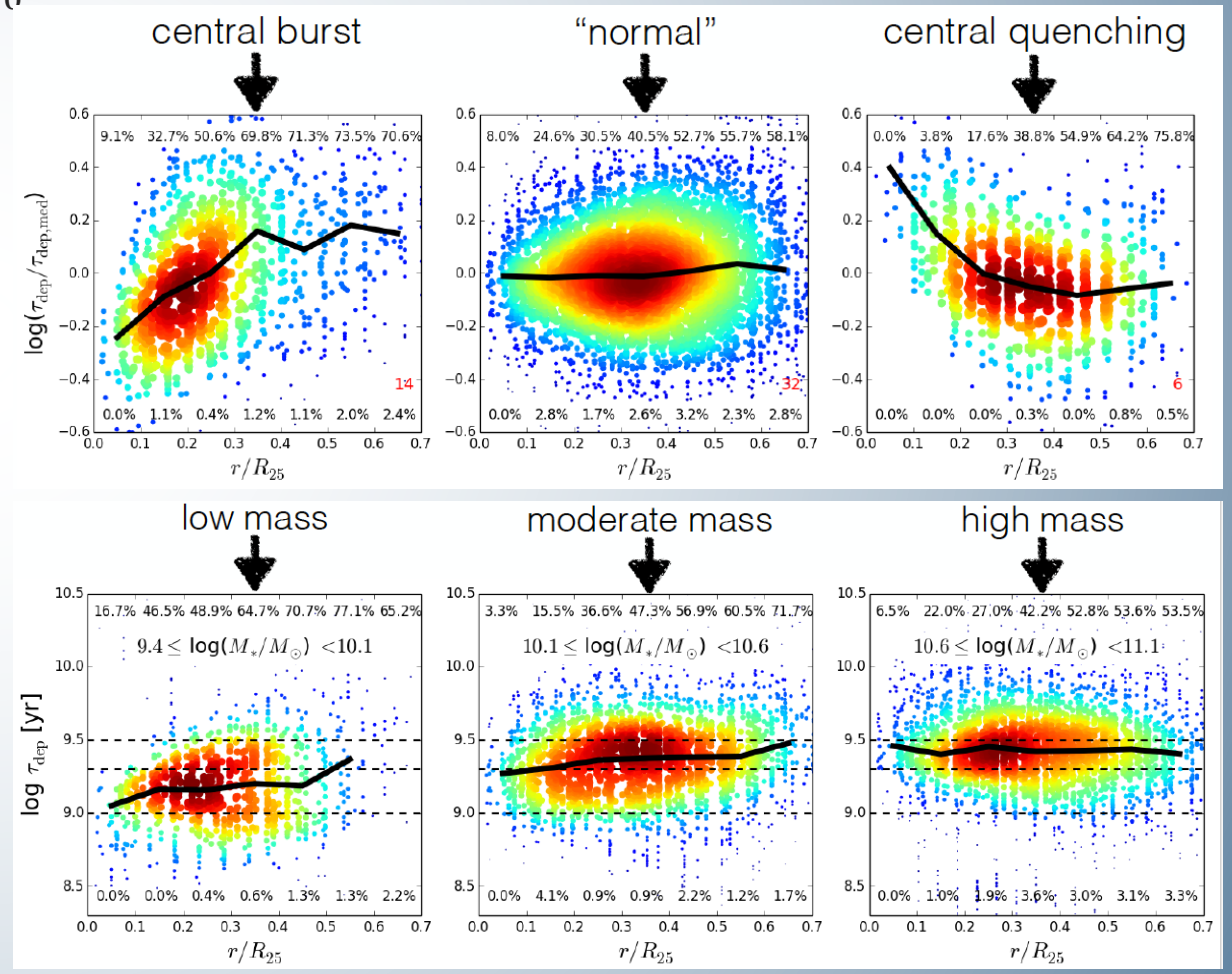


GALAXY CENTERS DEPART FROM DISKS

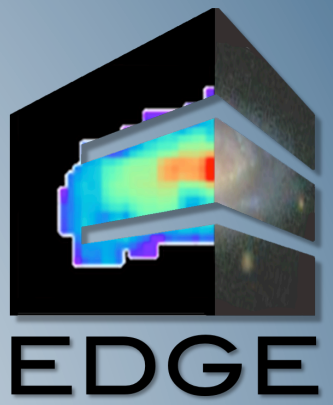


- Frequently galaxy centers show departures from their disks
  - 60% are similar, 30% are consuming the gas faster, 10% more slowly
  - This is driven by Σ_{SFR}, not Σ_{mol}
  - It is mildly correlated with galaxy mass
  - Drop in τ_{dep} is associated with younger luminosity-weighed ages for the central stellar population: they are "bursty"
  - It is correlated with the gradient of O/H: "bursty" centers have peaks in O/H. "Quenched" centers have flat O/H, underperforming their disks
  - "Bursty" centers are more common in galaxies with more compact molecular disks, and barred/interacting galaxies

Utomo et al. (ApJ, 2017)

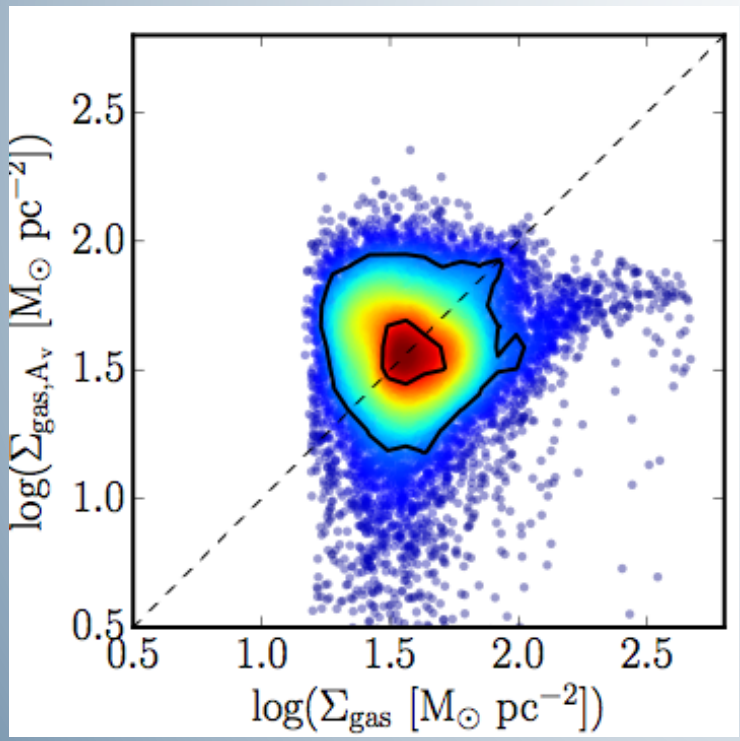


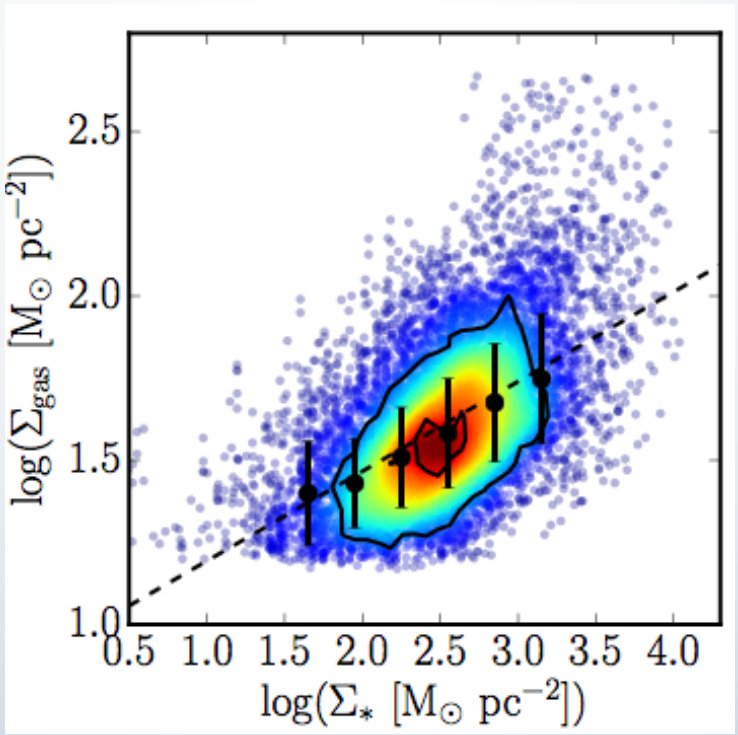
EXTINCTION AS A PREDICTOR OF MOLECULES

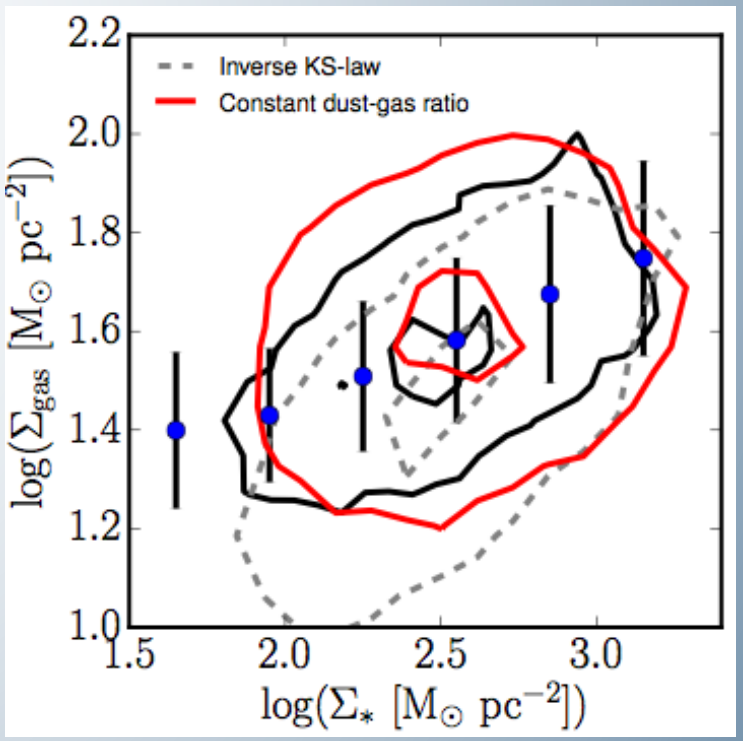


- Extinction and total gas column density are well correlated in Milky Way GMCs, $N(H)=1.9\times10^{21}$ cm^{-2} A_V (Bohlin+ 1978; Rachford+ 2009)
- For extragalactic data we assume ½ the column is in front (e.g., Imara & Blitz 2007), hence $\Sigma_{gas,Av}$ = 30 $M_\odot pc^{-2}$ A_V, with A_V from Balmer decrement
- For comparison use $\Sigma_{gas}=\Sigma_{mol}+\Sigma_{HI}$, assume typical Σ_{HI} = 10 $M_\odot pc^{-2}$

Barrera-Ballesteros et al. (in prep.)

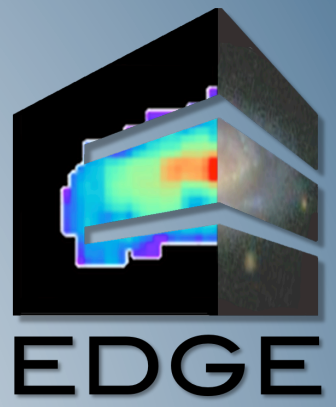




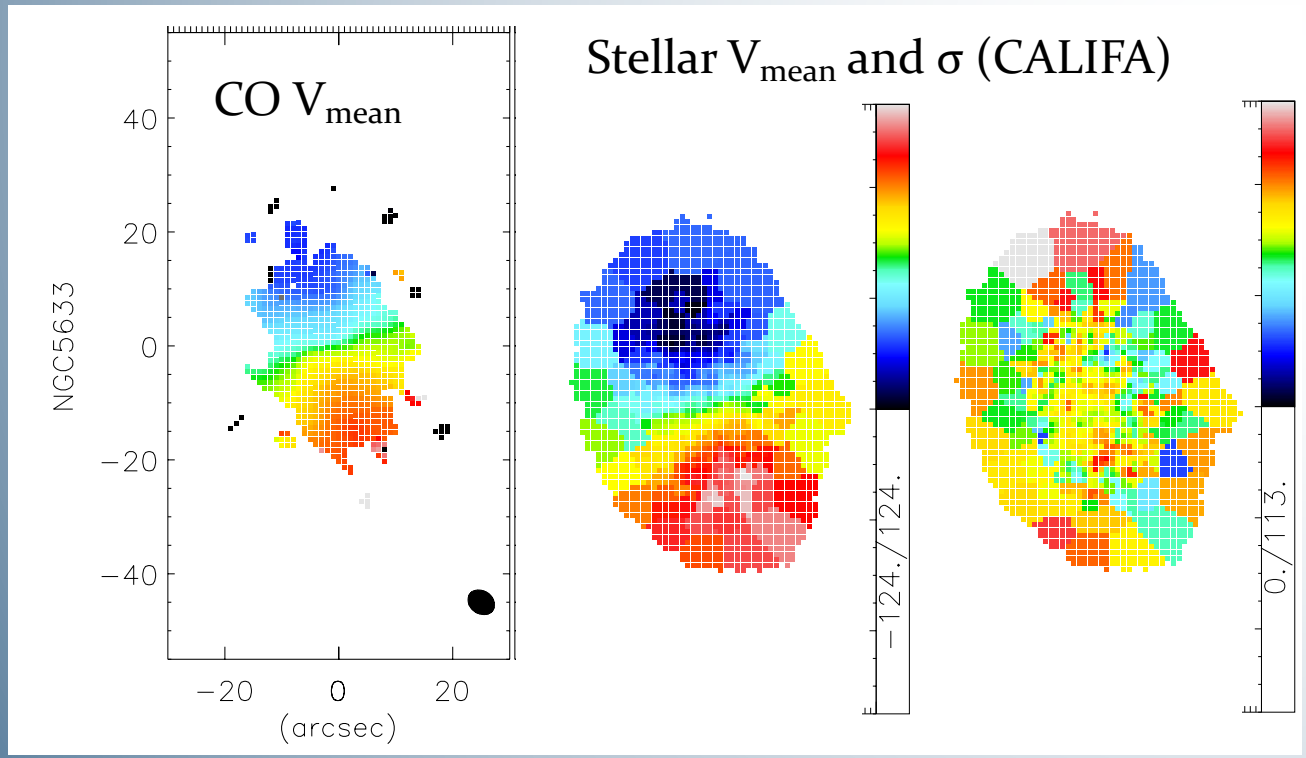


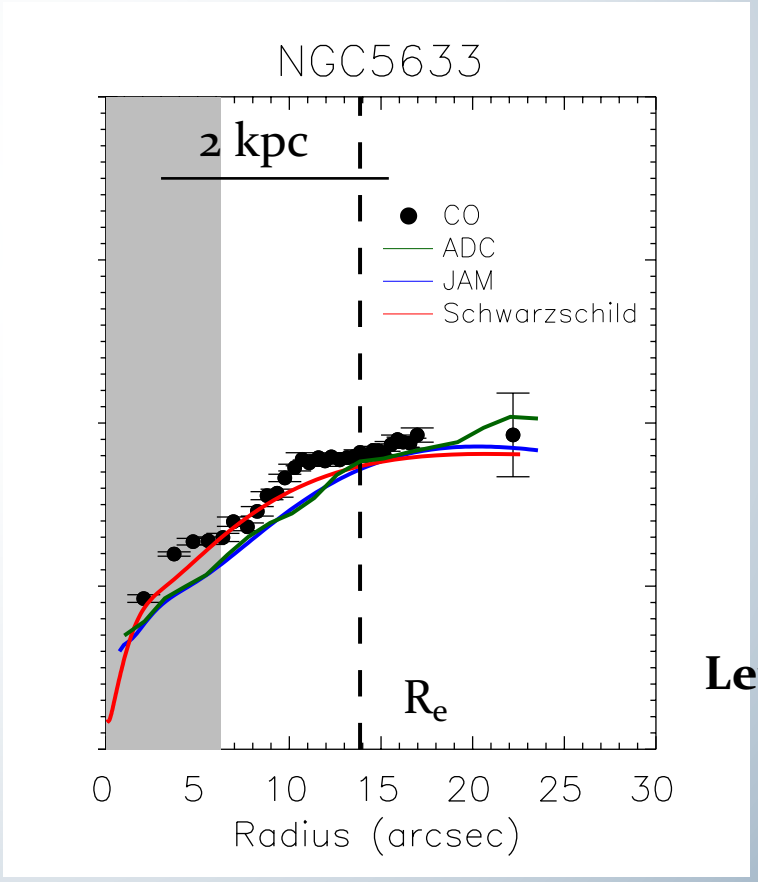
MULTI-TRACER DYNAMICS

See poster by Gigi Leung!



- With multiple tracers of the kinematics (stellar, ionized gas, molecular gas) we can do a good job at weighting the disks
- Modeling techniques of increasing sophistication (ADC, JAM, Schwartzschild) obtain circular stellar velocities in progressively better agreement with the gas measurements
- The agreement with CO is better than with Hα

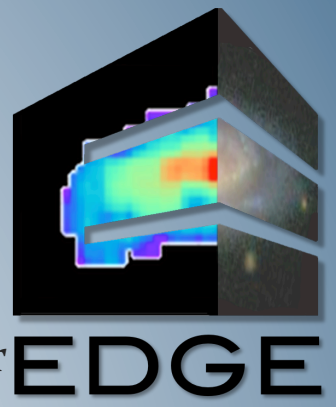




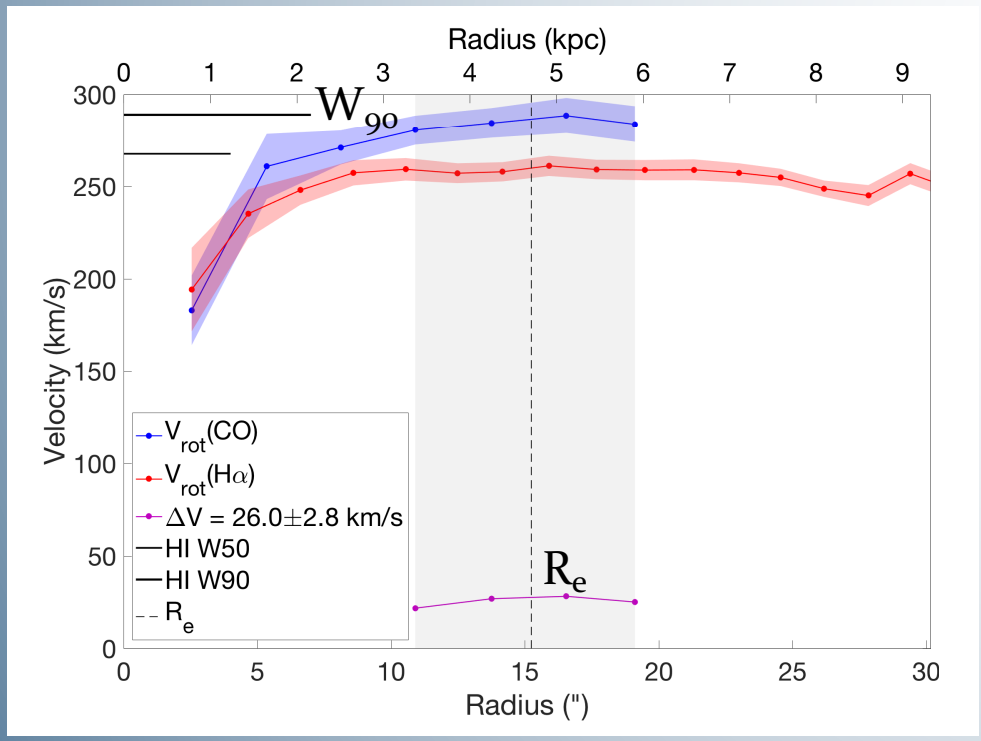
Leung et al. (MNRAS, submitted)

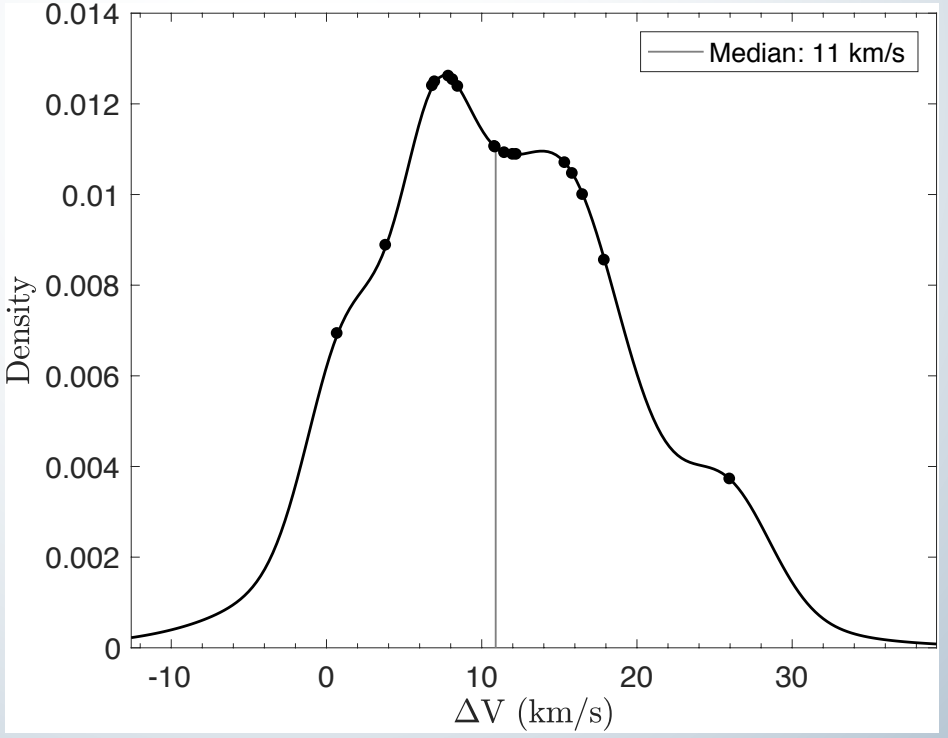
THICK IONIZED DISKS?

See poster by Rebecca Levy!



- Do ionized and molecular gas kinematics agree? Surprising disagreement in outer regions
  - Molecular gas rotates faster, typically ~5% ~ 11 km/s, evaluated on 17 high-quality galaxies. No clear correlation with galaxy parameters
  - Thick ionized disks with turbulent support and a vertical rotation velocity gradient? Hγ linewidth measurements suggest this is the case
    - Our galaxies are over the Σ_{SFR} threshold for thick ionized disks (Rossa & Dettmar 2003)





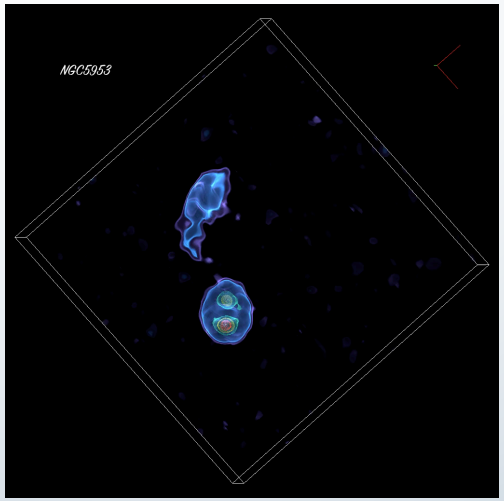
- Poster child of rotation velocity discrepancy, NGC2347. CO and HI agree.
- KDE histogram of the distribution of rotation veloc. diff. $\Delta V = V_{CO} - V_{H\alpha}$

Levy et al. (in prep.)

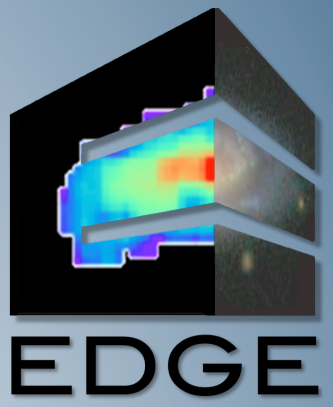
RELEASES AND FORTHCOMING WORK

- Other papers in the works (resolved HI, ^{13}CO, K-S relation, high density, AGN, etc)
- Data releases in weeks, check http://www.astro.umd.edu/EDGE
  - Plan is to release not just CO cubes and maps, but also companion Pipe3D CALIFA products
  - Relational database implemented in SQL-lite, with beam-matching and hex resampling
- Great opportunity for a complete sample with ALMA, representative of the local universe
  - ALMA can add another 180 CALIFA galaxies in 75 hours (after significant optimization)
  - Team and tools ready, exploitation of EDGE funded by NSF-AST 1615960
- Imagine the power of a 300-galaxies kpc-scale resolved database combining optical and mm-wave data!

CO in NGC 5953/54



SUMMARY



- Large resolved CO survey of 126 CALIFA galaxies, representative of local galaxy population. Data will be public (already possible to use it for projects, e.g. Galbany+ 2017)
- Disks regulate so that sizes for stars, molecular gas, and star formation match very well
- There is a measurable mass effect on the scaling relations: local or global controlling parameter?
- The star formation efficiency per orbital time changes systematically between galaxy types. Our (gas rich) early galaxies show evidence for molecular gas stabilization
- ~30% of the galaxies have "bursty" centers. They tend to be smaller galaxies, compact CO distributions, and have O/H peaks. "Quenched" centers underperform in O/H
- Statistically it is possible to use extinction as a predictor of gas, although scatter is large and metallicity is likely to have an impact
- Very good agreement between circular velocities in stellar kinematic modeling and CO kinematics, better than for ionized gas
- Measurable discrepancies in rotation velocity between CO and Hα, likely due to thick ionized disks vs. thin molecular disks

A 300-galaxies kpc-scale resolved database of optical and mm-wave observations on a representative sample of nearby universe is within reach

CAST OF CHARACTERS

EDGE

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