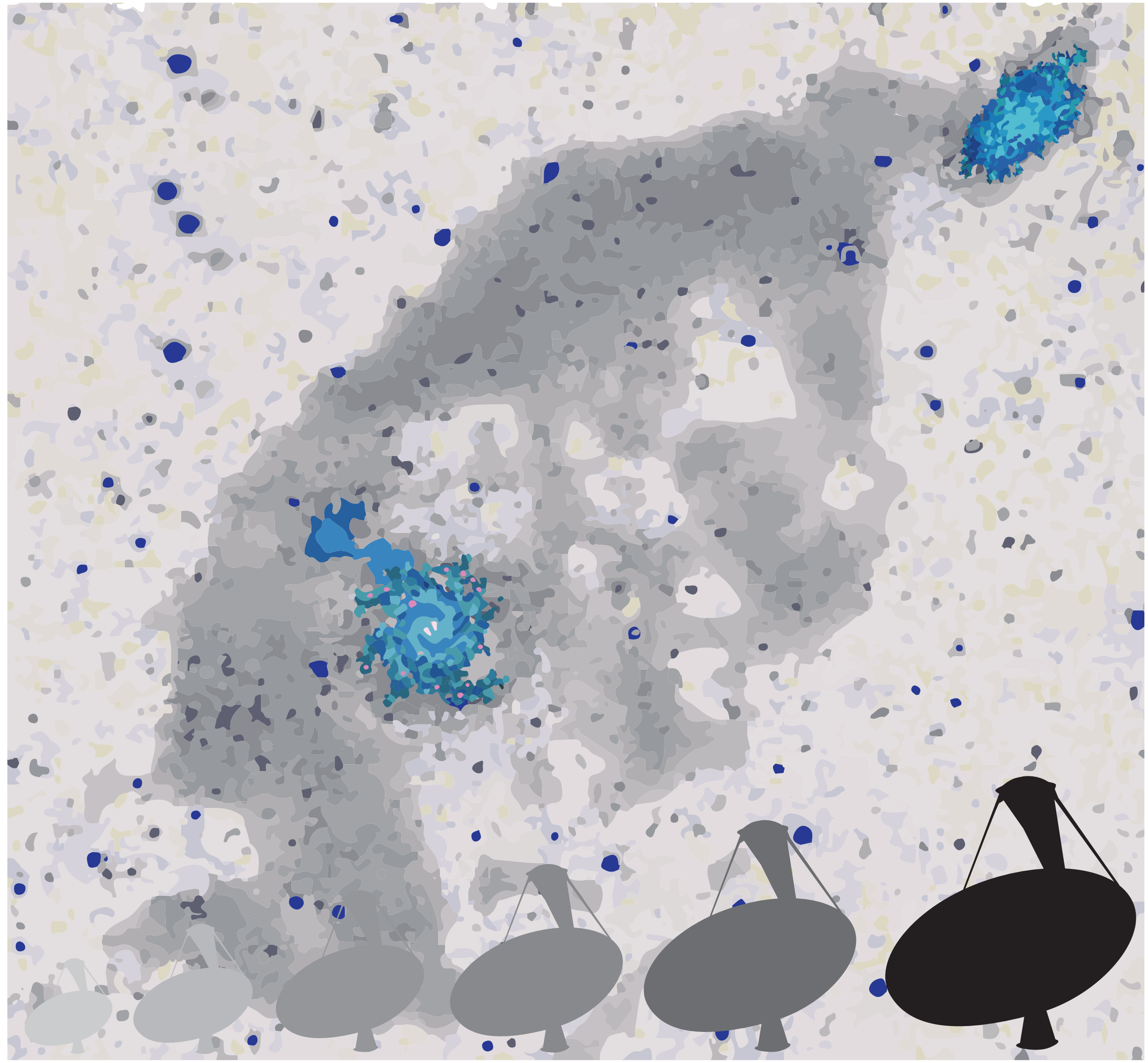
Empowering SKA as a Probe of Galaxy Evolution with HI (ESKAPE-HI)

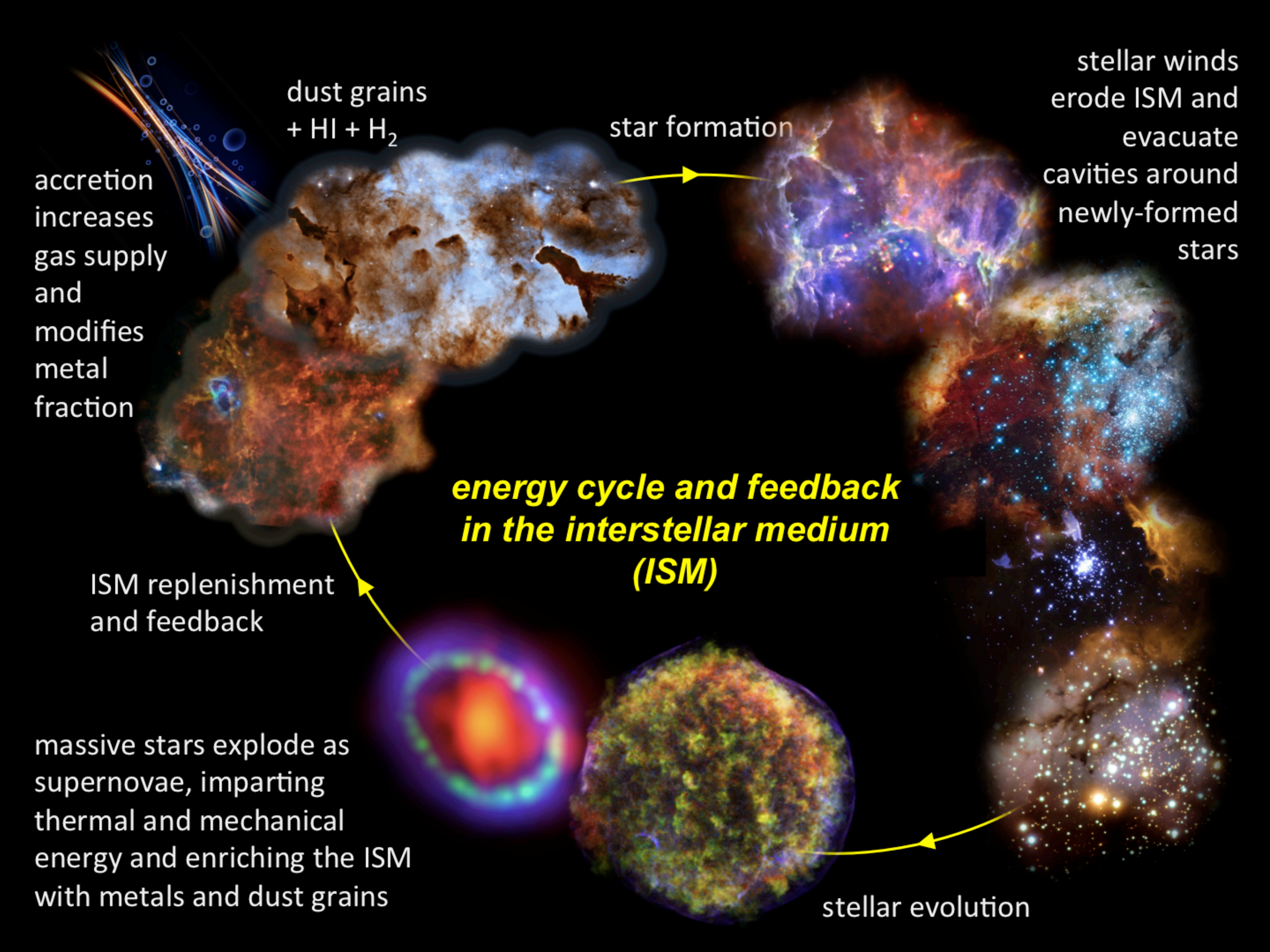
(an approved PRIN SKA/CTA project)

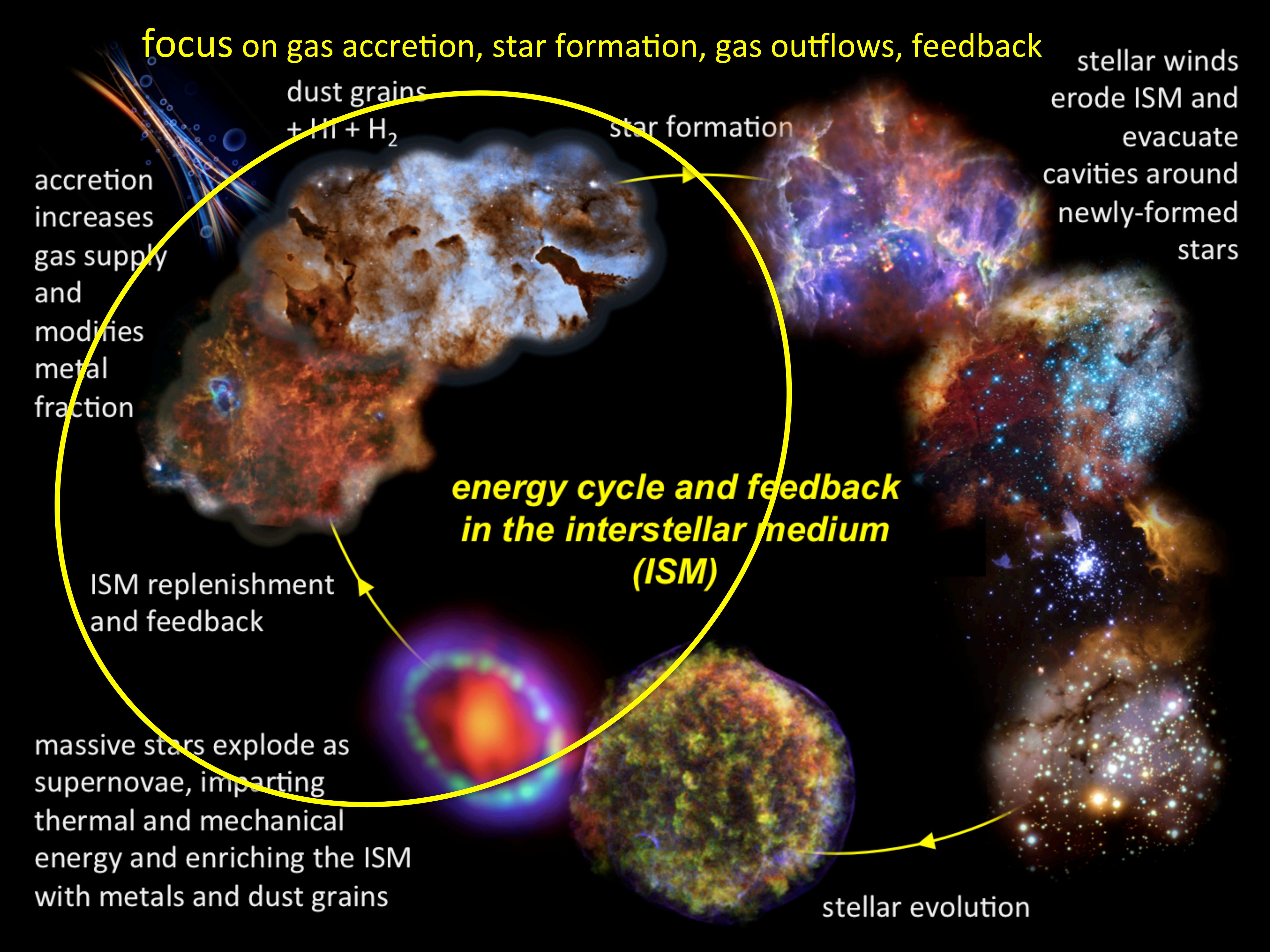
Leslie Hunt (INAF-OAA),

on behalf of the ESKAPE-HI collaboration (8 INAF institutes, 4 universities, 58 cols)

(logo thanks to Dalle Ave & Rampazzo, OAPd)




dust grains
+ HI + H_2
star formation
stellar winds erode ISM and evacuate cavities around newly-formed stars
accretion increases gas supply and modifies metal fraction
energy cycle and feedback in the interstellar medium (ISM)
ISM replenishment and feedback
massive stars explode as supernovae, imparting thermal and mechanical energy and enriching the ISM with metals and dust grains
stellar evolution


focus on gas accretion, star formation, gas outflows, feedback
dust grains + HI + H_2
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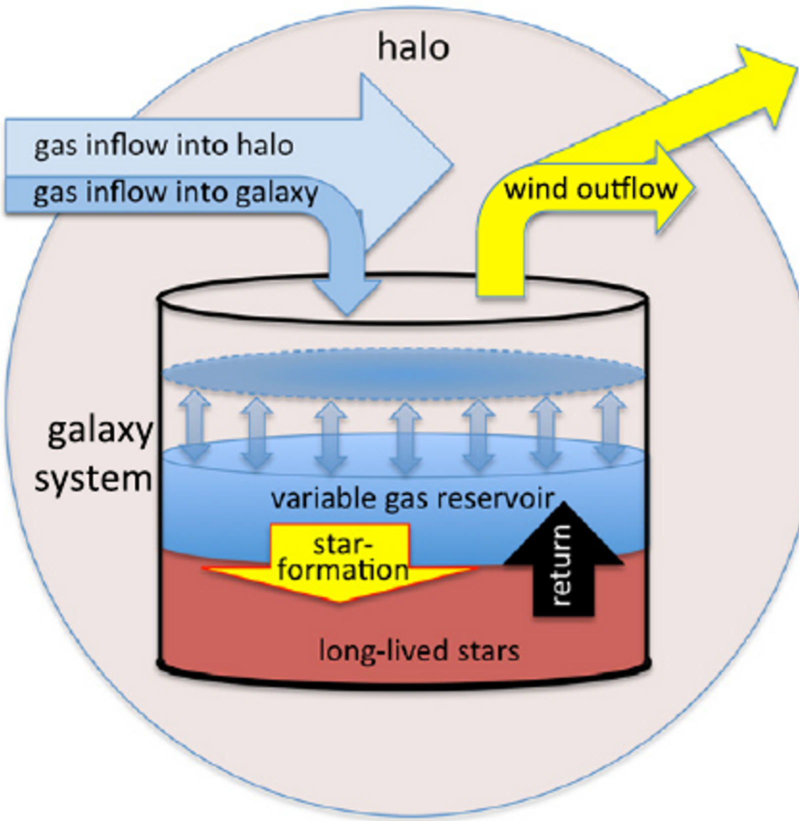
baryonic cycling



Lilly+ (2013) Illustration of the gas-regulated model in which SFR regulated by gas inflow

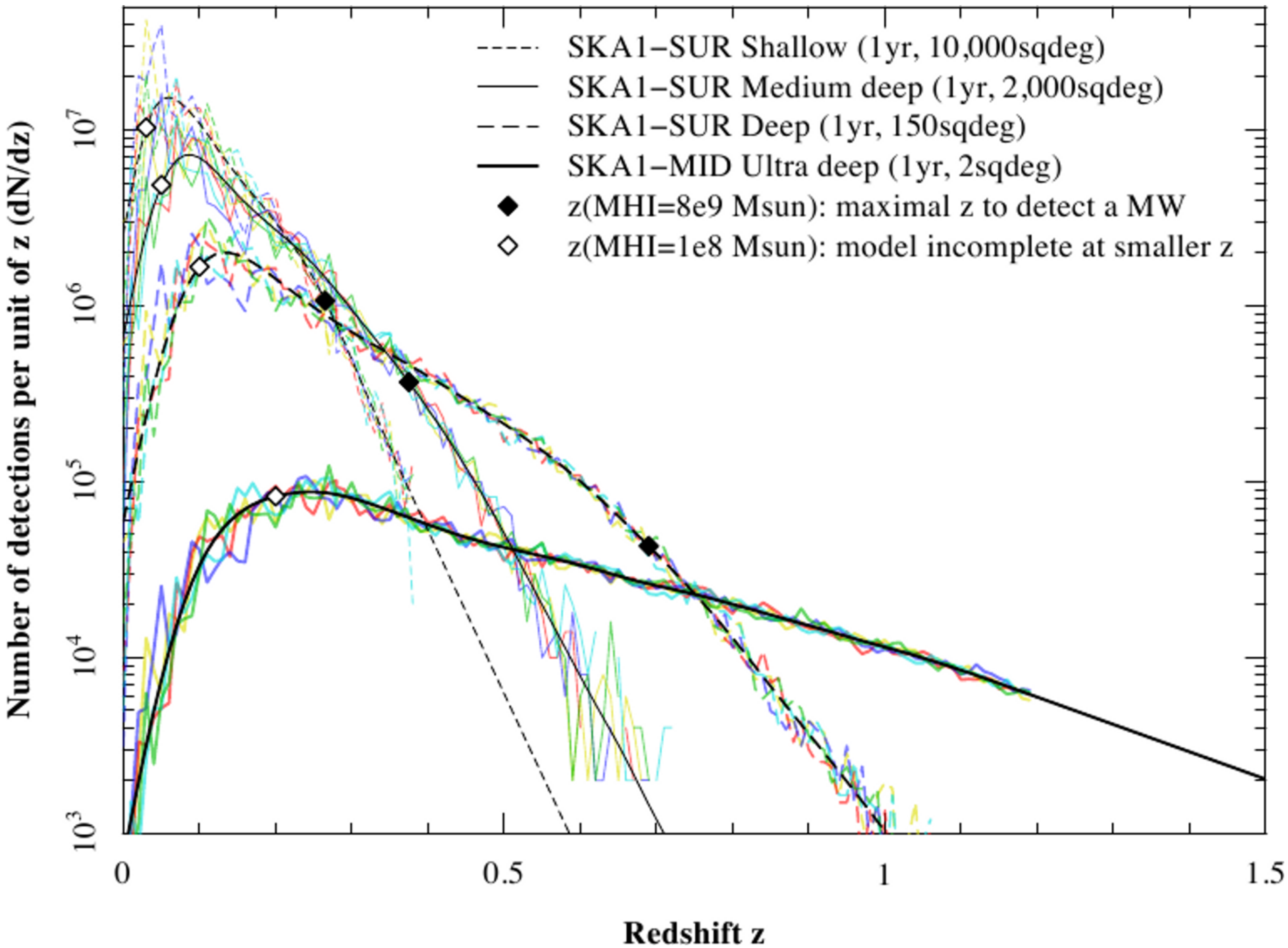
HI cooling/condensation, conversion to H_2 in molecular clouds **key to galaxy evolution**

baryon cycle process manifests in scaling relations, locally and at high z (remember talks by Popesso, Gallazzi):

- main sequence of star formation (MS)
- mass-metallicity relation (MZR)

for given M*, galaxies at higher z have increased SFR and decreased metallicity, with **increased gas content** likely cause

HI fundamental and possible with SKA to z ≤ 1-2

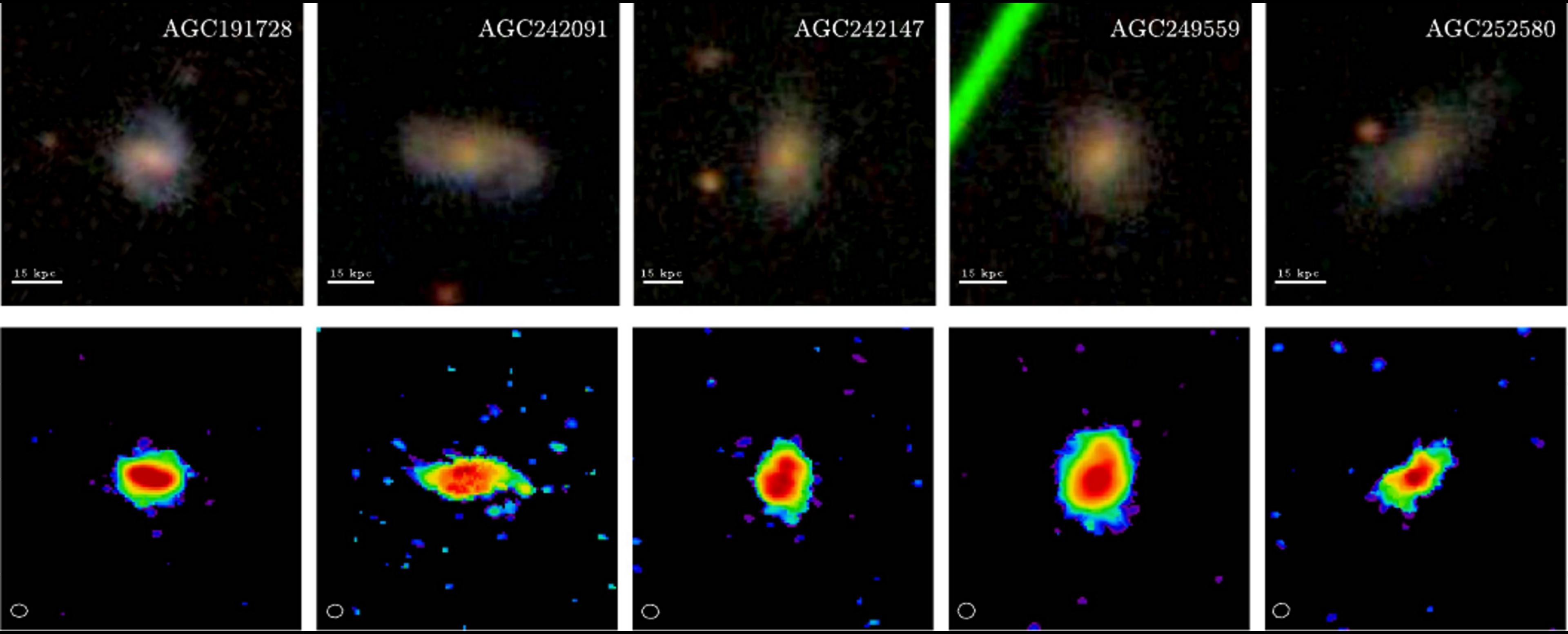


Simulations of HI detections as a function of redshift for the four strawman SKA1 surveys, taken from Blyth+ (2015).

premise that H_2 dominates gas budget outside Local Universe not necessarily true

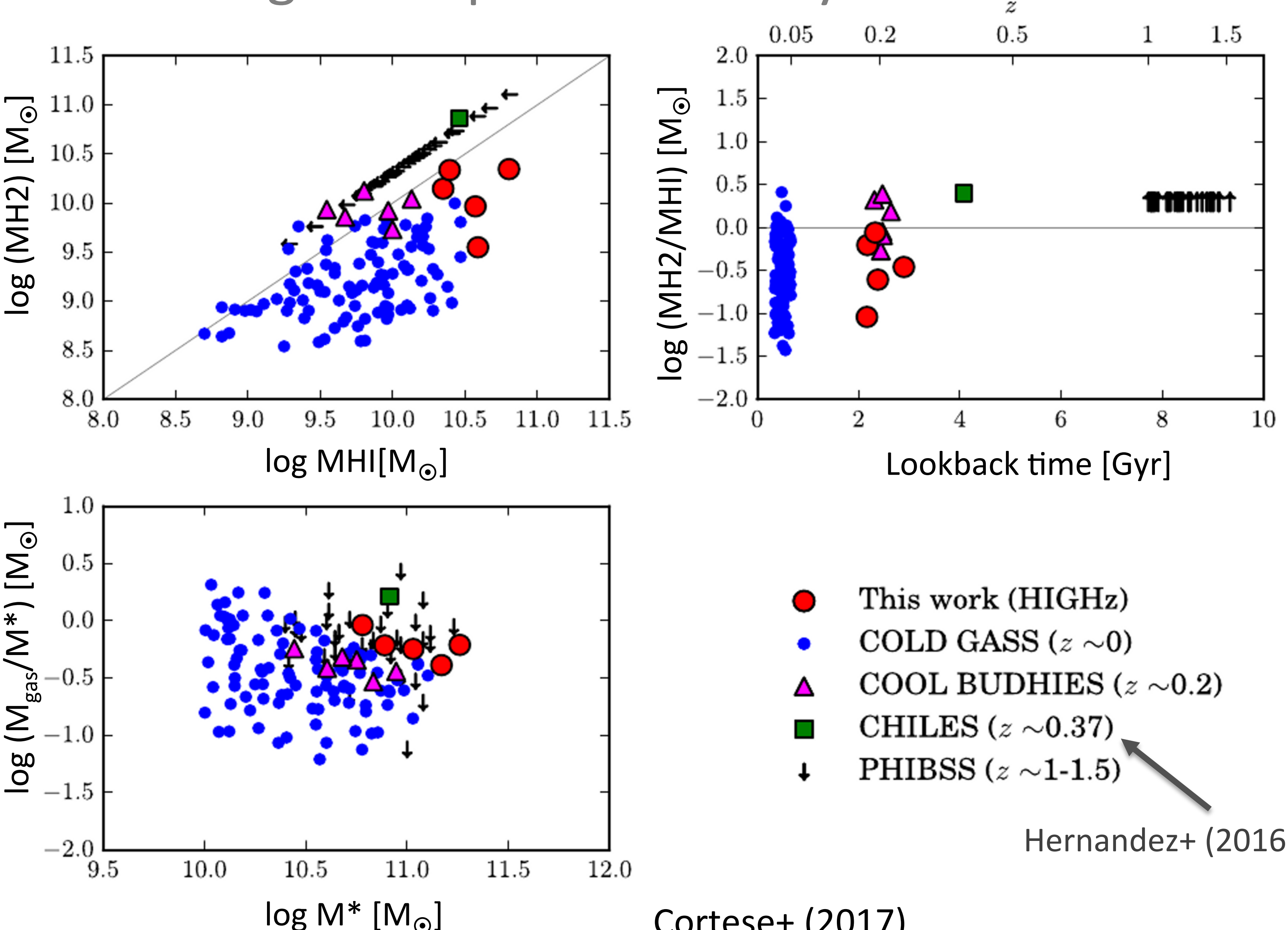
HIGHz galaxies at z=0.2 (Cortese+ 2017): galaxies selected to be massive and HI rich, but ALMA imaging shows significant H_2 as traced by CO

Cortese+ (2017)



see also Hernandez+ 2016 CHILES, VLA survey of COSMOS area, z=0.4, for CO detection with LMT

z > 0 gas not predominantly molecular



Cortese+ (2017)

Summary of ESKAPE-HI WPs

WP1 – Establishing the local benchmark

- WP1a: Gas scaling relations in the Local Universe
- WP1b: Environment, feedback, and baryonic cycling
- WP1c: Gas content and its connection with SFH and stellar populations

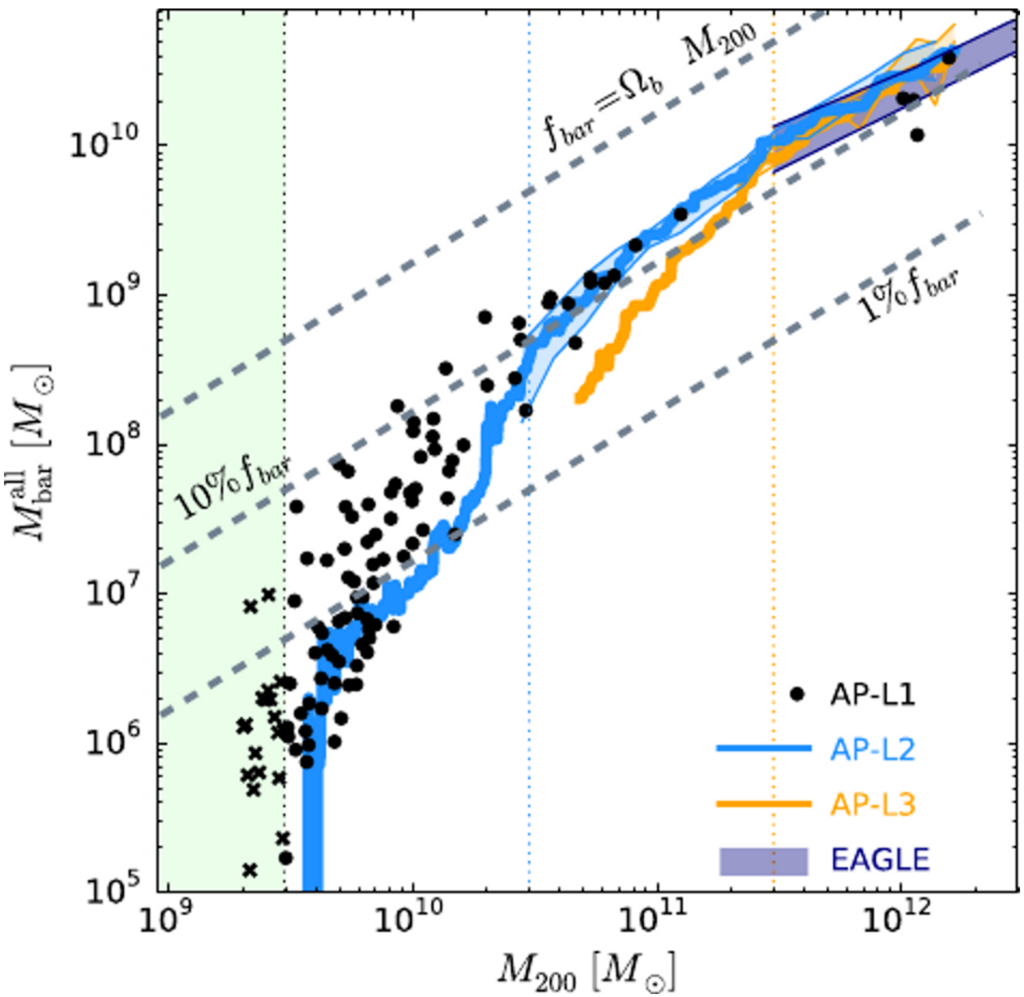
WP2 – Preparing for SKA1 HI surveys

- WP2a: Large-scale galaxy samples from high-z multi-wavelength surveys
- WP2b: Large-scale galaxy samples with CO observations for $0.5 < z < 3$
- WP2c: Models of evolution of gas content and scaling relations

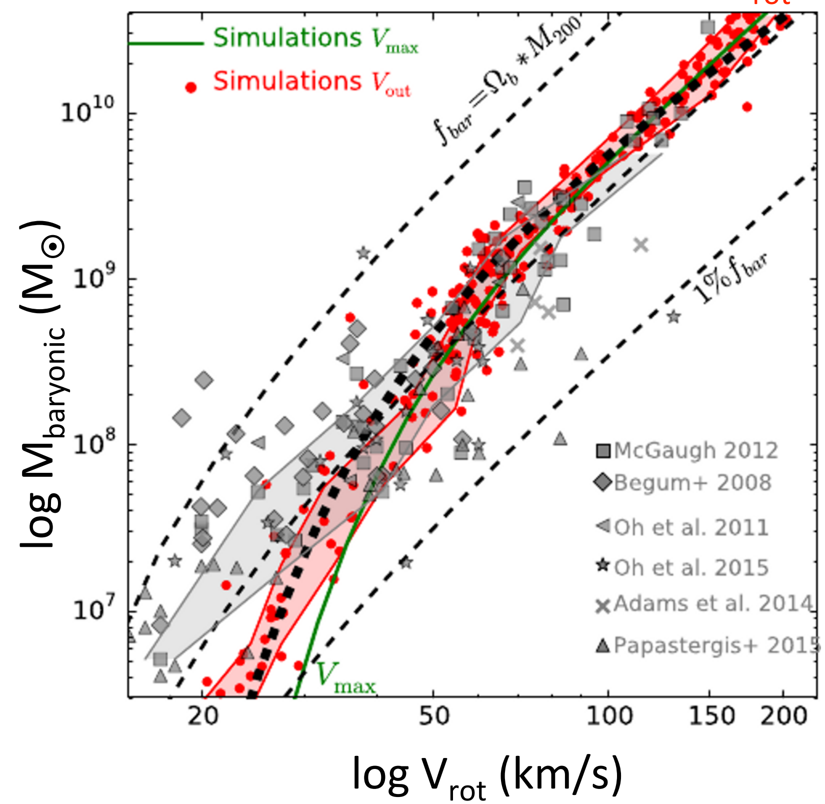
WP1a:
Gas scaling relations in the Local Universe
(lead Hunt)

baryonic mass and rotation velocity:

feedback affects the baryonic Tully-Fisher relation (BTFR) by suppressing baryonic fractions at low mass

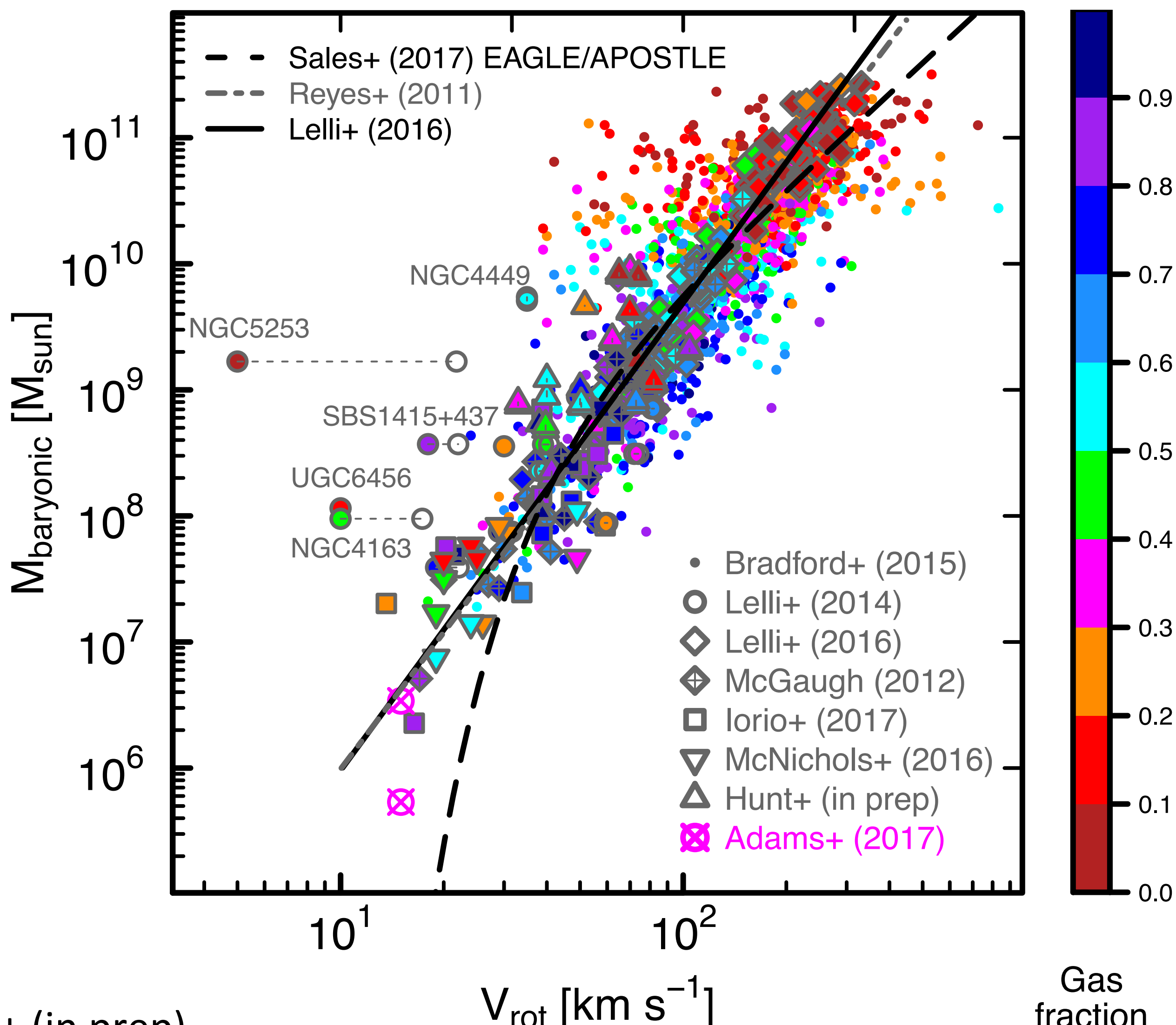


critical issue where to measure V_{rot}?



EAGLE/APOSTLE simulations (feedback via stochastic thermal energy injection) by Sales+ (2017)

HI samples follow a fairly tight BTFR over 5 orders of magnitude in mass



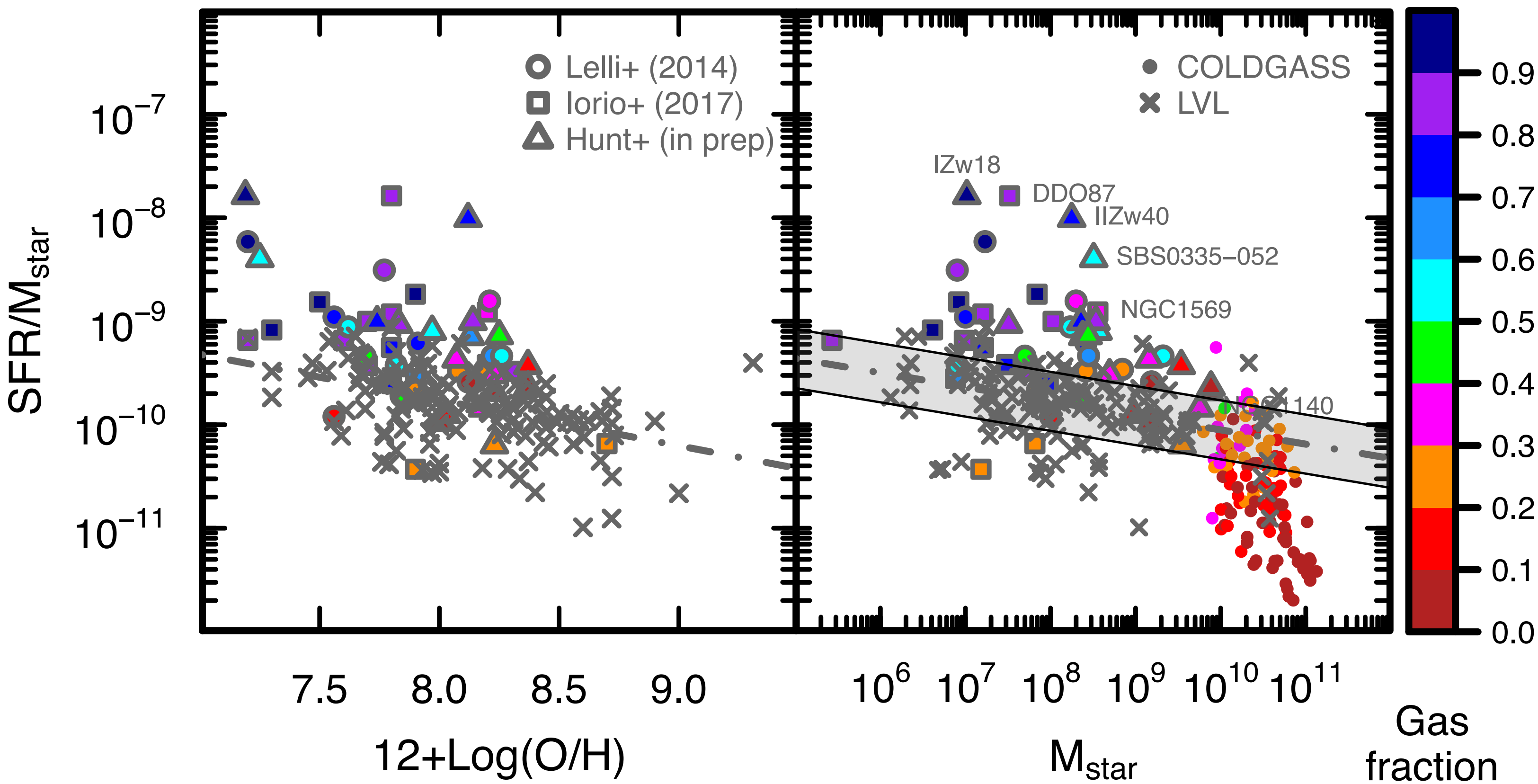
Reyes+ (2011) regression obtained by calibrating optical-color estimates of stellar mass (Bell+ 2003) and gas mass (using *u-r*, Kannappan 2004).

Can we improve such an estimate?

Hunt+ (in prep)

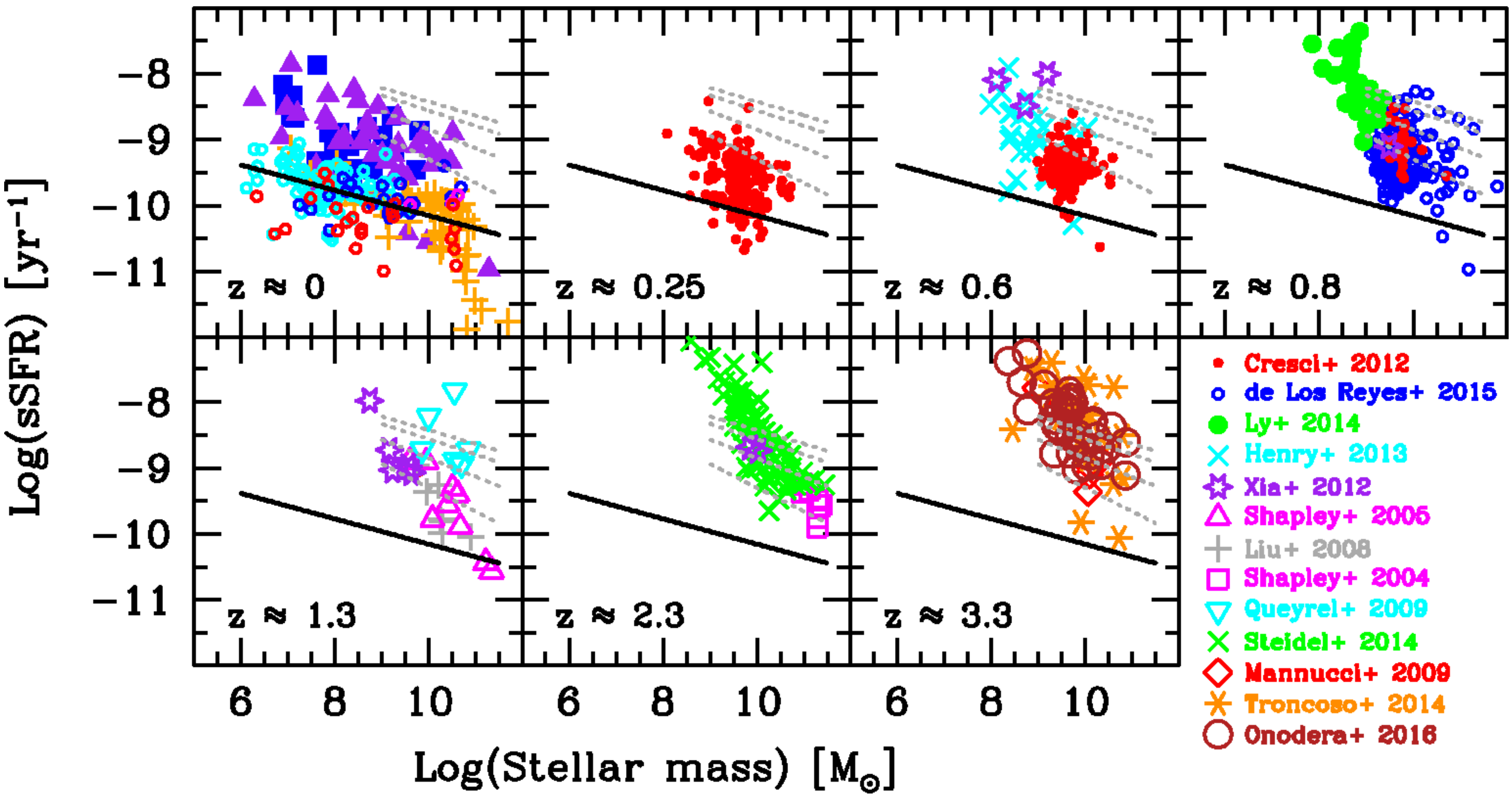
stellar mass and SFR: the SF "main sequence" (z~0)

galaxies above the main sequence have higher gas fractions



specific SFR and Mstar vs. 12+Log(O/H) illustrates mutual scaling among Mstar, O/H, SFR, adapted from Hunt+ (2016, see also Mannucci+ 2010).

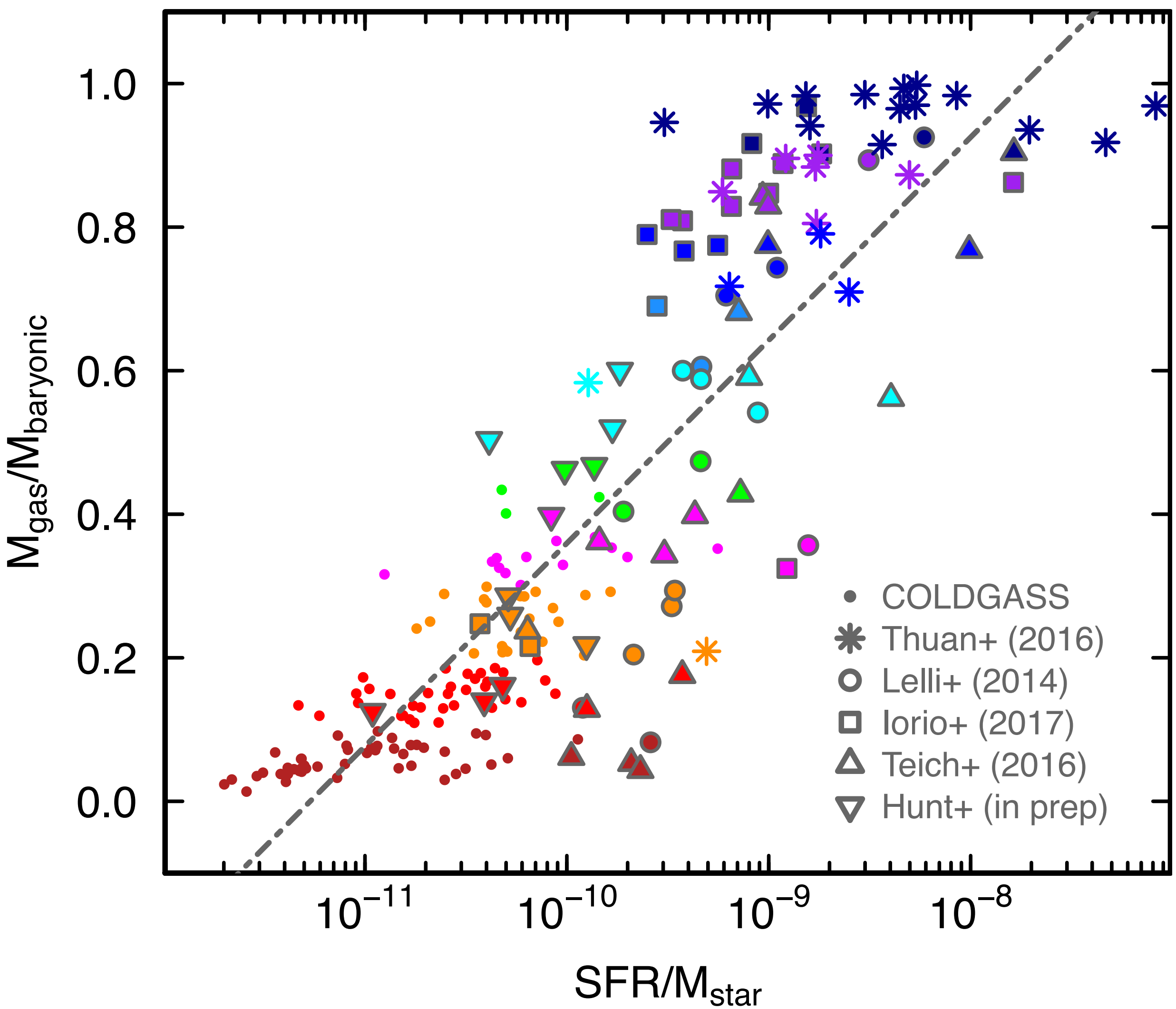
M_{star} and SFR: the SF "main sequence" (z ~ 0-3)



Notice the steeper slope in z>0 samples: selection effects?

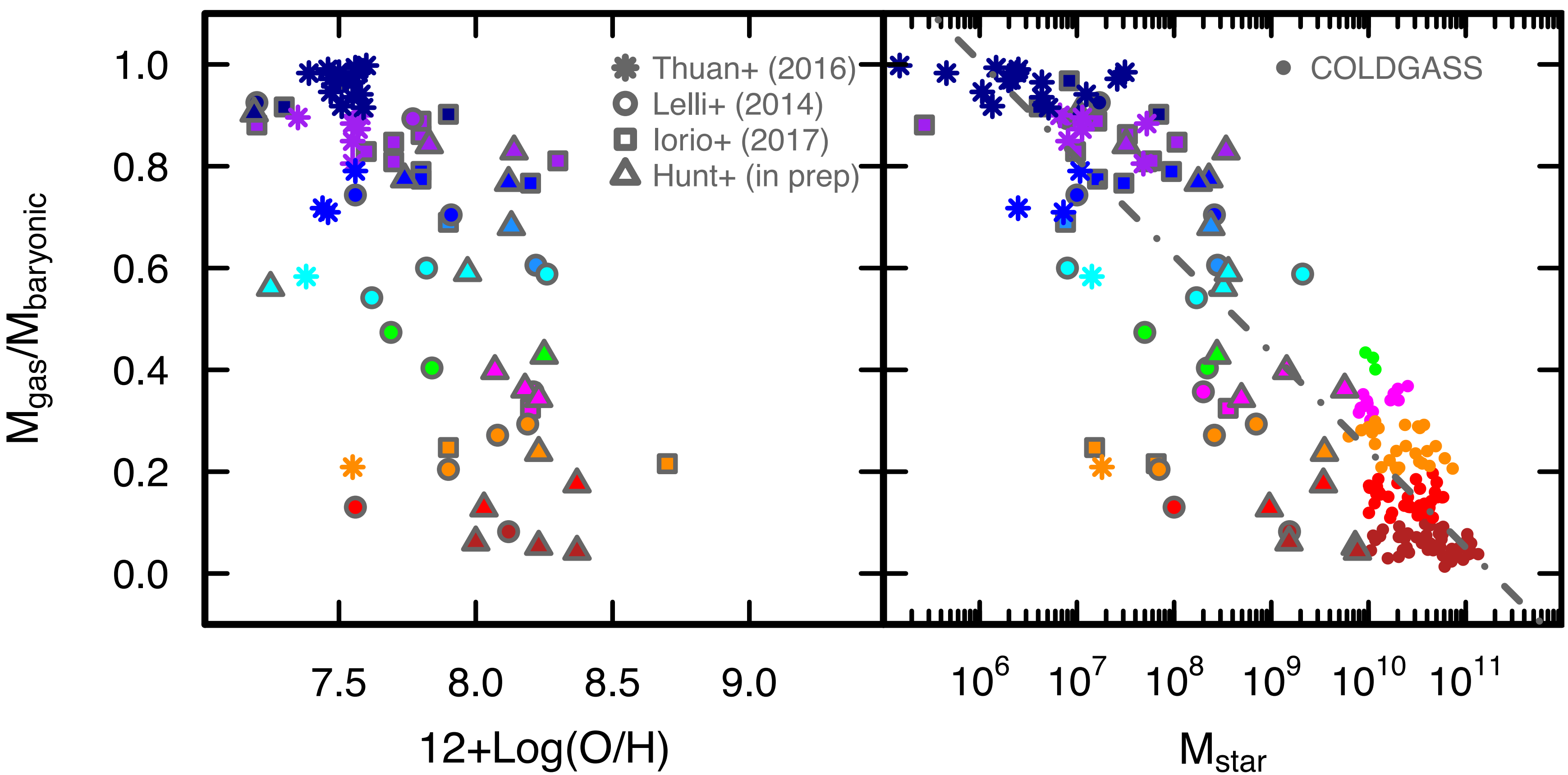
Hunt+ (2016)

gas fraction correlates with specific SFR (although with large spread)

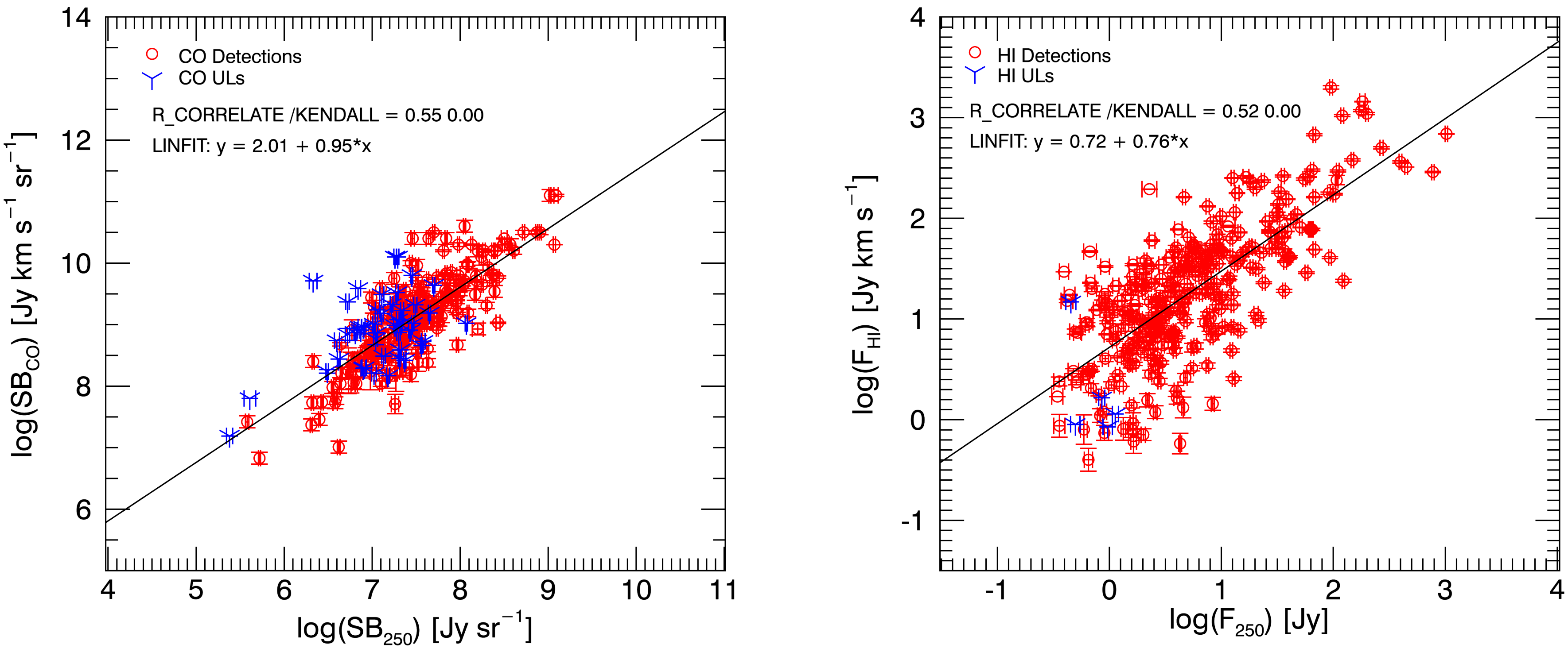


Hunt+ (in prep)

gas fraction correlates with M_{star}, less so with O/H



scaling relations between dust continuum and gas (HI, CO) from DustPedia



313 late-type **DustPedia** galaxies (see Davies+2017, Casasola+ 2017): both molecular gas (left) and atomic hydrogen (right) follow cool dust tracers (250 μm emission) - **see talk by Bianchi**

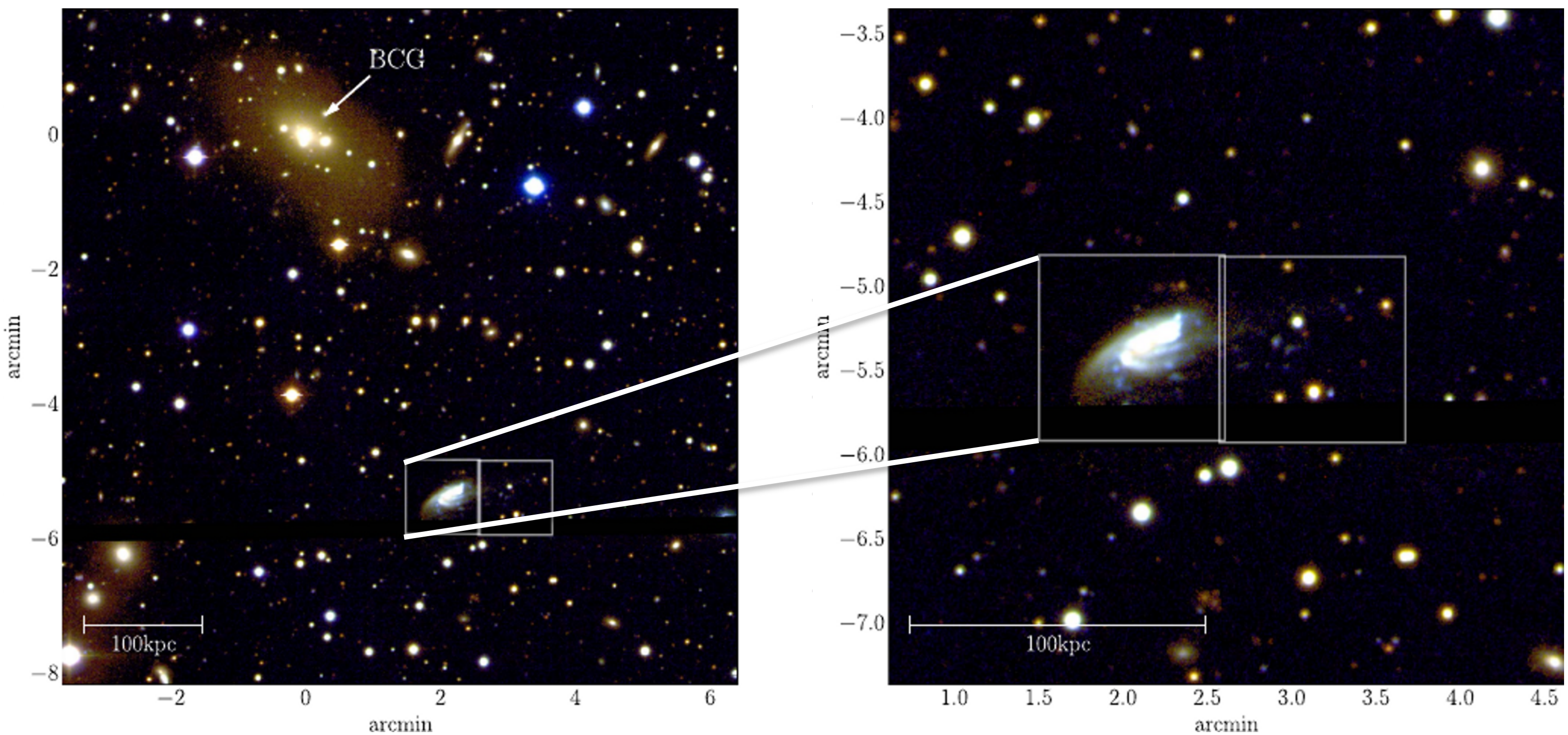
Important because dust may be "cheaper" than gas to observe at high redshift!

WP1b: Environment, feedback, baryonic cycling (lead Poggianti)

VLT LP GAs Stripping Phenomena (GASP), JVLA-GASP surveys

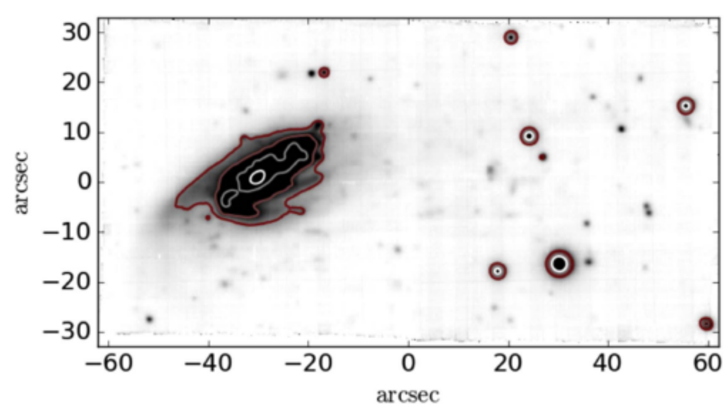
Measuring AGN Under the MUSE Microscope survey (MAGNUM)

GASP + WINGS (Poggianti+)



GAs Stripping Phenomena in galaxies with MUSE (GASP): Poggianti+ (2017)

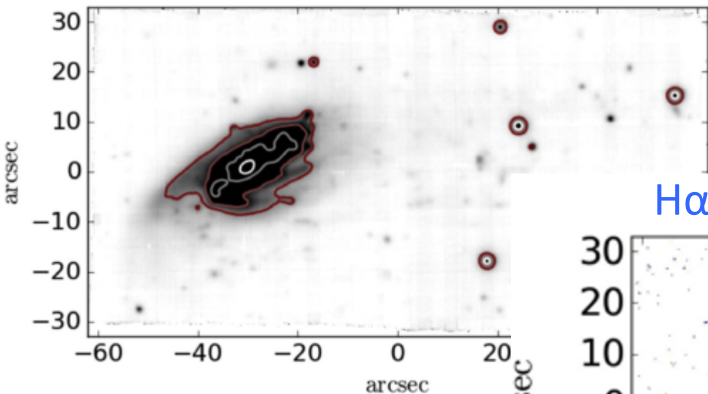
JO206 (z = 0.0513, WINGS J211347.41+022834.9), classical jellyfish galaxy (also see talks by Biviano, Gullieuszik, Moretti)



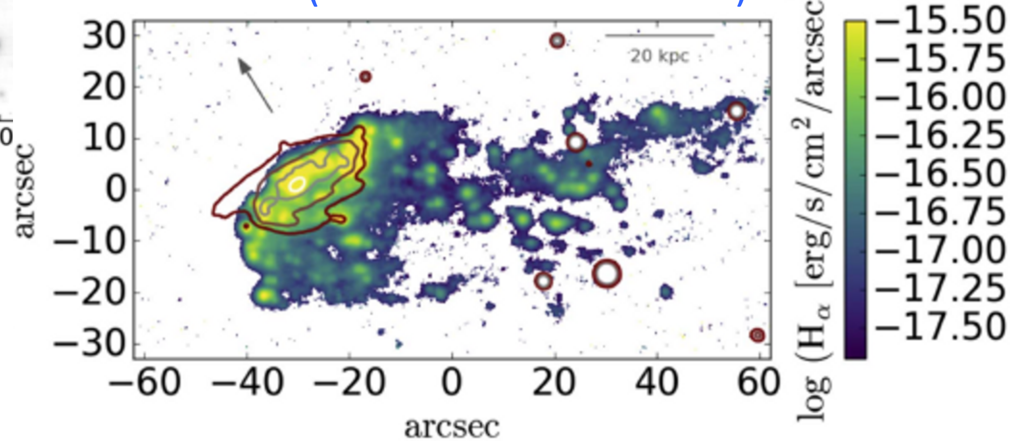
MUSE “white” light

JO206 (z=0.05)

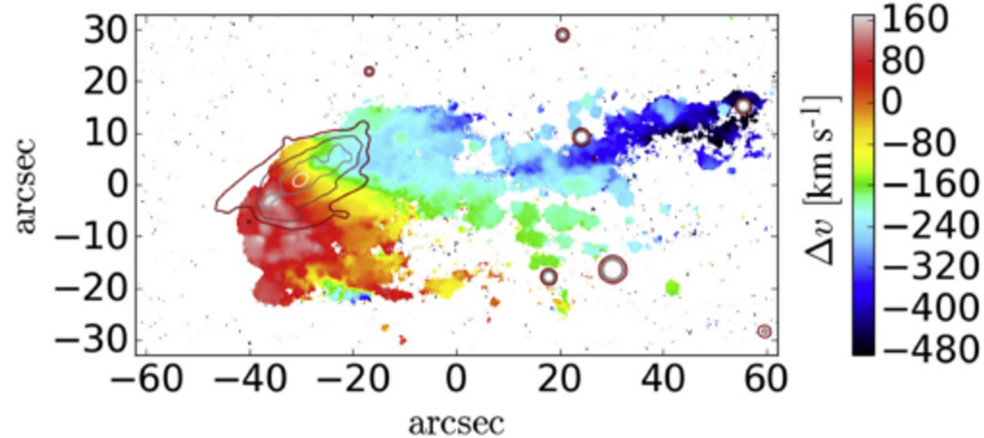
J0206 is massive (9 x 10^{10} $M_{\odot}$) at small projected clustercentric radius and a high relative velocity



Hα flux (contours stellar mass)



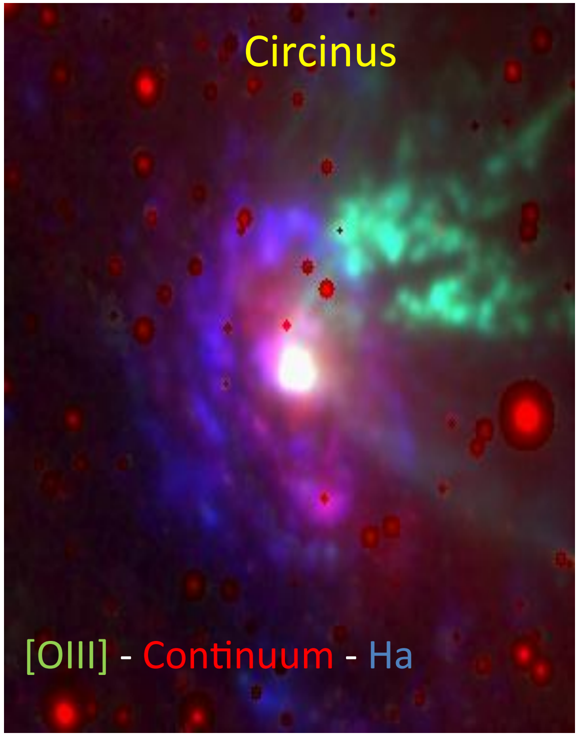
velocity field from Hα



MUSE Hα map shows ≥ 90 kpc long tentacles of ionized gas stripped away by ram pressure

Poggianti+ (2017)

MAGNUM: *Measuring Active Galactic Nuclei Under MUSE Microscope*



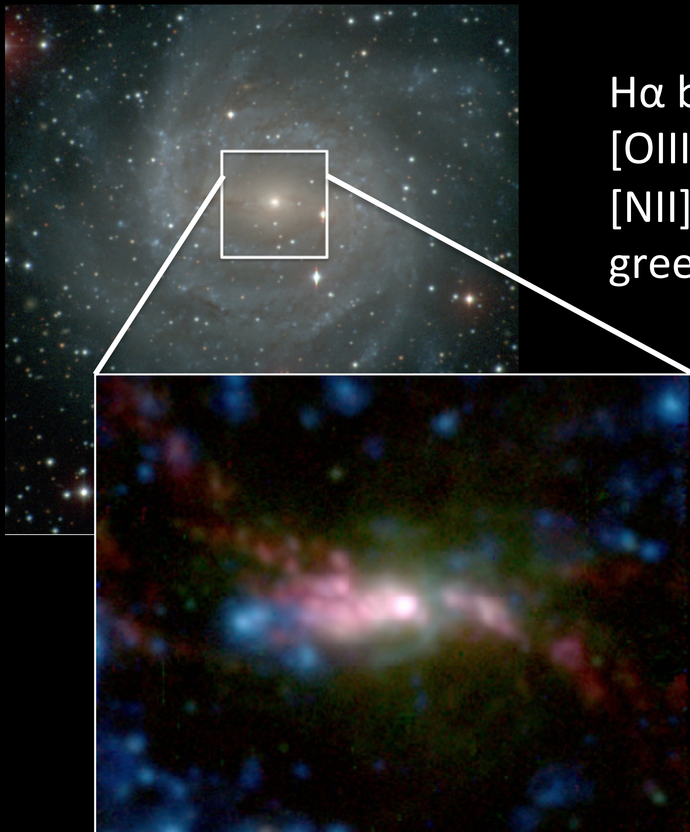
(Cresci+ 2015, Minghozzi+ 2017, Venturi+ 2017)

- ✓ Targeting Nearby AGNs (D < 30 Mpc) observable from ESO
- ✓ Seeing limited (~1"): 15 pc (@4Mpc) to 115 pc (@30Mpc)
- ✓ so far 10 objects observed with MUSE IFU (900,000 spectra!!)
- ✓ Multi-wavelength data available: *Chandra, XMM-Newton, Galex, HST, Spitzer, Herschel, ALMA, Radio…*

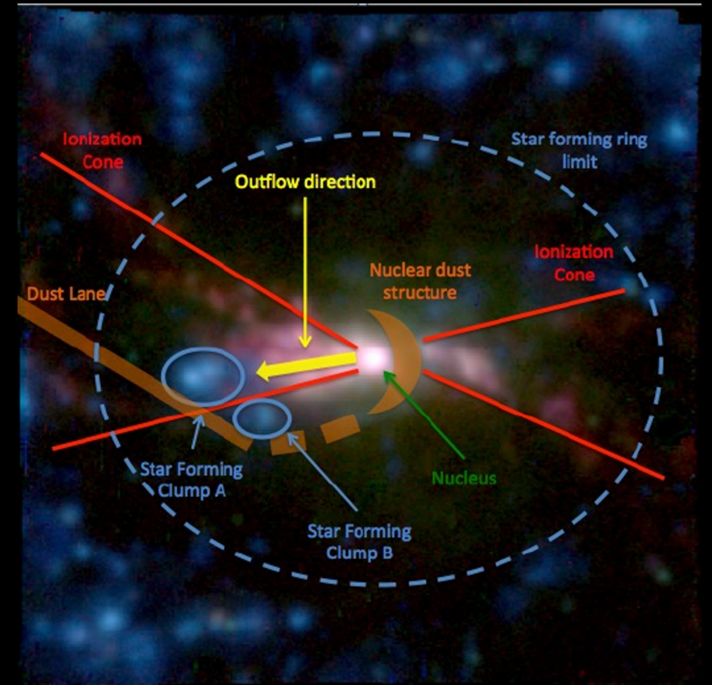
MAGNUM will quantify effects on ionized gas of feedback for a sample of nearby prototypical AGN.

Analysis of MAGNUM MUSE data will explore properties of galactic outflows and their positive/negative feedback, and prepare the way for future similar HI surveys with SKA (e.g. Morganti+ 2015).

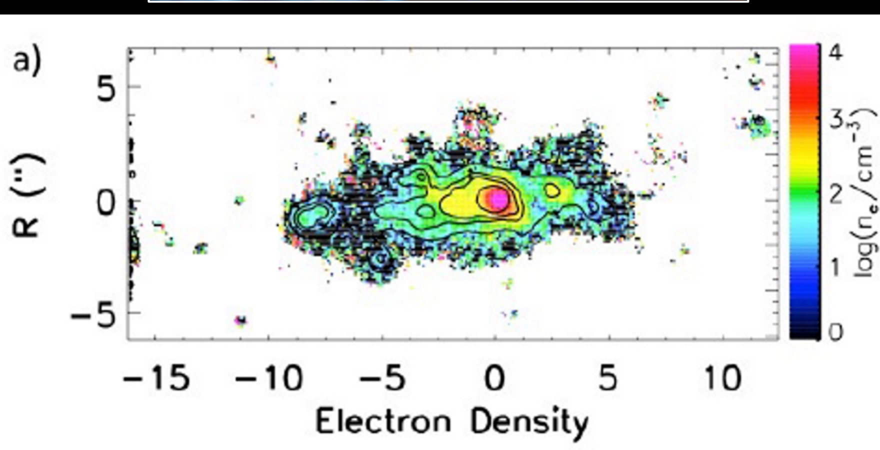
NGC 5643 (Cresci+ 2015)

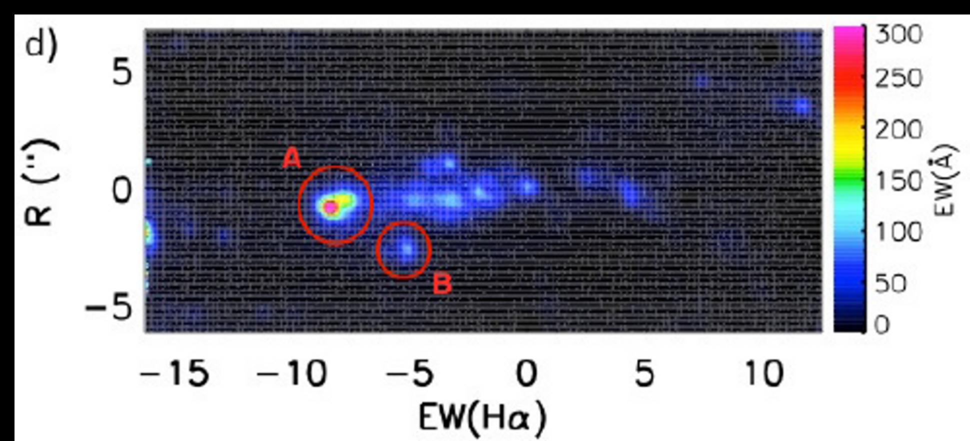


Hα blue, [OIII]λ5007 red, [NII]λ6584 green)



First results show that AGN feedback does not only remove gas from a galaxy, but can also trigger new star-formation events **(see also talks by Mingozzi, Venturi).**





WP1c: Gas content and its connection with SFH and stellar populations (lead Zibetti)

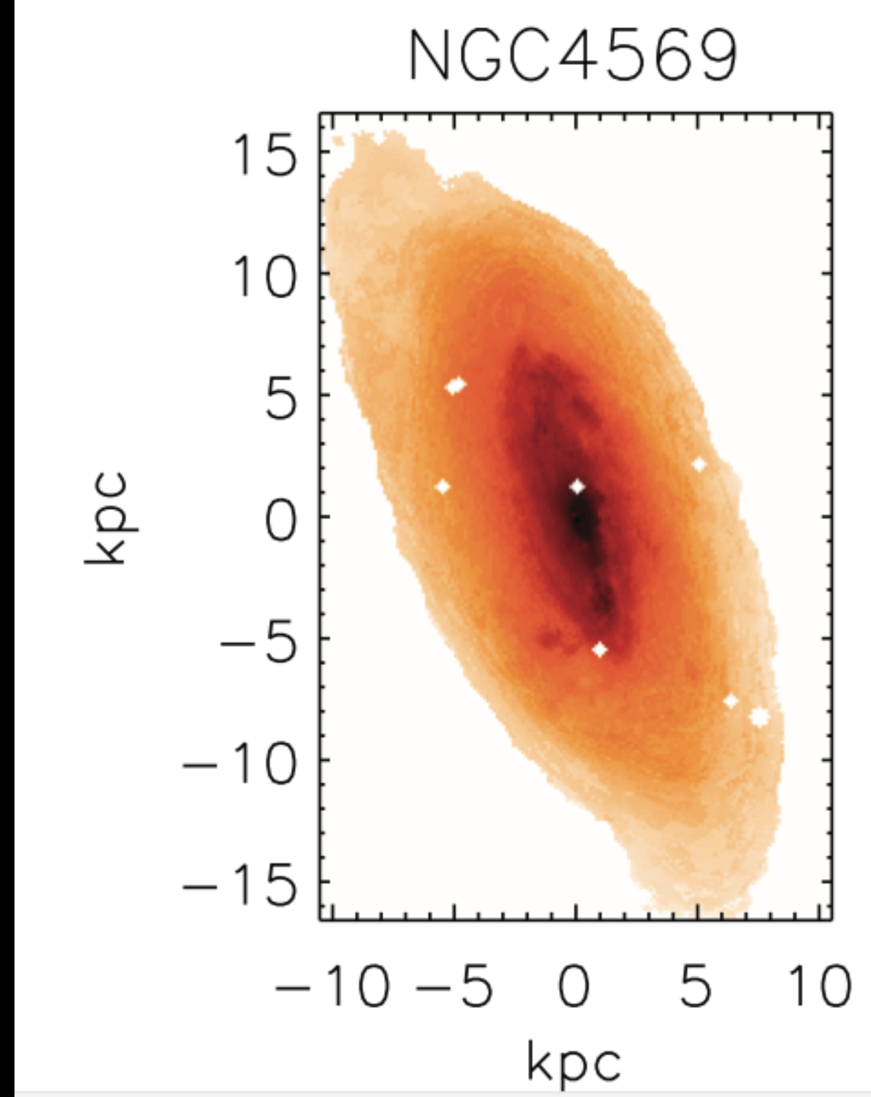
Compare/confront integrated stellar population analysis tools combined with CMDs for resolved populations calibrate mass-to-light relations with IRAC, especially for dwarf starbursts (starting from Zibetti+ 2009)

IRAC (3.6+5.6+8)

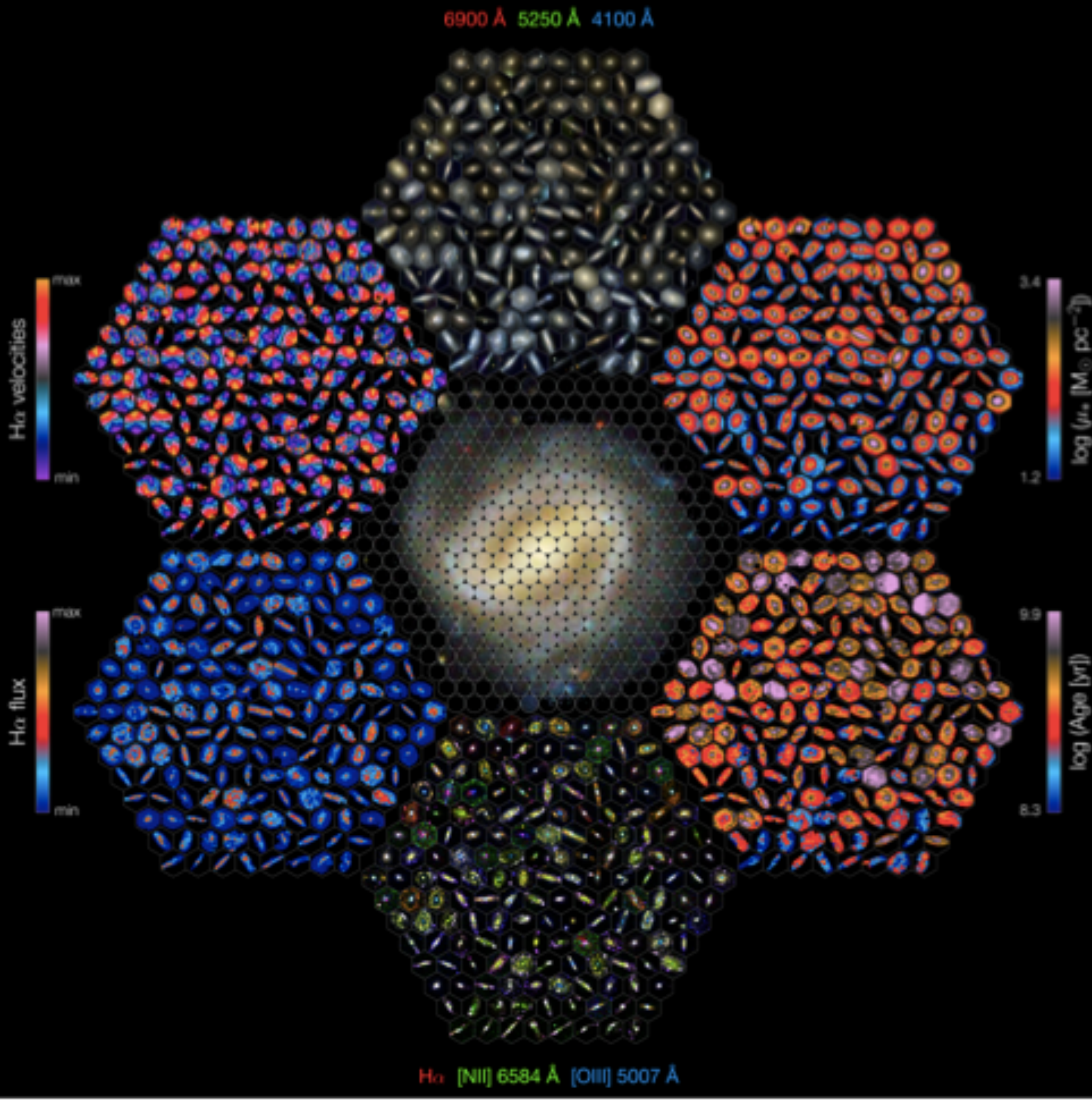
PACS (70+100+160)

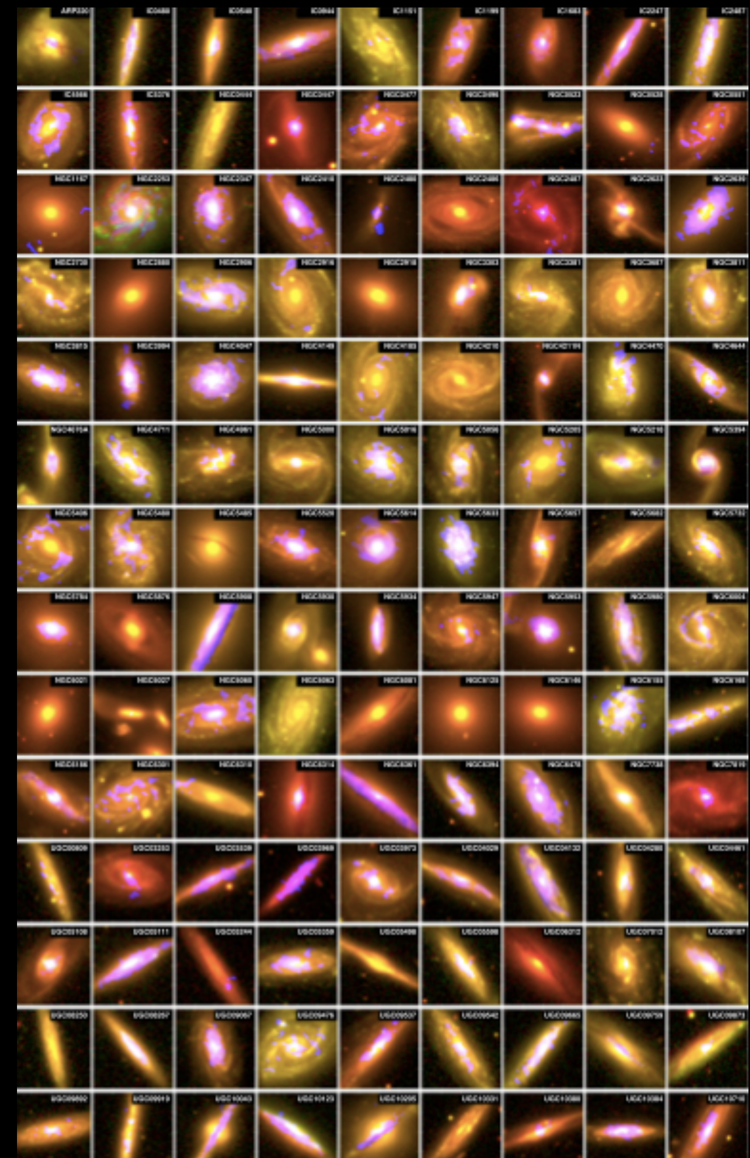
exploit KINGFISH multi-λ survey

compare M/L to results for SFH where stellar populations resolved in nearby dwarfs (Annibali, Cignone, Tosi+ 2018)



CALIFA spatially resolved ionized gas diagnostics (Garcia-Benito, Zibetti+ 2015) combined with CARMA CO data for CALIFA galaxies (Bolatto+ 2017) provide powerful spatially resolved diagnostics for baryonic recycling!





WP2. Preparing for high-z surveys

WP2a:
Galaxy samples from high-z multi-wavelength surveys
(lead Scodeggio)

WP2b:
Galaxy samples with CO observations for $0.5 < z < 3$
(lead Renzini)

WP2c:
Models of evolution of gas content and scaling relations
(lead Calura)

Contributions from SKA-Technology group

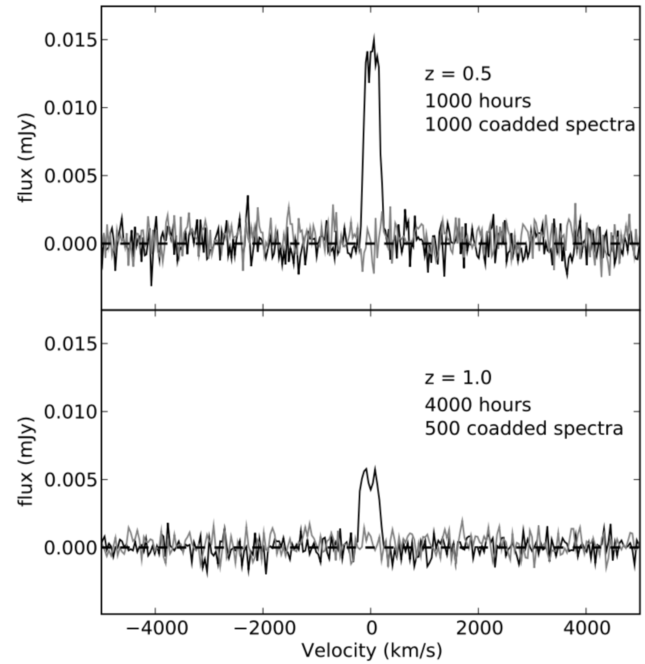
Low Frequency Aperture Array (SKA Low)

Central Signal Processor

- Optimize SKA1 HI surveys strategies.
- Exploit the knowledge of the internals of CSP and LFAA in order to:
  - Optimize the observation strategies taking into account instrument capabilities and limits in its initial phase
  - Select the best strategies for calibration

HI in galaxies from LADUMA

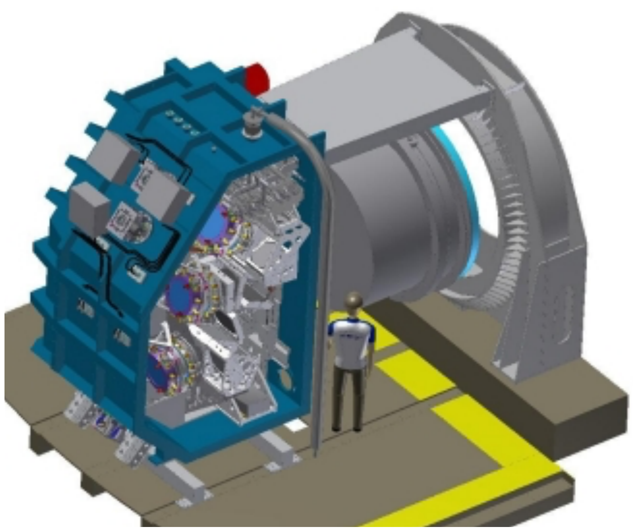
F. Mannucci, WP2



MEERKAT/LADUMA survey:

- ~ 5000h in the ECDFS, ~4sq.deg
- detection of HI in galaxies up to z~1.5 with single detections and stacking analysis

- Large number (>10.000) of redshifts are needed
- properties of galaxies: mass, SFR, metallicity, morphology.....



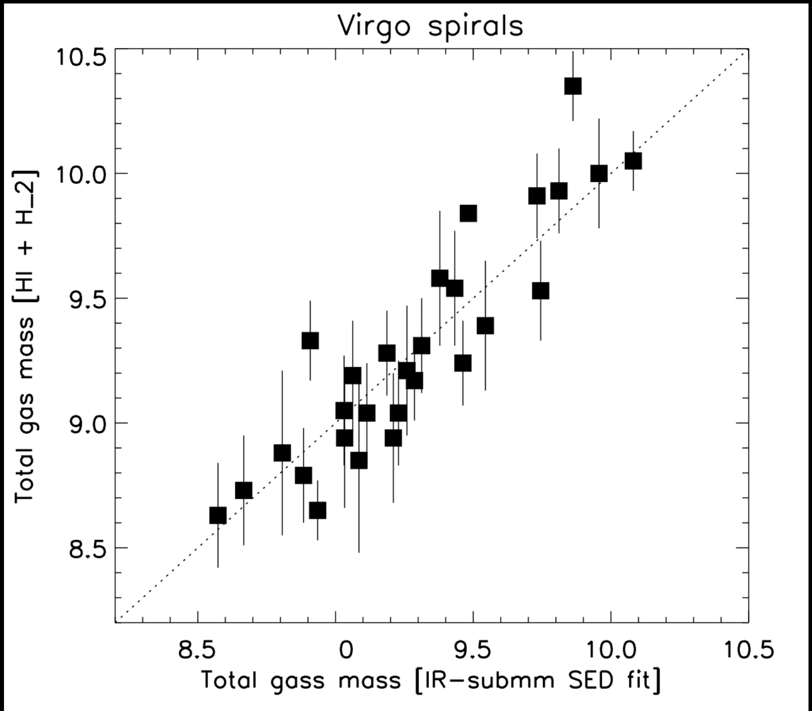
Project:

- study the role of MOONS
- optimize the observing strategy
- simulations
- target selection

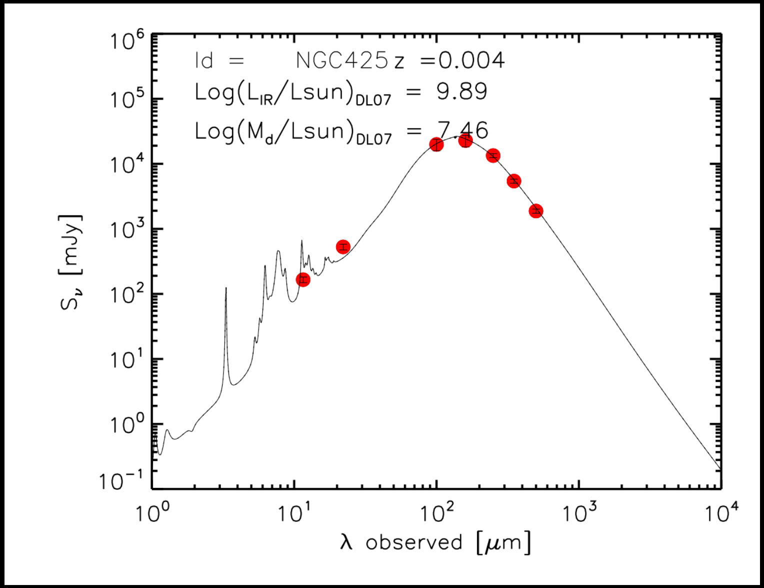
MOON SKA WORLD

calibration of dust continuum measurements to compute gas masses, in particular through proprietary (ALMA, LMT) and public CO derived gas masses of *Herschel* selected sources

Example: Testing total gas masses on local Virgo spirals



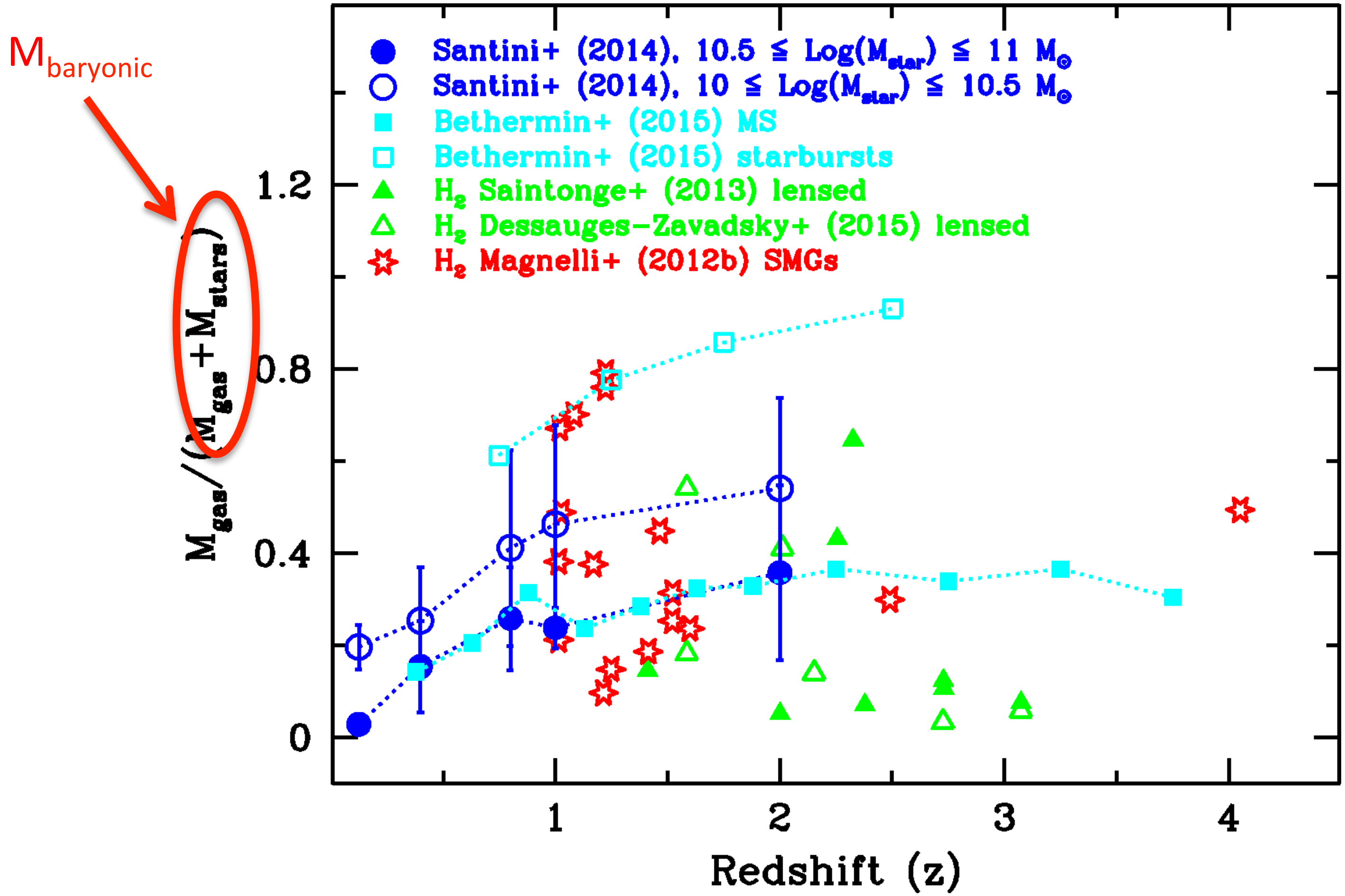
Rodighiero et al. in prep.



Herschel data from Corbelli+ (2012)
Mid-IR from WISE

Fits performed by Georgios Magdis (mainly based on Li & Draine 2007 models, but see Magdis+ 2012)

calibrating dust mass to estimate gas mass: mass segregation important for gas-mass fractions



(Hunt, Santini, Rodighiero, Gruppioni+ in prep)

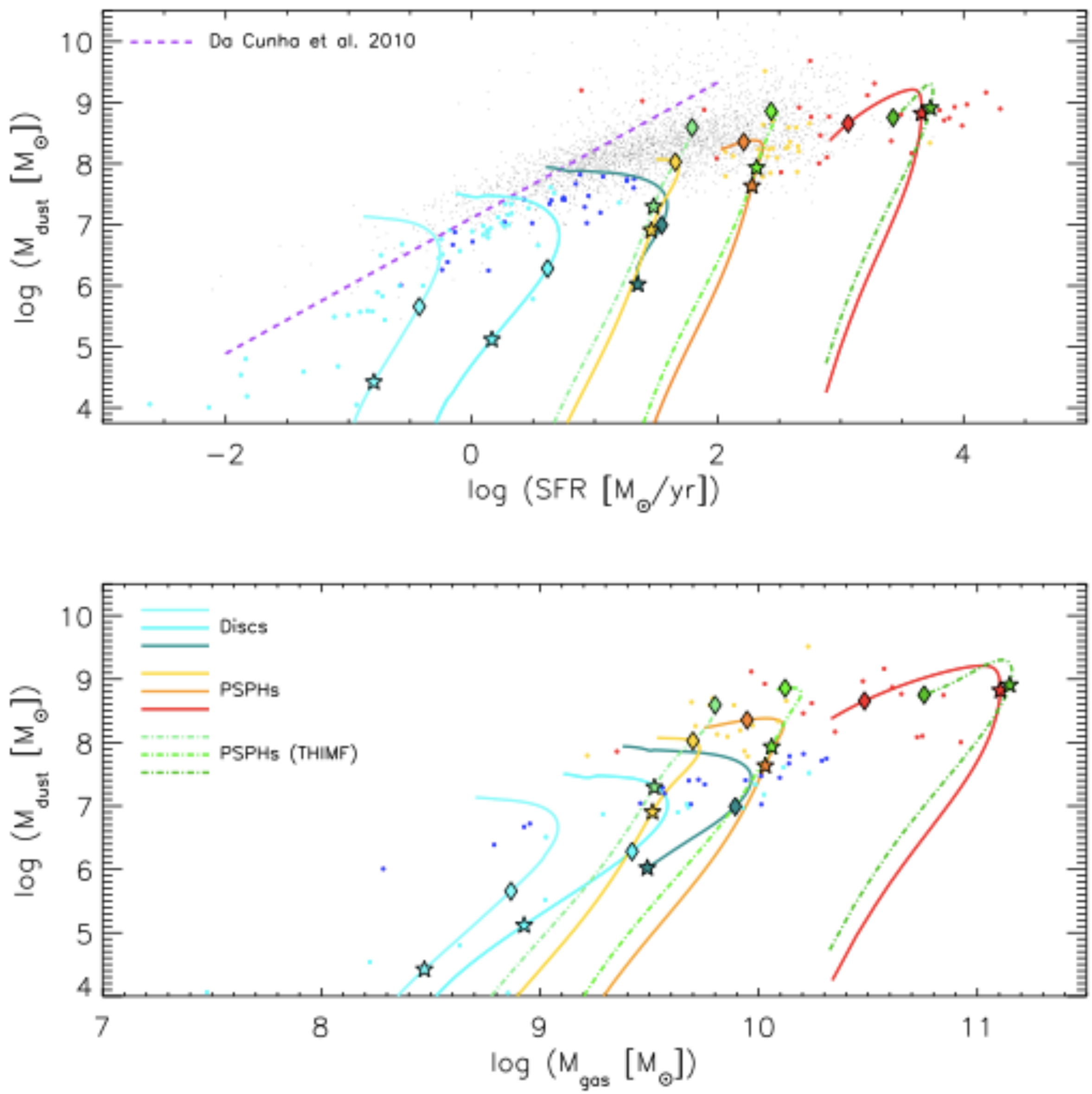
Gas-mass fraction vs redshift inferred from dust with the data from Santini+ (2014), Bethermin+ (2015) datasets using a metallicity-dependent gas-to-dust ratio, and directly from the others using a metallicity-dependent CO-H_2 conversion factor

models of dust mass vs. SFR and gas mass

Local data from KINGFISH (Skibba+ 2011), ULIRGs (Santini+ 2010); high-z from Gruppioni+ 2013, Santini+ 2014). Chemical-evolution models from **Calura+ (2017)** show that trends of dust mass with SFR and gas mass can be explained through:

a dependence of dust-to-stellar mass on early star-formation history (proto-spheroids change rapidly at early times, while spiral disks remain relatively unchanged.

(remember talk by Graziani for other models available to our group)



future perspectives for ESKAPE-HI: the role of HI in galaxy evolution with local benchmarks, high-z HI survey preparation

- M_{star}, SFR, O/H, M_{HI}, M_{dust}, M_{gas} for dwarf-dominated sample of ~700 galaxies
- feedback, environment assessment for GASP, WINGS samples including MUSE cubes and VLA HI observations (already approved)
- positive/negative feedback as a function of AGN luminosity, ionized gas probed by MUSE (MAGNUM)
- mass-to-light ratios reassessed for dwarf starbursts, compared to resolved stellar population estimates
- optimized SKA survey algorithms; set the stage for SKA HI surveys with planned MOONS observations (similar time frames);need to enter into SKA precursors in southern hemisphere
- homogeneous parameter estimates for possible SKA HI survey fields
- model comparisons with gas/star/dust observations of large-scale samples