Dwarf Galaxies in the context of galaxy evolution

Francesca Annibali (INAF-OAS)

on behalf of the *DwarfGalaxies* team

Audizioni RSN2, May 16th 2022

Why are dwarf galaxies interesting?

- Most numerous type of galaxies in the Universe and, according to Λ CDM, the first to form → **building blocks** of larger structures
- Primary candidate sources for cosmic reionization
- dIrrs and BCDs (low metallicity + gas + SF) in the local Universe are the closest analogues to primeval galaxies in the early Universe
- Best systems to study feedback from massive stars /supernovae and development of galactic winds

Some questions we want to address:

- Provide an observational test of the hierarchical merging paradigm at the dwarf galaxy scales
- Role of interaction/merging events in the evolution of dwarf galaxies
- Interplay between gas content, star formation and stellar feedback

and many others….

Our approach:

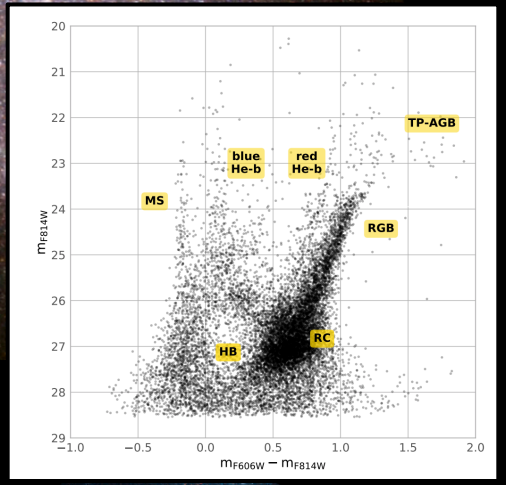
- **Multi – wavelength datasets** and **theoretical modelling** of nearby gas-rich dwarfs

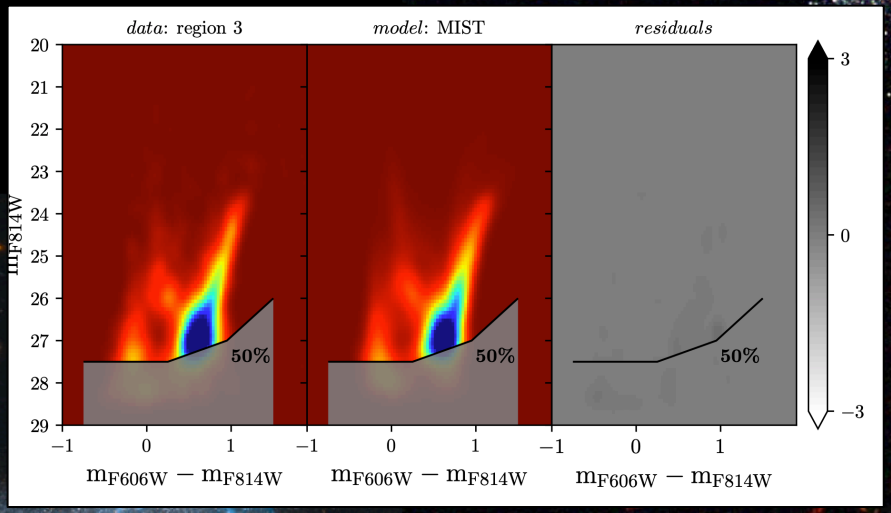
Stellar Populations and Star Formation Histories (SFHs) from resolved-star color-magnitude diagram (CMDs) modelling

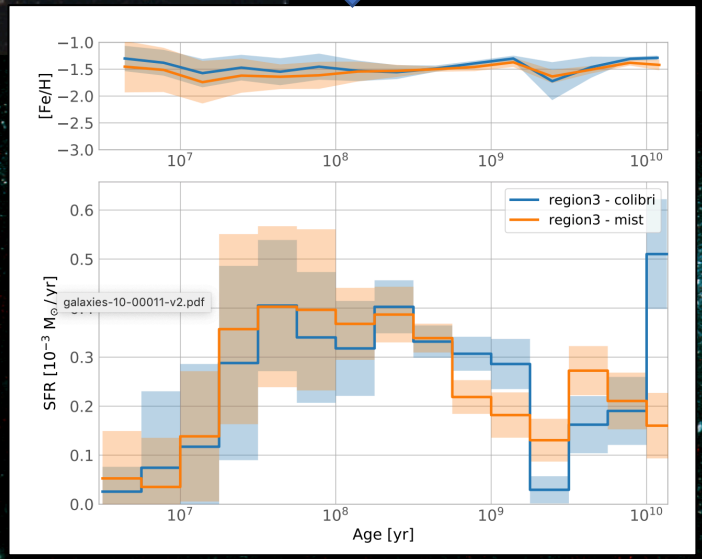
The interstellar medium and its gas phases (ionized, atomic, molecular), metallicity, and dust

Hydrodynamical N-body simulations, galaxy dynamics, chemical evolution models

Stellar Populations and Star Formation Histories (SFHs) from resolved-star color-magnitude diagram (CMDs) modelling



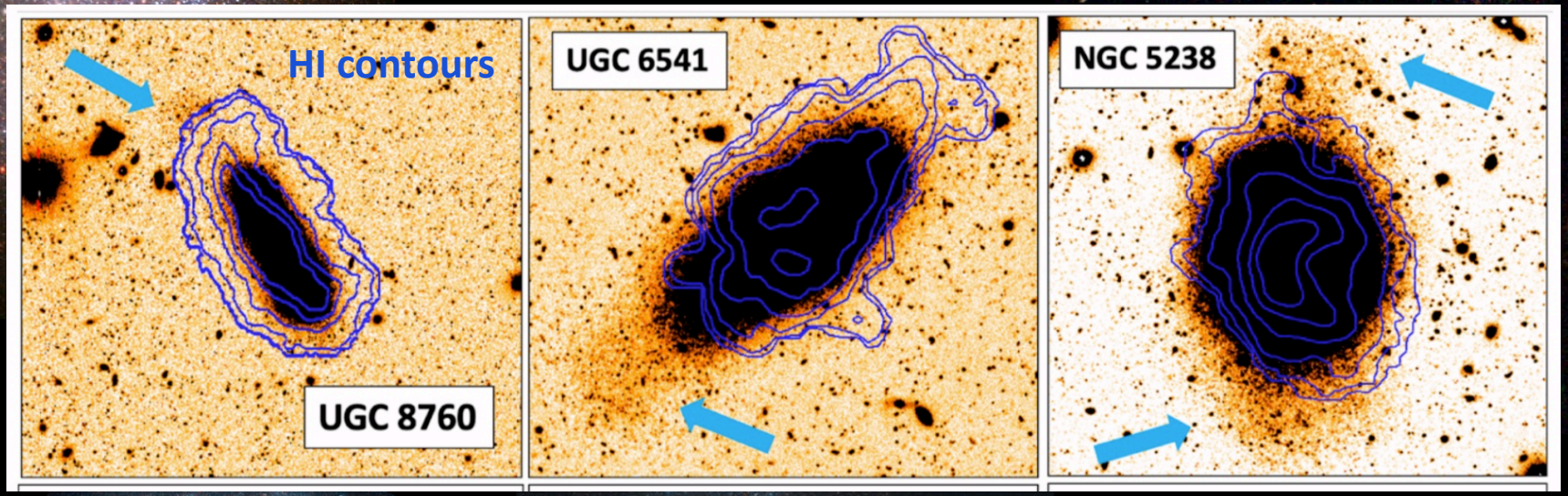




Ancient star formation in UGC 4483;
Sacchi *et al.* 2021, ApJ 911, 62S

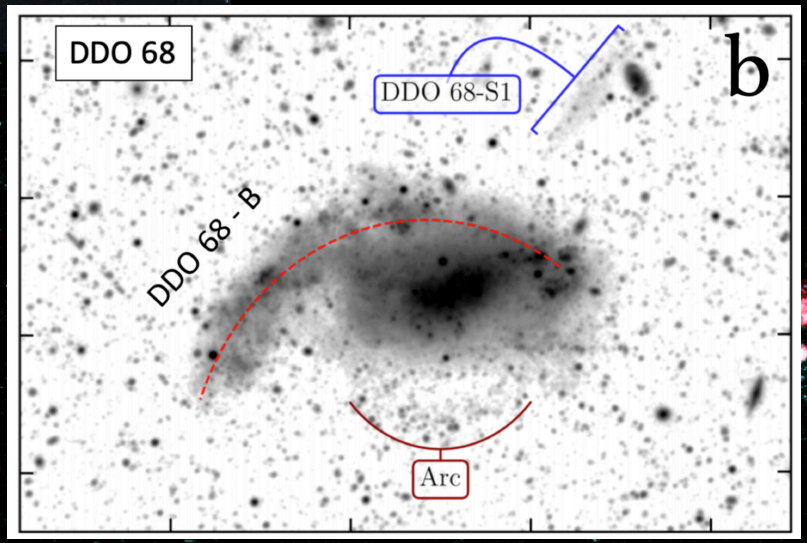
For a review:
Tolstoy, Hill & Tosi 2009, ARAA 47, 371
Annibali & Tosi 2022, *Nat. Astr.* 6, 48

Low surface brightness stellar features can trace accretion/merging events

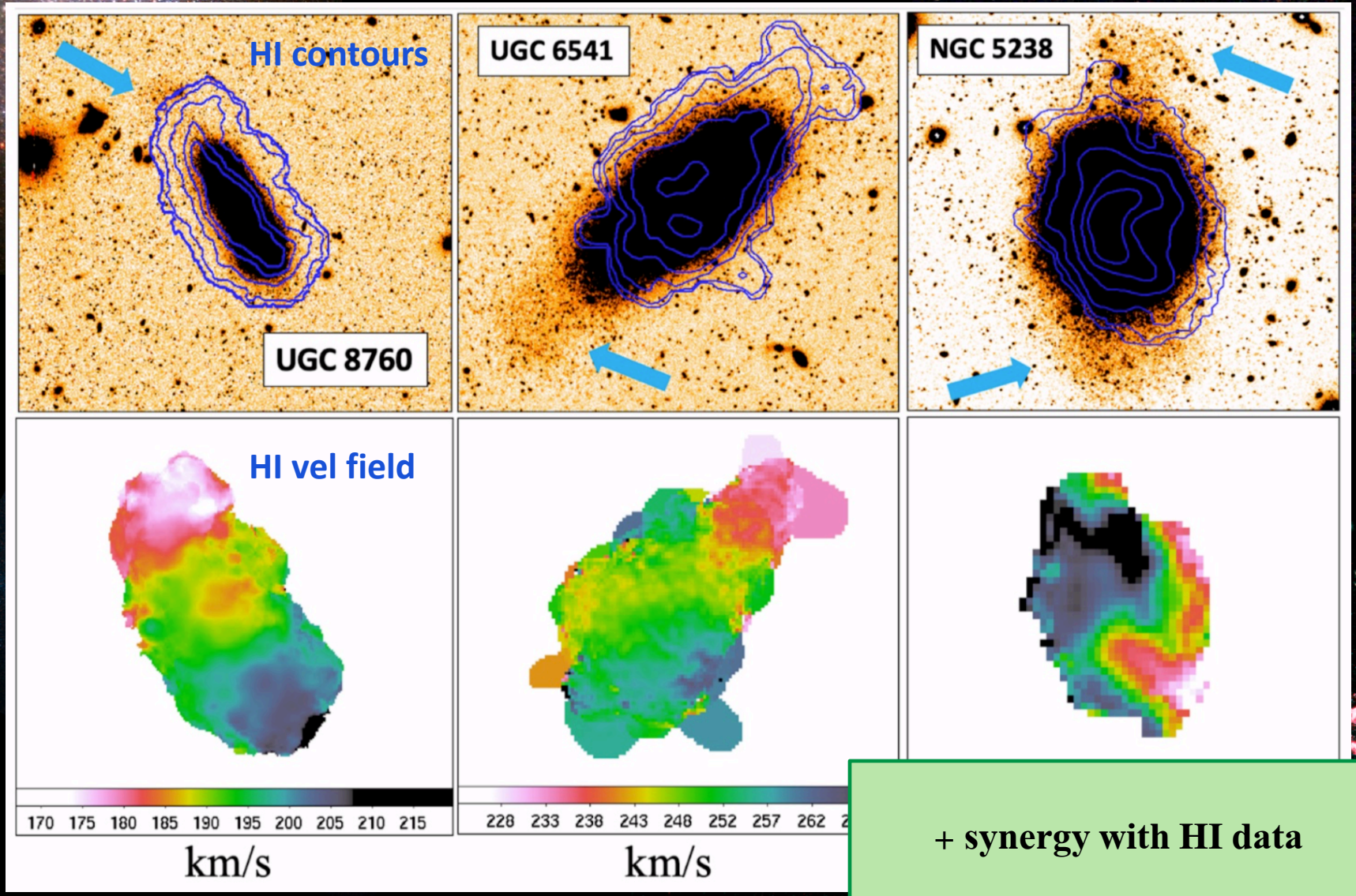


The smallest scale of hierarchy survey (SSH)"
LBT strategic program (PI Annibali)
Papers: Annibali et al, 2020; Annibali et al. 2022; Pascale et al. 2022

- Deep, wide field LBC imaging of 45 nearby (D<10 Mpc) dwarfs
- Complementary HST data [CMDs]
- Complementary HI data from public surveys
- [VLA, WSRT, GMRT]



Low surface brightness stellar features can trace accretion/merging events



+ synergy with HI data

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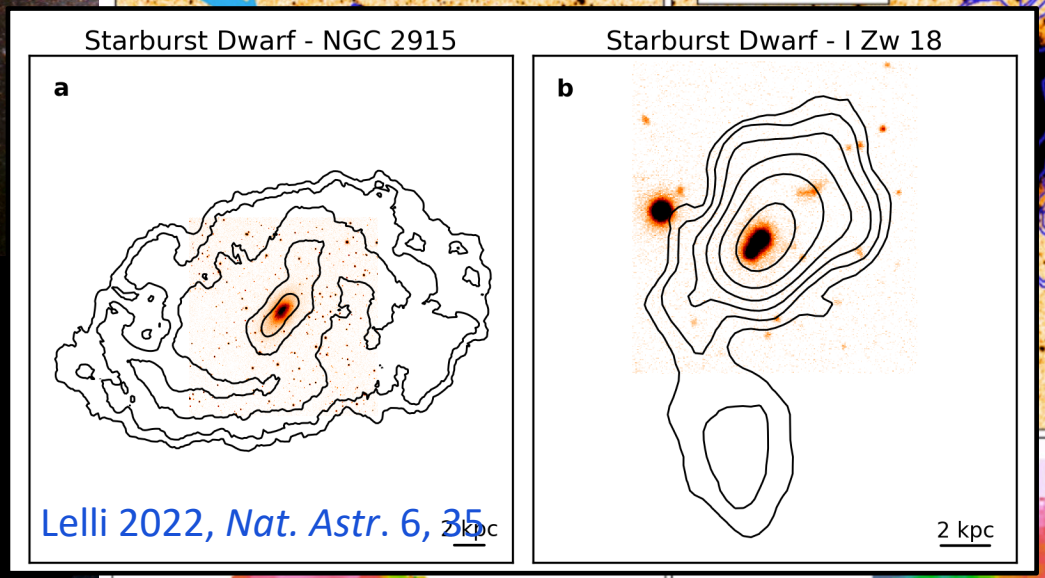


Lelli 2022, *Nat. Astr.* 6, 35

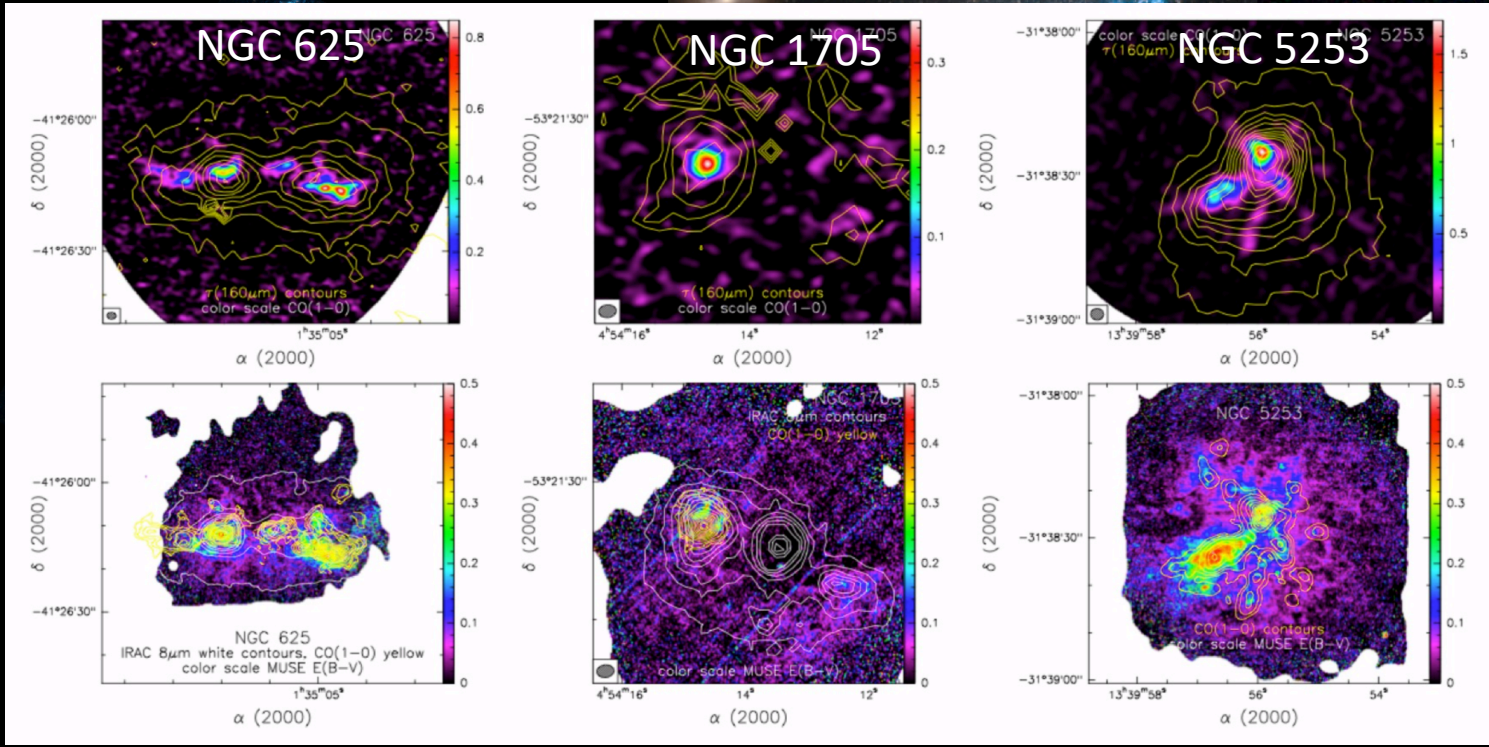
+ synergy with HI data

Multi-phase gas content of dwarf galaxies and its link with SF

- SF closely related to the properties of cold (**atomic and molecular) gas**; **ionized gas** is crucial to probe both feedback from SF and ISM metallicity
- Large datasets of CO, HI, HII with ALMA, IRAM, ATCA, VLA, VLT[MUSE];
- Complementary HST, Spitzer and Herschel data

See review by Henkel, Hunt & Izotov 2022, Galaxies, 10, 11

CO maps [ALMA]



CO maps [ALMA]

Hunt et al. in prep.

E(B-V) maps [MUSE]

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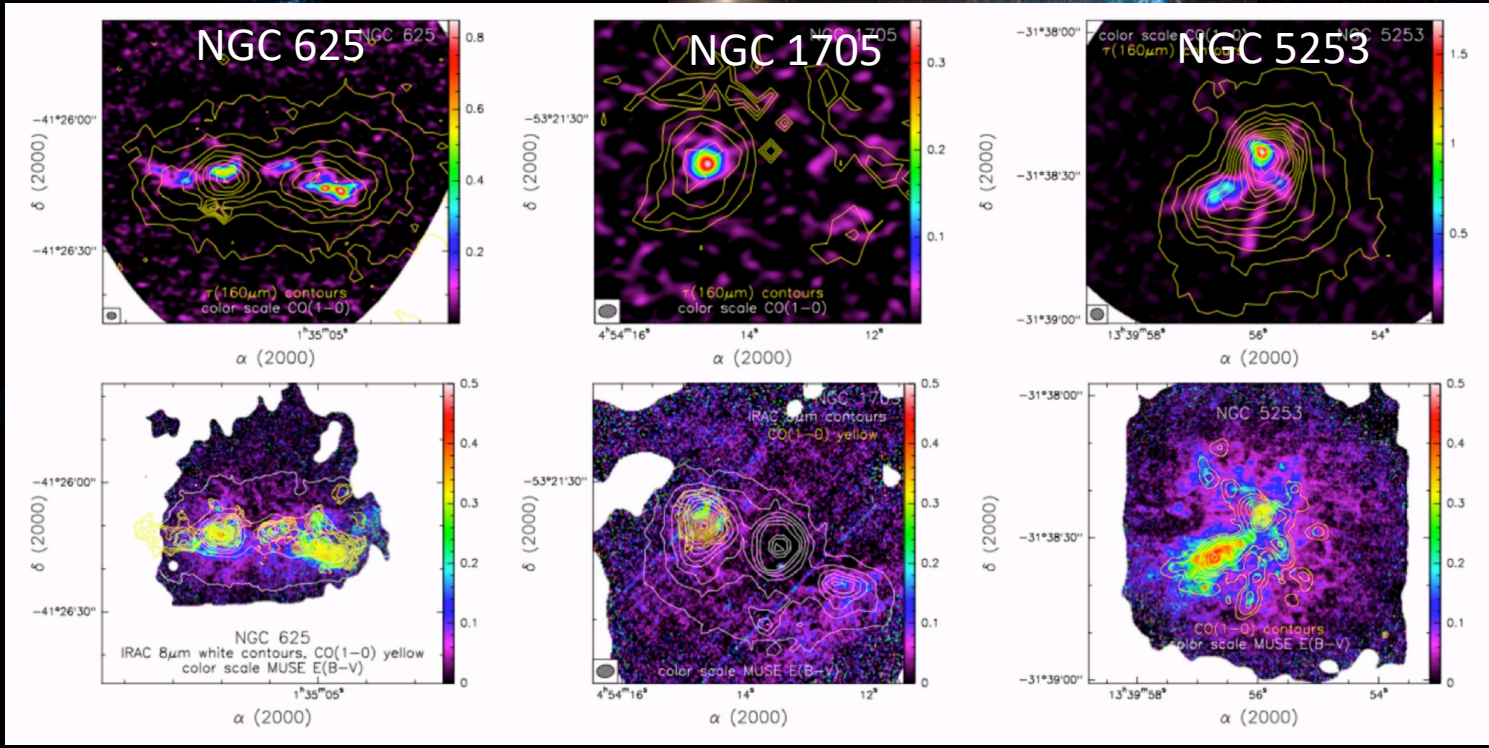
→ Interplay between SF, gas content and stellar feedback



CO maps [ALMA]

Hunt et al. in prep.

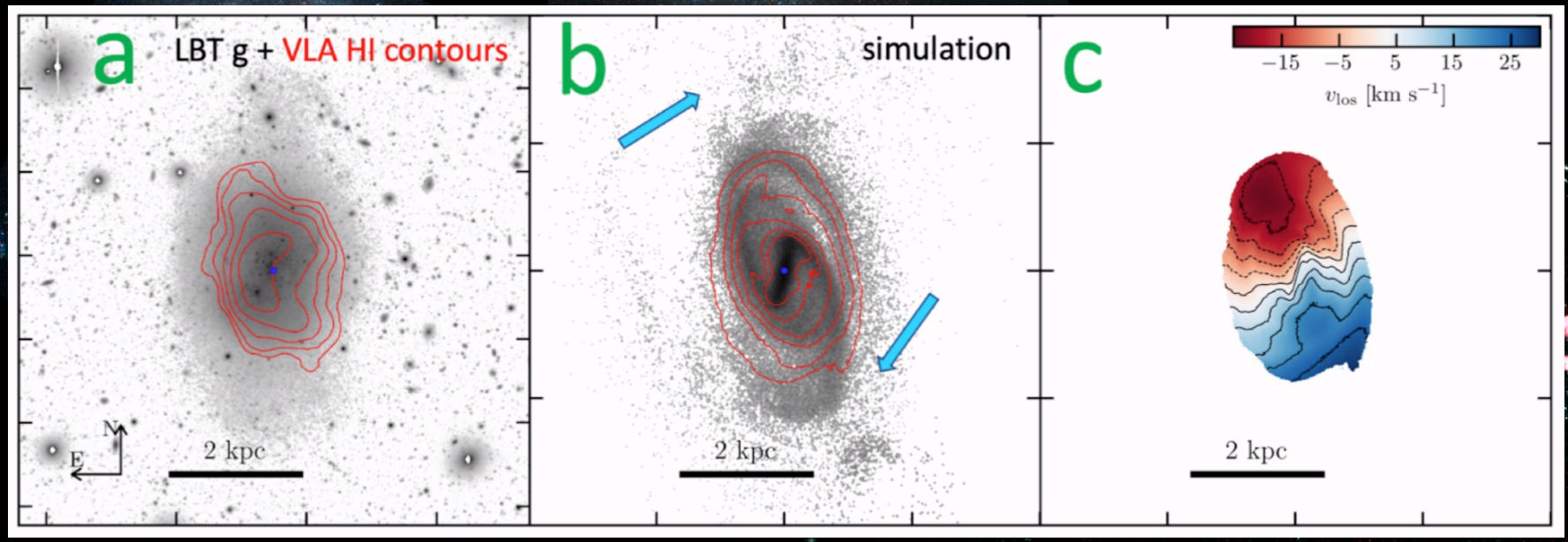
E(B-V) maps [MUSE]

N-body and hydrodynamical simulations, chemical ev. modelling

- N-body + hydro-dynamical simulations (AREPO, Springel 2010) of merging dwarfs
- Inclusion of radiative cooling, SF and feedback → comparison with SF and ISM
- Chemical evolution models (e.g. Romano et al. 2019)

NGC 5238, Pascale et al. in prep

see also Pascale et al. 2022, MNRAS, 509, 2940; Pascale et al. 2021, MNRAS, 501, 2091



Future perspectives

- JWST: new window on studies of stellar population and ISM in dwarf galaxies [approved medium program to study SFH, star clusters and ISM in a few dwarfs]
- EUCLID and Roman: full coverage of most external galaxy regions
- ELT: study the central galaxy regions with unprecedented resolution
- SKA (and precursors, ASKAP, MeerKAT) higher sensitivity and resolution for HI studies

Team

Stellar Populations
[Stellar photometry, SFHs]

Francesca Annibali (INAF-OAS)
Michele Bellazzini (INAF-OAS)
Michele Cignoni (Uni. Pisa)
Felice Cusano (INAF-OAS)
Marcella Marconi (INAF-OAC)
Ilaria Musella (INAF-OAC)
Diego Paris (INAF-OAR)
Vincenzo Ripepi (INAF-OAC)
Elena Sacchi (AIP, Potsdam)
Monica Tosi (INAF-OAS)

INAF FTE = 1.2/yr
non-INAF FTE = 0.2/yr

Interstellar medium
[HI, HII, CO properties]

Francesco Belfiore (INAF-OAS)
Stefano Carniani (SNS Pisa)
Edvige Corbelli (INAF-OAA)
Giovanni Cresci (INAF-OAA)
Leslie Hunt (INAF-OAA)
Federico Lelli (INAF-OAA)
Laura Magrini (INAF-OAA)
Filippoi Mannucci (INAF-OAA)
Antonino Marasco (INAF-OAPd)
Alessandro Marconi (OAA)
Crescenzo Tortora (INAF-OAC)
Giacomo Venturi (Uni.Catolica)

INAF FTE = 1.2/yr
non-INAF FTE = 0.2/yr

Theoretical modelling
[Cosmological, N-body, hydro-dyn. simulations, chemical evol. models]

Francesco Calura (INAF-OAS)
Gabriella de Lucia (INAF-OATs)
Federico Marinacci (Uni.Bo)
Carlo Nipoti (Uni.Bo)
Raffaele Pascale (INAF-OAS)
Donatella Romano (INAF-OAS)
Raffaella Schneider (Uni.Sapienza)

INAF FTE = 0.2/yr
non-INAF FTE = 0.4/yr

Leadership

- Recognized **international excellence** in dwarf galaxy studies [Annibali & Tosi 2022, *Nat. Astr*. 6, 48; Lelli 2022, *Nat. Astr*. 6, 35; Battaglia & Nipoti 2022, *Nat. Astr.* in press; Henkel, Hunt & Izotov 2022, *Galaxies,* 10, 11]

- Large Strategic Program at the LBT (SSH - 45 h, PI Annibali)
- Several programs with IRAM (total 140 h, PI Hunt)
- PI-ship of programs with LBT, HST, VLT, ALMA, ATCA (Pis Annibali, Belfiore, Bellazzini, Cresci, Hunt, Lelli)

- Leading roles for **future facilities** with important INAF involvement:
  - Hunt, lead of Local Universe Working Group in **EUCLID**
  - Annibali, co-lead for stellar photometry working package (**EUCLID** MWRSP WG) and co-lead for synthetic color predictions of dwarfs (**EUCLID** LU WG)
  - Annibali, project scientist for **MAORY@ELT**
  - Marconi, principal investigator for **ANDES@ELT**

Funding

No funds available for the next three years (2022/23/24)

Past funding:

- INAF **Mainstream Program** (1.05.01.86.28) "SSH: The smallest scale of Hierarchy Survey", 33 k euro

- Over the years, PRIN-SKA ''*ESKAPE-HI*'' and PRIN MIUR ''*Chemical evolution of the MW and of Local Group galaxies*'' helped promoting this research

Criticalities

To Maintain and consolidate INAF leadership in dwarf galaxy science:

- Large proprietary data volume in hand requires **a contract for data reduction and analysis** of radio/submm data and MUSE cubes

- A **contract** needed to pursue **N-body and hydrodynamical simulations** of dwarf galaxies in the context of hierarchical galaxy assembling [post-doc contract just terminated]

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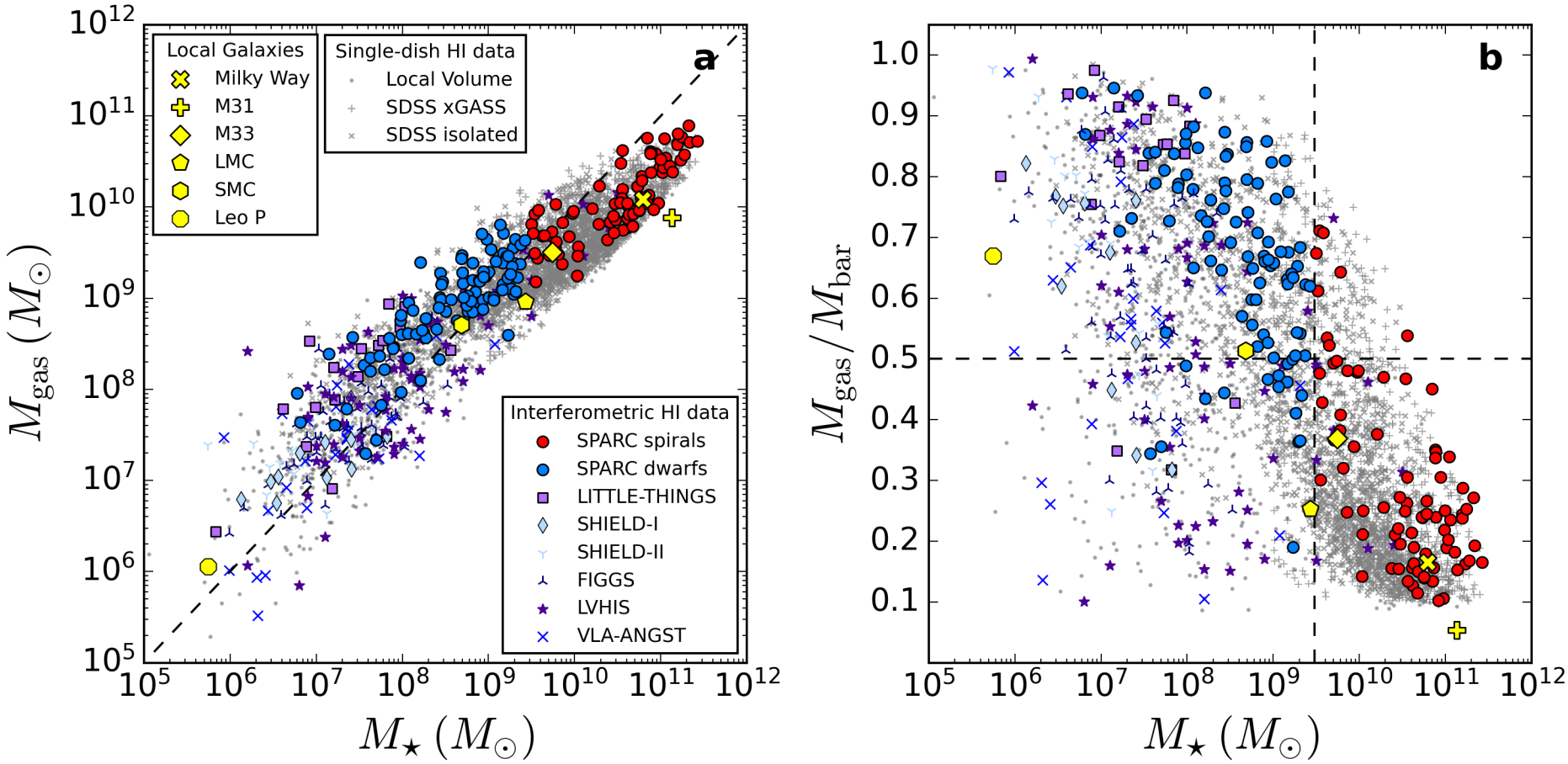
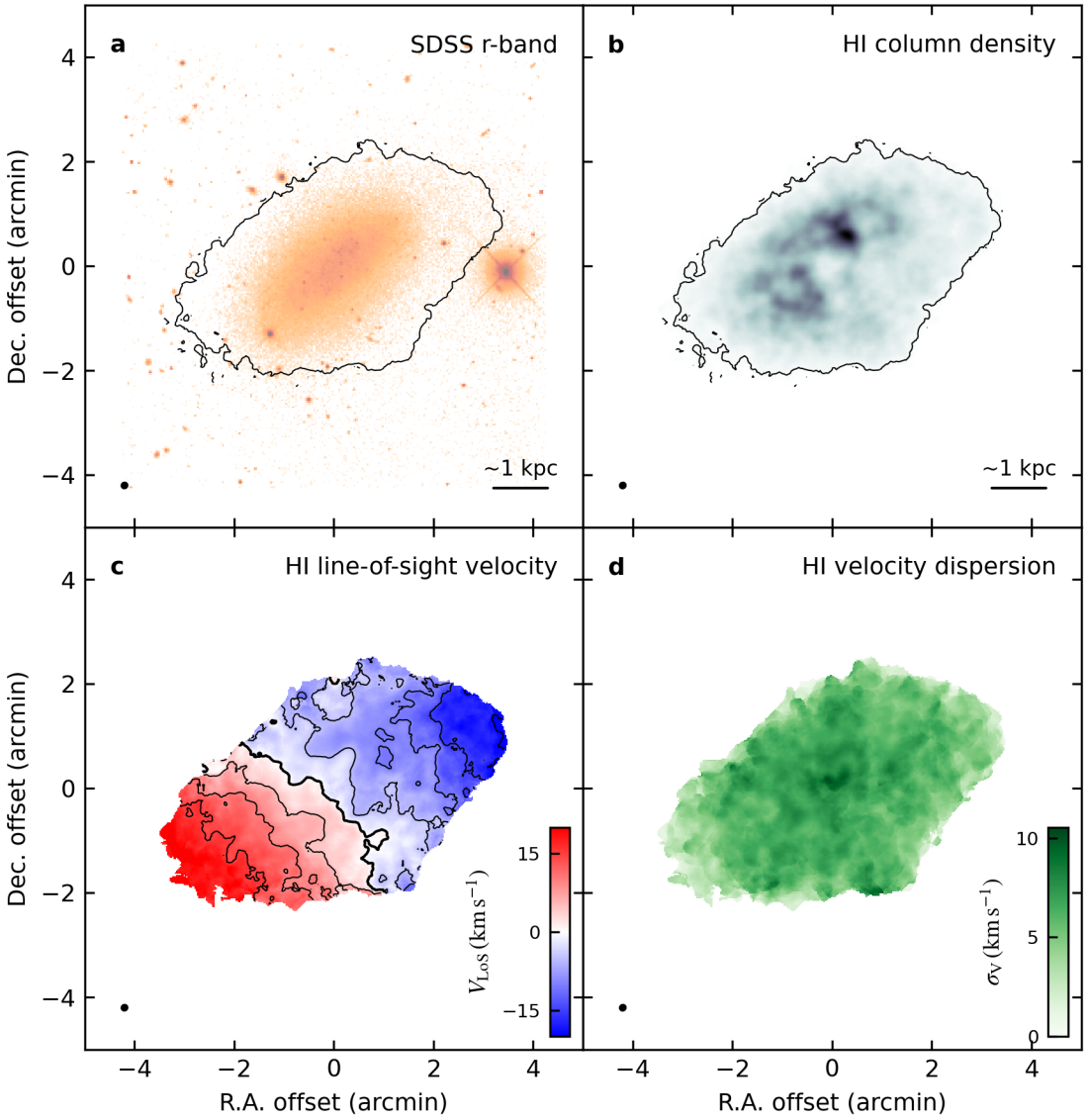
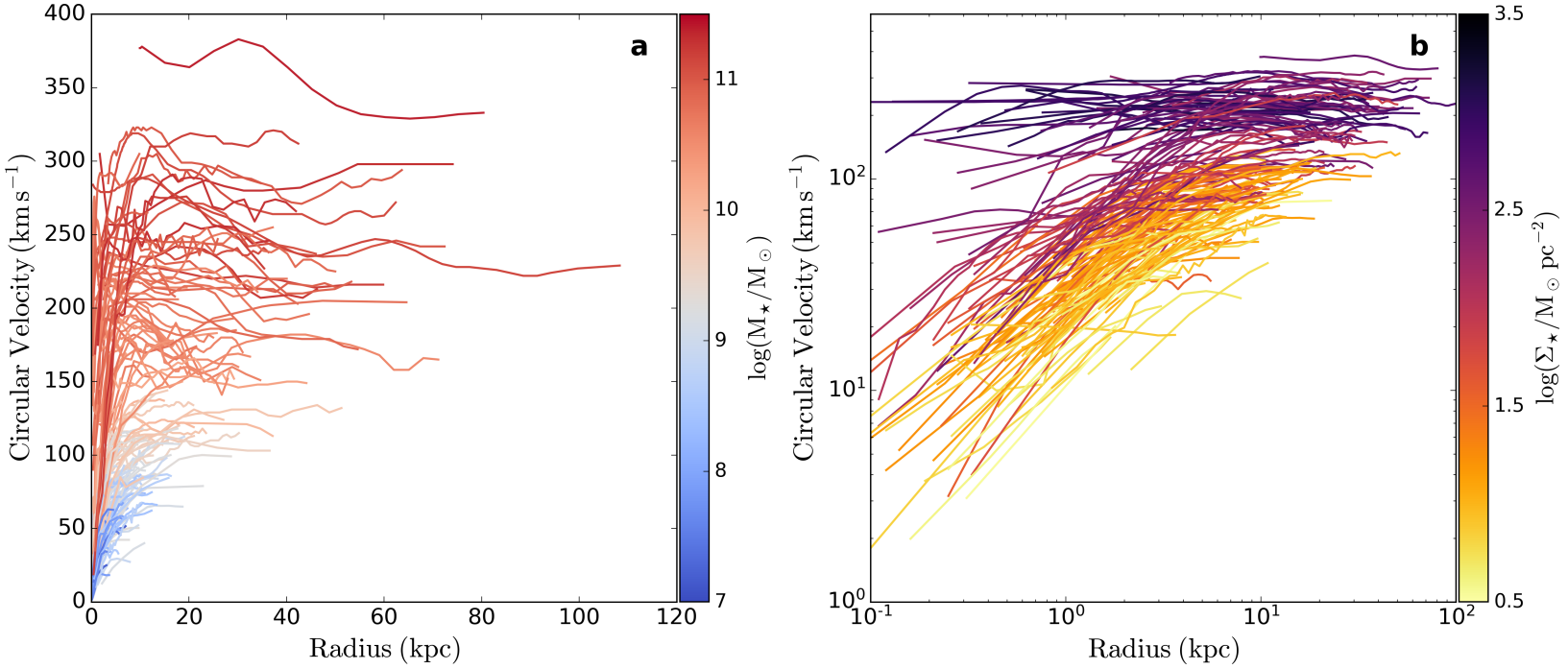
INAF Large Grant submitted

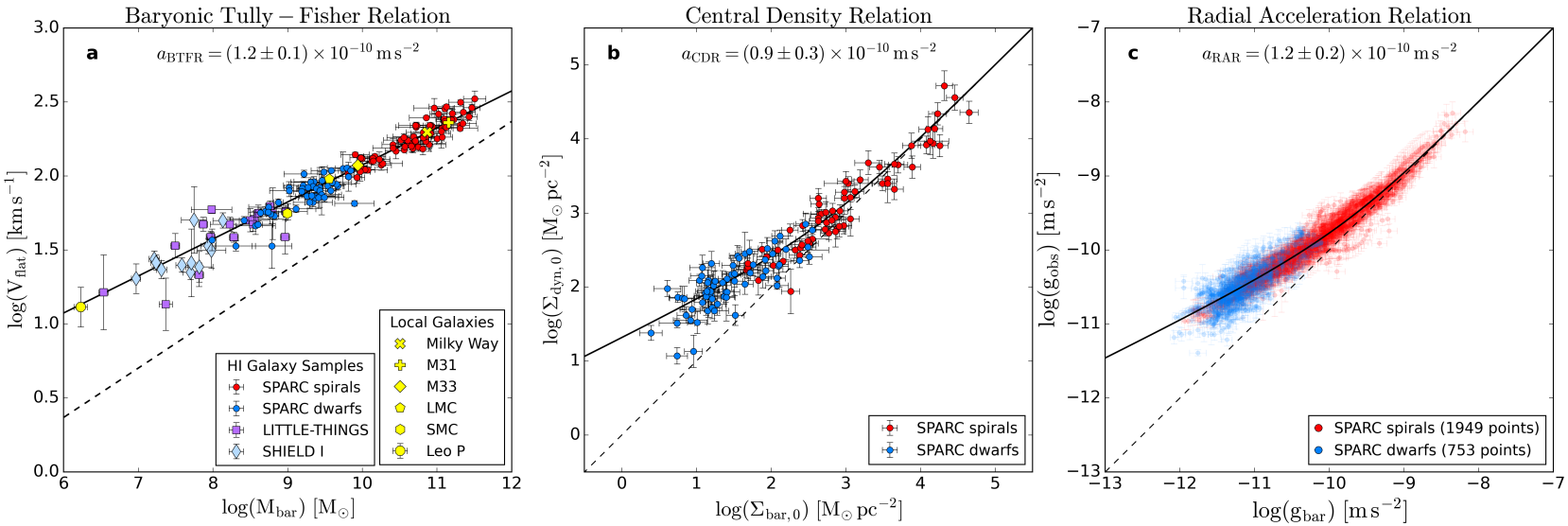
Timeline and milestones

	1st semester	2nd semester	3rd semester	4th semester
WP1a	SSH/LBT calibrated point-source photometry	Stellar sub-structures identification in SSH	Final star + HI maps of SSH galaxies: identification of candidate merging dwarfs	
WP1b	Re-analysis of HI archival datacubes, provide new HI maps and velocity fields*	HI morphological/ kinematical peculiarities identification in SSH*		
WP2a	In-depth multiwavelength study (CO from ALMA, ionized gas from MUSE, HI from VLA, CMDs from HST) of a sub-sample of three nearby starburst dwarfs.*		Analysis of MUSE data for a large sample of dwarfs (42) as well as HI and CO data for a sub-sample.*	
WP2b	SFH from archival HST data of the three dwarfs in WP2a	SFH from HST archival data of dwarfs in SSH. Priority will be given to dwarfs with merger signatures from WP1		
WP3a	Dwarfs' merging histories from N-body hydrodynamical simulations **		Include gas physics, star formation and feedback in the simulations**	
WP3b		Chemical evolution models of dwarf galaxies		


a
Local Galaxies
Milky Way
M31
M33
LMC
SMC
Leo P
Single-dish HI data
Local Volume
SDSS xGASS
SDSS isolated
Interferometric HI data
SPARC spirals
SPARC dwarfs
LITTLE-THINGS
SHIELD-I
SHIELD-II
FIGGS
LVHIS
VLA-ANGST
$M_{\rm gas}\,(M_\odot)$
$M_\star\,(M_\odot)$
b
$M_{\rm gas}/M_{\rm bar}$
$M_\star\,(M_\odot)$


a
SDSS r-band
~1 kpc
b
HI column density
~1 kpc
c
HI line-of-sight velocity
$V_{\rm LoS}\,({\rm km\,s^{-1}})$
15
0
−15
d
HI velocity dispersion
$\sigma_{\rm V}\,({\rm km\,s^{-1}})$
10
5
0
Dec. offset (arcmin)
R.A. offset (arcmin)
4
2
0
−2
−4


a
b
Circular Velocity (km s^{-1})
Radius (kpc)
log(M$_\star$/M$_\odot$)
log($\Sigma_\star$/M$_\odot$ pc^{-2})


Baryonic Tully – Fisher Relation
a
$a_{\rm BTFR} = (1.2 \pm 0.1) \times 10^{-10}\,{\rm m\,s^{-2}}$
$\log(V_{\rm flat})\ [{\rm km\,s^{-1}}]$
$\log(M_{\rm bar})\ [M_\odot]$
HI Galaxy Samples
SPARC spirals
SPARC dwarfs
LITTLE-THINGS
SHIELD I
Local Galaxies
Milky Way
M31
M33
LMC
SMC
Leo P
Central Density Relation
b
$a_{\rm CDR} = (0.9 \pm 0.3) \times 10^{-10}\,{\rm m\,s^{-2}}$
$\log(\Sigma_{\rm dyn,0})\ [M_\odot\,{\rm pc^{-2}}]$
$\log(\Sigma_{\rm bar,0})\ [M_\odot\,{\rm pc^{-2}}]$
SPARC spirals
SPARC dwarfs
Radial Acceleration Relation
c
$a_{\rm RAR} = (1.2 \pm 0.2) \times 10^{-10}\,{\rm m\,s^{-2}}$
$\log(g_{\rm obs})\ [{\rm m\,s^{-2}}]$
$\log(g_{\rm bar})\ [{\rm m\,s^{-2}}]$
SPARC spirals (1949 points)
SPARC dwarfs (753 points)