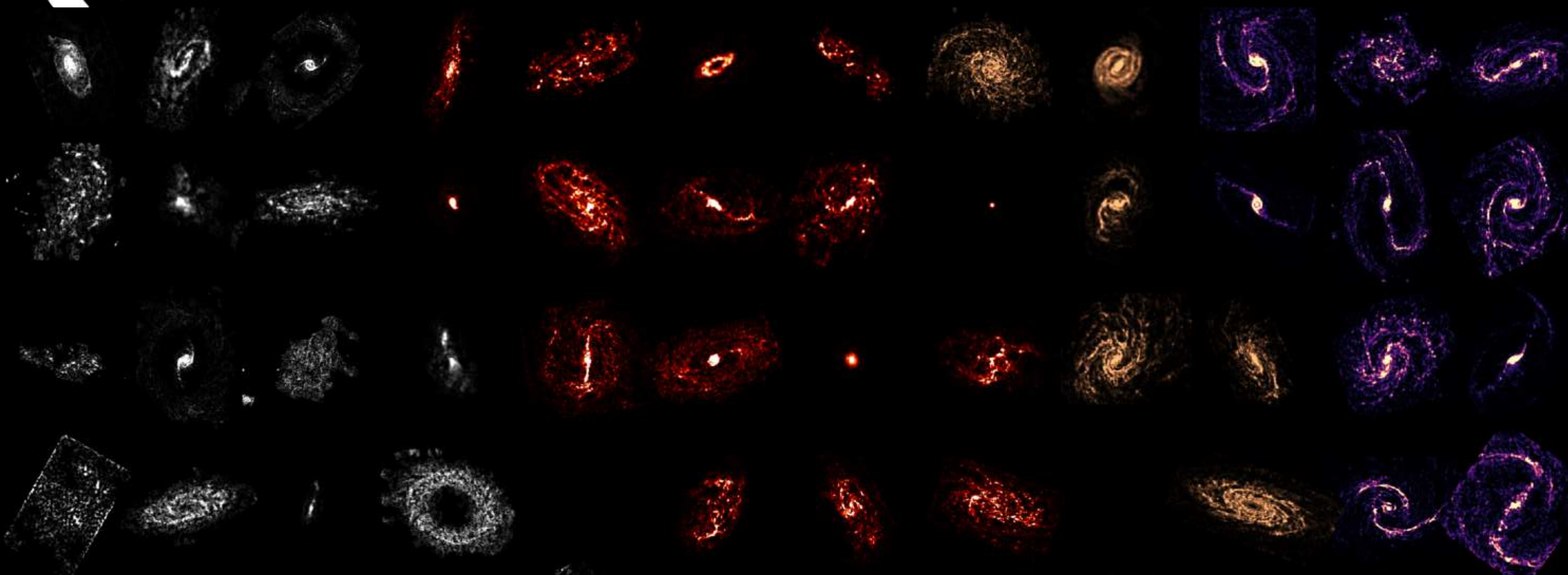
The PHANGS view of cold gas motions, star formation and SF feedback in nearby galaxies



Annie Hughes (IRAP) for PHANGS

and in particular: Sharon Meidt van der Wel, Raphael Maris, Antoine Zakardjian, Jiayi Sun, Jaeyeon Kim, Ashley Barnes, Philip Lang, Kathryn Kreckel, Liz Watson

pcmi

irap

PHANGS aims for a statistical description of the cycling between gas and SF across the local star-forming galaxy population

Aim

Understand the interplay between the small-scale physics of gas and star formation with galactic structure and galaxy evolution

Sample

Close: D ≲ 17 Mpc (1" ≈ 100pc)

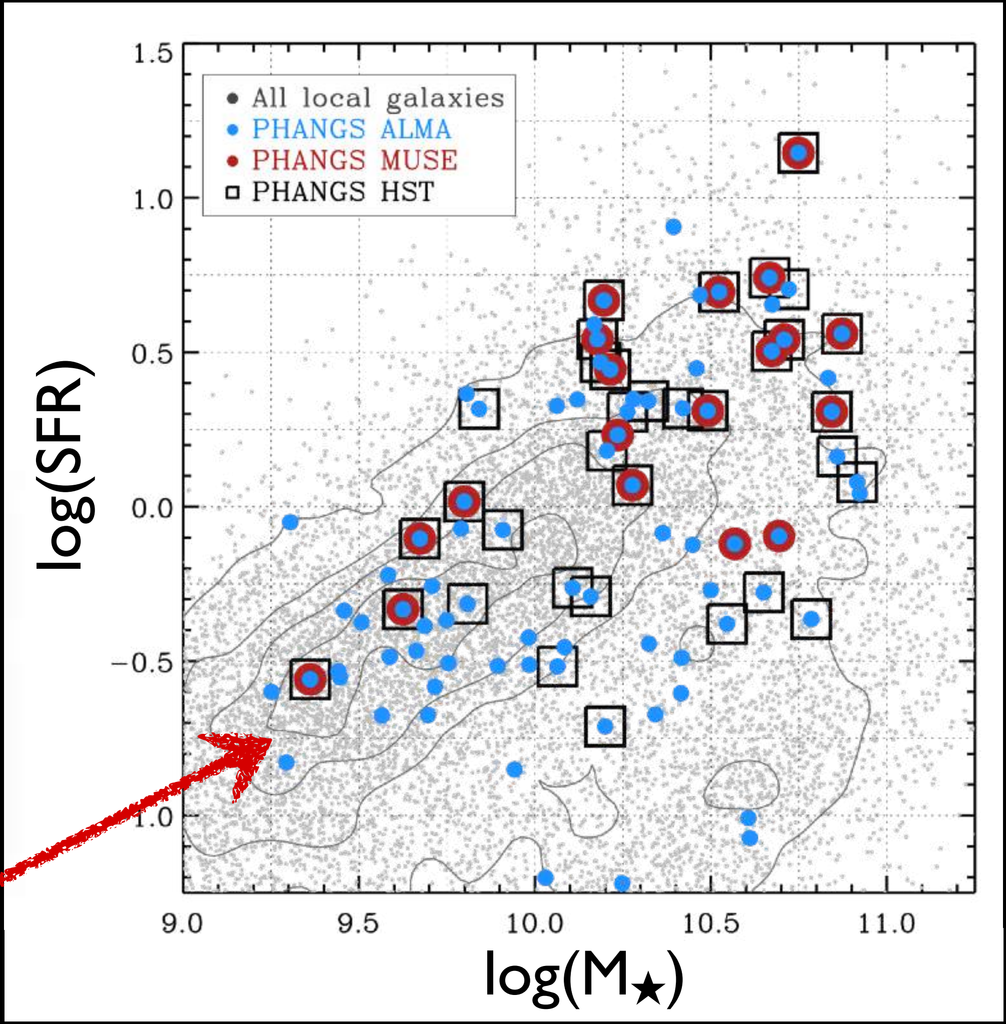
Not edge-on: inclination < 75°

ALMA visible: -75° < Dec. < +25°

9.75 < log M* < 11

74+26 = 90 total targets

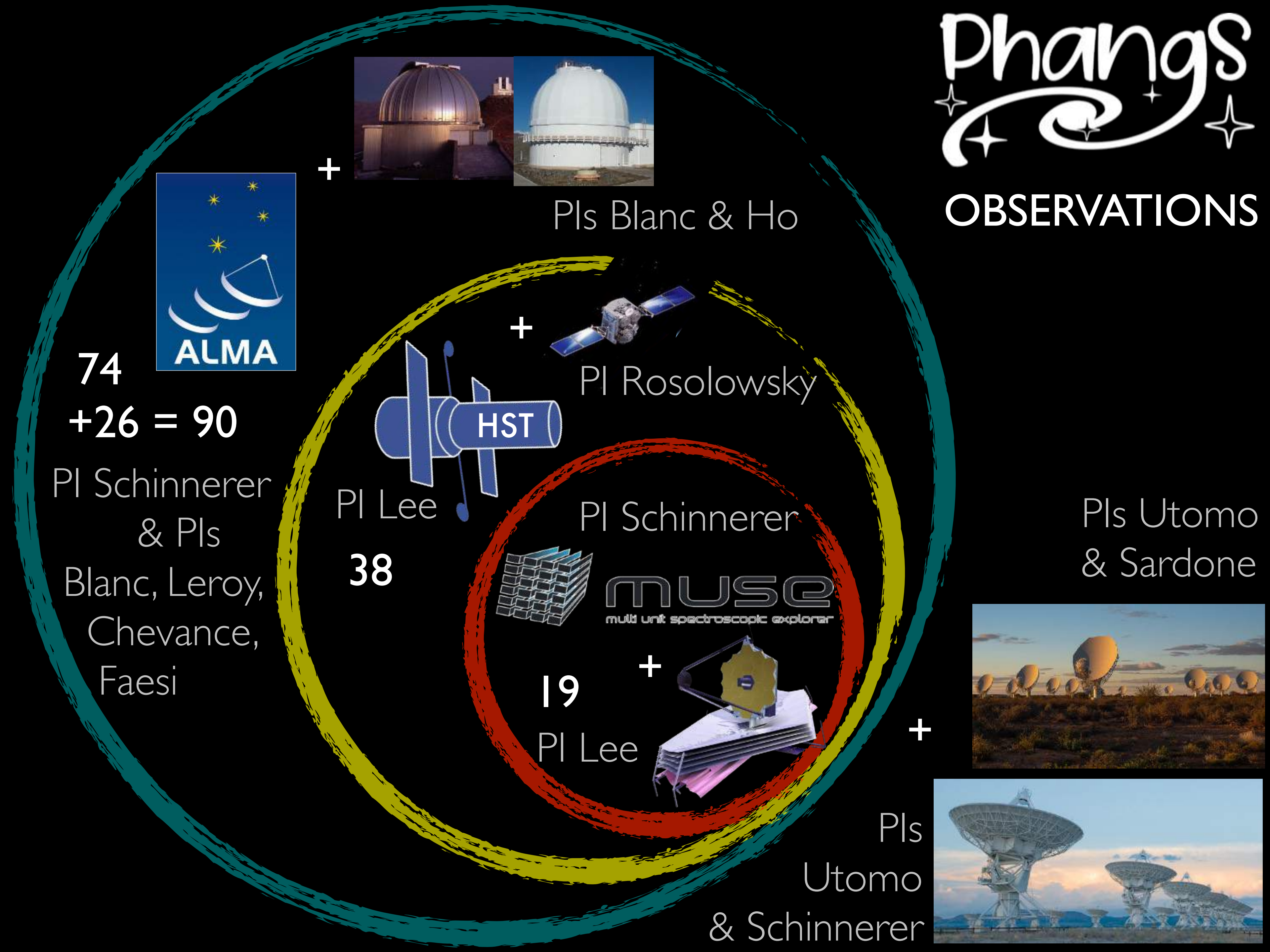
main sequence of star-forming galaxies (~70% of SF at z~0)



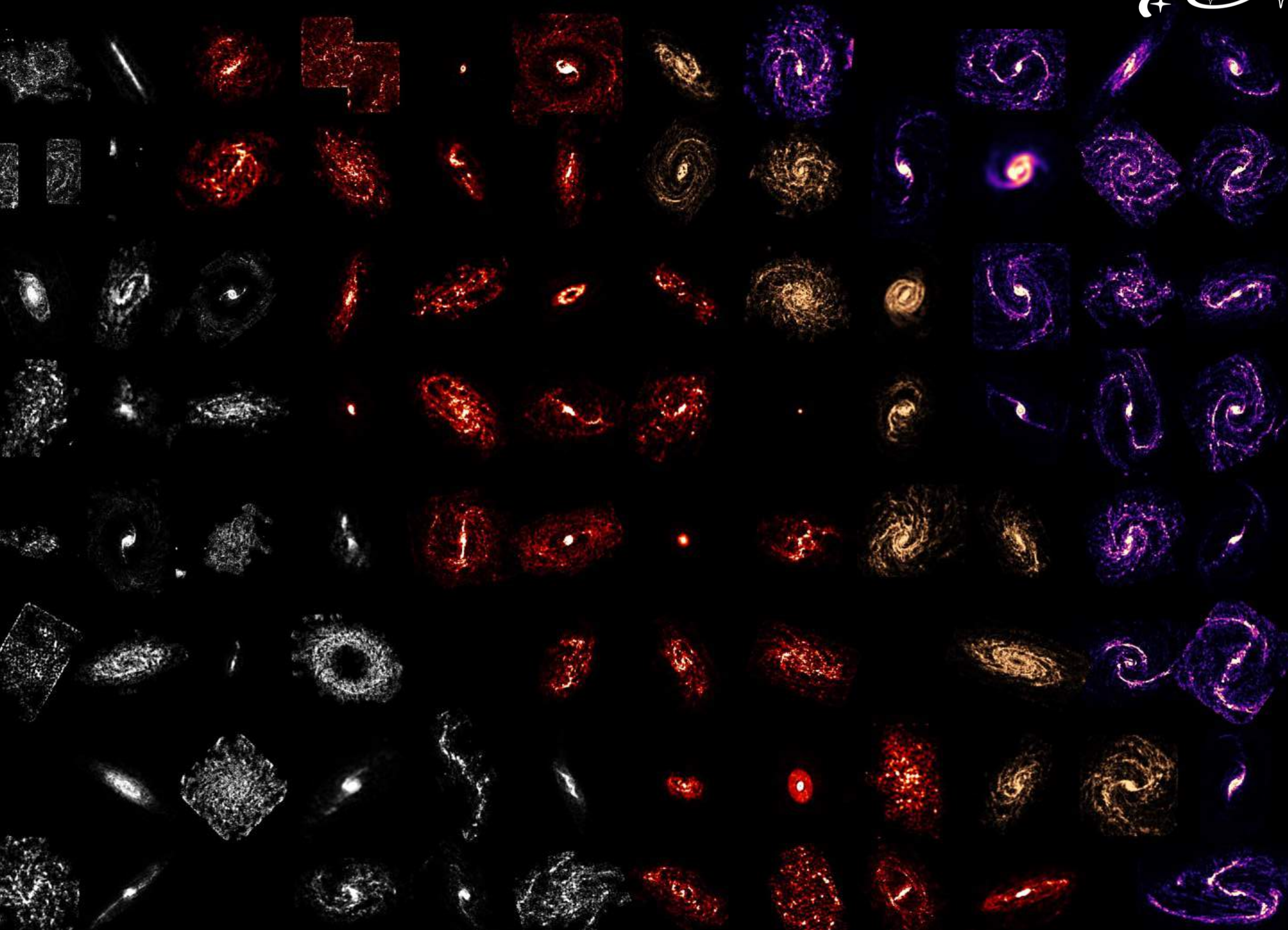
PHANGS sample covers diverse morphologies, ISM conditions

LEROY ET PHANGS, IN PREP

Composite WISE1, WISE2 & NUV
with ALMA FoV highlighted


Phangs
OBSERVATIONS
PIs Blanc & Ho
ALMA
74
+26 = 90
PI Schinnerer
& PIs
Blanc, Leroy,
Chevance,
Faesi
HST
PI Lee
38
PI Rosolowsky
PI Schinnerer
muse
multi unit spectroscopic explorer
19
PI Lee
PIs Utomo
& Sardone
PIs
Utomo
& Schinnerer

ALMA CO (2-1) Peak Intensity Maps



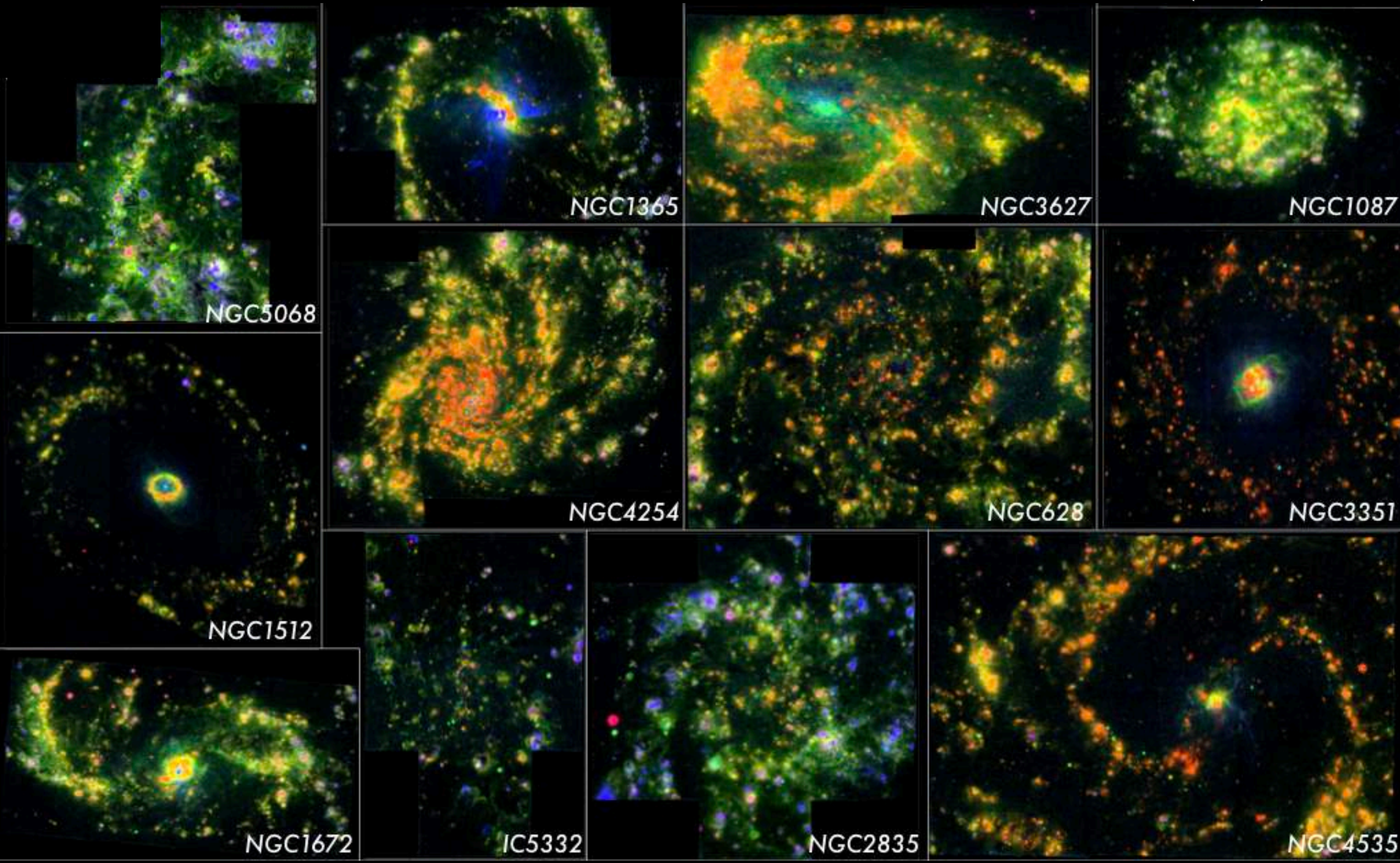
Credit: S. Stuber

Phangs

muse
multi unit spectroscopic explorer

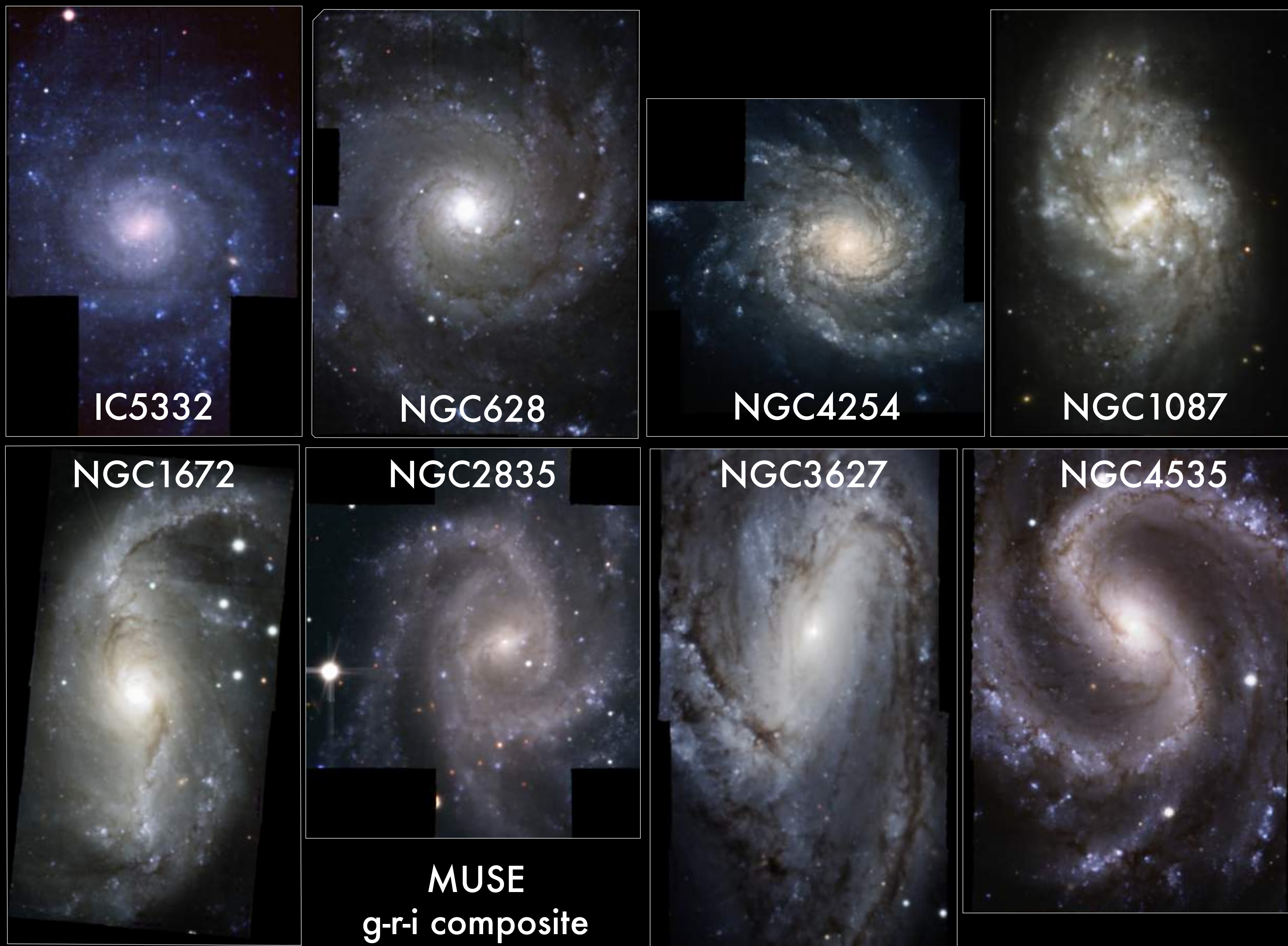
Santoro et al. (2022)

Hα
[OIII]
[SII]



Imaging of 19 galaxies across [4750-9350] Å: optical emission line maps

Emsellem et al. (2022)

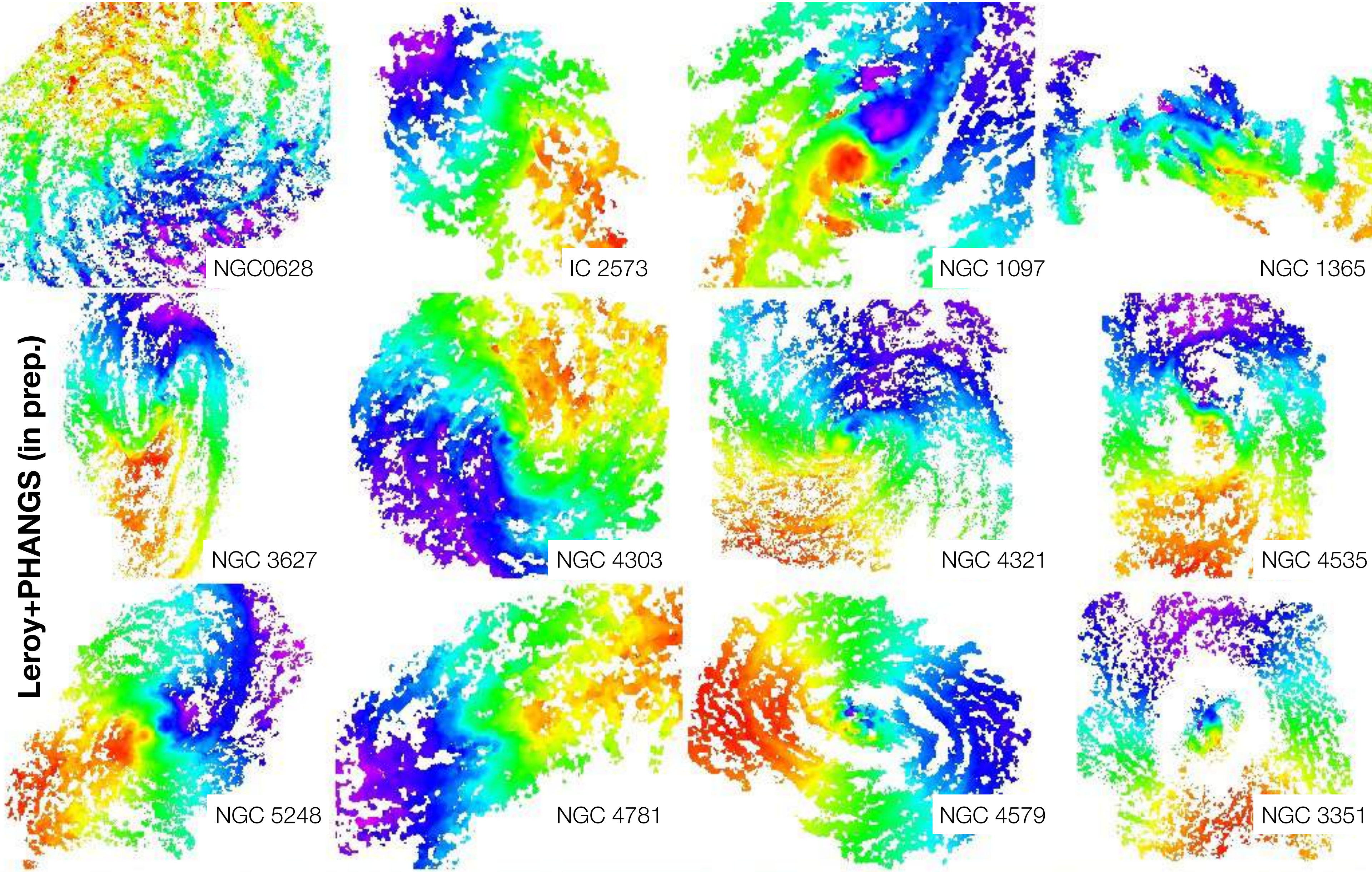


Imaging of 19 galaxies across [4750-9350] Å: stellar continuum

WFC3/ACS UV-optical imaging of 38 galaxies

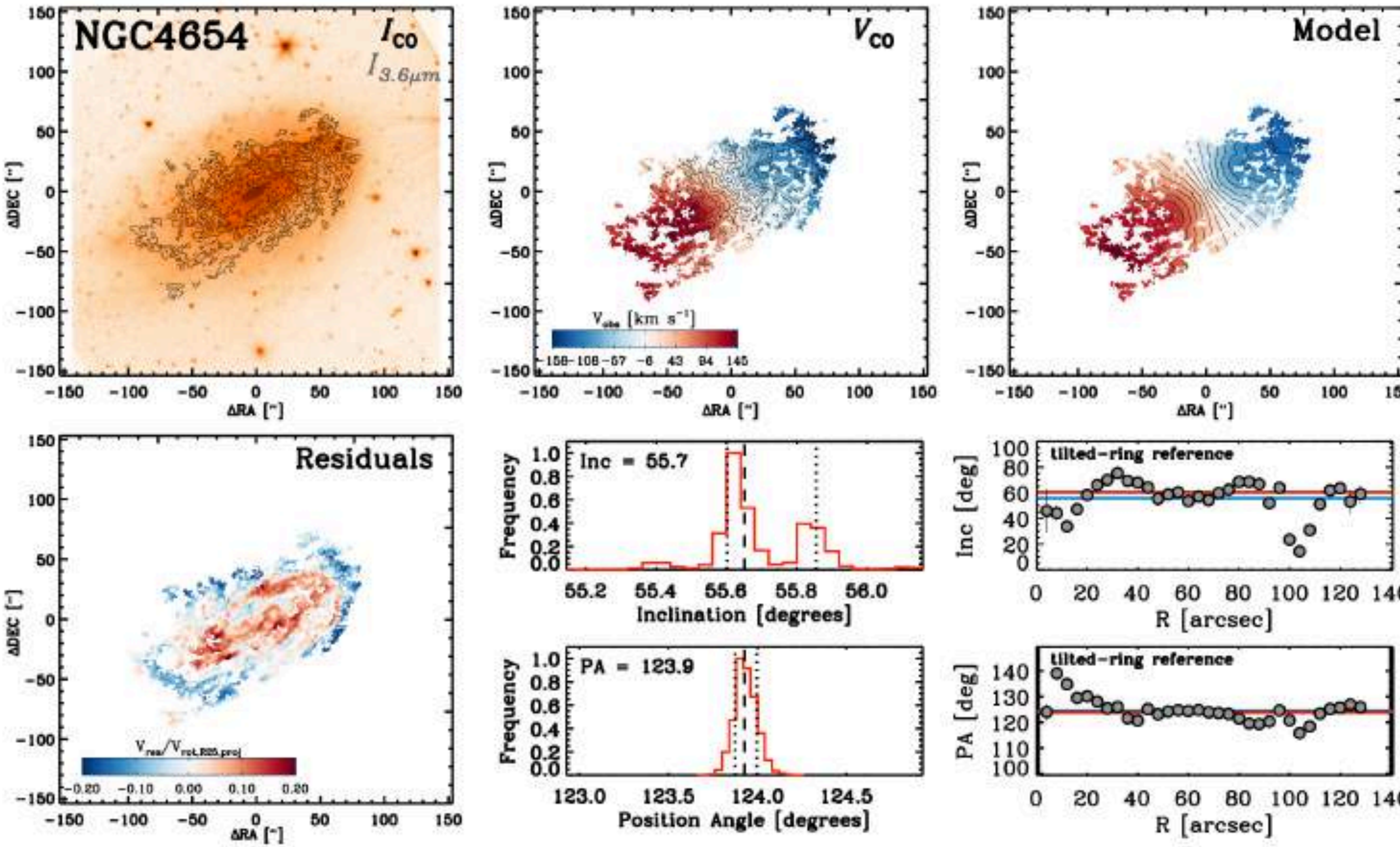
Lee et al. (2022)

cold gas organization: galactic scales


Leroy+PHANGS (in prep.)
NGC0628
IC 2573
NGC 1097
NGC 1365
NGC 3627
NGC 4303
NGC 4321
NGC 4535
NGC 5248
NGC 4781
NGC 4579
NGC 3351

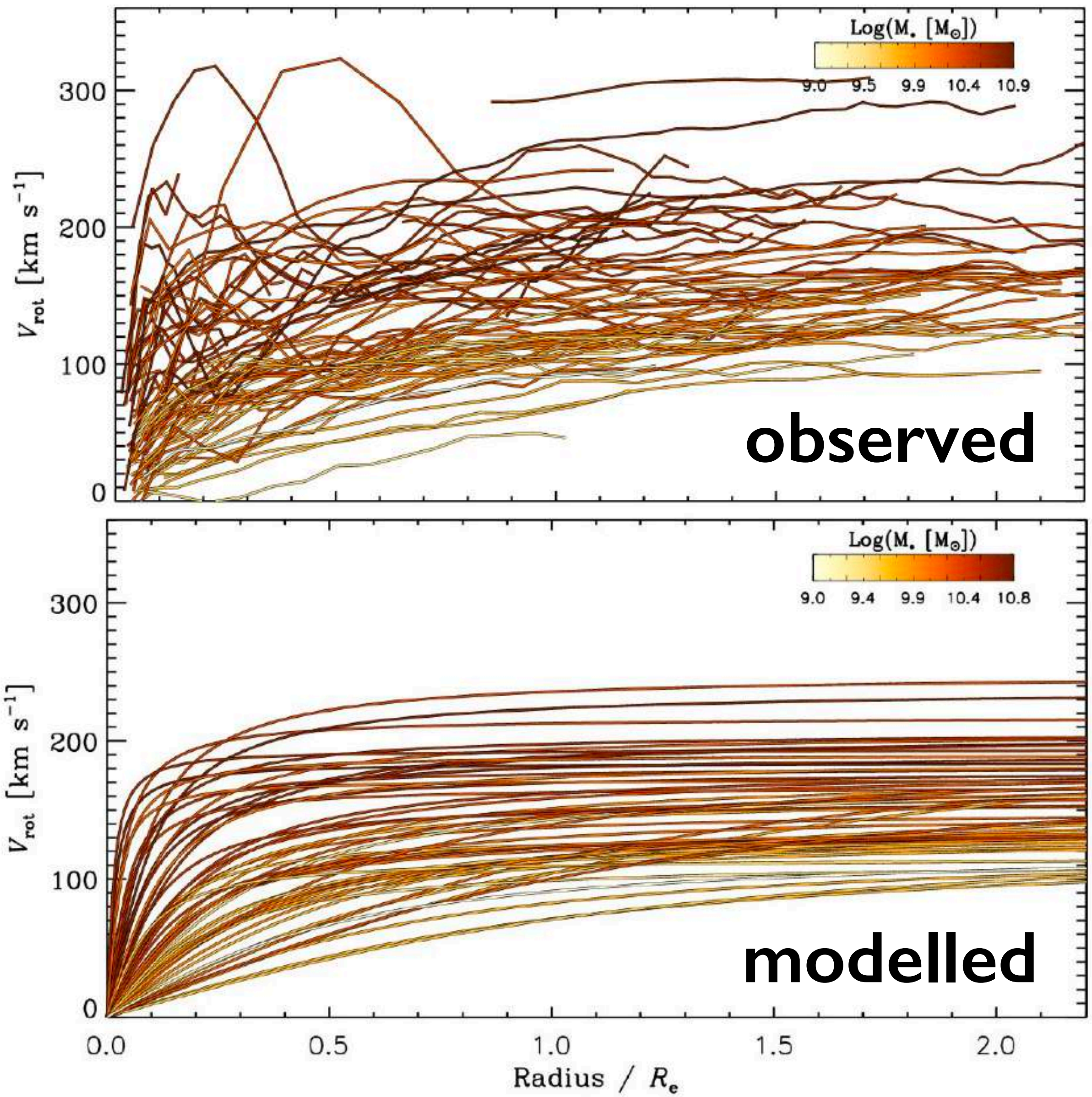
Towards the gravitational potential

CO velocity fields and rotation curves for 67 galaxies @ 150pc

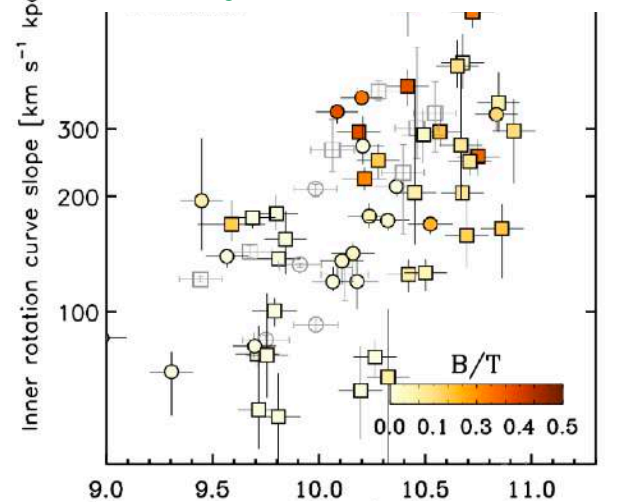


Lang et al. (accept.)

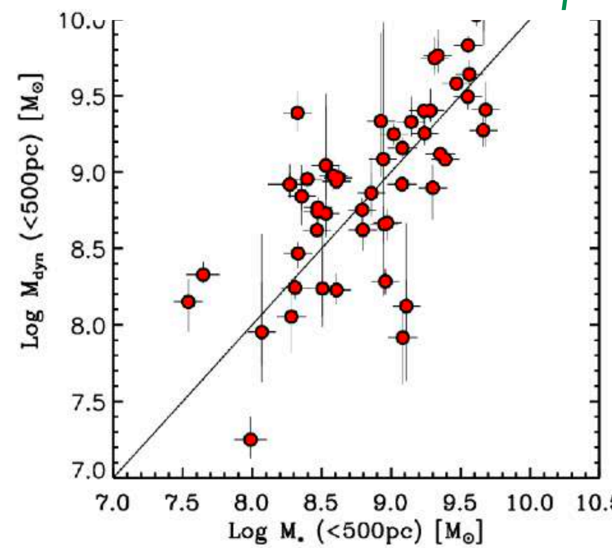
Towards the gravitational potential



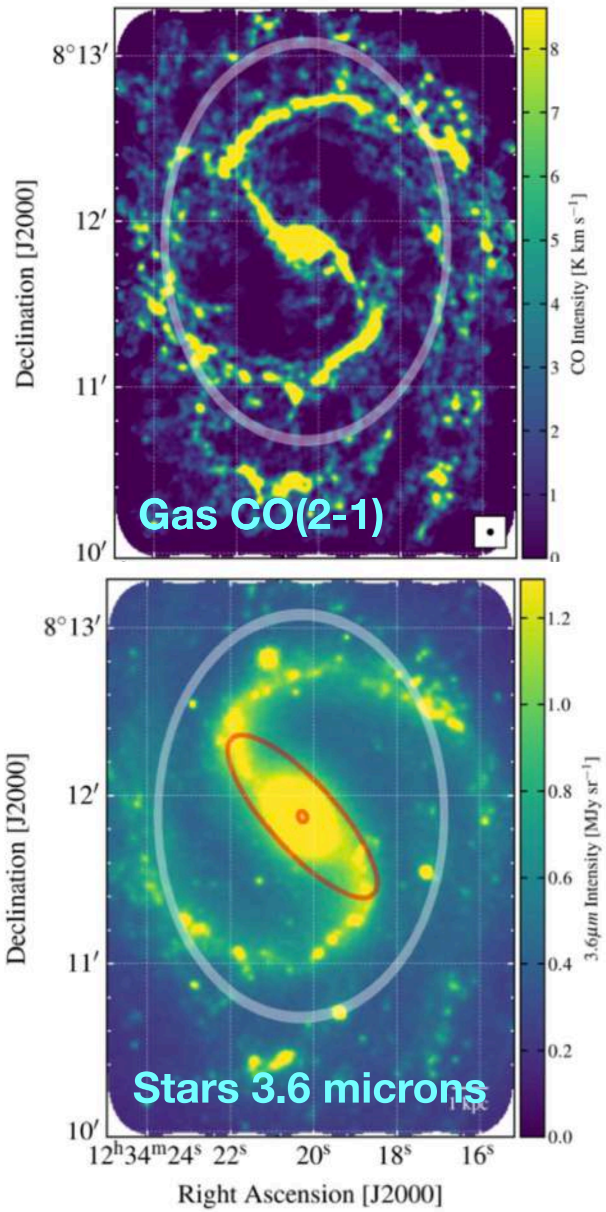
rotation curve slope (r<500pc) vs. global stellar mass



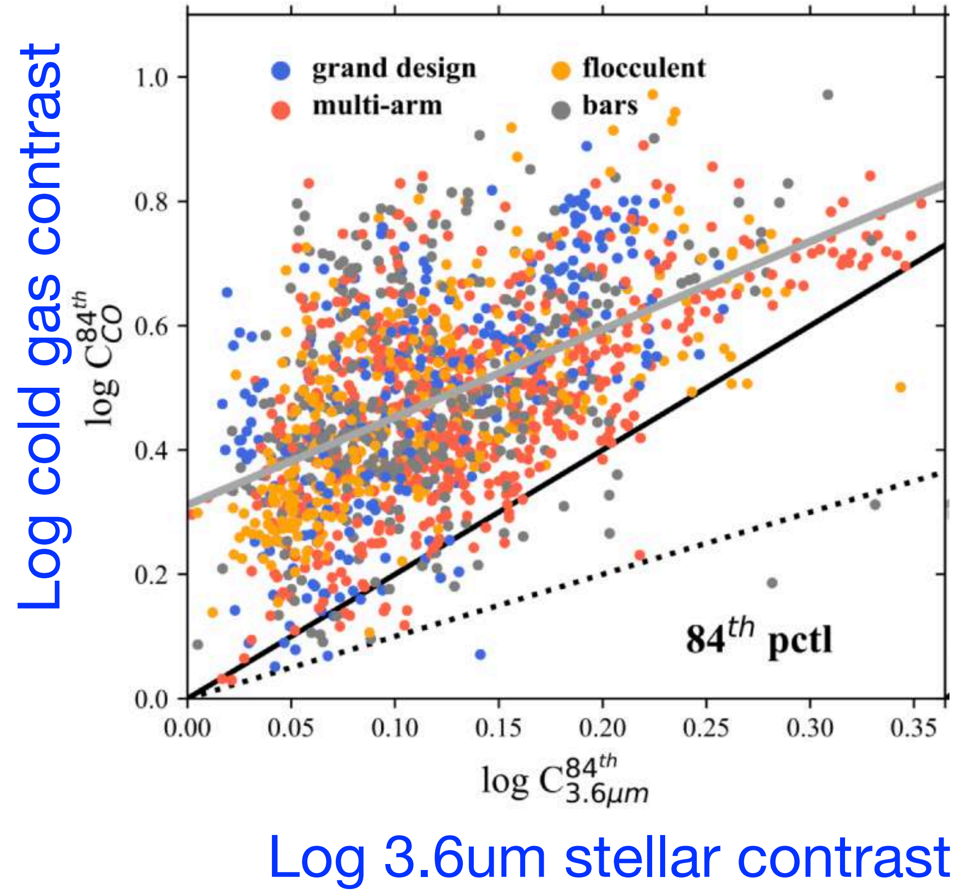
dynamical mass vs. stellar mass inside r=500pc



Stellar and cold gas arm-interarm contrasts



(Meidt+2021)



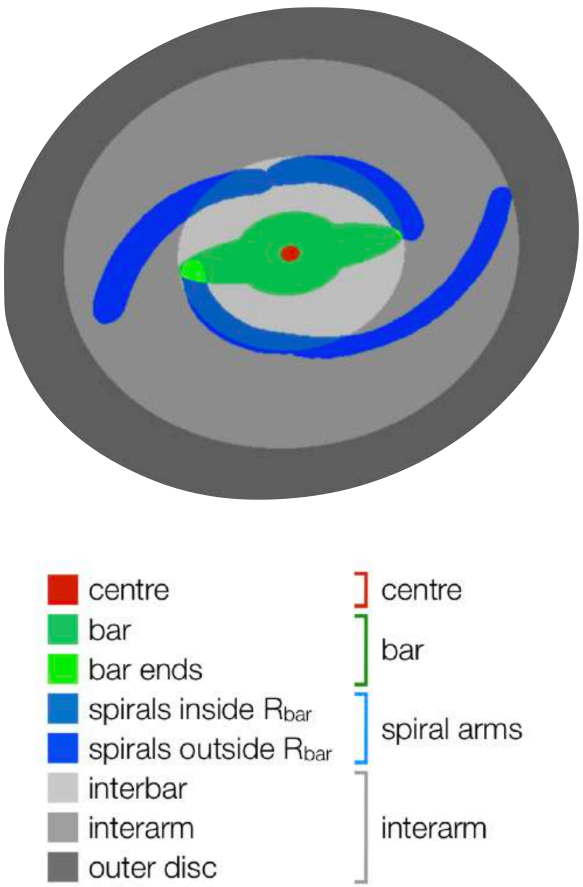
Cold gas arm-interarm contrasts track the contrast in the stellar structure, suggesting influence of galaxy on 150pc scales

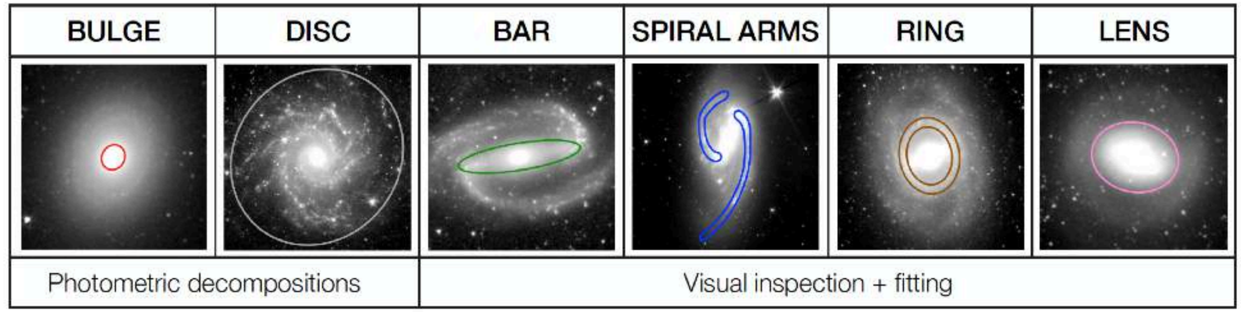
Where is the molecular gas in nearby galaxies?

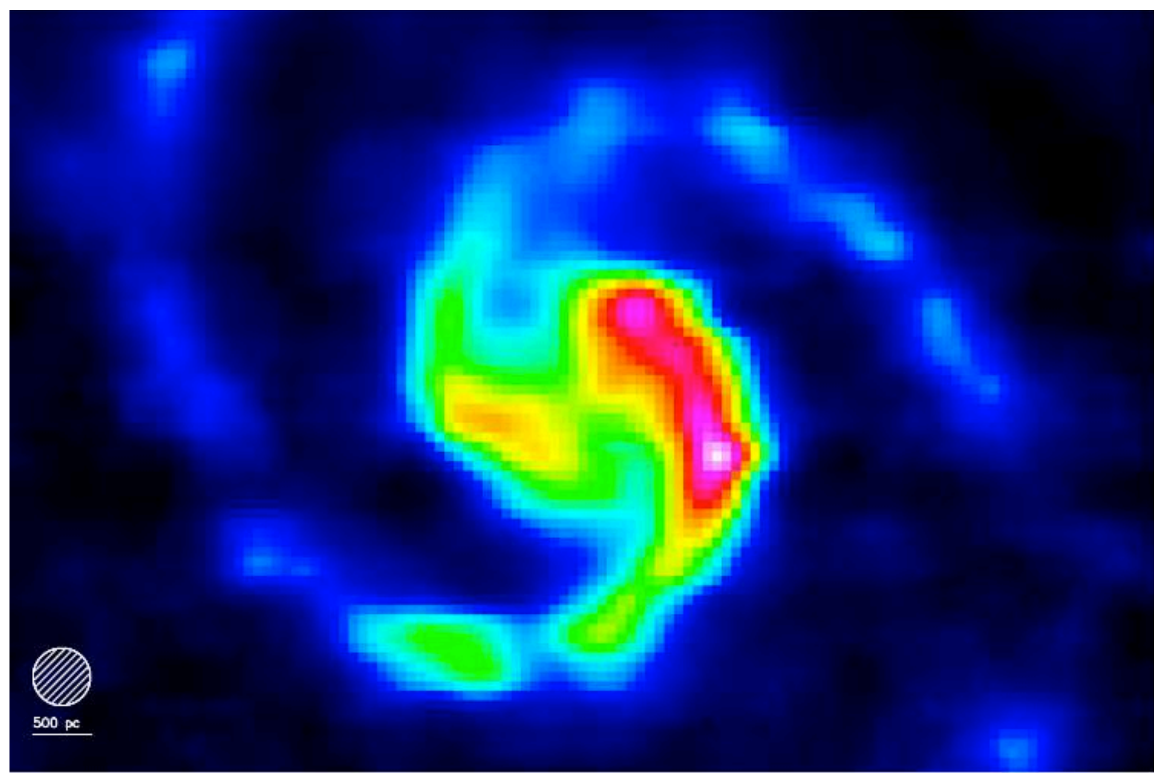
environmental masks

based on S^4G (Salo et al. 2015, Herrera-Endoqui et al. 2016)
3.6um imaging

Querejeta et al. (2021)







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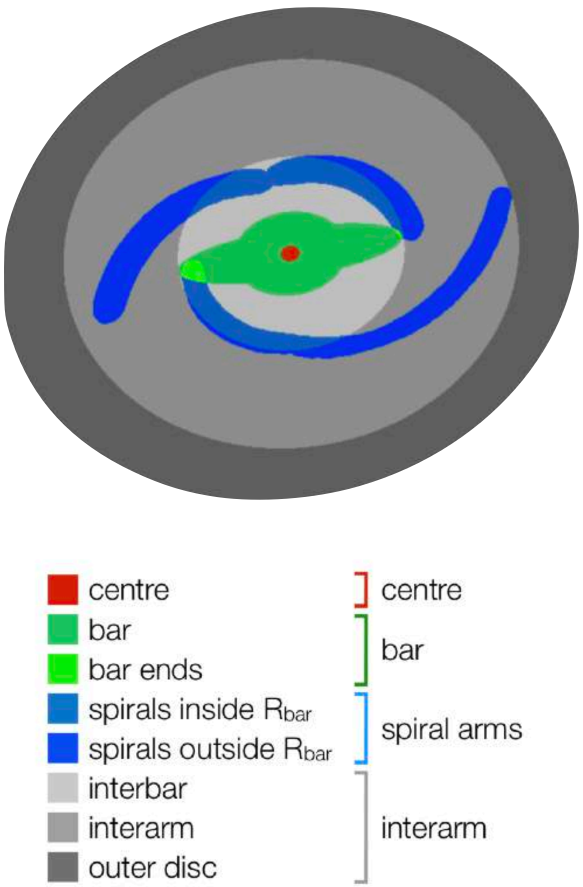
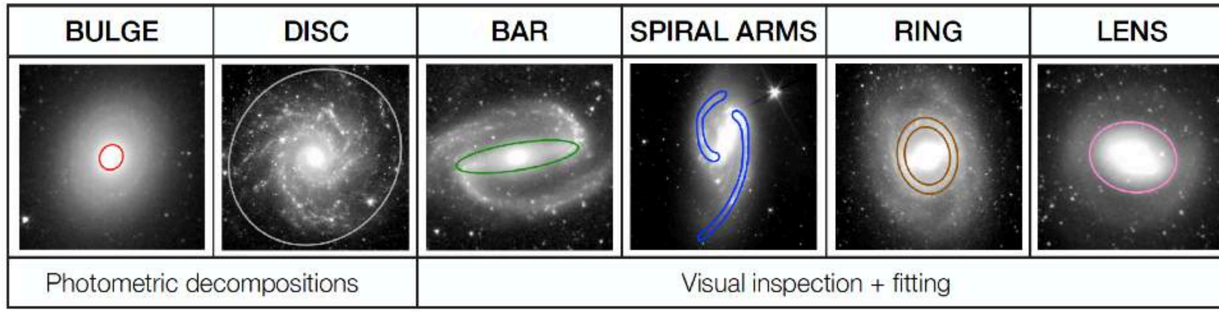
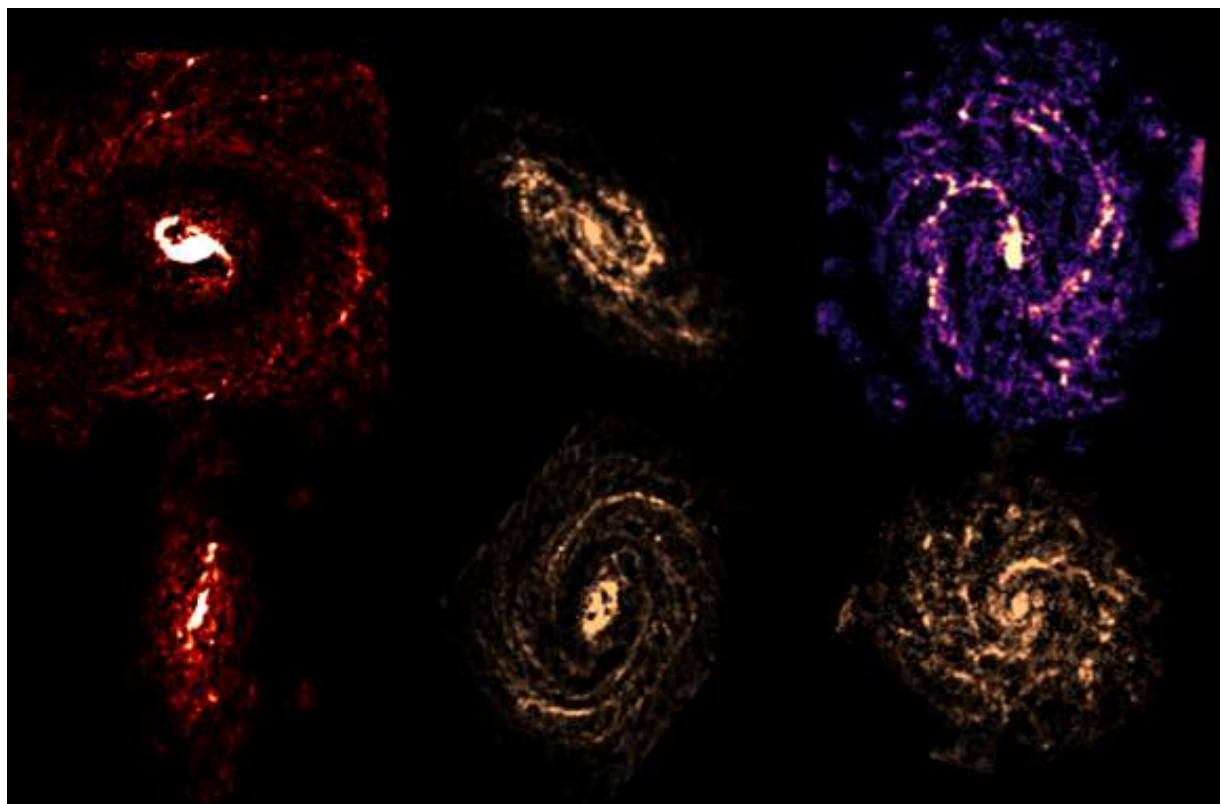




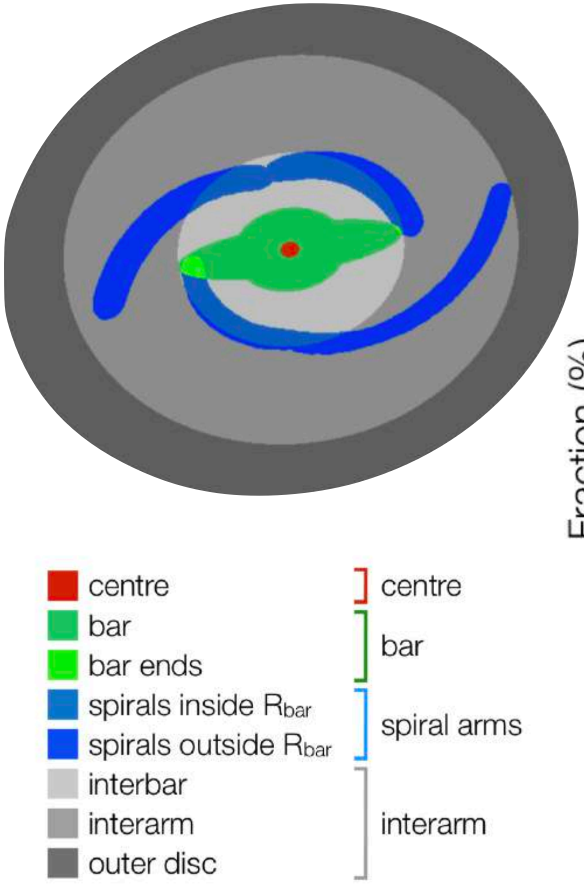


environment fractions per area, gas mass, SFR

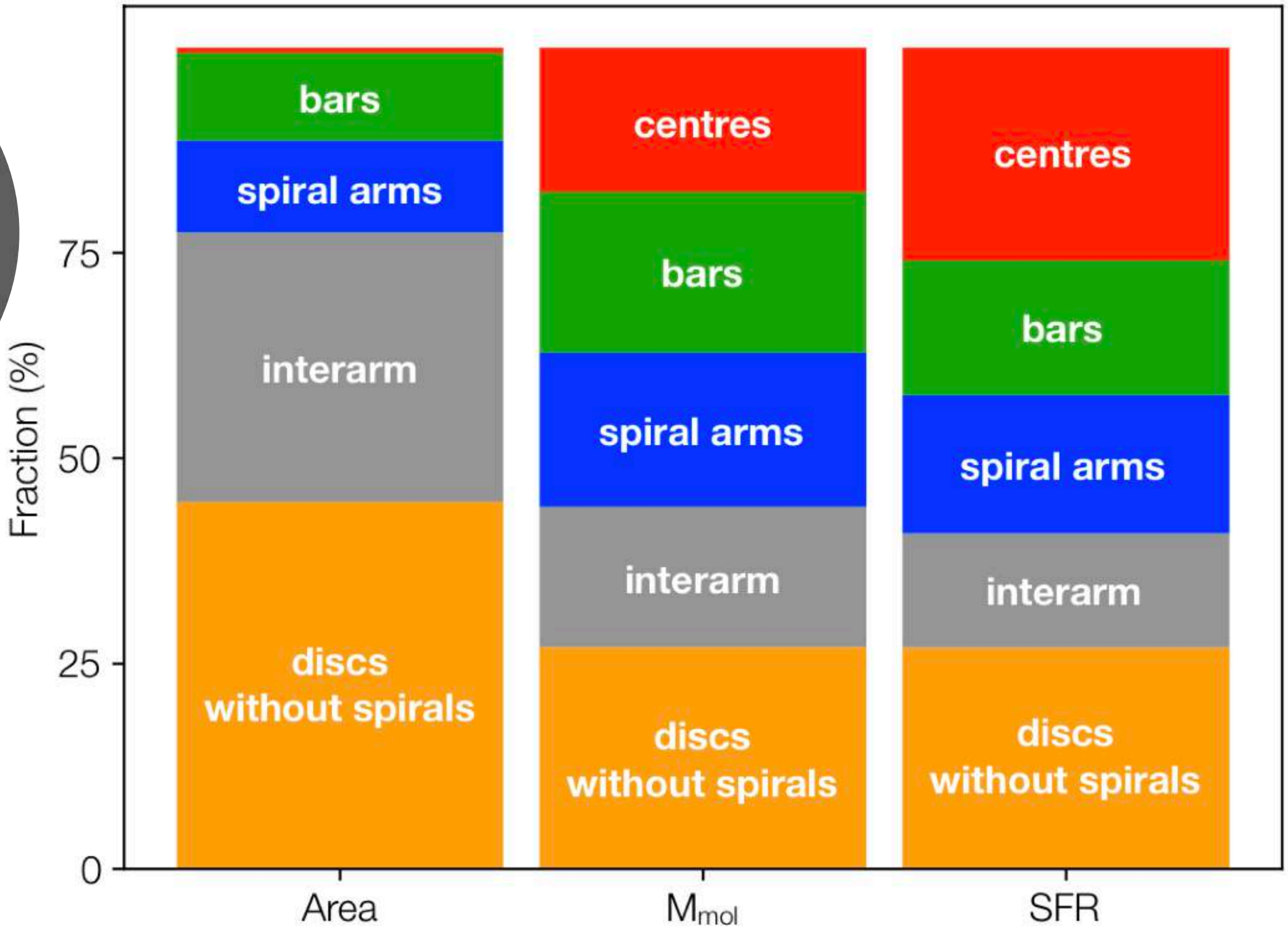
Querejeta et al. (2021)

environmental masks

based on S^4G (Salo et al. 2015, Herrera-Endoqui et al. 2016) 3.6um imaging



applied to PHANGS maps of molecular gas & SFR

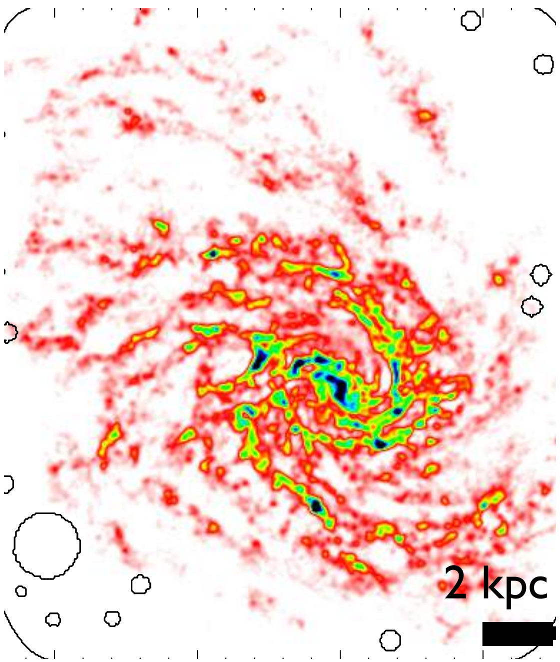


where is the star-forming gas in galaxies?

8 galaxies @ 140pc resolution
Schinnerer et al. (2019)

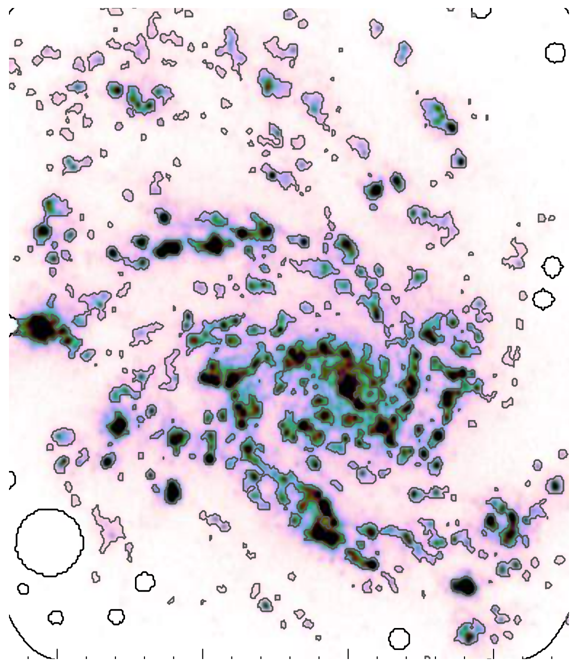
49 galaxies @ 150pc resolution
Pan et al (2022)

$\Sigma(H_2) > 12.6\ M_{sun} pc^{-2}$



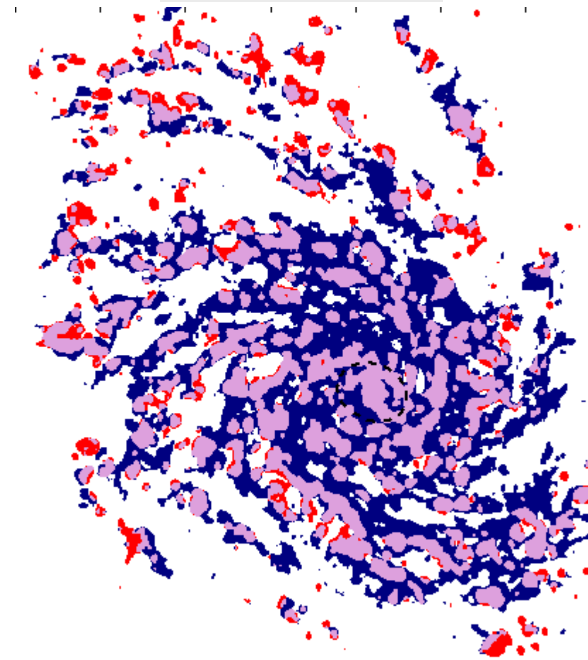
ALMA CO(2-1)
PHANGS ALMA
(Leroy et al. 2021b)

$\Sigma(SFR) \gtrsim 0.002 M_{sun} yr^{-1} kpc^{-2}$



Hα narrowband
literature
(mainly SINGS)

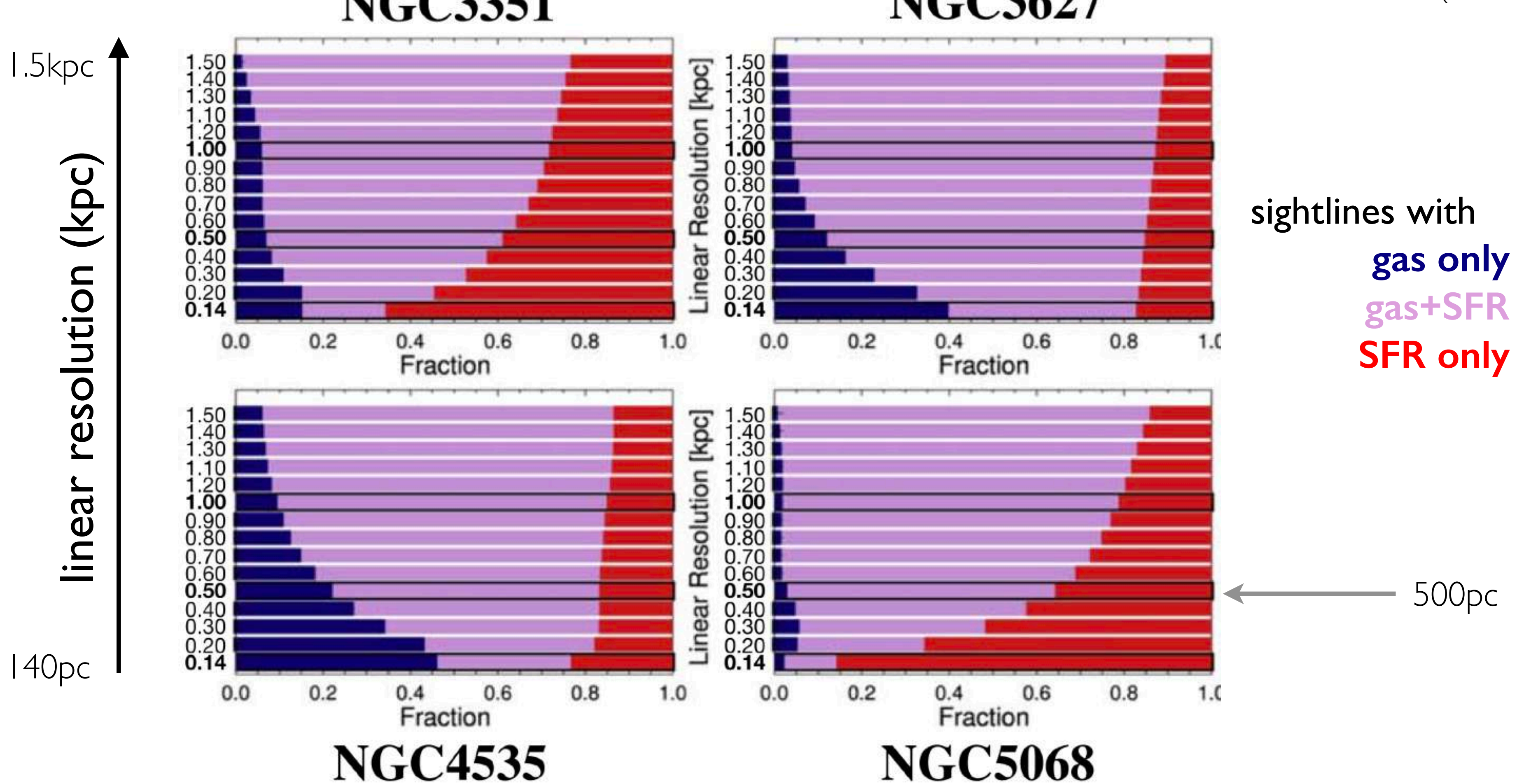
gas vs. SFR



sightlines with
gas only
gas+SFR
SFR only

fraction of star-forming gas in galaxies

Schinnerer et al. (2019)



in many galaxies, large reservoir of CO gas without high-mass SF

but need to reach scales below « 500pc to see it

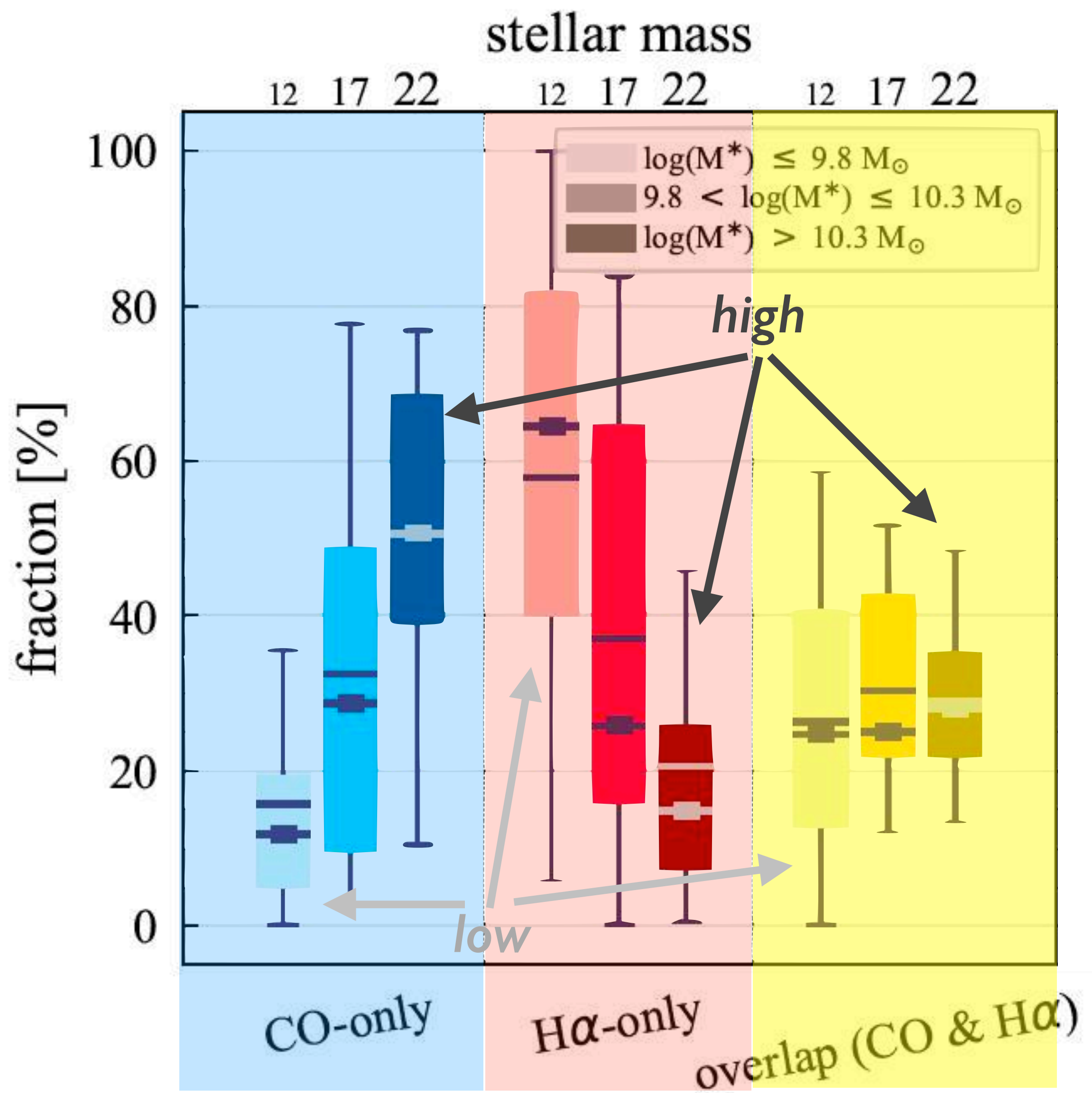
fraction of star-forming gas — variations

49 galaxies @ 150pc resolution
PHANGS-ALMA CO
PHANGS Narrowband Halpha
(Razza et al, in prep)

Pan et al. (2022)

overlap fraction (by area and mass) is roughly constant with stellar mass & Hubble type:

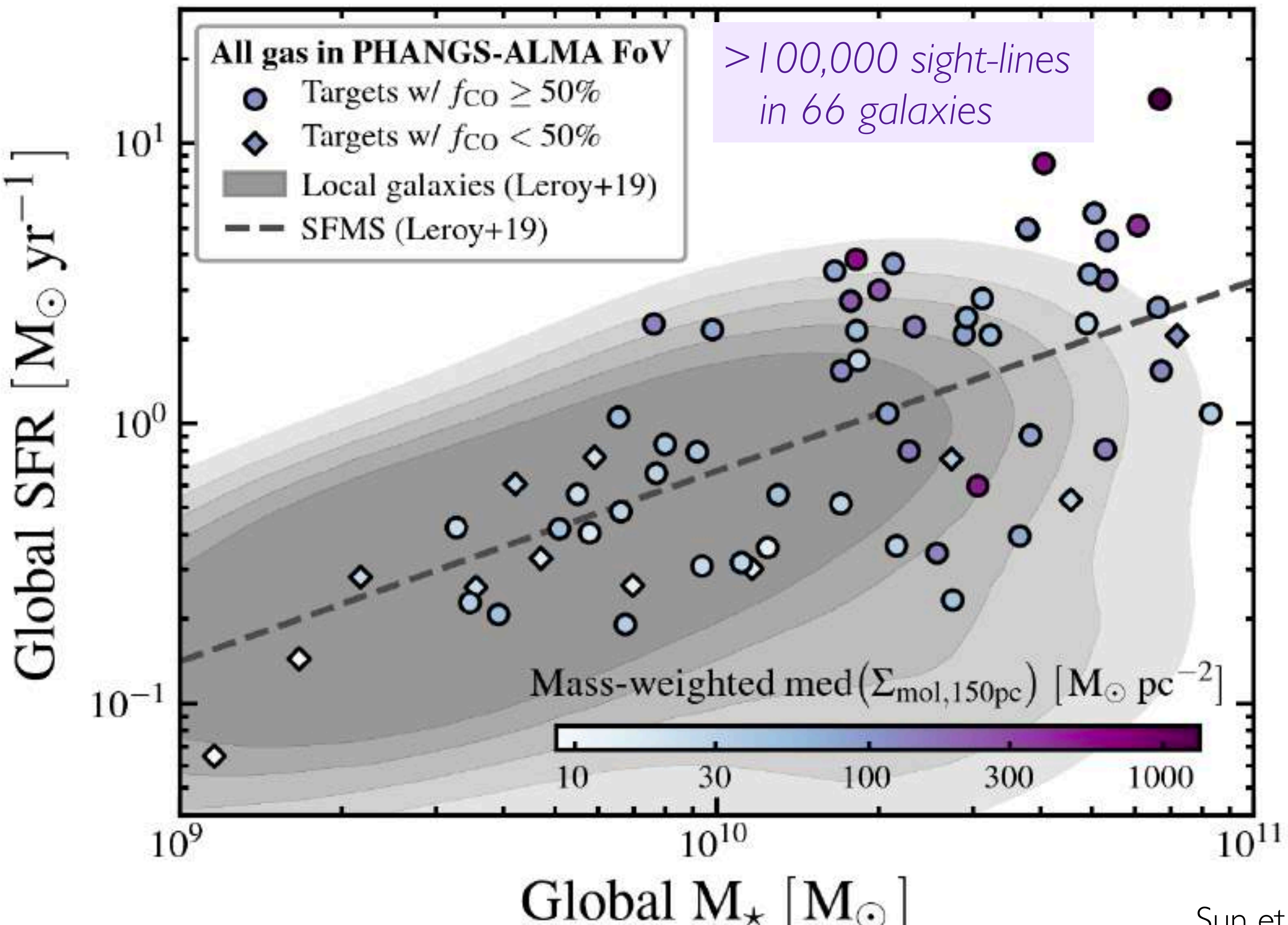
but non-star-forming gas & star-forming only sites show clear, but opposite trends



cold gas organization: cloud-scales

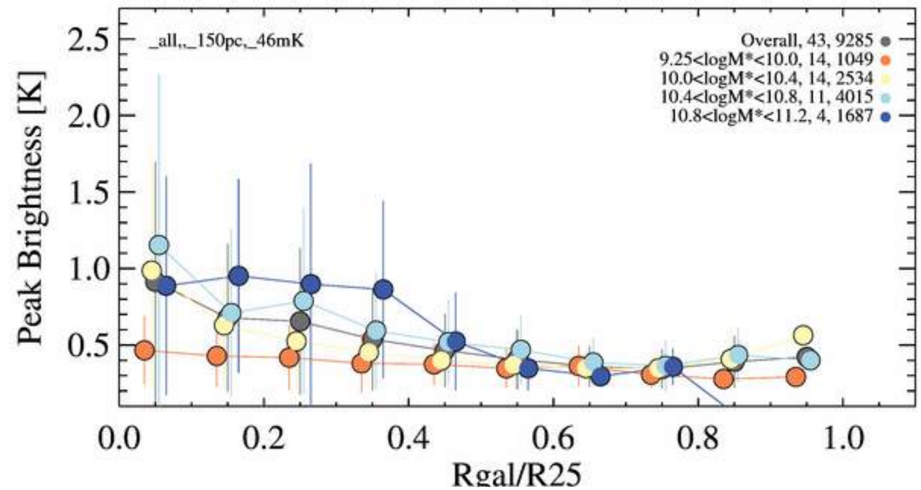
cold gas properties vary with galaxy properties

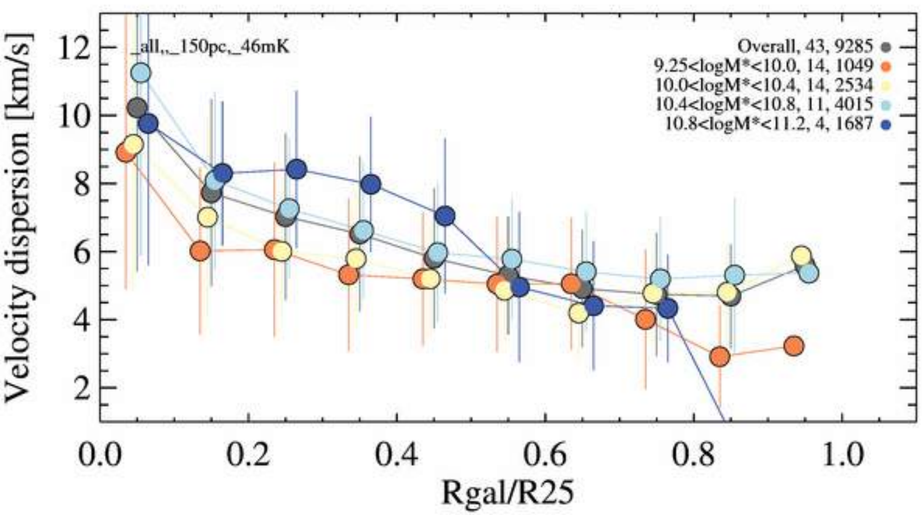
typical molecular gas surface density varies with global galaxy properties



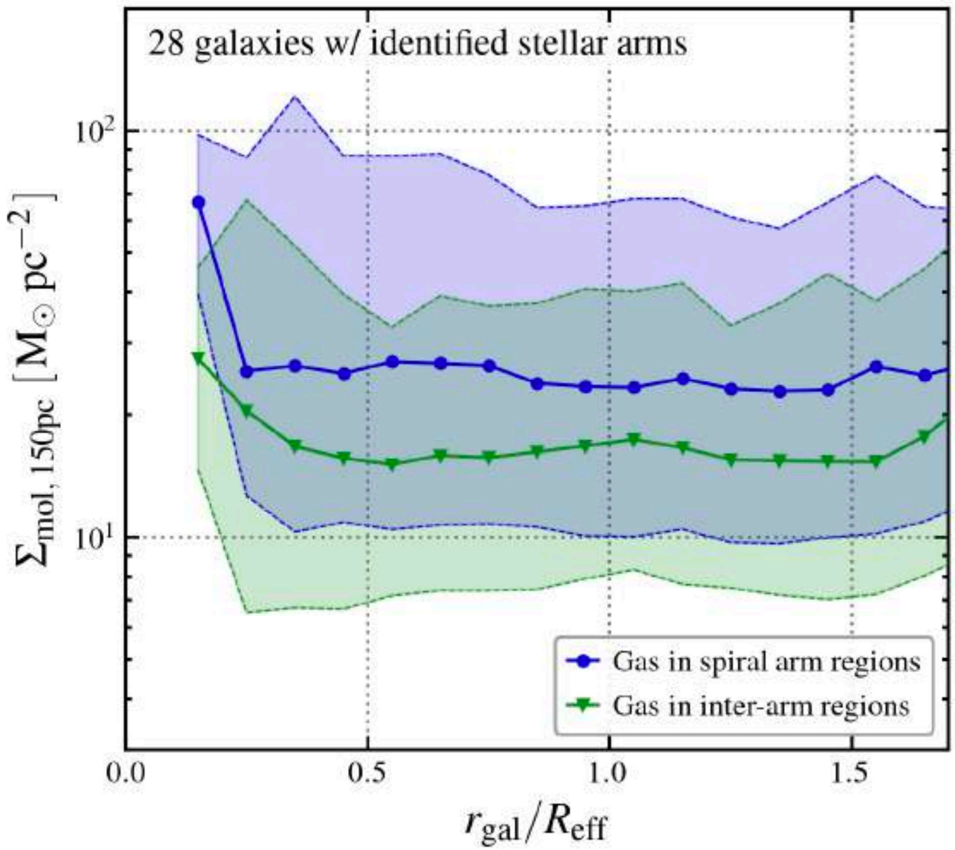
Sun et al. (2020b)

cold gas properties vary with environment





spiral arm vs. inter-arm



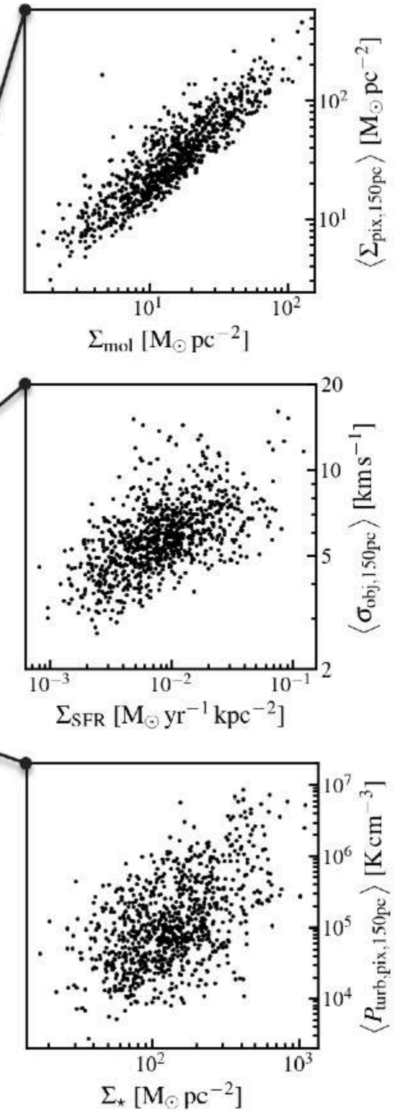
PHANGS-ALMA GMC catalogues ('as-is', plus fixed scale and sensitivity subsets) — available end 2022

cold gas properties vary with environment

150pc molecular gas properties — correlation, anti-correlation

Sun et al. (accepted)

		local environmental metrics							global galaxy properties				
		r_{gal}	Σ_{mol}	Σ_{atom}	$\Sigma_\star$	Σ_{SFR}	Ω_{circ}	A_{Oort}	r_{disk}	M_{mol}	M_{atom}	$M_\star$	SFR
mass	$\langle M_{obj,\,150pc} \rangle$	-0.10	0.78	0.30	0.42	0.62	0.18	0.13	-0.01	0.33	0.03	0.19	0.24
radius	$\langle R_{obj,\,150pc} \rangle$	0.02	-0.25	-0.15	-0.06	-0.29	-0.07	-0.14	0.04	-0.19	-0.07	0.04	-0.06
surface density	$\langle \Sigma_{obj,\,150pc} \rangle$	-0.11	0.87	0.35	0.42	0.76	0.22	0.24	-0.05	0.42	0.07	0.13	0.26
	$\langle \Sigma_{pix,\,150pc} \rangle$	-0.16	0.92	0.32	0.46	0.81	0.26	0.27	-0.02	0.46	0.09	0.16	0.32
line width	$\langle \sigma_{obj,\,150pc} \rangle$	-0.23	0.57	0.16	0.36	0.57	0.39	0.40	0.06	0.29	0.14	0.15	0.29
	$\langle \sigma_{pix,\,150pc} \rangle$	-0.25	0.79	0.20	0.52	0.74	0.38	0.37	0.09	0.40	0.12	0.21	0.34
pressure	$\langle P_{turb,\,obj,\,150pc} \rangle$	-0.19	0.84	0.31	0.48	0.77	0.33	0.33	0.02	0.40	0.12	0.17	0.31
	$\langle P_{turb,\,pix,\,150pc} \rangle$	-0.20	0.85	0.29	0.53	0.78	0.31	0.28	0.05	0.41	0.09	0.21	0.32
virial	$\langle \alpha_{vir,\,obj,\,150pc} \rangle$	-0.17	-0.35	-0.25	-0.05	-0.21	0.24	0.26	0.12	-0.17	0.08	-0.01	-0.00
	$\langle \alpha_{vir,\,pix,\,150pc} \rangle$	-0.29	-0.09	-0.29	0.10	0.01	0.38	0.39	0.15	-0.06	0.16	0.01	0.07

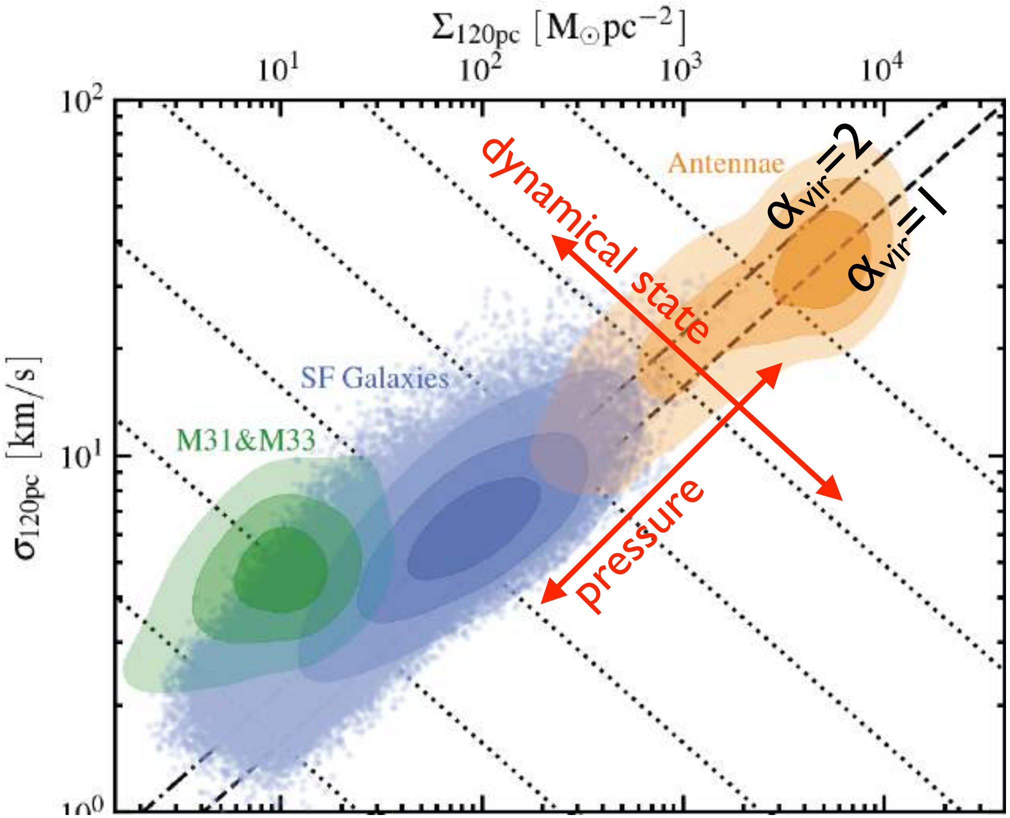


correlation(s)

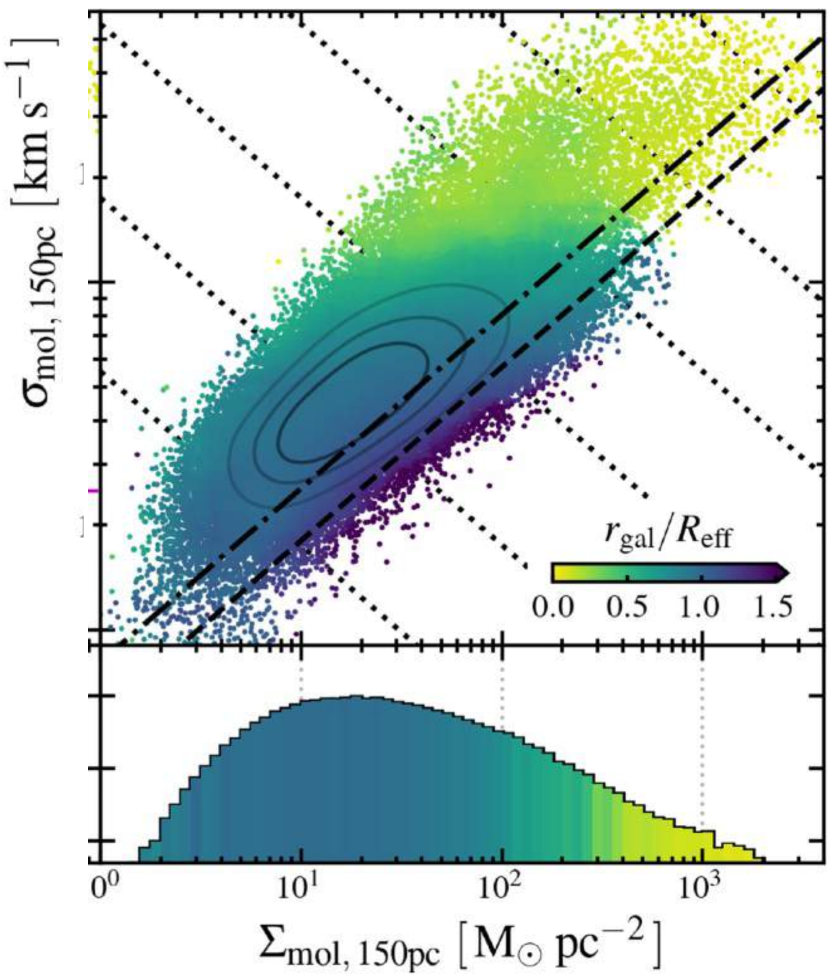
molecular gas in ≈ equilibrium

Sun et al. (2018, 2020a)

~30000 sightlines in 16 galaxies



~100000 sightlines in 66 galaxies

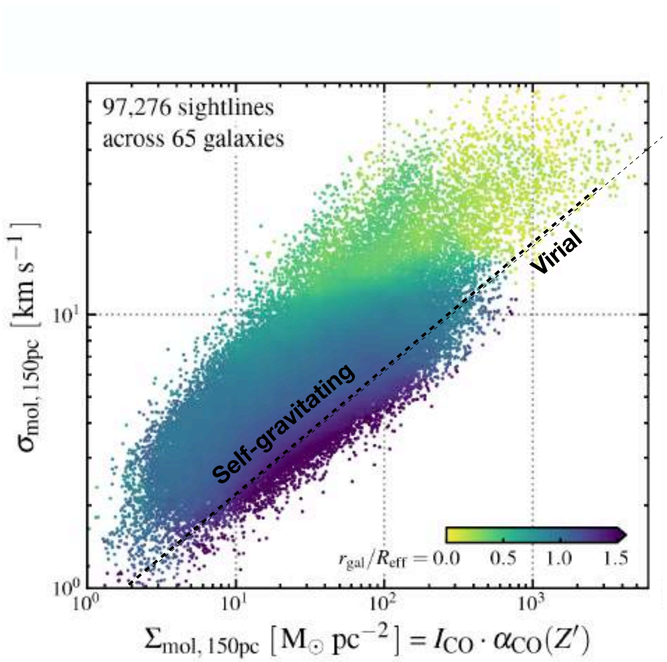


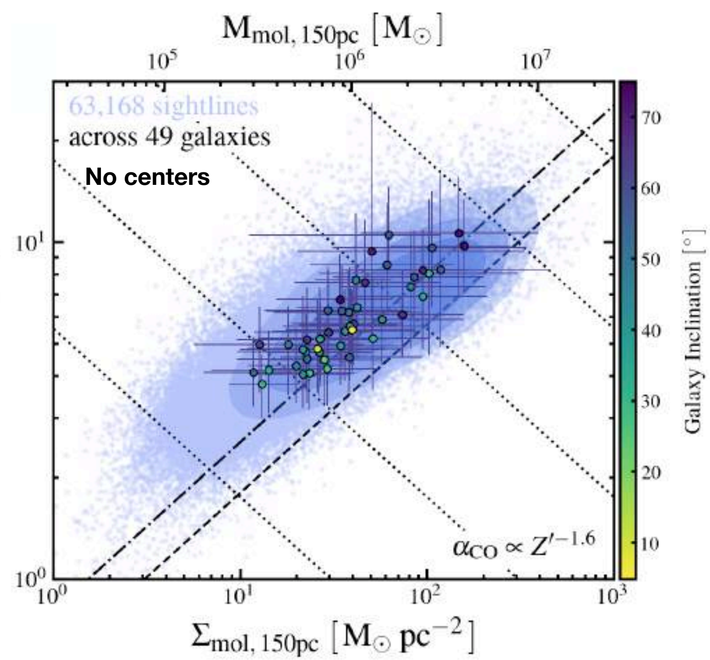
P_{turb}~$\sigma^2\Sigma$

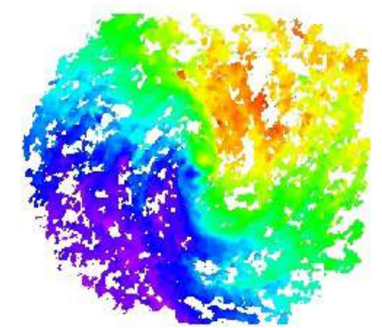
α_{vir}~σ^2/Σ
α_{vir}~ 2K/U_g

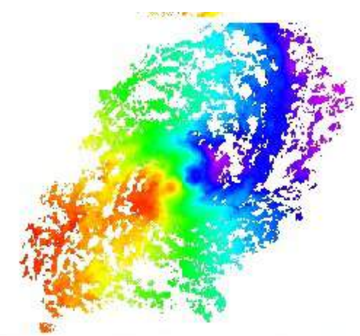
dynamically-regulated clouds and SF

Sharon Meidt has been developing a model for how gas motions induced by the background galactic potential influence cloud properties and may represent a bottle-neck to SF under certain conditions.









Starting point: we see systematic variations in the CO line widths that depend on position, galaxy mass and viewing angle: cloud-scale velocity dispersion measurements reflect a contribution from gas motions in the galactic potential.

LANG ET PHANGS 2021, MEIDT ET PHANGS 2018, MEIDT ET PHANGS, 2020

dynamically-regulated clouds and SF

Cloud EoM: $$\frac{d^2 r}{dt^2} = -\nabla_r \Phi_c \quad + 3\sigma_{gal}^2(R_{gal})r \quad + F_{ng}$$

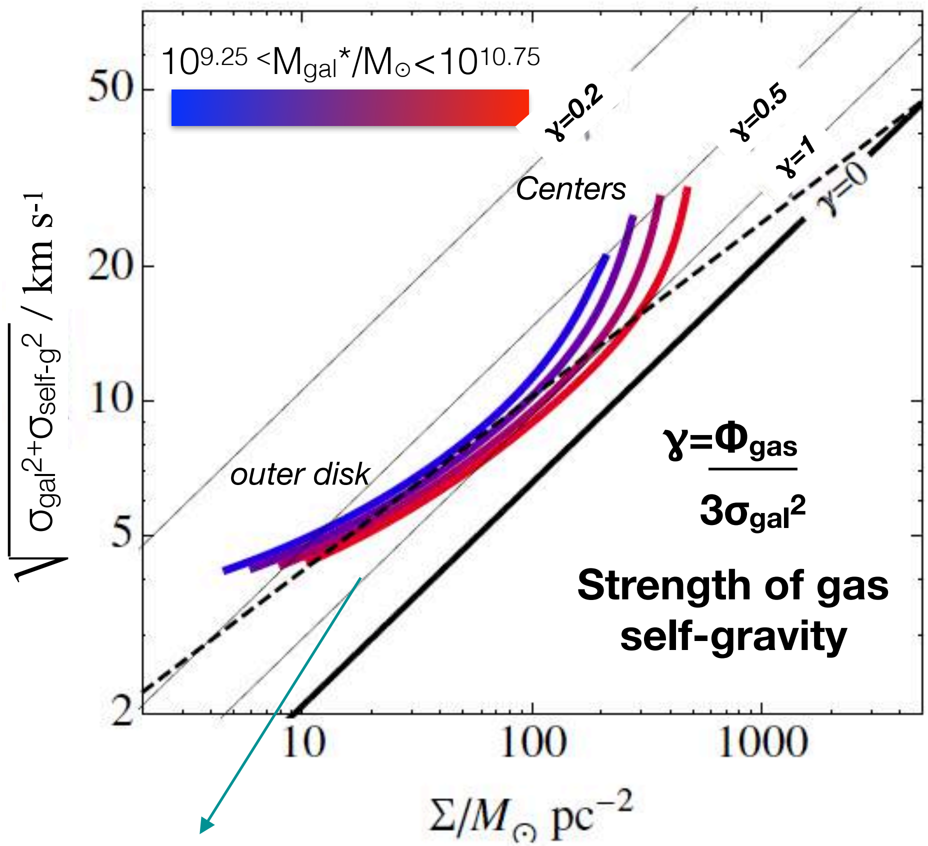
free-fall collapse

cloud self-gravity

opposed by

galactic-induced motions

Non-gravitational sources: e.g. feedback, magnetic fields



Semi-empirical 'global galaxy' models

<u>Dynamical equilibrium model</u>:

Galaxy organizes gas across range of scales (contrasts)

Large reservoir of cold gas without SF

Galactic environment influences cloud structure <u>and cloud-scale σ_{obs}</u>

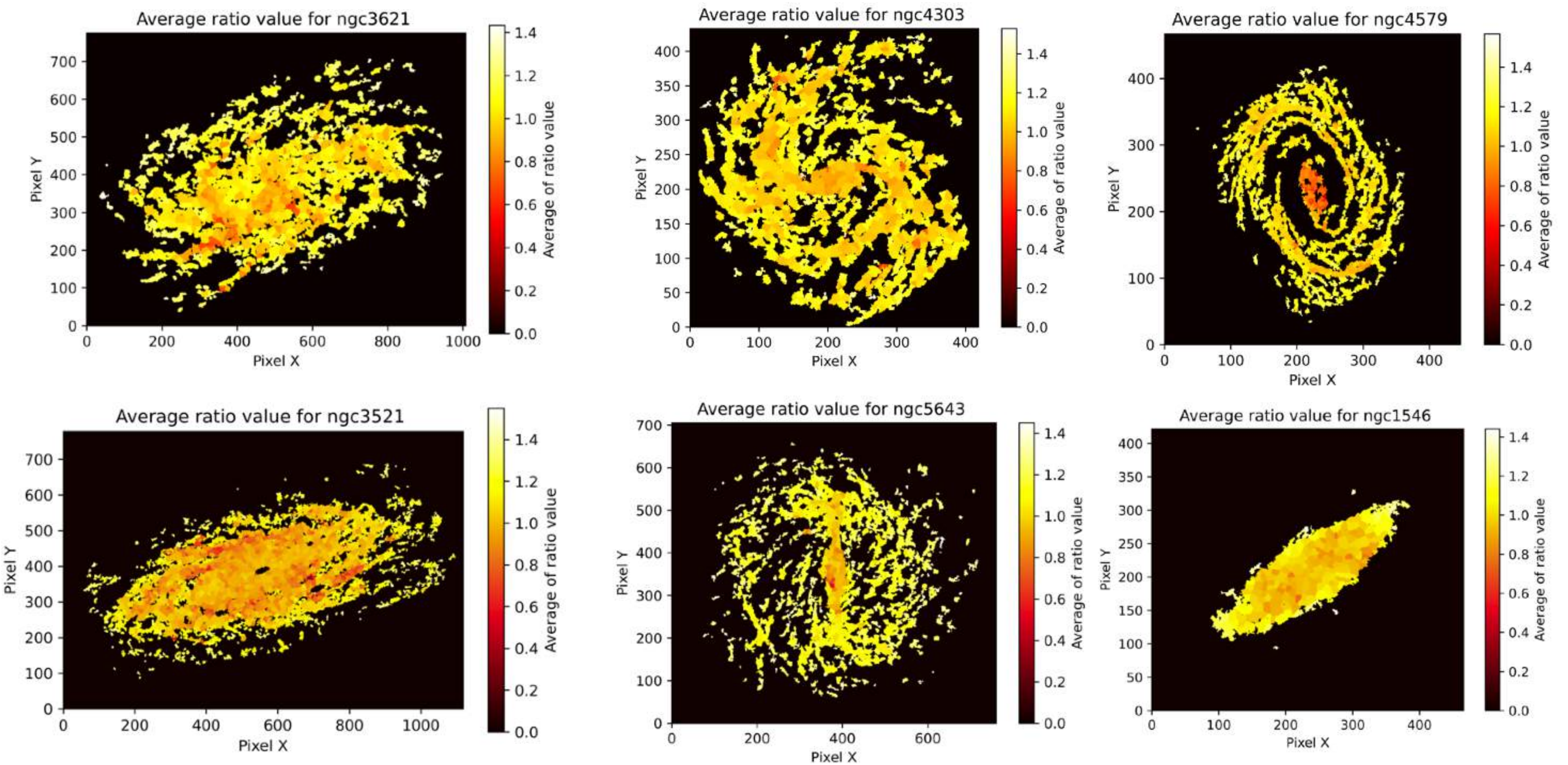
Contribution of inert (non-self-gravitating) gas component within clouds:

* lengthened collapse time tcoll>>tff
* reduced SF efficiency

MEIDT ET PHANGS 2018, 2020

… but can we measure it with PHANGS?

systematic variations in CO line profile shapes with galaxy environment

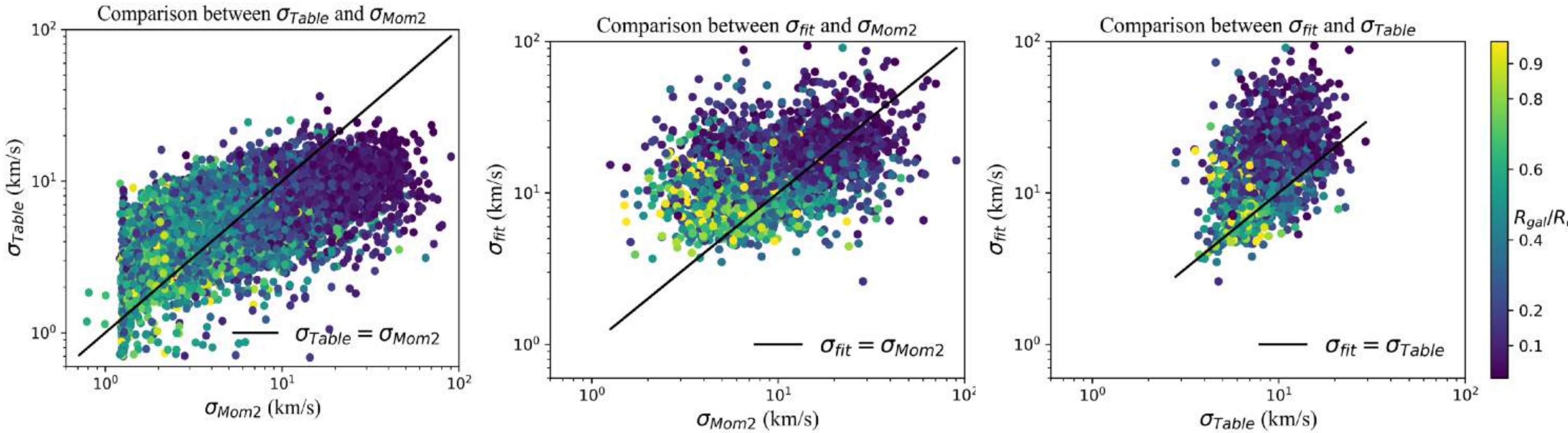


metric: equivalent width/moment-2 (~1 for a Gaussian)

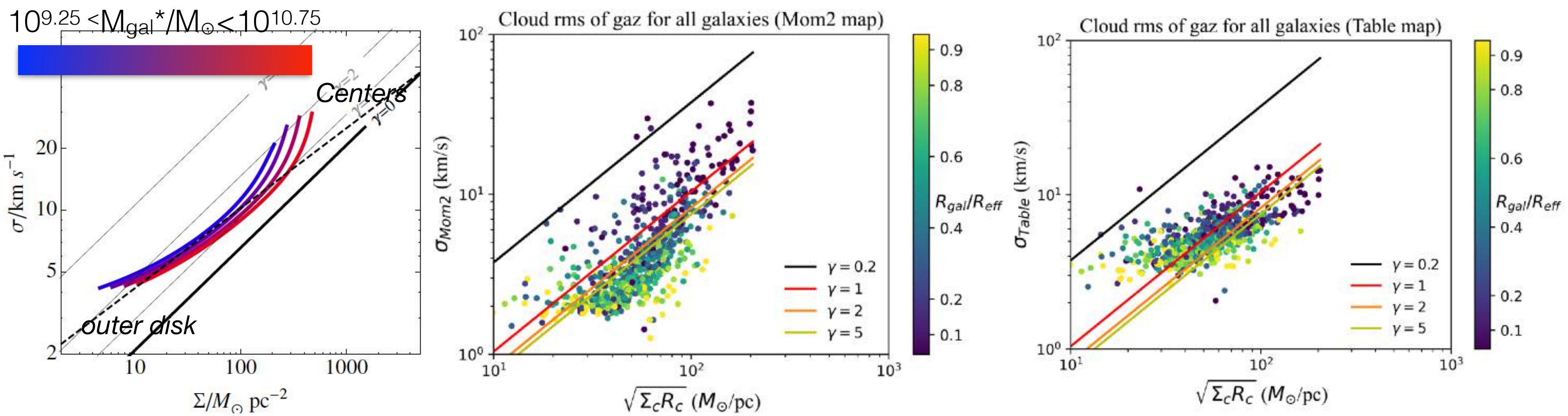
Raphael Maris, M2 project — work in progress!

… but can we measure it with PHANGS?

Comparison between different methods for measuring moment-2 from CO data:



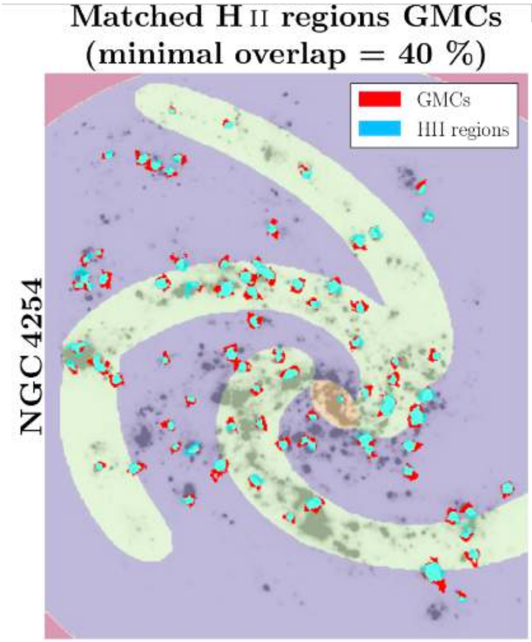
Comparison to Meidt et al prediction (average cloud properties in radial bins):



Raphael Maris, M2 project — work in progress!

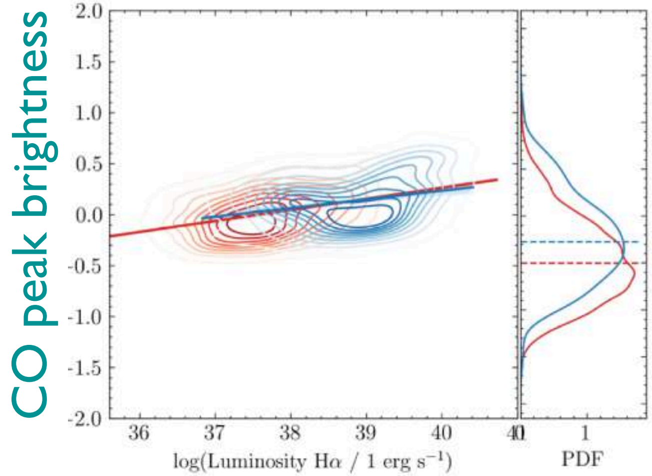
feedback: timescales, mechanisms, impact on cold gas properties, enrichment

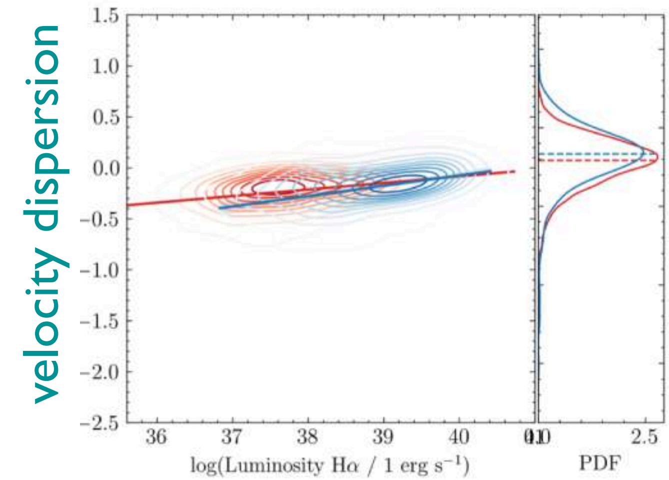
Search for SF feedback signatures on cold gas



cloud-based analysis

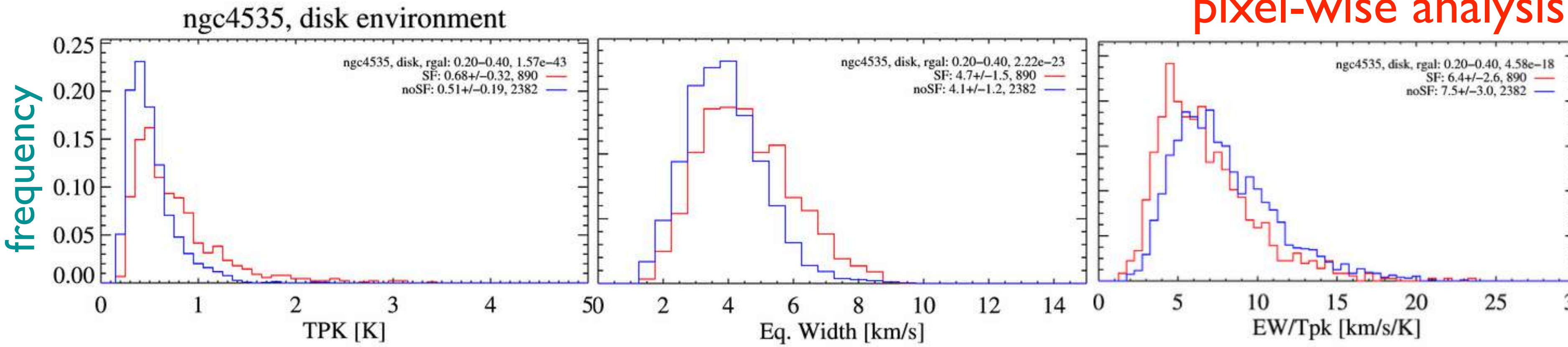
(Zakardjian et al. in prep)





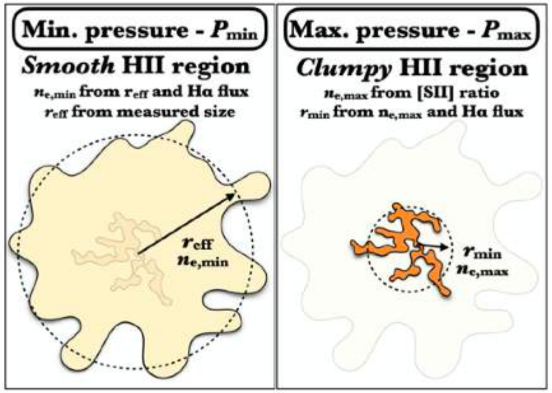
Halpha luminosity of associated HII region

pixel-wise analysis



Feedback from HII regions on molecular clouds may affect CO brightness, but evidence for an impact on the cold gas velocity dispersion is less clear

quantifying pre-SN feedback with MUSE HII regions



derive internal & external pressure for ~6000 HII regions in MUSE observations of 19 galaxies

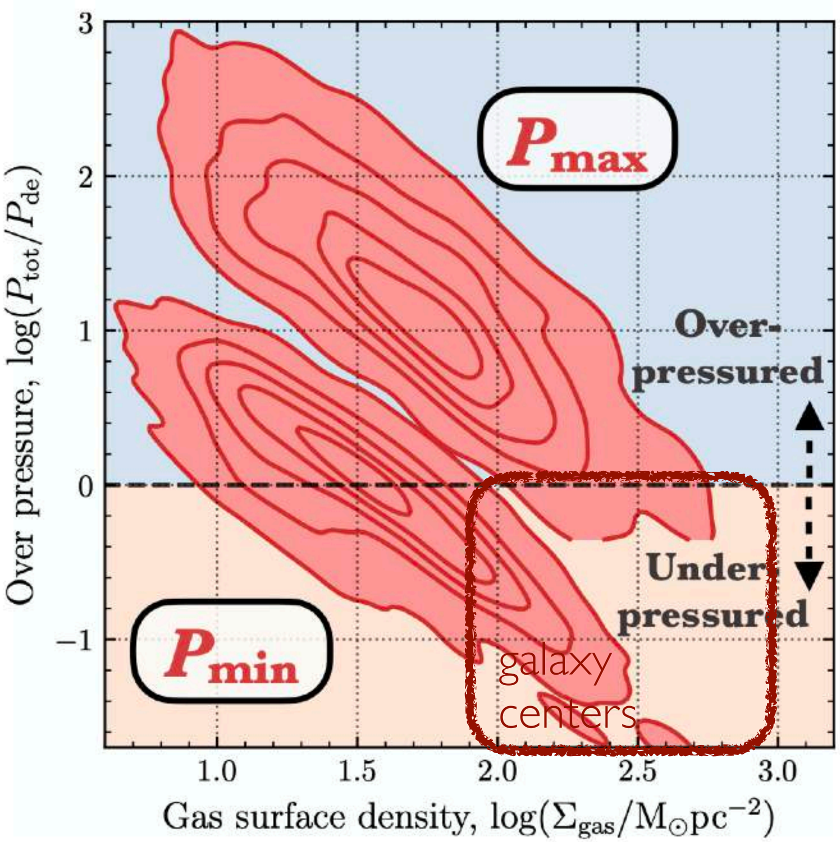
two limit scenarios to estimate Pmin & Pmax

external pressure:

- dynamical equilibrium pressure

internal pressure terms:

- thermal ionised gas pressure
- direct radiation pressure
- mechanical wind pressure

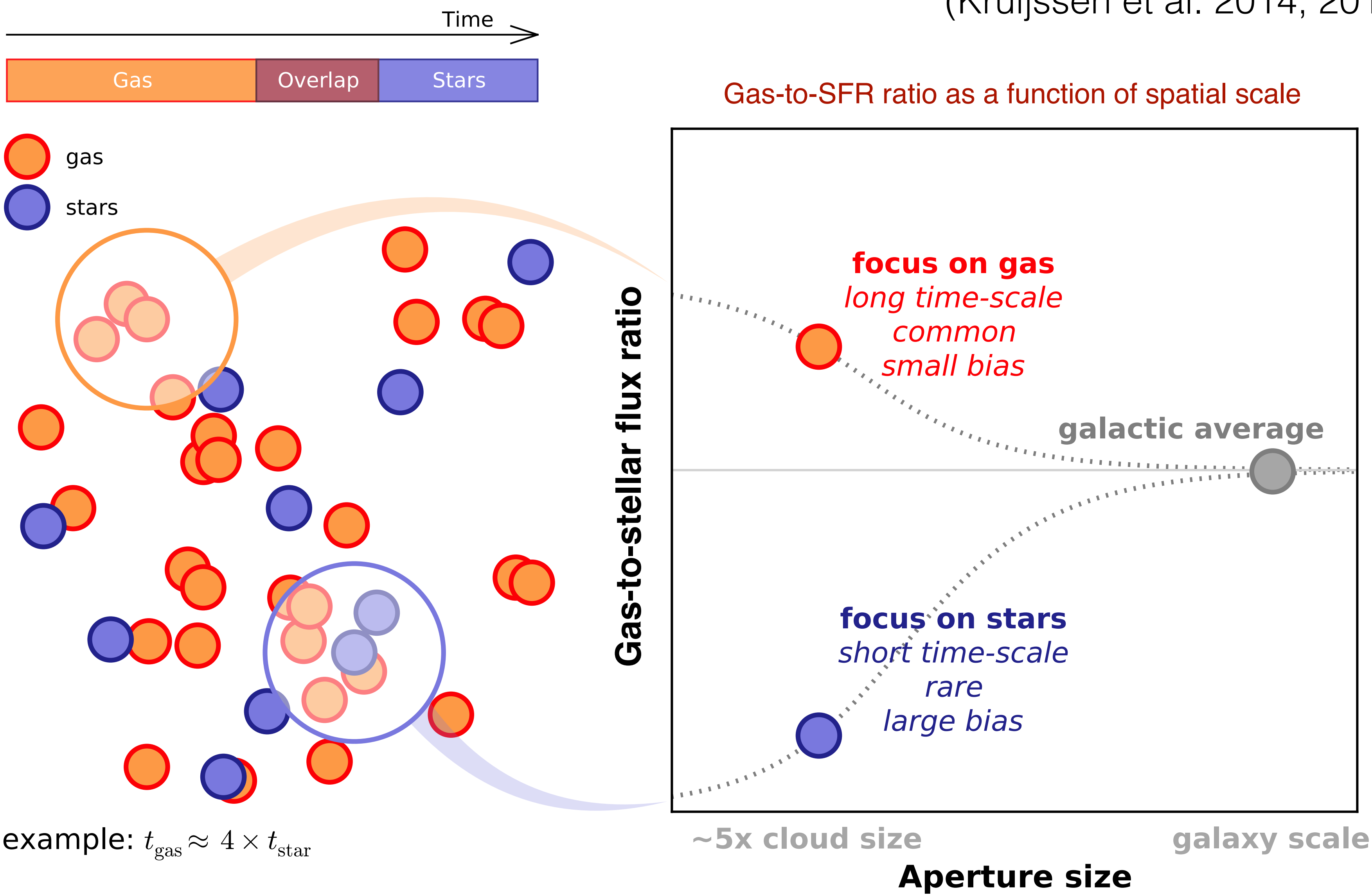


most HII regions are over-pressured and expanding, but some HII regions in centers appear under-pressured

(Barnes et al. 2021)

timescales from spatial distribution of gas&SF

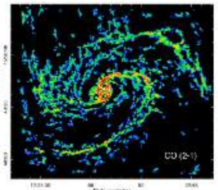
(Kruijssen et al. 2014, 2018)



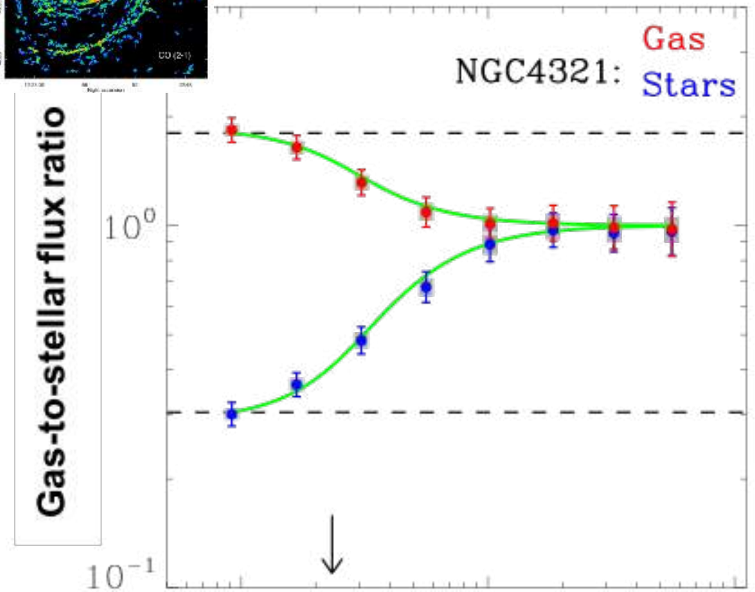
example: $t_{\rm gas} \approx 4 \times t_{\rm star}$

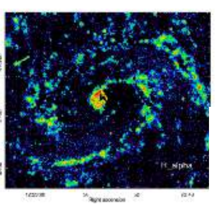
(see also Kawamura et al. 2009, Schruba et al. 2010, Gratier et al. 2012, Corbelli et al. 2017)

measuring cloud lifetimes & feedback timescales



CO

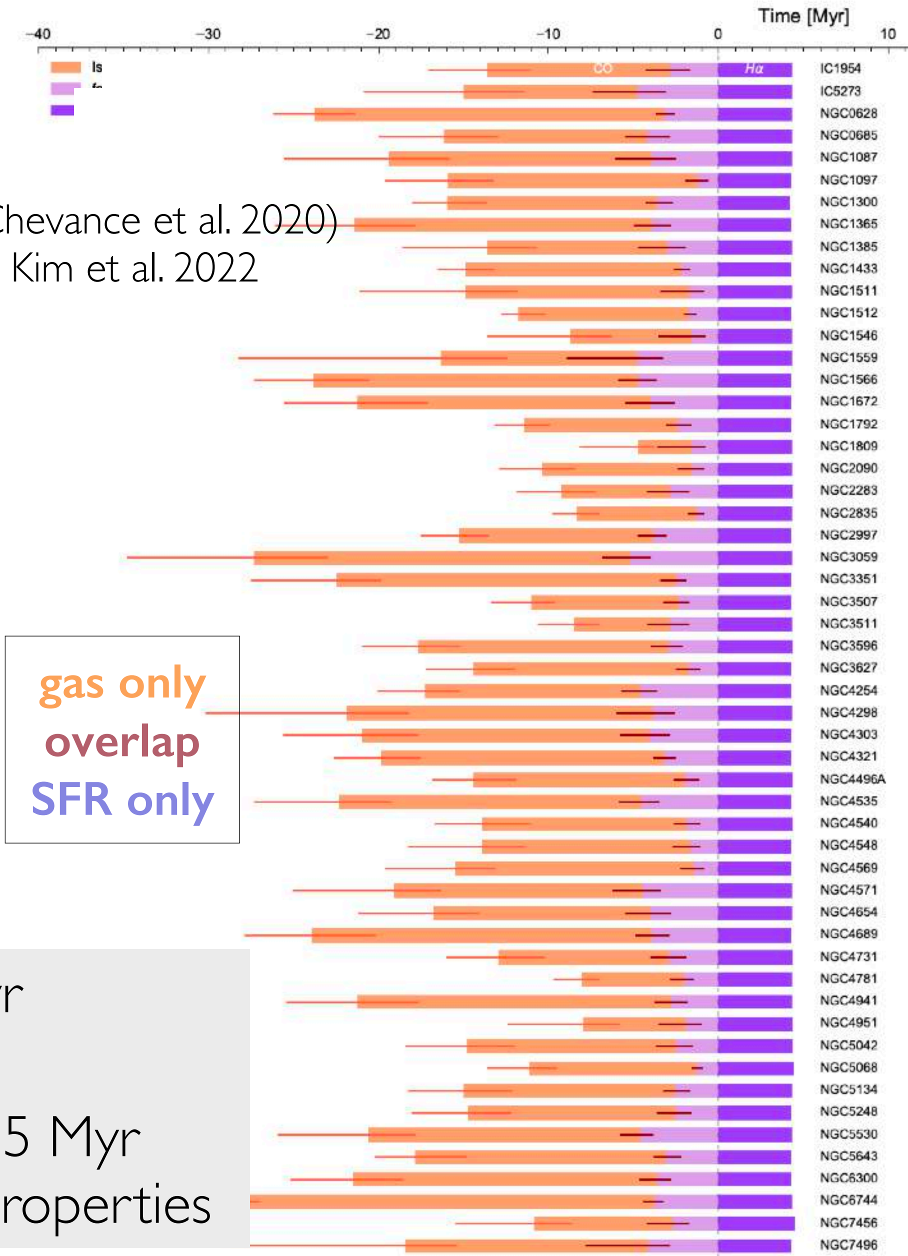




NB Halpha

(9 galaxies, Chevance et al. 2020)
~60 galaxies, Kim et al. 2022

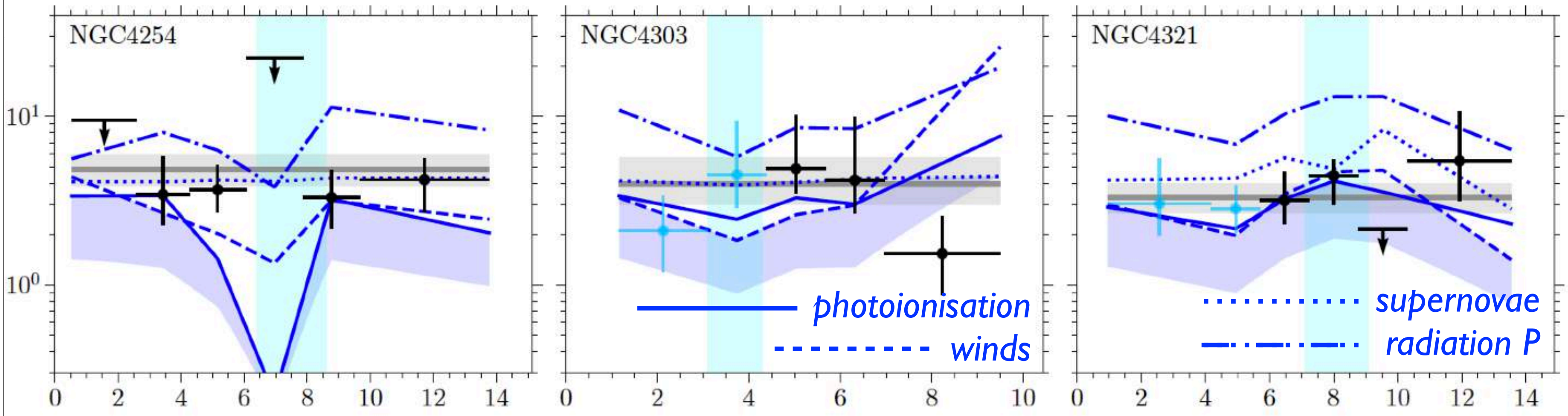
gas only
overlap
SFR only



typical GMC lifetime: 16.5±6 Myr
relatively long **inert** phase
typical **SF feedback** timescale: 3.5±1.5 Myr
subtle systematic variations with galaxy properties

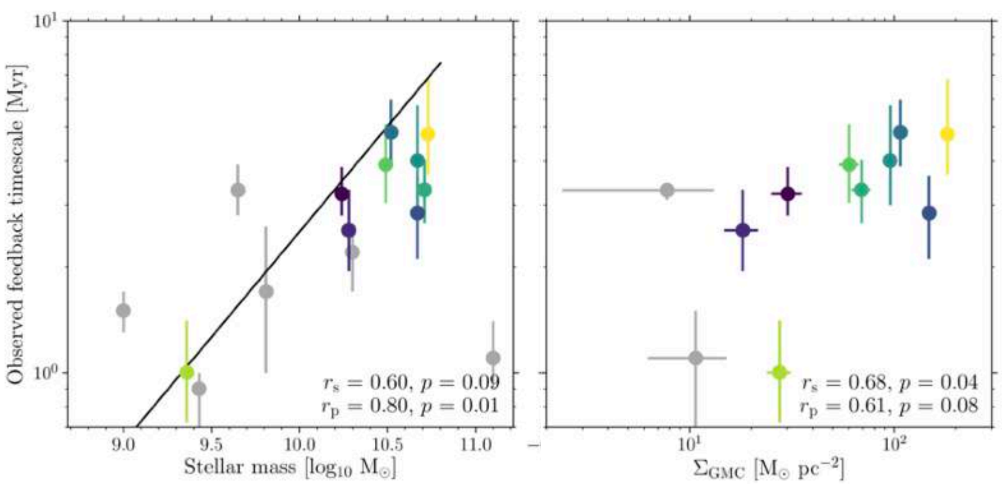
measurements vs predictions: SF feedback

overlap timescale (Myr)



Galactocentric Radius

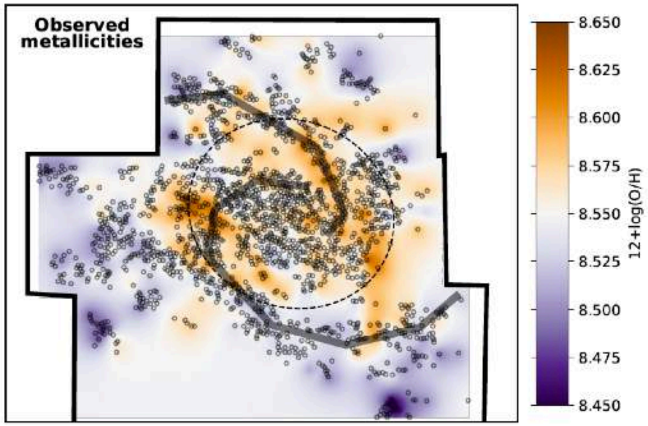
pre-supernova (<5Myr) feedback (winds, photoionisation) is important

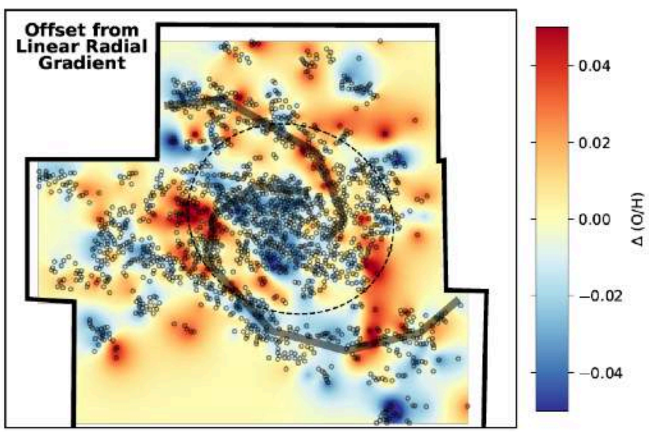


SF feedback timescale increases in more massive galaxies (which also tend to host higher density, more massive GMCs)

(Chevance et al. 2022)

chemical enrichment and mixing

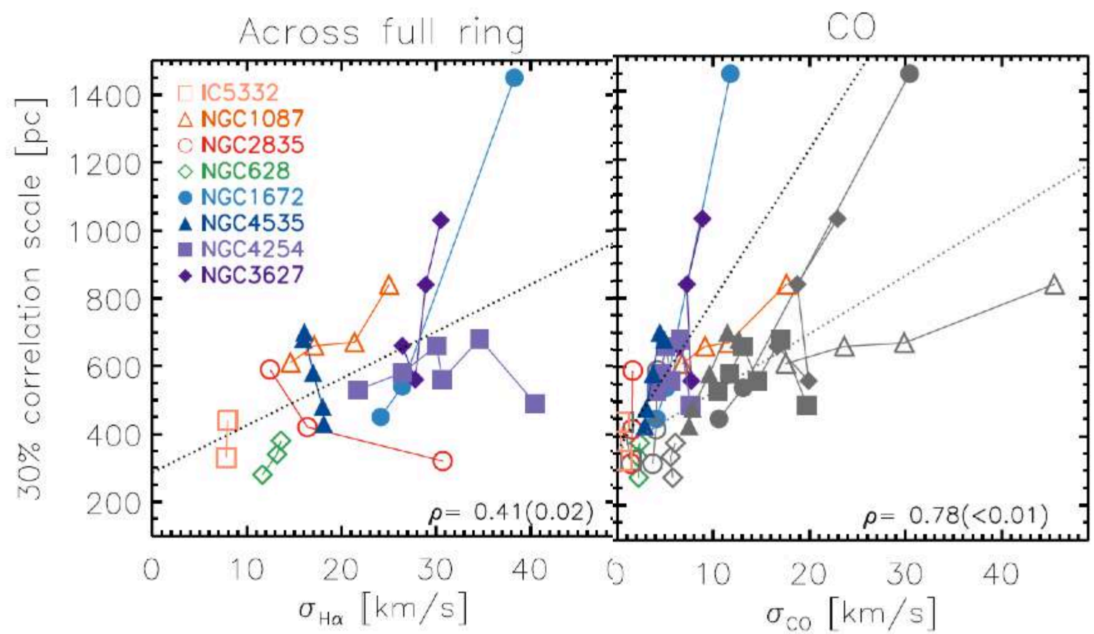




metallicity measurements for ~6000 HII regions in 17 galaxies with MUSE observation

after removing radial gradient, residual metallicity variations of ~0.05dex

characteristic homogeneity scale of ~600pc, but systematically larger for metal-poor HII regions than for metal-rich regions (infall of pristine material + enrichment with spiral arms?)



correlation scale increases with gas velocity dispersion —
broad agreement with KT (2018) stochastically forced diffusion model

(Kreckel et al 2019, 2020)

Talk Summary

Molecular gas properties and kinematics on cloud-scales appear linked to the properties of the local galactic environment and the host galaxy disk.

Joint analysis of high resolution CO and Hα data suggests rapid cycling between molecular gas and star formation, and a significant reservoir of molecular gas in many galaxies without associated high-mass star formation. GMC lifetimes and SF feedback timescales are short.

At 100pc resolution, we don’t unambiguously isolate the cold gas component that is being directly modified by star formation feedback

There is an overall high level of chemical homogeneity on large spatial scales in galaxies, suggesting efficient ISM mixing.