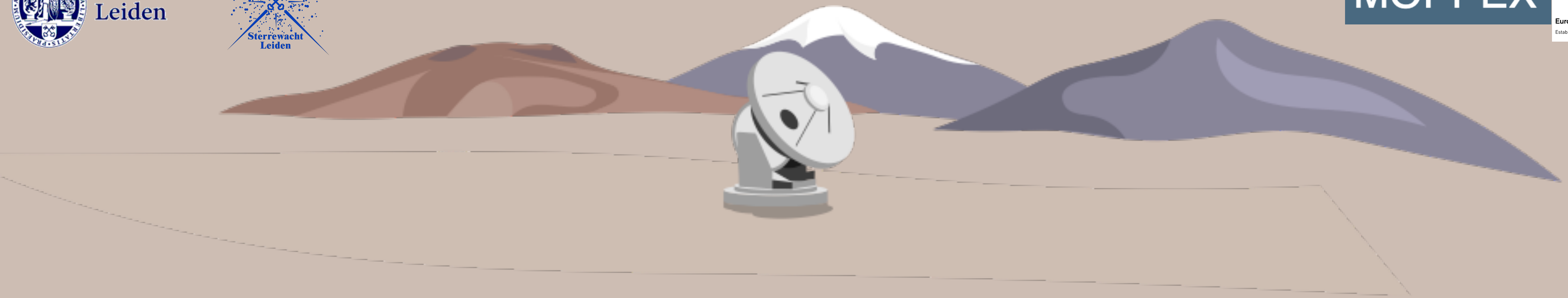
Transformational science with AtLAST

Bouvier, M.M.E.; Viti, S.

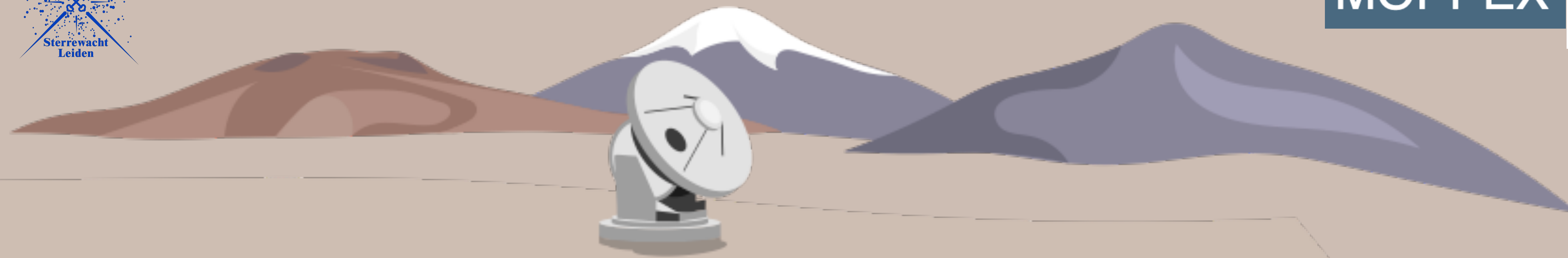


AtLAST's transformational science

Mathilde Bouvier[1] & Serena Viti[1]

[1]Leiden Observatory, Leiden University

May 21st 2024 - Mainz, Germany



AtLAST's transformational science

For nearby galaxies

May 21st 2024 - Mainz, Germany

A view on specific AtLAST capabilities for nearby galaxies

Frequency range of AtLAST:
~30-1000 GHz

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CO and isotopologues

HCN, HNC, HCO^+

N_2H^+

CS

Bulk gas &
dense gas tracers

A view on specific AtLAST capabilities for nearby galaxies

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Bulk gas &
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What do we use these tracers for?

Outline of the talk

General motivation

Star formation is one of the driving processes in galaxy evolution. It is thus crucial to understand the full picture of star formation across all environments, scales and cosmic times.

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Case 1: Bridging the gas-star formation relation at small- and large scales

Case 2: Characterising the physics and chemistry of nearby galaxies

Case 3: Understanding molecular clouds properties in nearby galaxies

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Case 1: Bridging the gas-star formation relation at small- and large scales

Case 2: Characterising the physics and chemistry of nearby galaxies

Case 3: Understanding molecular clouds properties in nearby galaxies

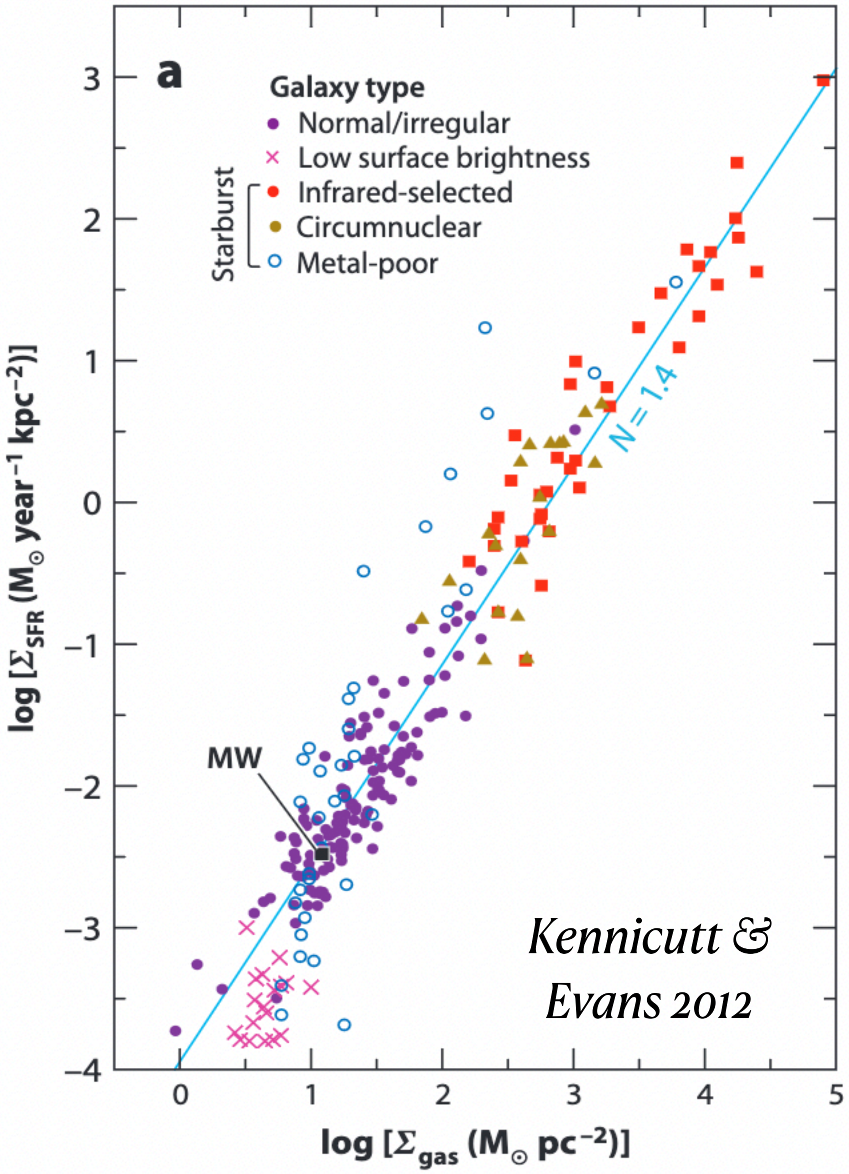
More talks about nearby galaxies in talks of Kemper & Bot, Correia, Andreani, Hagedorn, Lasrado and in the white paper by Liu+2024

Case 1: Bridging the gas-star formation relation at small- and large scales

Kennicutt-Schmidt (KS) law

$$\Sigma_{SFR} \propto \left(\Sigma_{gas}\right)^n \quad n \sim 1.4 - 1.5$$

(e.g. Schmidt 1959; Kennicutt 1998; Kennicutt & De Los Reyes 2021)



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- **Law holds on global galaxy scales**

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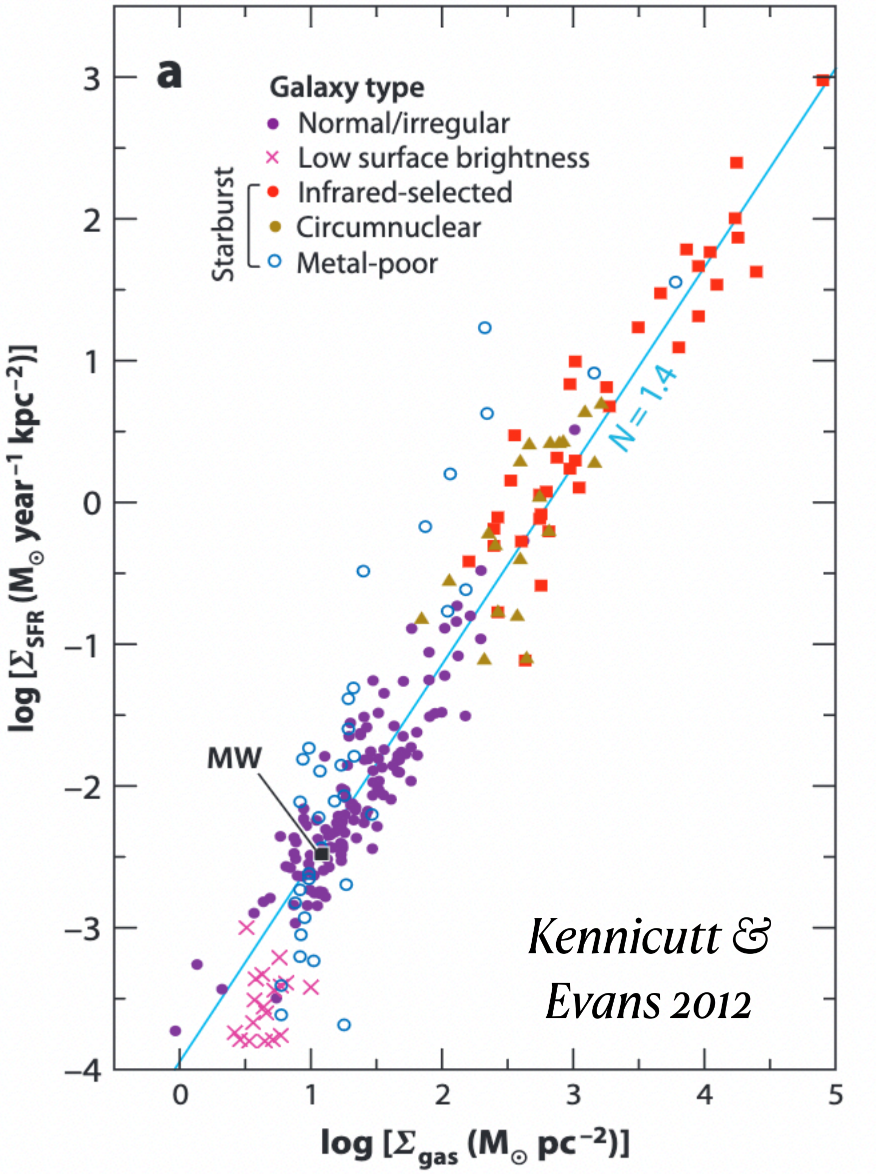


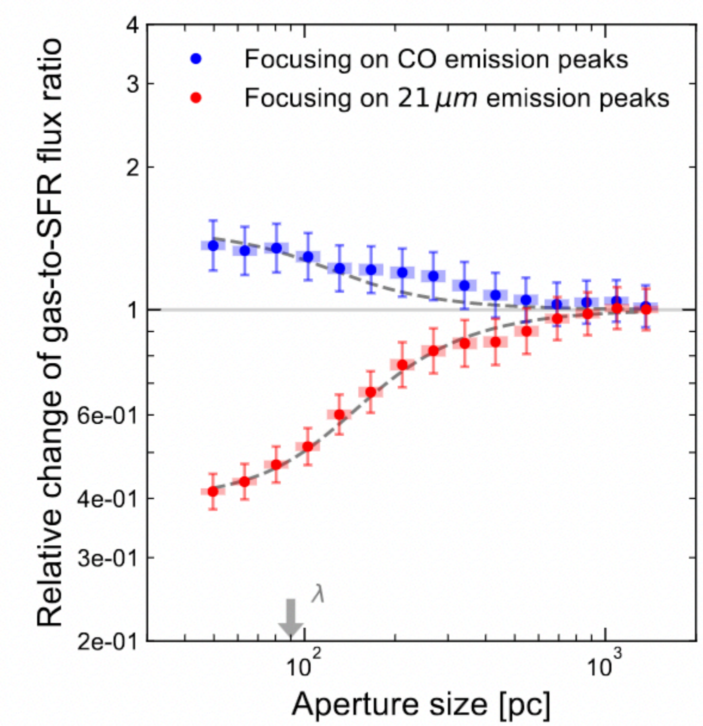
Kennicutt & Evans 2012

- **Derived from CO observations and assuming a constant CO-H_2 conversion factor**
- **Law holds on global galaxy scales**

Variation of the KS law at resolved kpc scales across galaxies and environments within galaxies *(e.g. Wong & Blitz 2002; Kennicutt+2007; Bigiel+2008; Wilson+2008; Schruba+2011; Garcia-Burillo+2012; Leroy+2013b; Dey+2019; Pessa+2021; 2022; Jiménez-Donaire+2023)*

Break down of KS law at sub-kpc scales *(e.g. Kruijssen & Longmore 2014; Schinnerer&Leroy and ref therein)*

Modelling break-down of KS relation vs scale



Schruba+2010; Kim+2023

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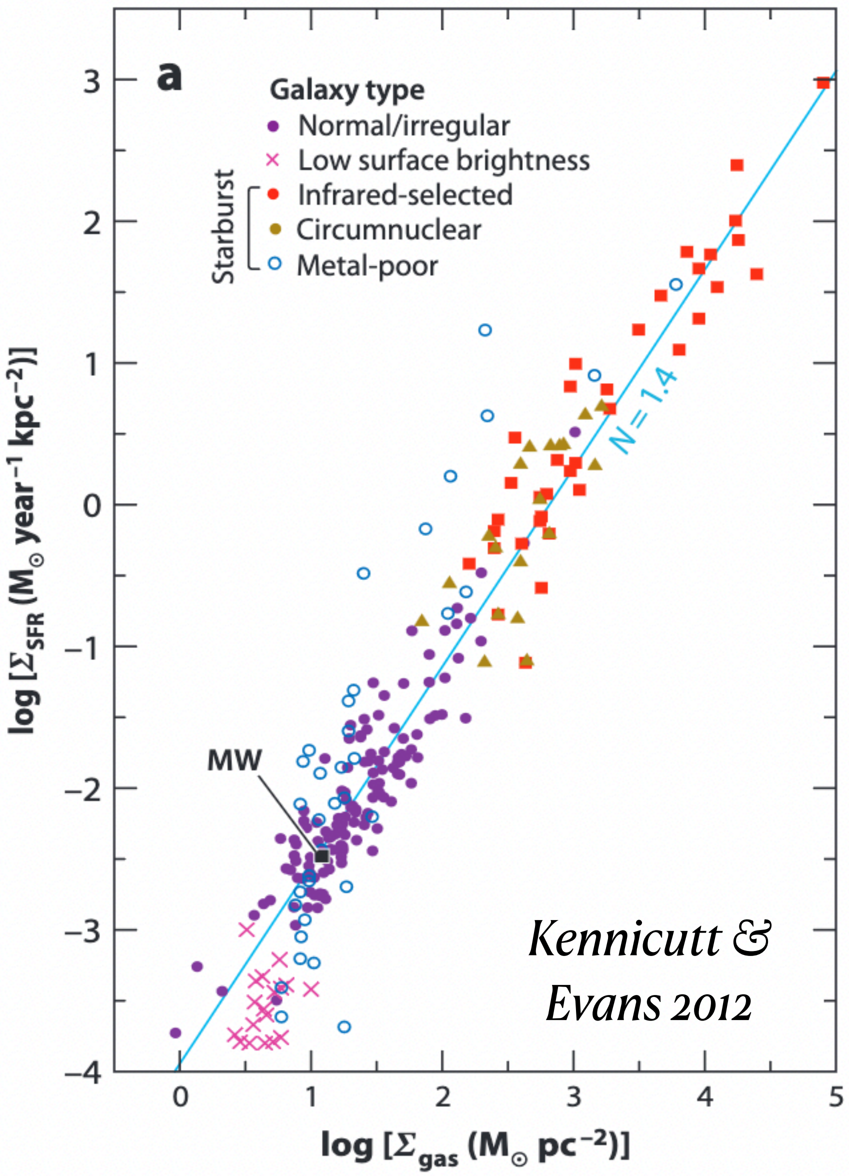

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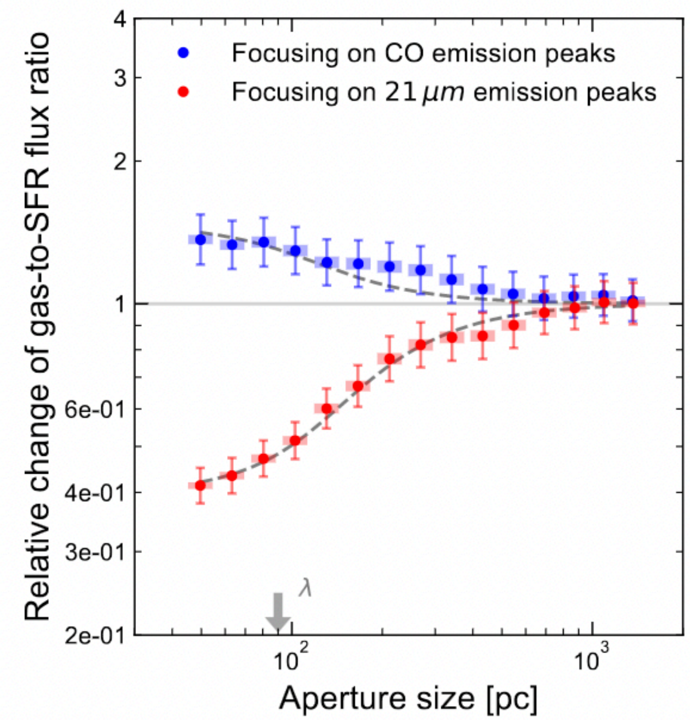

Schruba+2010; Kim+2023

How to reconcile the low- and large scale? It depends on the tracer: We need multiple gas tracers to probe the different phase of the ISM

Case 1: Bridging the gas-star formation relation at small- and large scales

The KS relation can be studied using other dense gas tracers: HCN, HCO^+ (J=1-0)

(e.g. Gao & Solomon 2004, Gracía-Carpio+2008;

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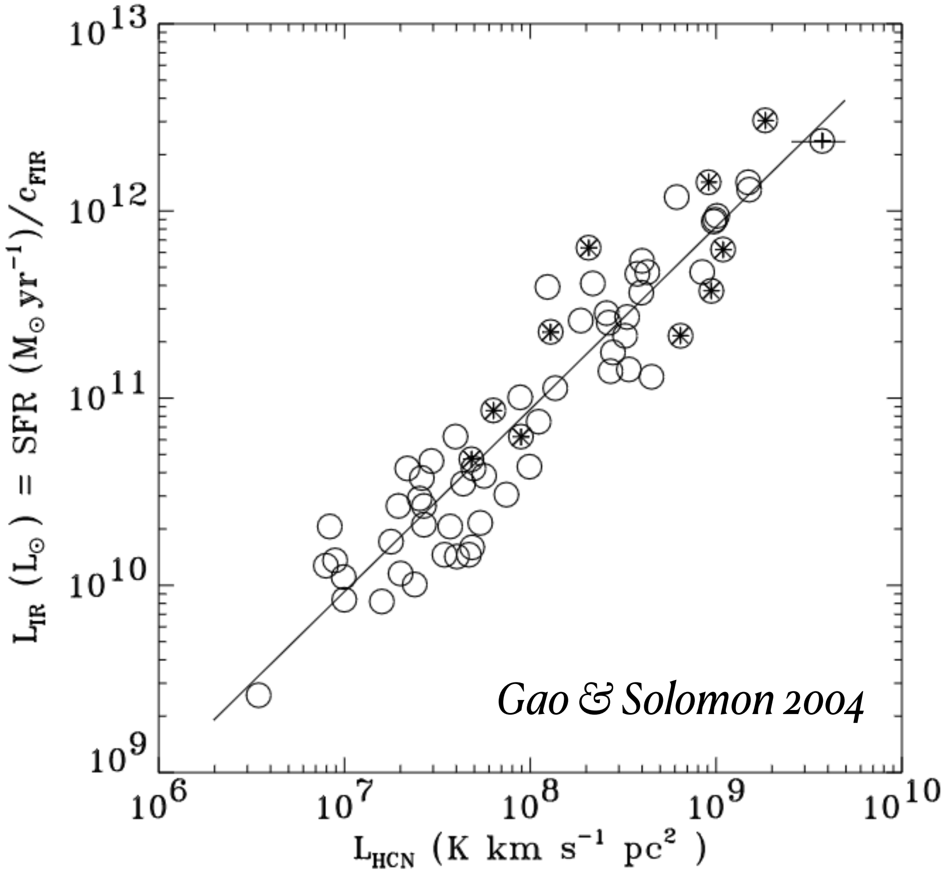

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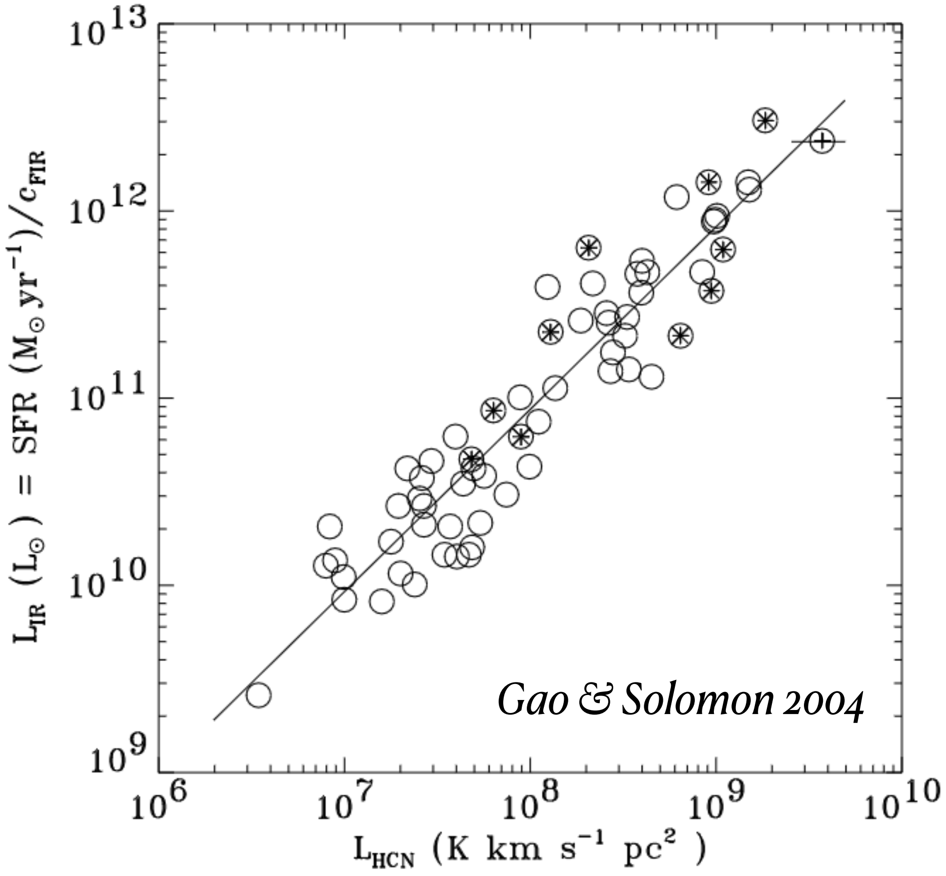

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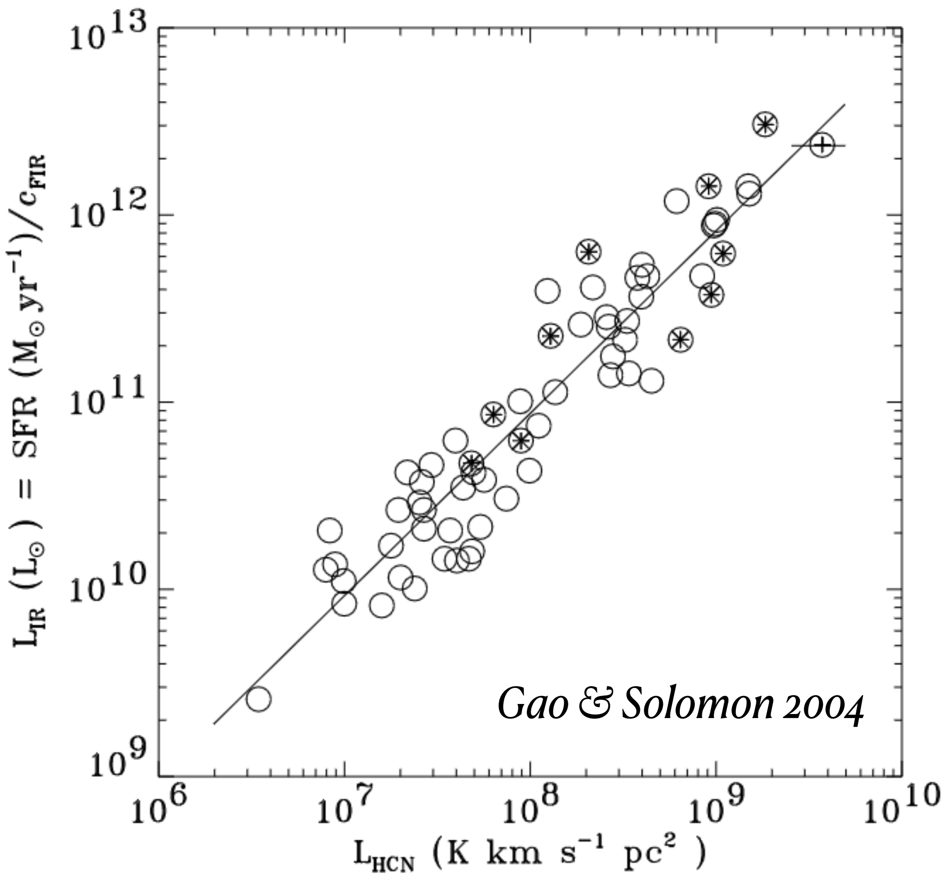

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HCN(1-0) could trace lower densities ($n \sim 10^{-3}$ cm^{-3}) than the estimated threshold for star formation

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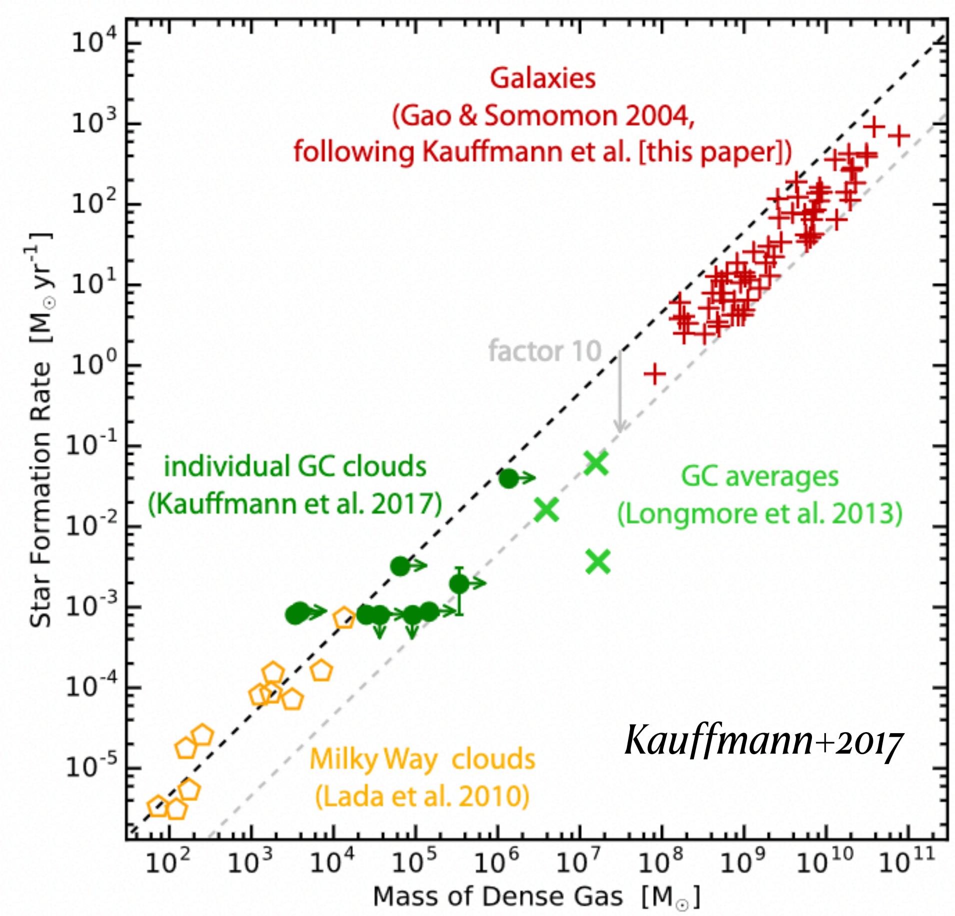

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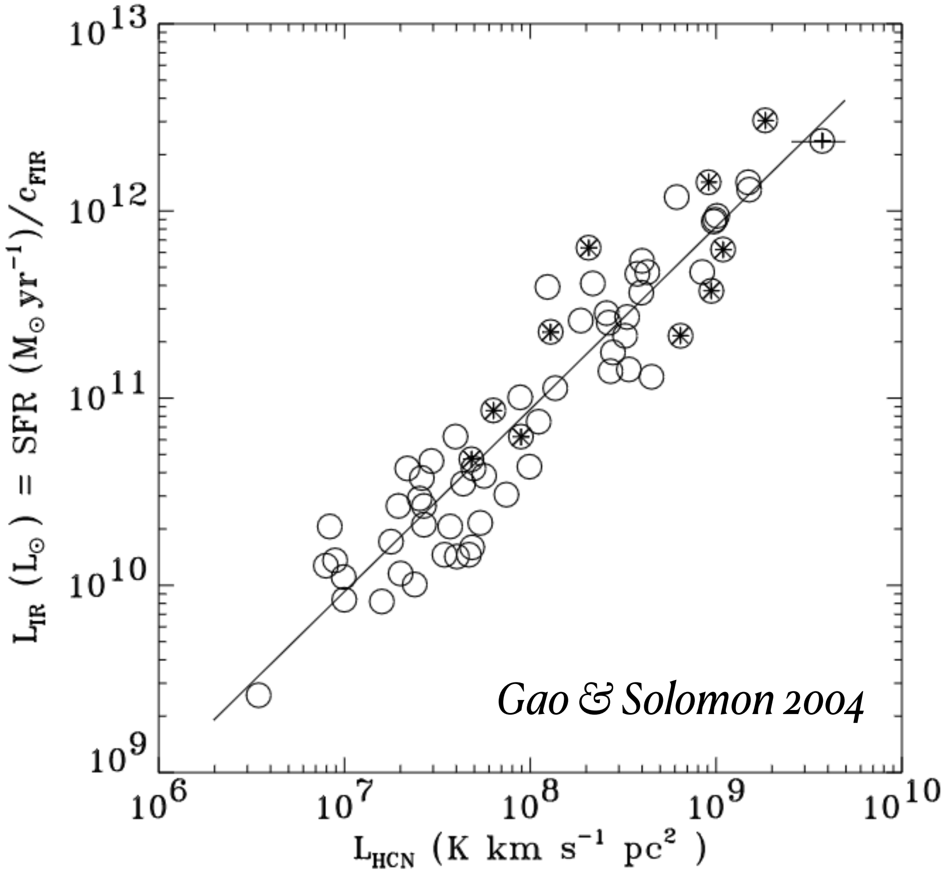

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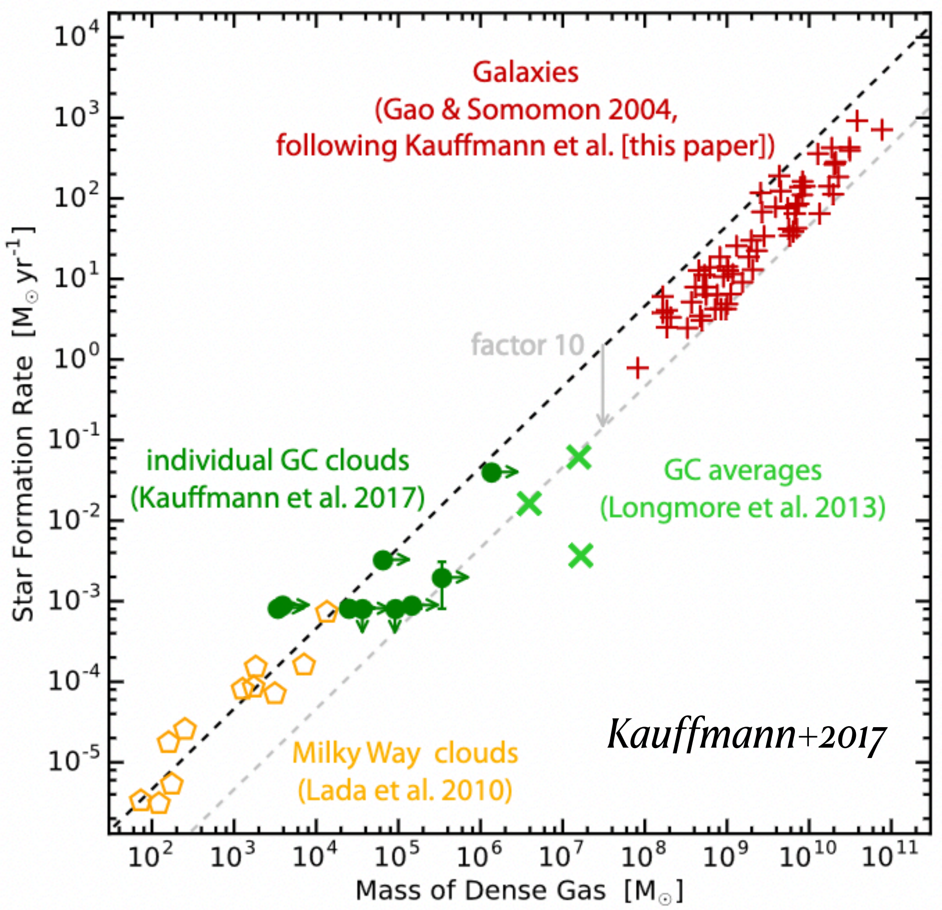


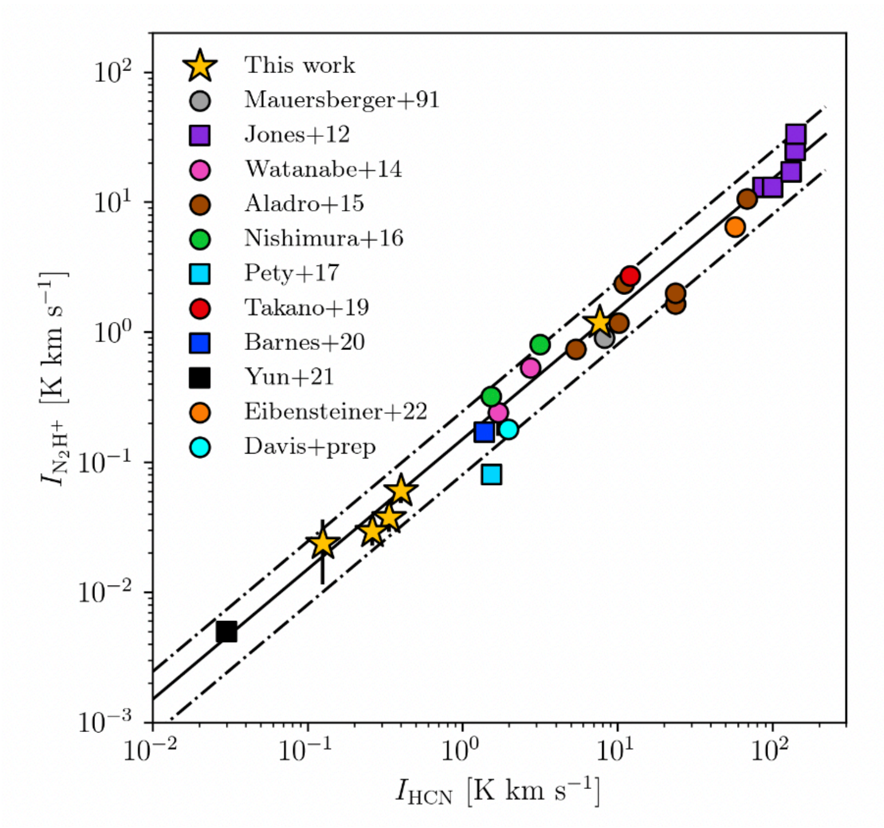
Galaxies deviate from the Milky Way star-formation relation. Can we find a better dense gas tracer?

Case 1: Bridging the gas-star formation relation at small and large scales

Which dense gas tracer for which scale?

N_2H^+ is a selective high-density tracer. *(e.g. Forbrich+2014; Pety+2017; Kauffmann+2017; Barnes+2020; Tafalla+2021, 2023; Beuther+2022; Santa-Maria+2023)*

Good correlation HCN-N_2H^+ at kpc scales



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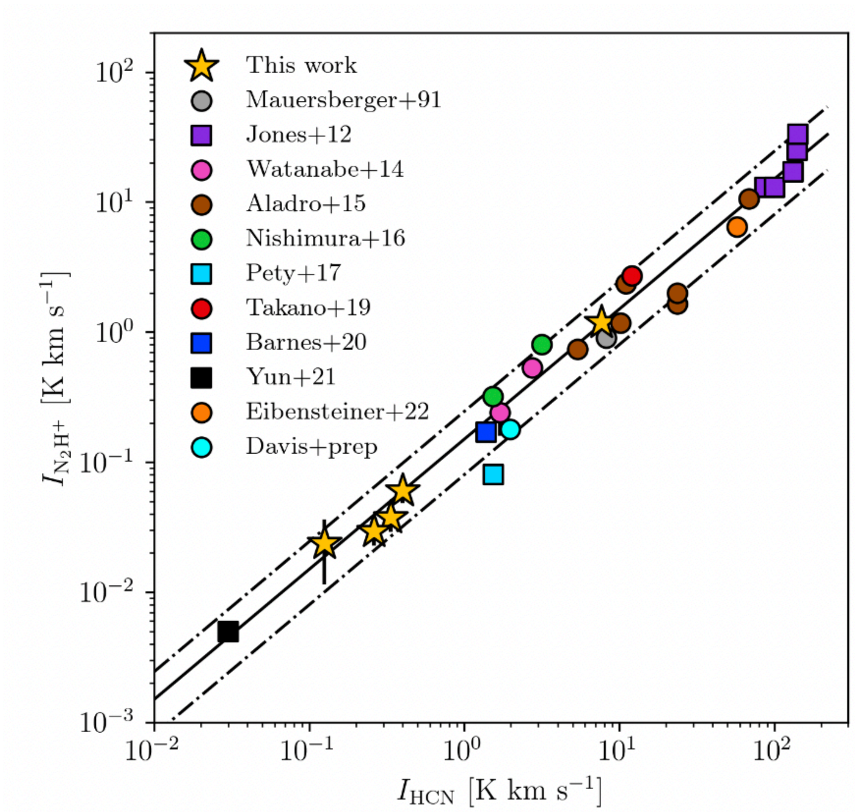
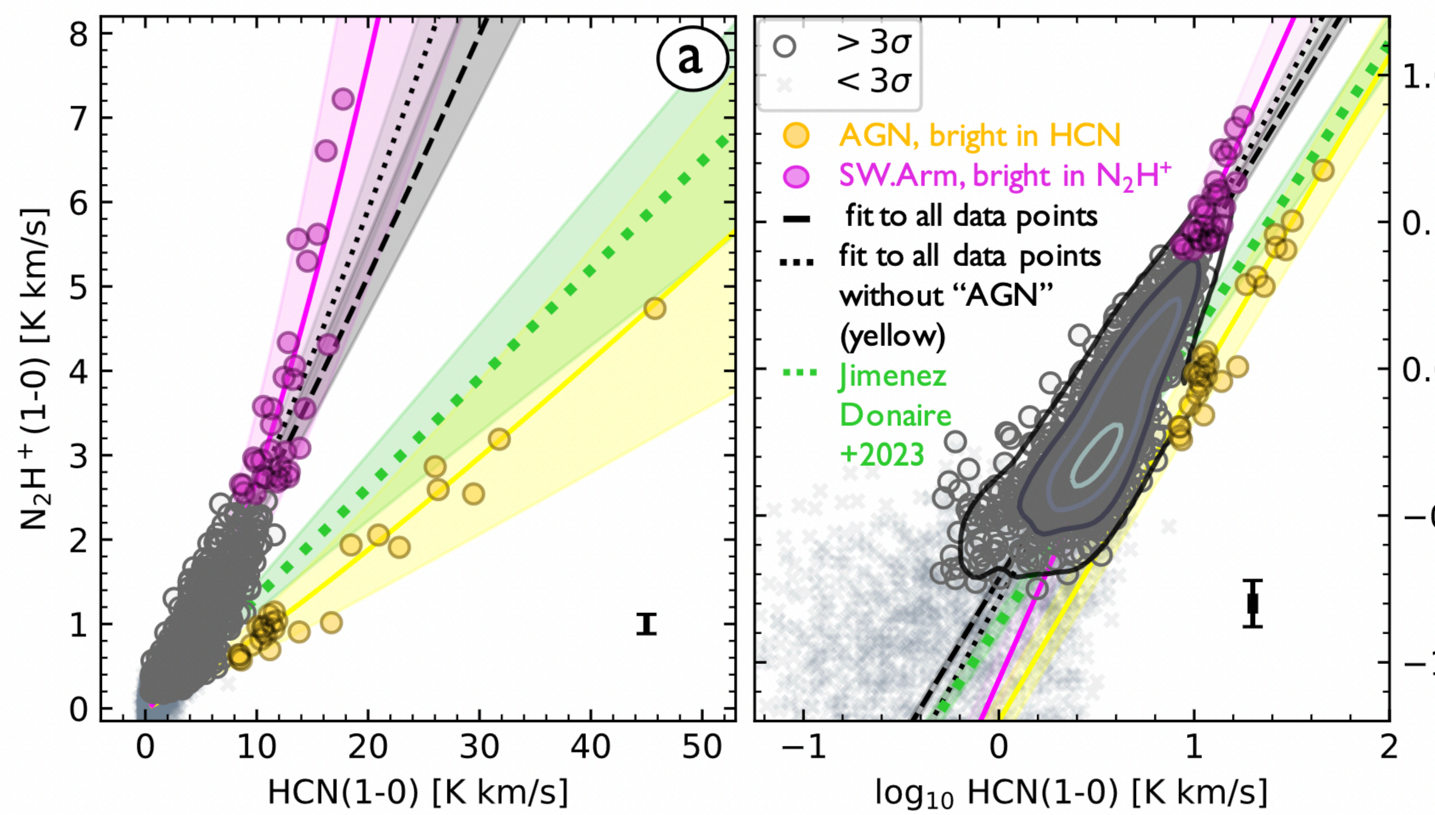


Jiménez-Donaire+2023

Different spatial distribution and variation of N_2H^+-to-HCN ratio at sub-kpc scales



Stuber+2023

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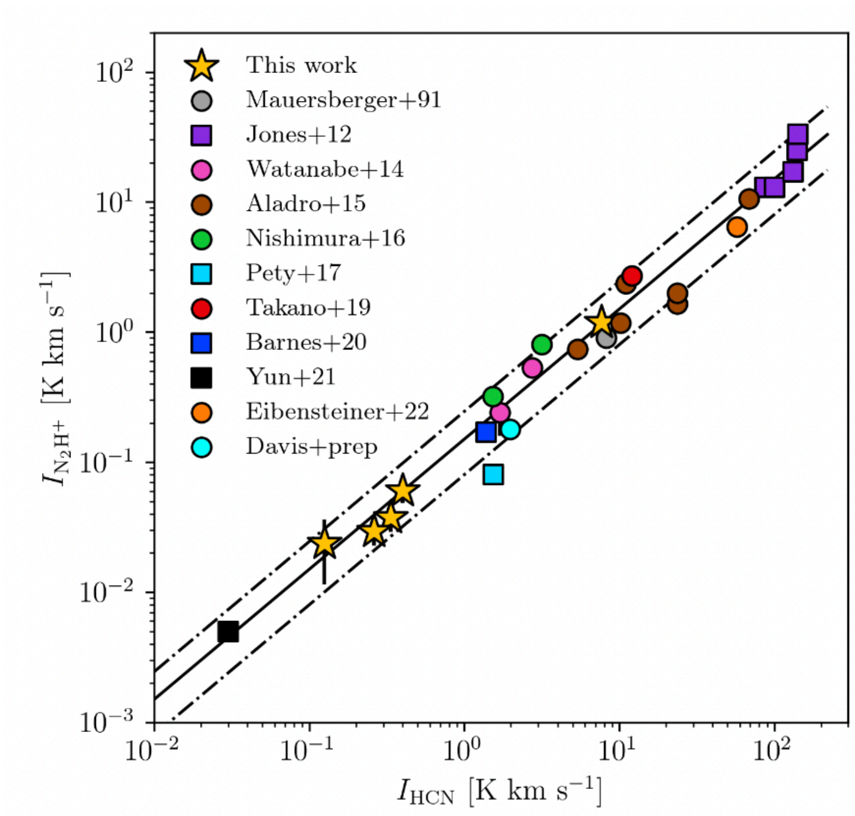

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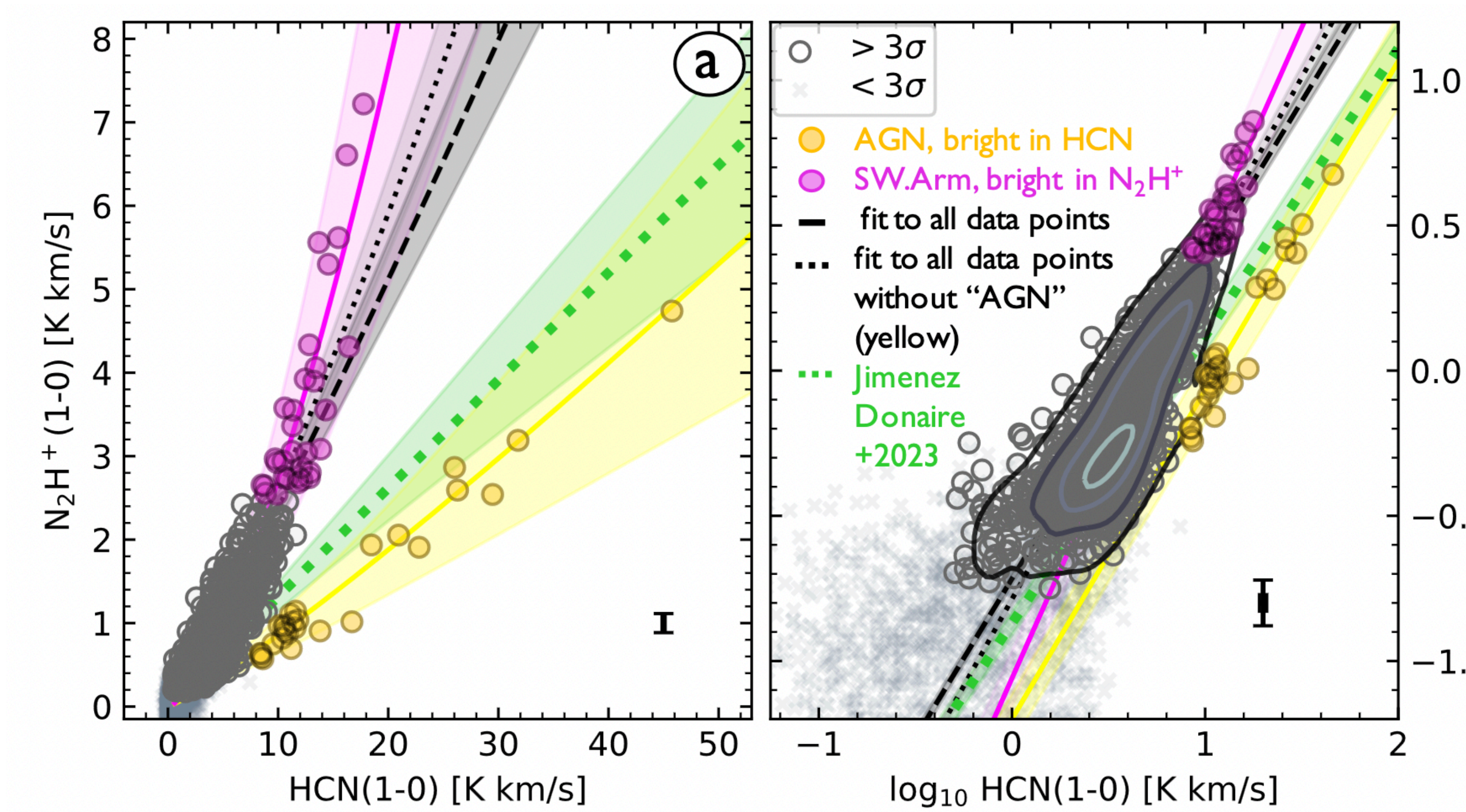

Stuber+2023

If we aim to build a full picture of star formation from small- to large scale, we need more studies of N_2H^+ in nearby galaxies

Case 1: Bridging the gas-star formation relation at small and large scales

Bridging the gas-star formation relation at small- and large scale requires:
- Performing statistical studies
- Resolving Giant molecular clouds (GMCs; sub-kpc scales)
- Observing better high density tracers such as N_2H^+ at sub-kpc scales

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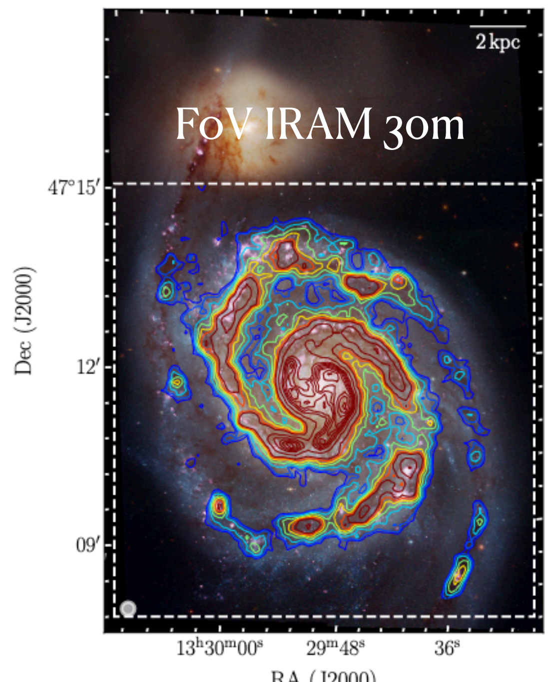
Limitations:
- N_2H^+ is less abundant than CO and HCN, HCO^+ : Extragalactic observations are challenging
- Interferometers have a too small FoV; spatial filtering
- Single-dish telescopes are limited in resolution and sensitivity

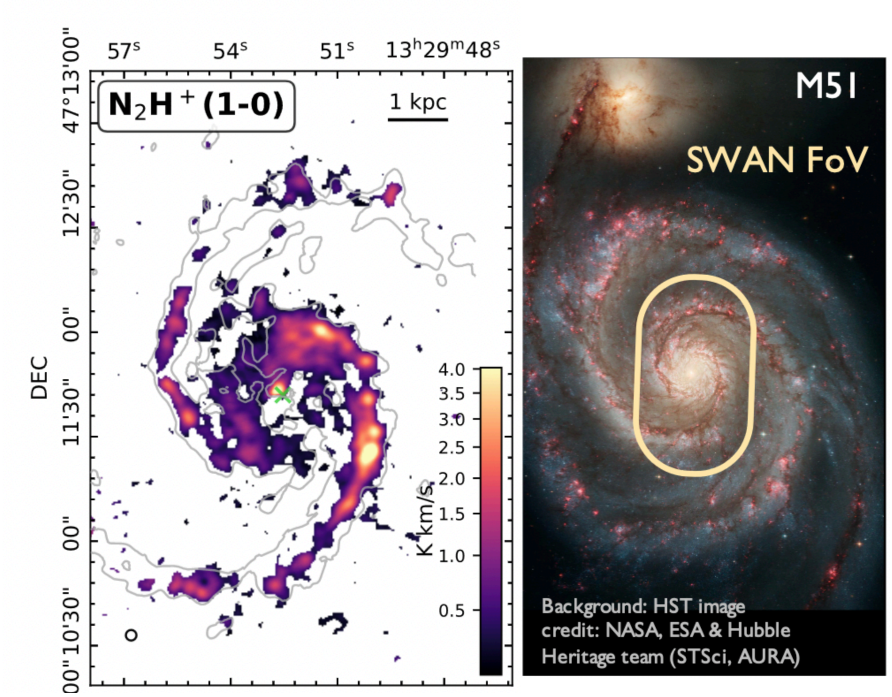
Requires long integration times!

Low-resolution studies
(e.g., ~kpc scales; den Brok et al. 2022; Jiménez-Donaire et al. 2023)



den Brok et al. 2022

Individual regions of galaxies



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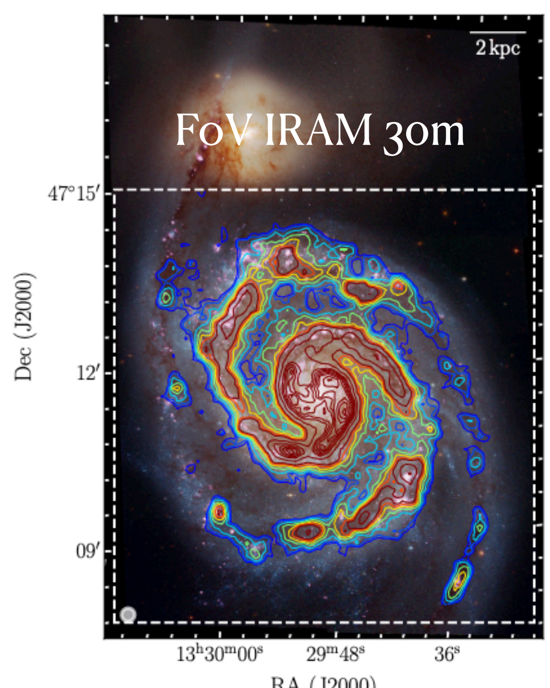

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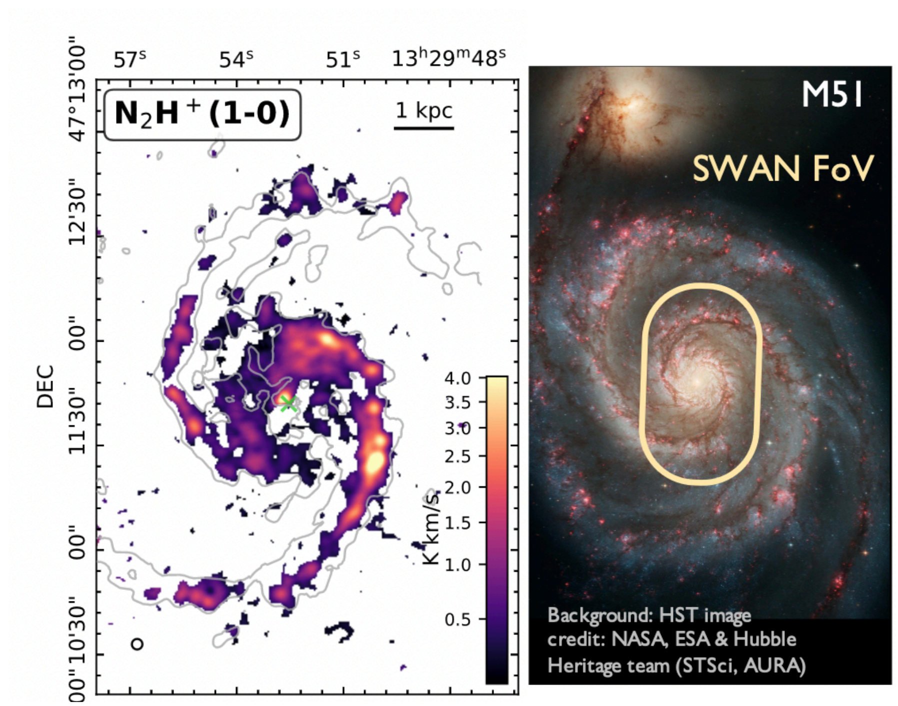

Stuber+2023

AtLAST:
Large FoV: 1-2°
Angular resolution down to 1.5"
allowing to resolve GMCs
High sensitivity

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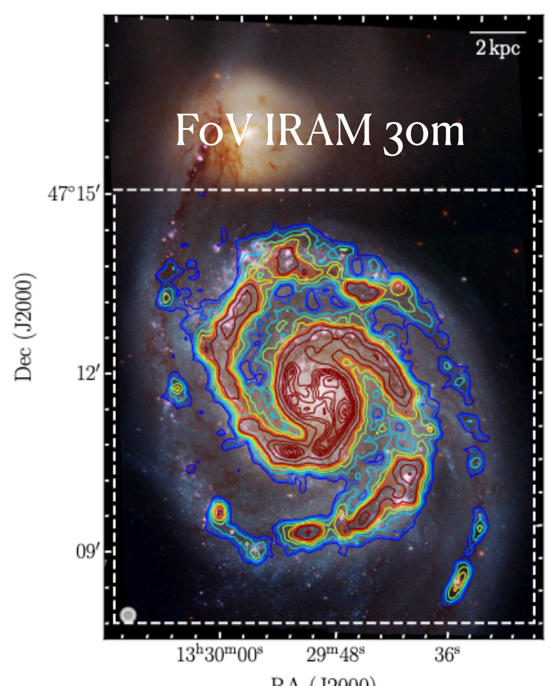

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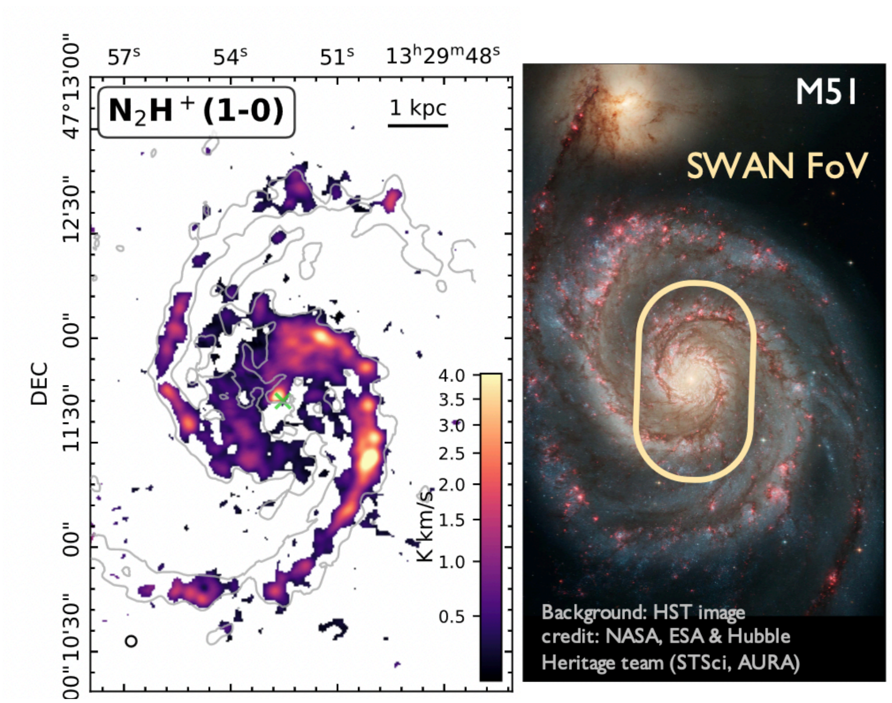

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AtLAST is the right instrument to perform statistical surveys of N_2H^+ at resolved GMC scales across galaxies

Case 2: Characterising the physics and chemistry of nearby galaxies

How to build a full picture of star formation in nearby galaxies?

→ We need to statistically characterise the physics and chemistry of the dense gas, where star formation takes place, across a wide range of galaxies and environments within galaxies

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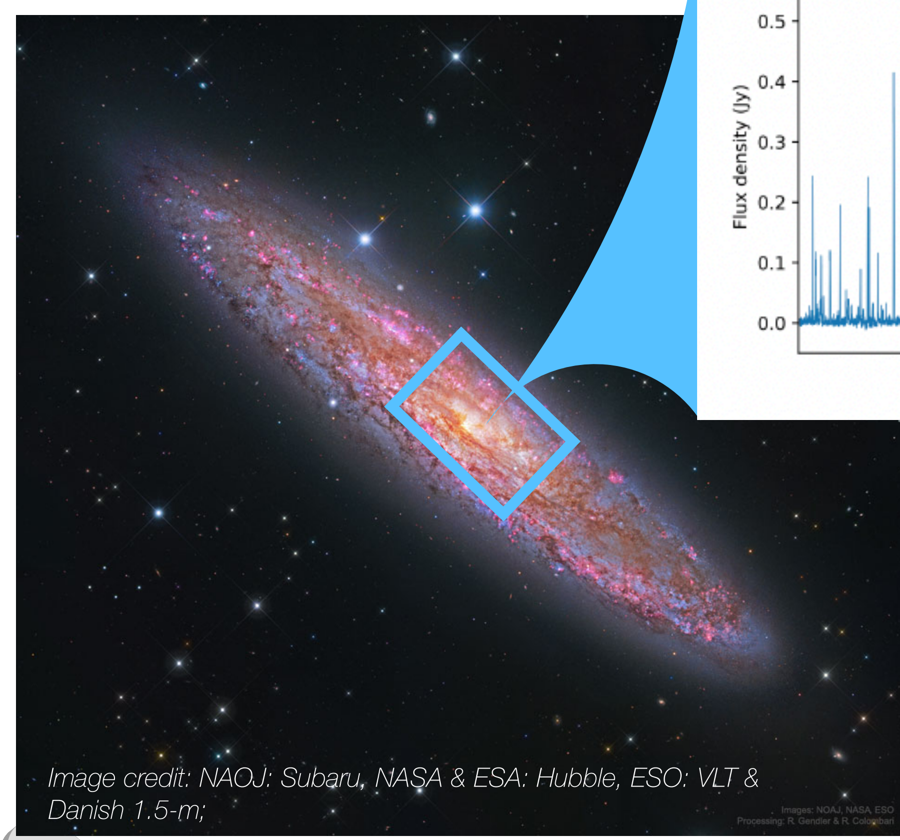
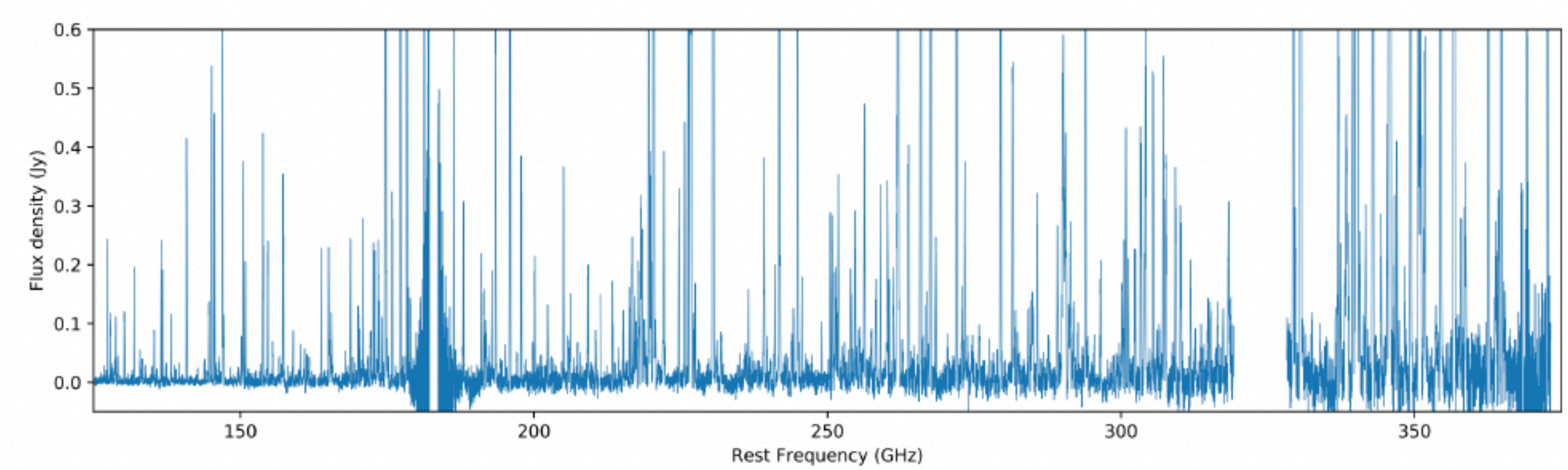
ALCHEMI (ALMA Comprehensive High-resolution Extragalactic Molecular Inventory; *Martín et al. 2021*)

Band 3-7 ALMA survey
At sub-GMC scale (~27pc) towards the CMZ of NGC 253

NGC 253





Chemical richness!

Excellent characterisation of the CMZ but vast range of other environments stays unexplored!

Case 2: Characterising the physics and chemistry of nearby galaxies

Lesson learned from ALCHEMI and why go beyond the standard tracers CO, HCN, HCO^+

High-resolution, multi-transitions multi-species analysis coupled with non-LTE modelling is a powerful tool to derive the gas densities, temperature and line excitation conditions of the multi phase gas.

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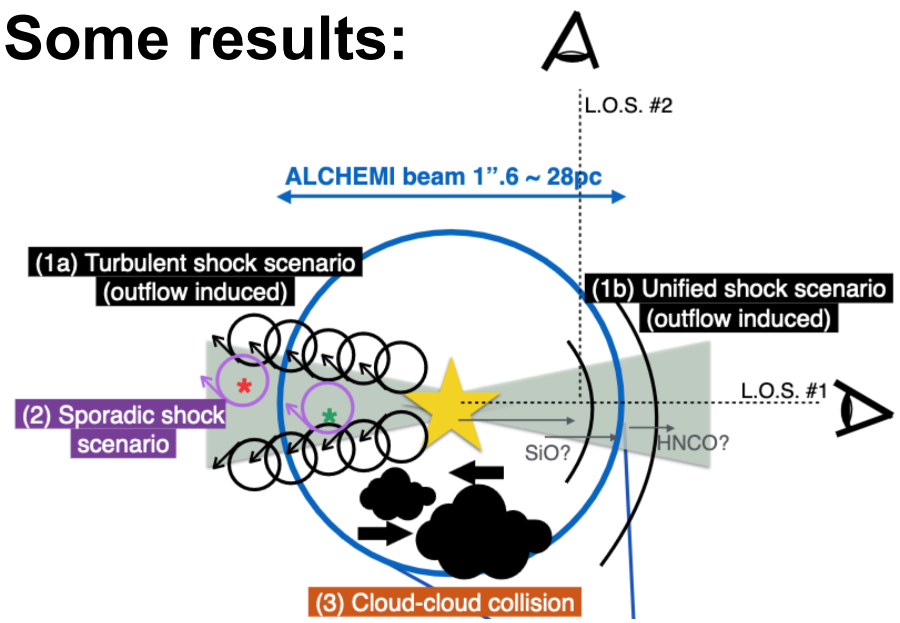
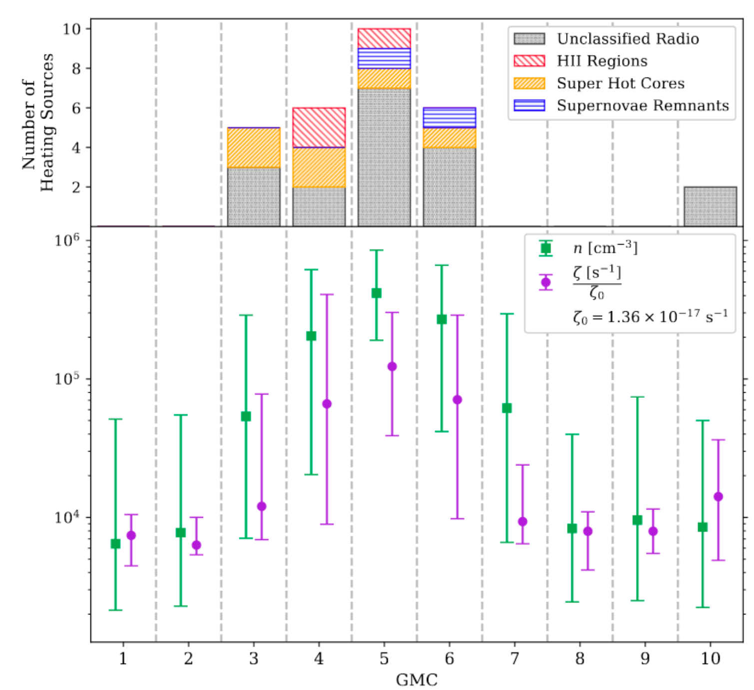
Some results:



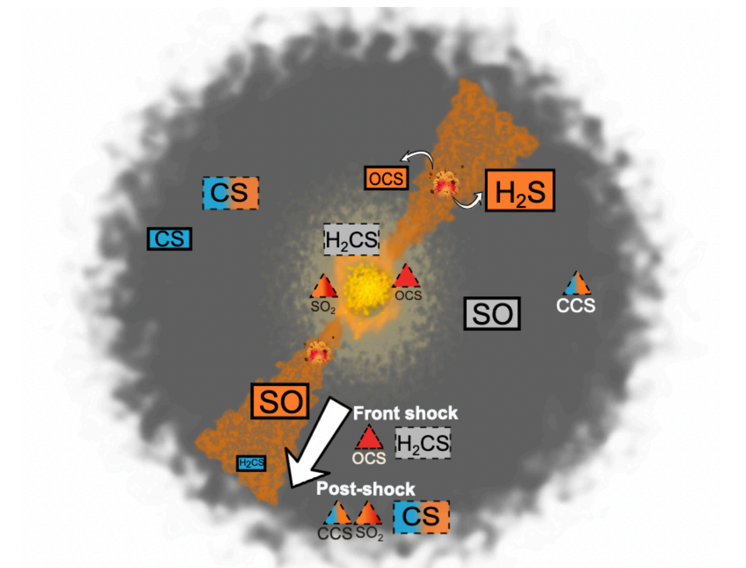
Shock history with SiO/HNCO

Huang+2023



Heating sources and CRIR constraints

Behrens+2022, and also Harada+2021, Holdship+2021, 2022



Shock type: S-bearing species (e.g. H_2S, OCS, H_2CS), CH_3OH, $HOCO^+$

Bouvier+2024 and also Harada+2022, Humire+2022

Case 2: Characterising the physics and chemistry of nearby galaxies

How do the gas properties of the CMZ of NGC253 compare with the rest of the galaxy?

Is NGC 253 representative of all starburst galaxies or do the gas properties vary with the environment and/or the galaxy?

→ We need to expand ALCHEMI to other galaxies of different types, shapes, energetics

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Large bandwidth (up to 32 GHz)

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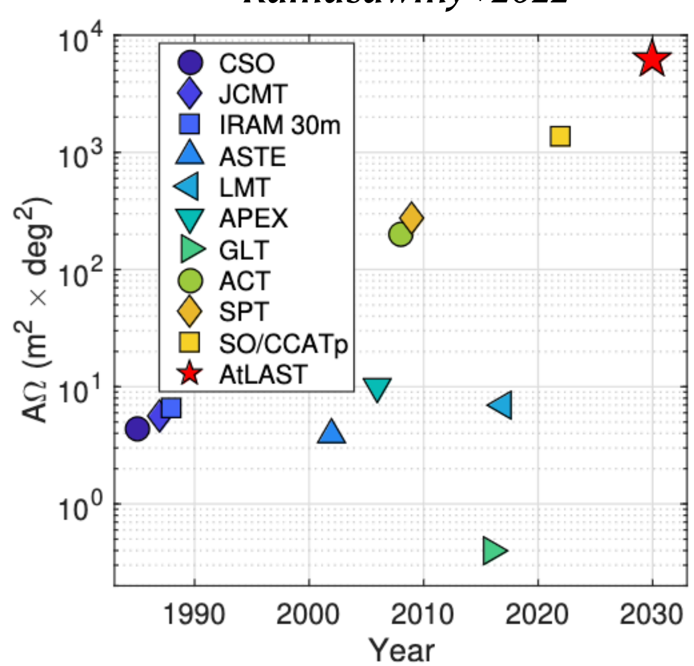
Ramasawmy+2022



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AtLAST is the right instrument to expand surveys such as ALCHEMI

Case 3: Understanding molecular clouds properties in nearby galaxies

The physical characteristics of GMCs and their evolution is linked to the star formation rate and efficiencies in nearby galaxies, and ultimately, the evolution of galaxies.

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But so far, we only have a limited understanding of the properties of the star-forming molecular structures.

➡What are the physical properties of GMCs and how do they evolve?

➡Are GMCs in nearby galaxies different than we we observe in our Galaxy? If so, how?

➡How do molecular clouds (MCs) fragment? Is is random or hierarchical? Does it vary from galaxy to galaxy?

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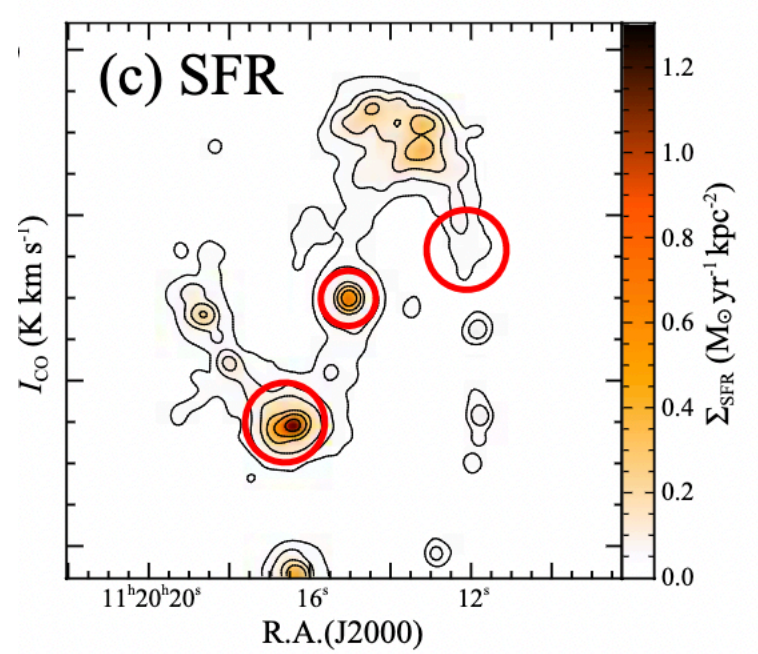
Single-dish studies provided an insight into distribution of dense molecular gas in the nearby galaxies *(e.g., Engargiola+2003; Rosolowsky+2007; Miura+2012; Kepley+2018; Viaene, Forbrich & Fritz 2018; Watanabe+2019)*

But pc-scale resolution maps only for the nearest galaxies (e.g. M33; 840 kpc; *e.g., Gardan+2007; Gratier+2010b; Druard+2014*)

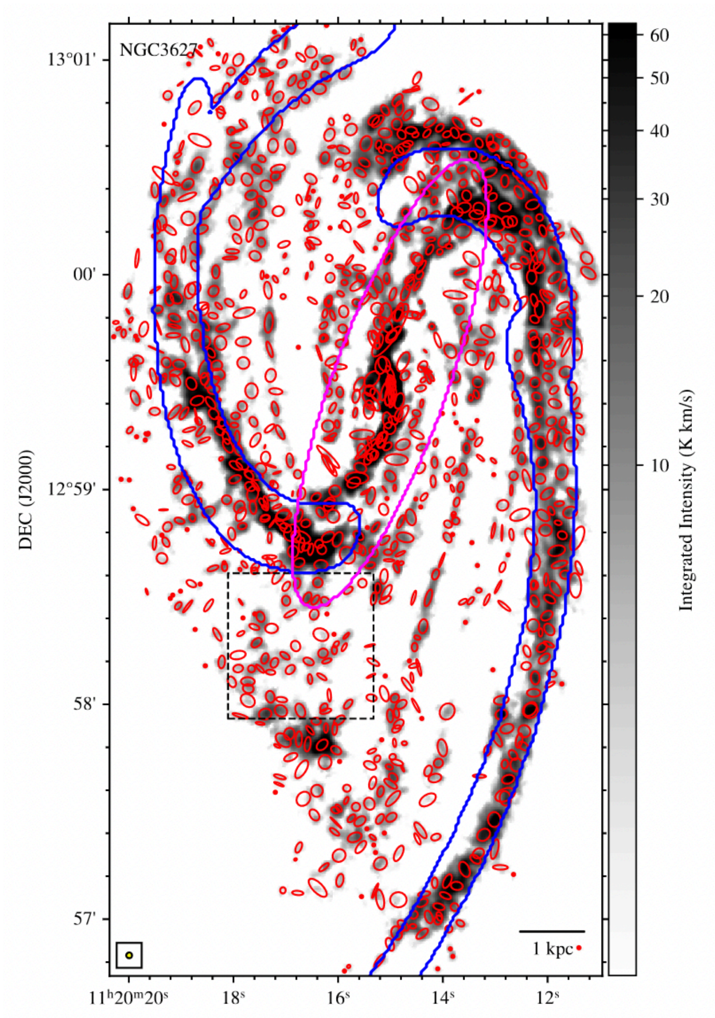
kpc resolution (D~11 Mpc)



Watanabe+2019
NGC3627
IRAM-30 and Nobeyama-45m

Physics at High Angular-resolution in Nearby GalaxieS with ALMA (PHANGS-ALMA) survey
(Leroy+2021b; Rosolowsky+2021)

High resolution (GMC resolved) CO(2–1) observations across a sample of 90 nearby (<20 Mpc) galaxies



Rosolowsky+2021

Case 3: Understanding molecular clouds properties in nearby galaxies

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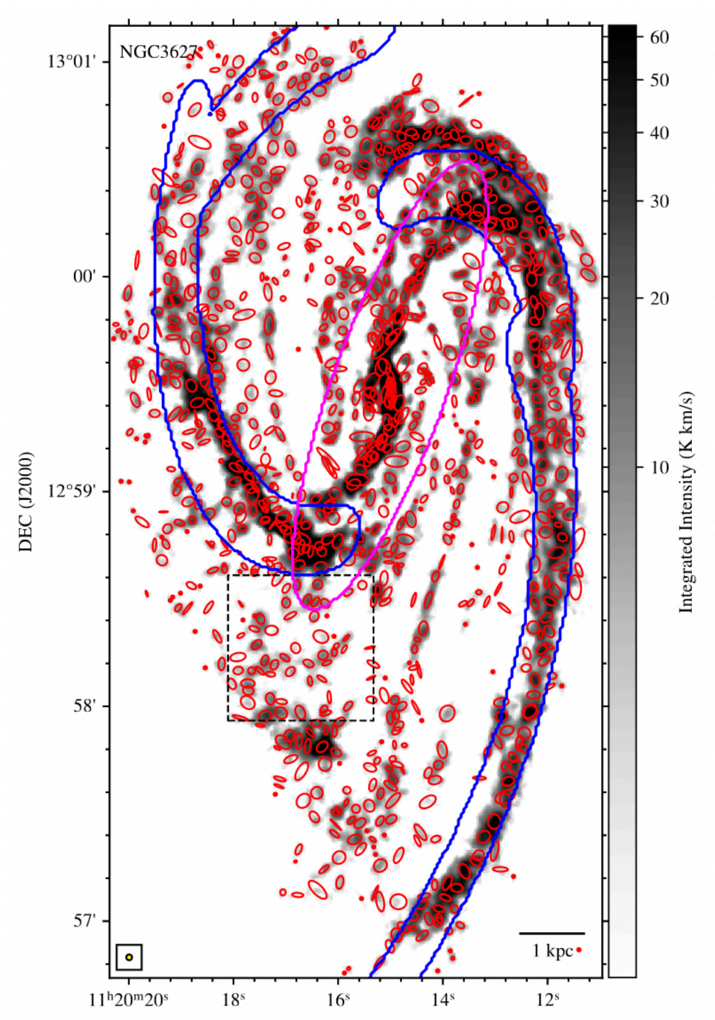
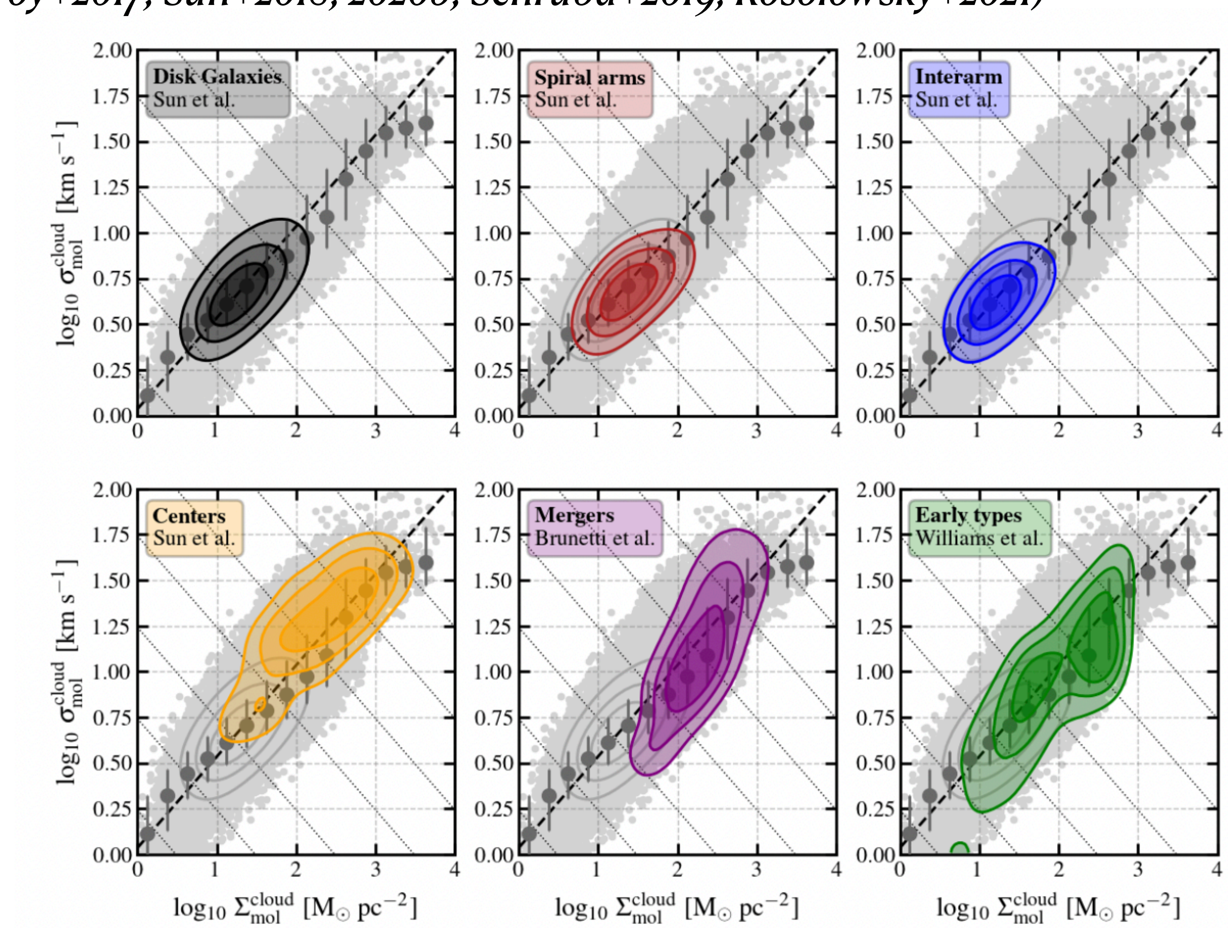


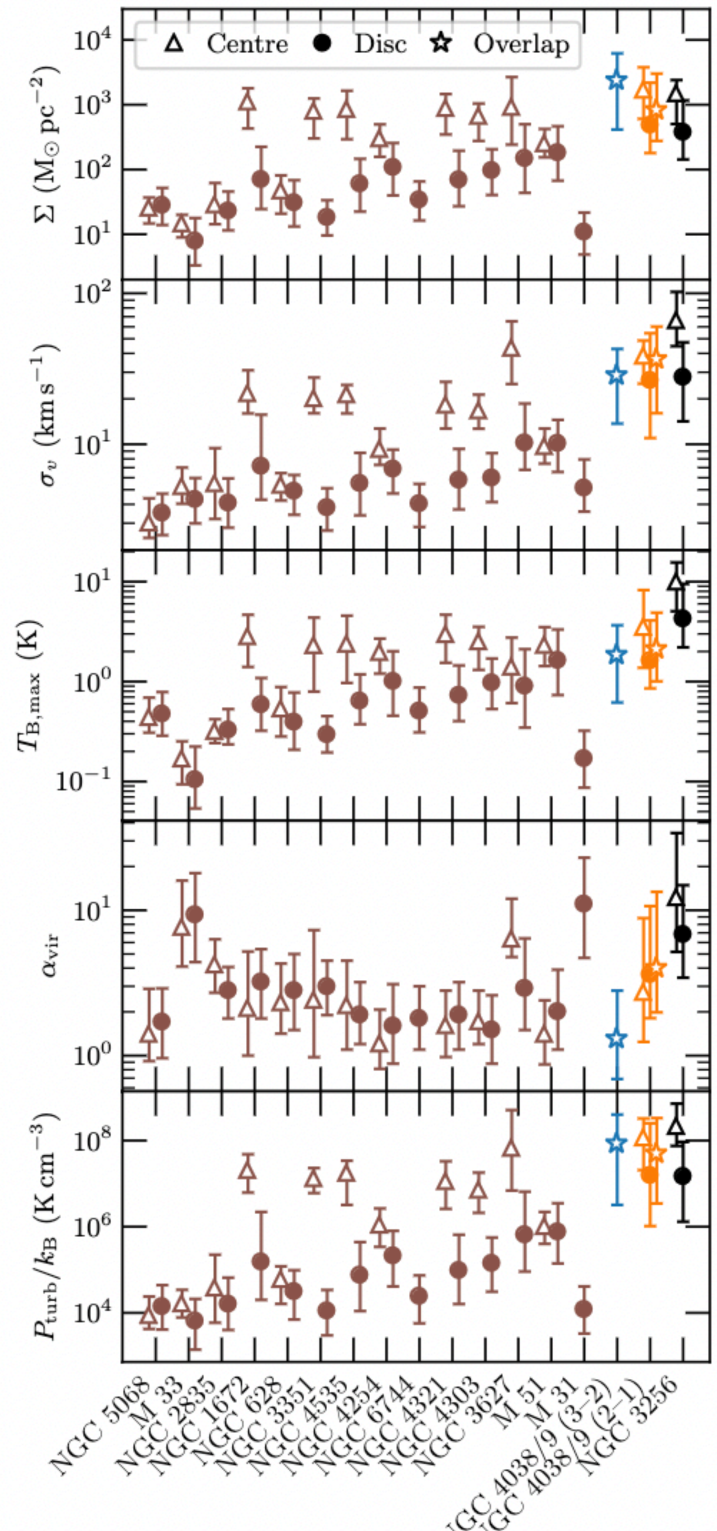
Rosolowsky+2021

Parsec-scales studies showed that the physical properties of GMC populations (gas surface density, lien width, internal pressure) vary among galaxies and among regions within galaxies *(e.g. Hughes+2013b; Colombo+2014a; Leroy+2017; Sun+2018, 2020b; Schruba+2019; Rosolowsky+2021)*



Schinnerer & Leroy+2024 (and refs therein)

Case 3: Understanding molecular clouds properties in nearby galaxies



Brunetti+2024

Recent comparison of cloud properties between two mergers merger and the PHANGS alma galaxies:

➡Difference in several cloud properties between mergers and PHANGS sources

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Need more statistical studies at GMC scales across a wide range of galaxies and environments within galaxies!

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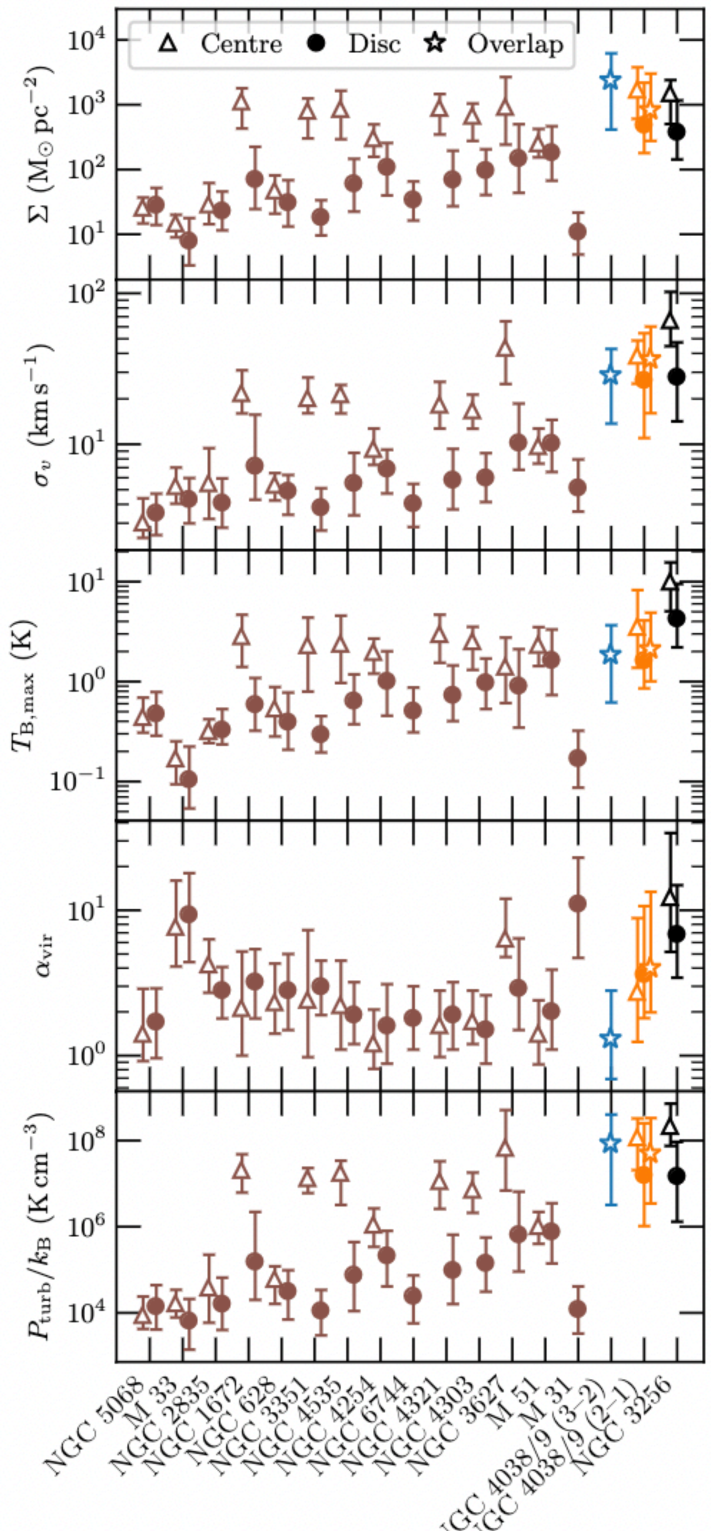

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AtLAST:

Large FoV: 1-2°

Angular resolution down to 1.5" allowing to resolve GMCs

Take home message: Why we need AtLAST

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The star formation process is one of the driving processes in galaxy evolution. It is thus crucial to understand the full picture of star formation across all environments, scales and cosmic times.

What we need:

- Perform statistical studies of large samples of galaxies and all environments within galaxies
- Resolving Giant molecular clouds (GMCs; sub-kpc scales)
- Observing other gas tracers, less abundant, including N_2H^+ which better traces dense gas at sub-kpc scales

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Common limitations for all the three cases:
- Interferometers: Small FoV, spatial filtering
- Single-dish telescopes: most with smaller FoV, limitation in resolution and sensitivity (related to dish size), limited in frequency range

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Common limitations = common solution!
AtLAST's capabilities will be transformational in the study for the nearby galaxy, and hence, will contribute to the overall understanding of galaxy formation & evolution!