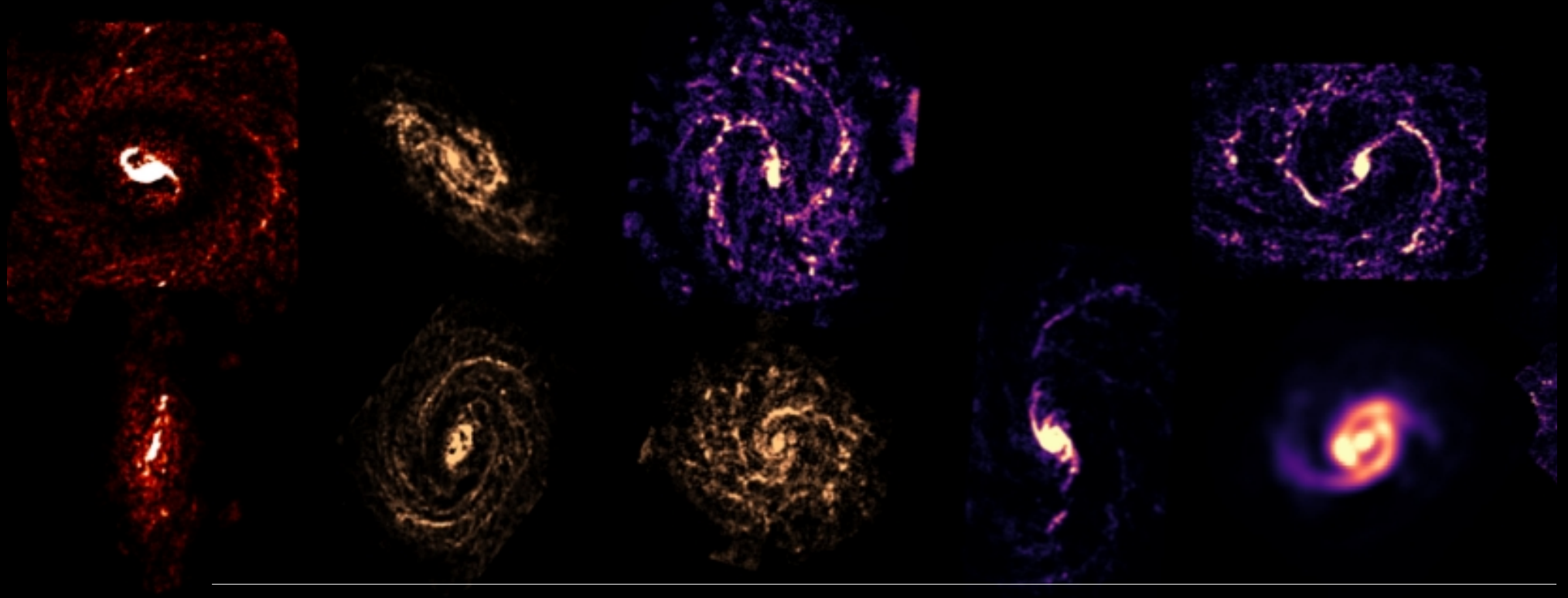


ATLAST and Nearby Galaxies

Annie Hughes, IRAP

DAOISM

PHANGS

pcmi

irap

Liu et al, 2024, ATLAST Science: Gas and Dust in Nearby Galaxies, arXiV:2403.01202

Talk Outline

Nearby Galaxies and Current Surveys

ATLAST Nearby Galaxies Science Case :


Physical Conditions and SF in Galaxy Disks


Dust Polarisation and Magnetic Fields


Cold Gas and Dust in the Local Group


Evolution of the local (z<0.2) galaxy population

Talk Outline

Nearby Galaxies and Current Surveys

ATLAST (Resolved) Nearby Galaxies Science Case :


Physical Conditions and SF in Galaxy Disks


Dust Polarisation and Magnetic Fields


Cold Gas and Dust in the Local Group

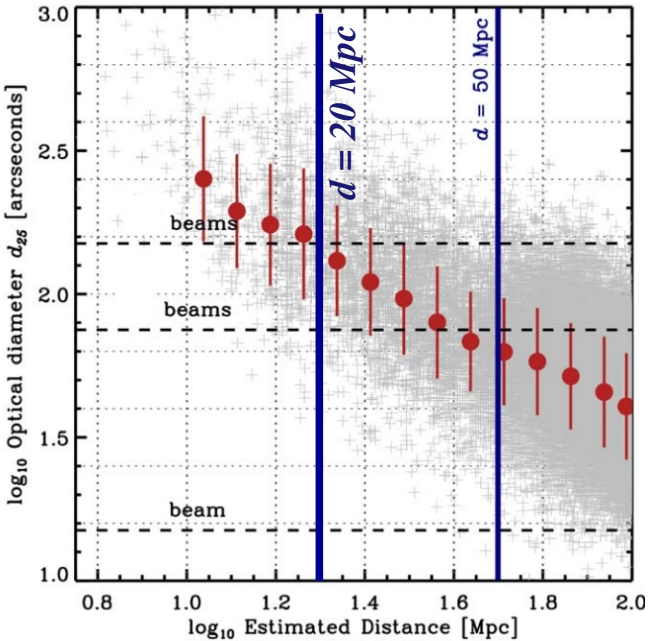

~~Evolution of the local (z<0.2) galaxy population~~

ATLAST → increase N known CO emitters by ~2 dex, decrease galaxy mass detection threshold by ~2 dex into the dwarf regime

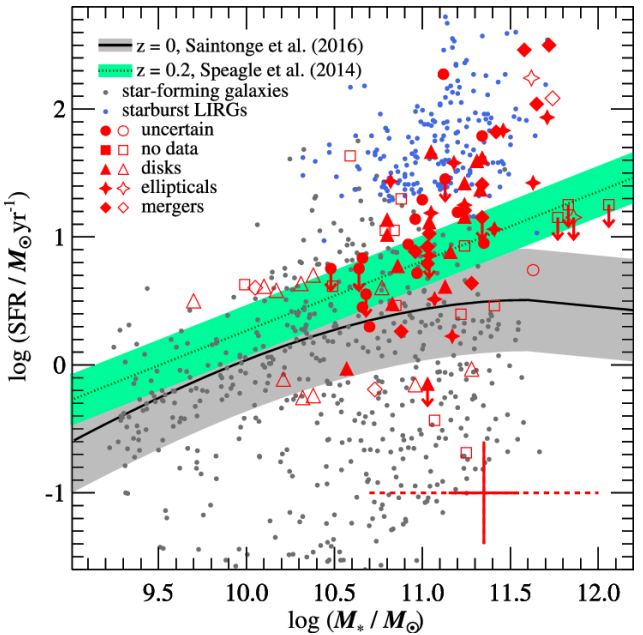
→ evolution of CO luminosity function, M_{gas}/M_{*}, SF quenching, cold gas in clusters

Nearby Galaxies at a glance

Figs adapted from Leroy et al (2019), Xie et al (2021), Young et al (1991), de Blok (2024)

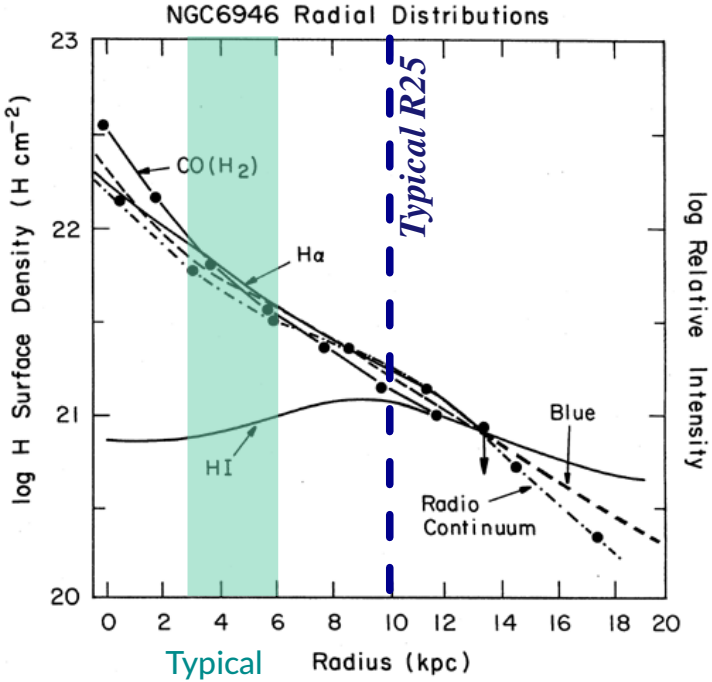


ATLAST will resolve nearby galaxies (θ~1.5kpc):
Band 3 ~ 20Mpc
Band 6 ~ 50Mpc
Bands 9/10 ~ 150Mpc



dwarf/disk/elliptical/starbursts
by number: 70/15-20/5-10/1 %
by mass: 60-70/30-40/<5/<1%

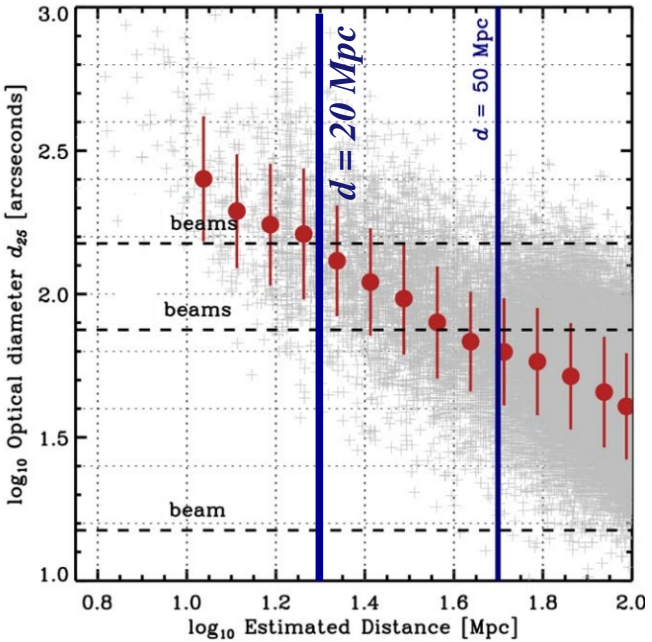
70% of SF at z=0 occurs on the star-forming main sequence



e.g. PHANGS surveys target the CO-bright, actively SF disk
~ 0.5 MJy/sr at WISE3 (7".5)
~ 3 MJy/sr at 500um (37")

Nearby Galaxies at a glance

Figs adapted from Leroy et al (2019), Xie et al (2021), Young et al (1991), de Blok (2024)



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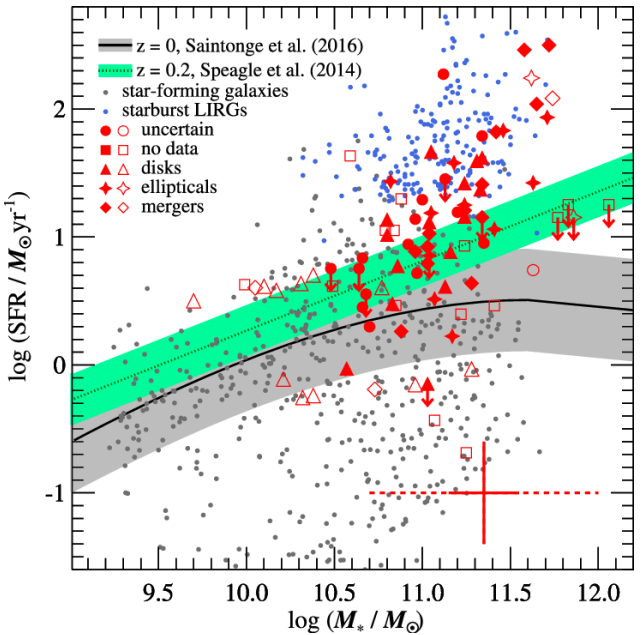

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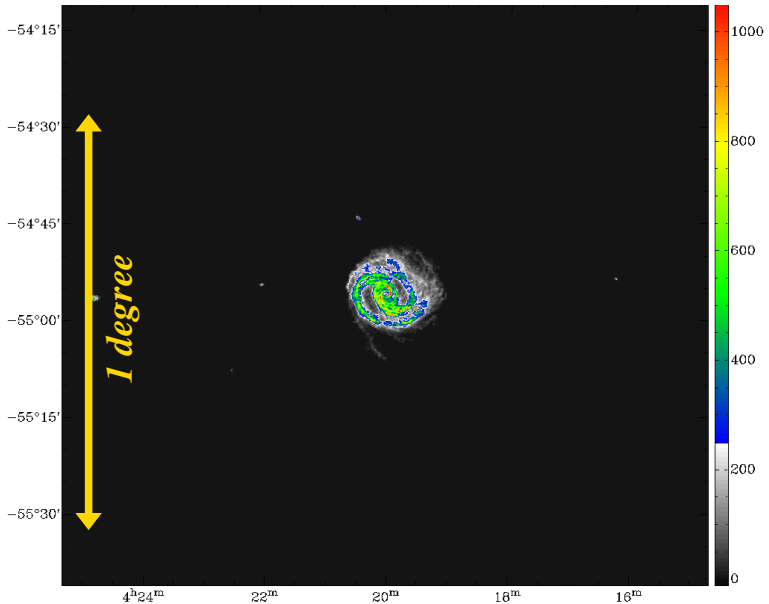

NGC1566 by MHONGOOSE
θ~7”, RMS N(H) ~ 10^{19} H/cm^2

Nearby Galaxies at a glance

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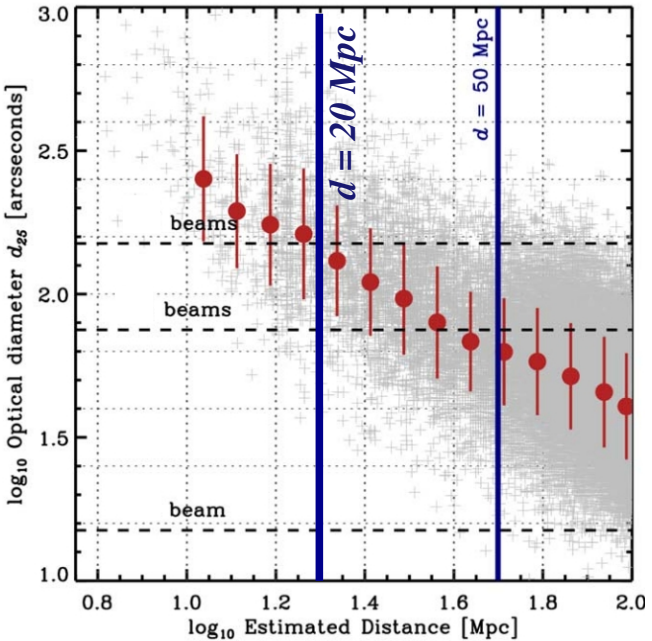

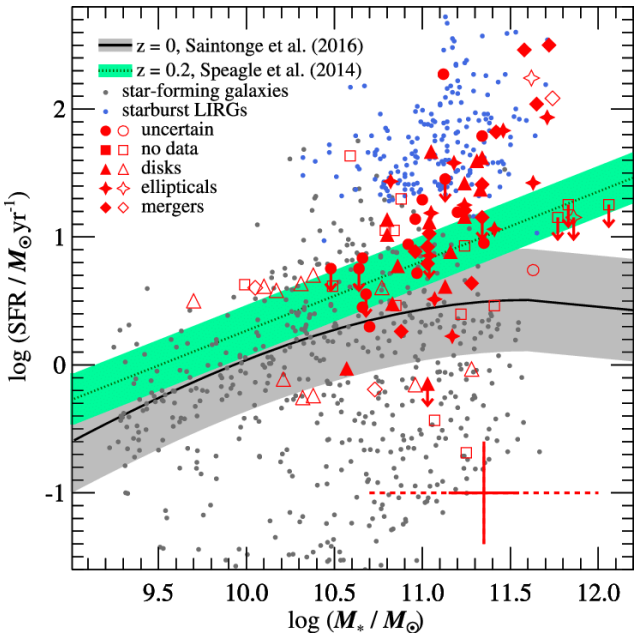

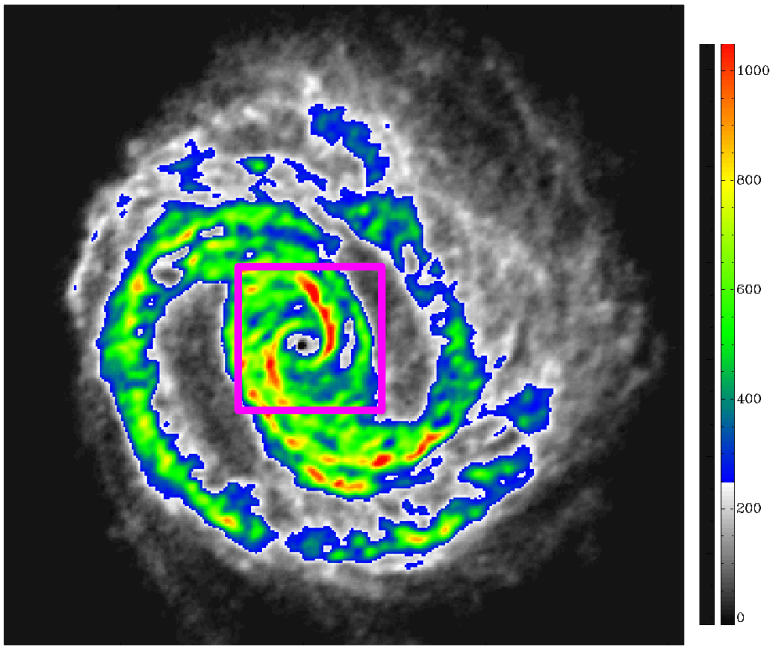

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ATLAST @350GHz, θ~4.3" :
B: 5e20 H/cm^2 ~ 0.1mJy/bm
R: 2e21 H/cm^2 ~ 1mJy/bm

50h on source ~ 3e19 H/cm^2

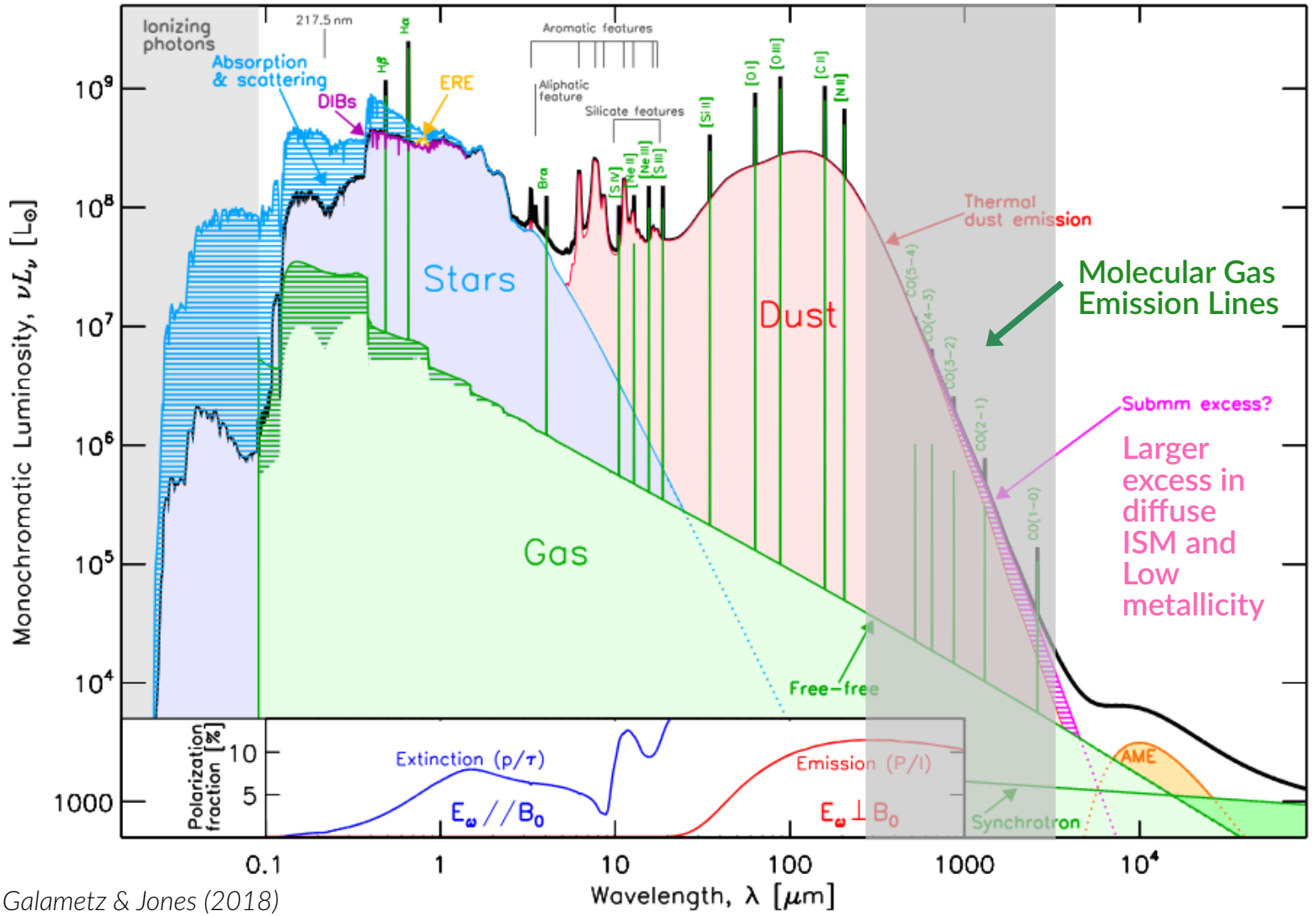
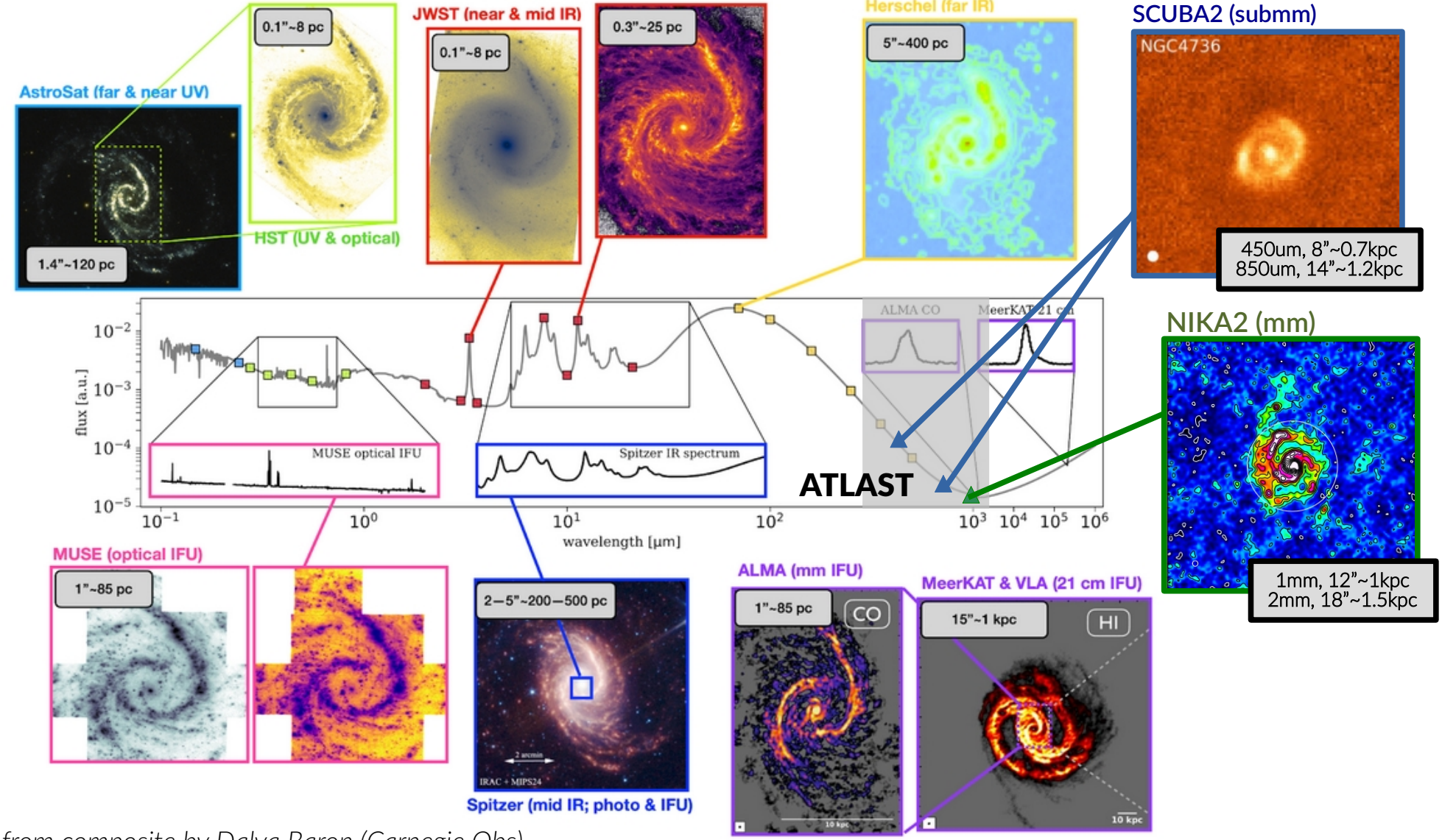
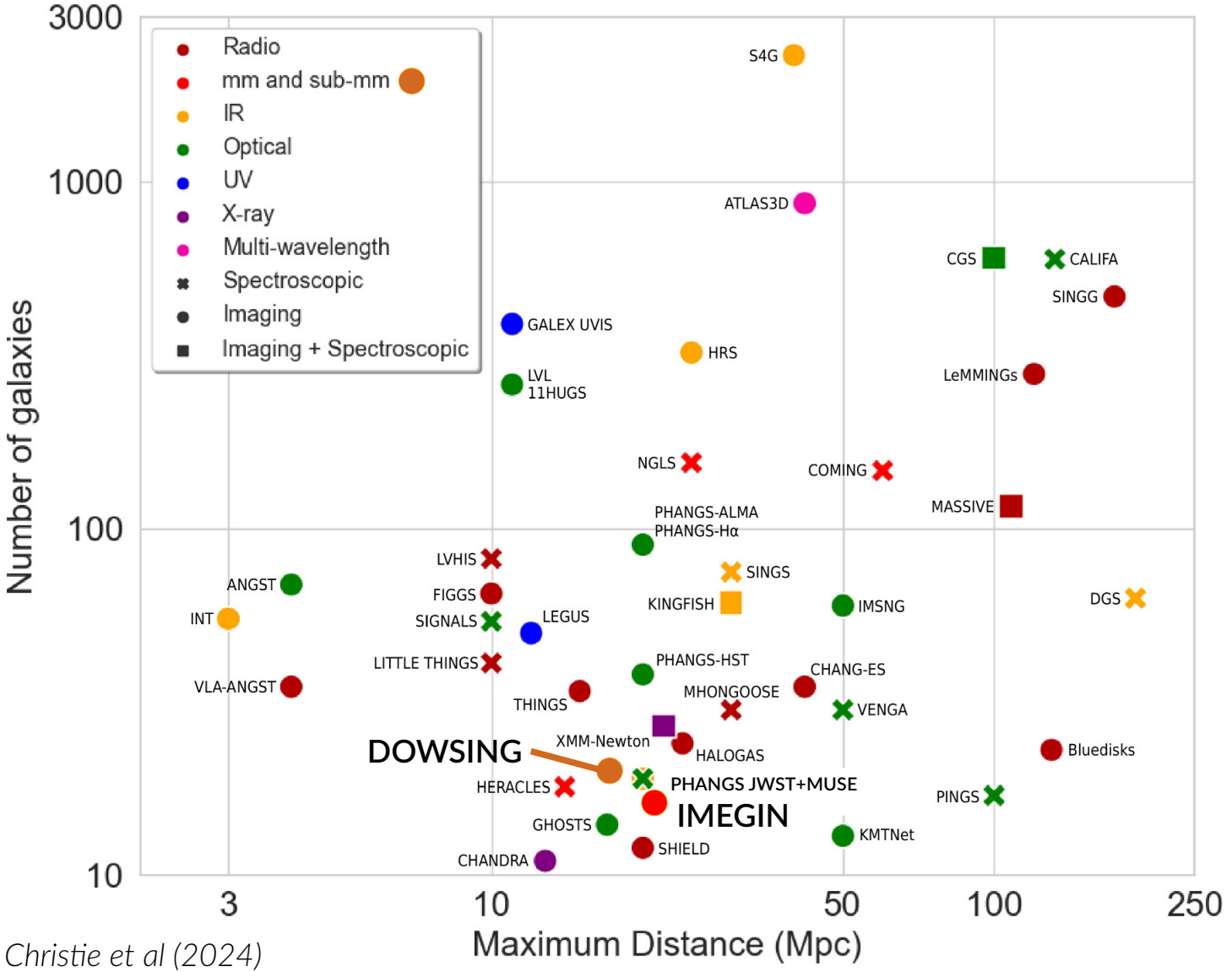


figure: Galliano, Galametz & Jones (2018)



Adapted from composite by Dalya Baron (Carnegie Obs)

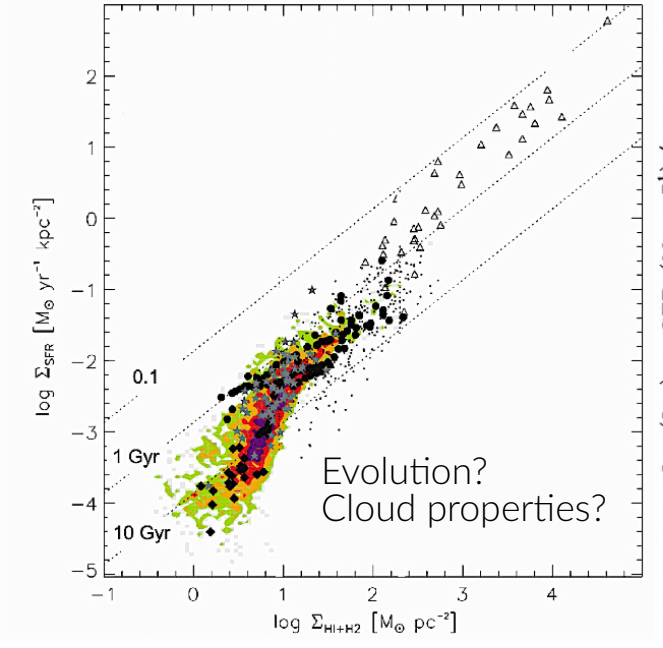


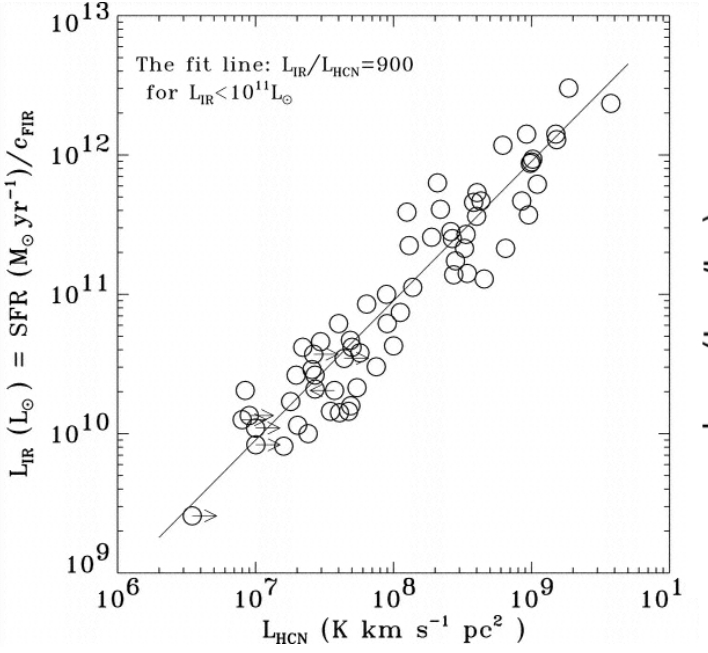
Christie et al (2024)

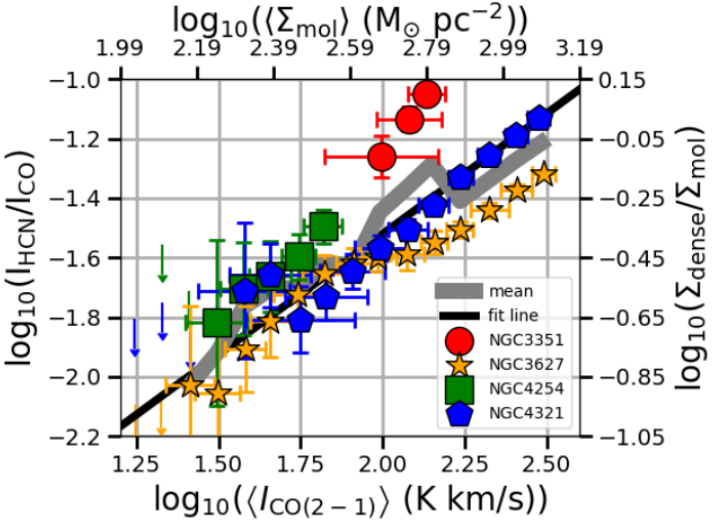
SF& ISM Conditions in NGs Galaxies with ATLAST

Measure physical & chemical conditions via cloud-scale ‘big N’ (i.e. many transitions of many species) molecular line mapping surveys

- What are gas densities, excitation conditions and temperatures?
- Universality of the gas – star formation relation (tracer, spatial scale…)
- Calibrate observational proxies for bulk / dense molecular gas



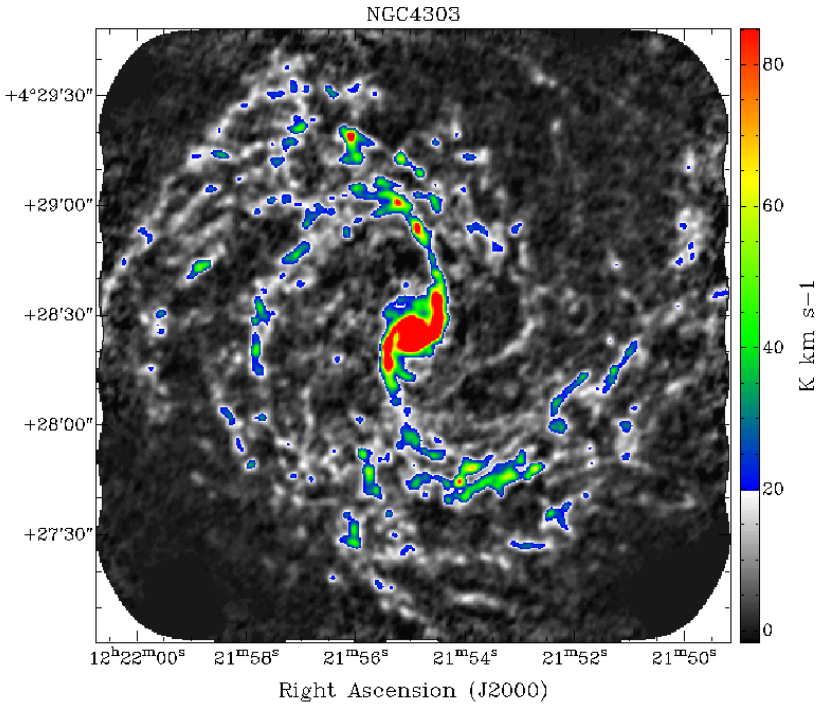




SF& ISM Conditions in NGs Galaxies with ATLAST

~1000 hours to map the CO-bright disk across a diverse galaxy sample for all transitions of key species (12CO, 13CO, HCN, HCO+ and CI ?) accessible in Bands 6 to 10.

GHz	θ (“)	PWV	t (min)	RMS mJy/bm
230	6.3	80	1	6.2
345	4.3	80	10	5.1
461	3.3	50	24	5.1
492	3.1	50	84	5.2
691	2.2	20	25	5.0
809	1.9	20	60	5.1



Assuming Δv = 30km/s, target RMS ~ 0.1 K.km/s
T_{pk} 12CO/CI/13CO/HCN/HCO+ = 1/0.2/0.1/0.03/0.01

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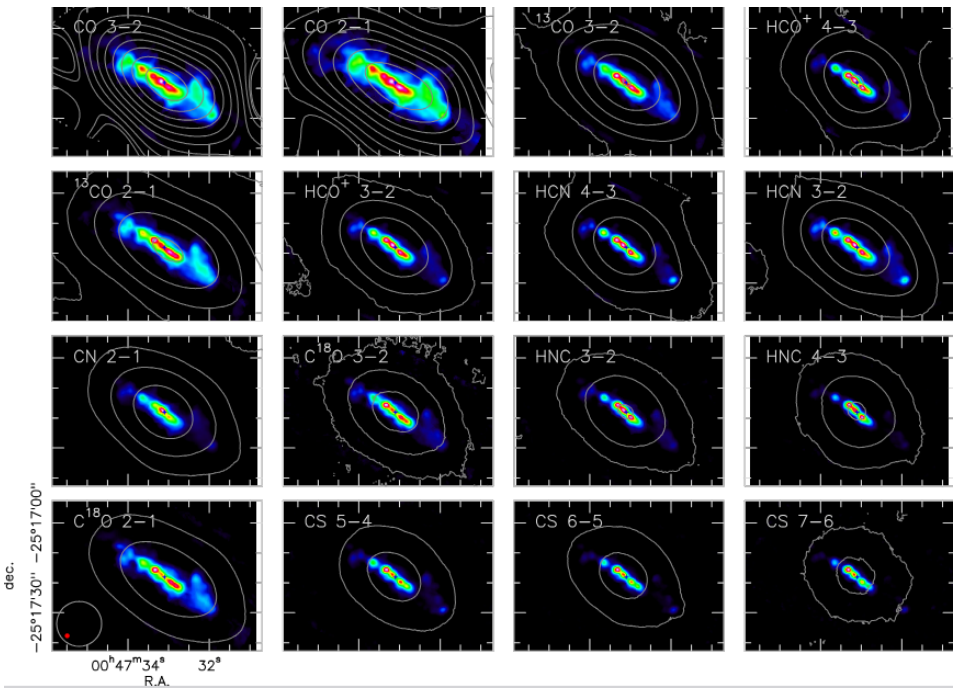
ALCHEMI Martin et al (2021)



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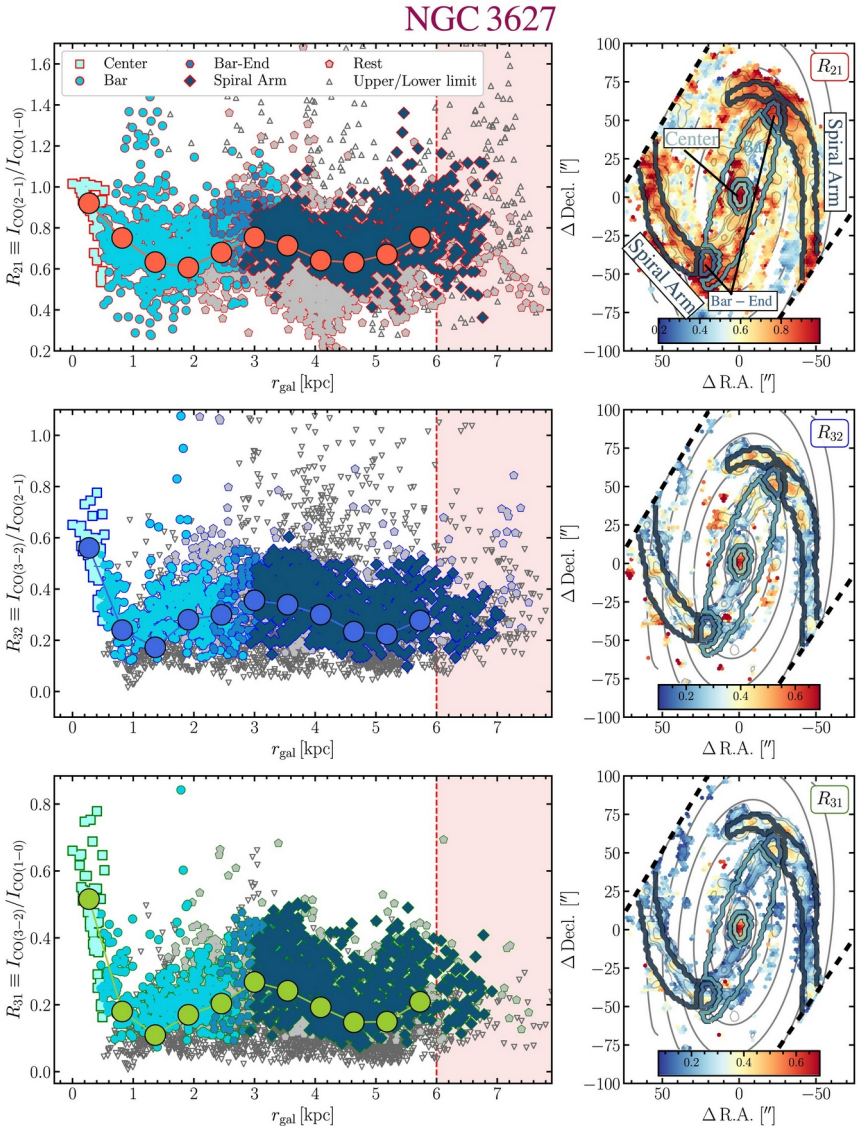
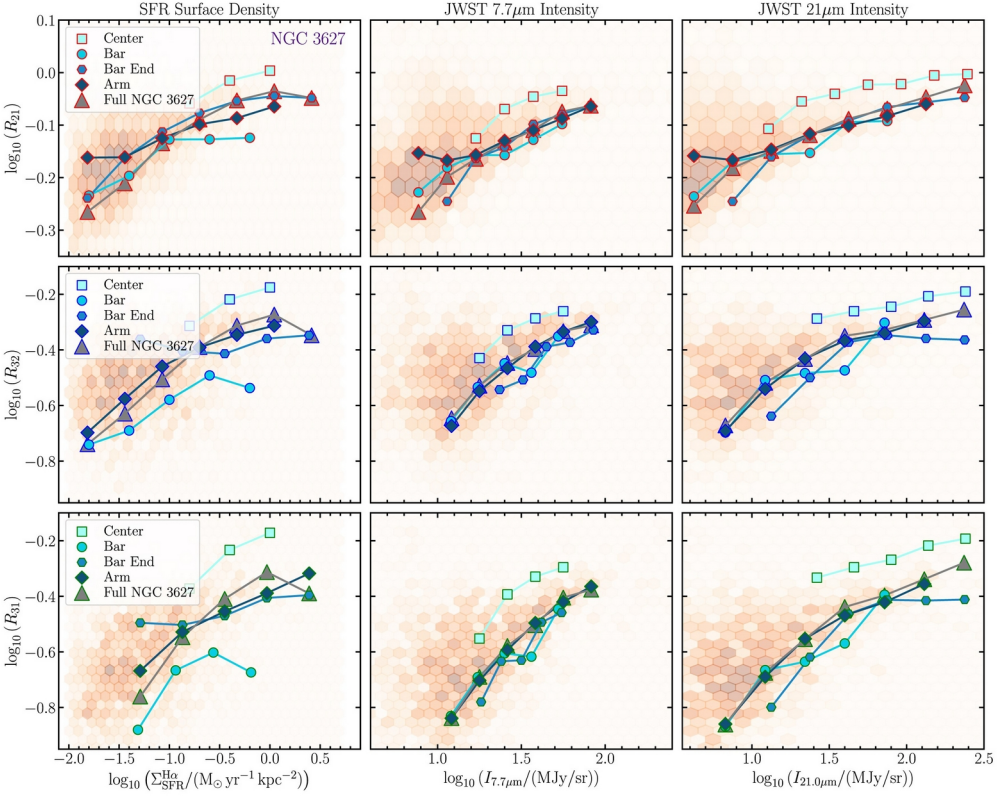
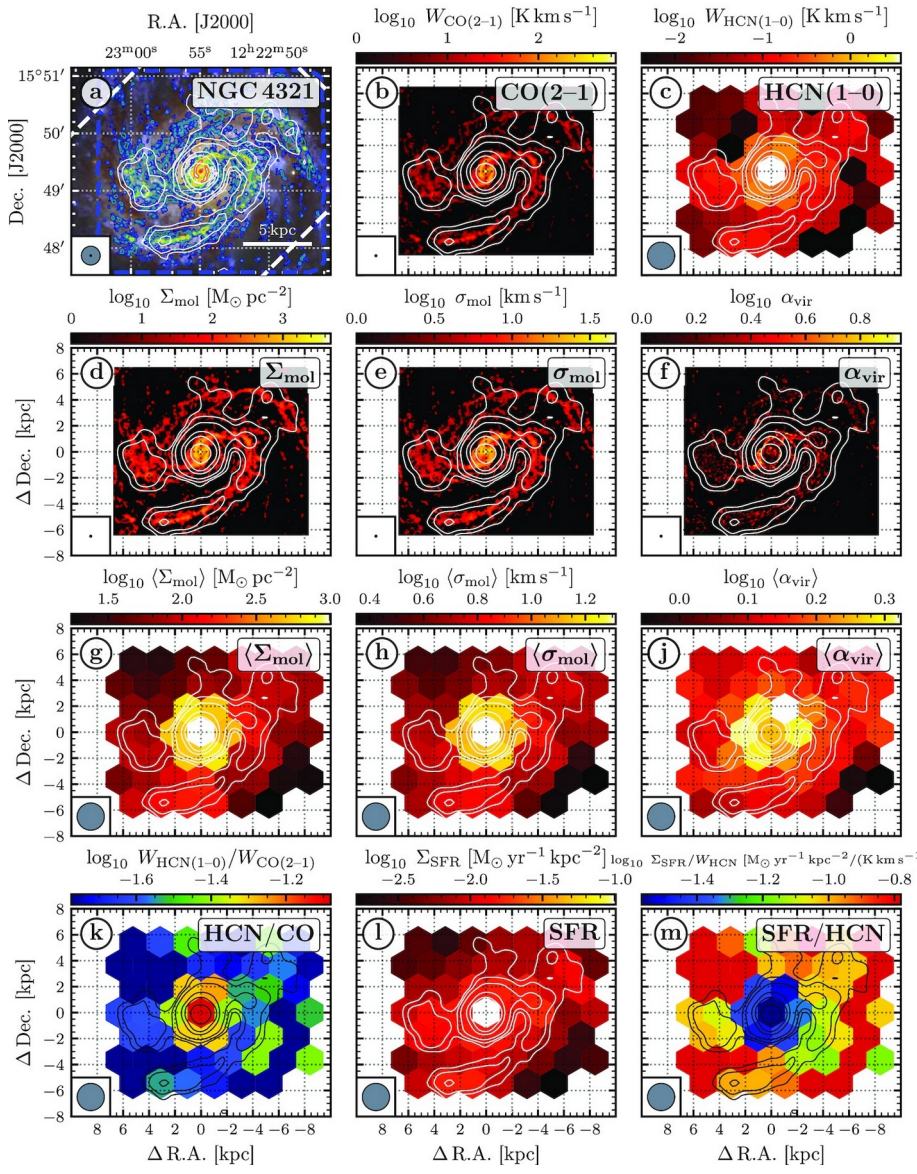


den Brok et al (2023), see also ALMA FACTS Komugi et al 2025



ALMA 12m+7m+TP CO(1-0) & CO(2-1) and 7m+TP CO(3-2), matched 4”~200pc : R21, R32, R31 in NGC3627 & NGC2903
(already 10 more galaxies in the pipeline)

mean values & environmental trends

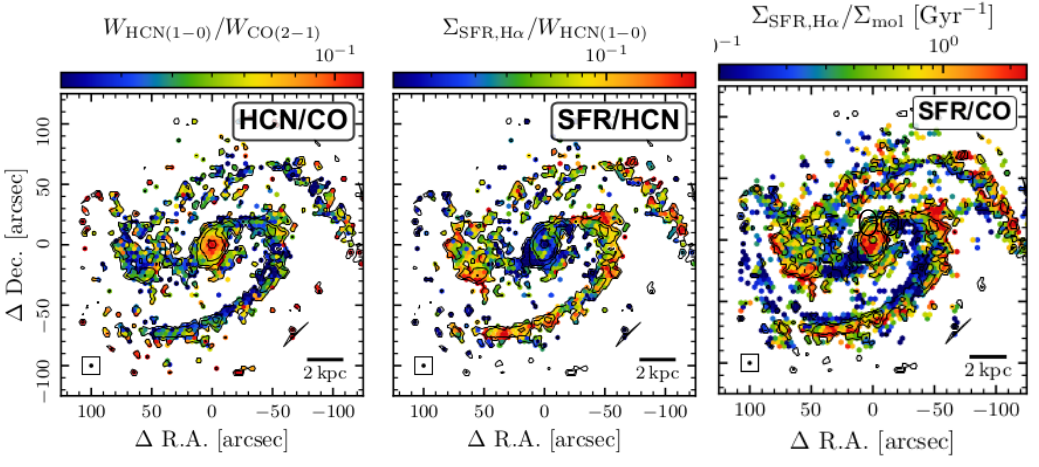


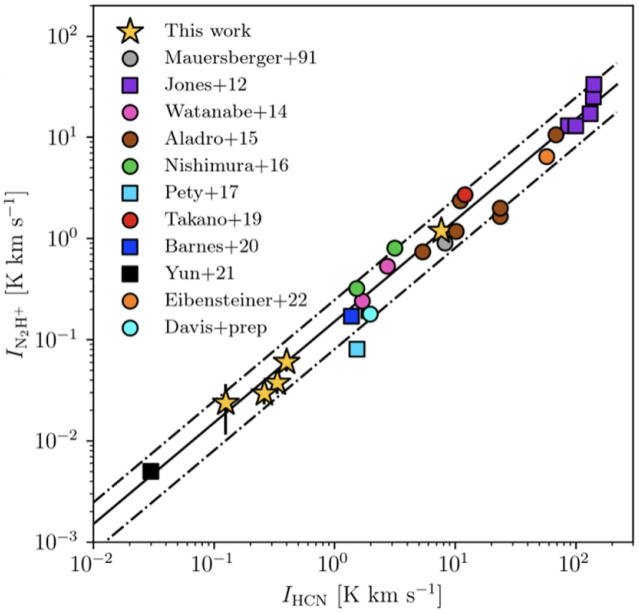
ALMOND Survey (Neumann et al, 2023)

ALMA 7m+TP HCN(1-0), HCO+(1-0) & CS(2-1)
25 galaxies, ~1 to 2kpc resolution

HCN/HCO+/CS/CO/SFR ratios :
typical values, environmental trends, variations with cloud-properties

12m+7m+TP HCN/HCO+/CS 250pc mapping of individual targets

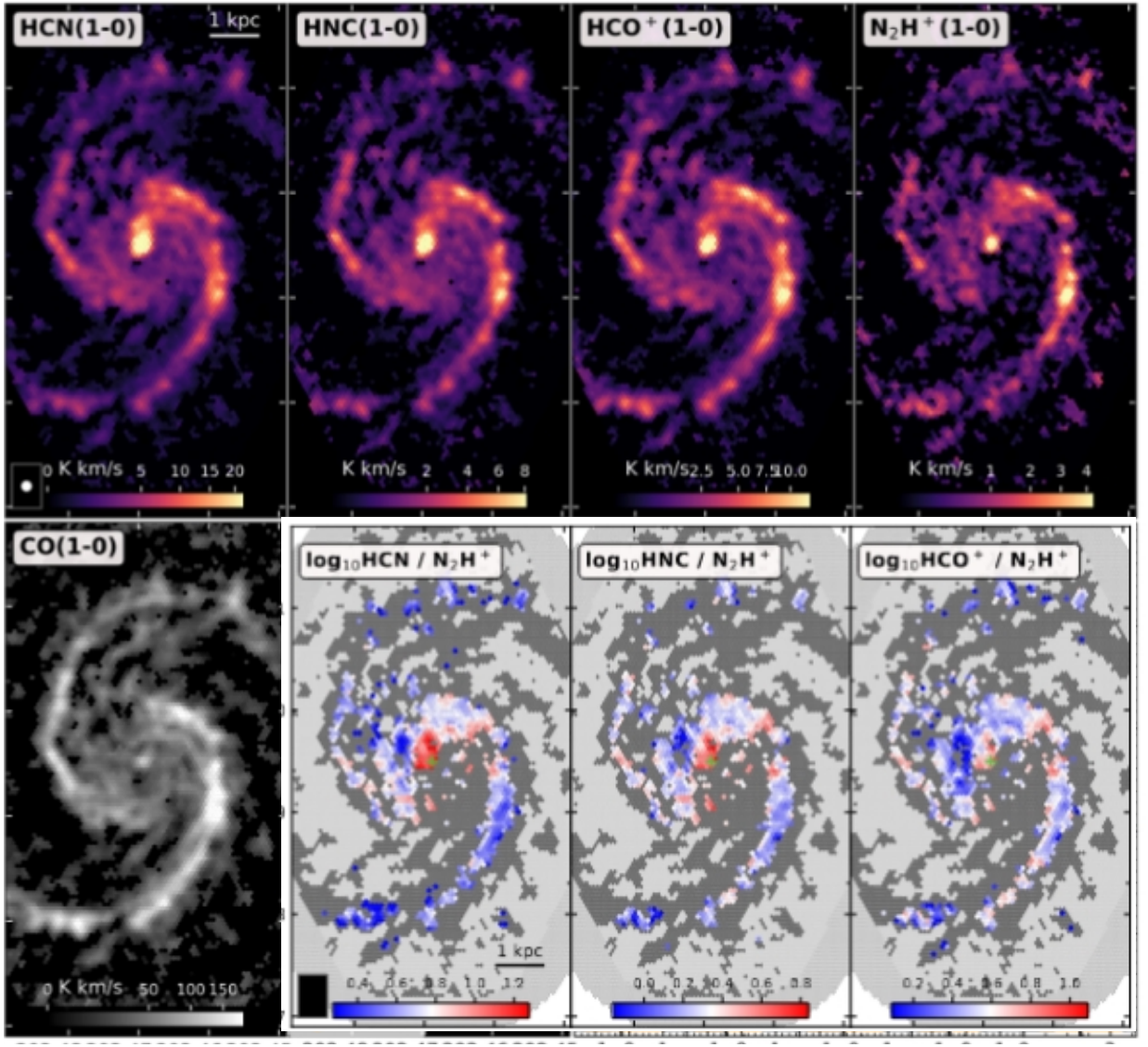




SWAN Survey
(Stuber et al, 2023, 2024, 2025)

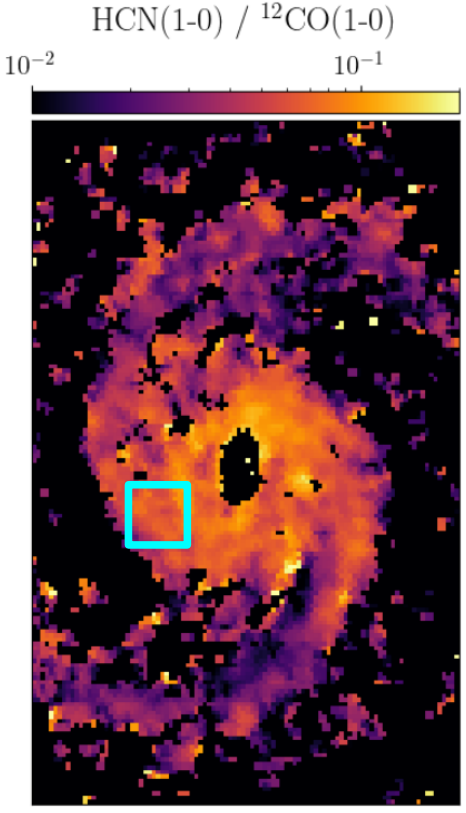
NOEMA+30m Band 3 line mapping survey of M51, including N_2H^+

variation of 'dense gas' line ratios with environment and spatial scale



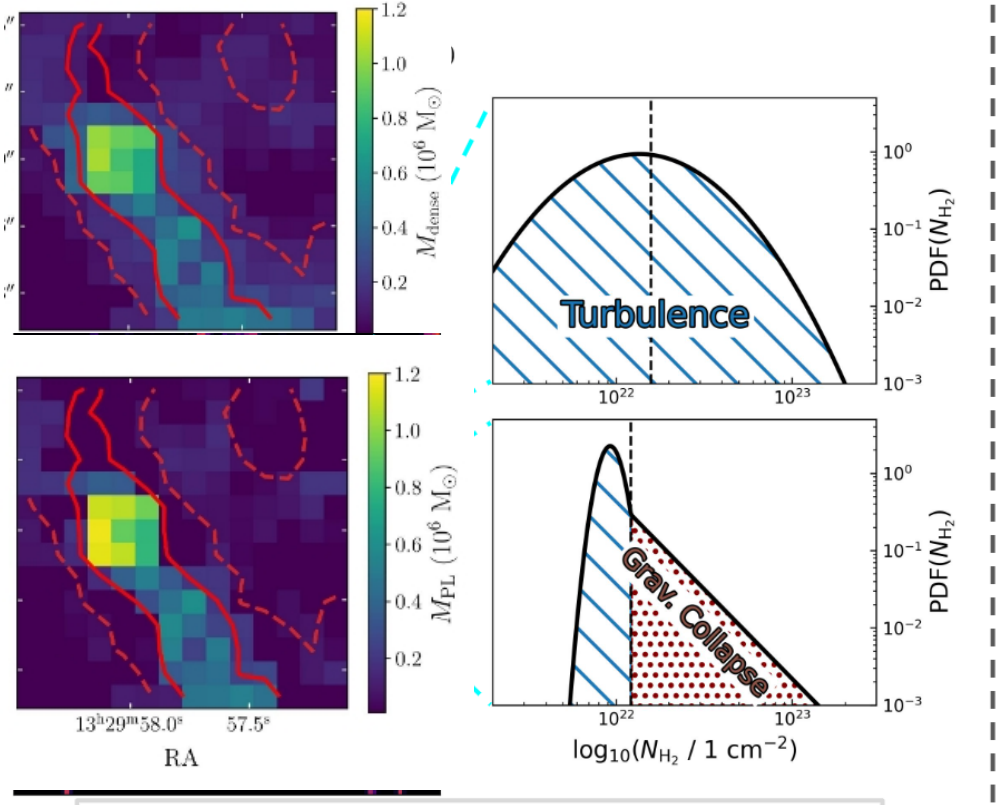
Zakardjian et al (in review)

Standard approach



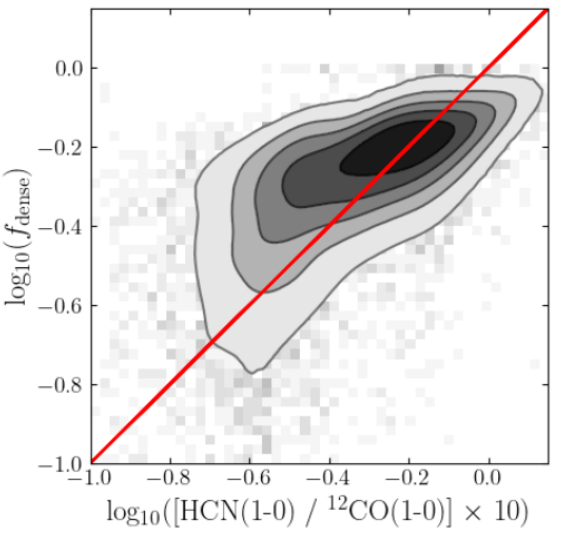
Empirical emission model
(I vs N(H2) for each line)
constructed from ORIONB data

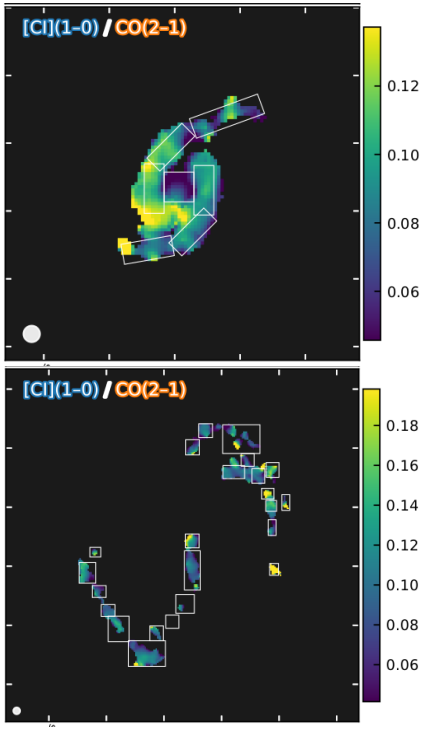
Bayesian inversion results

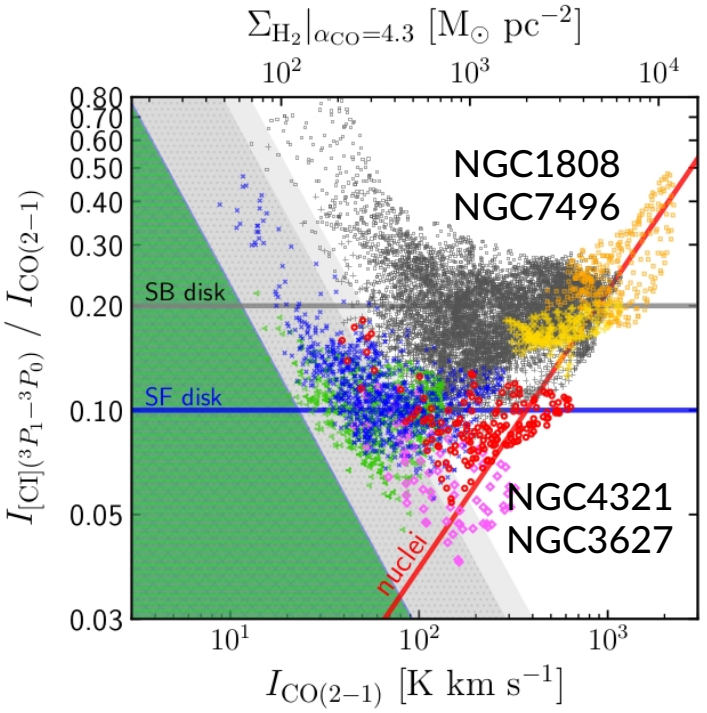


Lines used: 12CO(1-0) 13CO(1-0), C18O(1-0),
HCO+(1-0), HCN(1-0), HNC(1-0), N2H+(1-0)

Comparison



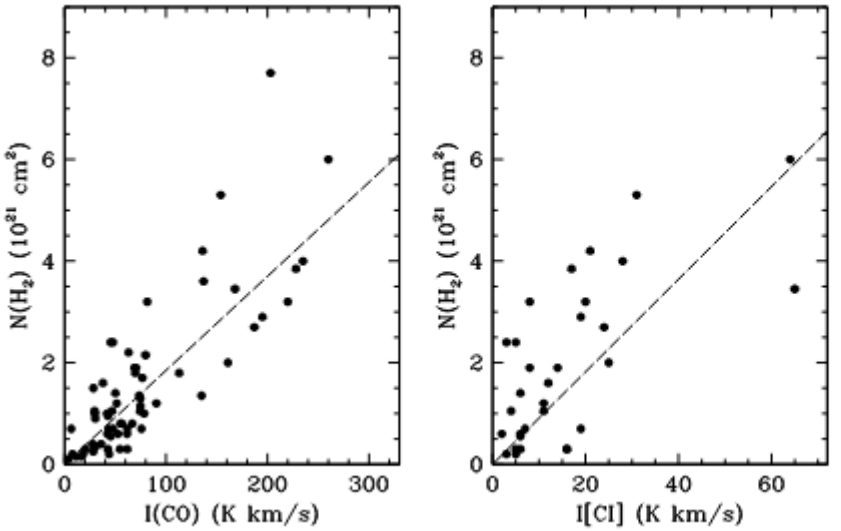




CI maps of 4 nearby galaxies (Liu et al, 2023)

4” ALMA 7m Band 8 (15-30h per galaxy)
+uv matched PHANGS CO(2-1)

<CI/CO> ~ 0.1 for disks
>1 in starburst/AGN-affected regions



Israel et al (2020)

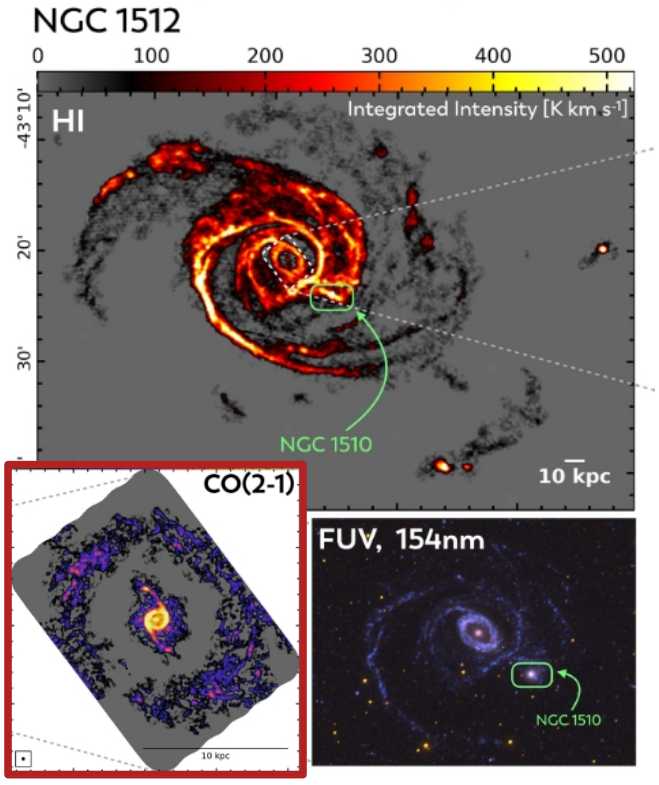
Single pointing observations of galaxy centers in low-J ^{12}CO & ^{13}CO (IRAM30m, SEST, JCMT) and CI & CII (Herschel)

RADEX modelling az two-phase gas to determine carbon budget and XCO

CO/CI/CII ~ 30/30/40%
XCO ~1 dex lower in galaxy centers, modest tension with dust based XCO

ISM Conditions in Nearby Galaxies in 2035:

- 25 years of ALMA, 10 years of NOEMA dual-band operations, regular ALHAMBRA science operations
  → trends for low J line ratios of CO, 13CO, HCN, HCO+ well-established in starbursts (including higher J) + disk galaxies
- 10 years of MEERKAT → low N(H) outer disks
- stellar populations, SFHs, ISRF, gas-phase metallicity, ionization parameter + ?? at ~1" from optical IFUs + JWST PAH studies
- Robust methods to infer 3D gas density and temperature (+ G0?) distribution within clouds
- Data-science driven 'Galaxy in a Machine' (observations ↔ physical parameters)



Some ideas….

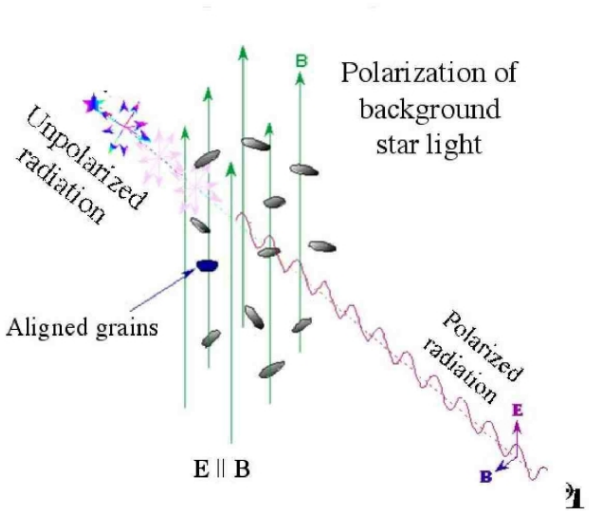
C+/C/CO: Carbon Budget Mapping Across Galaxy Disks

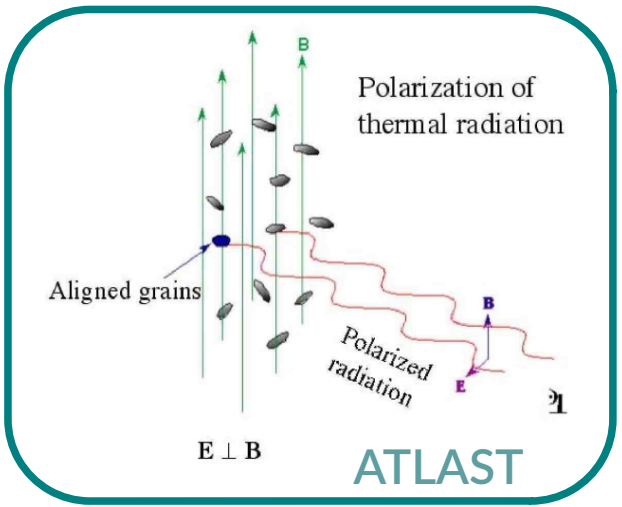
Need deeper dialogue between astrochemists, modellers and **extragalactic** observers to develop diagnostics of physical parameters other than density and temperature. Consideration of galaxy dynamics? (mixing of dust/molecules via feedback-driven/radial flows for astrochemical trends?

Magnetic Fields in Nearby Galaxies with ATLAST

Measure polarised intensity and angle of thermal dust emission → infer plane-of-sky magnetic field orientation (and strength via modified DCF)

- How do B-fields affect star formation at cloud scales?
- Does SFE correlate with B-field strength ?
- Dynamical interplay of B-field and turbulence for cold gas stability?
- Origin of magnetic fields in galaxies (via statistics of field structure)?





$PI = \sqrt{(Q^2+U^2)}$

$p = PI/I$

$\varphi_{dust} = 0.5 \arctan(Q/U)$

$\varphi_{mag} = \varphi_{dust,emission} + 90^o$

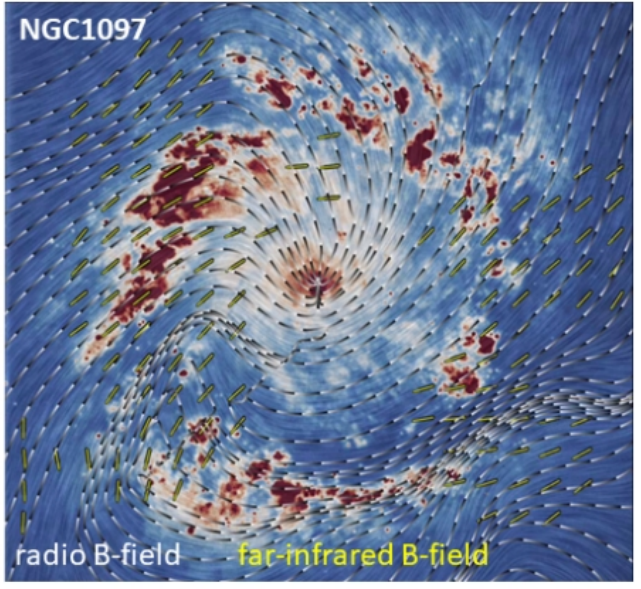
$\varphi_{mag} = \varphi_{synchrotron} + 90^o$

Figure from Lazarian (2007)

Magnetic Fields in Nearby Galaxies with ATLAST

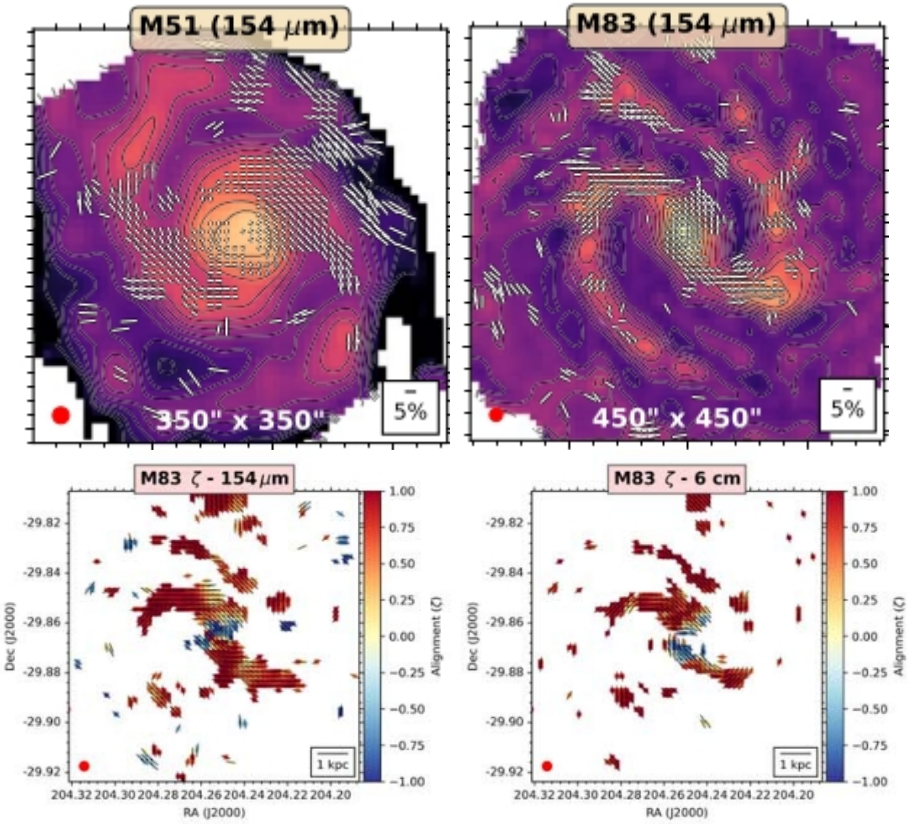
2000h (on source) program for multi-band polarisation observations[+] of a diverse sample of 100 nearby galaxies (dwarfs, disks, AGN, starbursts…)

GHz	θ (“)	PWV	RMS* (uJy/beam)	Integration time (hr)
345	4.4	50	10	18
460	3.3	20	16	29
660	2.3	20	31	36



** seem optimistic to me by a factor ~2-3 (cf. calculation from N(H) and dust T&κ)*
+ fabulous total intensity submm continuum maps !

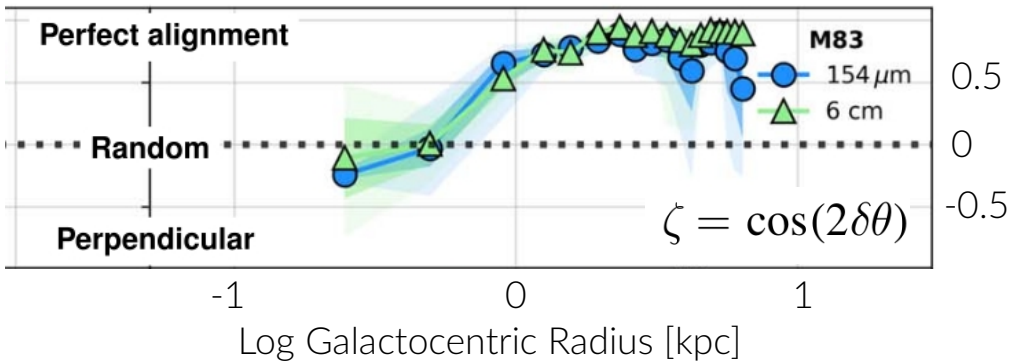
SALSA (PIs: Lopez Rodrigues & Mao)
Survey of extragALactic magnetiSm with SOFIA
14 galaxies (d<14Mpc) HAWC+ (53 – 214um)
Resolution: 5 – 18” / 100pc - 1kpc



Borlaff et al (2023), Lopez Rodrigues (2022)

Two SALSA highlights :
- systematic differences in radio vs FIR traced pitch angles, and trends of pitch angle with Rgal
- wavelength dependence of polarisation fraction depends on galaxy type

Some caveats :
- leakage (before correction) ~ polarised signal ~ 3% (particularly bad for diffuse emission next to bright region)
- Faraday Rotation at 3/6cm is still $\Delta\varphi_{RC} \sim \pm 5/20°$
- $\Delta\varphi \pm 10°$ at polarised intensity S/N=3



ζ = 1 → perfect alignment with axisymmetric spiral field model
ζ = 0 → random field

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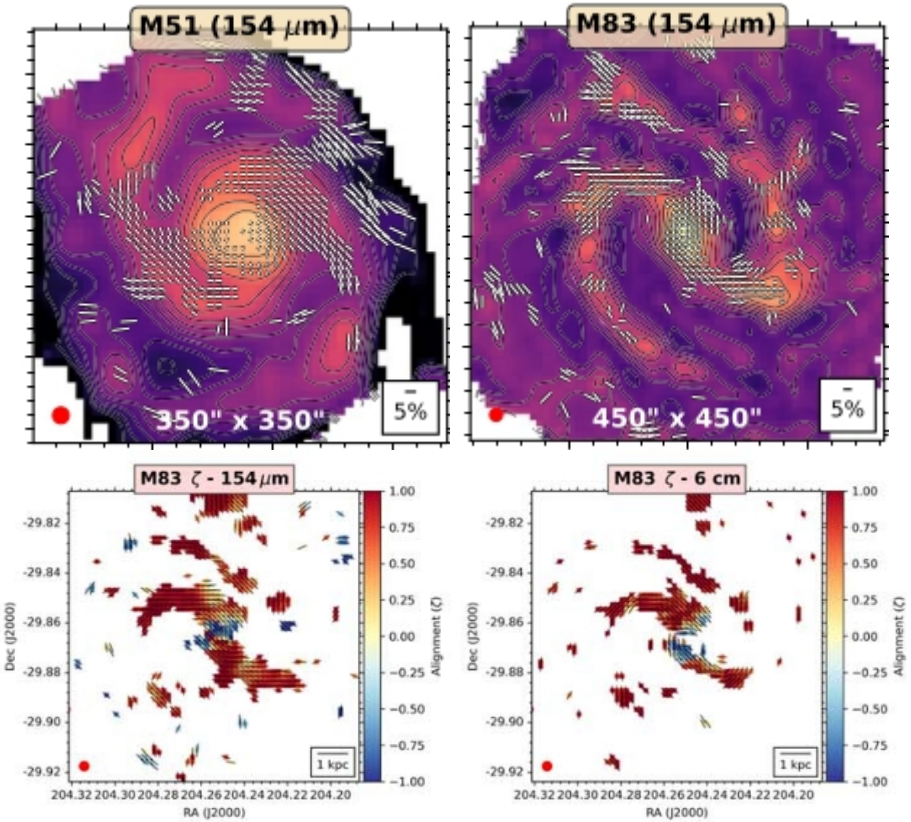

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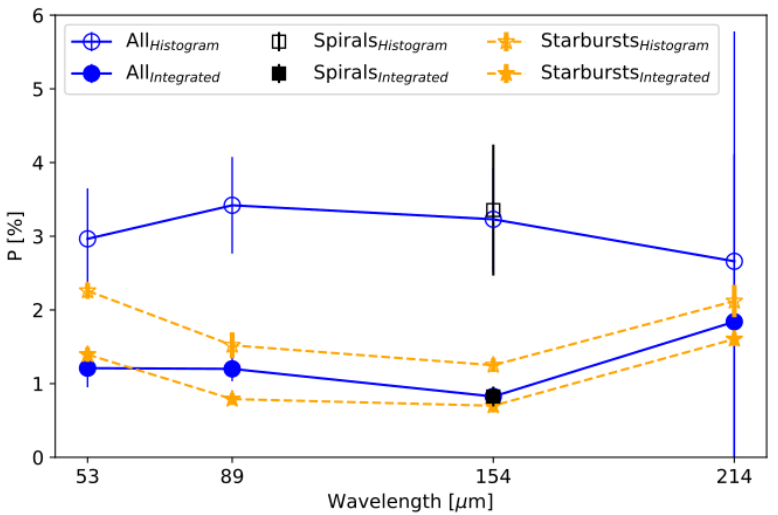
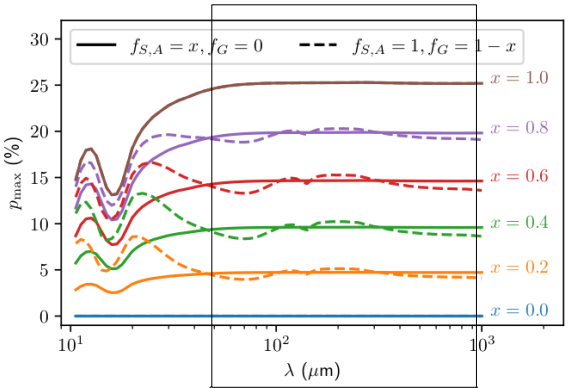
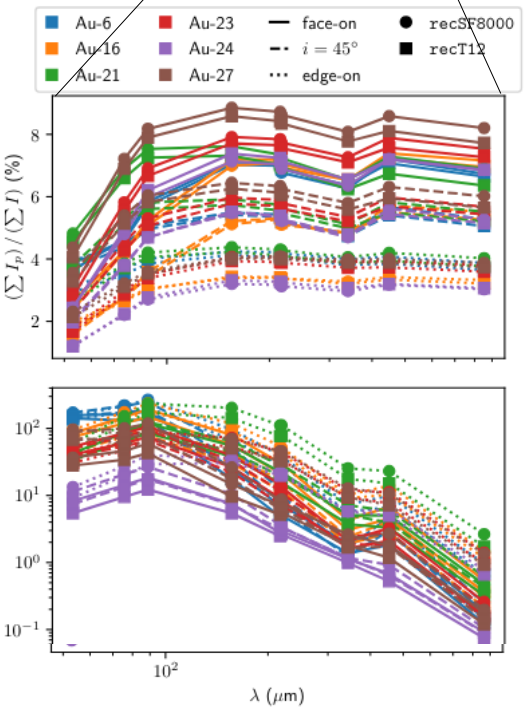
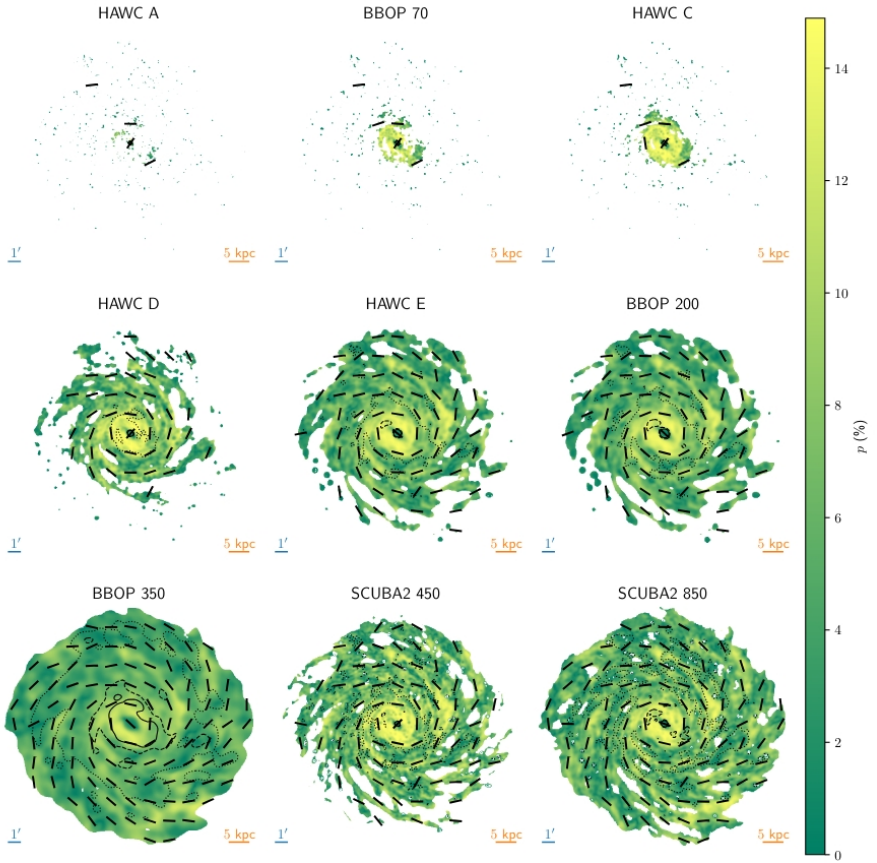






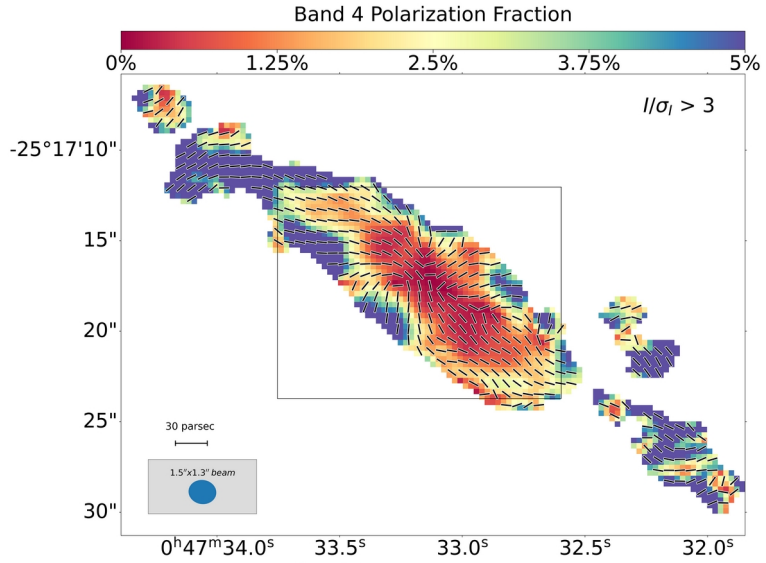


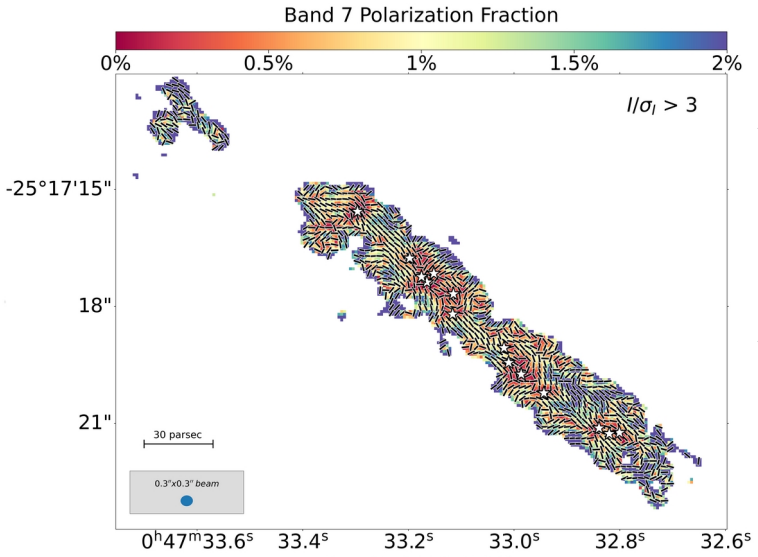
Auriga simulation galaxies
+ SKIRT
+ simple dust model CosTuum (fixed alignment efficiency, C+Si composition, size distribution, no intrinsic λ-dependence of polarisation)

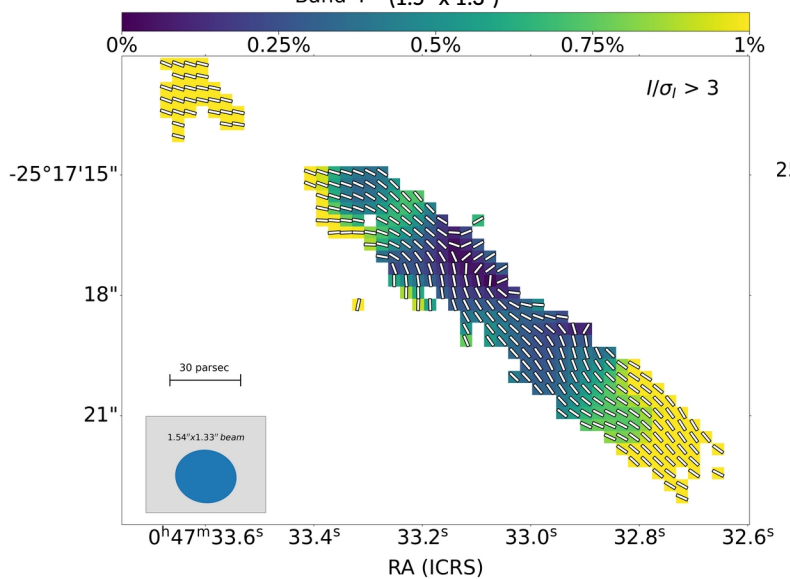
- synthetic observations show a variation in polarisation fraction of a few % due to geometry (dust at different temperatures is distributed differently in galaxies)

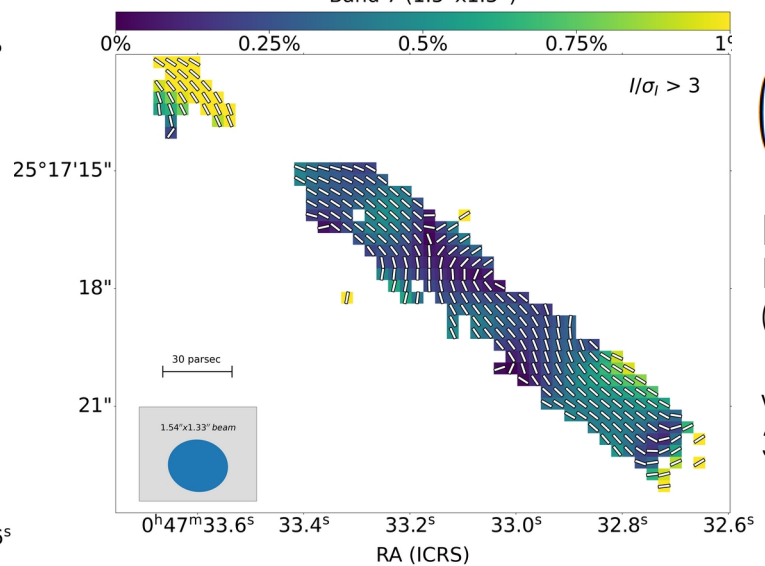
- high polarised intensity and high polarisation fraction → optimal band for mapping dust polarisation: λ = [100, 300] μm

Vandenbroucke et al (2021)









ALMA B4 & B7 polarisation observations of central ~200 pc of NGC253
Resolution: 5 – 30 pc

ALMA measures polarisation fractions <0.3% at S/N>5

350GHz: 90% dust
150GHz: 20% dust
20% synchrotron
60% free-free

$$\begin{pmatrix} PI_{B4} \\ PI_{B7} \end{pmatrix} = \begin{pmatrix} I_{syn,B4} & I_{dust,B4} \\ I_{syn,B7} & I_{dust,B7} \end{pmatrix} \times \begin{pmatrix} PF_{\mathrm{syn}} \\ PF_{\mathrm{dust}} \end{pmatrix}$$

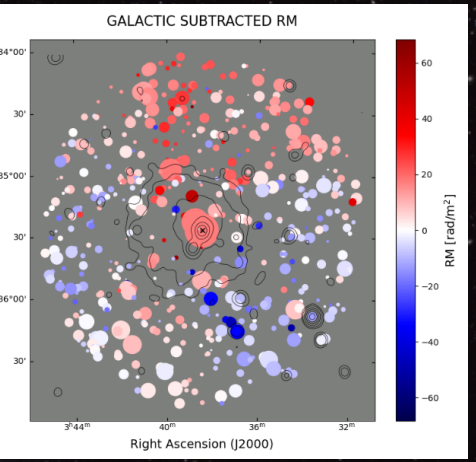
PF dust = 0.3 %
PF synchrotron = 3%
(we assume no λ dependence)

when uv-matched, 150 and 350GHz structure is similar

Belfiori et al (2025)

Matthews et al (2024)

5 arcmin



NGC1532, d=15Mpc
θ = 7", 30h inc overheads
σ N(HI) = 3e19 H/cm2
σ I = 2.6 uJy/beam
σ QUV = 1.4uJy/beam

Magnetic Field & Dust Polarisation in 2035:

- 10 years of MEERKAT operations
  → broadband GHz PI imaging of 100s galaxies
- SKA dense RM grid (+ broadband PI imaging) →
  3D B field structure of ~200 nearby galaxies
- PRIMAger → 10" polarisation maps @ 150um
  In 1hr, FoV = 1 sq deg, 5σ detection of
  2% polarisation from N(H)~3e19 H/cm^2
  (assuming Tdust = 20K, β=1.5)
  10" → cloud-scale for Local Group (d<2Mpc)
  → 'resolved' for targets d<20Mpc

  "Sensitivity alone does not make a polarimeter"

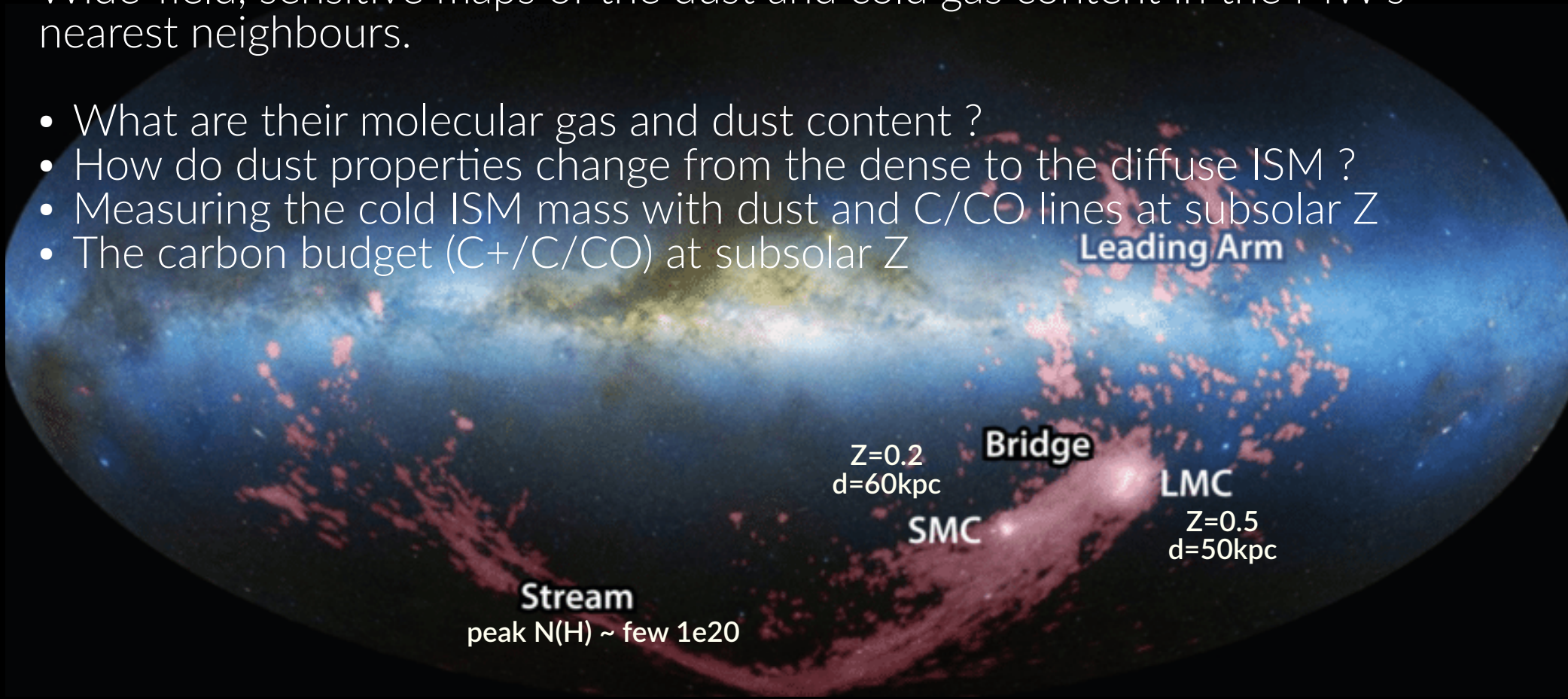
  Compelling motivation for an ATLAST
  345+460+660 GHz survey to study magnetic
  fields in nearby galaxies is not clear to me

  Dust polarisation observations of nearby galaxies
  with ALMA are not (AFAIK) oversubscribed ?

The LMC and SMC with ATLAST

Wide-field, sensitive maps of the dust and cold gas content in the MW's nearest neighbours.

- What are their molecular gas and dust content ?
- How do dust properties change from the dense to the diffuse ISM ?
- Measuring the cold ISM mass with dust and C/CO lines at subsolar Z
- The carbon budget (C+/C/CO) at subsolar Z

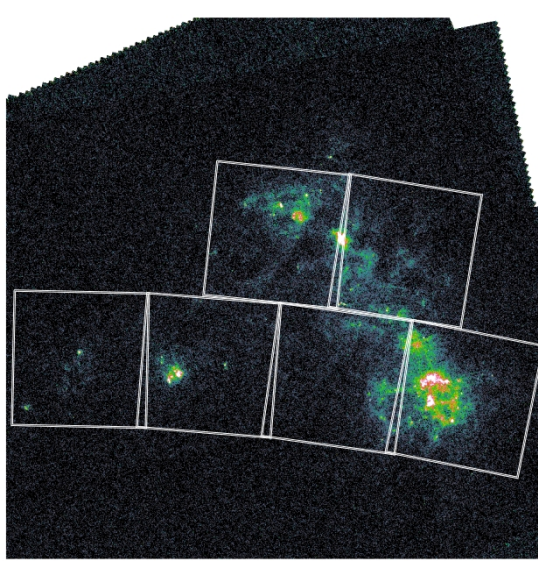


The LMC and SMC with ATLAST

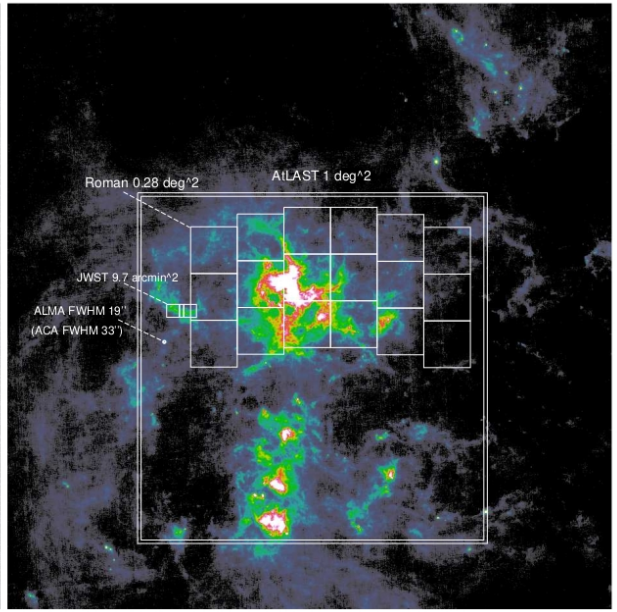
Deep, multiband (B3, B8 & B9) continuum maps

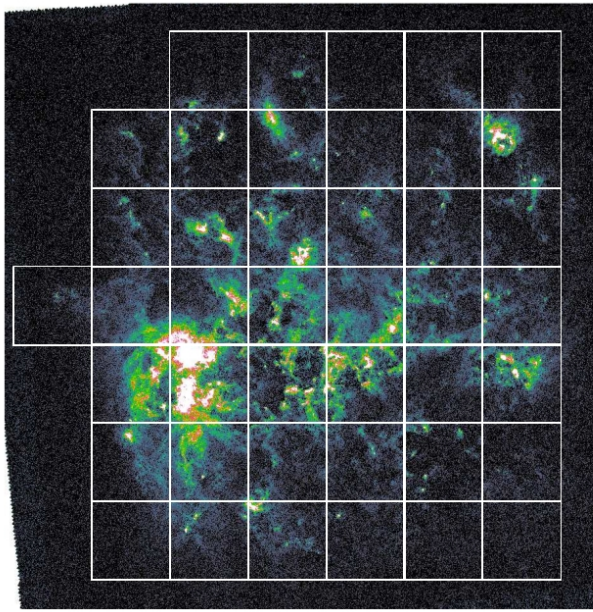
Spatially complete ^{12}CO(3-2)+^{13}CO(3-2) mapping survey

+ 1 sq deg 'deep' fields of CI (+other faint emission lines, 10-100x fainter than CO ?)

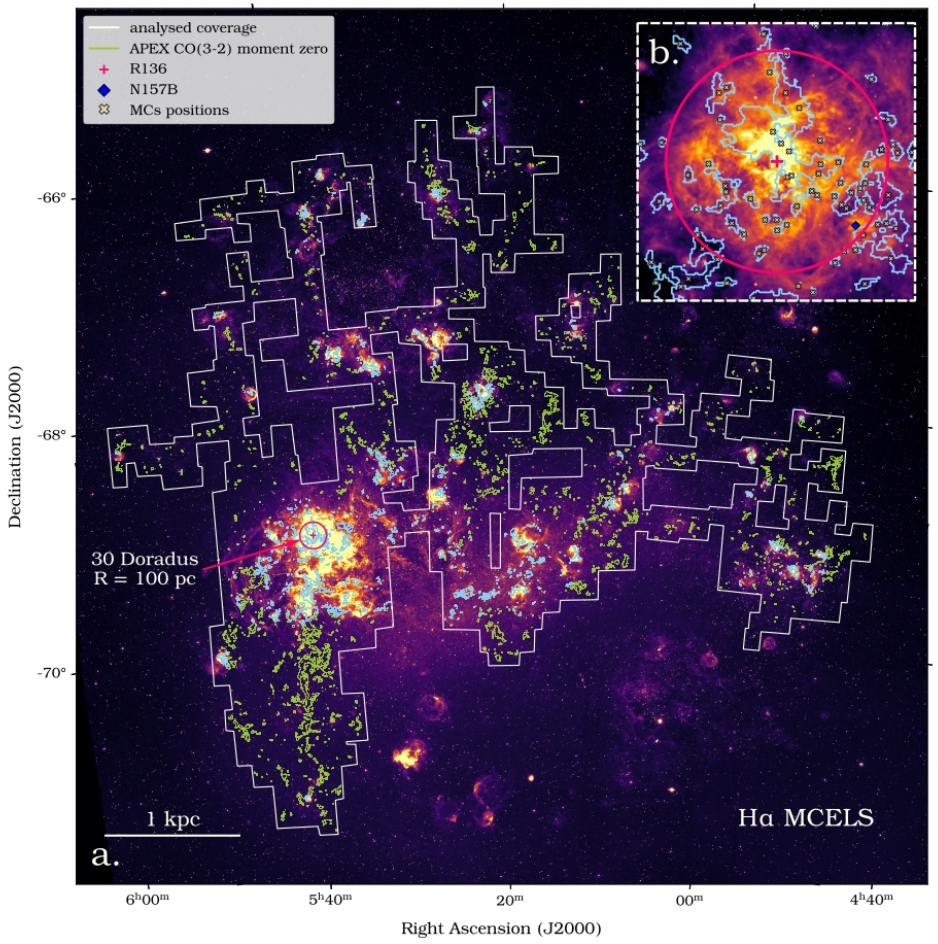


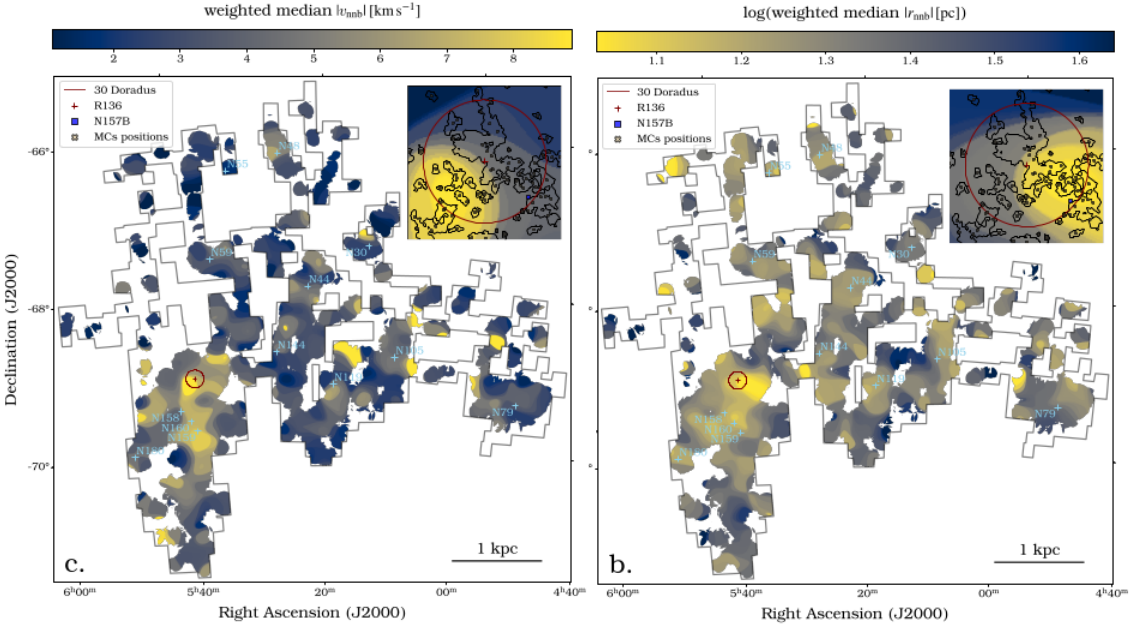
Band	θ [pc] @50kpc	3σ N(H) [H/cm^2]	time [h/sqdeg]
3	4	3e20 (LMC) 7e20 (SMC)	27
8	1	3e20 (LMC) 7e20 (SMC)	5
9	0.5	3e20 (LMC) 7e20 (SMC)	29

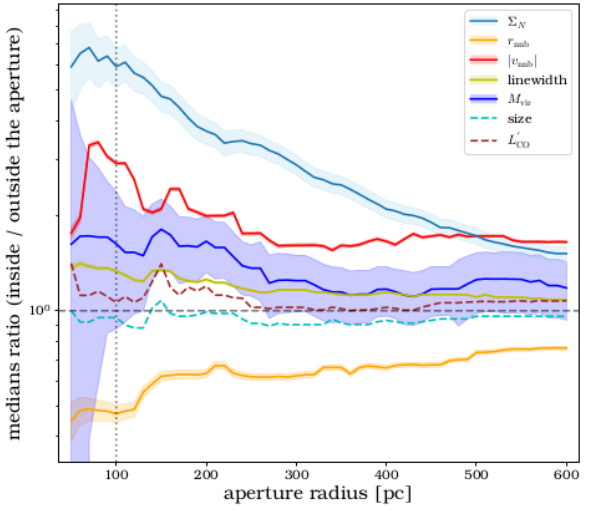




APEX ^{12}CO(3-2) LMC Survey
17.4 sq deg, 5pc, σ~0.2 K.km/s







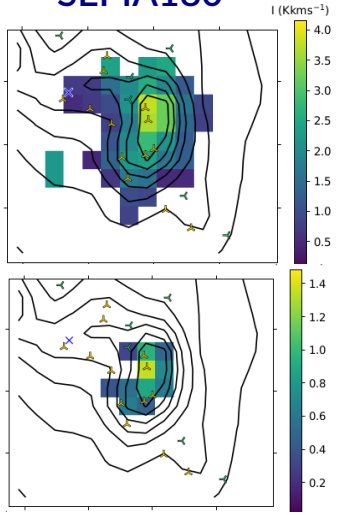
Evolution of cloud ensemble properties (nearest neighbour separation in r and v) as a function of distance from 30 Doradus to study feedback

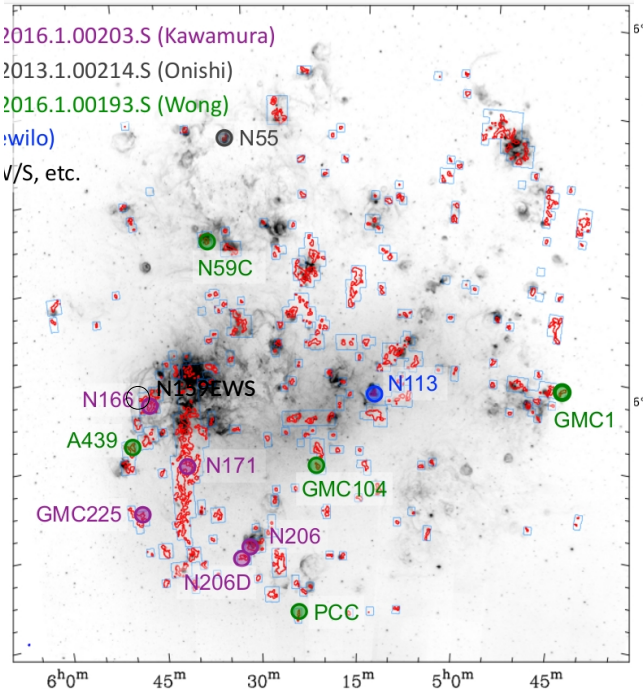
Evolution of physical cloud properties as a function of distance from 30 Doradus

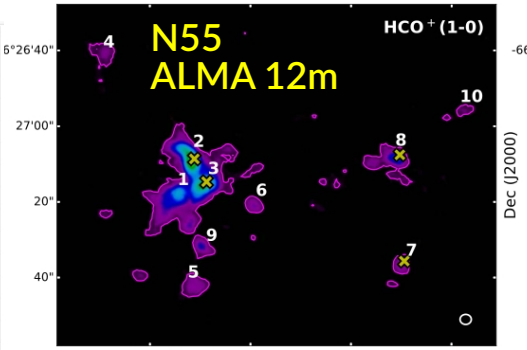
... high resolution + full FoV are essential

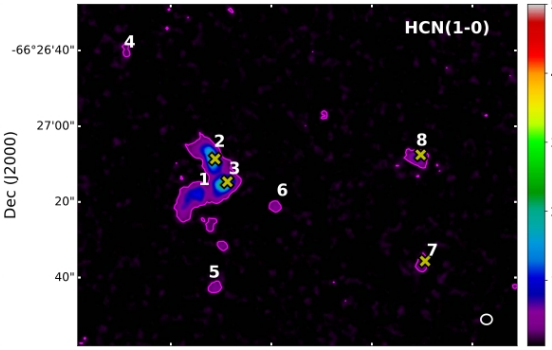
Grishnunin et al (2024)

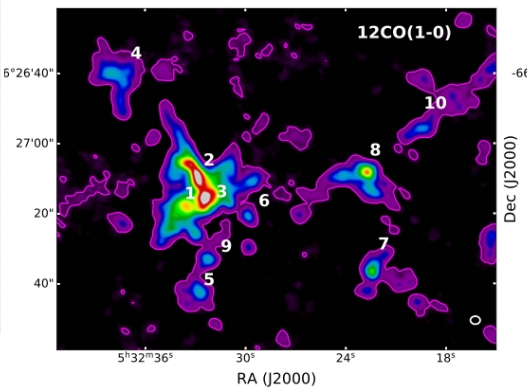
N159, APEX SEPIA180

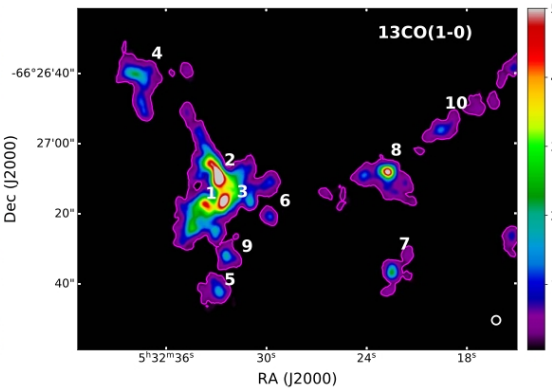


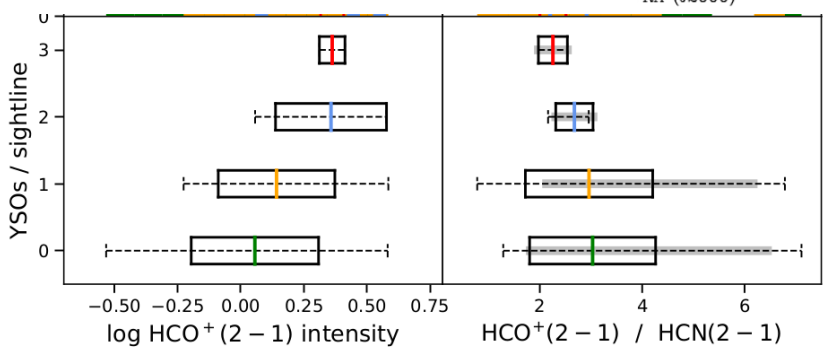


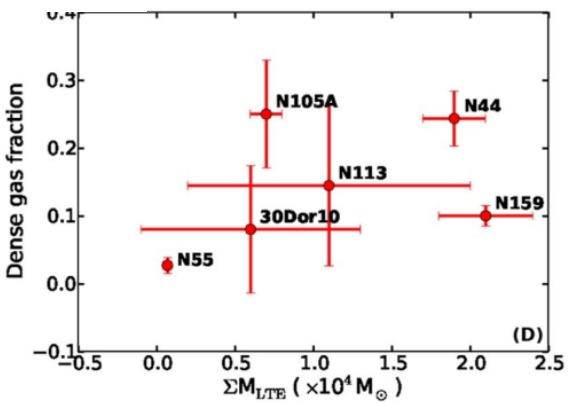










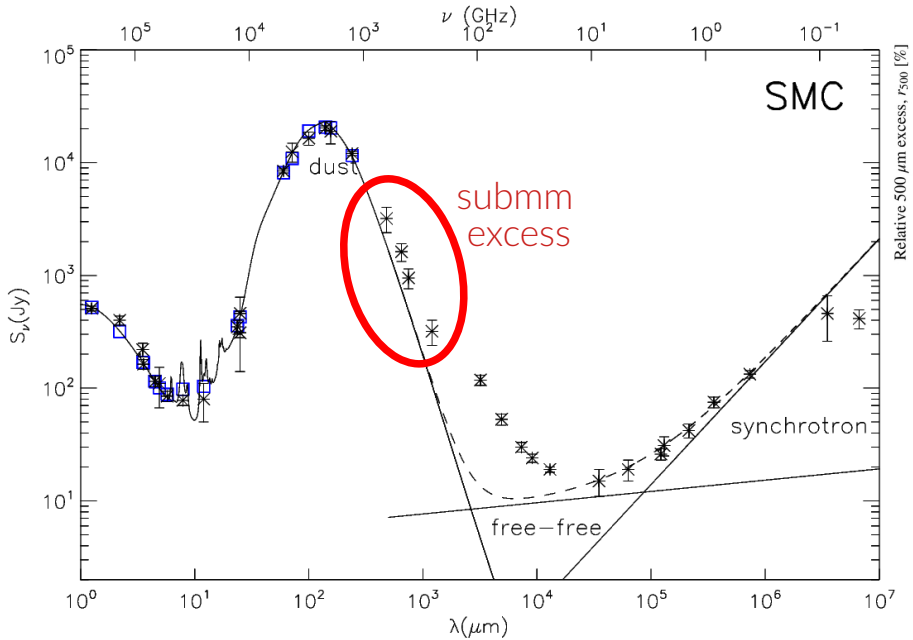


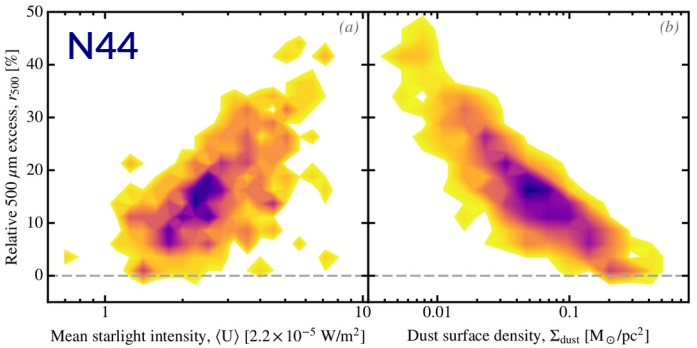
ALMA mapping of lines other than B3 and B6 12CO and 13CO in the LMC is practically non-existent…

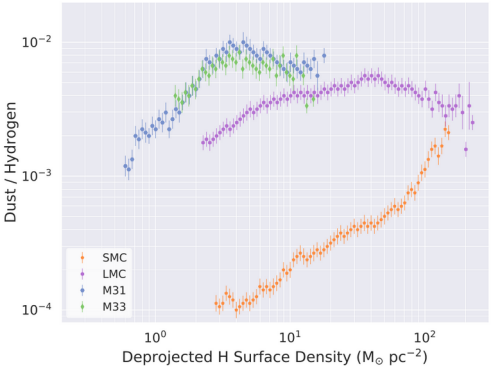
… even for CO, the spatial coverage of ALMA mapping remains limited

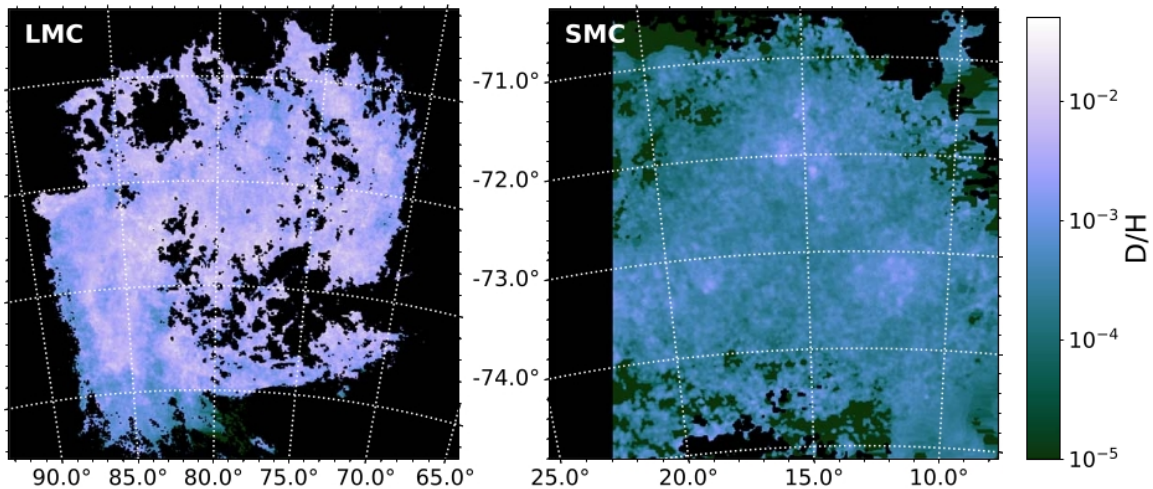
Establish link SF (YSOs) to cloud formation (CI) to cloud substructure + gas density distribution (dense gas)

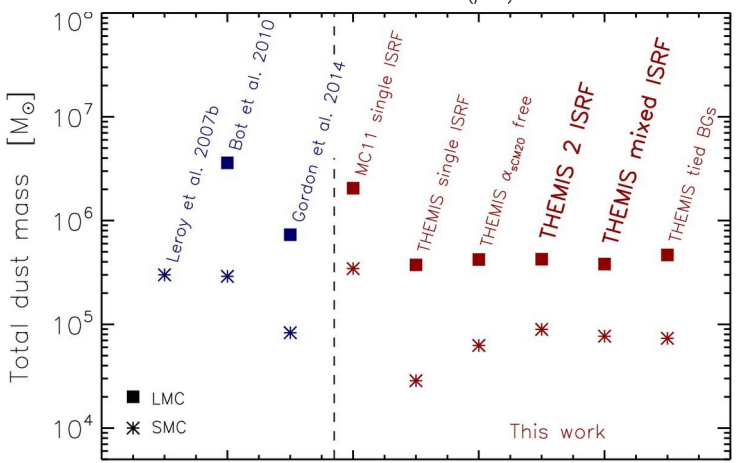
Nayana et al (2020), Galametz et al (2020)











"Dust emission is easy to measure but not so easy to interpret." - Frank Israel

IR/submm continuum → dust column density → gas column density
- conversions depend on dust composition, dielectric properties, size distribution, gas-to-dust ratio → likely vary ISM conditions (density, ISRF, Z)

observational effects also matter → e.g. large-scale filtering, contamination

Clark et al (2023), Chastenet et al (2017), Bot et al (2010), Fred Galliano's HDR

The LMC and SMC in 2035:

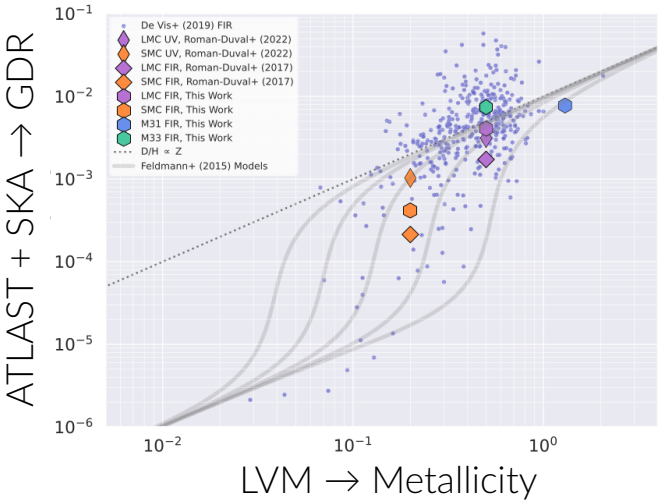
- 25 years of ALMA:
  → ALMA 7m+TP 12CO(1-0) cloud survey (N~100s clouds)
  → some wide-field 7m+TP low J 13CO, CS mapping
  → N~10s bright SF LMC clouds with 'dense gas tracers'
- LVM → 10pc maps of ionized gas parameters, Z, feedback diagnostics…
- SKA+Pathfinders: Atomic gas properties (CNM/WNM, low N(H) regime)

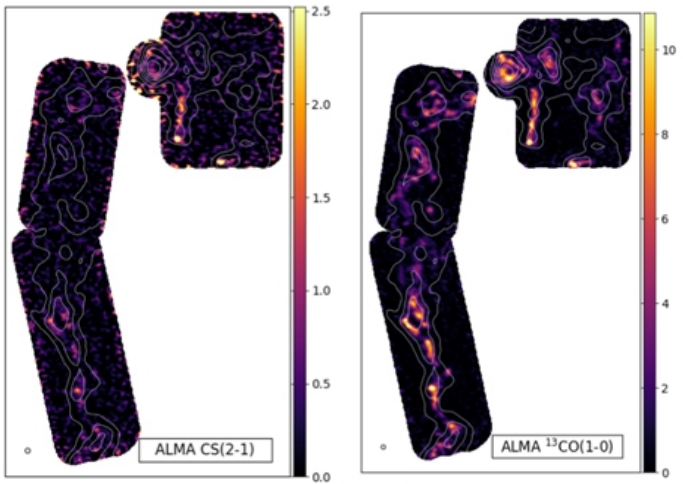
Some thoughts….

Fields to study all evolutionary stages of cloud&SF at pc-scale as function of galactic environment

French community has unique expertise (theory+lab +modelling) for studying dust

We need to make connection between the LMC/SMC and dust properties in diffuse (outer disks) + dense ISM of SFMS disk galaxies … and to even lower Z systems





Clark et al (2023), Finn et al (2021)

Nearby Galaxies with ATLAST : Take-aways

The landscape is changing very fast: data volumes, wavelength coverage and data science analysis methods

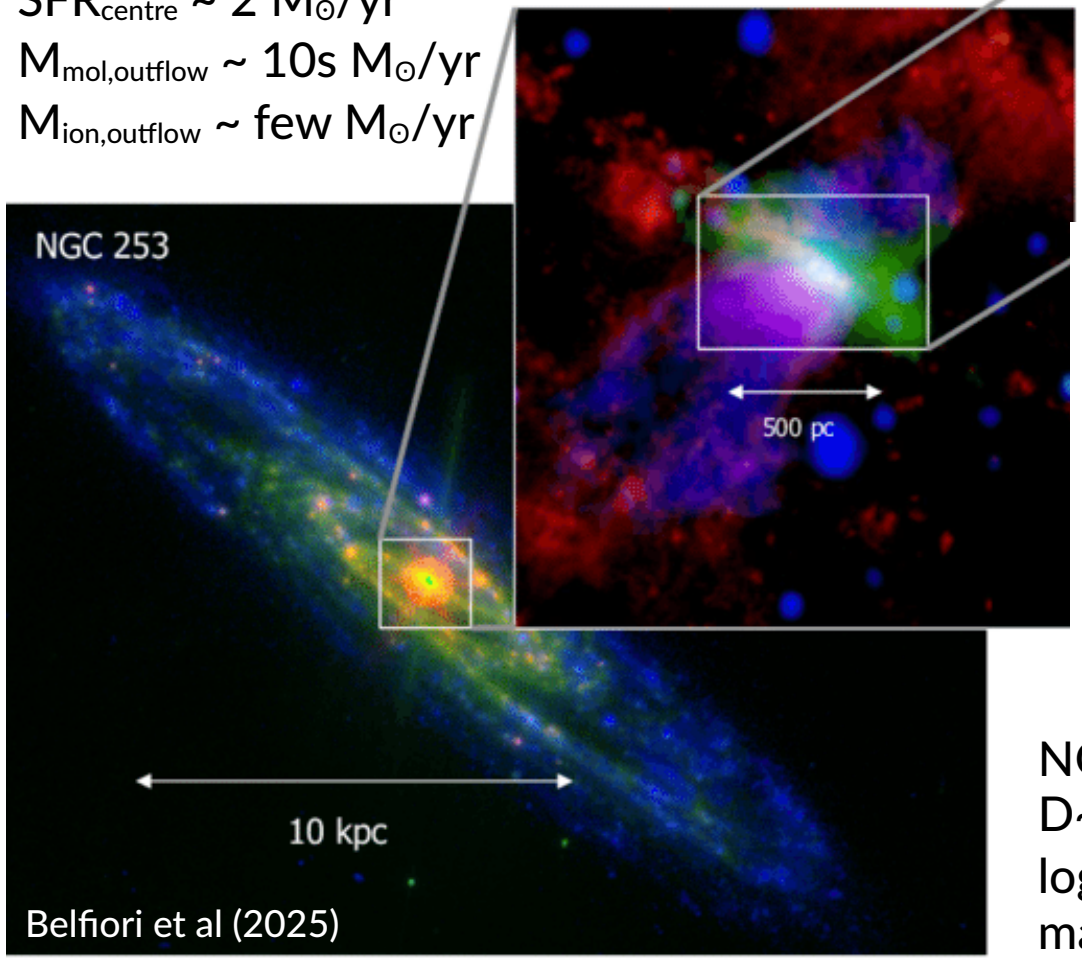
Just because observations are hard today doesn't mean people won't try, especially if the science return is high ('Chris Carilli 80% rule')

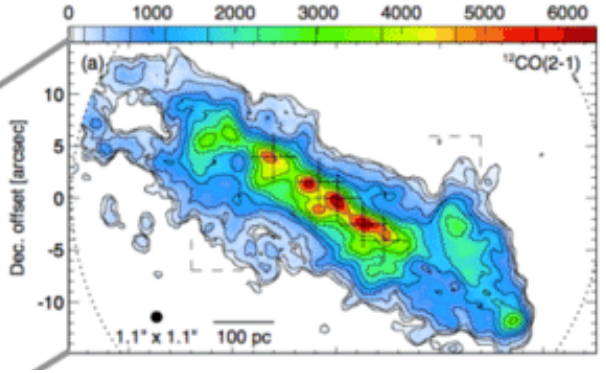
From little things, big things grow… pilot programmes for ATLAST 'key science' should be happening now

IRAM facilities are key for paving the way:
e.g. PAWS → PHANGS, M51 dense → SWAN, EMPIRE → ALMOND

Tuesday July 1st afternoon, SF2A Workshop 'L'interféromètre NOEMA et le télescope de 30m de l'IRAM: développements récents et futurs'

NGC253's starburst + multi-phase outflow
~20 SSCs (mass: 10^4-10^6 $M_\odot$, age: 0.01 – 3Myr)
SFR_{centre} ~ 2 $M_\odot$/yr
$M_{mol,outflow}$ ~ 10s $M_\odot$/yr
$M_{ion,outflow}$ ~ few $M_\odot$/yr





NGC253, an iconic nuclear starburst galaxy
D~3.7Mpc, SABc
log(M*) = 10.6, SFR_{global} = 5 $M_\odot$/yr
many ALMA projects (Early Science, ALCHEMI)