USING THE OST ON NEARBY GALAXIES

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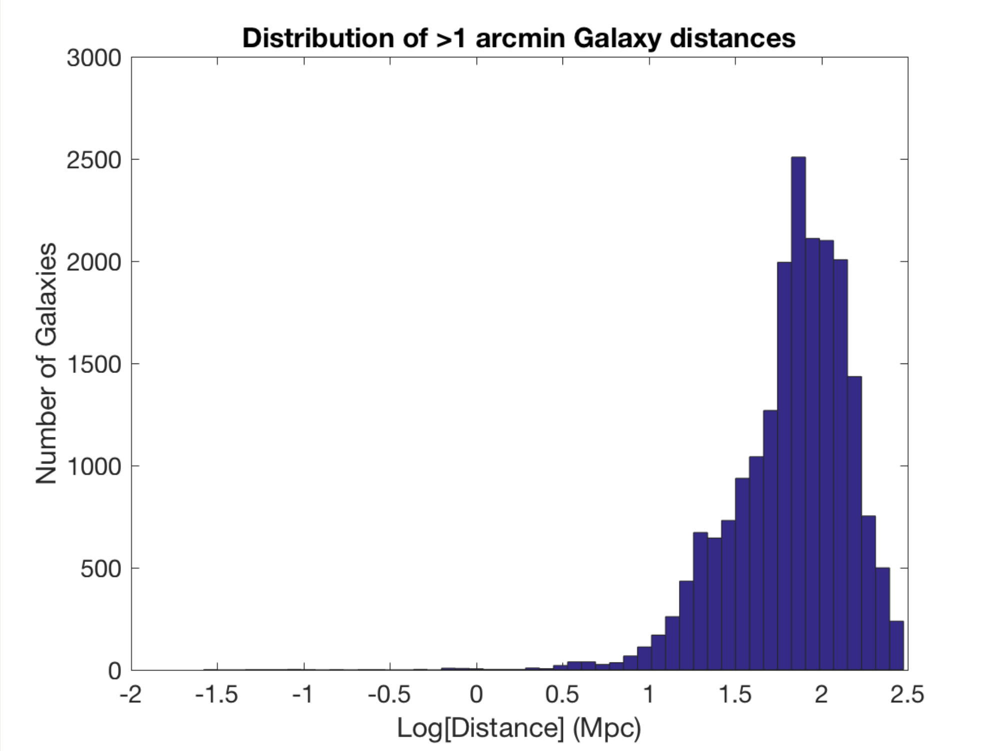
Exciting Science with MRSS

- Statistically significant surveys of galaxies in “bread and butter” FIR lines ([CII], [NII], [OI], [OIII], [NIII], etc). The spectroscopy of large galaxy samples.
  - *Mapping SFR, outflows, and kinematics (Herrera-Camus+ 2015, Kreckel+ 2014, de Blok+ 2016)*
  - *Photoelectric heating efficiency (Smith+ 2017)*
  - *Density of ionized gas in disks, ionized gas fractions (Herrera-Camus+ 2016, Croxall 2017)*
  - *ISM thermal pressure in atomic-dominated regions (Herrera-Camus 2017)*
  - *Cooling of low metallicity HII regions, ISM cooling budget (Cormier+ 2015, Rosenberg+ 2016)*
  - *High density neutral phases, shocks, etc*
- Beyond “bread and butter”: example, a new probe of the molecular gas using HD
  - *To my knowledge not yet done outside the galaxy (except for Tumlinson+ 2010 using L-W UV bands in high-z starbursts)*
- Probing outer disks and halos of galaxies with deep [CII] imaging
  - *The province of HI thus far. But [CII] can potentially do a very good job*

What Would it Take to do Large Surveys?

Data from Hyperleda database and WISE archive



- Most ”resolved” galaxies are beyond 30 Mpc
- There are ~21,000 galaxies with optical sizes larger than 1 arcmin

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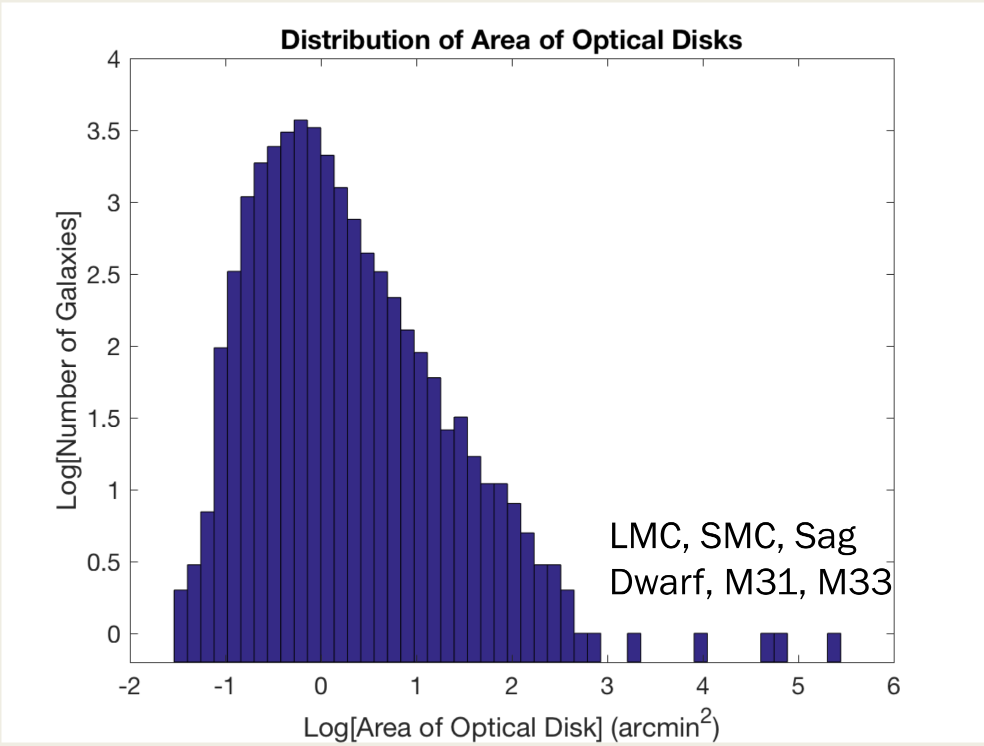

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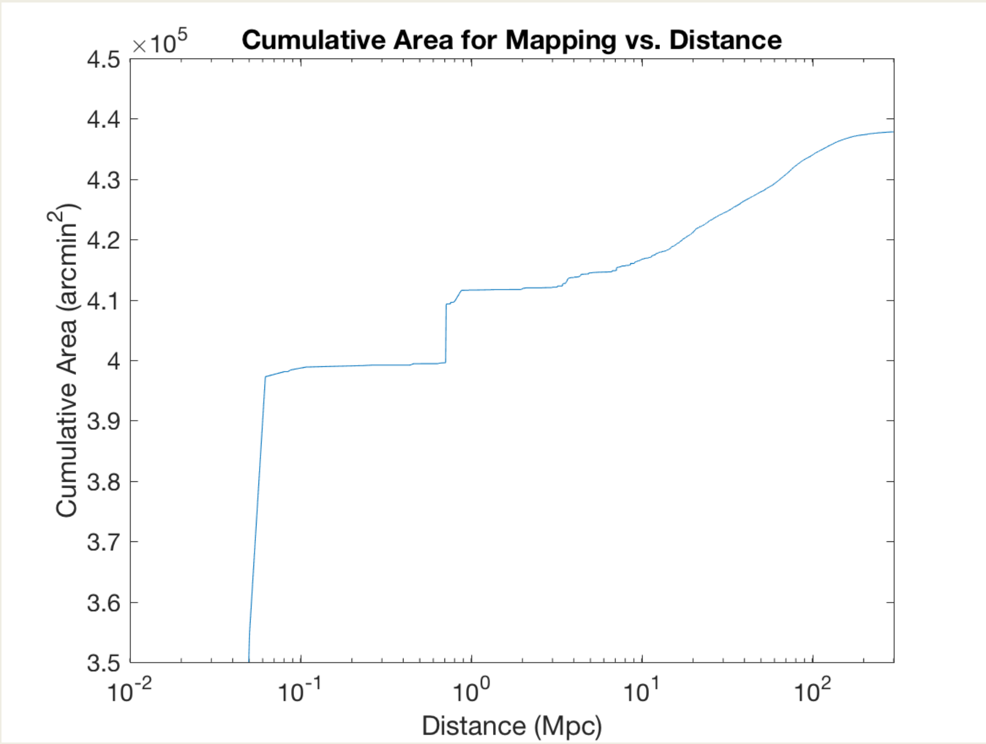

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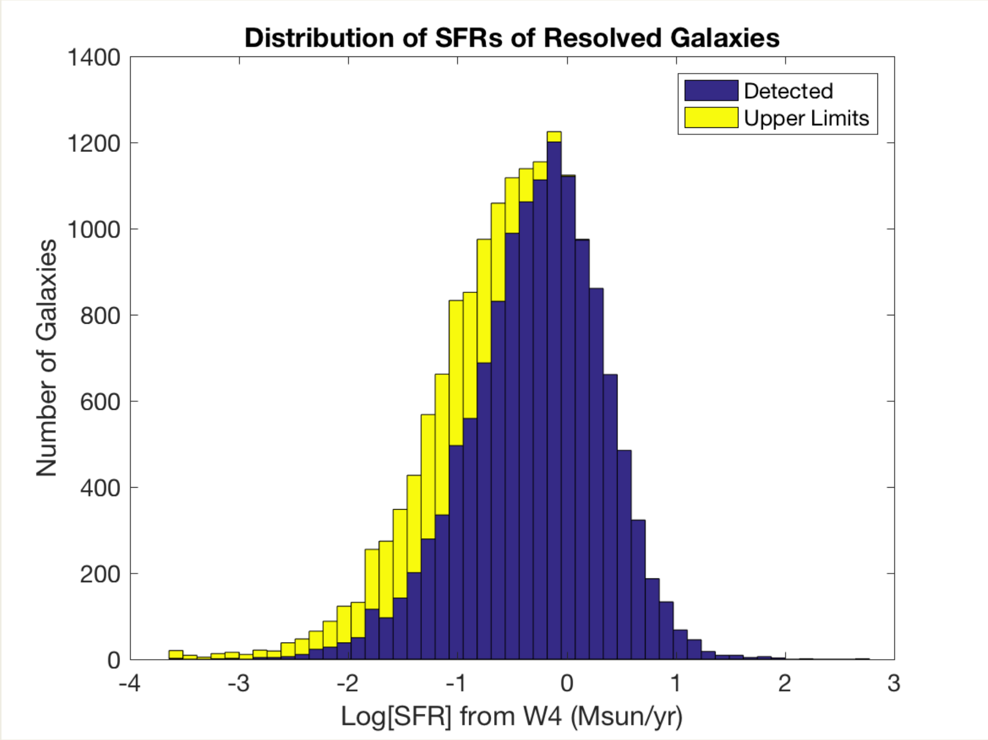

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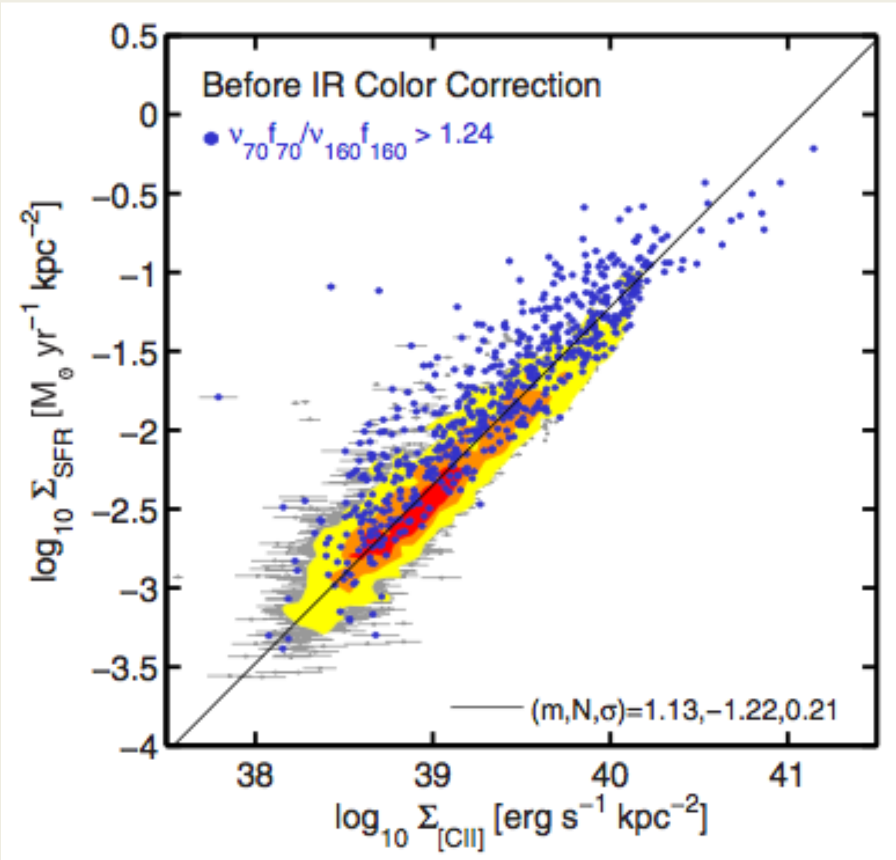
- About 30,000 arcmin^2 of optical disks beyond the Local Group
- Large fraction are star-forming objects detected by WISE (~16,000)

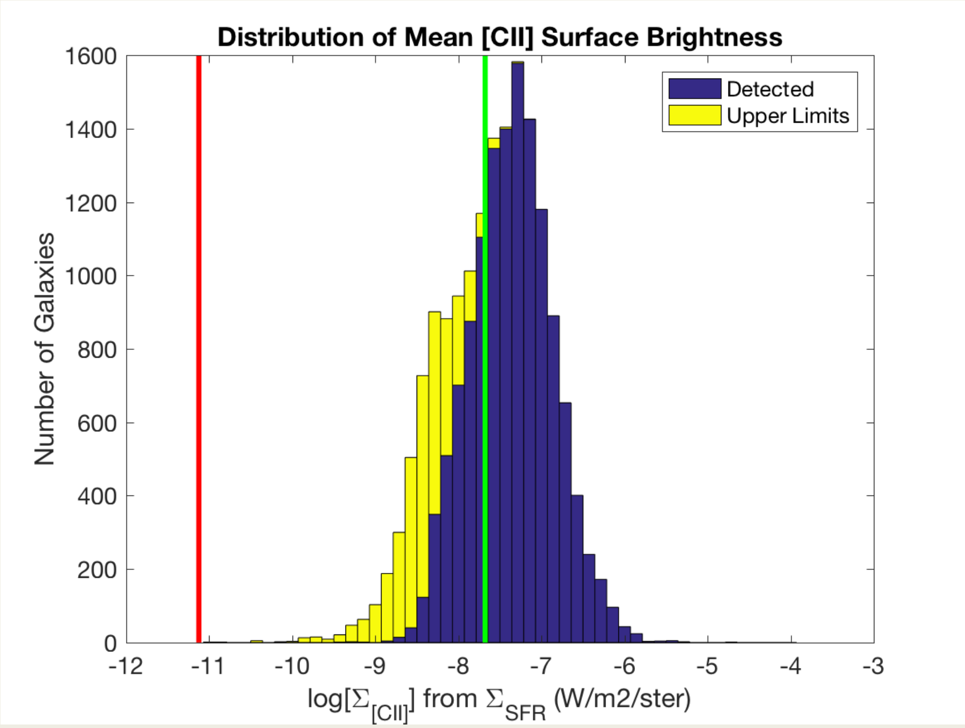
Using Σ_{SFR} to Compute $\Sigma_{[CII]}$



- SFR and [CII] have a tight relation over galaxy disks, except in "warm" sources (AGN, ULIRGs, low metallicity)
- Although it is possible to correct for some of this, there is no need to do so for our purpose here

Herrera-Camus et al. (2015)

What Would it Take to do Large Surveys?



- Projected "mean" brightness distribution
- The "practical" sensitivity for Herschel mapping in large projects is indicated by green line: KINGFISH mapped spectroscopically a fraction of the disk of ~50 galaxies
- The OST 8m 1-hour sensitivity is the red line: note that for truly extended emission the diameter of the telescope does not matter

What Would it Take to do Large Surveys?

COBE FIRAS OBSERVATIONS OF GALACTIC LINES

TABLE 1

LINE FLUX IN THE PLANE AND AT HIGH GALACTIC LATITUDE

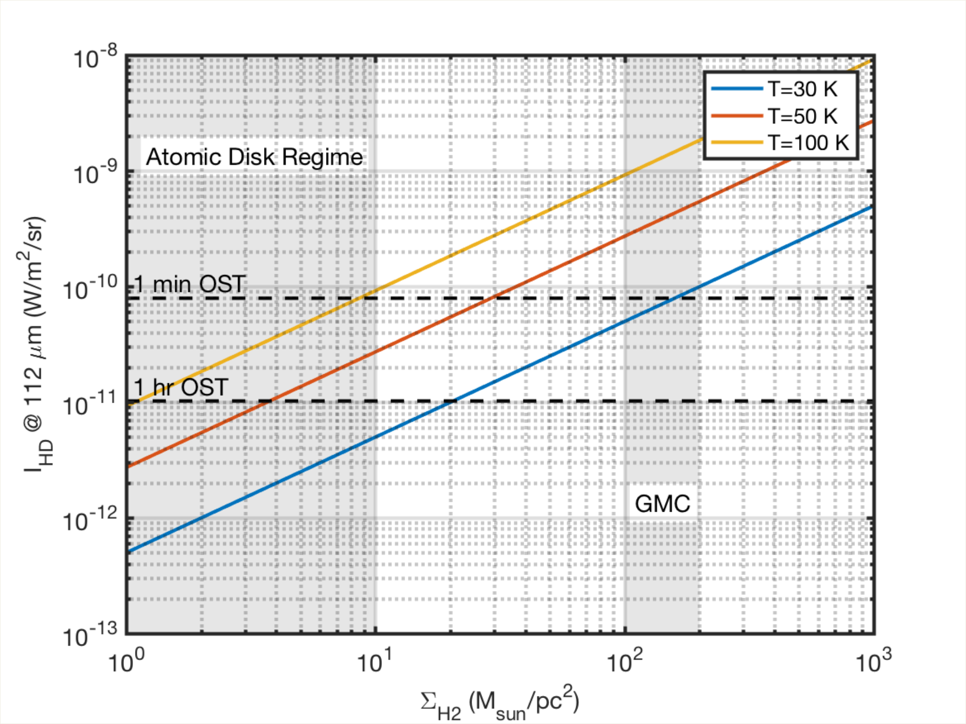
Line	Galactic Center (|l| < 2°.5)	Inner Galaxy (2°.5 < |l| < 32°.5)	Outer Galaxy (|l| > 32°.5)	High Latitudes (|b| > 10°)
CO 1–0	1.6 ± 0.5	0.5 ± 0.3	0.2 ± 0.2	0 ± 0.01
CO 2–1	6.4 ± 0.3	2.3 ± 0.2	0.5 ± 0.1	0 ± 0.01
CO 3–2	11.8 ± 0.5	3.8 ± 0.3	0.7 ± 0.2	0 ± 0.01
CO 4–3	17.7 ± 0.6	3.4 ± 0.3	0.5 ± 0.3	0 ± 0.01
CO 5–4	16.5 ± 1.0	2.9 ± 0.6	0.9 ± 0.5	0.01 ± 0.01
CO 6–5	11.5 ± 1.6	0.5 ± 1.0	−0.2 ± 0.7	0 ± 0.01
CO 7–6[a]	10 ± 1.5	0.3 ± 1.0	0.1 ± 0.3	0 ± 0.01
CO 8–7	10.8 ± 1.4	1.8 ± 0.8	0.1 ± 0.5	0.01 ± 0.01
C I 609 μm	11 ± 0.6	5 ± 0.4	1.4 ± 0.3	0.01 ± 0.01
C I 370 μm[a]	11 ± 1.9	7 ± 1.0	1.4 ± 0.5	0 ± 0.01
C II 158 μm	875 ± 32	1021 ± 17	254 ± 5	1.48 ± 0.07
N II 205 μm	97 ± 6	107 ± 3	18 ± 1	0.05 ± 0.02
N II 122 μm	76 ± 51	23 ± 22	2 ± 9	0.17 ± 0.14
O I 146 μm.........	29 ± 29	24 ± 13	5 ± 5	0.07 ± 0.08
CH 116 μm	149 ± 82	14 ± 34	15 ± 15	−0.05 ± 0.25
Dust emission......	130000	92000	25000	150

NOTE.—Units are in nW m^{-2} sr^{-1}. Uncertainties are 1 σ and include systematic effects.
[a] The CO 7–6 was estimated from the other CO lines, and the residual was ascribed to C I.

Fixsen et al. (1999)

- This means the OST has sensitivity to map lines 1000 fainter than [CII]
- Example from COBE is CH 116 um, a high density molecular gas tracer

Tracing the Molecular Component with HD



- The OST has the power to trace molecular surface densities independent of CO, by imaging HD
- The temperature of the molecular gas can be inferred from the ratio of the 2-1/1-0 transitions (56, 112 um)
- This is insensitive to Xco assumptions, although it may be sensitive to selective photo-dissociation and astration processes
- Line to continuum contrast at low R

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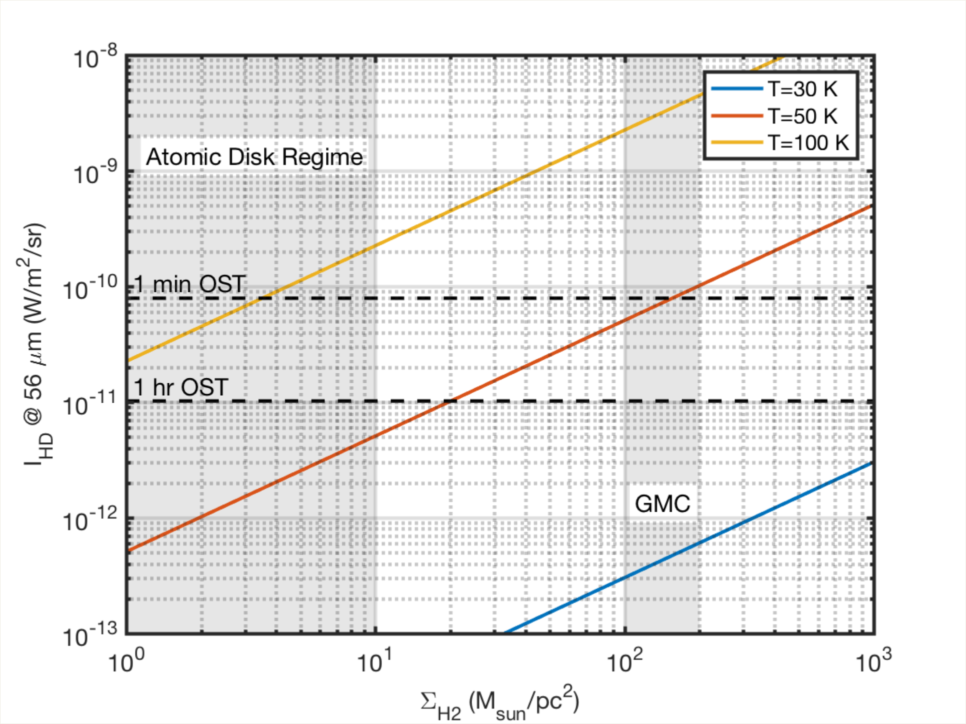

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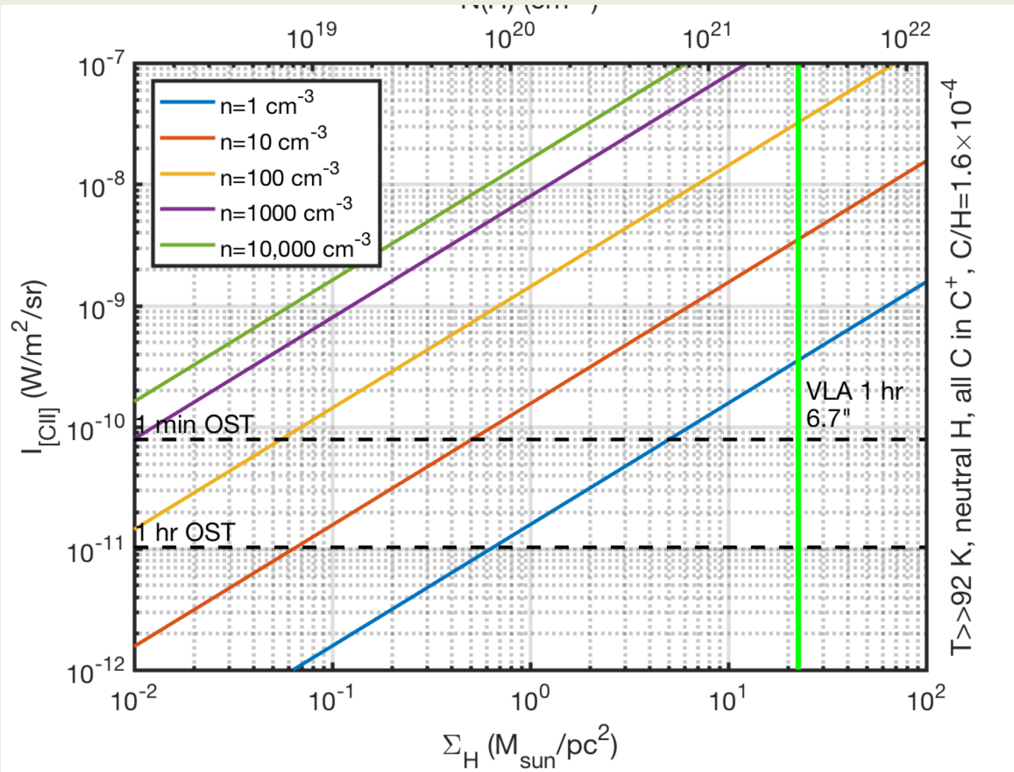
Tracing Extended Low Density Neutral Gas in [CII]



- The OST can trace very low column densities of warm neutral atomic gas in [CII]
- For partially ionized gas, this gets even better
- It is much more sensitive than the VLA for approx. matched resolution, but the VLA has ~260^2 mapping "pixels" because of ~30 arcmin FOV
- Variation in metagalactic radiation field (Lehner+ 2012)

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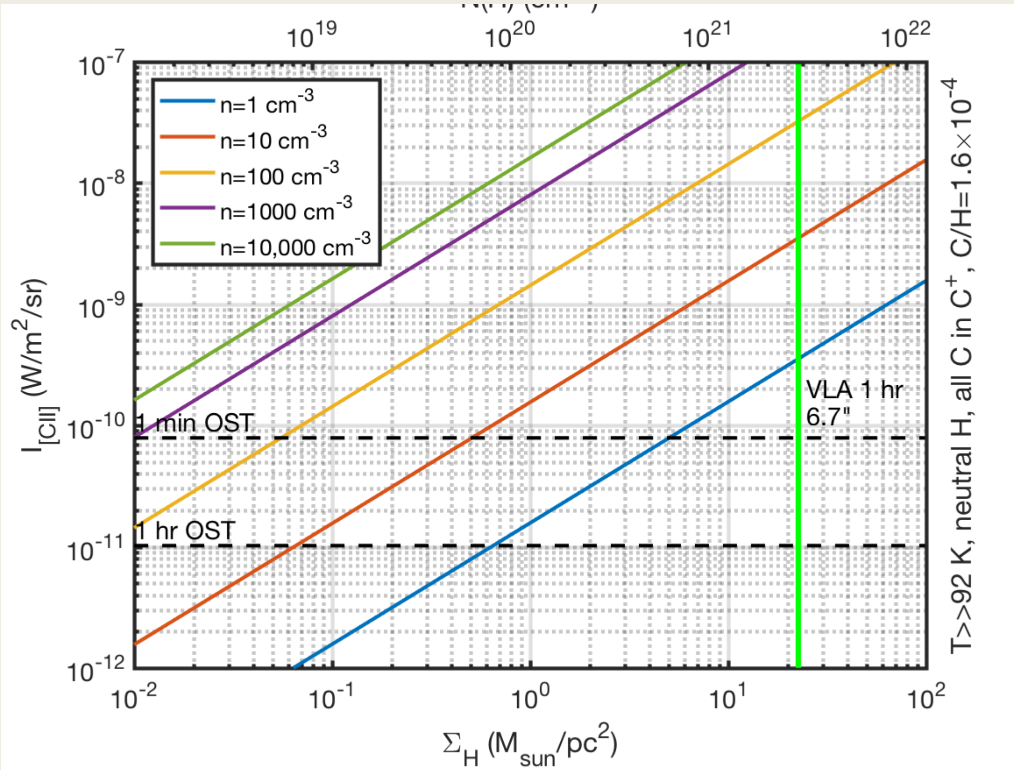

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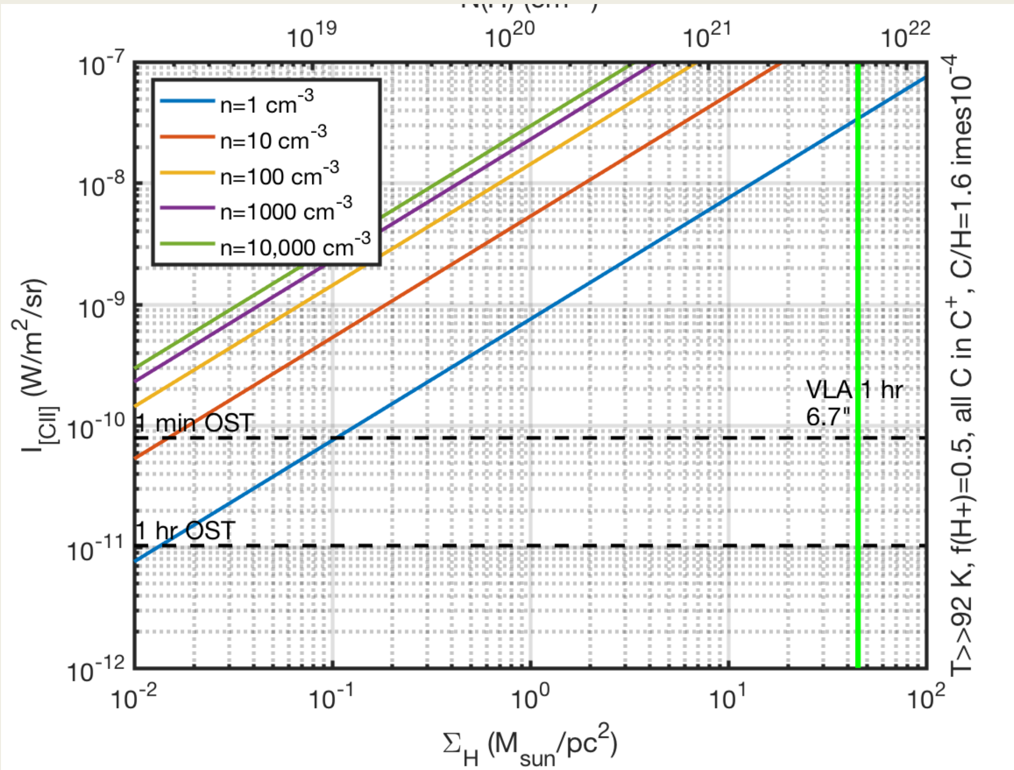

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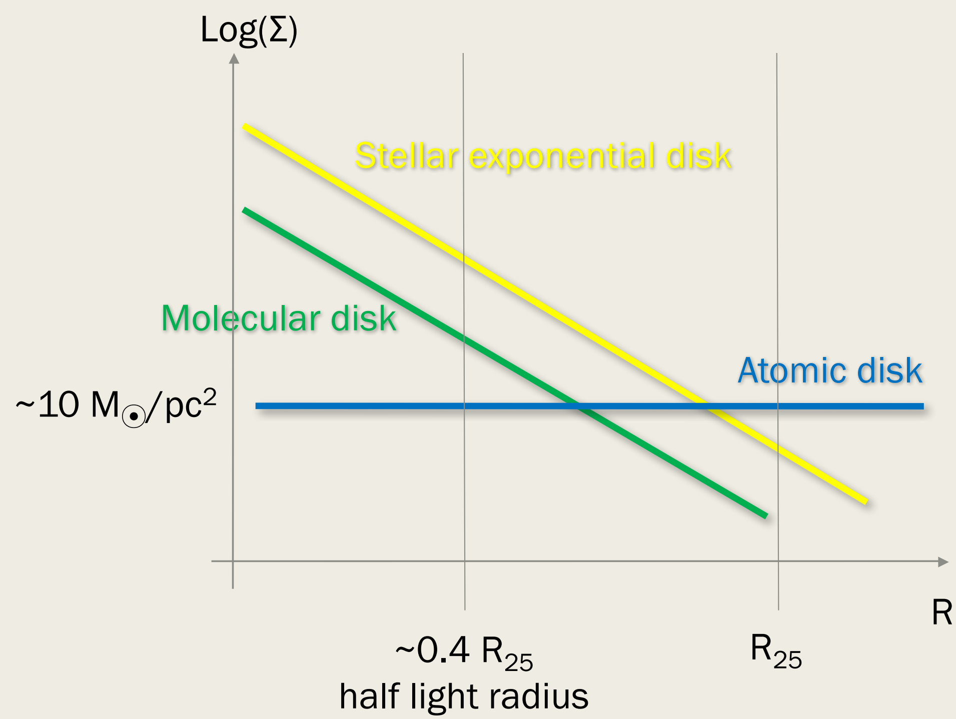
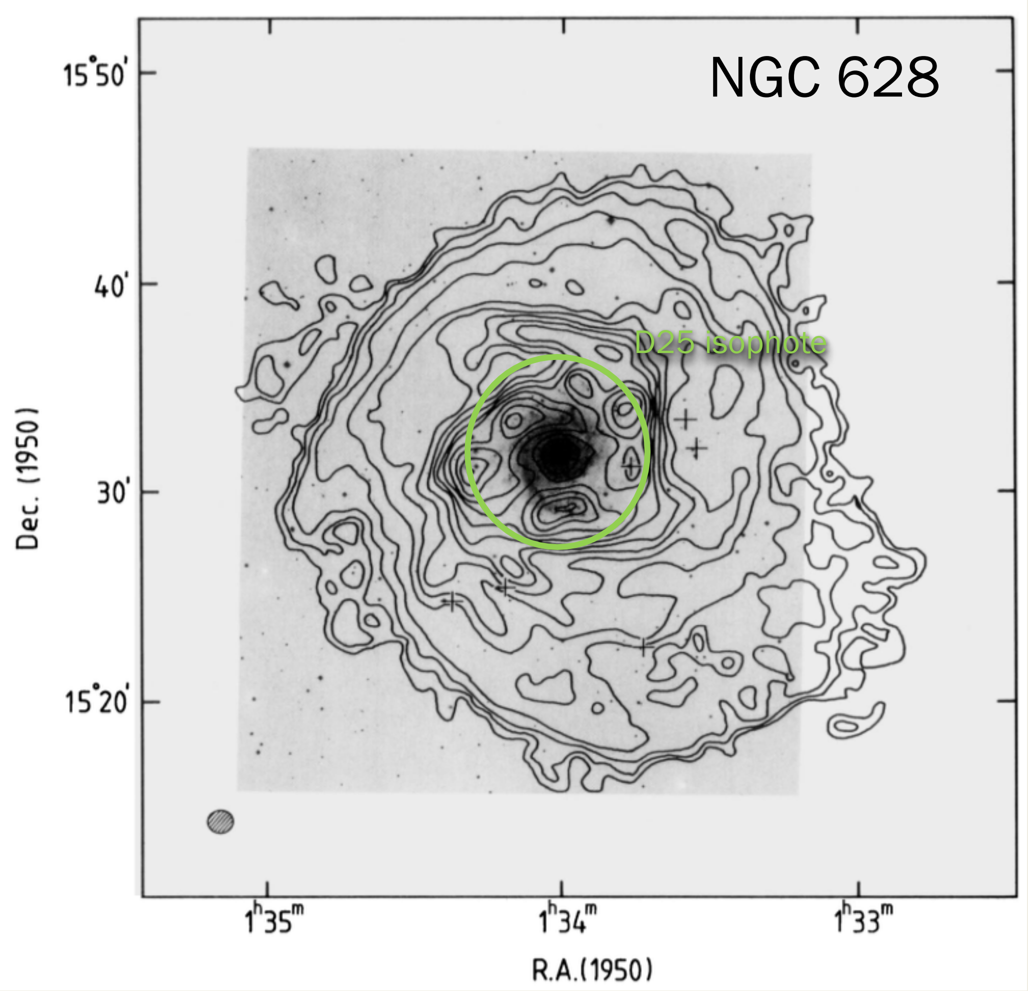
Disk galaxy basics: how far does the ISM extend?

- How large is the ISM emitting region we would expect from a galaxy?
- The stellar and molecular component track each other fairly well in the inner regions, with ½ the mass/light inside ~0.4 D_{25}
- However, HI disks are not exponential: they are rather flat or even increasing with radius, and can extend much beyond the bright optical emission



Extended ISM

- Many galaxies are known to possess extended HI disks that go well beyond their optical radius



Kamphuis & Briggs (1992)
Outer HI contour is 1.3×10^{20} cm^{-2}

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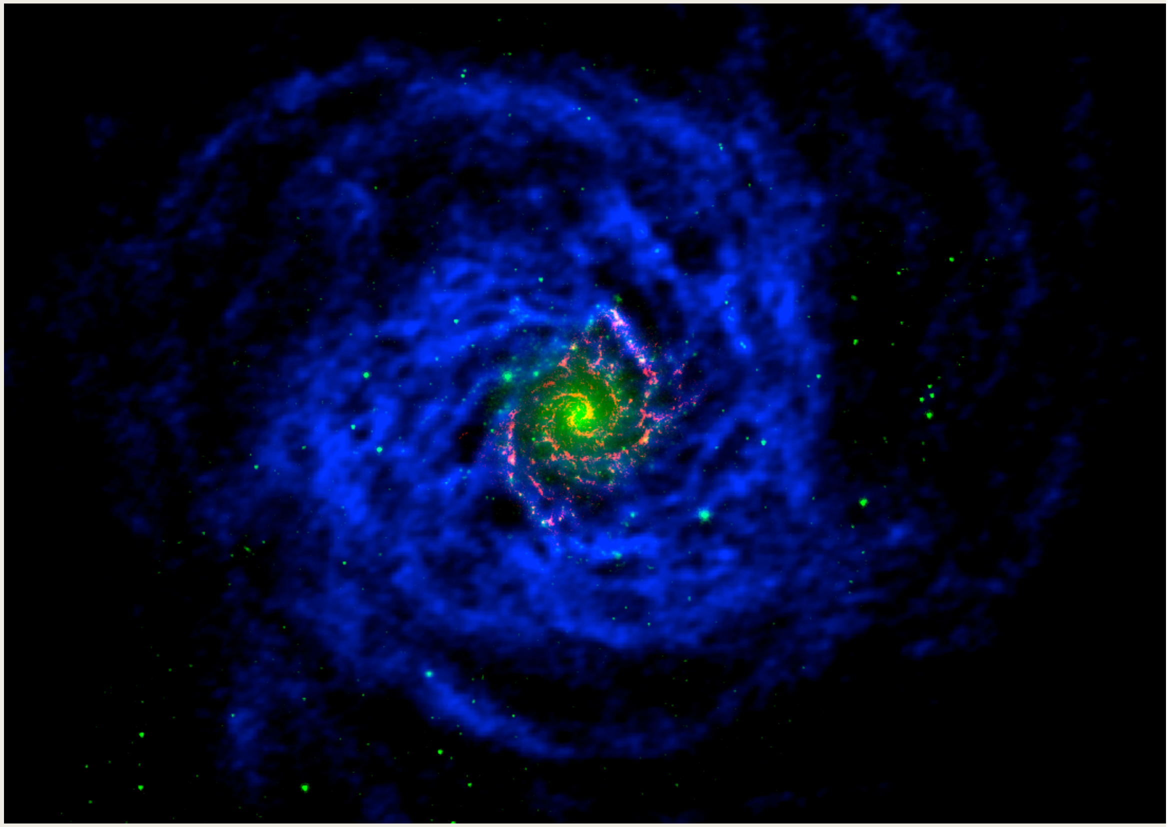
NGC 628



THINGS HI (blue), ALMA CO (red), Spitzer 4.5 um stellar disk (green)

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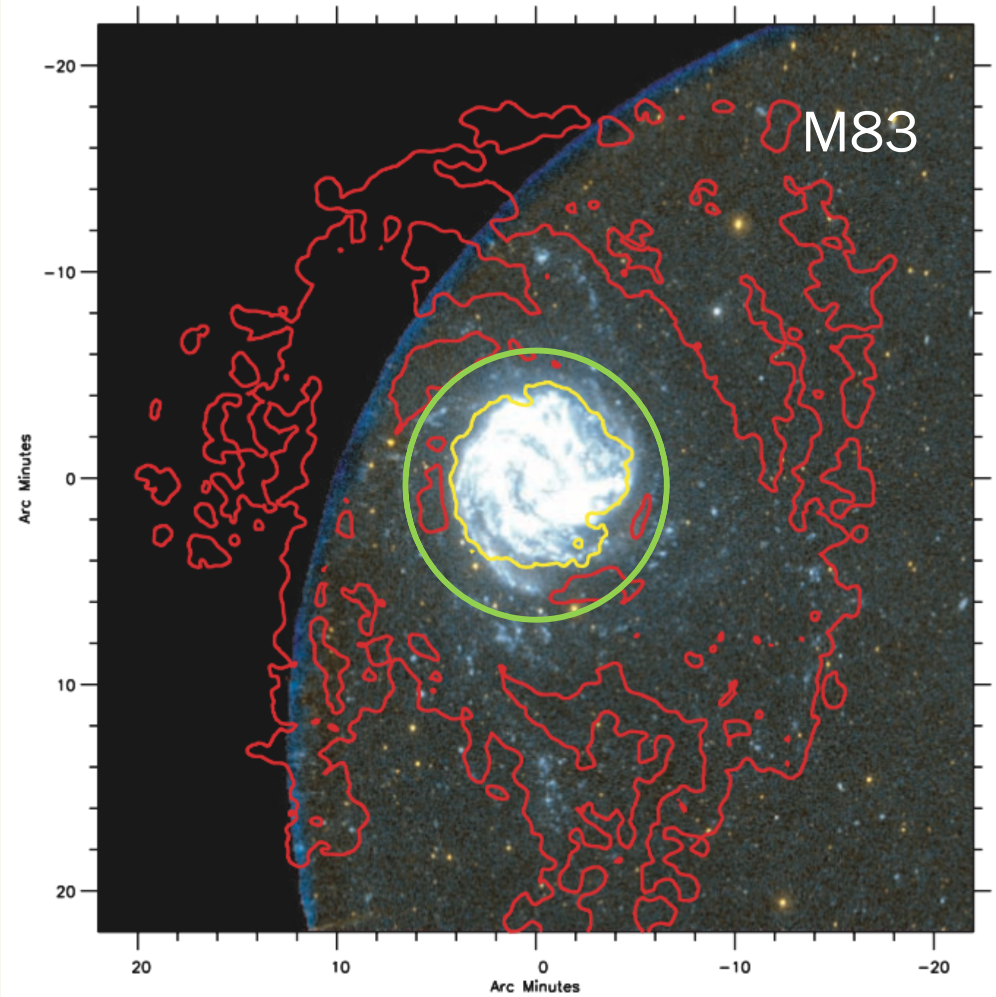
- Many galaxies are known to possess extended HI disks that go well beyond their optical radius
- These disks have, in many cases, associated star formation. They are also “extended UV disks” as seen by GALEX



Thilker et al. (2005)
Red is HI at 1.8×10^{20} cm^{-2}

Extended ISM

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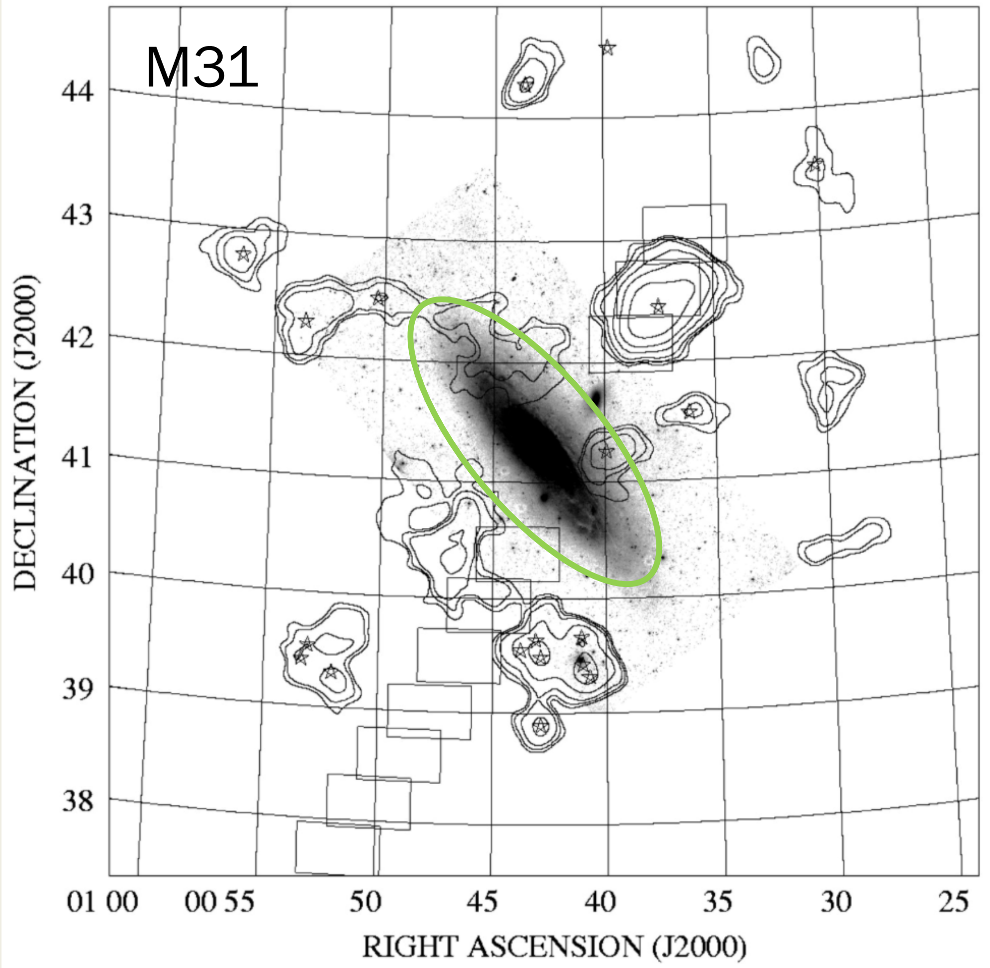
- But we also see likely ongoing accretion events from the “cosmic web” in the form of HVCs



Thilker et al. (2003)
HI contours start at 0.5×10^{18} cm^{-2}

Extended ISM

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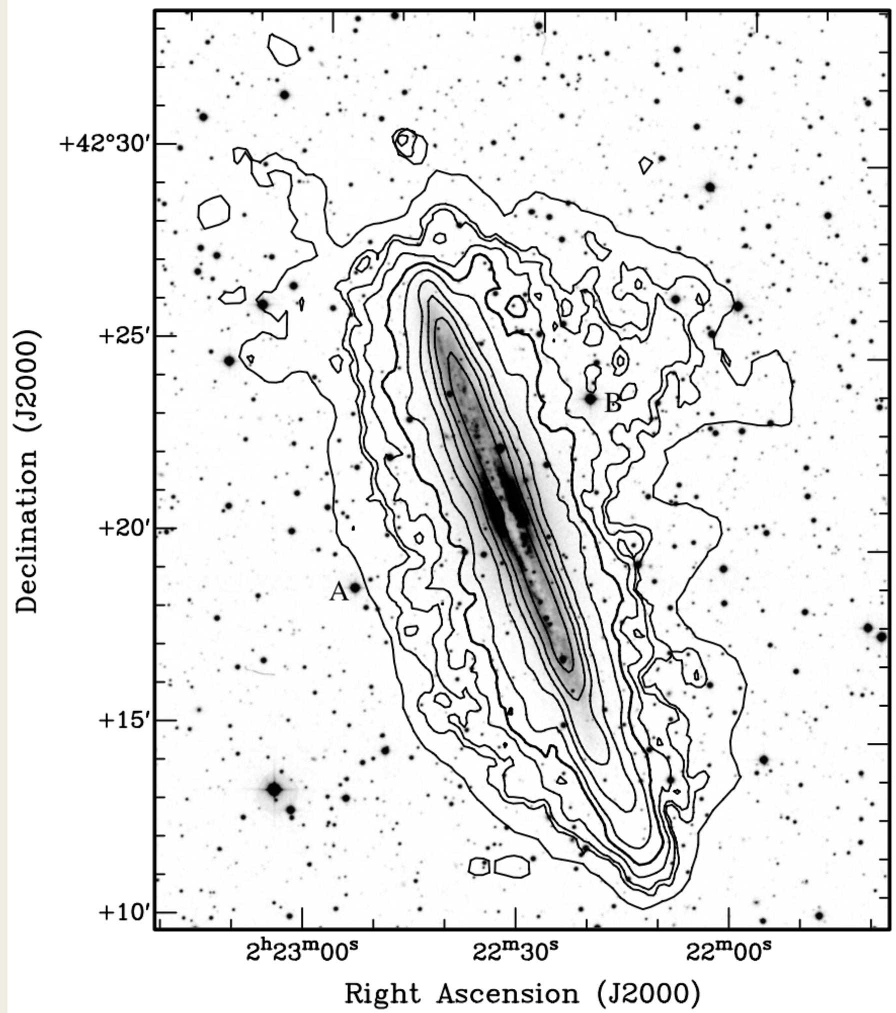
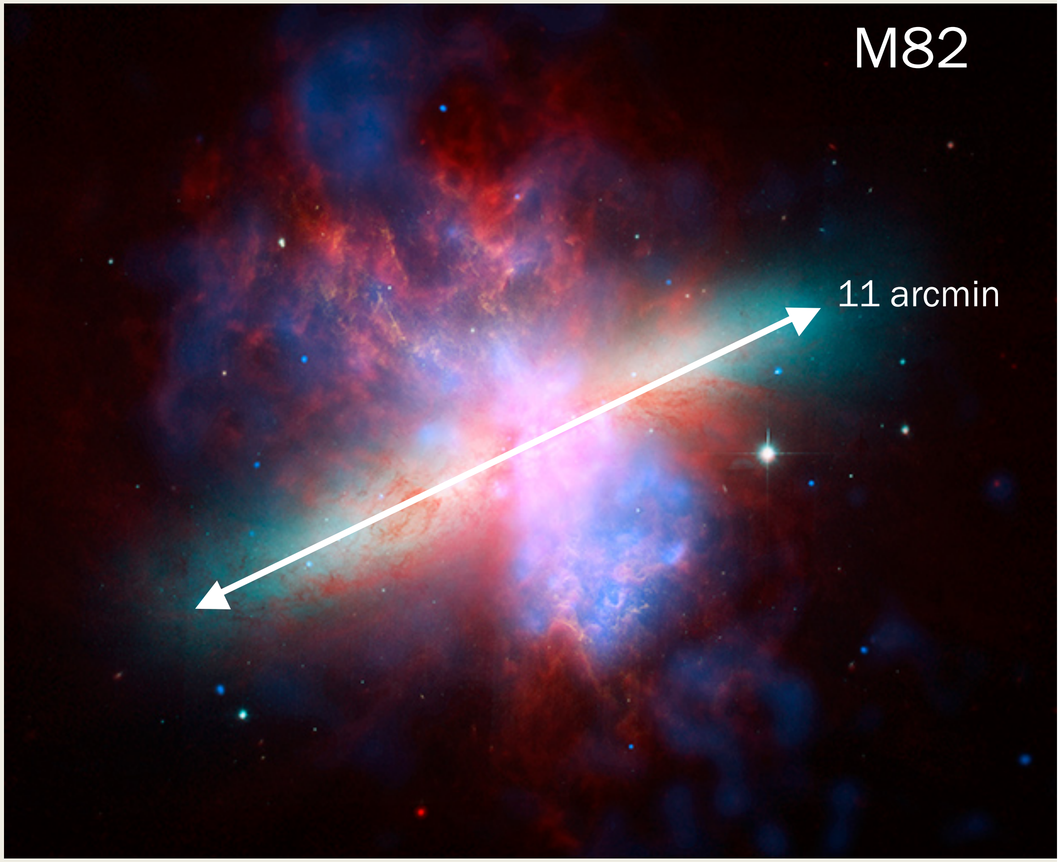
- But we also see likely ongoing accretion events from the “cosmic web” in the form of HVCs
- Besides radial extent, there is also evidence for vertically “thick” disks with differential rotation, likely connected with winds or “cosmic web” accretion (Fraternali & Binney 2008, Zschaechner & Rand 2015)



Oosterloo et al. (2005)
HI contours start at 5×10^{18} cm^{-2}

Extended ISM

- And, of course, there are also winds: material ejected by SF or accretion processes



FIR, stars, X-ray emission

Extended ISM

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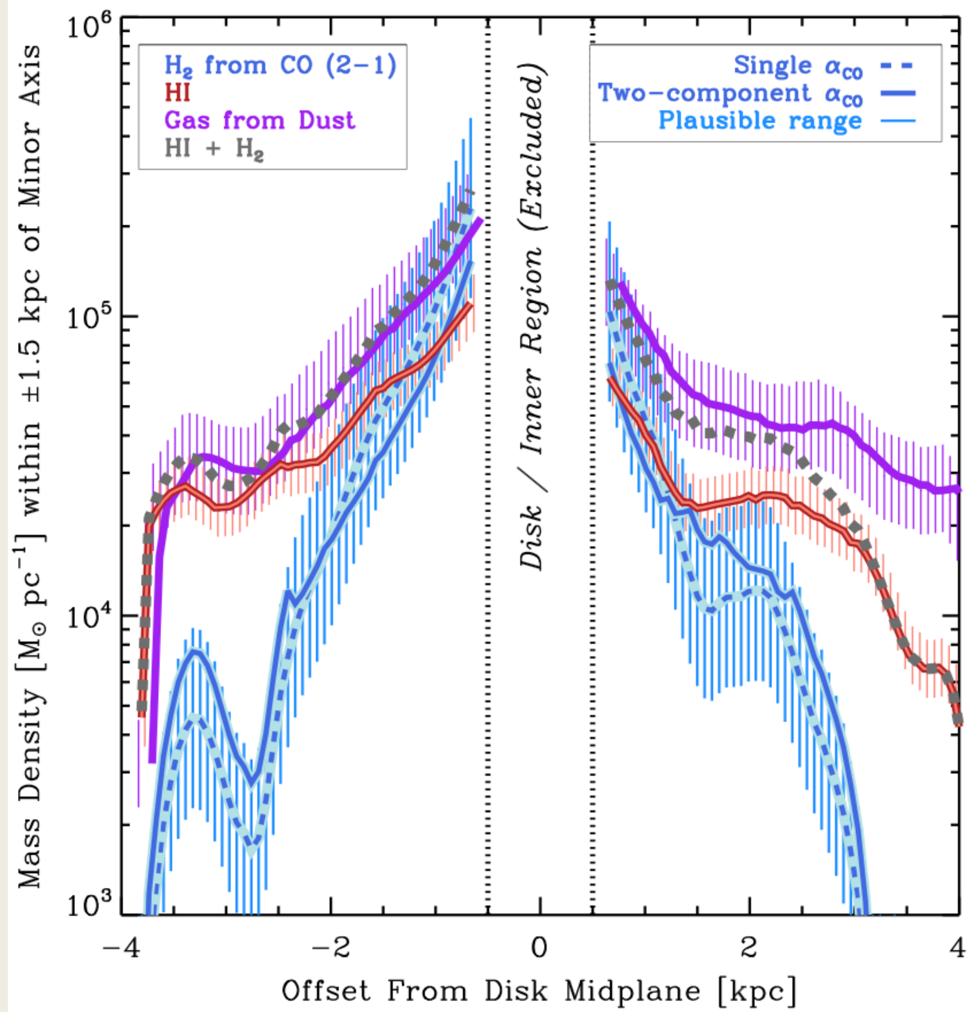
- It turns out that dust appears to provide a good measure of ejected “cool” phases (presumably there will be also FIR spectral lines)



M82 cut along wind axis, Leroy et al. (2015)
1 kpc ~ 1 arcmin

Extended ISM

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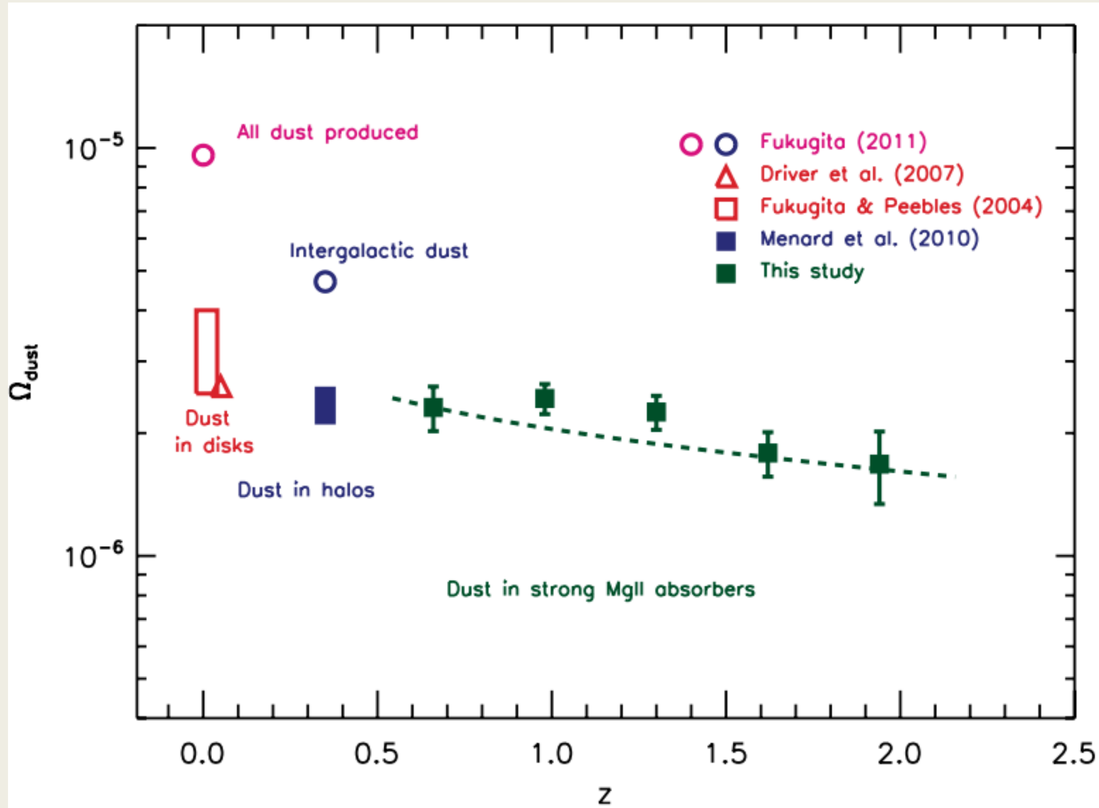

Menard & Fukugita (2012)

Extended ISM

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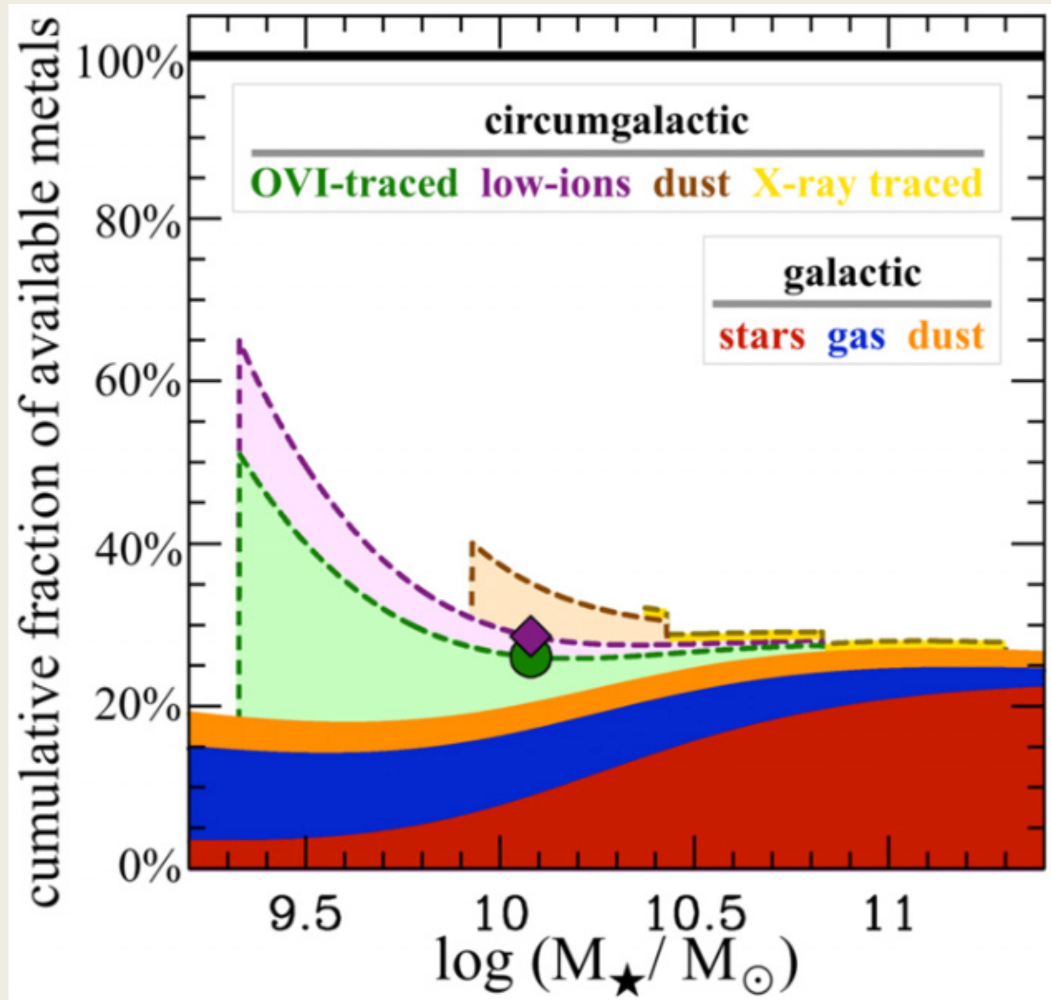
- It turns out that dust appears to provide a good measure of ejected "cool" phases (presumably there will be also FIR spectral lines)
- There is evidence for significant amounts of dust in the CGM (Menard & Fukugita 2012)
- And also "missing" metals: a lot of the material in the CGM is not primordial



Peeples et al. (2014)

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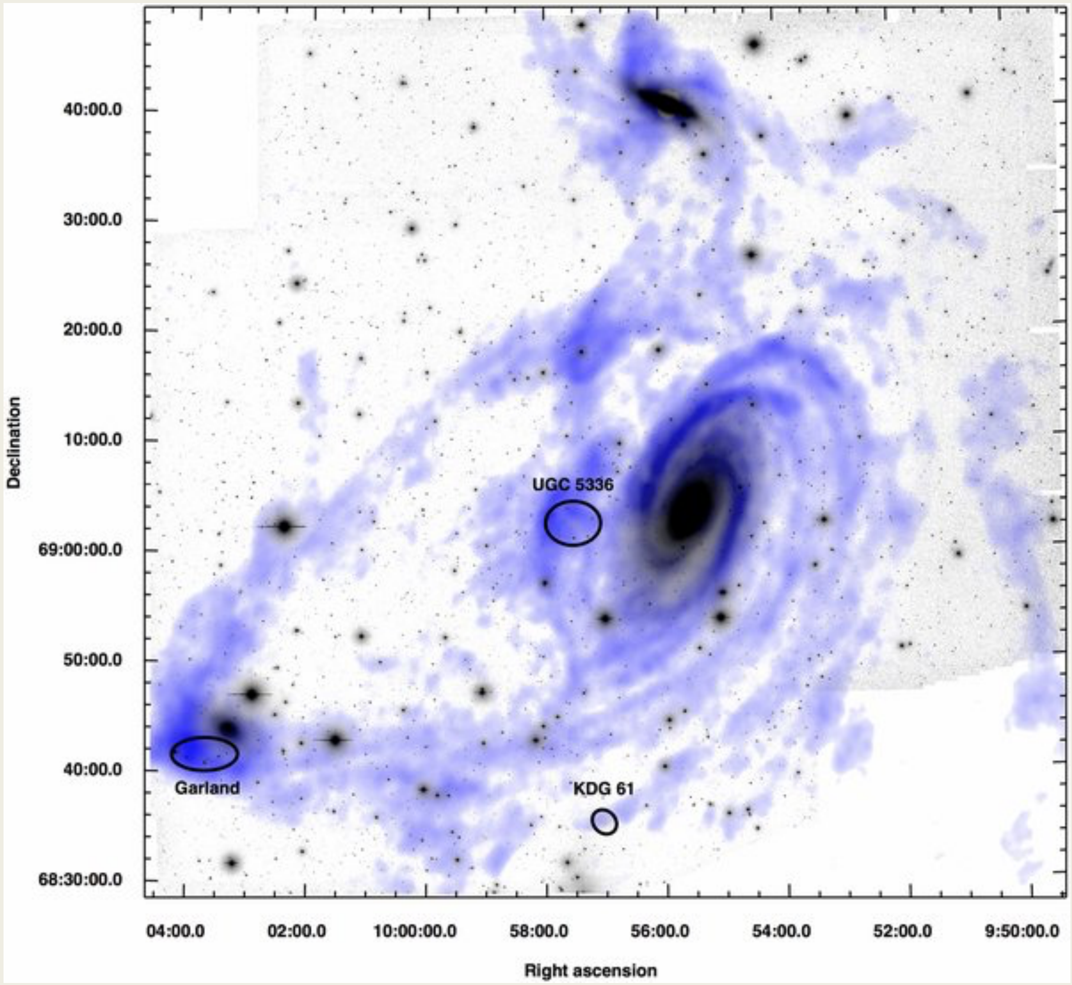
- There is evidence for significant amounts of dust in the CGM
- And also “missing” metals: a lot of the material in the CGM is not primordial
- Finally, there is also stripped gas (tidal or ram pressure)



HI mosaic from Yun et al. (1994), see also Chynoweth et al. (2008)