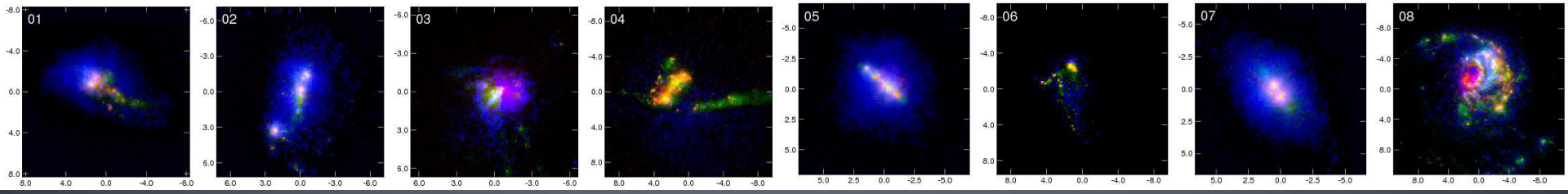
Stockholm University

Oskar Klein centre

Challenges and first results

# Molecular gas and dust in LARS






Johannes Puschnig

# Outline

**„ Hidden Track“**

## The Lyman Continuum Escape and ISM properties in Tololo 1247-232 – New Insights from HST and VLA

J. Puschnig[1]*, M. Hayes[1], G. Östlin[1], T. E. Rivera-Thorsen[1], J. Melinder[1], J. M. Cannon[2], V. Menacho[1], E. Zackrisson[3], N. Bergvall[3] and E. Leitet[3]
[1] *Department of Astronomy, Oskar Klein Centre, Stockholm University, AlbaNova University Centre, 106 91 Stockholm, Sweden*
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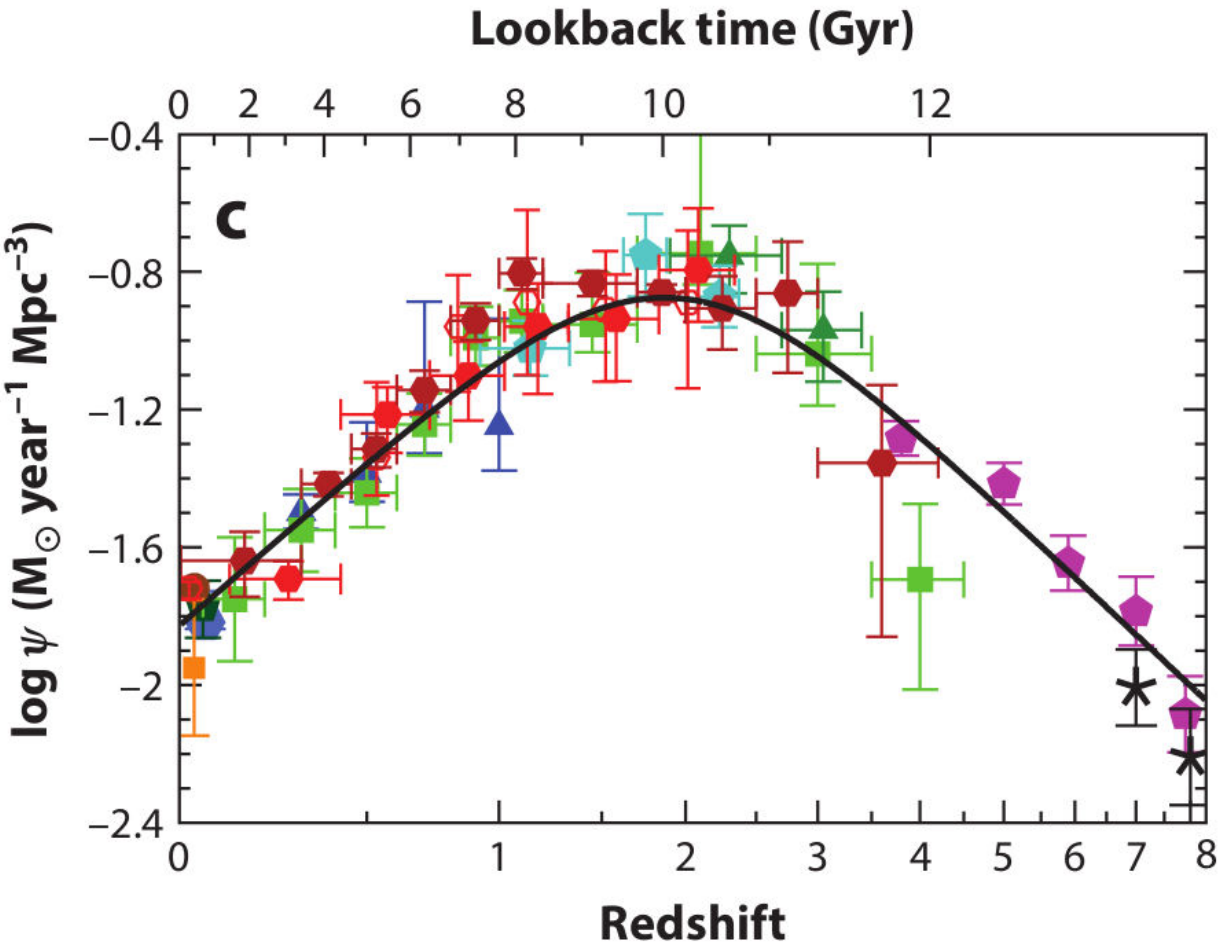
Submitted to MNRAS

# Background

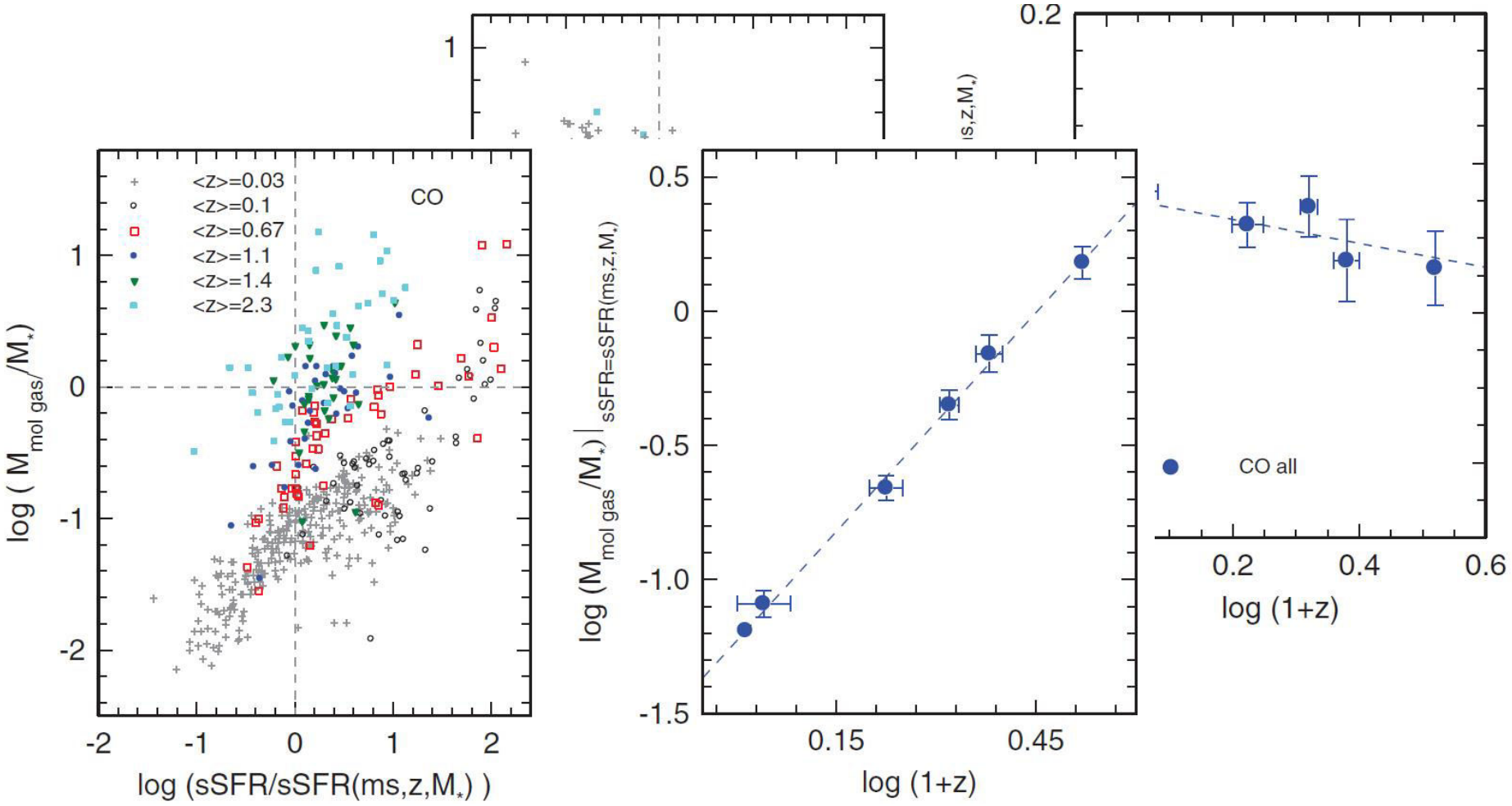
- Many efforts have been undertaken to study the evolution of (global) properties with redshift.
- Deep Field imaging/spectroscopy (COSMOS, GOODS, H(U)DF,…)
- Scaling relations such as the MS, MZR, KS could be established for galaxy populations at different redshifts.

# cosmic peak of star formation




Madau & Dickinson (2014)

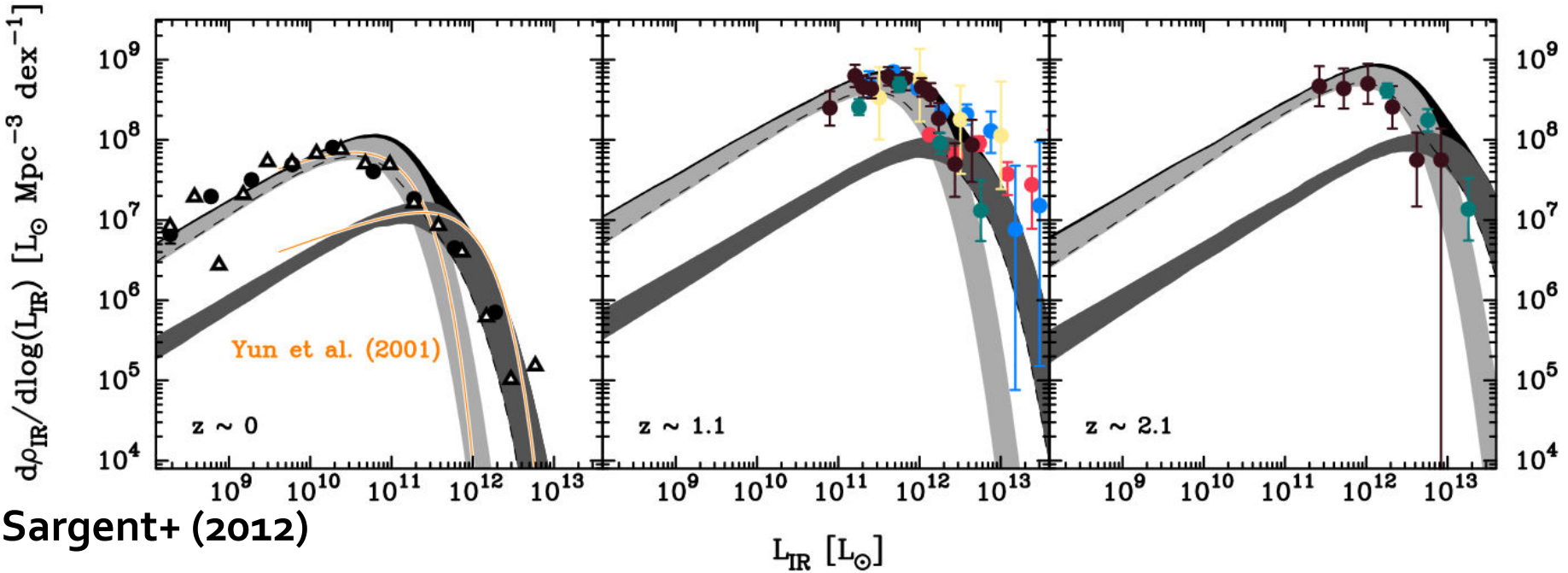
# Evolution of the MS: SFE or molecular gas fraction?




Genzel+ (2015)

# What about starbursts (in dwarf galaxies)?

- scatter above the MS
- outliers e.g. in the MZR (Janice Lee's talk)
- don't contribute much to cosmic star formation rate density (Françoise Combes' talk)

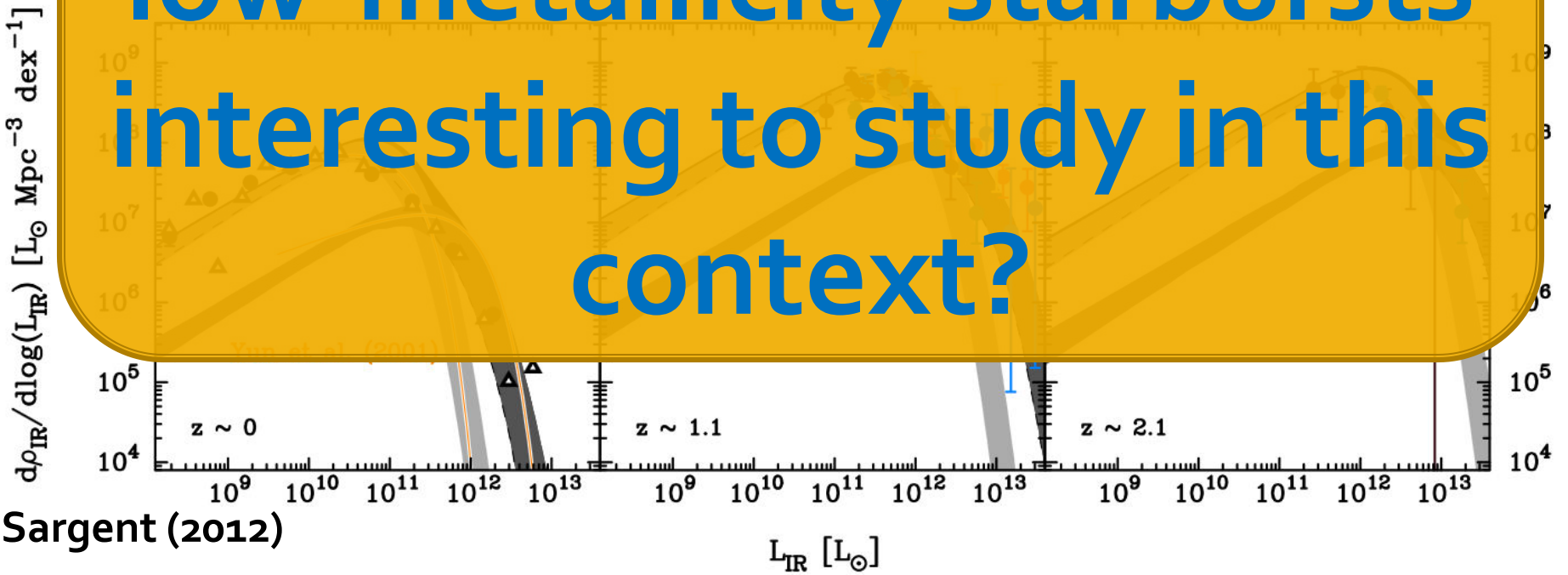



Sargent+ (2012)

# What about starbursts (in dwarf galaxies) ?

- scatter above the MS
- outliers e.g. in the MZR (Janice Lee's talk)
- don't contribute much to cosmic star formation rate density (François Combes' talk)

**Why are low-redshift, low-metallicity starbursts interesting to study in this context?**



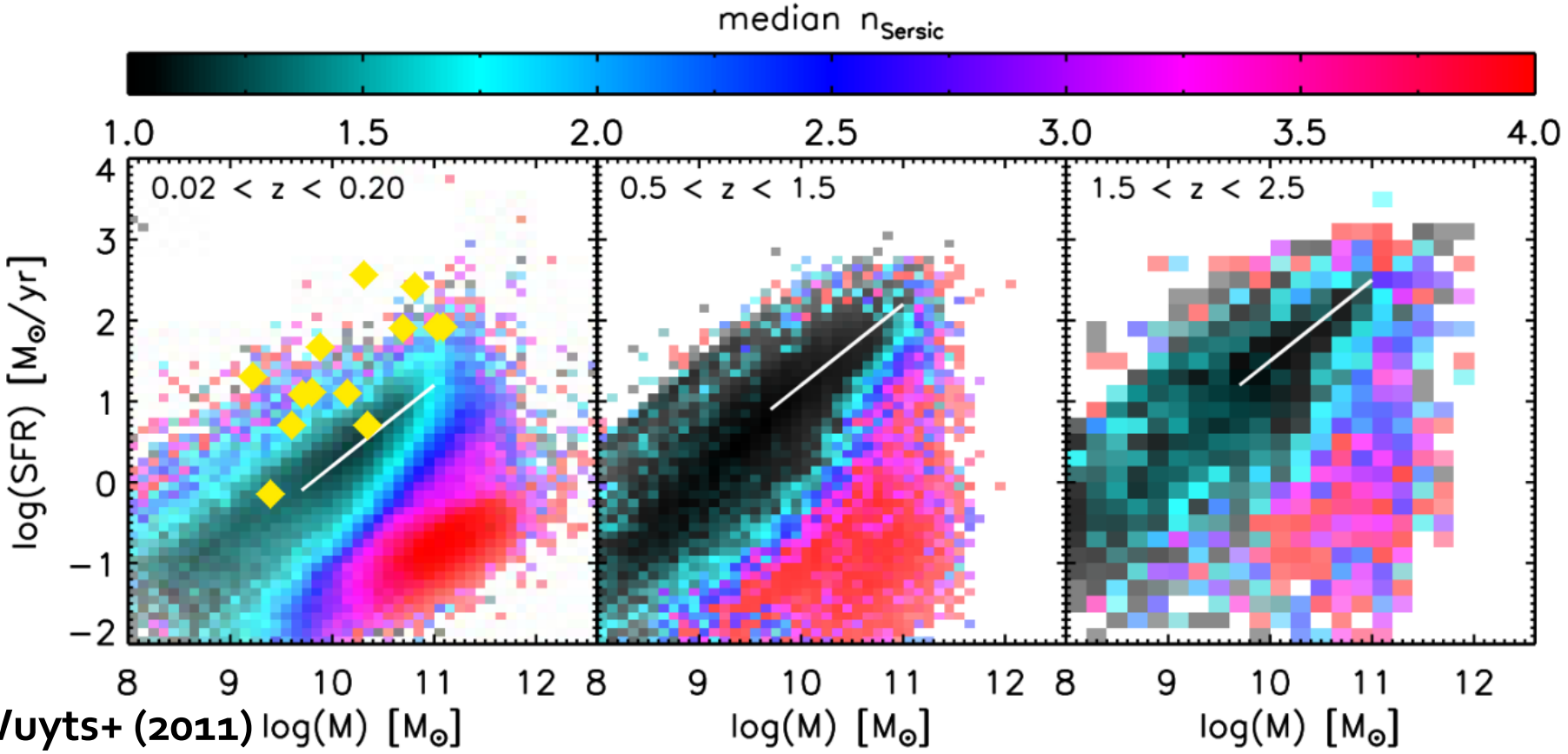

Sargent (2012)

# …because of evolution

- being an outlier at low-z *could* mean being totally „normal" at higher redshift
- with the huge advantage of having detailed insight (resolution) into ISM at low-z
- LARS not only allows to study mechanisms behind Lα escape (Jens Meldinder's talk), but also allows to get insight into the mechanism & ISM properties driving star formation itself; which in turn could help to (better) understand star formation processes going on at higher redshift.

# …because of evolution

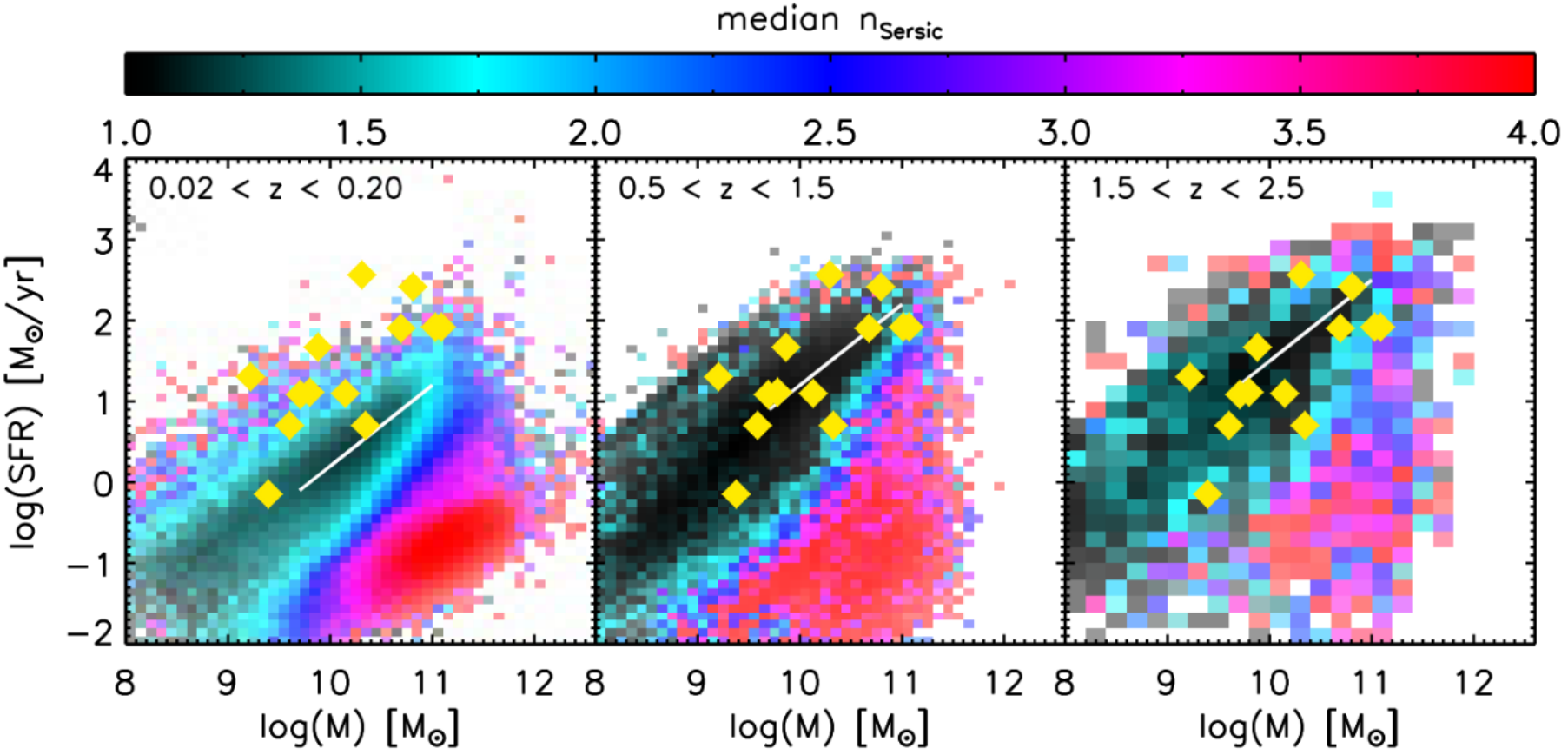
- being an outlier at low-z could mean being totally „normal" at higher redshift




**Wuyts+ (2011)**

# …because of evolution

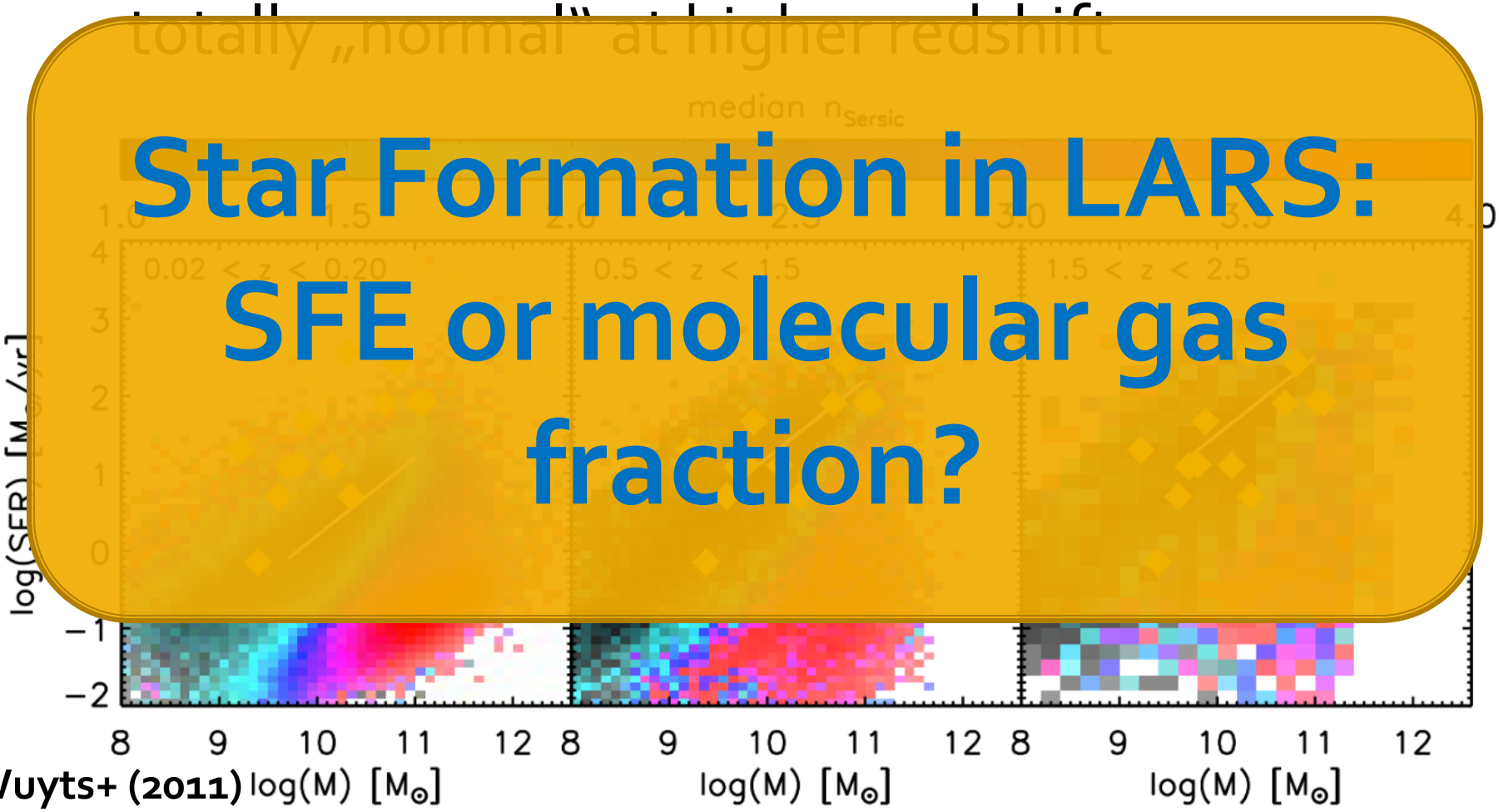
- being an outlier at low-z could mean being totally „normal" at higher redshift



# …because of evolution

- being an outlier at low-z could mean being totally „normal" at higher redshift

**Star Formation in LARS: SFE or molecular gas fraction?**




Wuyts+ (2011)

# Outline

- Background and motivation to study cold gas in local Lyman Alpha Emitters (LAEs)?
- Methods/Observations
- First/Preliminary Results
- Outlook
- „Hidden Track“

# LARS: SFE or mol. gas fraction? → CO observing strategy

- IRAM 30m: CO (1-0) and (2-1)
- Apex 12m: CO (3-2) if observable from Southern hemisphere and detected with IRAM 12m
- low metallicity makes this challenging due to CO-dark molecular gas (see Karl Schuster's talk)
- Use Z-dependent Conversion Factor (Magdis+ 2011, Schruba+ 2012, Accurso+ in prep) to derive molecular gas mass

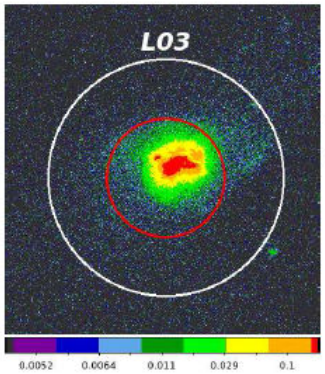
# Summary of CO Detections

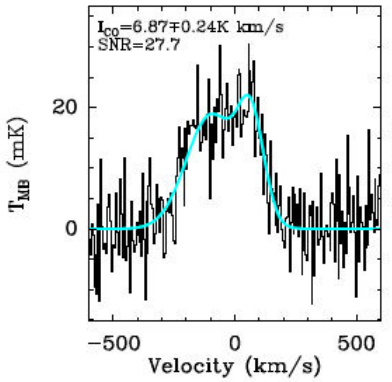
Table 1: Summary of the detected emission lines, Gaussian fit results and measured fluxes

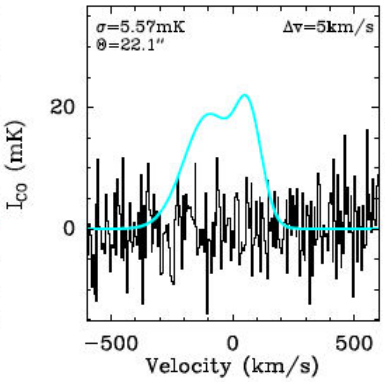
| id | Line | $B_{eff}$ | HPBW [arcsec] | $V_{0.Gauss}$ [km/s] | $DV_{Gauss}$ [km/s] | SNR | $I_{CO}$ [K km/s] | $S_{CO}$ [Jy km/s] |
|---|---|---|---|---|---|---|---|---|
| 3 | CO (1-0) | 0.79 | 22.1 | -98.4 (10.3) 66.9 (5.6) | 238.8 (19.73) 127 (16.01) | 27.7 | 6.87 (0.24) | 34.35 (1.23) |
| 3 | CO (2-1) | 0.58 | 11.0 | -127.5 (10) 53.3 (7.7) | 179.3 (16.42) 153.7 (12.05) | 53.9 | 16.57 (0.3) | 82.83 (1.53) |
| 3 | HCN (1-0) | 0.84 | 28.7 | -18.3 (54.1) | 544.8 (126.61) | 5.6 | 0.15 (0.02) | 0.79 (0.13) |
| 3 | $HCO^+$ (1-0) | 0.84 | 28.6 | -34.6 (63.3) | 454.8 (121.76) | 4.3 | 0.12 (0.02) | 0.63 (0.14) |
| 8 | CO (1-0) | 0.80 | 22.2 | -75.8 (2.8) 108.4 (3.8) | 127 (5.96) 144.7 (8.11) | 50.7 | 6.84 (0.134) | 34.17 (0.67) |
| 8 | CO (2-1) | 0.59 | 11.1 | -73 (2.3) 112.1 (4.6) | 130.7 (5.72) 128.3 (9.55) | 44.6 | 11.69 (0.26) | 58.41 (1.31) |
| 8 | HCN (1-0) | 0.84 | 28.9 | -125.3 (25.8) 161.2 (38.7) | 149.7 (54.55) 159.6 (61.75) | 3.9 | 0.009 (0.002) | 0.045 (0.011) |
| 8 | $HCO^+$ (1-0) | 0.84 | 28.7 | -24.3 (38.8) | 169.5 (64.53) | 1.3 | 0.002 (0.002) | 0.014 (0.011) |
| 9 | CO (1-0) | 0.80 | 22.4 | 90 (4.9) | 140.3 (14.73) | 10.7 | 0.61 (0.05) | 3.05 (0.28) |
| 9 | CO (2-1) | 0.59 | 11.2 | 151.9 (25.8) | 258.5 (84.73) | 2.1 | 0.42 (0.19) | 2.12 (0.97) |
| 11 | CO (1-0) | 0.80 | 23.2 | -73.7 (6.9) 131.1 (8.3) | 154 (3.36) 174.5 (15.16) | 18.2 | 1.53 (0.08) | 7.67 (0.42) |
| 11 | CO (2-1) | 0.60 | 11.6 | -105.5 (8.3) 80.6 (14.4) | 82.4 (19.42) 203.5 (30.18) | 11.0 | 1.94 (0.17) | 9.71 (0.88) |
| 13 | CO (1-0) | 0.82 | 24.6 | -14.2 (26.8) | 199.3 (56.04) | 3.3 | 0.03 (0.01) | 0.19 (0.05) |
| 13 | CO (2-1) | 0.63 | 12.3 | 39 (31.7) | 253.1 (75.79) | 4.5 | 0.19 (0.04) | 0.96 (0.21) |

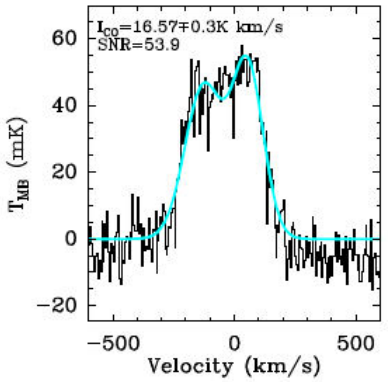
**Puschnig+ (in prep)**

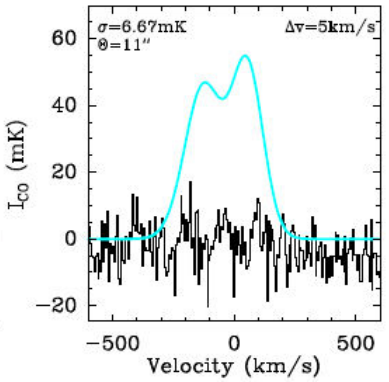
# Summary of CO Detections

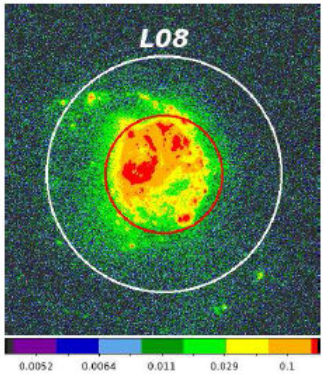


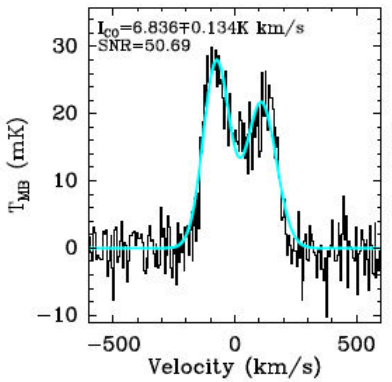



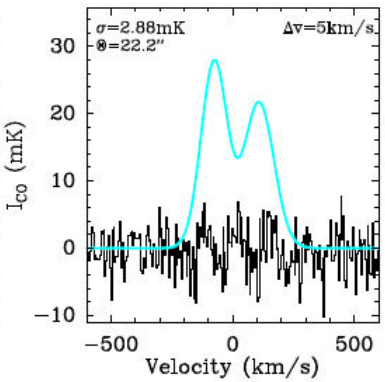



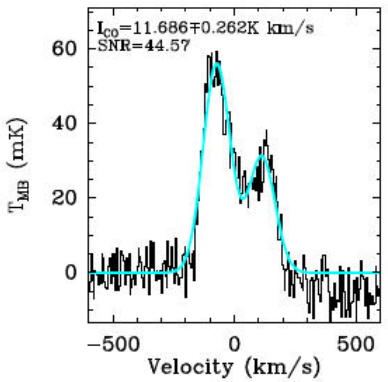



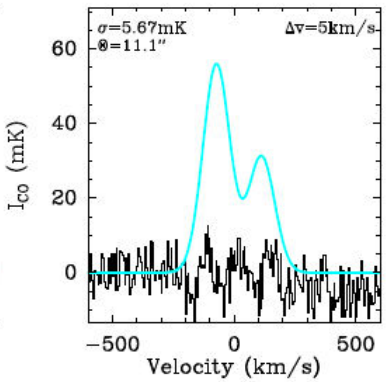



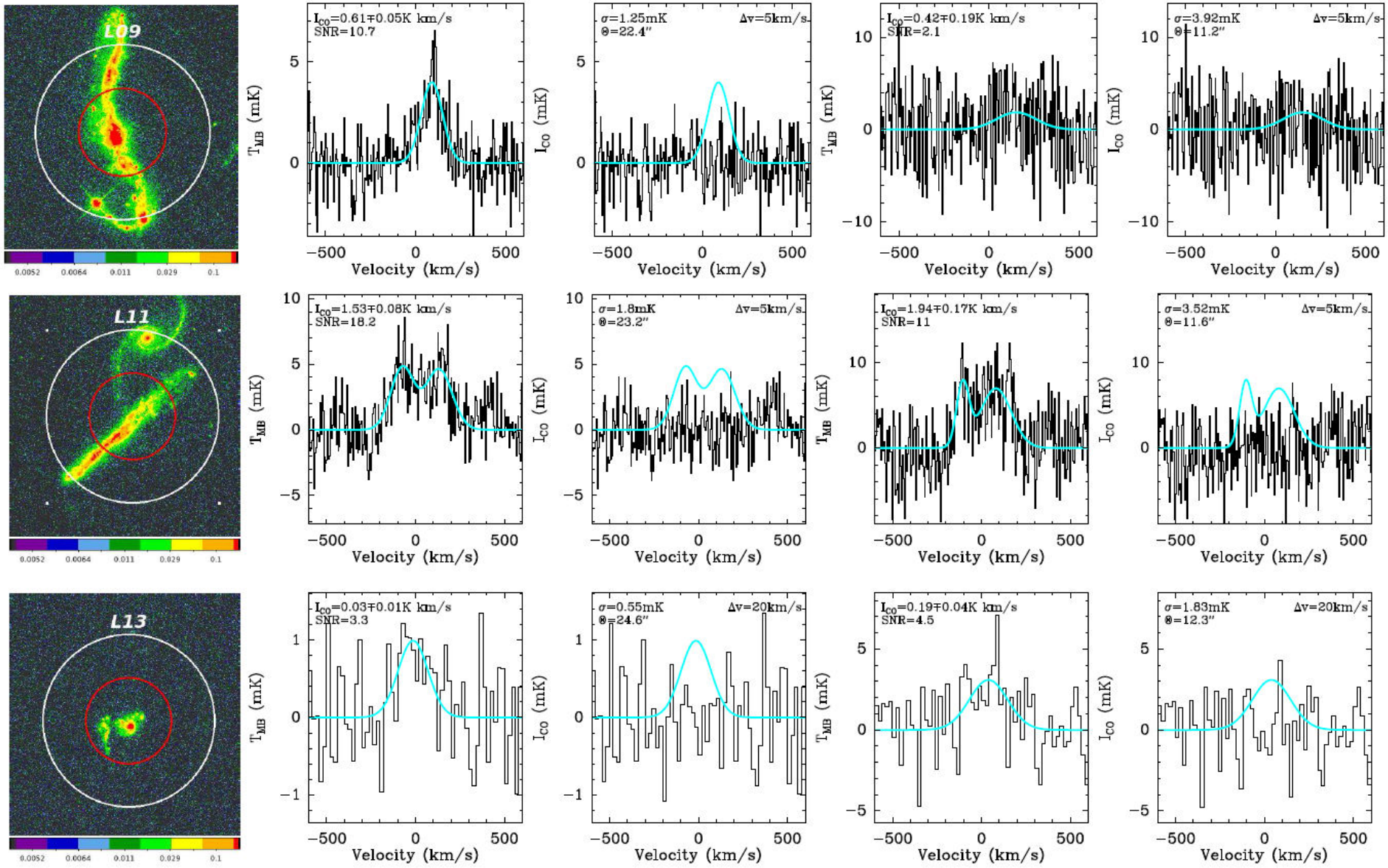



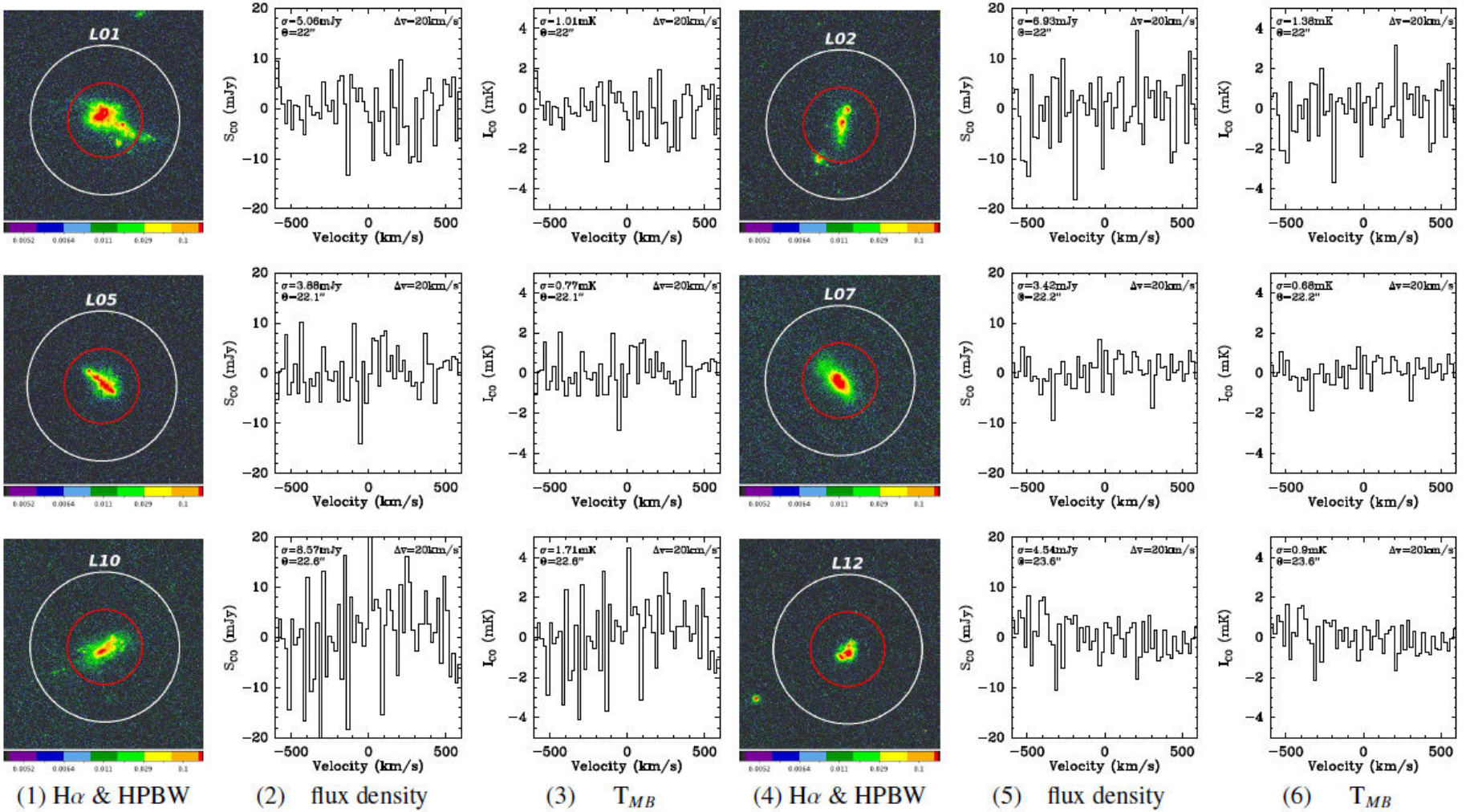

**Puschnig+ (in prep)**

# Summary of CO Detections




(1) Hα & HPBW (2) CO (1-0) (3) residual (4) CO (2-1) (5) residual

# CO Non-Detections



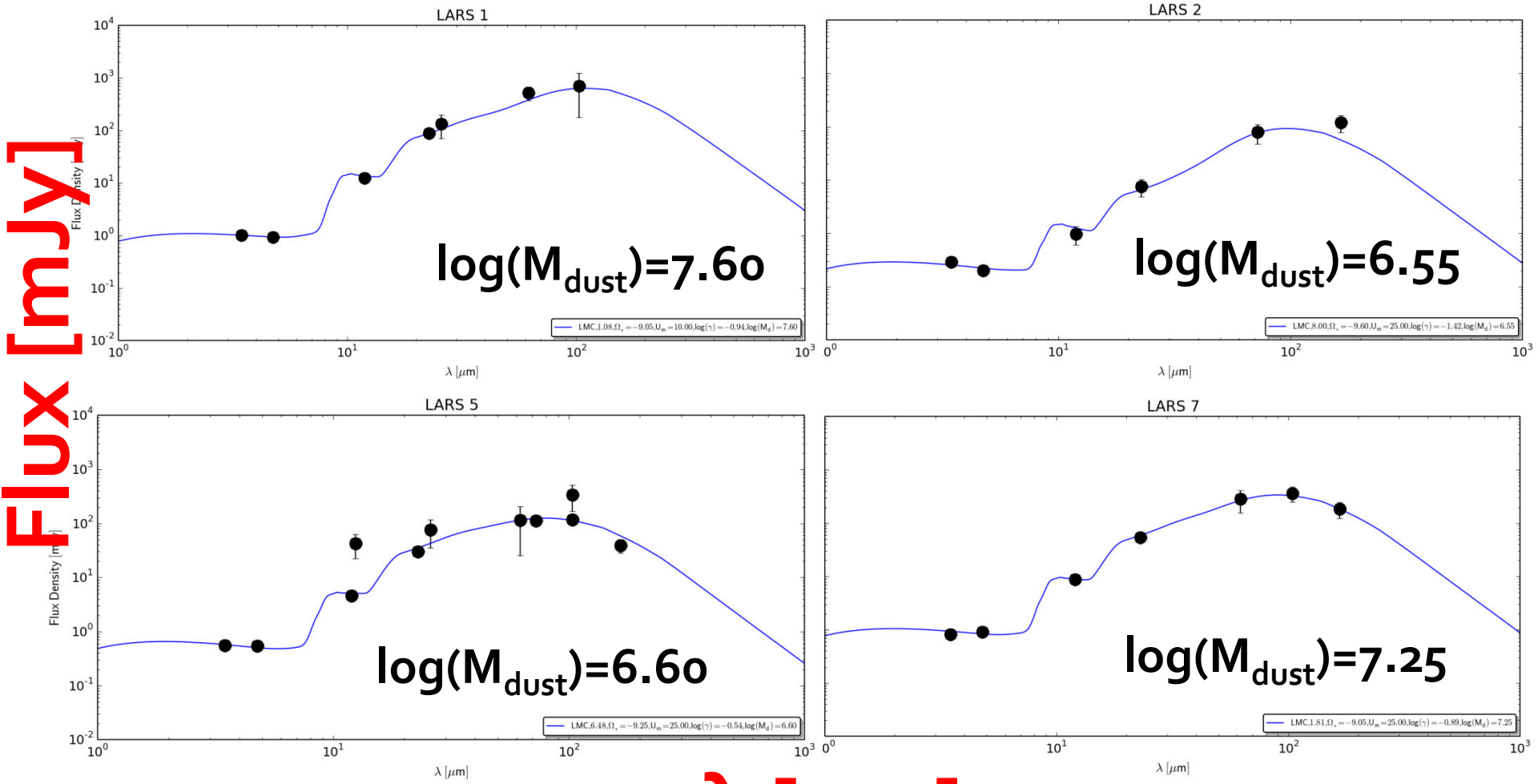

(1) H$\alpha$ & HPBW (2) flux density (3) $T_{MB}$ (4) H$\alpha$ & HPBW (5) flux density (6) $T_{MB}$

**Puschnig+ (in prep)**

# FIR/dust observations

- Constrain FIR SED by LSQ fitting of Draine & Li (2007) model (D07) parameters to photometric bands of WISE and Herschel/PACS.
- Derive $M_{dust}$, $\langle U_{min} \rangle$, $\Omega_*$
- Adopt Z-dependent dust-to-gas ratio from Leroy+ (2011) to constrain molecular gas mass.

# FIR SEDs of LARS galaxies




Puschnig+ (in prep)

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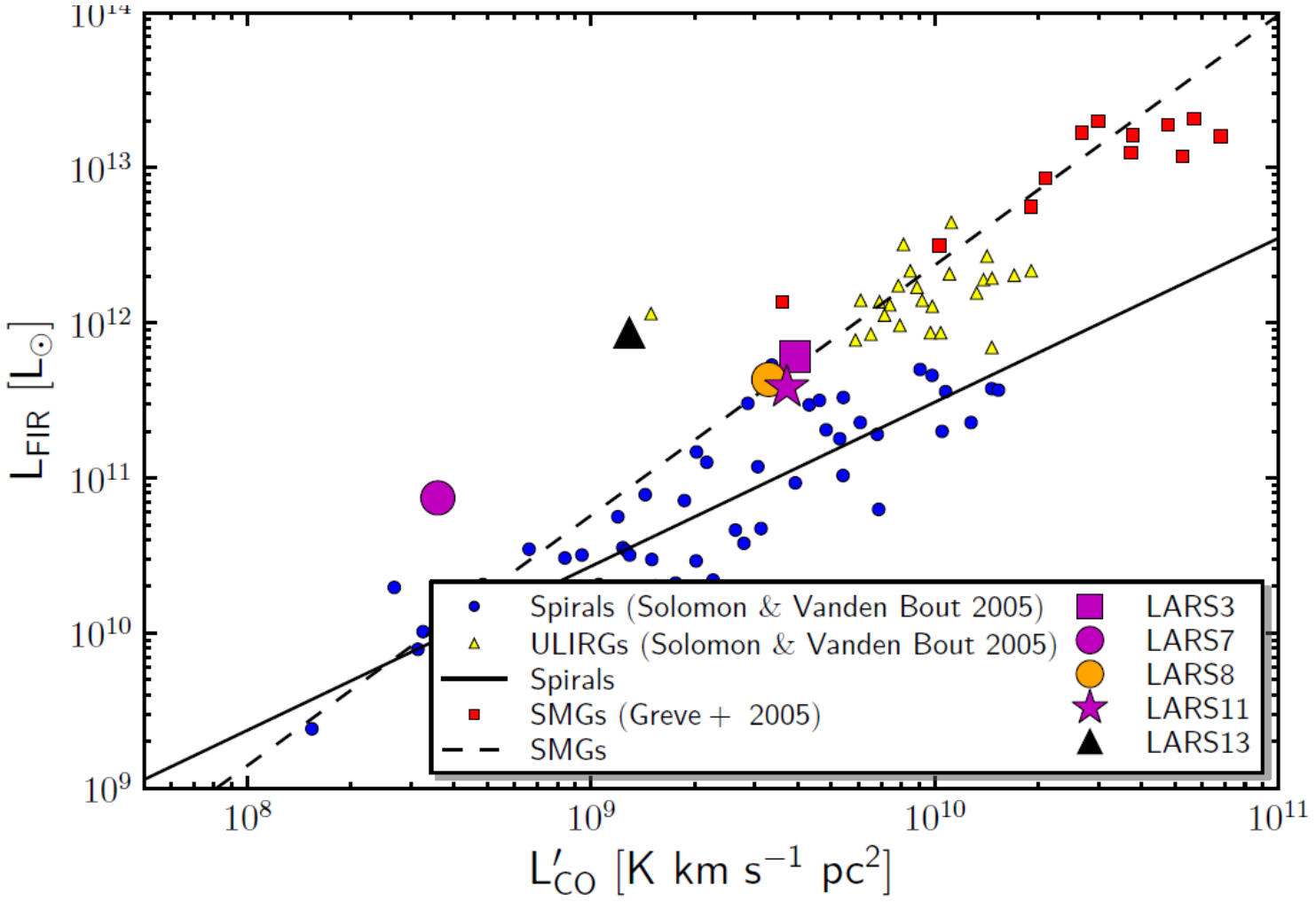
# Preliminary Results (CO)



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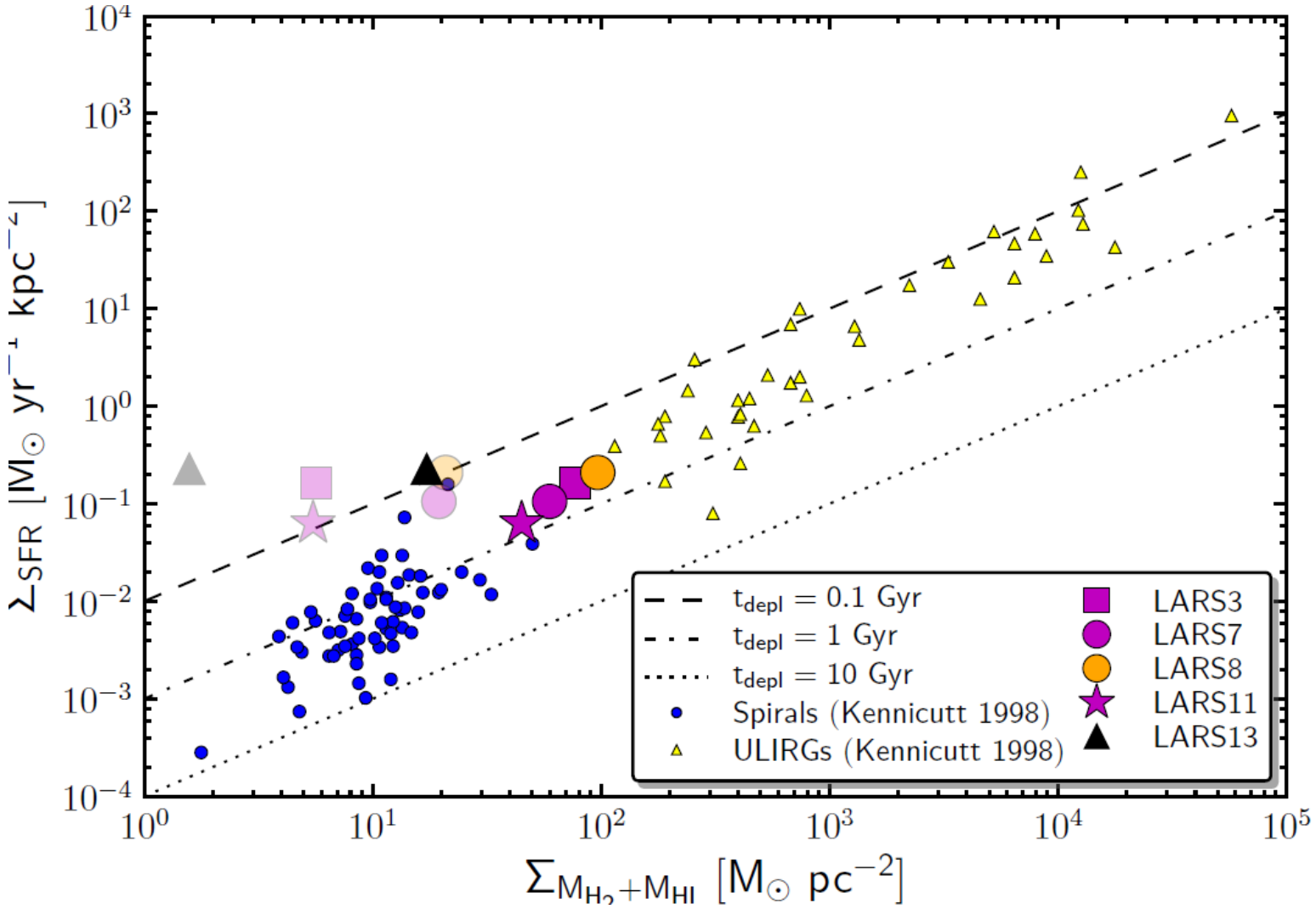
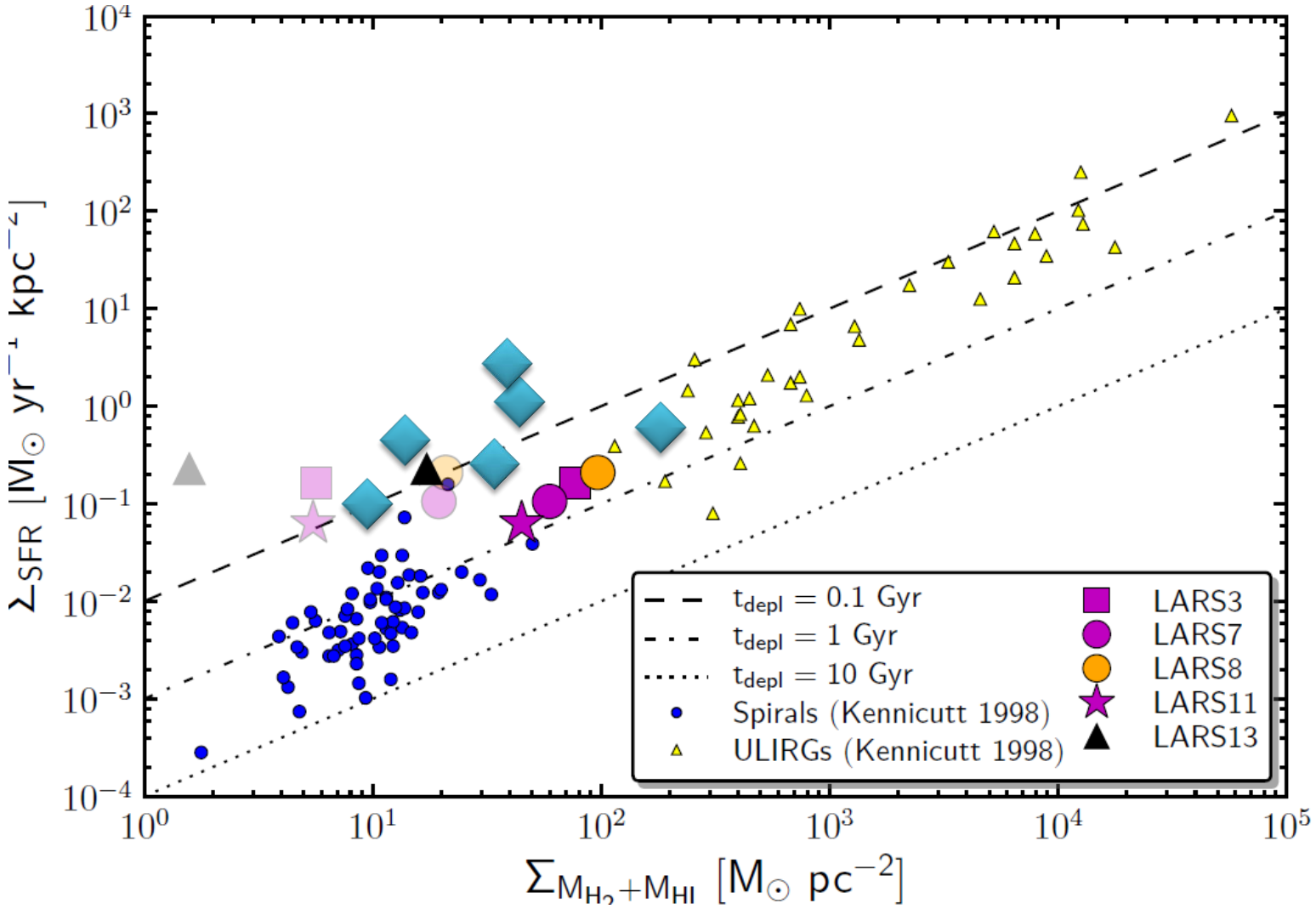
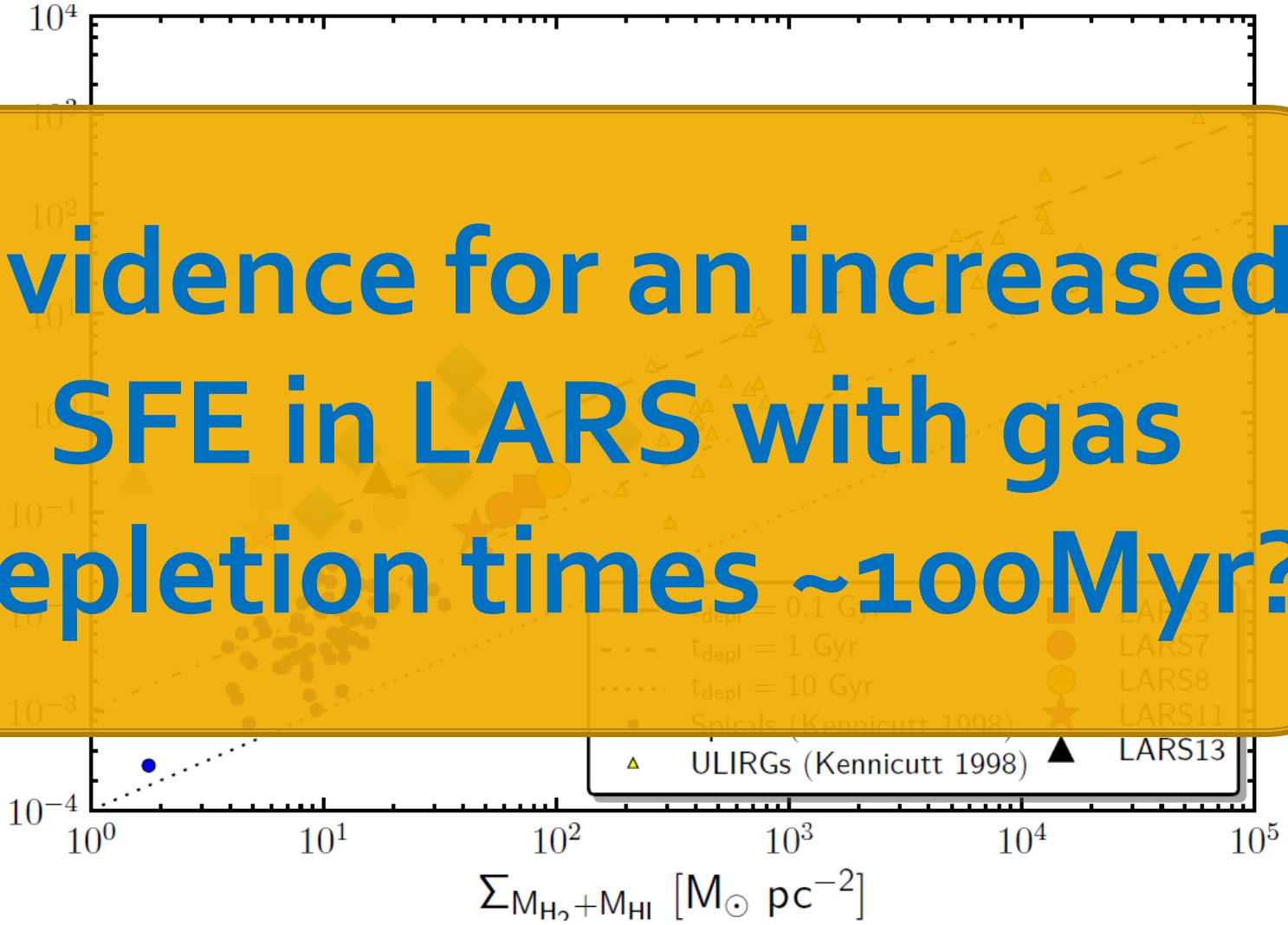


# Preliminary Results (CO+Dust)

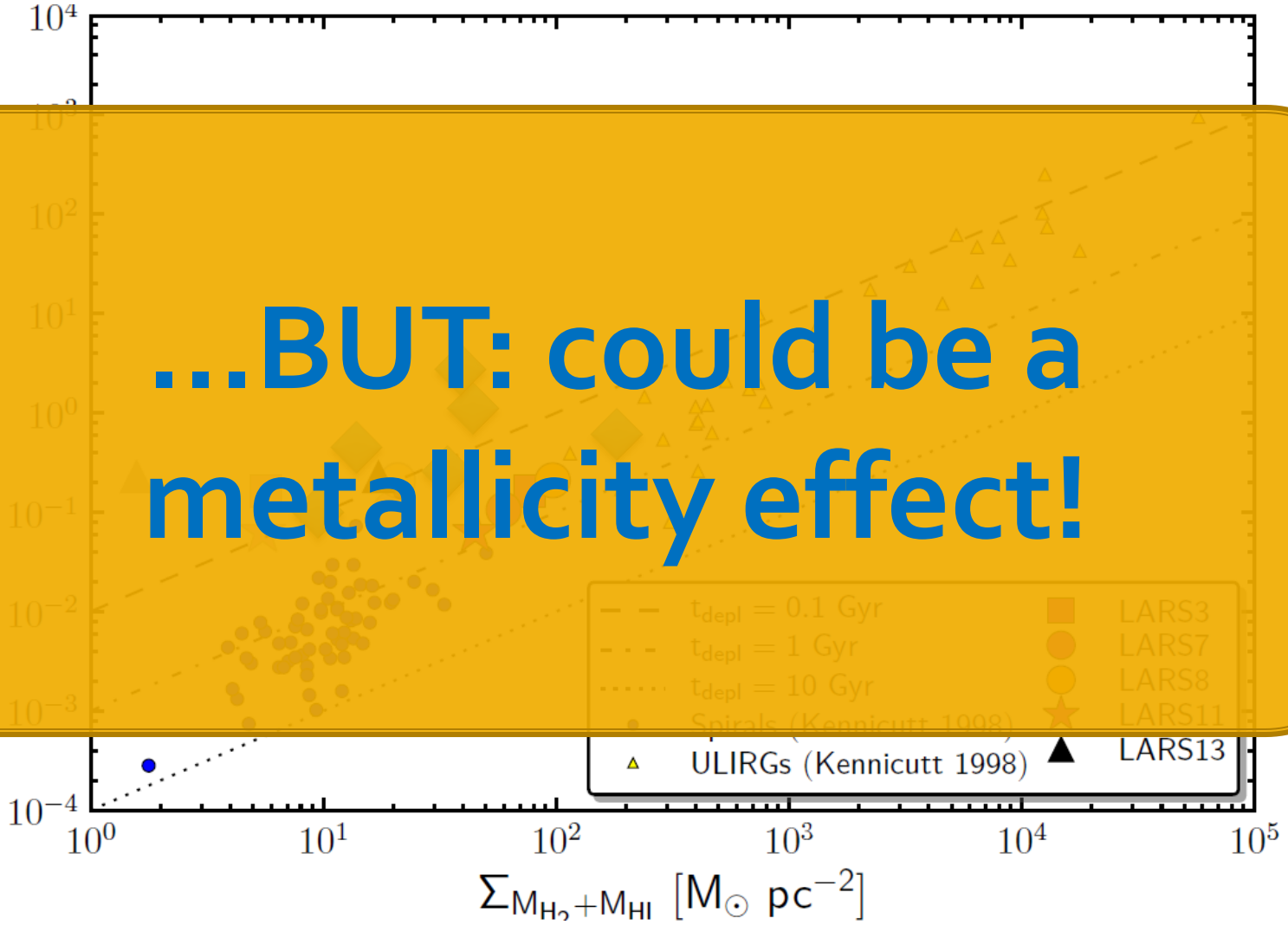


# Preliminary Results (Dust)




**Evidence for an increased SFE in LARS with gas depletion times ~100Myr?**

# Preliminary Results (Dust)




**...BUT: could be a metallicity effect!**

# Preliminary Results (Dust)

- „the ISRF intensity $G_0$ was 5 times higher with consequently higher $T_{dust}$ at z~3 than at z~0" (Magdis+ 2012)
- understood based on the redshift evolution of the $M_*$-Z and SFR-$M_*$ relations

→ In LARS, the mean UV interstellar radiation field $G_0$ ~ 10

→ Dust SEDs are LMC-like

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# Outlook

- Dynamical mass constraints (CO conversion factor)
- Use new prescriptions for sSFR/Z-dependence of conversion factor (Accurso in prep; Amélie Saintonge's talk)
- Use the CO lineratios yet available (CO J=1-0, J=2-1 and J=3-2) in combination with [CII]158µm, [OI] 63µm obtained with Herschel/PACS and SOFIA together with PDR models to derive density and temperature of the molecular gas.
- Single dish observations rely on an aperture correction that introduces additional uncertainty → interferometry needed

# Outline

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# The Lyman Continuum Escape and ISM properties in Tololo 1247-232 – New Insights from HST and VLA

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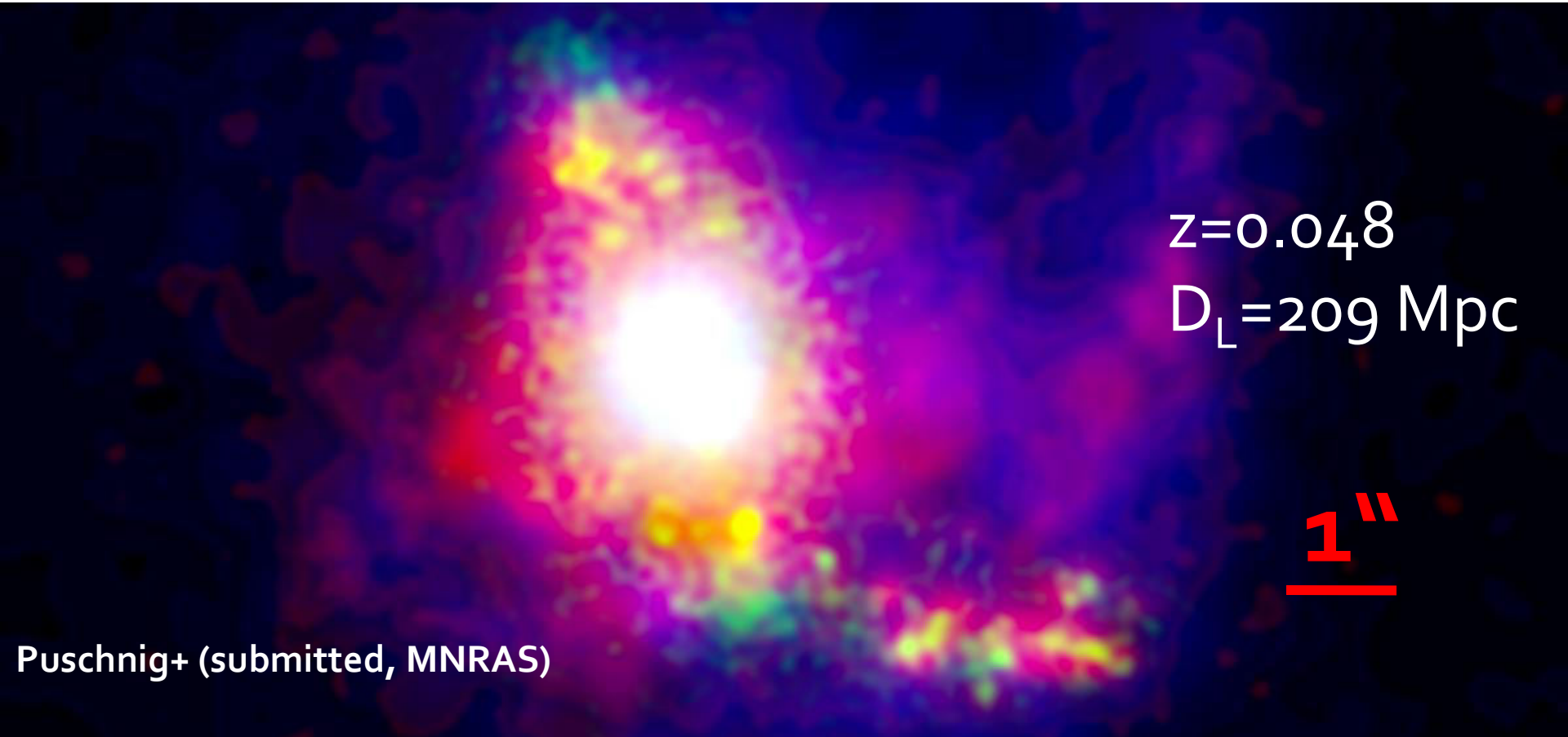


Puschnig+ (submitted, MNRAS)

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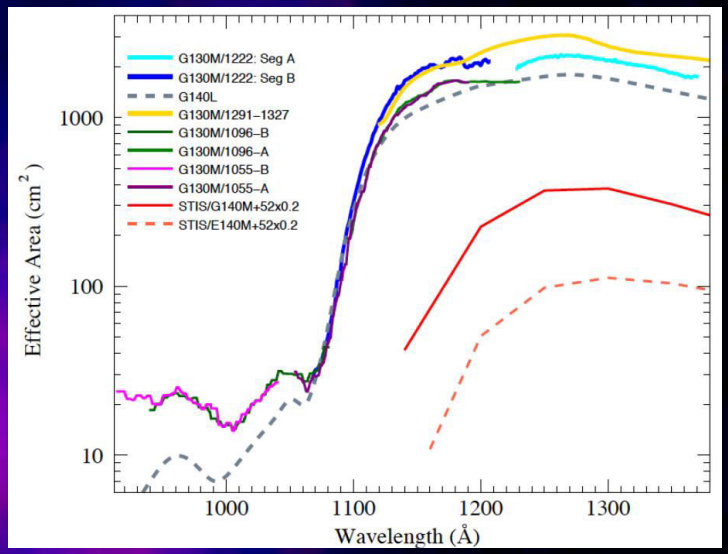
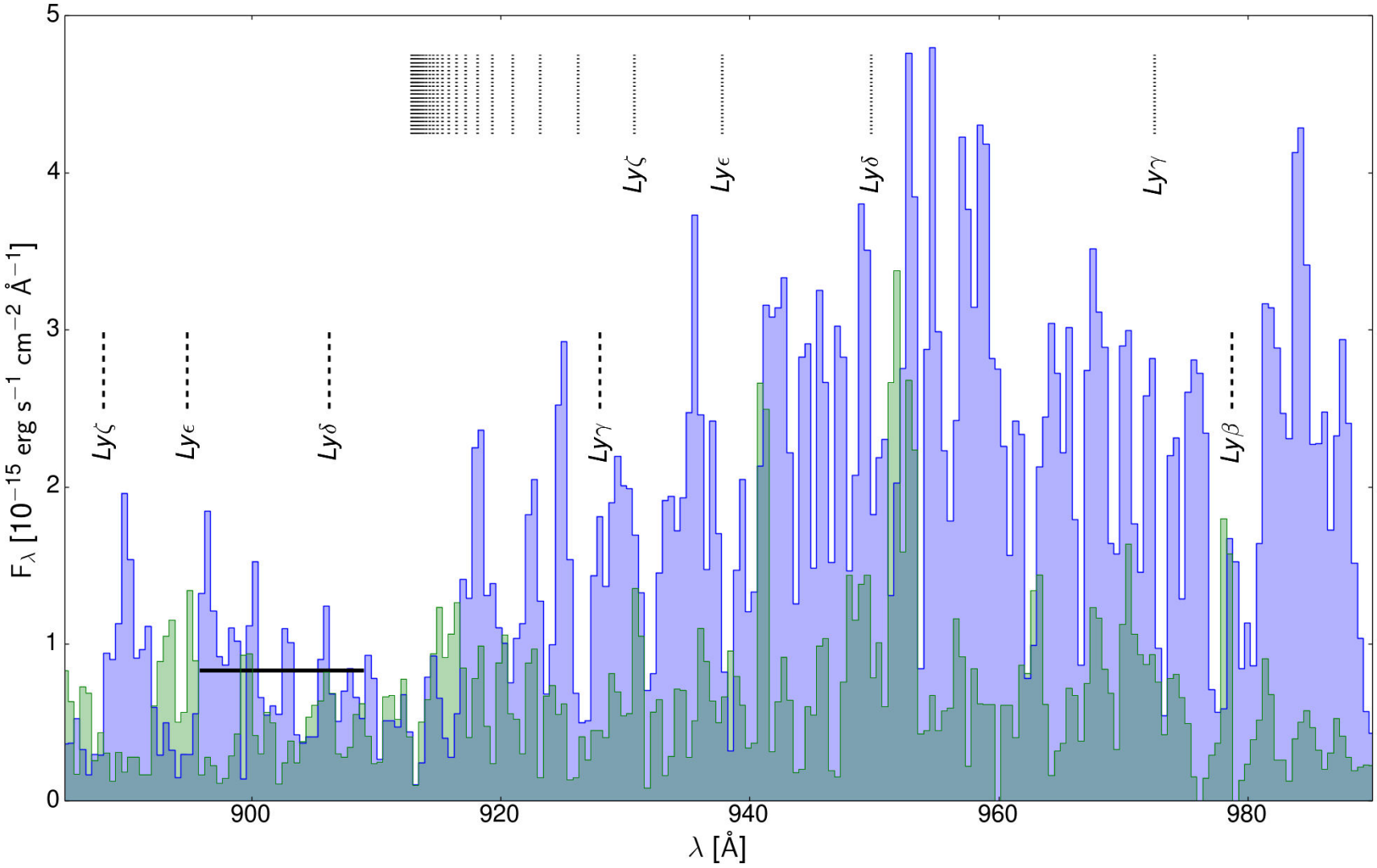
HST/COS setup:
- 2.5 arcsec fiber
- G130M grism
- CENWAVE: 1055AA and 1327AA
- approx. 3.3h in total

Throughput below~1100AA extremely low




→ **CALCOS pipeline modification needed:**
- Adjusting PHA (filtering of background photons)
- Orbital Night data only
- Improved BG subtraction

# Direct Detection of LyC in Tol1247



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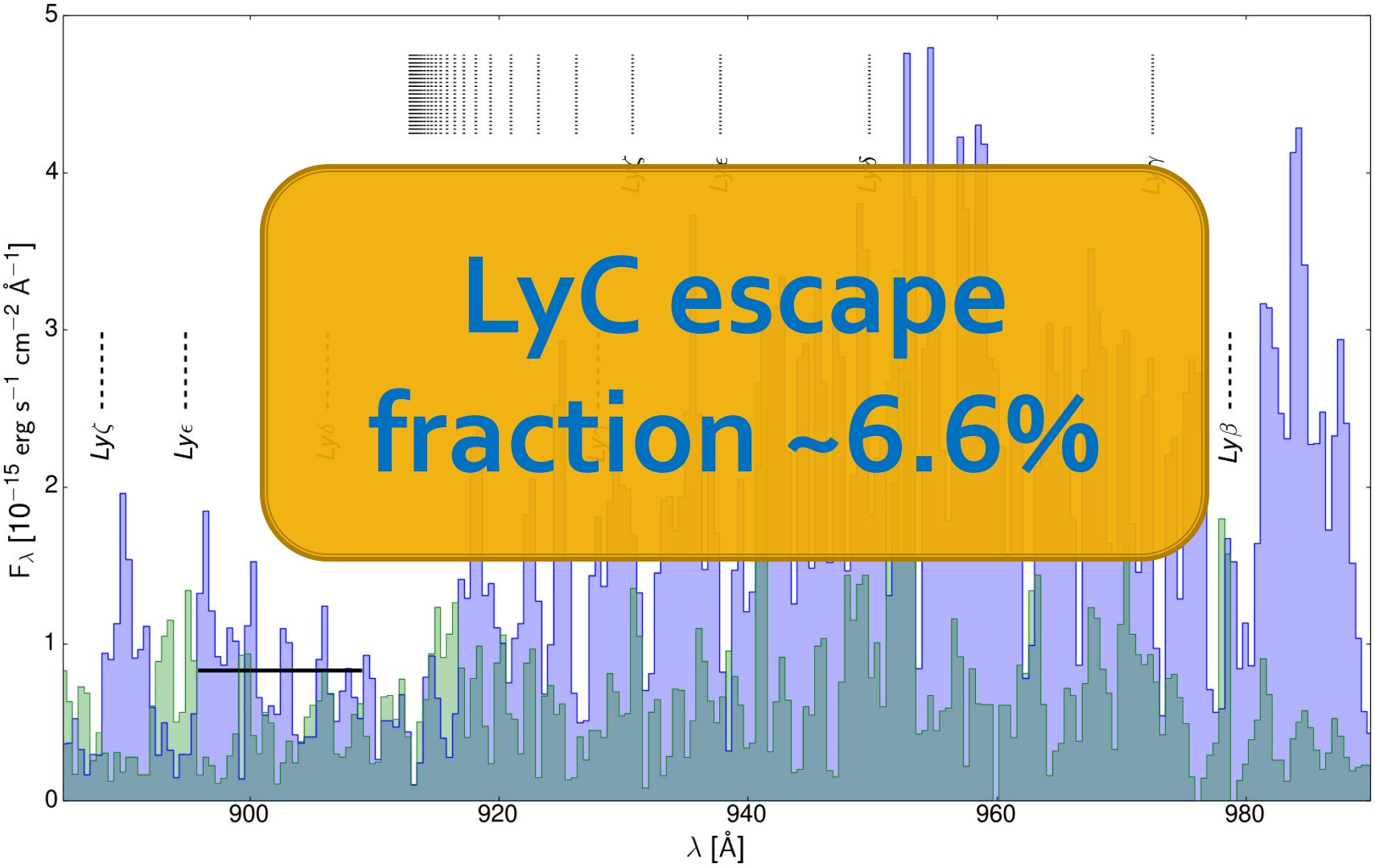
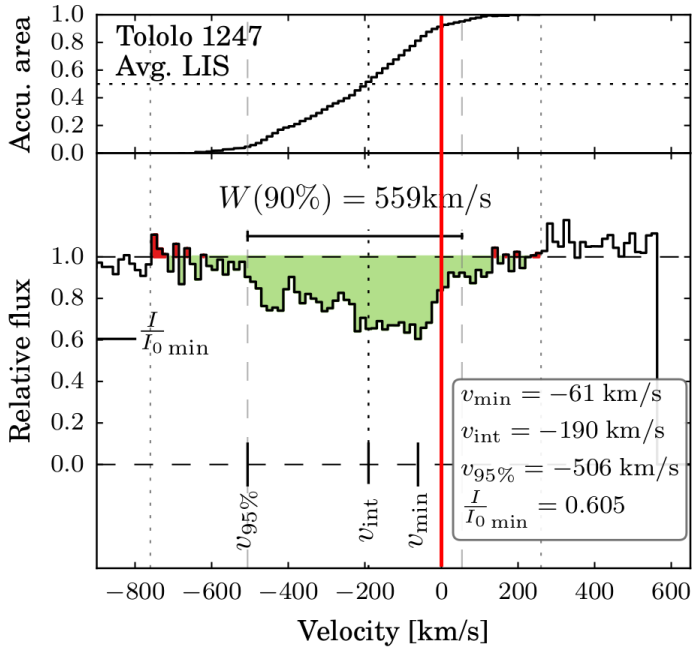
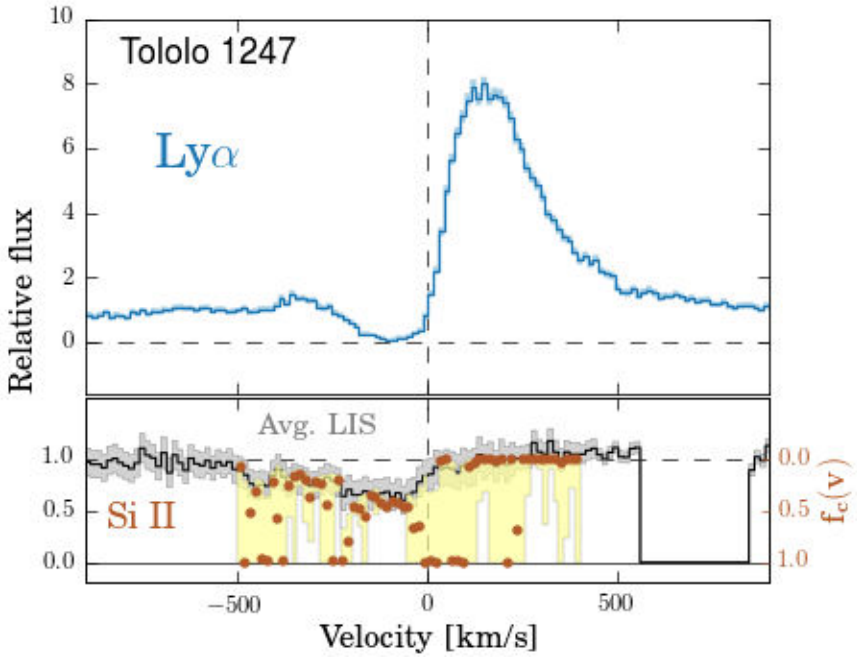


# Constraints from UV absorption lines

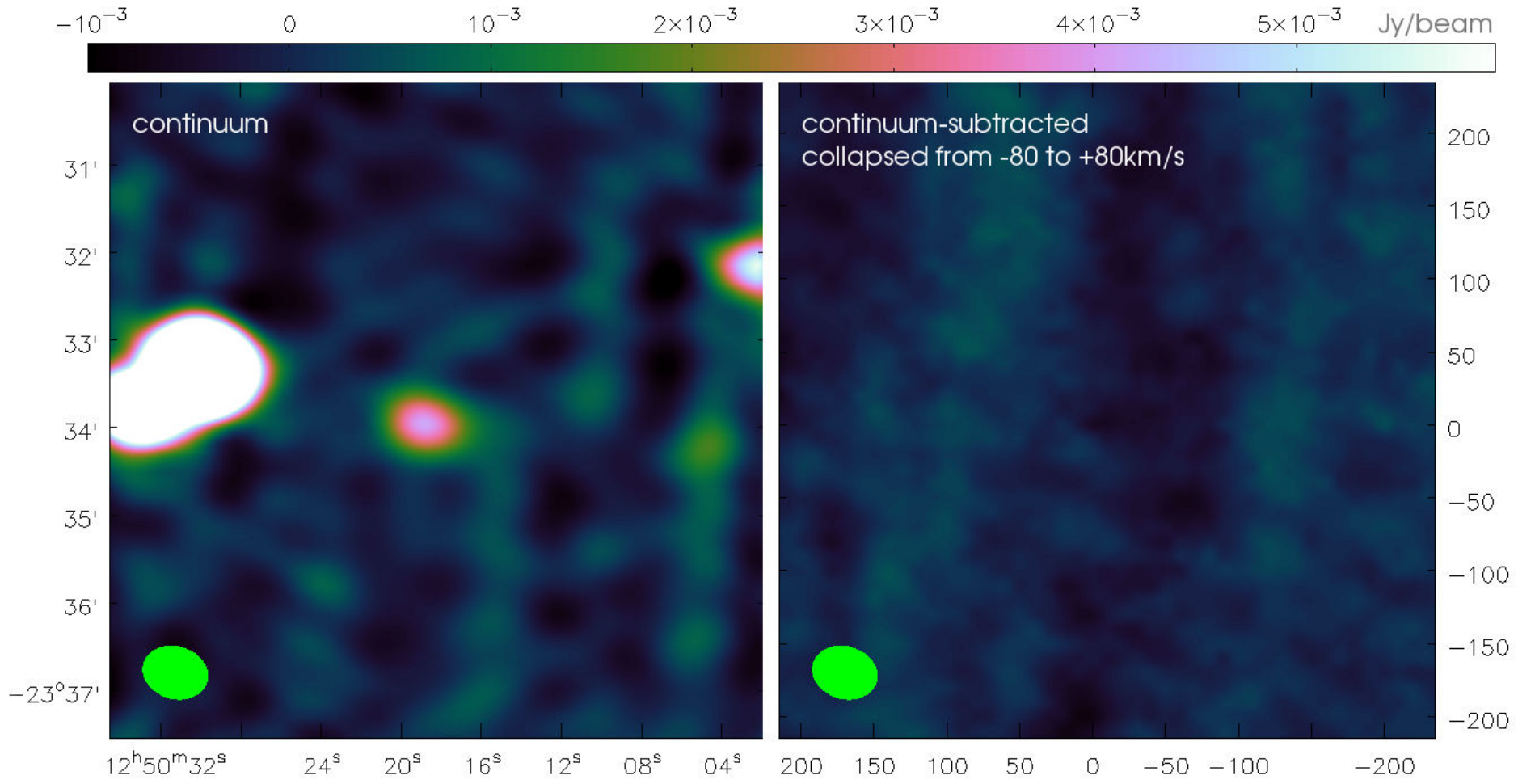
* Si II at 1190, 1193, 1260, 1304 Å
→ mean profile blueshifted/outflow
→ extremely wide line

* Apparent opt. depth method:
(Jones+ 2013, Rivera-Thorsen+ 2015)
→ gas is optically thick
→ residual at all v → CLUMPY
→ covering fraction very low



# VLA 21cm observations of Tol1247



# Summary of LyC escape in Tol1247

- Direct detection of LyC in the range 896-909 AA at a 2-sigma level after substantial modification of CALCOS pipeline
- LyC leakage is supported by UV absorption lines showing that the gas is optically thick, but residual is seen at all velocities → CLUMPY, very low covering fraction
- Using LaXs, a LyC escape fraction of 6.6% was computed.
- almost extinction-free sightlines in the innermost ~500pc were found
- Tol 1247-232 was not detected at 21cm → very low gas fraction $M_{gas}/M_*$ of <0.2

# Thank you for listening