Multi Wavelength Analysis of Star Forming Galaxies

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Uppsala April 11, 2014

1) Introduction

2) Empirical Findings

3) Constrain X_{CO}

4) SFR from WISE 22μm for LARS

5) Proposal Overview: CO in LARS

6) Conclusion

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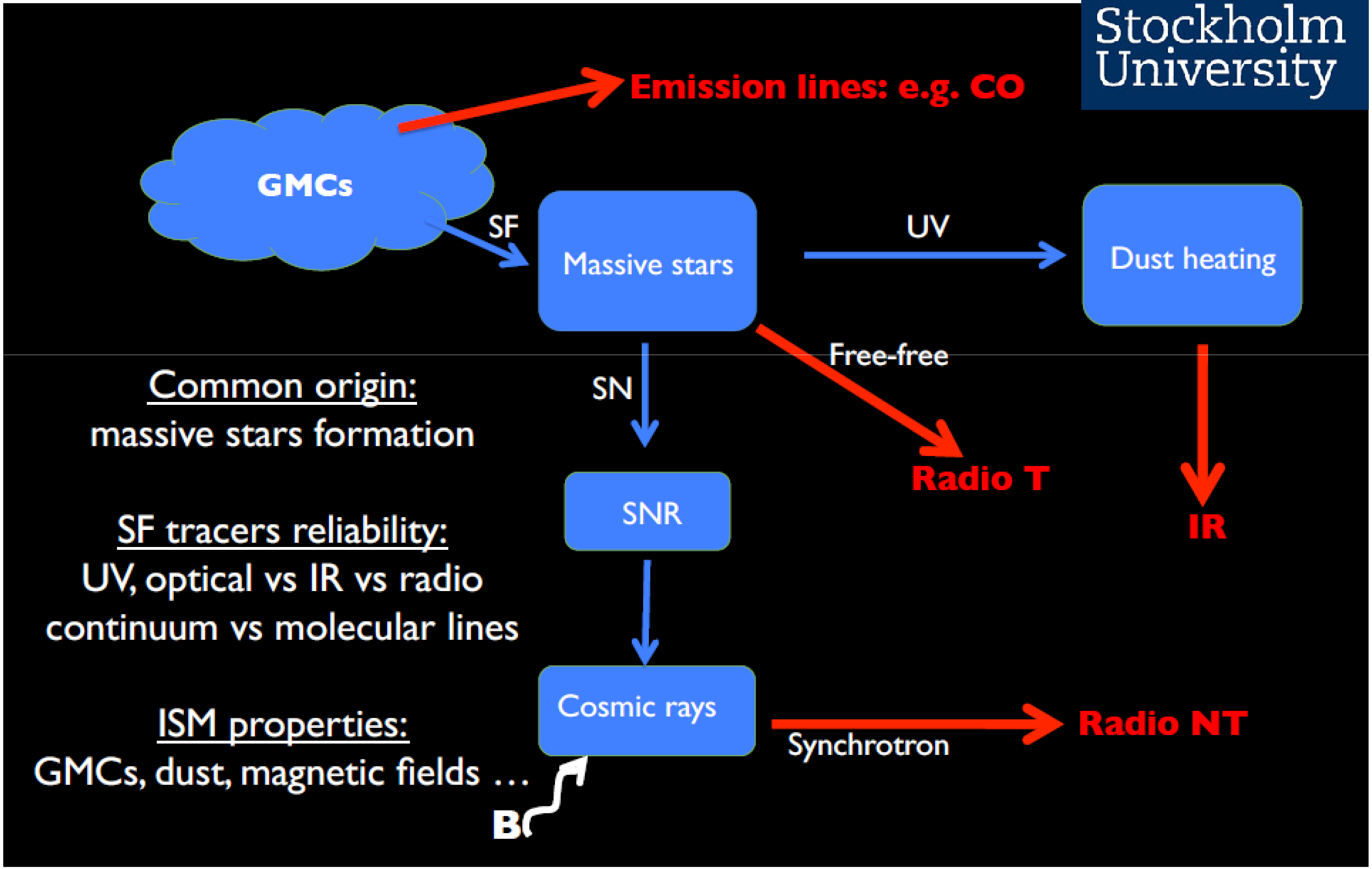
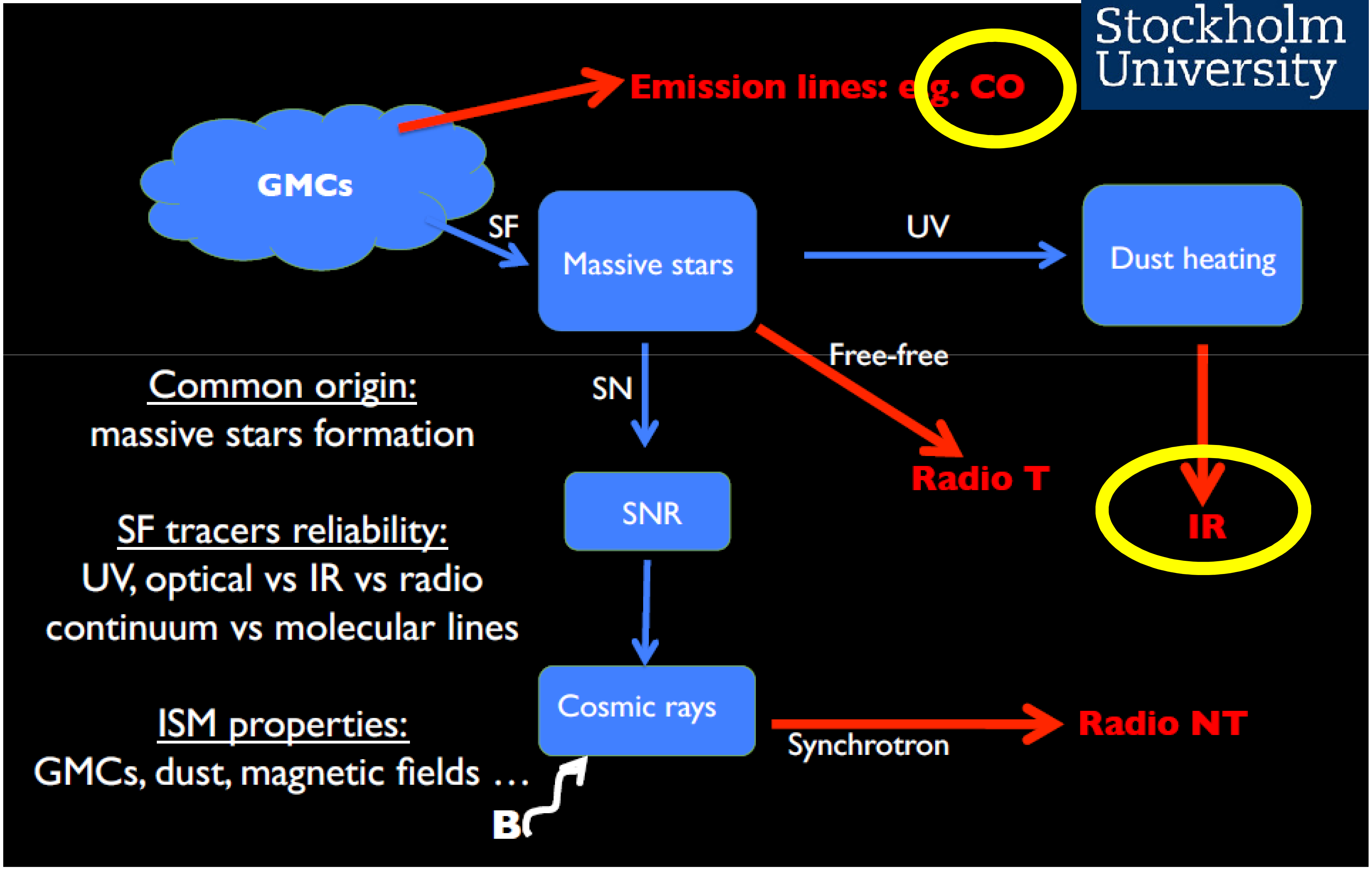
1) Introduction



1) Introduction



1) Molecular Gas

- H_2: fuel for star formation
- molecular emission lines can be used as tool for deriving astrophysical quantities of the cold ISM
- although it typically makes up only ~1% of the gas volume, it carries ~20% of the gas mass (MW)
- CO spectral lines contain information about kinematics on a galactic scale (e.g. Tully-Fisher)

1) The problem with CO

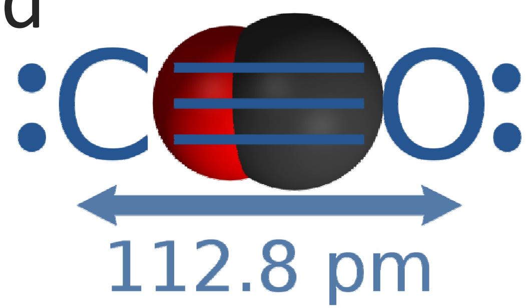
Problem!

H_2, which is the most abundant molecule lacks of rotational transitions at low temperatures.

→ CO emission is the best tracer of molecular hydrogen for two reasons:

1.) It is the most abundant molecule after H_2

2.) CO rotational levels are excited and thermalized by collisions with H_2 at a relatively low temperature of ~10K!



1) The problem with CO

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- ^{12}CO emission is optically thick!
- Thus, L_{CO} in principle depends on T_{ex} temperature and *NOT* on the column density!
- Interpretation of CO emission is a complex problem with the need of many assumptions on the physical properties of molecular clouds.
- X_{CO}, the conversion factor has to be derived individually for each galaxy.

1) SFR Tracers

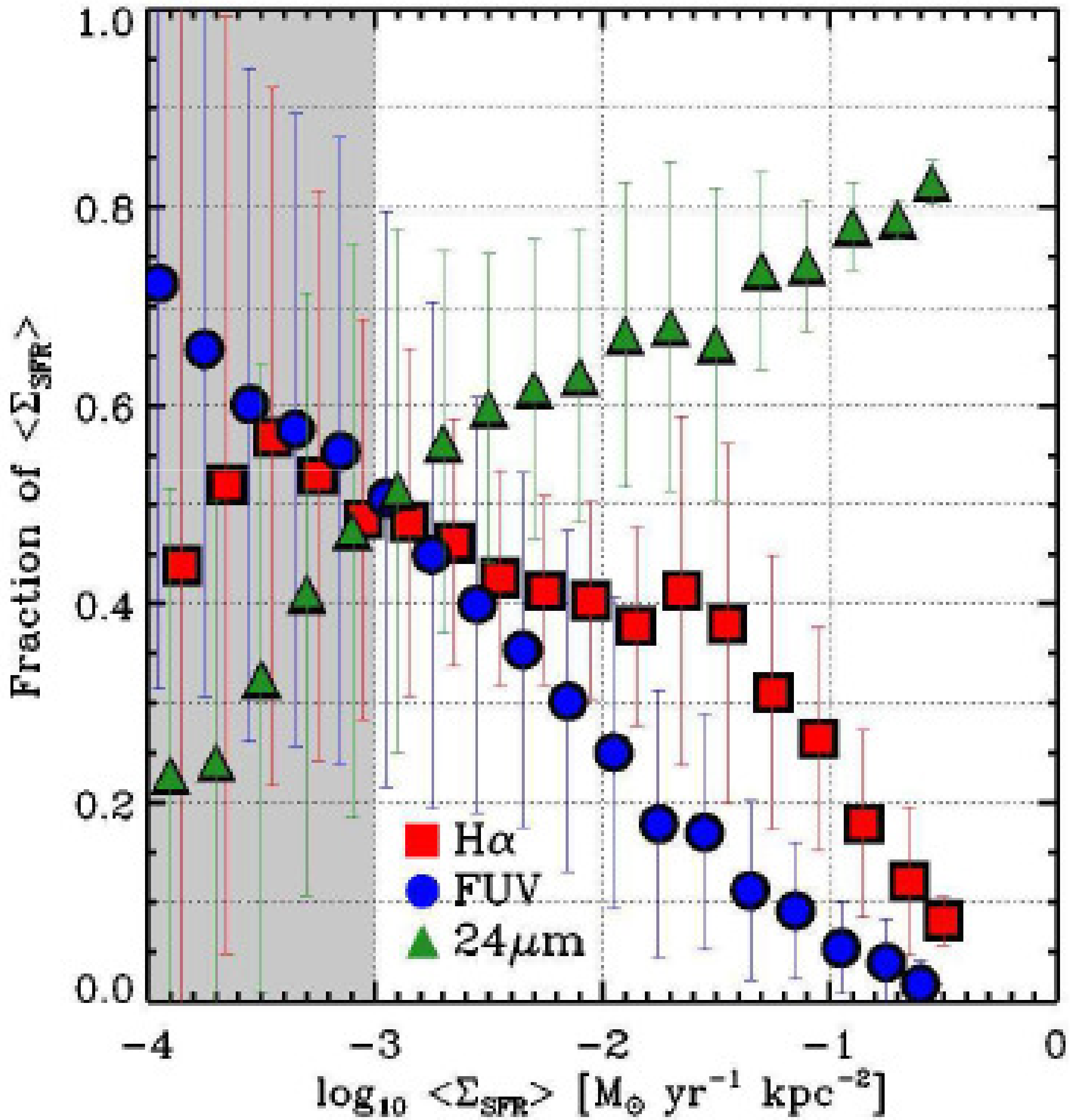
- Hα observations: high mass SF tracer, indicates presence of ionizing O stars (M > ~20 $M_{\odot}$)

- far-IR flux: assumes that a constant fraction of the emitted stellar energy is absorbed by dust

- far-UV flux: primarily emitted by young, hot stars, but older/less massive than those responsible for Hα

- radio continuum emission: statistically correlated with IR radiation - physics is complex (synchrotron radiation and thermal bremstrahlung from hot gas)

1) SFR Tracers



Bigiel et al. (2012), AJ

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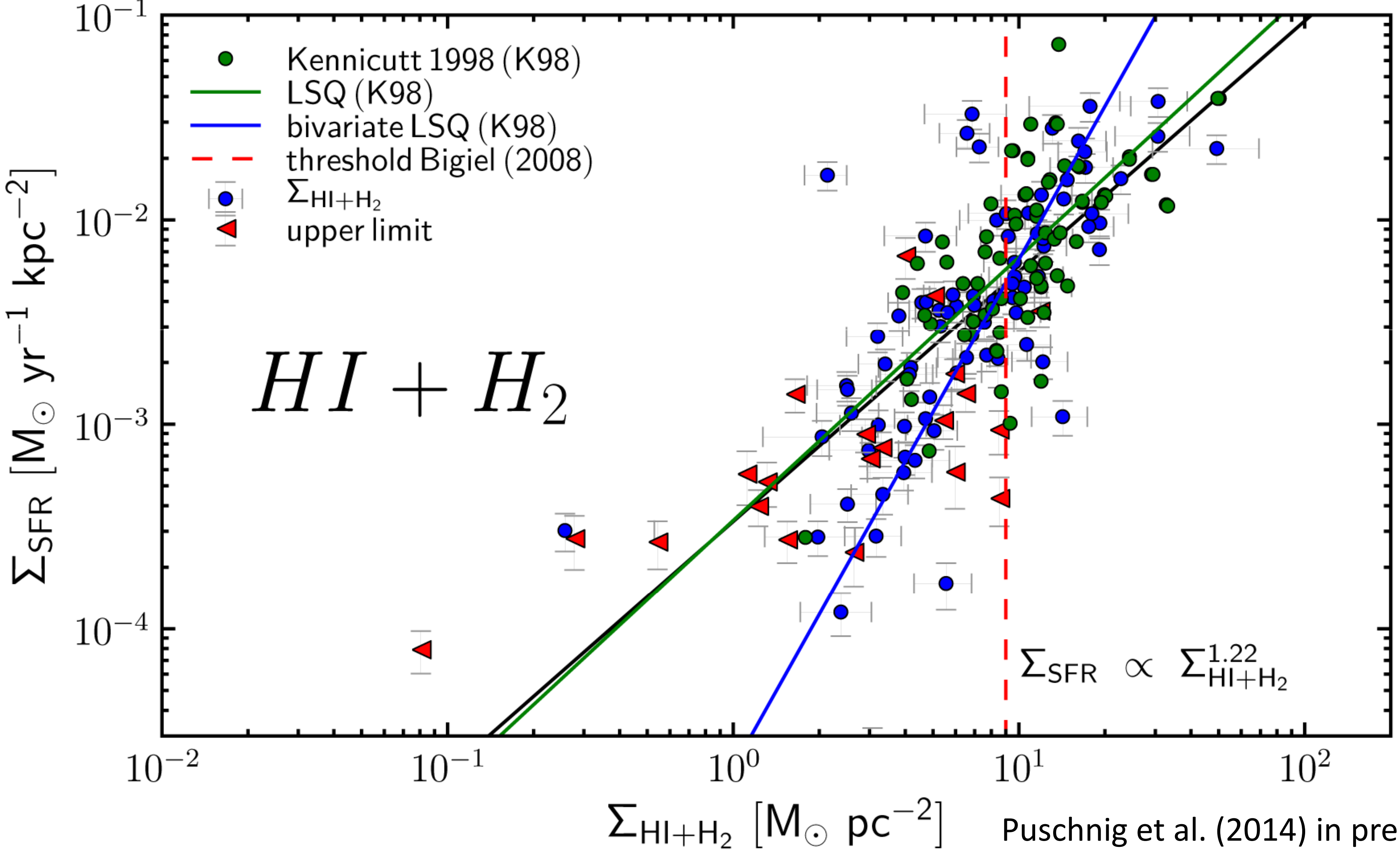
2) Kennicutt Schmidt Law



Puschnig et al. (2014) in prep

2) Kennicutt Schmidt Law

Assume that SFR rate is proportional to total amount of gas

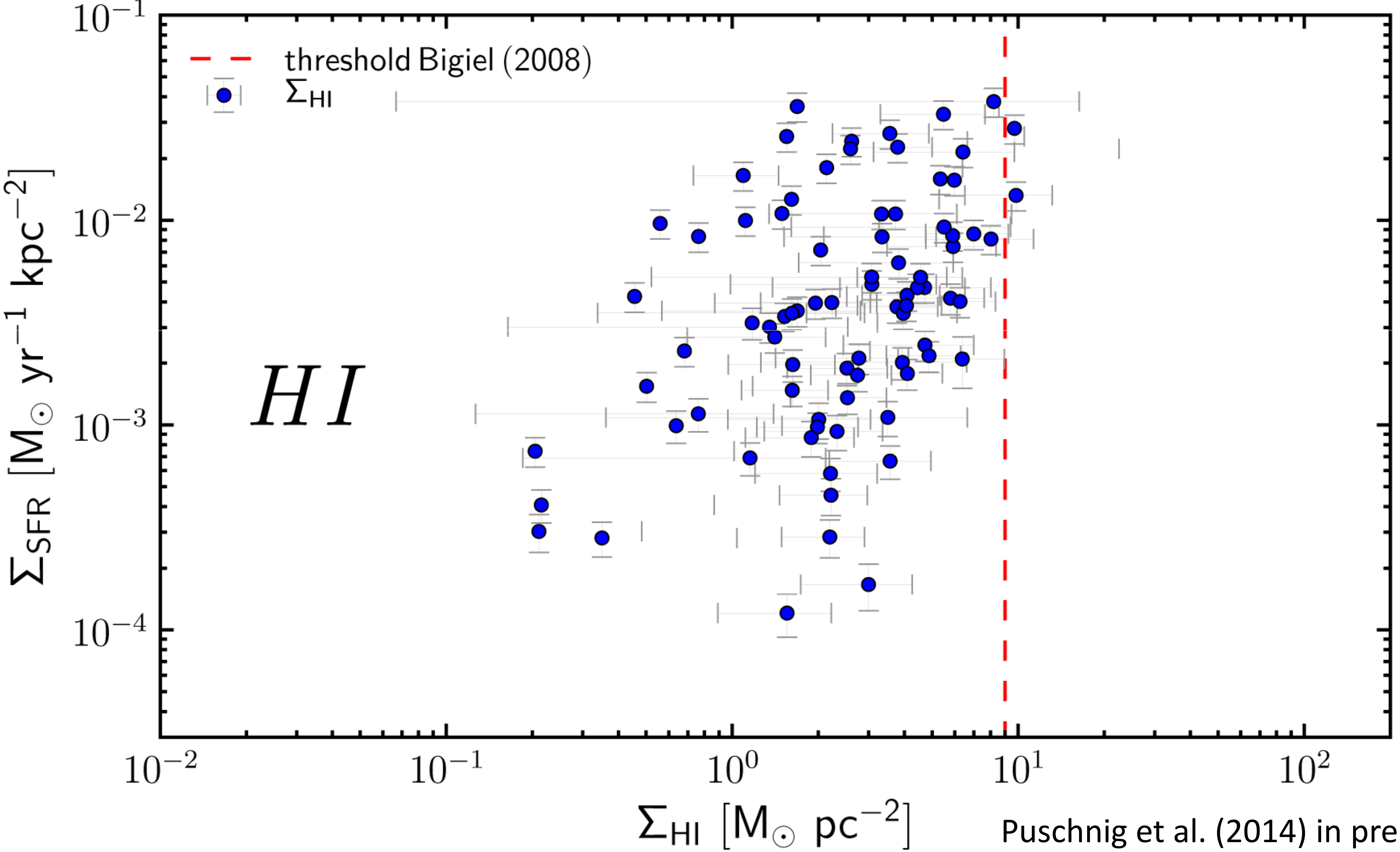
$\text{SFR} \sim \rho_{gas}$

$\text{SFR} \sim d\rho_{gas}/dt$

Solution: $\rho_{gas} \sim \rho(0) \cdot e^{-t/\tau}$

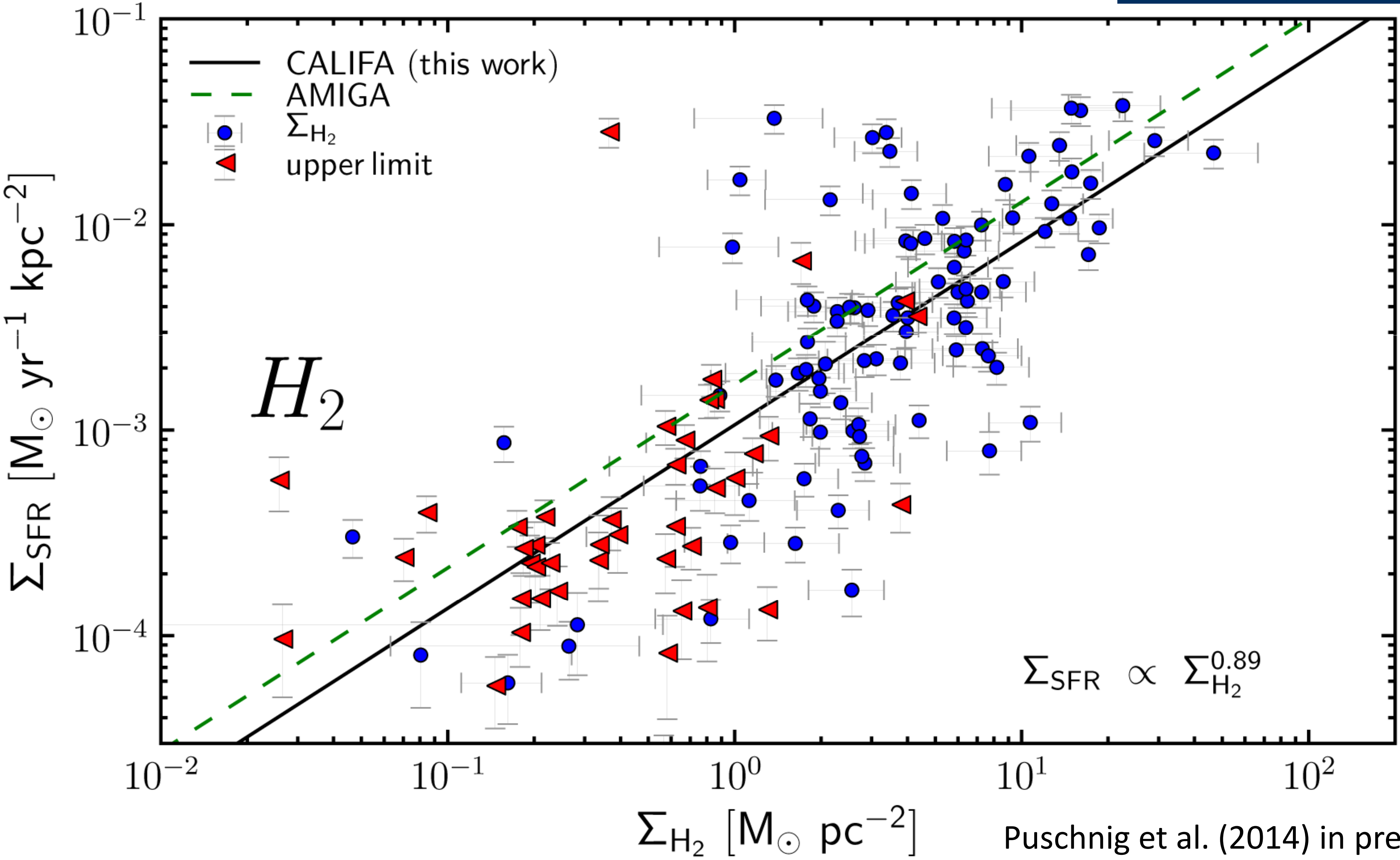
More general: $\text{SFR} \sim \rho^{N}_{gas}$

2) Atomic Gas only



Puschnig et al. (2014) in prep

2) Molecular Gas only



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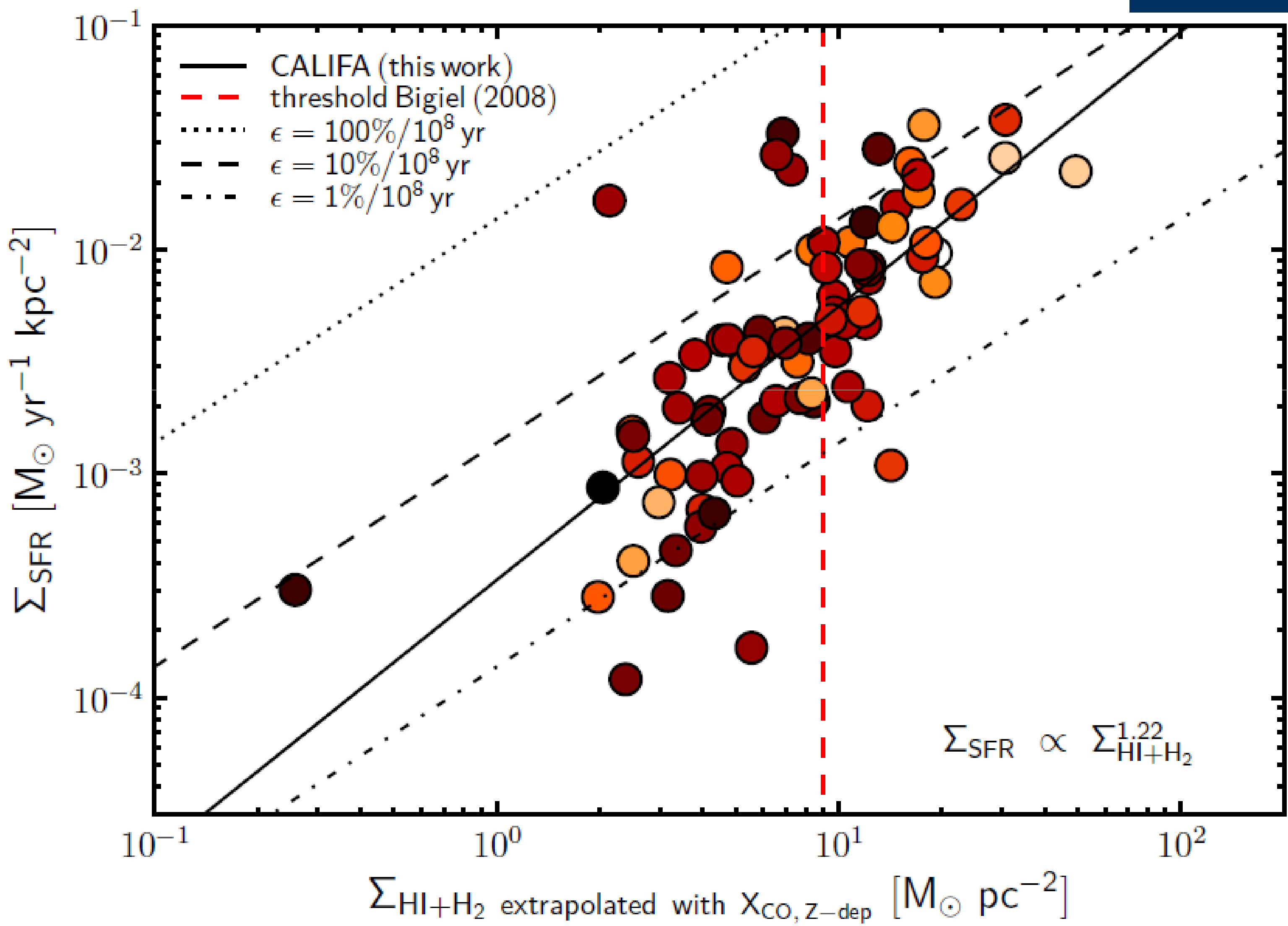
2) Star Formation Efficiency



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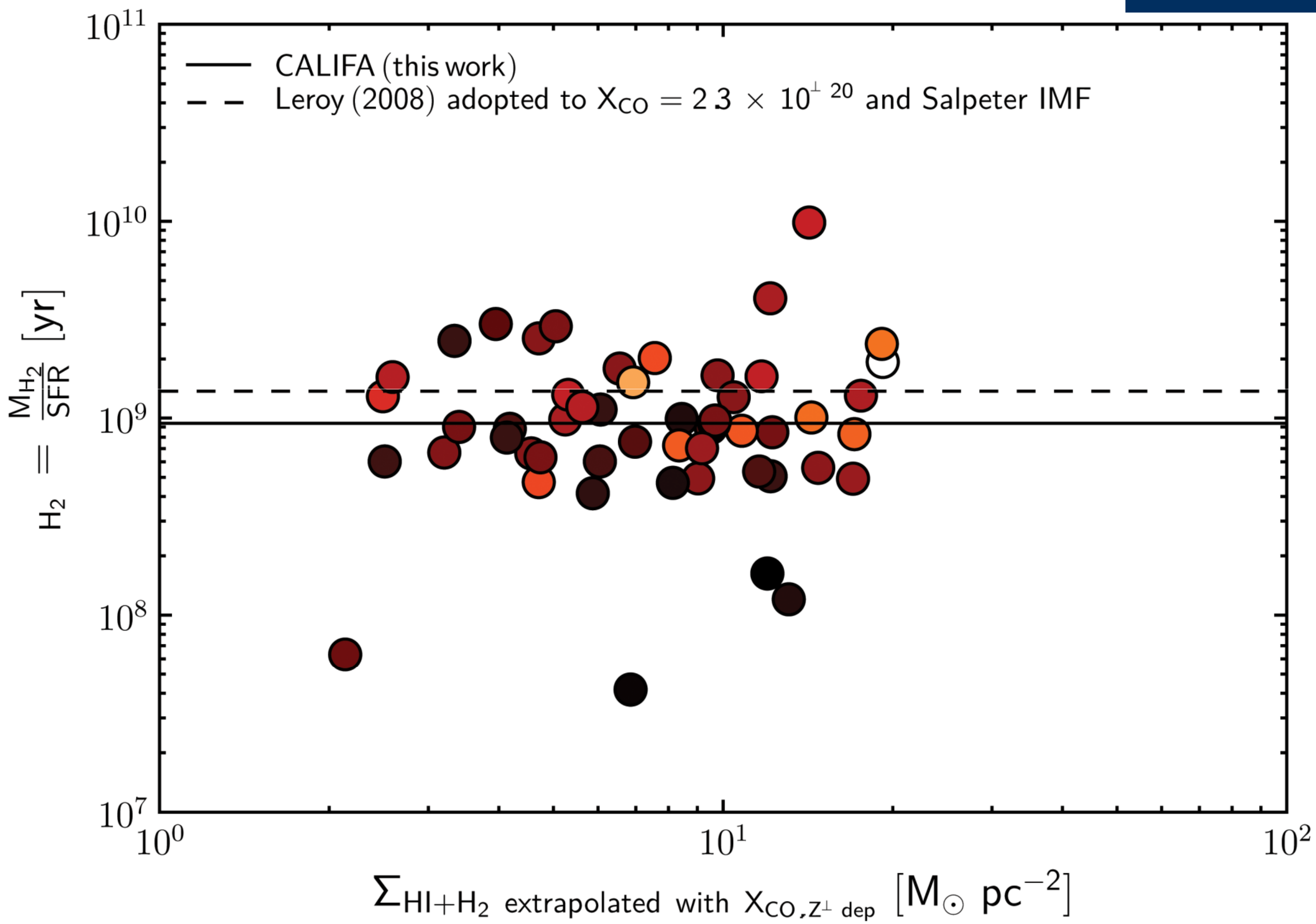
2) Molecular Gas Depletion Time



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3) Molecular Mass Calculations: X_{CO}

* Solomon 1987: $M_{vir} = \frac{3(5-2k)}{G(3-k)} R \sigma^2$

k ... power law index of the spherical volume density profile
M_{vir} is a good measure of the total cloud mass as long as H_2 *dominates* the total mass.

* Empirical Linewidth-Size relation: $\sigma = C \times R^{0.5}$

→ $M_{vir} \propto \sigma^4$;
→ Molecular clouds that are virialized and following the Linewidth-Size relation show *characteristic* surface density Σ_{GMC} .

3) Molecular Mass Calculations: X_{CO}

* Unfortunately, L_{CO} also depends on temperatur. Thus, an an *isothermal* cloud has to be assumed.

The Mass-to-Light ratio is then given by:

$$\alpha_{CO} = \frac{M_{vir}}{L_{CO}} \approx 6.1 L_{CO}^{0.2} \, T_B^{-0.8} \, \Sigma_{GMC}^{0.6}$$

Assumptions made:

- Molecular clouds are virialized
- MC are dominated by H2
- MC rely on the empirical linewidth-size relation
- isotherm

3) Molecular Mass Calculations: X_{CO}

Widely used values:

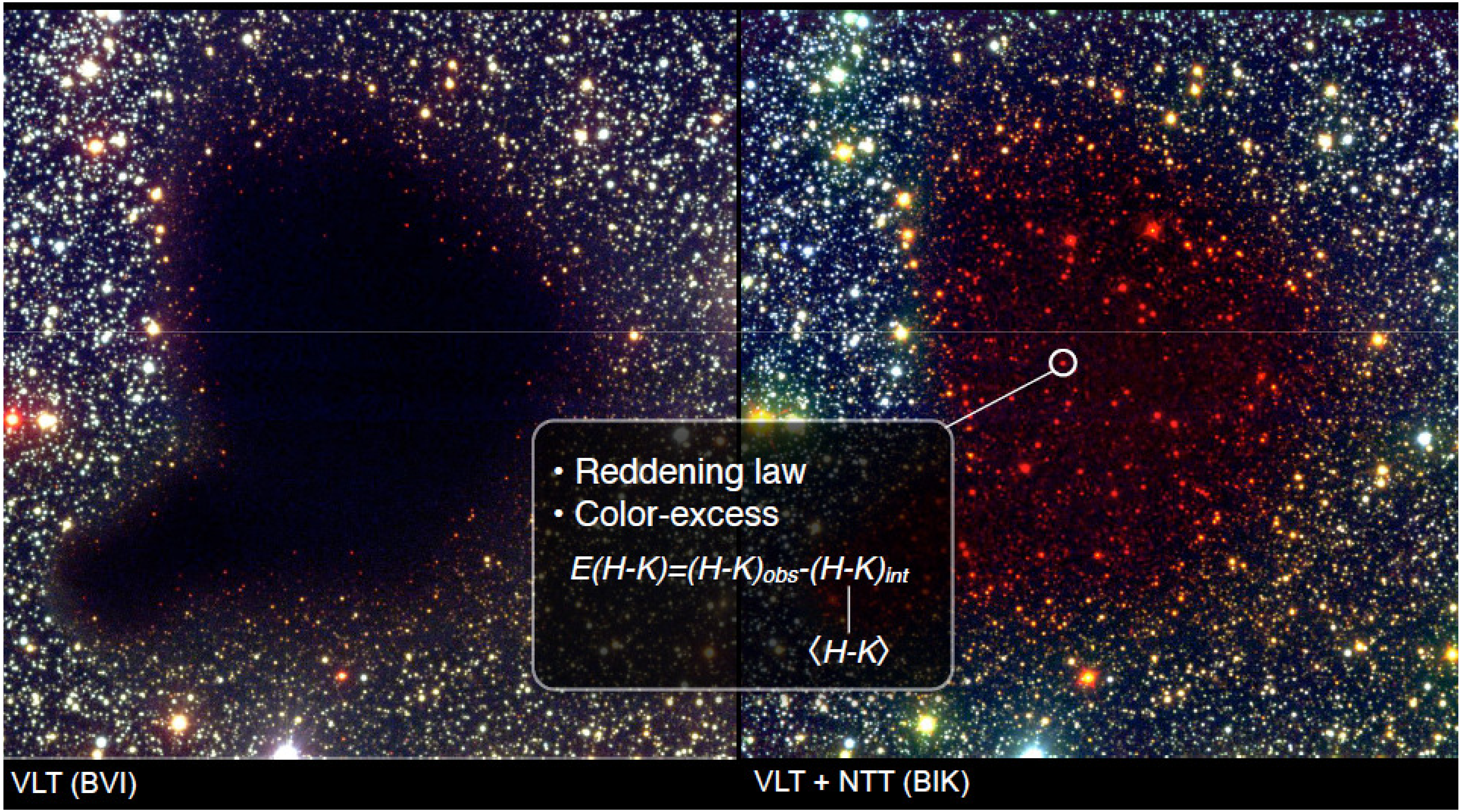
→ $X_{CO} = 0.8 \times 10^{20}$ for $L_{IR} > 10^{11}\ L_{\odot}$ (Downes & Solomon 1998)

→ $X_{CO} = 2.3 \times 10^{20}$ for $L_{IR} \leq 10^{11}\ L_{\odot}$ (Strong et al. 1988)

Unit: $(\mathrm{K\ km/s})^{-1}\ \mathrm{cm}^{-2}$

Better: Direct measurement of X_{CO}

3) Molecular Mass Calculations: X_{CO}



Alves et al. (2001), Nature

3) Molecular Mass Calculations: X_{CO}

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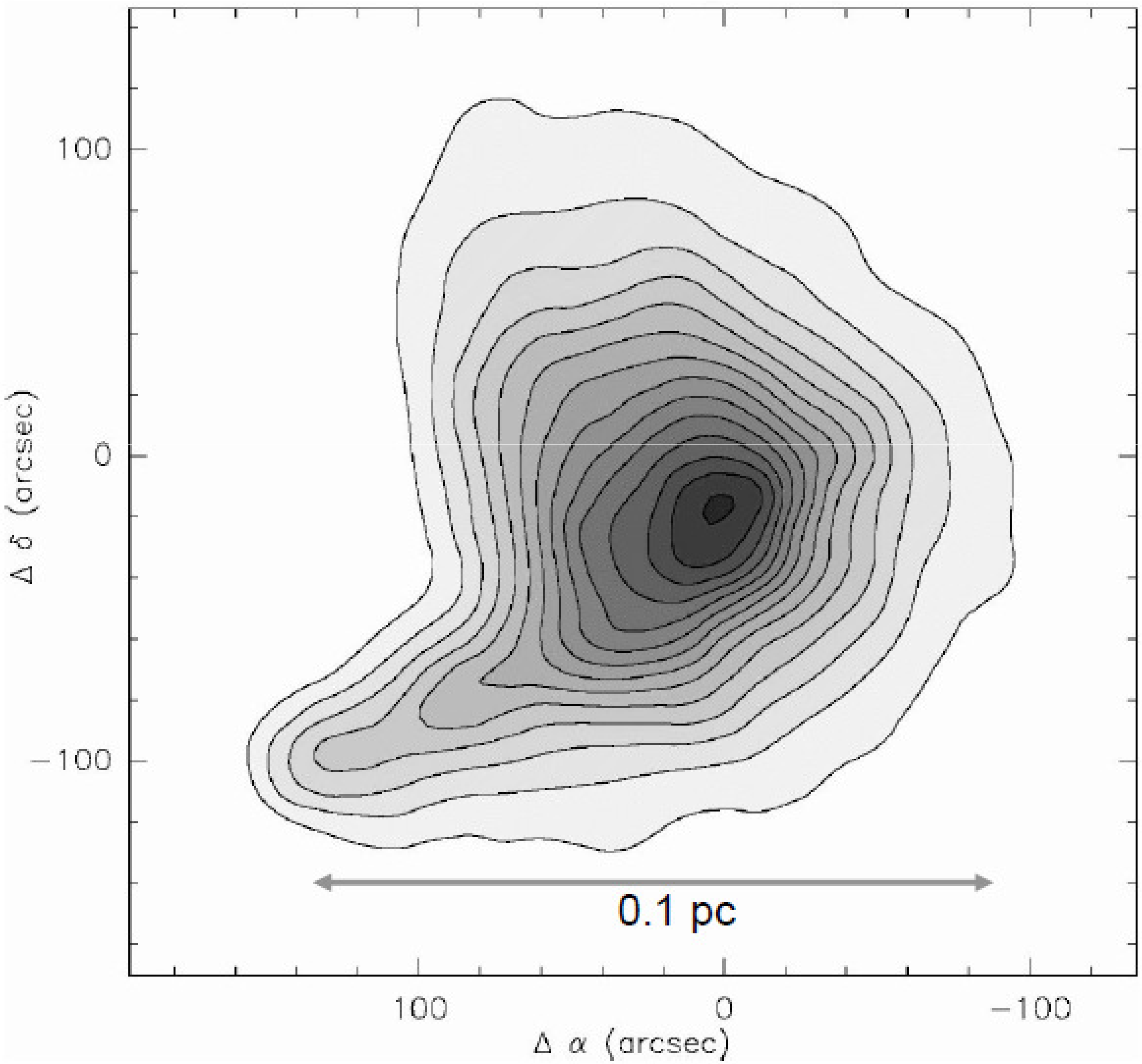


- **1 < Av < 33 mag, R=10"**
  First 10" resolution dust extinction map (1.5 dex higher spatial resolution than previously possible) and ~1order of magnitude better dynamic range.

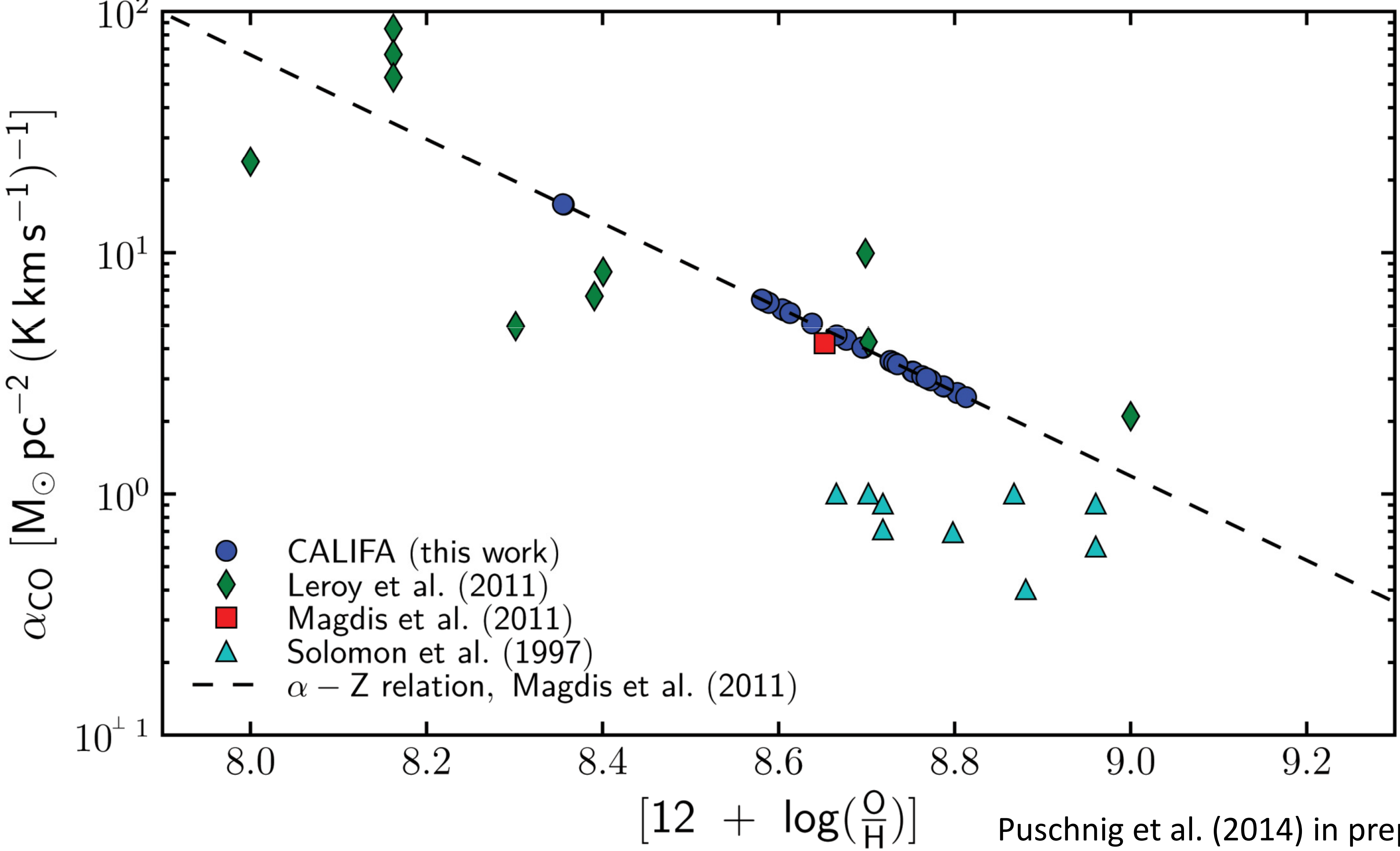
- **Mass: $1.2 \pm 0.1\ (d/100pc)^2\ M_{sun}$**
  $N(H+2H_2) = 2 \times 10^{21} cm^{-2}\ mag^{-1}$

  (Lilley 1955; Bohlin et al. 1978)
  The integration of the extinction map provides the most precise (accurate, apart a distance error) determination of mass of this molecular cloud.

- **Density Profile**
  This observations will allow the most finely sampled density profile of a cloud ever constructed.

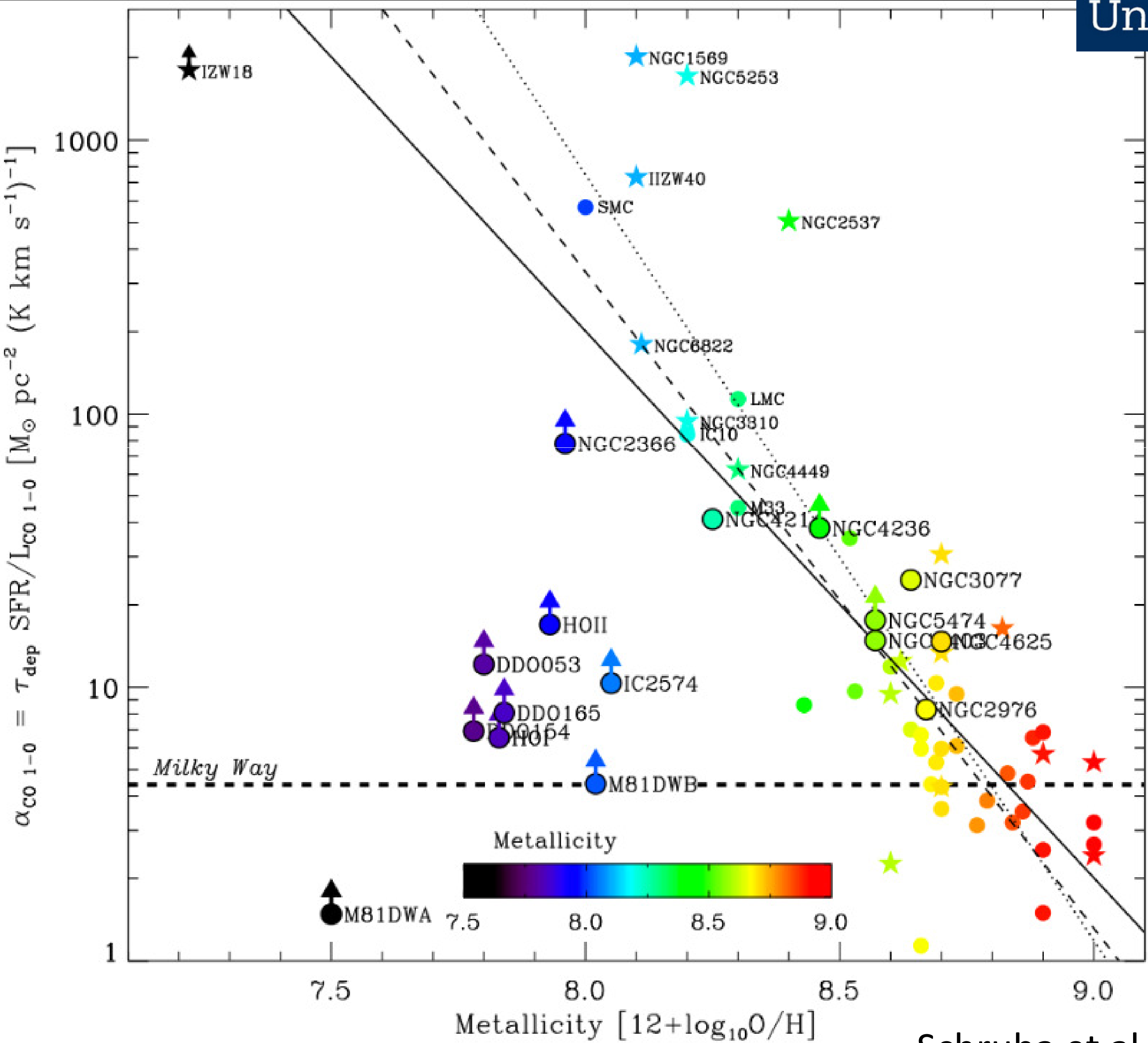
Alves et al. (2001), Nature

3) Molecular Mass Calculations: X_{CO}



Puschnig et al. (2014) in prep

3) Molecular Mass Calculations: X_{CO}



Schruba et al. (2012), Nature

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4) LARS at 22µm

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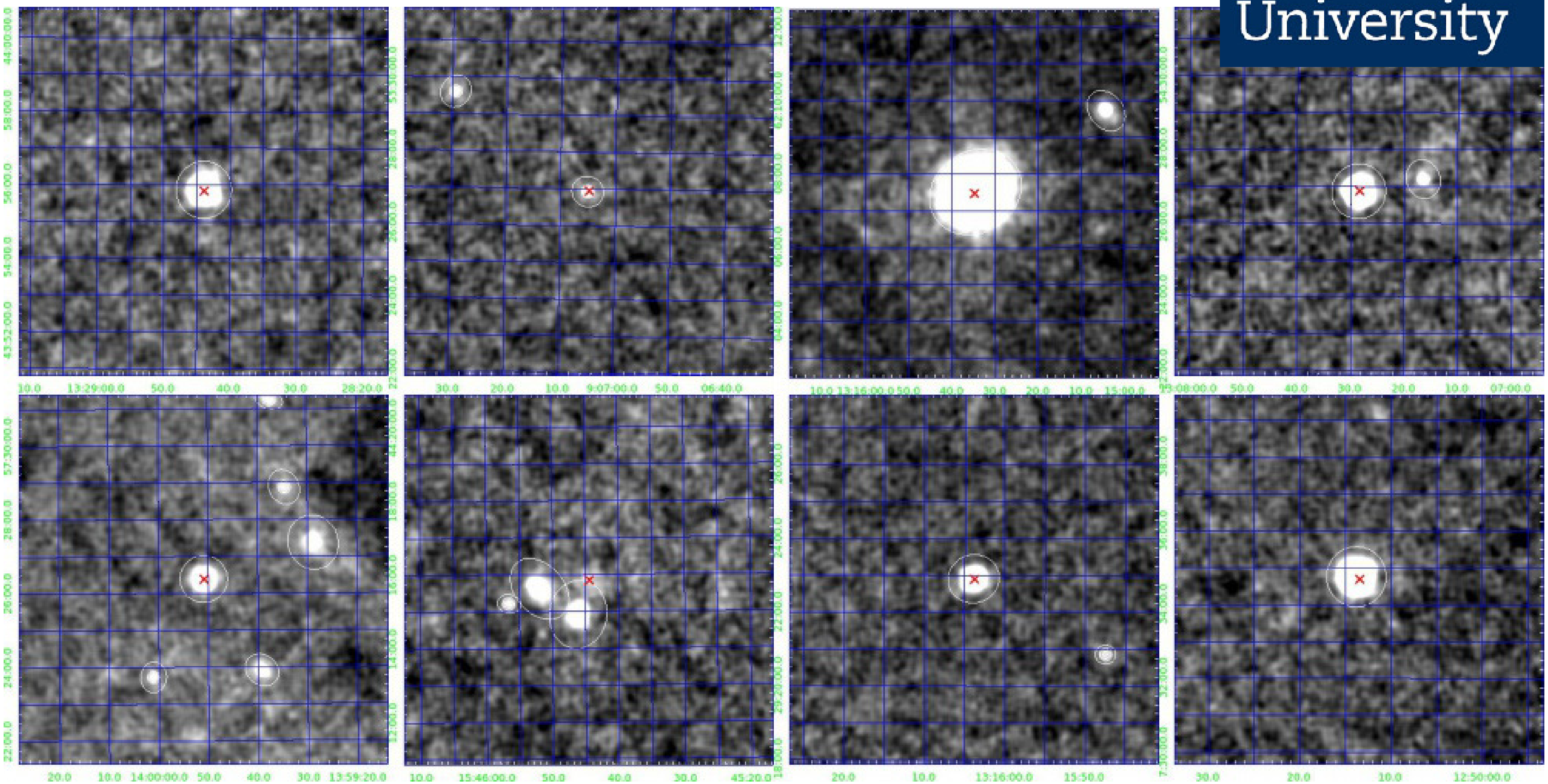
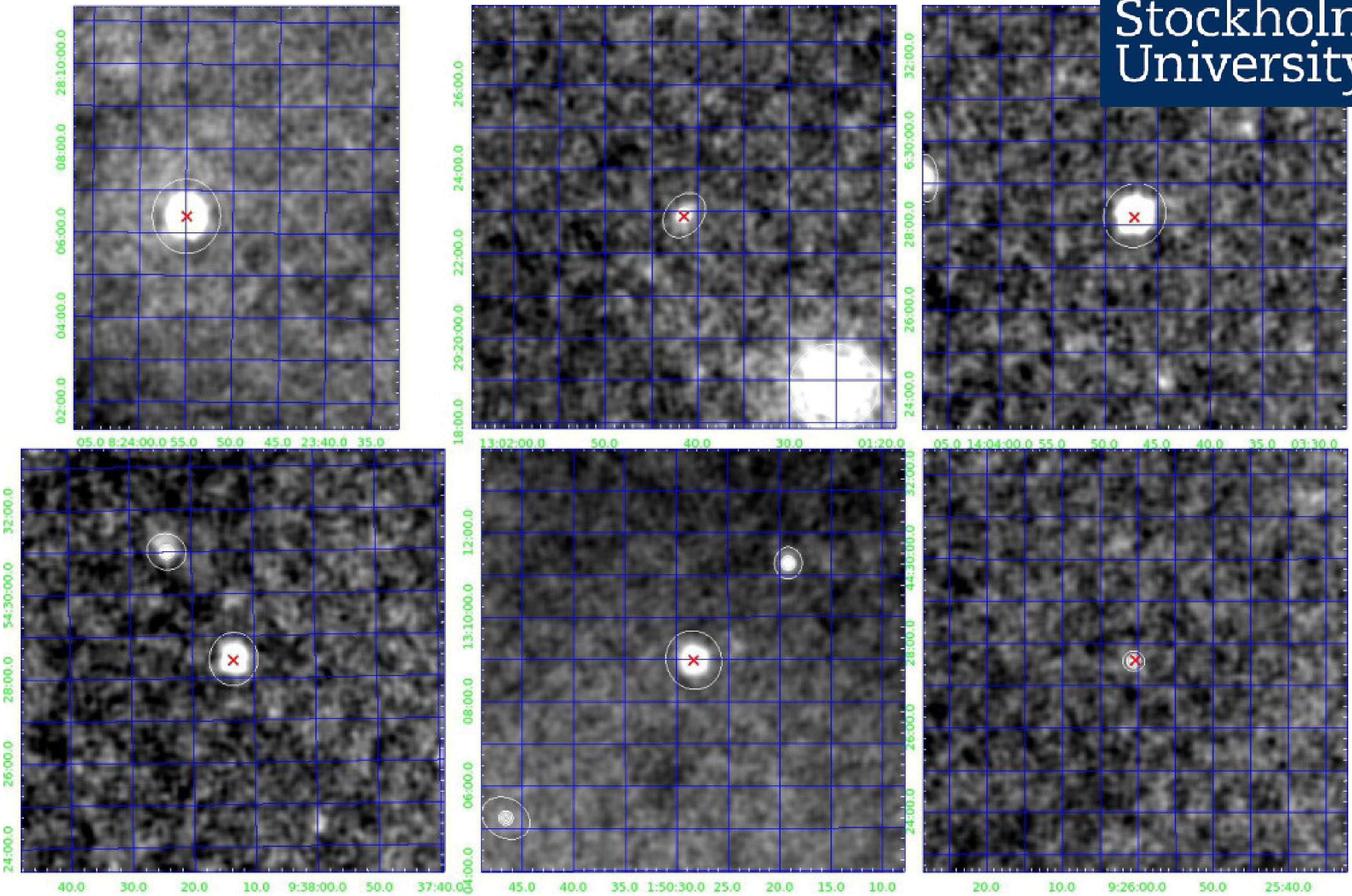
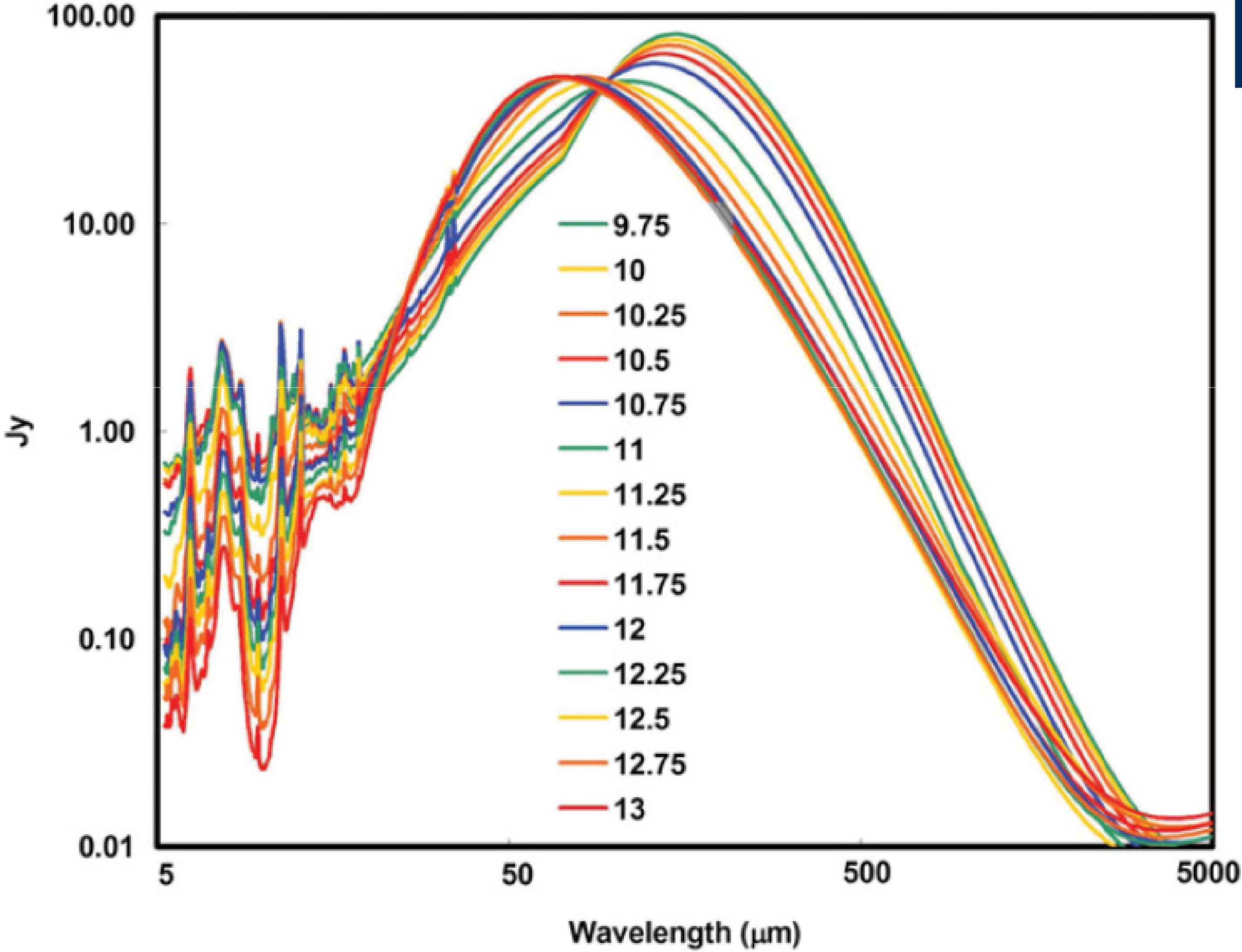


4) LARS at 22µm



4) Local (U)LIRG Templates



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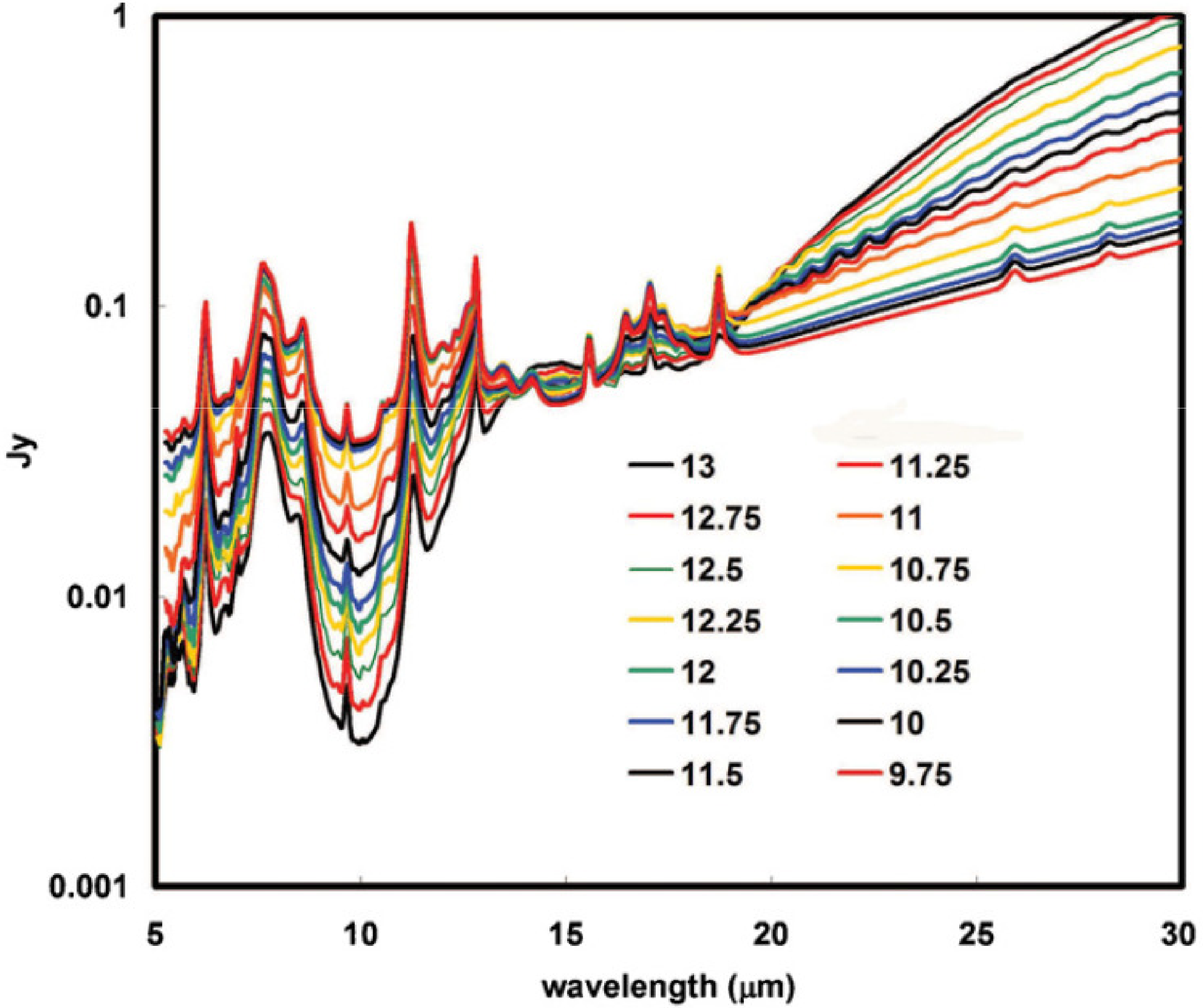
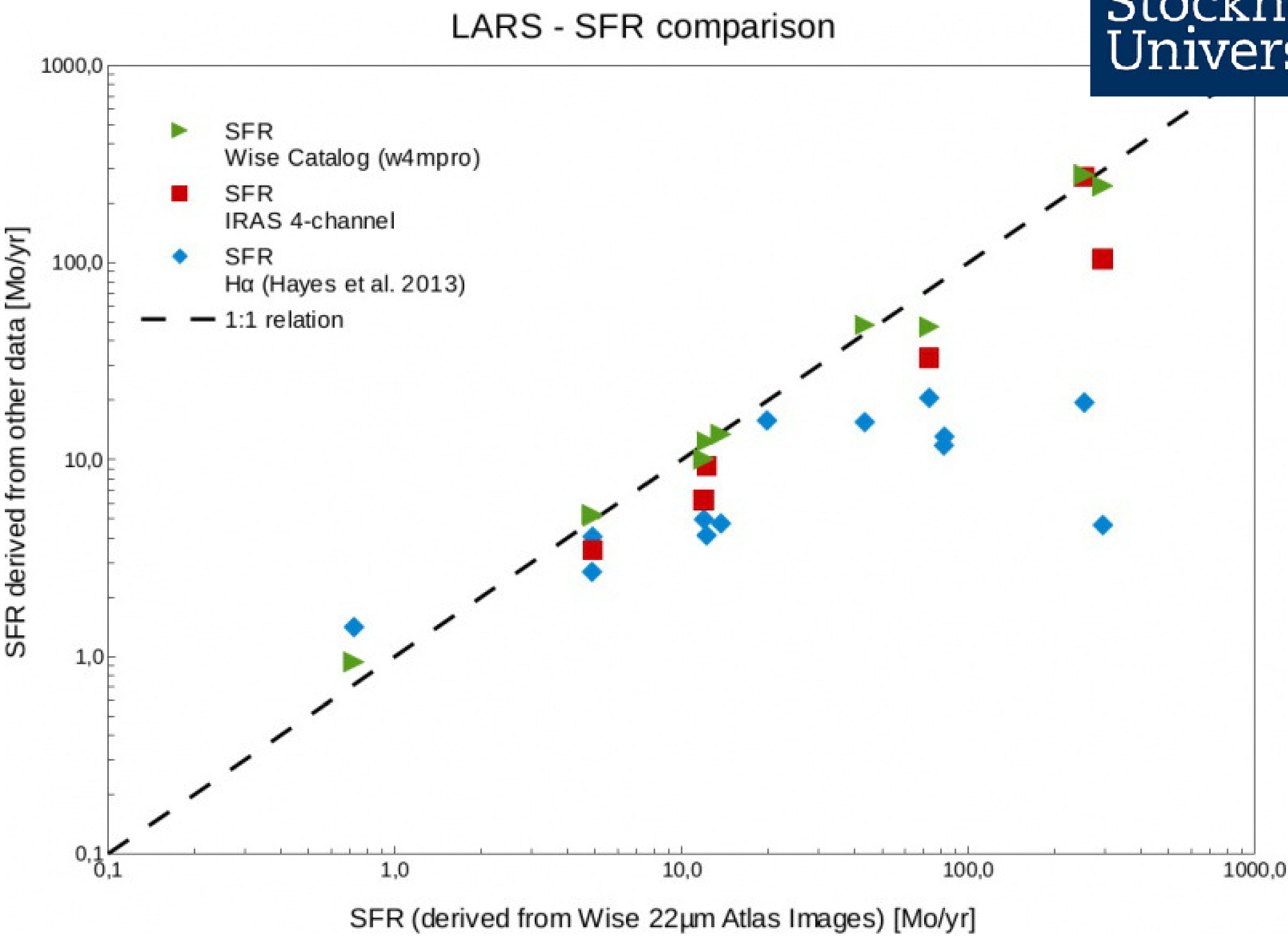


4) SFRs for LARS galaxies



5) Molecular Gas in LARS?

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CURRENT PROPOSALS

Single Dish:

* NRO 45m (37h total): LARS 01, 08, 09, 11 (APPROVED)
* LMT 30m (12h on-source): LARS 09, 10, 11, 12, 13 (REJECTED)
* IRAM 30m (66h total): LARS 04, 07, 13 (?)

Interferometry:

* CARMA (84h total, 2 transitions): LARS: 08, 09 (REJECTED)
* PdBI (15h total): LARS 03 (?)

6) Conclusions

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- Need more CO data, especially spatially resolved.
- X_{CO} derivation is a complex problem. Empirical relations have to be used and many assumptions have to be made. Validity should be discussed for each galaxy individually.
- SFR correlates almost linearly with H2
- Above a surface density threshold of around 9 M_{Sun} per pc^2 gas phase transition occurs.
- Molecular gas SFE, accordingly the molecular gas depletion time is almost fixed for normal spirals with a value of approx. 1Gyr.

Thank you for listening!