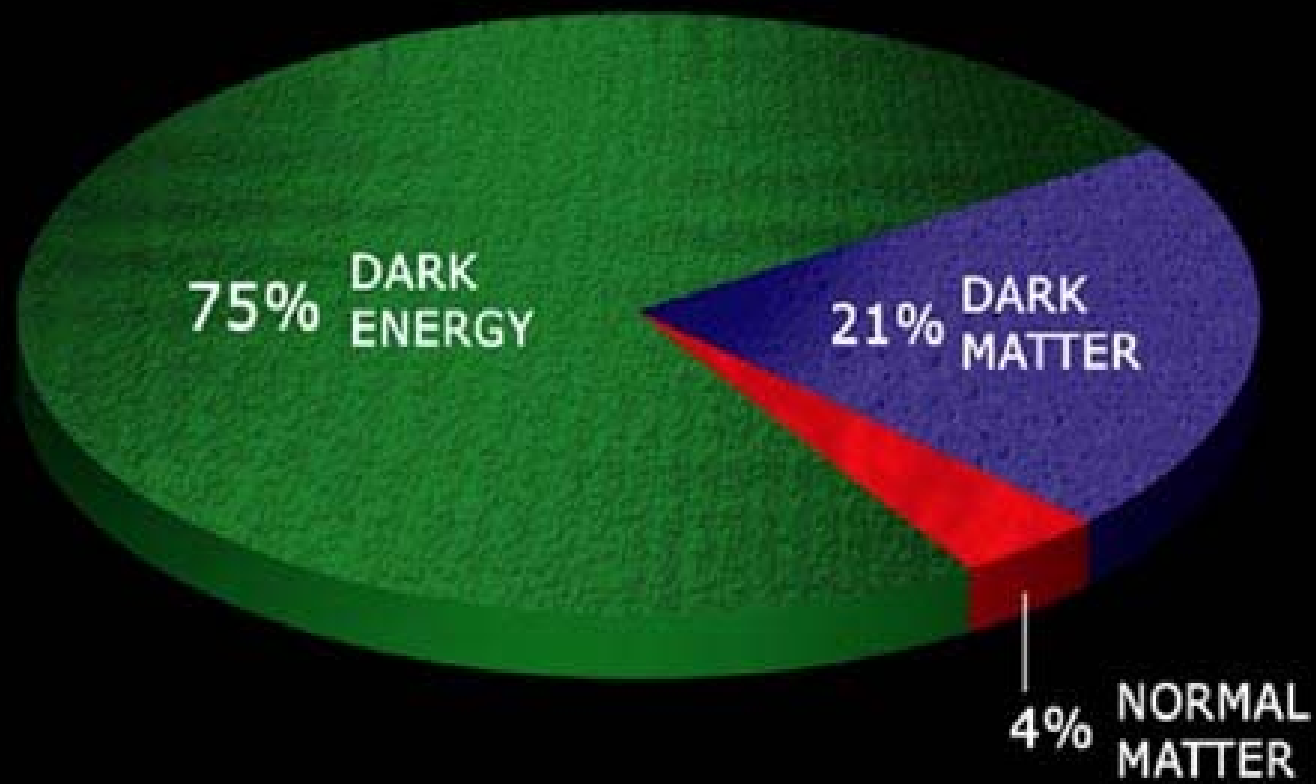




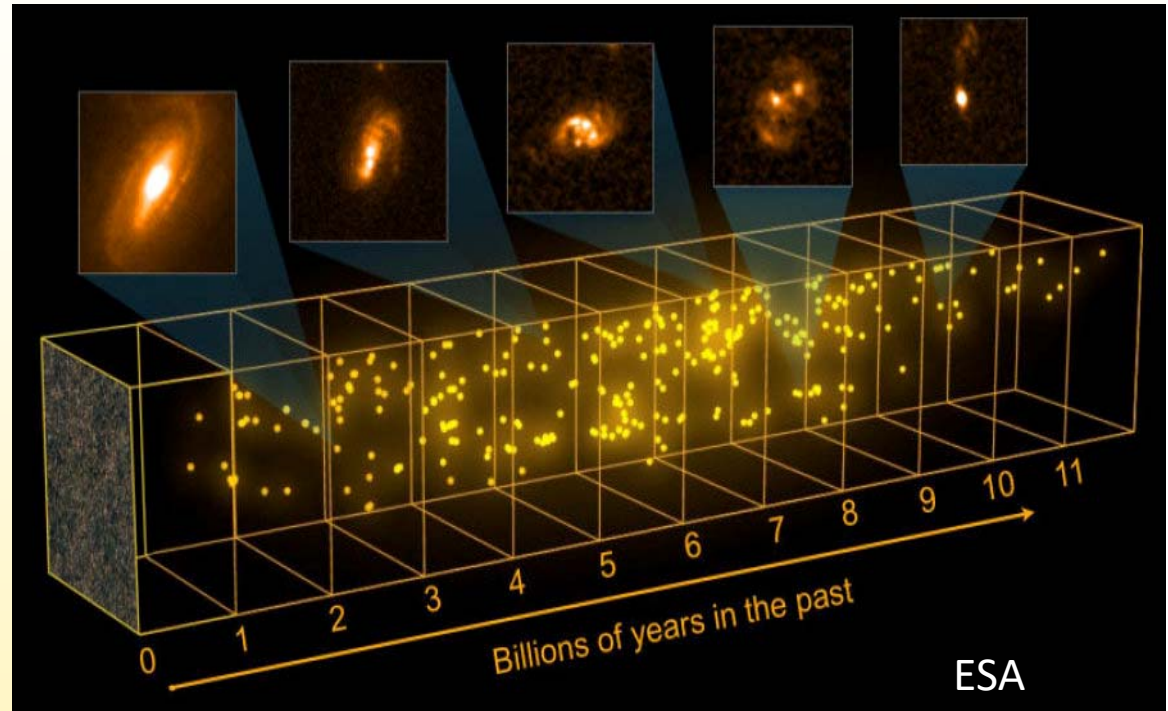
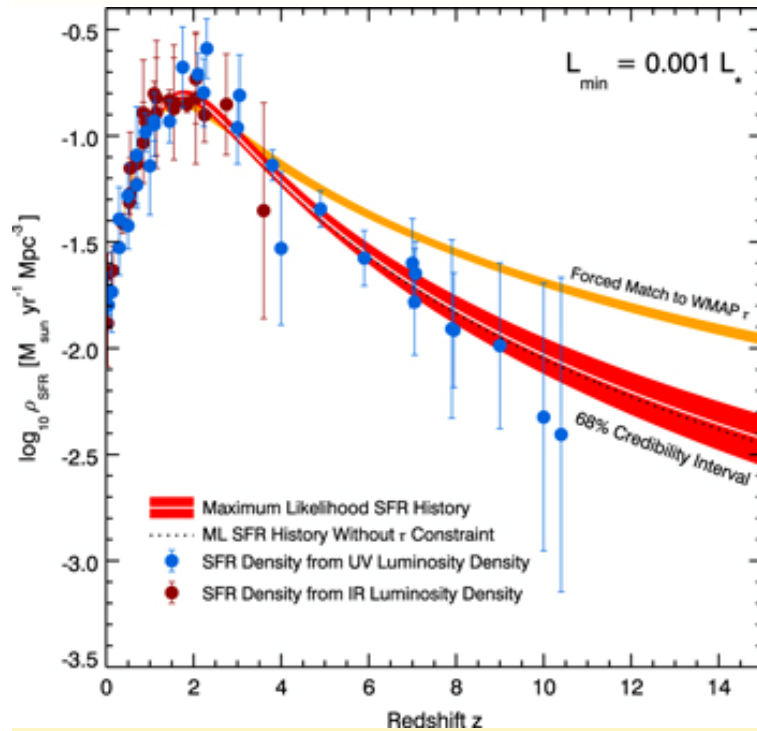
Star formation and molecular gas in local extremely metal-poor galaxies

Yong Shi (Nanjing University)

Collaborators: Junzhi Wang (SHAO, China), Zhi-Yu Zhang (Edinburgh, England), Lee Armus (Caltech, US), George Helou (Caltech, US), Yu Gao (PMO, China), Qiusheng Gu (NJU, China), Sabrina Stierwalt (U.of Virginia, US),

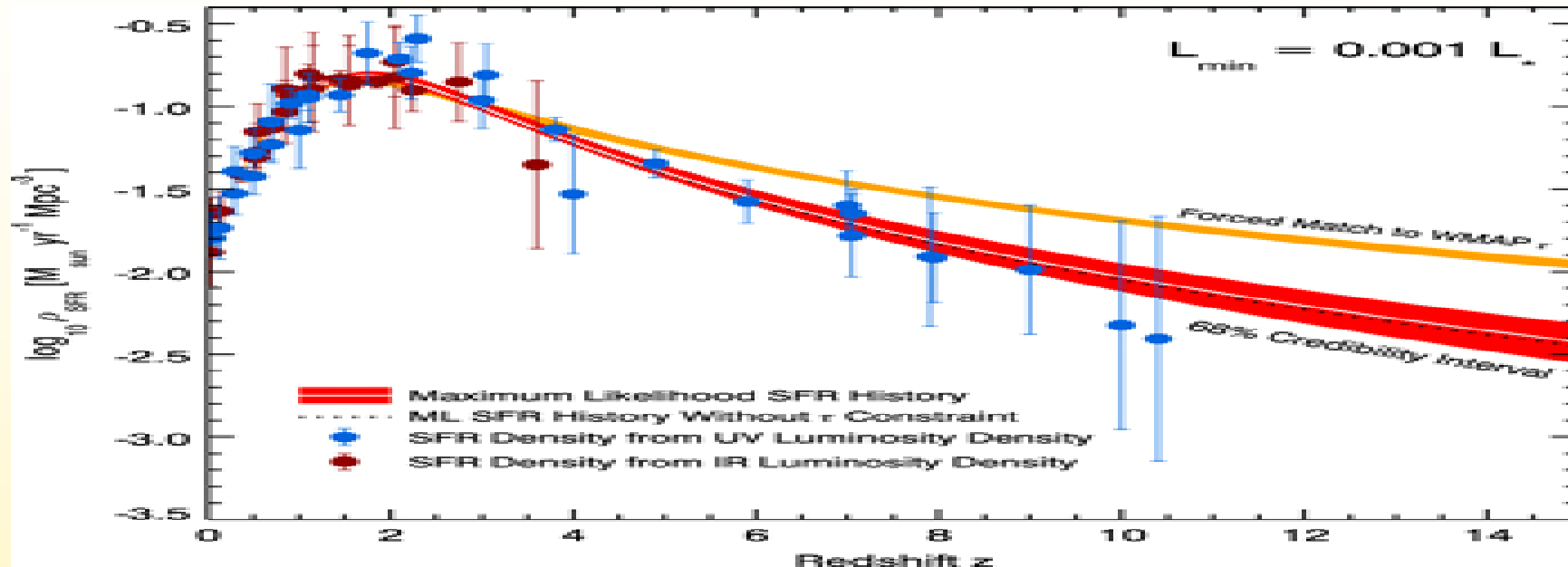


Cosmic evolution of star formation rate densities:



Madau & Dickinson (2014); Madau 1996; Lilly 1996

What drives cosmic SFR evolution?



How does it start?

metal-free/metal-poor primordial gas.

Introduction

- **Current facilities are limited in the abilities to probing star formation and ISM in the early Universe!**
- **Using nearby extremely metal poor galaxies as **local laboratories**.**

Extremely metal poor galaxies: $Z < 1/10 Z_{\odot}$

Outline

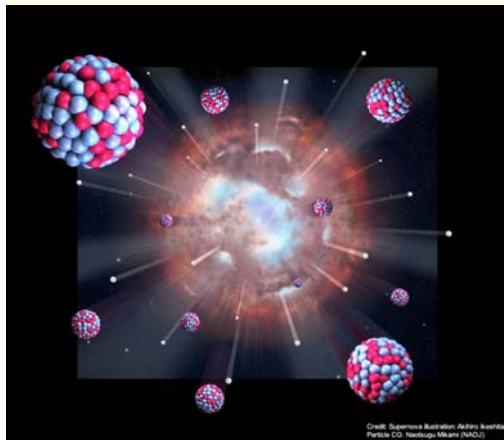
- Star formation efficiency at extremely low metallicity.
- Molecular gas at extremely low metallicity.

1. Star formation at low metallicity

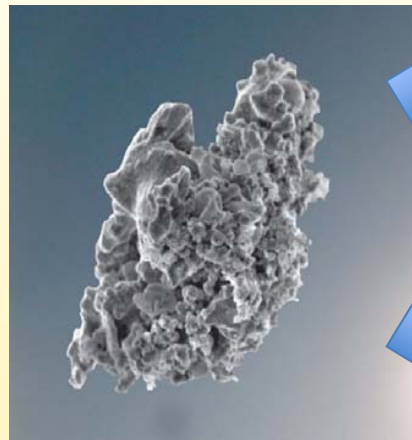


1. Star formation at low metallicity

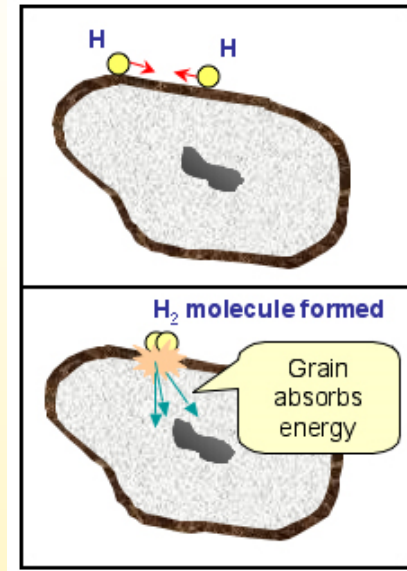
metals



dust grains

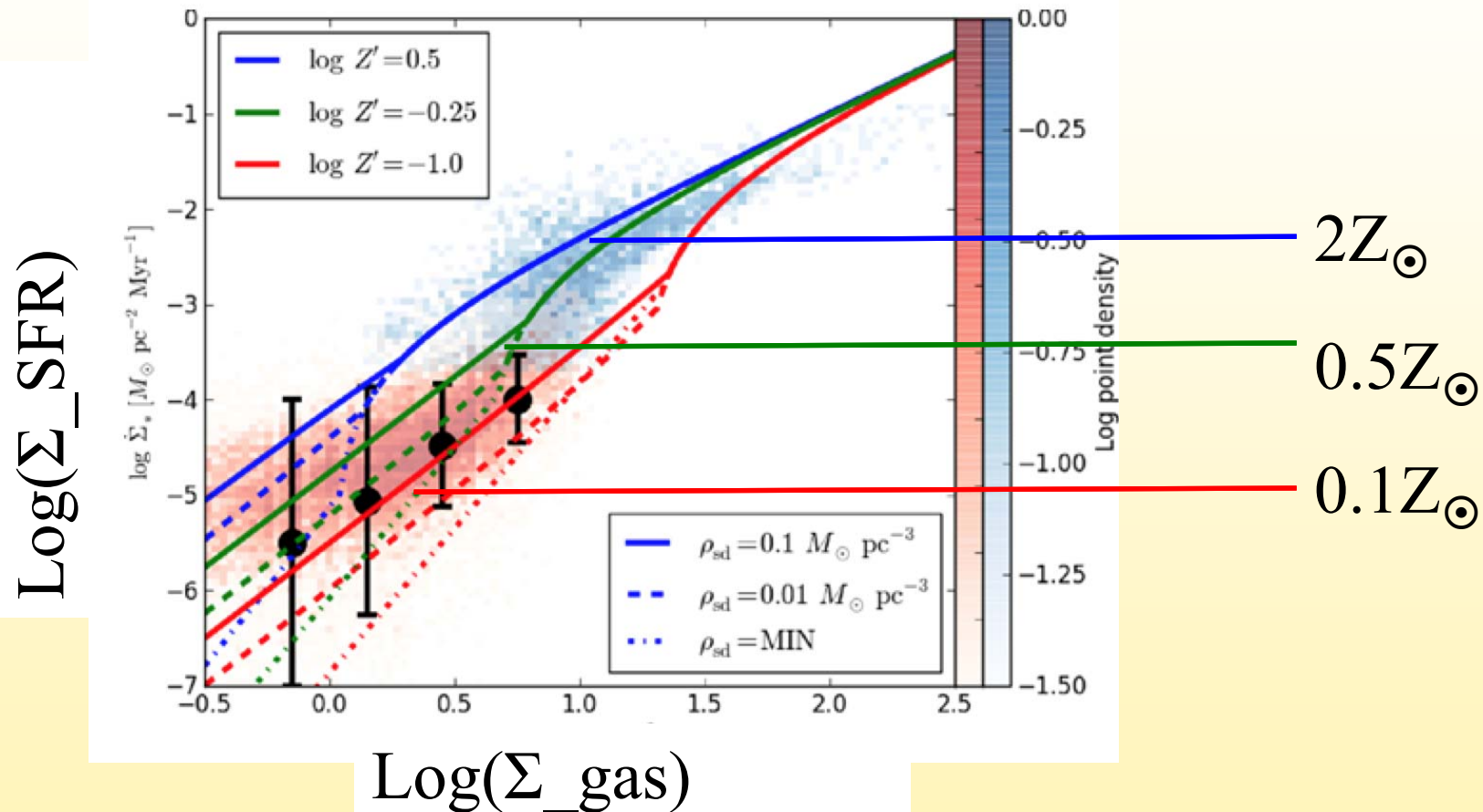


H₂ Formation



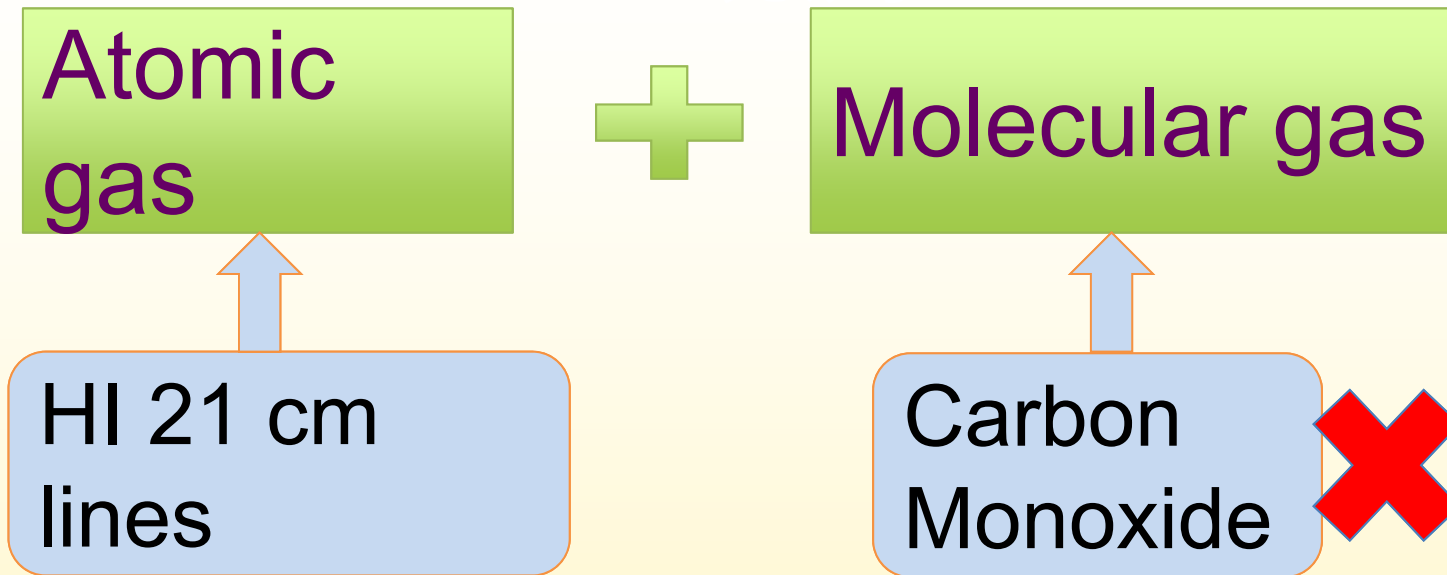
Efficient Cooling!

1. Star formation at low metallicity



Krumholz 2013, MNRAS (also see Ostriker et al. 2010, ApJ; Dib 2011 ApJL)

1. Star formation at low metallicity



CO is a poor tracer of H_2 in metal poor galaxies:

faint and unknown CO-to- H_2 factor.

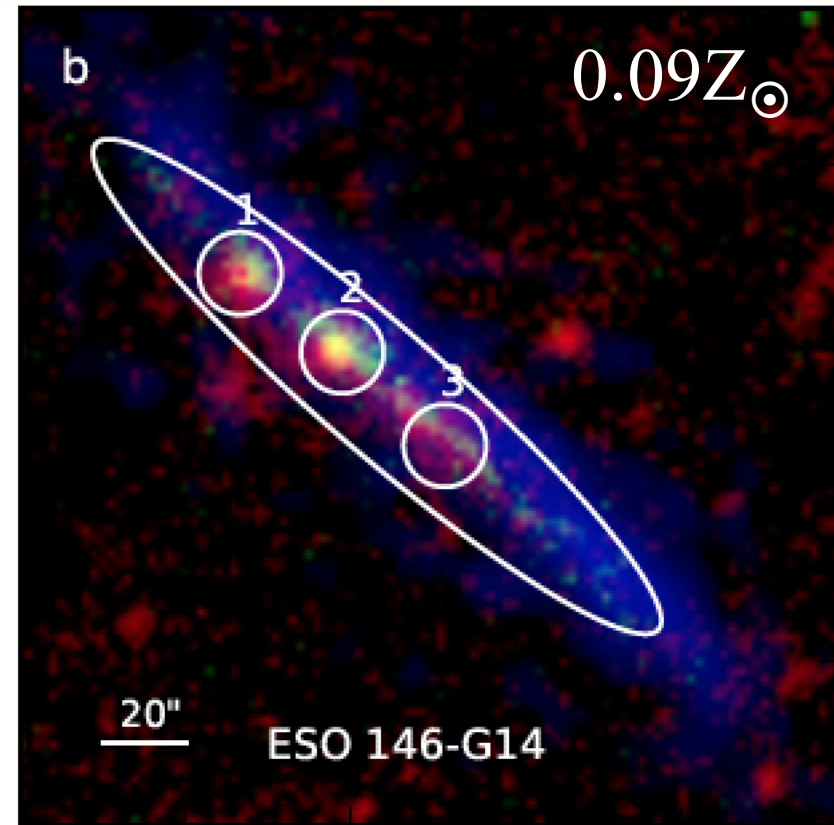
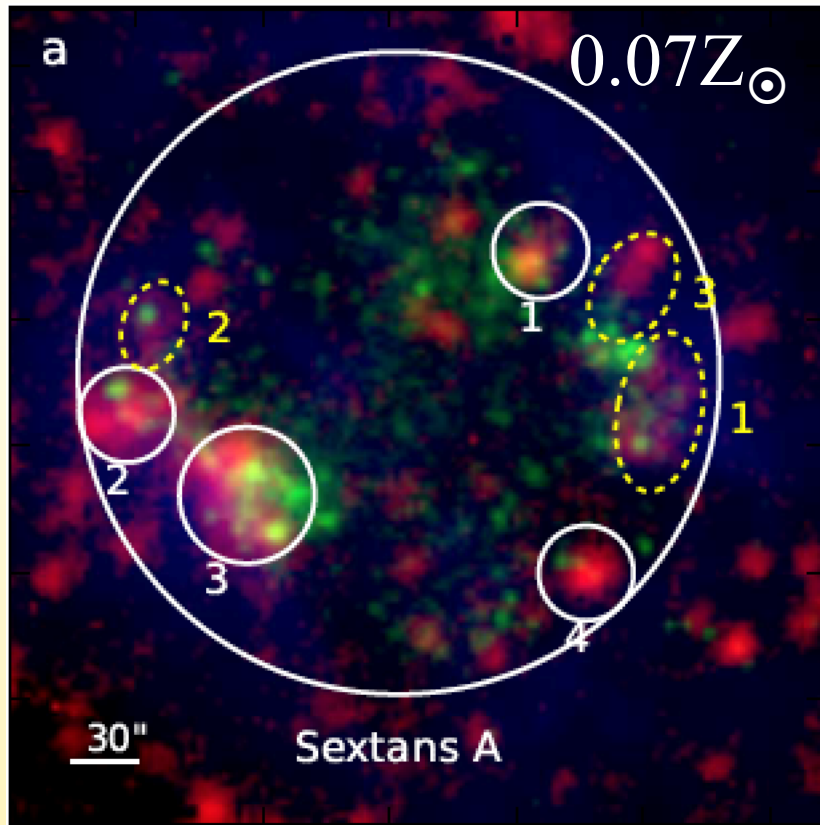
→ Employ dust to trace the cold gas content, with gas-to-dust ratio.

1. Star formation at low metallicity



1. Star formation at low metallicity

Sample (PI: Y. Shi)



Blue: HI gas, Green: Far-UV, RED: 70+250 um

1. Star formation at low metallicity

Spatially Resolved Dust Map!

Diffuse Region!

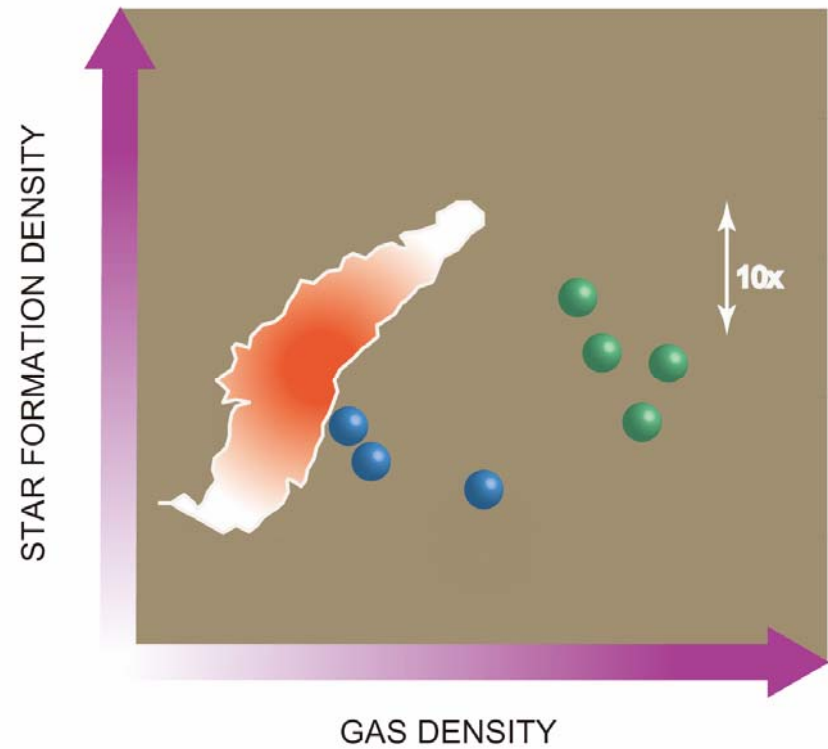
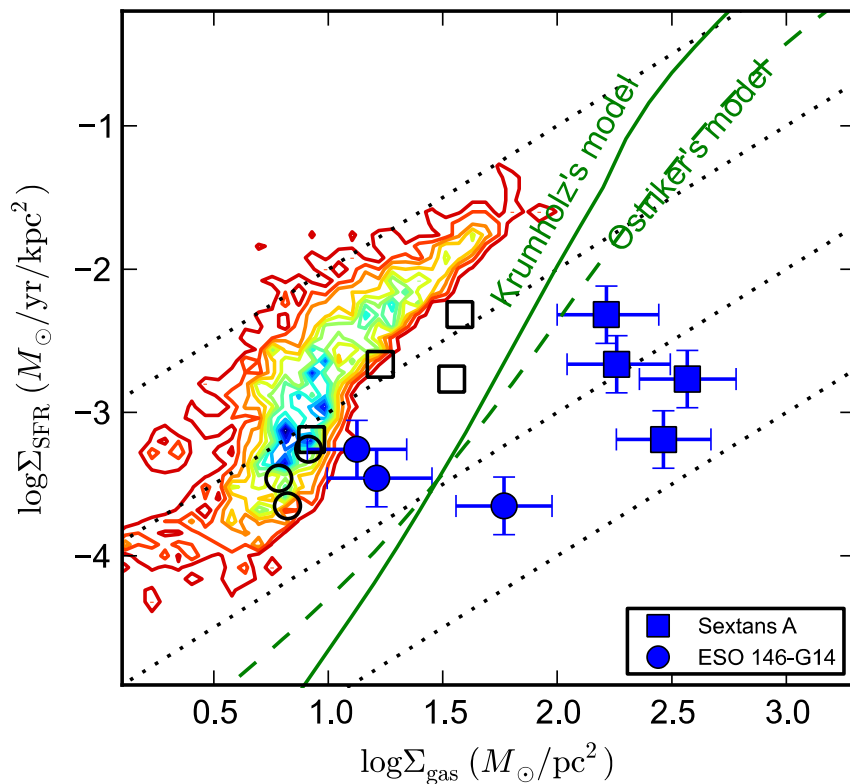
Star Forming Regions!

$GDR = \text{total-gas}(=HI\text{-gas-mass}) / \text{dust-mass}$

$GDR \times \text{Dust-Mass} = \text{Total Gas Mass}$

Inefficient star formation in extremely metal poor galaxies Shi et al. 2014 Nature

Yong Shi^{1,2}, Lee Armus³, George Helou³, Sabrina Stierwalt⁴, Yu Gao^{5,6}, Junzhi Wang⁷, Zhi-Yu Zhang⁸ & Qiusheng Gu^{1,2}



2. Molecular gas at low metallicity

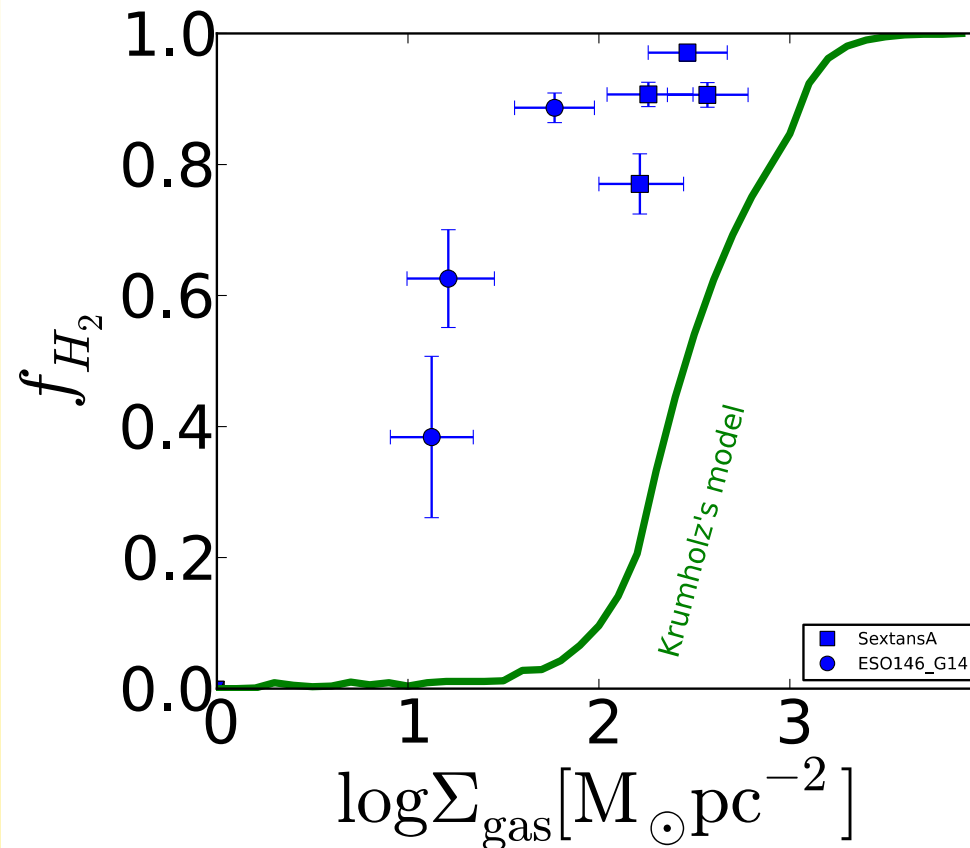
Material fuels for star formation at extremely low metallicity?

H_2 vs HI



2. Molecular gas at low metallicity

A much higher molecular gas fraction is seen than models' predictions (Shi et al. 2014 Nature).

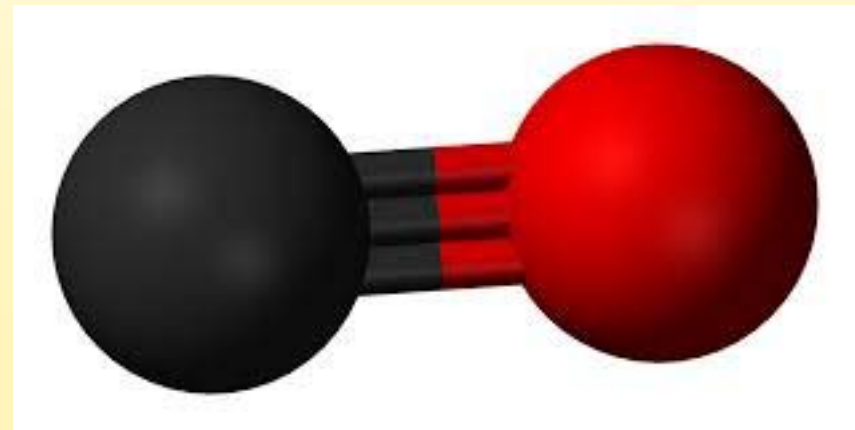


2. Molecular gas at low metallicity

CO offers a **direct** evidence for the existence of cold molecular gas in which star formation takes place.

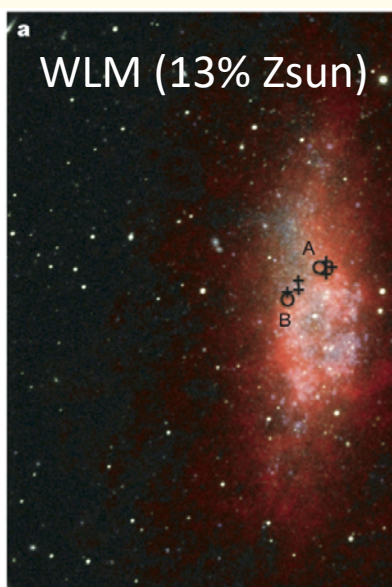
$$L_{\text{CO}} \times \alpha_{\text{CO}} = \text{H}_2 \text{ mass}$$

CO Dipole Mom.
excited at very low T.

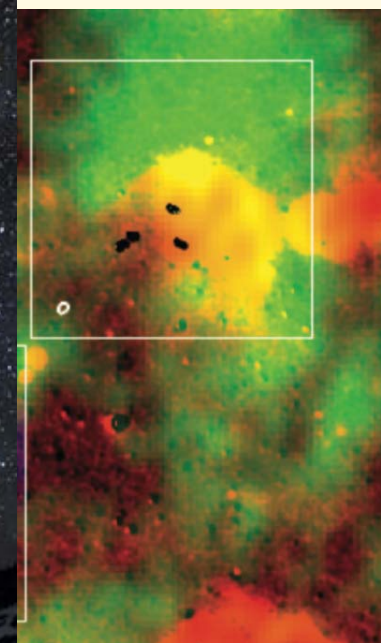


2. Molecular gas at low metallicity

No CO has been seen < 10% Solar, arising questions if star forms in molecular gas or just in atomic gas.



Elmegreen et al. 2005

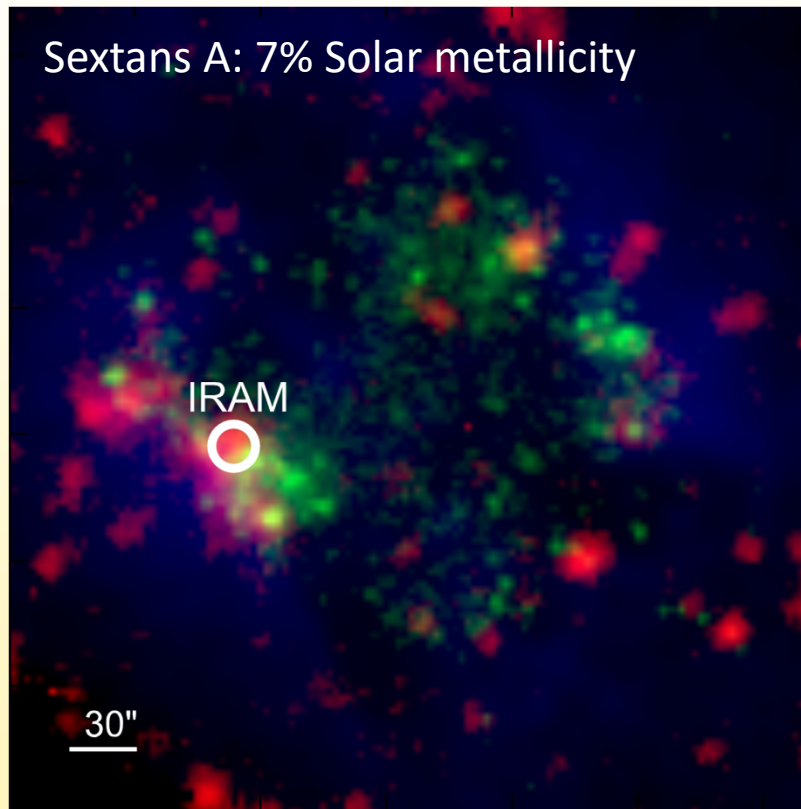


Nature, 525, 219

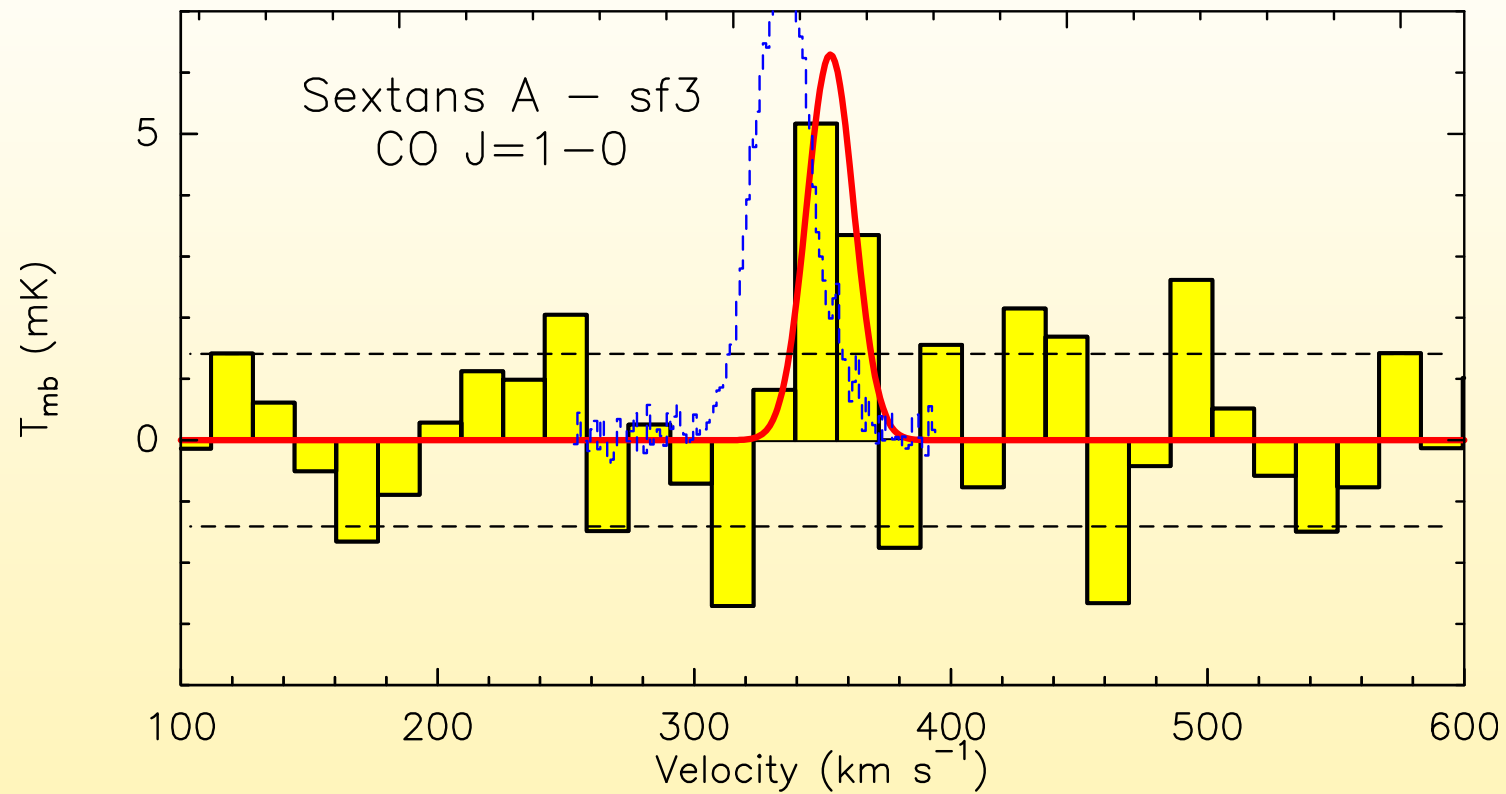
2. Molecular gas at low metallicity

- | | | |
|-----------------------|---------------------------|--------|
| • Leroy +2007 | PdBI | Failed |
| • Schrubba+2012 | IRAM 30m | Failed |
| • Warren+2015 | CARMA | Failed |
| • Amorin+2016 | IRAM 30m | Failed |
| • ALMA archive | ALMA (Sextans A, 10 mins) | Failed |
| • ALMA archive | ALMA (Sextans A, 1 hrs) | Failed |
| • Hunt et al. 2015 | ALMA (SBS 0335, 2.6 hrs) | Failed |
| • Cormier et al. 2017 | ALMA (SBS 0335, 2.7 hrs) | Failed |

2. Molecular gas at low metallicity

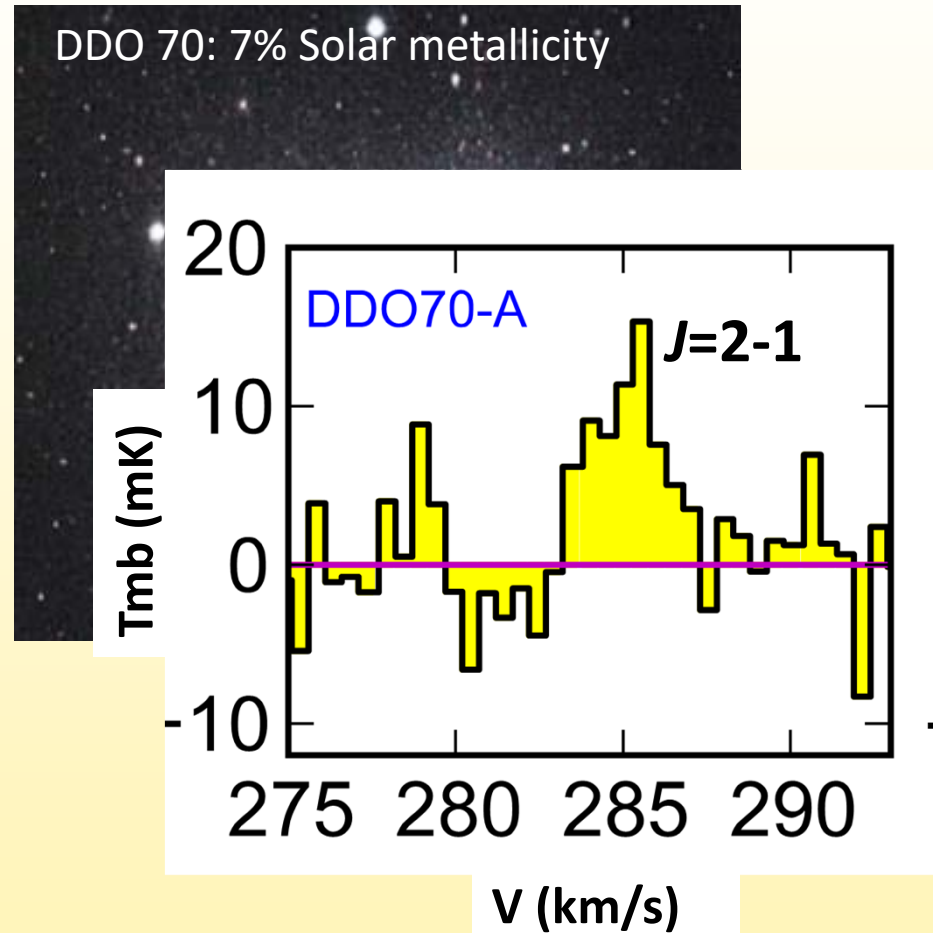


2. Molecular gas at low metallicity



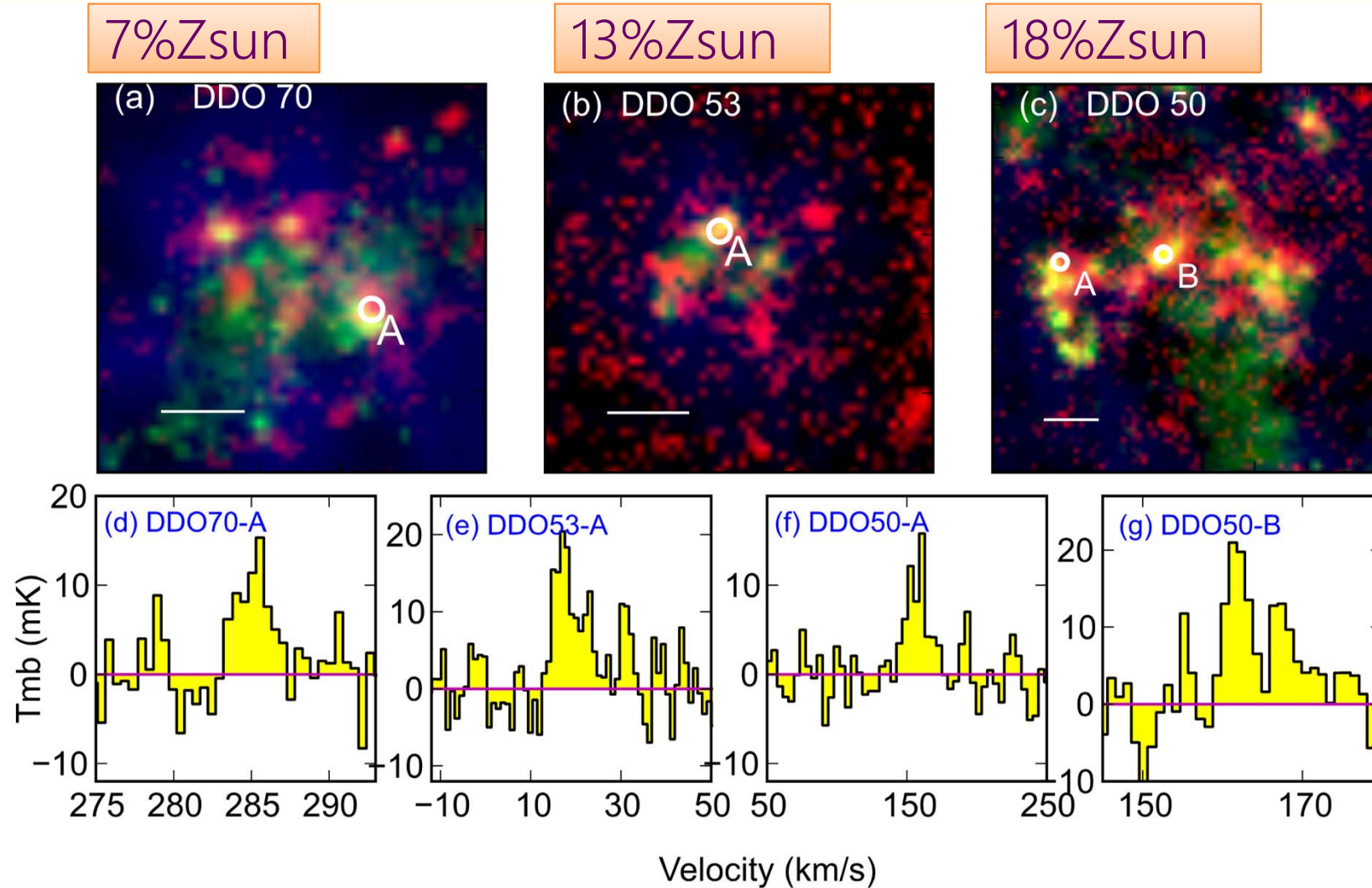
Shi et al.2015 ApJL

2. Molecular gas at low metallicity

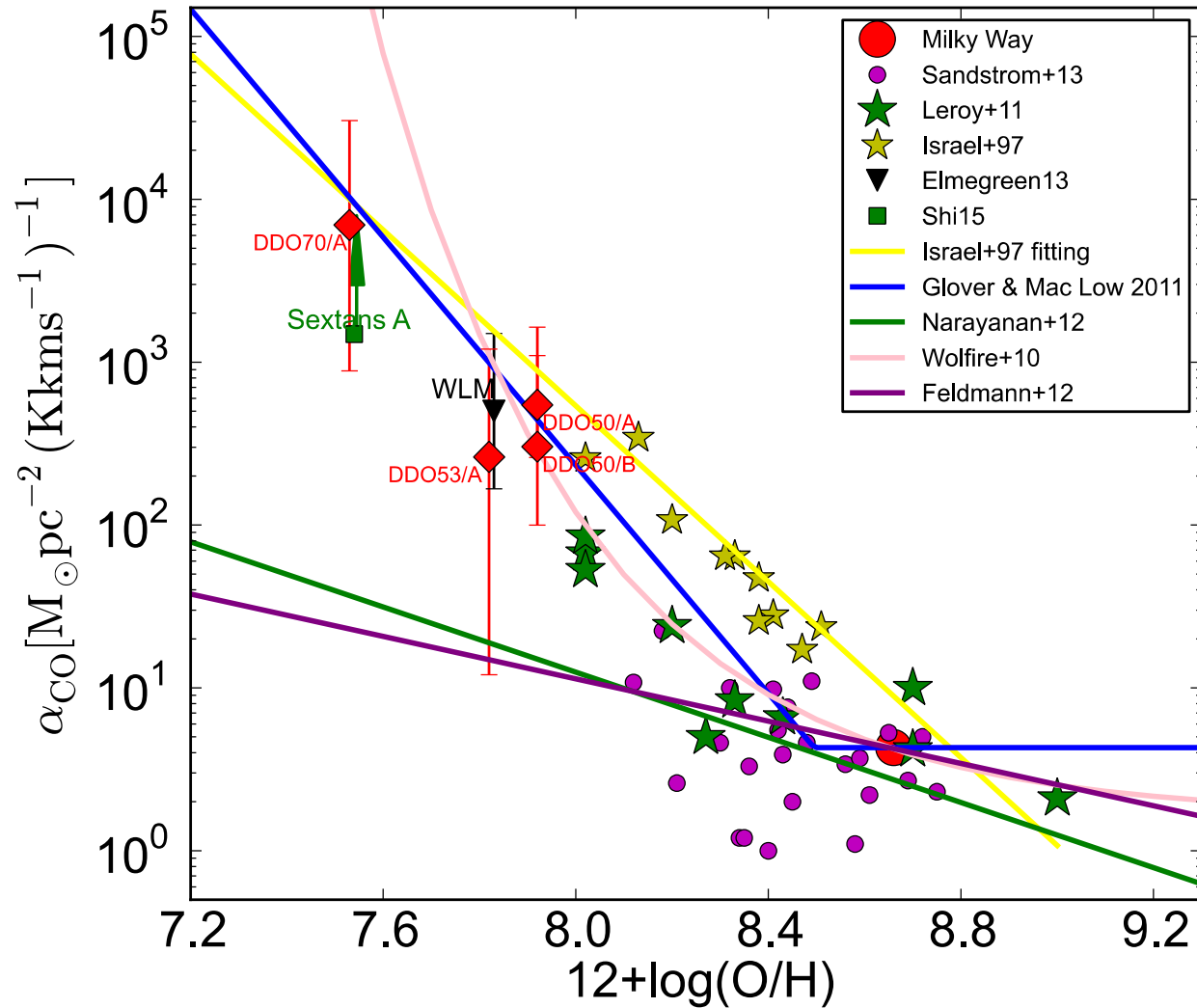


Shi et al. 2016, Nature Communication

2. Molecular gas at low metallicity



2. Molecular gas at low metallicity



2. Molecular gas at low metallicity

2016.1.00359.S

Resolving Carbon Monoxide Emission In An Extremely Metal Poor Galaxy

Yong Shi

(open-time, grade A)

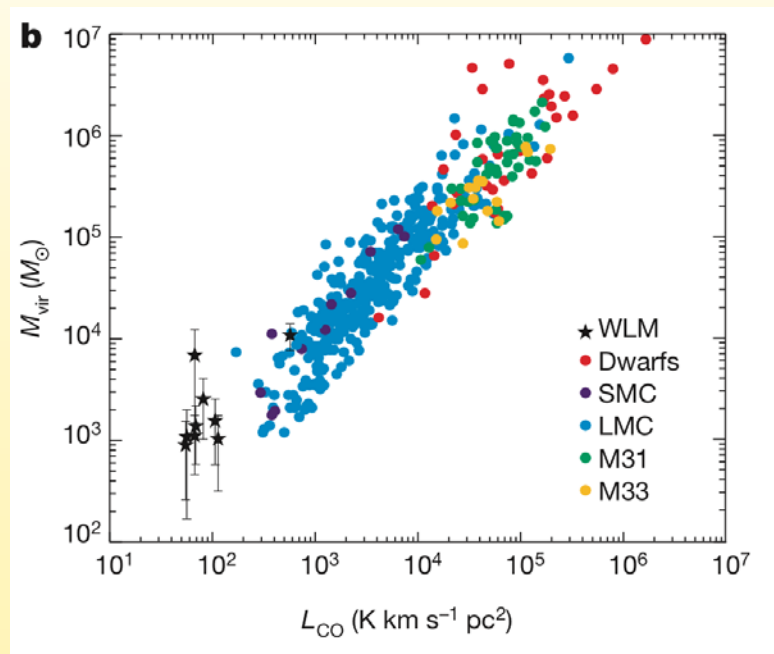
➤ $0.1'' = 0.7 \text{ pc}$

➤ 0.3 km/s



2. Molecular gas at low metallicity

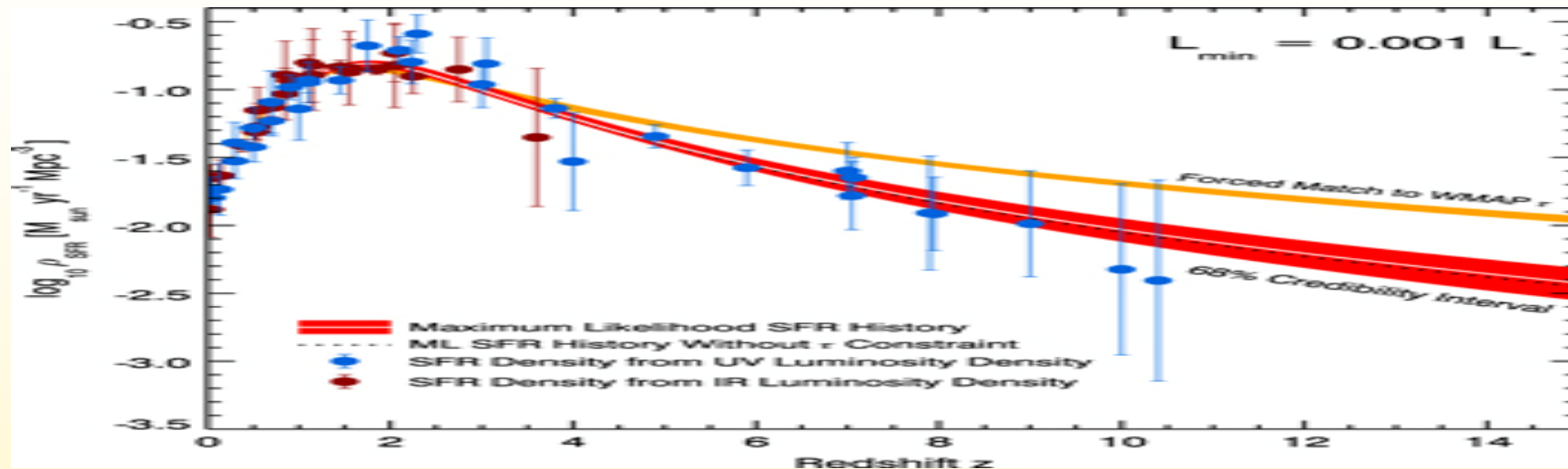
To test at **sub-pc scale**, if star-forming clouds at very low metallicity are different or the same as those in the Milky Way.



Larson's Law

Rubio, Elmegreen et al. 2015 Nature

What drives cosmic SFR evolution?



How does it start? metal-free/metal-poor primordial gas.

- (1) Decreased SFR/gas-mass in very metal-poor gas.
- (2) Existence of molecular gas at very low metallicity.