Warm Molecular Hydrogen at high redshift with JWST

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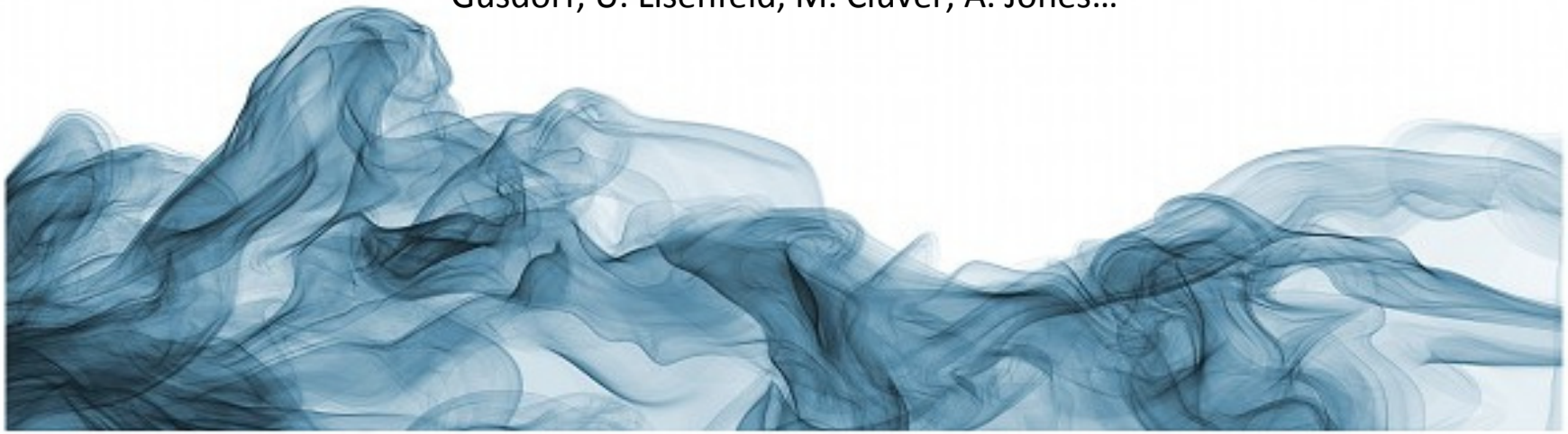
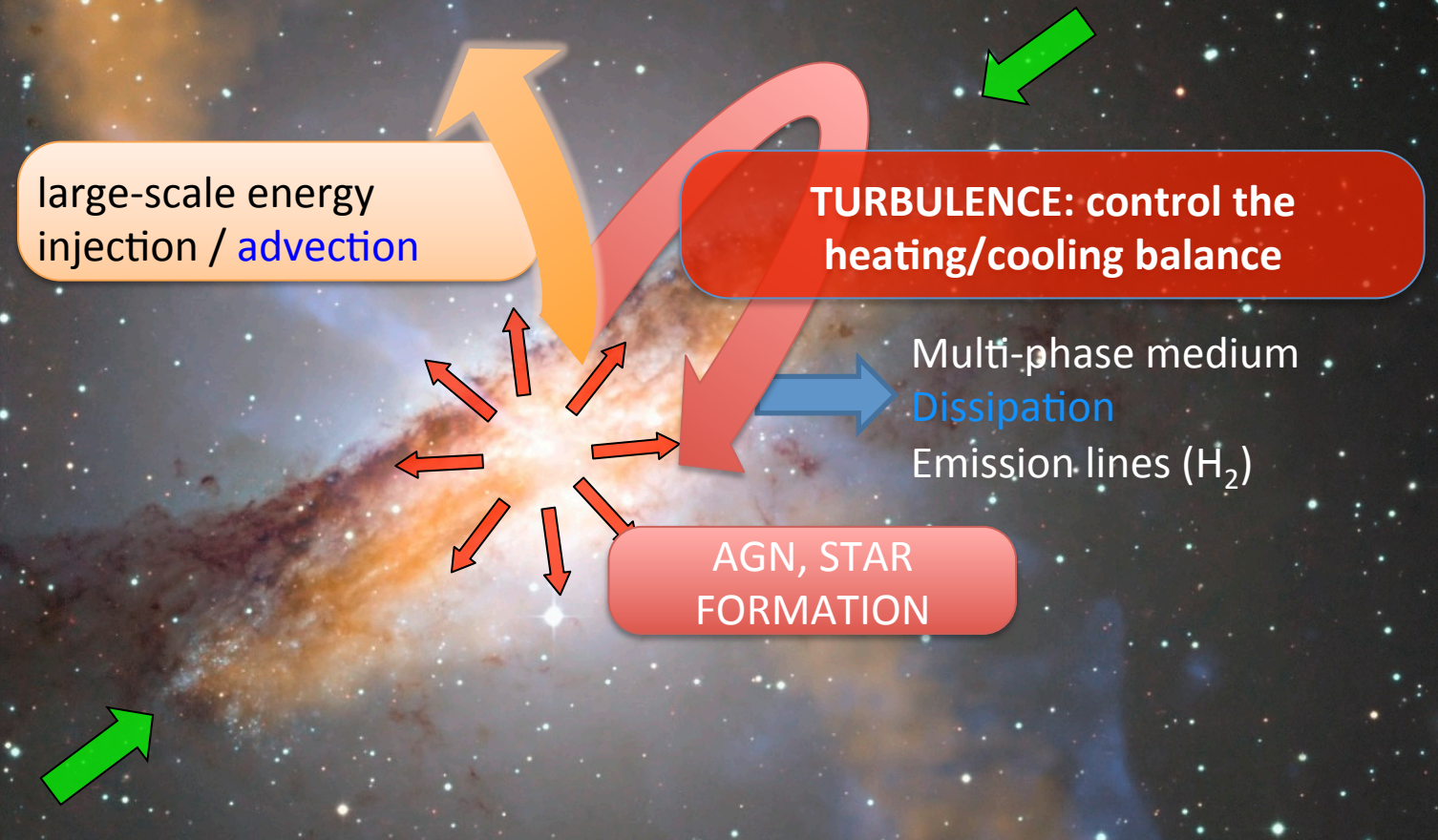


Gas Heating and Cooling in galaxy assembly

Cen A



JWST obs: cooling, dissipation & dynamical timescales

2

Warm H_2 with JWST

Outline and take-home messages

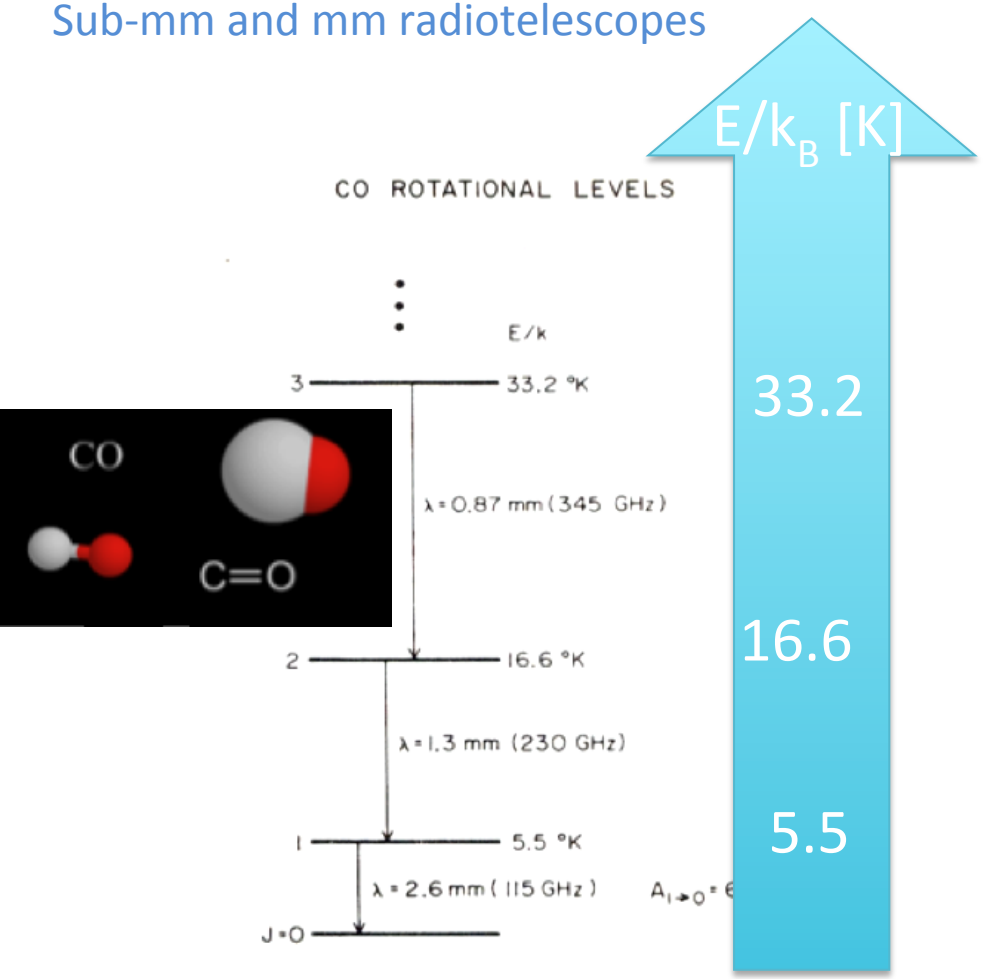
1. Observations of warm H_2 in nearby and distant galaxies
   → *a tracer of turbulent dissipation*

2. Mapping the kinematics of warm H_2 gas with NIRSPEC and MIRI
   → *unique capability up to z~2-3*

3. What could we learn about galaxy formation?
   → *Gas cooling in galaxy assembly*

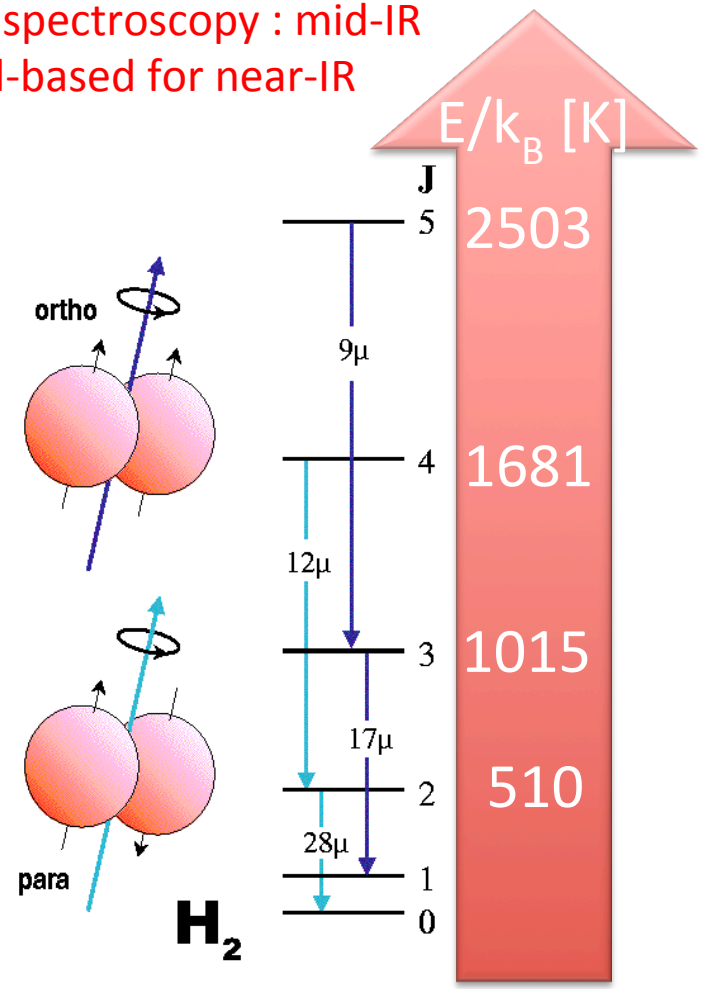
Why H_2?

Sub-mm and mm radiotelescopes



CO (cold H_2) : mass

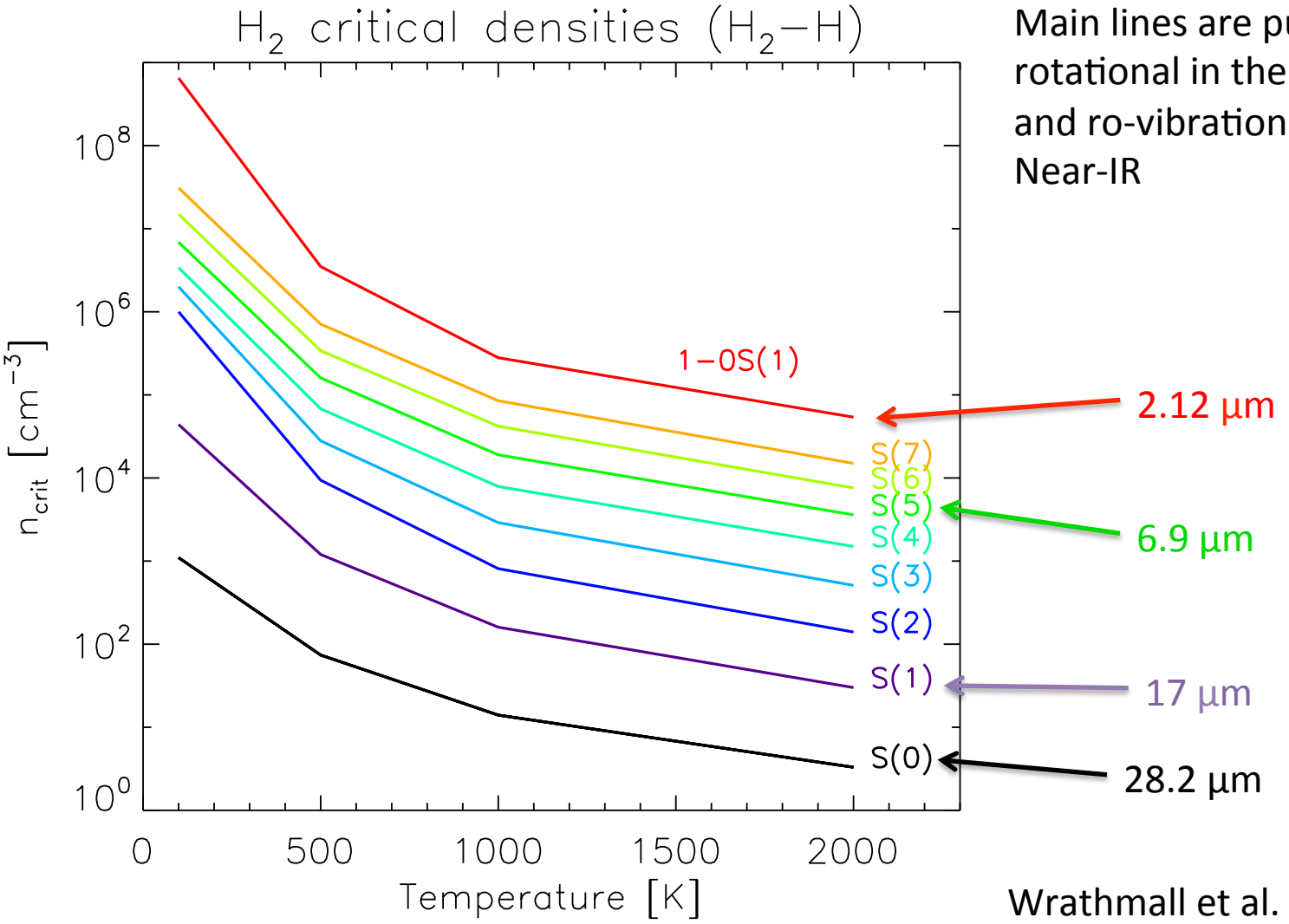
Spitzer spectroscopy : mid-IR
Ground-based for near-IR



Warm H_2: energetics

Gas cooling, Turbulent dissipation

Why H_2?

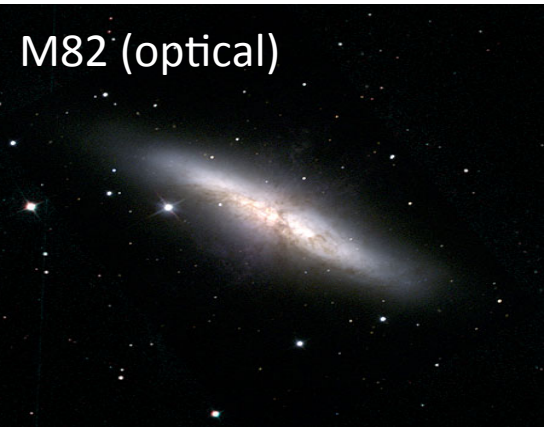


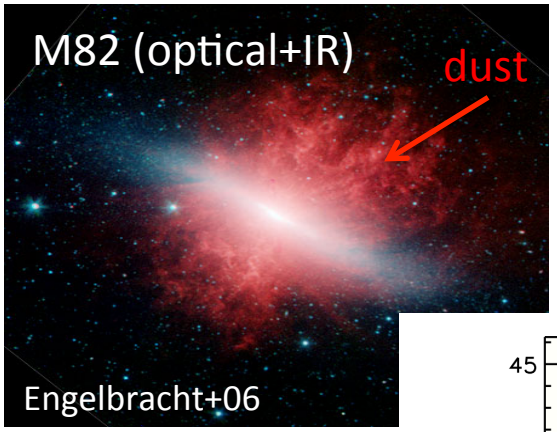
Main lines are pure-rotational in the mid-IR and ro-vibrational in the Near-IR

Wrathmall et al. 2007

H_2 emission: PDRs (UV heating), main coolant in shocks

Warm H_2 gas in the M82 outflow

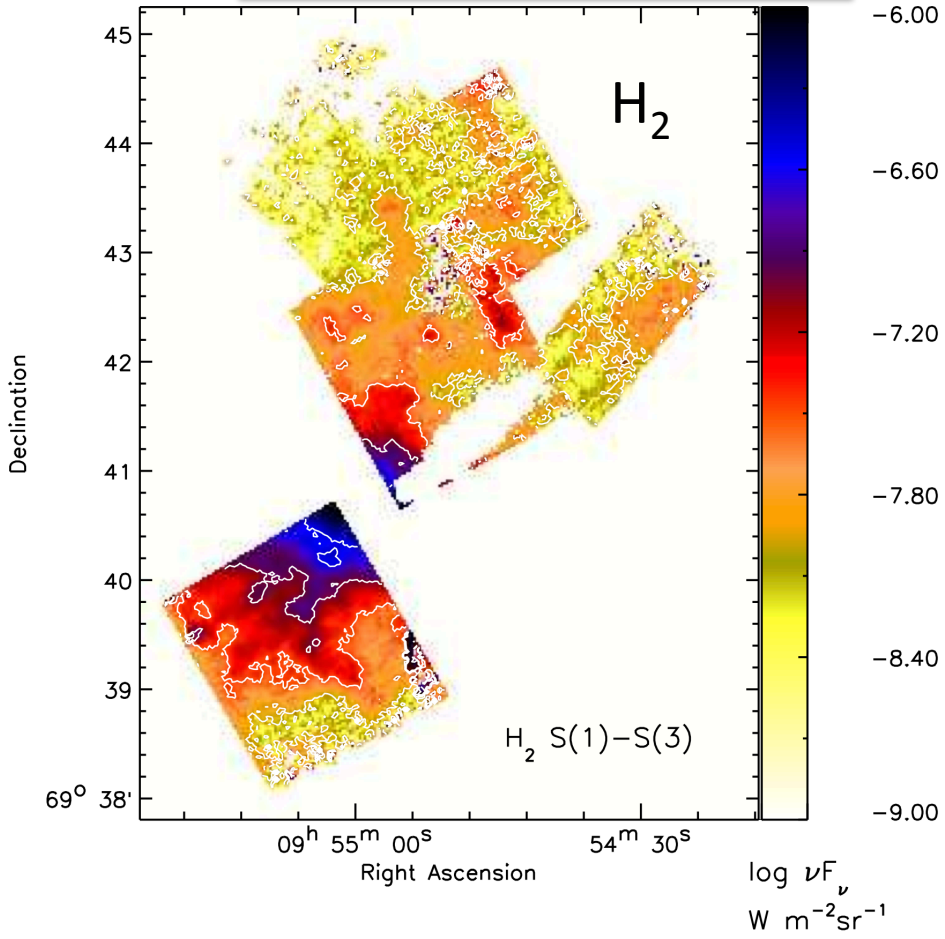




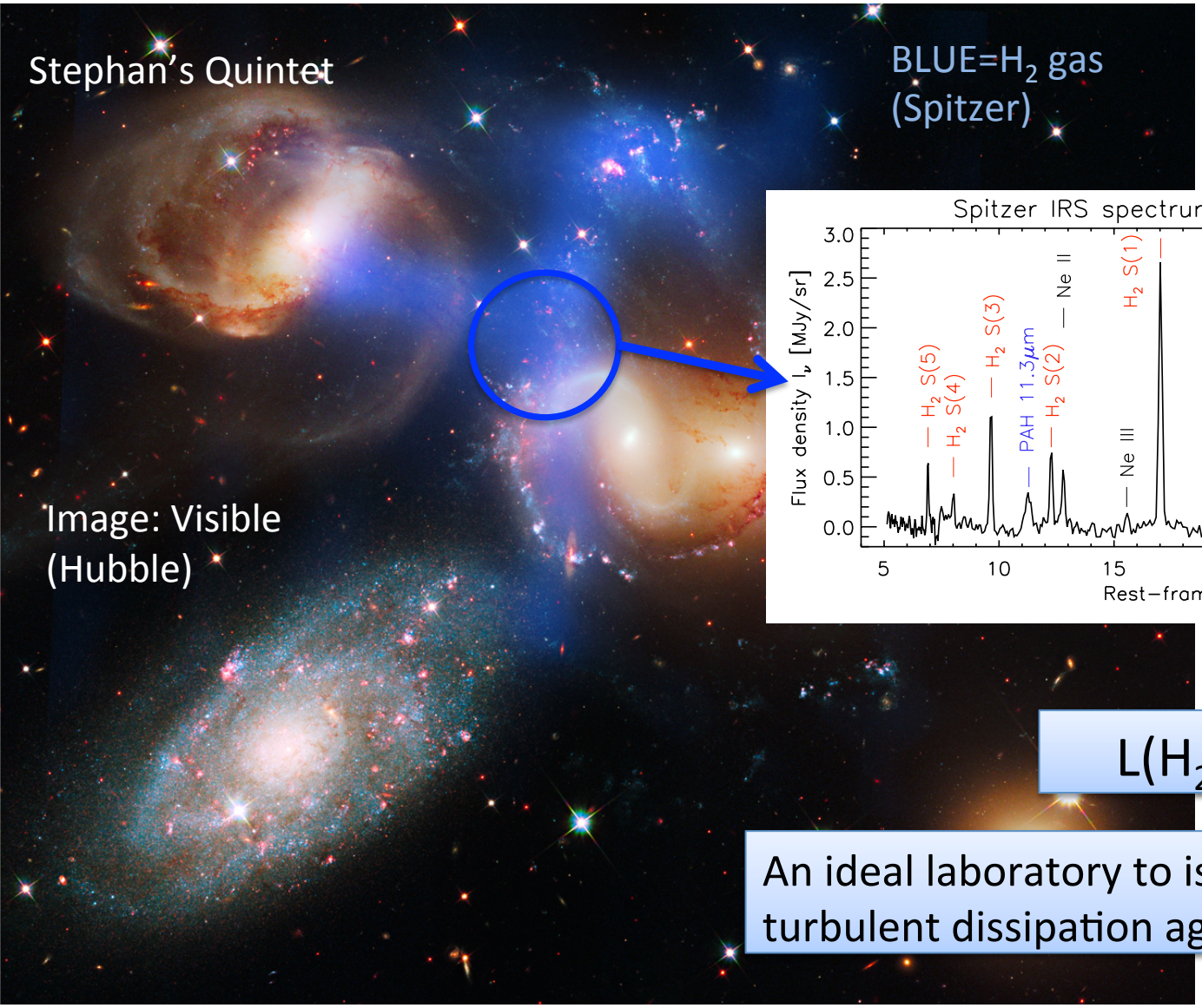
- Mass of warm H_2 ~ 10^7 $M_\odot$
- Spitzer spatial resolution ~ 35 pc
  No kinematical information
- What are the kinematics and small-scale structure of the warm H_2 ?
- What is the total outflow rate ?

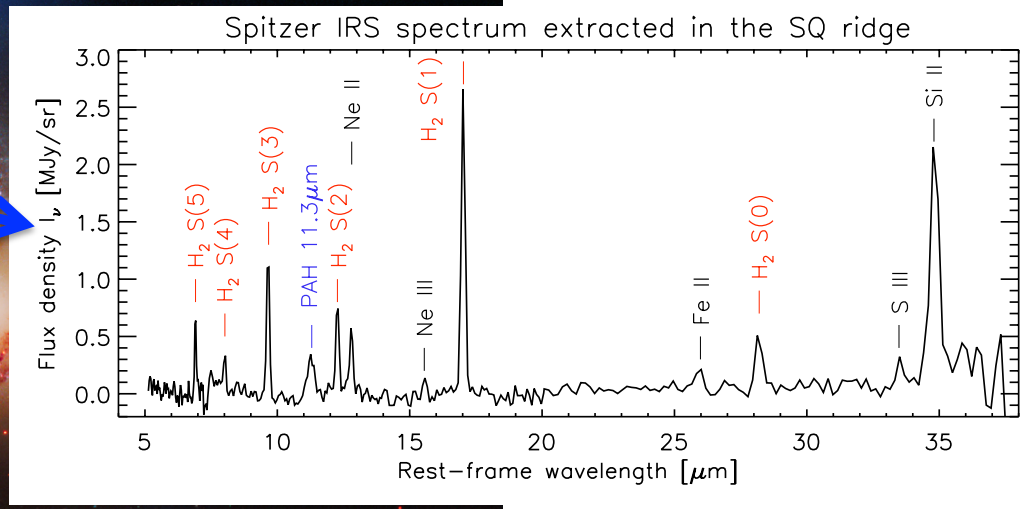
MIRI can (locally) map the morpho-kinematics at a spatial resolution of 1.5 pc !

Warm H_2 gas far out of the disk (Beirao et al. 2015)



Shock-powered H_2 emission in galaxy interactions





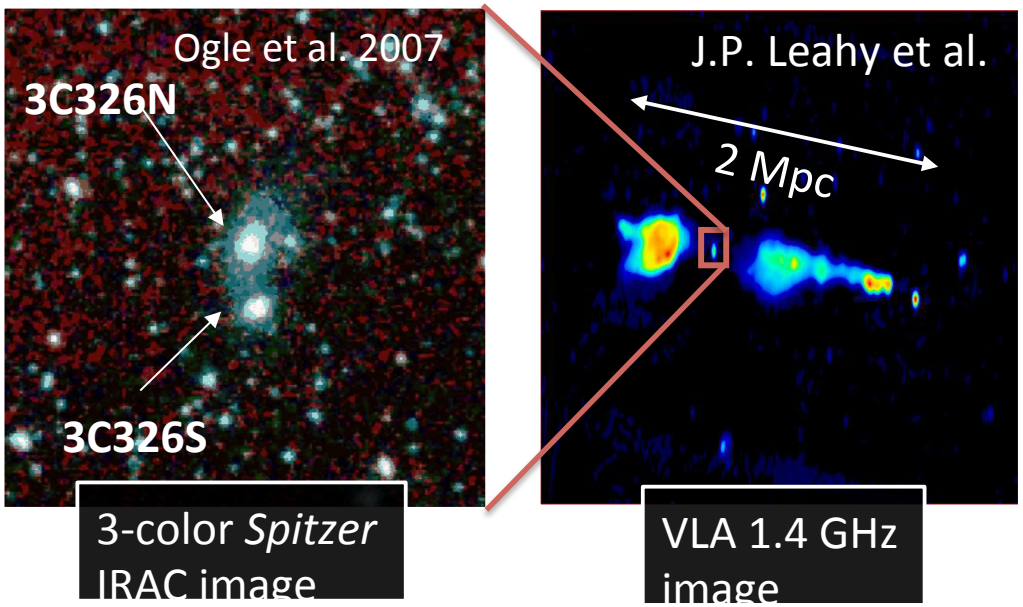
$L(H_2) = 3\ L(\text{X-rays})$

An ideal laboratory to isolate the physics of turbulent dissipation against the dark sky!

Guillard et al. 2009; Guillard et al. 2012b; Cluver et al. 2013
Appleton, Guillard et al. 2013

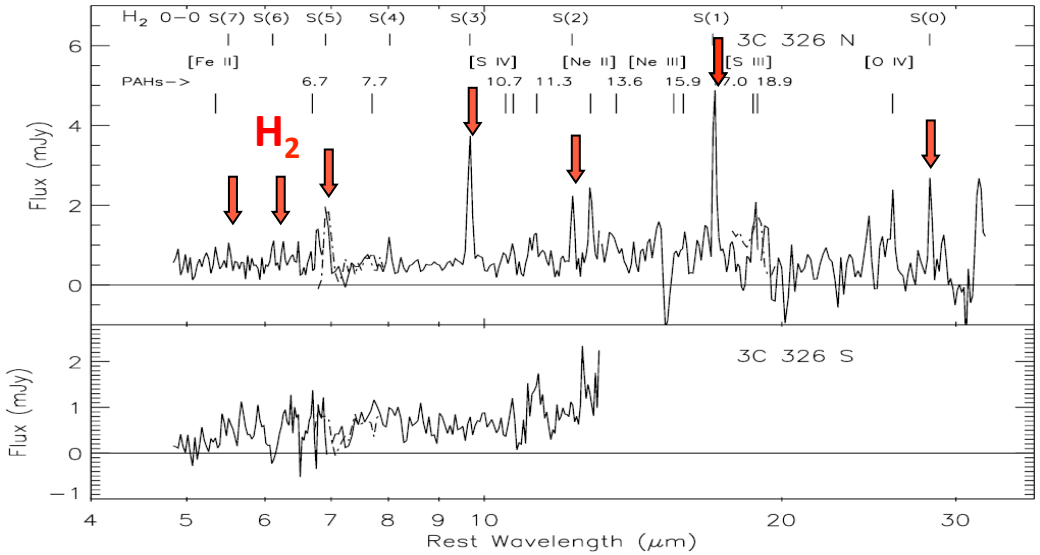
An H_2-rich radio-loud AGN with extremely weak star formation

Different input energy source, but same physical properties of the gas!



- Pair of galaxies 3C 326N & S at z=0.089

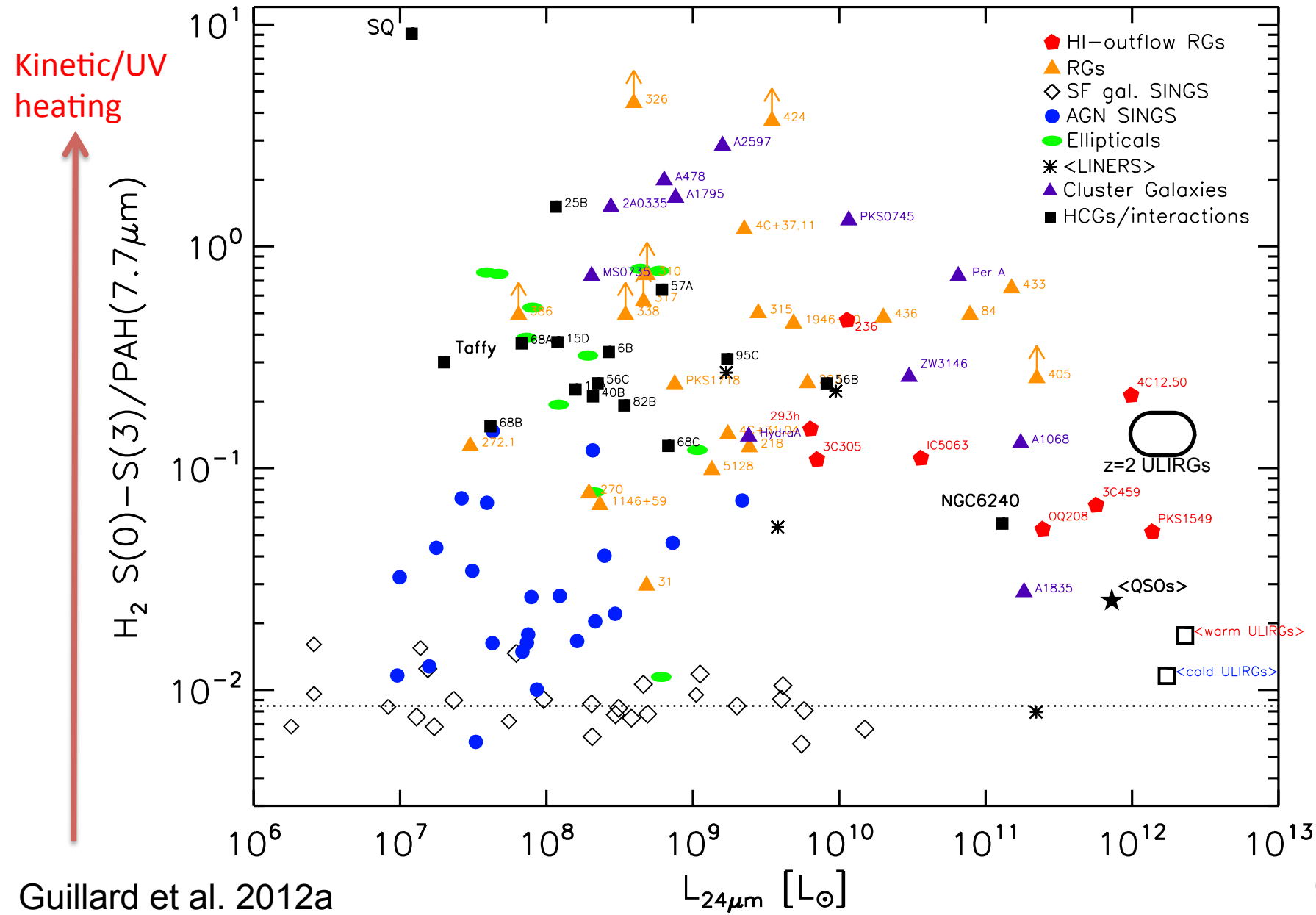
$L(H_2)=8\times10^{41}$ erg/s
- 10^9 M_0 of warm H_2
- SFR < 0.07 M_0 yr^{-1}
- $L(H_2)/L(IR) \sim 0.2$!!



H_2/PAH flux ratio: diagnostic of kinetic VS UV heating of the gas

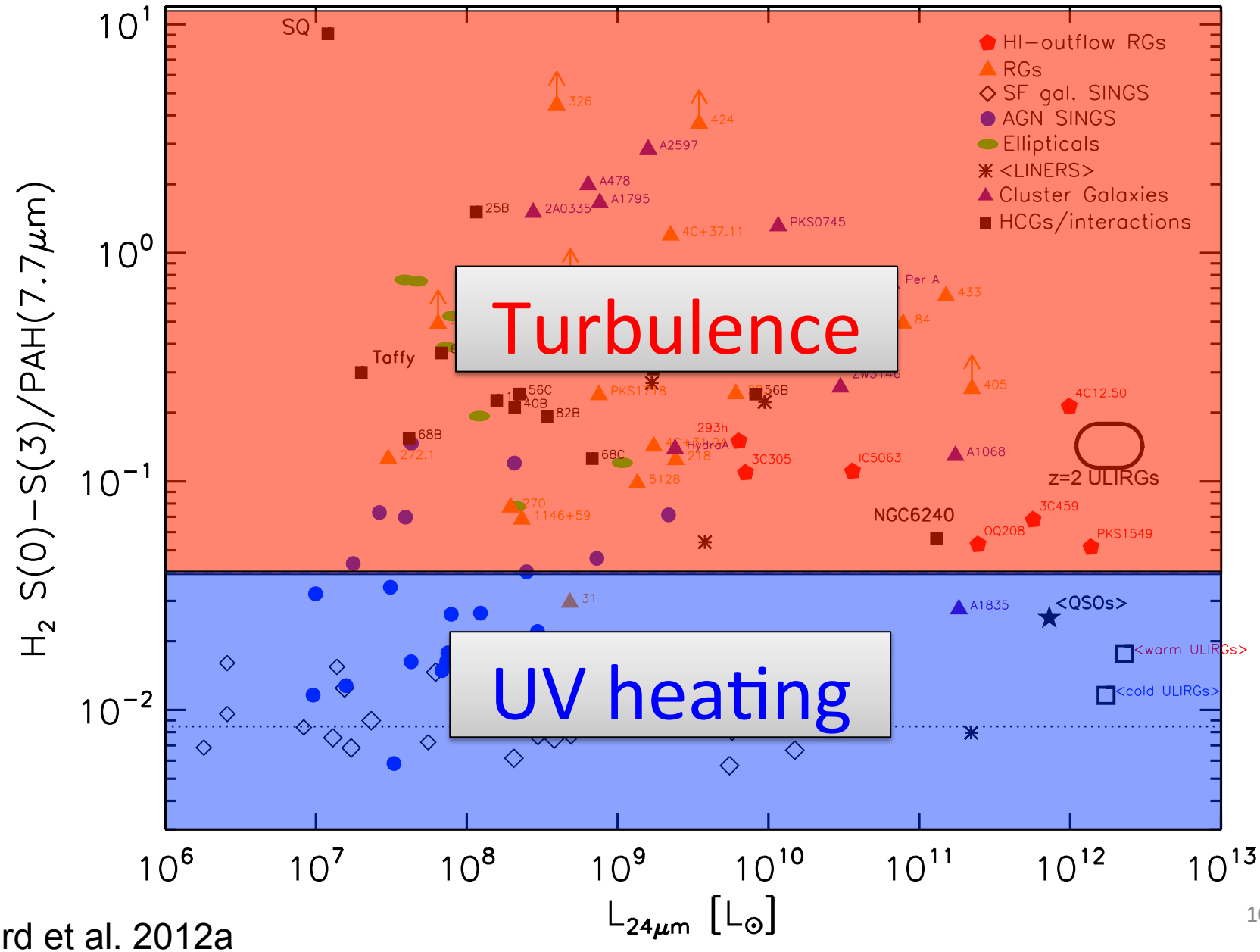
Ogle+07, Guillard+15a

H_2 line emission in galaxies (Spitzer)



Guillard et al. 2012a

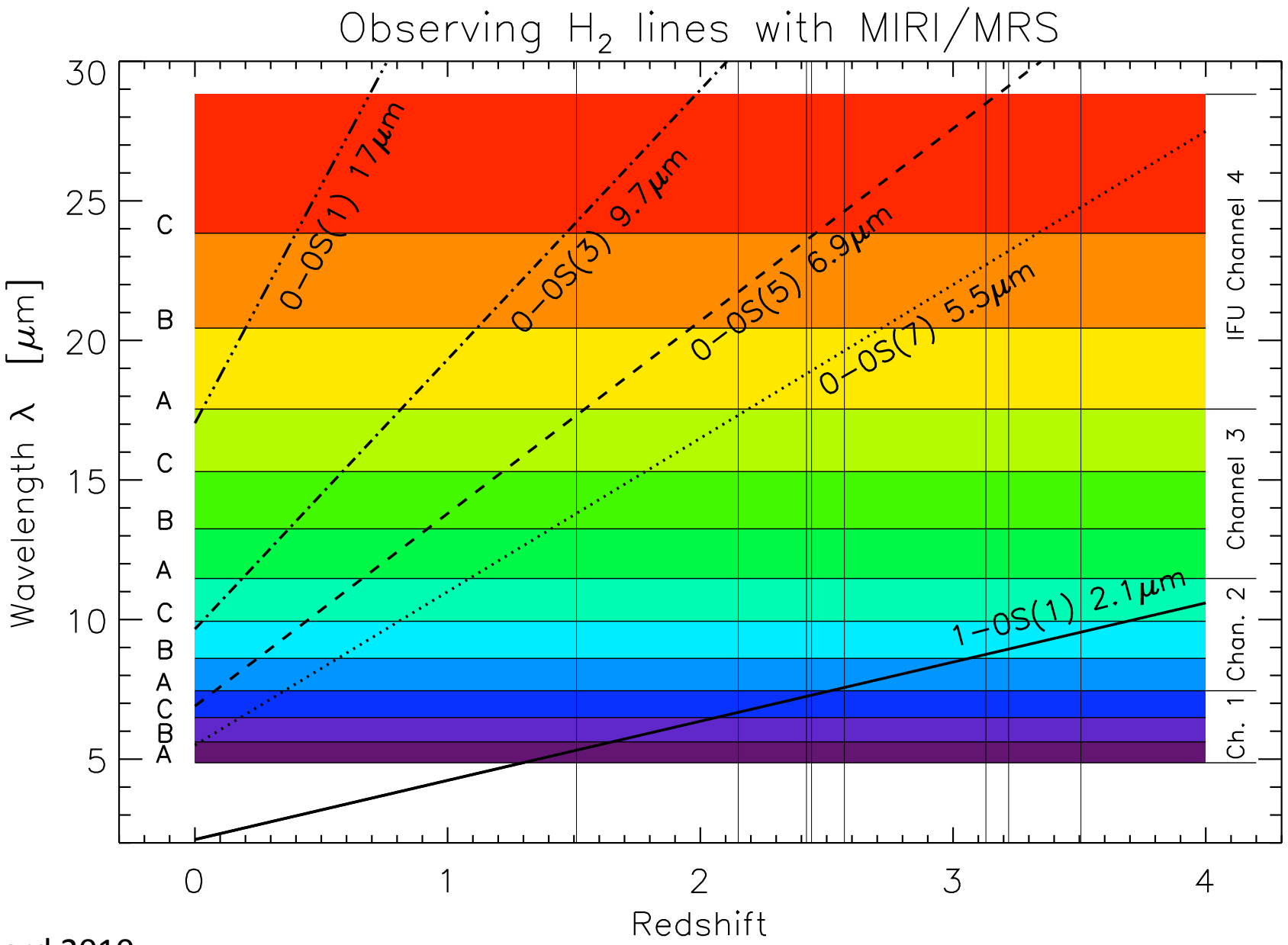
H_2 a tracer of the dissipation of turbulence



Guillard et al. 2012a

What about high redshift?

Example: Redshifted H_2 lines with MIRI

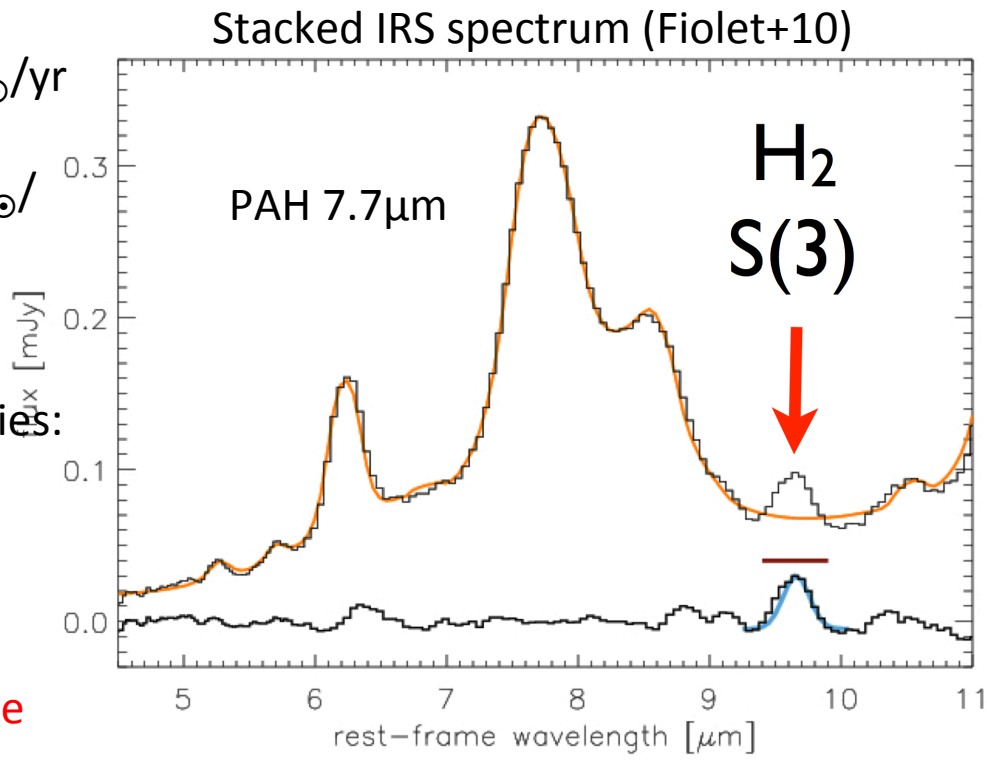


Guillard 2010

H_2 cooling in high-z starbursts

- 16 Spitzer-selected galaxies at z~2
  IRAC photometry: $\langle M_\star \rangle = 1.5\times10^{11}\ M_\odot$
  Mid-IR spectroscopy: <SFR> ~ 1000 $M_\odot$/yr
  Sub-mm photometry: $M_{gas} \sim 5\times10^{10}\ M_\odot$
  $\Sigma_{gas} \sim 2000\ M_\odot$/pc^2

- $L_{H2}(S(3)) = 1.5\ 10^9\ L_\odot$
- Based on spectra of local H_2 luminous galaxies:
  $L_{H2}(S(0)\text{-}S(5)) \sim 6\ 10^9\ L_\odot$
  $M_{H2}(T>150K) \sim 10^{10}\ M_\odot$: 20% M_{gas}
  $L_{H2}/M_{gas} \sim 0.12\ L_\odot/M_\odot$
  $\equiv 4\ 10^{-25}$ erg/s/H
  ~ 500 times the Milky Way value

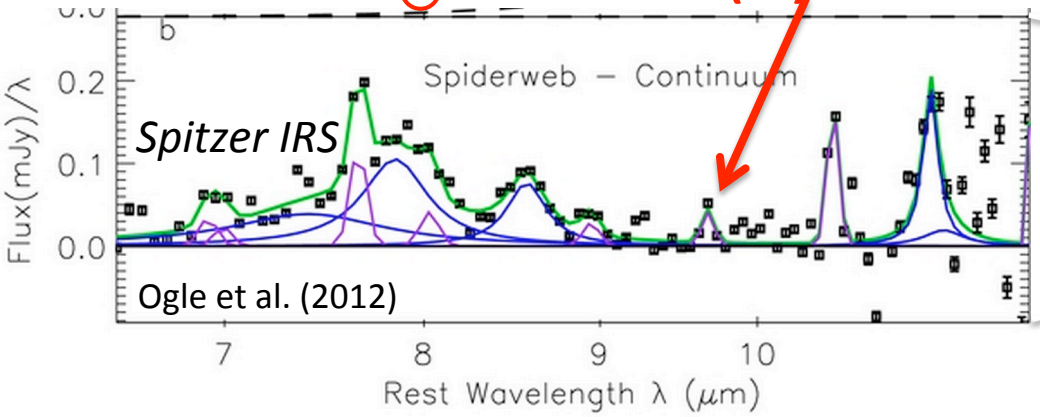


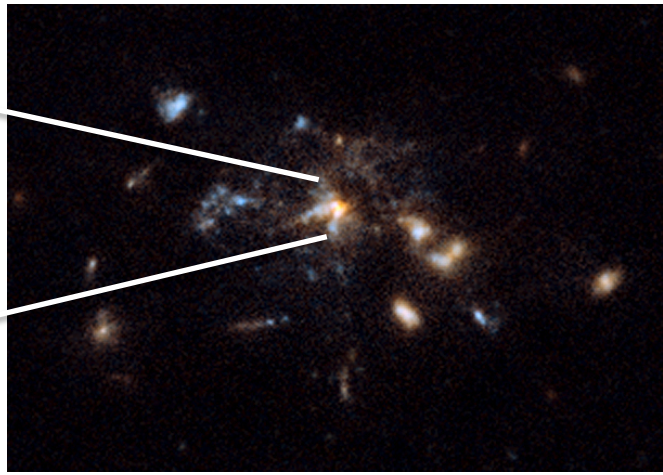
H_2/PAH ratio above what may accounted by UV heating of molecular clouds based on CO, FIR, [CII]λ158μm (Stacey+10)

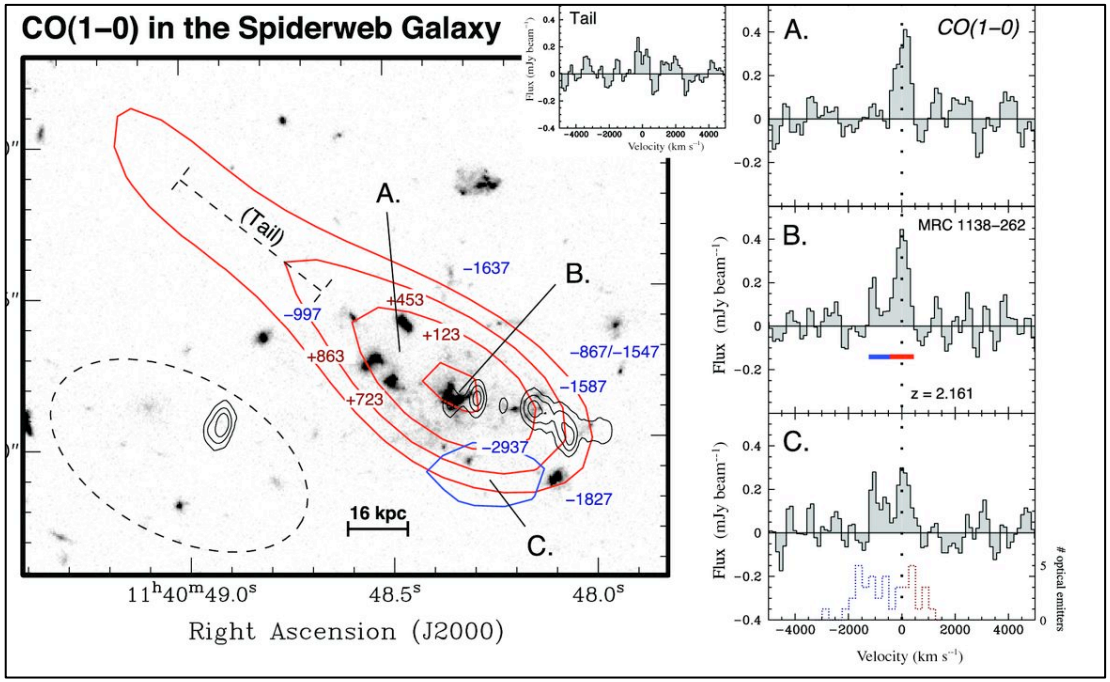
H_2 may be powered by dissipation of turbulence (possible sources: SN, radiation pressure, gas accretion)

The Spiderweb Radio Galaxy z = 2.16

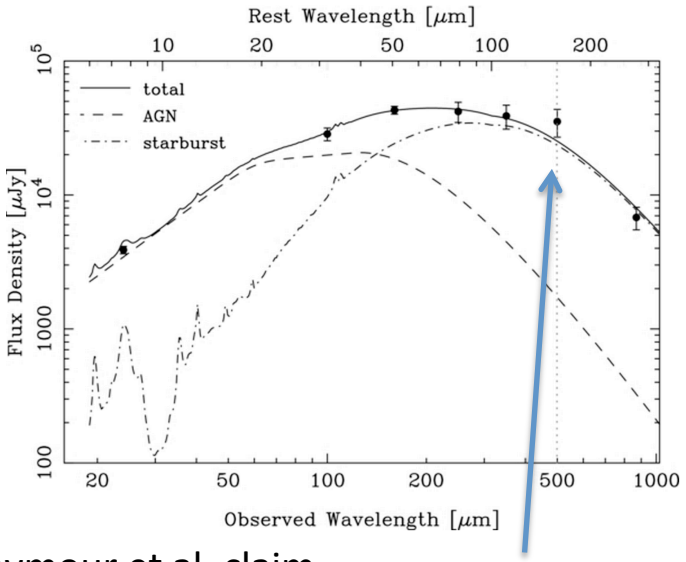
3.7 x 10^{10} $L_\odot$ in 0-0 S(3) line alone!





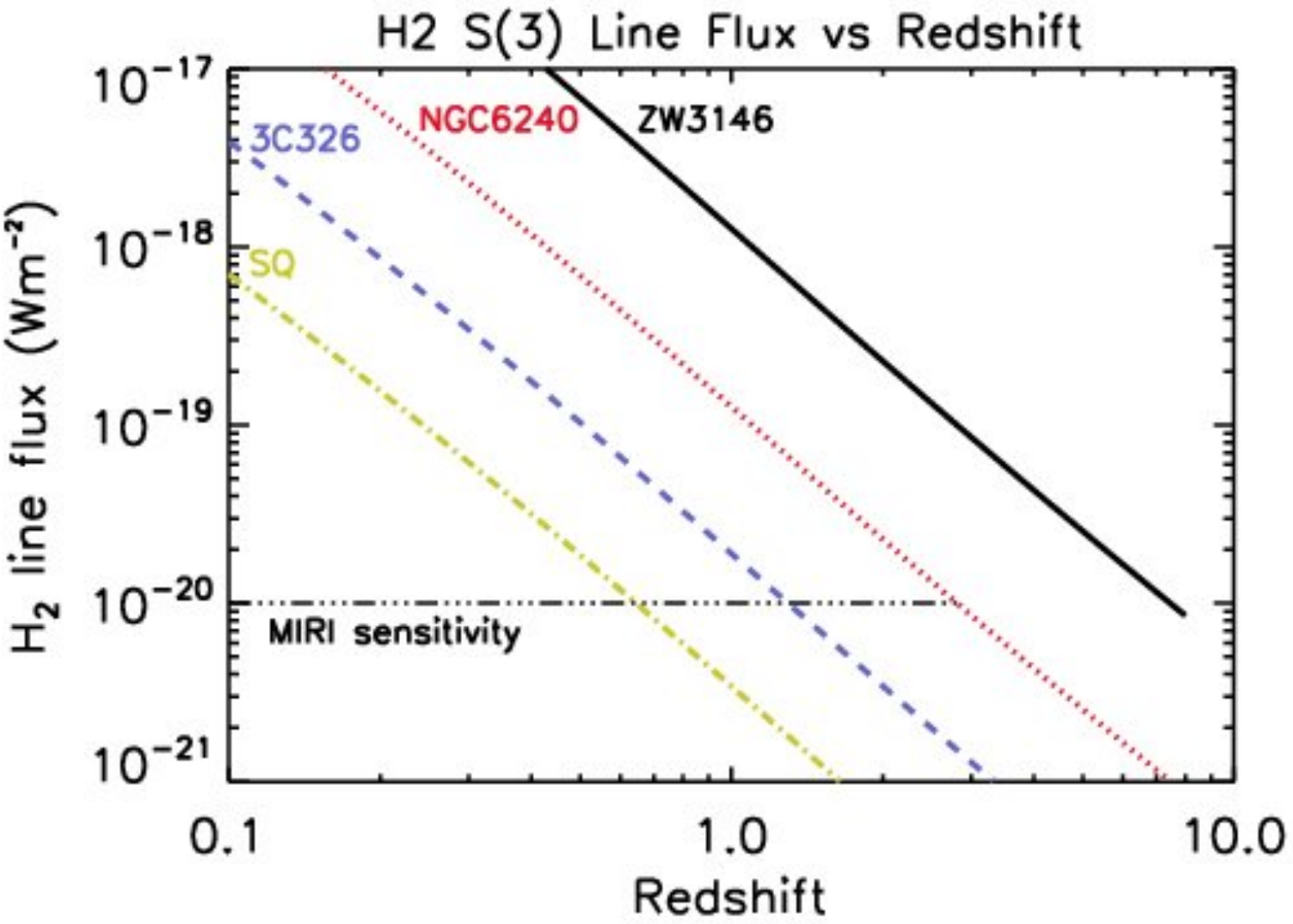


Emonts et al. (2013) ATCA CO



Seymour et al. claim Detection of [CII] with C+/FIR = 2% based on SED detection. Could some of this be shocked gas??

Detecting H_2-bright objects with JWST



Warm H_2 with JWST

To take-away:

→ *Cooling of multiphase ISM through H_2 lines. A tracer of the dissipation of turbulence.*

→ *H_2 lines are expected to be enhanced in high-z turbulent galaxies*

→ *NIRSPEC and MIRI will allow to map the kinematics of warm H_2 gas at high spatial resolution up to z~2-3*

→ *Tracing the turbulent energy cascade associated with feedback processes, shedding light on the self-regulation of star formation*

→ *What is the role of H_2 as a gas coolant at the peak of the star forming activity of the Universe?*