Dusty star-forming galaxies observed with the Herschel-SPIRE Fourier-Transform Spectrometer

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On behalf of HerMES and H-ATLAS teams

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Content

The tool

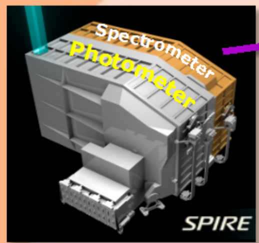
- SPIRE-FTS, quick intro

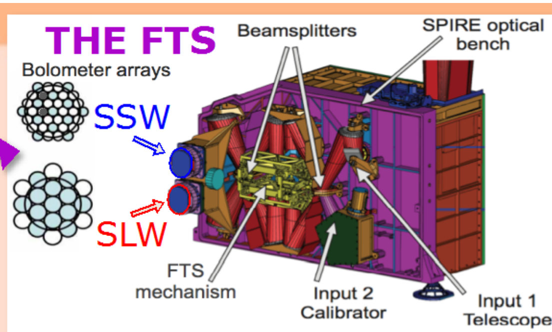
The context

- Observing star-forming galaxies
- Stacking spectra: results on faint star-forming galaxies
    - Based on a recent work by
      Wilson,… Valtchanov, et al., 2017ApJ…848…30W
      197 targets
    - Other Herschel-PACS based work with stacking:
      Wardlow, … Valtchanov, et al., 2017ApJ…837…12W
      13 targets

The method
And some results

Herschel-SPIRE Fourier-Transform Spectrometer



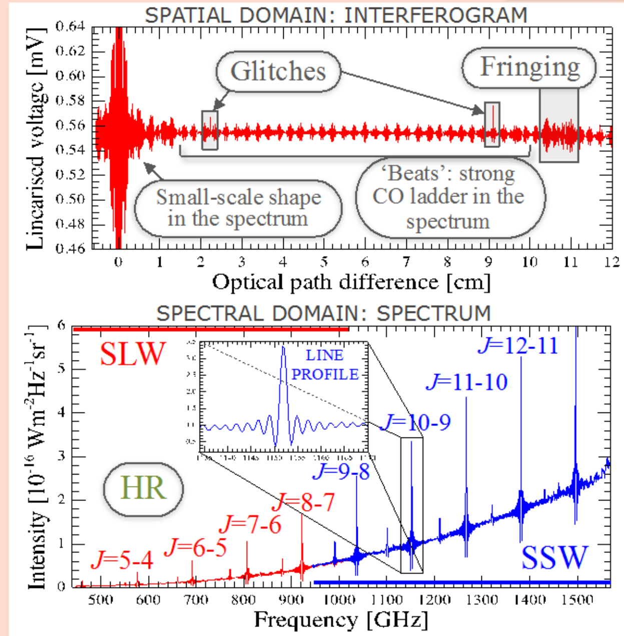


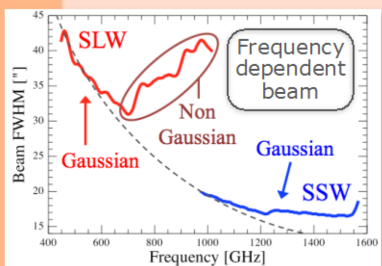
The SPIRE Fourier Transform Spectrometer

Herschel

KEY LITERATURE
SPIRE Handbook,
SPIRE Data Reduction Guide
Swinyard et al., 2014
Hopwood et al., 2015

	SLW	SSW
WAVELENGTH COVERAGE	447-1018 GHz 671-294 µm	944-1568 GHz 318-191 µm
INSTRUMENTAL LINE WIDTH HR	970-440 kms^{-1} 1.2 GHz	450-280 kms^{-1} 1.2 GHz



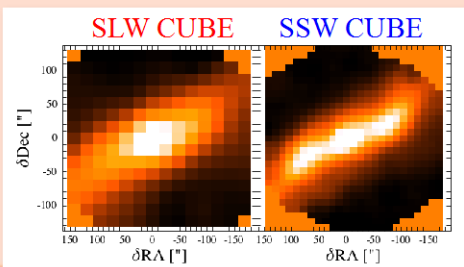


CALIBRATION ACCURACY
Point-source : 6%
Extended-source :
1% sparse mode & 7% mapping mode
AVG. CONTINUUM OFFSET (additive):

	SLW	SSW
Point-source calibration	0.4 Jy	0.3 Jy
Extended calibration	9.4×10^{-20} $Wm^{-2}Hz^{-1}sr^{-1}$	2.3×10^{-19} $Wm^{-2}Hz^{-1}sr^{-1}$

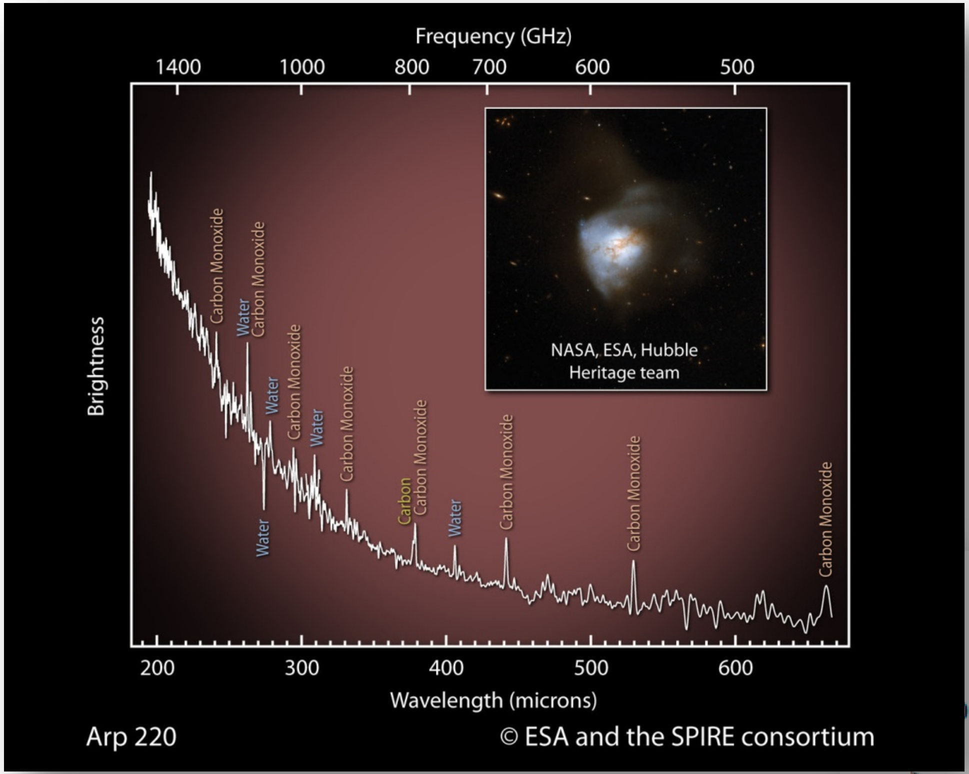
SPECTRAL RESOLUTION
HIGH (HR) 1.2 GHz, LOW (LR) 25 GHz

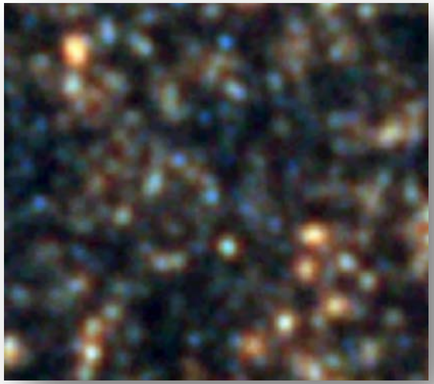
MAPPING MODES
2.6′ FoV
Sparse: single pointing
Intermediate: 4 point jiggle
Full: 16 point jiggle
SPARSE OR MAPPING RASTER PATTEREN
User defined FoV



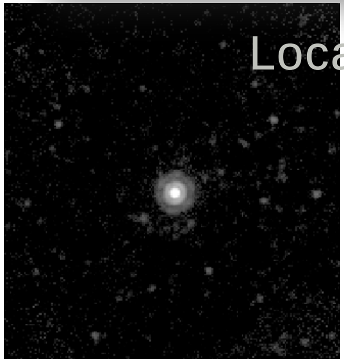
***Herschel* Science Archive Level-2**
SPARSE naming example for HR
Point-source calibrated Spectra → *"HR_spectrum_point"*
Extended calibrated → *"HR_spectrum_ext"*
MAPPING naming example for HR SLW
Spectral cubes → *"HR_SLW_cube"/"HR_SLW_cube_convol"*
spectra → *"HR_SLW_spectrum2d"*

Observing distant star-forming galaxies

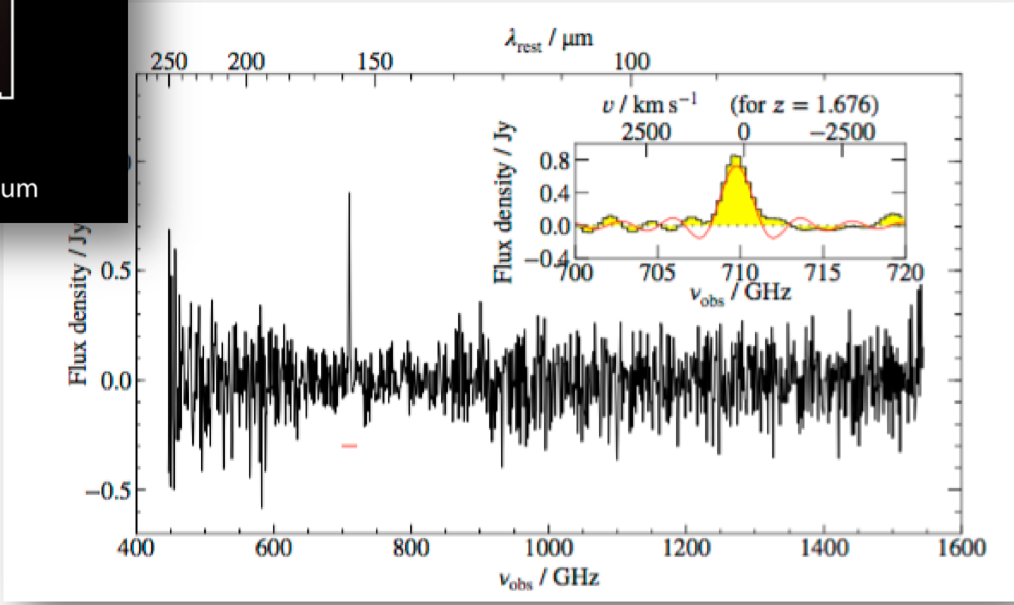




Distant (z=1.7)
1/3rd of $t_{Universe}$

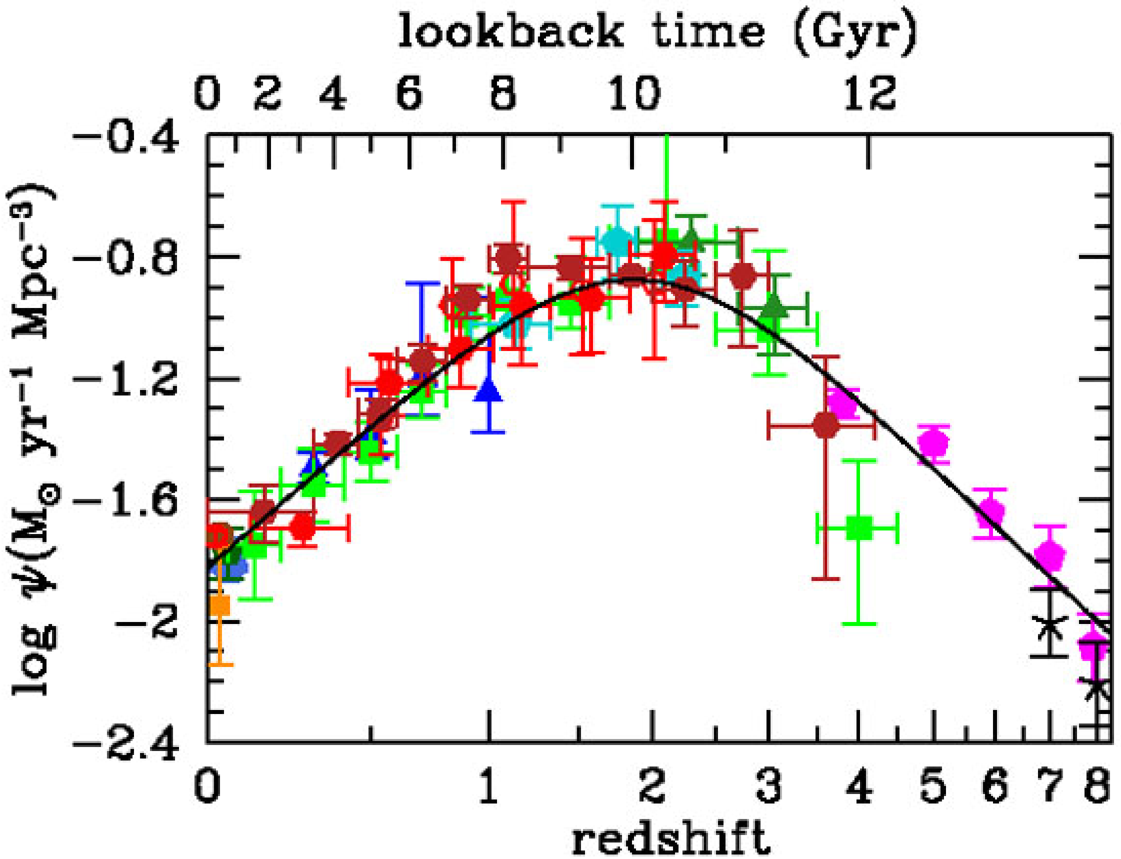


Local ULIRG (z=0.018)



The big question

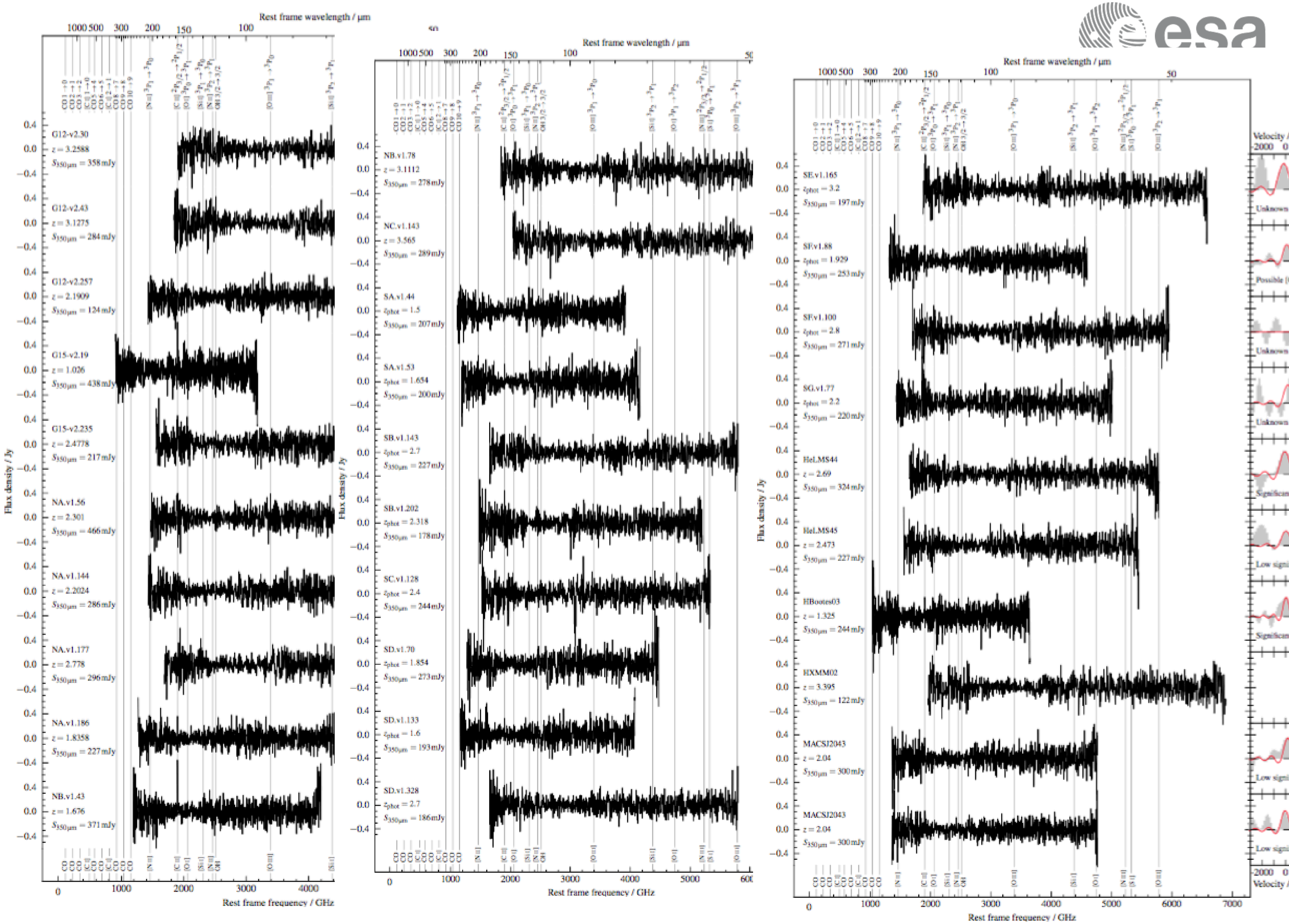
- Star formation rate density:



Madau & Dickinson (2014)

European Space Agency

Sta



Rest frame wavelength / μm
Rest frame frequency / GHz
Flux density / Jy
G12-v2.30
G12-v2.43
G12-v2.257
G15-v2.19
G15-v2.235
NA.v1.56
NA.v1.144
NA.v1.177
NA.v1.186
NB.v1.43
NB.v1.78
NC.v1.143
SA.v1.44
SA.v1.53
SB.v1.143
SB.v1.202
SC.v1.128
SD.v1.70
SD.v1.133
SD.v1.328
SE.v1.165
SF.v1.88
SF.v1.100
SG.v1.77
HeLMS44
HeLMS45
HBootes03
HXMM02
MACSJ2043
MACSJ2043

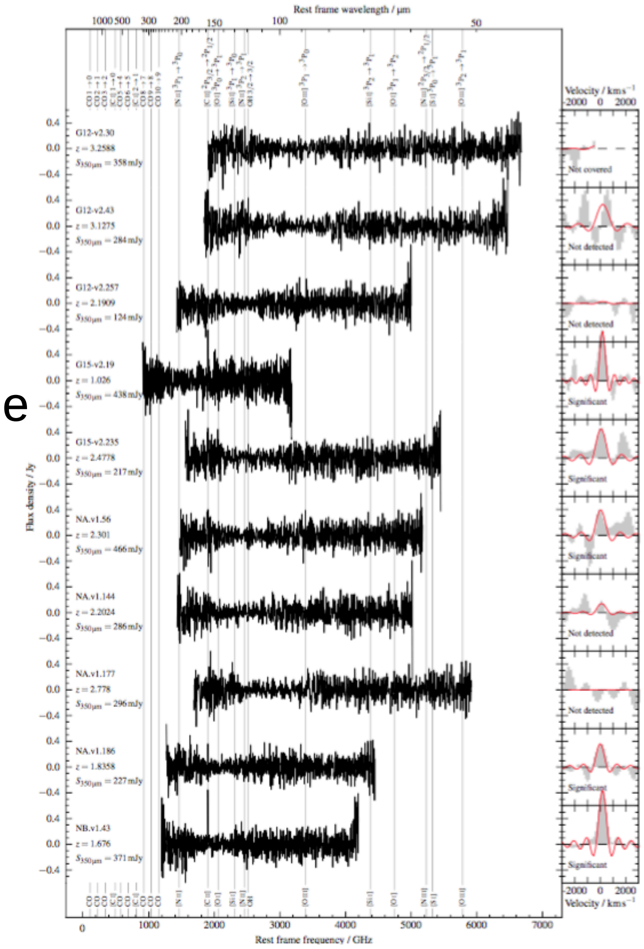
Stacking with spectra

- Good estimate of the redshift

➔ ALMA or other ground based facilities

- Sample: 197 SFG at 0.005 < z < 4
    - 90% of the FTS extragalactic archive

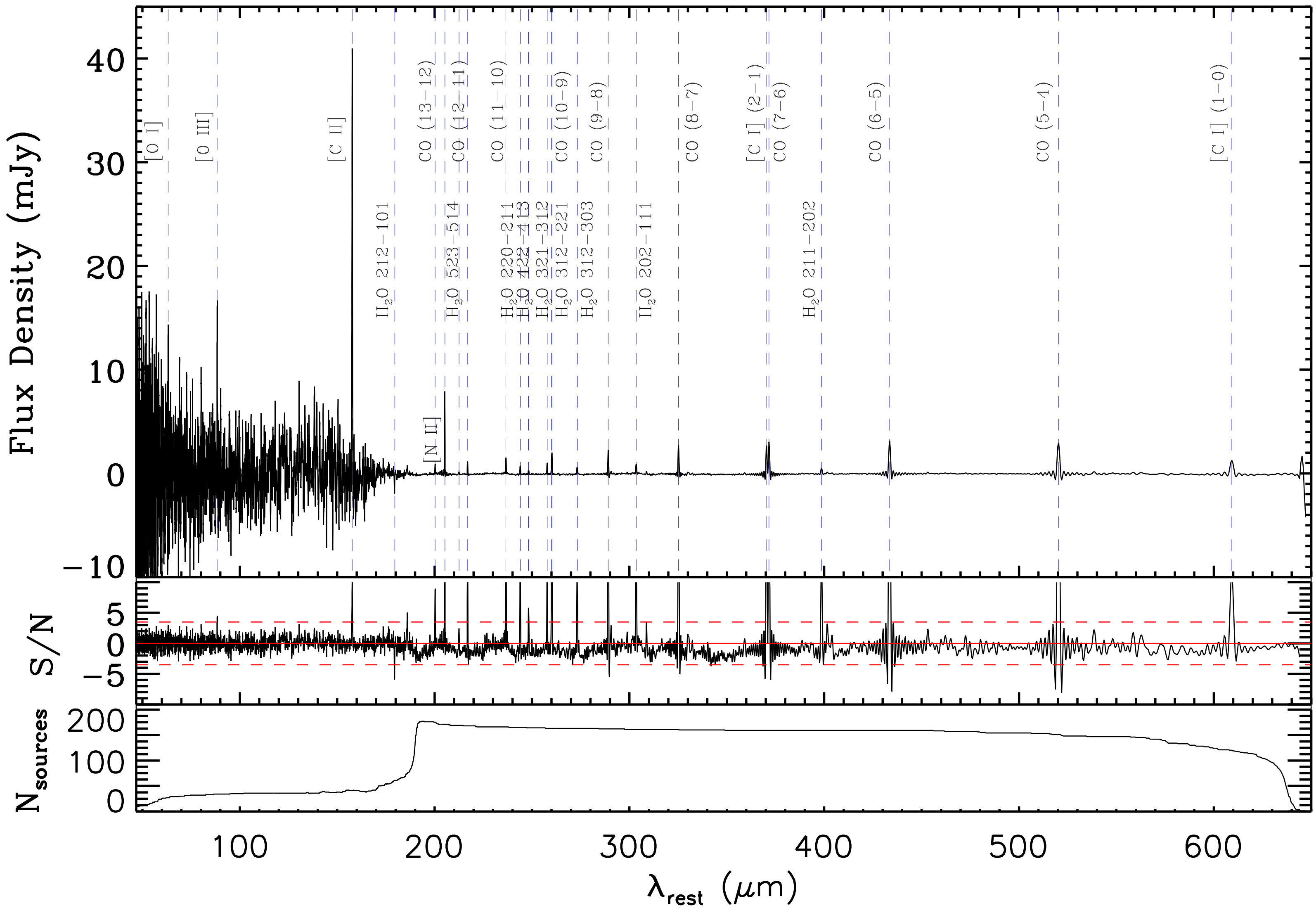
- Stack galaxies in different redshift bins:
    - 0.005 < z < 0.05
    - 0.02 < z < 0.2
    - 0.2 < z < 0.5
    - 0.8 < z < 2 (n=8)
    - 2 < z < 4 (n=28)



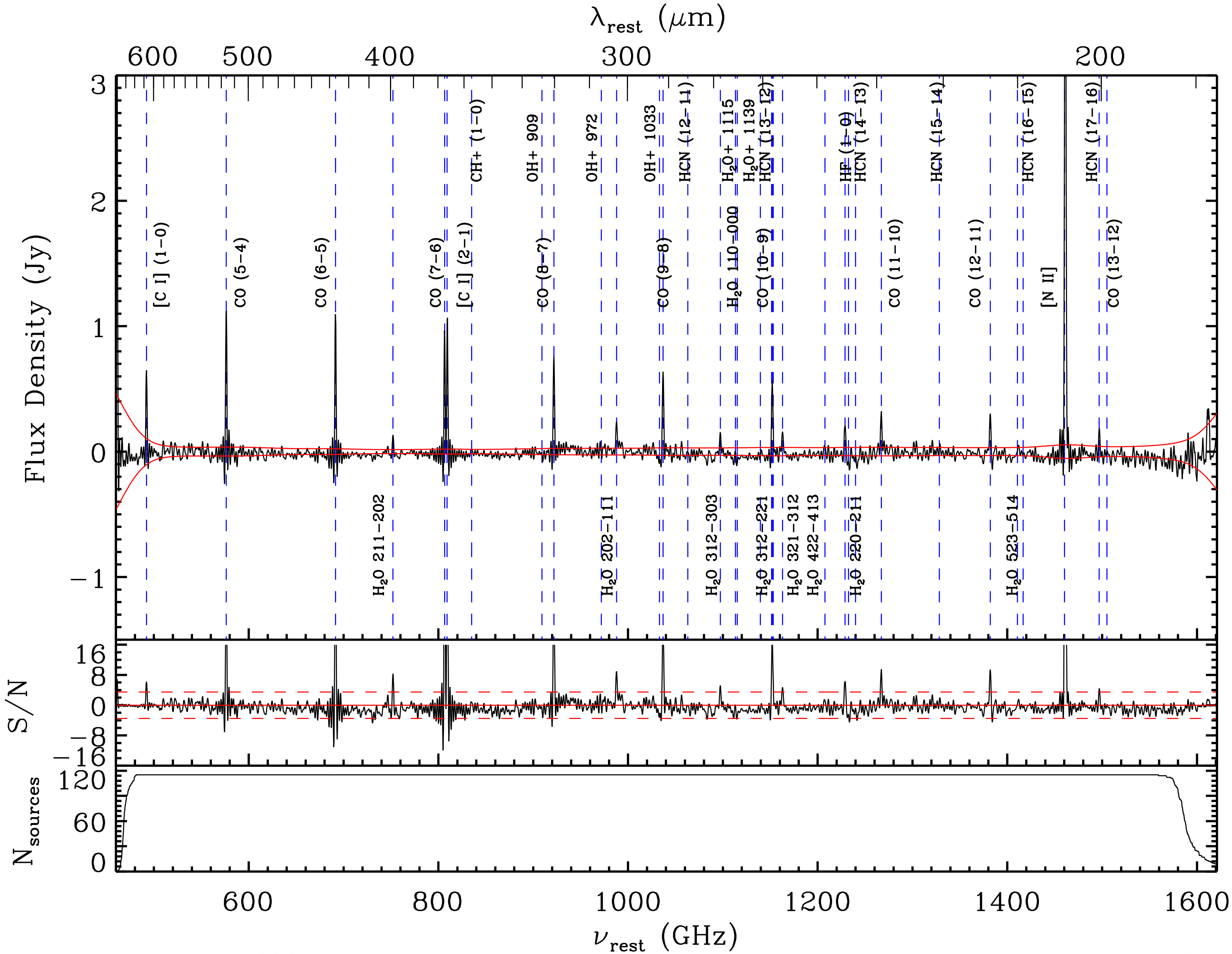
Stacking details

- Spectra need correcting for background and pointing
- Some sources are lensed by foreground galaxies/clusters
- Scale the spectra to a common redshift (bin centre) and normalise to the same $L_{IR\ (8\text{-}1000\mu m)}$
  - L_{IR} comes from SED fit (modified blackbody) to photometry.
- Multiple spectra of the same source are averaged before adding to the stack.
- Each spectrum has an error spectrum (from pipeline), this error is propagated to the stack
- Each spectrum entering the stack is weighted by the variance (to avoid sources dominating the stack).

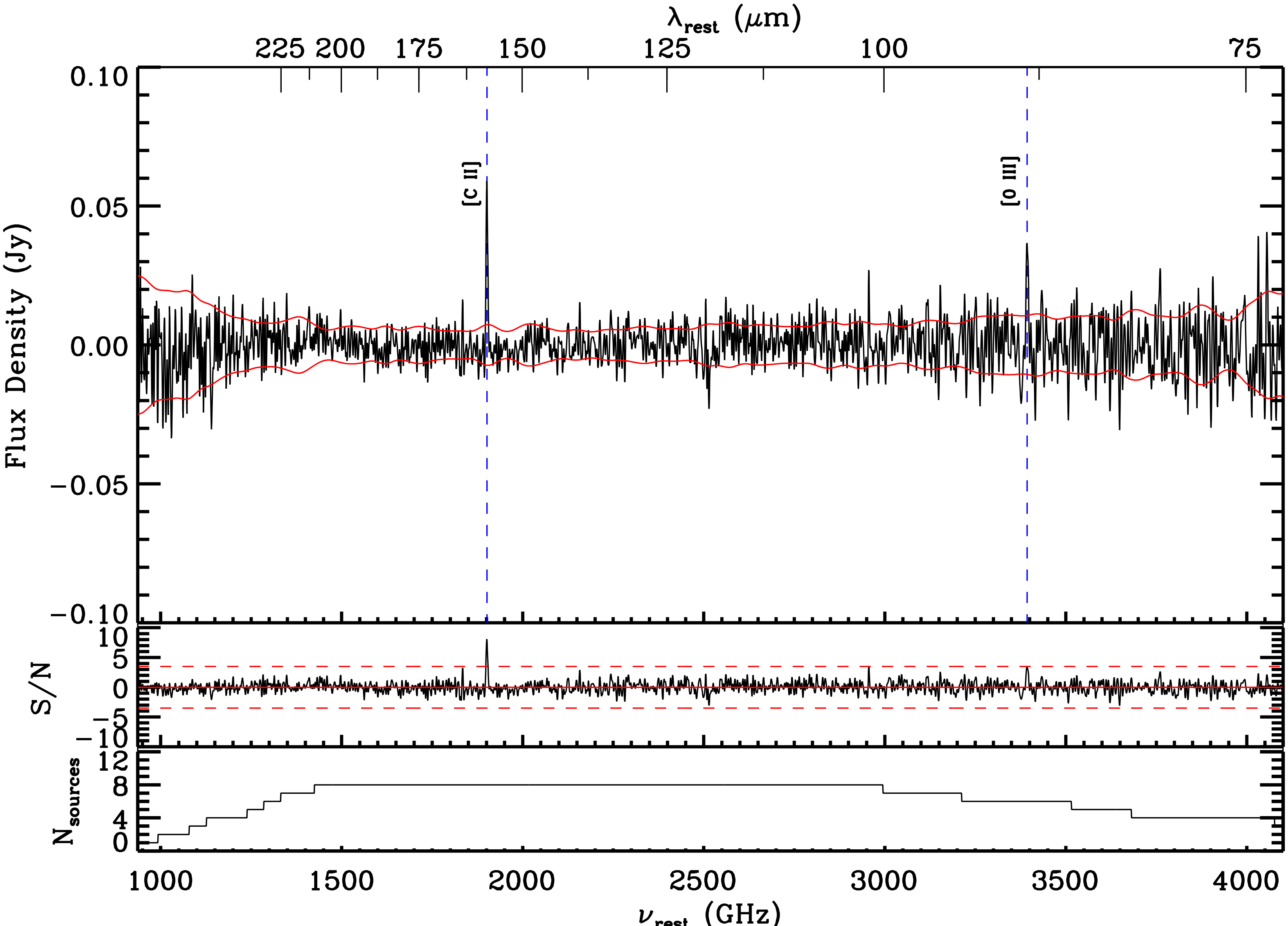
Results: total stack



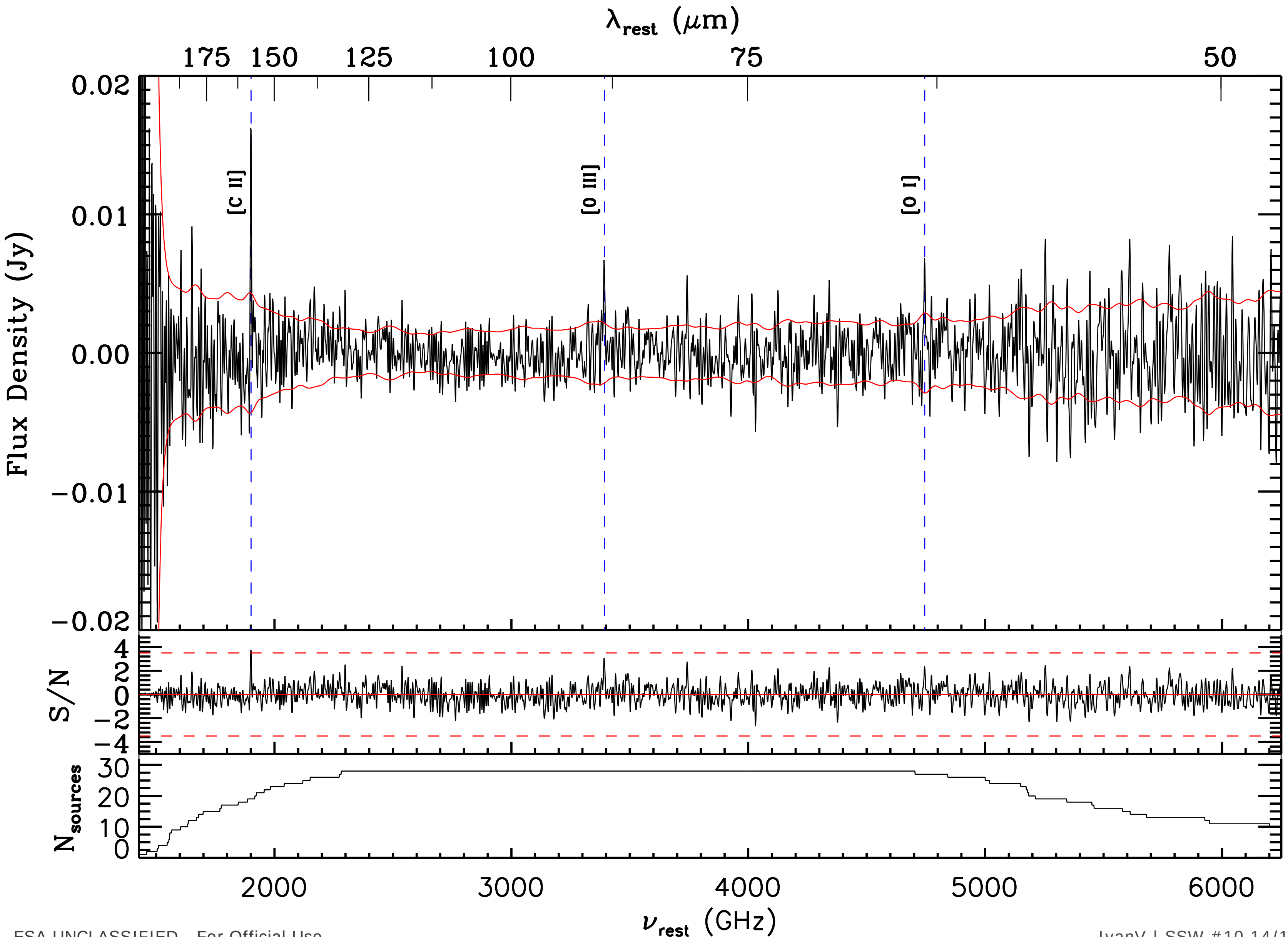
Results: nearby sample 0.005 < z < 0.05



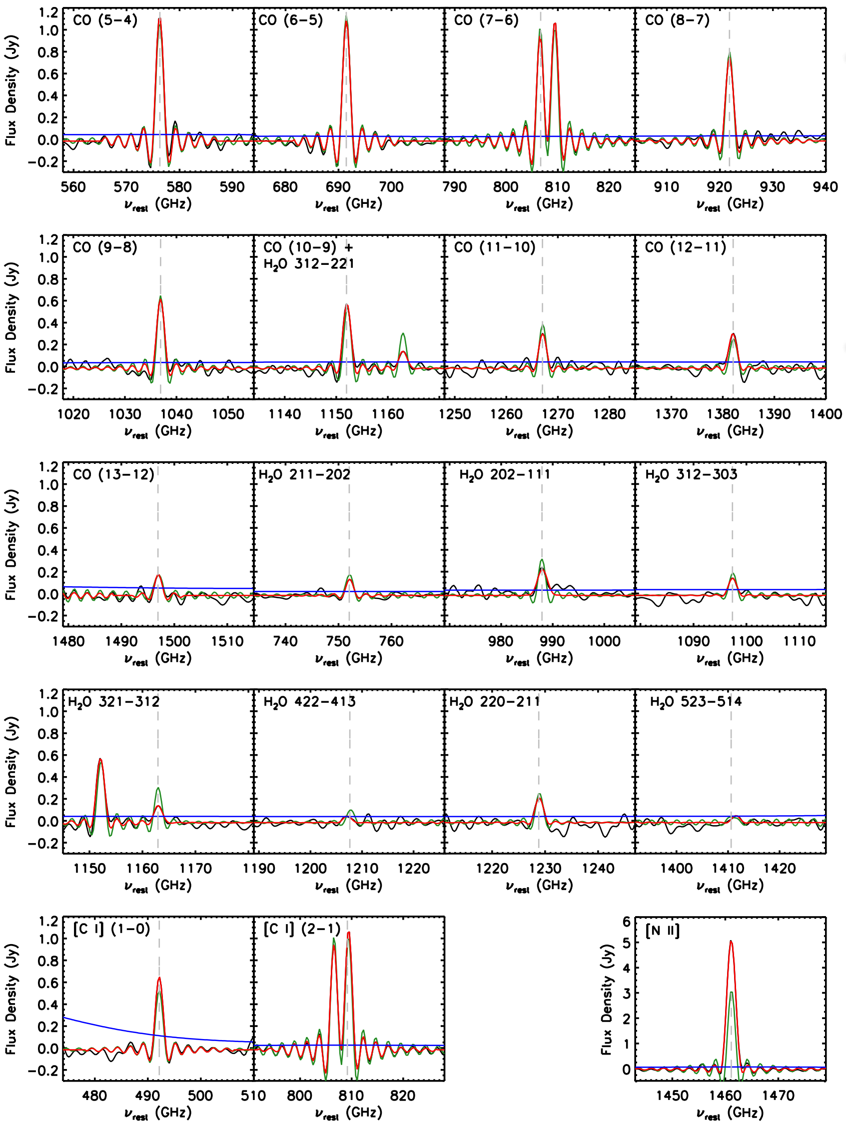
Results: high redshift sample 0.8 < z < 2



Results: highest redshift sample 2 < z < 4



Results: atomic and molecular lines

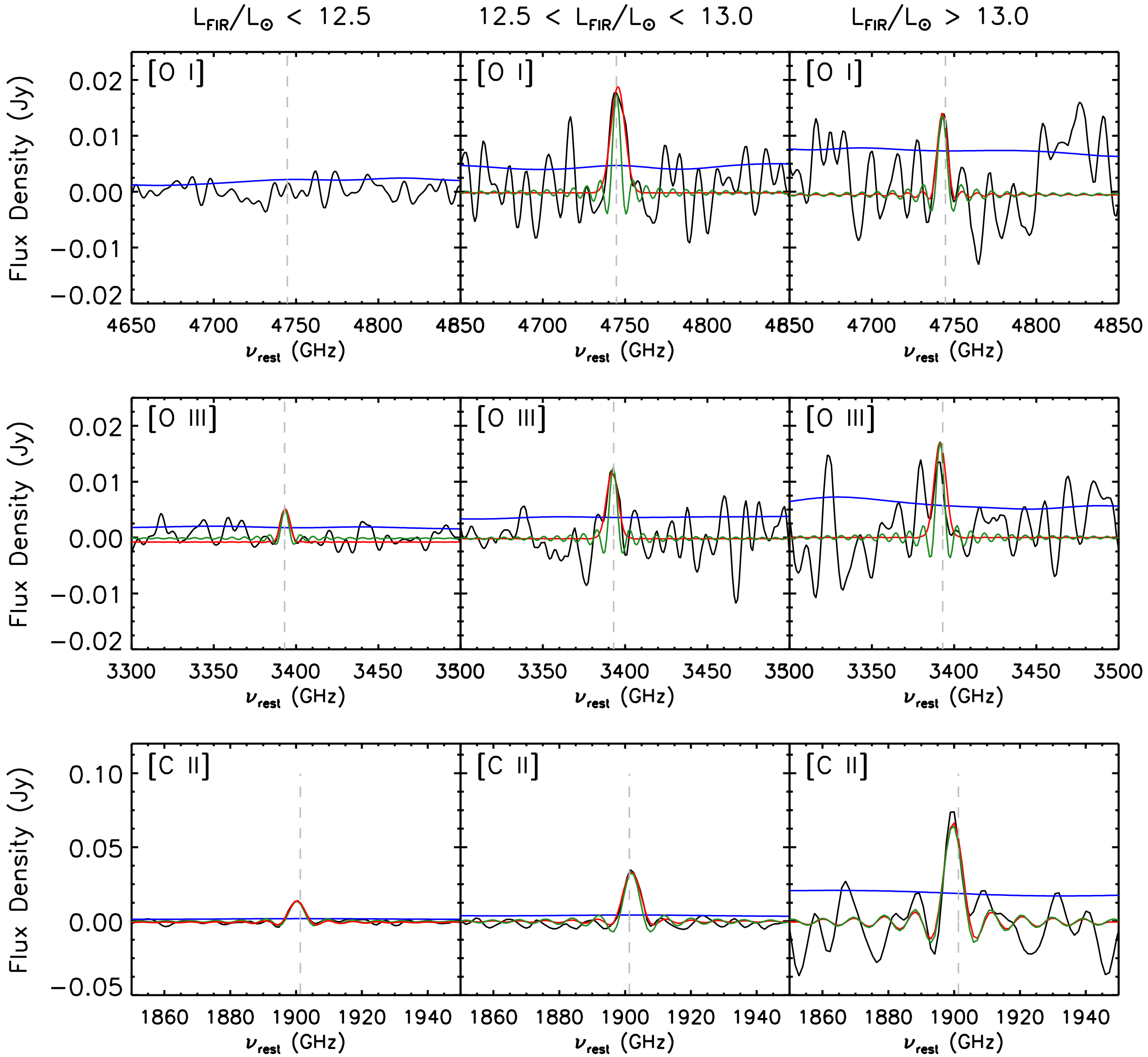


^{12}CO lines

H2O lines in lowest redshift bin

Other lines in lowest redshift bin

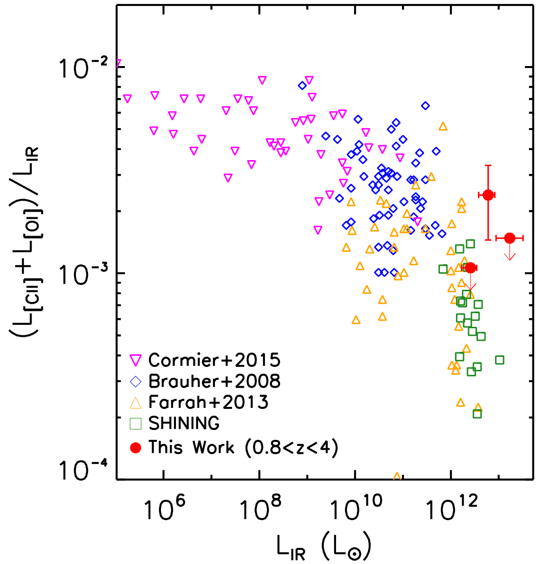
Results: atomic lines in the highest redshift bin



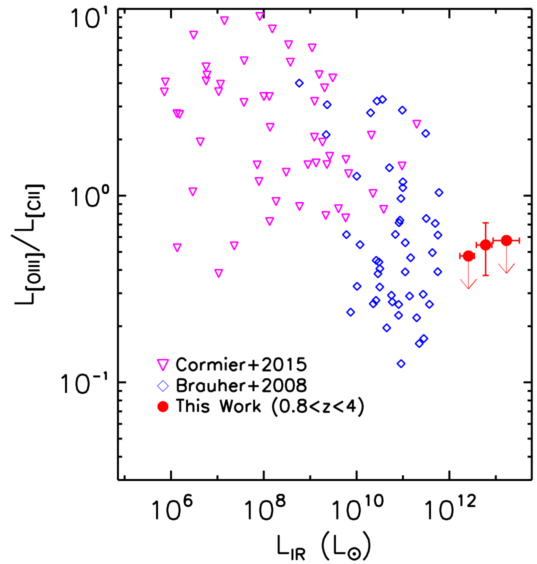
Luminosity dependent.

European Space Agency

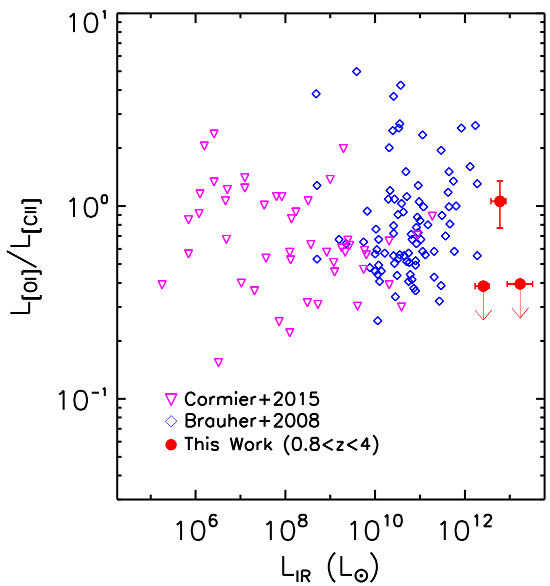
Results: lines/L_{IR}



([CII] + [OI])/L_{IR}



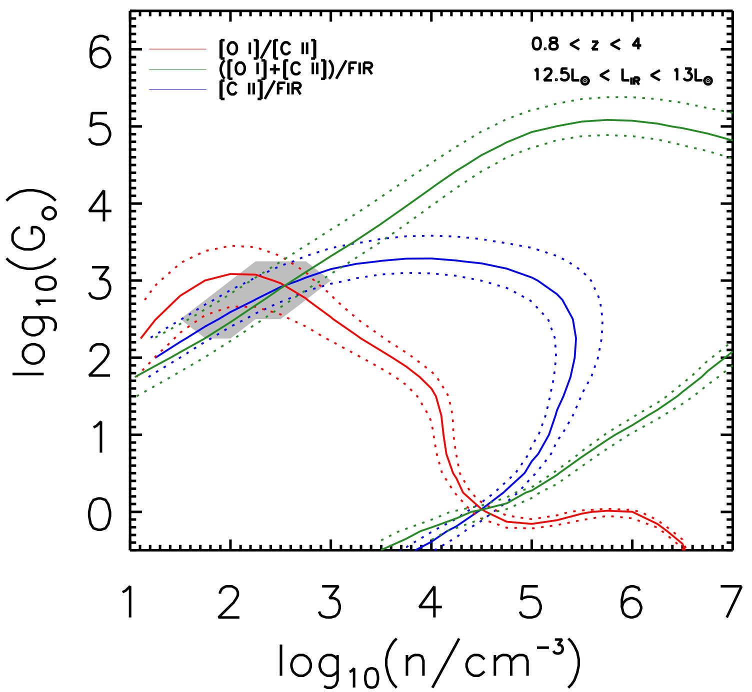
[OIII]/[CII]



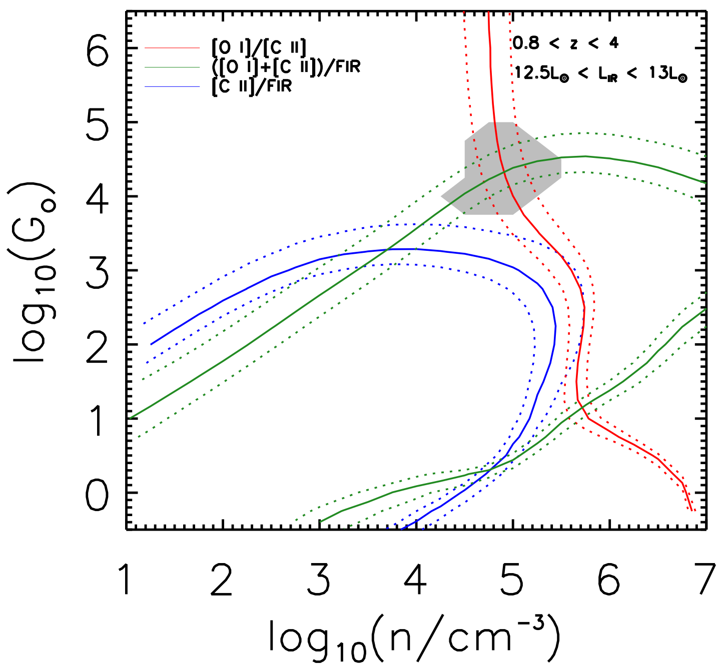
[OI]/[CII]

Results: PDR modeling

Uncorrected [OI] 63 μm

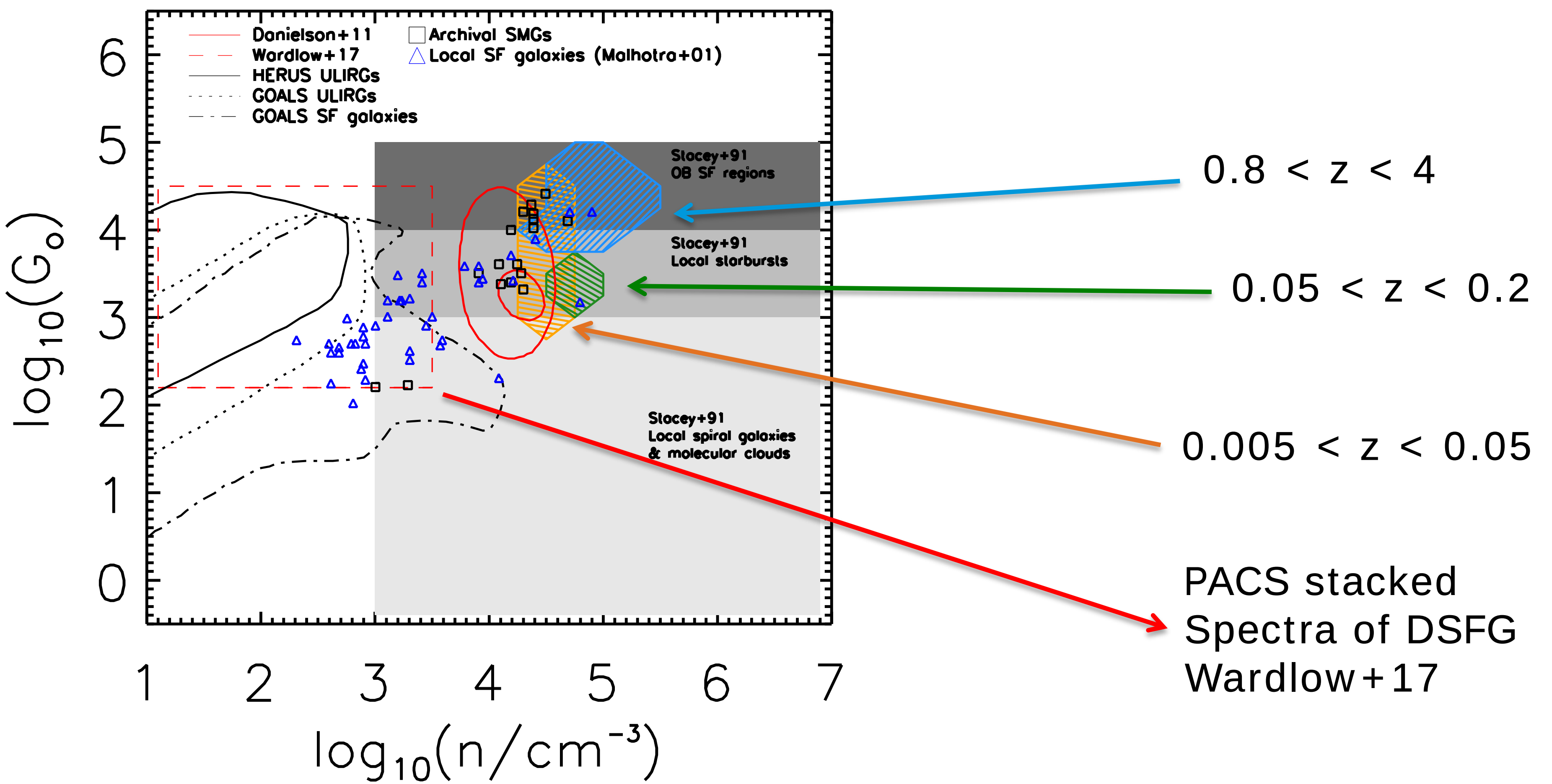


Corrected [OI] 63μm



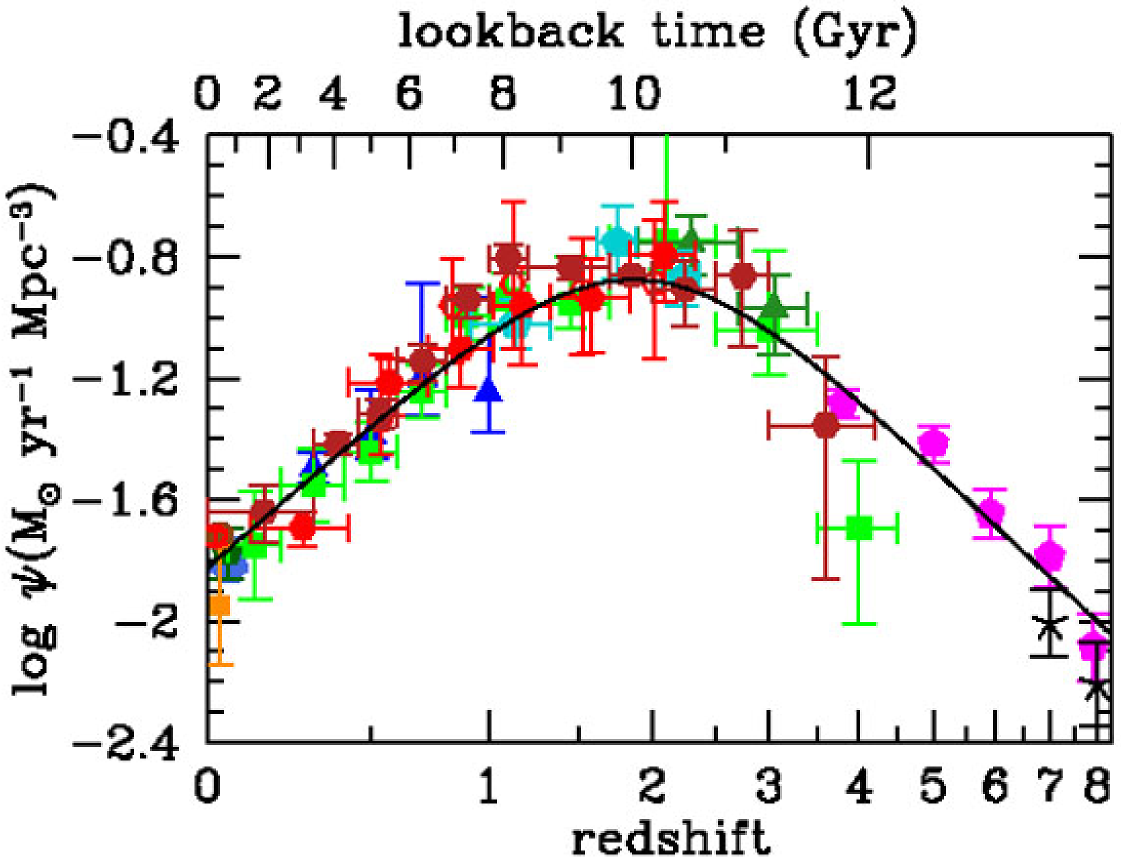
Using line ratios to infer gas density (n) and strength of the incident FUV radiation (G_0)➔ the averaged physical conditions for the sample

Results: comparison with other studies

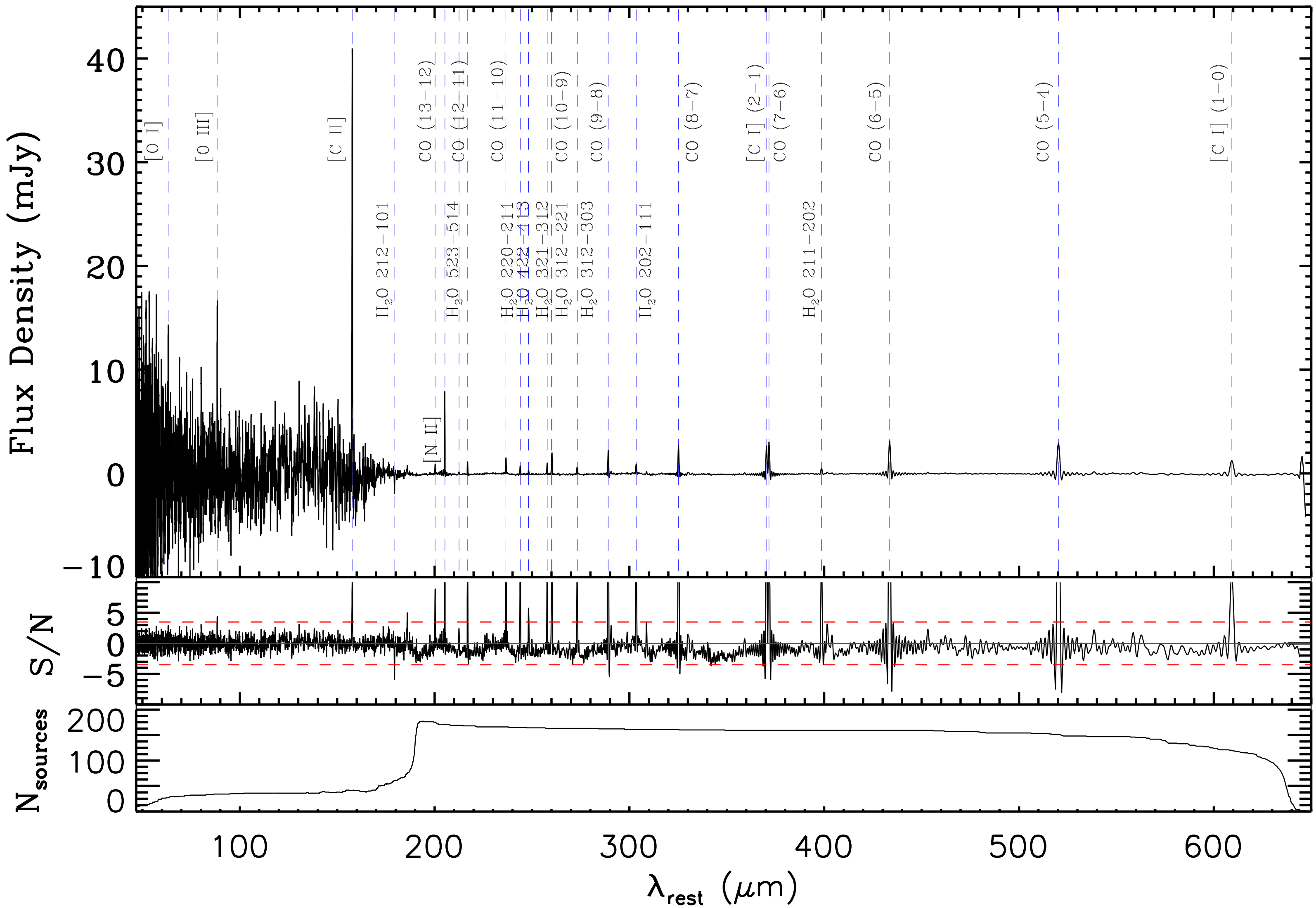


The big question

- still remains…



The end



Flux Density (mJy)
S/N
$N_{sources}$
λ_{rest} (μm)
[O I]
[O III]
[C II]
[N II]
CO (13−12)
CO (12−11)
CO (11−10)
CO (10−9)
CO (9−8)
CO (8−7)
[C I] (2−1)
CO (7−6)
CO (6−5)
CO (5−4)
[C I] (1−0)
H_2O 212−101
H_2O 523−514
H_2O 220−211
H_2O 422−413
H_2O 321−312
H_2O 312−221
H_2O 312−303
H_2O 202−111
H_2O 211−202

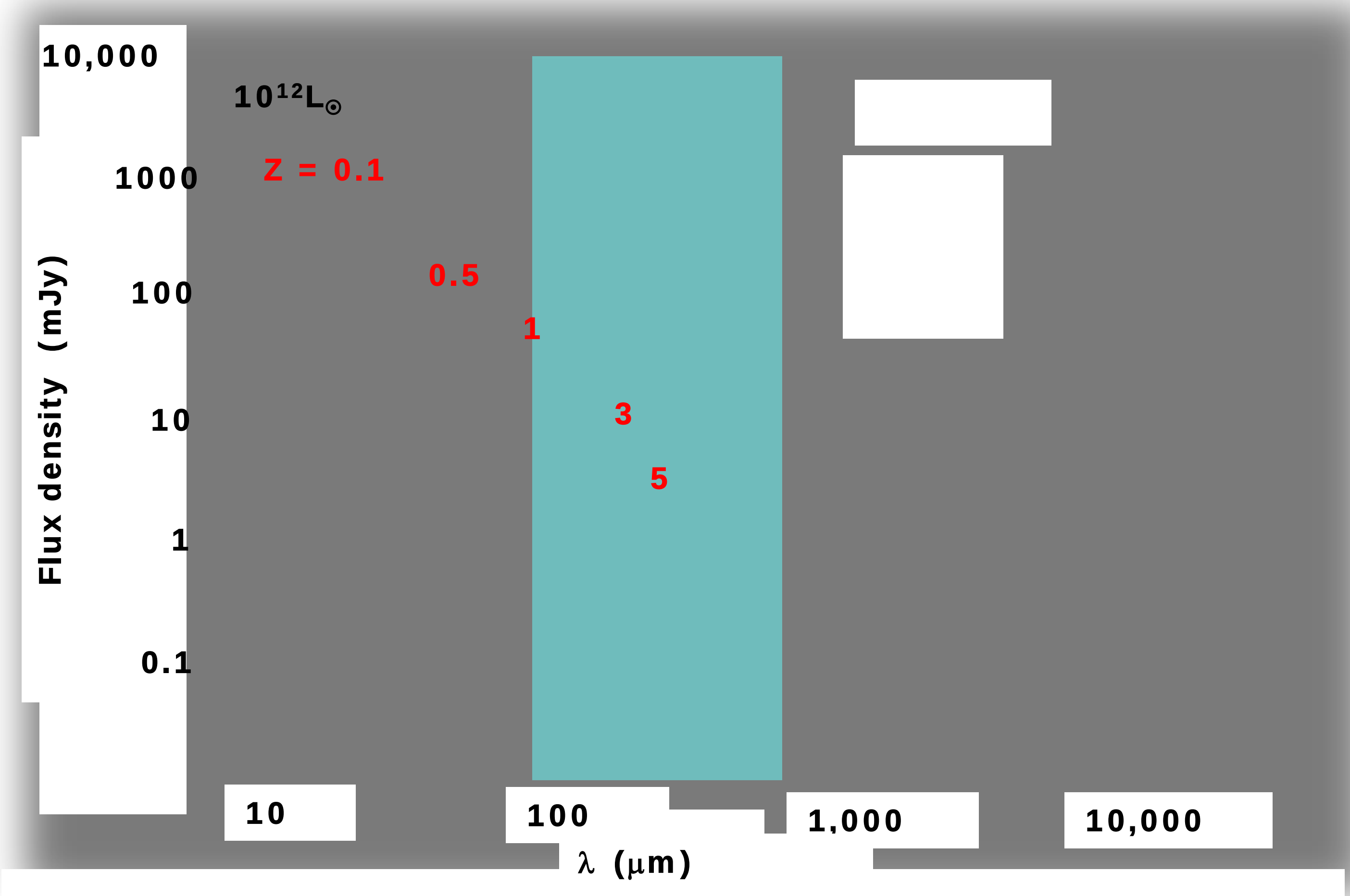
Overflow

- The stacking is a powerful technic to access far away galaxies

- We used it on a heterogeneous sample of Herschel DSFG at $0.005 < z < 4$ and derived constrains on the interstellar gas density (n) and the FUV radiation field (G0):

  $\log(n/\mathrm{cm}^{-3}) \sim 4.5\text{-}5.5$,

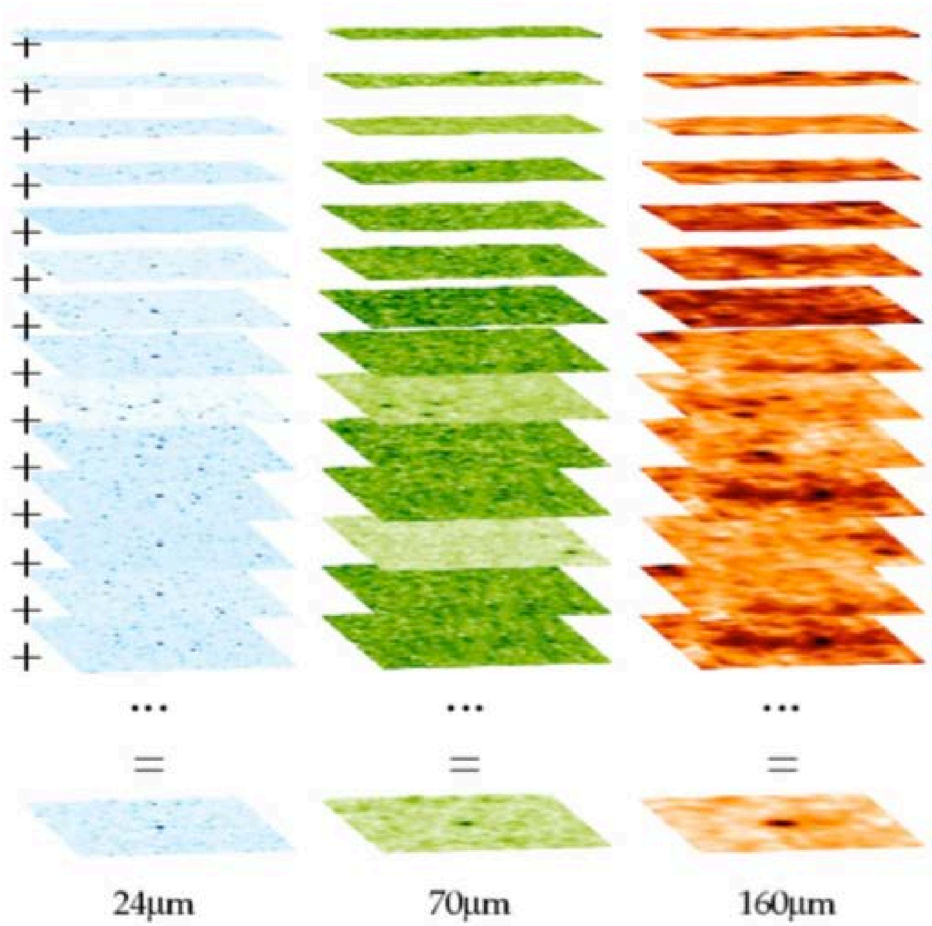
  $\log(G_0) \sim 3\text{-}5$



After Guiderdoni et al. MNRAS 295, 877, 1998

Stacking with maps

Stack ~19000 Galaxies



Dole et al., 2006, A&A, 451, 417