



ALMA Band 2 as a redshift machine

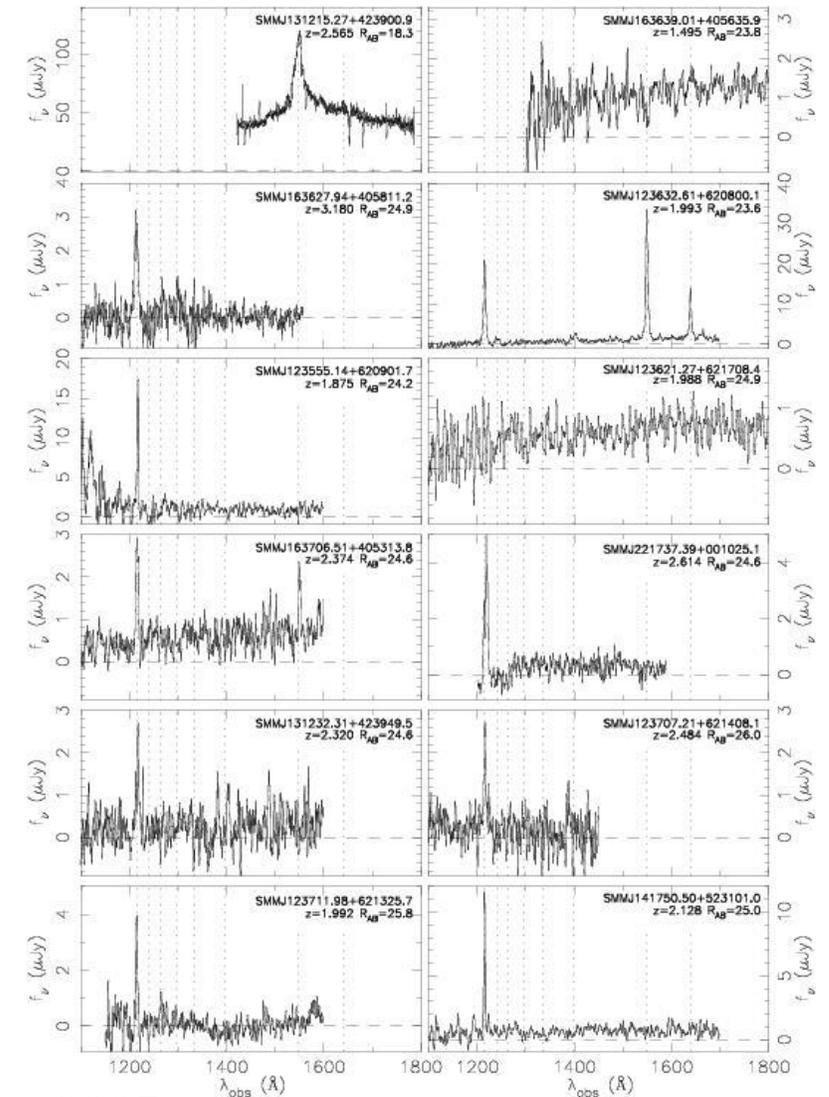
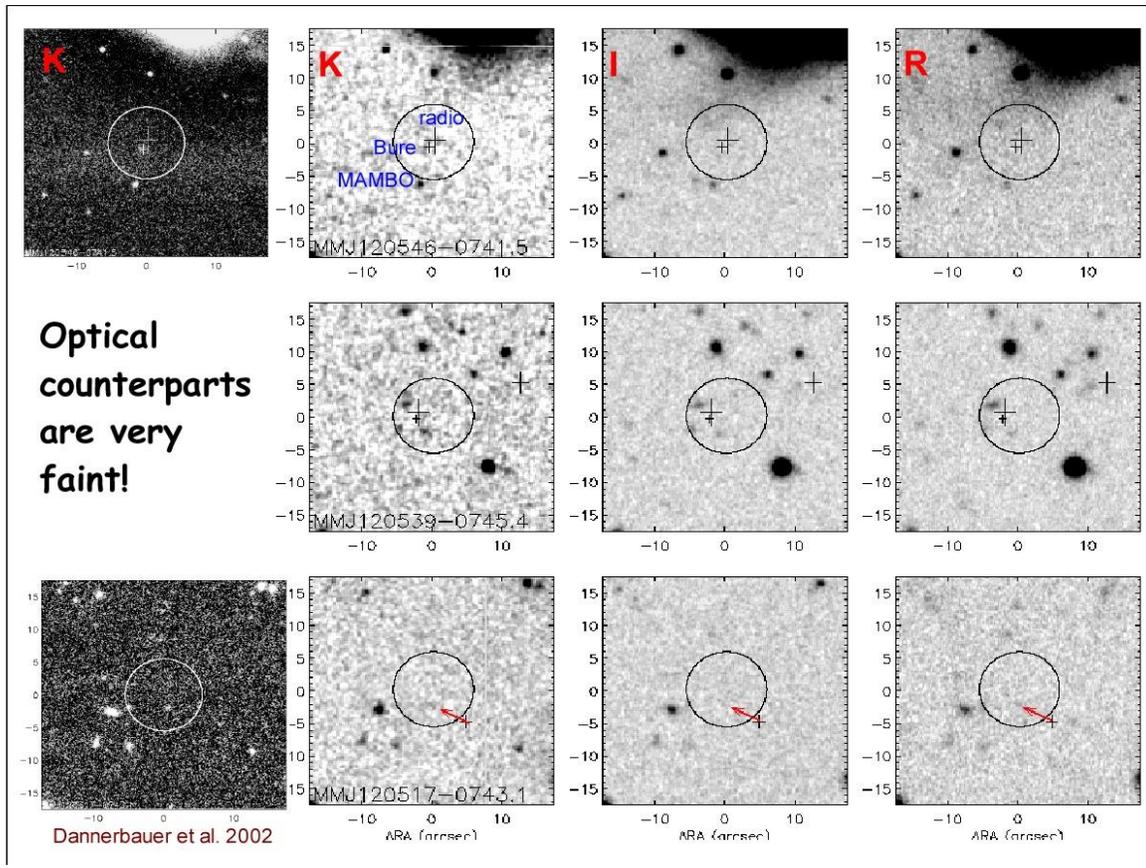
Carlos De Breuck
(ESO, Garching)



How to determine redshifts of dusty sources?

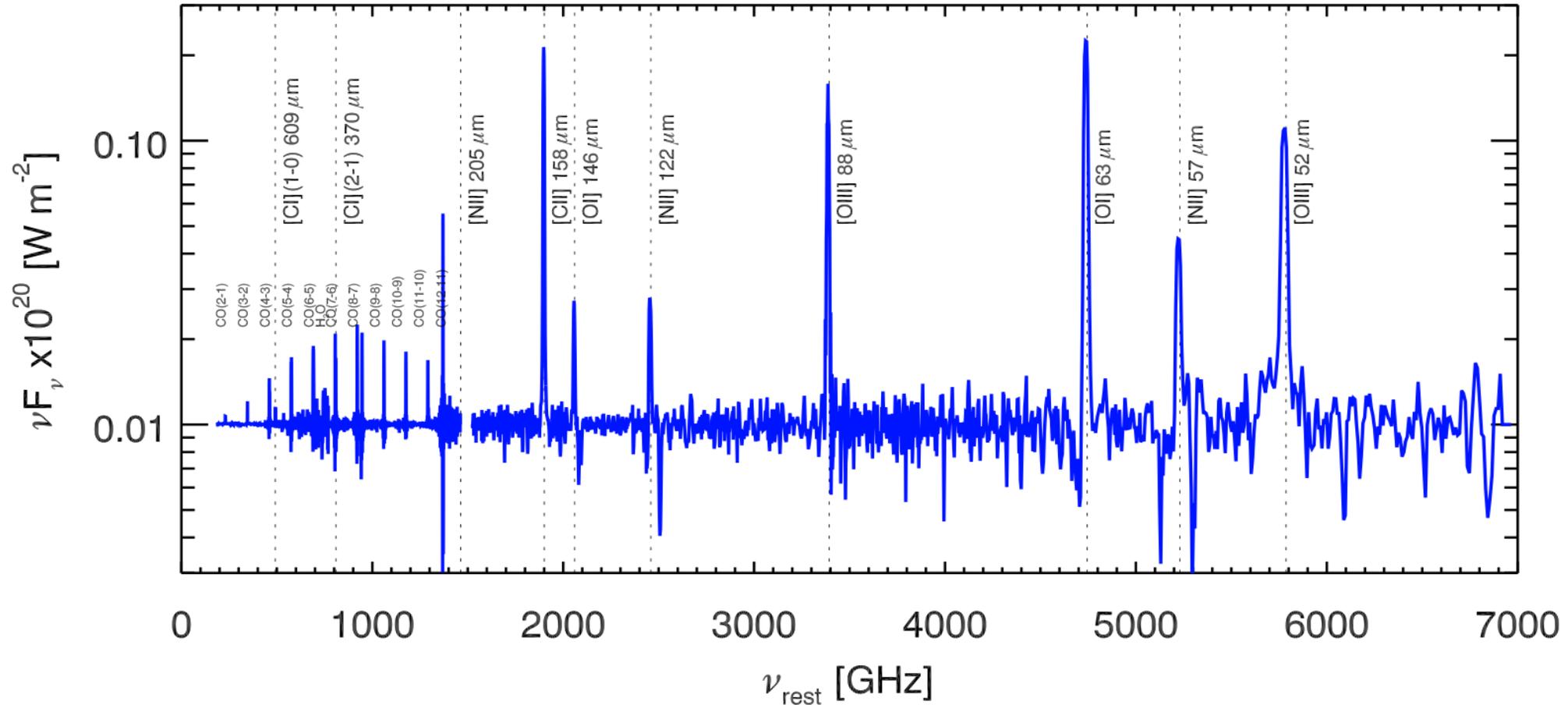
Historically: get optical identification, then optical redshifts

Painstakingly slow, inefficient and incomplete



More efficient to use molecular & atomic submm lines

FIR and submm lines

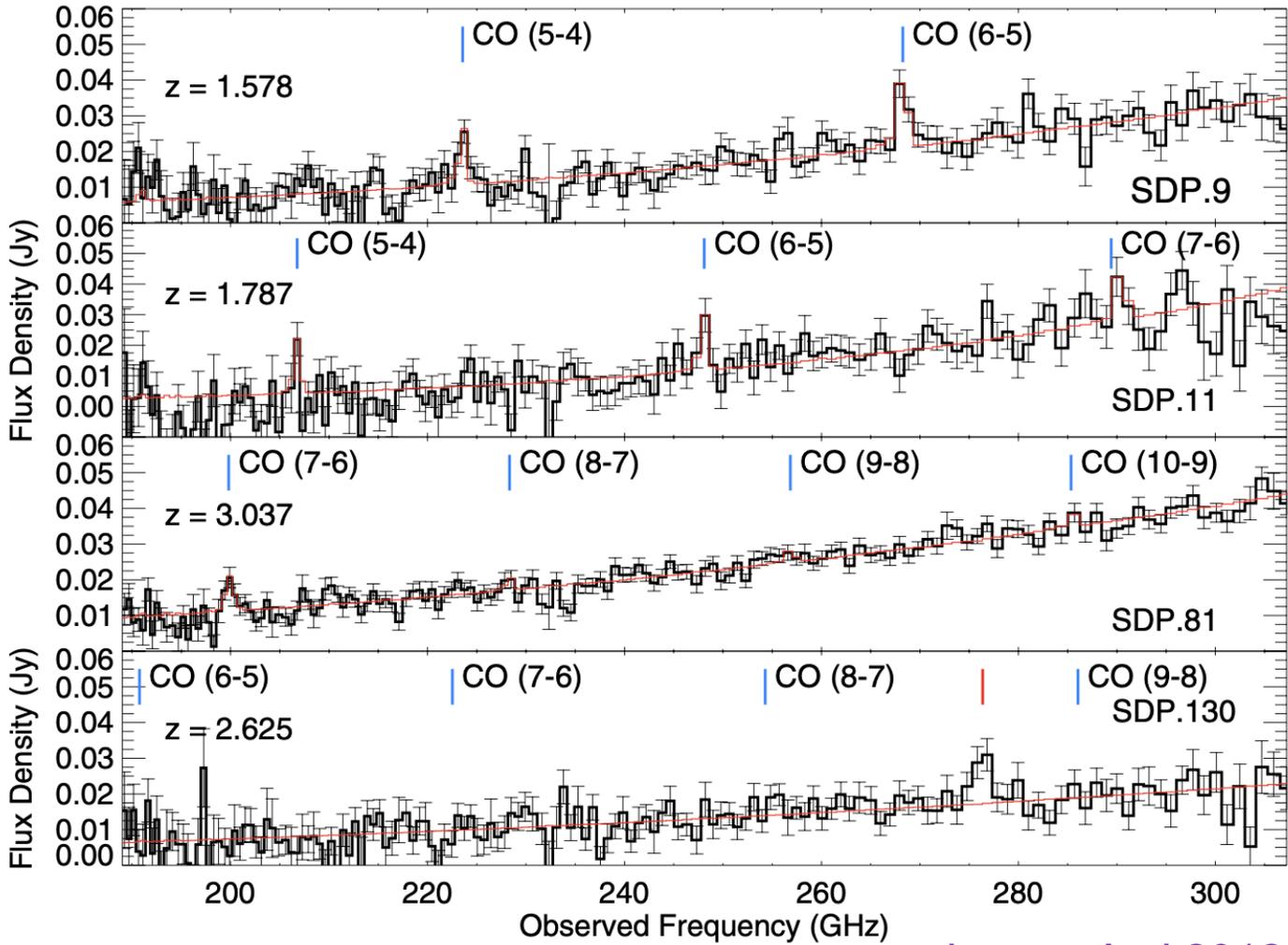


Can use the CO ladder and far-IR fine-structure lines to determine redshifts directly in the submm

Dedicated broad-band sub/mm instruments designed for z searches

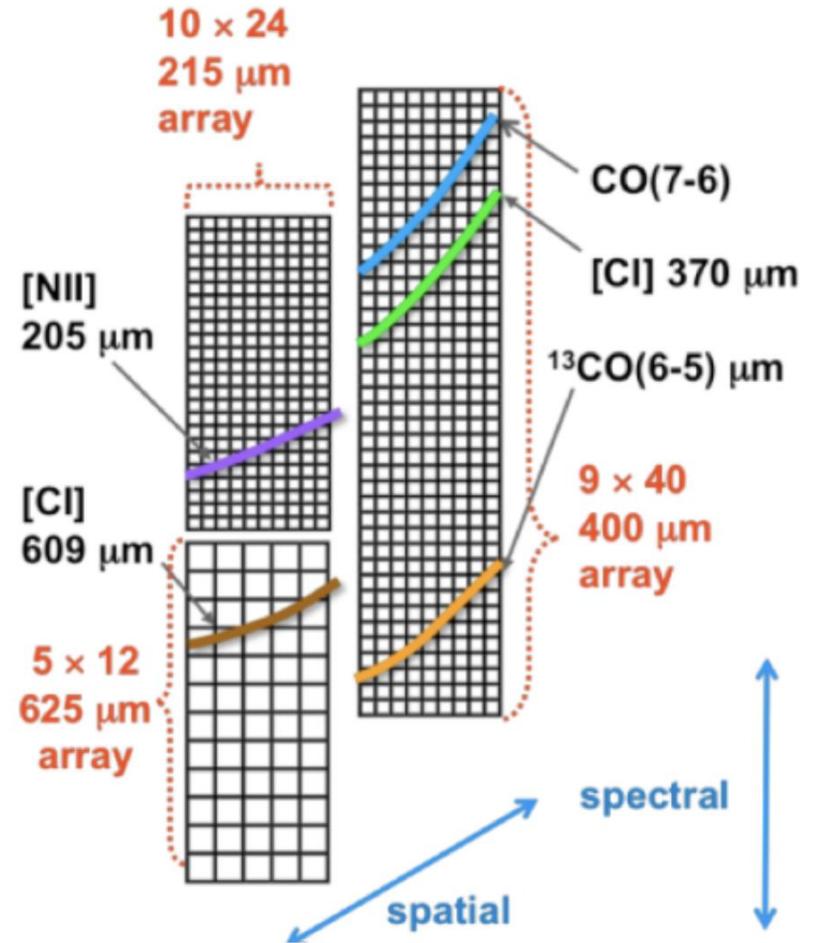


Zspec @ CSO and APEX



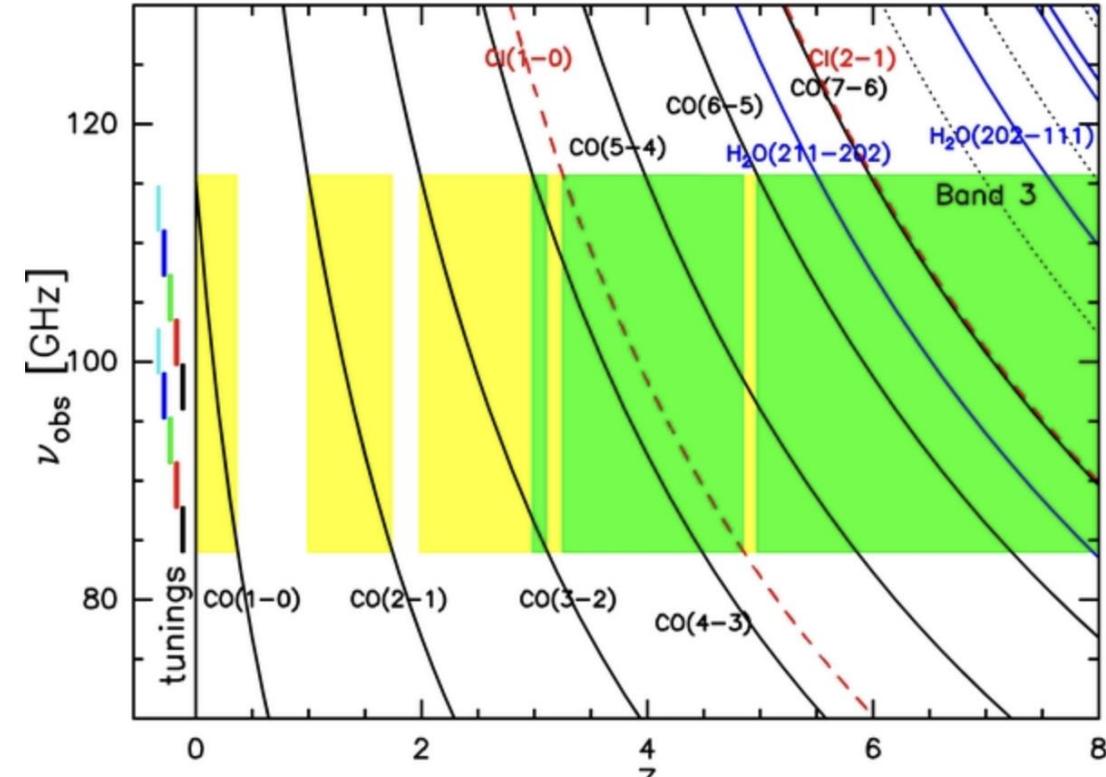
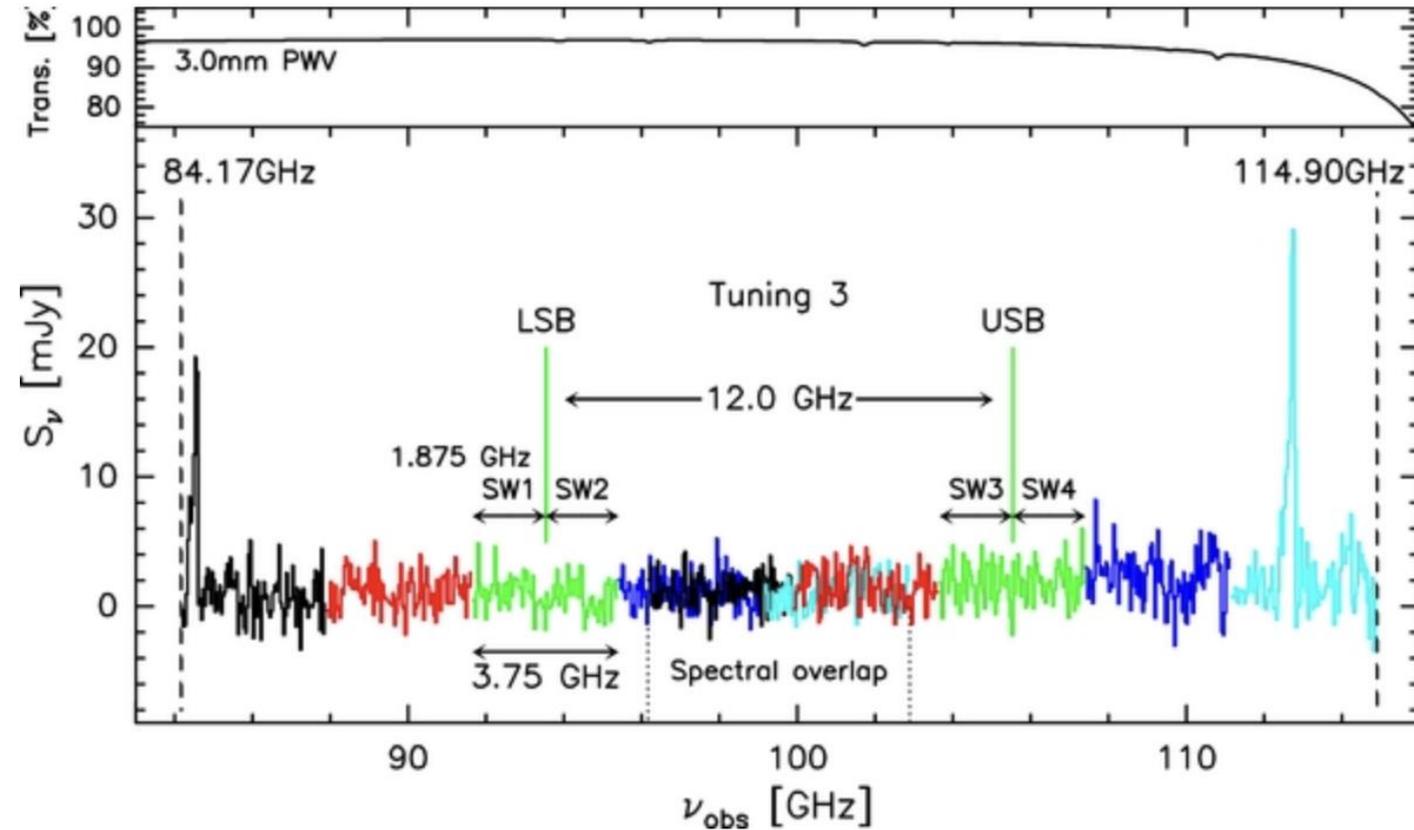
Lupu + ApJ 2012

ZEUS-2 @ APEX



Ferkinhoff + SPIE 2010

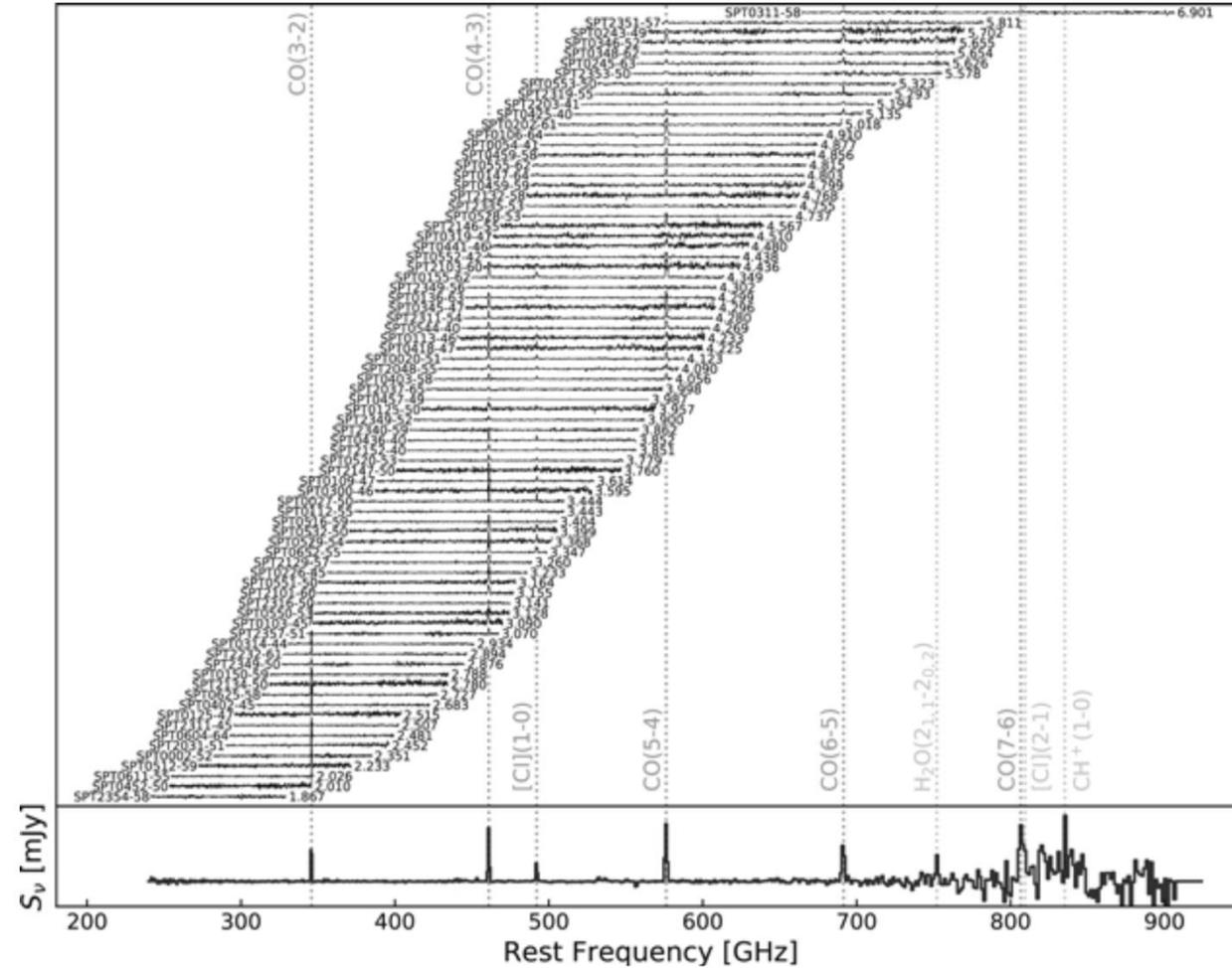
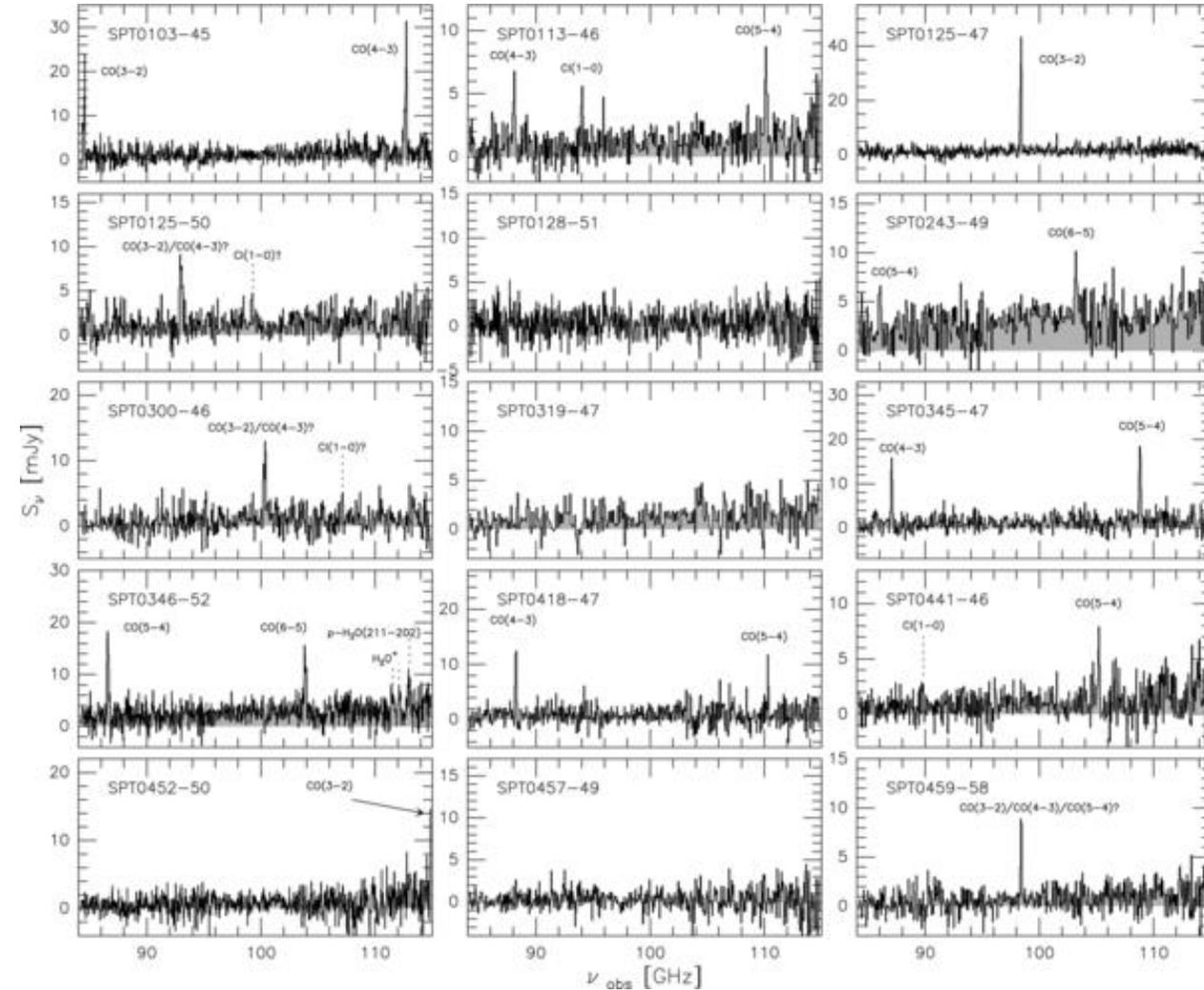
Redshift searches with ALMA: Band 3



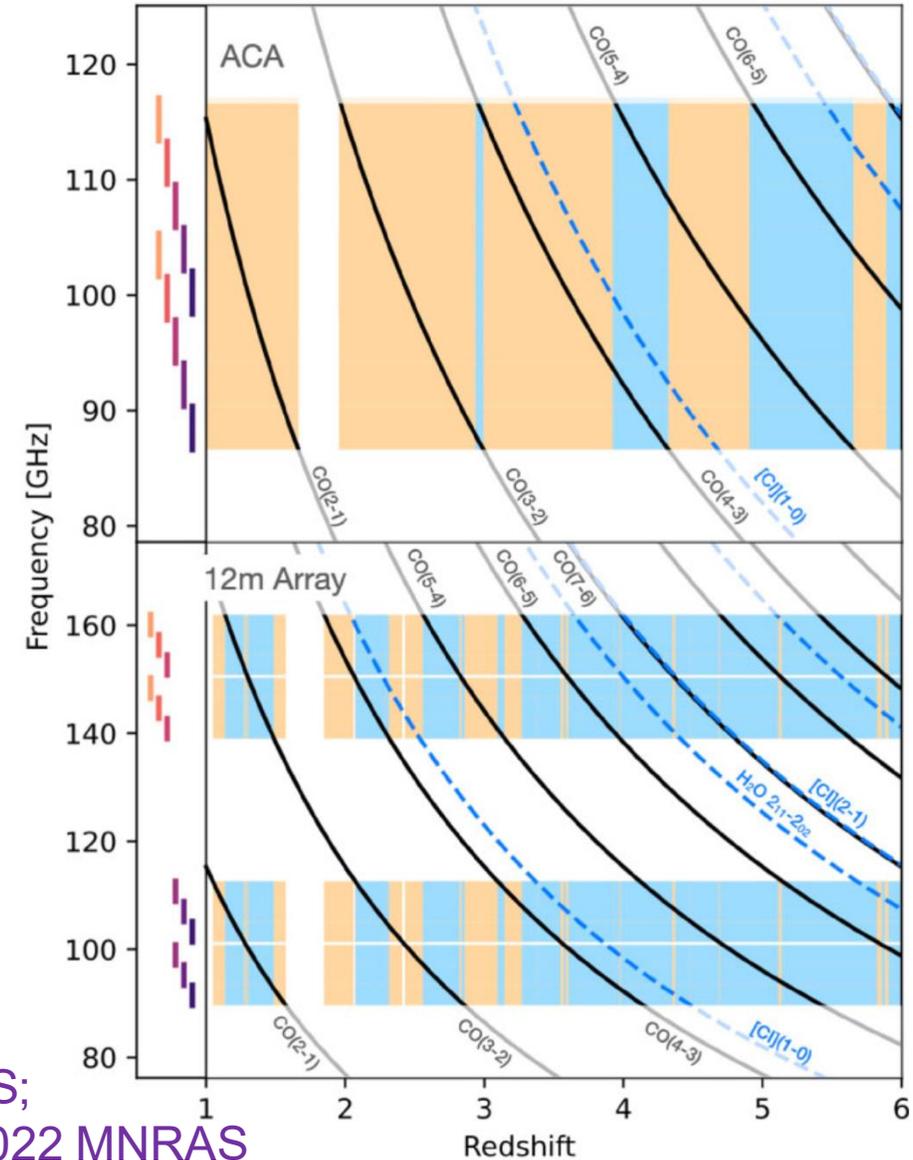
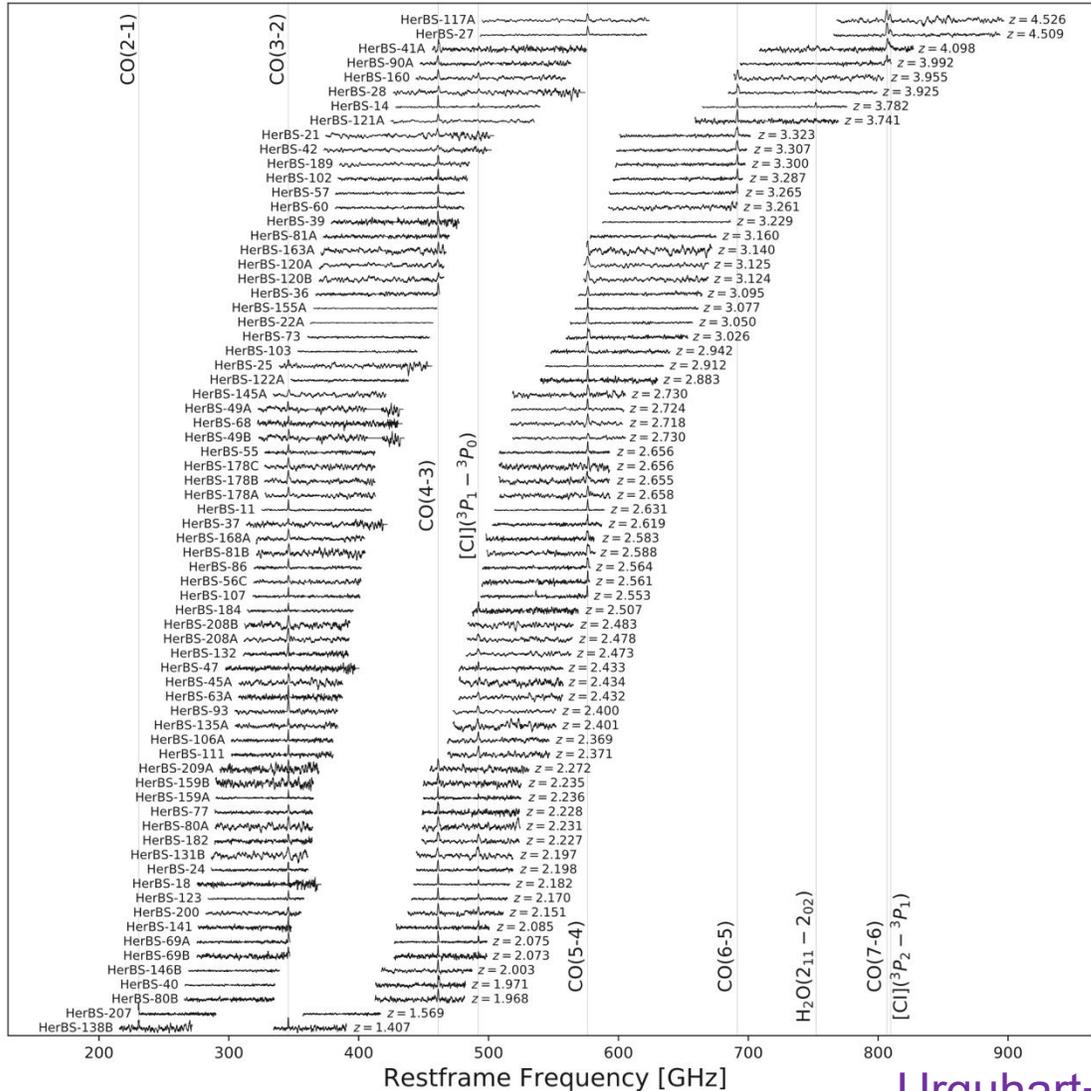
Single line – redshift ambiguity
 Multiple lines – solid redshifts

Already in Cycle 0, the first spectral scans of Band 3 were more successful than previous efforts!

Redshift searches with ALMA: Band 3



Redshift searches with ALMA: Band 3+4



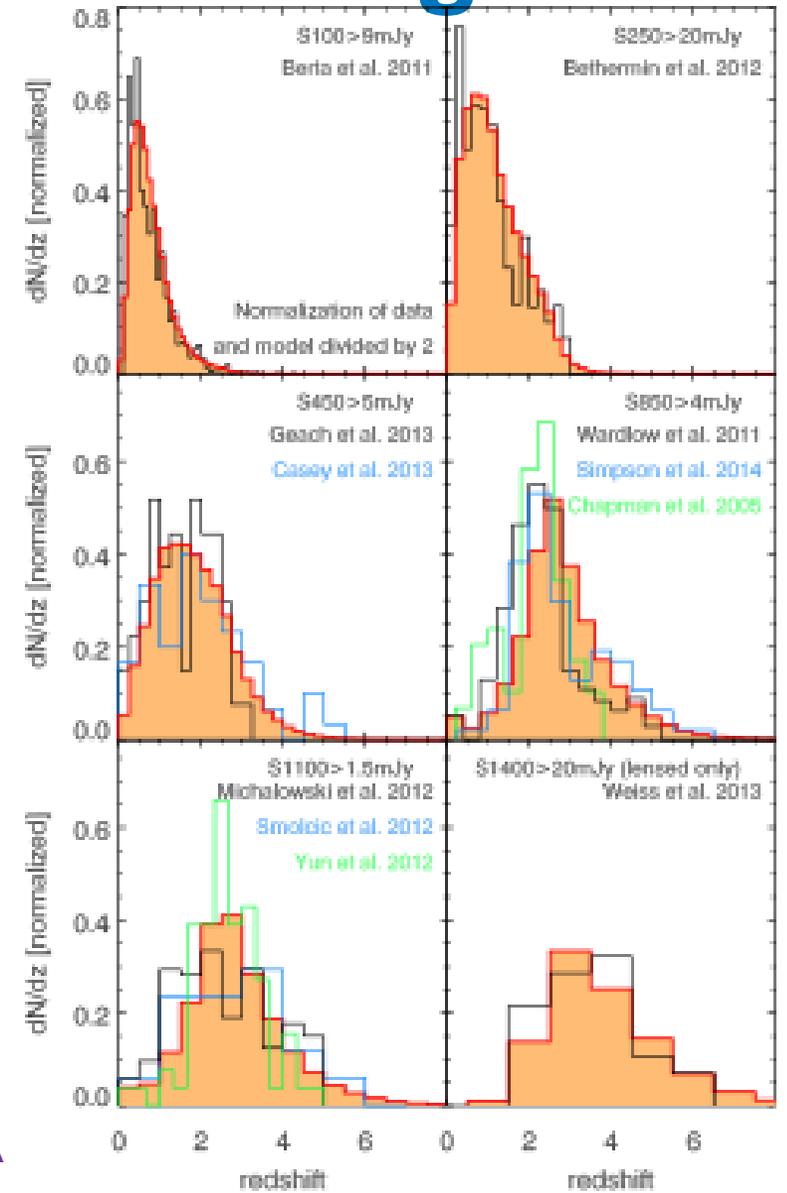
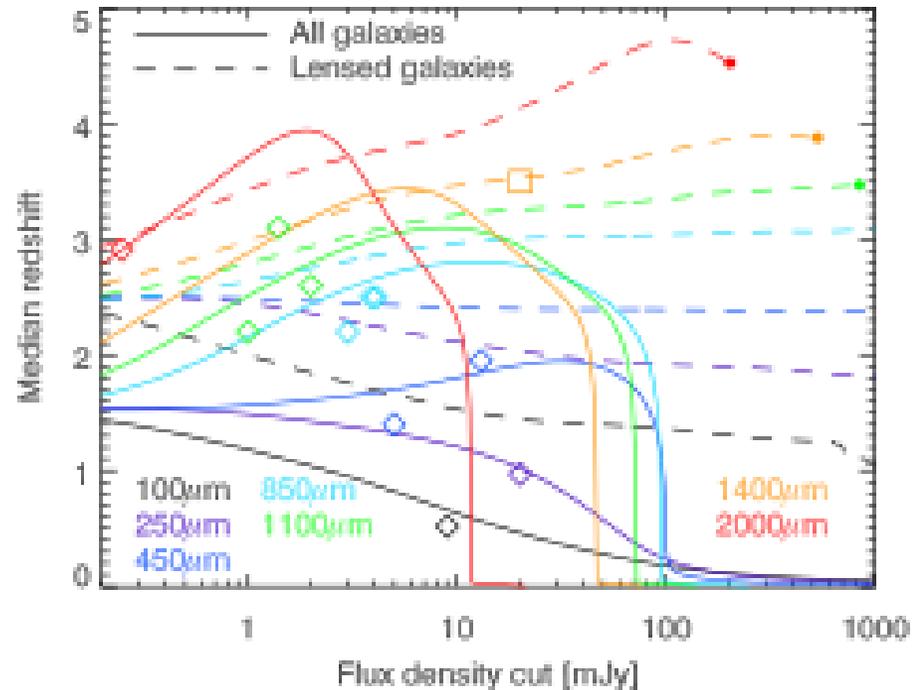
Single line – redshift ambiguity
Multiple lines – solid redshifts

Urquhart+ 2022 MNRAS;
Bakx & Dannerbauer 2022 MNRAS

Expected redshift distribution for dusty galaxies depends on selection wavelength



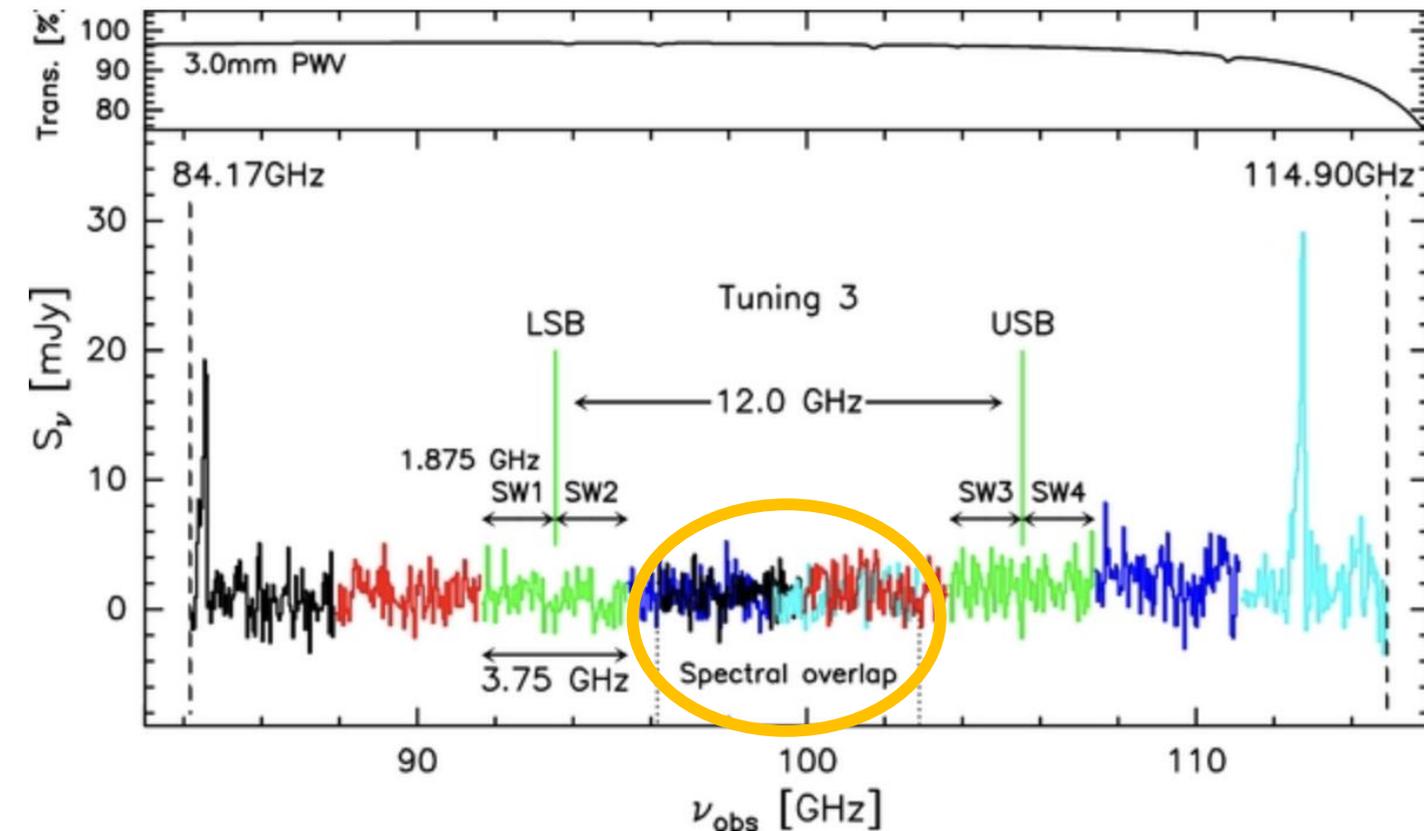
- Median z mainly depends on selection wavelength of flux-limited sample
- Gravitational lensing and survey depth have a smaller influence
- Prior knowledge of expected redshift distribution helps to determine which bands to scan



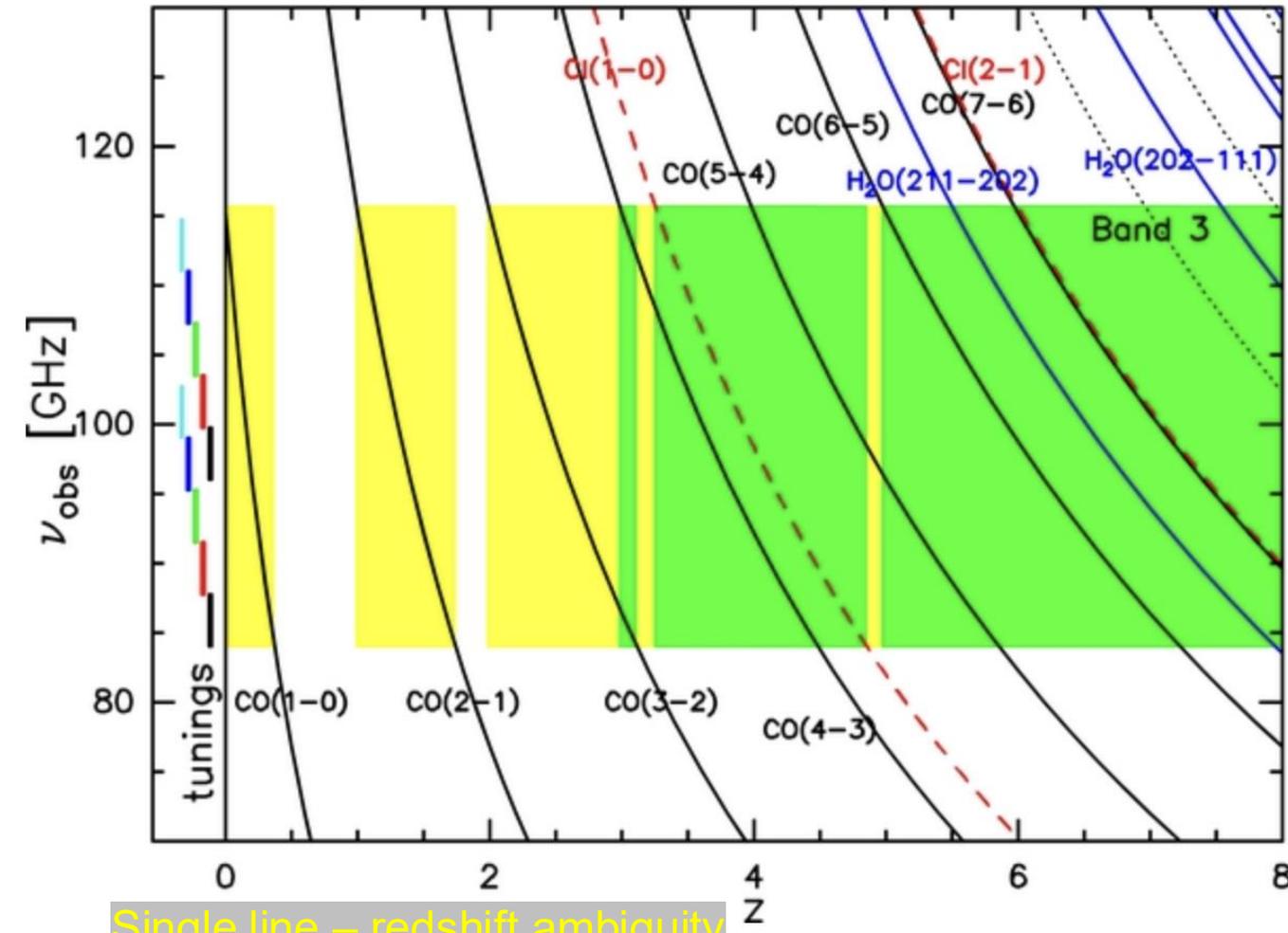
Limitations of the current ALMA system

Inefficient spectral coverage

- Bands 3 and 4 do have only 4.0 GHz IF bandwidth → cannot put 4 consecutive spectral windows
- Due to anti-aliasing filters, effective spectral coverage 1.875 GHz per spectral window → 3.75 GHz per sideband
- Two adjacent tunings cover only 7.5 GHz, while gap between sidebands is 8.0 GHz



Limitations of the current ALMA system



Single line – redshift ambiguity

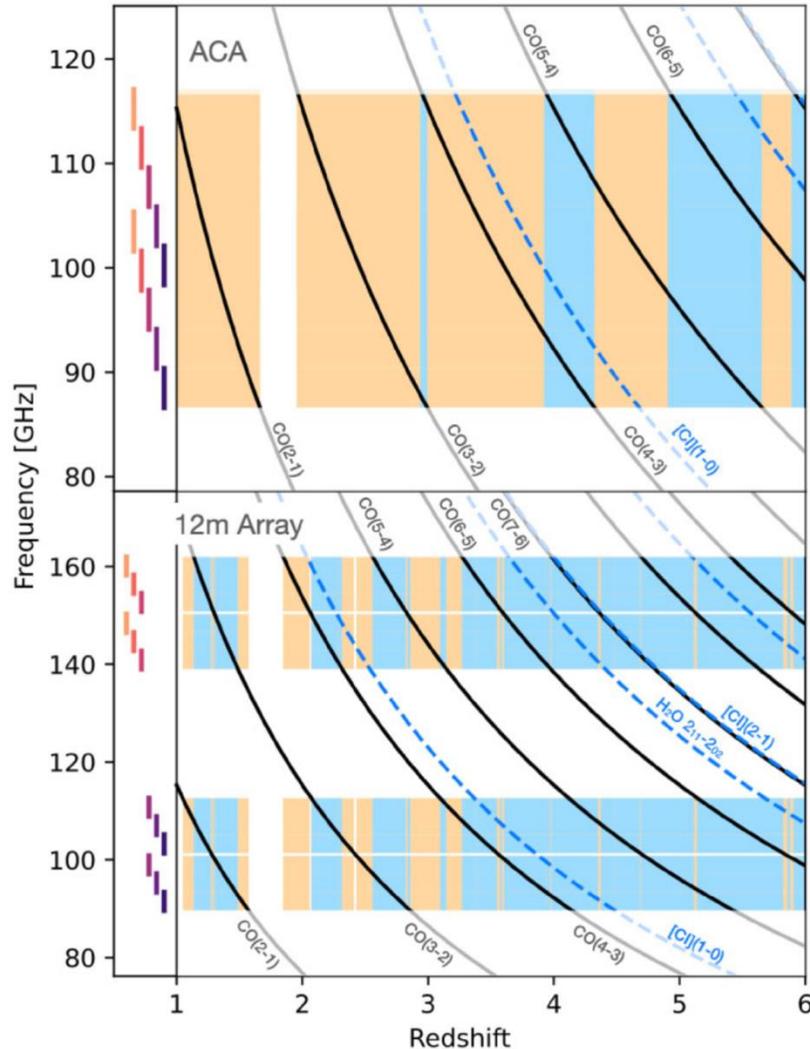
Multiple lines – solid redshifts

Unambiguous redshift ranges:

- Full 84-116 GHz Band 3 coverage provides multiple lines only at $z > 3$
- Band 3 redshift deserts at $0.37 < z < 0.99$ and $1.74 < z < 1.98$
- Single line redshifts need to be followed up in another Band (using other CO lines or [CII])
→ often takes several years to complete

Limitations of the current ALMA system

Single line – redshift ambiguity
Multiple lines – solid redshifts

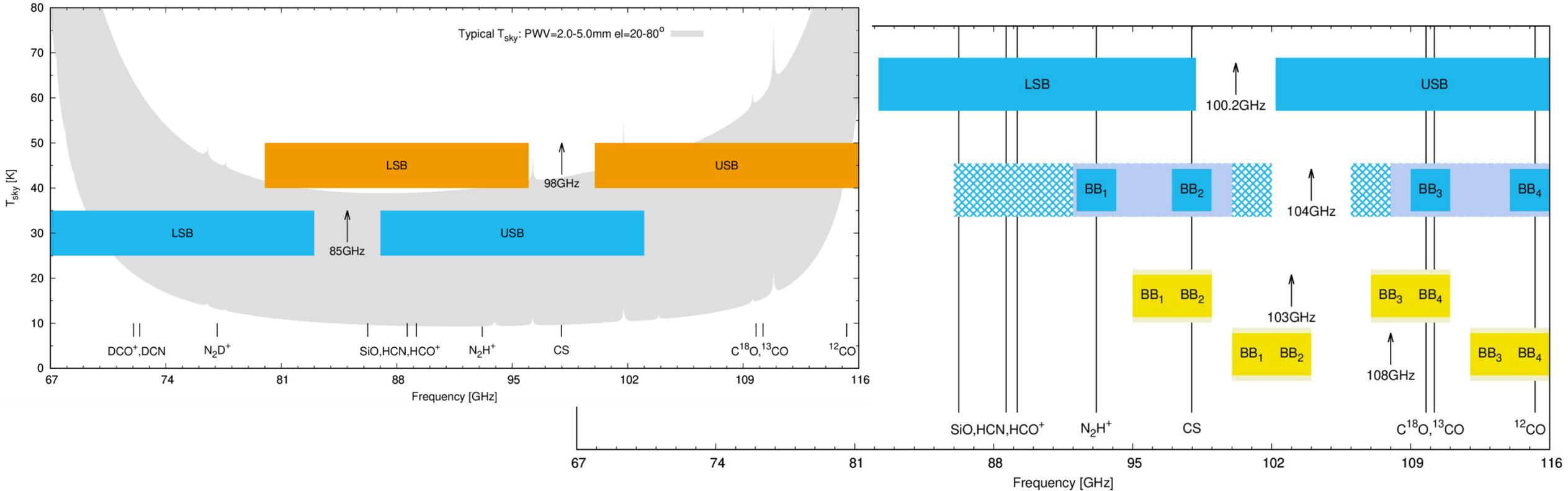


Unambiguous redshift ranges:

- Full 84-116 GHz Band 3 coverage provides multiple lines only at $z > 3$
- Band 3 redshift deserts at $0.37 < z < 0.99$ and $1.74 < z < 1.98$
- Spreading 6 tunings over Bands 3 and 4 provides more multiple-line coverage, but the $1.74 < z < 1.98$ redshift desert remains

Urquhart+ 2022 MNRAS;
Bakx & Dannerbauer 2022 MNRAS

Big efficiency improvement with Band 2

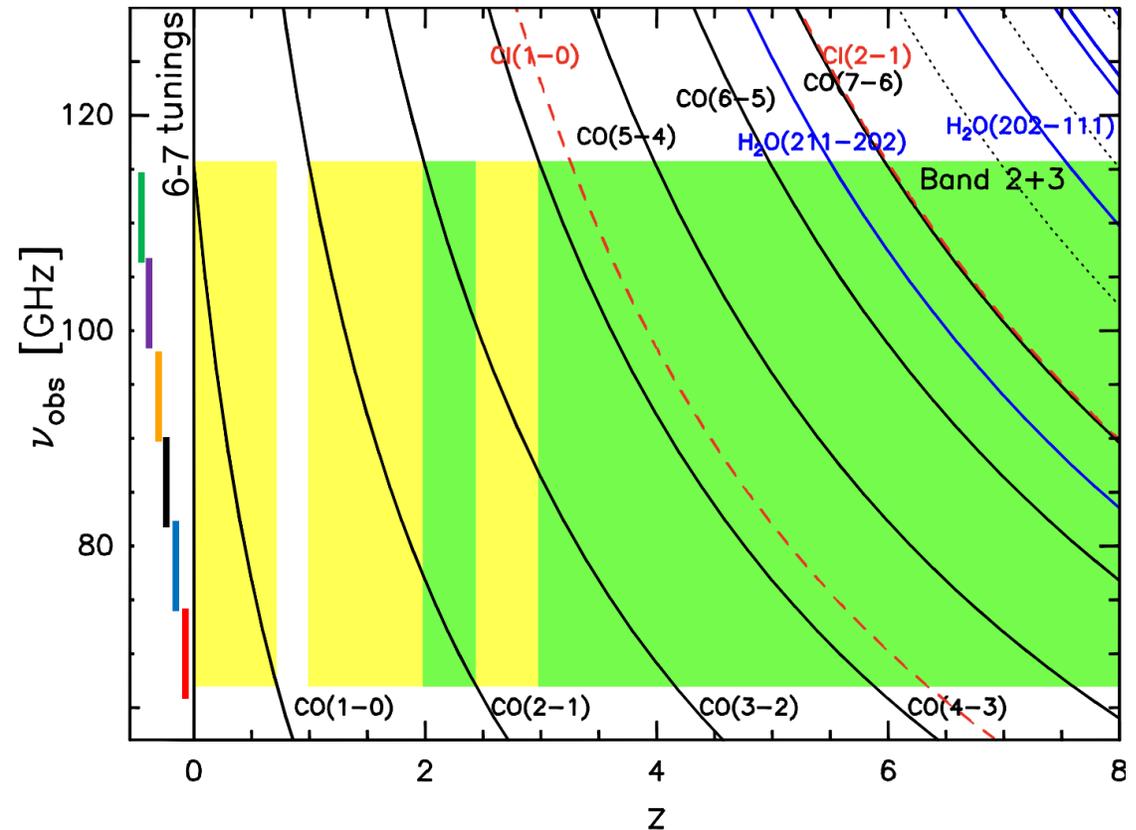
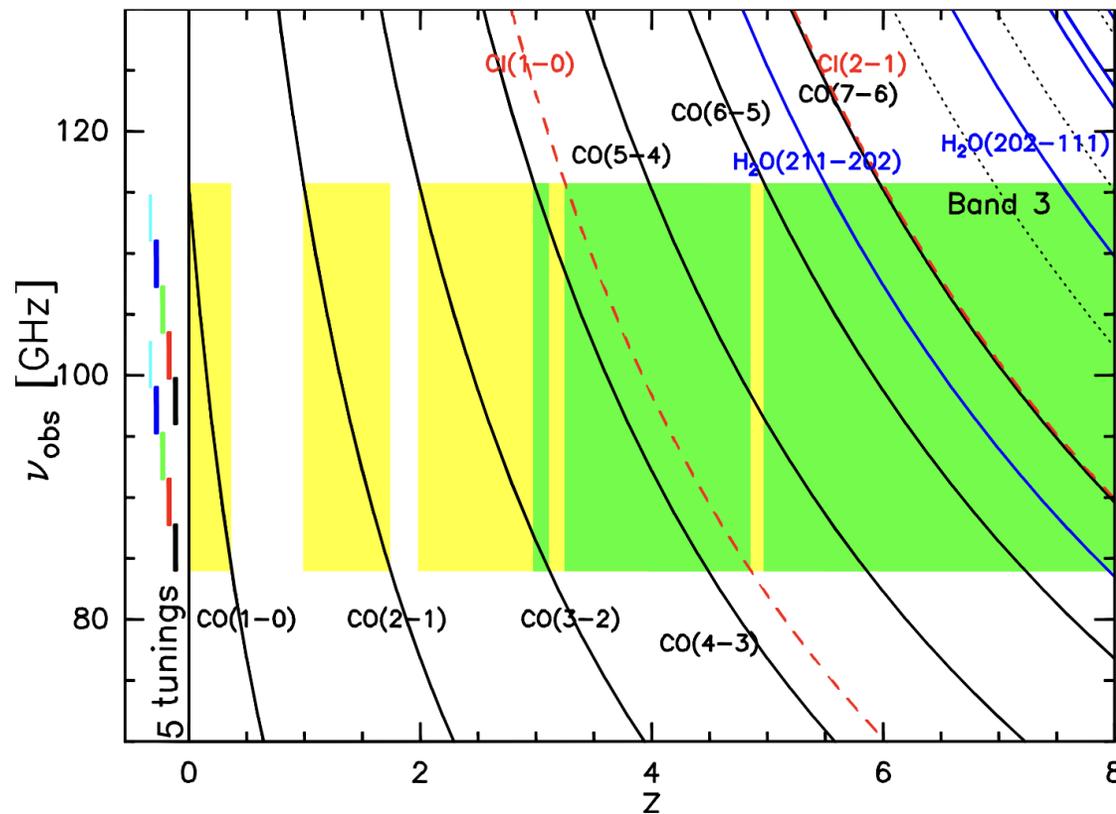


- Legacy system: 2-18 GHz IF coverage allows to place 4 spectral windows contiguously
- Early WSU (16 GHz IF coverage): allows to cover 8.0 GHz per sideband → exactly filling gap between sidebands
- Full WSU (32 GHz IF coverage): two tunings cover full Band 2 coverage!

Band 2 with early current legacy system



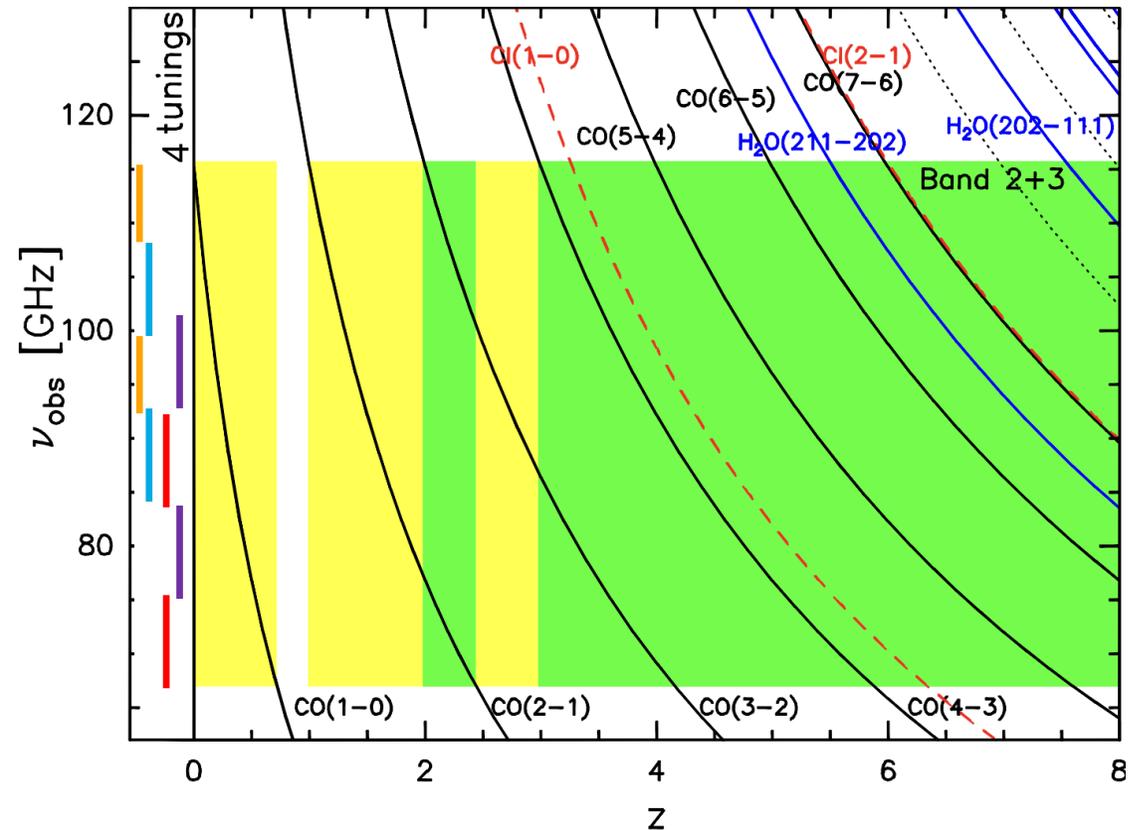
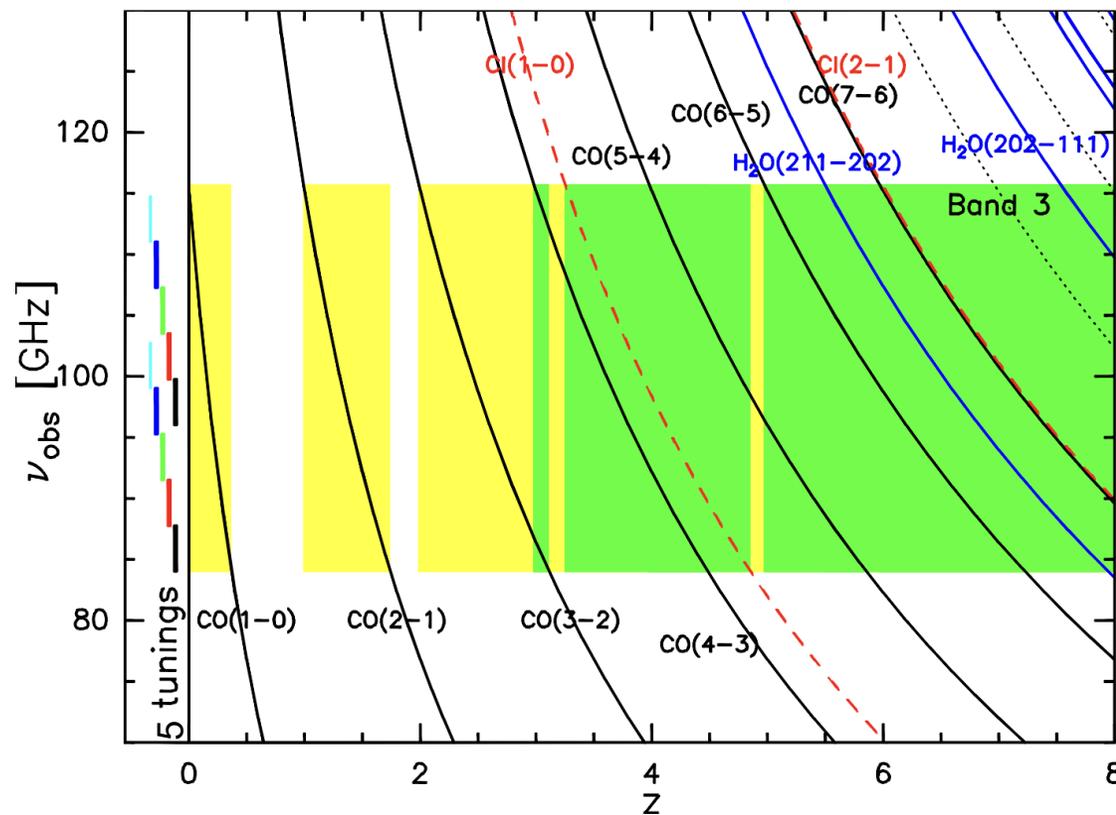
- Can place all spectral windows in the same sideband to provide 7.5 GHz contiguous spectral coverage
- Six tunings can cover 67-112 GHz → still missing 4 GHz
- Seven tunings would cover full 67-116 GHz coverage with 3.5 GHz of overlap



Band 2 with 2x bandwidth early WSU



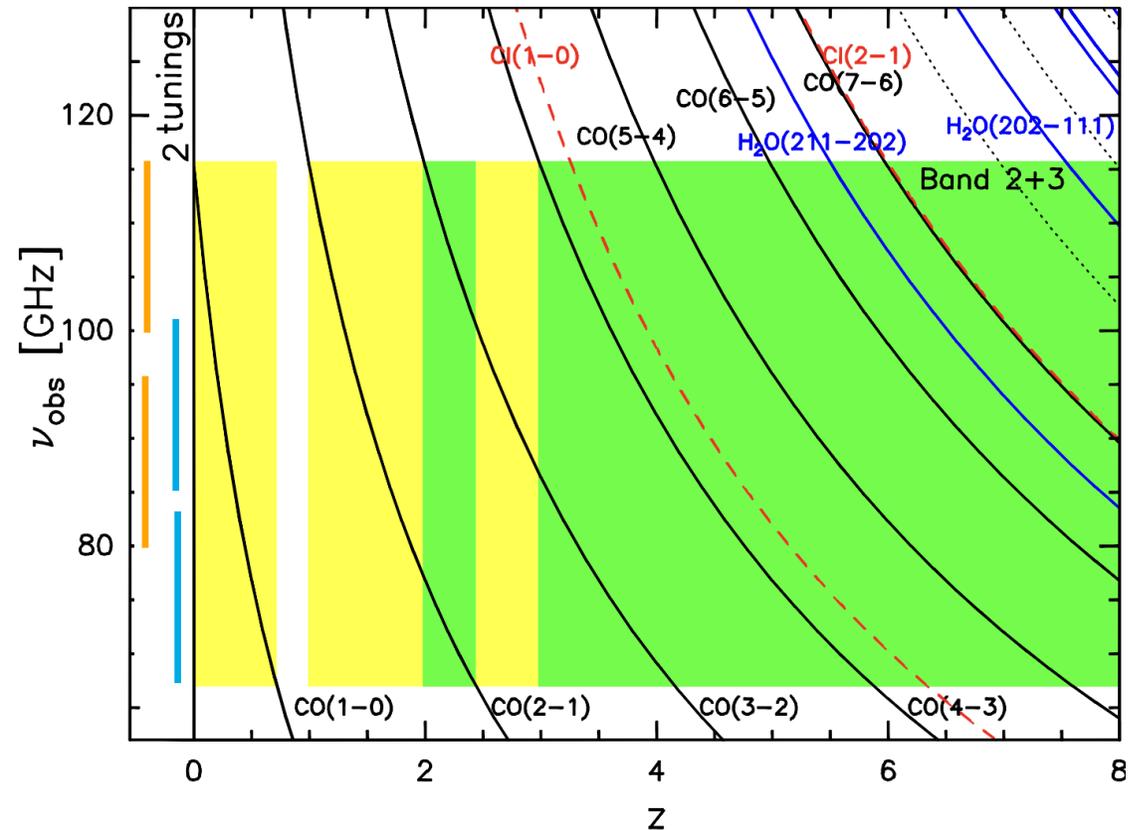
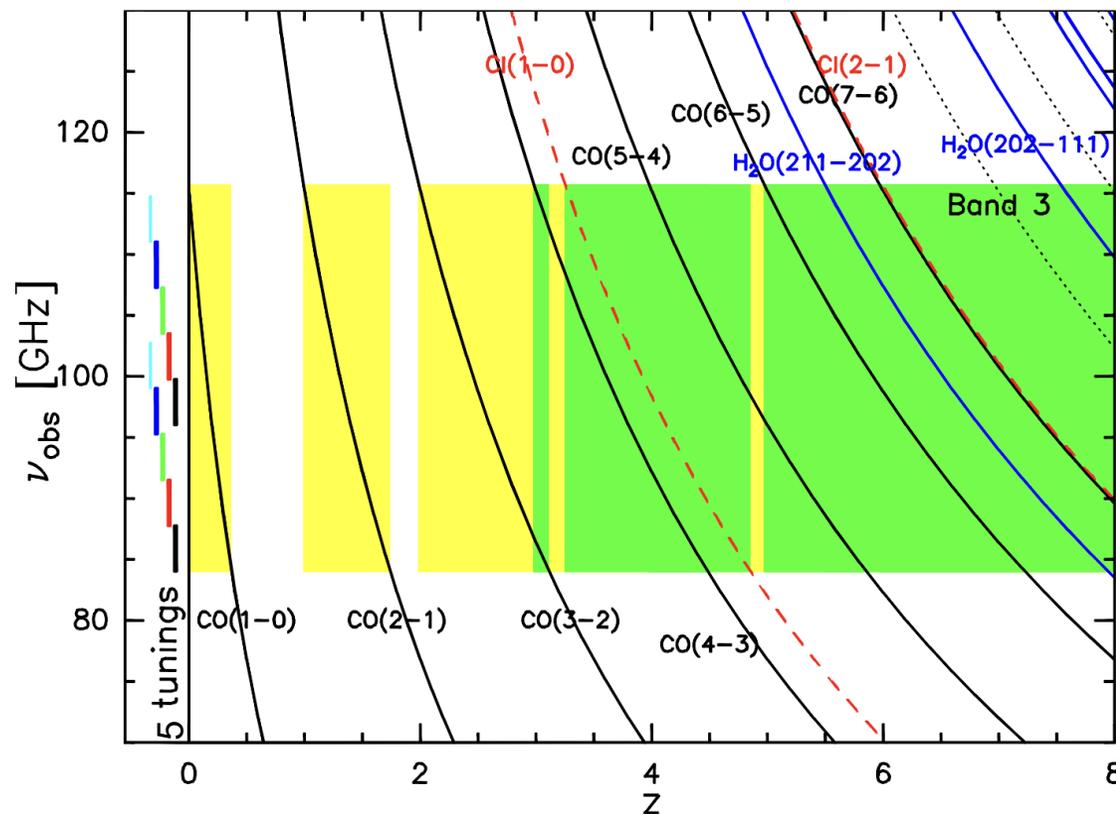
- IF bandwidth of 8 GHz per sideband/polarization would fit the 8.0 GHz gap between both sidebands
- However, would only cover 32 GHz, while Band 2 RF range is 49 GHz
- Would still require 4 tunings with significant overlap → non-uniform depth (or only Band 3 in 2 tunings)



Band 2 with 4x bandwidth full WSU



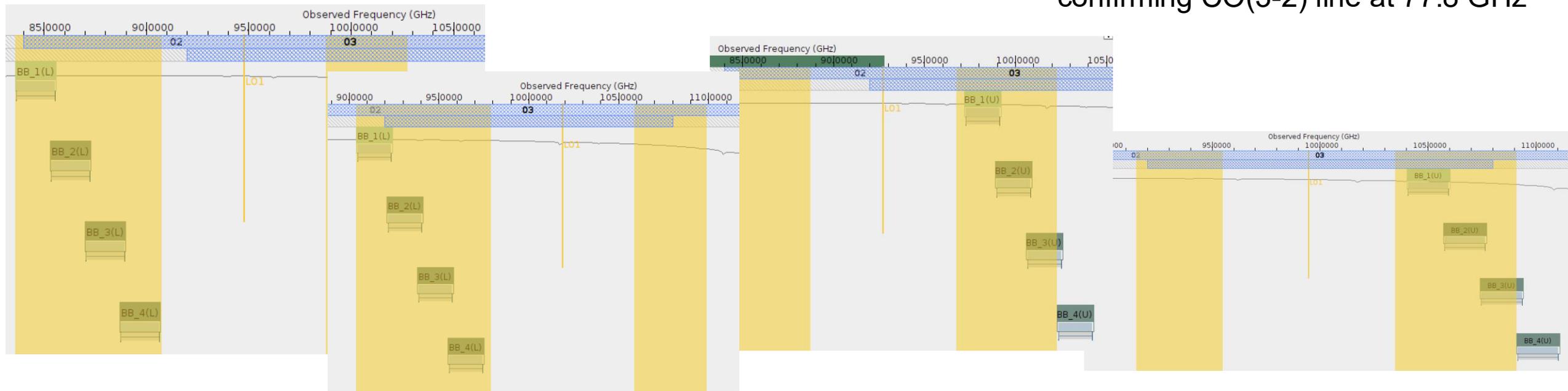
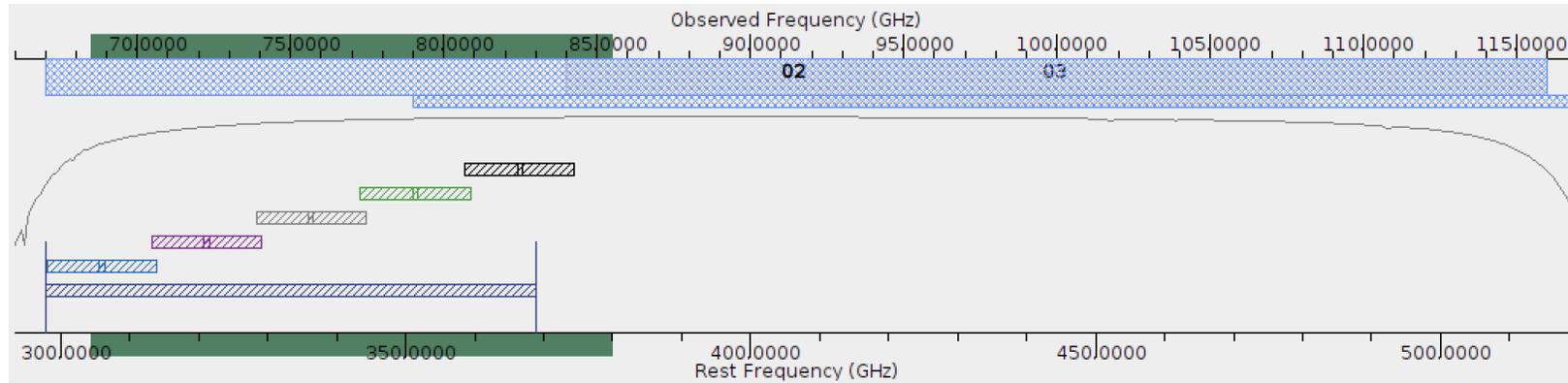
- At least 1 line at $z > 1$; only $0.72 < z < 0.98$ redshift desert remains, where dusty sources are much rarer
- Multiple lines in important $2 < z < 2.44$ and $z > 3$ ranges → much reduced “decision tree” follow-up needed
- Only 2 tunings needed in the same band → reduced calibration overheads, easier scheduling



Spectral setup used for Band 2 SV data on SPT0027-50

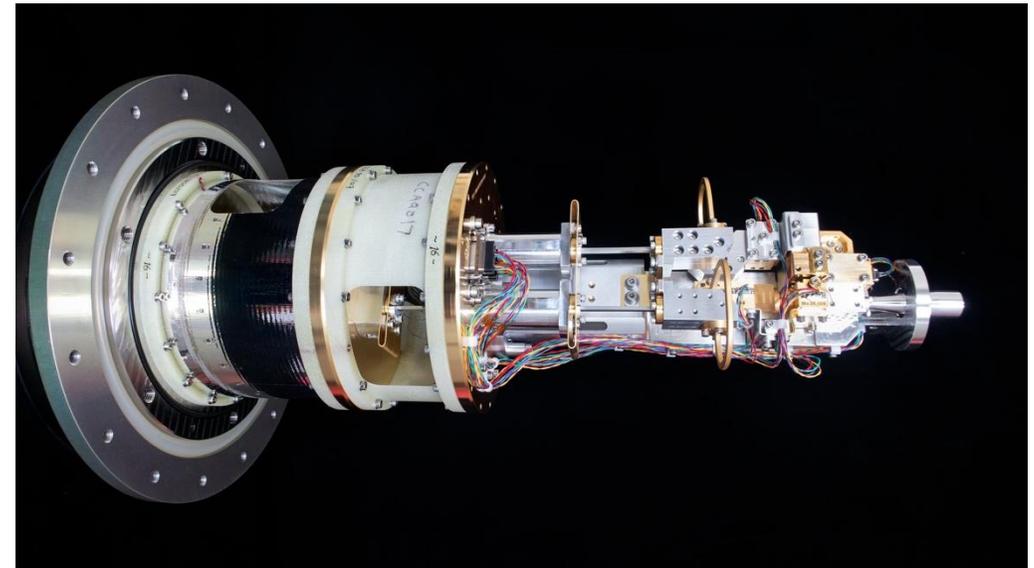


- Demonstration of Band 2 spectral scanning mode with current system
- Five tunings covering 77 to 111 GHz
- Redshift $z=3.444$ previously known from Band 3 scan, now additional confirming CO(3-2) line at 77.8 GHz



Conclusions

- The low-frequency bands of ALMA are ideal to determine redshifts using the CO, [CI] and H₂O lines
- The optimal band to scan depends on the expected redshift distribution; Band 2 is in the sweet spot at the peak of the z distribution
- Having a broad IF bandwidth (2-18 GHz for Band 2) makes spectral scans much more efficient
- Even pre-WSU, Band 2 with 6 tunings is already a lot more efficient to avoid redshift ambiguities
- Full potential really needs the 4x bandwidth full WSU! Band 2 is ready for it!





Thank you!

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