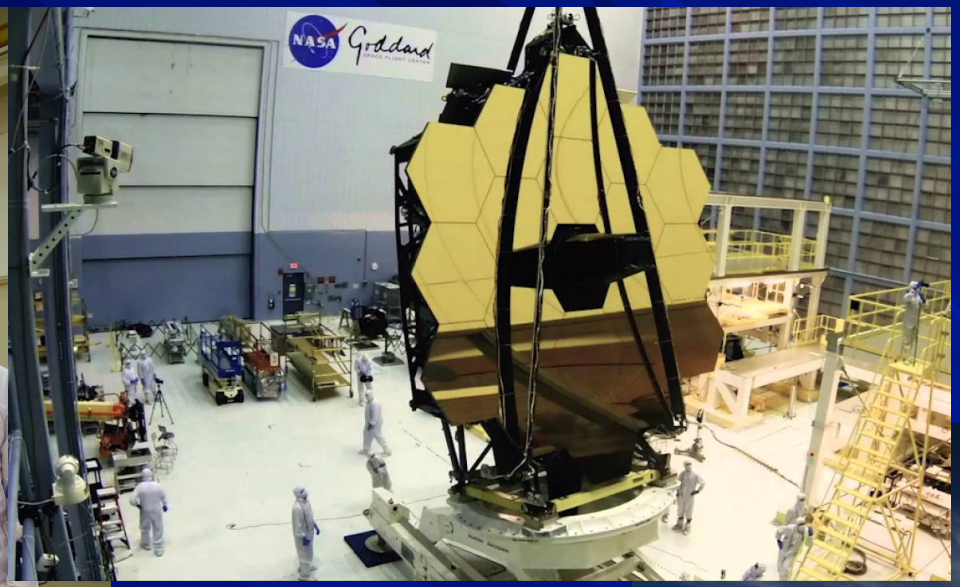


Webb and ALMA: first light and first dust

Andrew Blain, Leicester, JWST@ROE, July 2016

Contents

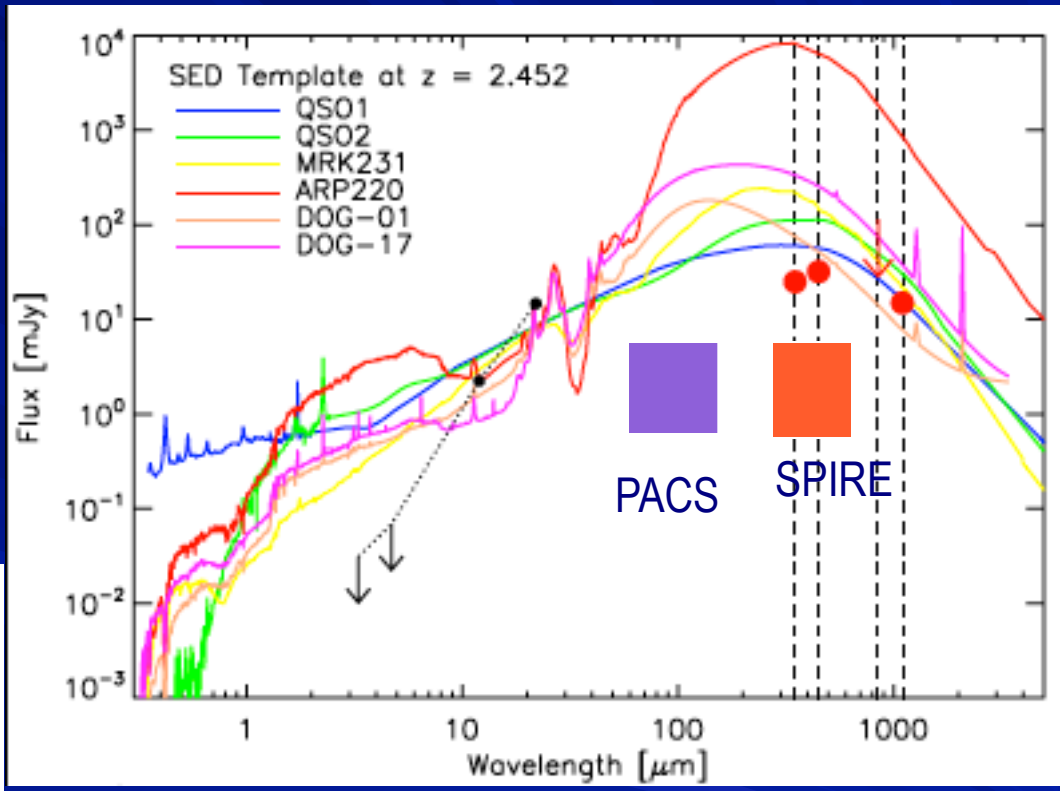
- ALMA results are bursting out (here?)
  - "ASPECS" inside "ALMA UDF"
  - ~0.04mJy, 1 sq arcmin; ~0.1mJy, 4 sq arcmin
- IR SEDs from Spitzer, Herschel, WISE – await JWST
- Push to match with ALMA – tough goal this faint
  - Exploitation of lensing?
- Relationship between galaxy evolution and SED, FIR-UV ratio - ALMA vs JWST

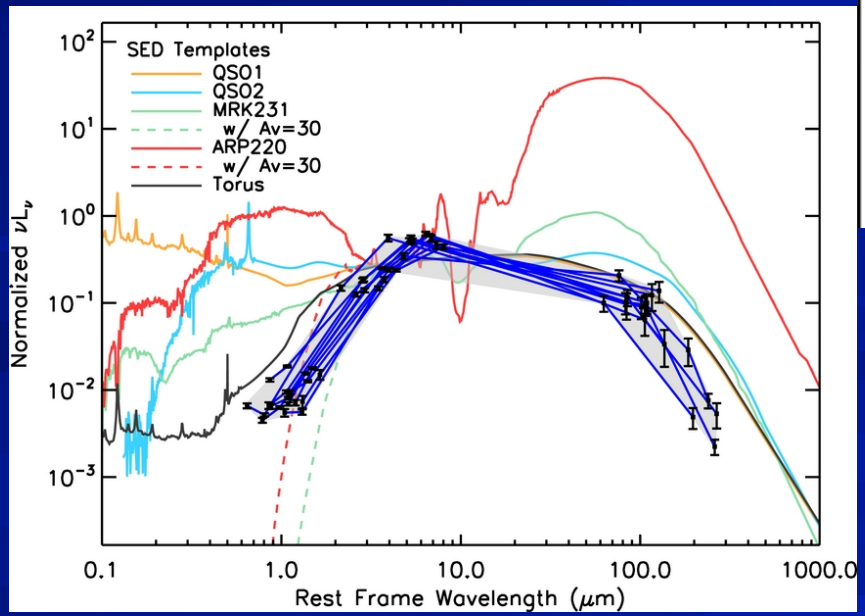
SEDs

- Meurer relation, UV slope - far-IR power
- Doesn't hold for "UV-frosted" IR-luminous galaxies
- May not hold at highest z
- Stellar masses – Main Sequence
- Range of IR templates may be incomplete
  - Spitzer DOGs?; WISE "HotDOGs"
  - AGN contributions, evolution of opacity

WISE "HotDOGs": odd SEDs

- WISE sources are sampling different regime of L,ρ (bright, rare!)
- Libraries of far-IR SEDs don't stretch far enough
  - Laura Hainline (2010)
  - WISE hot/blue far-IR objects



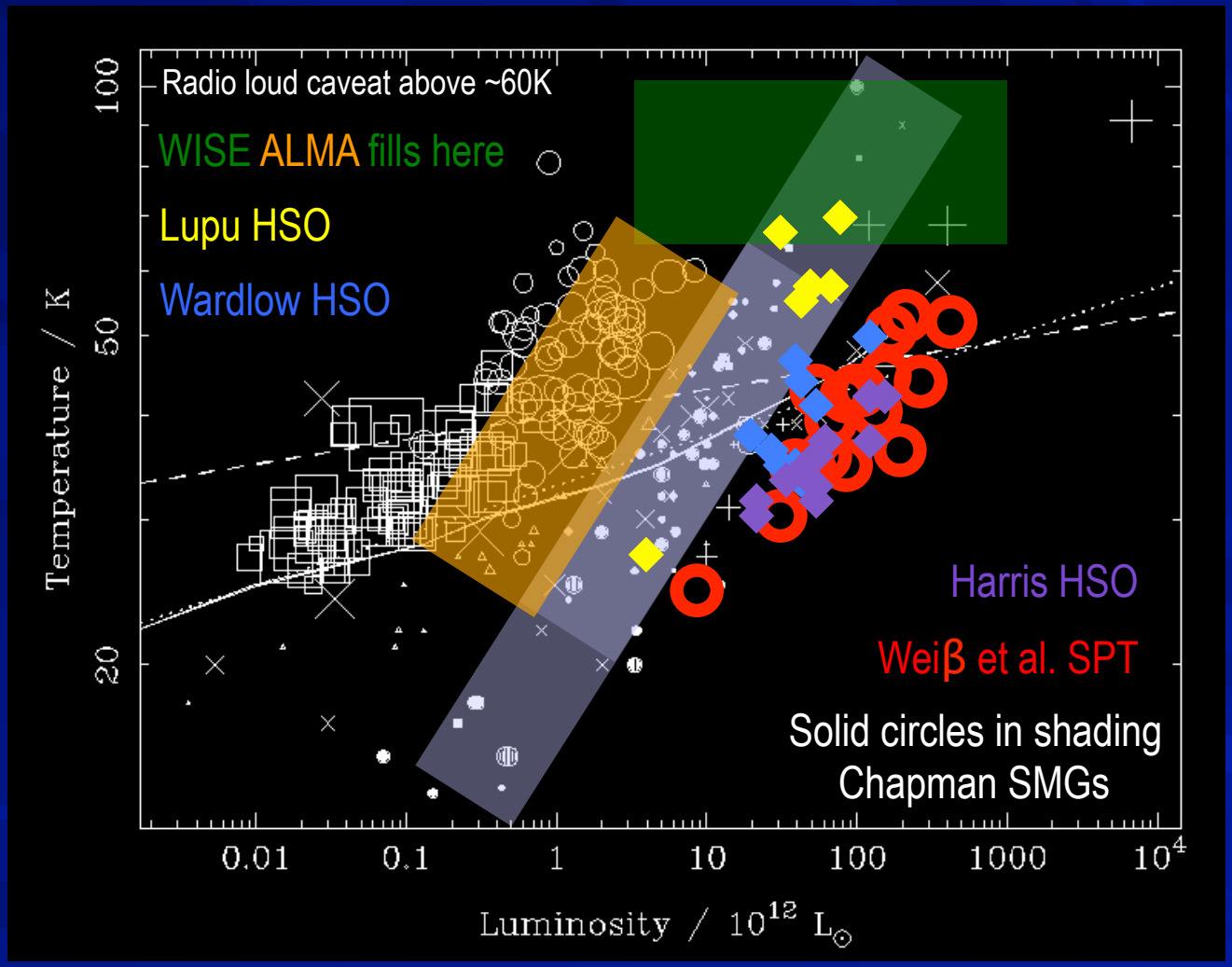


Compiled CSO results on 1814
Eisenhardt et al. (2012)
Tsai et al. (2015)

Jingwen Wu
et al. (2012)

Plus JCMT from Suzy Jones

High-z ULIRGs with redshifts/SEDs



Blain, Barnard & Chapman 2003 & Chapman et al. 2003

Uncapped magnification μ distribution?

2-5: 3, 5-10: 4, 10-20: 5, 20-50: 9, 50-100: 7

Squares: low-z, Dunne et al.

Empty circles: moderate z, mainly Stanford et al.

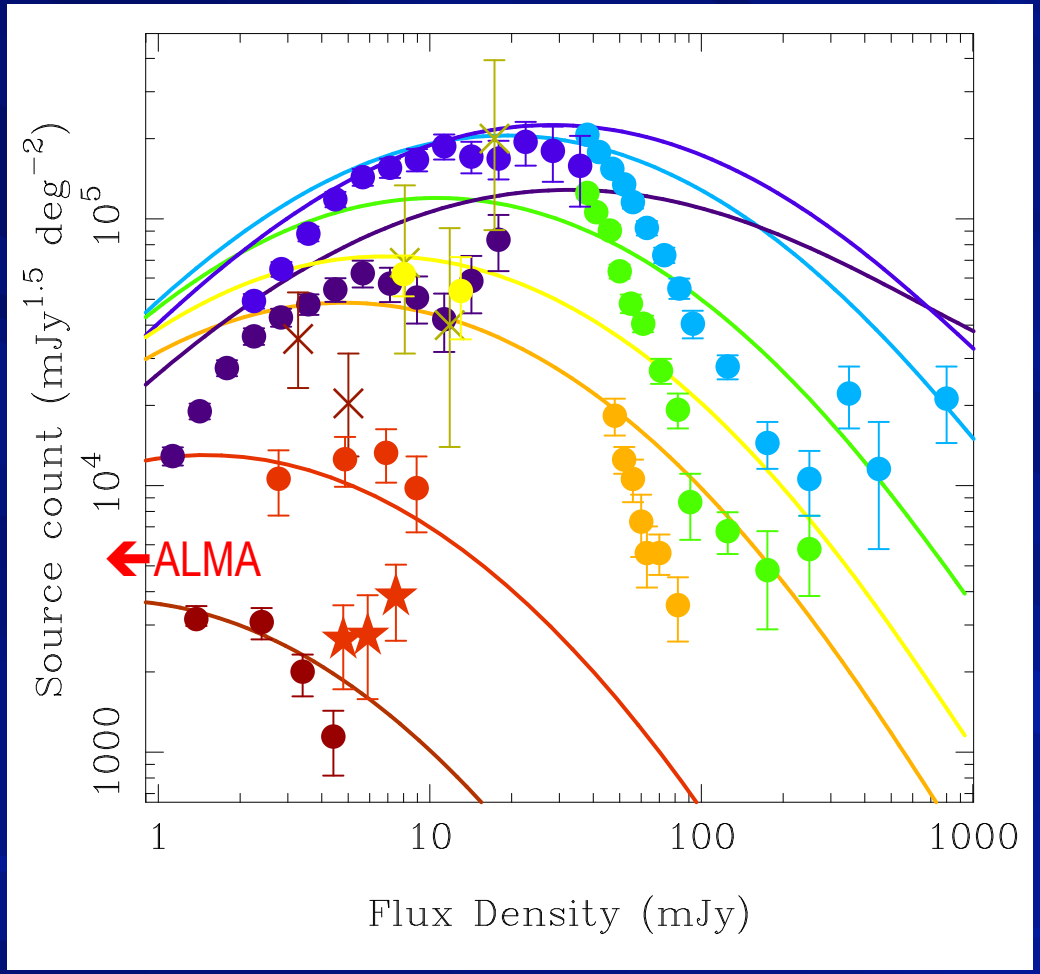
Crosses: variety of known redshifts (vertical = lensed)

Lines: low-z trends

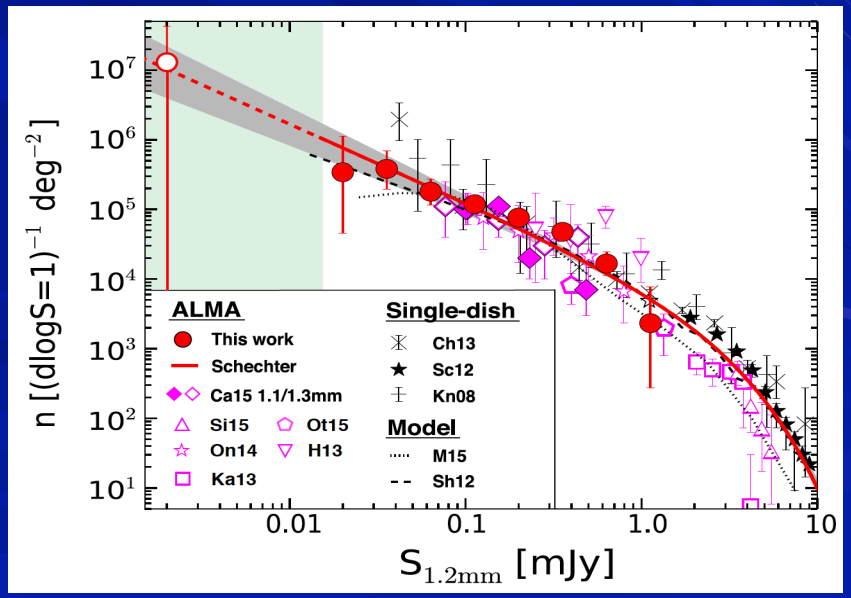
Scatter in T by at least ~40%

Argues for cap at mag' μ~50, Harris

Ancient models with current data

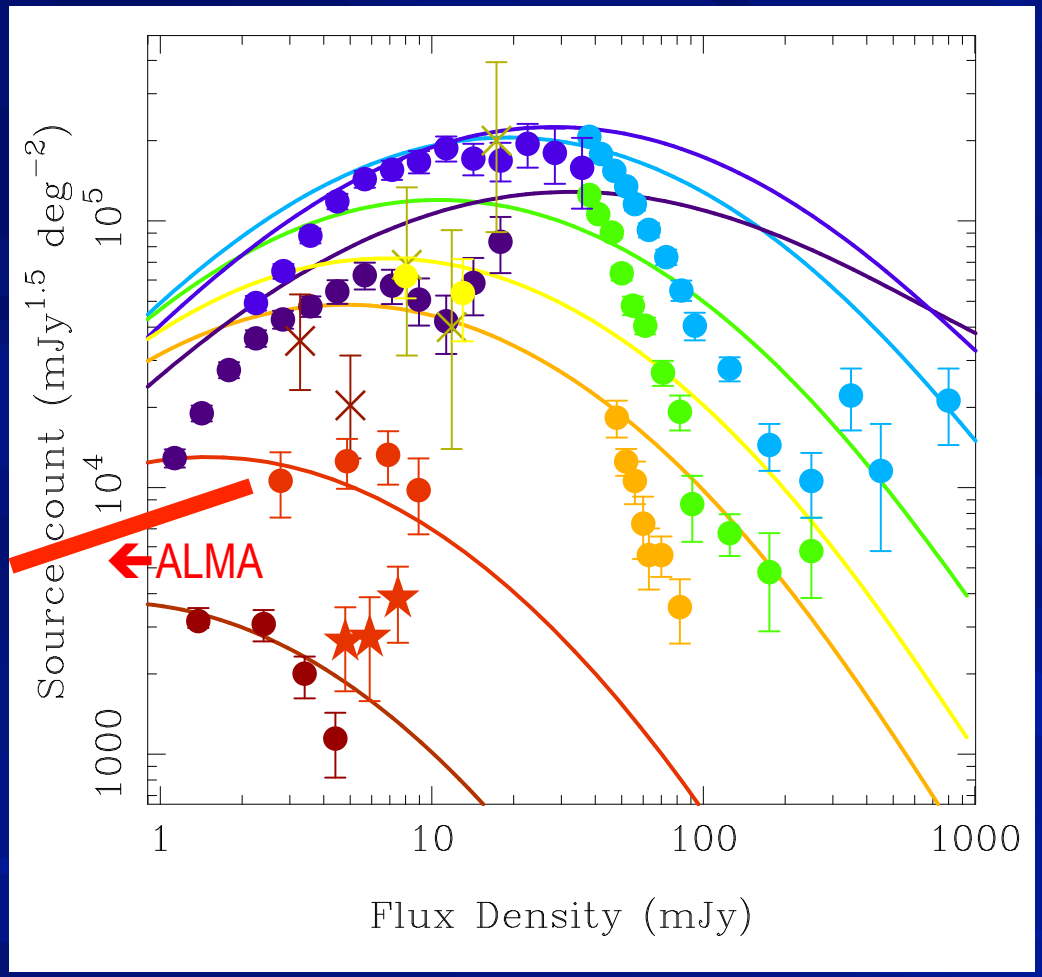


- Models - 2002 – IRAS LF
  - Right cosmology
  - Matched to ~175/850 microns
- Miss sharp upturn at SPIRE
  - More hierarchical behaviour?
  - Needs low-z cool things?
- Too many faint PACS objects
  - Not incompleteness
  - Needs tweak near z~1 with hotter SEDs in too



Fujimoto et al. 2016 ApJS 222 1
Faint slope (right) is -1.12 = 0.38 (above)

Ancient models with current data



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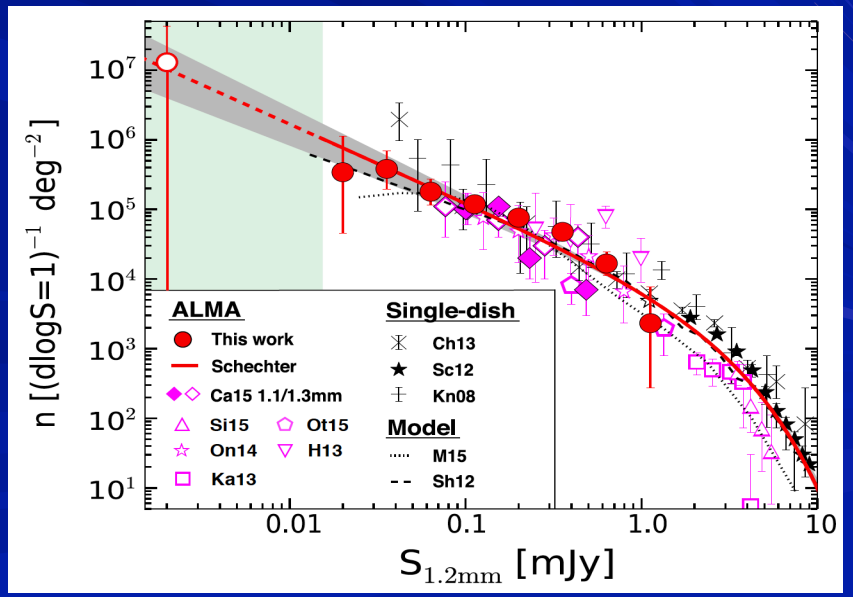
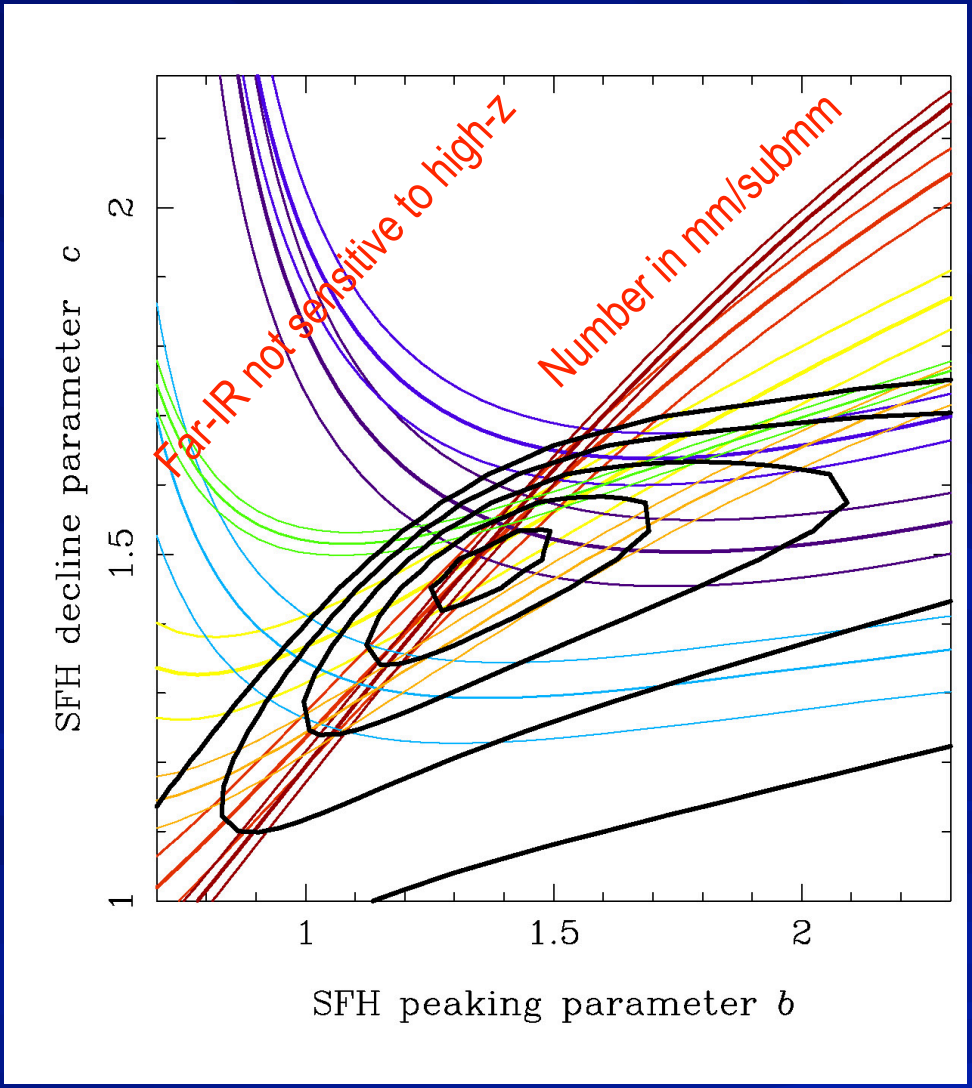


Fujimoto et al. 2016 ApJS 222 1

Representative/sub-L* galaxy populations

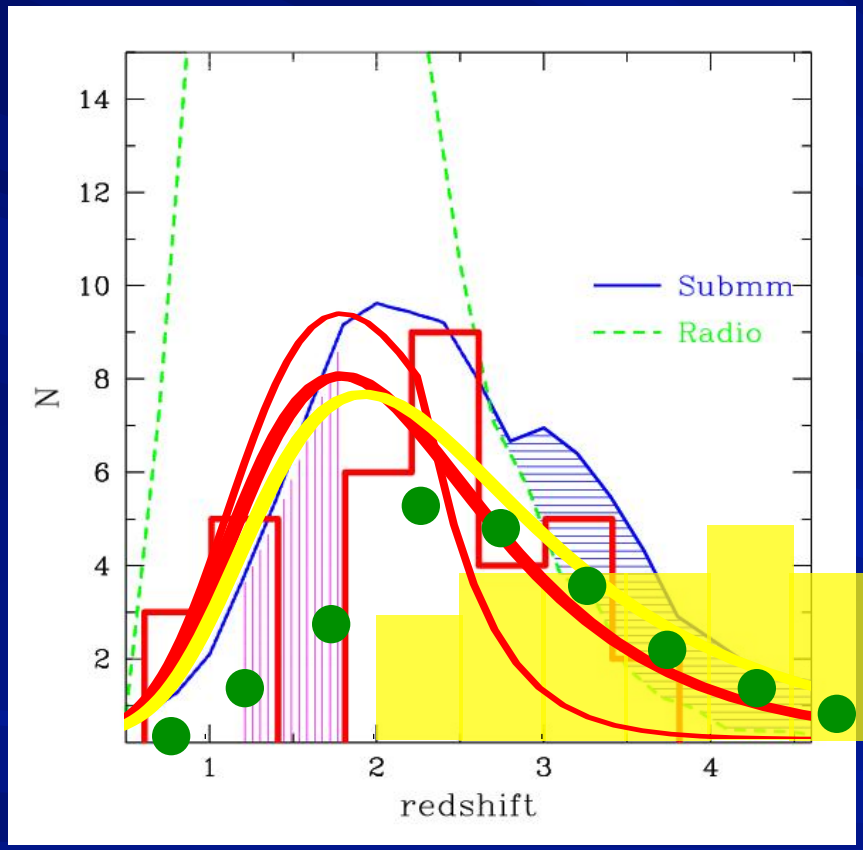
- Much fainter than WISE examples/SMGs
- Extend deeper than Herschel reached
- Extend deeper than Spitzer reached
  - JWST covers high-z UV/optical and Spitzer equivalent sources – and soon
- Evolution of these populations, overall evolution in UV from deep fields from HST, reionization
  - JWST will reveal starlight (& AGNs) to z>10

Luminosity density history



- Shape of peak
  - b,c parameters
- Counts from far-IR to mm
  - Without redshift information
  - Add redshifts "consensus" gets more complex

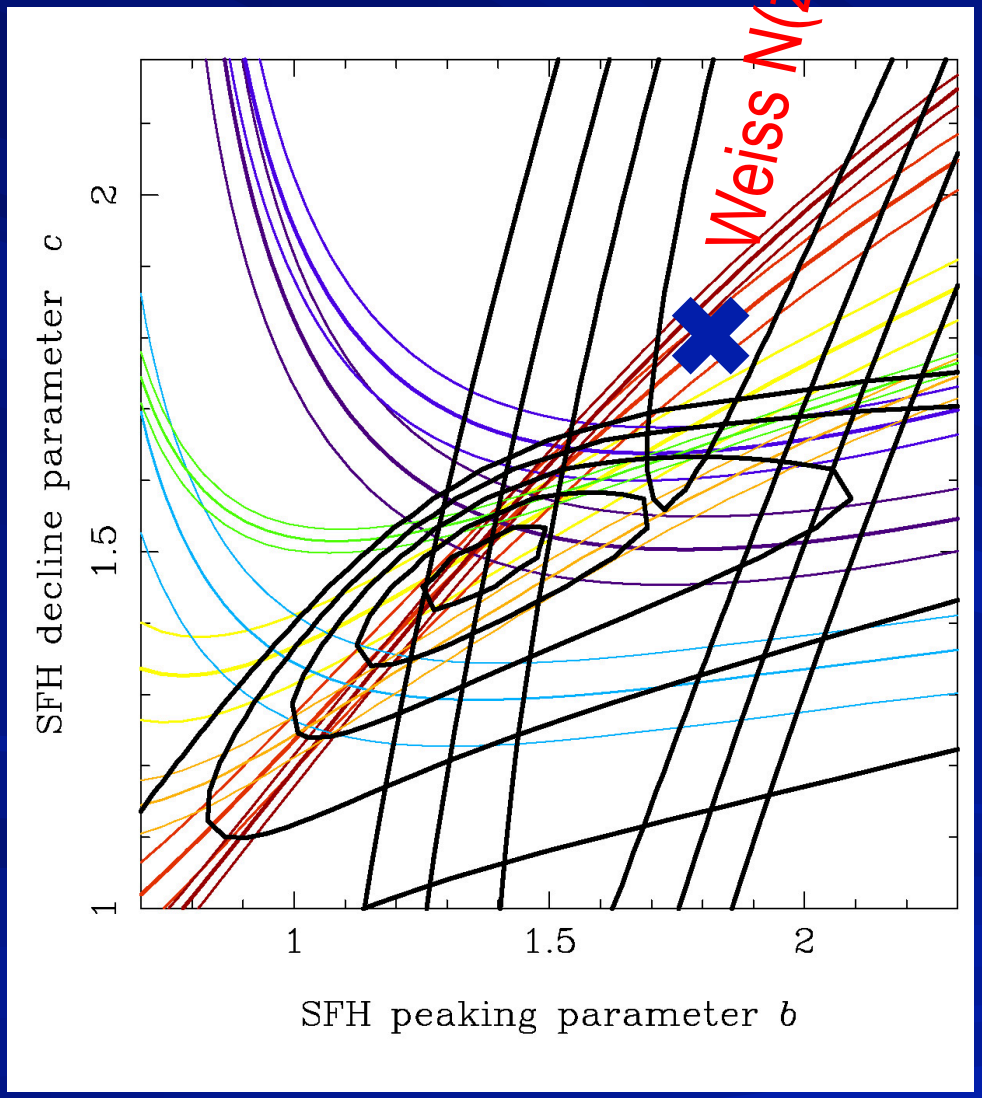
Redshift distribution N(z) for SMGs



Chapman et al. (2003; 2005); Weiβ et al. (2013)
Red lines: BSIKF 0.85mm 5mJy, w/wo radio cut
Yellow line: BSIKF 1.4mm 1mJy, green lenses

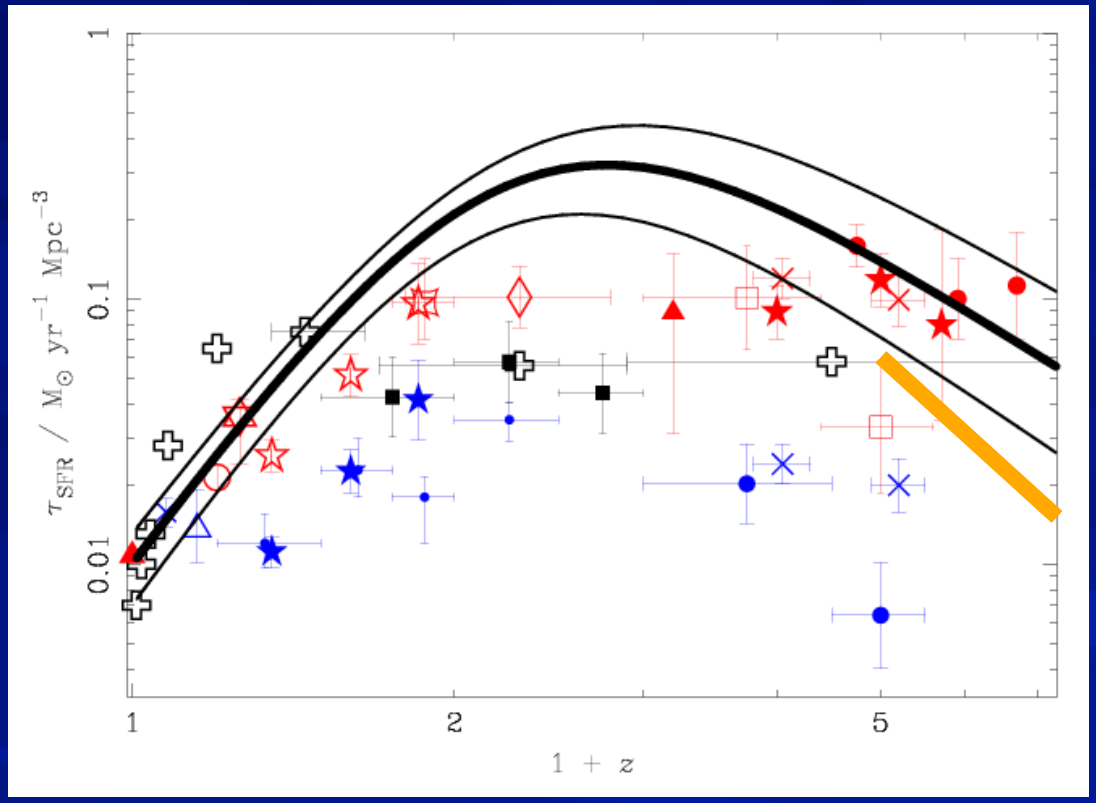
- Red histogram, blue & green
  - Chapman et al. (2005)
- Red lines: previous model
  - With and without radio cut
- Yellow histogram: SPT N(z)
  - SPT selected, ALMA confirmed with CO-line redshift
  - Censored modestly by lensing, in both redshift and size (distant, small objects preferred).
- Yellow line. Previous model
- Green dots. Censured by lensing. Effects clear?
- Significant tension
  - COSMOS (Smolcic)
  - Disk lens (Maller/Moeller)
  - Multiple components (Hodge…)
- Redshifts most powerful constraints

SPT/ALMA redshifts and N(S)



- Weiß et al. (2013)
- Modest change b~1.7, c~1.7
  - Bet on X for simple high-z dust model?
- Not great fit!
  - But minimal model
- Caveats:
  - SED range
  - Cool/warm far-IR
  - Other populations
    - WISE, ALMA

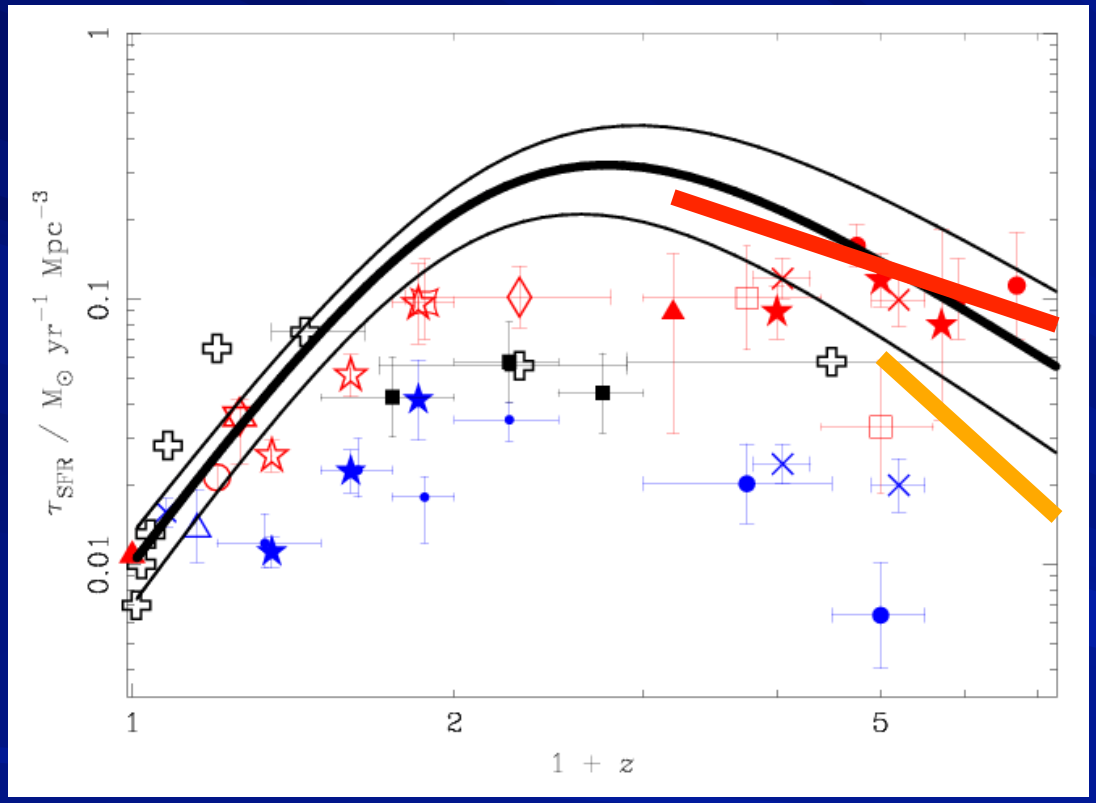
Global luminosity evolution



Bouwens Fig 15 1606.05955
UV selected galaxies

- Points
  - Blue: optical / UV
  - Red: IR and dust corrected
  - Black: SDSS fossil record
  - Uncertainty remains
- Black Lines:
  - results from combined submm/ far-IR information
  - Note high-z decline certain
  - Less rapid than for QSOs?
- Caveats
  - AGN power (modest?)
  - High-z / high-L IMF change
- Submm-selected samples probe most intense epoch of galaxy evolution directly

Global luminosity evolution

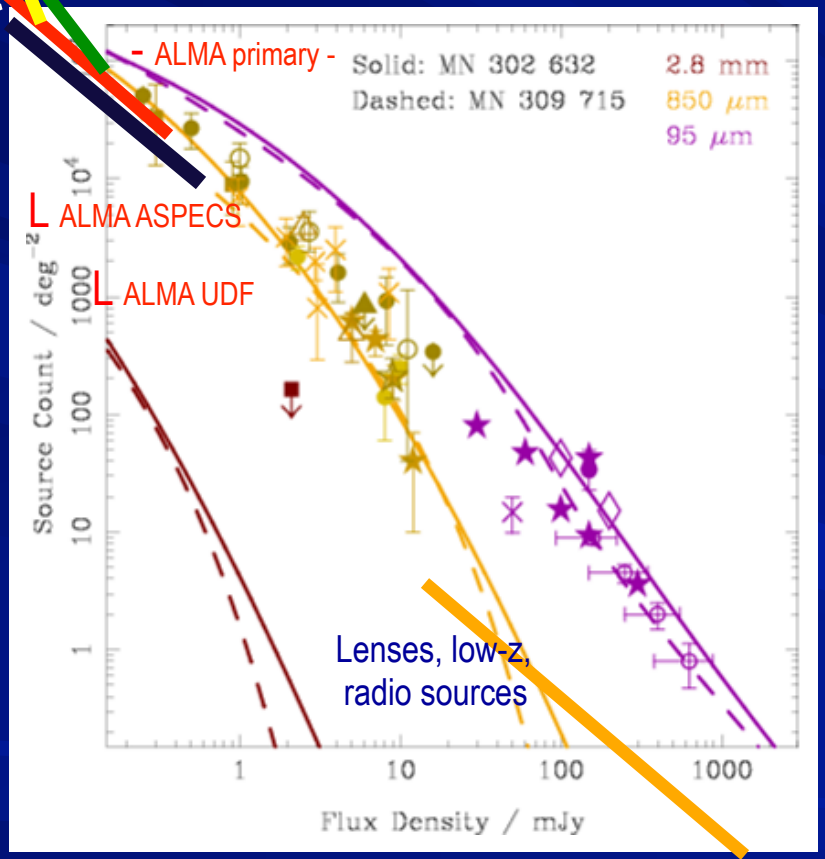


Bouwens Fig 15 1606.05955
UV selected galaxies

Pivot line to better match Weiss N(z) from SPT/ALMA

- Points
  - Blue: optical / UV
  - Red: IR and dust corrected
  - Black: SDSS fossil record
  - Uncertainty remains
- Black Lines:
  - results from combined submm/ far-IR information
  - Note high-z decline
  - Less rapid than for QSOs?
- Orange line
  - UV-selected – dust corrected
- Red line
  - Shifted black line for N(z)
  - To z~6 continues to have lots of hidden dust?
  - Consistent with background
- Address wedge between orange and red?

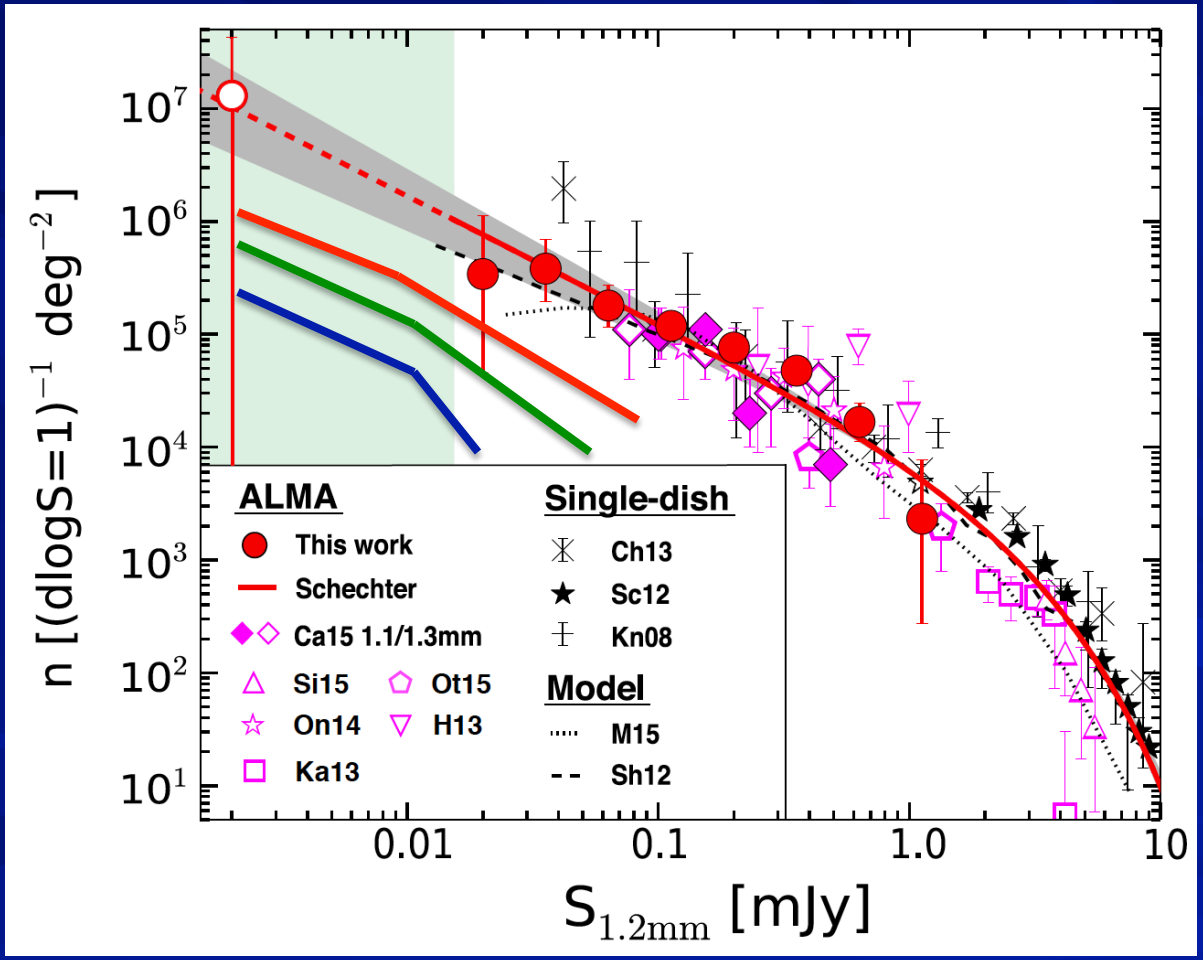
Dusty galaxy populations extended



Deeper than current ALMA;
ALMA beam; * and black line - ALMA 0.03mJy
(Fujimoto et al. 1.2mm, increase by ~3 for 0.85mm)

- Bright 95 (&175) μm counts from ISO dramatically improved at 70 & 160 μm by Spitzer-MIPS, Herschel-PACS
- Also data at IRAM's MAMBO/ GISMO); CSO's BOLOCAM/ SHARC-2; APEX's LABOCA; Herschel SPIRE; ALMA.
- Little more so far at <mJy level
  - IRAM & ALMA deep fields
- Faint counts ill- constrained by background/N(z) results
  - Faint dwarf population (green – limited by ALMA)
  - Additional very distant LIRGS (yellow – L* limited by ALMA)
  - Could be μJy 1st light fragments (red) – link to UV re-ionization

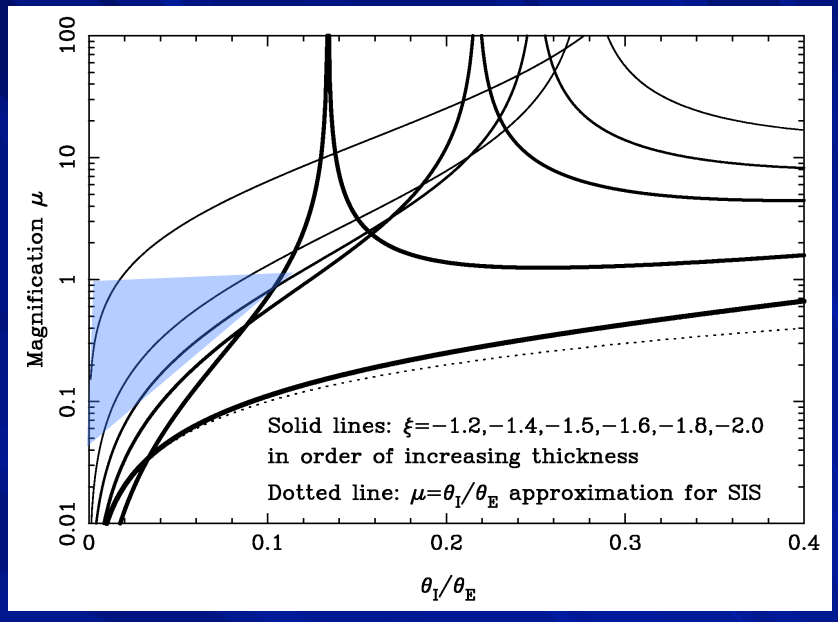
UV-selected UDF sources

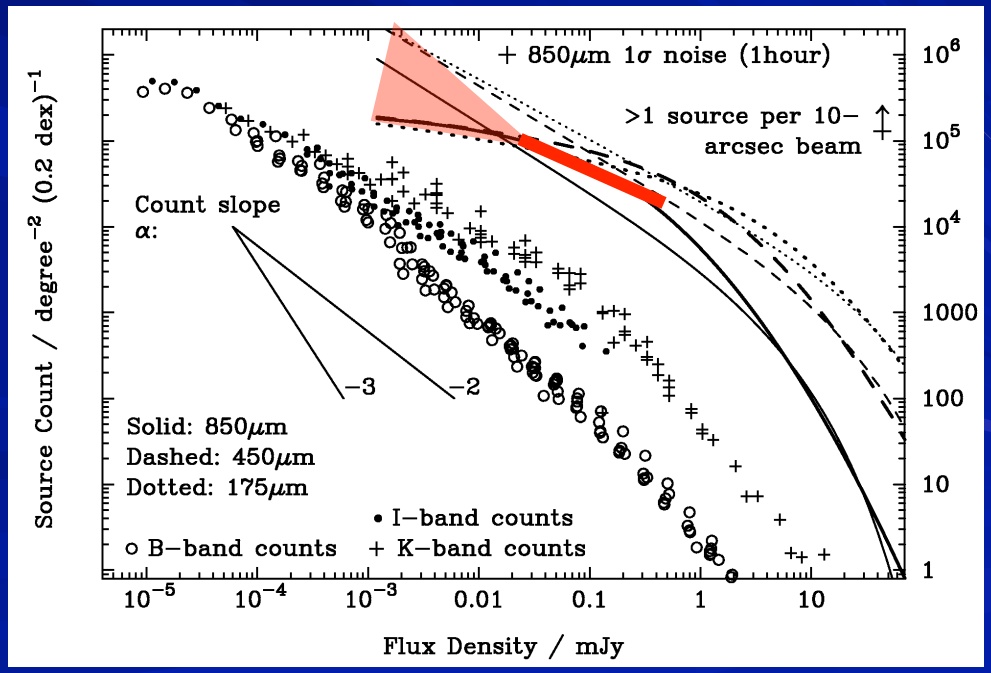


- UV Bouwens dropout LF, Meurer relation, β=-2, 3<z<10.
- Dust T assumed
  - Red – 30K
  - Green – 40K
  - Blue – 60K
  - CMB offset
  - β=-1.5, boost x3
- Wedge fits with this picture?
  - High-z galaxies offset by factor of a few
- Reionization sources much fainter?

Lensing

- "Regular" image formation occurs in tangential arcs
- Radial arcs inwards if slope correct (Treu)
  - Demagnified images too
  - Whole Einstein disk is imaging in lens core (in single ALMA primary beam)
  - If counts/mass distribution is appropriate
    - Flatter than -1.5 in dN/dS
    - Density profile ~ -1.5.
- "Free" SLACS-like survey
- Both push ALMA's reach deeper/wider





Summary

- ALMA is starting to reach “typical” high-z galaxies, and can do much more
  - Serendipitous archive searches
  - Ultradeep critical line / Einstein ring mapping
  - Chase/stack known sources
  - First dust?
- JWST will reach out to first stars
  - Will we see first dust clear in comparison?
  - Mop up UV-dark, dust-bright sources – explain contents of “SFH plot’s high-z wedge”?
- Much structure on ~10” to 5’ scales (from submm/ALMA)
  - May need care, with both JWST & ALMA. FLARE?

SED Variation: Composite IR SEDs of SMGs

Use all mid-IR to radio data for Chapman SMGz sample & compare "cold" and "warm" ULIRG templates.

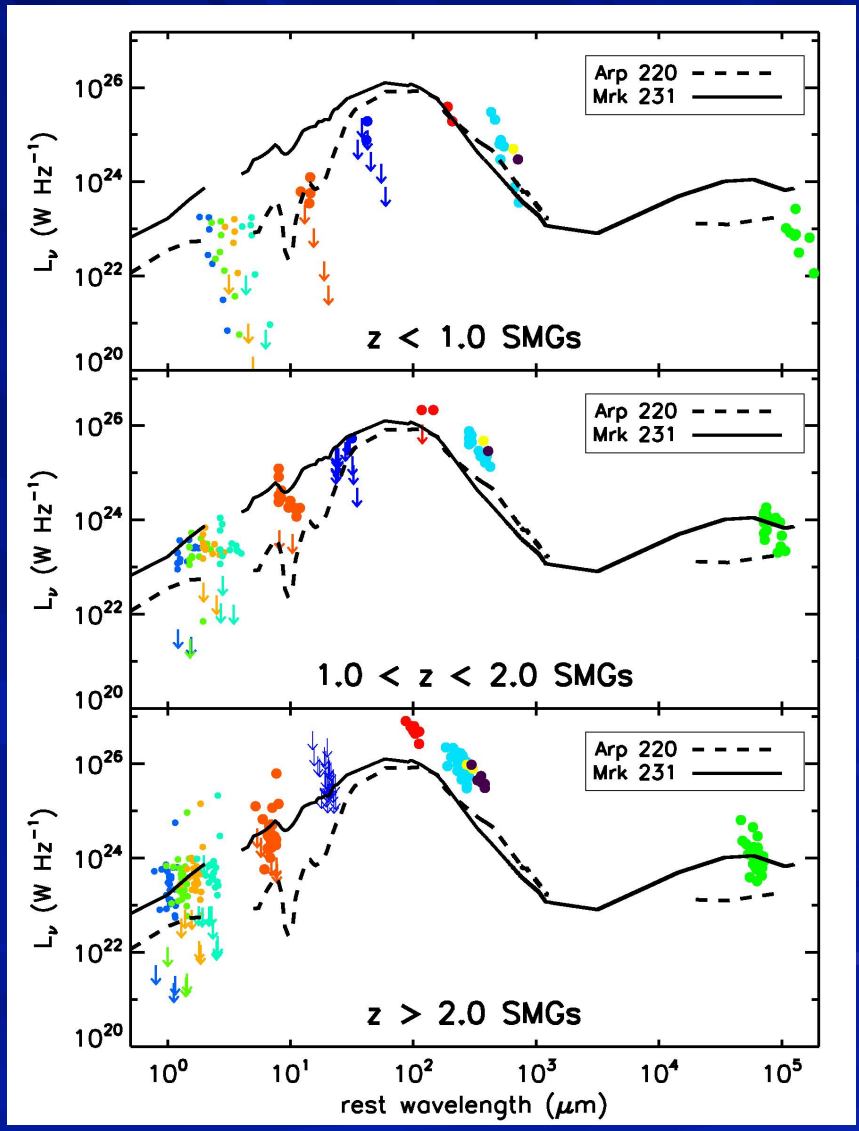
Composite SEDs change with redshift (and luminosity?)

- Low-*z* SMGs: less luminous than Arp 220, cold (like low-*z* disks?)

- *z* > 1 SMGs: brighter in mid & far-IR than Arp 220; SEDs peak longer

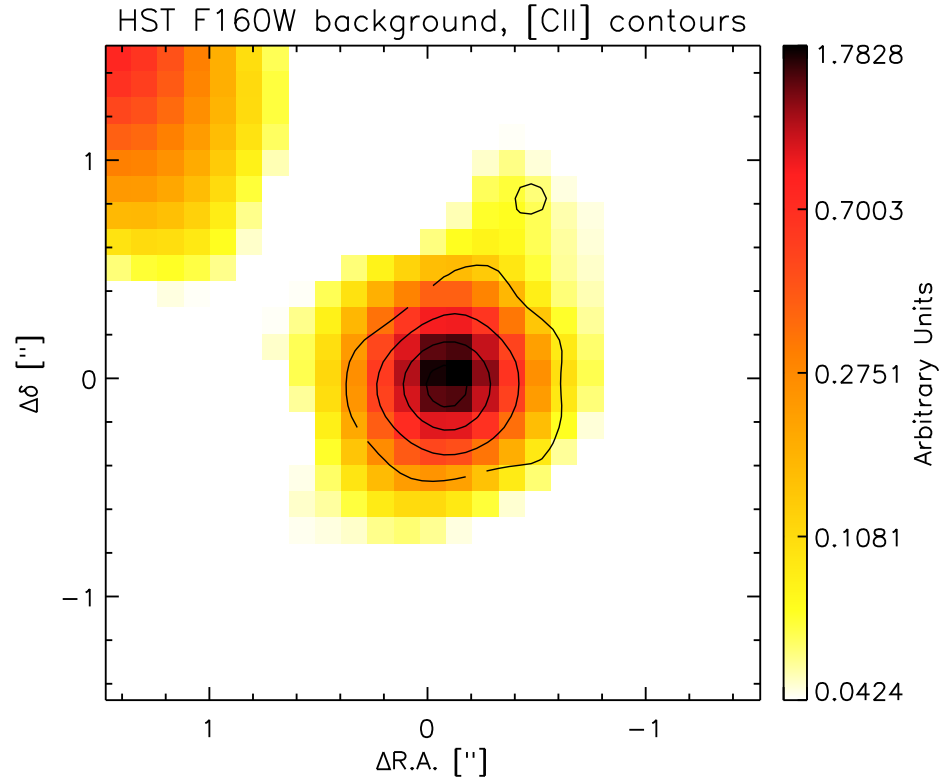
- Greater scatter in mid-IR and radio in *z* > 2 galaxies

  - More varied mid-IR properties?
  - Probably not a luminosity effect?

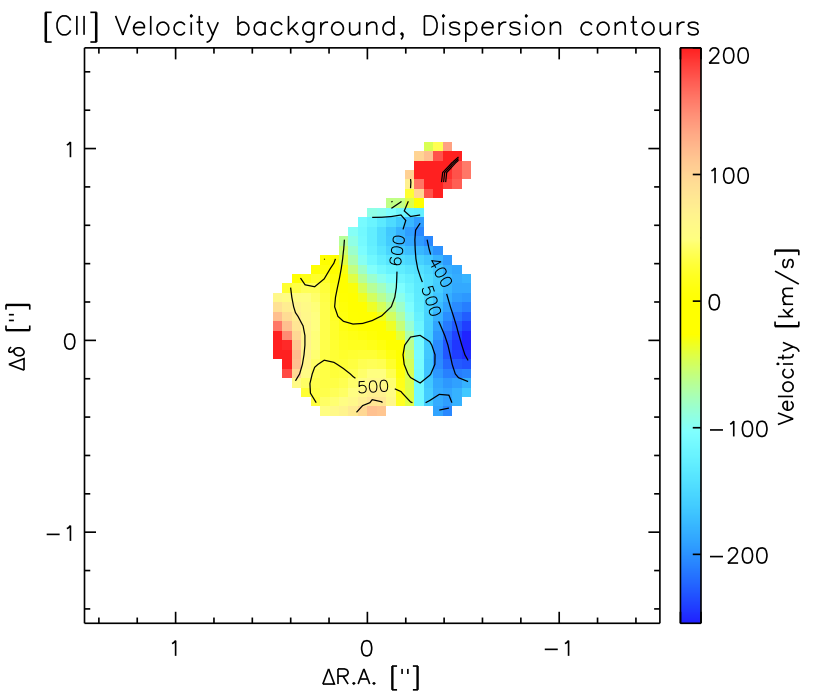


Hainline et al 2010

Example of resolved case

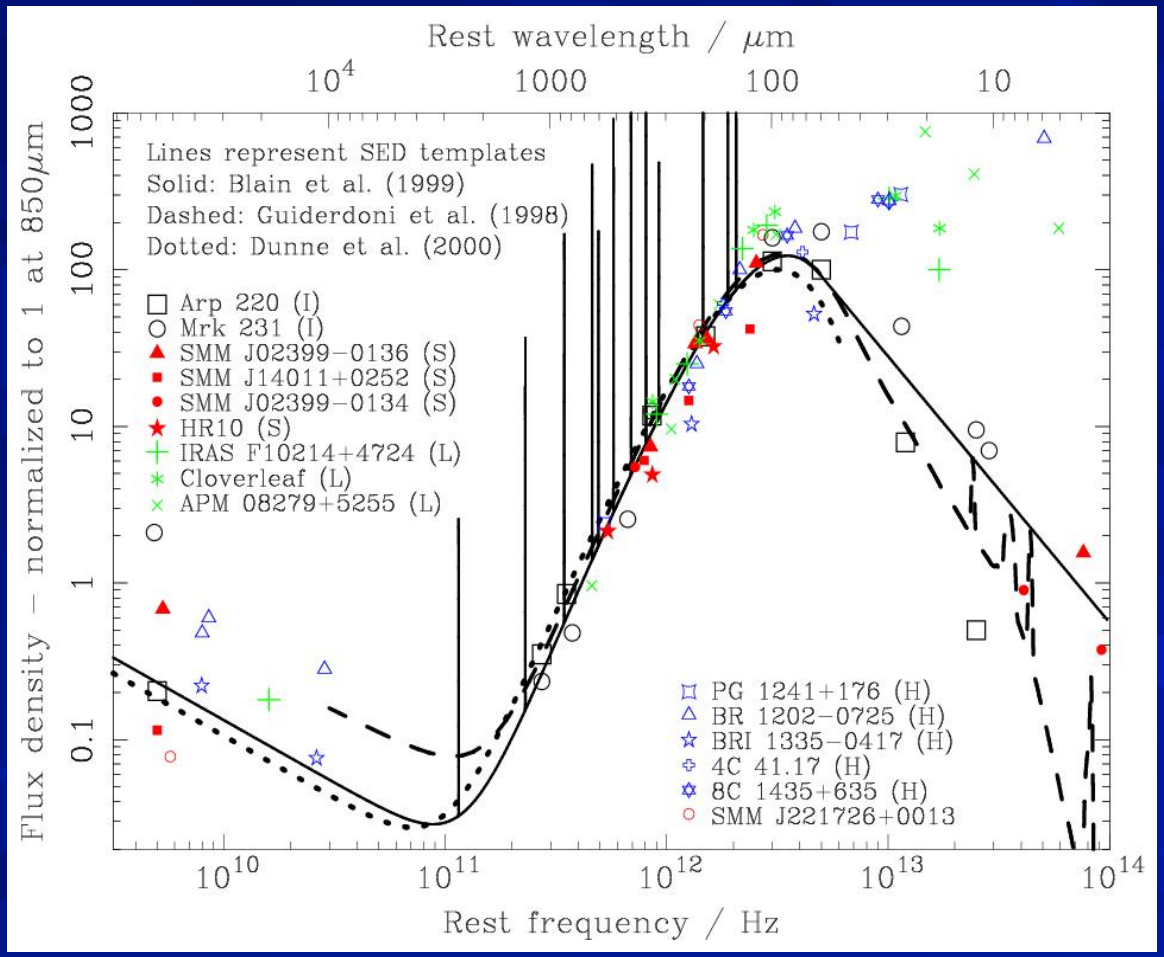


Diaz-Santos et al (2015)



- ALMA, CII & continuum; W2246
- ~600 km/s dispersion; uniform; CII less extended than UV; Companions (in CII). Nature of wind?

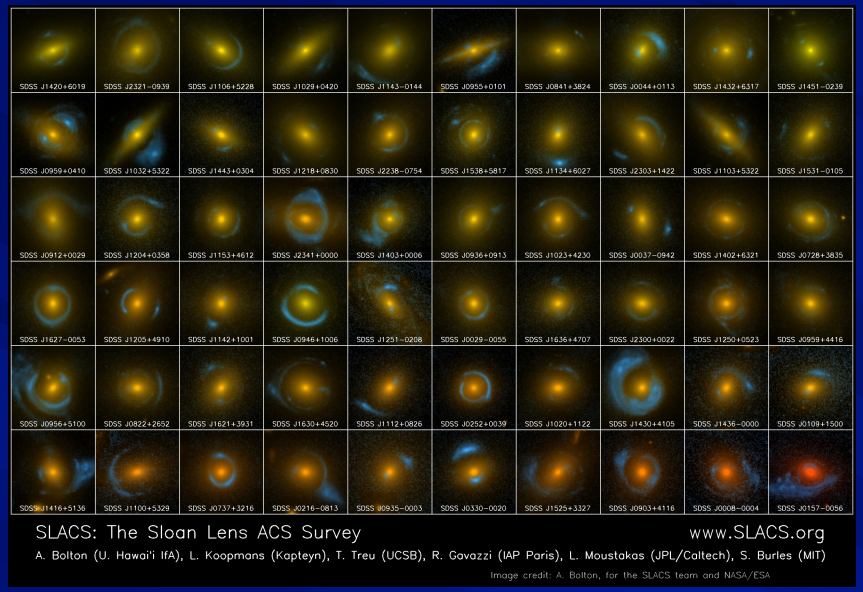
Far-IR/submm galaxies' SEDs



Normalized where sizeable sample of `submm galaxies' are selected. Redshifts z~2-3 from Chapman et al.

- Mix of different sources traces out **some** of the range of SEDs properties
  - Milky Way & APM08279 are extremes
- Non-thermal radio
  - Radio-far-IR link
- Thermal dust dominates luminosity
- CO, HCN, HCO+, C fine structure lines carry redshift, dynamical, and physical information

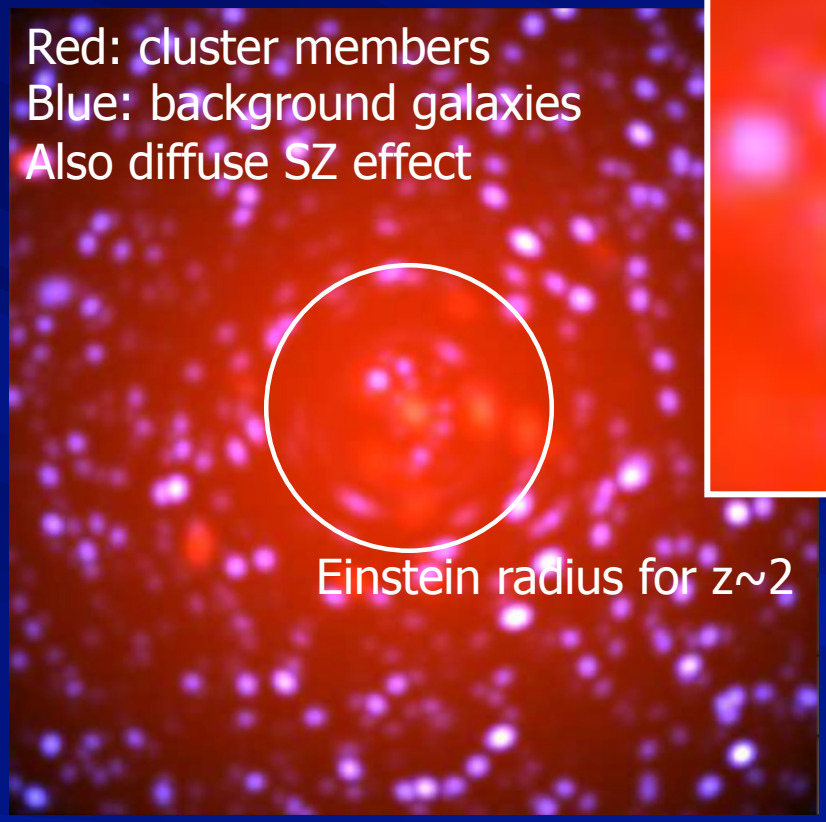
Gravitational lensing: galaxies



SLACS

- Also saw long-baseline campaign (no publicity!)
- Note looked like picture at bottom left
- But also had central point
  - SMBH in lens galaxy
  - Or radial arc/demagnified swarm?
- Can obtain total mass of lens, and potential slope
  - Excellent astrophysics of lensed images
- ALMA can also image whole Einstein disc into core – **single beam survey**
- Unlike SLACS, lens is dark

Gravitational lensing: clusters

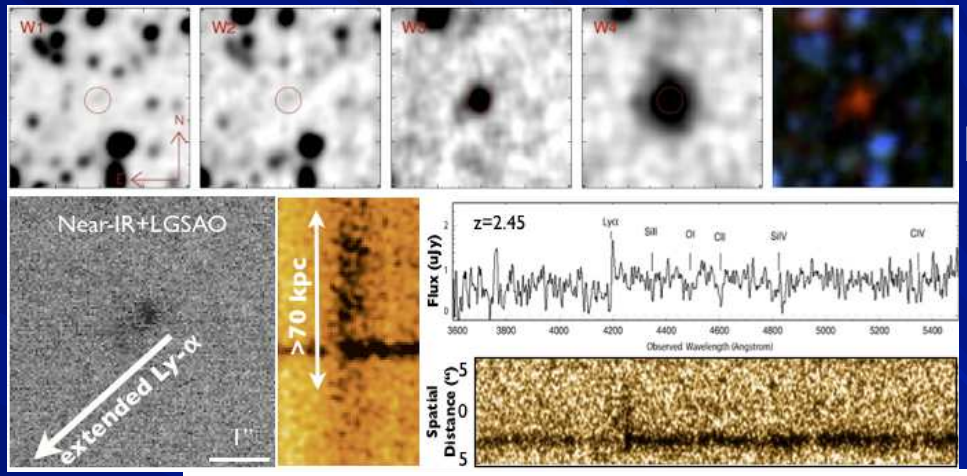


Cartoon simulation shows swarm of faint sources expected in the cluster core if the potential strongly peaked. (For galaxies too.)

Excellent probe of clusters' & galaxies' strong lensing with ALMA angular resolution

WISE Lyman-α blobs (WLABs)

- Follow-up spectra of hot dusty WISE ULIRGs at z~1-5
  - Bridge, Blain et al.
  - ApJ (2013) 769 91
- Unusually large No. of large (~50kpc) LA emitters
  - Including Eisenhardt's first WISE `HyLIRG'
- WISE colours alone can select ~1000
  - Red, bright in WISE
  - No other selection finds dusty LABs
  - Feedback in action?



Top: WISE Bands, Bottom: NIR image & Spectra

Bridge et al.