



A Herschel far-infrared view of the Spiderweb proto-cluster

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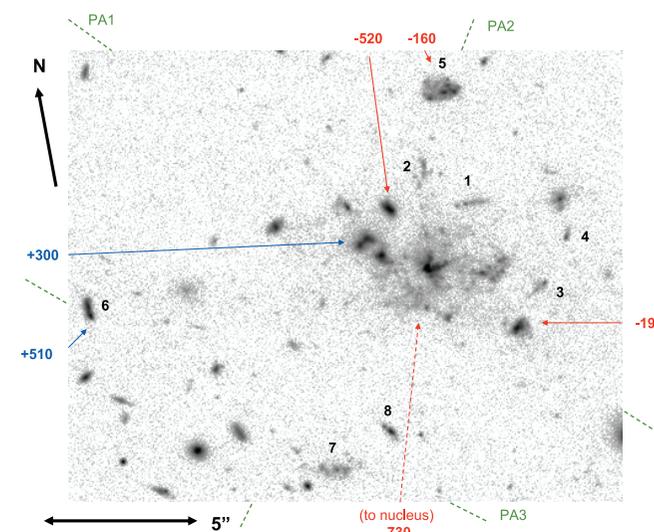


Introduction

- Galaxy evolution in clusters is supported by mid-IR observations.
- The fraction of dusty star-forming galaxies increases with redshift (e.g. from 3% locally to around 13% at $z \sim 0.83$; Saintonge+08).
- At $z < 0.85$, dust-obscured SF is preferentially taking place in intermediate-density regions (Koyama+08, Pintos-Castro+12) or groups (Tran+09).
- At higher redshift, the situation becomes even less clear, with environment playing a key role. At $z > 1$, there are evidences of reversal of SF-density relation.
- In order to get a complete picture, we should trace the star formation properties of clusters and proto-clusters at $1 \leq z \leq 3$, when the bulk of the assembly of local massive early-type galaxies took place.
- Herschel is an ideal tool for such an study, probing for the first time close to the peak of the SED of SF galaxies. Our Guaranteed Time Herschel program (PI B. Altieri) has imaged several high-redshift clusters and proto-clusters using the PACS and SPIRE instruments.
- Here we report on the progress on one of the GT program targets, the proto-cluster PKS1138-262 (a.k.a “The Spiderweb”).

The Spiderweb proto-cluster

- The HzRG PKS1138-262, known as the “Spiderweb galaxy” shows properties of a cD galaxy progenitor (e.g. its stellar mass is $\sim 10^{12} M_{\odot}$, i.e. one of the most massive galaxies at $z > 2$).
- It shows a clumpy morphology
- The Spiderweb galaxy hosts a powerful AGN and a very high star-formation activity ($1390 M_{\odot}/\text{yr}$; Seymour+12)
- Kurk+00 reported an overdensity of SF galaxies around the HzRG.
- Currently, there are more than 20 proto-cluster members spectroscopically confirmed, Ly α and H α emitters (Pentericci+00, Kurk+04).
- Tanaka+10 report an overdensity of red galaxies around the HzRG, comprising a mix of low and high SFR galaxies, suggesting a red sequence in formation.
- Ogle+12, based on IRS observations of PAHs in several galaxies of the proto-cluster, reports a very intense and highly obscured star formation activity.

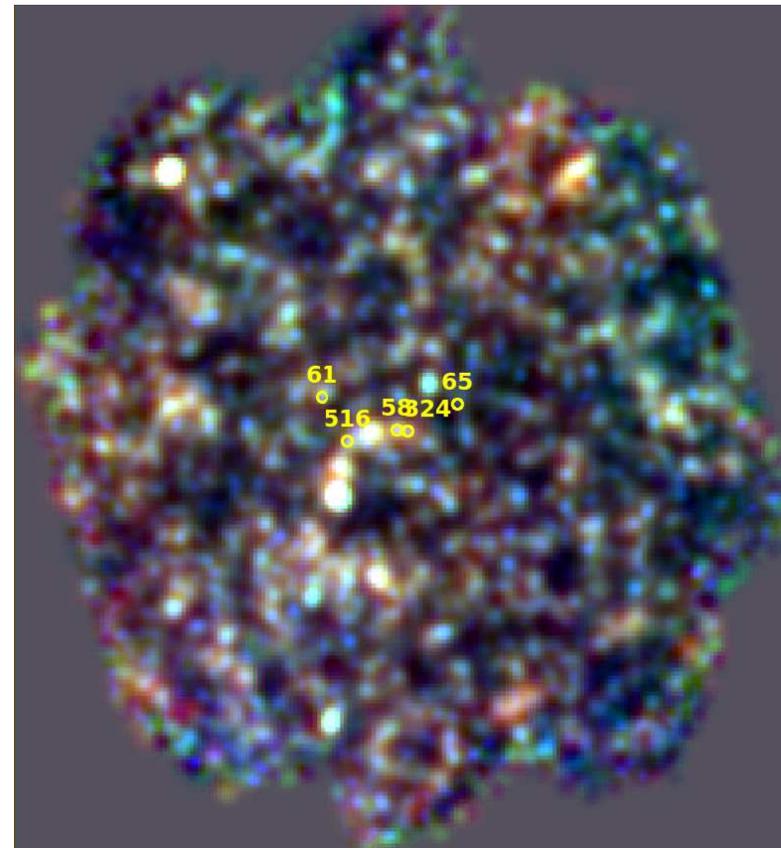
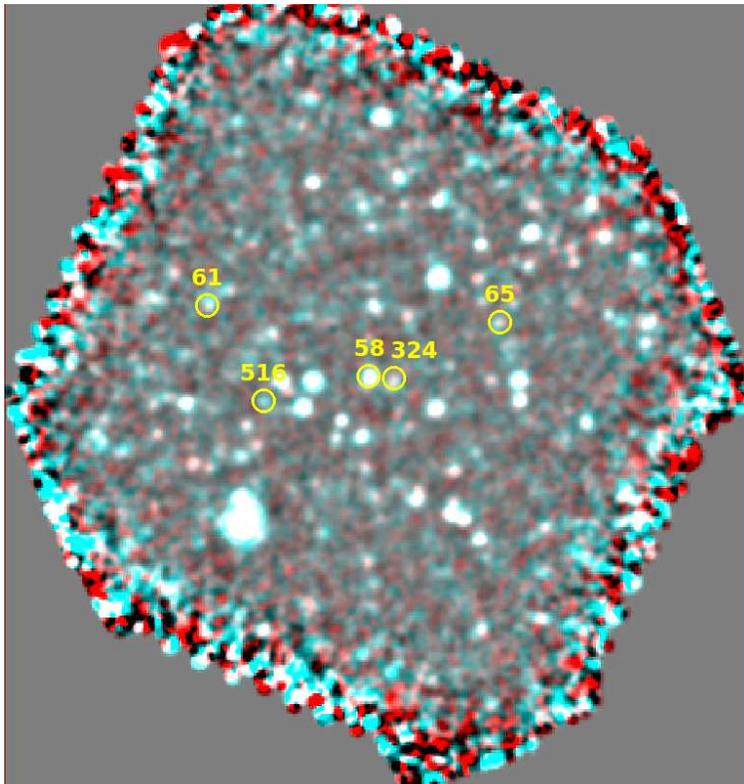


Observational data



For the analysis presented here, only MIR-FIR data have been included. Herschel observations include both PACS and SPIRE imaging:

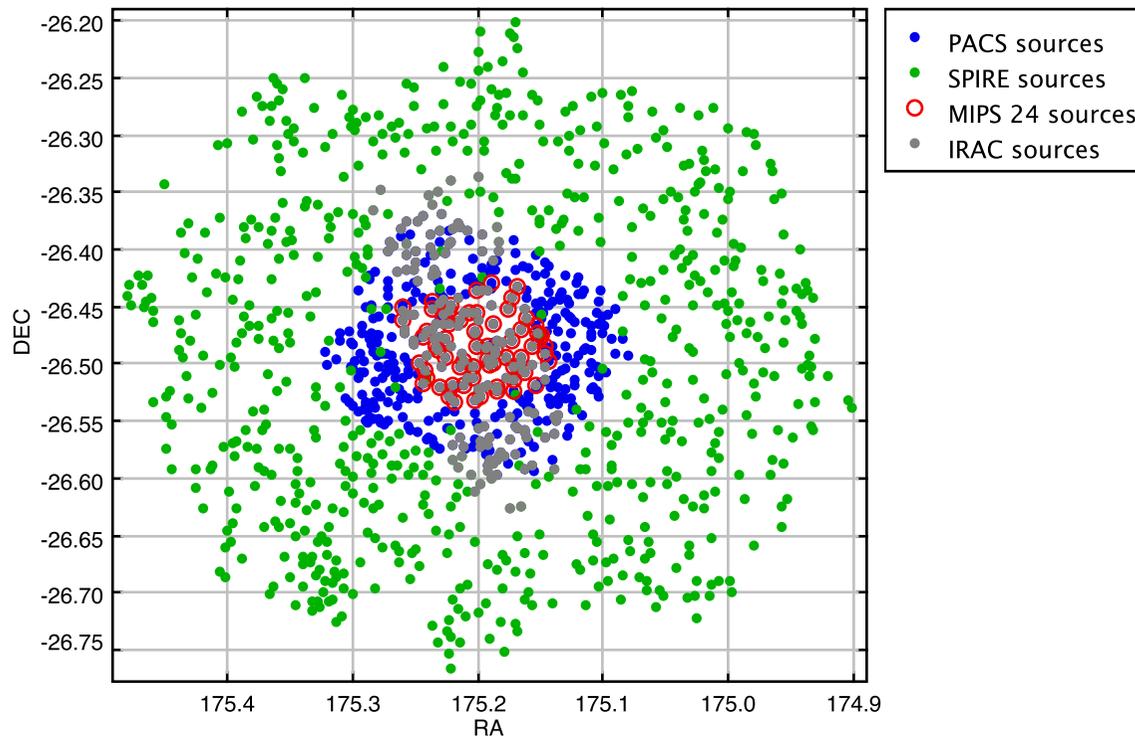
- **PACS:** 2 crossed maps covering an area of 6.67×6.67 arcmin (some 3.4 Mpc with standard cosmology) and 3h exposure time. $100\mu\text{m}$ and $160\mu\text{m}$ bands. 1σ sensitivity is 1.5 mJy and 3.0 mJy, respectively.
- **SPIRE:** crossed-scan map of 15×15 arcmin with 4 repetitions (34 min exposure time). 3 bands: $250\mu\text{m}$, $350\mu\text{m}$ and $500\mu\text{m}$ bands. 1σ sensitivity is 3.5, 4.8 and 5.4 mJy, respectively.



Observational data



- In addition, public IRAC and MIPS 24 μ m data reduced and included in the analysis.



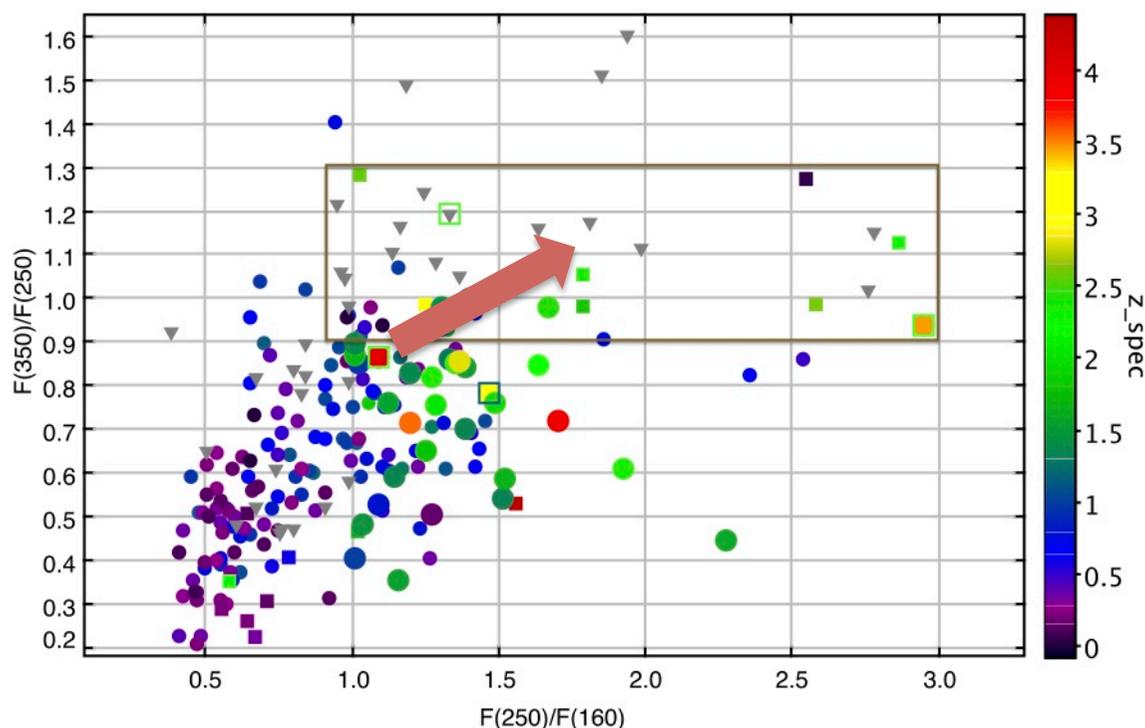
Optical (VLT VIMOS U, FORS2 R, z) and NIR (Subaru MOIRCS J, Ks) are publicly available.

- U-band data used to help identifying and cross-matching objects
- But the footprint of the available data barely covers the area surveyed by PACS.
- We have started to exploit new, deep and large area HAWK-I NIR (Ks) data (PI. J. Kurk)



Catalog and source selection

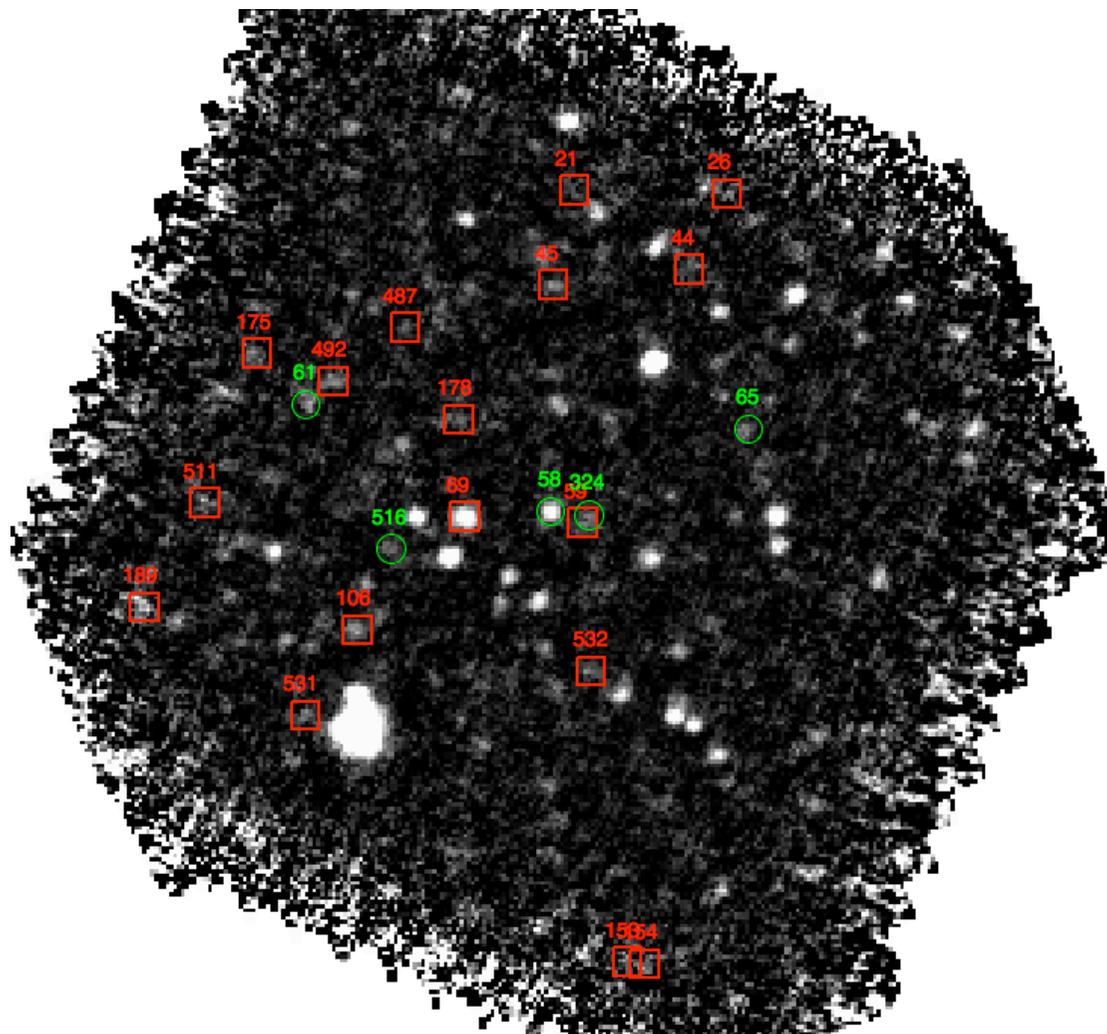
- The PACS Sextractor catalog contains 130 sources detected at 100 & 160 μ m, 252 sources at 100 μ m and 113 at 160 μ m only. Used as priors for SPIRE source detection
- 9 Herschel sources have spectroscopic redshift. From these, 5 sources are proto-cluster members.
- MID&FIR-only photometric redshifts computed with LePhare and the CHARLYPEP IR SED library (Gruppioni+10, Rieke+09, Polletta+07) do not yield meaningful results in our search for additional proto-cluster candidates.



- Rather, we have selected our candidates based on a FIR colour criterion, using a control sample of HerMES (Oliver+2010) and PEP (Lutz+2010) sources with known spectroscopic redshifts in the COSMOS and GOODS-S fields, plus the available Herschel sources confirmed as cluster members

- *Small filled, coloured circles, reference sources from COSMOS*
- *Small filled, coloured squares, reference sources from GOODS-VIMOS*
- *Grey triangles, our spiderweb sources without redshift (either spec or photo)*
- *Large filled, coloured circles, spiderweb sources with photo-z from LePhare.*
- *Large open, coloured squares, spiderweb sources with spec-z.*

Spatial distribution of candidates

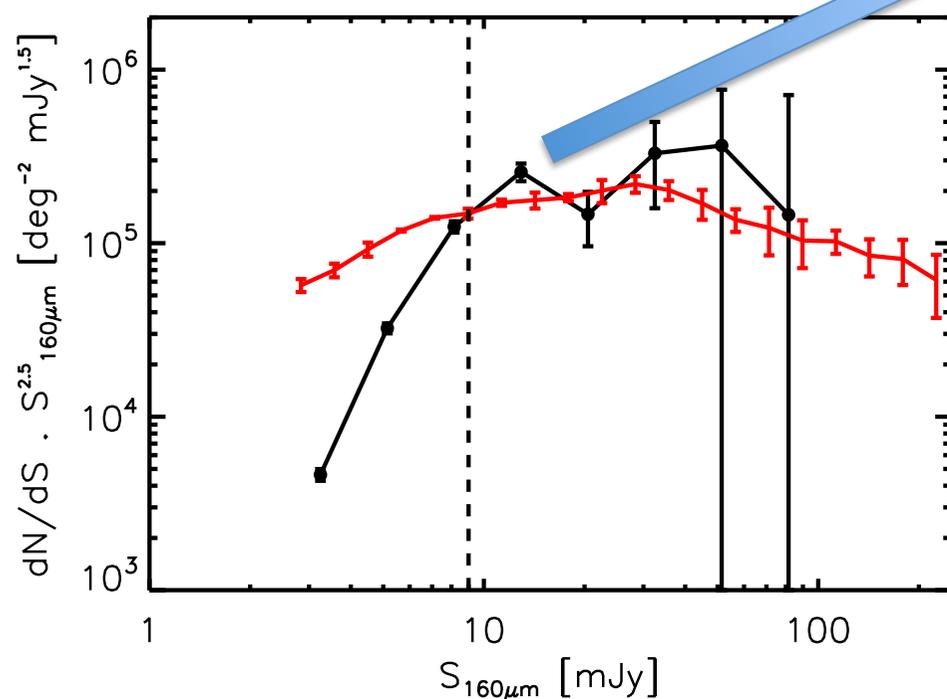


- Green circles – confirmed proto-cluster sources (5)
- Red squares – colour-selected candidates (17)
- Most colour-selected candidates have F160 in the range 10-20 mJy (consistent with those observed in the confirmed members).
- The Spiderweb HzRG has F160 ~ 42 mJy.
- Source 69 has a very large flux (F160 ~ 60 mJy) and is very likely a foreground contaminant.



Number counts and FIR overdensity

- Number counts computed at 160 μm (not affected by source confusion).
- Incompleteness affects progressively fluxes below 9 mJy.
- The number counts have been compared with field values from Berta et al. (2011).
- High-flux values have a large uncertainty due to the very small-number statistics.

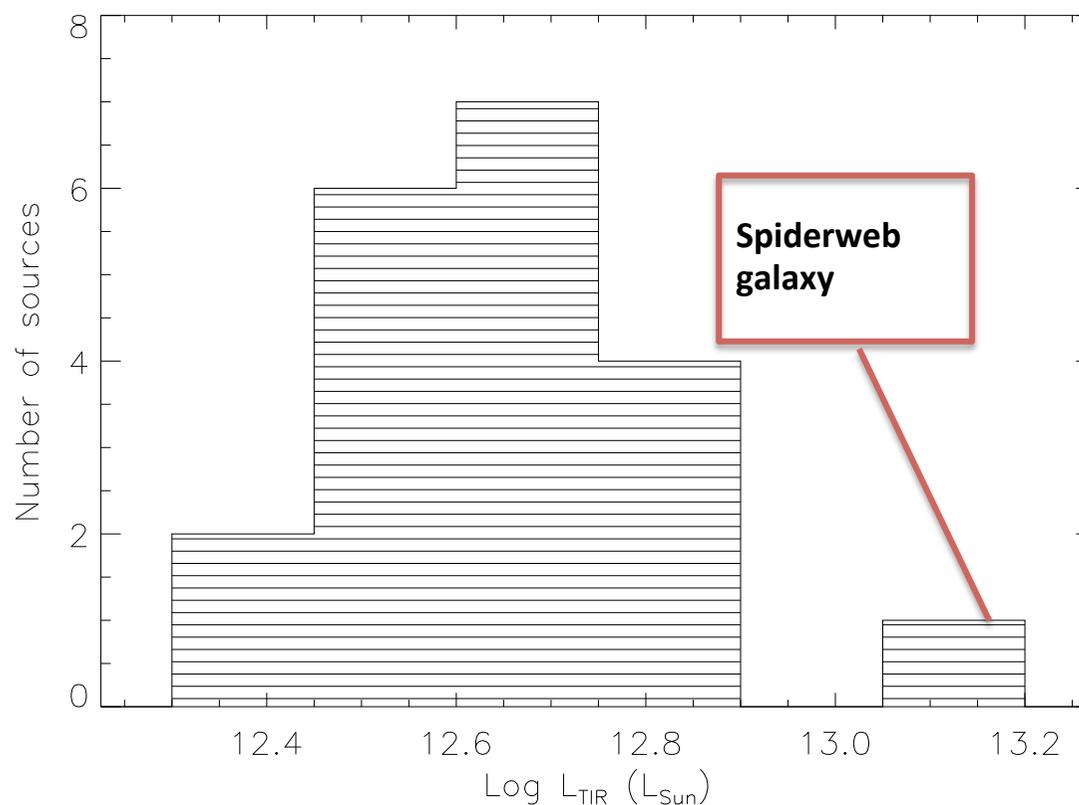


- There is a statistically significant overabundance of sources in the 15 mJy bin (w.r.t. field values).
- Consistent with the typical values found in colour-selected candidates.
- This is also consistent with a very clear positive clustering signal obtained by means of 2p-ACF with SPIRE data.



Total IR luminosity

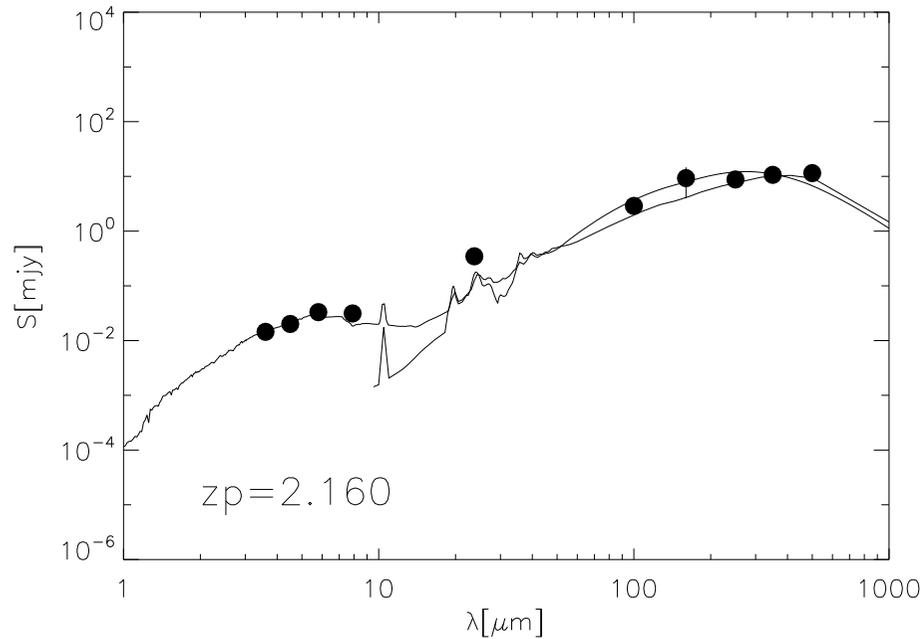
- The Total IR luminosity ($L_{8-1000\mu\text{m}}$) has been computed for the proto-cluster confirmed members and colour-selected candidates.
- The MIR/FIR SED has been fitted with LePhare to templates from Chary & Elbaz 2001 (CE01).
- Similar luminosities found for spectroscopic members and colour-selected candidates.



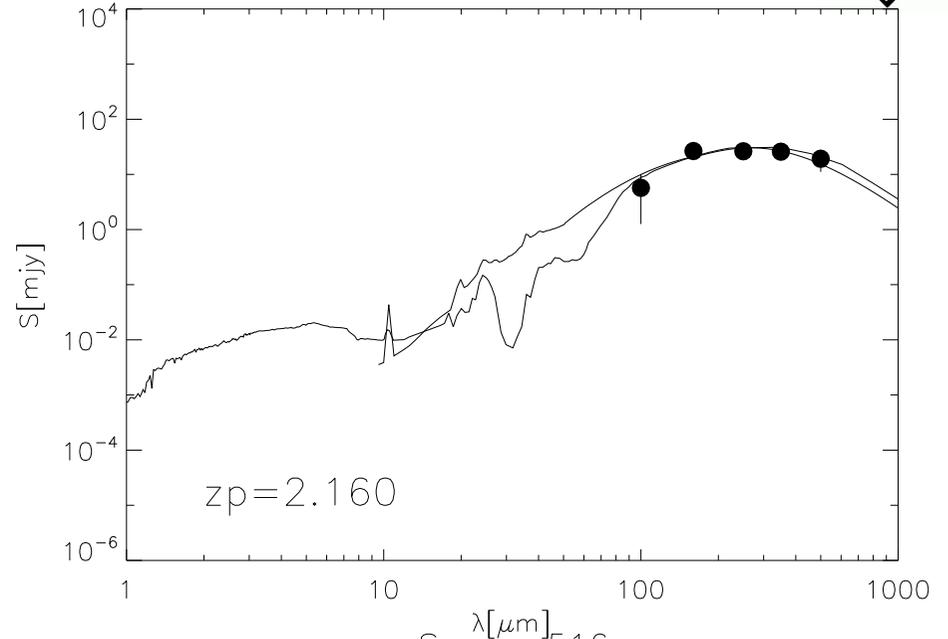
Some SED fitting examples...



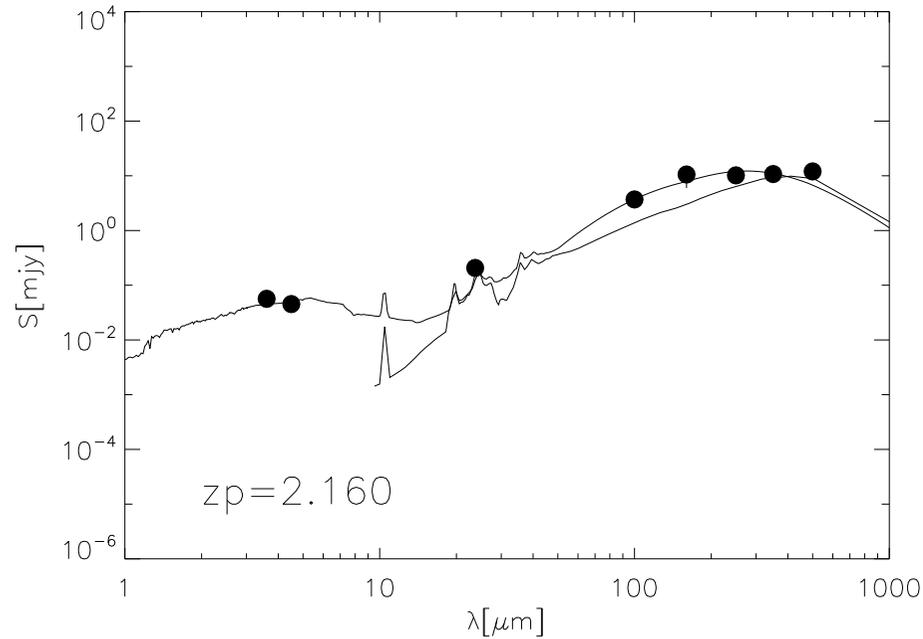
Source 178



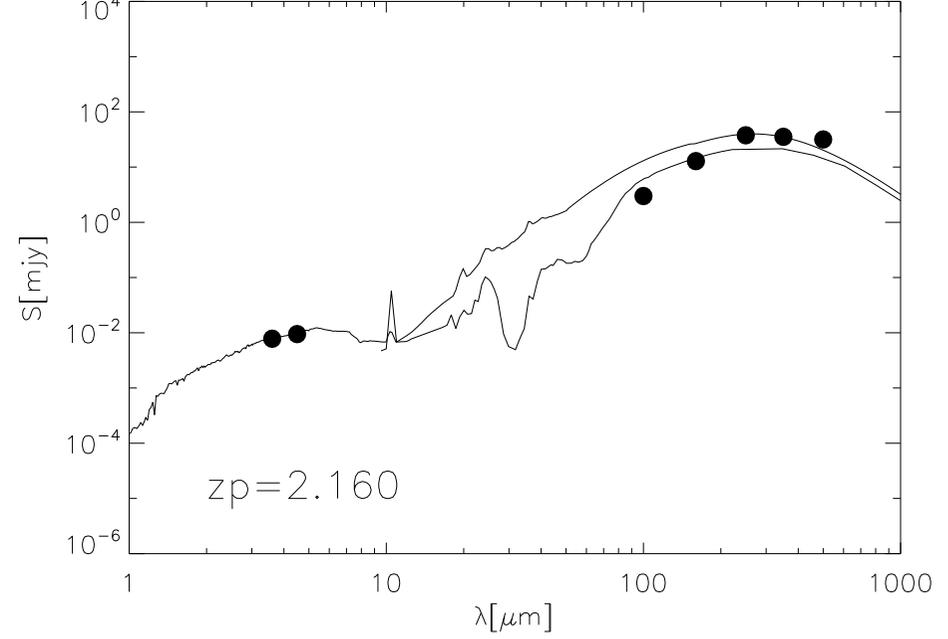
Source 189



Source 44



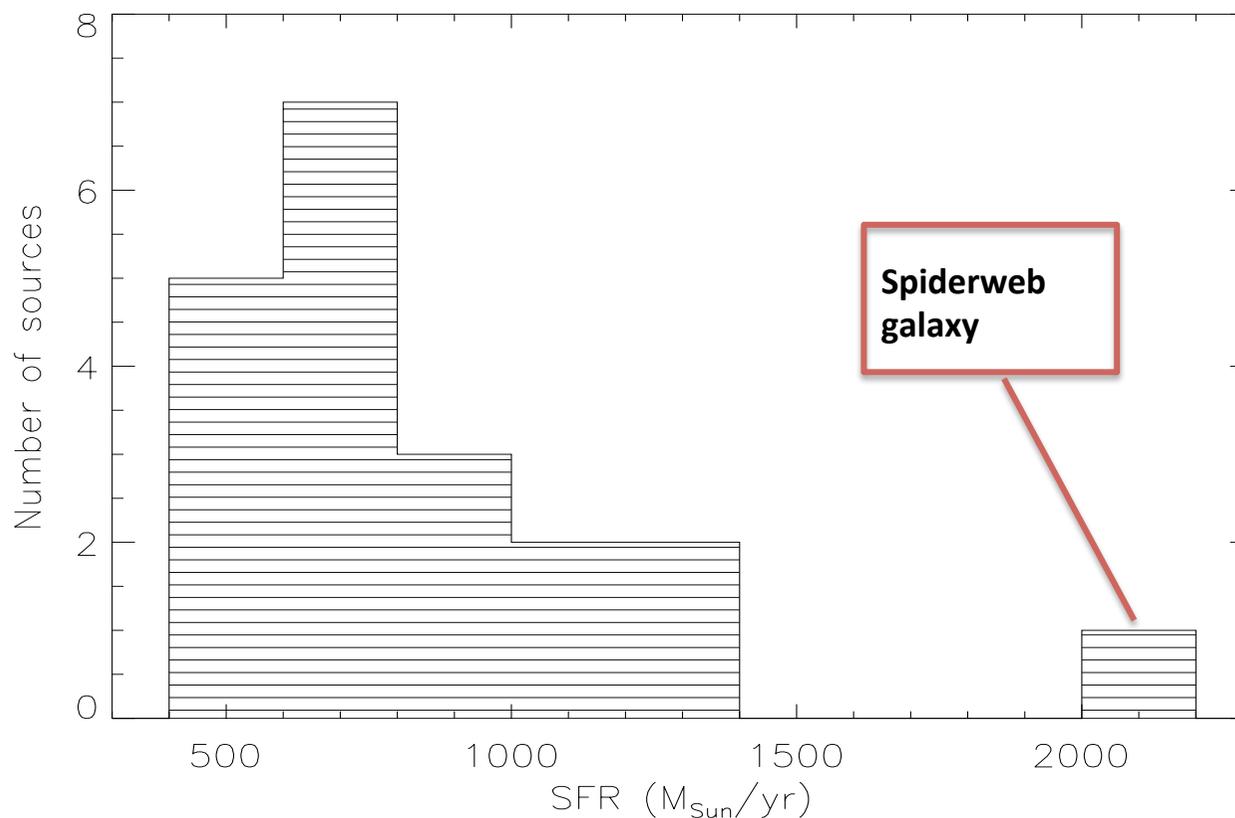
Source 516





Star-formation rates

- The SFR has been computed following Kennicutt (1998).
- The SFR from the Spiderweb galaxy is overestimated due to contamination from the AGN. Its SFR has been computed by Seymour+2012 as $1390 \pm 150 M_{\odot}/\text{yr}$.
- The very high SFR is consistent with that found by Ogle+2012 (500-1100 M_{\odot}/yr) from PAH emission.
- The SFRs found are much larger than those derived from $\text{H}\alpha$ (typically $< 40 M_{\odot}/\text{yr}$, Kurk +04) suggesting a highly obscured star formation.



Summary, conclusions, forecast...



- We have conducted a FIR-only study of the PKS1138-262 proto-cluster.
- We have devised a simple method to select proto-cluster candidates based on PACS & SPIRE –derived colours.
- The average flux of the candidates is very similar to that of the confirmed members (beside the HzRG) and consistent with the excess in number counts.
- We have derived the total IR luminosities. The very high star formation rates observed (~ 500 to $\sim 1000 M_{\odot}/\text{yr}$) are consistent with those derived from mid-IR spectroscopy.
- The $H\alpha$ -derived SFRs are much smaller than the values quoted above, suggesting a highly obscured SF activity.
- But we need to confirm the membership of our candidates. Optical/NIR photometric redshifts would help, but of course spectroscopic ones are the ultimate answer!