

A Deep Herschel View of Obscured Star Formation in the Bullet Cluster

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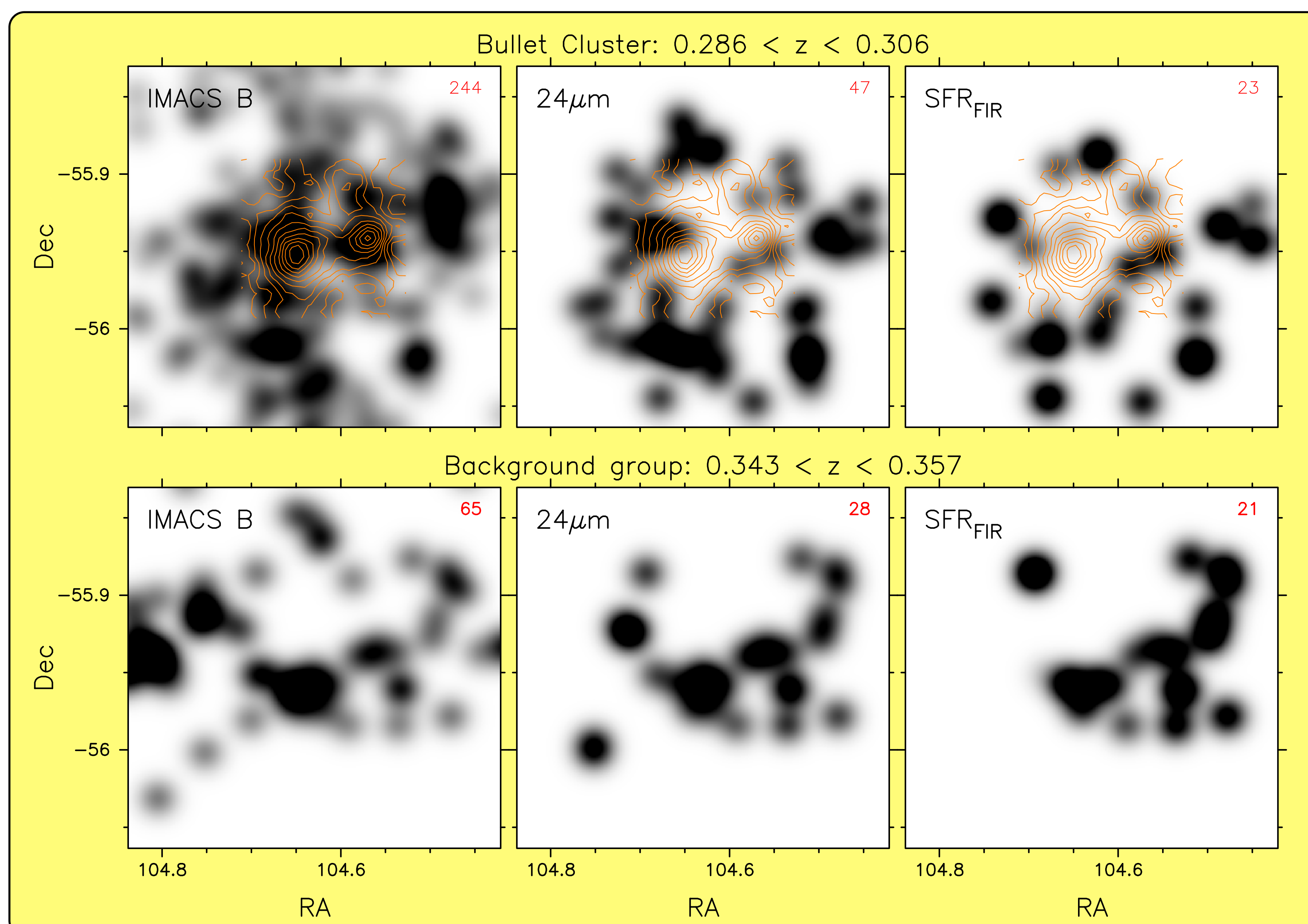
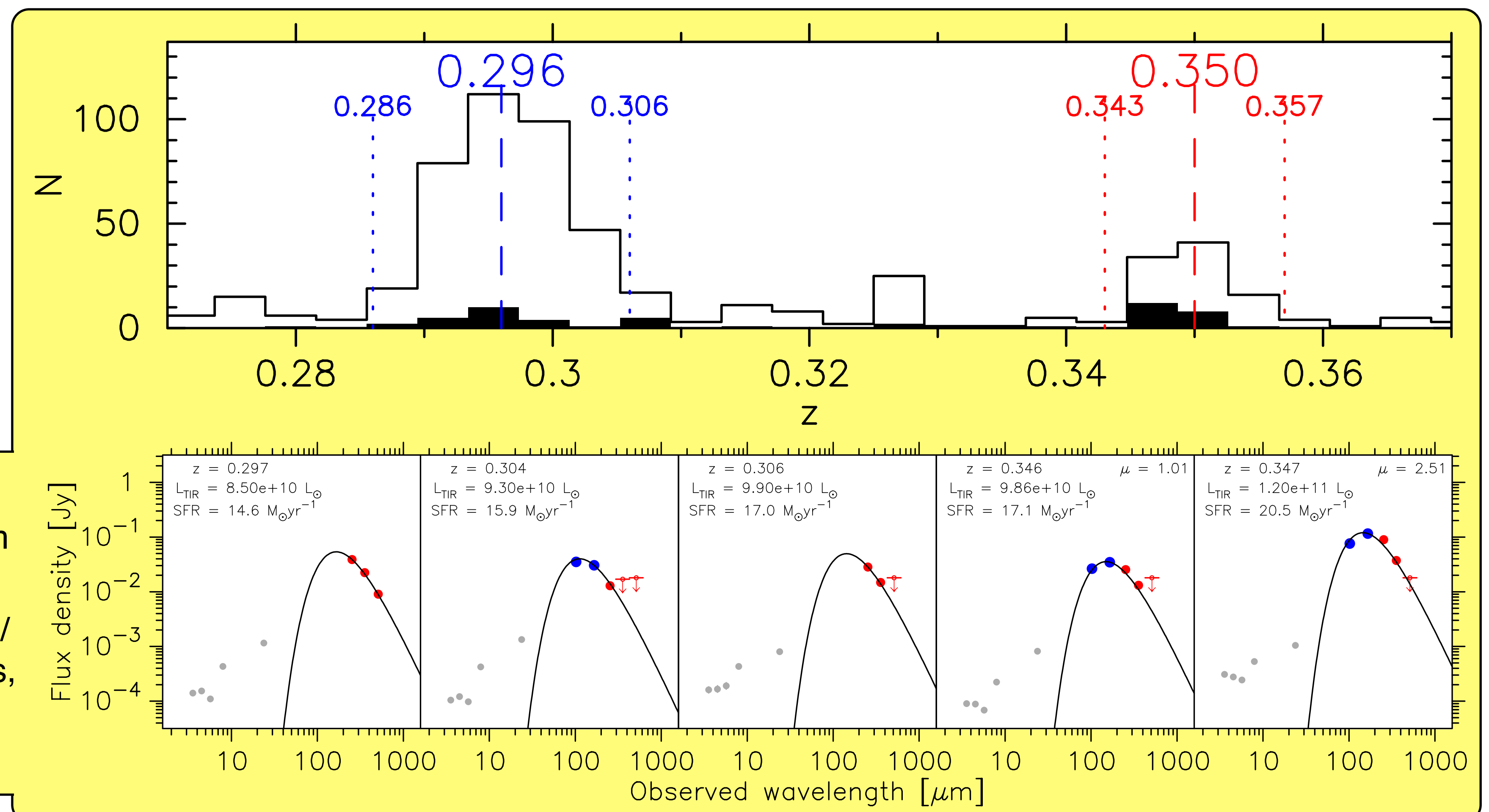
We use deep 5-band (100–500 μ m) Herschel data from the Herschel Lensing Survey (HLS), to constrain the far-infrared luminosity, and hence total obscured star formation rate, of spectroscopically confirmed cluster members within the Bullet Cluster (1E0657-56).

The Bullet Cluster ($z=0.3$) is a recent collision of two clusters in the plane of the sky (Markevitch+04), offering a unique laboratory for the study of star formation in a dynamic environment. A recent mid-infrared study (Chung+09) concluded that ram pressure from the merger event had no significant impact on the star formation rates of nearby galaxies.

Using 5 band (PACS+SPIRE; 100–500 μ m) data from the Herschel Lensing Survey (HLS), we can accurately constrain the dust component and hence the obscured star formation rate (SFR_{FIR}) in these cluster galaxies.

Upper: Spectroscopic redshift distribution for galaxies in the Bullet Cluster field (outline). Herschel detected galaxies are shown filled. The smaller background system ($z=0.35$) has a higher fraction of IR bright galaxies than the Bullet Cluster ($z=0.3$).

Lower: Observed SEDs for five of the most FIR luminous galaxies in the sample. Blue/red = PACS/SPIRE; grey = IRAC/MIPS. Redshift and, for background system galaxies, magnification factor μ , are displayed at the top of each panel. L_{TIR} and SFR_{FIR} are derived from the best fit, single-temperature blackbody (black line).



Smoothed density maps for B-band flux (left), 24 μ m flux (central) and SFR_{FIR} (right) for the Bullet Cluster (upper row) and $z=0.35$ system (lower). SFR in the Bullet Cluster appears to exhibit a radial trend. In the $z=0.3$ system, IR and optical flux trace similar distributions, whereas in the Bullet Cluster, B-band flux is centrally concentrated, away from the IR, indicating a different trend in dust retention for the two systems. While 24 μ m and SFR_{FIR} generally trace the same distribution, there are significant outliers: bright 24 μ m sources with relatively low SFRs, and vice versa.

The total SFR of the 23 Herschel-detected Bullet Cluster galaxies is $144 \pm 14 M_{\odot}yr^{-1}$. The 21 galaxies in the background system are, on average, $\sim 50\%$ more active, with a total SFR = $207 \pm 9 M_{\odot}yr^{-1}$. This suggests that cluster-cluster mergers are not important for triggering FIR starbursts. While the 24 μ m and Herschel FIR SFR density maps generally trace the same distribution, there are significant outliers: i.e. bright 24 μ m sources with relatively lower SFRs, and vice versa.

Left panel: Ratio of SFR_{FIR} (derived from the FIR blackbody) to SFR_{24} (estimated from 24 μ m via Rieke+09 templates) versus S_{100}/S_{24} . For galaxies without PACS data, 100 μ m flux is estimated from the blackbody fit. 40% of the cluster members have severely under-predicted SFR_{24} . The same galaxies are also systematically redder in S_{100}/S_{24} . Is this the main source of the SFR_{24} under-prediction?

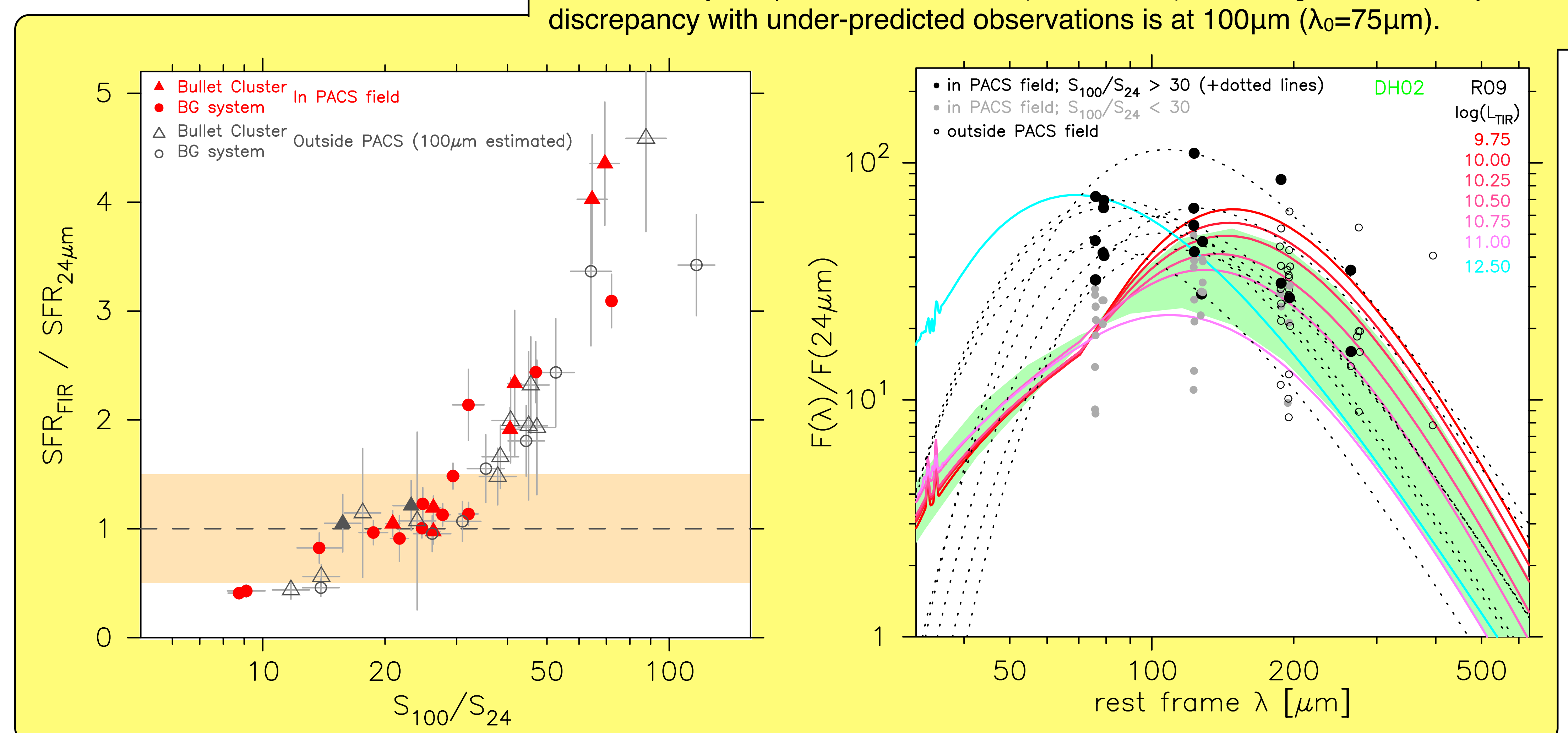
Right: Observed Herschel fluxes normalized at $\lambda_{obs}=24\mu$ m ($\lambda_0=18\mu$ m). Rieke+09 average templates (red \rightarrow pink) plus one example high- L_{TIR} template (cyan). Locus of low-activity templates from Dale02 ($\alpha = 1.8-2.5$) shaded green. The major discrepancy with under-predicted observations is at 100 μ m ($\lambda_0=75\mu$ m).

Templates spanning the observed range in L_{TIR} agree well for $\lambda_0 \geq 200\mu$ m. However, at 100 μ m there are 8 significant outliers. We define 100 μ m excess galaxies as S_{100}/S_{24} (rest frame S_{75}/S_{18}) > 30 .

100 μ m excess galaxies account for $\sim 40\%$ of cluster members detected with PACS, and cover the entire range of L_{TIR} sampled. Above a nominal luminosity limit of $10^{10}L_{\odot}$, 55% of Bullet Cluster galaxies show the excess, but only 35% of galaxies in the background system. This may indicate a trend with environment, or could be due to the off-centre view of the latter system (i.e. a potential radial trend).

SPIRE data discounts generally colder dust as the root cause, and AGN are unlikely to be a factor as no 100 μ m excess galaxy has a predicted AGN fraction $> 30\%$. Additional warm dust may be the source.

The high- z field sample in the HLS companion paper Rex+10, finds no galaxies with a comparable excess at $\lambda_0=75\mu$ m. This shows that the phenomenon could be redshift dependent or cluster specific.



Conclusions

- Herschel detects $\sim 50\%$ more obscured SF in a $z=0.35$ background system than in the Bullet Cluster, so cluster-cluster mergers may not be important for triggering FIR starbursts. The spatial distribution of optical flux compared to this SF suggests a different trend in dust retention between the two systems.
- SFR_{FIR} agrees well with template-estimated SFR_{24} for 60% of galaxies. However, the remaining 40% display a significant excess at 100 μ m ($\lambda_0 \approx 75\mu$ m) compared to the templates. This excess is not found in any of the high- z field sample galaxies.