Synergies between Herschel and ALMA for the study of the high redshift universe

Gianfranco De Zotti (INAF-OAPd)
thanks to: Andrea Lapi, Mattia Negrello, Joaquin González-Nuevo, Luigi Danese
Something we learned from Herschel
Sub-mm/mm counts of dusty galaxies

References:
- Planck Collaboration
- Serjeant & Harrison (2005)
- Clements et al. (2010)
- Oliver et al. (2010)
- Coppin et al. (2006)
- Vieira et al. (2010)

Models
- un-lensed spheroids (Lapi et al. 2011)
- lensed spheroids (Negrello et al. 2007)
- late-type galaxies (Negrello et al. 2007)
- TOTAL

Courtesy of M. Negrello & A. Lapi
100 µm luminosity functions

Lapi et al. (2011)
250 µm luminosity functions

Lapi et al. (2011)
Stellar mass function (Lapi et al. 2011)
From the SFR function to the stellar mass function

- The stellar mass function of massive galaxies mirrors the SFR function for a typical duration of the star-formation phase $\sim 0.7$ Gyr, with a trend towards shorter durations for more massive galaxies.

- SF timescale consistent with that expected for quenching by AGN feedback if a small fraction ($\sim 5\%$) of the Eddington luminosity is transferred to the ISM (Lapi et al. 2006). The same fraction of $L_{\text{Edd}}$ can account for the ‘entropy plateau’ of the ICM (Platania et al. 2002; Lapi et al. 2005).
In massive early-type galaxies the star formation must have been stopped before the ISM could have been enriched in Fe by SN Ia (SFR duration < 1 Gyr). Not consistent with merger driven star formation implying a sequence of short (~0.1 Gyr) SF episodes, spanning altogether >> 1 Gyr.
Halo mass vs velocity evolution
(Zhao et al. 2003)

\[ a = \frac{1}{1+z} \]
Mass within size of visible galaxy

Diemand et al. (2007)
Size comparison: stars vs dark matter

Effective radii of the most massive galaxies: \( \sim 10 \text{ kpc} \)

Virial radius (dark matter):

\[
R_v \approx 170 \times \frac{4}{1+z_v} \times \left( \frac{M_v}{10^{13} \text{ M}_{\odot}} \right)^{1/3} \text{ kpc}
\]
Counter-check

$\Phi(L_{\text{FIR}}) \sim N(M_h) \times \tau_{\text{SFR}}$: if $\tau_{\text{SFR}}$ is short need higher N i.e. smaller $M_h$ and higher $L_{\text{FIR}}/M_h \rightarrow$ top-heavy IMF $\rightarrow$ problems with accounting for the stellar mass function, but also with sub-mm counts, even playing with dust properties.

Lapi et al. (2011)
SAM with 2 SF modes (quiescent & starburst)
(Somerville et al. 2011)

Niemi et al. (2012)

Hirschmann et al. (2012)
The effective halo mass can be estimated from clustering properties. From the Lapi et al. (2011) model:

\[ M_{\text{eff}} = 5 \times 10^{12} \, M_{\odot} \] at \( z=2 \), consistent with independent estimates for most efficient star-formers. The merger-driven SF scenario implies substantially lower effective halo masses (Almeida et al. 2011; Kim et al. 2011).
Comparison between counts of strongly lensed galaxies at 1.4 mm predicted by Negrello et al. (2007; long dashed line) with the counts of SPT galaxies without IRAS counterparts (hence presumably at high z). Predictions by Pearson & Khan (2009; solid) and Lagache et al. (2004; short dashes) also shown.

H-ATLAS counts from Clements et al. (2010); predictions by Negrello et al. (2007), based on model by Granato et al. (2004) and Lapi et al. (2006).
The H-ATLAS SDP catalog contains 10 sources (plus a Galactic dust cloud) with 500 μm flux density above 100mJy: 4 galaxies with spectroscopic redshifts in the range 0.01–0.05, 1 blazar and 5 strongly lensed galaxies in the redshift range 1.6 – 3.1. The figures show the corresponding predictions by Negrello et al. (2007).
AGN evolution
Merger-driven evolution (Hopkins et al. 2008)

Light curve with multiple peaks and SFR well correlated with $L_{QSO}$
Predicted relationship between the BH accretion rate (BHAR) and the star formation rate (SFR) inside a given radius for a merger +isolated bar-(un)stable disk scenario (Hopkins & Quataert 2010)
We expect a correlation between SFR and AGN luminosity *at high z* because both are correlated with the halo mass, but not linear (because the AGN accretion rate is mostly Eddington limited, not determined by the SFR; the brightest AGN phase is associated to low SFR) and with a large dispersion. Bonfield et al. (2010) find $L_{\text{FIR}} \sim L_{\text{QSO}}^{0.32}$ (with some uncertain dependence on $z$). Hatziminaoglou et al. (2010) find $L_{\text{FIR}} \sim L_{\text{QSO}}^{0.35}$ for objects at $z > 2$, with a large dispersion (see figure).
No correlation between far-IR luminosity (i.e. SFR) determined with Herschel/SPIRE observations (HerMES fields) and $L_x$ (i.e. accretion luminosity) for X-ray selected moderate luminosity AGNs (Mullaney et al. 2011).
Sources of the ionizing background

Comparison of the ionization rate estimated, as a function of $z$, from $\tau_{\text{eff}}$ (data points) with the 2 estimated contributions from quasars and star-forming galaxies (Faucher-Giguère et al. 2008).
Conclusion - 1

• Sub-mm observations, particularly from Herschel surveys, are clarifying the reference scenario for the formation and early evolution of galaxies.

• The “merger-driven galaxy evolution paradigm” faces serious difficulties. Several observational indications seem to favour a scenario whereby star-formation and BH accretion are mostly driven by self-regulation processes and intrinsic galaxy properties.

• However, most evidences are circumstantial. ALMA will be crucial to provide direct measurements of the spatially resolved morphology and dynamics of high-z star-forming galaxies.
Conclusion - 2

In particular ALMA will provide direct answers to questions like:

• Are high-z SMGs really massive?
• How frequently are they associated to major mergers?
• Are they dynamically stable? Rotationally supported?
• Are they going to evolve into giant ellipticals?
• What is the relationship between SFR and nuclear activity?
• What drives the growth of black holes? What is the role of large-scale environment on the fueling of BHs? Is the gas flowing directly into the SMBH (via the accretion disc) or is it first piling in a reservoir?
• How does stellar and AGN feedback operate?
• Which are the properties of the different ISM phases in these galaxies?

Strongly lensed galaxies selected by Herschel surveys are obvious primary targets for these studies.