Modeling sub-mm galaxies

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Mass-Loss Return from Stars to Galaxies, 20-21 May 2010
Collaborators

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Outline

• What is an SMG and why should you care?
• Modeling SMGs
• Dust masses in SMGs
What is an SMG and why should you care?
Sub-millimeter galaxies (SMGs)

- Population of sources detected b/c high sub-mm flux ($S_{850} > \sim 5$ mJy; Smail+97, Barger+98, Hughes+98, Eales+99)

- Highly obscured: 99% of L is emitted in IR

- Powered by SF rather than AGN (Alexander+05)

- $L_{IR} \sim 10^{12} - \text{few} \times 10^{13} L_{sun} \Rightarrow \text{SFR} \sim 100s-1000s M_{sun}/yr$

- Median $z \sim 2.2$ (Chapman+05)

- See Blain+02 for a review

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Some properties of SMGs

- Stellar masses: few \( \times 10^{11} \) M\(_{\text{sun}}\) (Swinbank+04)
- \( \text{H}_2 \) masses \( \sim 10^{10-11} \) M\(_{\text{sun}}\) (e.g., Greve+05, Tacconi+06,08); \( f_g \) \( \sim 0.2-0.5 \)
- Dust masses: few \( \times 10^8 \) - few \( \times 10^9 \) M\(_{\text{sun}}\) (median 9e8; Kovacs +06)
- Gas-to-dust \( \sim 50-60 \) (MW \( \sim 120 \))
- Metallicities: median slightly sub-solar; up to 2x solar (Swinbank +04, Nesvadba+07)
Key questions

• Are SMGs mergers? Gas-rich disks fueled by cold flows? Something else?

• Given a model, what L & dust mass do we need to achieve the observed 850 μm fluxes?

• Can we trust the large dust masses inferred from observations? If so, how do SMGs create that much dust by z ~ 2?
Modeling SMGs
Merger simulations

- Large suite of major & minor mergers, isolated disks
- GADGET-2 N-body/SPH (Springel 05)
- Schmidt-Kennicutt SF recipe
- Two-phase ISM of Springel & Hernquist (03)
- Radiative heating & cooling (Katz+96)
- Gas particles enriched as closed boxes
- BH growth & feedback (Springel+05)
Sunrise radiative transfer code

- Use the Monte Carlo RT code *Sunrise*, primarily developed by Patrik Jonsson (CfA)

- Publicly available: [http://www.ucolick.org/~patrik/sunrise](http://www.ucolick.org/~patrik/sunrise)
Sunrise radiative transfer code

1. Assign SEDs to star & BH particles
2. Project Gadget gas/metal density onto grid and convert to dust density via dtg or dtm ratio
3. Sources emit photons which are scattered and absorbed by dust
4. Dust re-emits absorbed energy
5. Iterate dust absorption & emission until converged
Example SED
How to make an SMG

$S_{850} = 5 \text{ mJy}$
Dust masses in SMGs
How much can we trust observed dust masses?

Fit (few) FIR photometric points w/ optically thin graybody to get “dust T”

Then assume all dust emits with same T to get dust mass

But...

1. Galaxies do not have a single dust T

2. T degenerate w/ z, β

3. ULIRGs/SMGs optically thick to >100 μm; only see τ = 1 surface

\[ S(\nu, T) \propto \nu^\beta B(\nu, T) \]

\[ M_d = \frac{S(\nu, T)D_L^2}{(1 + z)\kappa_d(\nu_{\text{rest}})}B(\nu_{\text{rest}}, T_d) \]

\[ S(\nu, T) \propto \left(1 - e^{-(\nu/\nu_0)^\beta}\right) B(\nu, T) \]
Observed dust $T$ potentially inaccurate; however, for $z = 2$ and fixed observed 850 $\mu$m flux, changing $T$ from 30 to 60 K decreases $M_d$ by only 2x.
Dust mass in simulations

Simulations have dust masses broadly consistent with observed values - we need > 5e8 M$_{\text{sun}}$ at peak of merger (SFR ~ 500-1000) to get S$_{850}$ ~ 5 mJy

We can probably trust observed dust masses to a factor of 2-3
Can SMGs make that much dust?

- for $\eta = 0.4$, yield = 0.02, $M_b = 2 \times 10^{11}$, $M_d < 6 \times 10^8$
- Assumes no in/outflow? is $y = 0.02$ reasonable?
- BUT, $2 \times 10^{11}$ $M_{\text{sun}} \Rightarrow \approx 2 \times 10^9$ SNe II $\times 0.02$
  $M_{\text{sun}}/\text{SN} \Rightarrow < 2 \times 10^7$ $M_{\text{sun}}$ in dust
- assuming dust survives forever
- AGB stars? Could work if dust from early stellar mass assembly survives
- Do we need a top-heavy IMF? #
  counts can help answer (Baugh+05)

$f_g = 1/e, Z = y$

$M_d < 0.37\eta y M_b$

Edmunds & Eales 98

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Points to take home

1. SMGs are few Gyr old galaxies w/ extremely high $L_{\text{bol}}$/SFR and large amounts of dust

2. Both models & observations suggest dust masses of few $10^8 - 10^9$ needed to create typical SMGs

3. Very difficult to create this much dust with SNe (amount?) or AGB stars (timescale?)
For more details...

see

- Narayanan, CCH+10 (850 fluxes)
- Narayanan, Cox, CCH+09 (CO emission)
- CCH+ in prep (number counts, dust T/mass)

or, better yet, talk to me. Thanks!

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