A Sub-Dominant Starburst-Driven Outflow at z~5.7

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With Roberto Maiolino, Paola Caselli, Stefano Carniani
THE RAMP-UP EPOCH (z>4)

A SUB-DOMINANT STARBURST-DRIVEN OUTFLOW AT z~5.7

Bouwens+ 2016
A MULTITUDE OF EARLY STARBURSTS

<table>
<thead>
<tr>
<th>Source</th>
<th>$z$</th>
<th>SFR</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>GN20</td>
<td>4.05</td>
<td>1890 ± 90</td>
<td>Tan et al. (2014)</td>
</tr>
<tr>
<td>ID141</td>
<td>4.240</td>
<td>~ 2000 ± 400</td>
<td>Cheng et al. (2020)</td>
</tr>
<tr>
<td>BRI 1335-0417</td>
<td>4.407</td>
<td>5040 ± 1304</td>
<td>Wagg et al. (2014)</td>
</tr>
<tr>
<td>BRI 1202-0725 SMG</td>
<td>4.693</td>
<td>6900 ± 2070</td>
<td>Lu et al. (2017)</td>
</tr>
<tr>
<td>BRI 1202-0725 QSO</td>
<td>4.695</td>
<td>5100 ± 1530</td>
<td>Lu et al. (2017)</td>
</tr>
<tr>
<td>AzTEC-3</td>
<td>5.298</td>
<td>2500 ± 700</td>
<td>Riechers et al. (2020)</td>
</tr>
<tr>
<td>GN10</td>
<td>5.303</td>
<td>1030$^{+190}_{−150}$</td>
<td>Riechers et al. (2020)</td>
</tr>
<tr>
<td>SPT0346-52</td>
<td>5.656</td>
<td>3800 ± 100</td>
<td>Jones et al. (In Press)</td>
</tr>
<tr>
<td>PSOJ215-16</td>
<td>5.73</td>
<td>1100 ± 900</td>
<td>Li et al. (2020)</td>
</tr>
<tr>
<td>SDSS J2310+1855</td>
<td>6.003</td>
<td>4100 ± 600</td>
<td>Carniani et al. (2019)</td>
</tr>
<tr>
<td>ULAS J1319+0959</td>
<td>6.133</td>
<td>2500 ± 1700</td>
<td>Carniani et al. (2019)</td>
</tr>
<tr>
<td>HFLS3</td>
<td>6.34</td>
<td>~ 2900</td>
<td>Riechers et al. (2013)</td>
</tr>
<tr>
<td>SDSS J1148+5251</td>
<td>6.4</td>
<td>3200 ± 1500</td>
<td>Carniani et al. (2019)</td>
</tr>
<tr>
<td>J0305-3150</td>
<td>6.6145</td>
<td>1020 ± 160</td>
<td>Li et al. (2020)</td>
</tr>
</tbody>
</table>

$+ 4 \quad SFR > 1000 \, M_\odot \, \text{year}^{-1}$

+ Dozens from Reuters et al. (2020) and other works
A SUB-DOMINANT STARBURST-DRIVEN OUTFLOW AT $z\sim 5.7$

**SPT0346-52**

- Originally detected in SPT survey
- $z = 5.656$ (~1Gyr after BB)
- $\mu \sim 5.6$
- $\text{SFR} \sim 4000 \text{M}_\odot \text{year}^{-1}$
- $L_{\text{FIR}} > 10^{13} \text{L}_\odot$ (HyLIRG)
- $M_{\text{H}_2} \sim 10^{11} \text{M}_\odot$
- Detected in CO(2-1, 5-4, 6-5, 8-7, 9-8), $\text{H}_2\text{O}(2_{0,2} - 1_{1,1}, 2_{1,1} - 2_{0,2})$, [CII]158$\mu$m

Carlstrom et al. (2011), Weiss et al. (2013), Ma et al. (2015), Spilker et al. (2015), Ma et al. (2016), Spilker et al. (2016), Aravena et al. (2016), Litke et al. (2019), Dong et al. (2019), Apostolovski et al. (2019), Jones et al. (In Press)
A SUB-DOMINANT STARBURST-DRIVEN OUTFLOW AT z~5.7

AN EARLY STARBURST

<table>
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<tr>
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- Star formation only:
  - $t_{\text{depl}} \sim 30\,\text{Myr} \rightarrow z \sim 2 - 4$ passive galaxy

- New gas (Filamentary accretion, major/minor mergers):
  - $\uparrow t_{\text{depl}}$

- Quenching:
  - $\downarrow t_{\text{depl}}$: Removal of intrinsic gas (AGN/SF feedback), Shutoff of gas source (strangulation), Stripping (environmental, ram pressure)
  - $\uparrow t_{\text{depl}}$: Unsuitable conditions for SF (AGN/SF feedback, shock heating)

How is this early starburst quenched?
OBSERVATIONS

- ALMA band 7, cycle 4
- 1.95 hours on-source
- Beam $0.19'' \times 0.17''$
  - $\sim 1.0 \times 1.1$ kpc
- $\text{H}_2\text{O}(4_{1,4} - 4_{2,3})$
- $\text{H}_2\text{O}(3_{3,0} - 3_{2,1})$

González-Alfonso et al. (2012)
RESULTS

A SUB-DOMINANT STARBURST-DRIVEN OUTFLOW AT z~5.7

-52°05'01.0"

H₂O 3₃,0-3₂,1
H₂O 4₂,3-4₁,4
A SUB-DOMINANT STARBURST-DRIVEN OUTFLOW AT z~5.7

RESULTS

Dong et al. (2019)

Gonzalez-Alfonso et al. (2012)
OUTFLOW MODELLING

A SUB-DOMINANT STARBURST-DRIVEN OUTFLOW AT $z \sim 5.7$

\[ \tau(r) = \frac{\pi e^2 f_{\text{ld}} \lambda_{\text{ld}} \rho_{\text{f}}(r)}{m_e c m_{\text{H}_2} \text{O} \left| \frac{dv}{dr} \right|} \]

\[ B = 1 - e^{-\tau(r)} \]

\[ \dot{M}_{\text{H}_2} \]

Model

Application

PyMultiNest
A SUB-DOMINANT STARBURST-DRIVEN OUTFLOW AT $z \approx 5.7$

OUTFLOW MODELLING
CONCLUSIONS

- Detection of two water absorption lines in an early (z~5.7) starburst (SFR~4000)
- Find evidence for highest-SFR molecular outflow
- Using spherical shell outflow model, find $\dot{M} < $ SFR

For gas depletion, starburst $\gg$ outflows
Accretion, group effects, SF conditions also matter

Next: Additional high-excitation OH/H$_2$O observations of z>4, SFR>1000 galaxies

"Detection of a high-redshift molecular outflow in a primeval hyperstarburst galaxy"