how (not) to cross-correlate
or: the quest for an optimal cross-correlation target
for the CO Mapping Array Pathfinder

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why cross-correlate?

extremely valuable to a novel, complex subfield

cross-correlating data from independent observations

- improves confidence in a tentative detection
- potentially allows science not possible with either in isolation

  - 21 cm × galaxies: HI content of galaxies
  - CO × Ly-α: molecular fraction of LAEs
  - as many synergies as there are pairings

Figure: Switzer+13 (arXiv:1304.3712)
COMAP Phase I
CO(1-0), \( z = 2.4\text{–}3.4 \), degree-scale field

- 19-pixel, single-pol, heterodyne, 26–34 GHz
- targeting initial detection of CO clustering signal
- \textit{noise} dominates errors, not sample variance
available targets

what to cross-correlate with at $z \sim 3$?

- line-intensity surveys

- spectroscopic galaxy surveys

- photometric galaxy surveys

are these encouraging cross-correlation targets for COMAP?
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  - $\sigma_z \ll 0.01(1 + z)$
  - many examples represented here, many coming online soon
  - possible in future with coordination, but what’s available now?

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- photometric galaxy surveys
  - e.g. COSMOS2015 (Laigle+16)
  - sizeable catalogue with good source abundance even at $z \gtrsim 2$, but ...
  - $\sigma_z \gtrsim 0.01(1 + z)$—how does this affect signal?

*are these encouraging cross-correlation targets for COMAP?*
COMAP × galaxy surveys?

presenting the photo-z problem

- even limits in spectroscopic redshift precision can attenuate the cross spectrum

\[ \frac{\sigma_z}{1 + z} = 0 \]
\[ \frac{\sigma_z}{1 + z} = 0.0007 \]
\[ \frac{\sigma_z}{1 + z} = 0.003 \]
\[ \frac{\sigma_z}{1 + z} = 0.02 \]

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- even limits in spectroscopic redshift precision can attenuate the cross spectrum
- but the effect is more severe for galaxy redshift errors of $\sigma_z \gtrsim 0.01(1 + z)$
  - attenuating cross spectrum by $3–10 \times$
    (enough for pointing COMAP at COSMOS to no longer make overwhelming sense)

Figure: DTC+ in prep
COMAP × HETDEX?
both as LAE survey and as LIM survey

- natural target for cross-correlation
  - redshift overlap ($z \sim 3$)
  - both instruments north of the equator
- initial projections promising!
  - best detection may be from using HETDEX as a Ly-$\alpha$ intensity mapper
  - but could still obtain detection for COMAP × HETDEX LAE

![Graph showing cross-correlation]

Figure: DTC+ in prep
in summary

a few general takeaways

- designing our surveys to enable cross-correlation will be crucial for validation and for multi-tracer science
- medium/broad-band photometric surveys form much of the ancillary data *currently* available at $z \gtrsim 2$, but line-intensity surveys relying on finer line-of-sight information should instead look forward to near-future spectroscopic surveys
- never too early to start conversations on coordinating efforts to enable/propose wide-field ($\gtrsim \text{deg}^2$) spectroscopic surveys at intermediate redshifts ($z \sim 3$) and nearer to reionisation ($z \gtrsim 6$)
backup slides!
why? what’d I miss?
photo-z: quick solutions?
no such thing as a free lunch

- coarsen CO cube in the z-direction?
  - gains signal by ‘integrating away’ photo-z errors ...
  - ... but loses signal by discarding line-of-sight information

- clustering redshifts?
  - usually requires spectroscopic sample
  - more sensible to cross-correlate against that sample to start with?

![Graph showing total signal-to-noise for CO auto and CO-galaxy cross spectra.](image)

\[
\frac{\sigma_z}{(1 + z)} = 0.02
\]
Lyman-alpha model

simplistic $L(M_h, z)$ relation w/ some physical motivation

- basic form:

$$L_{\text{Ly} \alpha} \propto \text{SFR} \cdot f_{\text{esc}}(\text{SFR}, z)$$

- use Behroozi+13 SFR($M_h, z$) relation

- use fine-tuned escape fraction function strongly evolving with SFR/mass
  - tuned to Sobral+17 ($z \sim 2$) and Gronwall+07 ($z \sim 3$)

- built for intermediate redshifts $z \in (2, 5)$
Lyman-alpha model comparison against S-SC4K LAE LFs (Sobral+18)