Measuring source-subtracted CIB fluctuations and their relation to early stellar populations

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CIB fluctuations contain contributions from sources spanning the entire cosmic history. Including sources inaccessible to direct telescopic studies (now approaching \(z\sim 6-8\)).

One particularly important class of these are sources from first star epochs, \(z>10\) or so.

*Where these sources Pop 3 stars, BHs, and in what proportions, when and how many?*

**Reasons why Pop 3 should produce significant CIB fluctuations**

- If massive, each unit of mass emits \(L/M\sim 10^5\) as normal stars (\(\sim L_\odot/M_\odot\))
- Pop 3 era spans a smaller volume (\(\Delta t<\sim 0.5\) Gyr), hence larger relative fluctuations
- Pop 3 systems form out of rare peaks on the underlying density field, hence their correlations are amplified

*Population 3 could leave a unique imprint in the CIB structure. Measuring it would offer evidence of and a glimpse into the Pop 3 era (Cooray et al 2004, Kashlinsky et al 2004)*
CIB anisotropies contain two terms:

- Shot noise

  from galaxies occasionally entering the beam

  \[ \frac{\delta F}{F} \sim \frac{1}{N_{\text{beam}}^{\frac{1}{2}}} \]

- Clustered component

  Reflects clustering of the emitters, their epochs and how long their era lasted
Early and non-Spitzer attempts

- Shectman (1973,1974) was the first to deduce EBL from optical fluctuations measurements
- Kashlinsky et al (1996a,b,2000) applied similar methods to measure/constrain CIB fluctuations at ~0.5 deg from DIRBE data – *large beam, no foreground galaxies can be removed*
- Matsumoto et al (2000) measured power spectrum of CIB fluctuations on ~ degree scales from IRTS data – *again, large beam, no foreground galaxies can be removed*
- Kashlinsky et al (2002), Odenwald et al (2003) applied them to deep 2MASS at J,H, K bands (1-2 micron) – foreground galaxies remove sources to ~ m_Vega~18.5 on sub-arcmin scales. *But atmospheric fluctuations in these ground-based data prevent measurements on larger angular scales or further foreground galaxy removal.*
- Thompson et al (2007) reconstructed CIB fluctuations from galaxy populations observed in HUDF data at 1.6 mic. *Good agreement with deep 2MASS-based detections, but cannot measure fluctuations at scales > 1 arcmin as the field is small.*

- HENCE, ON TO Spitzer:
Cosmic infrared background fluctuations from deep Spitzer images

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Results briefly:

• Source-subtracted IRAC images contain significant CIB fluctuations at 3.6 to 8µm.
• These fluctuations come from populations with significant clustering component but only low levels of the shot-noise component.
• There are no correlations between source-subtracted IRAC maps and ACS source catalog maps (< 0.9 µm).
• These imply that the CIB fluctuations originate in populations in either 1) 1st 0.5 Gyr or z>6-7 (t<0.5 Gyr), or 2) very faint more local populations not yet observed.
• If at high z, these populations have projected number density of up to a few arcsec⁻² and are within the confusion noise of the present-day instruments.
• JWST can resolve them (beam<0.04”).
• But so far there is no direct info on the epochs of these populations
Requirements for CIB fluctuations studies – in order to measure signals as faint as those expected from P3 era

MAP ASSEMBLY

• Maps must be assembled removing artifacts to below ~ 0.01-0.02 nW/m²/sr
• No correlations should be introduced in map construction
• Filters (e.g. median) which remove confusion populations must be avoided

ANALYSIS TOOLS

• Instrument noise (A-B) must be evaluated and subtracted from P(q)
• Proper tools must be used for computing the signal: FFT only when >70% of pixels are left; correlation functions otherwise
• Beam must be reconstructed and its small and large-scale properties evaluated

INTERPRETATION

• Cosmological signal must be tested for isotropy wherever possible
• End-to-end simulations must be done to prove that no artifacts mimic the signal
• Foreground contributions must be estimated: cirrus (e.g. 8μm) and zodi (via E1-E2)
• Observations need to be done in one epoch to avoid zodiacal gradients
IRAC image processing:

- Data were assembled using a least-squares self-calibration methods from Fixsen, Moseley & Arendt (2000).
- Selected fields w. homogeneous coverage.
- Individual sources have been clipped out at $>N_{\text{cut}} \sigma$ w $N_{\text{mask}} = 3-7$
- Residual extended parts were removed by subtracting a “Model” via CLEAN algorithm iteratively identifying brightest pixel and subtracting a fixed fraction of normalized PSF from that location in image.
- Clipped image minus Model had its linear gradient subtracted, FFT’d, muxbleed removed in Fourier space and P(q) computed.
- Using SExtractor constructed a source catalog to identify the magnitude ceiling of the removed sources (and remaining shot noise)
- In order to reliably compute FFT, the clipping fraction was kept at $>75\%$ ($N_{\text{cut}}=4$)
- Noise was evaluated from difference (A-B) maps
- With GOODS data find the same signal at different detector orientations
- Note: for GOODS data E1 and E2 data must be treated separately because of the (very) different zodiacal gradients.
Comparison of self-calibration w standard image assembly

From AKMM (2010)
GOODS – results (color symbols)  
(black symbols show the QSO1700 field results)

Shot noise reached in QSO1700

\[ P_{SN}(3.6\mu m) \approx 6 \times 10^{-11} \text{nW}^2/\text{m}^4/\text{sr} \]

Shot noise reached in GOODS:
HDFN-E1, HDFN-E2
CDFS-E1, CFDS-E2

\[ P_{SN}(3.6\mu m) \approx 2 \times 10^{-11} \text{nW}^2/\text{m}^4/\text{sr} \]

Fluctuations are made up of two components:
1) Remaining shot noise (scales < 20 arcsec)
2) Fluctuations arising from clustering (>0.5 arcmin)

Remaining shot noise is:

\[ P_{SN} = \int S^2(m) \, dN/dm \, dm \]

Different datasets must be compared at the same \( P_{SN} \).
Spitzer/IRAC GOODS vs HST/ACS GOODS

- GOODS fields were observed by ACS/HST at B,V,i,z (0.4 to 0.9 micron)
- We selected four regions (HDFN-E1,2; CDFS-E1,2) of 972 0.6” pixels on side (10’)
- Used ACS source catalog (Giavalisco et al 2004) to produce ACS maps for the fields
- Convolved ACS source maps with IRAC 3.6 and 4.5 beams
- Processed IRAC maps as in KAMM and computed fluctuations and cross-correlation

Results

- Source-subtracted IRAC maps have different power spectra than those in ACS
- The amplitude of CIB fluctuations than can be contributed by ACS sources is small
- There are very good correlations between ACS sources and the sources removed by KAMM, but
- Completely negligible correlations between ACS and source-subtracted IRAC maps

Conclusions

- ACS sources cannot contribute significantly to KAMM IRAC fluctuations
IRAC/GOODS source-subtracted CIB fluctuations.

ACS source maps.
- $m_{AB} > 22$
- $m_{AB} > 24$
- $m_{AB} > 26$
- $m_{AB} > 28$
- $m_{AB} > 24$, no mask

ACS vs KAMM sources (open symbols).
ACS source maps vs source subtracted IRAC data (filled).

Solid lines: ACS B,V,I,z
Dotted line: IRAC Ch 1
Future (almost imminent) measurements: SEDS

Want to constrain the epochs of the new populations from large-scale power spectrum:

For LCDM spectrum, the peak of the CIB fluctuations coming from $z \sim 7-10$ should be at 0.2-0.3 deg.
Plan, methods and science for SEDS data

- Will map several regions of *low cirrus* emission of ~1 deg$^2$ (100-200 FOV)
- Exposure ~12 hr/pix to reach <~0.2 mJy at 3-sigma
- Observations need to be sorted at a single epoch (to minimize zodi grads)
- Self-calibration image assembly
- Remove sources and evaluate source-subtracted CIB fluctuations at sub-degree scales
- STAY TUNED