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~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~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

$\delta F/F \sim 1/N_{beam}^{1/2}$

- 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

A. Kashlinsky, R. Arendt, J. Mather & H. Moseley
(Nature, 2005, 438, 45; ApJL, 2007, 654, L1; 654, L5; 666, L1 – KAMM1-4)
R. Arendt, A. Kashlinsky, H. Moseley & J. Mather
(2010, ApJS, 186,10 – AKMM)

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/m^2/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

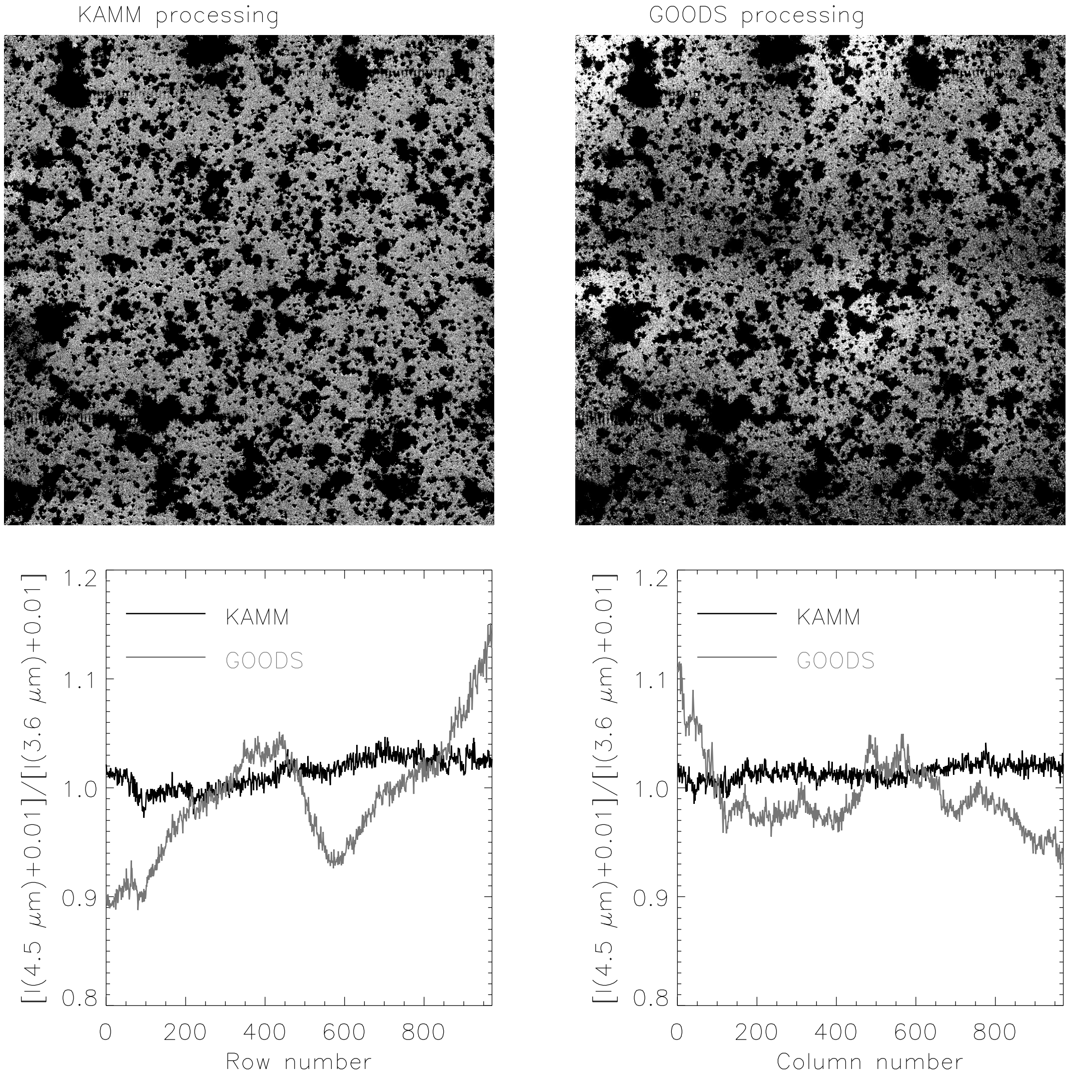
INTERPRETATION

- 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 $>N_{cut}\sigma$ w N_{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_{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

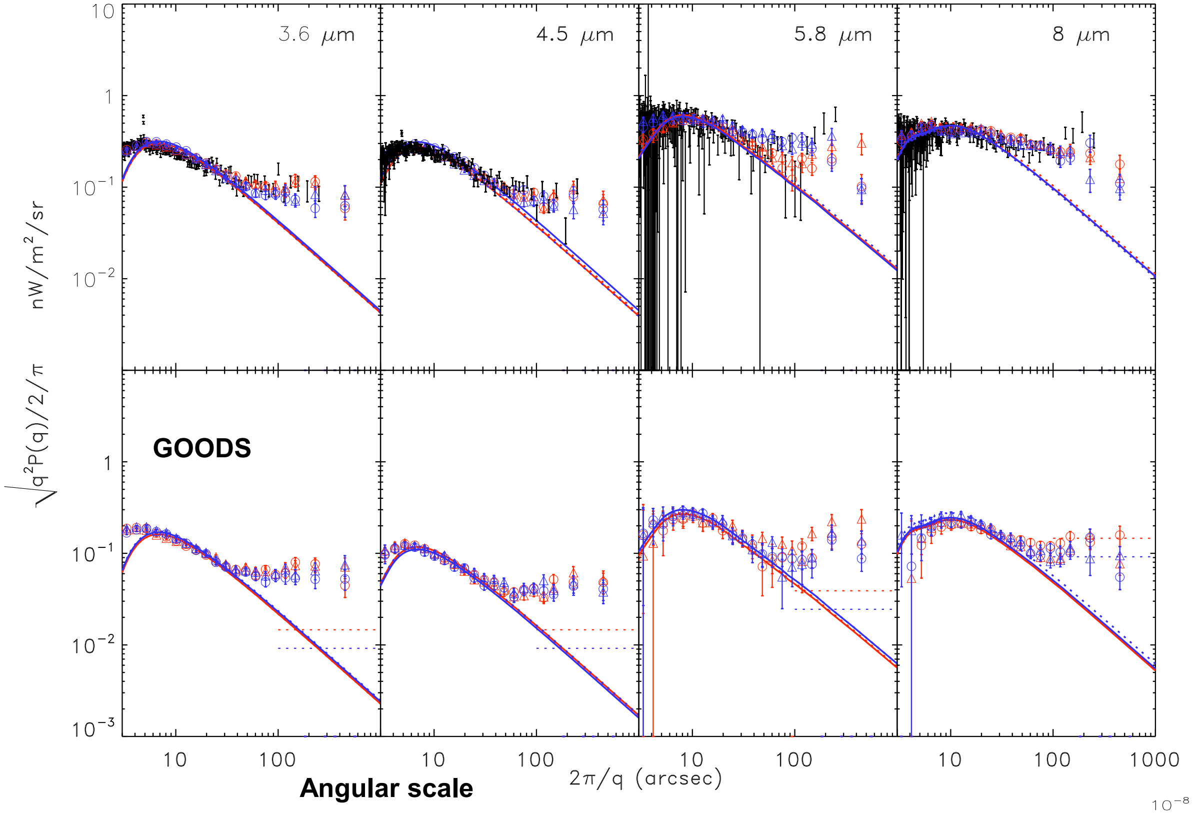


(Median across the array)

From AKMM (2010)

GOODS – results (color symbols)

(black symbols show the QSO1700 field results)

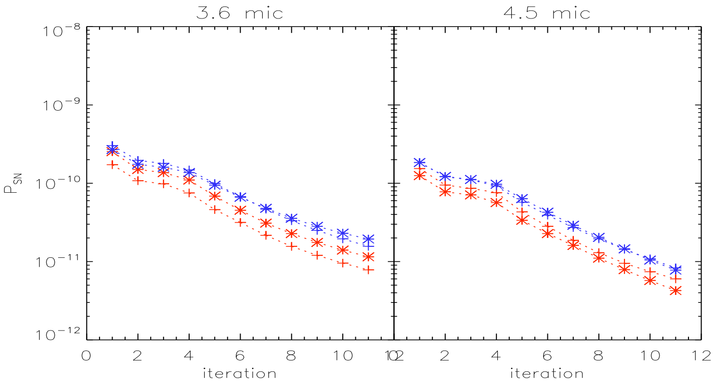


Shot noise reached in QSO1700

P_{SN} (3.6μm) ≈ 6 x 10^{-11} nW^2/m^4/sr

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

P_{SN} (3.6μm) ≈ 2 x 10^{-11} nW^2/m^4/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

(Kashlinsky, Arendt, Mather & Moseley 2007, Ap.J.Letters, 666, L1)

- 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

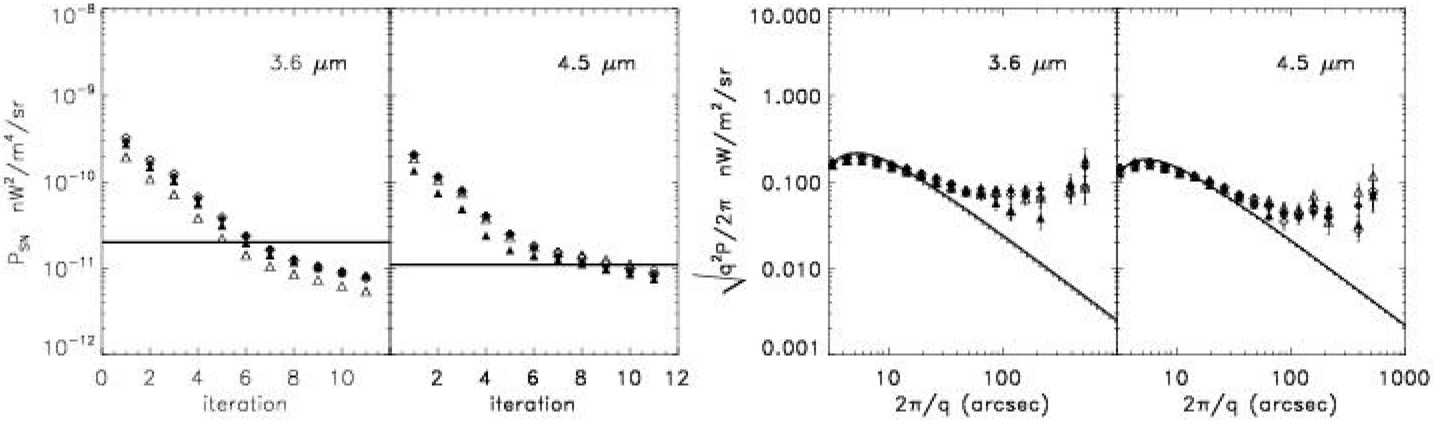
Results

- 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

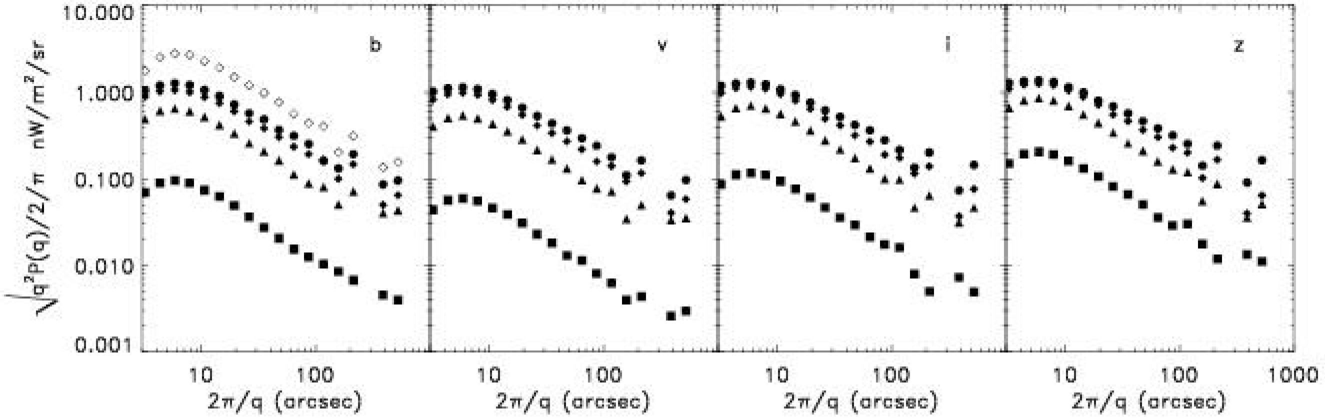
- ACS sources cannot contribute significantly to KAMM IRAC fluctuations

IRAC/GOODS source-subtracted CIB fluctuations.



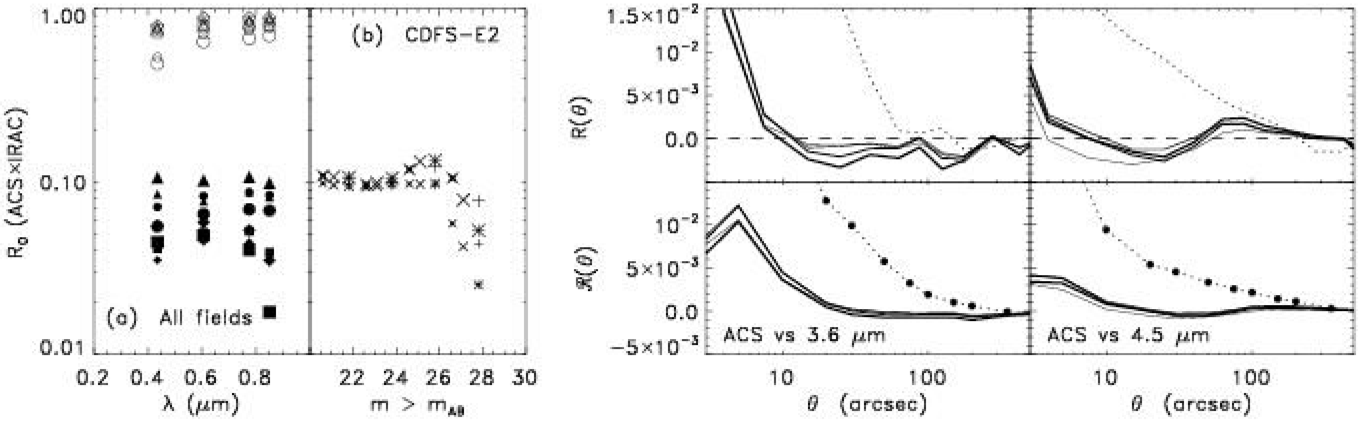
ACS source maps.

- $m_{AB}>22$
- ♦ $m_{AB}>24$
- ▲ $m_{AB}>26$
- ■ $m_{AB}>28$
- ◊ $m_{AB}>24$, no mask



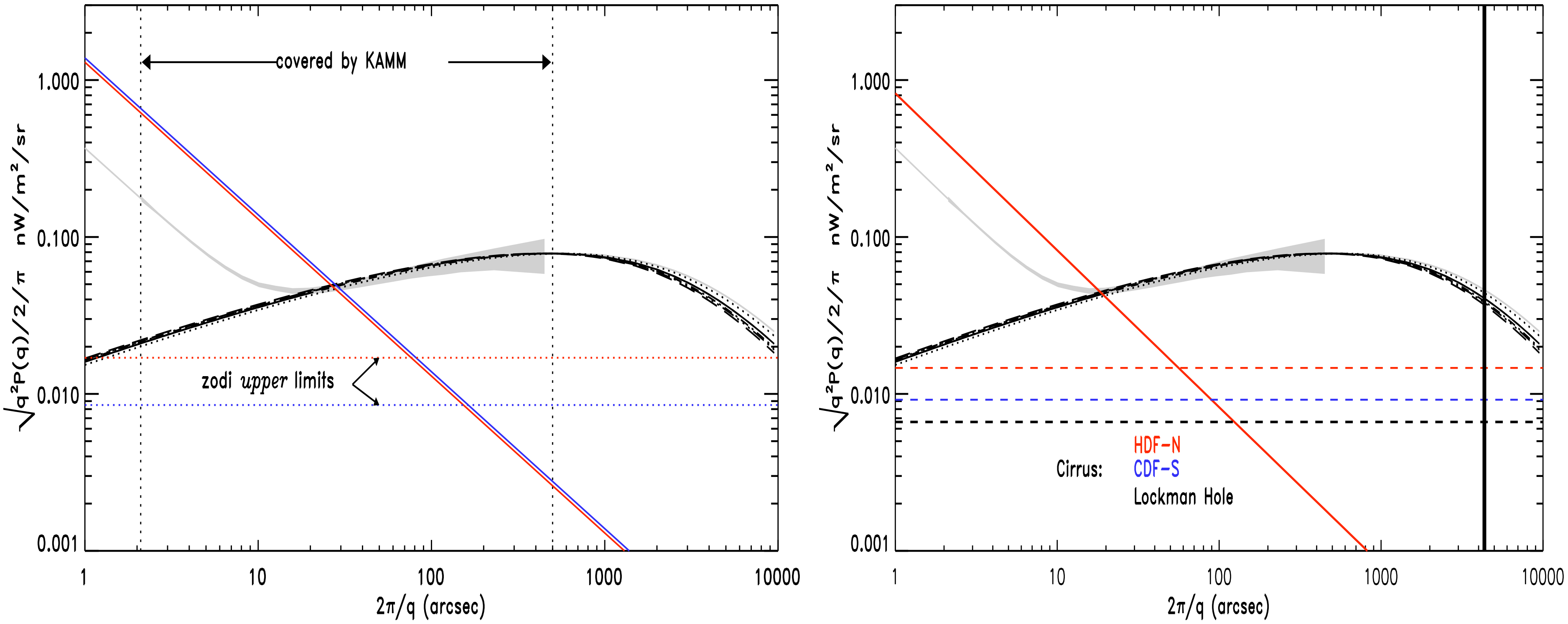
ACS vs KAMM sources (open symbols).
ACS source maps vs source subtracted IRAC data (filled).

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~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