ISO and the Cosmic Infrared Background

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Outline

- Extragalactic Background Light
- MIR Surveys
  - Source Counts
  - Galaxy Population
- FIR Surveys
  - Source Counts
  - Galaxy Population
  - Fluctuation Analysis
- Models
- Potential of ISO data
- Next Step: SIRTF
The Extragalactic Background Light
Extragalactic Background Light

Nature
- Integrated Emission of
  - all galaxies
  - at every redshift
- Isotropic
- Integrate the history of galaxy formation and evolution
- Different from CMB!

Questions
- How and when galaxies form? How do they evolve?
- How do evolve the Luminosity Function (w/ z & λ)?
- What is the nature of the galaxies w/ z?
- Which population contributes at what level to the Extragalactic Background Light?
- What is the global star formation rate (SFR) history?
Extragalactic Background

Star Light

Light reprocessed by Dust

Hauser & Dwek, 2001 ARAA

ISOCAM

ISOPHOT

SCUBA + MAMBO
Why Deep Infrared Surveys?

- **Local Universe**
  - 30% of the total energy output of galaxies emerges in the Mid- to Far- Infrared
  - Optical/UV observations relevant

- **Cosmic Infrared Background**
  - More (or equal) energy output in the IR than in the optical/UV it tells us that the dust plays an important role in the processes of galaxy formation/evolution

- IR observations: a key to understand these processes
ISO Cosmological Surveys

Oliver, 2000
ISO Mid Infrared Surveys
Mid Infrared Surveys

15 μm
- More relevant for cosmological studies
- Favorable K-Correction

7 μm
- More stellar contamination
- Less favorable K-correction

Franceschini et al, 2001
ISOCAM 7 \( \mu m \)

**Lockman Hole**

0.0025\(^\circ\) 2

DISTANT BUT POWERFUL INFRARED GALAXIES

ISO observation (red) and ground-based infrared observation (blue)
Credit: ESA/ISO and ISOCAM (7 microns), University of Hawai'i 2.2-metre telescope
(2 microns) and Y. Taniguchi et al.

**HDF-S**

0.005\(^\circ\) 2

Oliver et al, 2002
ISOCAM 15 \( \mu m \)

**HDF-S**

\[ 0.005^{o2} \]

Oliver et al, 2002

**Lockman Hole**

\[ 0.15^{o2} \]

Fadda et al, in prep
15 μm Source Counts

\[ \frac{dN(S_{15\mu m})}{dS_{15\mu m}} \times S_{15\mu m}^2 \]

Elbaz et al, 99

No Evolution
ELAIS MIR Source Counts

Differential 15 microns

Gruppioni et al, 2002

(see also Oliver et al, 2002)

Serjeant et al, 2000

Differential 7µm counts
15 μm Sources

Elbaz et al, 2002

![Graph showing the distribution of sources at different redshifts and their contribution to the star formation rate.](image)

- 17% ULIGs
- 57% LiGs
- 14% starbursts
- 12% normal

Star Formation Rate (M_☉/yr)
Star Formation Rate

Flores et al, 99

Flores et al, 99
15 $\mu$m Universe

Source Counts
- Strong Evolution below 1 mJy

Sources and Evolution
- $z$ distribution: between 0.5 and 1.2; $z$ median = 0.8
- < 20% AGNs
- 75% LIRG, SFR $\sim$ 100 $M_\odot$/yr
- Comoving light density increased by $70 \pm 35$ from $z=0$ to $z=1$
  - At $z=0$, LIRGs represent only 2% of bolometric luminosity density
  - At $z=1$, LIRGs represent a major contributor

CIB
- $\sim 70\%$ CIB resolved at 15 $\mu$m
- 15 $\mu$m sources contribute to $\sim 70\pm30\%$ CIB at 140 $\mu$m
ISO Far Infrared Surveys
Far Infrared Surveys

- **50-100 μm**
  - Peak of rest-frame emission from obscured SF ~60-80 μm

- **100-200 μm**
  - Advantageous K-correction
  - Cool galaxies
    - Local cool galaxies
    - Redshifted SB

- **FIR**
  - Total Bolometric Luminosity: Unbiased Measurement

![Graph showing 60, 90, and 170 μm emissions with K-correction curves for redshifted SB.](image-url)
SA57 at 60 and 90 $\mu$m

Linden-Vornle et al, 2000
ELAIS 90 µm Source Counts

60 and/or 90 µm Source Counts:
Kawara et al, 1998
Efstathiou et al, 2000
Juvela et al, 2000
Linden-Vornle et al, 2000
Serjeant et al, 2000
Matsuhara et al, 2000
FIRBACK at 170 $\mu$m

Puget et al, 1999
Lagache & Dole, 2001
Dole et al, 2001

FIRBACK-ELAIS N1
FIRBACK-ELAIS N2
FIRBACK South Marano

$4^\circ$2
170 μm Source Counts

~ 5% CIB resolved at 170 μm
Predicted bulk: 2-10 mJy

170 μm Source Counts:
Kawara et al, 1998
Puget et al, 1999
Juvela et al, 2000
Matsuhara et al, 2000
Dole et al, 2001

Dole et al, 2000
Dole et al, 2001

Guiderdoni et al, 98
Model E

Guiderdoni et al, 98
Model A
Lockman Hole at 90 and 170 μm

Kawara et al, 98
Matsuhara et al, 2000
Multi $\lambda$ maps in the FIR

Juvela et al, 2000

1.5°

150μm

90μm

180μm
Cirrus/Source SEDs

Multi-\(\lambda\) approach: useful for component separation

Juvela et al, 2000

Fig. 5. Cirrus spectrum and source spectra in the field EBL22.
Fig. 6. Cirrus spectrum and source spectra in the field EBL2.
Serendipity Sources: Cold, Low L

Stickel et al, 2000
90 μm LF

- Shaded: this work
- Dots: Local 100 μm LF (Rowan-Robinson et al, 87)
- Black Line: Fit
- Red dash: "cirrus" population (RR, 2000)
- Green dash: Starburst (RR, 2000)
- Blue Dash-Dot: Arp220 (RR, 2000)
- Purple: AGN (RR, 2000)

Serjeant et al, 2000

37 sources
170 μm Sources

Redshift

- Most $z < 0.3$
- Some $0.3 < z < 1$
- A Few $z > 1$
  - Kakazu et al, 2002
  - Sajina et al, 2002
  - Chapman et al, 2002

Luminosity

- Local: $L < 10^{11}L_\odot$
- Higher-z: $L > 10^{11}L_\odot$
- A few HyLIGs
  - Serjeant et al, 2000
  - Kakazu et al, 2002
Fluctuations: Why Bother?

Predicted Redshift Distribution of Sources
Creating the Fluctuations at 170 μm

Lagache, Dole, Puget, 2002

Probing Faint Sources
CIB Fluctuations at 170 $\mu$m

Lagache & Puget, 2000
Puget & Lagache, 2001

Extragalactic Component
Detector Noise
Cirrus: Best Fit Model
Cirrus: range from Miville-Deschenes et al

Power spectrum in FN2 $1^\circ^2$
Fluctuations at 90 and 170 µm

Power Spectra

Color of the Fluctuations

Matsuhara et al., 2000
University of Arizona

90 µm: without Sources $S_{90} > 150$ mJy

170 µm: without Sources $S_{170} > 250$ mJy
Fluctuation Analysis at 170 $\mu$m

Constraints of the source counts' faint end at 170 $\mu$m in the Lockman Hole using simulations to fit the observed fluctuations

Matsuhara et al, 2000
Fluctuations of CIB

90 and 170 µm
- Fluctuations Detected w/ High S/N
- Extension of Source Counts to Lower Fluxes
- Color of CIB Fluctuations

170 µm
- Clustering Detected in FIRBACK N1/N2

All Cases
- Foreground Removal limits Larger Scales
- FIR Observations limited by Sky Fluctuations
  - e.g Herbstmeier et al, 98; Kiss et al, 2001
Models
Models

ISO Data strongly constraint models

- Counts at 15, 170 μm
  - Also counts at 7, 60 & 90 μm
- Redshift Distributions at 15 & 170 μm
- Fluctuations of the CIB at 90 & 170 μm

CIB SED

Models

- (1st auth) Chary, Devriendt, Dole, Franceschini, Guiderdoni, Malkan, Pearson, Takeuchi, Totani, Roche, Rowan-Robinson, Tan, Wang, Xu
- Lagache, Dole, Puget 2002 (submitted)
- Franceschini et al, 2001
- Chary & Elbaz, 2001
Evolving LF to Fit ISO Data

Lagache, Dole, Puget, 2002 (sub)

Fit of:
- 15, 60, 90, 170, 850 µm and 1.2 mm Source Counts
- Redshift Distributions at 15 and 170 µm
- CIB SED
- CIB Fluctuations
Franceschini et al, 2001

Source Counts

Franceschini et al, 2001

15 µm

170 µm
Star Formation Rate

See Also
Gispert, Lagache, Puget, 2000
The Potential of ISO Data for Cosmology
Published Data

- Re-Analysis of Published Data
  - Better understanding of ISO detectors
    - e.g. Lari Method, SLICE
  - HDF-S ISOCAM
    - Oliver et al, 97 - Oliver et al, 2002
  - Lockman Hole ISOPHOT
    - Kawara et al, 98
    - Matsuhara et al, 2000
    - Rodighiero et al
Reexplore / Correlate Data

- **Influence of Foregrounds**
  - Herbstmeier et al, 98
  - Kiss et al, 2001

- **Nature of the Sources**
  - LIRGs

- **Extragalactic Background**
  - Multi $\lambda$ approach
    - Matsuhara et al, 2000, Juvela et al, 2000
  - Knowledge of CIB properties in ISO data allows discovery in IRAS data
    - Miville-Deschênes et al, 2002

Miville-Deschênes et al, 2002

IRAS 100 $\mu$m
Unpublished Results

- **Galaxy Clusters**
  - Stellar Populations, SZ, Arclets, intermediate and high-
    z Clusters, search for Early Clusters

- **Quasars**
  - Dust Mass, z>4, radio-quiet, low L radio, photometry

- **ULIRGs, FSS-IRAS**
  - SED, Identification, Power Source

- **Galaxies**
  - Ellipticals, Reds, Young, Faint Blue μJy radio sources
Preparation - Comparison

○ SIRTF
  □ Launch: Next January

○ Herschel
  □ Launch: March 2007

○ Preparation / Comparison - Intercalibration
  □ Like ISO/COBE/IRAS
    □ e.g. Lagache & Dole, 2001
The Next Step: SIRTF
SIRTF
Extragalactic Background

Hauser & Dwek, 2001 ARAA

SIRTF
IRAC
MIPS

CMB
IRAS, ISO, SIRTF

IRAS

1a
IRAS 100 µm

1b
IRAS 60 µm

1c
IRAS 25 µm

ISO

IRAS 100 µm

ISO 170 µm

ISO 90 µm

ISO 25 µm

SIRTF

MIPS 160 µm

MIPS 70 µm

MIPS 24 µm

Dole, Lagache, Puget, 2002 in p47
Panchromatic IR Sky

Simulated sky: 5 squares degrees

MIPS 24 $\mu$m  
MIPS 70 $\mu$m  
MIPS 160 $\mu$m  
+ IRAC: 4 filters

Dole, Lagache, Puget, 2002 in prep
Redshift Distributions @ 24 μm

Dole, Lagache, Puget, 2002 in prep
Resolution of the CIB

Predictions

<table>
<thead>
<tr>
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<th>24 µm</th>
<th>70 µm</th>
<th>160 µm</th>
</tr>
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<tbody>
<tr>
<td>%</td>
<td>62%</td>
<td>47%</td>
<td>19%</td>
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</tbody>
</table>

Lagache, Dole, Puget, 2002 (sub)
Dole, Lagache, Puget, 2002 in prep

15 µm

- 70% w/ ISOCAM at 15 µm (Chary & Elbaz, 2001)

170 µm

- 4-8% w/ ISOPHOT at 170 µm (Dole et al, 2001)
MIPS Tower of Babel

GTO Deep
~ 2 sq deg

GTO Shallow
~ 9 sq deg

GOODS (24 μm)
~ 300 sq arcmin

Lensing clusters
~ 60 sq arcmin

SWIRE
~ 70 sq deg

MIPS Surveys

http://lully.as.arizona.edu

The Tower of Babel by Pieter Breughel the Elder
Hervé Dole, University of Arizona

Courtesy G. Rieke
IRAS 1984 vs ISO 2000

\( \lambda = 100 \mu m \)
\( t = \text{few s/sky pix} \)
\( r = < 4.5 \text{ arcmin} \)

\( \lambda = 170 \mu m \)
\( t = 256 \text{ s/sky pix} \)
\( r = < 92 \text{ arcsec} \)