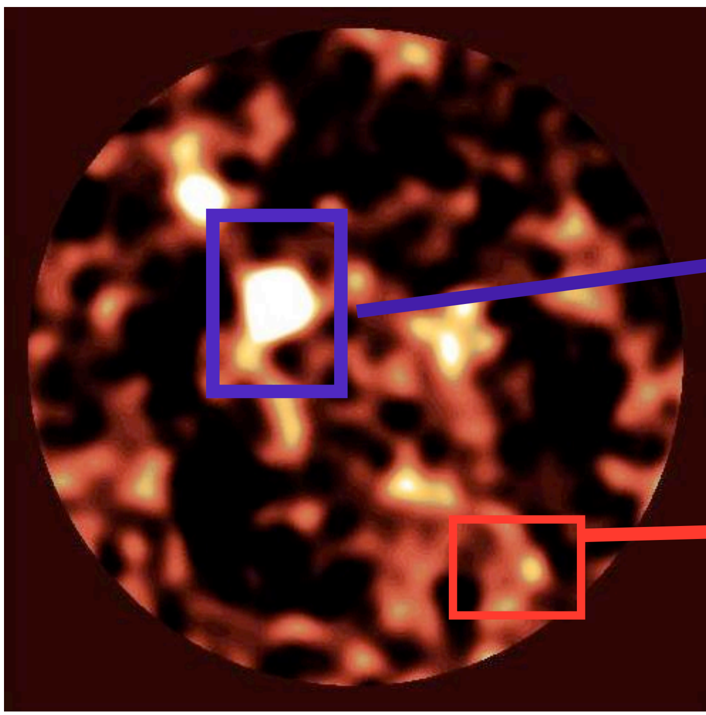
Cosmology with Cosmic Infra-Red Backgrounds

Asantha Cooray

UCIrvine
University of California, Irvine



Resolved sources

Measure angular C_l's
If z's known, measure
P(k) - 3d power spectrum

Unresolved background

Measure angular C_l's
Treat as CMB
(no z-information)

Outline

Near-IR Wavelengths: What is the nature of excess light?

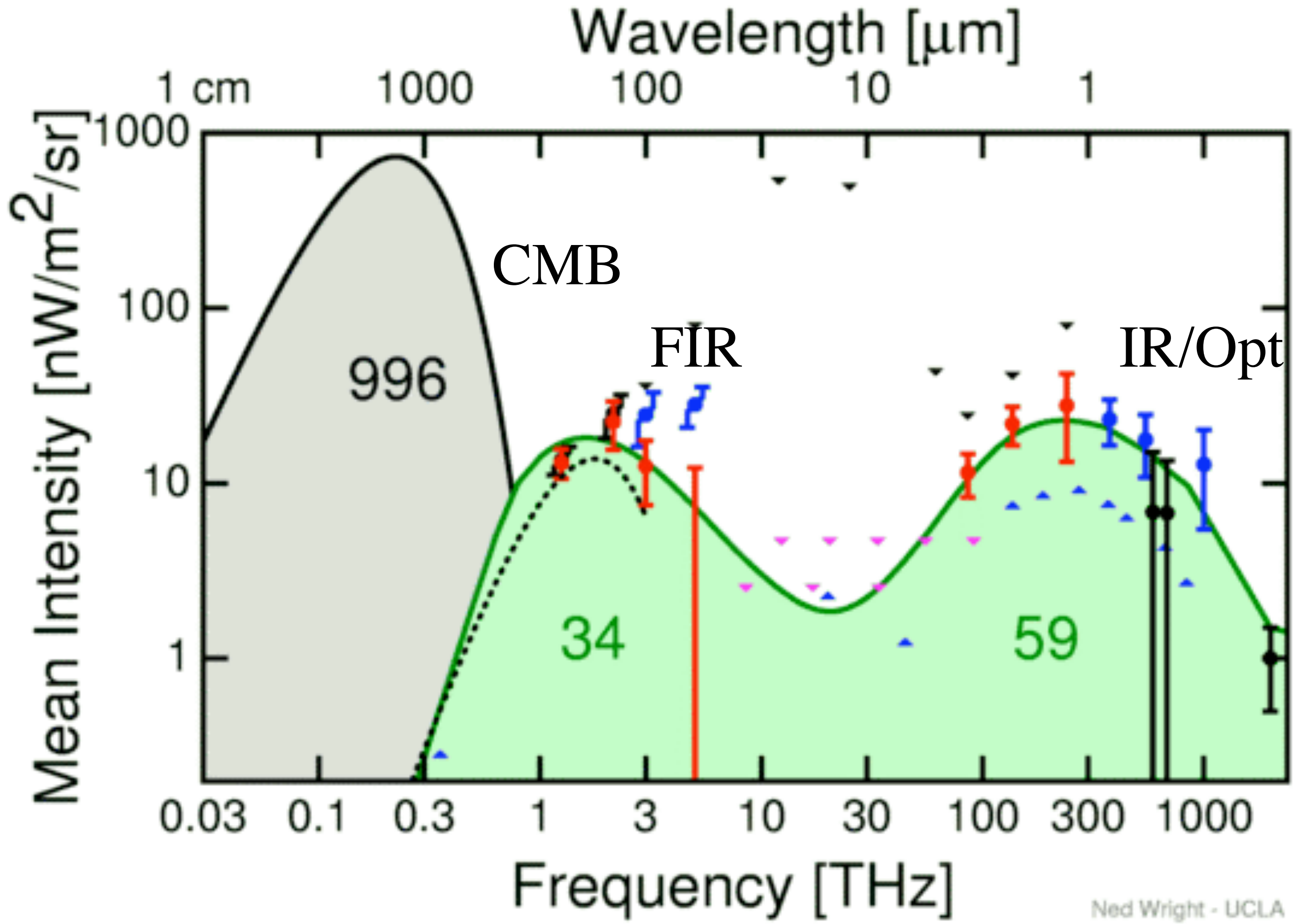
Far-IR Wavelengths: Anisotropies as a way to study ~80% of light unresolved with upcoming surveys.

On going data analysis programs, future prospects

Key coauthors/collaborators on research discussed today:

Alex Amblard, Ian Sullivan (grad. student), Jamie Bock,
Ranga Chary, Brian Keating, Ned Wright,
Mark Dickinson & *GOODS Team*,
Peter Eisenhardt & *IRAC GTO Team*,
Herschel-SPIRE Instrument Science Team
Herschel-ATLAS survey team

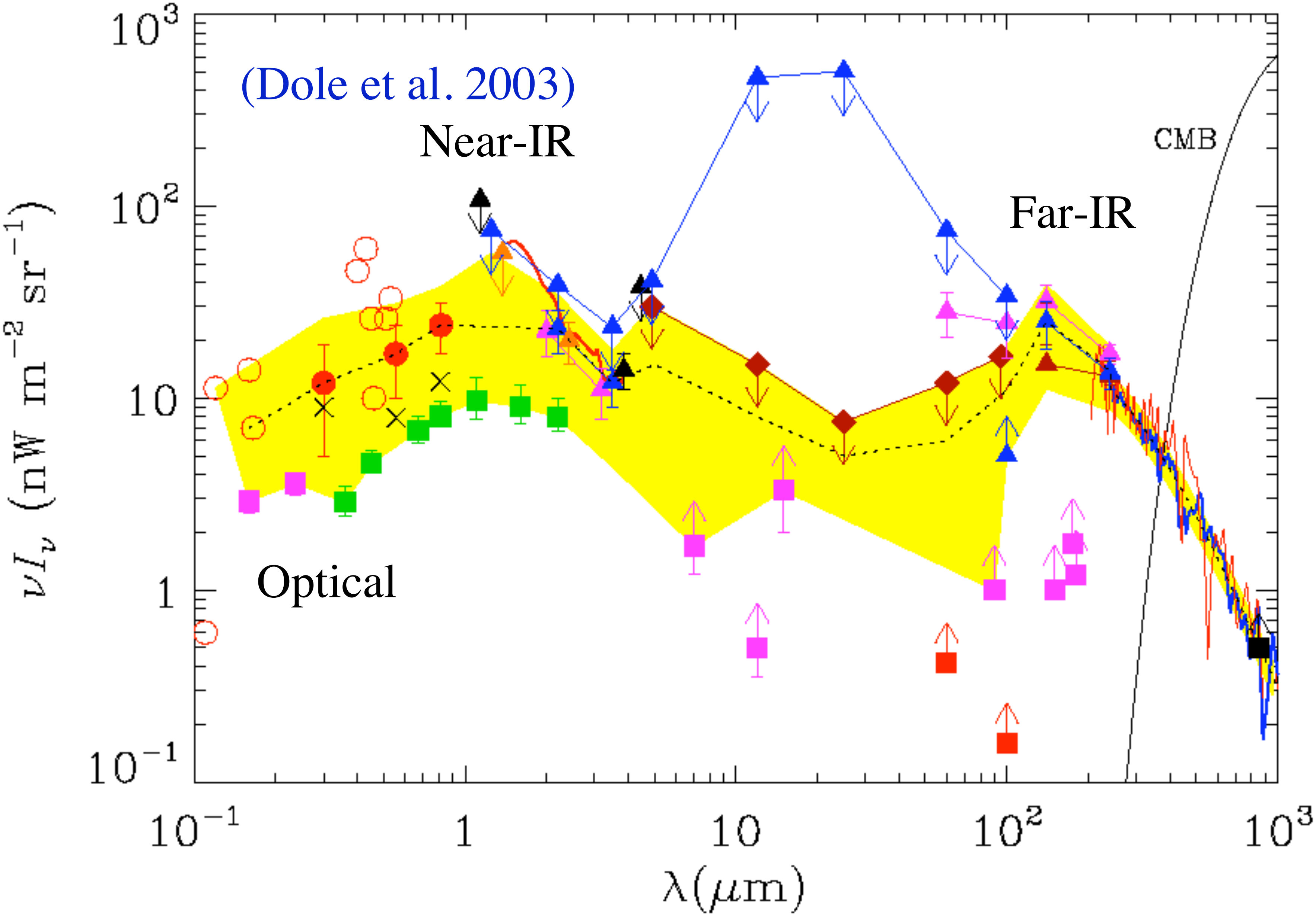
Cosmic Backgrounds



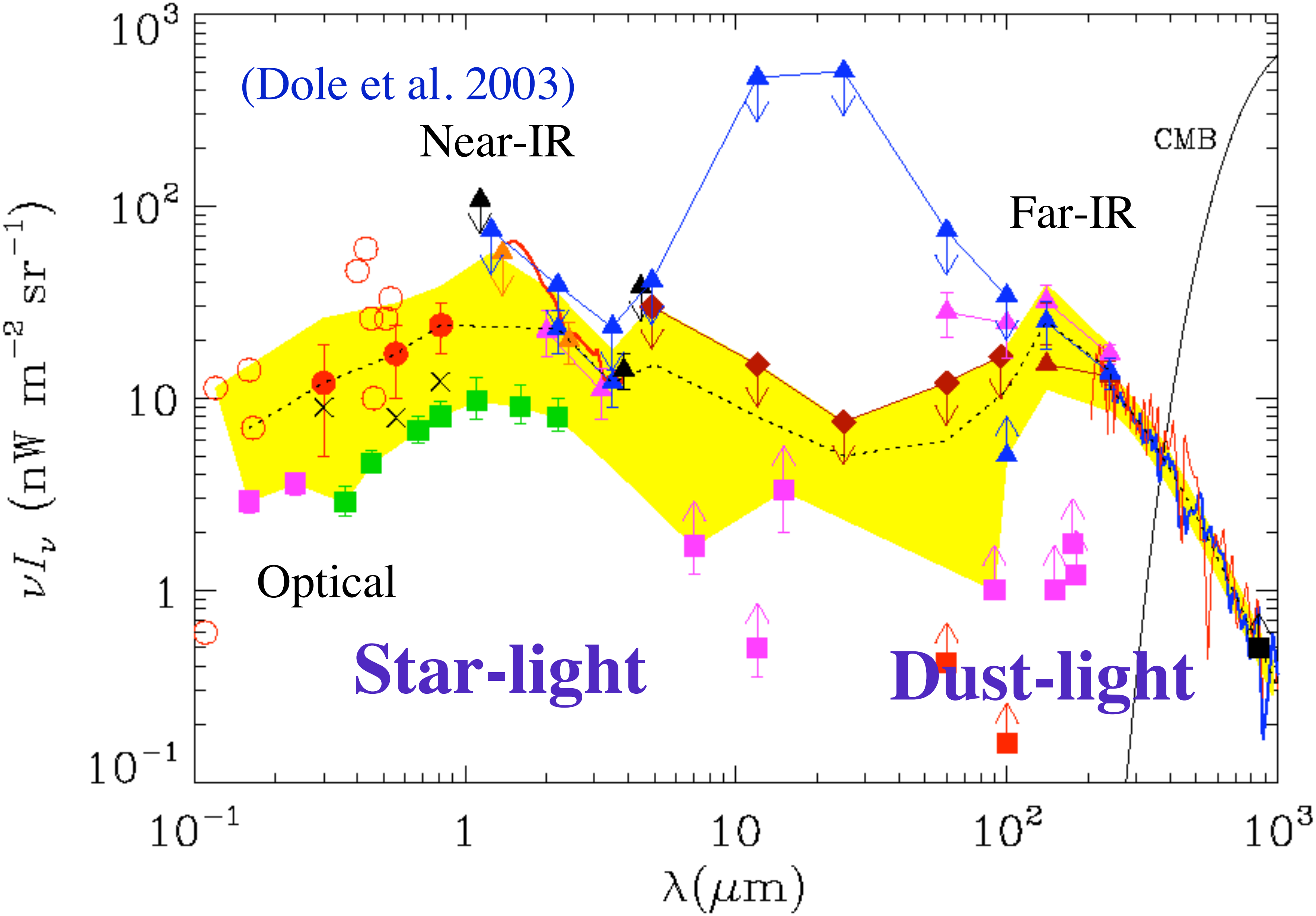
IR/Opt: Direct emission from stars

FIR: Processed emission of Opt/IR light by dust

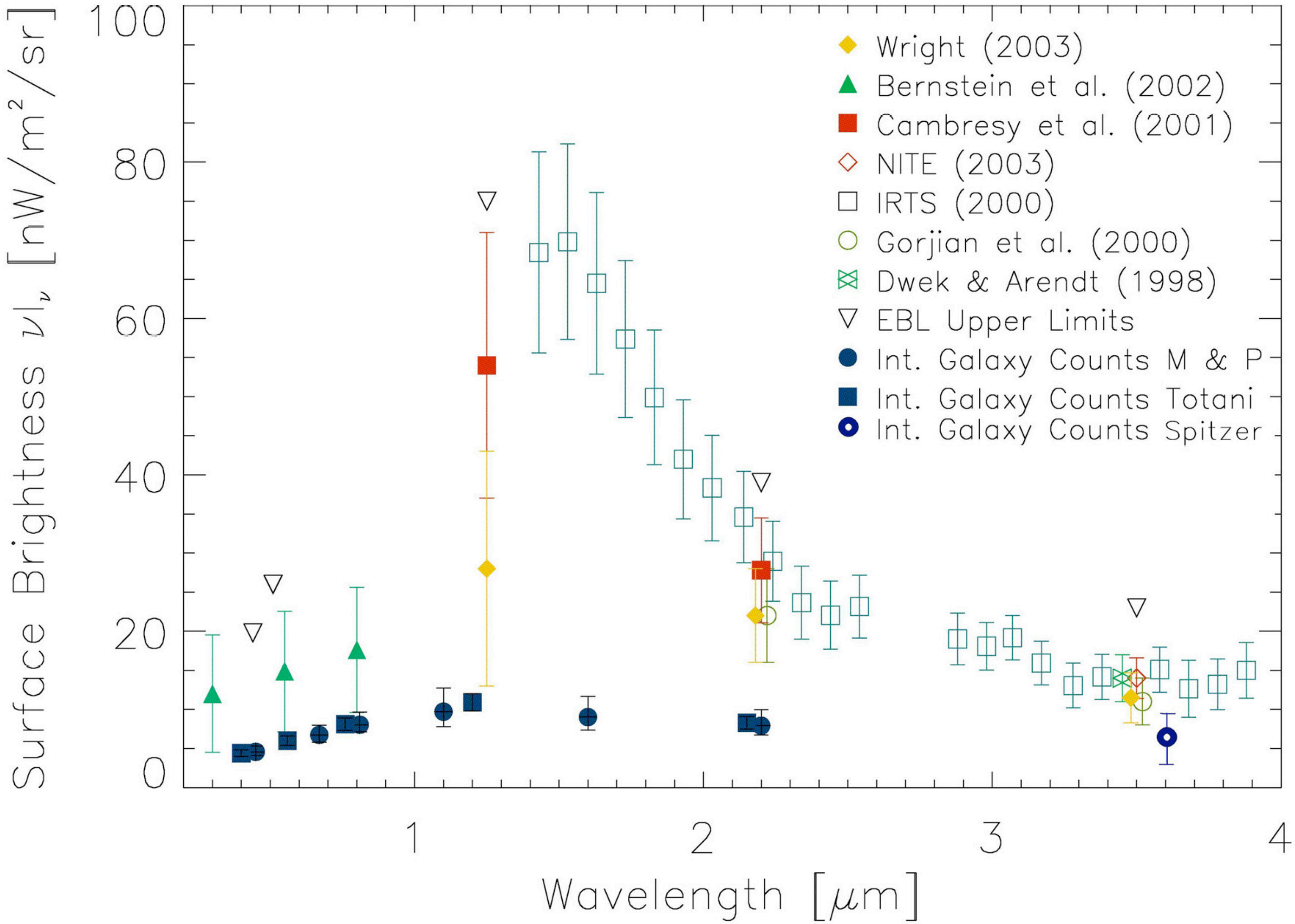
Cosmic Backgrounds



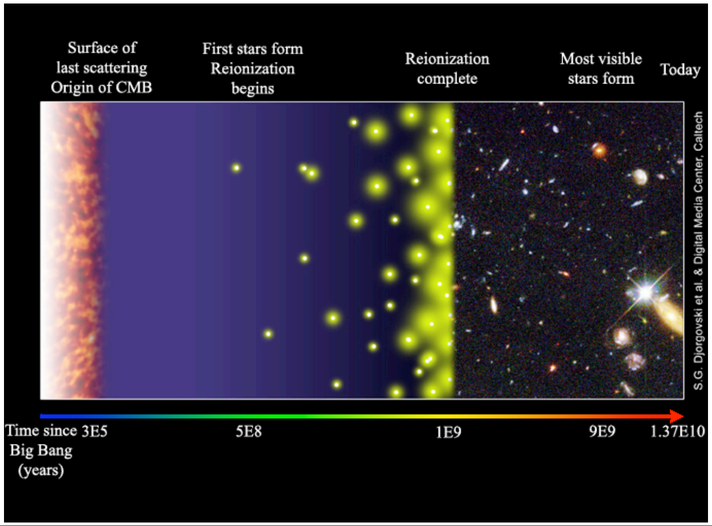
Cosmic Backgrounds

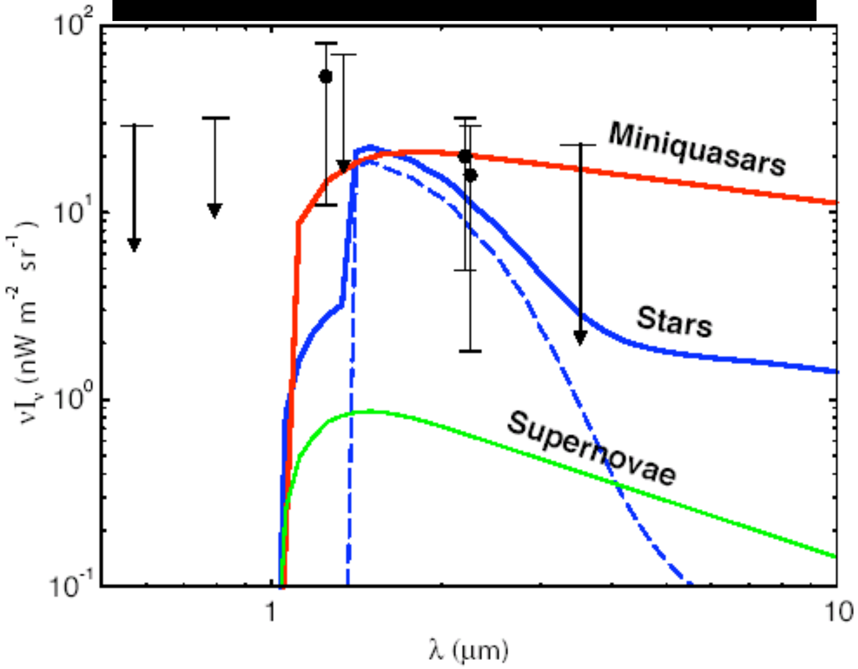


Is the Infrared Background Trying to Tell Us Something?



Could Exotic Sources Produce the IRB Excess?





Santos *et al*. 2002; Salvaterra & Ferrara 2003; Magliocchetti *et al*. 2003; Cooray & Yoshida 2004

Yes! …but there are difficulties

Do not need large IRB to explain WMAP

for τ_e = 0.1 +/- 0.03

-need $n_\gamma = 2\ C_{IGM}\ (\tau_e / 0.10)$ [γ/baryon]

-IRB excess: $n_\gamma = f_{esc}\ (1+z)\ u_J / 0.7\ E_a\ n_b = 4000\ f_{esc}$

Population III Stars

-Must convert 5-10 % of Baryons into Pop III stars
- High star formation fraction in collapsed structures
- Many recombinations to suppress Ly continuum

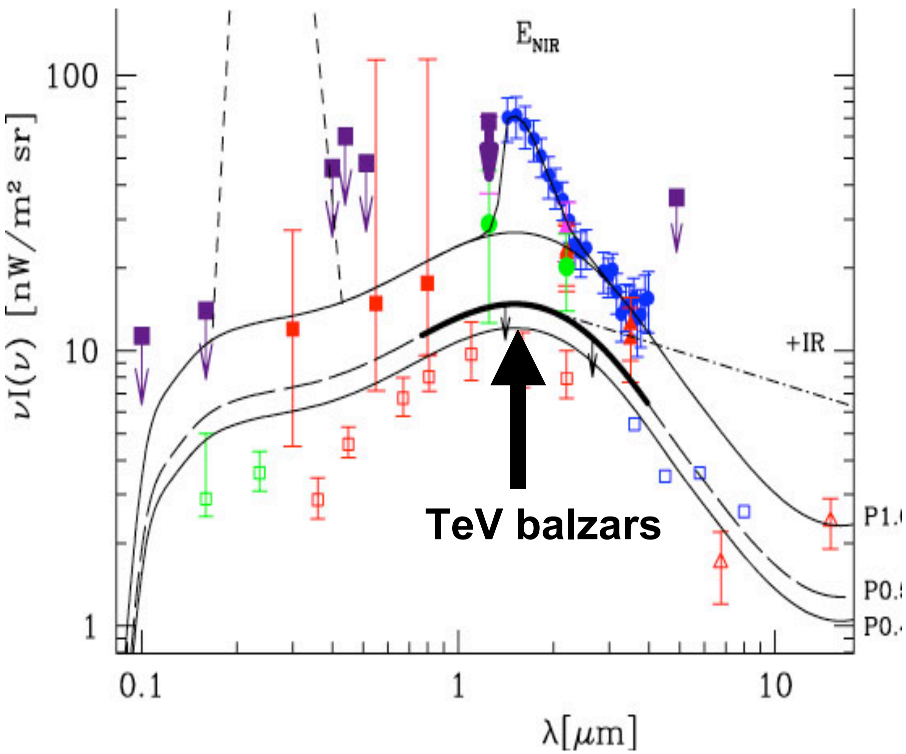
-Hard to avoid metal overproduction
- Stars between 140 – 260 solar masses give PISN, eject half the star's mass in metals

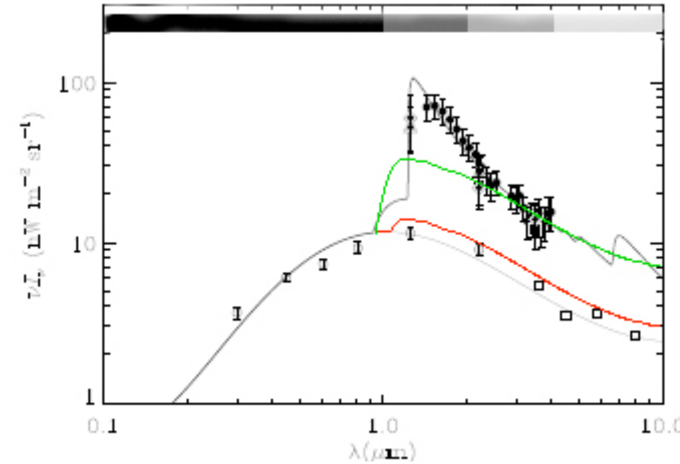
Mini-Quasars

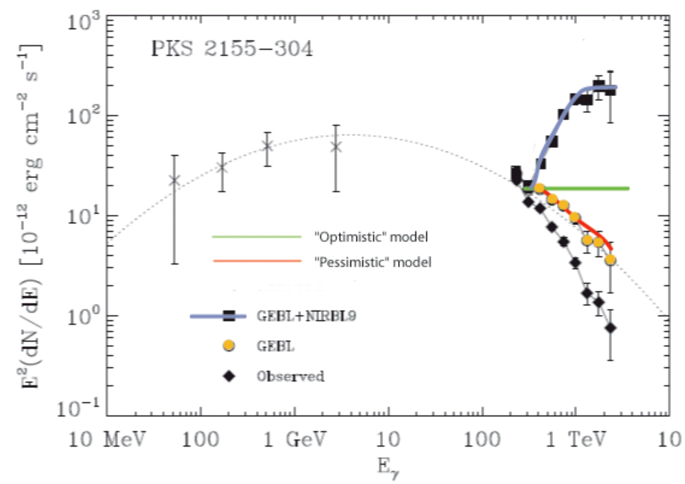
-Need 1/3000th the formation rate of Pop III stars, but
- Overproduce SXB unless very X-ray quiet
- Exceed current estimated black hole densities

Madau & Silk 2004

May be the background is not measured properly?





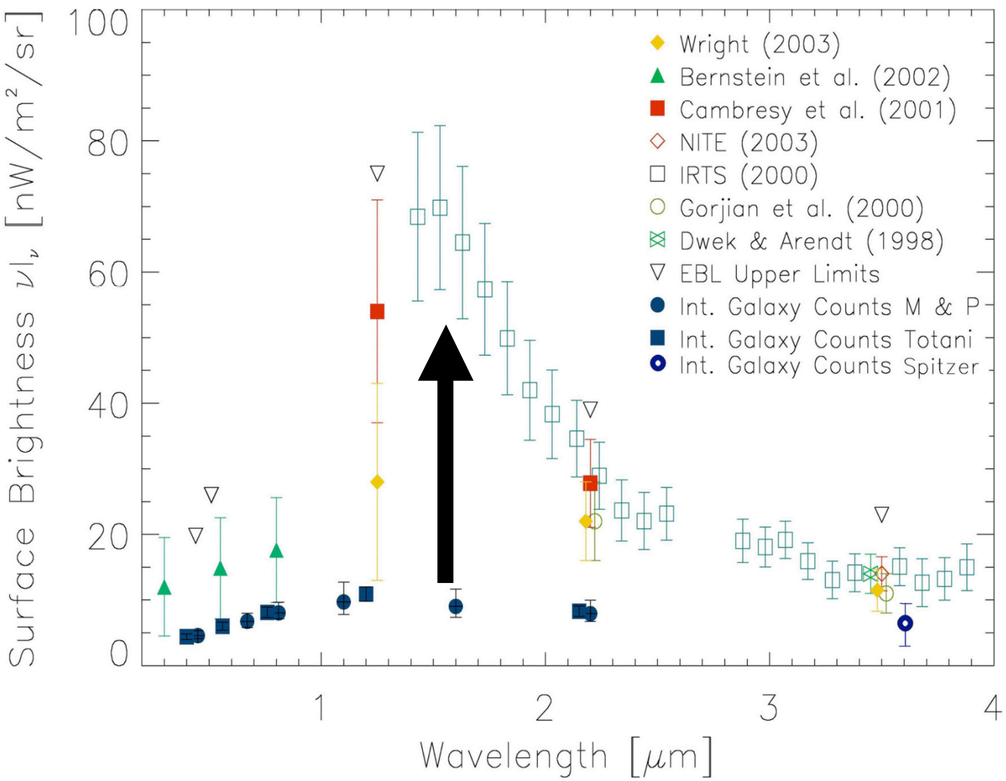


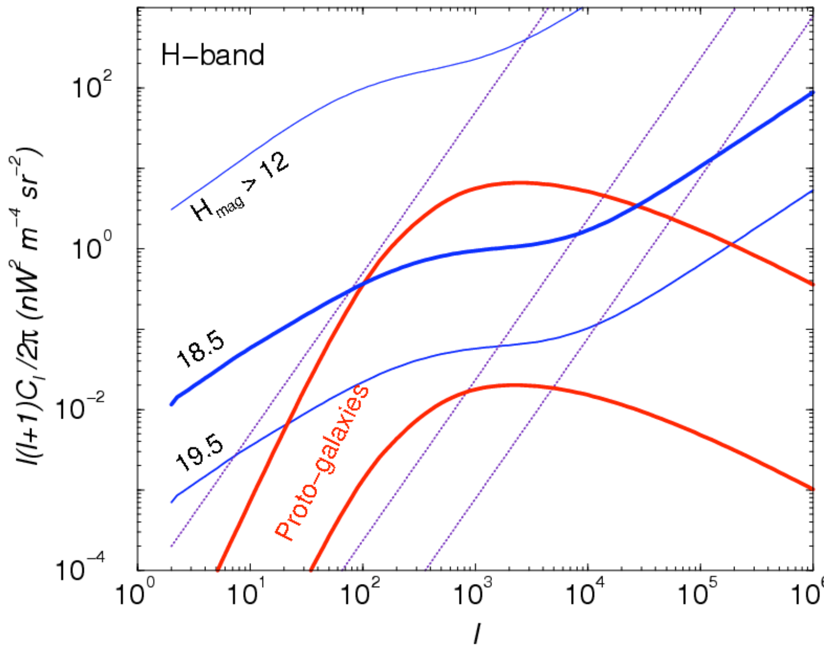
HESS (Aharonian et al, Nature, 2006).

(a model dependent conclusion as the intrinsic spectra not measured)

Conclusive test? look for the z-dependence of absorption

Challenges at IR wavelengths for Absolute Measurements





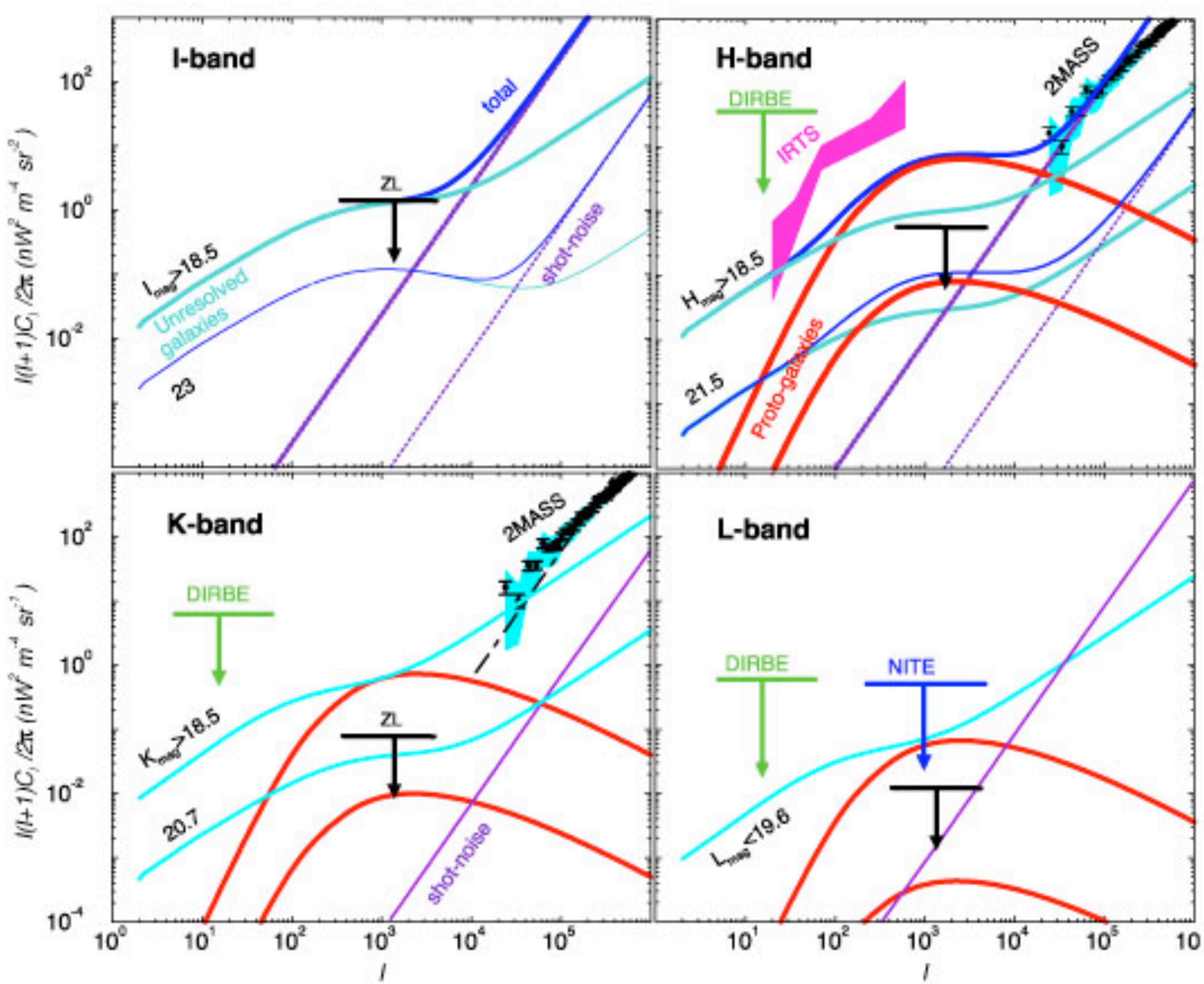
High-z galaxies? Study IRB anisotropies.

Biggest challenge zodiacal light (solar system dust particles scattering sunlight)

To study the origin of IRB light, instead of the absolute total IRB intensity, measure anisotropies or fluctuations of the intensity (just like in CMB)

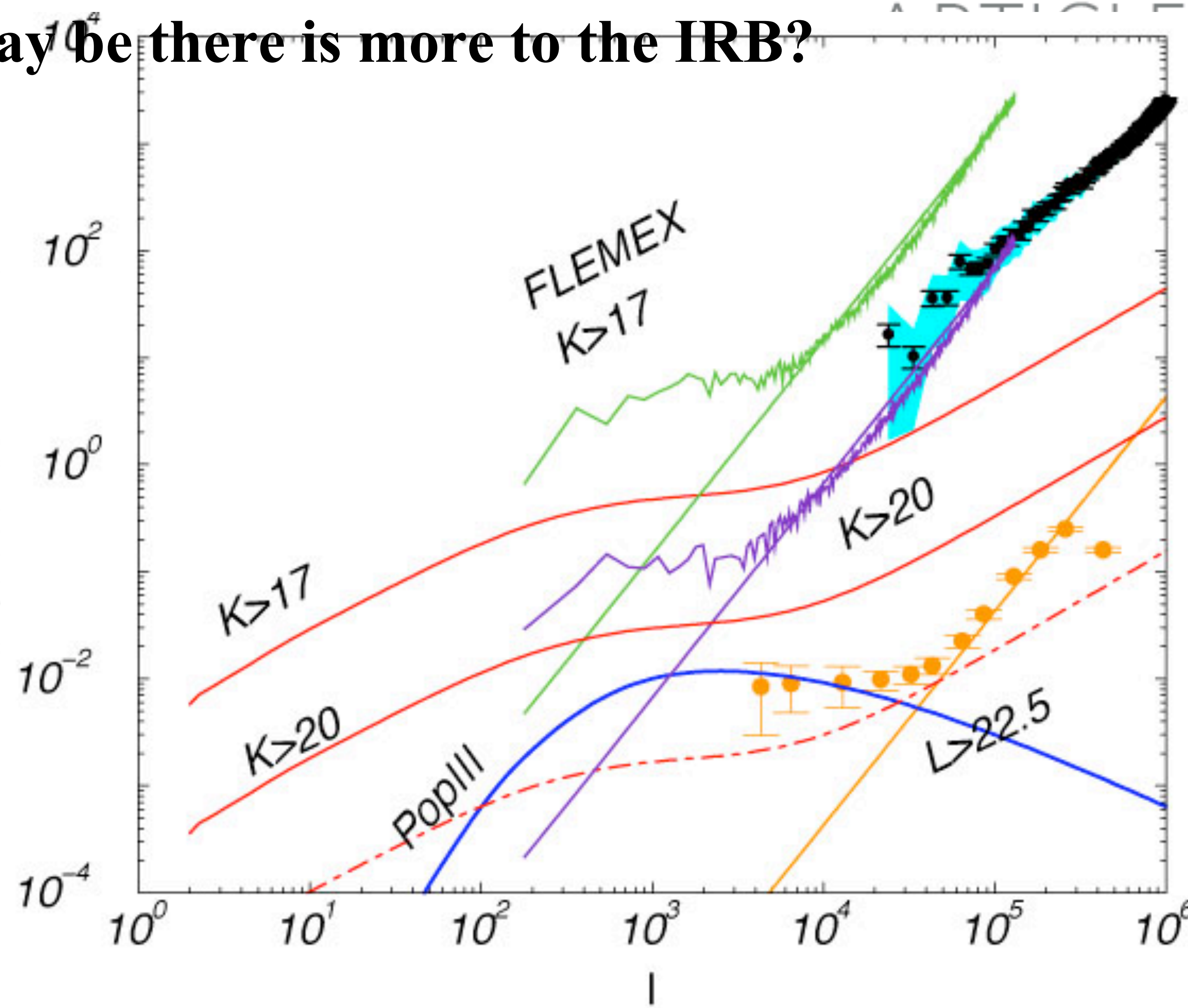
(science case in Cooray, Bock, Keating, Lange & Matsumoto 2004, ApJ)

Background Fluctuation Measurements before 2005

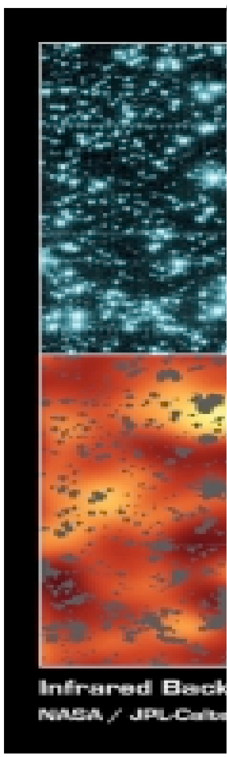


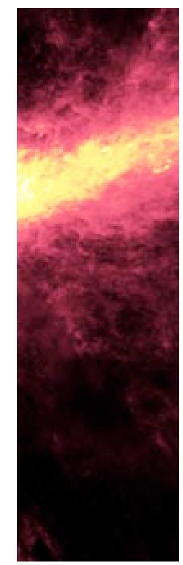
Vol 438|3 November 2005|doi:10.1038/nature04143 nature

Or, may be there is more to the IRB?



Tra
the
A. Kashlin





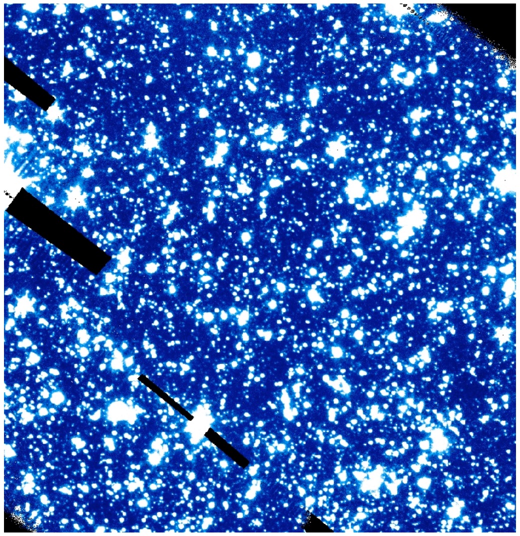
Spitzer IRAC Shallow Survey + GOODS + NUDF

IRAC Spitzer Bootes field

8.5 square degrees

(6200 pointings; ~2 weeks)

Large, but a shallow survey



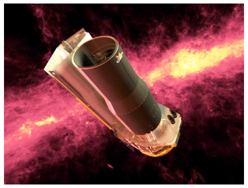
IRAC Spitzer GOODS field

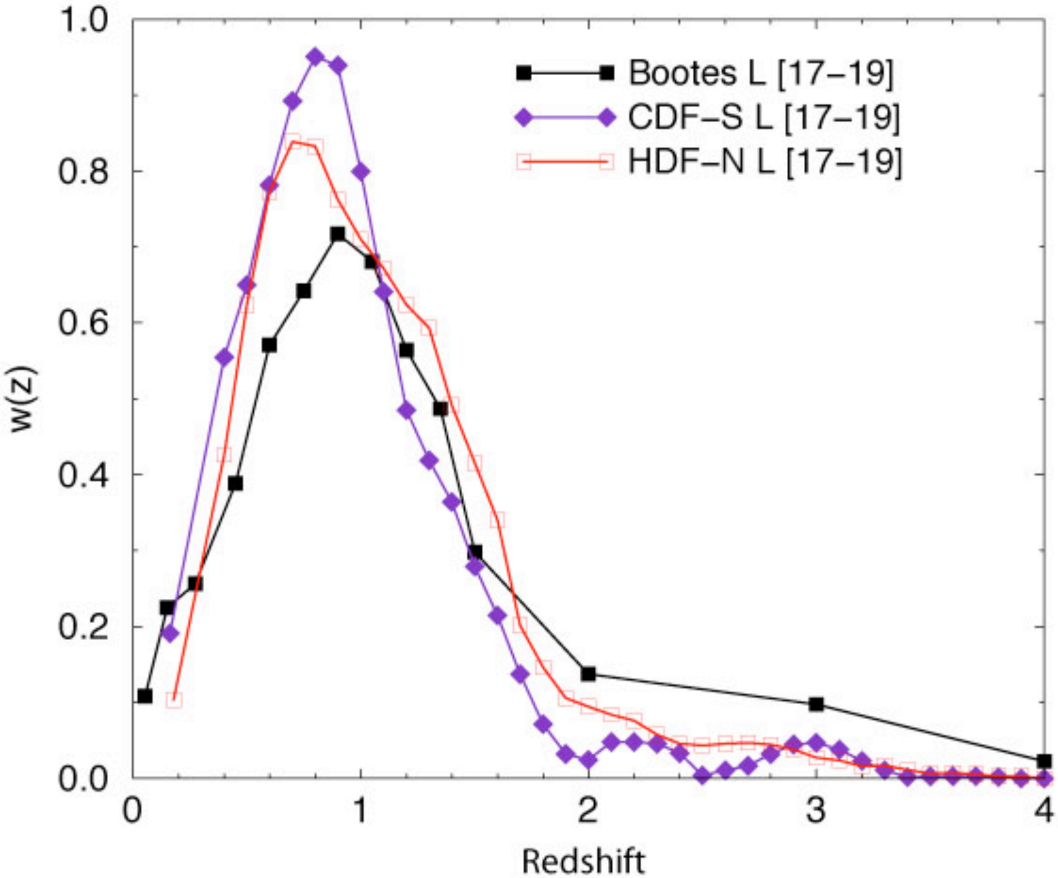
2x0.05 square degrees

HDF-N/CDF-S

Very deep, but a narrow survey

Photo-z's in the Shallow Survey Field





Multi-wavelength coverage over 7 optical to IR bands

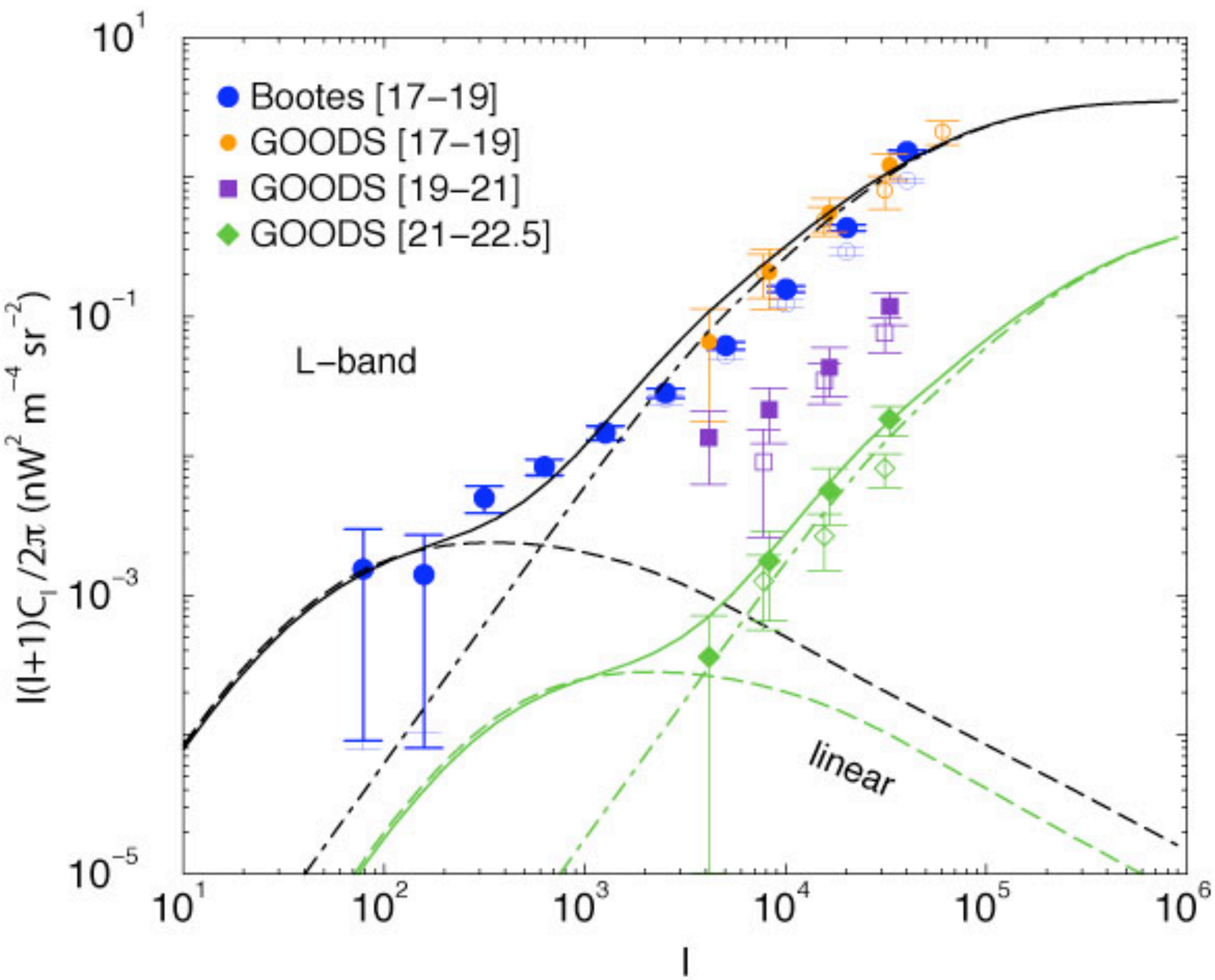
(from ground+Spitzer)

Photo-z's accurate to 0.05 to 0.12 at z of 1 to 2

Sullivan, AC et al. 07

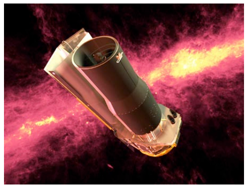
Clustering in Bootes/GOODS: Resolved Sources

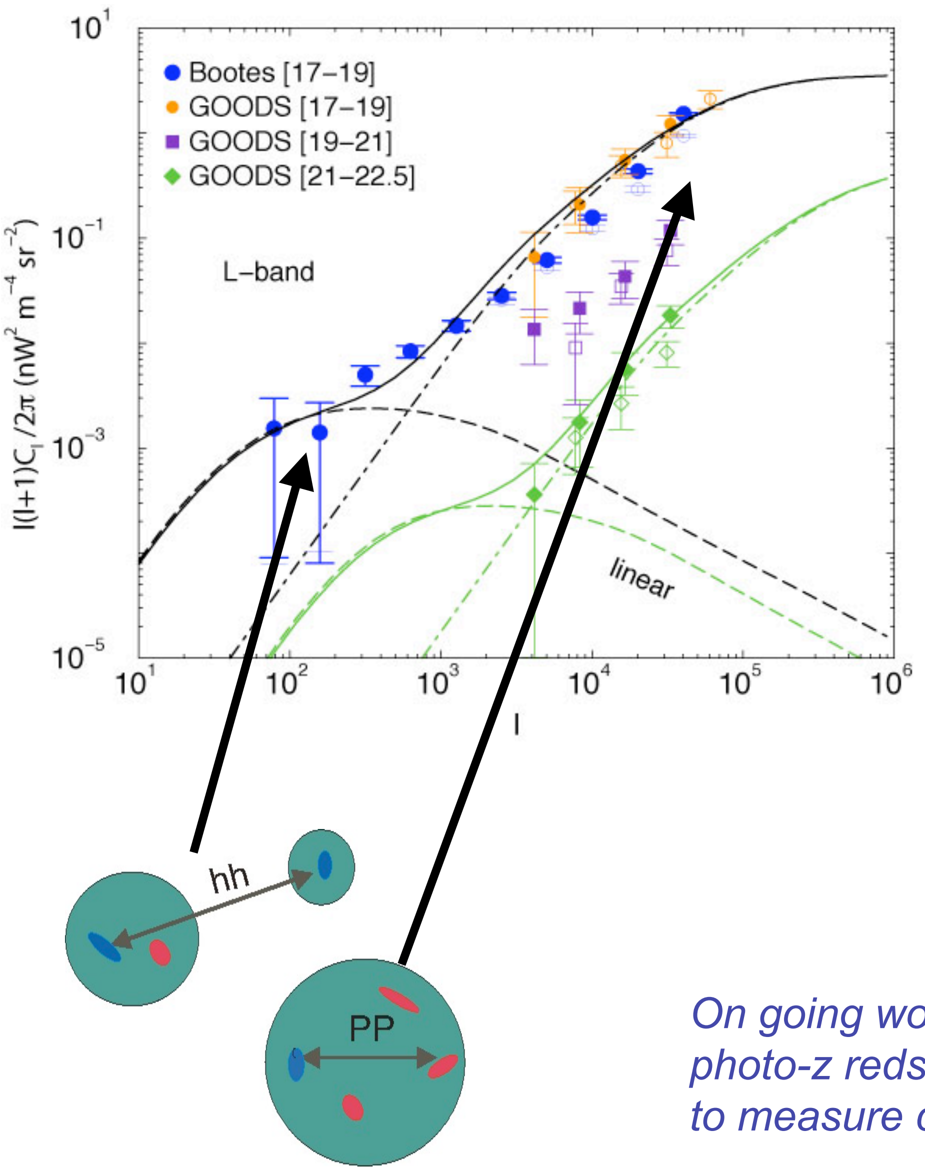
Lines: model predictions from the conditional luminosity Function/halo models

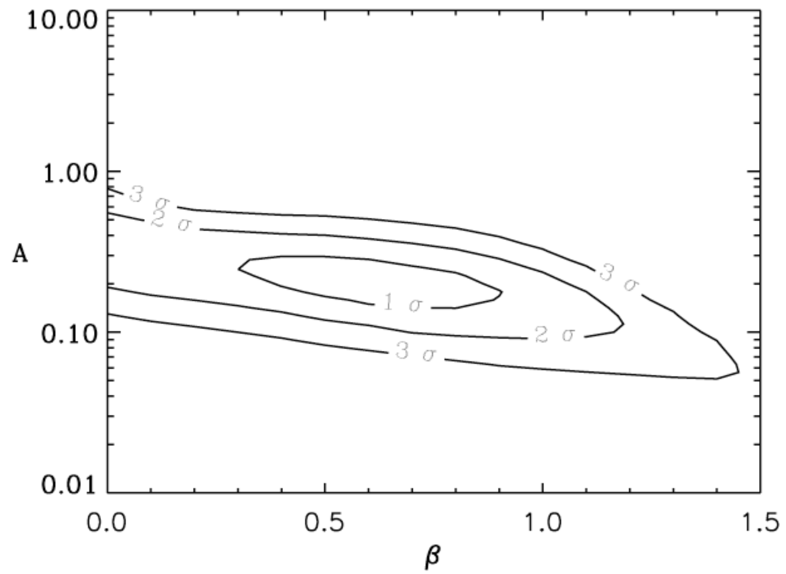


Sullivan, AC et al. 07

Clustering in Bootes





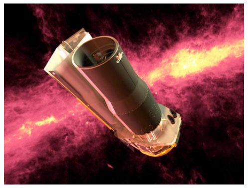


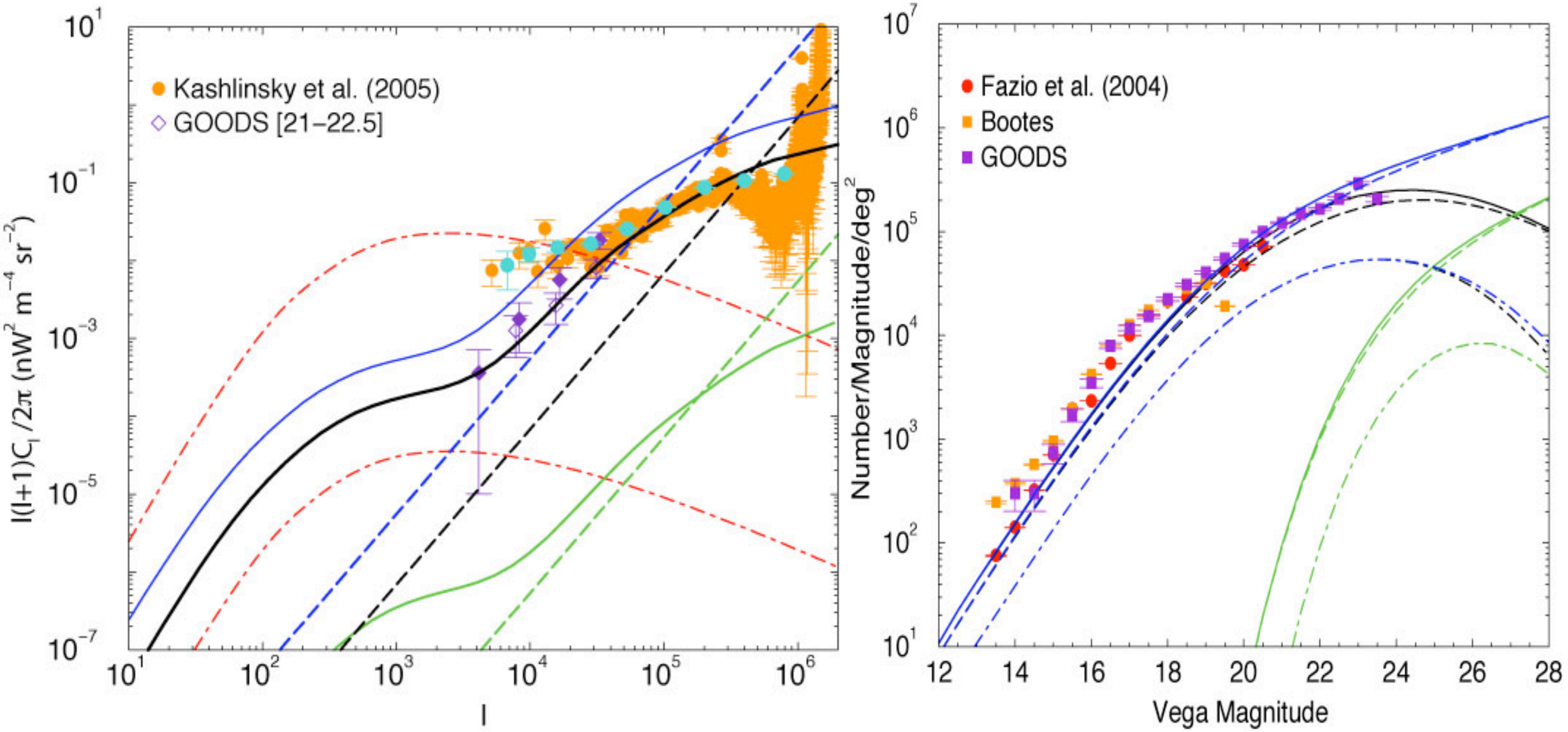
Establish the mass scale for L~17 to 19 IR galaxies at z of 1

~ 5×10^{11} M_{sun}

On going work: to combine IR galaxy bias as a function of photo-z redshifts from 0.5 to 2 + WMAP + z~0 SDSS/2DF to measure cosmology (Smith et al. in prep)

Number counts of IR galaxies

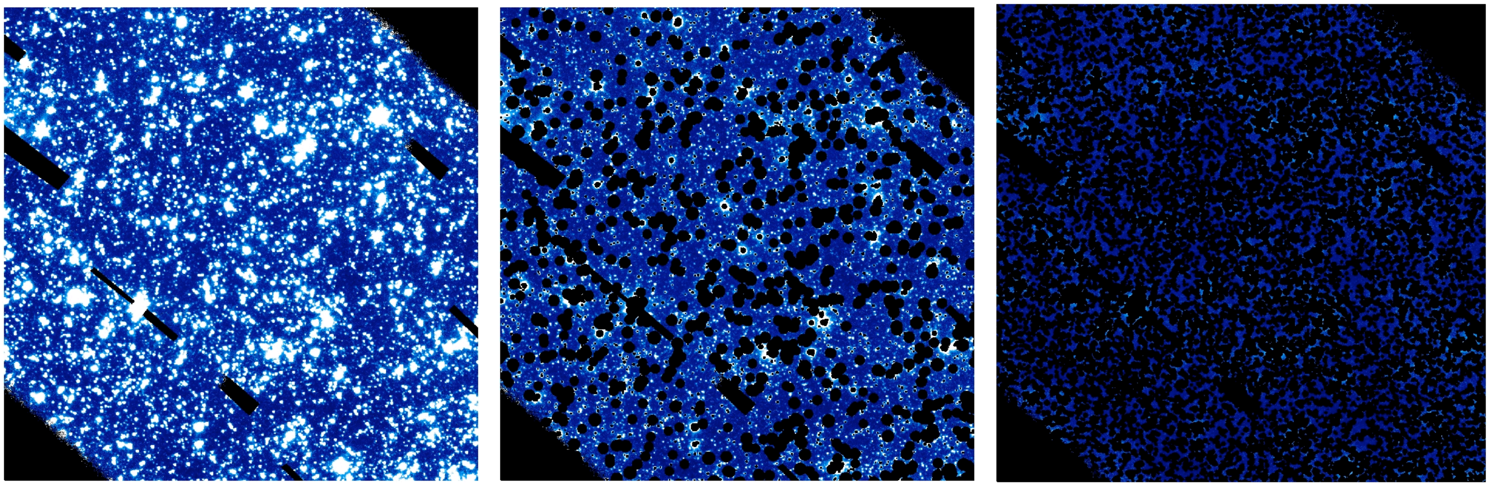




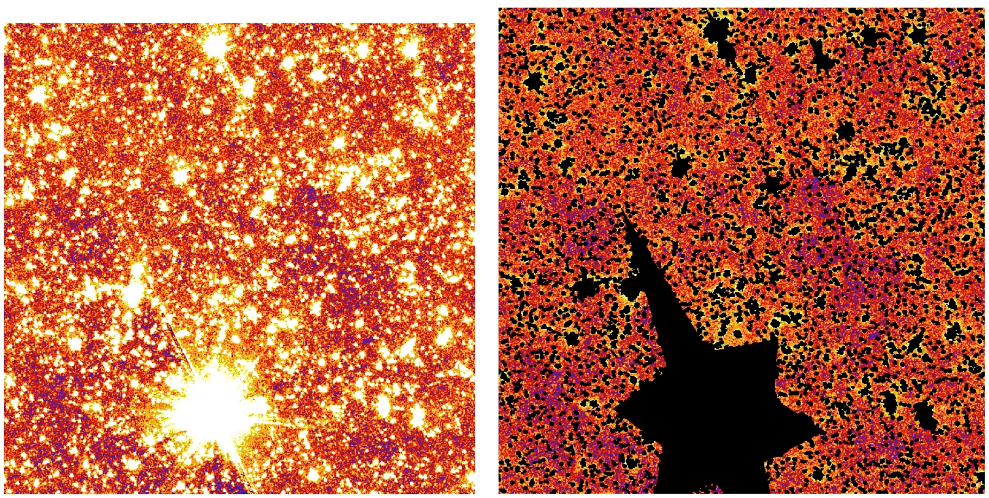
Excess clustering different from z < 1 resolved source clustering

Sullivan, AC et al. 07

Unresolved Clustering in Spitzer and deep IR fields



GOODS CDF-S



COSMOS

What do we do?

Measure statistics of “empty” pixels.

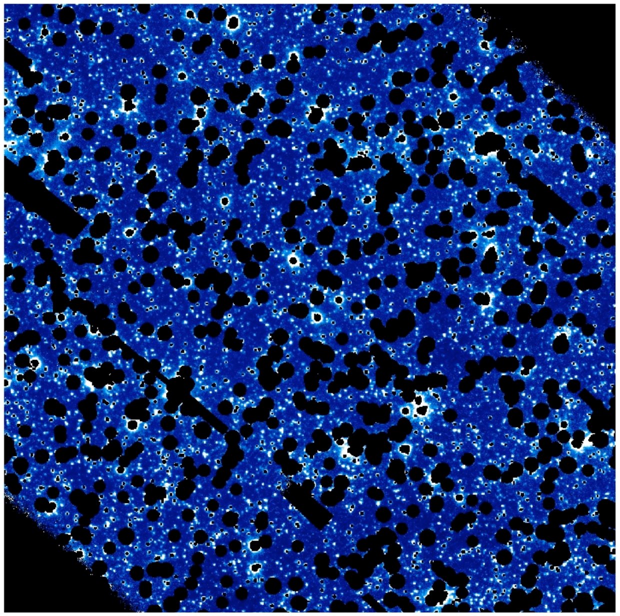
If unresolved faint galaxies are hidden in noise, then there is a clustering excess to noise (due to clustering of those sources)

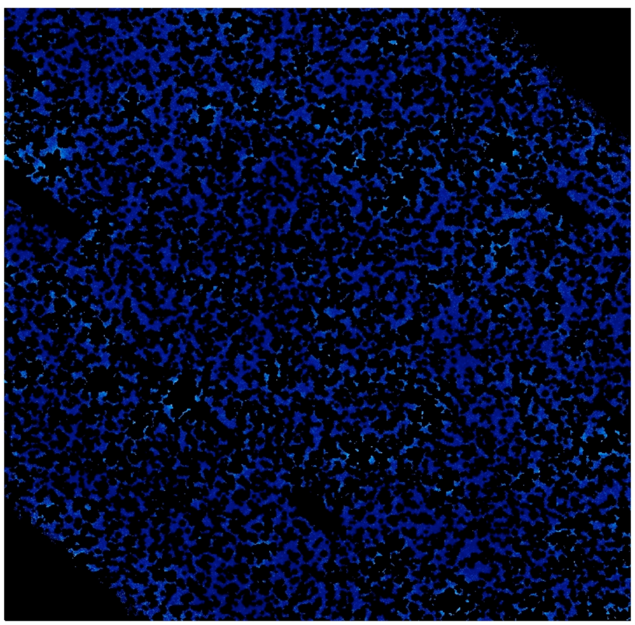
Challenges: > 10 million of pixels (higher complexity than analyzing WMAP data.)

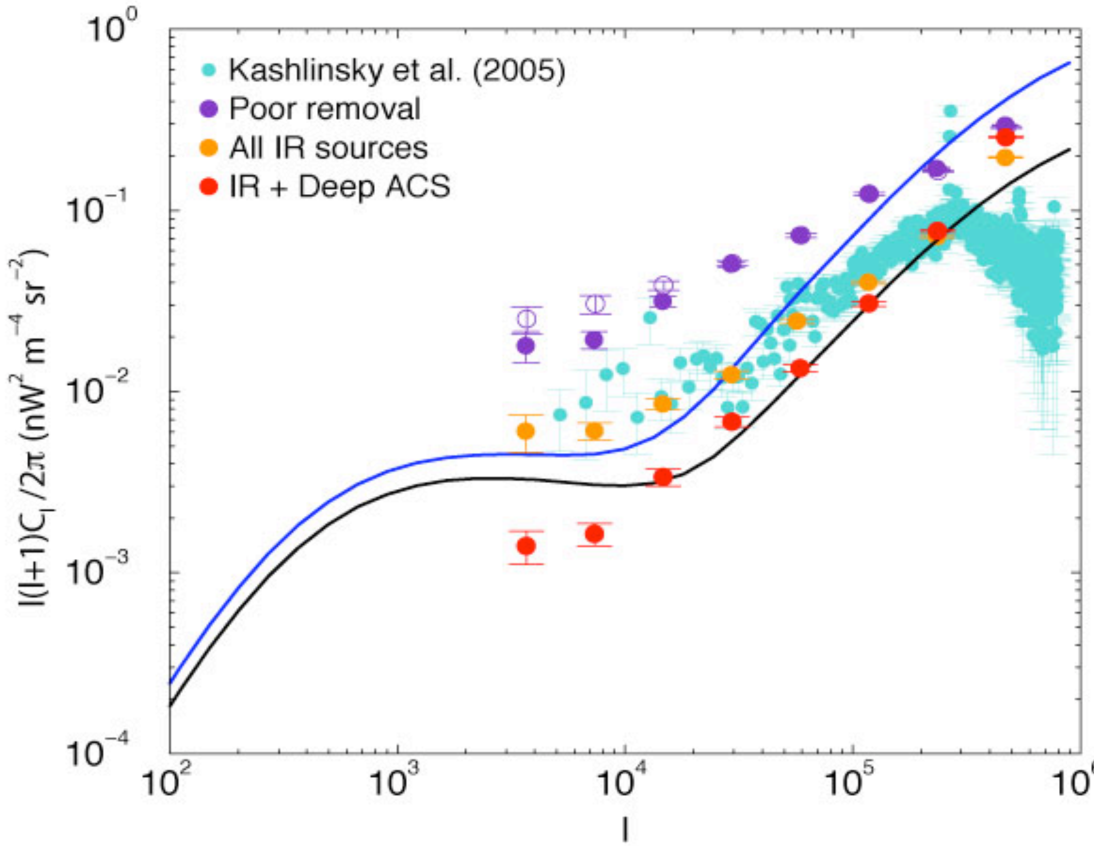
We also mask > 50% of pixels (GOODS we masked 70% of pixels).

Techniques to handle mask - borrowed from CMB analyses.

First stars?: Unresolved Clustering in GOODS







Fluctuations level consistent with Kashlinsky et al. after masking IR-based detections.

But, we masked pixels of faint ACS sources with no IR counterparts. This removed at least half of clustering excess at arcminute scales after removing IRAC sources.

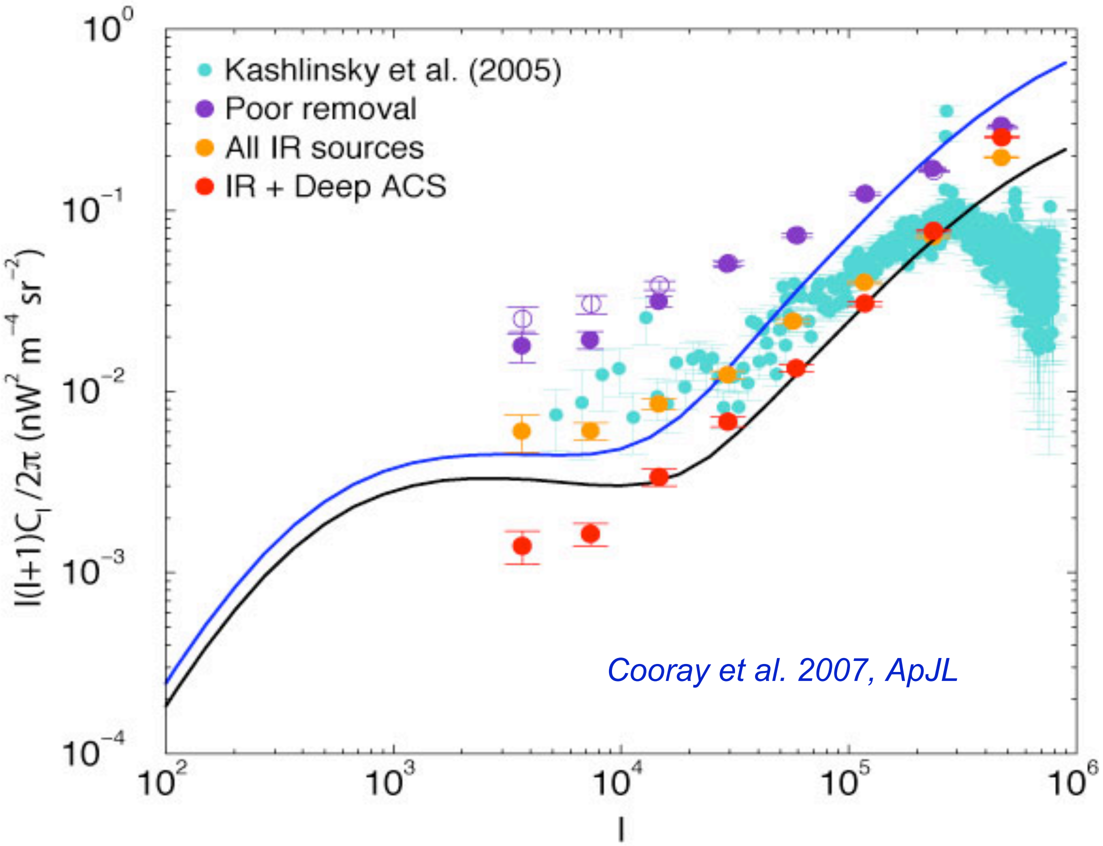
Cooray et al. 2007, ApJL

First stars?: Unresolved Clustering in GOODS

What we find:

50% of fluctuations in deep IR images are from faint unresolved galaxies at z around 1

We limit the L-band total IR intensity to be below 6.5 nW m^{-2} sr^{-1} (~6 nW m^{-2} sr^{-1} already resolved)



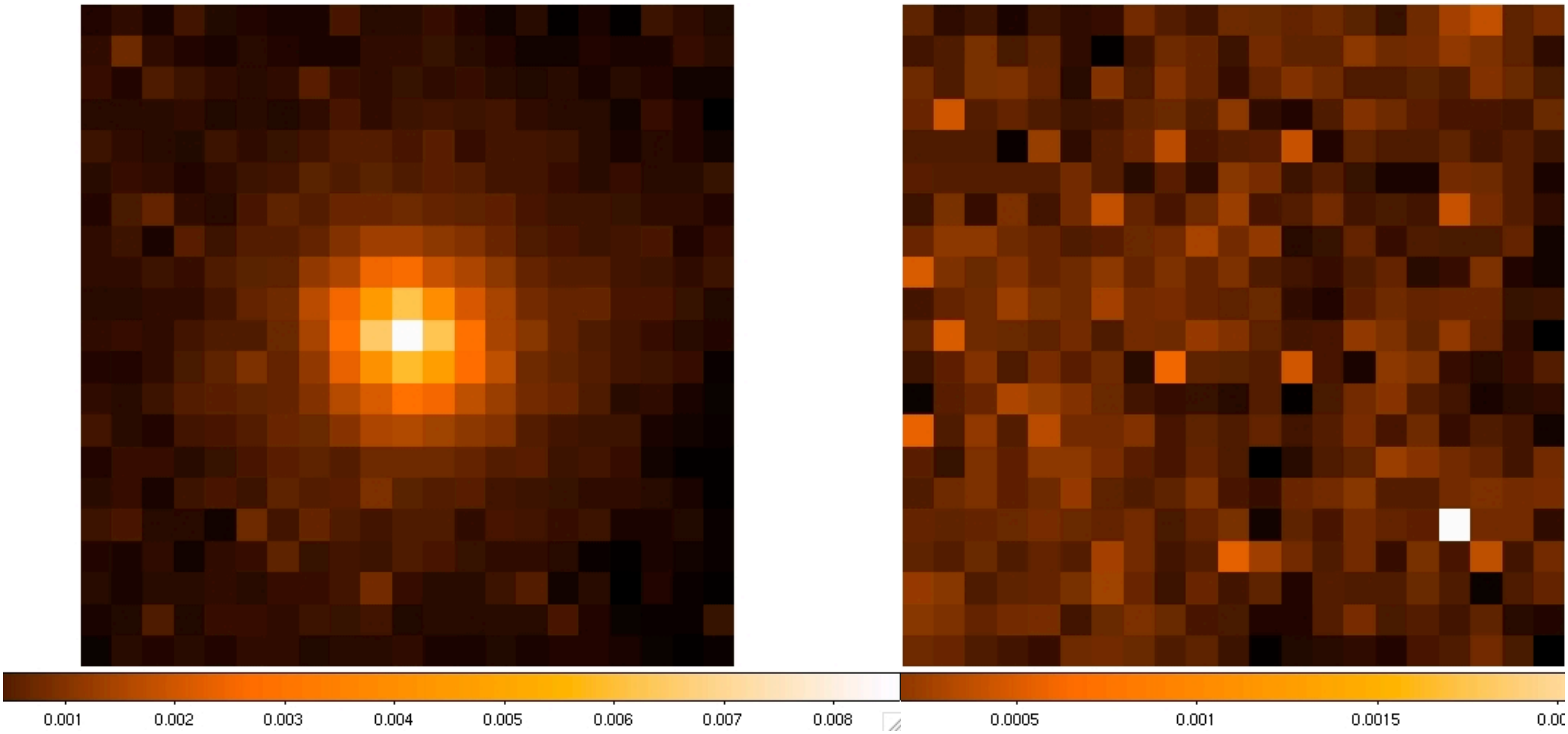
Two interpretations:

1. ***Kashlinsky et al.:*** Fluctuations are z>8 galaxies, intensity > 1 nW m^{-2} sr^{-1} but each source very faint (~10nJy), many per Spitzer IRAC resolution element. (>35% of background still unresolved; lots of new sources to be resolved by JWST)

2. ***Cooray et al:*** Fluctuations are mostly z~2-3 dwarf galaxies, intensity < 0.5 nW m^{-2} sr^{--1} Sources are just below detection in deepest Spitzer images (each ~100-200 nJy). (background light almost all resolved, no large density of hidden sources)

How bright are the faint optical sources at IR wavelengths?

Stacking analysis resolves 50% of flux attributed to low-z sources (< 0.5 nW m^{-2} sr^{-1})



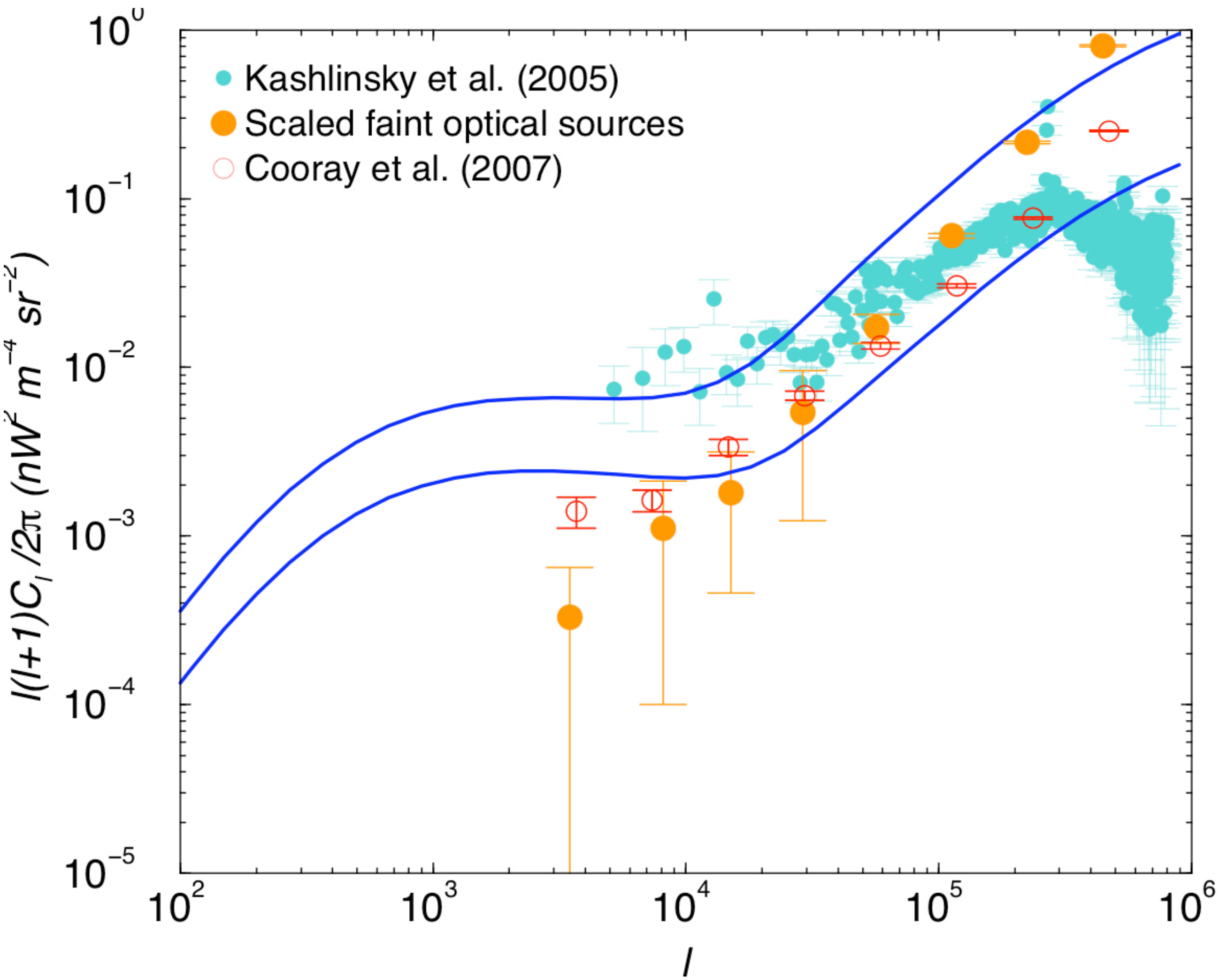
Stack IRAC locations of ~6000 faint optical ACS sources (30 sigma detection)
Average Source flux ~ 200 nJy

Stack random IRAC locations of an equal number
(no detection)

Chary, Cooray, Sullivan 2008

Predicted clustering from stacking analysis

Assign fluxes to faint optical source locations in the Spitzer IRAC image (based on average and extrapolated counts)



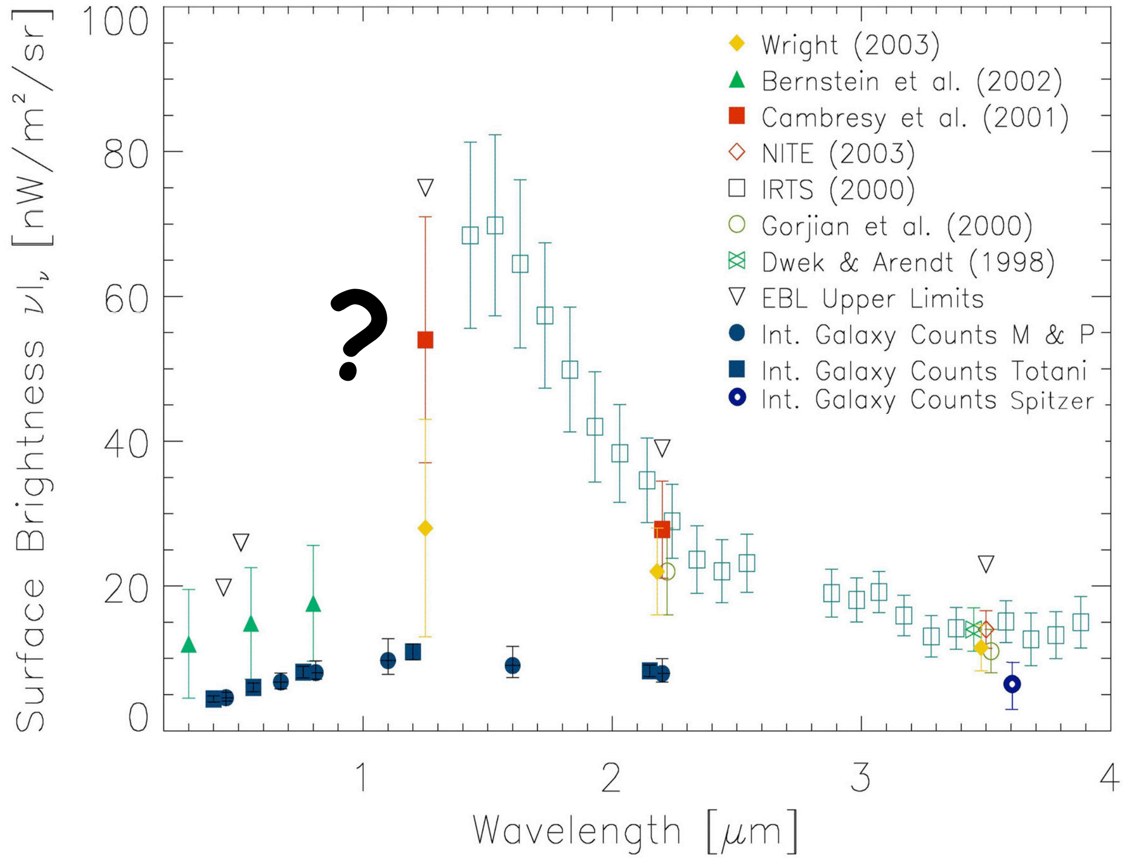
Given ~100 nJy average sources over 150 arcmin^2, we find an 3.6 μm intensity about 0.35 nW m^{-2} sr^{-1} associated with faint optical sources.

About 50% of flux needed to explain Kashlinsky result still missing…(some in fainter low-z optical sources below ACS, but some flux must be in high-z sources).

No evidence for a large unresolved background as interpreted by Kashlinsky et al.

Chary, Cooray, Sullivan 2008

But, still an unsolved problem?

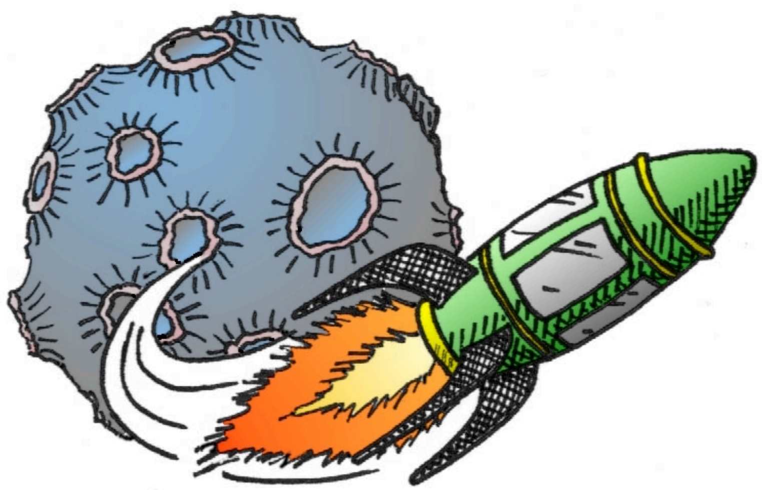


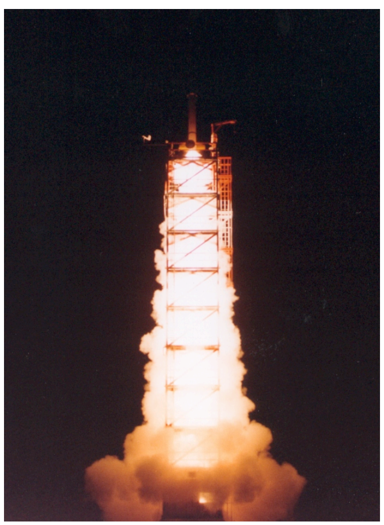
With existing IR source counts and fluctuations, intensity of total background light is constrained to be well below total intensity measurements from DIRBE/IRTS/ etc.

Is the excess real? Or did DIRBE get the background incorrectly?

CIBER

Cosmic Infrared Background ExpeRiment





UC Irvine
Asantha Cooray
Alex Amblard
Devdeep Sarkar

Caltech / JPL
John Battle
Jamie Bock
Andrew Lange
Ian Sullivan

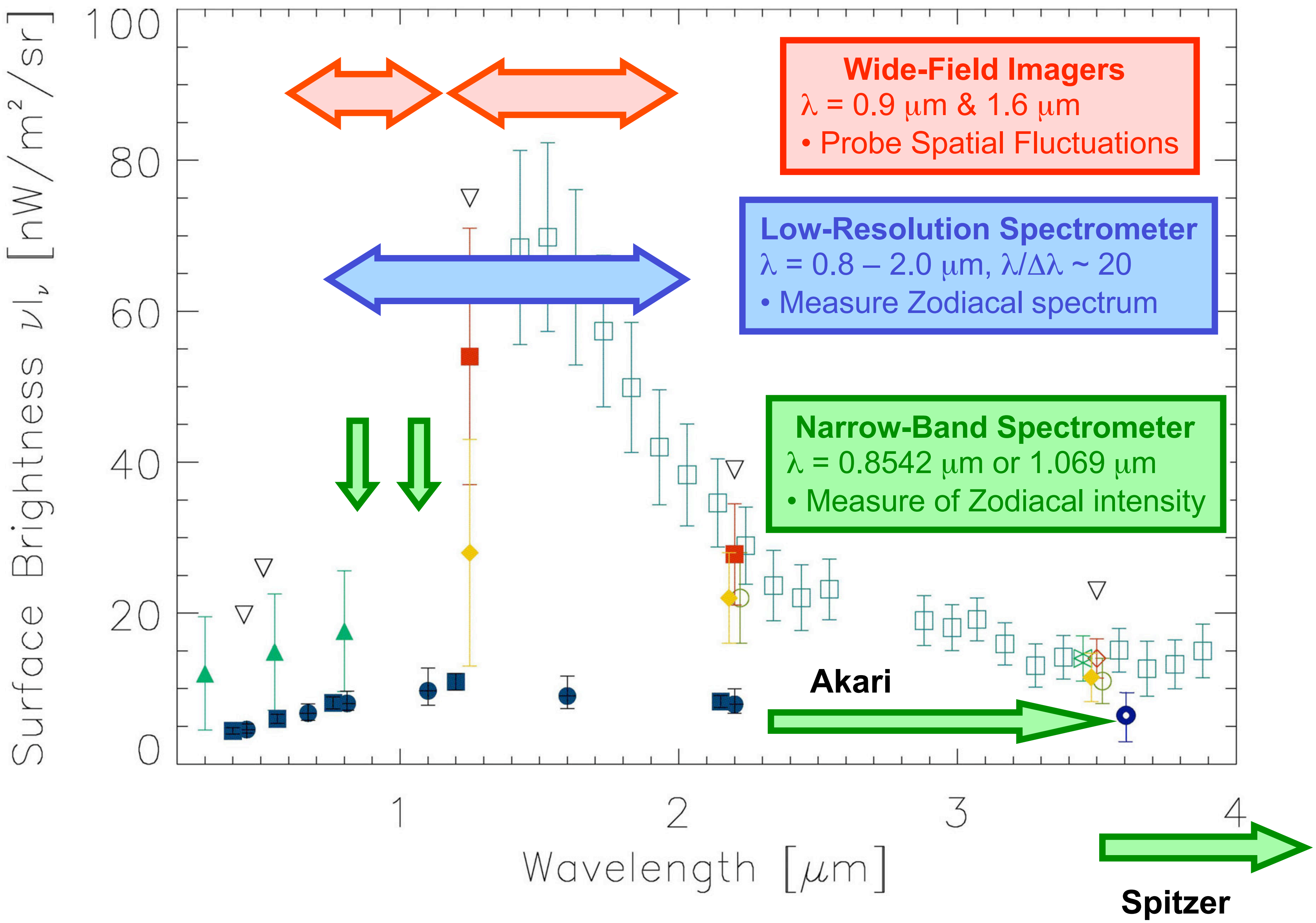
UC San Diego
Brian Keating
Tom Renbarger

ISAS / JAXA
Toshio Matsumoto
Shuji Matsuura
Kohji Tsumura
Takehiko Wada

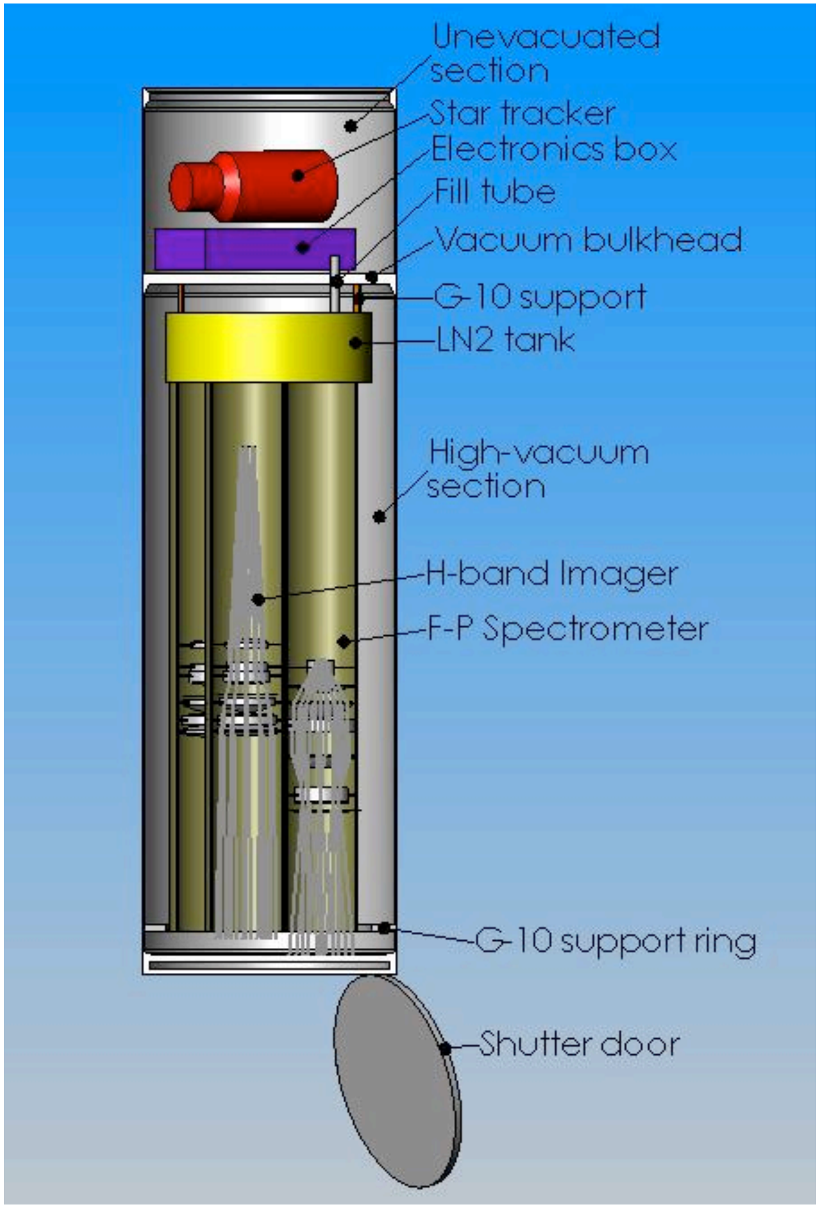
Nagoya U.
Mitsunobu Kawada
Toyoki Watabe

KASSI
Dae-Hee Lee
Soojong Pak

CIBER: As a Probe of the IR Background



CIBER Science Goals



Dual Wide-Field Imagers

λ= 0.8 μm & 1.6 μm — $\lambda/\Delta\lambda$ = 2

7" pixels — 2° x 2° FOV

- Measure IR fluctuations from 7" to 2 degrees

Low-Resolution Spectrometer

λ = 0.8 – 2.0 μm — $\lambda/\Delta\lambda$ ~ 20

60" pixels — 4° x 4° FOV

- Combine with Fabry-Perot spectrometer for new absolute measurement of IRB

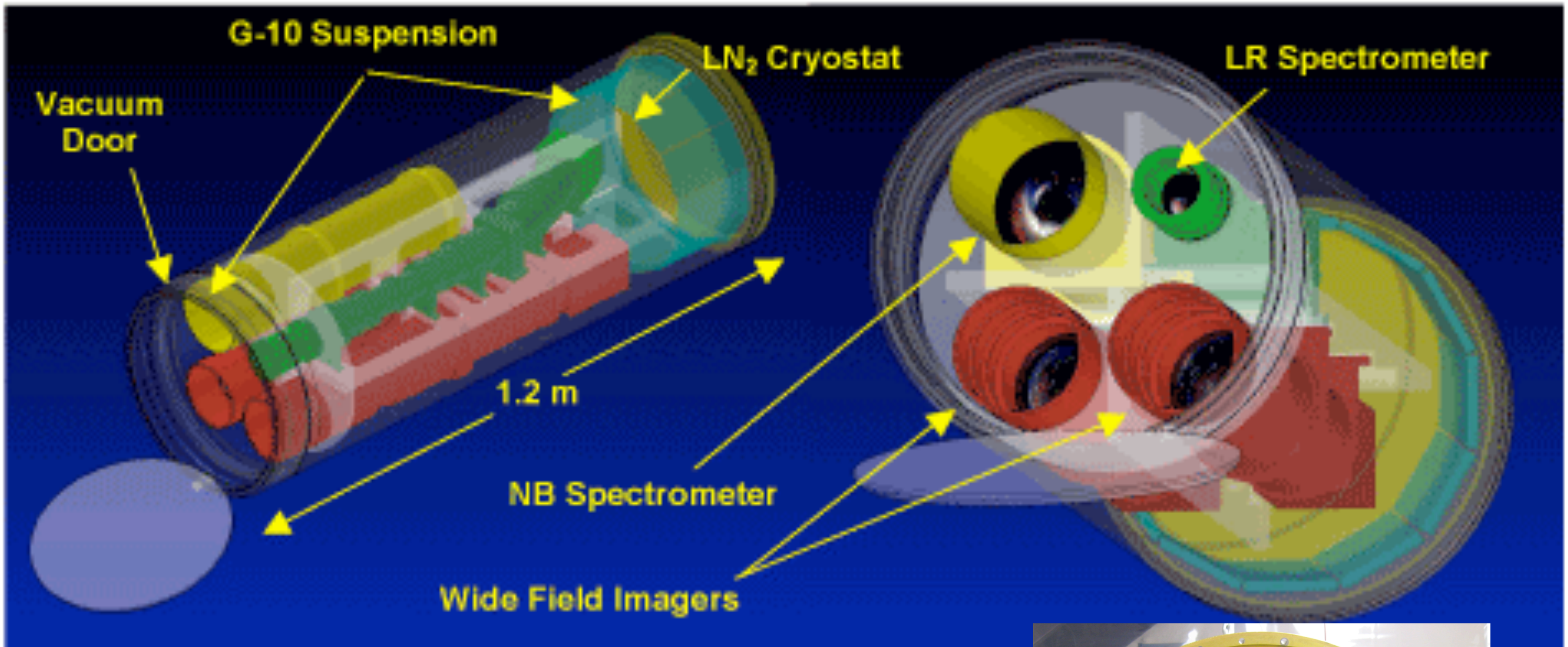
Narrow-Band Spectrometer

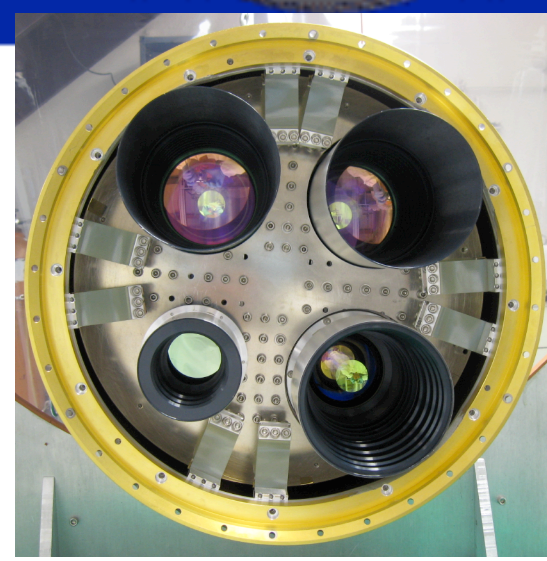
λ= 0.8542 μm or 1.069 μm — $\lambda/\Delta\lambda$ = 1000

120" pixels — 8° x 8° FOV

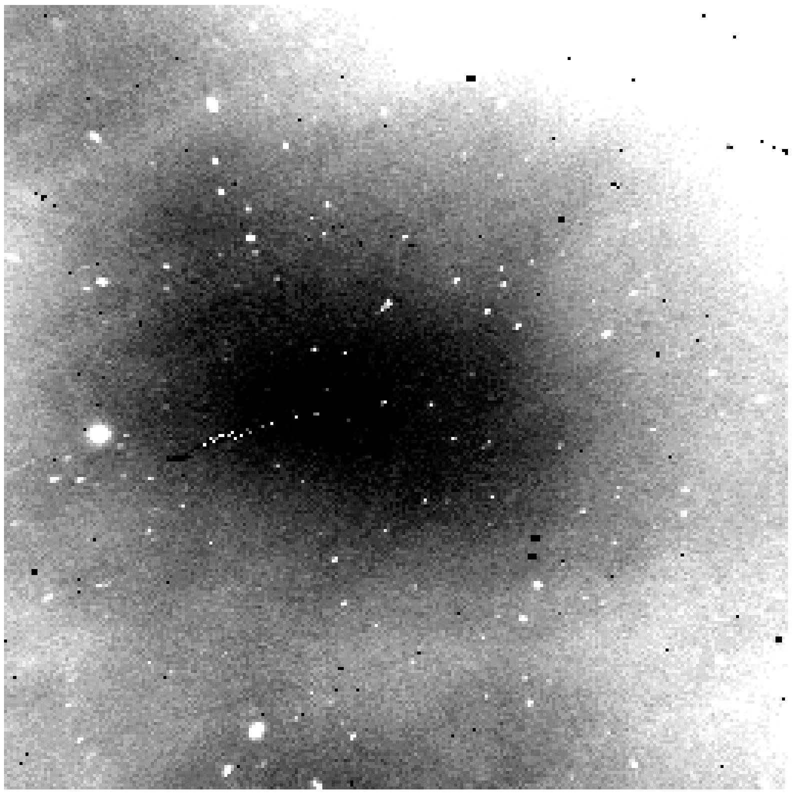
- Use Fraunhofer lines to measure absolute Zodiacal intensity
- Systematic test of DIRBE/Kelsall Zodiacal model

CIBER Payload





The Case for Space



Airglow Emission

- Atmosphere is **500 – 2500** times brighter than the astrophysical sky at 1-2 μm

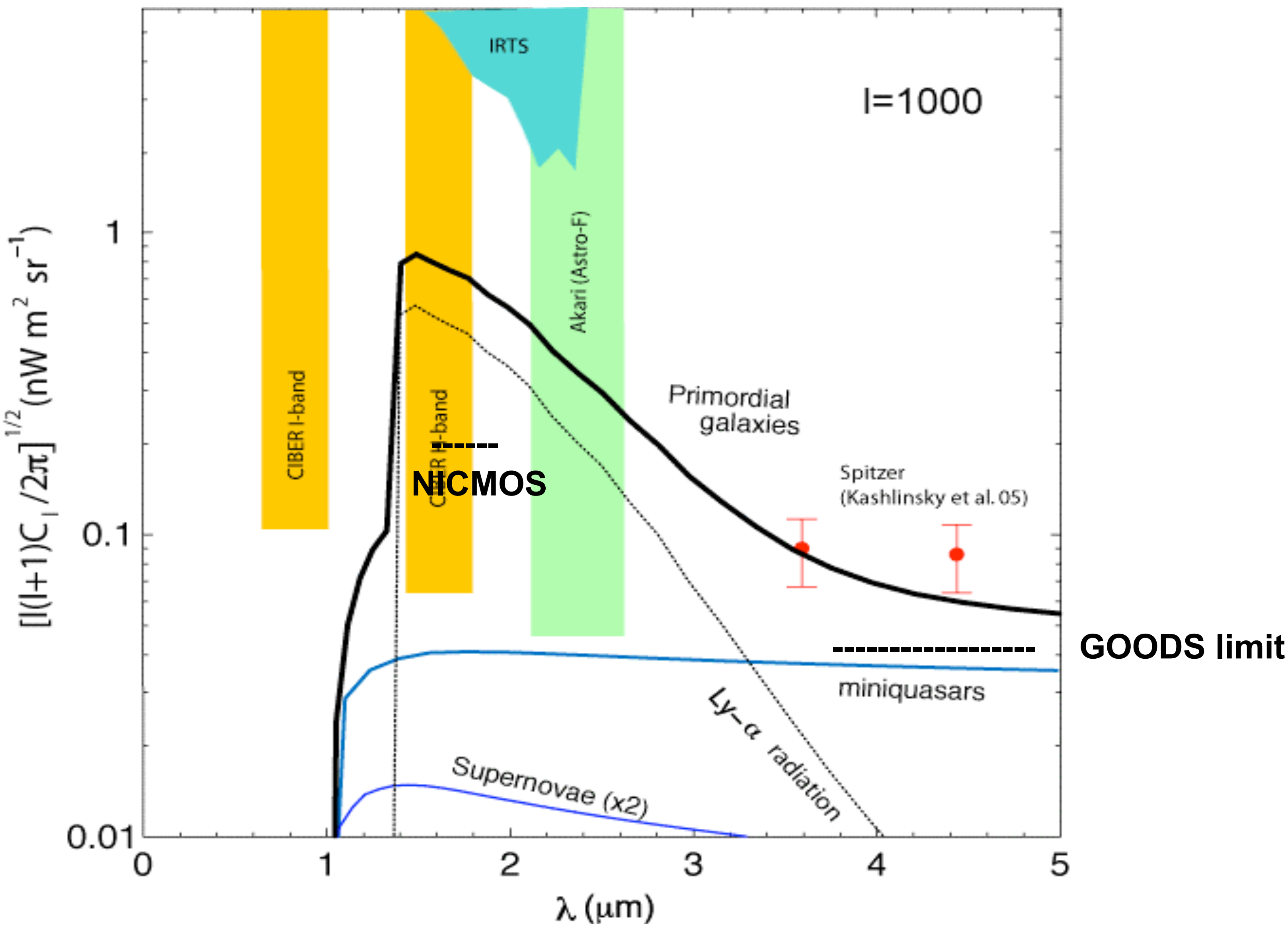
- Airglow fluctuations in a **1-degree** patch are **10^6** times brighter than CIBER's sensitivity in 50 s

- Brightest airglow layer at an altitude of **100 km**… can't even use a balloon

H-band 9º x 9º image over 45 minutes from Kitt Peak

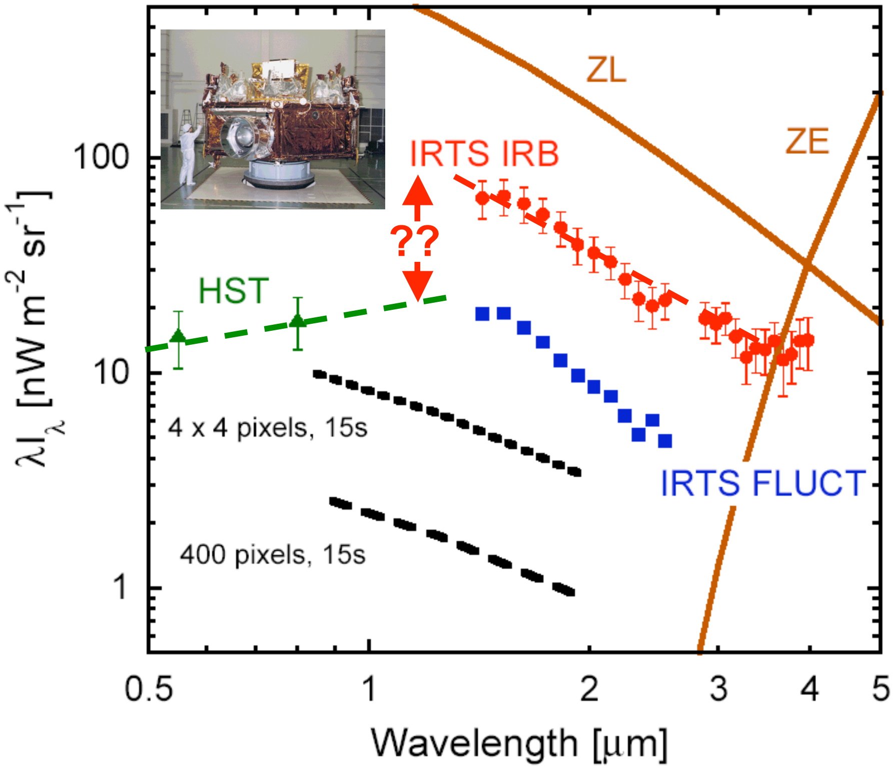
Wide-field airglow experiment: http://pegasus.phast.umass.edu/2mass/teaminfo/airglow.html

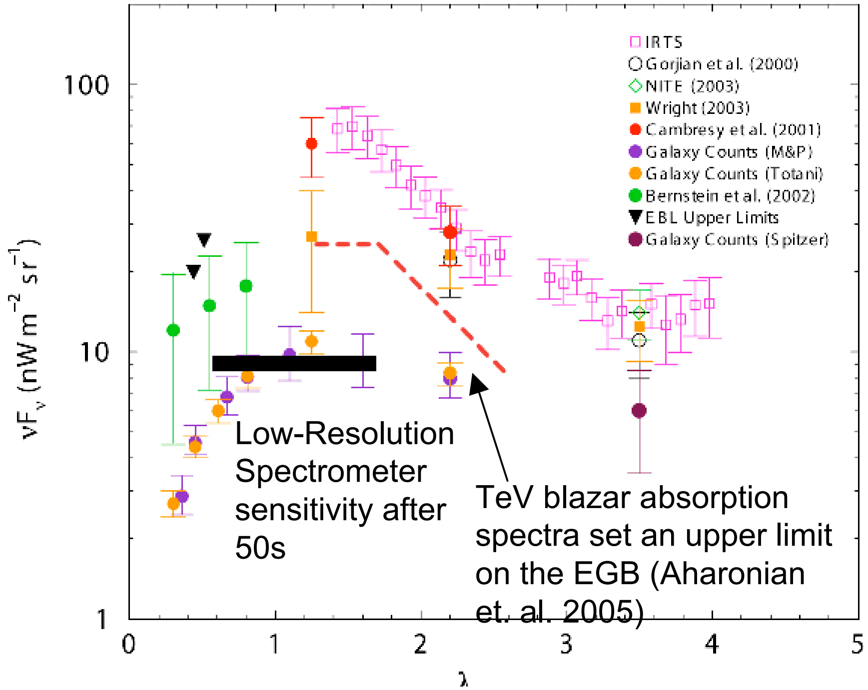
What CIBER will do….



Low-Resolution Spectrometer Science

Spectrometer Sensitivity





Is the gap between IRTS/DIRBE and HST real?

CIBER would see it easily, *without any* Zodiacal subtraction

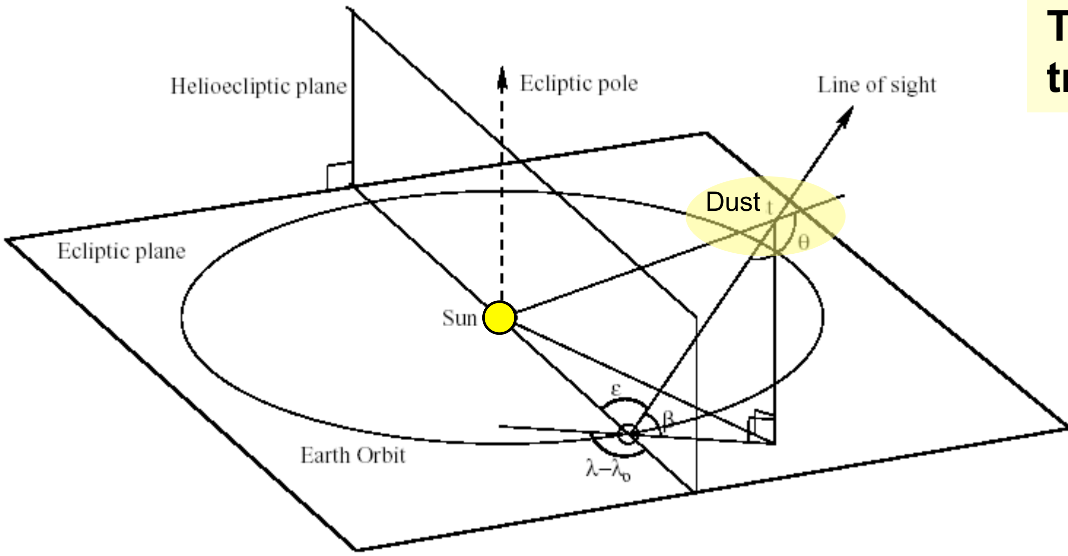
Precisely measure Zodiacal color, link with narrow-band spectrometer

Low-resolution spectrometer sensitivity is 1-2 nW m^{-2} sr^{-1}

NB Spectrometer Zodiacal zero point is 3 nW m^{-2} sr^{-1} at 0.85 μm

Controversy at J-band is ~30 nW m^{-2} sr^{-1}

Using Fraunhofer Lines to Trace Zodiacal Intensity



Zodiacal Light is just scattered sunlight

Features in the solar spectrum are mimiced in Zodiacal light

The solar spectrum gives a precise tracer of the absolute Zodiacal intensity

But reality is messy

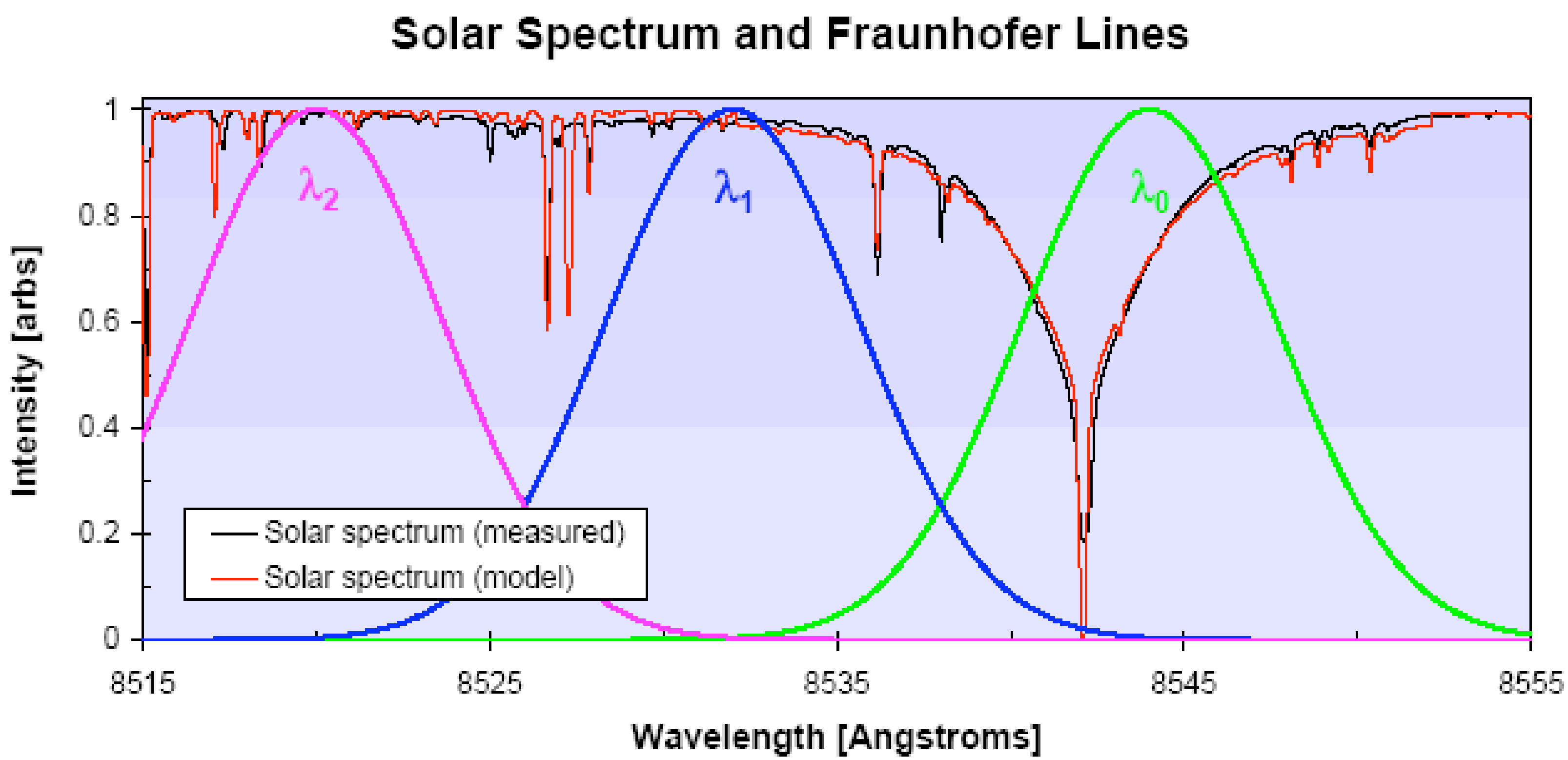
Atmospheric scattering, emission, and extinction

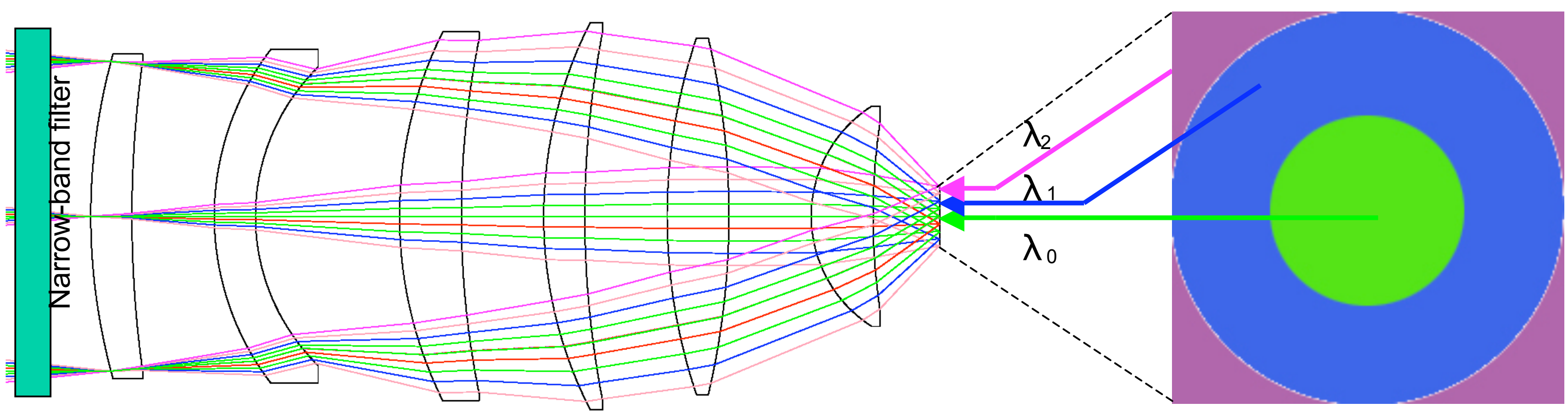
- **scattered ZL**
- **scattered starlight**
- **airglow**
- **etc**

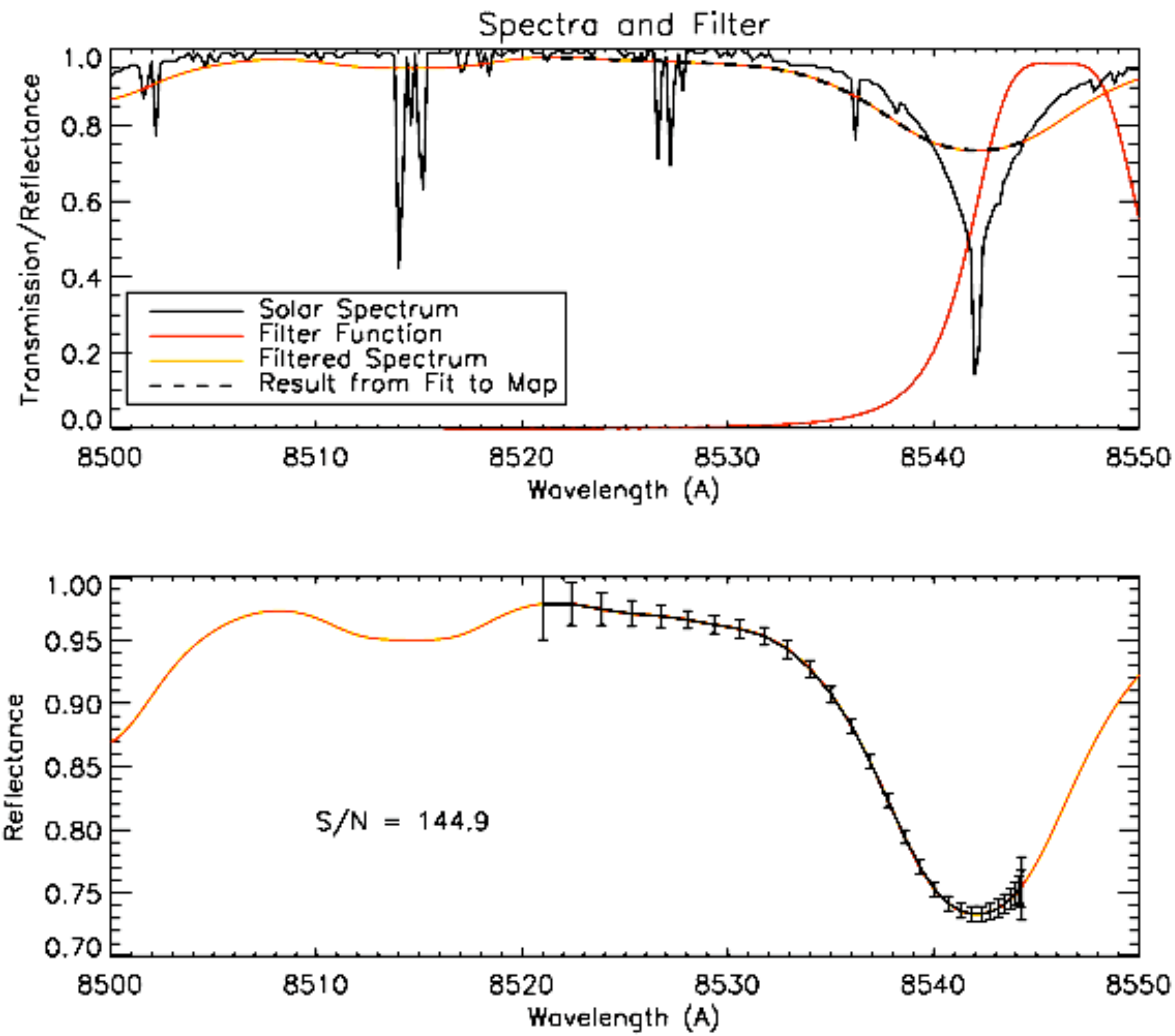
Calibration on diffuse sources

For details see: Dube *et al*. 1979
Bernstein *et al*. 2002
Matilla 2003

Instrument Response to 8542 Å Ca II Line

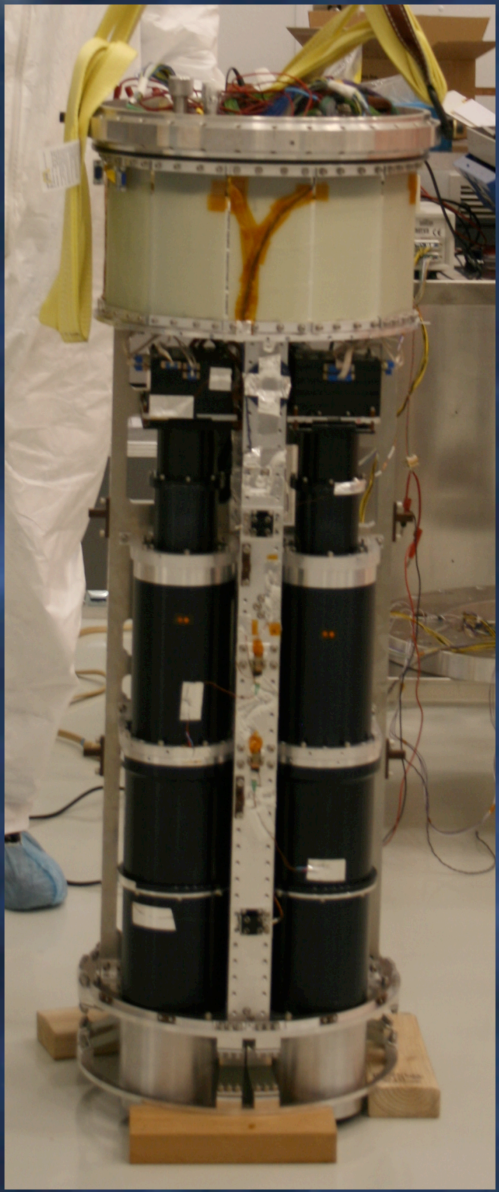





Spectra and Filter
Transmission/Reflectance
Solar Spectrum
Filter Function
Filtered Spectrum
Result from Fit to Map
Wavelength (A)
Reflectance
S/N = 144.9
Wavelength (A)

Integration Plan

- 2007, First Half: Experiment section insert fabricated in Japan.
- 2007, August: Instrument integration at Caltech/JPL
- 2007, Sept: Cryogenic and mechanical commissioning.
- 2007, Oct - 2008, Jan: Optical testing and refinement of instruments, readout electronics and cryogenic performance.
- 2008, Feb & Mar: Integration as part of rocket payload at NASA Wallops Flight Facility, VA.

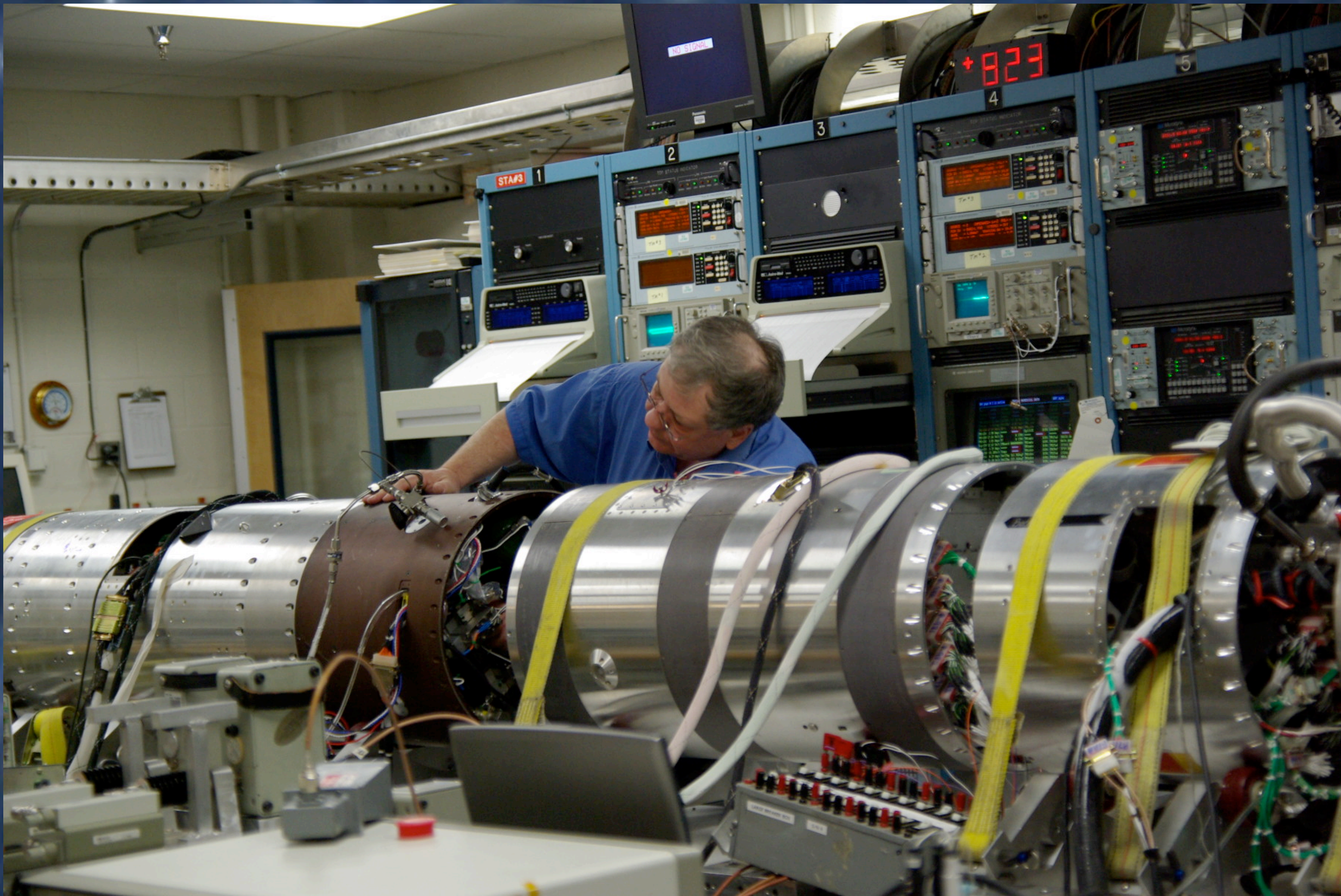


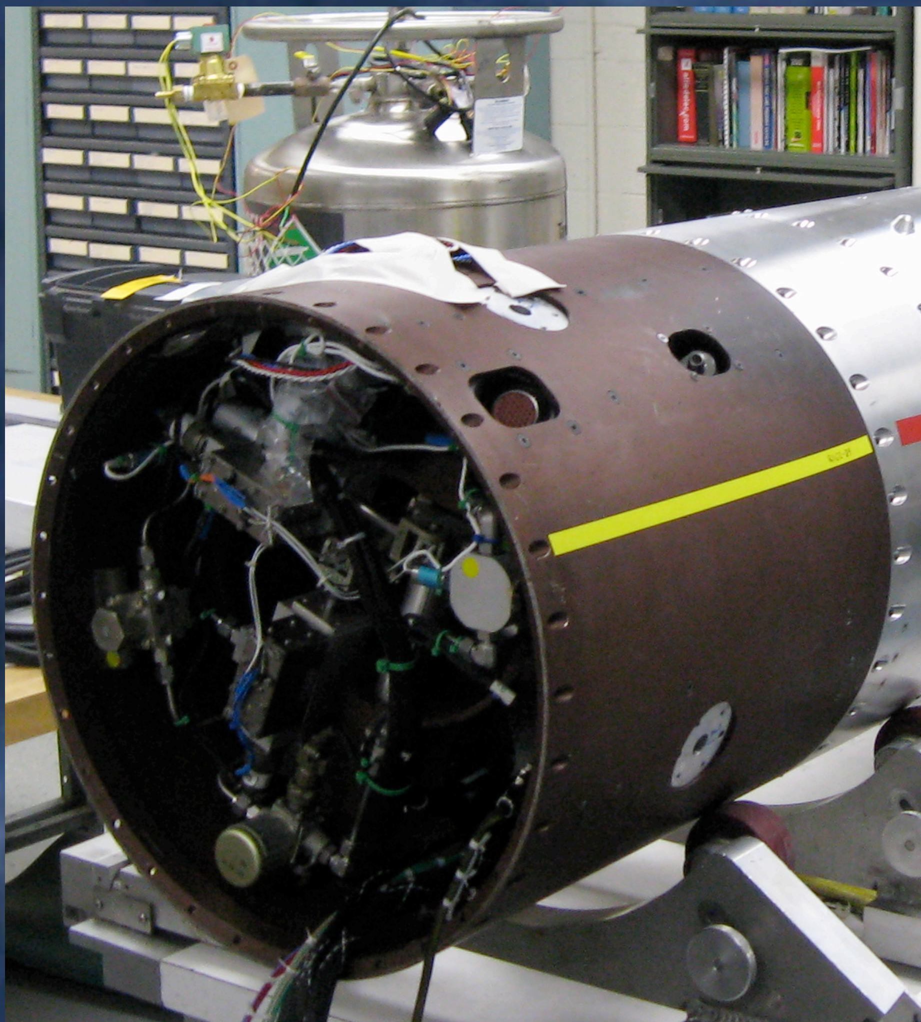
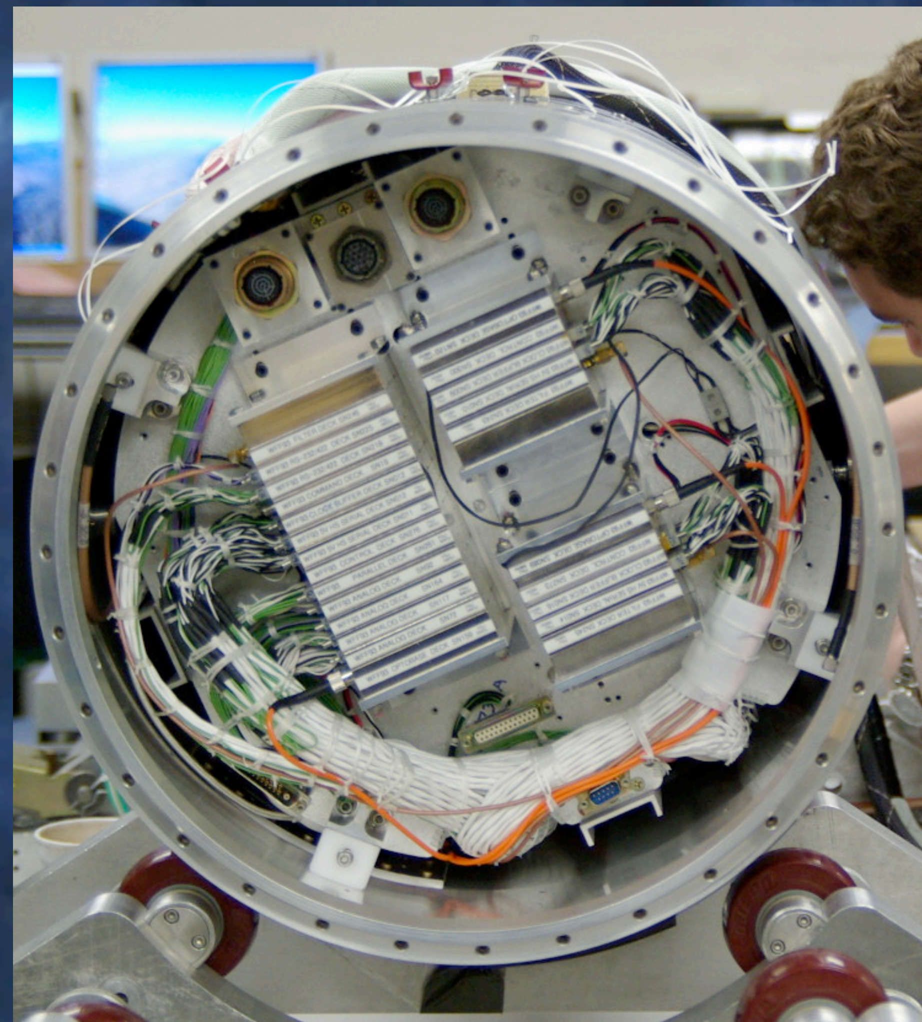
Wallops Flight Facility: Integration & Testing

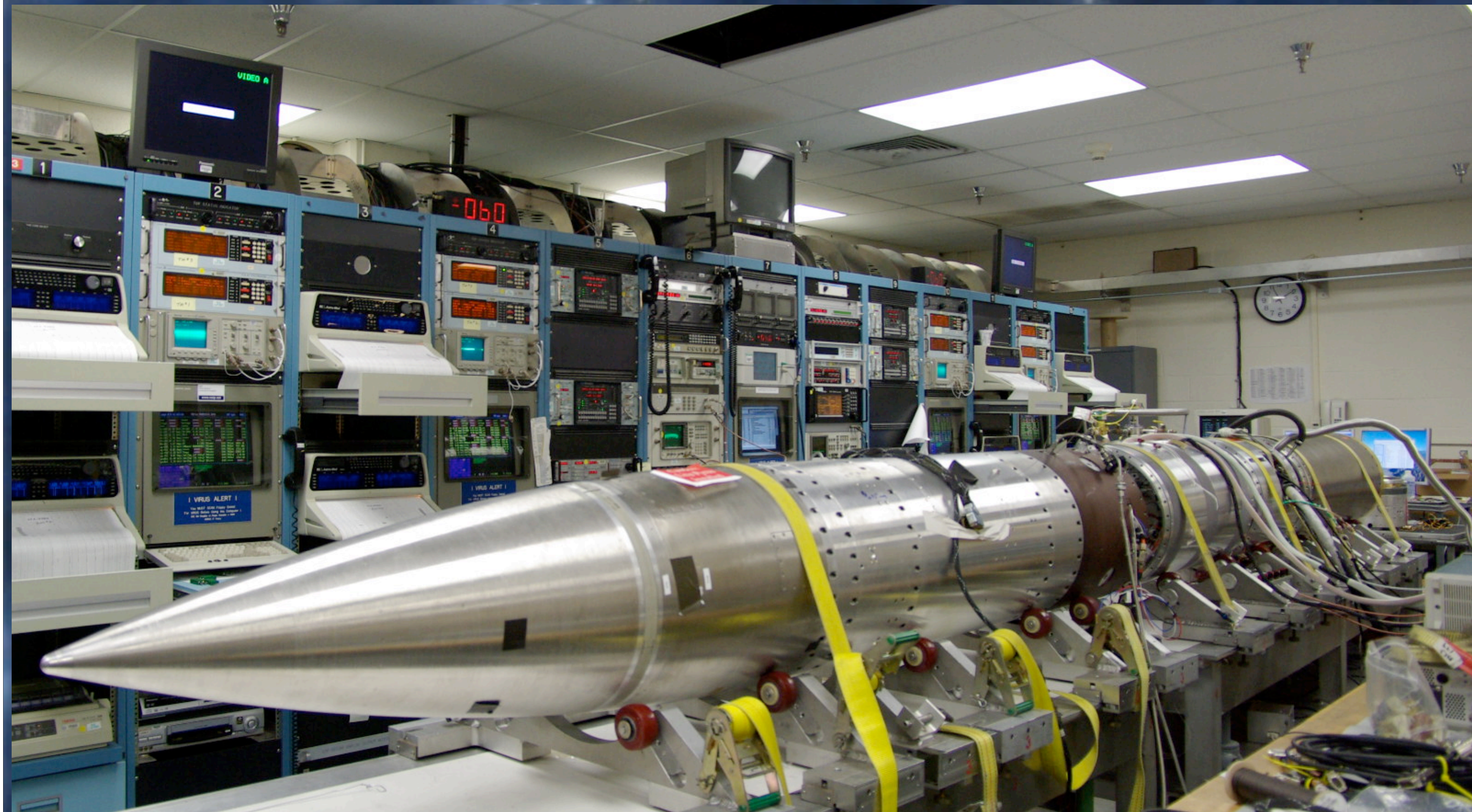
Testing at Wallops comprises 4 major tasks:

- Task 1: Integrate and test electronics chain.
- Task 2: Characterize the instruments before vibration.
- Task 3: Environmental testing and evaluation of entire payload section.
- Task 4: Characterize the instruments after vibration.

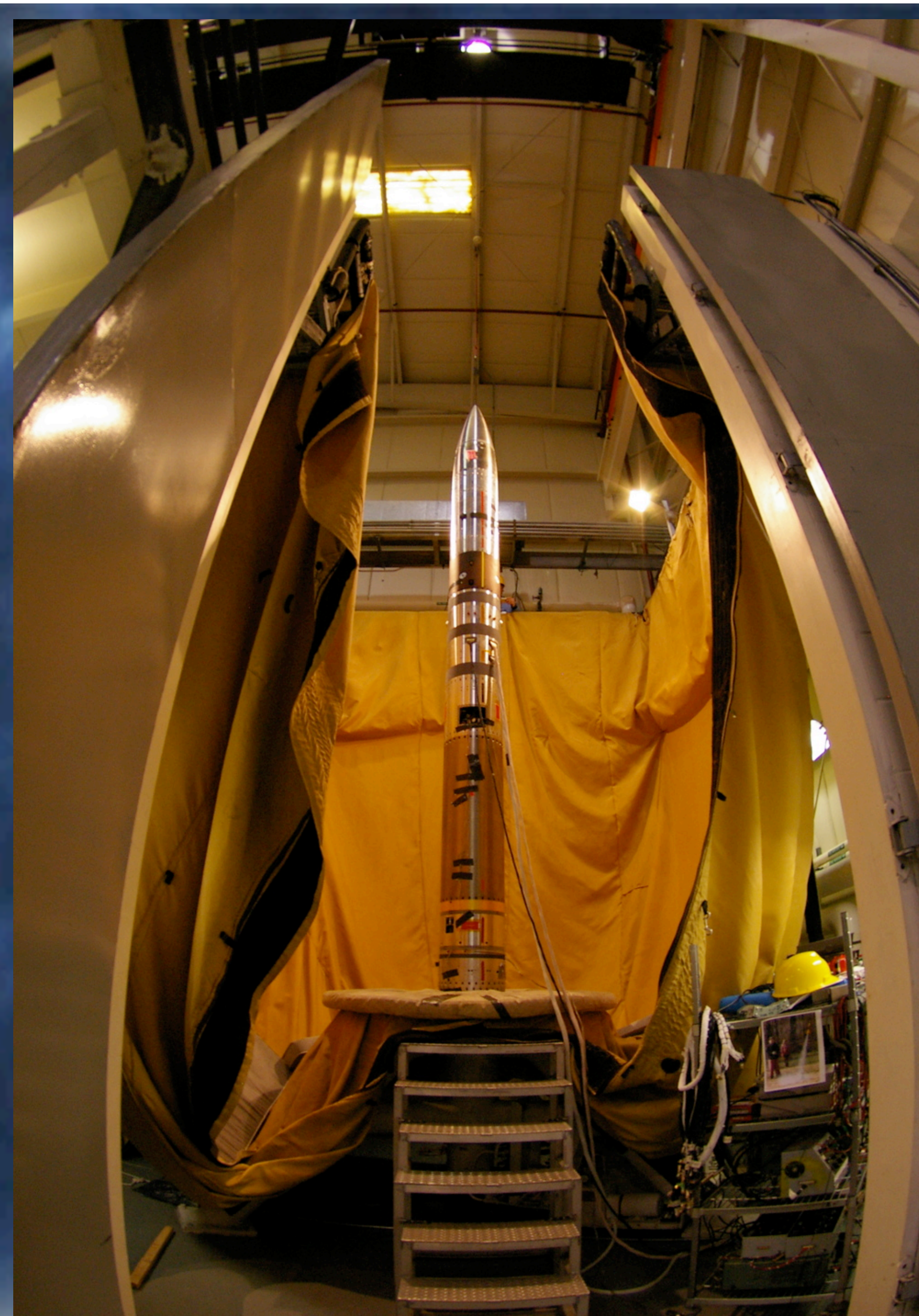
Campaign requires ~ 6 weeks in the field.


NO SIGNAL
STA#3
1
2
3
4
5
+823


060
! VIRUS ALERT !

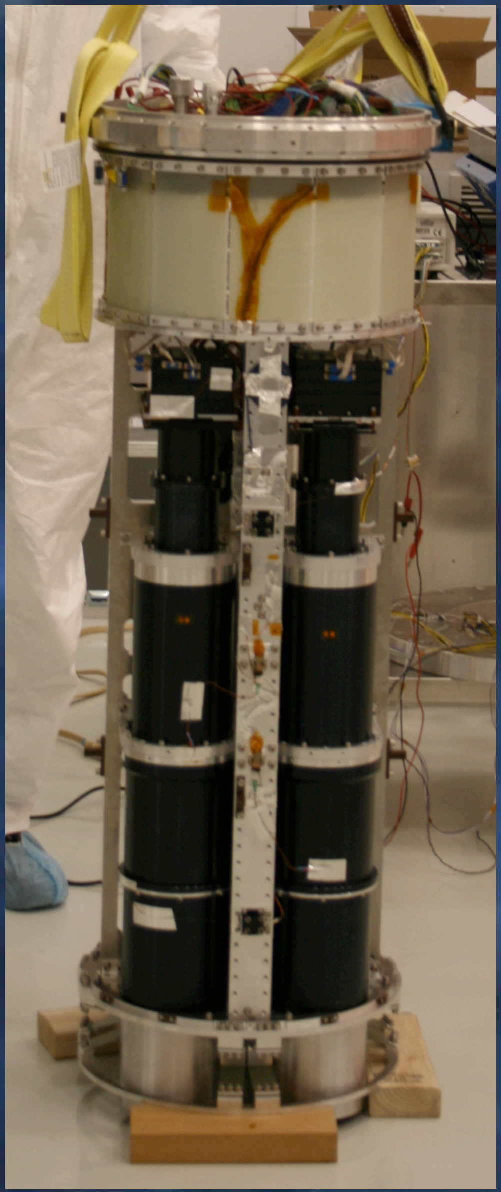

Mezzanine Load
Limit Not to
Exceed 150 Lbs.
Per Square Foot
CAUTION
High Noise Level
Use Ear Protection
BOCK
36.226
Bock
36.226



Integration Plan

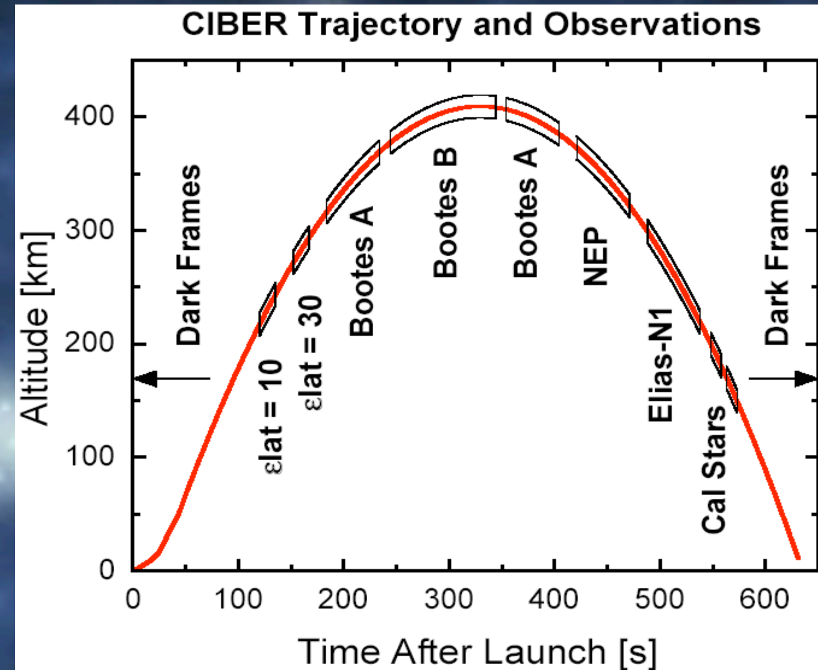
- 2007, First Half: Experiment section insert fabricated in Japan.
- 2007, August: Instrument integration at Caltech/JPL
- 2007, Sept: Cryogenic and mechanical commissioning.
- 2007, Oct - 2008, Jan: Optical testing and refinement of instruments, readout electronics and cryogenic performance.
- 2008, Feb & Mar: Integration as part of rocket payload at NASA Wallops Flight Facility, VA.
- 2008, Apr - Jun: Calibration campaign and final changes at White Sands, NM
- **2008, July 25 - first launch date! On target**

•2009 (+6 months) - second launch

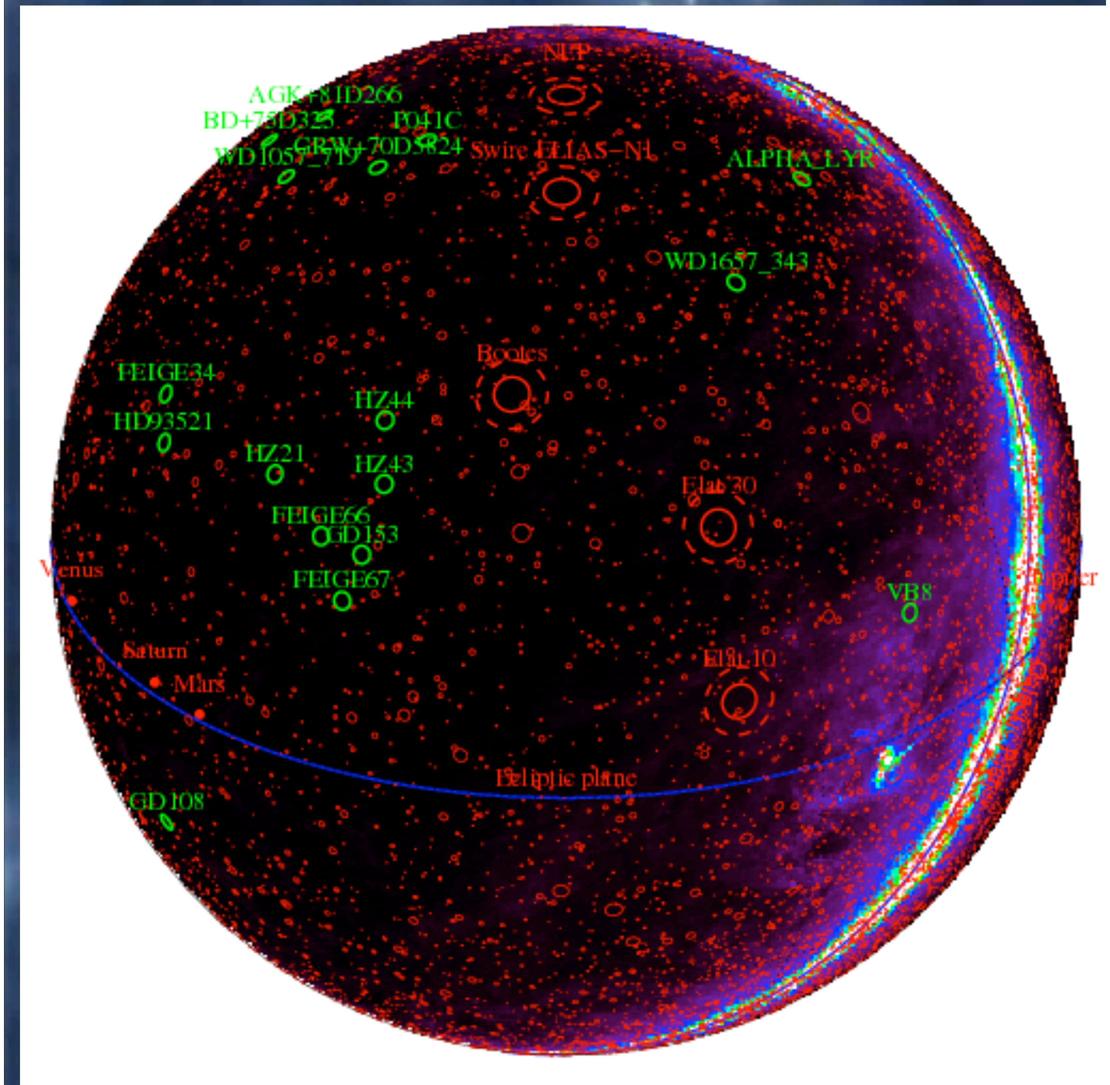


CIBER's Flight

- Current flight parameters yield a 15 minute flight with ~ 1 minute upleg and ~4 minute downleg.
- Apogee is strongly sensitive to the payload mass; current best estimate is ~350 km.



- We plan to observe 4 cosmological fields, 2 foreground assessment fields, and Vega for calibration.
- The cosmological fields are chosen to enjoy exceptional ancillary coverage to minimize point source contamination.



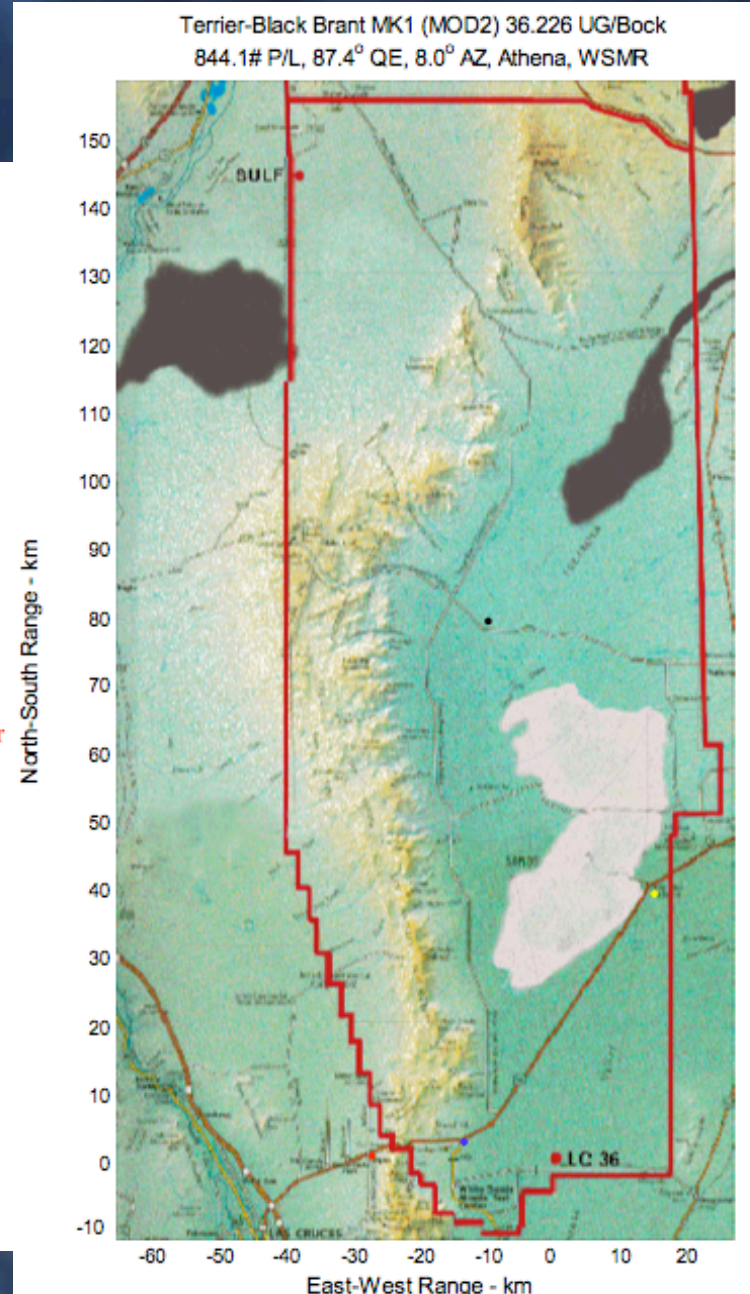
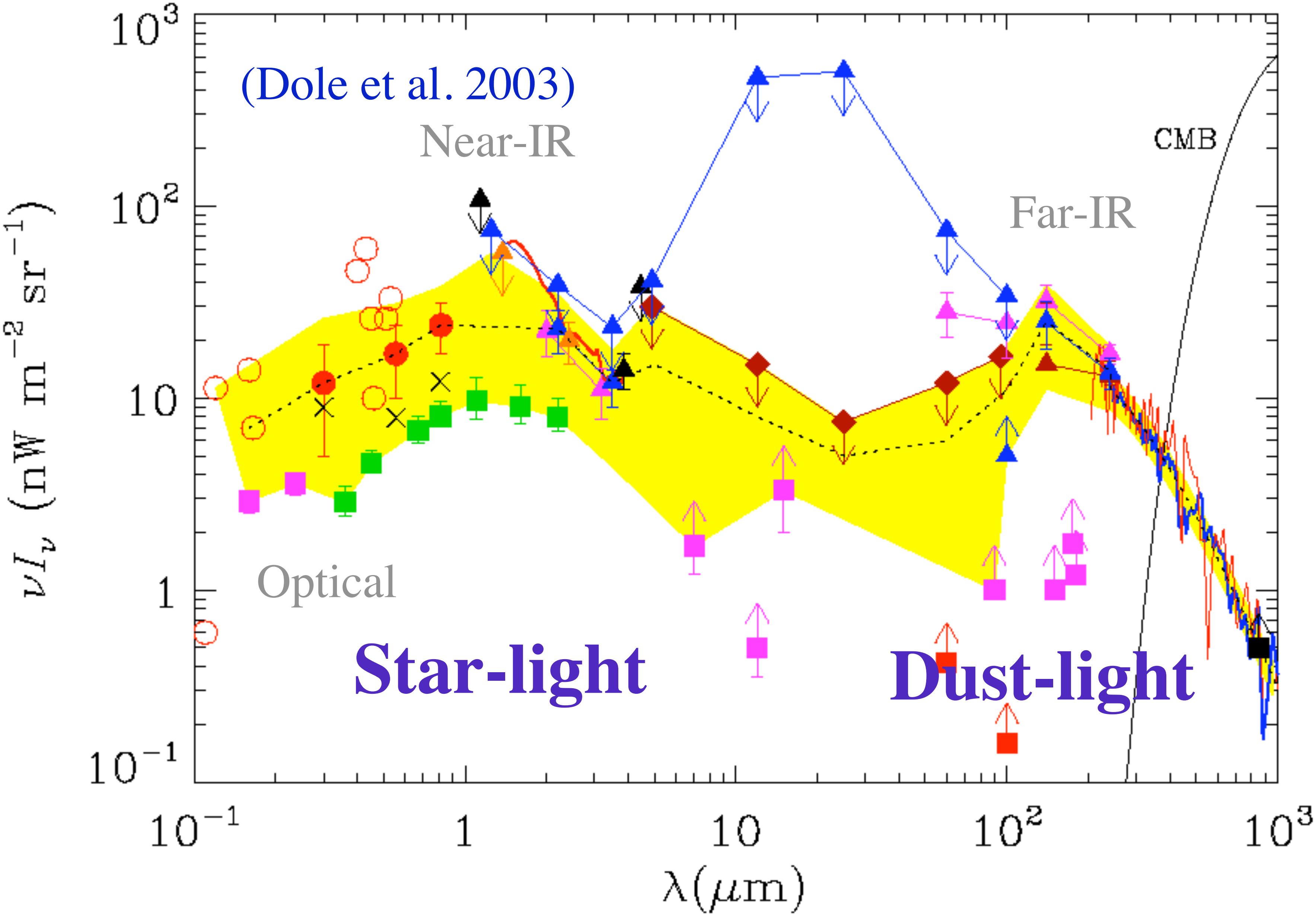
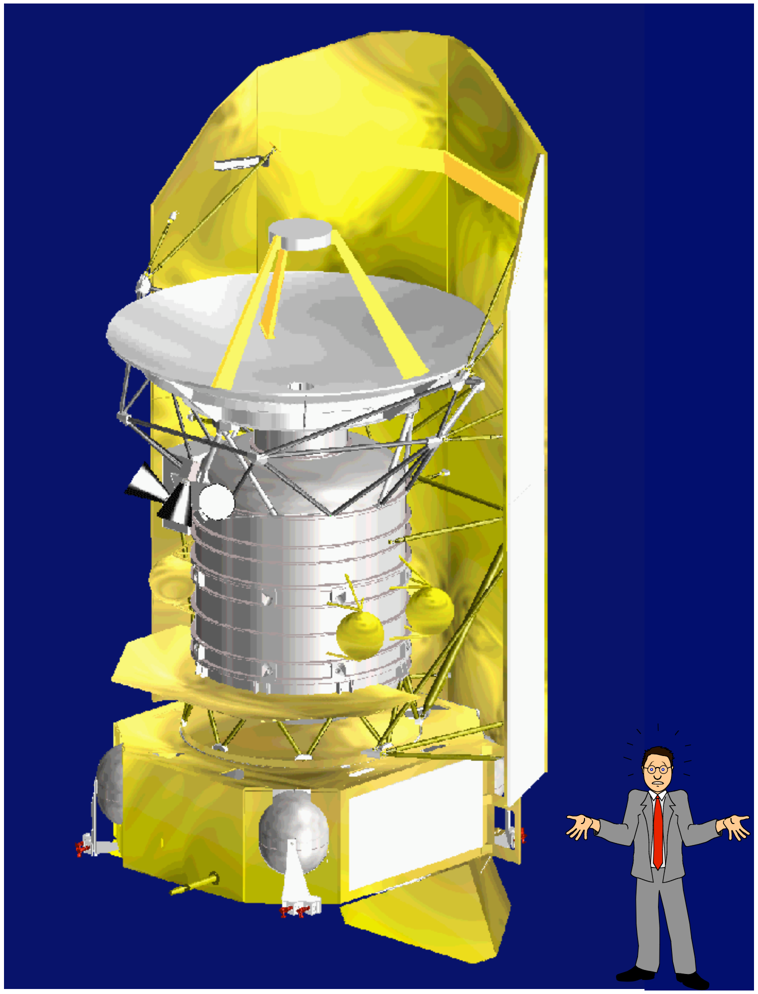


Figure 2. WSMR Impact Map

Part II: Cosmic far-IR Background

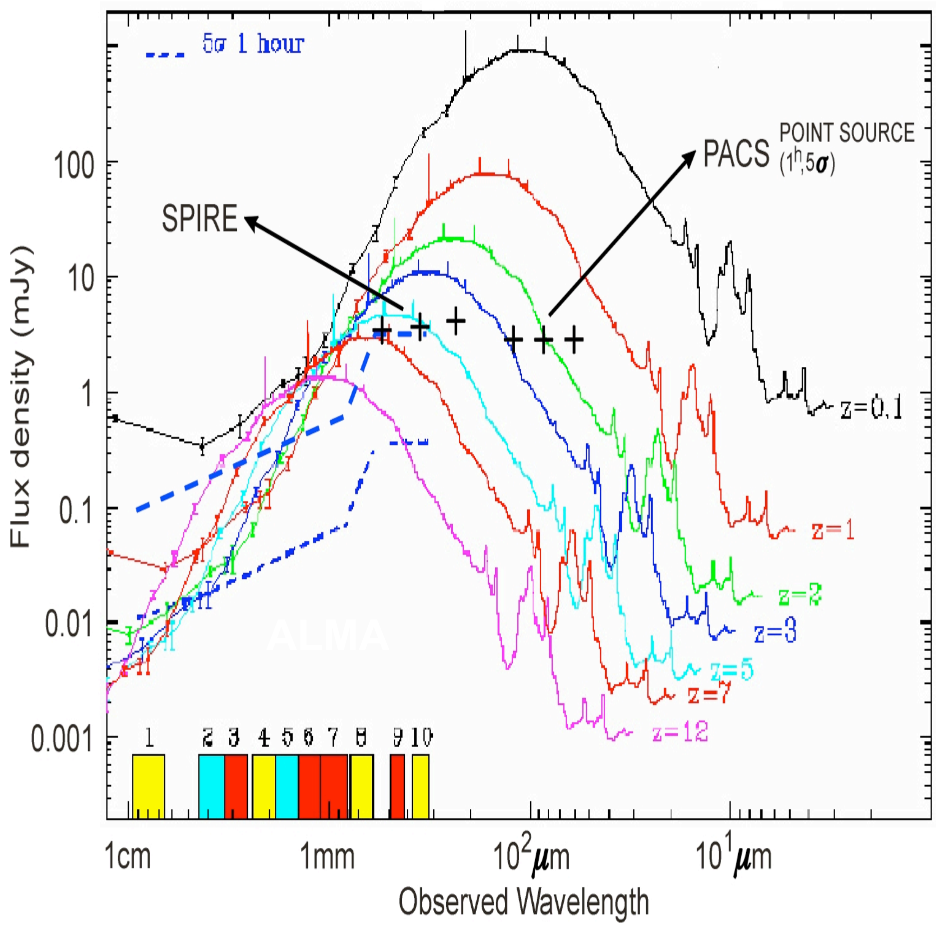


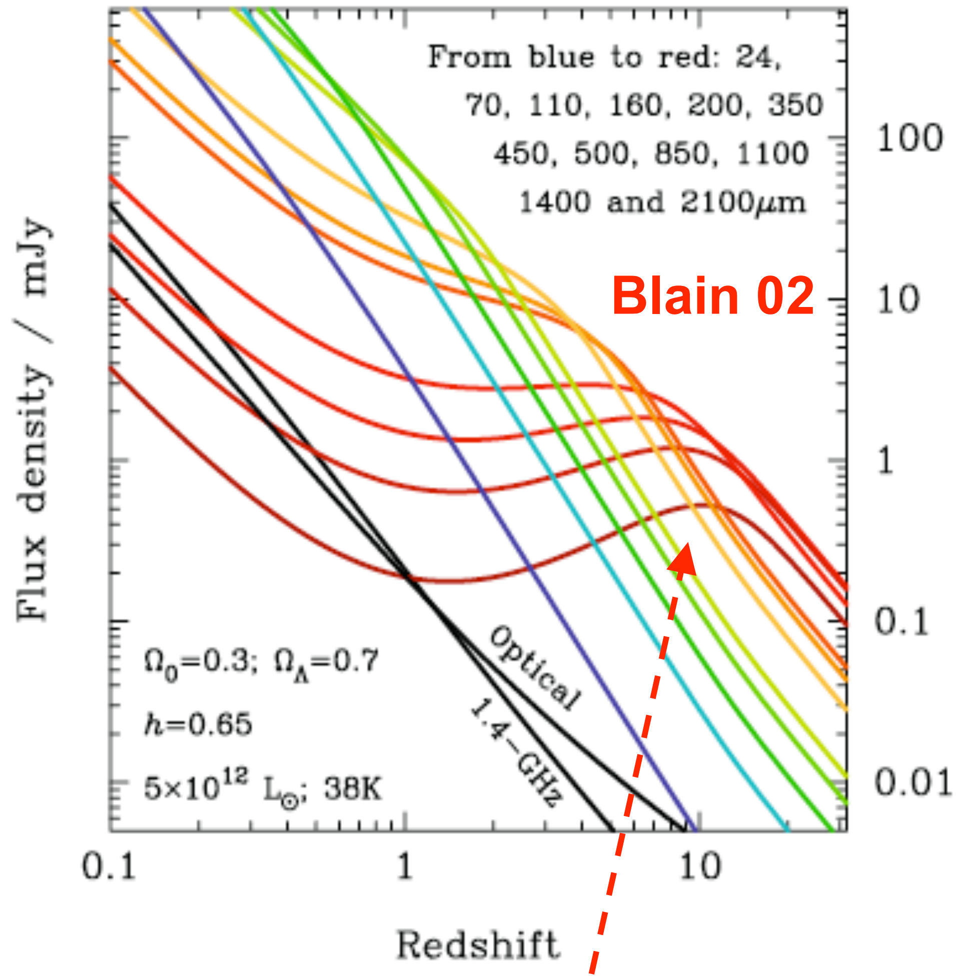
Extragalactic Far-IR Studies with Hershcel-SPIRE



- Herschel is an astronomical observatory for photometry and spectroscopy over the spectral range 80 – 670 μm
- Large (3.5m), cold (80K), low-emissivity (4%) telescope
- Cooled to 4K using liquid He (as in ISO)
- Launch: early'09(?) on Ariane 5 with Planck in the same pay-load; Sun-Earth L2 point; 1000 days of nominal observations
- Primarily ESA. NASA participation through JPL (e.g., bolometers for SPIRE)

Far-IR Sources: Negative k-correction!





In the Rayleigh-Jeans tail of the dust blackbody spectrum, galaxies get ***brighter*** as they are redshifted to greater distance!

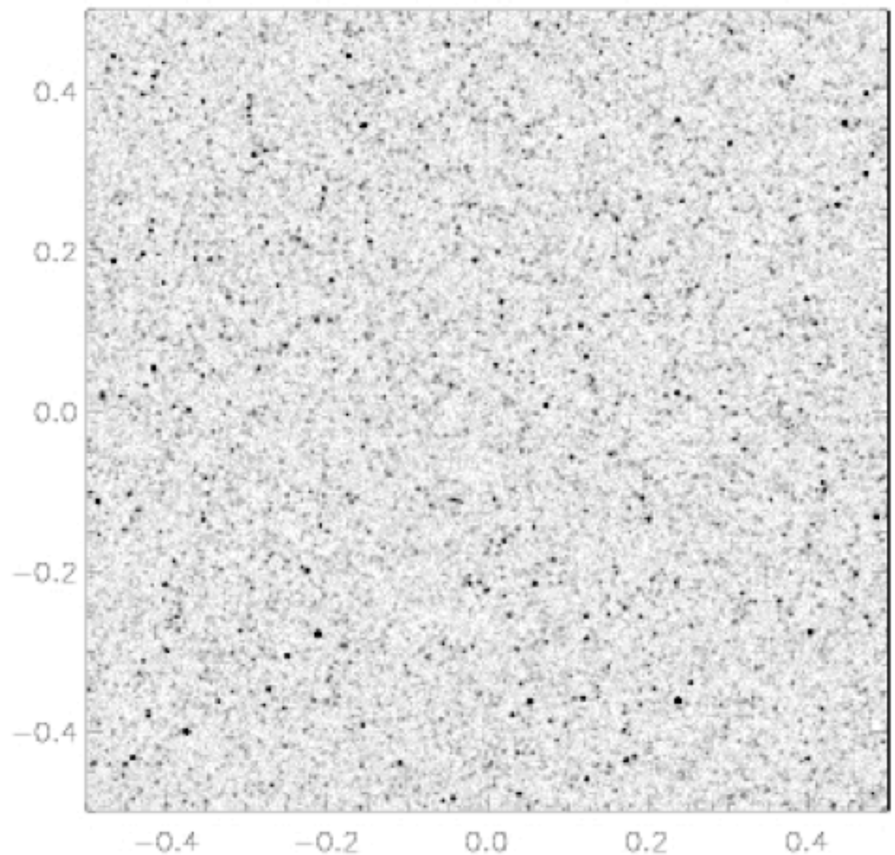
Photometry with Herschel

		PACS			SPIRE	
λ_{cent}	75μm	110μm	170μm	250μm	350μm	500μm
$\Delta\lambda$	60-90	90-130	130-210	210-290	290-400	410-580
Sensitivity mJy,5σ,1h	3	3	3	1.1	1.2	1.5
FOV (arcmin)	1.8x3.5	1.8x3.5	1.8x3.5	4x8	4x8	4x8
Angular res.	5"	8"	12"	17"	24"	35"

SPIRE: Survey instrument, confusion limited
Can only resolve < 10% of EBL at 350 μm

Confusion limits (at 5σ)

- 250 microns: 20 mJy, FWHM= 17 arcsec, 1800 sources/sq.deg
- 350 microns: 19 mJy, FWHM= 24 arcsec, 945 sources/sq.deg
- 500 microns: 19 mJy, FWHM= 35 arcsec, 420 sources/sq.deg



(Buat)

The Herschel ATLAS

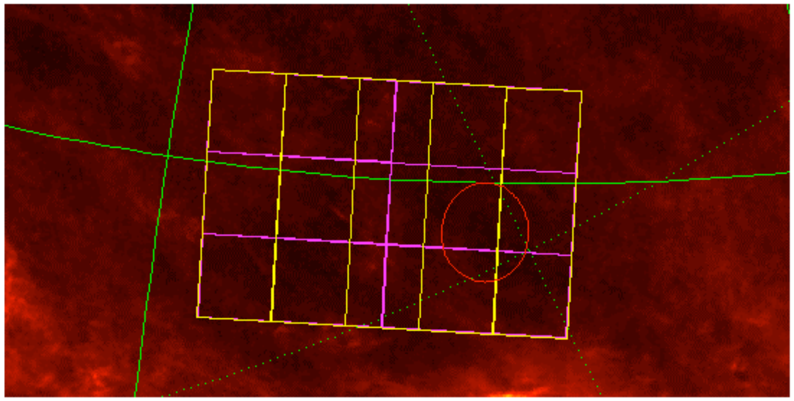
Astrophysical Terahertz Large Area Survey

The widest-area survey with Herschel: 600 square degrees
Steve Eales & Loretta Dunne, Cardiff/Nottingham Survey PIs
Asantha Cooray, Irvine US, NASA PI
+ close to 100 Co-I's from > 30 institutions

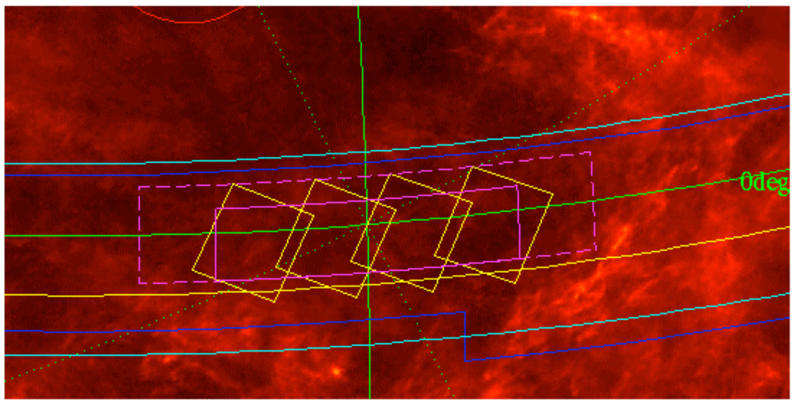
In 5 bands with PACS and SPIRE

SDSS/2dF equivalent at far-IR wavelengths

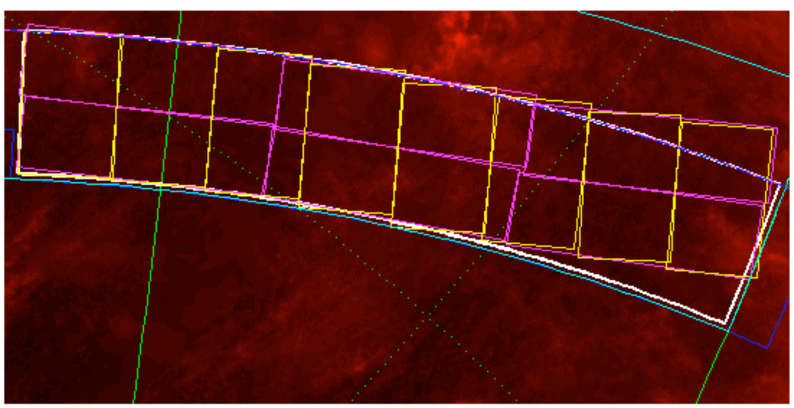
NGP Main Block



GAMA 12hr



SGP main block



Survey Strategy

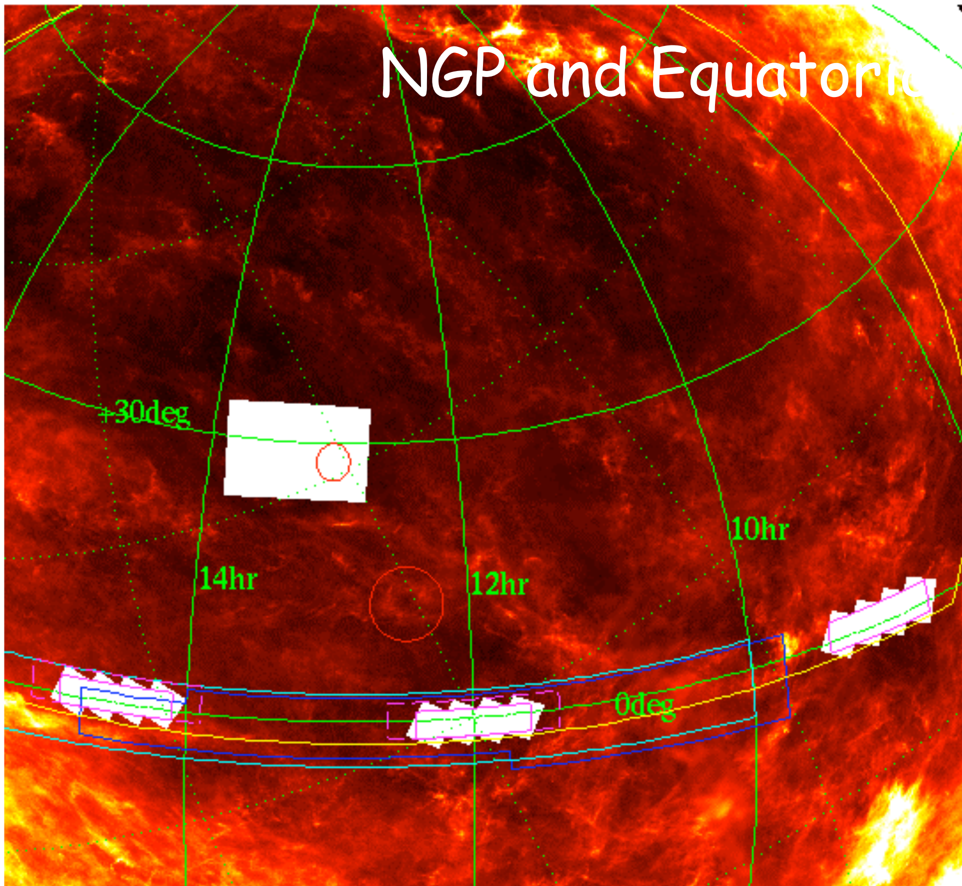
5 sigma depths: 110 = 67 mJy
170 = 94 mJy
250 = 46 mJy
350 = 62 mJy
500 = 53 mJy

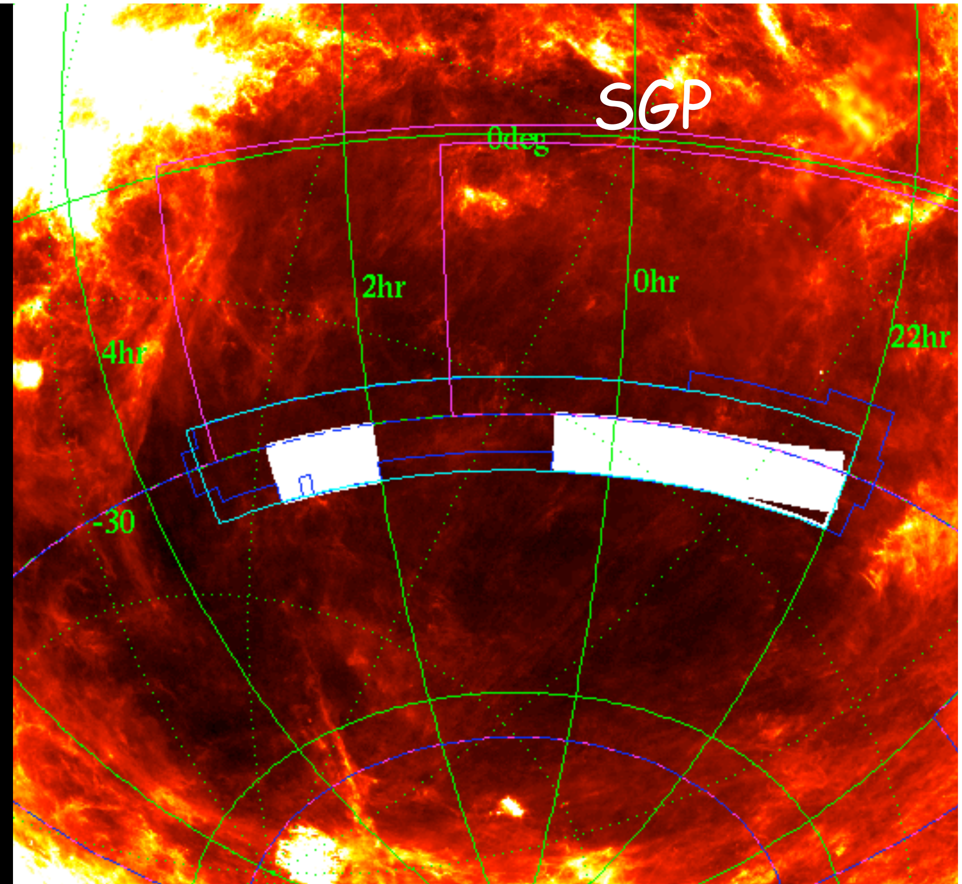
Using Parallel mode with fast scanning

Large scan legs to maximise efficiency

2 orthogonal scans to improve reliability and minimise 1/f noise

Must have sky orientation constraints





Fields chosen to allow maximum overlap with existing and planned surveys
2dF, SDSS, GAMA, KIDS, VIKING, PanSTARRS, DES, SPT, SASSy

and to be accessible to new facilities which will be valuable for follow-up
ALMA, SKA and prototypes, SCUBA2, LOFAR, e-MERLIN

What we know …

- Current measurements of luminosity and dust mass functions at >100 microns either biased or not statistically significant
- IRAS biased to galaxies with large amounts of warm dust
- Most dust in galaxies is colder than ~25 K
- Galaxies selected in other ways (optical/sub-mm) show different properties to IRAS selected

ATLAS provides an unbiased and statistically useful measure of the total dust content of the local Universe

Key Science Themes

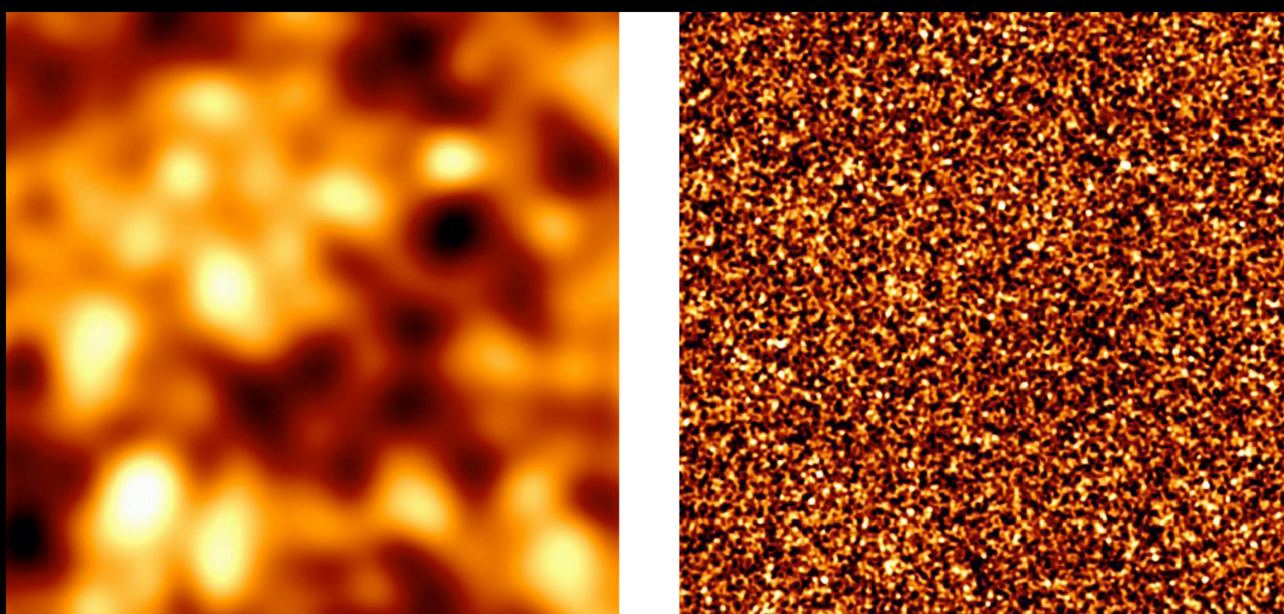
1. Local Universe Survey
2. The ATLAS-Planck collaboration
3. The Herschel Lens Survey
4. Active Galactic Nuclei
5. Large scale structure
6. Galactic dust and proto-stars …….

2. The Herschel/Planck collaboration

De Zotti, Clements

ATLAS good for Planck point source follow up

High resolution imaging at 250-500 micron can be used to decontaminate thermal signatures from Planck SZ signals



Simulation of a 1 x 1 sq deg field as seen by Planck (left) and ATLAS (right)

3. The Herschel Lens Survey

Negrello, Dye

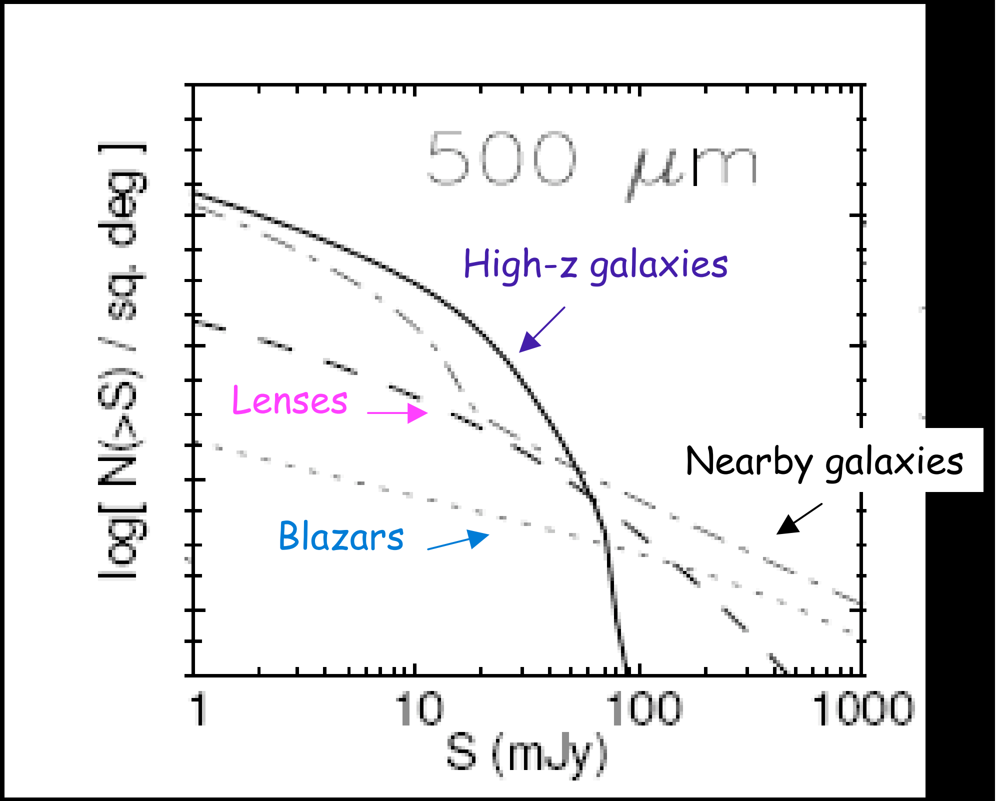
Strong negative K-correction makes sub-mm a good place to look for lenses.

Best radio survey to date has success rate of only 0.14% (22 lenses from 16000 sources)

Can get lens yield of close to 100% at 500 microns – producing 350 lenses.

Requires follow-up to study lens and lensed source

Lenses are useful for studying the evolution of galaxy mass profiles and probing below confusion in the sub-mm



Negrello et al. 2007

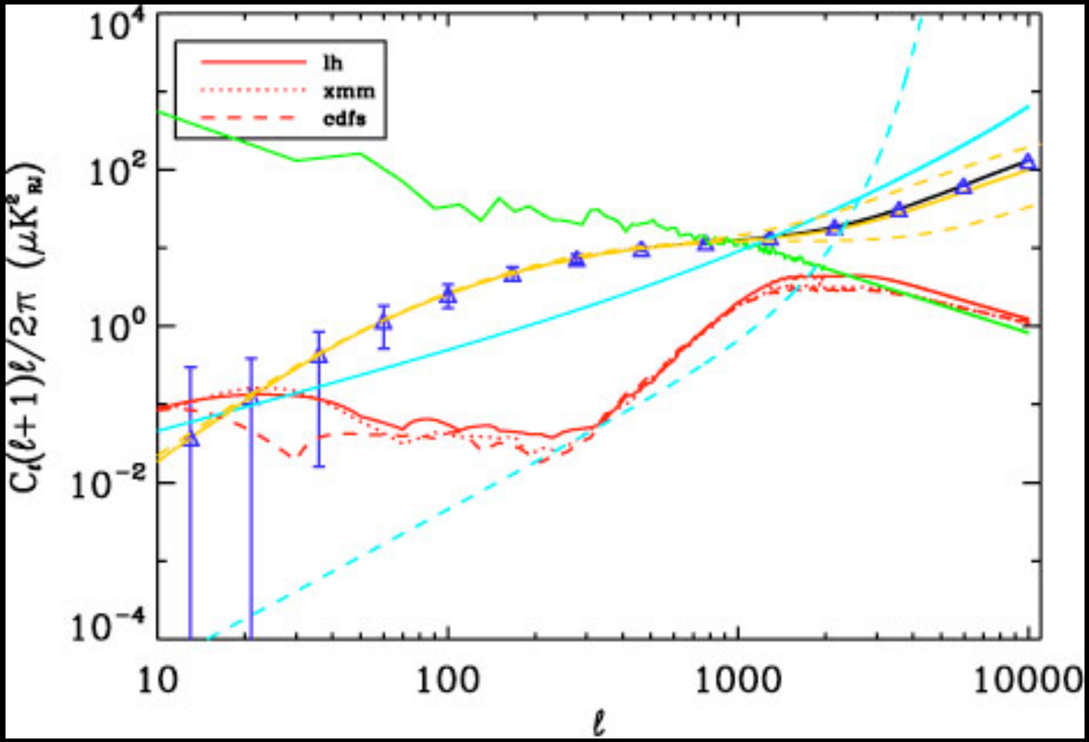
5. Large Scale Structure

Cooray, Maddox

Survey should detect ~300,000 sources with <z>~1, probe scales of 1000 Mpc at z=1.

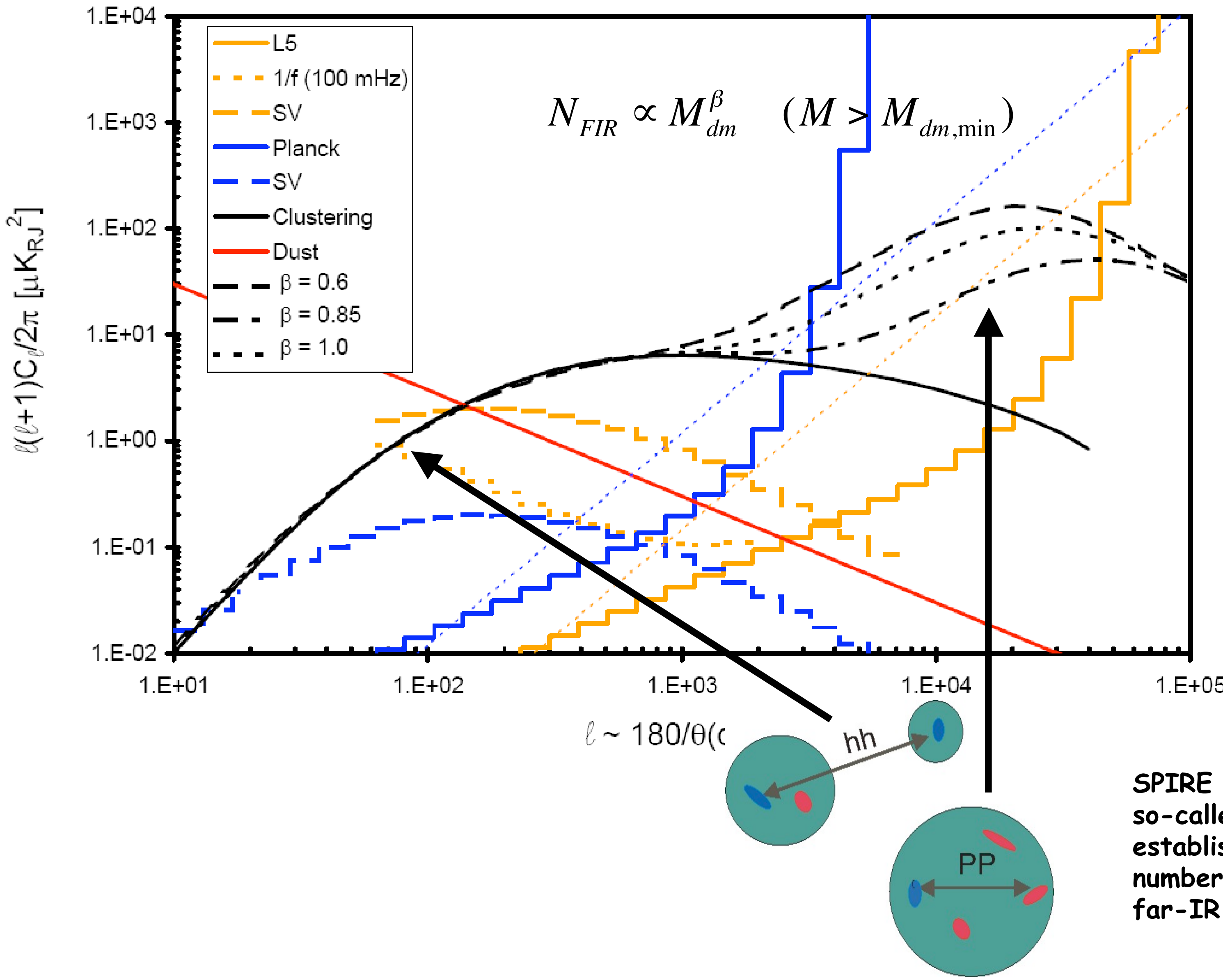
2 ways to measure LSS:

Resolved sources – clustering analysis. Tells us about the mass of halo this class of galaxy resides in.



Below confusion – fluctuation analysis. Measure power spectrum of unresolved sources. Large scale – average halo mass, small scales – halo occupation

350 microns: Herschel vs. Planck



SPIRE can probe the so-called 1-halo term to establish halo occupation number of unresolved far-IR galaxies

Dust/foreground separation

The signal received at each frequency can be modeled as the sum of the different signals contribution, and separated with a linear combination for each mode in spherical harmonic space :

$$a_{\ell m} = \sum_{freq=i} w_\ell^i a_{\ell m}^i \quad \text{with} \quad a_{\ell m}^i = c_{\ell m} + s_{\ell m}^i + d_{\ell m}^i + n_{\ell m}^i$$

Far-IR CMB Dust Noise

Then we minimize the resulting C_l for far-IR anisotropies

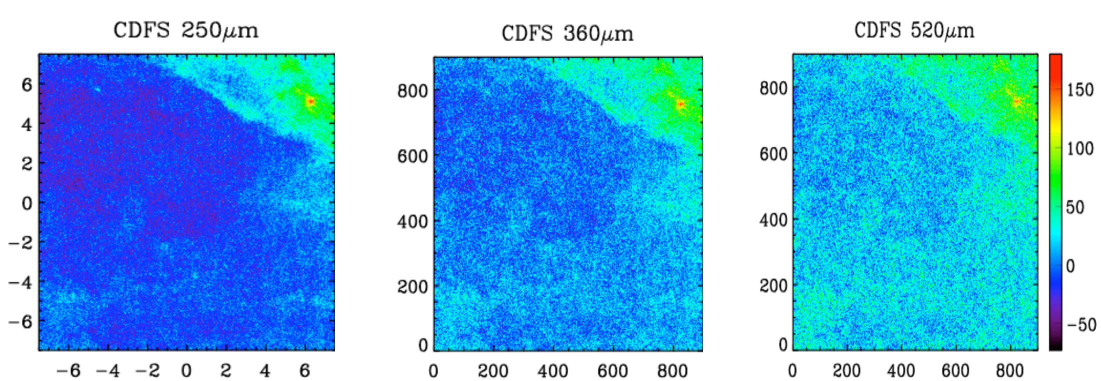
(modified from Tegmark et al. for CMB foreground removal)

Pros :

- only assumption : spectrum of the Cosmic far-IR background
- quite simple to compute

Cons :

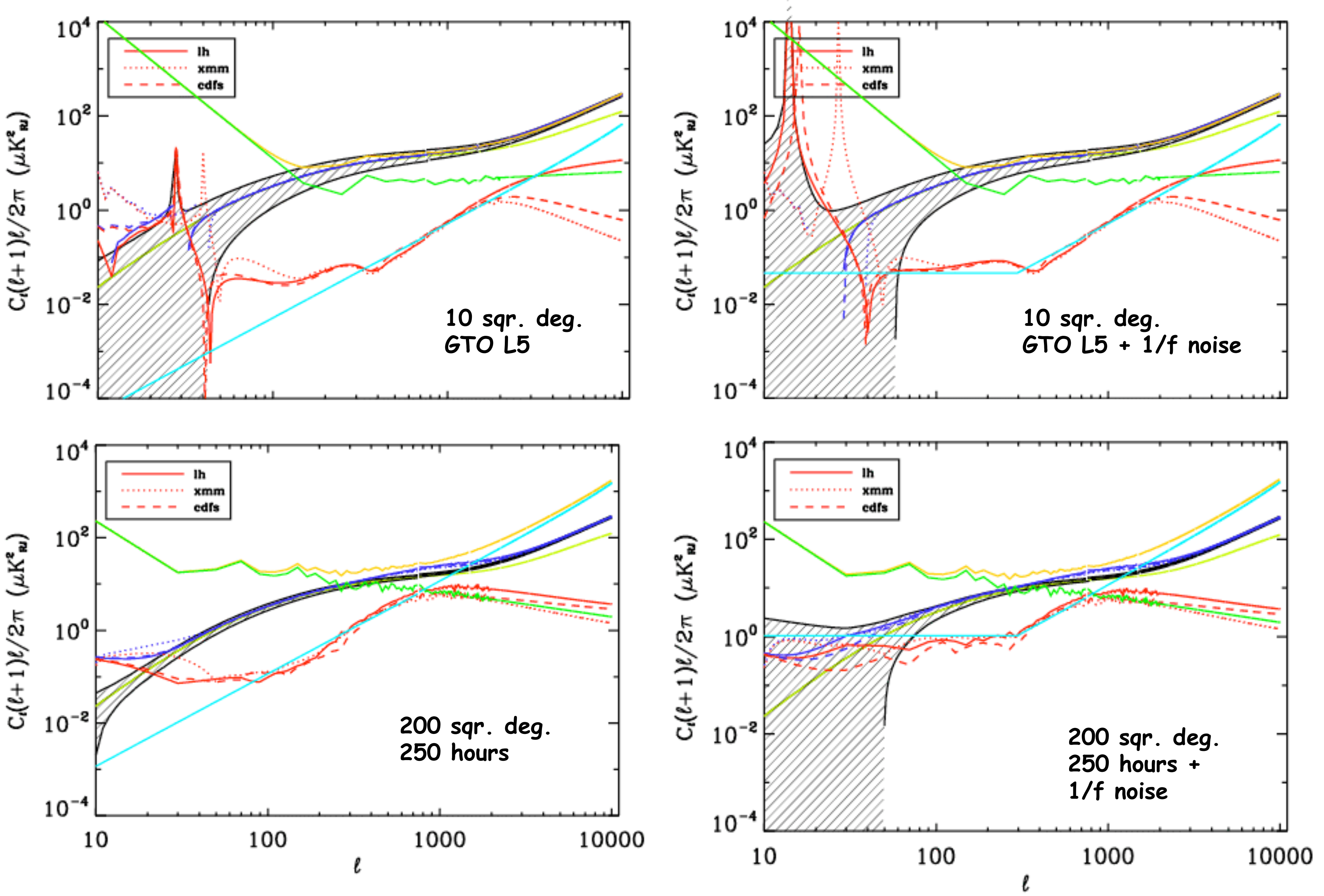
- no assumption on the noise ps
- not local (except if we cut the map in several pieces)



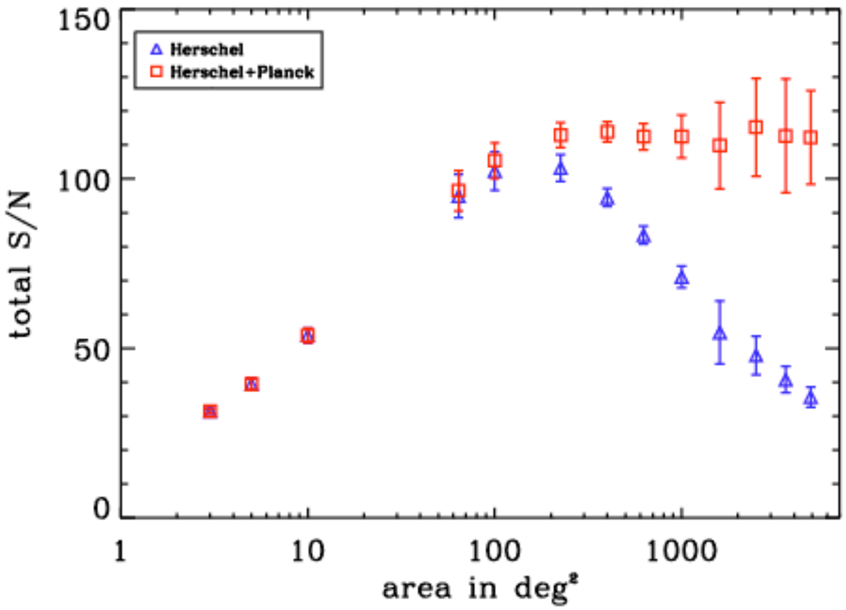
Need to know the spectrum beforehand.

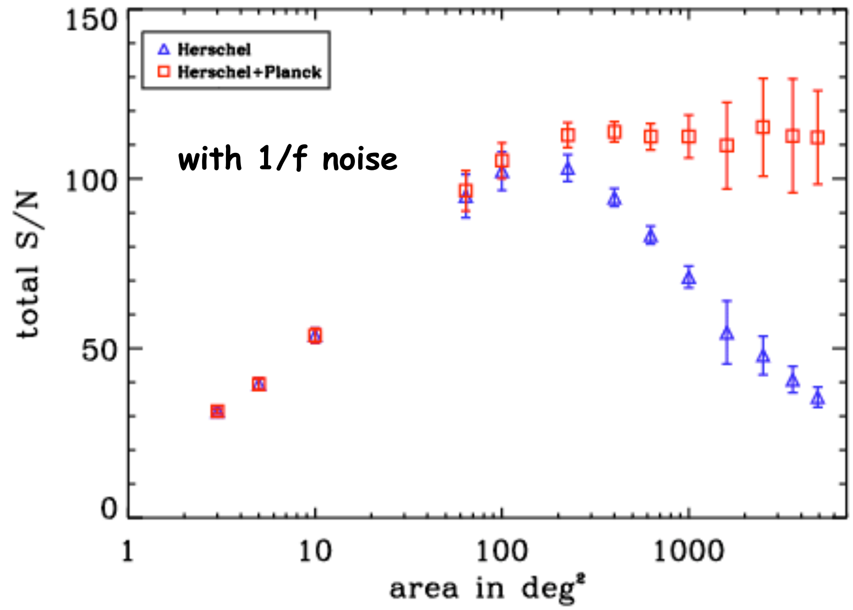
Can add uncertainty to the spectrum

Anisotropy power measurement

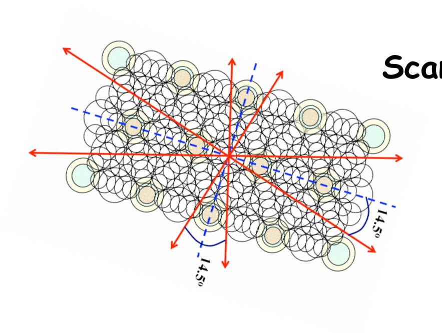


Signal-to-noises

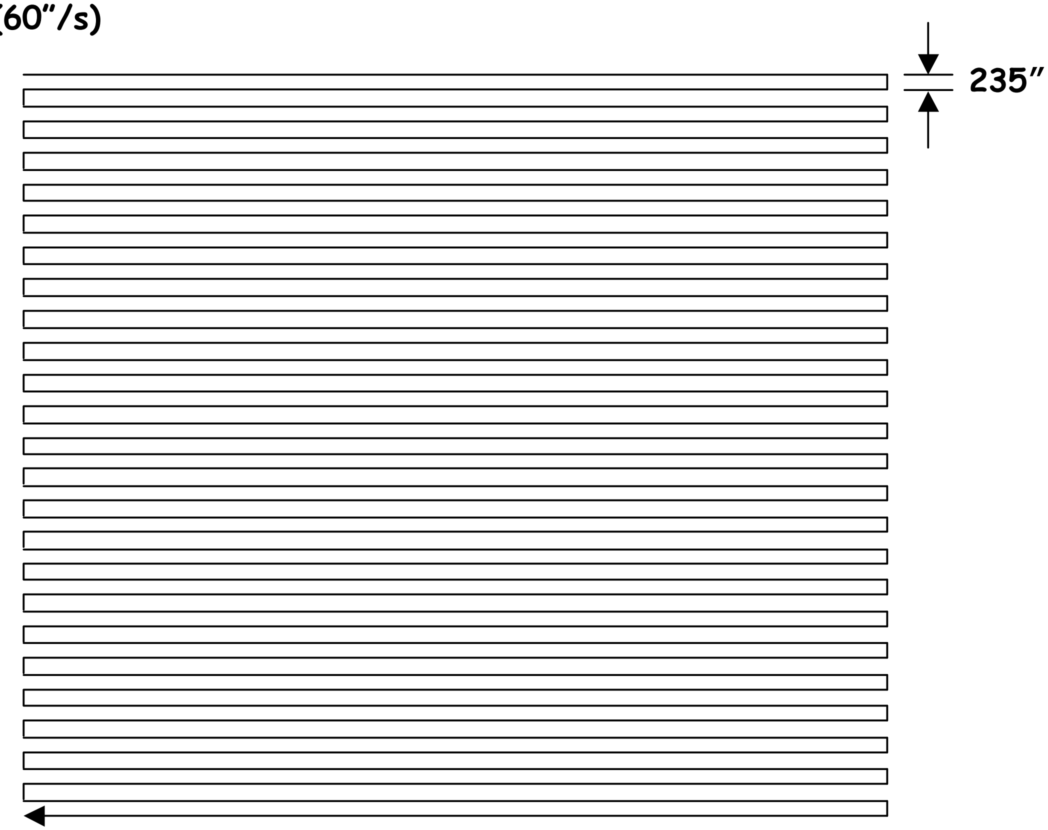




L5 Baseline Scan Strategy (1)

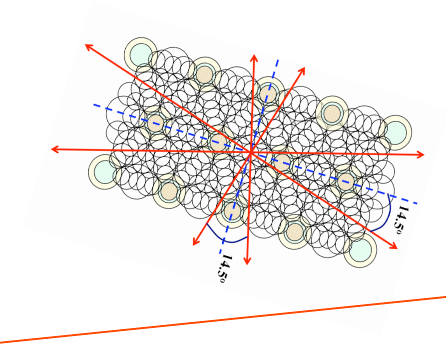


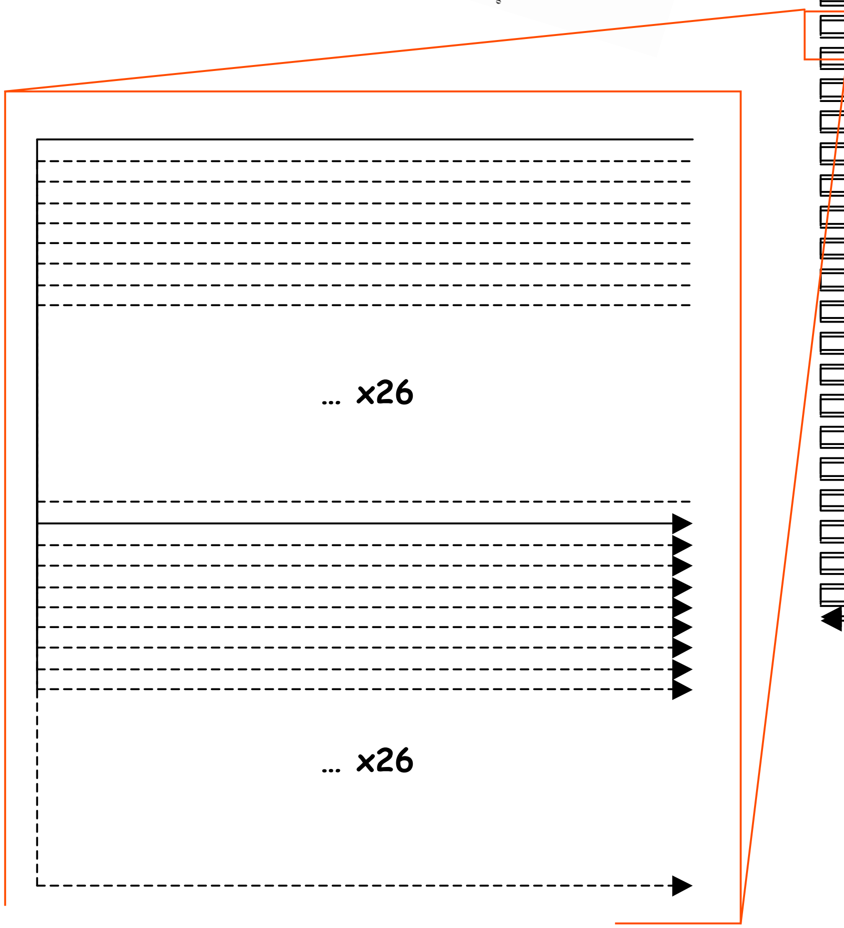
Scan at maximum rate (60”/s)



1) Drift scan along critical angle with 235” steps to make a Nyquist-sampled map
2) Repeat 26 times, stepping pattern by 9”
3) Repeat rotated by 90 degrees

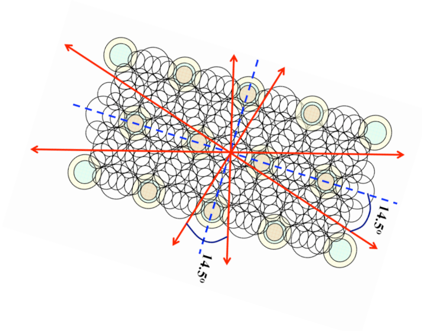
L5 Baseline Scan Strategy (2)

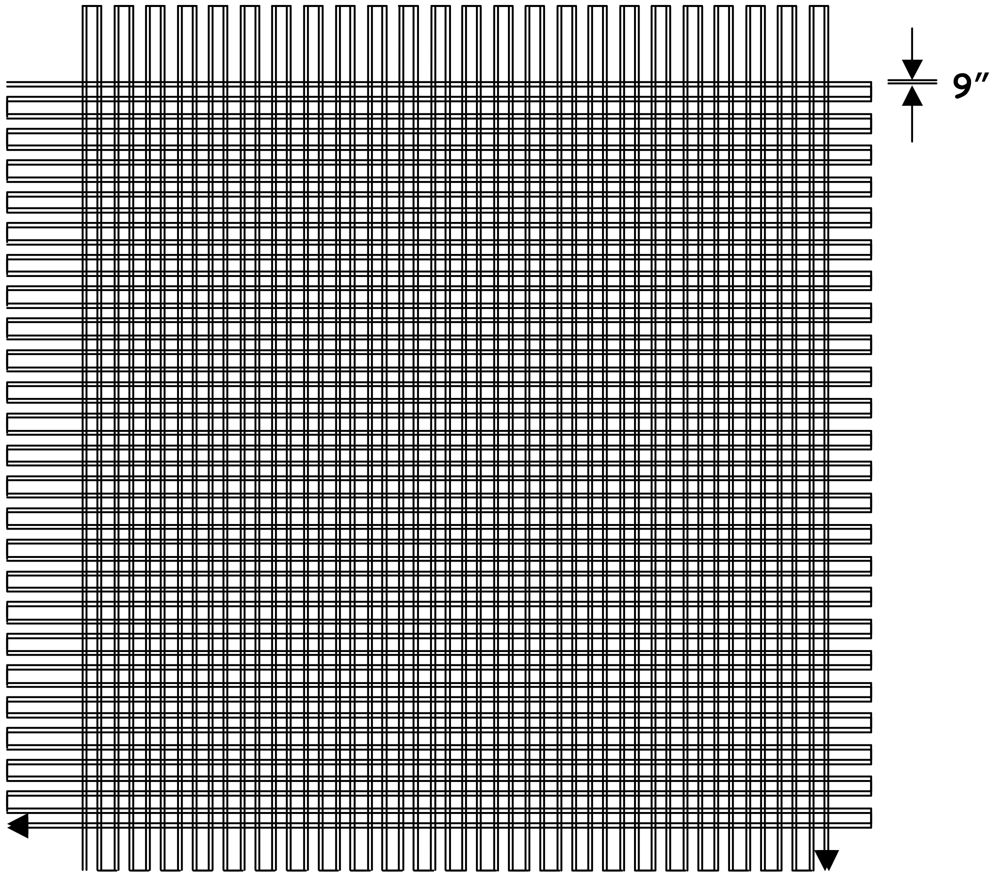




1) Drift scan along critical angle with 235" steps to make a Nyquist-sampled map
2) **Repeat 26 times, stepping pattern by 9"**
3) Repeat rotated by 90 degrees

L5 Baseline Scan Strategy (3)

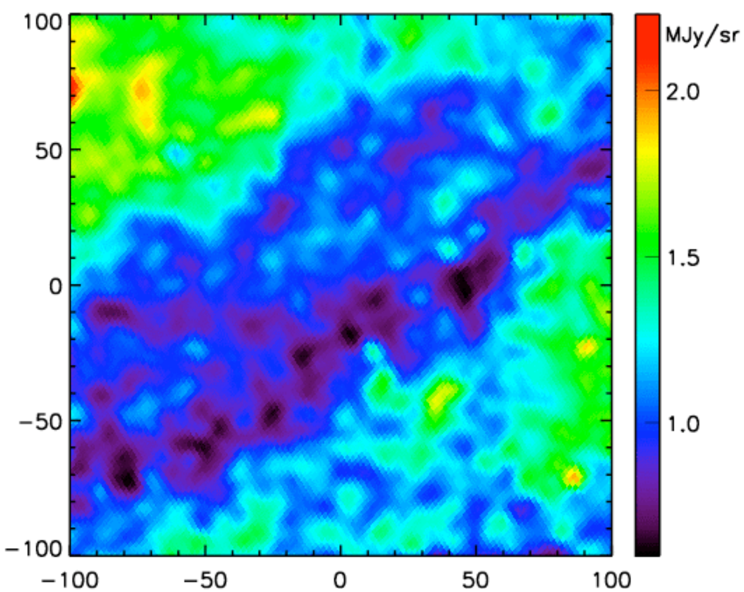


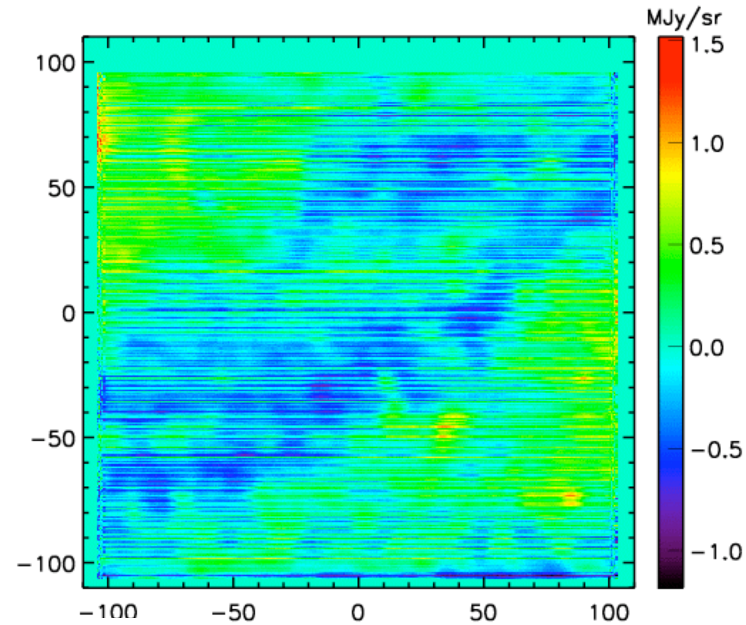


1) Drift scan along critical angle with 235″ steps to make a Nyquist-sampled map
2) Repeat 26 times, stepping pattern by 9″
3) **Repeat rotated by 90 degrees**

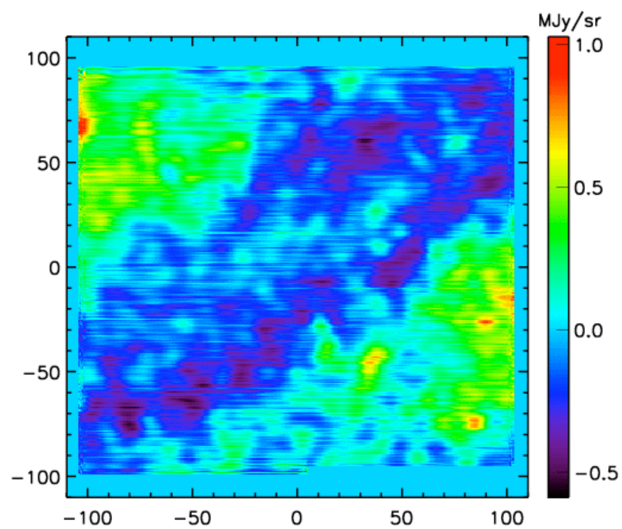
Where we are….

Simulate surveys & Characterize systematics





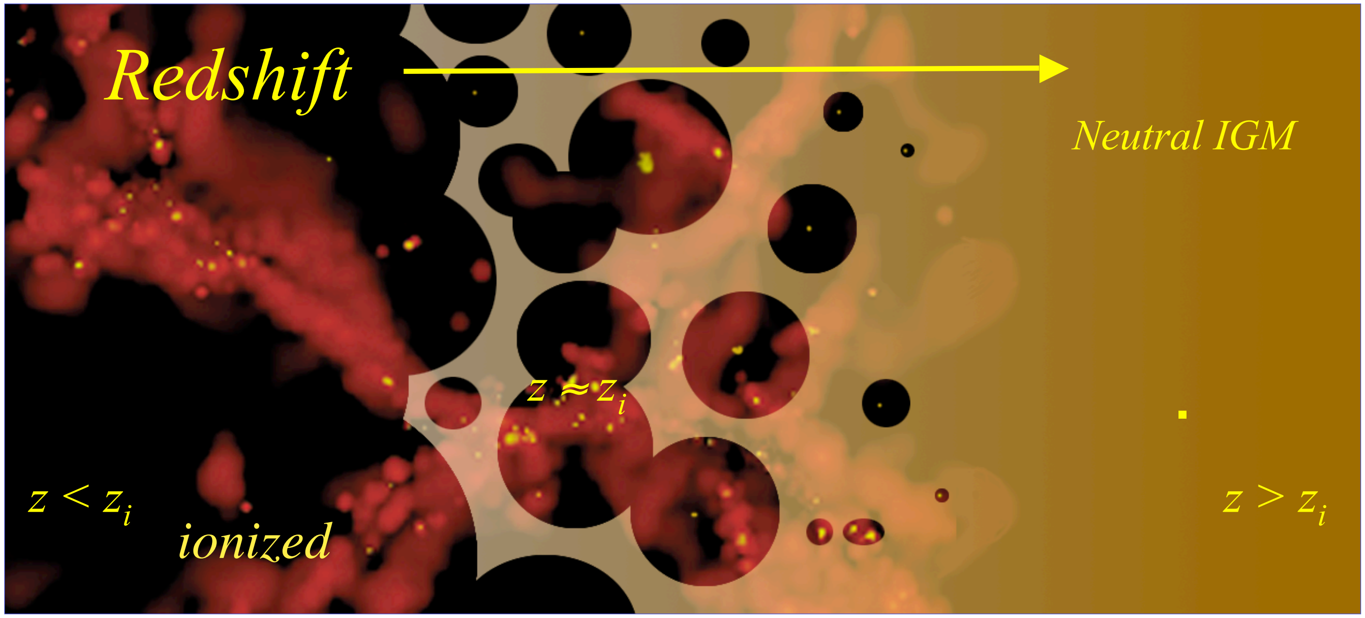
Input (11 deg^2

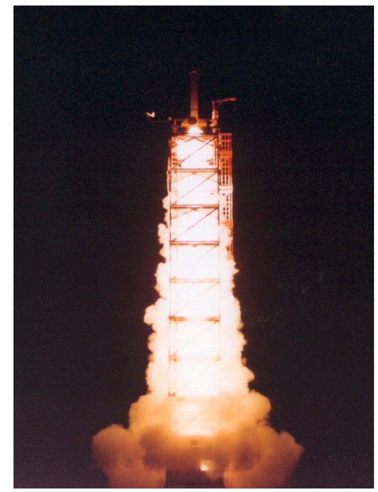


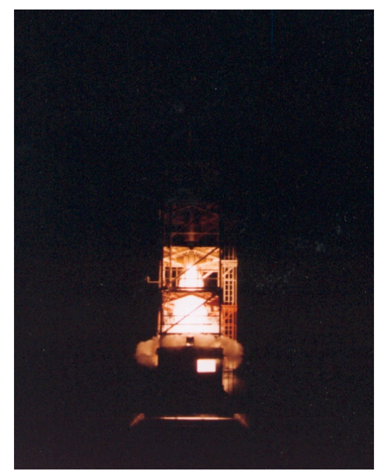
Output (1/f noise dominated)

Post-processed time stream data

Conclusions







Infrared backgrounds are cosmologically important

Current measurements are wanting in near-IR

- fluctuations
  - limited in l range,
  - no cohesive wavelength coverage
- no absolute spectroscopy from 0.8 – 1.4 μm
- uncertainty in Zodiacal light subtraction (CIBER soon)

Far-IR: Herschel will soon open up far-IR sky in detail for survey studies