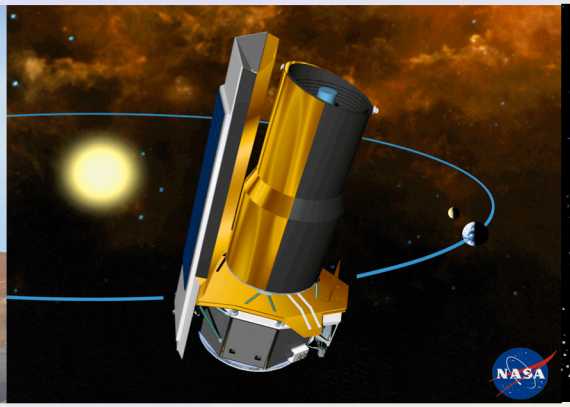
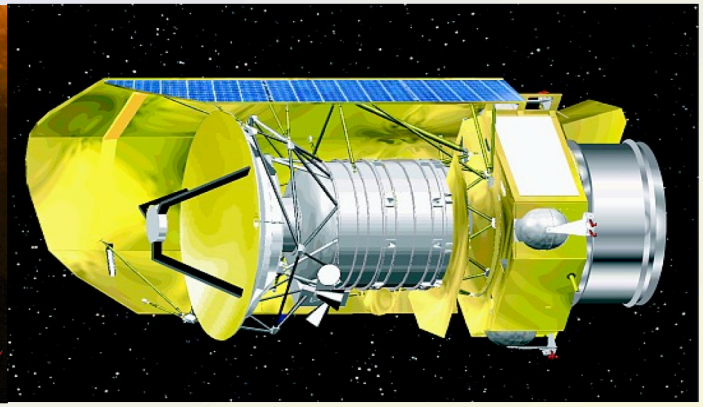
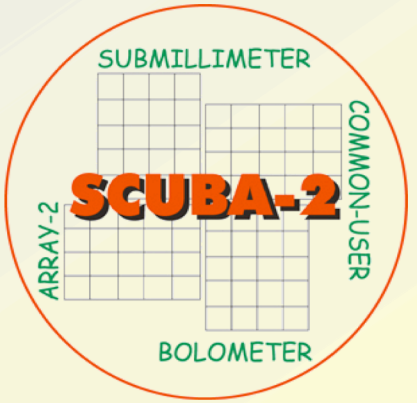
A FIR & Sub-mm View on Galaxy Formation & Evolution

Taking Stock of Spitzer & SCUBA

Planning for (Herschel & SCUBA2 &) Dome C







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Thanks also to Carol, Jim, Matt, Michael, Seb & all the ISOCAM, ELAIS, SHADES, SWIRE, SPIRE & SCUBA2 folks

Introductory Considerations

- Science case for a large far-IR and sub-mm single-dish telescope (either in space or from dry ground sites) was already discussed at length during the last 10 yrs

- Particularly noteworthy are the *ASTRONOMY AND ASTROPHYSICS IN THE NEW MILLENNIUM* 2001 decadal survey of the US National Research Council (NRC) and the "Cosmic Vision" process developed by ESA which both recommended a Far-Infrared Observatory (see e.g. FIRI)

- A South Pole Sub-mm Telescope (not the > 1 mm SPT!) was also recommended by the NRC (but not pursued!)

*The effects of dust extinction and the **degeneracy of optical observables***

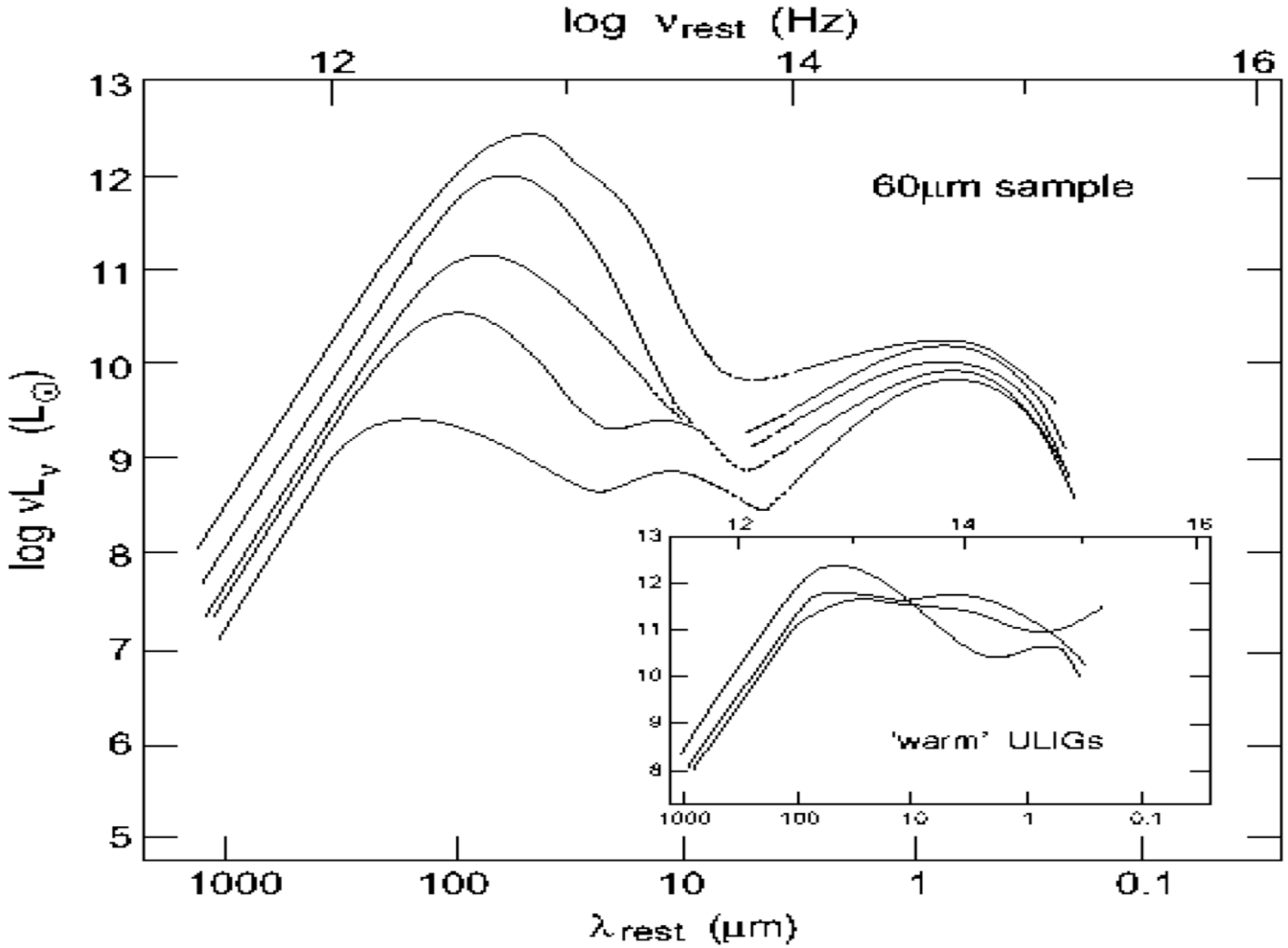


Figure 2 Variation of the mean SEDs (from submillimeter to UV wavelengths) with increasing L_{IR} for a 60 μm sample of infrared galaxies. (*Insert*) Examples of the subset ($\sim$ 15%) of ULIGs with "warm" infrared color ($f_{25}/f_{60} > 0.3$). Data for the three objects (1—the powerful Wolf-Rayet galaxy IRAS 01002–2238, 2—the "infrared QSO" IRAS 07598+6508, 3—the optically selected QSO I Zw 1) are from Sanders et al (1988b).

Key Scientific Goals in Galaxy Formation & Evolution

- Resolving the CIRB into individual sources
- Characterizing the primeval galaxies and forming QSO's and study them spectroscopically
  - Observe star formation to z > 5
  - Role of AGN in galaxy formation
  - Chemical and luminosity evolution of galaxies
  - Assembly of Milky-Way type galaxies

The "astronomical facility" context

- Many of the telescopes planned for the next few decades are designed to observe high-redshift galaxies in the process of formation. These instruments, such as JWST, ALMA and ELTs will have sufficient sensitivity and resolution to observe detailed structure within protogalaxies
- They will not, however, have sufficient field of view to survey large areas of sky and discover objects to study
- Protogalaxies typically have a flux density at 450μm which is < 10 mJy. ALMA can detect such a source in 3 minutes. That's really fast. The size of an ALMA map, however, is 2×10^{-5} square degree, so to survey a square degree at this sensitivity would require ~ 100 days.
- If ALMA were dedicated to a sky survey for ten years, it would be able to cover about 0.1% of the entire sky

The "astronomical facility" context

- Let's assume a Dome C telescope configuration with
  - 12-m diffraction-limited performance at 200 μm (⇒ 900 μm)
  - operations at 10-40 μm with with a *somewhat degraded* PSF
- Its main competitors would be ALMA, APEX, JCMT & JWST but:
  - ALMA will NOT operate at λ < 450 μm (at least < 2015)
  - ALMA will in any case NOT be a survey telescope
  - SCUBA2@JCMT will operate at 450 μm but only in very good weather and at very low mapping speeds
  - APEX will NOT operate at λ < 350 μm
  - JWST will NOT work at λ > 25 μm
  - Dome C might potentially compete with JWST for spectroscopy due to x 4 in collecting area at λ~10-25 μm and complement it at λ ~ 25 - 40 μm
  - NB : SPICA will operate throughout the 10-200 μm range employing much faster detectors than Herschel's but will still be hampered by the same small (3.5 m) aperture and thus by extragalactic confusion

Spitzer MIPS Counts : 24 μm

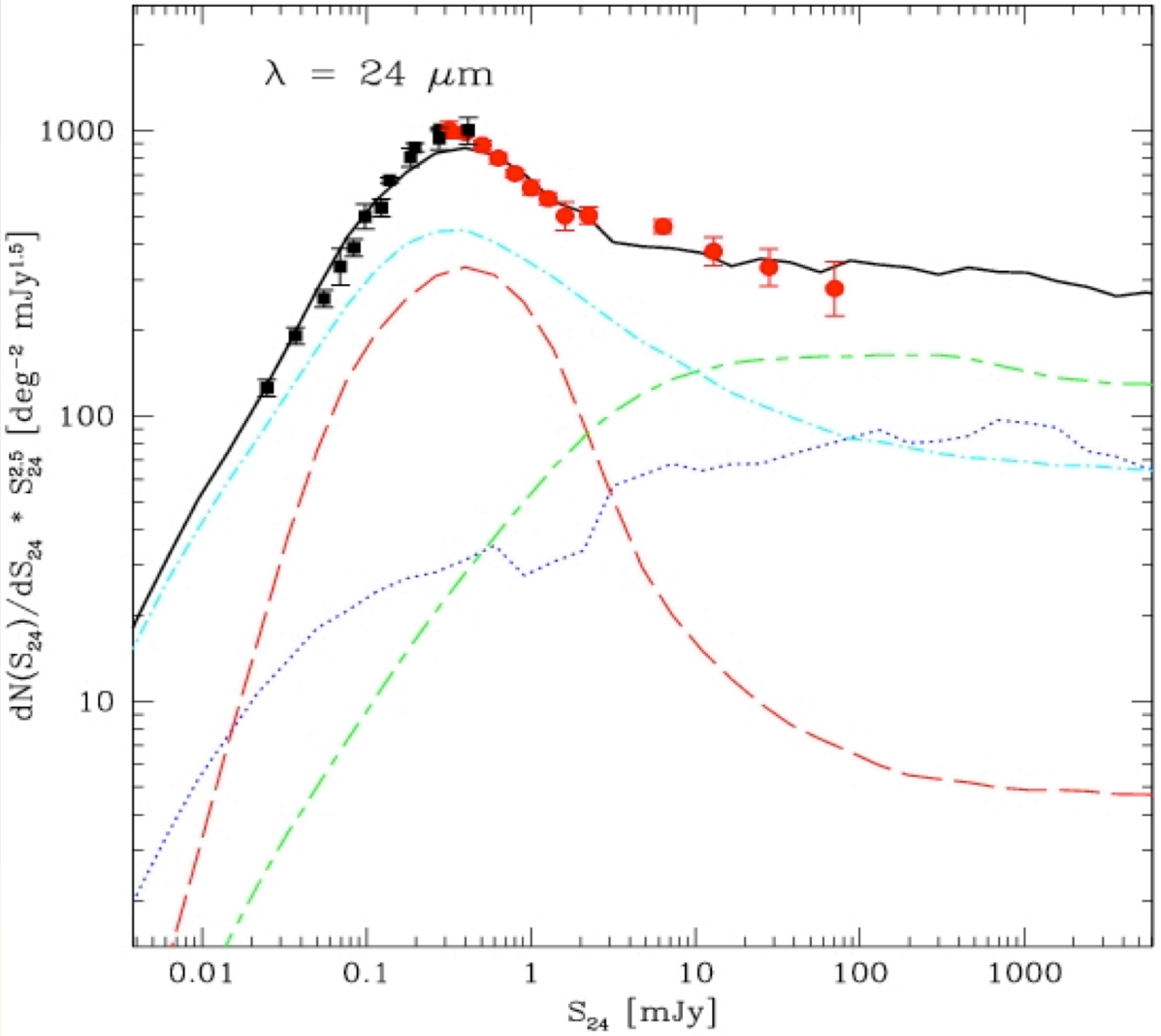
SWIRE (Shupe in prep)
GTO (Chary 04)

but also (not shown)

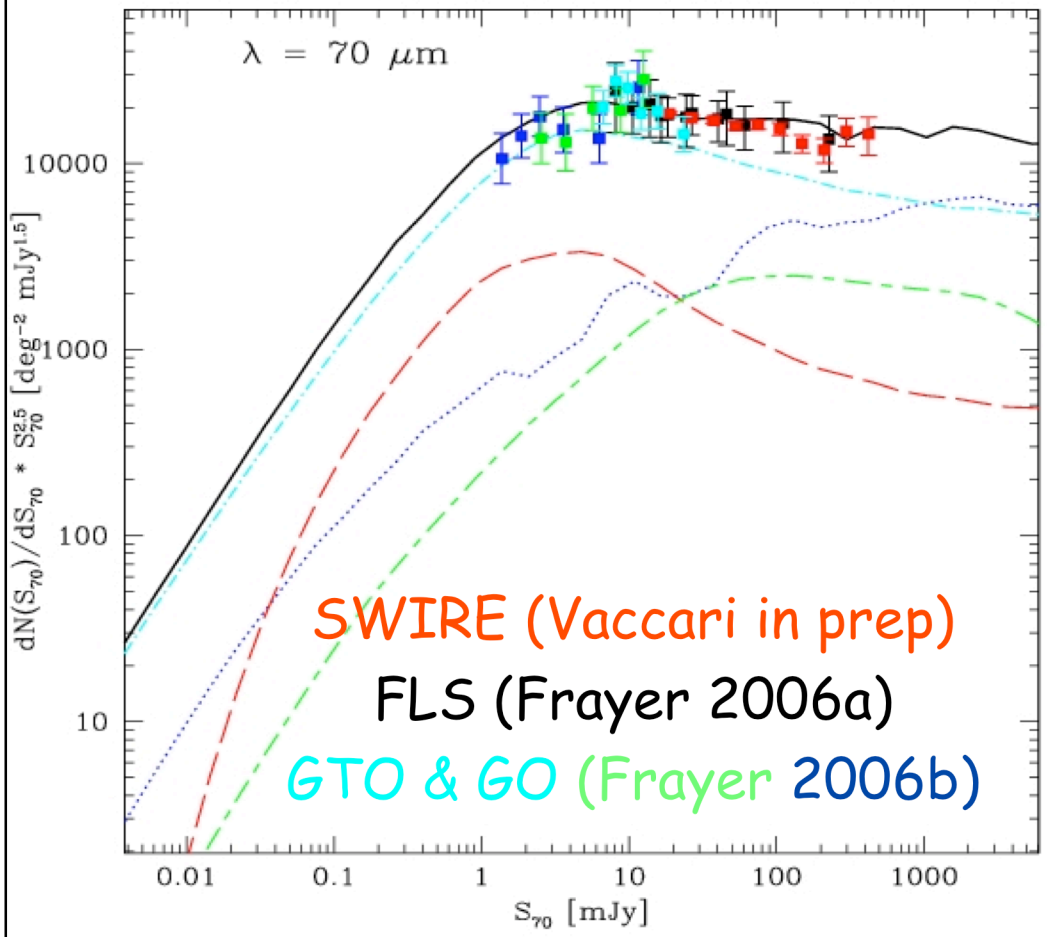
GTO (Papovich 04)
FLS (Fadda 06)

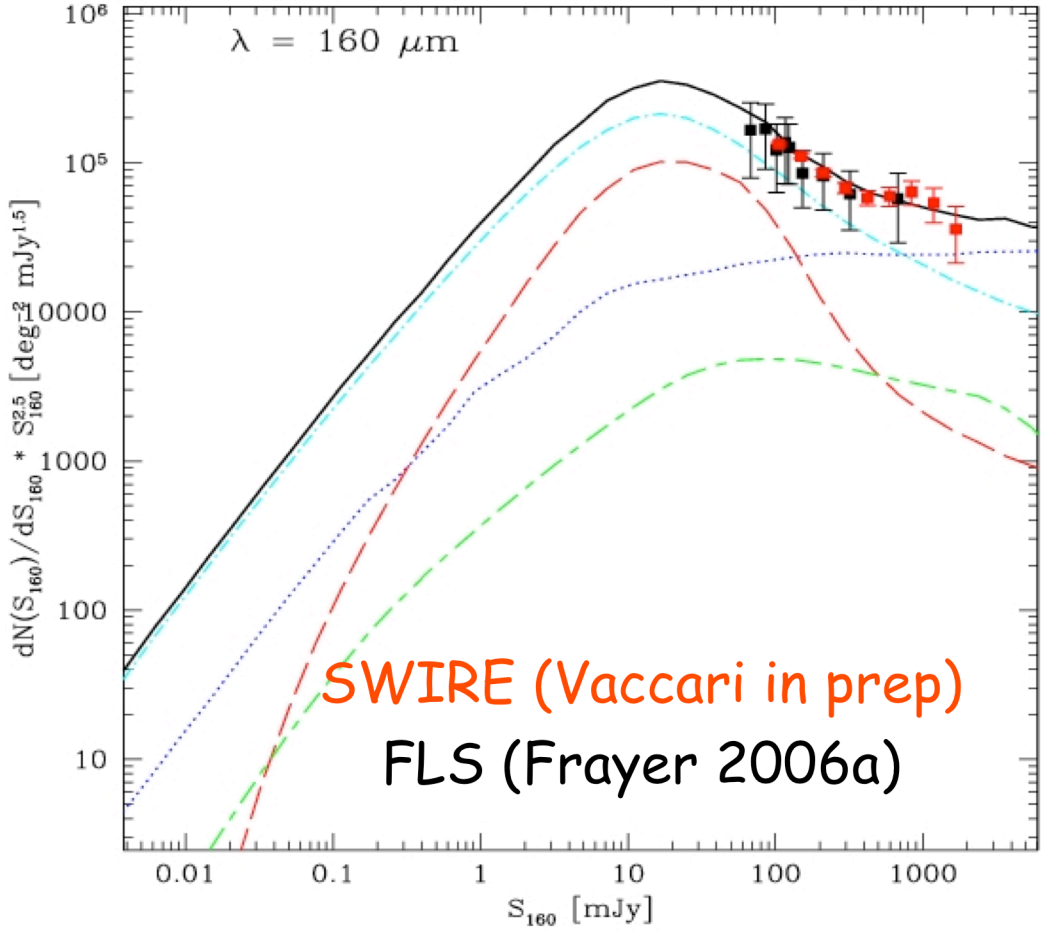
Remarkable agreement!

Most stringent constraint provided by Spitzer to date



Spitzer MIPS-Ge Counts : 70 & 160 μm

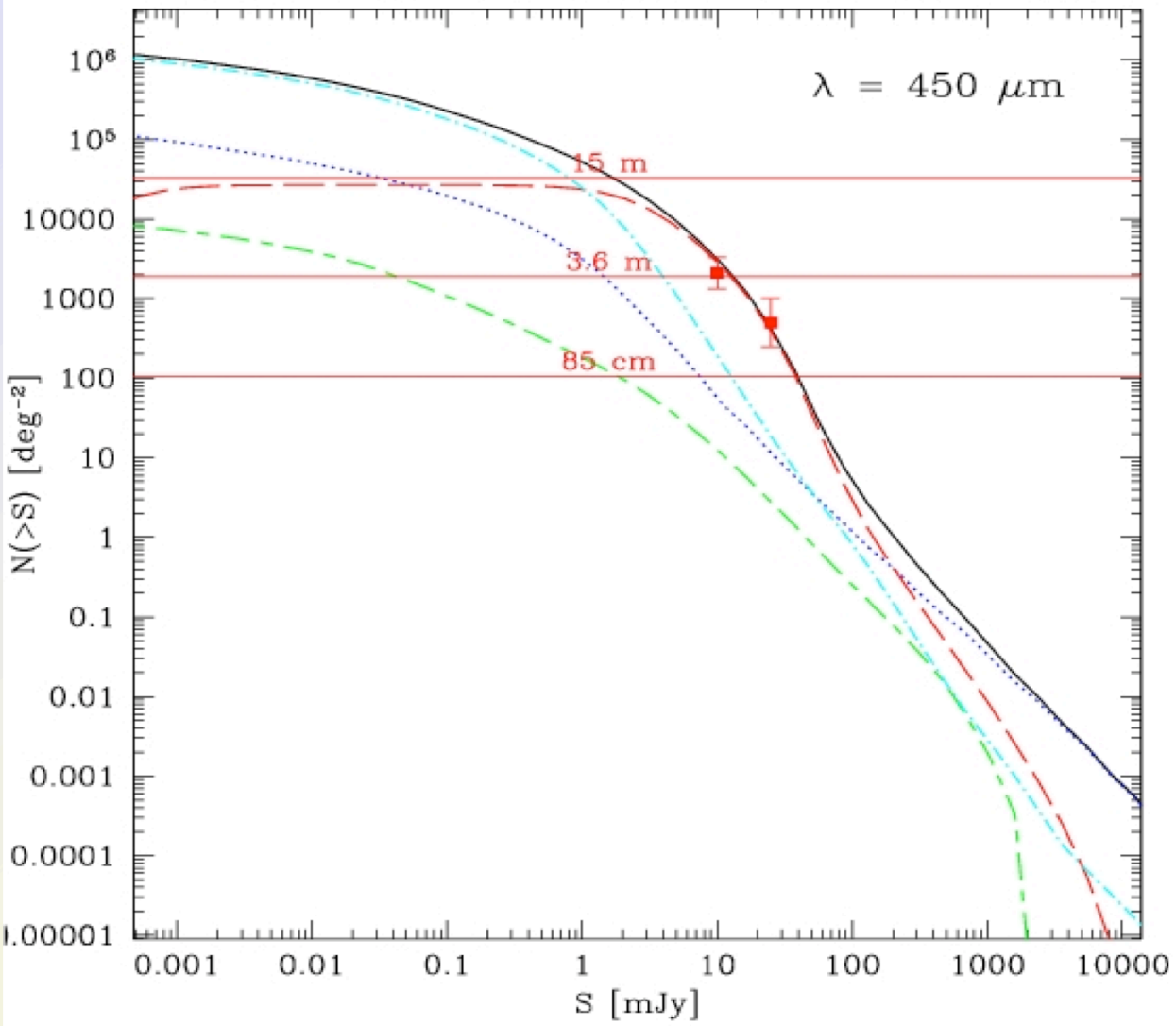




Reasonable agreement but comparison is hampered by poor areal coverage and sensitivity at 70 and 160 μm respectively

First Hints At Herschel Counts
450 μm SCUBA Counts

Smail et al. 2002



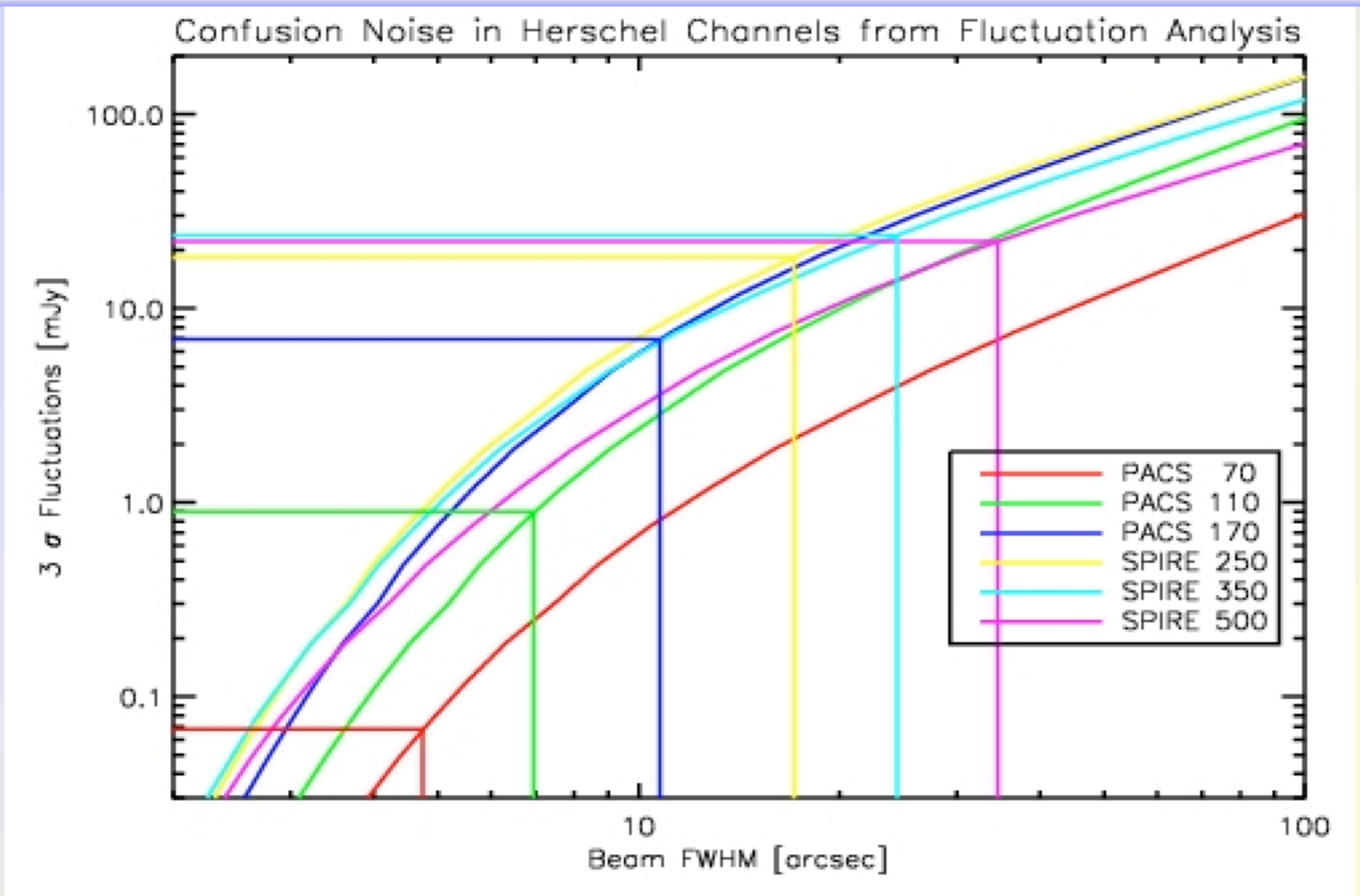
Extragalactic Confusion

- Two methods are routinely used to evaluate EG confusion
  - The "Fluctuations" approach measures fluctuations in the background due to unresolved sources and sets confusion at q (e.g. q=3,4,5) times that level
  - The "Counts" approach measures source counts and sets confusion where a maximum number of sources per beam,(or rather a minimum number of beams per source, e.g. bps=10,30,50) is reached
- Values provided by the two mostly depend on what's happening
  - fainter than the confusion limit (Fluctuations)
  - brighter than the confusion limit (Counts)
- Roughly speaking, the level of agreement between the two approaches depend on the slope of the counts ~ AT the confusion limit
- Generally, and particularly so for "worthy" projects

  expected confusion limits <~ current detection limits

  and as a consequence estimating confusion levels can be thorny but also provide you with some remarkably passionate friends & enemies

"Fluctuations" Criterion



What might be in it for you?

- A handy modeling code & simulation tool generating
  - source counts
  - redshift & luminosity distributions
  - mock catalogues

at a complete set of relevant FIR & sub-mm wavelengths

- A companion tool to estimate confusion limits based on the model above as well as on competing models

- A set of simulated surveys reproducing lots of completed & planned surveys by ISO, Spitzer, Herschel, Planck, Akari, SCUBA2 (and soon SPICA & FIRI?), e.g. the Herschel GT Wedding Cake and the SCUBA2 Legacy Surveys

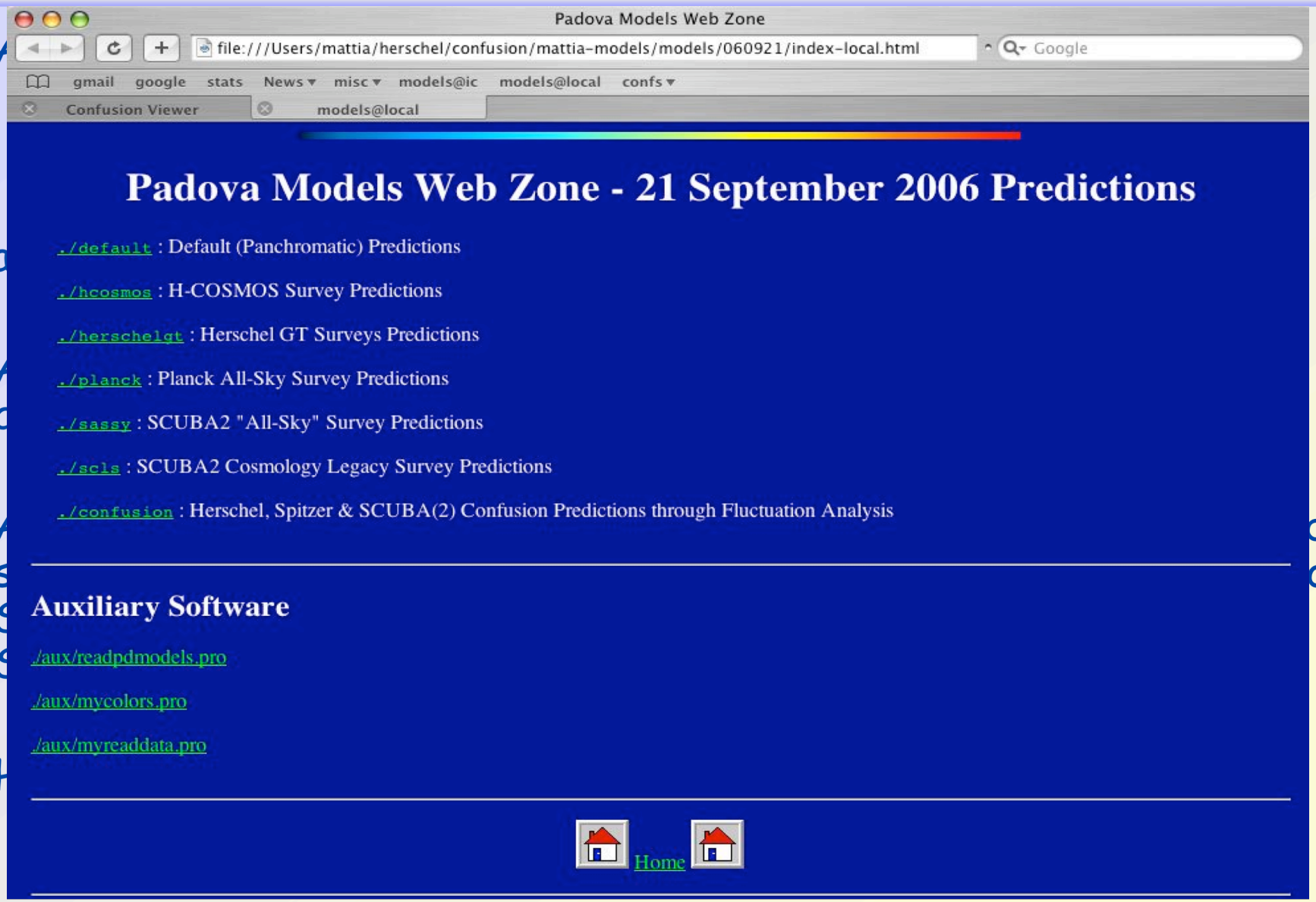
- Hopefully sometime soon publicly available through the www

What might be in it for you?

- A

at a

- A
  a
- A
  s
  S
  s
- H



d

on

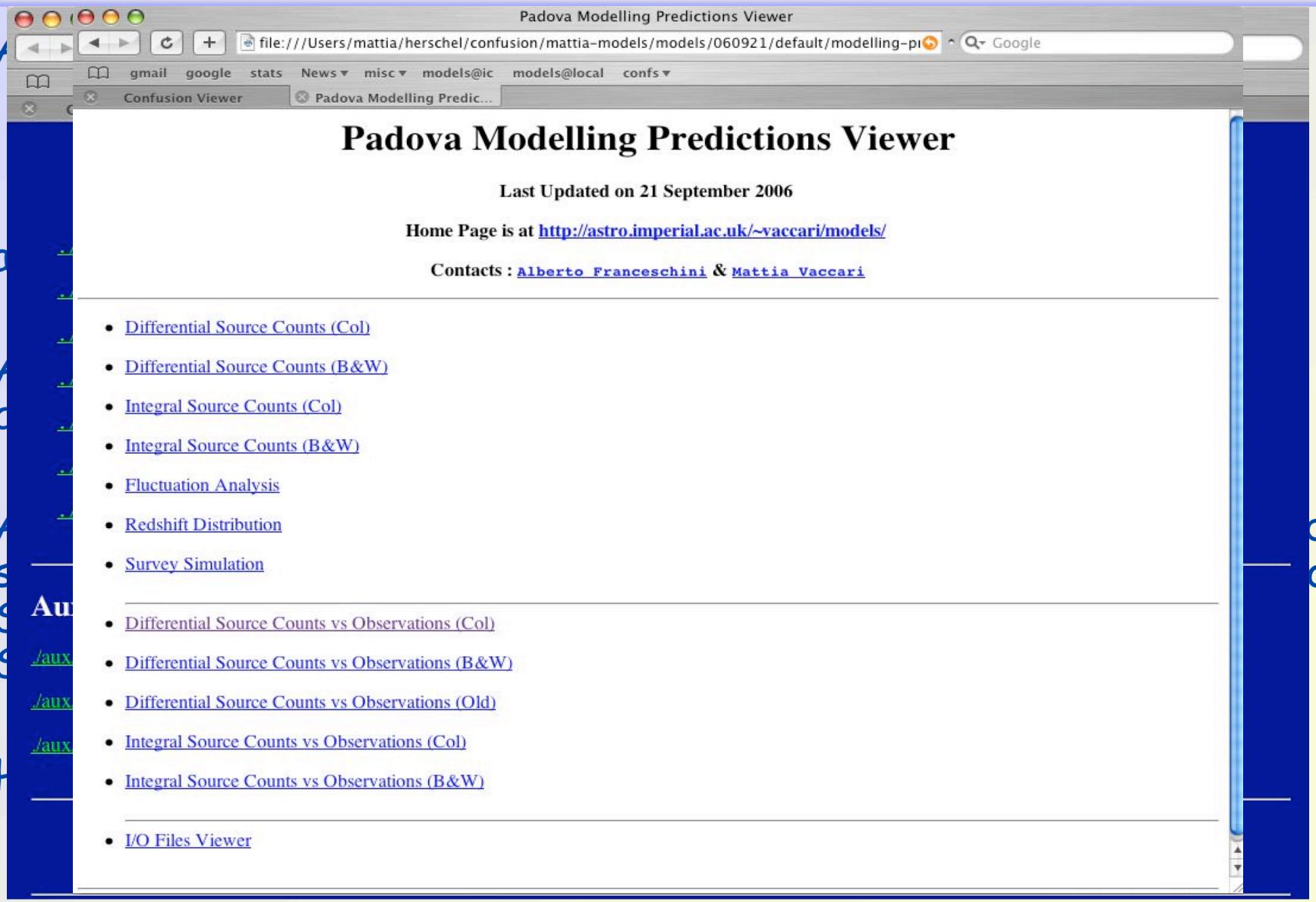
What might be in it for you?

- A
- A
- A
- H

at a

d

on



What might be in it for you?

- A
- A
- A
- H

at a

d

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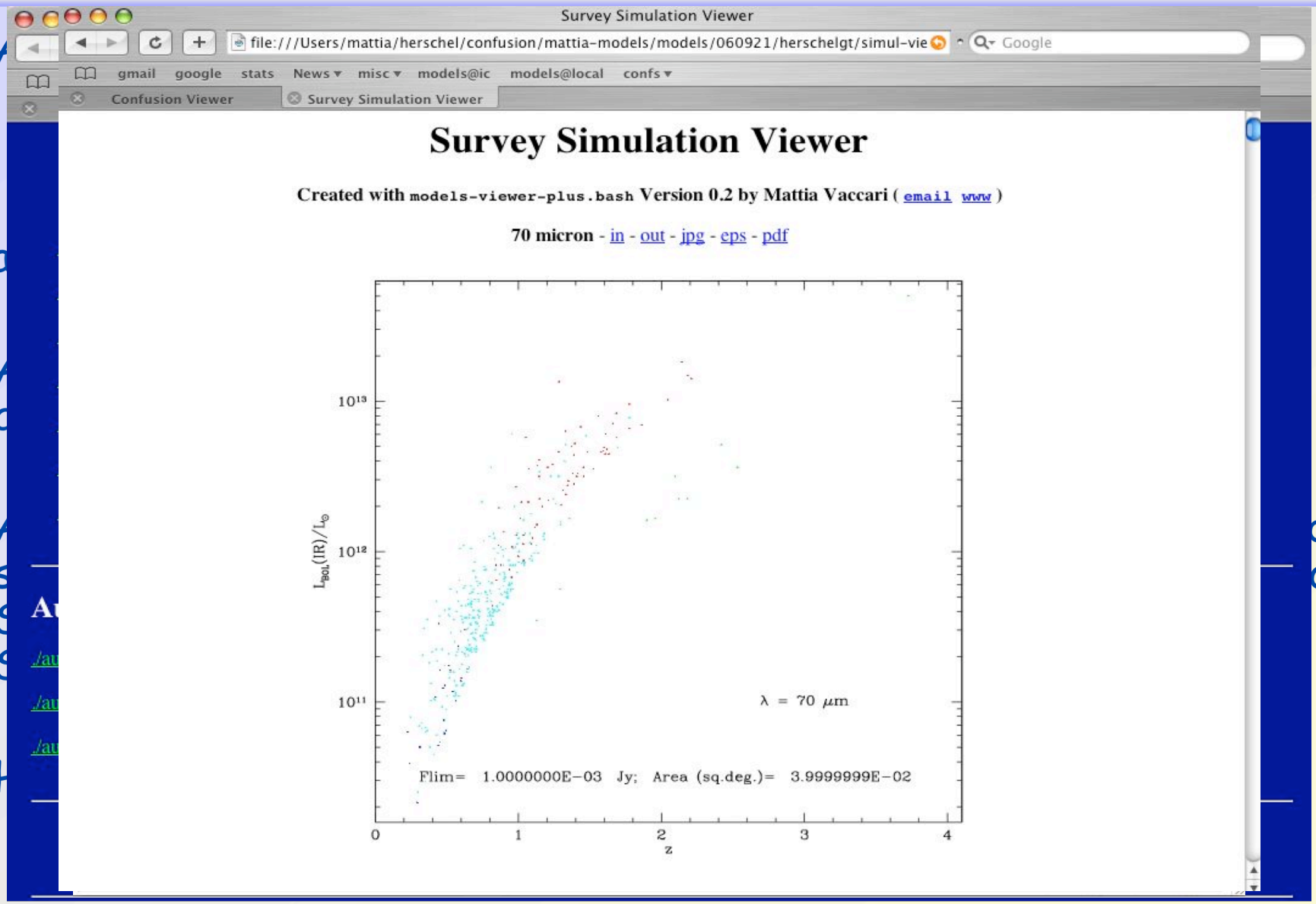
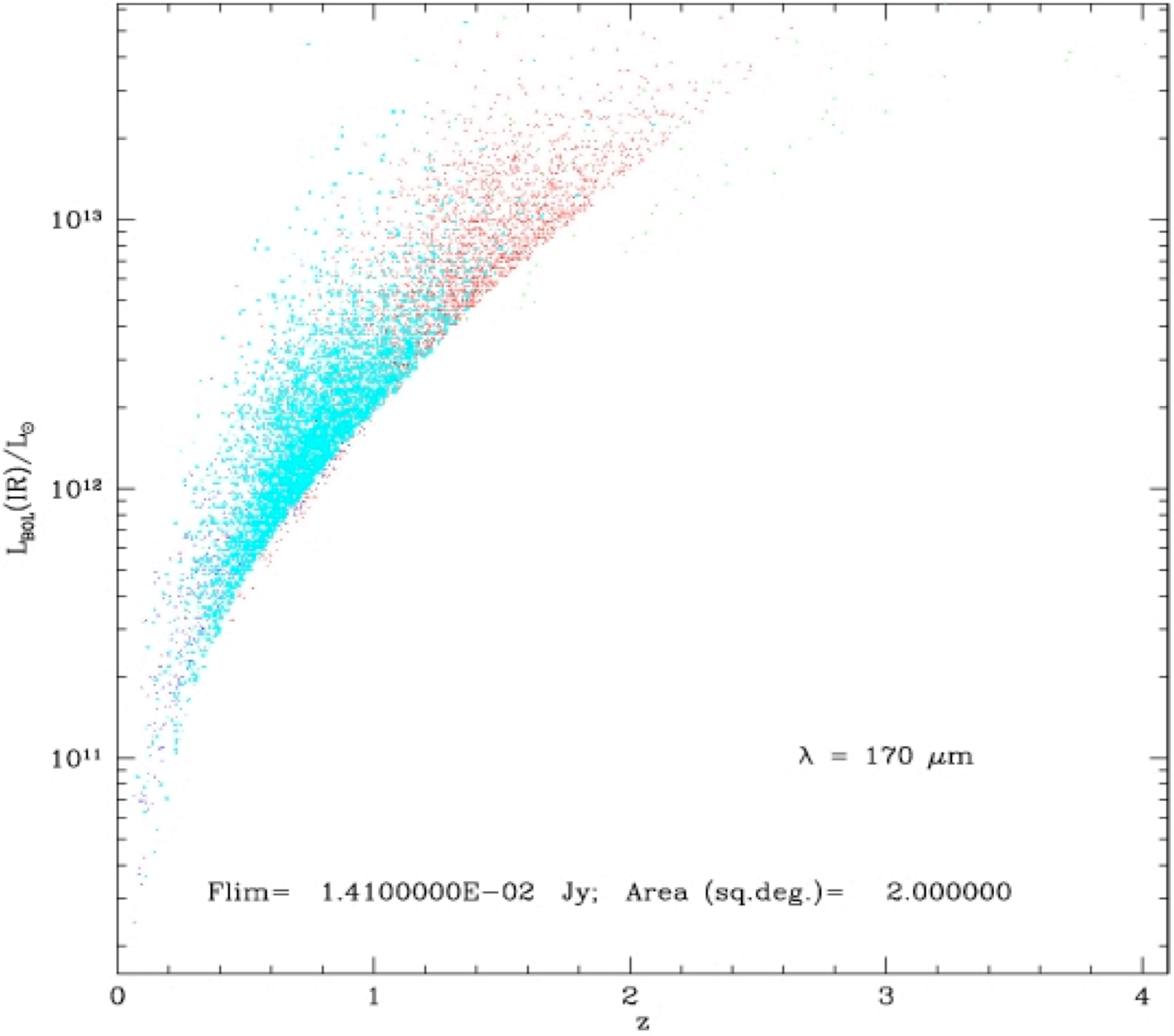
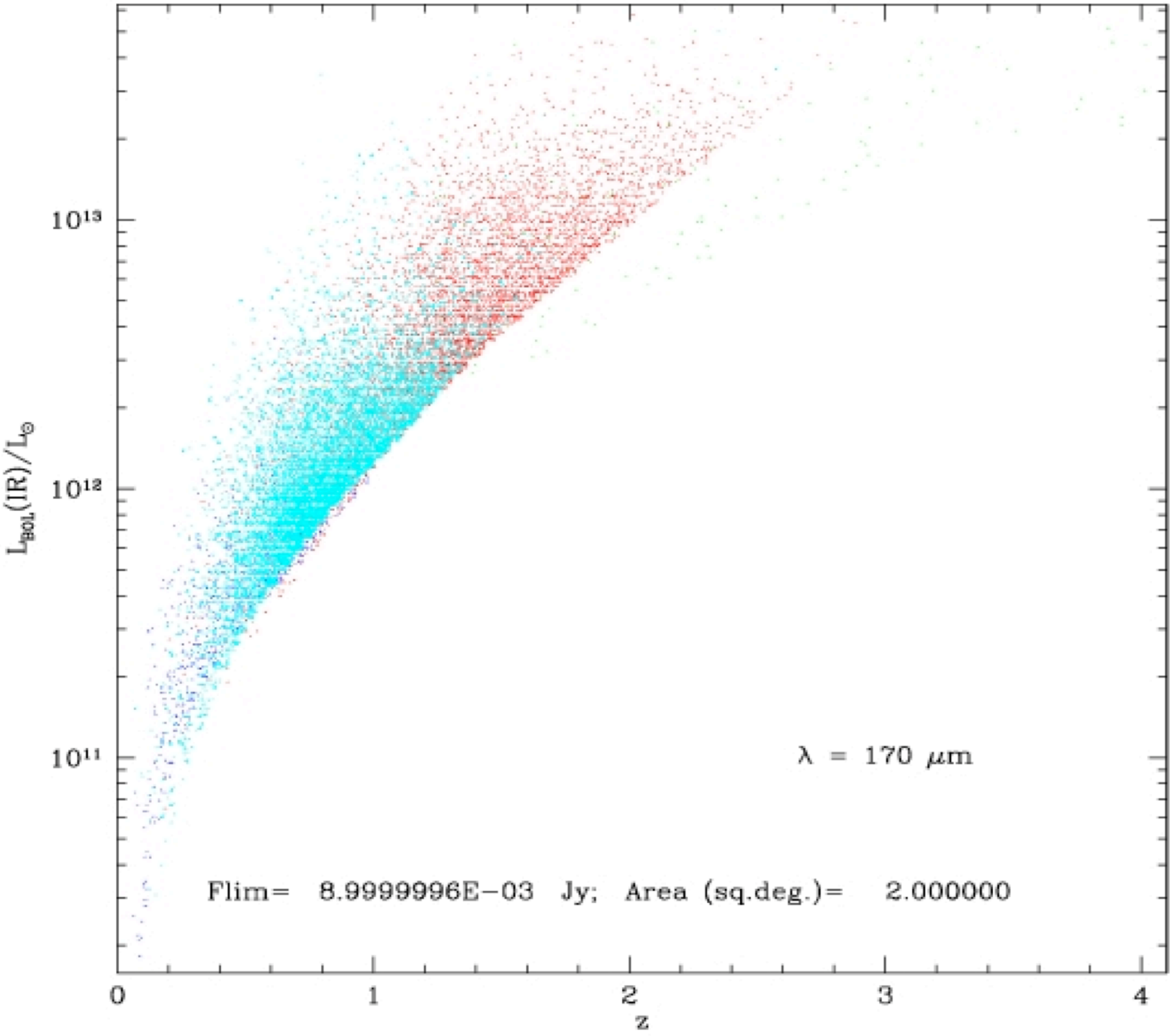
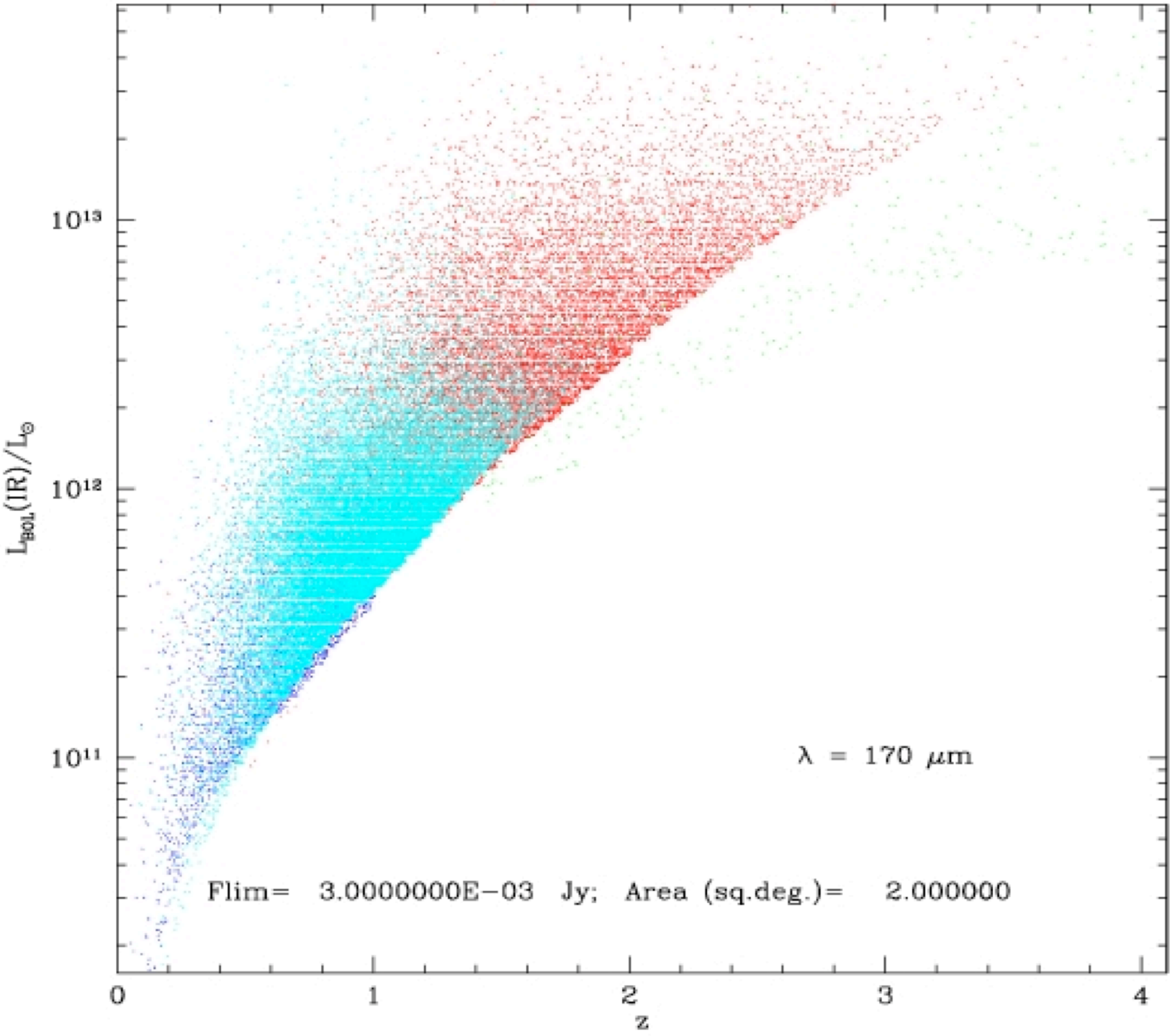


Simulations @ 170 μm

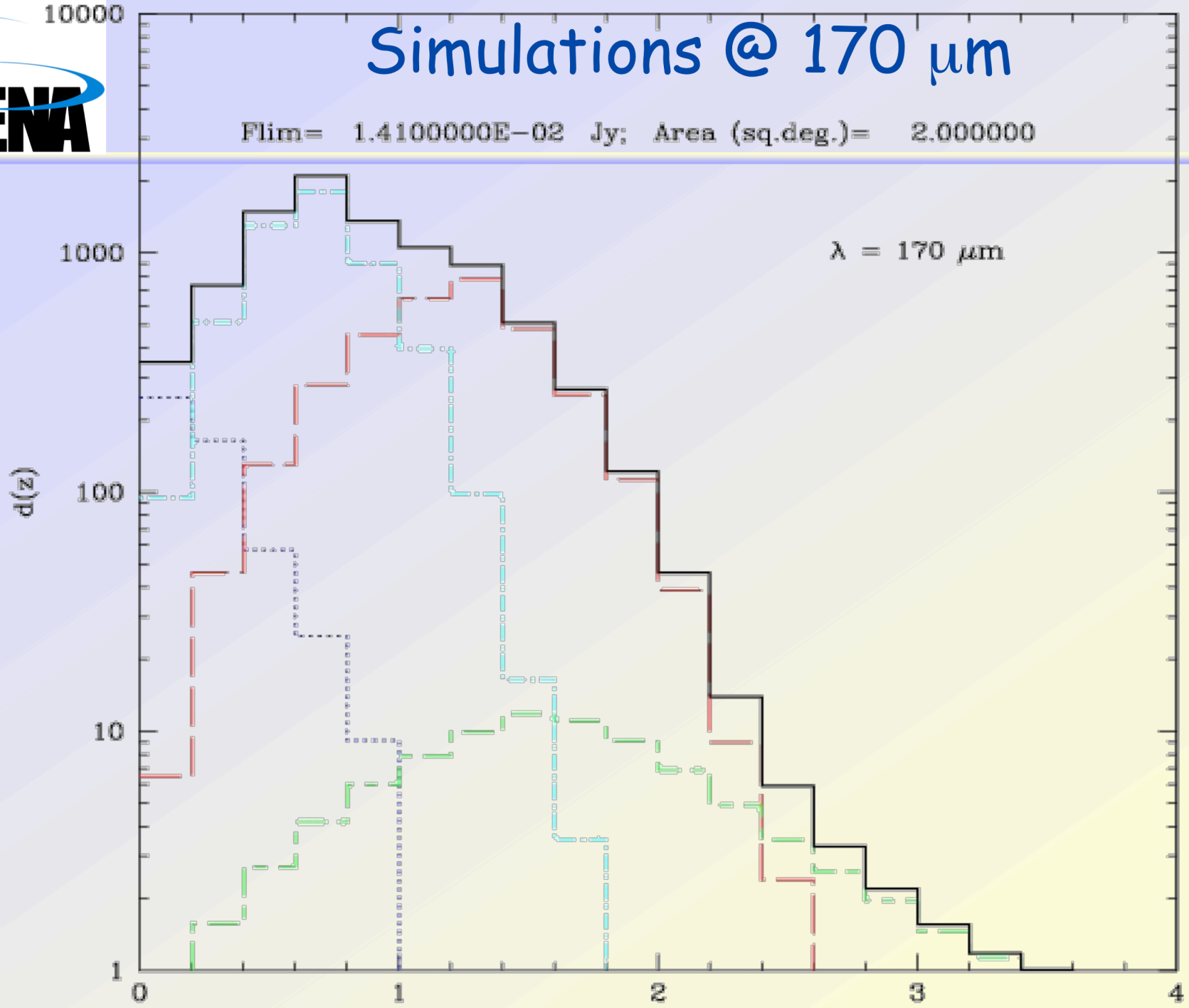

10^{13}
10^{12}
10^{11}
$L_{BOL}(IR)/L_{\odot}$
λ = 170 μm
Flim= 1.4100000E-02 Jy; Area (sq.deg.)= 2.000000
0
1
2
3
4
z


10^{13}
10^{12}
10^{11}
$L_{BOL}(IR)/L_{\odot}$
λ = 170 μm
Flim= 8.9999996E-03 Jy; Area (sq.deg.)= 2.000000
0
1
2
3
4
z

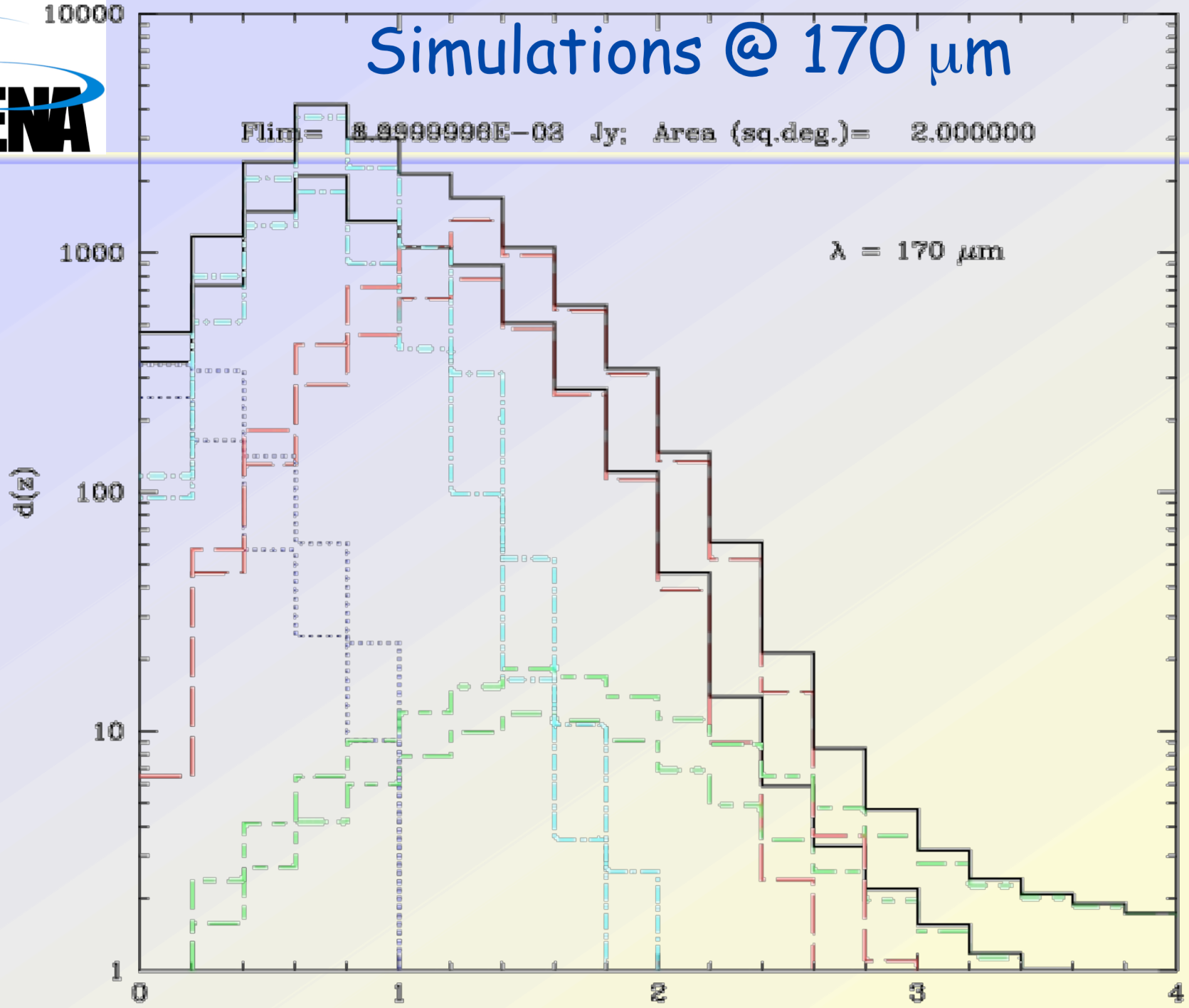

10^{13}
10^{12}
10^{11}
$L_{BOL}(IR)/L_{\odot}$
λ = 170 μm
Flim= 3.0000000E−03 Jy; Area (sq.deg.)= 2.000000
0
1
2
3
4
z

Simulations @ 170 μm

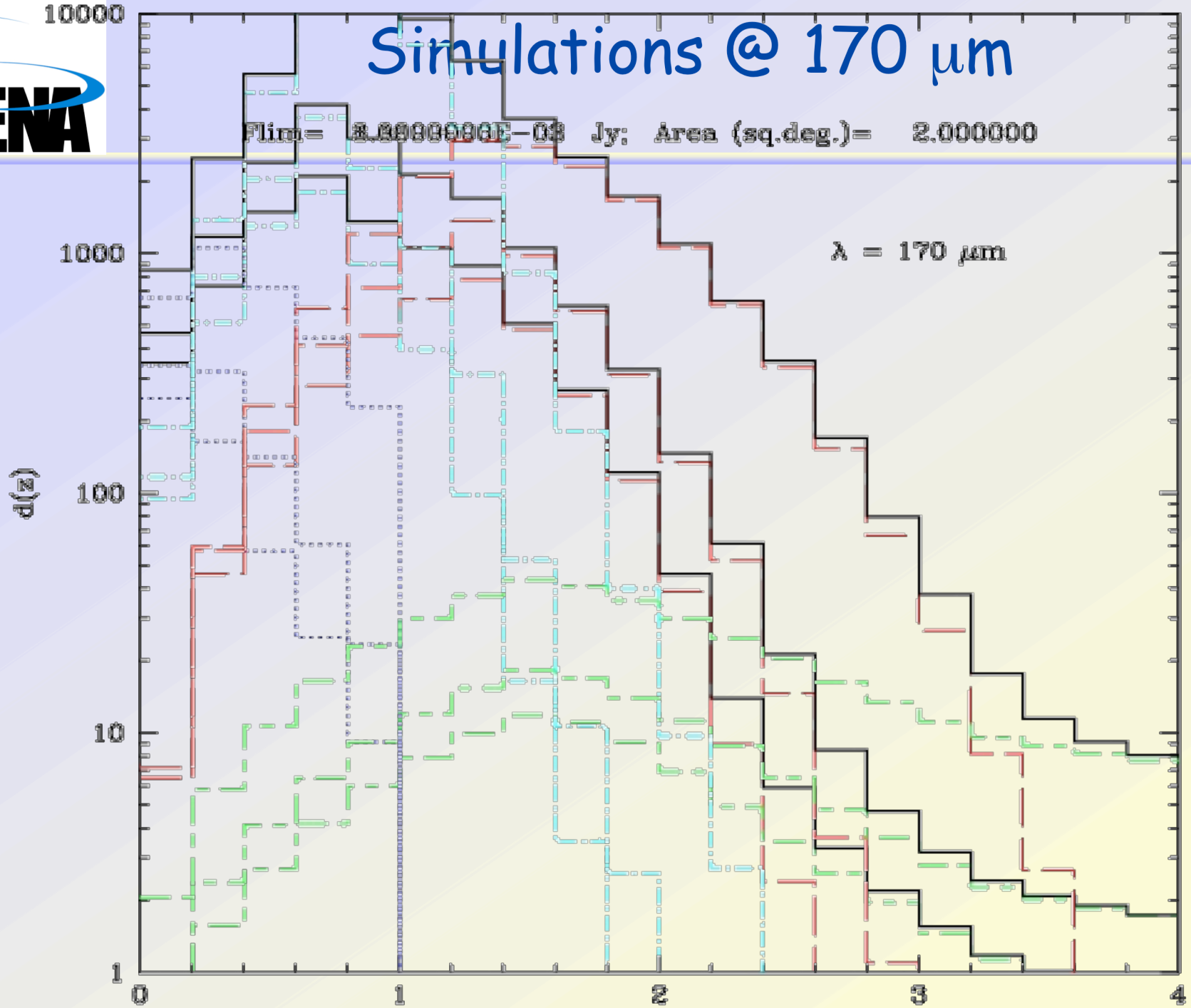
Simulations @ 170 μm

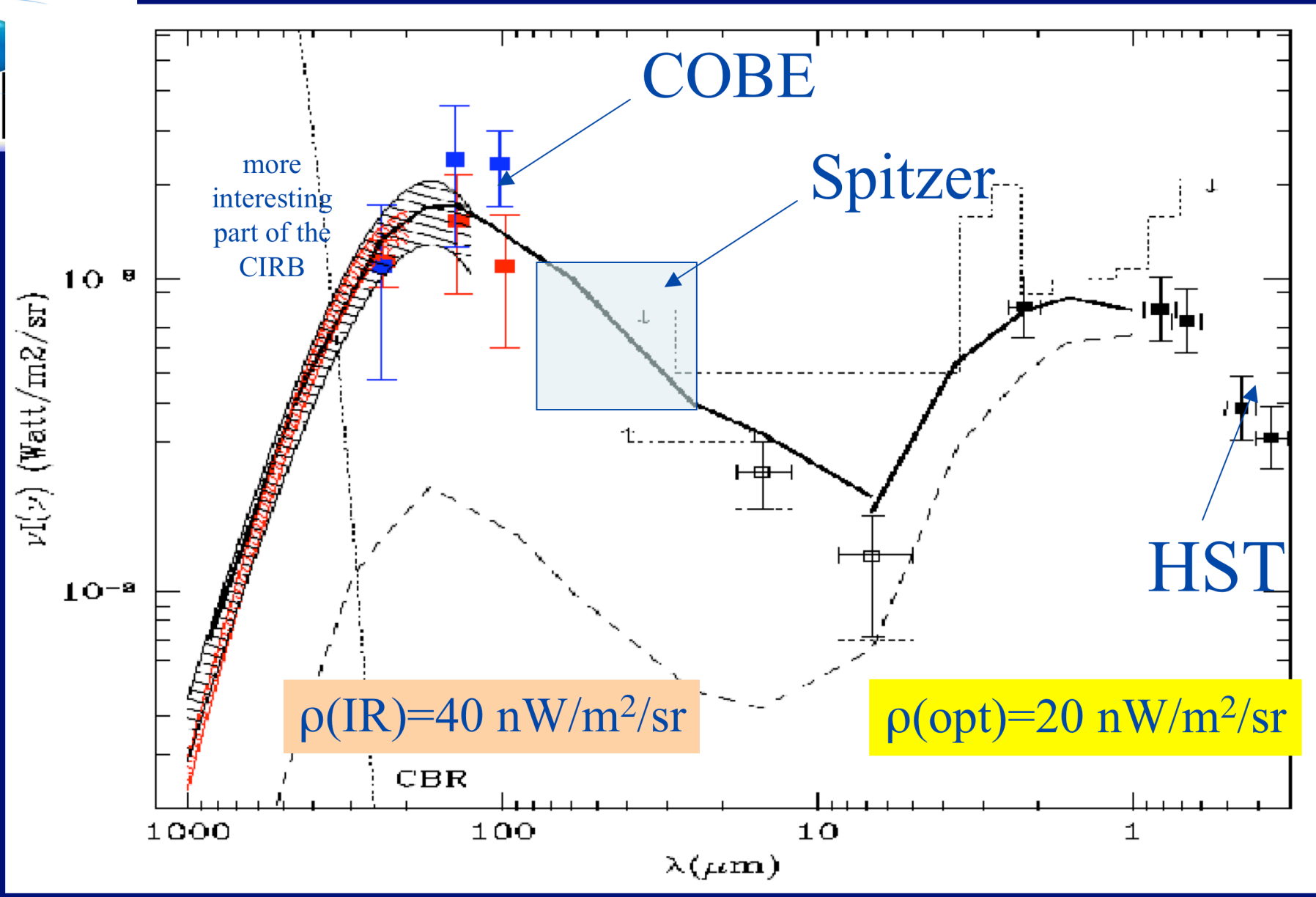


Simulations @ 170 μm

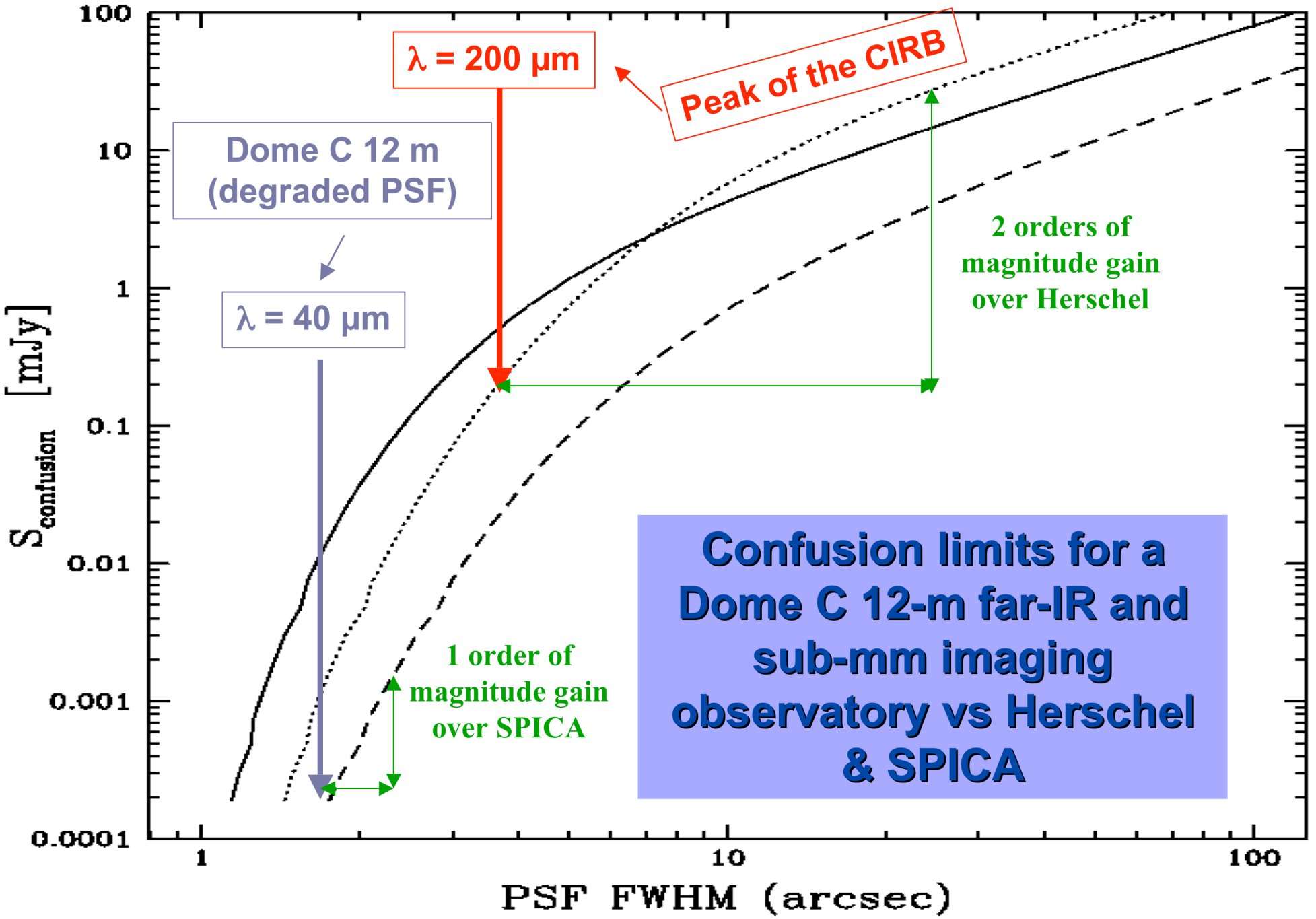


Simulations @ 170 μm

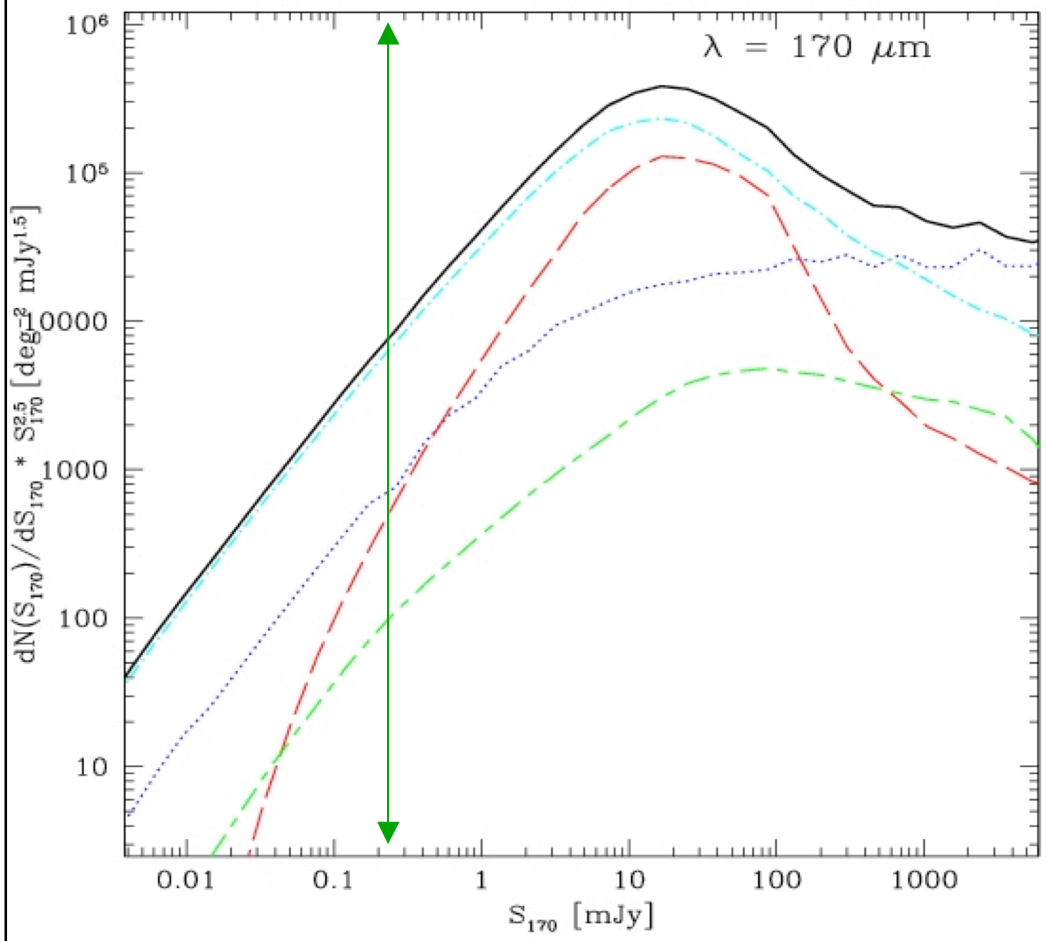


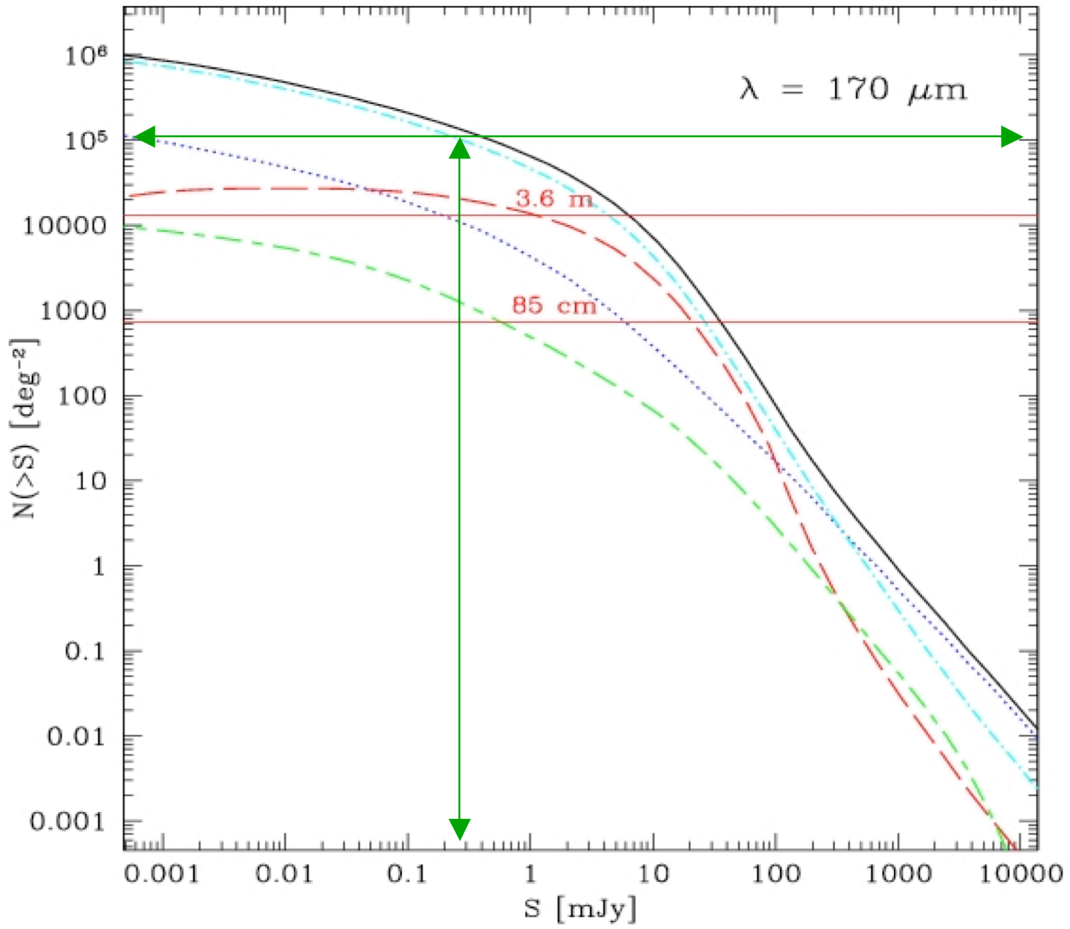


The Infrared Background Radiation (CIRB)


λ = 200 μm
Peak of the CIRB
Dome C 12 m
(degraded PSF)
λ = 40 μm
2 orders of
magnitude gain
over Herschel
1 order of
magnitude gain
over SPICA
Confusion limits for a
Dome C 12-m far-IR and
sub-mm imaging
observatory vs Herschel
& SPICA
S confusion [mJy]
PSF FWHM (arcsec)
100
10
1
0.1
0.01
0.001
0.0001
1
10
100

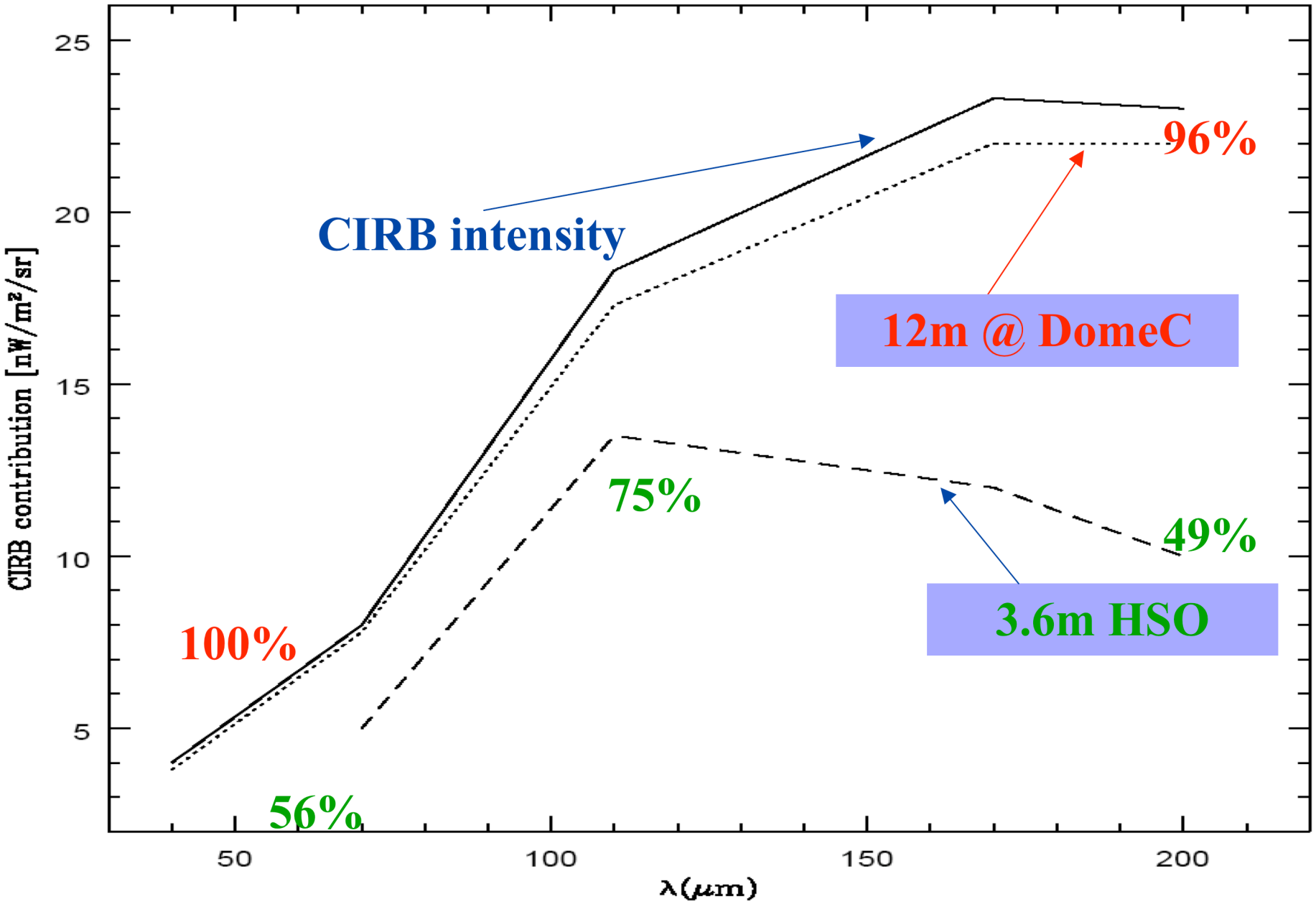
What about the counts?



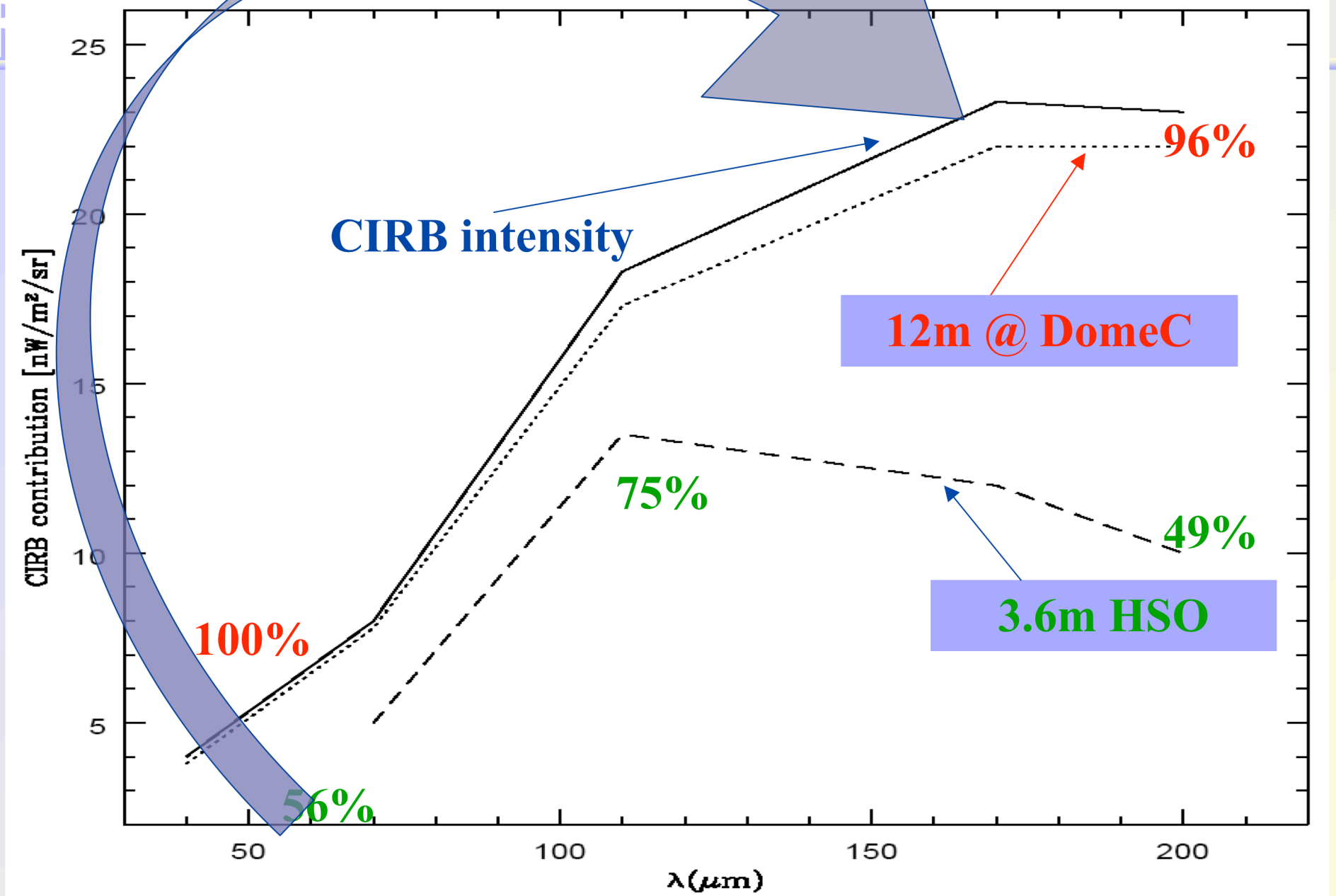


Reaching well fainter than (differential) counts downturn!

"The CIRB fully resolved at 40 and 200 μm..."



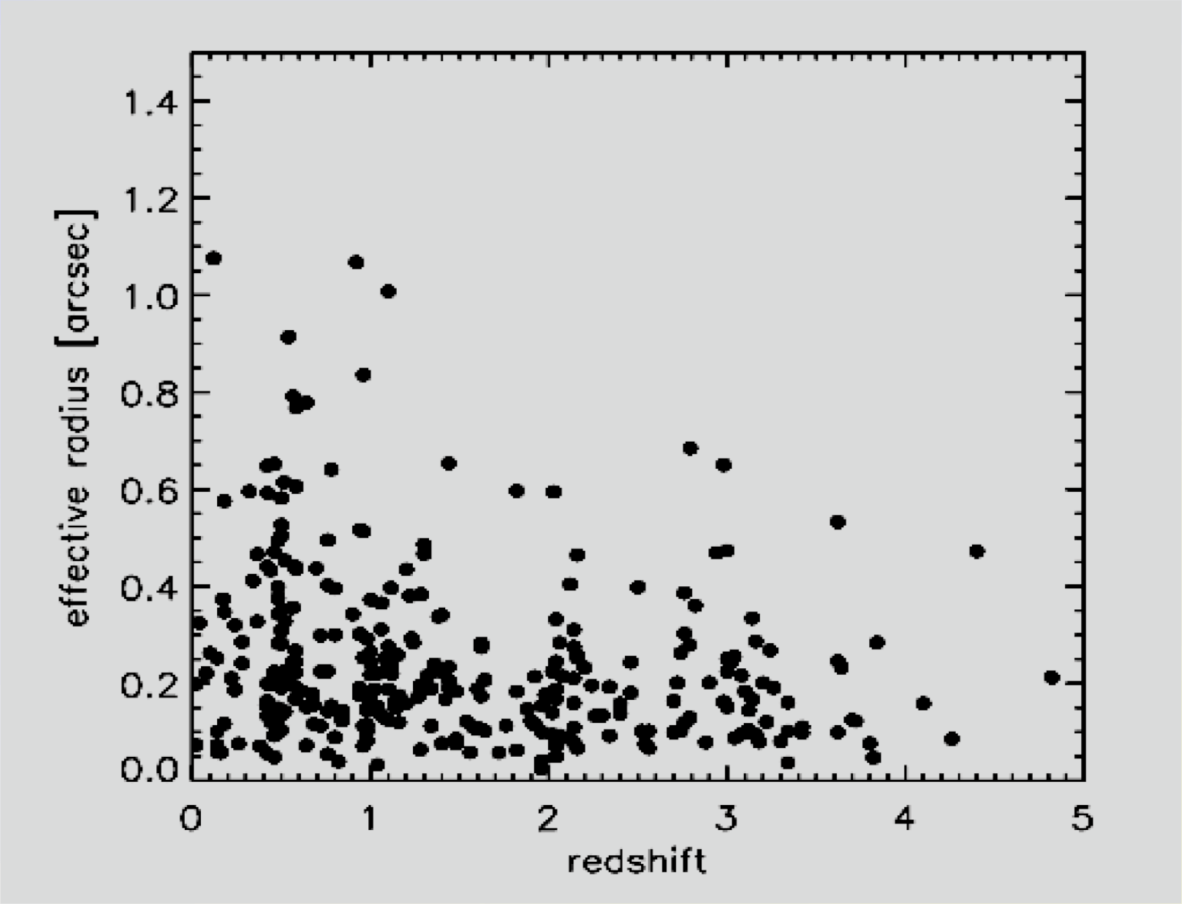
"The CIRB fully resolved at 40 and 200 µm..."



CIRB resolved by Dome C 12-m ?

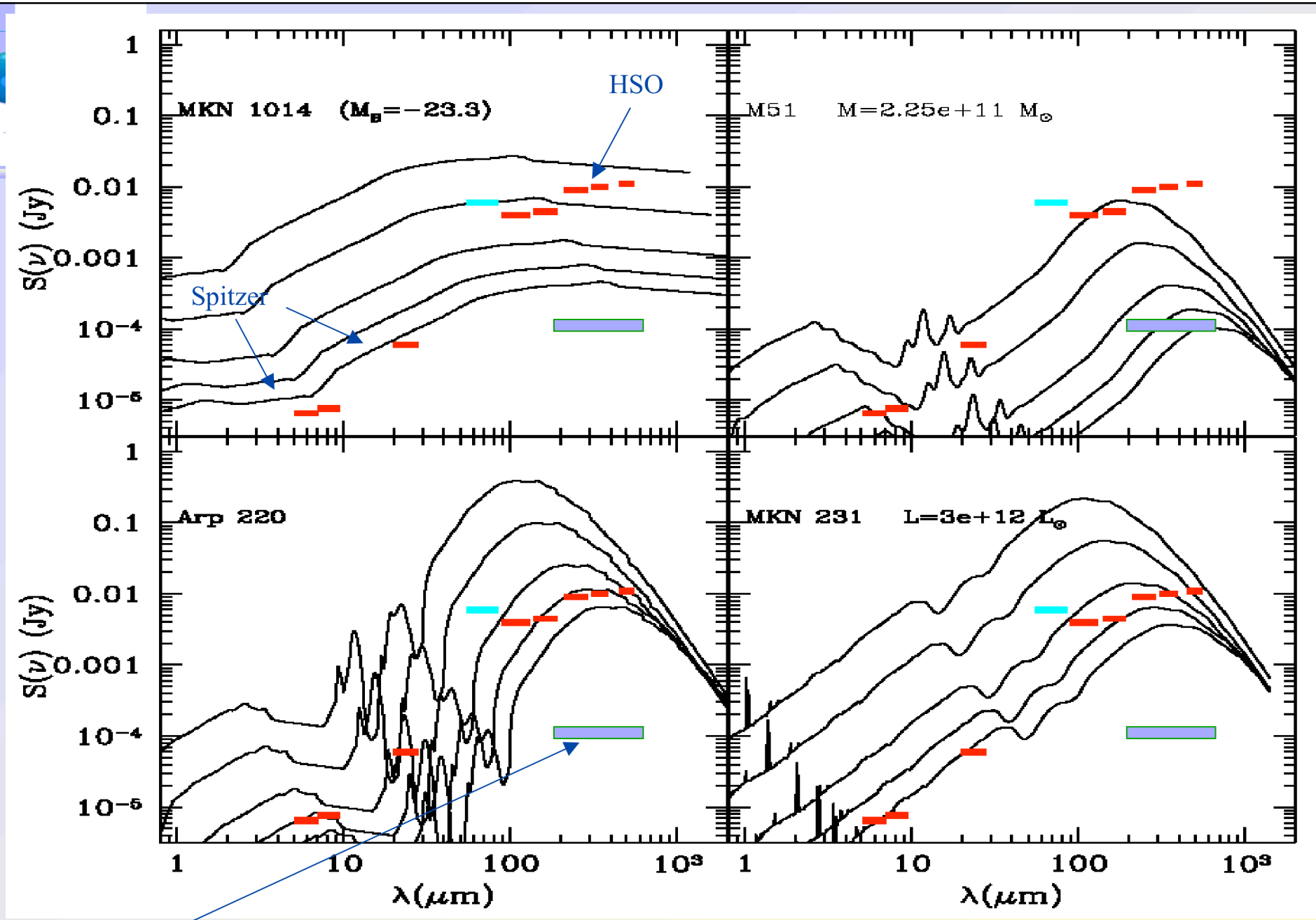
- The CIRB at 40 & 200 μm can be "easily" resolved into individual sources by Dome C single dishes with "moderate" spatial resolution
- This would complement and build upon a similar effort at 450 μm which could be carried out with mapping speeds larger than SCUBA2's (850 μm providing further icing on the Dome C cake?)
- Such a panchromatic approach would also provide a rough proxy for the bolometric luminosity of detected sources
- Physically ***resolving*** into substructures the sources of the ***resolved*** background (early galaxy mergers, SB/AGN sub-components, etc.) will be perfectly feasible with ALMA
- Envisaged Dome C 12-m sensitivities at 200 μm, however, would severely limit such a program and instead call for a larger (25-m?) antenna or for a 200 μm follow-up rather than survey instrument

Some model-independent observational constraints on high-z galaxy sizes



Effective K-band radii for a subset of FIRES K_{AB}>25 galaxies

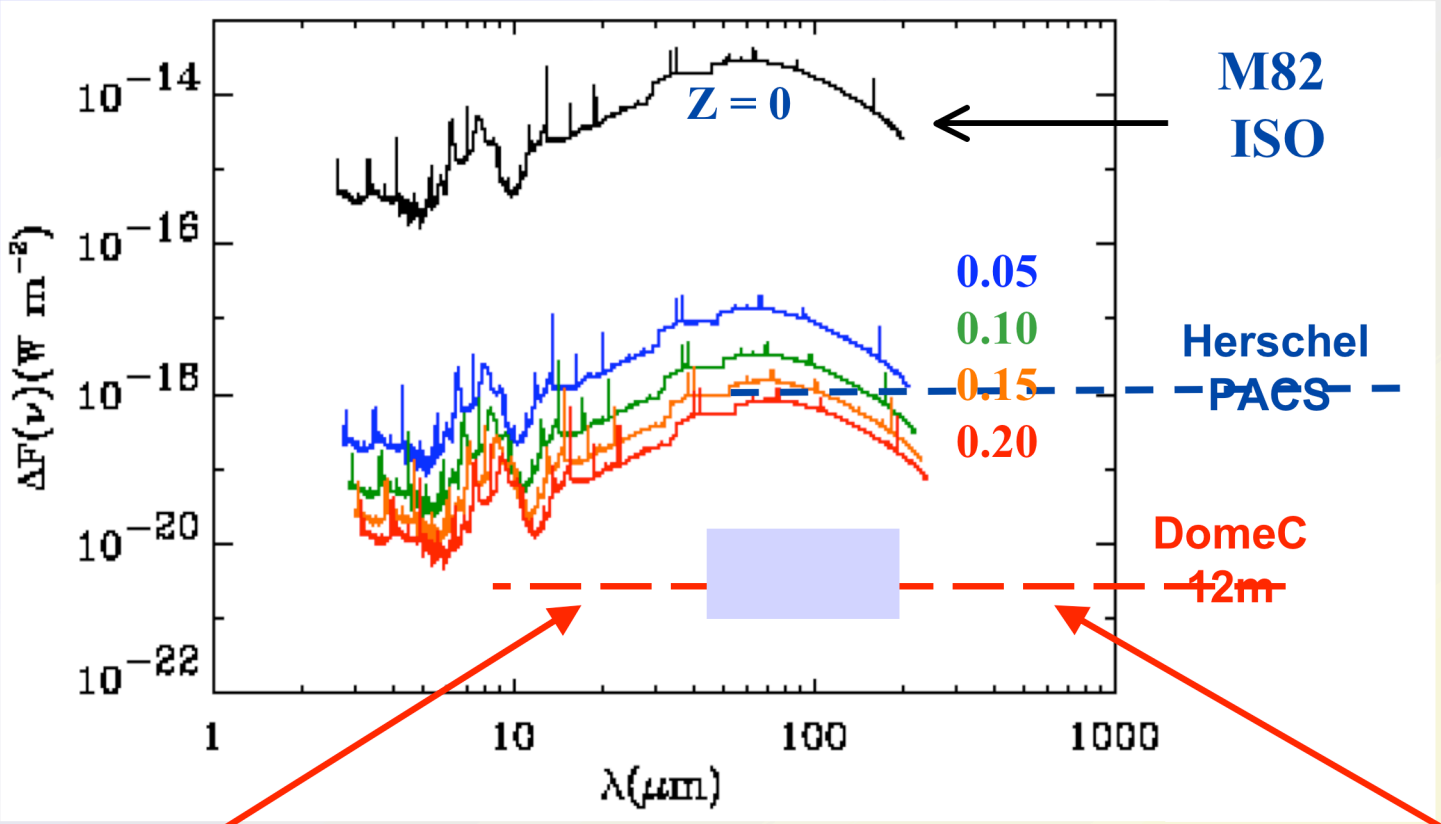
⇒ ~0.1" essential to resolve normal and star-forming galaxies



Dome C 12-m confusion-limited sensitivities

Spectroscopic characterization of high-z objects

FIR spectroscopy of galaxies and accreting AGNs at high z



Wealth of recombination, ionic, molecular, coronal lines, dust features and PAH line bundles

Spectra very rich of information, particularly in the short-wavelength part

C+ 158 μm,
O 63 μm, molecules

Conclusions

- In conclusion, a Dome C "twin" observatory with capabilities both in the sub-mm (200-900 μm) and in the mid- far-IR (10-40 μm) could bring a substantial contribution to the astrophysics of enshrouded star formation and AGN accretion

- Such an instrument would address a variety of topics with observations over a wide range of λ, and could thus make a full-title observatory (modulo operational issues), and a particulary interesting topic would be the resolution of the CIRB at its peak wavelength into individual sources

- The sensitivity of the present 12-m telescope concept, however, seems inadequate for this latter purpose, which would rather require a 25-m dish.

- The surveyor-type vs observatory-type instrument issue can only be dealt with when some harder numbers and more elements about the operational isseus at Dome C are fed into the picture

Where do we go from here?

- In order to develop a rock-solid panchromatic science case for a Dome C 12-m (or for any other instrumental option, e.g. a 25-m) one now needs
  - Models of long-wavelength extragalactic populations
  - Tools to compute extragalactic confusion noise / limits
  - Tools to generate simulated surveys
  - A complete list of available multi-wavelength EG surveys in Dome C-accessible fields, and a "plan" to identify and characterize sources detected in Dome C EG surveys in these and other fields (PILOT synergy)
  - A set of "metrics" for the goodness of expected scientific performance
  - A very limited set of straw-man instrumental concepts
  - Operational assumptions about 10-40/200/350/450/850 μm sensitivities and mapping speeds of such competing instrumental concepts
  - Finally & painfully, a working group discussing high-z science from Dome C