The Atacama 25m Science Goals and Telescope Requirements

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Outline

- Assumptions
  - Atmospheric transmission
  - Sensitivity
- Important requirements
- Top level science
  - Galaxy Formation and Evolution
  - CMB and the SZE
  - ISM, Disks, Star and Planet Forming Regions
  - Solar System Studies

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Assumptions/Key Issues

- Aperture: 25 meter
  - Ensures that it is not confusion limited in exposures of 24 hours or less.
- Water Vapor Burden:
  - Consistently lower burden than 1 mm to reach the short submm windows (< 0.5 mm for 200 μm work)
- Surface Accuracy: ~ 10 μm rms
  - Good efficiency & PSF in the 200 μm window (1.5 THz)
- Field of View: TBD
  - Faint source surveys a forte – therefore requires large FOV > 5' (> 18' ?) which could be populated > 10,000 element arrays.

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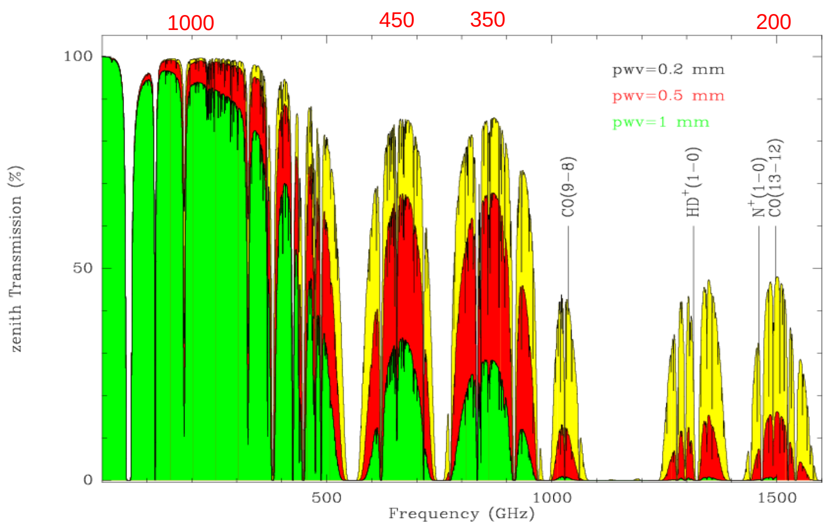
Water Vapor Issue



For reasonable work in the 200 μm window we need pwv < 0.5 mm.

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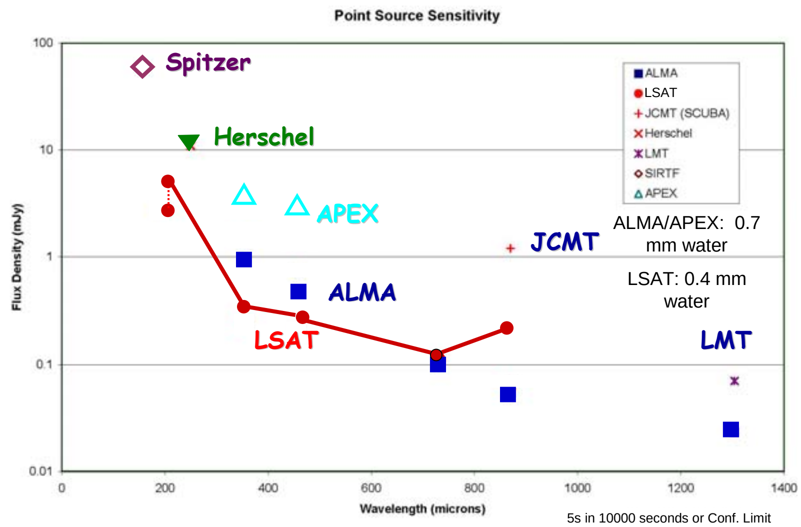
Continuum Sensitivity Comparisons



Backup

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Important Requirements

- Sensitivity
  - Confusion
  - Emissivity
- Image quality
  - Affects sensitivity
- Field-of-View

Table 2.1 FIR/Submm Confusion Limits

Telescope/λ)	Ω_b	counts	confusion limit
	10^{-6} deg^2	10^3 deg^{-2}	mJy
JCMT/870 μm	19.8	5	1.2
LMT/1.1 mm	4.3	23	0.07
APEX/450 μm	7.7	13	0.2
SIRTF/160 μm	197.	0.5	60
Herschel/250 μm	28.	3.5	11
Atacama/870 μm	6.7	15	0.2
Atacama/350 μm	1.08	93	< 0.01
Atacama/200 μm	0.35	286	$\ll 0.01$

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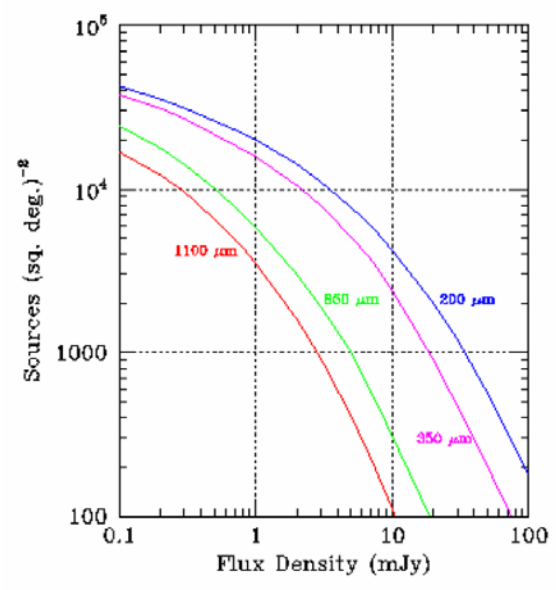
Far-IR/Sub-mm Number counts



Hughes and Gaztanaga

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Science Goals

- Galaxy Formation and Evolution
- ISM, Disks, Star and Planet Forming Regions
- CMB and the SZE
- Solar System Studies
  - KBOs and Irregular Satellites

Group	Topic	Group Chair
S1	Solar System	Don Campbell
S2	Star Formation	Paul Goldsmith, Hal Yorke
S3	Galaxies	Andrew Blain
S4	Cosmology	Sunil Golwala

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Galaxy Formation and Evolution

- Science goals
  - Characterize star formation and galaxy formation history of the Universe from the present to z > 5.
  - Need ~ 1,000,000 objects to get statistical samples in a significant number of redshift and luminosity bins
- Technique
  - Do a multi-band continuum survey in the sub-mm
    - Band ratios give approximate redshifts
    - Integrated flux give luminosity
  - Follow-up selected candidates with line searches
    - Verification of photometric redshifts
    - Get physical conditions in galaxies
  - Requires sky coverage ~ 10 deg^2
- The combination of band coverage, sensitivity, spatial resolution, and sky coverage make LSAT is uniquely suited to approaching this problem.

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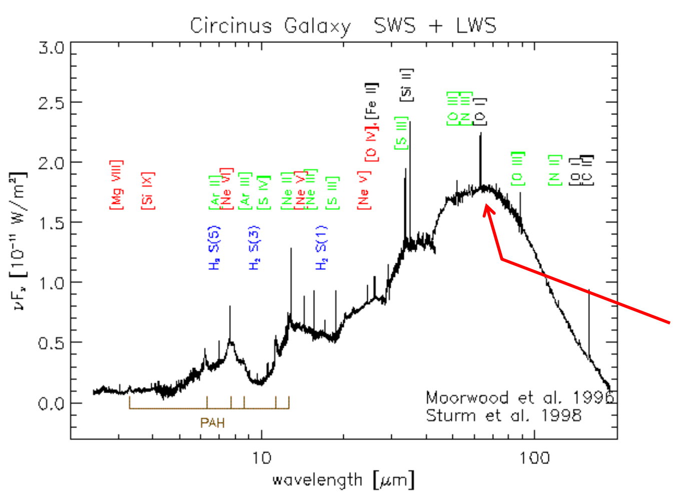
Starburst Galaxies



Strong peak in the far-IR

Starburst systems emit the vast majority of their light in the far-IR .

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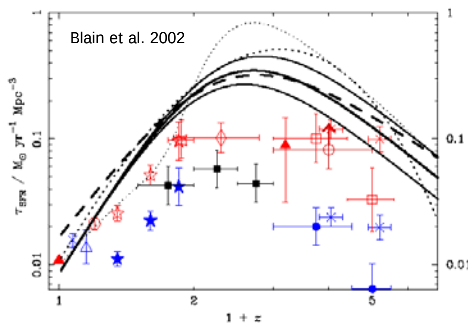
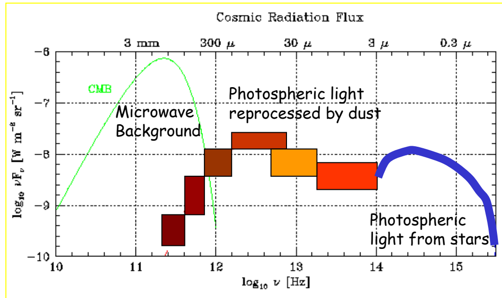
Star Formation in the Early Universe

- Optical surveys indicate that the mean SFR in the Universe was much greater at z > 1 (e.g. Madau et al. 1996)
- COBE revealed a cosmic far-IR background with energy > the integrated UV/optical light ⇒ dust extinction is important in the early Universe!
- IR/sub-mm surveys indicate even greater rates of star formation than seen in optical.

⇒ To accurately determine the SFR requires both optical and far-IR/submm surveys.





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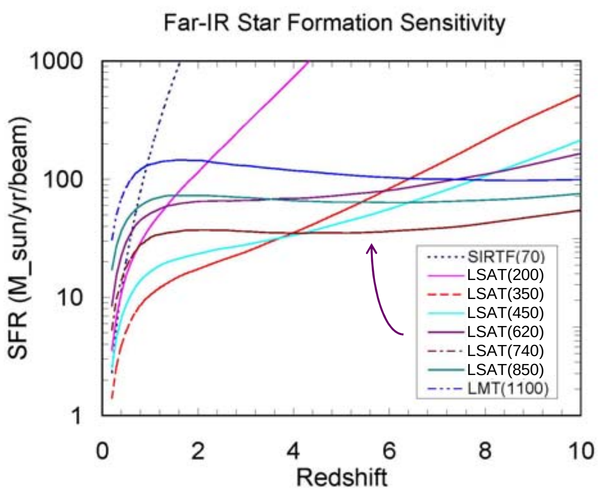
Star Formation Sensitivity



For star forming galaxies, the far-IR luminosity is proportional to the star formation rate.

LSAT will detect SFR ~ 10-30 $M_{\odot}$/yr for z < 3, and SFR ~ 40 - 100 at z ~ 10!

LSAT 5σ, 10,000 s

SIRTF, LMT confusion limited

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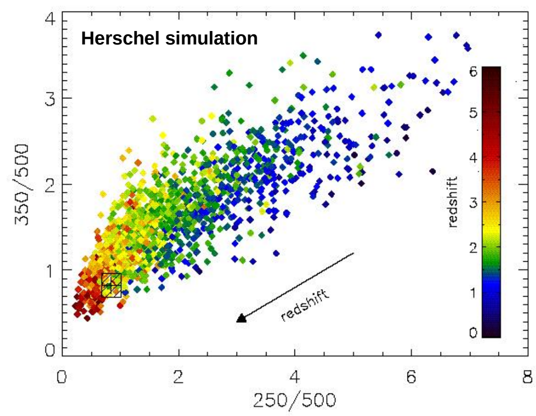
Submm Photometric Redshifts

A 3000 hr survey with the LSAT might detect ~ 500,000 galaxies, mostly with z ~ 2 - 4, but easily up to z ~ 10 (if they exist).

Access to multiple FIR bands yield photometric redshifts accurate enough (~ 20%) to allow investigation:

- Star formation history of the Universe
- Evolution of large scale structure



Redshifted far-IR Lines

- Many of the galaxies detected in the continuum will be detectable also in spectral lines such as [OI] 63 um, [OIII] 88 um, [NII] 122 & 205 um and, especially, [CII] 158 um
  - [CII] 158 um emission from 5×10^{10} $L_{\odot}$ galaxy traceable between z=0.25 and z=4.8, as it gets redshifted across the submm telluric windows
  - [OIII] 88 um line emission from 2×10^{11} $L_{\odot}$ galaxy traceable at z ~ 1.3, 3 and 4.1
  - [OI] 63 um line emission from 7×10^{11} $L_{\odot}$ galaxy traceable at z ~ 2.2, 4.6 and 6.1
- This will verify the rough photometric redshift procedure and give accurate redshifts
- Will also allow the study of:
  - Gas cooling, the physical conditions in the star forming gas, the properties of the interstellar radiation field, the internal dynamics of primeval galaxies and of their merger histories.

Galaxy Survey Requirements

- Sensitivity
  - Need LSAT sensitivities to reached "low" star formation rates
  - Large aperture (25m class) needed to reduce confusion limit
- Field of view
  - > 5'
- Pointing
  - Spectroscopy in the 200 μm window requires pointing to 0.2" and stability to ~ 0.1".

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CMB and SZE* Science

- Science goals
  - Measure H(z), Ω_m(z), w, the abundance of clusters of galaxies in the Universe, and the gas mass fraction
  - Measure peculiar velocities of clusters and hence overall mass density fluctuations in space
- Technique
  - Image each cluster at 450, 620, 870 μm with LSAT
    - Combine with longer wavelength data (1 mm – 1 cm) & x-ray observations
  - Decompose first (thermal) and second (kinematic) order SZE
    - 1st order yields H(z), Wm(z), etc.
    - 2nd order gives peculiar velocities
  - Requires ~ 5' FOV since cluster at 1-2' in diameter
- LSAT is key. It combines field-of-view with good PSF to allow mapping of cluster substructure and removal of background sources.
  - Need short wavelengths to help constrain first order effect well enough to determine kinematic SZE.

*Sunyaev-Zel'dovich Effect

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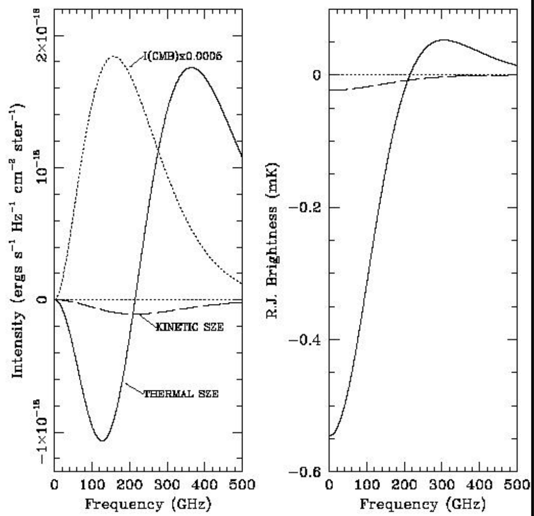
SZE

- The SZE results from the distortion of the CMB as a result of its propagation through the intracluster gas in galaxy clusters.
- The SZE has been detected in a number of clusters, mainly through interferometric means on the RJ side of the CMB spectrum. It has huge cosmological potential, as the amplitude of the SZE is independent on the cluster distance.



The SZE has two components: one referred to as the "thermal" SZE which is the main effect, and a second, weaker, which is a perturbation on the first produced by the peculiar velocity of the cluster, which is referred to as the "kinematic" SZE.

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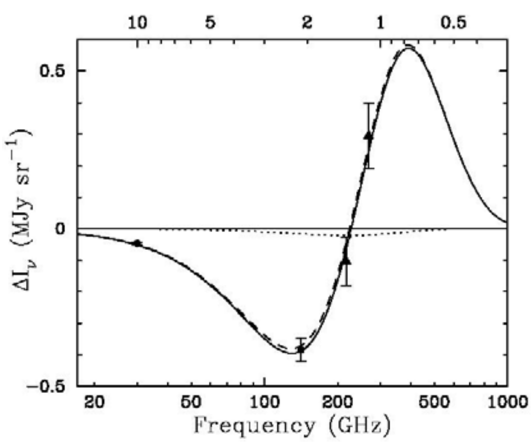
Wien side SZE

Little SZE (and CMB) work has been done on the Wien side of the CMB spectrum,but:

"Operating from high astronomical sites with stable atmospheres and exceptionally low PWV, future large format bolometer arrays have the potential to produce high S/N SZE images and search for SZE clusters with unprecedented speed" (Carlstrom 2003)



Holzapfel et al. 1997

Measuring the SZE at short λ will be of particular importance in connection with the detection of the kinematic SZE, which has not been achieved yet: access to a large FOV, submm/mm telescope capable of reaching mK sensitivities w/o becoming confusion-limited will be key.

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SZE Requirements

- Sensitivity
  - 25m class telescope needed to remove contaminating point sources & get sensitivity.
    - For example with 25m at 870 μm, expect 6-8 sources per sq-arcmin at S ~ 0.06 mJy. These are resolvable so that μK sensitivities may be achievable.
  - Needs modeling work
- Field of view
  - > 5' needed to cover cluster
- Pointing
  - Not critical

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Debris Disk Science

- Science goals
  - Measure spatial structure and potential temporal evolution of disks
- Technique
  - Image system at 200 and/350 μm at different epochs
  - Requires ~ 1-2' FOV
- LSAT is key because of field size, wavelength coverage, and spatial resolution

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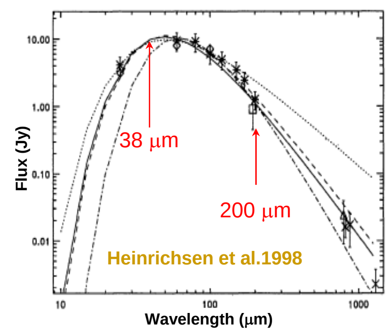
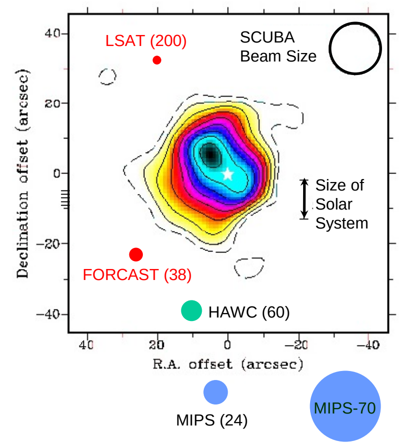
Circumstellar Disks: Vega

SCUBA 850 μm: r_{disk} **~ 20" (160AU)**
⇒ T_{dust} ~ 80 K ⇒ λ_{peak} ~ 35 μm

ISO *observed* λ_{peak}~35 μm
⇒ little dust at r < 160 AU
⇒ *hole in distribution*





Resolve disk and hole ⇒ distribution of dust…

and planets?

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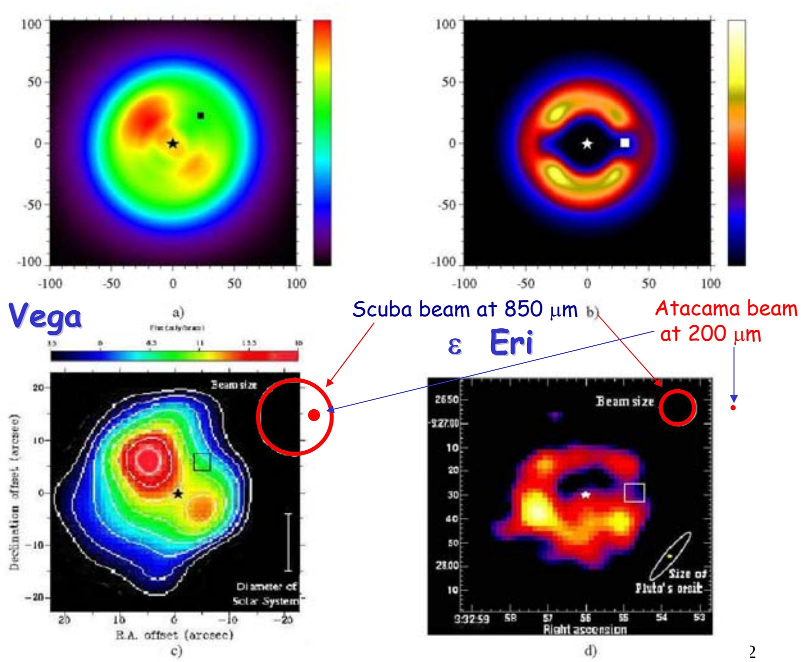

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Debris Disk Requirements

- Sensitivity
  - Need good sensitivity at the shortest wavelengths
- Field of view
  - 1-2' needed to cover source well
- Pointing
  - Reconstructed pointing will be important for placing disk relative to star.
  - ~0.1 – 0.2" accuracy.

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KBO studies

- Science goals
  - Determine sizes/albedos of Kuiper Belt Objects
  - Search for optically "dark" KBO
- Technique
  - Measure known KBOs in one or more submm bands
    - Combining with the optical get albedo
    - Different bands could be useful because of potential scattering effect
  - Sub-mm continuum survey looking for new KBOs
    - Requires sky coverage ~ TBD degrees
- The combination of sensitivity, spatial resolution, and sky coverage make LSAT is uniquely suited to approaching this problem.

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Kuiper Belt Objects

- Trans-Neptunian objects at ~ 40 to 50 AU
- Formed early in the outer reaches of the solar protoplanetary disk
- Several hundred known
  - Pluto (D~2400km)
  - Charon (D~1200 km)
  - Varuna (D~900km)
  - Chaor
- Optical/NIR observations yield orbital parameters – flux, not size
- KBOs have equilibrium temperatures ~ 45 K ⇒ far-IR emitters
- Pluto, Charon, Varuna & Chaor have been detected at 850 mm by JCMT, yielding sizes, albedos and surface properties.

Irregular Satellites

- Current state-of-the-art in detecting KBOs
  - SCUBA is confusion limited to ~ 500 km
  - LMT will be confusion limited to ~ 200 km
- LSAT will be able to go down to ~ 30 km in size
  - Hundreds of thousands KBOs with D > 30 km may exist
- The LSAT could reveal the size function and surface properties of the KBO population.

- During the deep searches for primeval galaxies, KBO science could run in a serendipity mode:

⇒ may be able to detect ~ 1 KBO per frame.

LSAT Instrumentation

- Bolometer Array Cameras – more than 10,000 pixels
  - 350 and 450 μm at first light
  - 620 and 850 μm, likely in same dewar – filter wheel?
  - 200 μm likely 3rd band
- Direct Detection Spectrometers
  - R =1000, 16 x 128 short slit grating spectrometer
    - Spatial multiplexing
    - Resolving power well matched to extragalactic science
  - R = 100-1000, Z-Spec like wave-mode coupled spectrometer
- Coherent spectrometers for high spectral resolution science: e.g. Galactic star formation studies
  - Spatial multiplexing important for extended sources
  - Focus on shorter submm science, where we have a more distinct niche

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Conclusions

- Science for LSAT is very exciting
- Requirements include:
  - 25m class telescope
  - Operation from 200 – 1000 μm
  - >5’ field-of-view for cameras
  - 0.2” pointing for spectrographs

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Spare Slides Follow

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Sensitivity Comparisons

- Surprisingly enough, in the continuum, the LSAT is competitive with ALMA in raw point source sensitivity. At 350 um with PWV_{LSAT} = 0.5 mm, PWV_{ALMA} = 0.8 mm:

$$\Delta F \propto ((T_{rec}+T_{bk}) \cdot \sqrt{BW}) \div ((\eta_{sky} \cdot \eta_{tel}) \cdot A_{tel} \cdot n_{tel})$$

	η_{sky}	η_{tel}	$T_{rec}+T_{bk}$	BW	A_{tel}	n_{tel}
LSAT	0.53	0.83	150	100	490	1
ALMA	0.35	0.60	400	8	113	64

$\Delta F_{LSAT}/\Delta F_{ALMA}$ ~ 3/4

- The large format arrays with single dish observatories ensure the mapping speed is much higher
- Of course, no single disk will approach the angular resolution of ALMA
- LSAT finds the interesting sources for which ALMA can obtain vital spatial information

return

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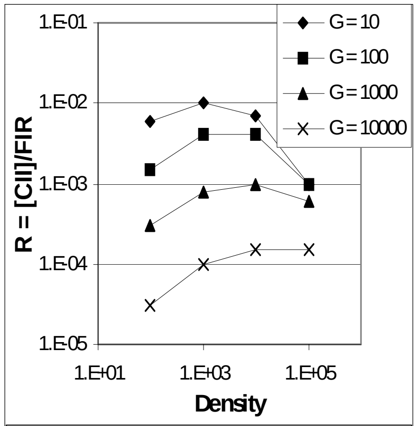
Redshifted [CII]

- The [CII]/far-IR continuum is a sensitive indicator of the strength of the ambient ISRF ⇒ Detection yields concentration of the starburst
  - High density systems cooling can come out in [OI] 63 um line
  - Line ratio yields PDR parameters
- ULIGS often have weak [CII] suggesting an AGN contribution to the far-IR

The physics is in the line to continuum ratio!

- Detecting [CII] from highly redshifted galaxies probes star formation in the epoch of galaxy formation



The [CII]/far-IR continuum ratio as a function of G (from Kaufmann et al)

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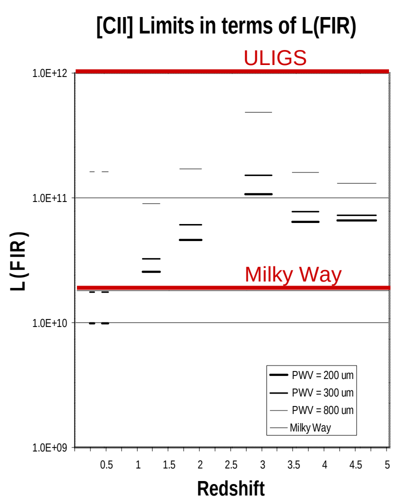
Redshifted [CII] Emission Yields Far-UV Field Strength and Redshifts

- *The [CII] line is detectable at z > 5 for $L_{far-IR} > 5 \times 10^{10} L_{\odot} \sim 2 L_{Milky\ Way}$!*
- *For ULIGS with [CII]/far-IR > 1.5 x 10^{-4} [CII] is easily detected at z > 5!*
- *However, it is the lower luminosity systems that are most interesting with respect to galaxy assembly – these will likely have relatively bright [CII] line emission*
- *[CII] line is uniquely bright, but redshifts can be verified (again with a gain to the physical understanding) by observing the [OI], [OIII] or [NII] lines*



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LSAT m Primeval Galaxy Survey

- LSAT brings a unique combination of properties:
  - statistical wealth (number of detections)
  - access to multiple submm bands (photometric z)
  - quality of SED determination
  - redshift and star formation rate stretch
  - access to fine structure FIR lines
  - ability to carry out deep surveys

These ensure that the LSAT telescope will be a prime instrument for study of galaxy formation

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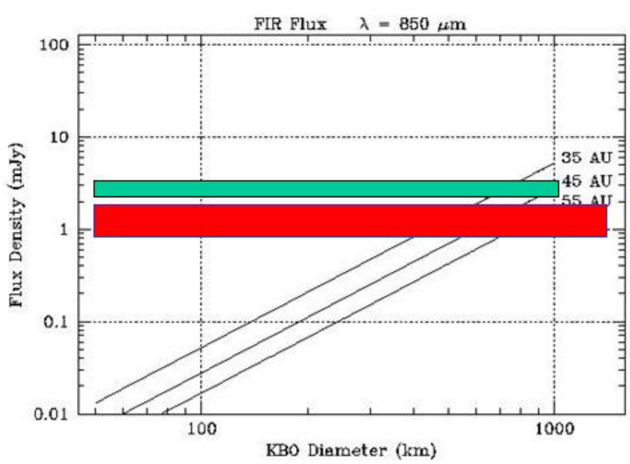
KBOs and Confusion: SCUBA

SCUBA

5-sigma
10,000 secs
PWV = 1.5 mm



JCMT confusion limit

- **SCUBA confusion limit is about a diameter of 500 km**
- **Not many KBOs that large!**

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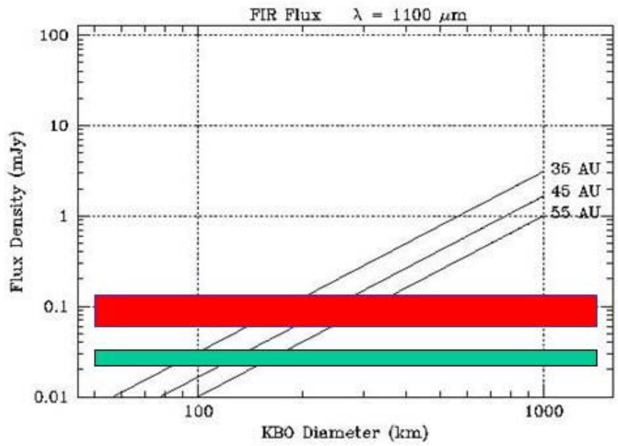
KBOs and Confusion: LBT

LMT

5-sigma
10,000 secs
PWV = 1.5 mm



LMT confusion limit

- **Due to its much larger aperture, the LBT does better – but its confusion limit corresponds to ~ 200 km KBOs**

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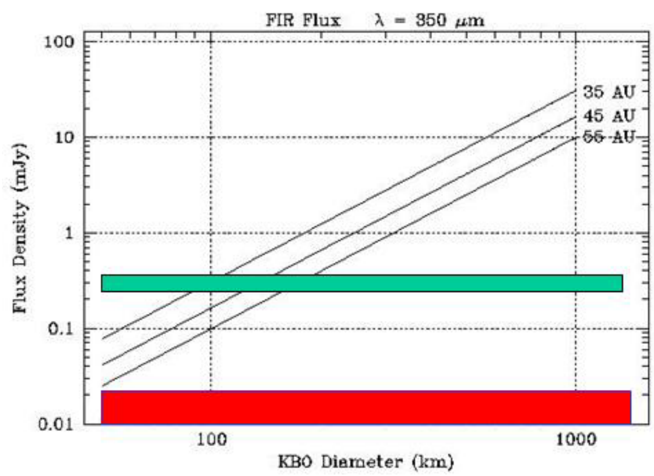
KBOs and Confusion: LSAT

LSAT

5-sigma
10,000 secs
PWV = 1.5 mm



LSAT confusion limit

- **LSAT easily detects KBOs with D~120 km in few hours**
- **Confusion level much lower –**
  With sufficient integration, can go to 30 km or so!

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