Science Questions for the Post-SIRTF and Herschel Era

Presented at the 2nd Workshop on New Concepts for Far-IR/Submillimeter Space Astronomy

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[http://sirtf.caltech.edu/]

An Outline of the Talk

- **SIRTF**
- **Polarimetry**
- **Confusion**
- **Extragalactic Science**
- **Galactic Science**

SIRTF: Status Summary

- **Optical/thermal/cryogenic performance of now-completed CTA appear excellent**
- **Performance of instruments within CTA is excellent: consistent with that needed on-orbit**
- **Spacecraft hardware completed; software supporting S/C testing**
- **We are proceeding with revised plan: Launch on January 9, 2003**
- **Next major milestone is integration of CTA and Spacecraft, set for this month**
- **First call for GO Proposals – November, 2002.**
  - *Consult sirtf.caltech.edu for updates to plan and details of submission process*

CTA Arrives at Lockheed

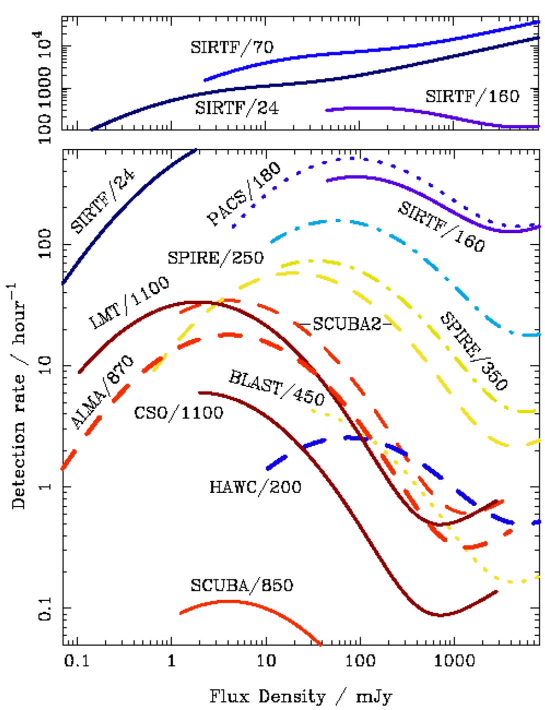
LONG WAVELENGTH SURVEYS PLANNED FOR SIRTF*

TYPE	AREA (DEG^2)	5-σ LIMITING FLUX, mJy		
		24um	*70um*	*160um*
WIDE*(GTO)	9	0.6	3.6	33
DEEP‡ (GTO)	2	0.15	1	30
REAL DEEP† (GTO)	0.02	0.06	0.7	
FIRST LOOK§ (SSC)	5	1.1	3.8	33
SWIRES (LEGACY)	≈70	≈0.45	≈2.75	≈(17.5)

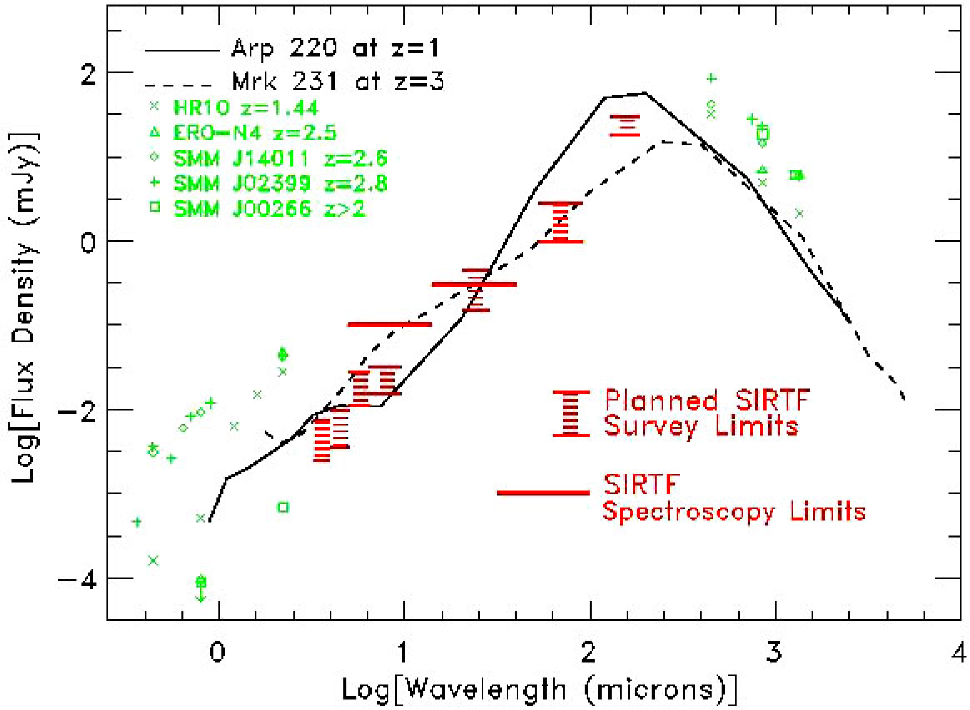
* NOAO Deep Field
‡ HDF-N, Groth strip, CXO-S, SSA –13, Lockman Hole, XMM Deep
† Groth strip
§ North Ecliptic Pole

See Werner, Reach, Rieke paper in Manchester IAU Background Symposium. Note that due to confusion we may fall a factor of ~3 short of reaching the deep survey limits

Galaxy Discovery Rates for Future Missions (Blain et al)



SIRTF Fills the Gap.SIRTF survey limits compared with data from ground-based near ir and SCUBA surveys.



Impact of SIRTF's Improved Resolution at 160um: Resolving the Background

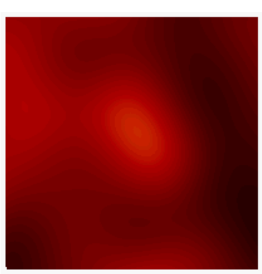
(H. Dole, MIPS)

Simulations of a 34′ x 34′ sky at **160 μm**

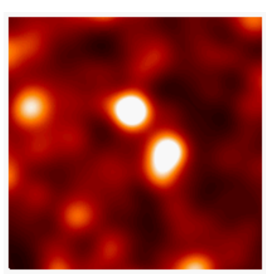
ZOOM on a 6.7 ′ x 6.7 ′ square

Extragalactic Sources: ~ 600.000 sources between 1 μJy and 2 Jy (Dole H. et al astro-ph/0002283)

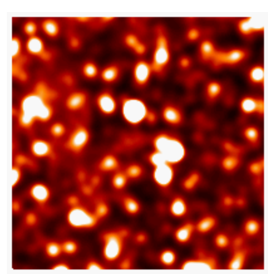
Foreground: Galactic Cirrus N_H ~10^{20} cm^{-2}



IRAS resolution



ISOPHOT resolution



MIPS resolution

These are noiseless simulations indicative of ultimate gain to be achieved in long integrations.

SIRTF Follow on

- SIRTF will provide major advances in areas such as number counts, resolving the background, the IR-Xray-AGN connection, and leave a legacy of 1000's of far infrared-selected galaxies at redshifts z. SIRTF will complement its long wavelength observations with very sensitive 3-8um surveys sensitive to redshifted starlight, so that the relationship between the distant universe as seen in the near ir and the far ir can be probed.
- Spectroscopic follow-on will be very important and will be carried out from SIRTF on the brighter sources, but higher sensitivity and spectroscopy beyond the SIRTF limit of ~40um will be needed.
- Extrapolating from nearby examples, we estimate the following line fluxes (units are 1e-18 w/m+2) for the faintest SIRTF detections

	Z=1	Z=3
F(OIV, 26um)	1	0.2
F(CII, 158um)	5	0.9

- These fluxes are not bright compared to Herschel limits, particularly if redshift is not known, but within range of larger telescopes, WaFIRS, etc.

- ***Spectroscopic follow-on of SIRTF discoveries should be an important objective of upcoming submillimeter missions***

Submillimeter Polarimetry – The State of Play

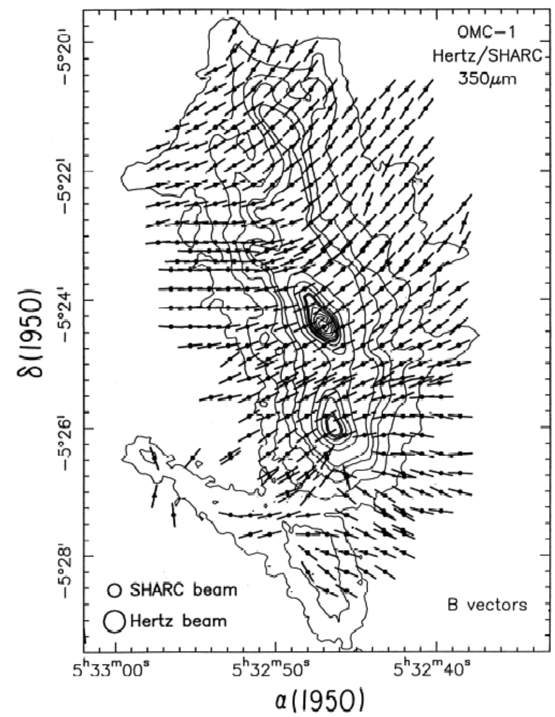
- Magnetic fields are like Ross Perot's crazy aunt in the basement: everyone knows she's there, but nobody talks about her.

- Polarimetry is the best means of probing them, and the phenomena to be studied in the far-infrared and sub-millimeter may be particularly affected by magnetic effects

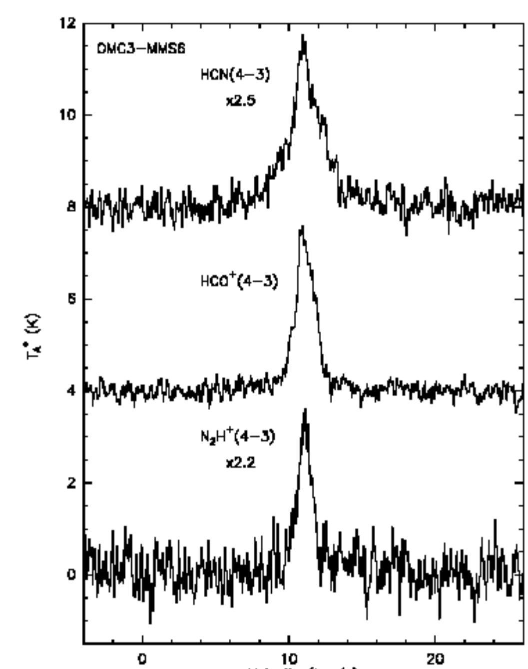
- Hildebrand et al (and others) have shown that the far-ir/submm emission from dust in bright galactic sources shows strong and coherent polarization (up to ~10%)! – and can be used to study:
  - *Field strength and orientation*
  - *Effects of field on gas dynamics/turbulence/cloud evolution/etc.*
  - *Grain properties*
  - *Alignment mechanisms/cloud properties*

- Extending this work by including Zeeman and linewidth measurements from molecular lines may allow field strength and three-dimensional field orientation to be teased out (Houde et al)
  - *With sufficient spatial resolution, this could be a very powerful probe of cloud collapse, star formation, jet formation, etc.*

Magnetic Vectors Across the Orion Molecular Cloud Core (Dowell et al)



Neutral & Ionized Molecular Spectral Lines (Houde et al)

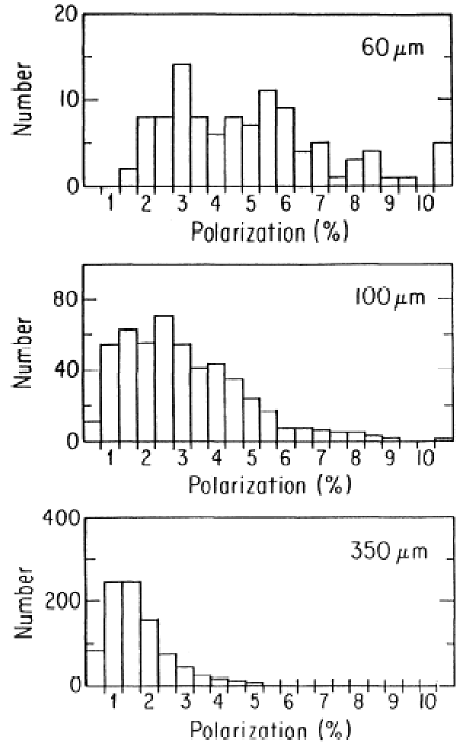


HCN

HCO^+

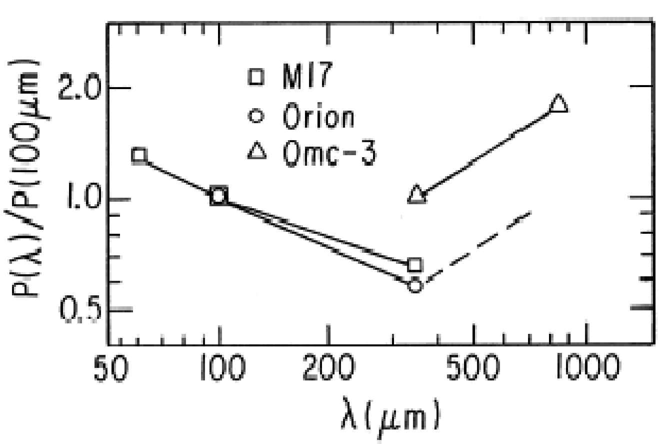
N_2H^+

Variation of Polarization With Wavelength (Hildebrand et al)



The Polarization Spectrum

(Hildebrand et al)



Submillimeter Polarimetry – Looking Ahead

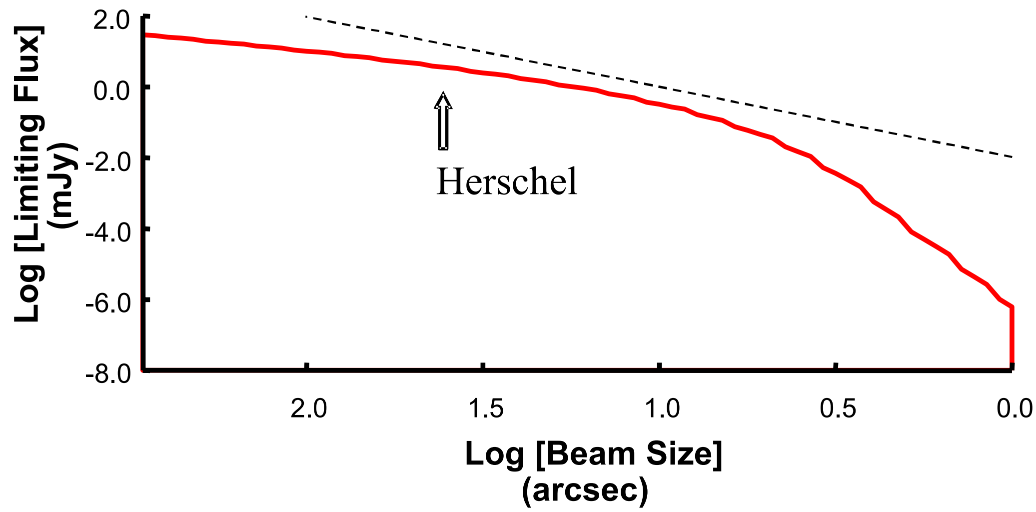
- *Work to date has been compromised by warm telescopes, atmospheric effects, and – in the far-infrared – limited spatial resolution*
    - ***A polarimeter is a must for SOFIA, but it could probe only the local Universe***
- *In addition to major contributions to studies of star formation, solar system evolution and jet formation, these capabilities could provide surprises*
    - For example, if the polarization characteristics of edge-on spirals vary with redshift, we might be witnessing evolution of cosmic magnetic fields and/or grain properties
- *Understanding the polarization of the galactic foreground seems a necessary precursor to polarimetry of the cosmic microwave background*
    - Fractional effects – relative to cosmological signal - could be larger than for imaging studies carried out to date
    - Jackson, Werner, and Gautier have produced catalog of high latitude cirrus filaments which might be starting point for foreground polarization studies
- ***A robust program of polarimetry should be a component of future far-ir/sub-mm programs***
    - Options beyond SOFIA include both a dedicated polarimetric explorer and serious polarimetric instrumentation on any large free-flyers, or perhaps a combined photometric/polarimetric survey

Confusion

- A small cryogenic telescope like SIRTF reaches its confusion limit for photometric observations rather quickly:
    - *~10s of s at 160um, ~100s of s at 70um for 1-sigma photon noise to equal 1-sigma confusion noise*
- Time to reach confusion limit and confusion limit as a function of beam size should be borne in mind in designing next generation of instruments and in defining cooling strategies.
- Modelling by Blain et al suggests that flux at confusion limit drops more quickly than D^{-2} for telescopes larger than Herschel and SIRTF in far-ir and sub-millimeter.
- This suggests that there are gains in photometric speed to be achieved with cooling larger apertures
    - ***High priority should be given with SIRTF and Herschel to whatever can be done to determine confusion and extrapolate it into the >~10m aperture ranges***
    - *Important to understand use of spectroscopy to break distance degeneracy and further combat confusion*
    - *Observing strategies which go deep into confusion should be evaluated*

Confusion at 500 μm

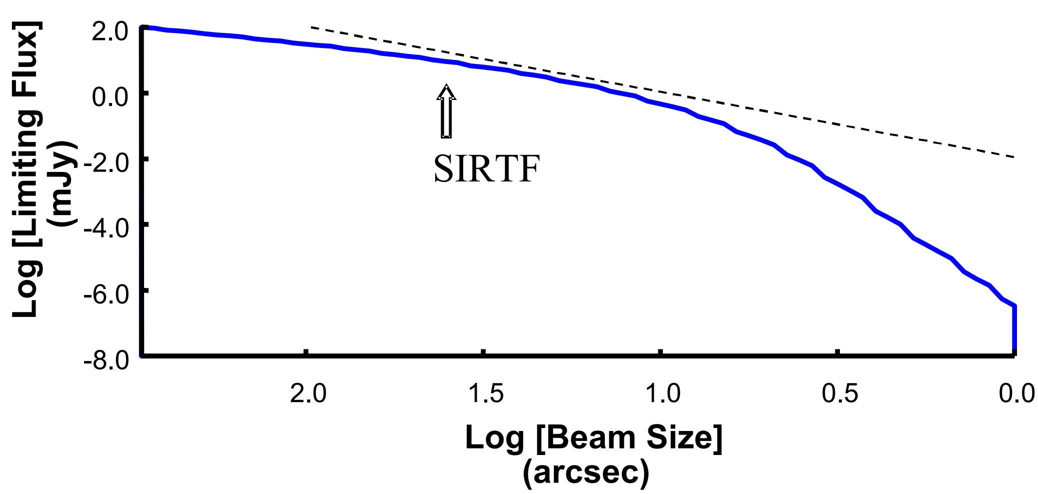
(1σ, Blain et al)



The diagonal line has a slope of –2. The fact that slope of the predicted confusion limit vs. beamsize is steeper suggests that for beam sizes smaller than ~10" confusion it will take increasingly longer [with the same instrumental+sky background] to reach the confusion limit than it will with Herschel. A colder telescope would be well-justified if these predictions are true. They should be studied by SIRTF and Herschel to the greatest extent possible.

Confusion at 160 μm

(1σ, Blain et al)



The diagonal line has a slope of –2. The fact that slope of the predicted confusion limit vs. beamsize is steeper suggests that for beam sizes smaller than ~10" confusion it will take increasingly longer [with the same instrumental+sky background] to reach the confusion limit than it will with SIRTF. Thus a ~10-m class cold telescope will be considerably less plagued by confusion than SIRTF, if these predictions are true. They should be studied by SIRTF and Herschel to the greatest extent possible.

Do Massive Black Holes and Galaxy Bulges form Together?

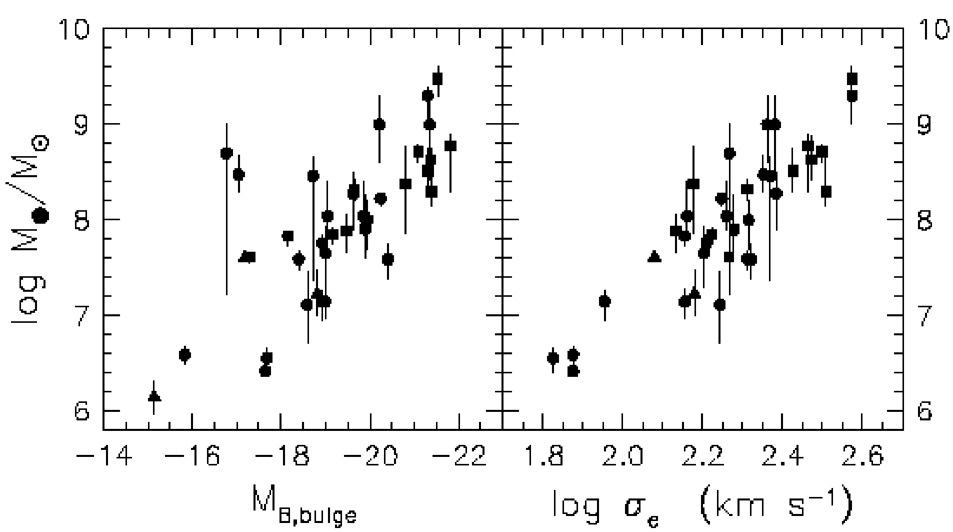
- Correlation of central black hole mass with stellar bulge magnitude and velocity dispersion suggests they may
  - *Assuming they do, and that the bulge is formed in a burst of star formation, this links nuclear and gravitational energy release – the two main forms of energy generation in the Universe*
  - *Results from Kormendy et al suggest E(starburst)/E(AGN) ~ 5*

- Comparing far-ir/submillimeter and x-ray emission is one way of probing this
  - *Page et al claim to have seen the process in action via SCUBA detections of 4 of 8 ROSAT sources in range 1<z<3*
  - *By contrast, Severgnini et al claim that submillimeter and x-ray background come from different populations*

- Exploring this connection is a prime near-term goal for far-ir/sub-mm astronomy
  - *Exploration out to Z~3 – region of maximum AGN activity – may do*
  - *Spectral diagnostics of starbursts and AGN contained within the band*
  - *Comparisons of SIRTF/Herschel/SCUBA/Chandra/XMM will be a good start*

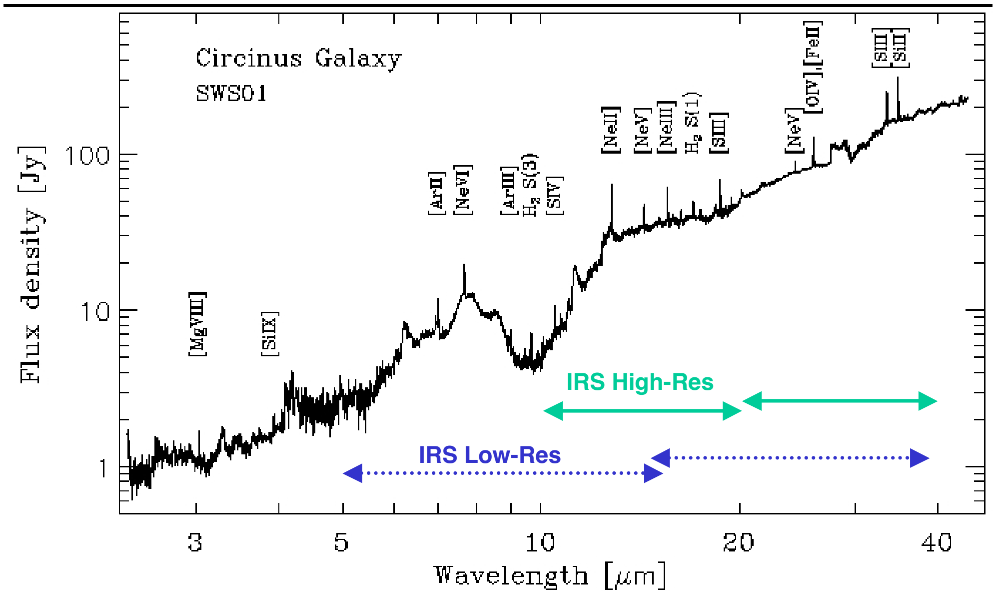
Blackhole Mass – Bulge Mass/Velocity Correlation

(Kormendy et al)



Infrared Spectral Diagnostics

(IRS Team)



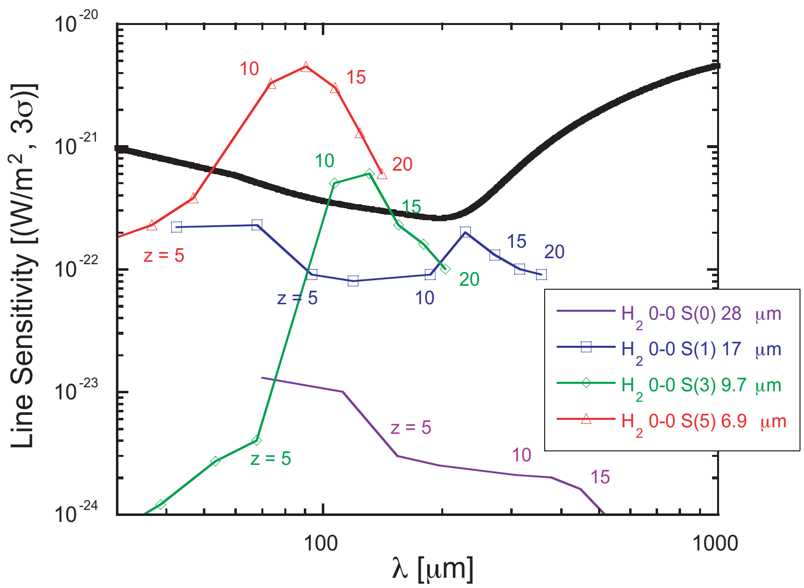
The 2.5 to 45 micron spectrum of the Circinus galaxy

The richness of the mid-infrared spectrum is such that infrared spectral observations alone may be able to assess the relative importance of starburst and AGN activity in distant objects.

Can We See the First Generations of Stars and Metal Formation?

- The far-infrared and submillimeter is a place to look for the earliest action as objects condense in the Universe….but who knows where or when?
- Options include:
  - *Redshifted H2 lines from collapsing objects*
  - *Starlight reprocessed by first generation of dust*
  - *………*
- Serious theoretical work has begun on this intriguing question:
  - *Spergel*
  - *Ciardi and Ferrara*
  - *Abel et al*
  - *…………..*
- The emission may be within reach of next generation instrumentation

WaFIRS Sensitivity to Redshifted H_2 Lines

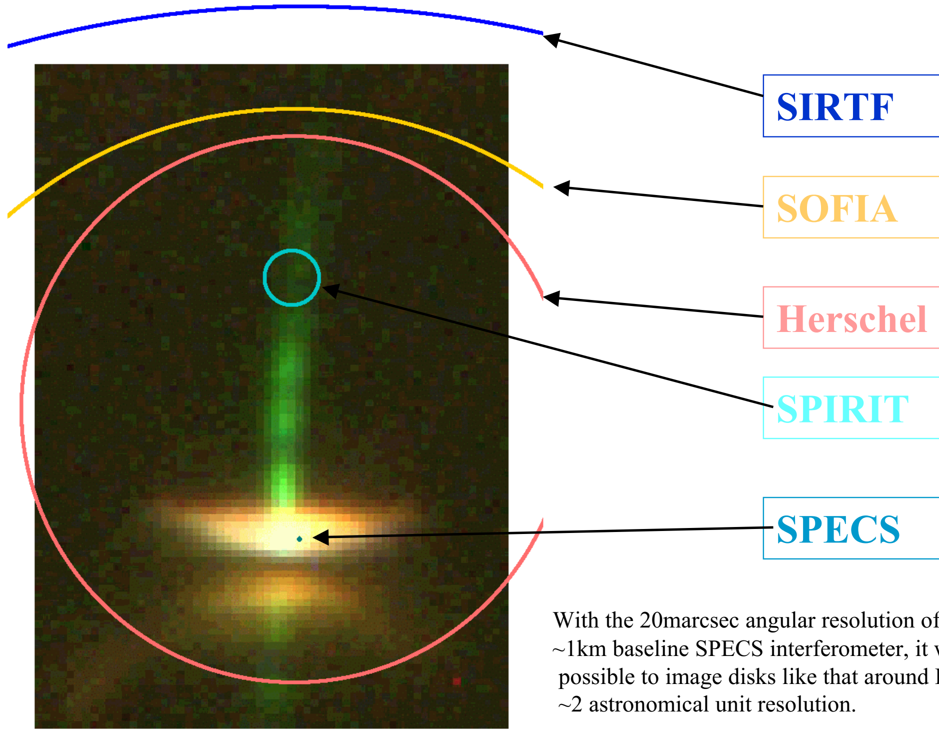


Molecular hydrogen line emission driven by the first generation of star formation, calculated according to the model of Ciardi and Ferrara (2000). Line emission is detectable out to large redshift (z = 20) in moderate integration time. WaFIRS is a concept for a highly efficient cooled spectrograph presented at this meeting by Jamie Bock et al

The Birth of Planets and the Origins of Life

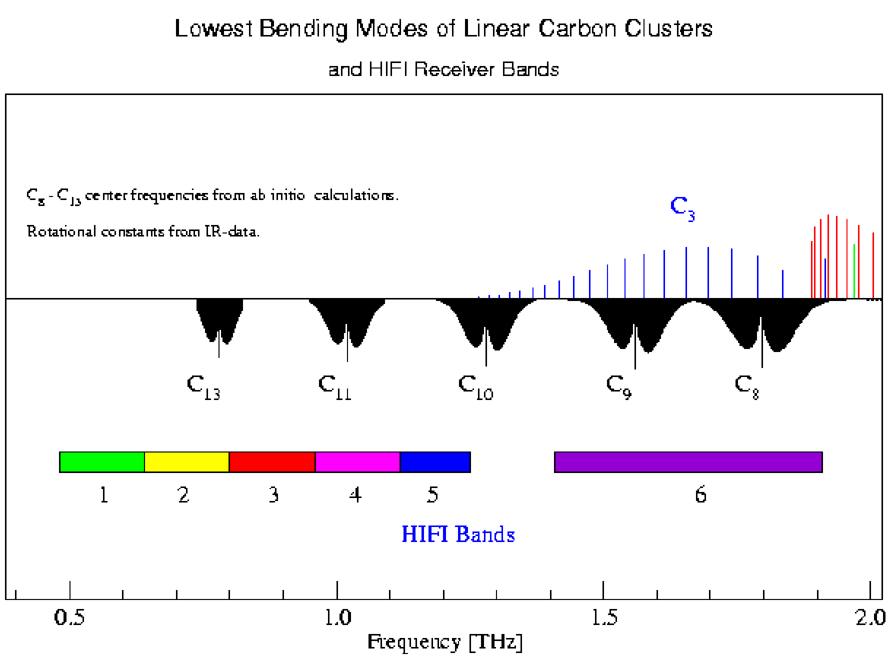
- The increasingly improved spatial resolution of successive generations of instruments will allow us to zoom in on the star and planet formation process (will also be invaluable for extragalactic studies)
- There will always be more objects detectable than resolvable, so detailed spatial studies and modelling of those which can be resolved are critical along the way – cf. SIRTF program to study Fabulous Four Debris Disks
- Far-ir imaging, polarimetry, and spectroscopy of planetary systems at all stages from the initial collapse phase through to the last stage evolution of solar systems like our own, we can attack fundamental questions of our origins and our fate
  - *Condensation of planets within the protosolar nebula*
  - *Composition of condensing material*
  - *Timescales and other influences – jets/magnetic fields*
  - *Prevalence of planetary systems in the solar neighborhood*
- Spectroscopy at high spatial resolution may even indicate what the organic/biogenic carryover into the forming planets might be, as key markers of organic molecules like in the far-ir/sub-mm

Spatial Resolution at 100um

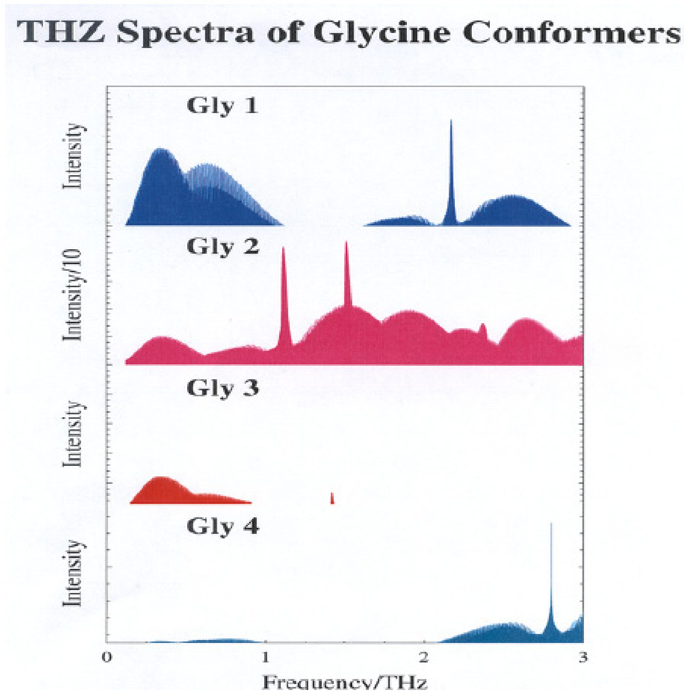


With the 20marcsec angular resolution of a ~1km baseline SPECS interferometer, it will be possible to image disks like that around HH-30 ~2 astronomical unit resolution.

Far-ir/Sub-mm Transitions of Linear Carbon Clusters



Predicted Spectra of Glycine



SIRTF Science Plans

Keep abreast of your opportunity to propose for observing time with SIRTF at sirtf.caltech.edu

Substantial Progress Made in Planning Year One