FIRST Extra-Galactic Surveys

Practical Considerations

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Choices in Designing a Survey

- Bands
- Depth
- Area
- Fields

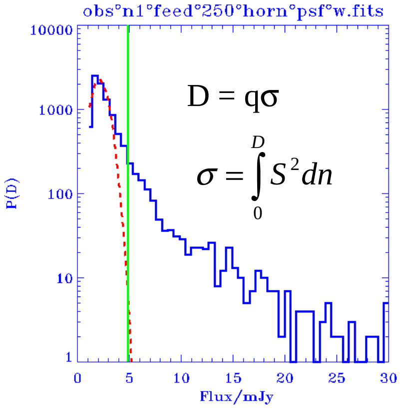
Depth

Depth

- Source confusion places strong constraints on depth
- Classical confusion limit from Condon 1974
- Super-resolution can improve things but is very expensive

Classical Confusion

(Condon 1974)



D = qσ

$$\sigma = \int_0^D S^2 dn$$

Power-law counts

$$\frac{dn}{dS} = -kS^{-\gamma}$$

Euclidean

$\gamma = 5/2$

$$\sigma = \left(\frac{q^{3-\gamma}}{3-\gamma}\right)^{\frac{1}{\gamma-1}} (k\Omega_{\text{effective}})^{\frac{1}{\gamma-1}}$$

$$\Omega_{\text{effective}} = \int [\, f(\theta,\phi)]^{\gamma-1} d\Omega$$

$$n_q = \frac{1}{3q^2}\Omega^{-1}{}_{\text{effective}}$$

$$n_q = \frac{1}{q^2}\frac{3-\gamma}{\gamma-1}\Omega^{-1}{}_{\text{effective}}$$

Classical Confusion

Effective beam for Gaussian Profile

$$\Omega_{\text{effective}} = \frac{1}{(\gamma-1)\ln 2}\frac{1}{4}\pi\theta_1\theta_2$$

Effective beam for Airy Profile

if γ = 2.5

$$\Omega_{\text{effective}} = 0.18\pi\left(1.2\frac{\lambda}{D}\right)^2$$

rough approximation assuming same functional form as for Gaussian

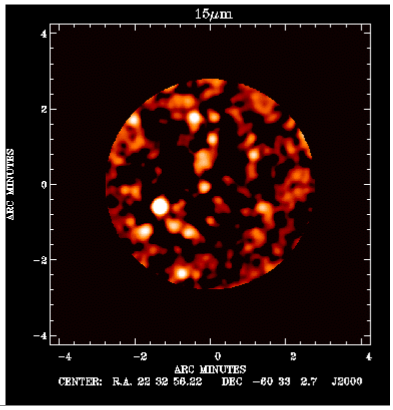
$$\Omega_{\text{effective}} \sim \frac{0.27}{\gamma-1}\pi\left(1.2\frac{\lambda}{D}\right)^2$$

Example: ISO HDF South

$$\Omega_{\text{effective}}(\lambda = 15\mu\text{m}) = 6\times10^{-3}\,\text{arcmin}^2 \qquad n_5 = 2.2\ \text{arcmin}^{-2}$$

$$N_5 = 43\left[2.5'\,\text{radius circle}\right]^{-1}$$

c.f. ~30 Oliver et al. 2000



UK-SCUBA 850 µm Surveys

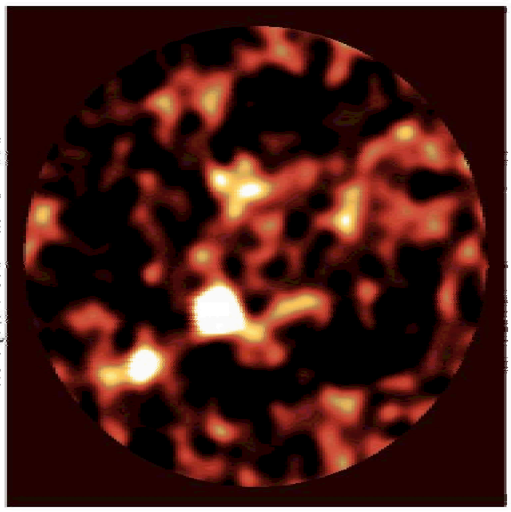
Classical 5σ confusion limit
0.43 sources arc min^{-2}

Area = 8.7 arc min^2

5σ limit 3.8 sources

c.f. 5 sources in

Hughes et al. 1998
Nature 394 241



Classical Confusion Limits from FIRST

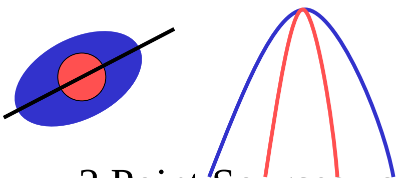
λ/μm	70	120	175	250	350	500
D/m	3.5	3.5	3.5	3.5	3.5	3.5
Ω/arc^2	13.9	40.7	86.6	176.8	346.4	707.0
n5	12469	4243	1995	978	499	244
4.3σ	0.74	3.2	11	18.6	20	16.6

Last row is flux at which number of sources hits the 4.3σ confusion limit threshold using models of Rowan-Robinson 2000 ApJ in press

Limits to Super-Resolution

Perfect Instrument: records exact position of ν
Ideal reconstruction

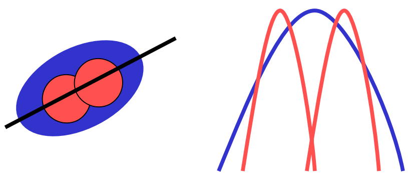
- Point Sources vs. Extended Sources



$$\frac{\theta_{Natural}}{\theta_{Super}} \propto N^{1/4}$$

Lucy 1991
Proc. 3rd ESO/ST-ECF data analysis workshop eds Grosbøl & Warmels

- 2 Point Sources vs. Extended Source



$$\frac{\theta_{Natural}}{\theta_{Super}} \propto N^{1/8}$$

Lucy 1992
AJ, 104, 1260

Lucy 1992
Astron Astro 261, 706

Limits to Super-Resolution (ctd.)

- Assuming super-resolved profile can be considered the same shape

$$\Omega_{\text{effective}} \propto N^{-1/8} - N^{-1/16} \propto t^{-1/8} - t^{-1/16}$$

$$\sigma \propto \Omega_{\text{effective}}^{1/(\gamma-1)} \propto t^{1/8(\gamma-1)} - t^{1/16(\gamma-1)}$$

$$\sigma \propto t^{-1/12} - t^{-1/24}$$

$$n_q \propto \Omega^{-1}{}_{\text{effective}} \qquad n \propto t^{1/8} - t^{-1/16}$$

e.g. moving from a 15 min exposure to 100 hours would increase the number of sources at the idealised super resolved confusion limit by between 2.1 - 1.5

reducing the confusion noise by 1.6-1.3

Area

Choice of Area

- Major survey projects are going to be large area classical confusion limited surveys
  - Large to detect rare/high luminosity objects
  - Large to produce statistically significant sub-samples
  - Say 100 square degrees
- Niche projects over smaller areas may attempt to go deeper in regions of specific interest but should not drive design.

Field

Factors affecting choice of Fields

- Factors affecting quality of data
  - Cirrus Confusion Noise
  - Zodiacal photon noise
- Factors affecting the ease of conducting the survey
  - FIRST visibility
  - Existing survey data
  - Easy of ground based follow-up

Cirrus Confusion

$$\frac{\sigma}{1\text{mJy}} \approx \left(\frac{\lambda}{100\mu\text{m}}\right)^{2.5}\left(\frac{D}{1\text{m}}\right)^{-2.5}\left(\frac{B(\lambda)}{1\text{MJysr}^{-1}}\right)^{1.5}$$

From Gautier et al. (1992, AJ 103, 1313) and
Helou & Beichman (1990, Proc. 29th Liege Int. Astro. Colloq. ESA SP-314).

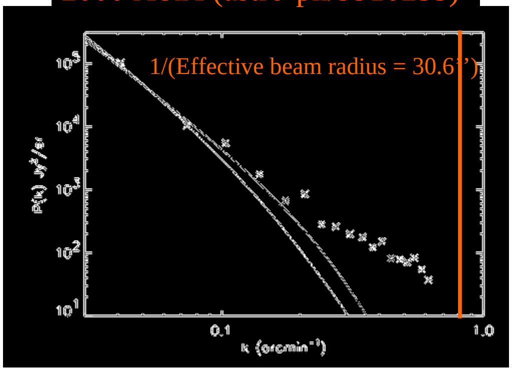
Equating $20\sigma_{\text{cirrus}} = 4.3\sigma_{\text{source}}$

Normalising to B_{100} using cirrus spectrum (Rowan-Robinson et al 1992, MNRAS, 258, 787)

Factor of ~5 is safety margin ensuring 2x better than Marano at 175µm

Example: ISO 175μm observations of Marano

Lagache and Puget
2000 A&A (astro-ph/9910255)



Arguably the limit at which you believe distinction between confused sources and cirrus

$4.3\sigma_{source}$=107 mJy

B_{100} = 0.88 MJy/sr

$10\sigma_{cirrus}$ = 116 mJy

Sources extracted to 100 mJy

Cirrus Confusion limits

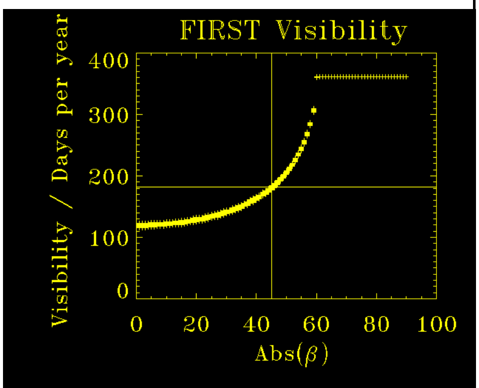
λ/μm	70	120	175	250	350	500
D/m	3.5	3.5	3.5	3.5	3.5	3.5
B100/MJy/sr	2.36	1.85	2.34	3.18	4.23	5.81

Good Visibility

- Ease of scheduling FIRST survey observations
  - Ease of FIRST follow-up observations
  - Minimum impact on other FIRST science
  - Flexibility for orientation of maps
- Good visibility for other satellite observations

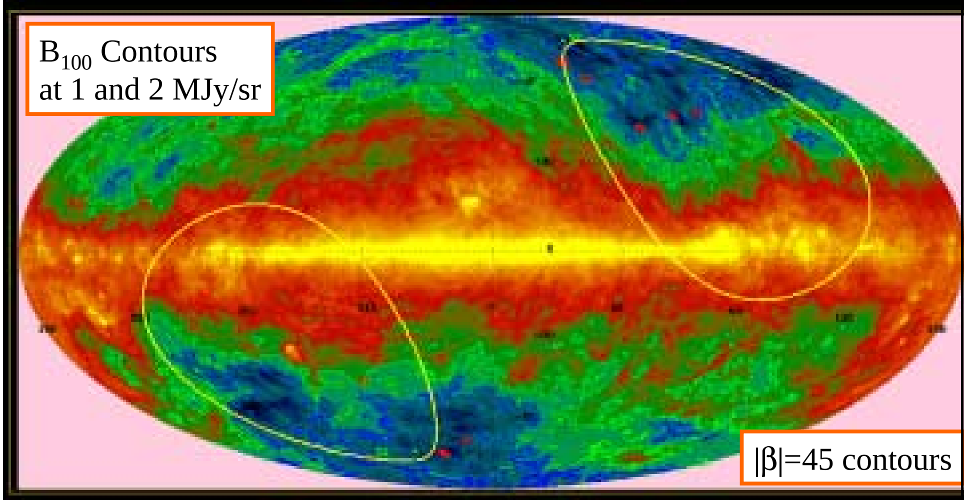
Visibility Constraints

- Solar elongation
  - >60 and <120
- Consider this over a year
- |β|>45 gives visibility >50%
- Lower visibility is possible but a number of fields should then be distributed in λ so that some fields are always visible



Visibility & Cirrus Constraints

IRAS 100μm Cirrus map from Schlegel et al. 1998



Practical need for other survey data

- Degeneracy between T and z means FIRST data on it own is limited
- Large error circle and large dispersion between FIR and other bands mean identification difficult

$$N_{IDs} = \Omega \int P(S_\nu \mid S_{\rm FIR}) \frac{dn}{dS_\nu} dS_\nu \sim \Omega \frac{dn}{dS_\nu} \Delta S_\nu$$

- more bands decreases number of IDs

$$P(S_\nu, S_{\nu 2} \mid S_{\rm FIR}) < P(S_\nu \mid S_{\rm FIR})$$

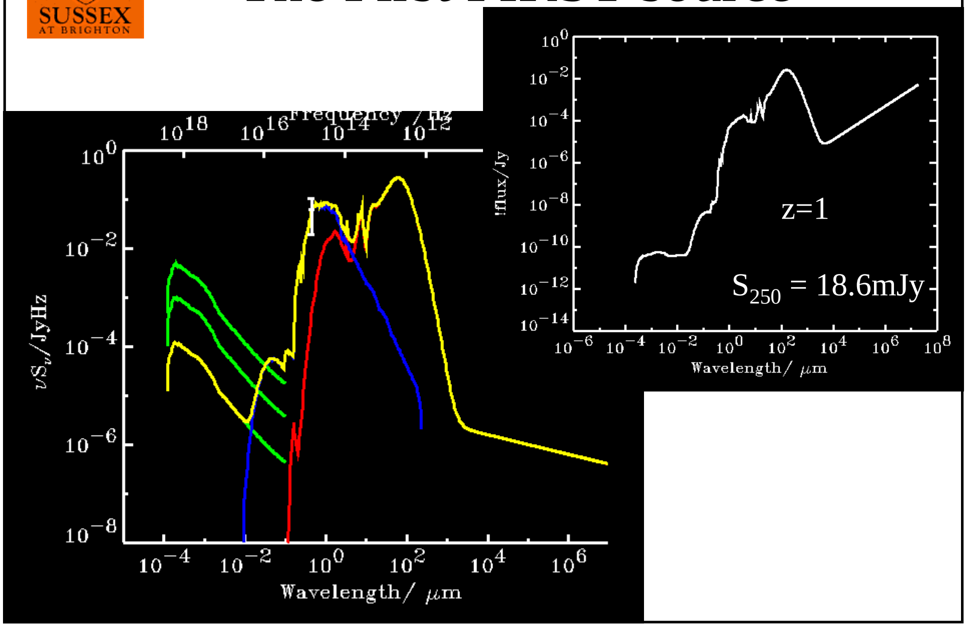
Criteria for other surveys

- Area > 10 sq. deg.
  - smaller fields can be tackled individually on case by case basis
- Area < 10,000 sq. deg
  - larger surveys do not constrain the fields
- Flux limits
  - minimum to detect at least half the objects
  - deeper surveys would of course be much better

The First FIRST source

- SED
  - FIR starburst from Efstathiou & Rowan-Robinson
  - Optical SED from Bruzual & Charlot 1996
  - X-ray M82 from Tsuru et al. 199
  - X-ray Sy1/2 from Barcons et al. 1995
  - Radio, $S_\nu = \nu^{-0.8}$
- Normalisations
  - $L_B|L_{60}$ from Saunders et al. 1990 at $L_{60}=10^{11}$
  - X-ray using S_{15} of M82
  - Radio, $S_{1.4GHz}/S_{90}$~100
- Source
  - z = 1(approximate median redshift of Rowan-Robinson 2000)
  - S_{250} = 18.6 mJy (confusion limit from Rowan-Robinson 2000)

The First FIRST source



Existing/Potential Surveys

- SIRTF SWIRE Legacy Programme Lonsdale et al.
  - ~ 70 sq. deg at all SIRTF photom. bands
  - Constraints more severe than for FIRST
  - should be able to detect first FIRST source in IRAC bands

	IRAC				MIPS		
λ	3.6	4.5	5.8	8.0	24	70	160
5σ	7.3 μJy	9.7 μJy	27.5 μJy	32.5 μJy	0.45 mJy	2.75 mJy	17.5 mJy

Existing/Potential Surveys

- XMM-LSS
  - $5x10^{-15}$ erg cm^2 s^{-1}
  - 64 square degrees (low-β)
  - should detect first FIRST source if a Seyfert 1/2 not if star-bust
- GALEX
  - 200 square degrees U_{AB} =26 - fields?
- Radio
  - needs to be ~100μJy or better over 100 sq deg.?

Existing/Potential Surveys

- ESO-VIRMOS
  - Fields scattered making total of 16deg^2
- NOAO
  - SIRTF Legacy follow-up
- Follow-up of XMM-LSS fields 64 sq deg. CFHT & VLT
- UKIDSS
  - 100 sq deg K=21 (J, H, to similar depth)
- ESO VST
  - commitment to SIRTF Legacy & XMM-LSS
- VISTA
  - 250 sq deg. g'=28, r'=26.7, i'=26.2, z'=24.5, J=23.5, H=22.5, K=22

Conclusions

- Major survey project with FIRST is likely to be a confusion limited 100 sq deg.
- FIRST specific constraints are not severe
- Complementary surveys will be very important to science of FIRST
- Need to actively ensure that surveys planned now are suitable for FIRST
- SIRTF SWIRE Legacy fields are likely to be most appropriate