Infrared Processing and Analysis Center, Caltech/JPL.
IPAC is NASA's Infrared Astrophysics Data Center.

Search for Dyson Spheres using the IRAS catalog

Dick Carrigan

Fermilab

Marching plan

- **Searching for signs of life, extraterrestrial intelligence**
- **The Dyson Sphere conjecture**
- **IRAS and other infrared instruments**
- **Dyson Sphere search scheme**
- **Illustrative sources including mimics**
- **Results, and other searches**
- **Future possibilities?**

THE RADIO SETI PARADIGM

A substantial fraction of sun-like stars out to several hundred light years have been monitored for ETI with radio SETI.

Arecibo via satellite

SETI radio beacon (acquisition signal) –but why?

Material and electromagnetic artifacts like a Dyson Sphere don't require reason to communicate

Stat Mus-Berlin

COSMIC ARCHAEOLOGY (CA)

Kardashev civilizations:

I-planet (10^{16} W) your world now: 10^{13} W
II-star ($4*10^{26}$ W for sun) -Dyson Sphere
III-galaxy (10^{36} W) -- Jim Annis search

SETI

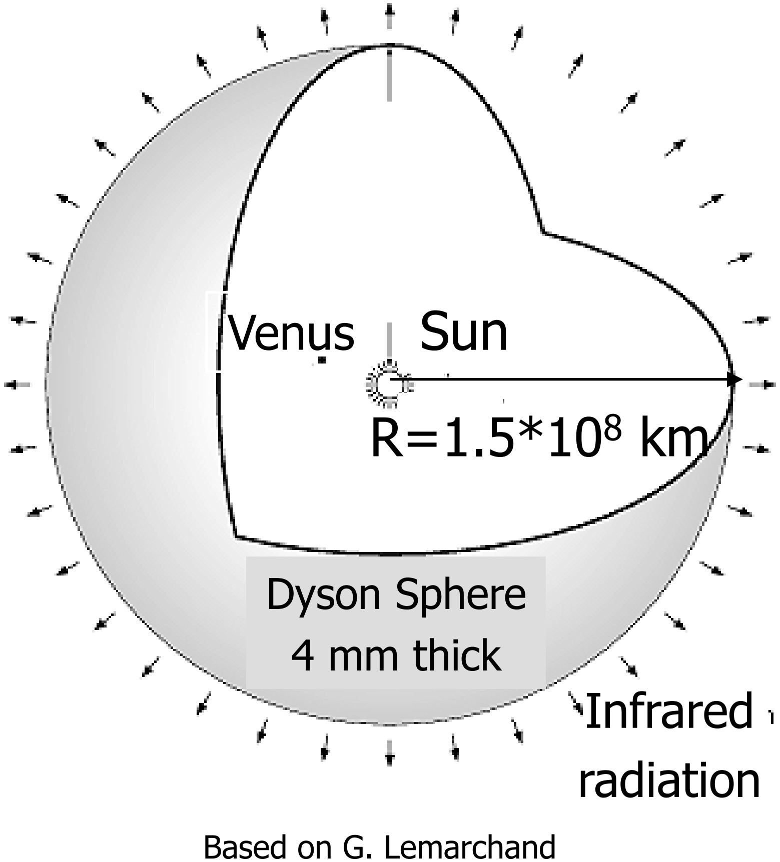
Extrasolar planetary atmospheres -Type I

Radioactive waste disposal in a star – Type I

Stellar engineering – Type II – M. Beech's book

G. Lemarchand, SETIQuest, Volume 1, Number 1, p. 3.
On the web at http://www.coseti.org/lemarch1.htm

AN EXAMPLE OF CA: DYSON SPHERES



Dyson conjecture - 1960

"loose collection or swarm of objects traveling on independent orbits…"

Types

pure – star completely obscured

partial

Signature

infrared

stellar luminosity (distance problem)

pure Planck

no star for pure DS

Searches-problem fixing distance.

Earlier-Sylsh, TKP, Jugaku, …

Sagan and Walker, Astrophysical Journal **144(3)**, 1216 (1966)

search feasible even with sixties technology but that the possible confusion with natural signatures could require searches for other artifacts of intelligence

Dyson Sphere engineering

Scale of a Dyson Sphere

- **Jupiter-scale Dyson Sphere $2*10^{27}$ kg**
- **Earth's biosphere 10^{15} – 10^{16} kg**
- **Great Wall of China 10^{12} kg**
- **International Space Station weighs $2*10^{5}$ kg, ocean liner $1.5*10^{8}$ kg**

Energy cost to build?

- **800 years of total solar radiation, not amount falling on planet's surface. (The 800 year number is of the order of the gravitational energy of Jupiter.)**
- **Poses a bootstrap problem**

Is a Dyson Sphere rigid?

- **Dyson - swarm of objects**
- **Papagiannis: rigid shell for gravitational case alone unstable**

Stability of a Dyson Sphere swarm?

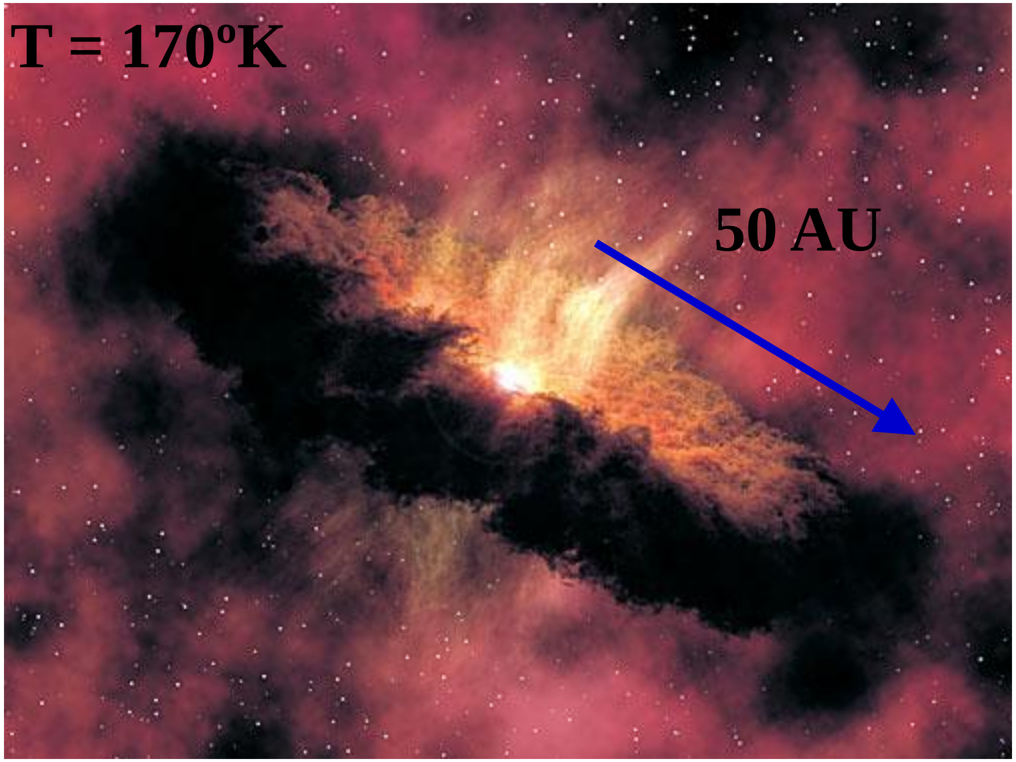
- **stability of elliptic and spiral galaxies**
  planetary formation in the solar system
- **actively steered, perhaps by solar sails**

But some other objects act sort of like a Dyson Sphere

From p. 14 of May, 2008 Physics Today

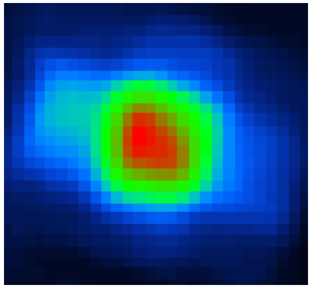
reporting on Spitzer IR results on water vapor in regions where terrestrial planets form

(artist rendition supplied by Robert Hurt, NASA/JPL-Caltech)



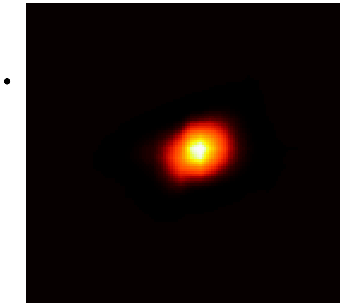
DYSON SPHERE SURROGATES

Stars are born and die in clouds of dust



←Planetary nebula from IRAS dumbbell M22.

IRAS 06176-1036 "Red Rectangle" →



Mira (Omicron Ceti) in visible (Hubble image)

Miras variables, old, short-lived, circumstellar dust

Sum of many Planck spectra. Often have masers

at ~1650 MHz from inverted hydroxyl population.

Also C stars, AGB, and post AGB (old)

← Protostars forming in Orion dust cloud (IRAS image)

Brown dwarfs but temperature is typically higher

absolute luminosity is lower. **Not candidate**.

IRAS

Requirement for Dyson Sphere search

all sky – useful

100 < T < 600 K

Only available all-sky survey at 12 μm

12, 25, 60, 100 μm micron filters

A main purpose – dust, mirror only 0.6 m

cosmic cirrus problems in 100, 60 μm

Performance

sensitivity – 0.5 Jy 12 – 60 μm,

1 Jy for 100 μm

250 K point sources

angular resolution – O(1')

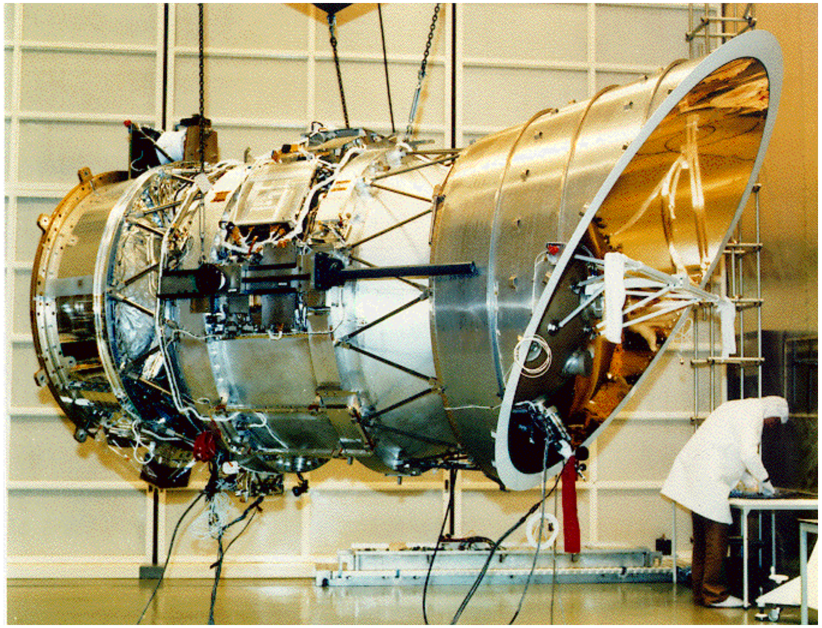
positional – 2 to 6" in-scan, 8 – 16" cross

Low Resolution Spectrometer (LRS)

sensitivity: 2 Jy in 12 – 24 μm filters

very useful Calgary LRS database

11224 sources



From Infrared Processing and Analysis Center, Caltech/JPL. IPAC is NASA's Infrared Astrophysics Data Center.

2MASS (ground based)

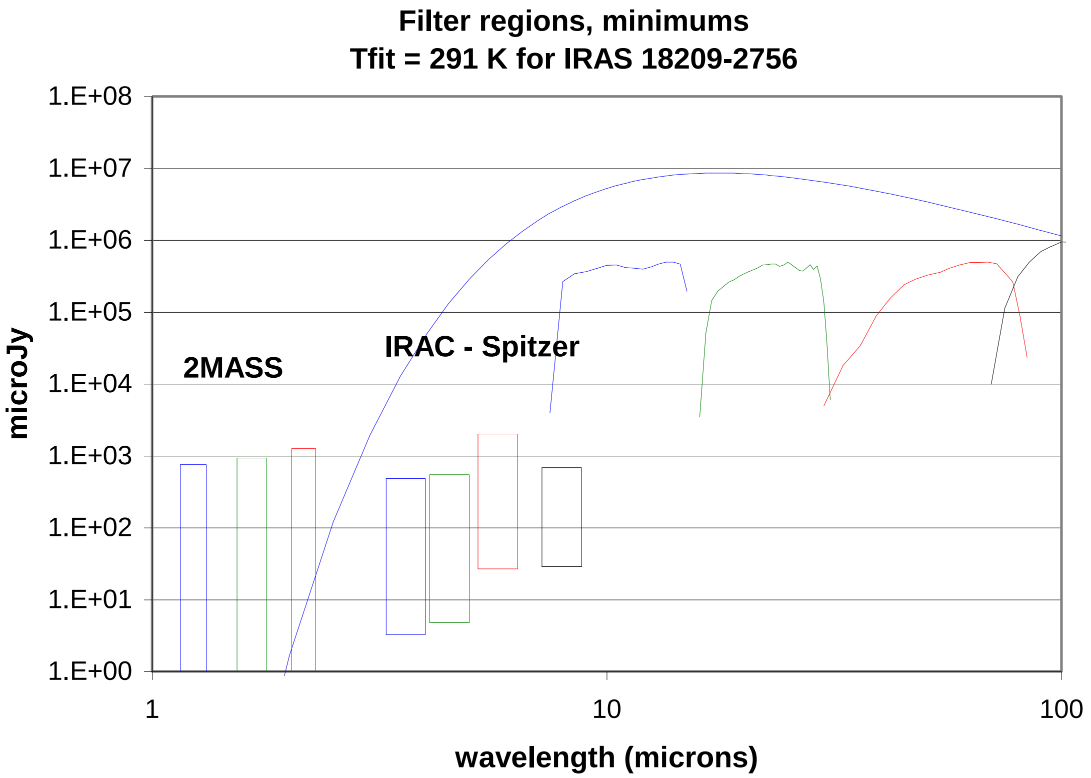
much more sensitive,

500 M point sources

IRAS 12 μm must be at least 10 Jy to register in the 2MASS 2.17 μm filter

Infrared resources and databases

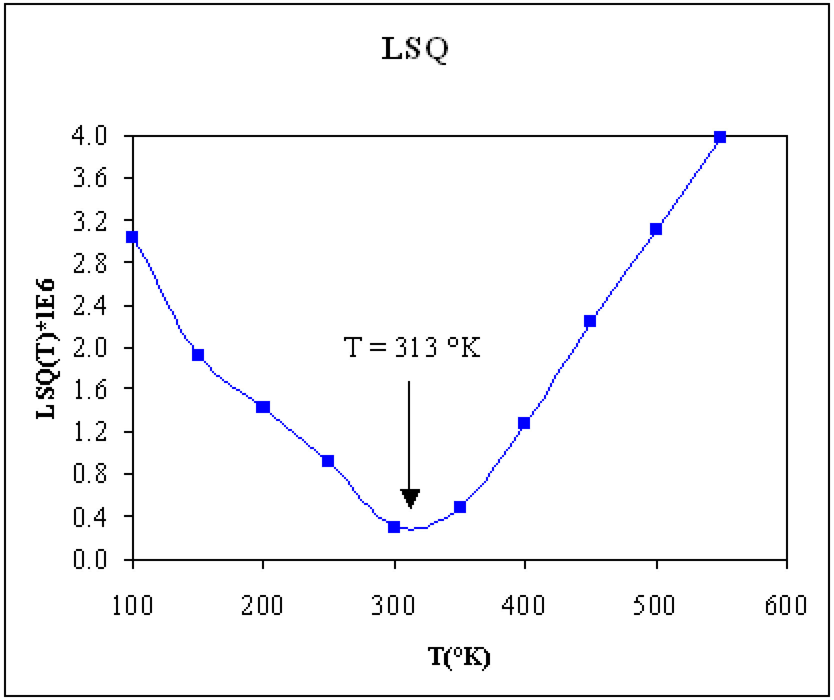
Other resources include MSX (fills in IRAS dead region), DIRBE (on COBE), Gemini (S. Allam: earth-based including spectroscopy), AKARI satellite, NICMOS (Hubble), and Spitzer



First search with filters –**Planck fit with three filters**

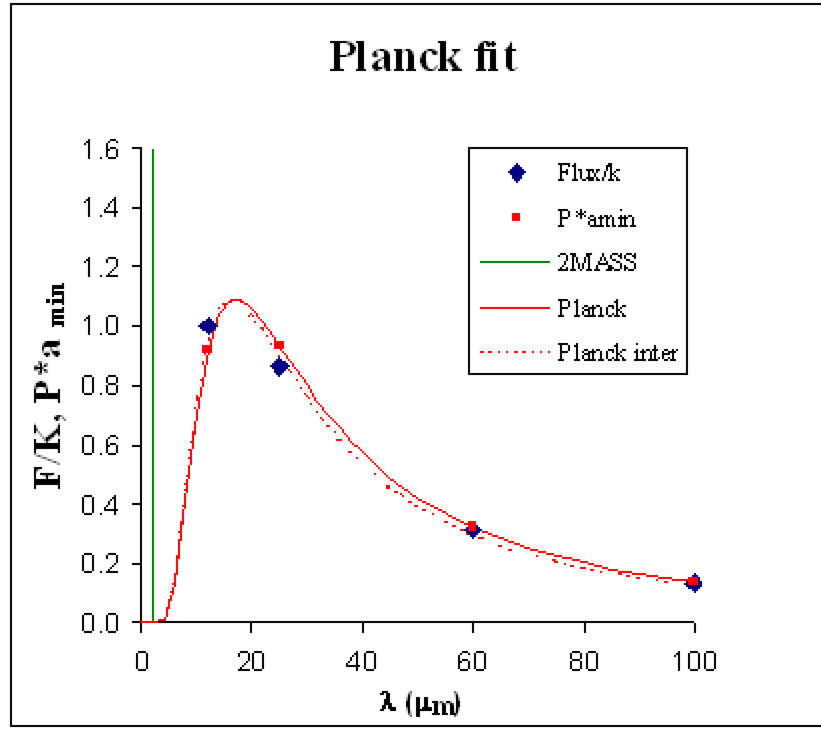
(R. Carrigan, IAC-04-IAA-1.1.1.06, 55th IAC 2004)

(IRAS 06176-1036 “Red Rectangle”)



$$LSQ_n(T_m) = \sum_k \left(\frac{(F_{nk}/K_{km} - a_{nm}P_{km})}{\sigma_{km}^2} \right)^2$$

F is IRAS flux, K is Planck color correction,
P is Planck dist., sigma is weight,
a is fit parameter, k is filter index, m is temp index, and n is source index



Solid is trial fit to 3 points, dotted-final

But look out!

IRAS has problems with Cirrus and Zodiacal dust in the 60, 100 μm filters

SEARCH WITH IRAS LOW RESOLUTION SPECTROMETER

UNIVERSITY OF CALGARY

Calgary atlas – 11224 sources

FQUAL(12), FQUAL(25) > 1

Temperature cut:

$$T1 = c_0 + \sum_k c_k (f_{12} / f_{25})^k$$

$$100 \leq T1 \leq 600\ ^{o}K$$

Select C, F, H, U, ~~P~~ ⟶
the classification scheme

Table I Calgary LRS Groups (Groups searched are underlined)

A	9.7 μm silicate absorption feature *typically O-rich AGB, thick cloud*
C	11 μm SiC dust emission *typically evolved C stars*
E	9.7 μm silicate emission feature *typically O-rich AGB, thick cloud*
F	flat, featureless spectrum *evolved O and C stars, little dust*
H	red continuum, 9.7 μm silicate abs or PAH *planetary nebulae of HII*
I	noisy or incomplete spectra
L	Spectra with emission lines above a continuum (few sources)
P	red continuum with sharp blue rise or 11.3 or 23 μm PAH feature *PAH*
S	Rayligh-Jeans optical tail (few) *stars earlier than M5 with little mass loss*
U	unusual spectra with flat continua *unknown*

Source flow through cuts

IDTPYE = 0, 2

(no source or stellar association in catalogs)

Fit to Planck distribution

Visually scanned for:

- non-Planck shapes
- obvious spectral lines
- large data scatter
- visible stars with something else
- identification of the source with a known object

Source flow through cuts

Selection	Sources
IRAS sample	245,889
Calgary LRS sample	11224
FQUAL(12), FQUAL(25)>1	10982
100 ≤ Temperature ≤ 600 ºK	6521
Selecting C†, F, H(*), P(*), U	2240
IDTYPE = 0, 2, 3, 4	1527
Possible sources by direct scan	295
-Line(166),cl(40),T(14),H(9),np(1)	65

* later eliminated, †C mostly lines

FITTING TO A PLANCK DISTRIBUTION

weighted case

$$L(T,a_m) = \sqrt{\sum_i \left(\left(P_{\nu i} - a_n \lambda_i C_i\right)^2 / P_{\nu i} \right) / 92}$$

$$P_{\nu i}(a_m, T) = \frac{2\pi hc a_m a_n}{\lambda_i^3 \left(e^{hc/\lambda_i kT} - 1 \right)}$$

unweighted case

$$uL(T,a_m) = \sqrt{\sum_i \left(P_{\nu i} - a_n \lambda_i C_i\right)^2 / 92} / N$$

$$N = \sum P_{\nu i} / 92$$

a_m is the fitting amplitude,

a_n is a graphical normalization factor,

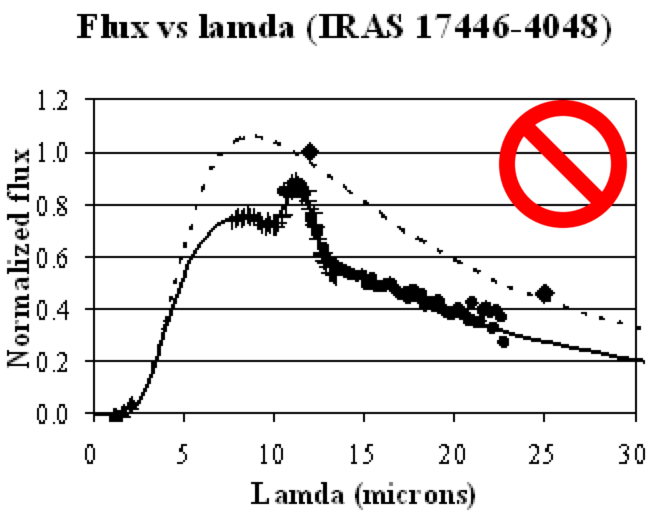
C_i are the Calgary spectral values

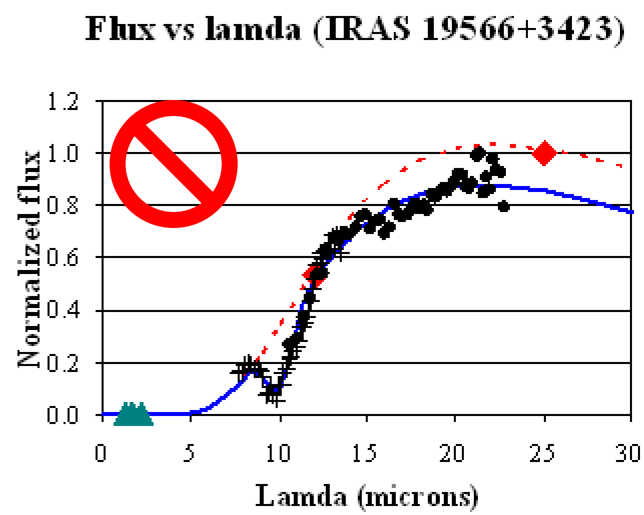
Source flow through cuts

Selection	Sources
IRAS sample	245,889
Calgary LRS sample	11224
FQUAL(12), FQUAL(25)>1	10982
100 ≤ Temperature ≤ 600 ºK	6521
Selecting C†, F, H(*), P(*), U	2240
IDTYPE = 0, 2, 3, 4	1527
Possible sources by direct scan	295
-Line(166),cl(40),T(14),H(9),np(1)	65
Statistical uncertainty <0.25	22
Somewhat interesting sources	17
Most interesting but with questions	4

* later eliminated, †C mostly lines

SOME PARTIAL MIMICS





Illustrates a common case, an 11.3 µm SiC emission feature typical of C stars. Often the background is a BB spectrum. Notice the 2MASS points on BB distribution. Line is not a natural DS feature. IRAS IVAR is 99%.

T = 594 ºK (with line), no visible star.

(Scale: F(Jy) = y axis/0.0046)

F[12], etc are temperature color corrected

Shows a 10 µm absorption feature that sometimes occurs in OH/IR stars. SIMBAD classifies it as a star with an OH/IR envelope. T = 246 ºK (with line), no visible star.

(Scale: F(Jy) = y axis/0.0103)

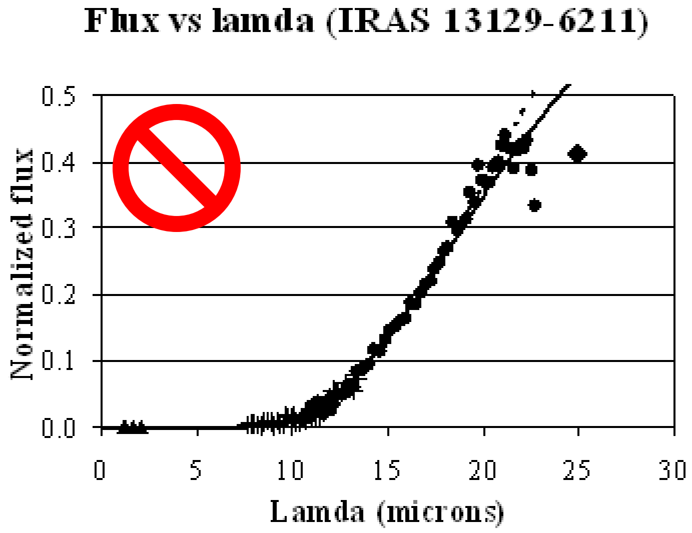
LRS short + , long – dots,

filters – diamonds, 2MASS - triangles

dotted curve - fit to 12, 25, 60 filters,

LRS Planck distribution fit - solid curve.

ANOTHER MIMIC

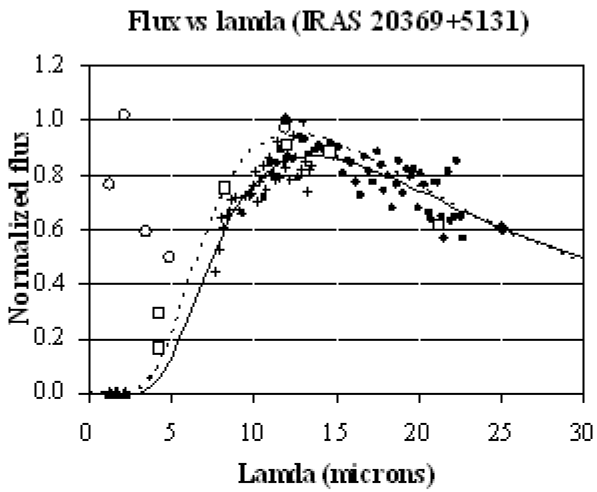


Looks like a Planck spectrum but has another explanation. Calgary classifies it as H. It may be near an H_{II} region. Typically these H sources have low temperatures.

T = 132 ºK, source near a visible star

(Scale: F(Jy) = y axis/0.0051)

Closest "candidate", one of best fits



SIMBAD says C star but Calgary gives U

can't find classification literature

may be based on millimeter region

Open circles – DIRBE but may be second source, open squares - MSX

T = 376 ºK, no visible star

(Scale: F(Jy) = y axis/0.0168)

Distance estimates

Possibilities:

proper motion (2/17)

visible star (10/17)

red shift via

maser signal or

binary companion.

galactic scale height for

rough limit

bolometric

Slysh peak flux formula

$$S(Jy)_m = \frac{35}{T}\frac{1}{D^2}\frac{L}{L_o}$$

D is source distance (kpc)

L, Lo are luminosities of putative DS and Sun.

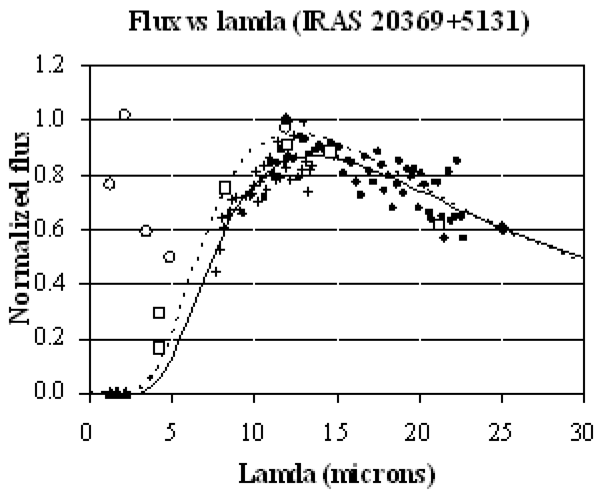
Distance

$$D(L)_{bol} = \sqrt{\frac{35}{S_m T}\left(\frac{L}{L_o}\right)}$$

Partial (nearer)

$$D_r = D_{bol} \times \sqrt{2 \times f_c}$$

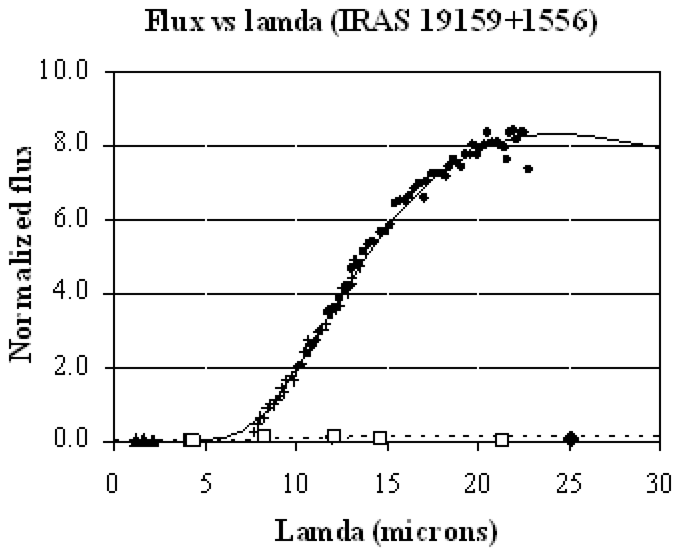
Closest "candidate" - continued

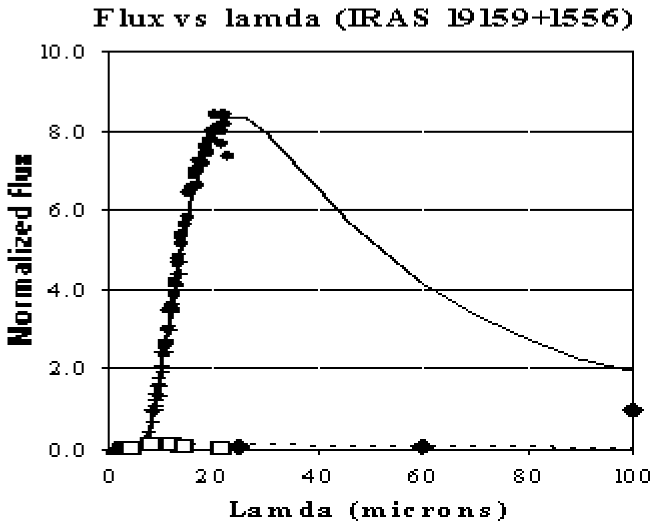


D(1 sun)$_{bol}$ = 42 pc

Dscl(galactic) is O(2000pc)

Another good fit





wide discrepancy between filters, MSX, spectrometer

variability 99%

F[100] filter is 10-20 > low filters

temperature is low, 208 ºK

H rather than U?

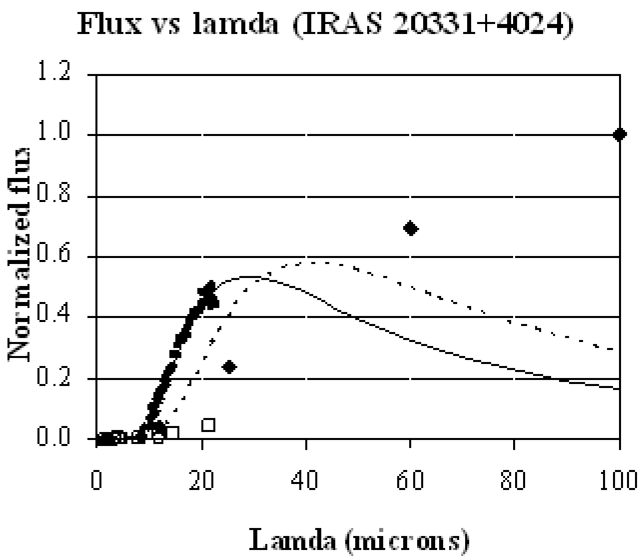
one sun bolometric distance is 34 pc

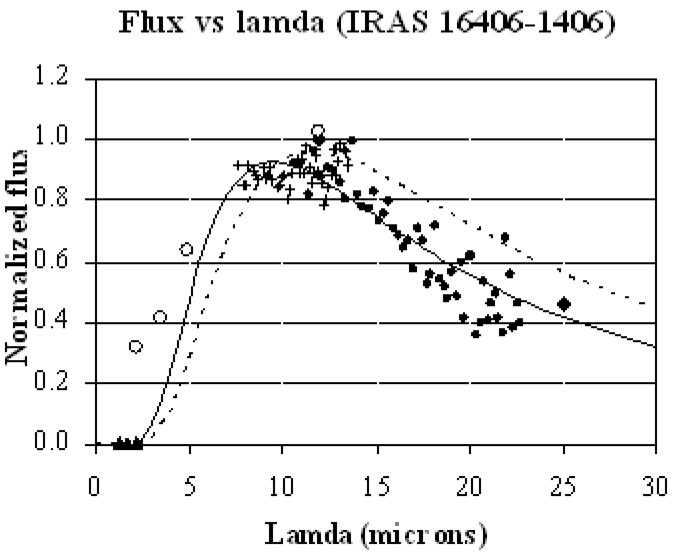
(Scale: F(Jy) = y axis/0.0563)

source region was observed with the Arecibo telescope in the SETI SERENDIP program (later slide)

No SETI detection

Two other low least squares fits





Classified U but maybe H?

Hint of structure at 8 µm

T = 177 ºK

Note F[60], F[100] filters high,
suggests an even lower temperature.

The bolometric distance is 45 pc

(Scale: F(Jy) = y axis/0.0055)

T = 538 ºK

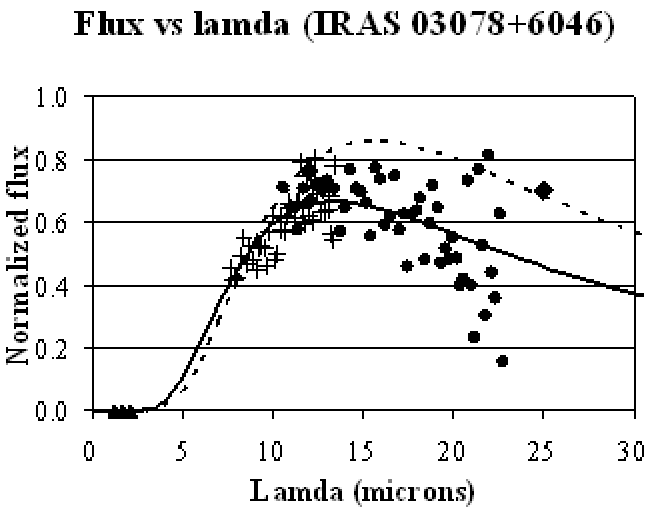
DIRBE suggests higher temperature

13.5 µm emission artifact?

bolometric distance is 55 pc

(Scale: F(Jy) = y axis/0.0425)

ANOTHER NEAR CANDIDATE



Planck spectrum? Polynomial better. Scatter high. This is the problem when deviations become larger. Kerton and Brunt - no CO associations for this source.

Calgary F

T = 381 ºK, apparently no visible star.

(Scale: F(Jy) = y axis/0.0541)

Summary slide – 17 sources

IRAS name	Galactic coordinates longitude (mod 180)	latitude	Other names	VAR	IDTYPE	Vis star	Calgary class	T fit (K)	amin (LRS)	unLSQ	DS rating	Facc	Notes
16406-1406	4.10	20.20		74	0	y	F	538	2.353	0.096	3	0.0425	Hint of 13.5 mic
19159+1556	50.21	1.51		99	0	y	U	208	275	0.037	3	0.056	Filter-LRS discrepancy
20331+4024	79.83	0.10	CPR2002 A10	33	3		U	177	294	0.066	3	0.0055	Hint of 8 µm, H?, MSX, filt ≠ LRS
20369+5131	89.09	6.29	CGCS 6868, …	43	0		U	376	16.42	0.072	2	0.0168	C* but no reference?
00477-4900	-56.44	-68.40	PPM 305293 ,V* CR Phe, …	4	0	y	F	550	1.64	0.159	1	0.0598	Prominent 2MASS, DIRBE
02566+2938	153.54	-25.31		2	2	y	F	429	3.26	0.188	2	0.0717	M7, brt 2MASS
03078+6046	139.17	2.59	IRAS 0307+607P02	69	0		F	381	3.742	0.163	3	0.0541	MSX > LRS
11544-6408	-62.91	-2.17	GLMP 315 -- Post-AGB Star	21	3		U	211	39.1	0.191	1	0.0372	post AGB, PN?,hint of 8 µm
18013-2045	9.21	0.47		93	0	y	U	330	7.66	0.208	0	0.0191	2MASS means higher T?
18094-1505	15.08	1.56	NSV 10353 -- Variable Star	8	2	y	F	333	6.84	0.208	3	0.0191	2MASS means higher T?
18112-1353	16.34	1.77		99	0		F	387	3.48	0.218	3	0.0038	MSX > LRS
18209-2756	5.03	-6.88		99	3		U	291	5.91	0.246	3	0.1033	Weak hint of 12 µm
18287-1447	17.56	-2.39		20	0	y	F	386	5.65	0.195	3	0.0082	MSX < LRS
18298-2026	12.66	-5.25		35	0		F	377	3.602	0.249	3	0.0242	
19405-7851	-44.51	-29.33	PPM 374361,V* RX Oct, …	4	2	y	F	518	2.17	0.154	2	0.0566	Prominent 2MASS, DIRBE
20035+3242	70.13	0.57	[HSD93b] Peculiar star	11	0	y	U	185	46.03	0.176	2	0.0367	Peculiar star
20212+4301	80.64	3.42		7	3	y	F	412	3.06	0.246	1	0.014	MSX, 2MASS: T > 600 ºK?

Reach of search

Largest D_{sol} (17 source sample) = **118 pc** (S_m = 8.6 Jy)

For 65 source sample: F > 4 Jy

then could have D_{sol} ~150 pc

LRS: down to ~ 1-2 Janskys in 11000 source sample

Could have found Sun-sized Dyson Spheres out to **300 pc**

O(1 M) solar type stars

For galactic disk scale height of 100-200 pc

(and assuming one solar luminosity estimate ~150 pc)

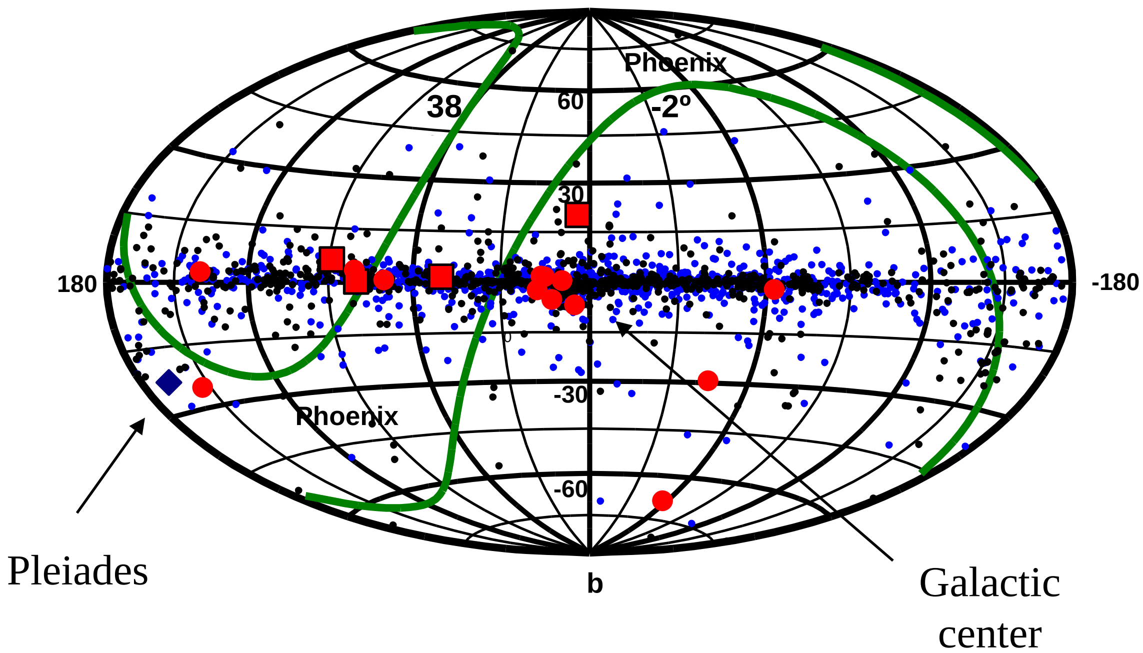
then this IRAS LRS sample would be scattered over the whole sky rather than lying near the galactic plane

Actually **1/4 scattered over whole sky**

other 3/4 in galactic plane

These sources are probably more luminous and at greater distances.

WHERE ARE THE INTERESTING SOURCES?



2240 event sample
follows galaxy, although less in core?

17 interesting events
Some away from plane (meaning nearer?)
biased to left side

EARLIER SEARCHES (typically for partial Dyson Spheres)

Slysh, in *The Search for Extraterrestrial Life: Recent Developments*, Papagiannis (Ed) 1985. Timofeev, Kardashev, and Promyslov, AAJournal, **46**, 655 (2000) [TKP]

Four filter IRAS Planck fit. Several candidates, limited sky. 100, 300 K. 98 stars

Jugaku and Nishimura, *Bioastronomy 2002: Life Among the Stars*, Norris and Stootman, eds, IAU Symposium, **213**, 437 (2002) and earlier

use the **2.2 μm K band as an indicator** of the photospheric radiation **hosting partial DS**

then look for an infrared **excess in the IRAS infrared satellite 12 μm** band

1 mag difference for 1% sphere. See less than 0.3 mag for 384 stars inside 25 pc.

Conroy and Werthimer, preprint (2003)

Jugaku technique to **older stars**. 1000 nearby older stars from Wright and Marcy Older stars eliminate dust clouds around young stars. Also planet hosts. Correlate with the K band near-infrared data from 2MASS. **For partial Dyson Spheres**

33 in the IRAS 12 μm with 3 σ excesses from mean. About ½ LRS. None in 17.

Globus, Backman, and Witteborn, preprint (2003)

temperature/luminosity anomaly due to the fact that the luminosity of a star surrounded by a **partial DS** would be lowered compared to naked star with same T

Reprise on Slysh and Timofeev, Kardashev, and Promyslov (TKP)

TKP lists 14 sources - only six have LRS spectra

(Calgary classifications would have excluded)

for 5 of 6 with LRS data T_{LRS} differed from T_{4filt} differed by average of 110 ºK

(LRS temperatures all higher - filter temperatures can be misleading)

2 of the 6 have FQ[12] values of 1 which would also have excluded

Most associated with definite stellar types.

Slysh - four out of six had LRS information - 1 in 1527 source sample

IRAS 04530+4427 (Slysh 0453+444) - carbon star (CGCS 6092)

12 µm emission line

IRAS 05073+5248 (Slysh 0507+528) - NV Aur, Mira Cet has an OH/IR maser

excluded from the 1527 source set because of E classification

IRAS 05361+4644 (Slysh 0536+467) - carbon star BD+46 1033

12 µm peak - classified as E by Calgary and therefore excluded

IRAS 17411-3154 (Slysh G 357.3-1.3) - strong absorption feature at 10 µm

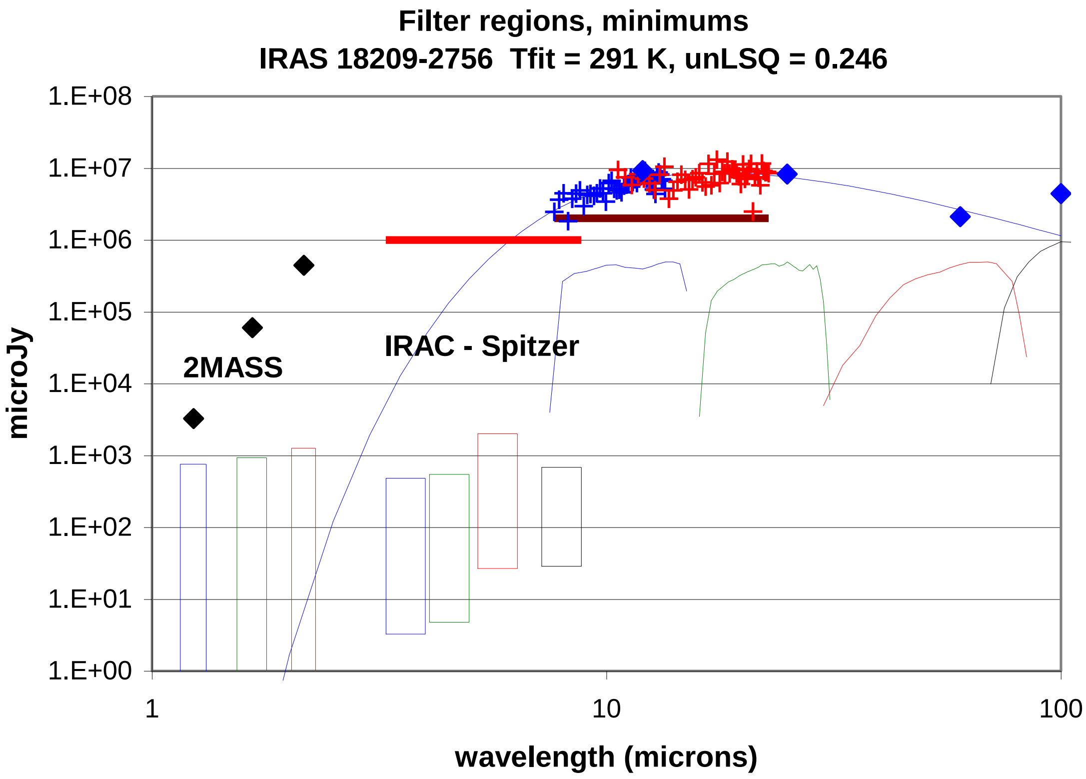
it was classified A by Calgary and excluded

For four with LRS data T_{LRS} differ from T_{4filt} the four filter by average of 44 ºK

(the LRS temperatures are all higher).

No Slysh or TKM included here, 1 in 1527 sample. LRS is an effective tool

Can Spitzer, 2MASS be used? AKARI? Gemini?

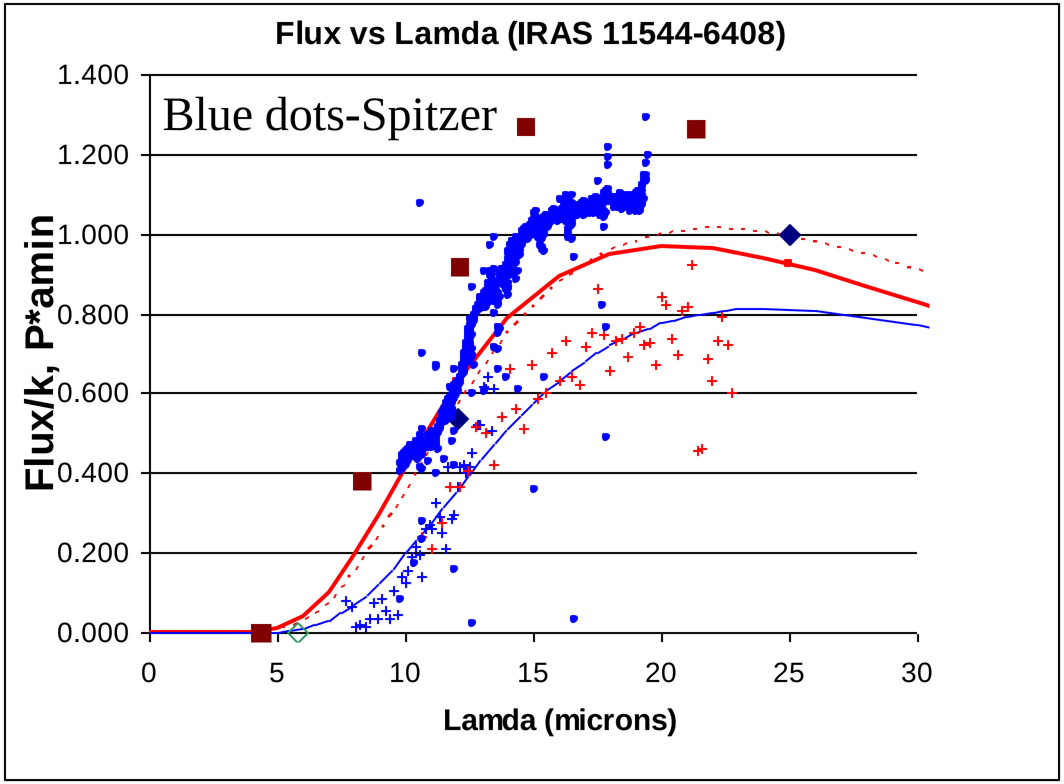


For IRAS filter values in 1-2 Jy regime could fit to IRAC get up to 300 ºK

Limited to galactic plane for GLIMPSE (80 K IRAS sources)

Does not extend reach much for 300 ºK (factors of 2)

Spitzer spectroscopy for IRAS 11544-6408

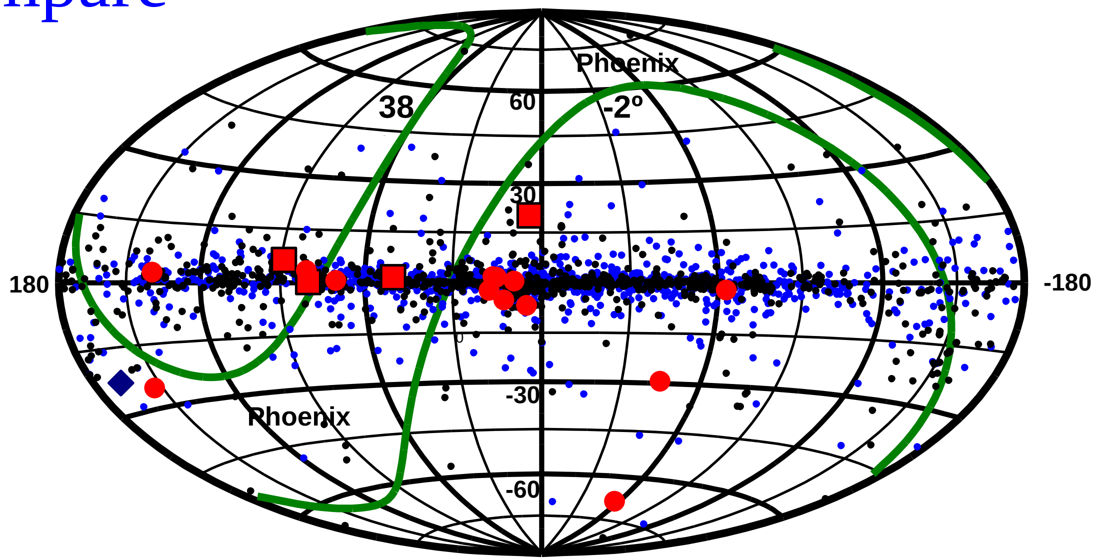


Spitzer release from April 15, 2008 (Garcia-Lario et al.)

Spectroscopy intermediate between MSX, LRS. IVAR =0%?

Shape shows non-Planck features

SETI compare



SERENDIP Berkeley (SETI@home)

collected data in Arecibo side lobe
continuous survey measurements.
angular coverage like Phoenix but uniform
loss of order of magnitude in sensitivity compared to Phoenix
Sampled over ~1 Hz in 100 MHz around 21 cm
3 of 17 sources in SERENDIP region
No signals found in SERENDIP
--so that 3 of 17 interesting IRAS sources free of SETI signatures

Phoenix Arecibo 300 m, Green Bank, ..
O(1000) targets < 250 light years
(F, G (Sun-like) and K stars) [life]
A region from -2º to +38º declination
sensitivity of O(1 Jy)
“point and shoot”.
1.2 to 3 GHz (includes 21 cm hydrogen line)
No ETI signals detected
None of 17 sources in Phoenix target list

Allen Telescope Array

(Credit: Allen Telescope)

Allen Telescope is a distributed array (about 42 dishes, 350 when complete in 2011) coming on line for SETI in Northern California,

Advantages: 1) wide field of view, 2) frequency 0.5 to 11.2 GHz , 3) multiple back ends, 4) active interference mitigation

Carrigan, Annis, Backus (SETI Institute) proposal

Concept – look for SETI signals from 17 interesting sources

also look for hydroxyl masers (1612-1720 MHz) to see if they can be used to rule out some sources

Can the IRAS data accumulated for the Dyson Sphere search be used for something else?

- Have an interesting collection of C stars with lines
- Variability of dust shells
- Some IR stars which appear to be misclassified

Some recent studies:

- M. Busso, et al., AJ **133**, 2310(2007)

  infrared photometry of AGBs

- J. Rodmann, et al., A&A **446**, 211 (2006)

  large dust particles in disks

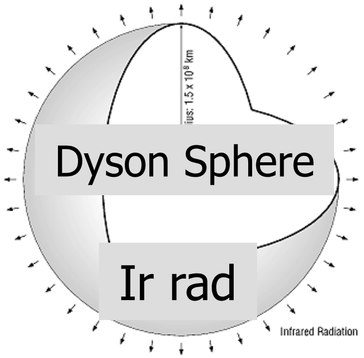
- P. Whitelock, et al., MNRAS **369**, 751 (2006)

  photometry on C stars

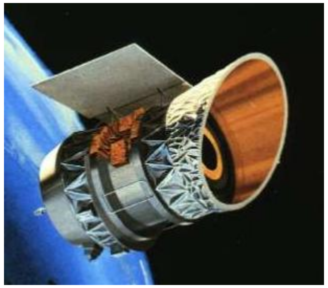
- R. Szczerba et al., A&A **469**, 799 (2007)

  post AGB catalog

Summary



Artifacts like pyramids, Dyson Spheres, and Kardashev civilizations are "natural" and don't require purposeful ETI signals



IRAS – good Dyson Sphere search instrument

Searches are confounded by many other signatures

Few sources at most with

IRAS Low Resolution Spectrometer

Cosmic archaeology

- SETI cultural signals
- Type III Kardashev ala Annis
- Cultural planetary atmosphere signal
- Astroengineering – Dyson Spheres
- Stellar engineering – Martin Beech