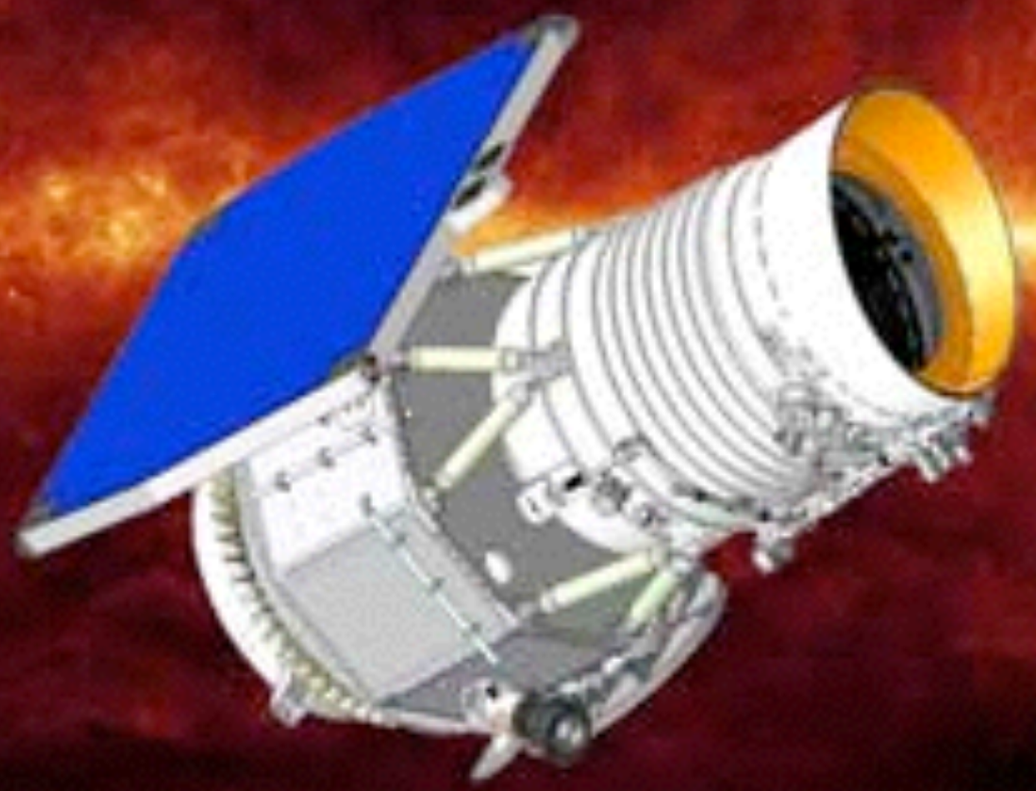
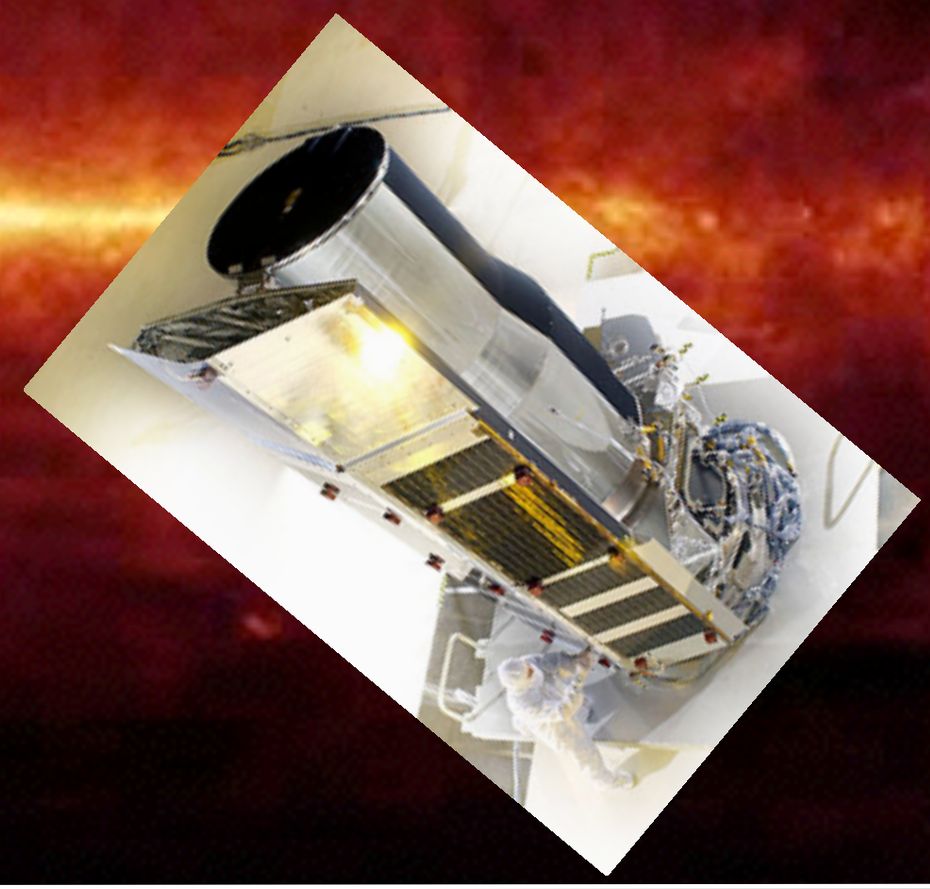
The $\hat{G}$ Search for Extraterrestrial Civilizations





PENNSTATE

1855

Jason T. Wright
Roger Griffith, Steinn Sigurðsson
Matthew Povich (Cal Poly Pomona)

Communication SETI

Radio SETI

Kardashev (1963) calculated the optimum radio spectrum for matching transmission bandwidth to background astrophysical noise:

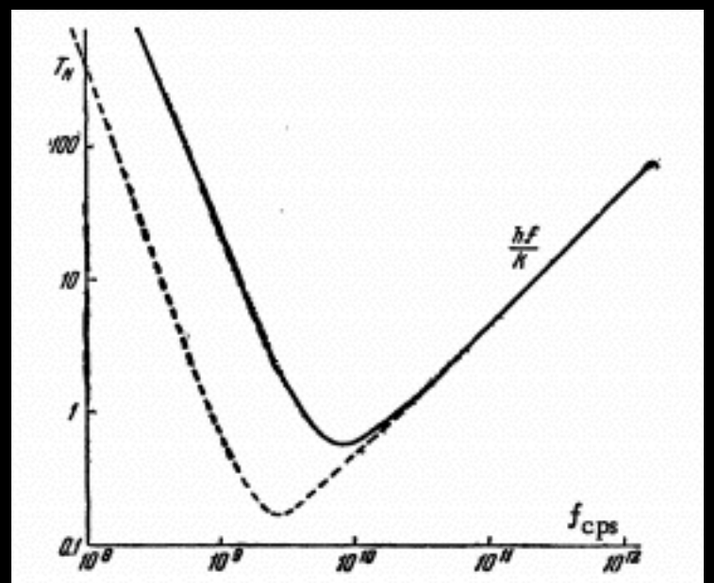


Fig. 1. Noise spectrum outside the confines of the earth's atmosphere: ——) In the direction pointing toward the center of the Galaxy; – – – –) in the direction toward the galactic pole.

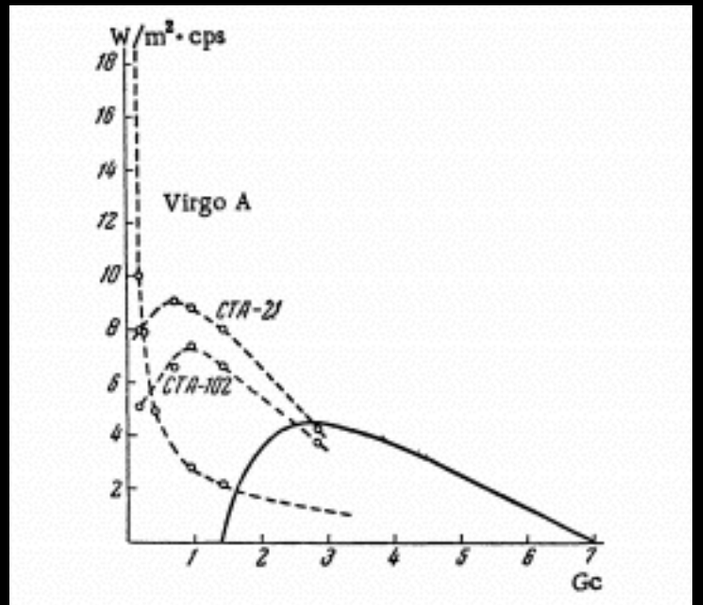


Fig. 2. ——) Anticipated emission spectrum of radio transmitters of extraterrestrial civilizations; – – – –) spectrum of radio sources CTA-21 and CTA-102, suspected of being artificial radio sources, and spectrum of a typical natural radio source Virgo A.

But how do we find them?

Radio SETI

CTA-102 had its "15 minutes" in pop-culture as an alien civilization

But how do we find them?

Radio SETI

CTA-102 had its "15 minutes" in pop-culture as an alien civilization

Today, we know CTA-102 as a quasar.

The Kardashev scale

Classify extraterrestrial intelligences by their total power supply (i.e. potential for transmission power)

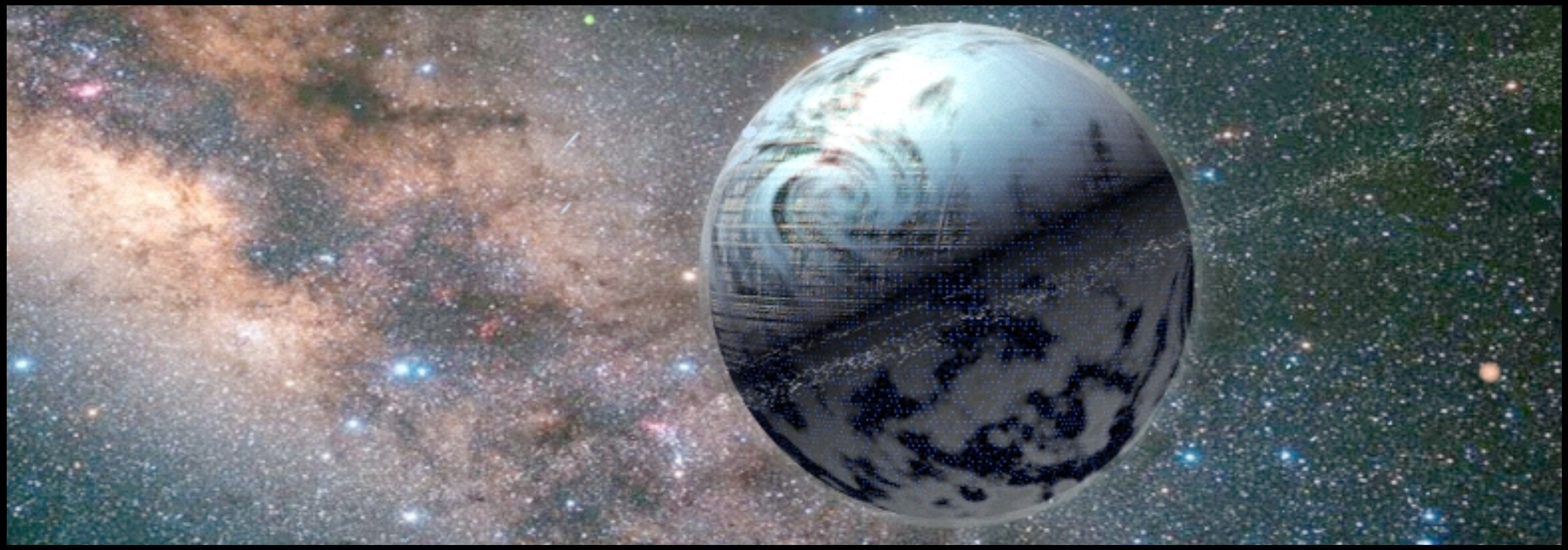
Class I: Equal to humanity's present energy supply
Class II : A solar luminosity
Class III: A galactic luminosity

Kardashev (1964)

Zubrin's adaptation

Zubrin loosely applied this scheme to describe the extent and approximate energy supply of a civilization:

K1: Any planet-spanning civilization (Humanity counts)

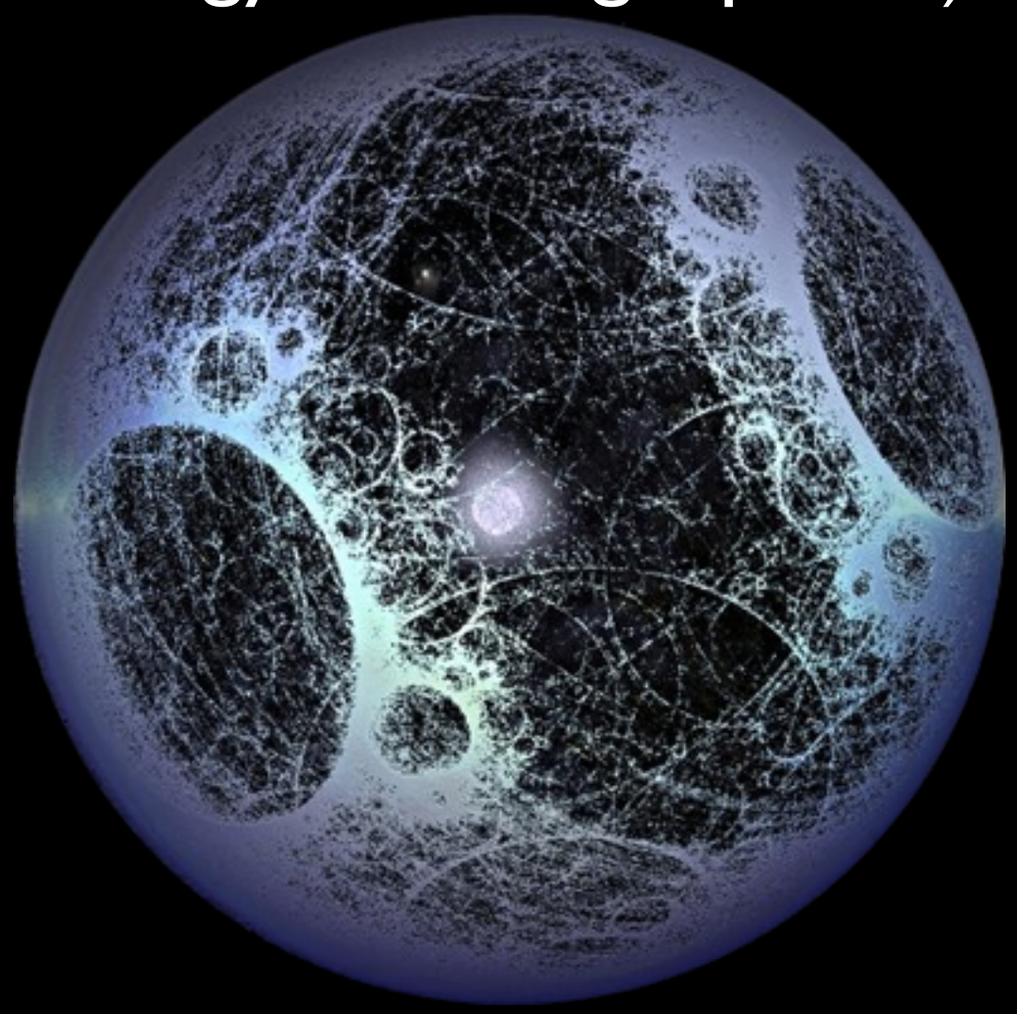


"Trantor from space" by Slawek Wojtowicz

Zubrin's adaptation

Zubrin loosely applied this scheme to describe the extent and approximate energy supply of a civilization:

K2: Any star-system-spanning civilization (with energy supply far beyond the incident energy on a single planet)



Dyson (1960); image by Steve Bowers

Zubrin's adaptation

Zubrin loosely applied this scheme to describe the extent and approximate energy supply of a civilization:

K3: Any galaxy-spanning civilization (with energy supply far beyond one stellar luminosity)

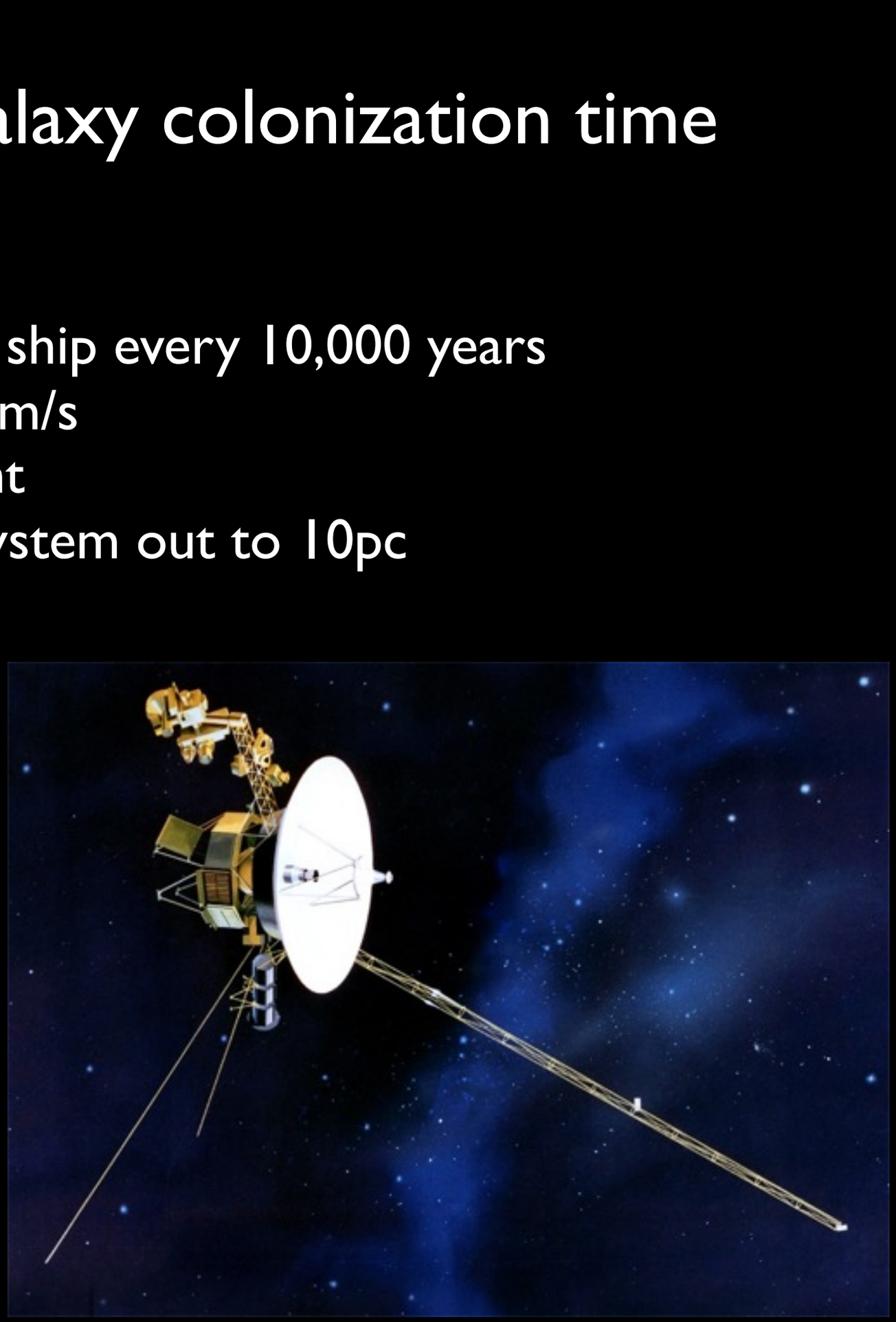
“Where is Everybody?”

- Enrico Fermi pointed out that the time for ships to cross and colonize the Galaxy is short compared to its age
- Evidence of alien civilization in the Milky Way is nonexistent. This has been called “The Great Silence” (Brin 1983)

Model for *minimum* galaxy colonization time

Assume:

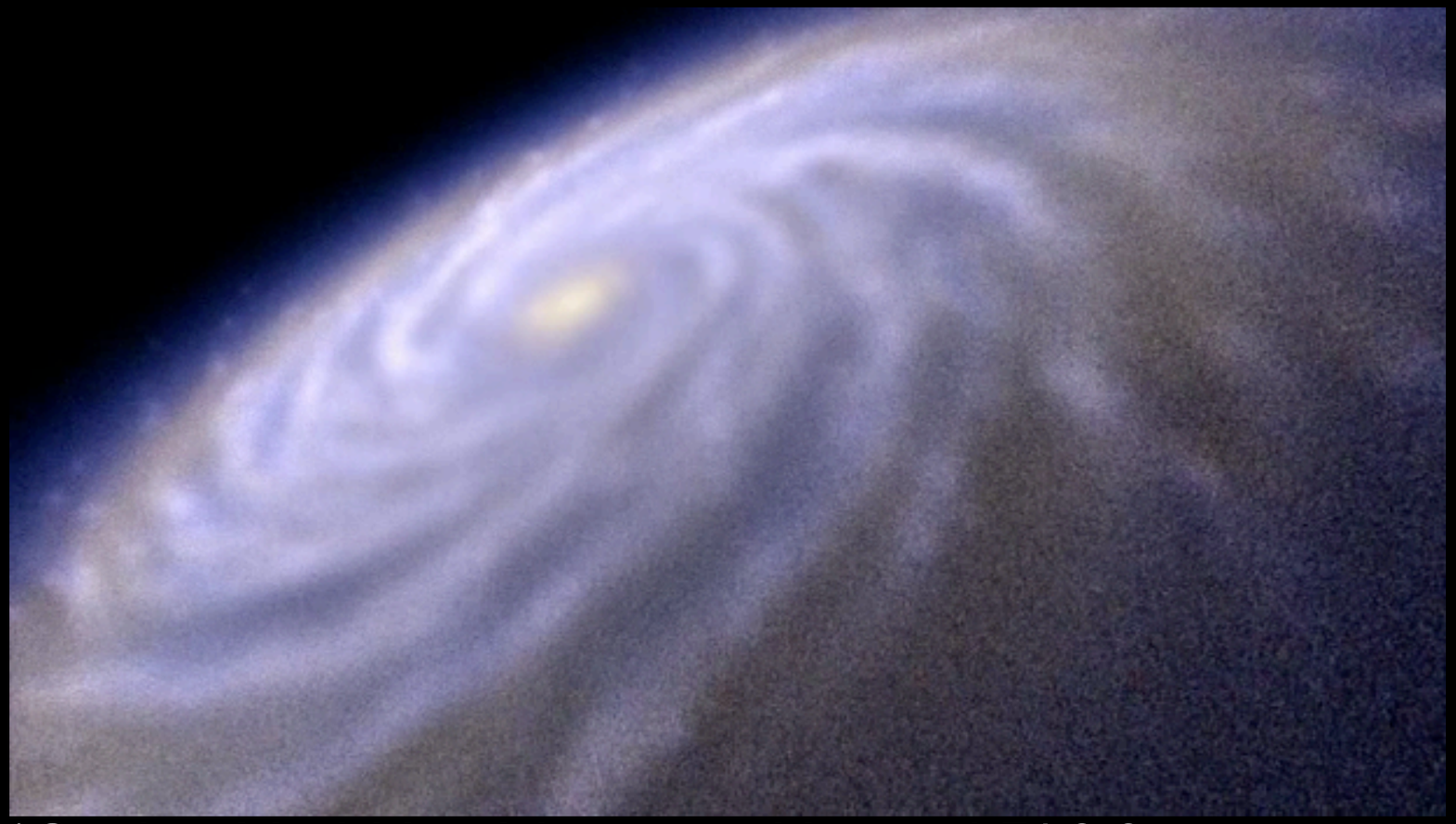
- Every colony launches a colony ship every 10,000 years
- Best cruise velocity is only 30 km/s
- Zero technological advancement
- Colonize nearest unoccupied system out to 10pc
- No boosts from halo stars



Maximum galaxy-filling time is a few galaxy rotations

Result:

- Cruise time to nearest star is 100,000 years
- In that time 10 colony ships launched
- In that time 10 nearest stars have changed!
- Colonies now separating at ~30 km/s (disk stellar velocity dispersion)
- Each colony has independent trajectory through galaxy

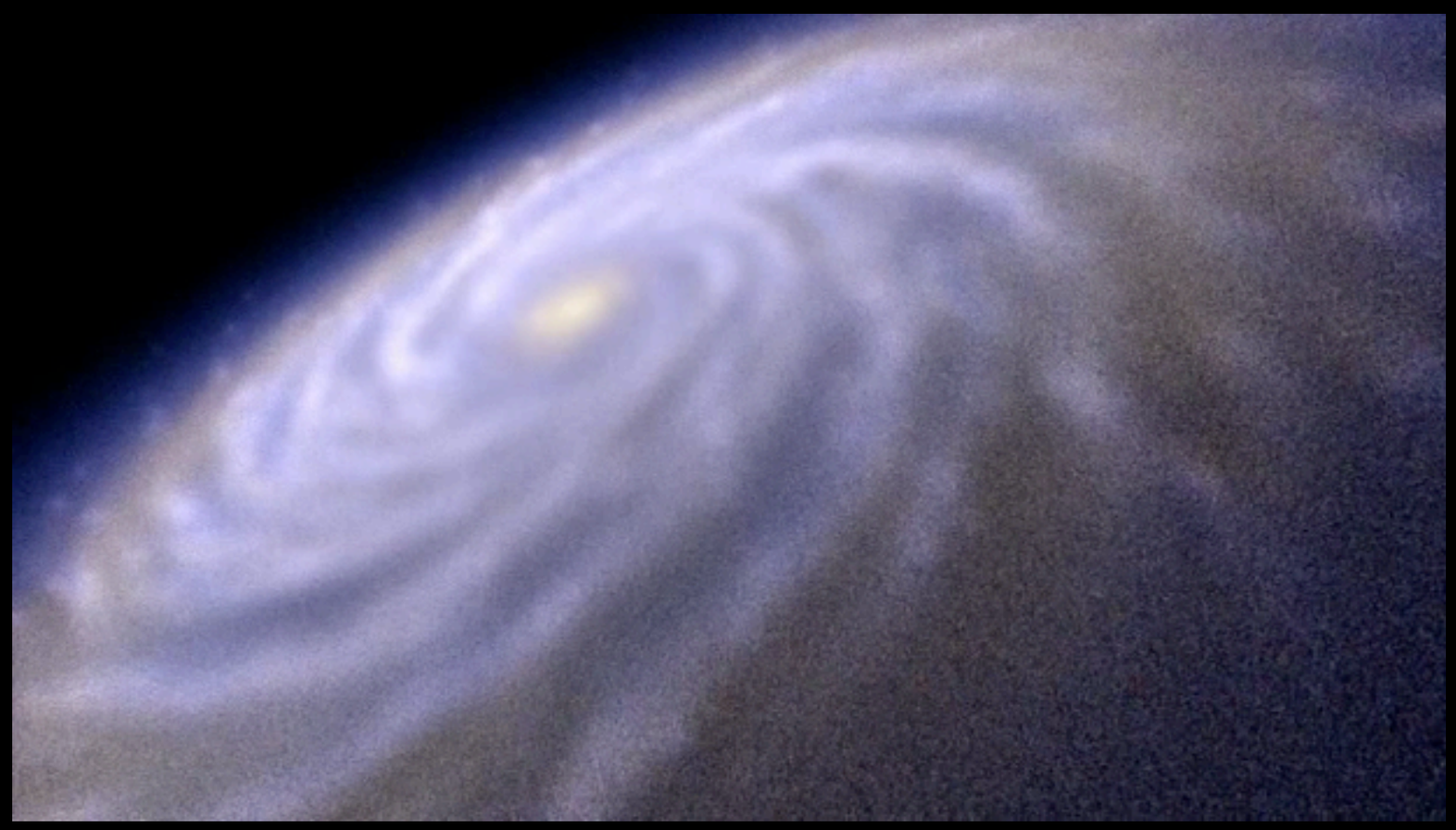


Credit: Elena D'Onghia, Mark Vogelsberger – Harvard FAS Supercomputer Odyssey, Thiago ize – Scientific Computing and Imaging (SCI) Institute – University of Utah

Maximum galaxy-filling time is a few galaxy rotations

Result:

- We should not expect Fermi "bubbles" or "voids" unless expansion is faster than stellar velocities
- If expansion is faster, galaxy-filling time is even shorter
- Either way, the chances of catching a galaxy in "transition" from K2 to K3 is <1%

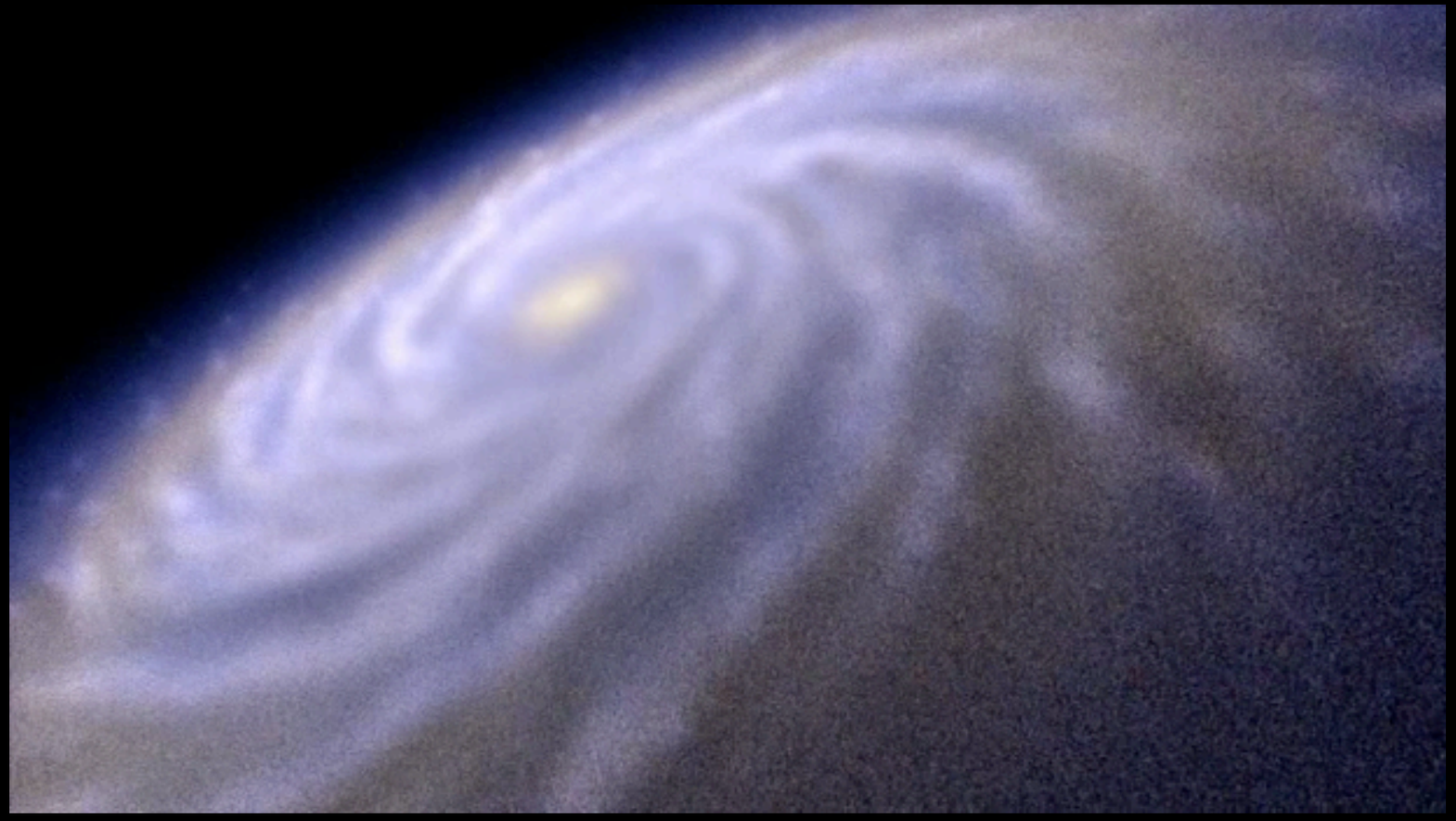


Credit: Elena D'Onghia, Mark Vogelsberger – Harvard FAS Supercomputer Odyssey, Thiago Ize – Scientific Computing and Imaging (SCI) Institute – University of Utah

Maximum galaxy crossing time as a few galaxy rotations

Corollaries:

- Nearly all galaxies should have zero spacefaring civilizations or be filled with them
- Either the Milky Way is filled with spacefaring ETIs or we are the first



Credit: Elena D'Onghia, Mark Vogelsberger – Harvard FAS Supercomputer Odyssey, Thiago Ize – Scientific Computing and Imaging (SCI) Institute – University of Utah

Hart Argued there should be no K2's if a galaxy is not a K3

This argument formed the basis of Michael Hart's argument that we should be alone in the MW, because it manifestly does not host a K3

...but unless spacefaring life is unique to Earth...

If Hart is correct:
Other galaxies should be filled with advanced civilizations.
A search for K3's will eventually succeed

If Hart is incorrect:
The Milky Way should be filled with K2's.
A search for K2's will eventually succeed

We should test Hart's hypothesis by pursuing *both* routes

Cosmic archaeology

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Is interstellar archeology possible?

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ABSTRACT

Searching for signatures of cosmic-scale archeological artifacts such as Dyson spheres is an interesting alternative to conventional radio SETI. Uncovering such an artifact does not require the intentional transmission of a signal on the part of the original civilization. This type of search is called *interstellar archeology* or sometimes *cosmic archeology*. A variety of interstellar archeology signatures is discussed including non-natural planetary atmospheric constituents, stellar doping, Dyson spheres, as well as signatures of stellar, and galactic-scale engineering. The concept of a Fermi bubble due to interstellar migration is reviewed in the discussion of galactic signatures. These potential interstellar archeological signatures are classified using the Kardashev scale. A modified Drake equation is introduced. With few exceptions interstellar archeological signatures are clouded and beyond current technological capabilities. However SETI for so-called cultural transmissions and planetary atmosphere signatures are within reach.

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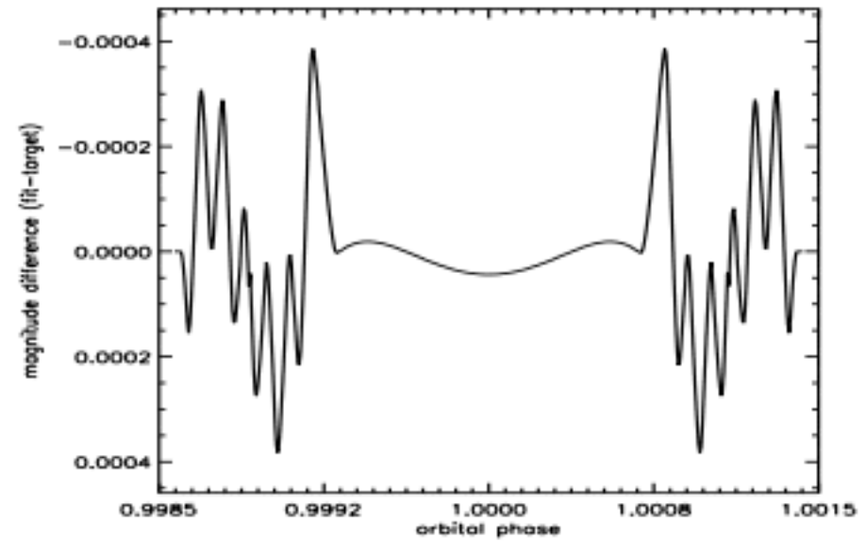
Communication SETI, but also artifact SETI:

- Planetary atmosphere alteration
- Stellar abundances "beacons"
- Stellar engineering
- "Dyson spheres"
- Galactic ensembles of "Dyson spheres"

Artifact SETI

Arnold (2005) showed how giant artifacts could produce clearly artificial transit signatures, and even communicate low-bandwidth information

Fig. 6.— Transiting objects: A louver-like 6-screen object (upper strip) and the best-fit spherical planet and star (lower strip, same scale as upper strip). The fit gives a transiting sphere of 2.08 $R_{Jupiter}$ at $b = 0.79$ and a star with $u_1 + u_2 = 0.57$, $u_1 - u_2 = 0$ and $R_* = 1.85\ R_\odot$.



Artifact SETI

Arnold (2005) showed how giant artifacts could produce clearly artificial transit signatures, and even communicate low-bandwidth information

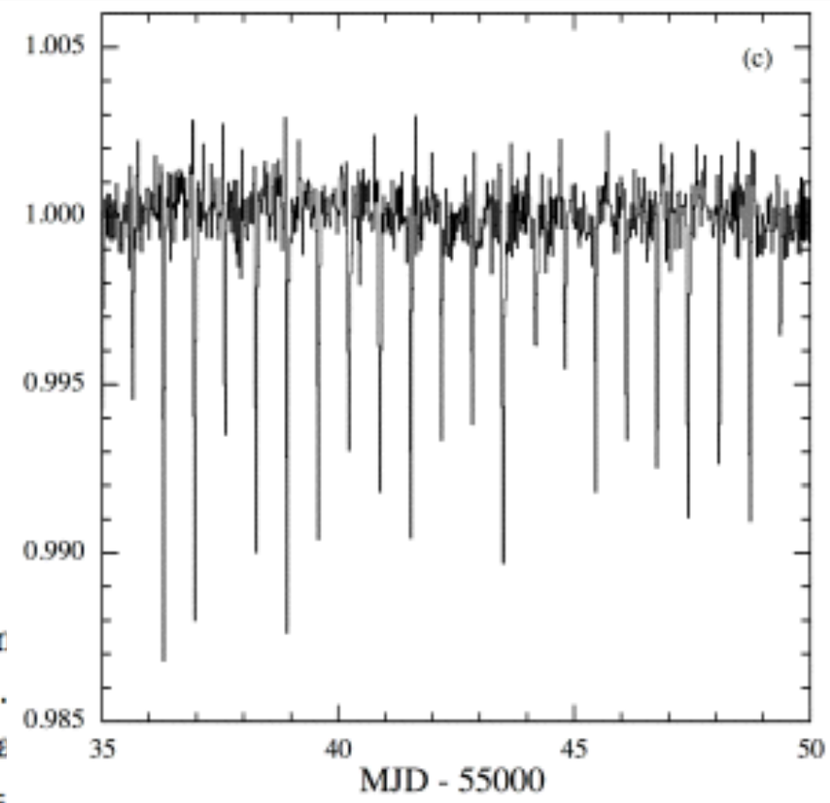


Fig. 8.— Example of r d in prime numbers (1, 2, 3 and 5 objects). as a prime numbers series. Each object ha HD209458 with an impact parameter $b =$ em, only 5 objects can be simultaneously in front of the star for a given observer. The first transit of a single object allows to deconvolve the transits of multiple objects (upper curve).

KIC 12557548 (Rappaport et al. 2012)

Artifact SETI

Dyson (1960)

Energy is never "used up", it is just converted to a lower temperature

If a civilization uses energy, that energy <u>must</u> emerge as waste heat in the mid-infrared

A civilization using most of its star's energy would have little optical luminosity but be a very bright infrared source.

This approach is totally general: <u>any</u> energy use by a civilization would give a star a mid-infrared excess

Advantages to a waste heat approach

Assumes only:

- Conservation of energy
- Laws of thermodynamics
- No “obvious” new physics

Makes no “sociological” assumptions about alien behavior or communication willingness or methods

Can be applied out to very large (cosmological) distances

Disadvantages to waste heat approach

- Most easily applies to power supplies similar to stellar luminosity
- For some classes of sources, need to deal with heavy contamination from dusty objects (dust reprocesses starlight into MIR radiation very similarly to Dyson spheres)
- Long road to prove source is of alien origin

A Philosophical Challenge of SETI

"Any sufficiently advanced technology is indistinguishable from magic" (Clarke's 3rd Law)

"Magic" is the suspension of Natural Law

Science *assumes* the Universe is governed by Natural Law

If Clarke is correct, SETI risks being inherently unscientific, since it assumes we can identify *apparent* violations of Natural Law

Unless care is taken, SETI can lead to an "aliens of the gaps" approach

Communication SETI resolves this: find a signal of unambiguously intelligent origin — no naturalistic interpretation is possible

Communication and Artifact SETI are complementary

Artifact SETI
hard-pressed to prove phenomena cannot be natural

Fig. 6.— Transiting objects: A louver-like 6-screen object (upper strip) and the best-fit spherical planet and star (lower strip, same scale as upper strip). The fit gives a transiting sphere of 2.08 $R_{Jupiter}$ at $b = 0.79$ and a star with $u_1 + u_2 = 0.57$, $u_1 - u_2 = 0$ and $R_* = 1.85\ R_\odot$.

Communication SETI
must cast an impossibly wide net
(frequencies, duty cycles, bandwidth, power, targets...)

Communication and Artifact SETI are complementary

Artifact SETI provides candidates → Communication SETI identifies candidates as alien

Communication SETI provides candidates → Artifact SETI identifies other technological signatures

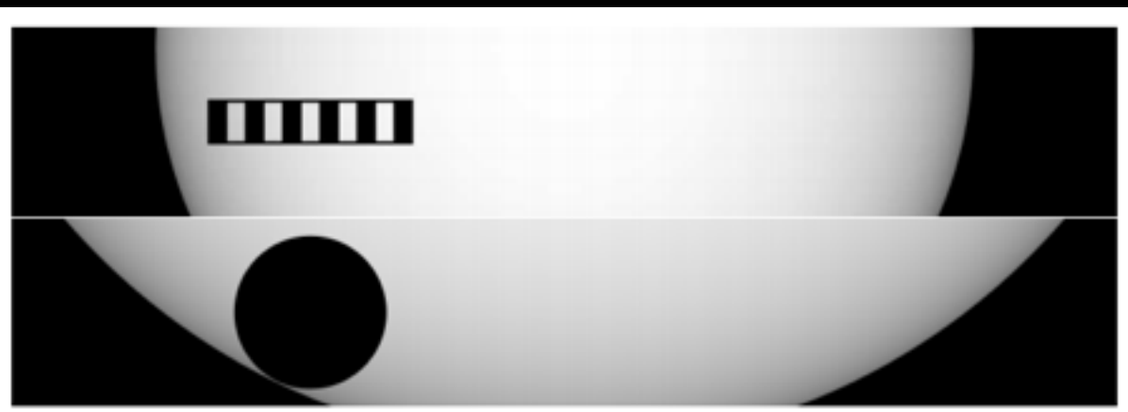


Fig. 6.— Transiting objects: A louver-like 6-screen object (upper strip) and the best-fit spherical planet and star (lower strip, same scale as upper strip). The fit gives a transiting sphere of 2.08 $R_{Jupiter}$ at $b = 0.79$ and a star with $u_1 + u_2 = 0.57$, $u_1 - u_2 = 0$ and $R_* = 1.85\ R_\odot$.

We can use conservation of energy to parameterize a civilization's energy budget

Artifact SETI

α	power collected from starlight
ε	power generated by other means (fossil fuel, nuclear, direct mass-to-energy)
γ	power expelled as thermal photons
ν	all other power expelled (radio waves, neutrinos, KE, gravity waves, etc.)
T	typical temperature of waste heat radiators

Communication SETI

$$\alpha + \varepsilon = \gamma + \nu$$

We can use conservation of energy to parameterize a civilization's energy budget

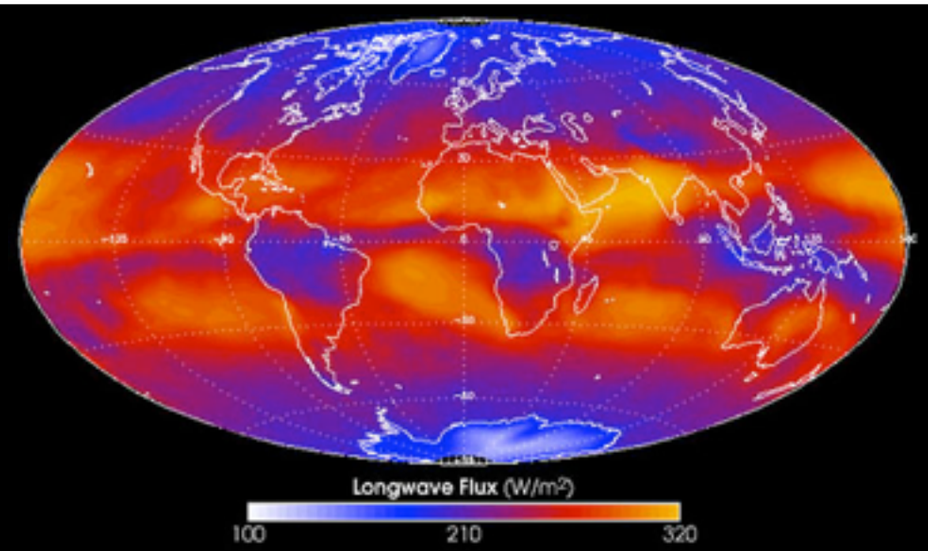
α	power collected from starlight
ε	power generated by other means
γ	power expelled as photon waste heat
ν	all other power expelled

We normalize these parameters by:

- Starlight striking the planet (for a K1)
- Total stellar luminosity (for a K2)
- Total galactic luminosity (for a K3)

Humanity's current parameterization:

α	~10
ε	~10
γ	~10
ν	~0
T	~300 K



The Earth has 0.01% excess mid-infrared radiation because of human activity

What are realistic values for T_{waste} for a many-billion year-old civilization?

- Waste heat temperature set by the maximum thermodynamic efficiency of a civilization $\eta=1-T_{waste}/T_{\star}$
- Conservation of energy requires ($L = A\,T_{waste}^4$) to be conserved (A=area of radiating surfaces, L=luminosity)
- Increasing efficiency from η=90% to η=99% requires a 10^4 increase in A
- Optimal values of A are uncertain, but likely roughly 1 AU^2 surface area (T_{waste} = 150–600 K) constrained by available mass and existence of solids
- Peak emission is then at 5-30 microns

We can quantify the effects of waste heat on spectra

Assume that for large civilizations: $\nu \sim 0$

$$F \propto [(1-\alpha)\, B(T_\star) + \gamma\, B(T_{waste})\, (T_\star / T_{waste})^4] / d^2$$

Order-of-magnitude estimate in mid-infrared (Rayleigh-Jeans limit) for $T_\star >> T_{waste}$, *any* α:

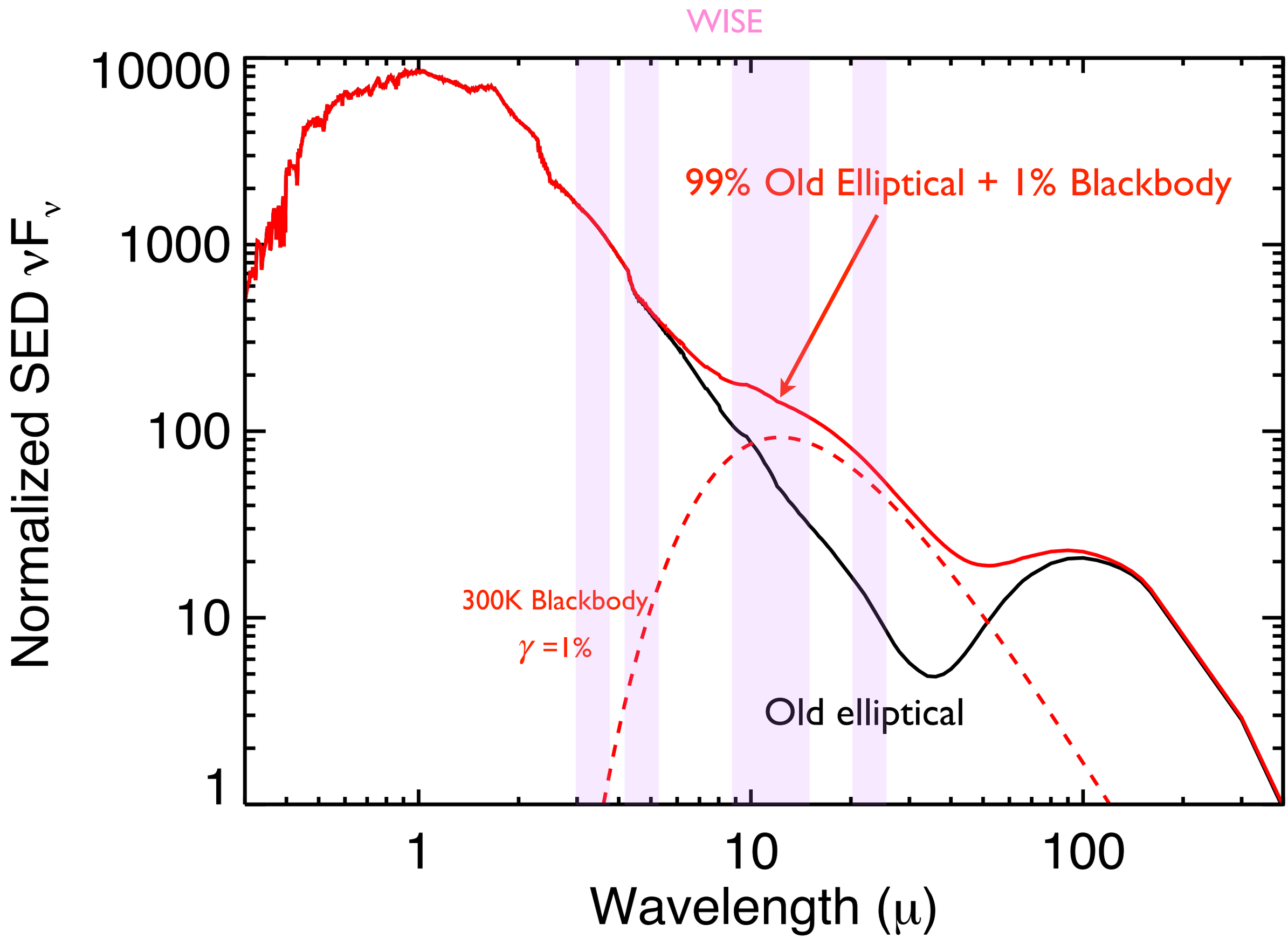
$$F_{MIR} = (F_{MIR,no\ civ})\, [\gamma\, (T_\star / T_{waste})^3]$$

For $T_\star = 4000K$, $T_{waste}=250K$, $\gamma=1$, $F/F_{no\ civ} = 4000$

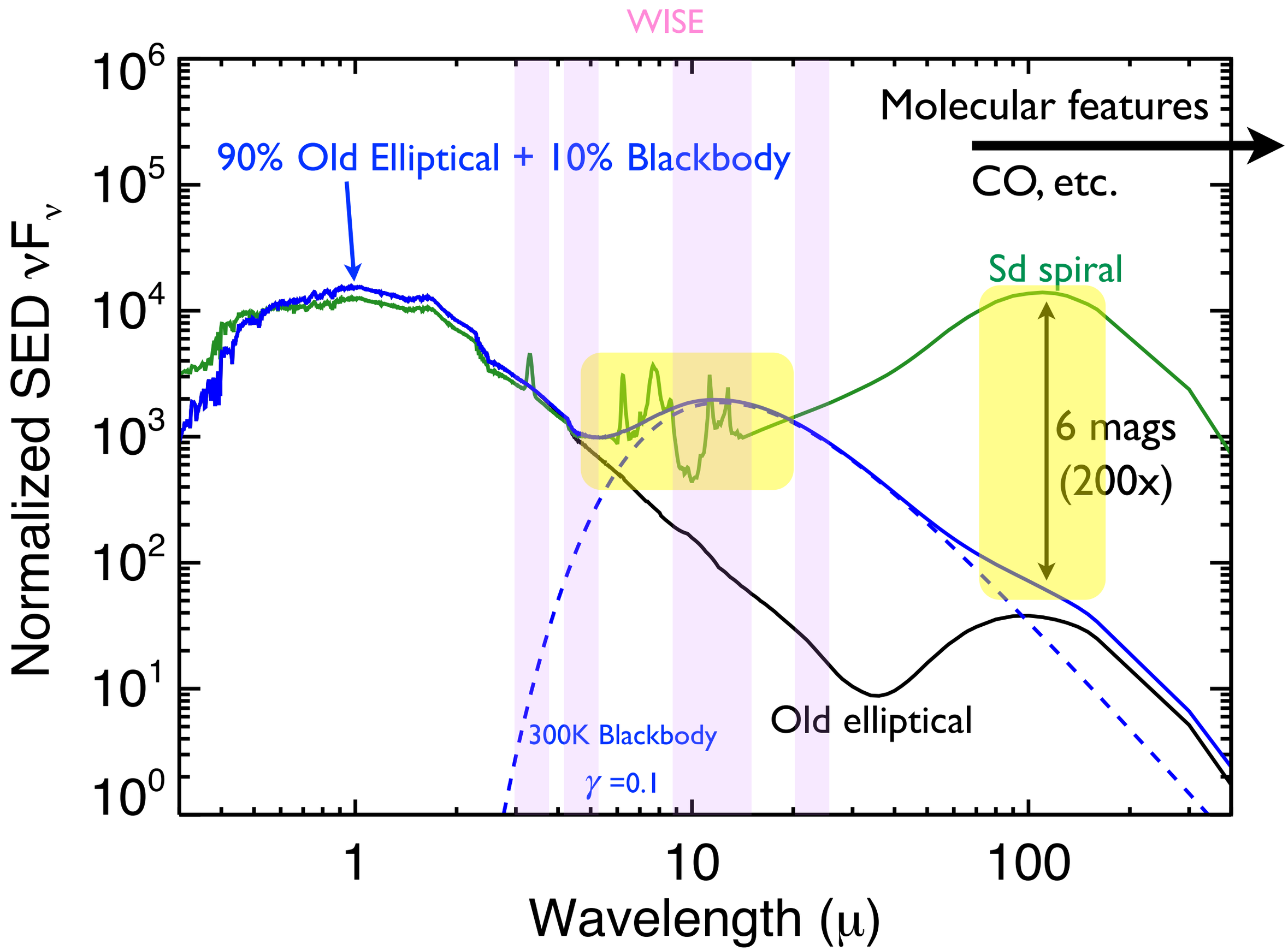
(9 magnitudes MIR excess)

For $T_\star = 4000K$, $T_{waste}=250K$, $\gamma=0.1$, $F/F_{no\ civ} = 400$

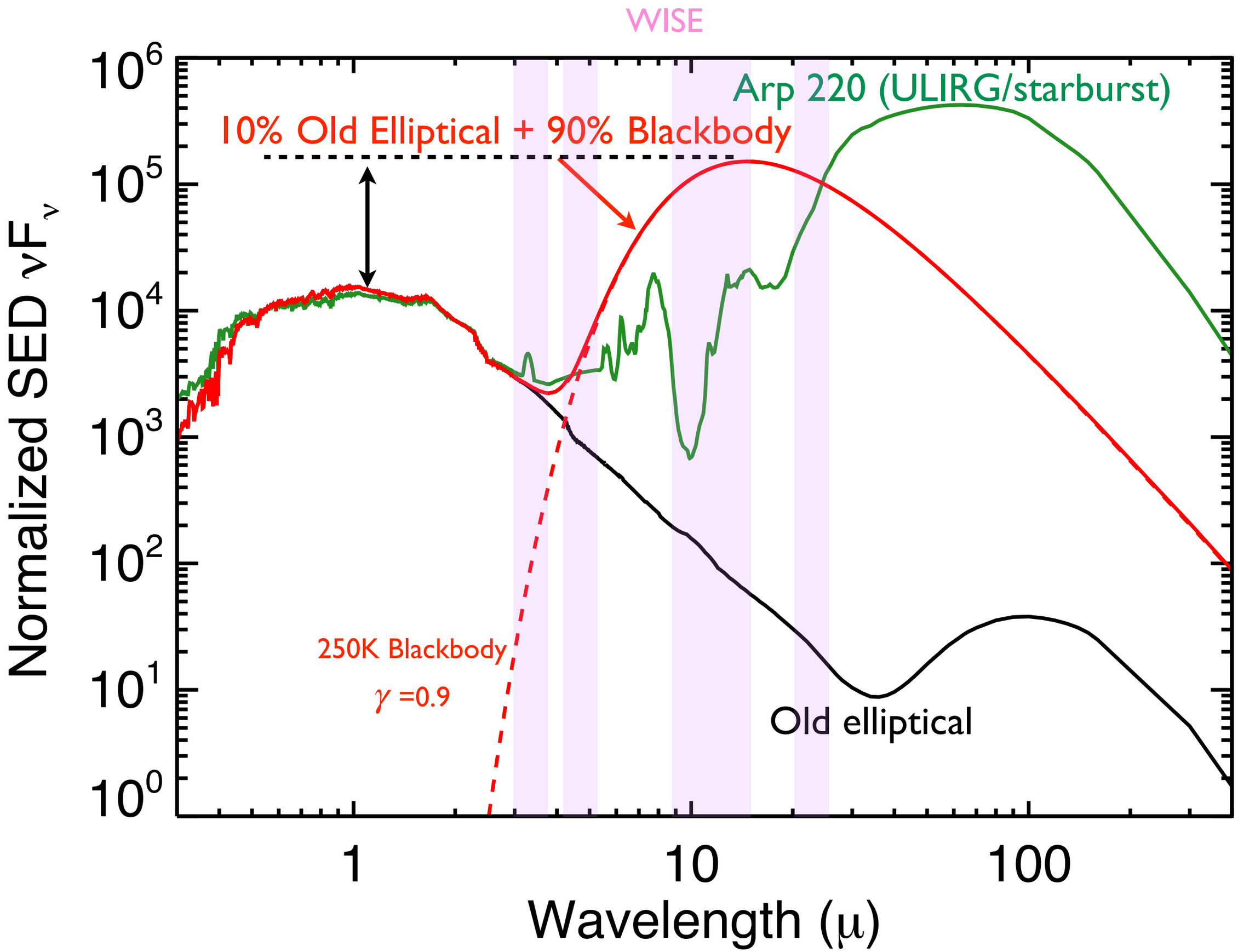
(6.5 magnitudes MIR excess)



SED from Silva et al. (1998)



SEDs from Silva et al. (1998)


WISE
Arp 220 (ULIRG/starburst)
10% Old Elliptical + 90% Blackbody
250K Blackbody
γ =0.9
Old elliptical
Normalized SED νF_ν
Wavelength (μ)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1
10
100

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IRAS-BASED WHOLE-SKY UPPER LIMIT ON DYSON SPHERES

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ABSTRACT

A Dyson sphere is a hypothetical construct of a star purposely shrouded by a cloak of broken-up planetary material to better utilize all of the stellar energy. A clean Dyson sphere identification would give a significant signature for intelligence at work. A search for Dyson spheres has been carried out using the 250,000 source database of the *IRAS* infrared satellite which covered 96% of the sky. The search has used the Calgary database for the *IRAS* Low Resolution Spectrometer (LRS) to look for fits to blackbody spectra. Searches have been conducted for both pure (fully cloaked) and partial Dyson spheres in the blackbody temperature region $100\,\mathrm{K} \leqslant T \leqslant 600$ K. When other stellar signatures that resemble a Dyson sphere are used to eliminate sources that mimic Dyson spheres very few candidates remain and even these are ambiguous. Upper limits are presented for both pure and partial Dyson spheres. The sensitivity of the LRS was enough to find Dyson spheres with the luminosity of the Sun out to 300 pc, a reach that encompasses a million solar-type stars.

Key words: astrobiology – extraterrestrial intelligence – infrared: stars – stars: carbon – stars: fundamental parameters

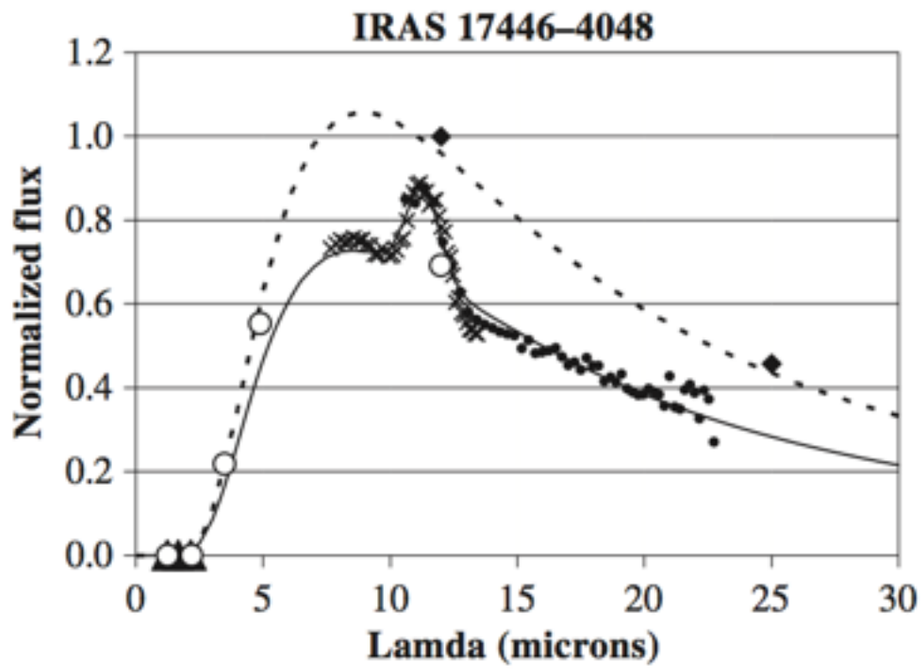

Figure 1. IRAS 17446−4048, a typical carbon star. The 11.3 μm SiC emission feature is characteristic of C stars. *IRAS* filter values: diamonds; DIRBE points: open circles; 2MASS: triangles; LRS (low): crosses; LRS (high): dot; fit to filter: dotted line; fit to LRS: solid line (scale: F(Jy) = y-axis/0.0046).

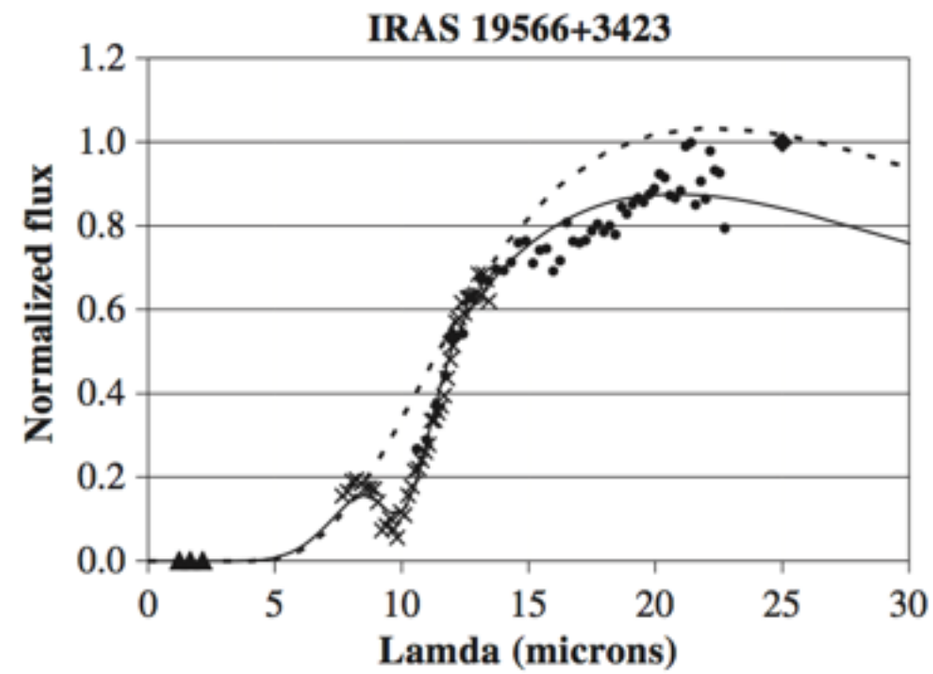

Figure 2. IRAS 19566+3423 showing 10.2 μm silicate absorption feature occurring in OH/IR stars. The solid triangles are 2MASS points. (Same legend as Figure 1, scale: F(Jy) = y-axis/0.0103).

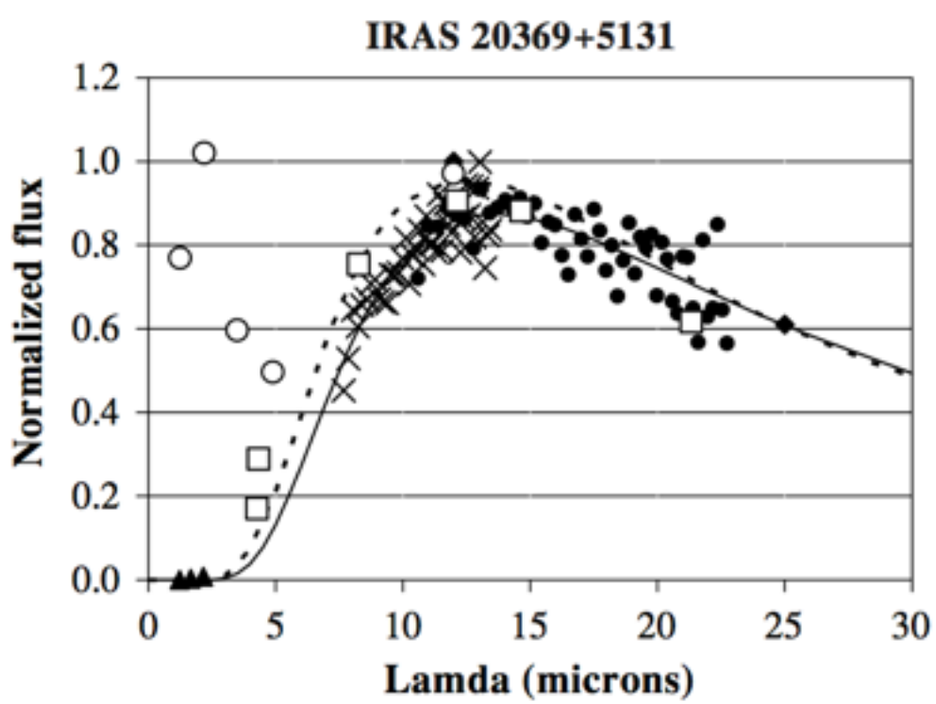

Figure 5. IRAS 20369+5131, the closest approximation to a Dyson sphere spectrum found in the search. *MSX* points: open squares. DIRBE points (open circles) do not agree with the 2MASS values and are possibly from another source. (Same legend as Figure 1, scale: F(Jy) = y-axis/0.0168).

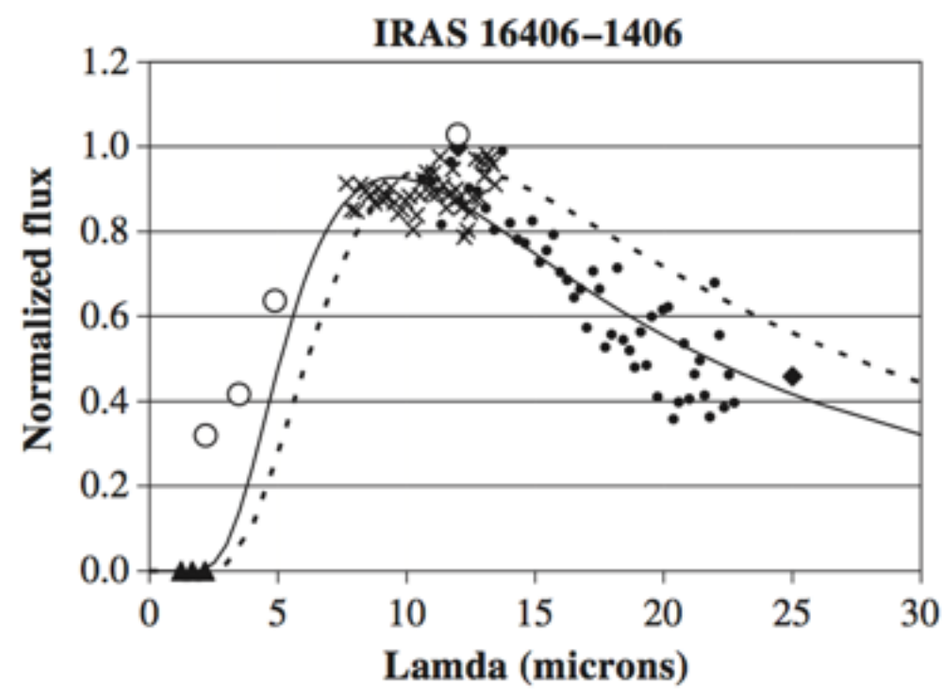

Figure 6. IRAS 16406−1406, a third possible source but with a high deviation and a relatively high temperature. Note hint of an emission feature at 13.5 μm. (Same legend as Figure 1, scale: F(Jy) = y-axis/0.00425).

Search for K3's with 0.75<α<~0.95

Placing a Limit on Star-Fed Kardashev Type III Civilizations

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A civilization that uses the bulk of a galaxy's starlight for it's own power requirements is a remarkably obvious entity. This is because galaxies naturally obey scaling laws between the surface brightness, the radius of the stellar distribution, and the thermal velocities of the stars. The latter two quantities reflect the mass and its resulting gravitational potential, while the former is the result of this same mass emitting light as stars. If a civilization takes that light for it's own purposes, the scaling laws are broken, and the galaxy becomes an outlier on plots showing the scaling laws. For a sample of 137 galaxies, no such outliers are found.

Dynamical masses are compared to luminosities to find low L/M galaxies

Search for K3's with 0.75<α<~0.95

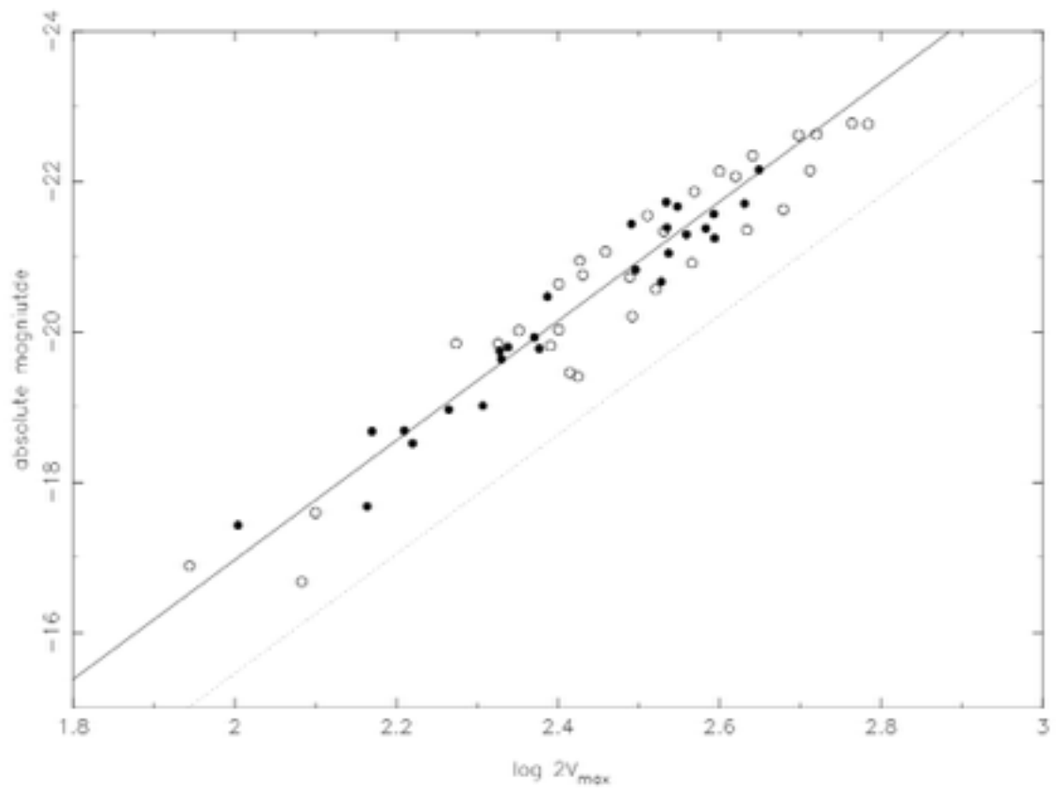


Figure 1. The spiral galaxy *L-T* scaling relation, also known as the Tully-Fisher relation. Luminosity (in terms of absolute magnitude) is plotted versus temperature (in terms of log maximum rotation velocity, *V*). The open circles are Virgo cluster spirals, the black circles are Ursa Major cluster spirals. The solid line is a least squares fit to the data, showing the mean relation. The scatter about the line is small. The dotted line shows the mean relation with *L* dimmed by 1.5 magnitudes, corresponding to a dimmunation of total starlight by 75%. No spiral exhibit this amount of dimmunation.

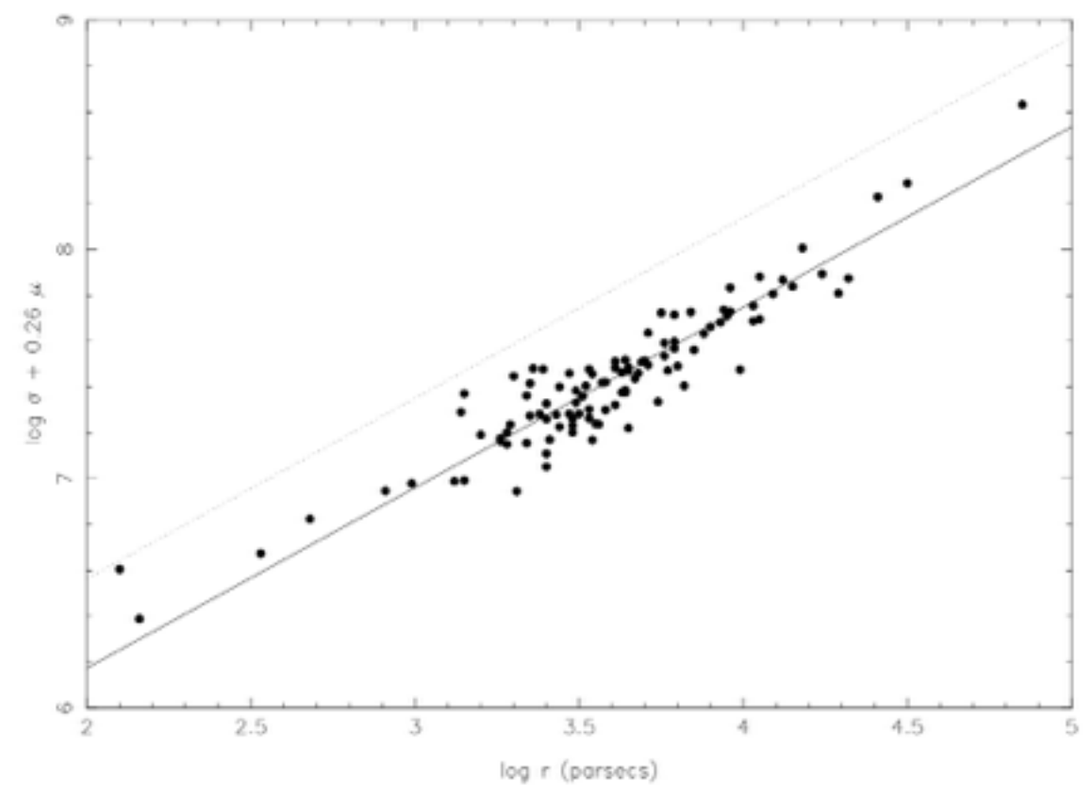
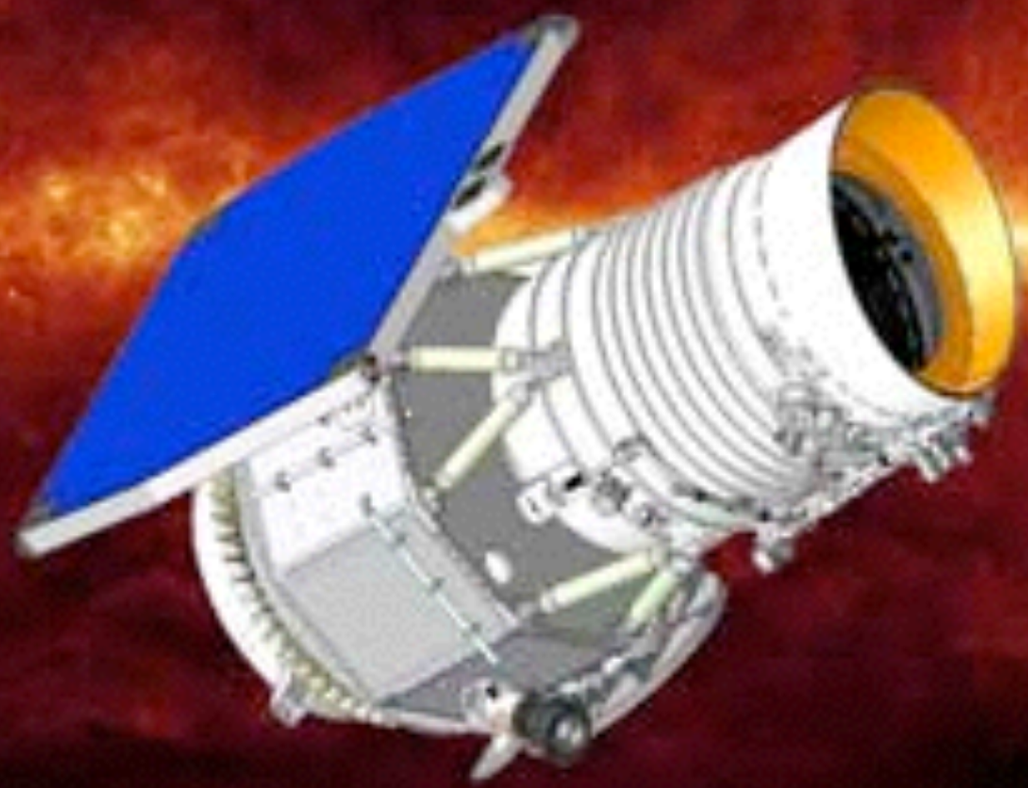
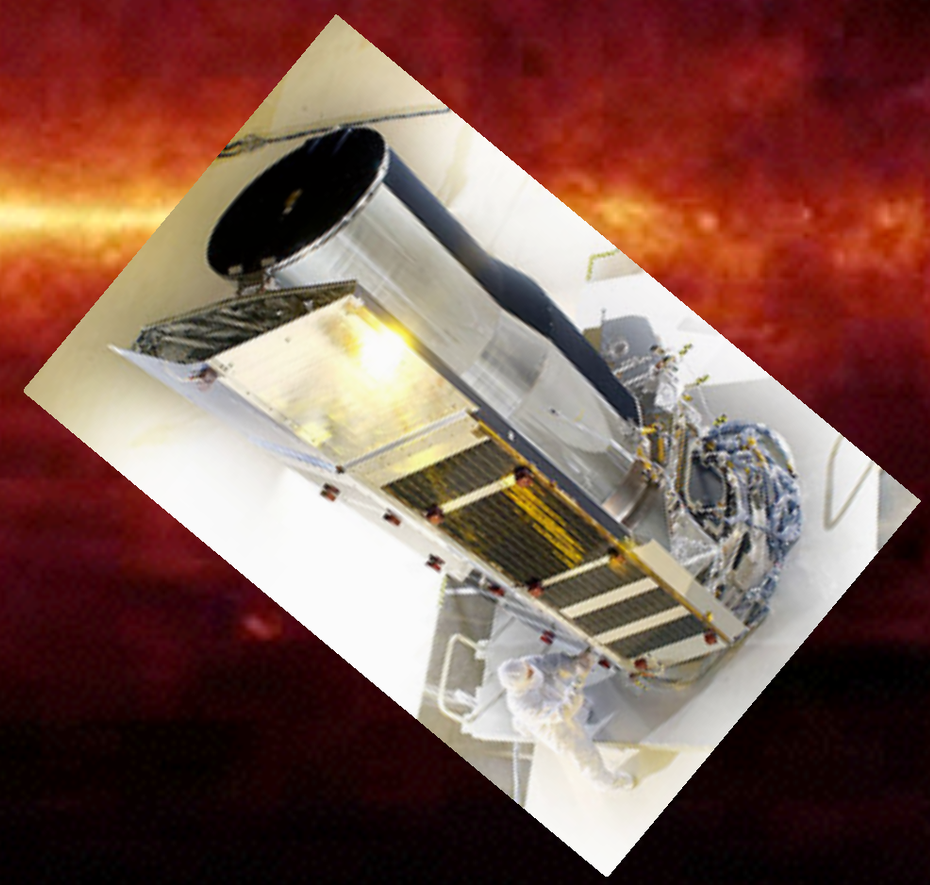


Figure 2. The elliptical galaxy *R-I-T* scaling relation, also known as the fundamental plane. A linear combination of surface brightness (μ, which is I in magnitudes) and thermal velocity (in terms of $\log \sigma$, the velocity dispersion) is plotted against log radius. The solid line is a least squares fit to the data, and the scatter about this line is small. The dotted line shows the mean relation after μ is dimmed by 1.5 magnitudes, corresponding to the 75% criteria. No elliptical galaxy exhibits this dimmunation.

Small bias against high α in that low-surface galaxies are absent from most catalogs because they are faint

Ĝ: Glimpsing Heat from Alien Technologies



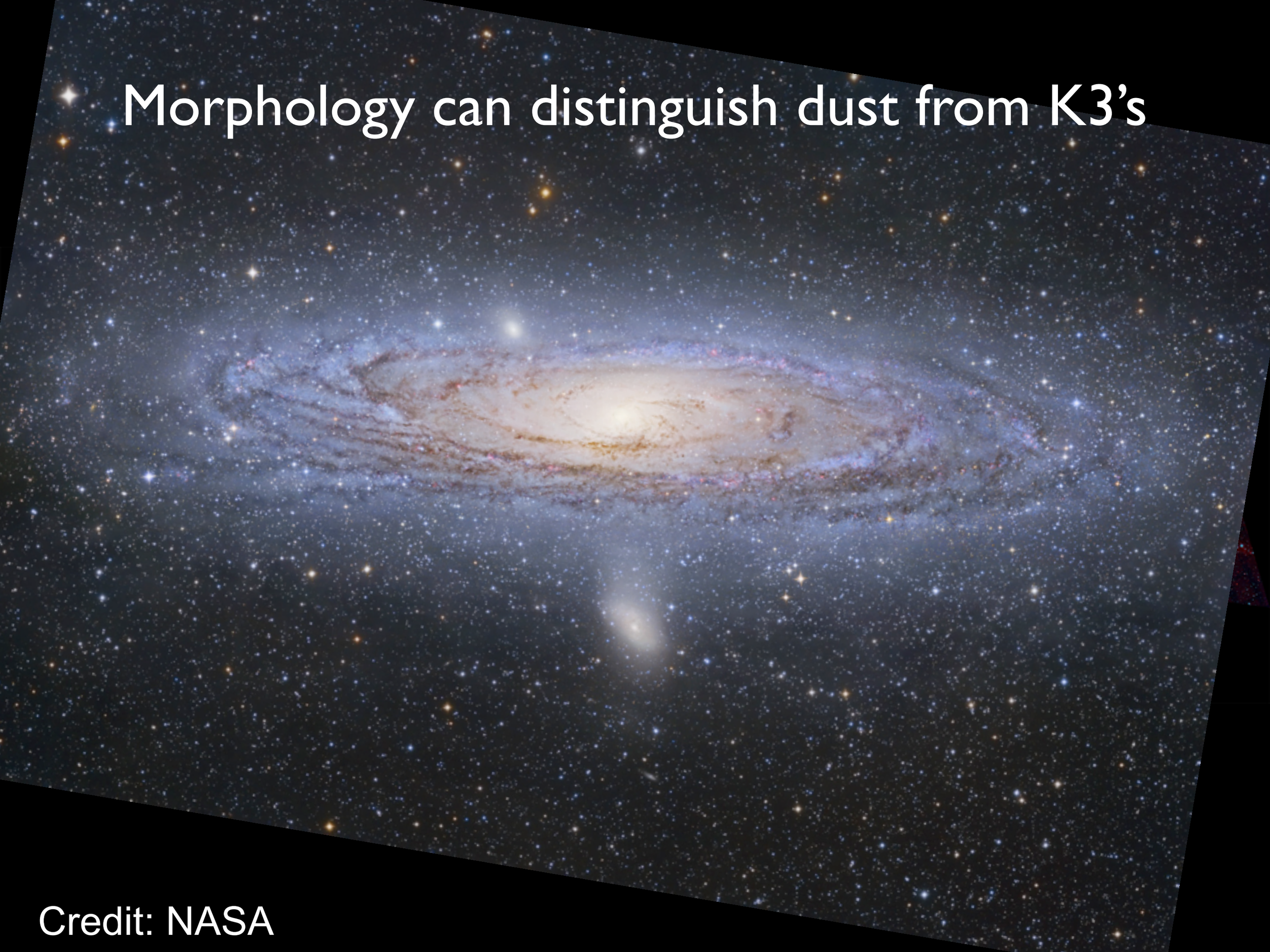


Phase I: K3 search of resolved galaxies
Phase II: K2 search of point sources
Phase III: K3 search of unresolved galaxies

Resolved galaxy-spannning civilizations will be easier to uniquely identify

We can distinguish K3's from most other sources because the will be <u>above the Galactic plane</u>, and they will be <u>resolved by WISE</u> if they are galaxies in the local universe. This rules out most Galactic sources and cosmological (redshifted) false positives

Morphology can distinguish dust from K3's

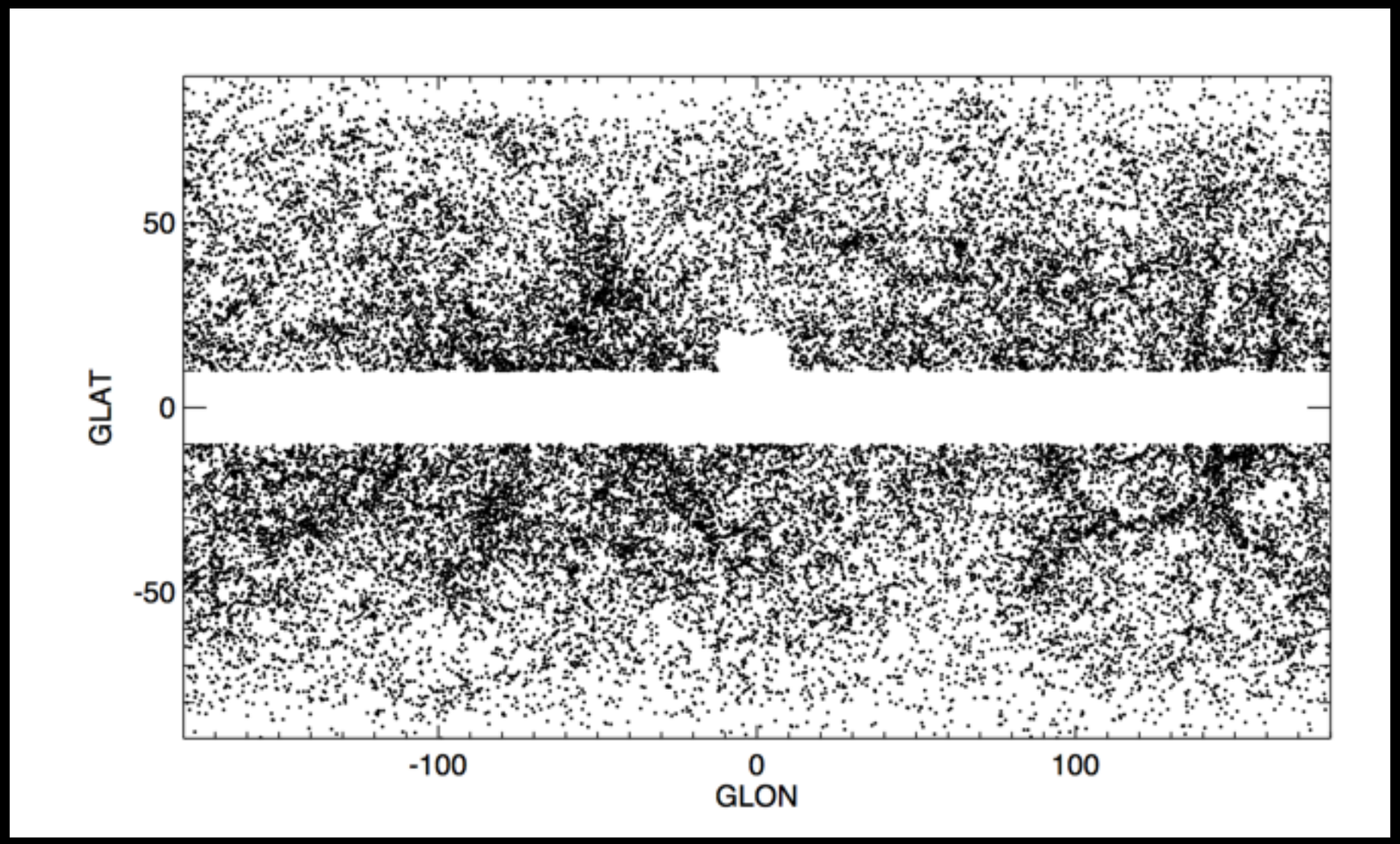


Credit: NASA

The WISE All-Sky Catalog contains many spurious sources

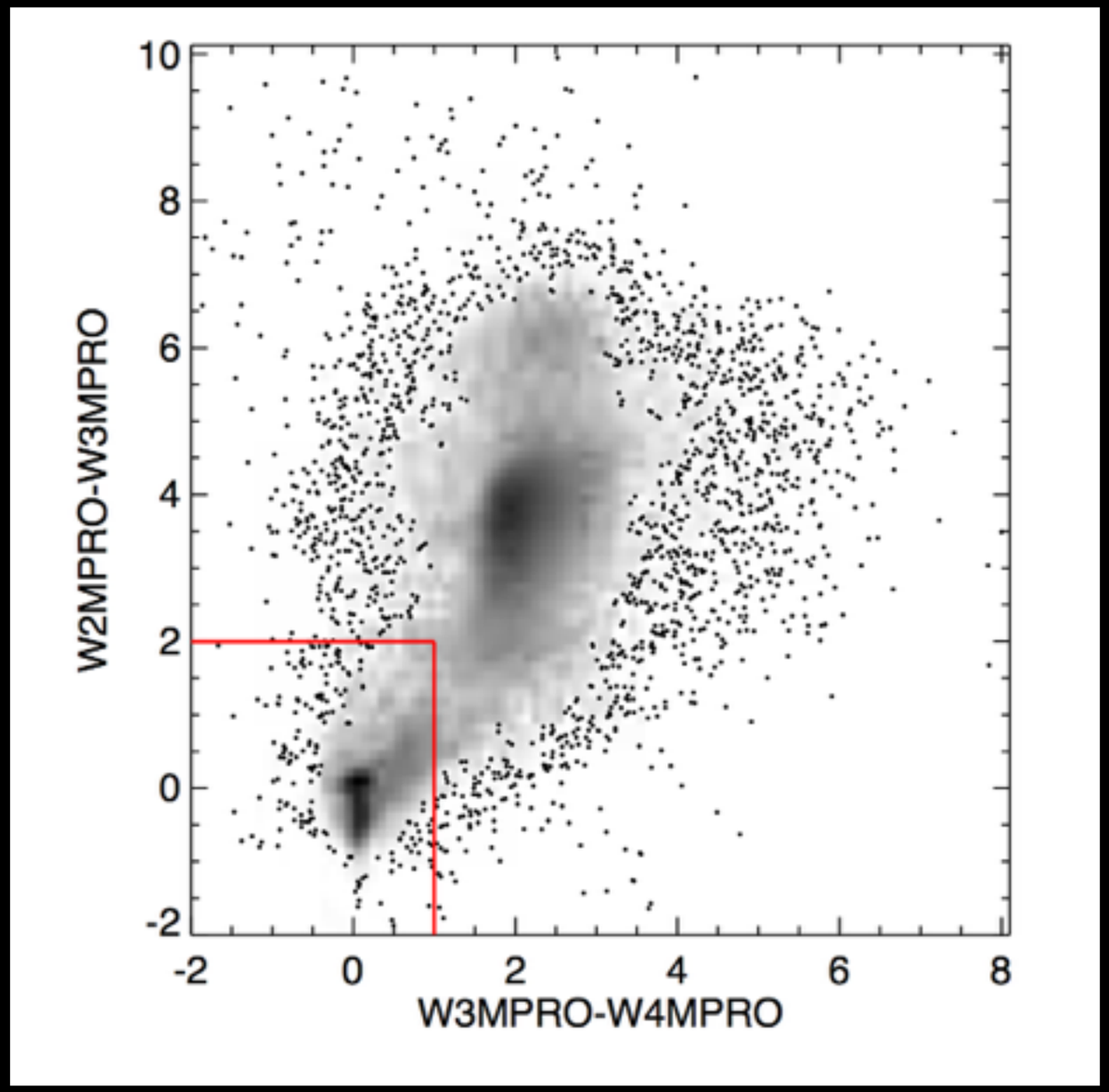
W3 CC flag	N total	
0	= 103847	**0 (number zero)** - Source is unaffected by known artifacts.
P	= 17614	**P,p** - Persistence. Source may be a spurious detection of (**P**) or contaminated by (**p**) a short-term latent image left by a bright source
p	= 516	
D	= 17789	**D,d** - Diffraction spike. Source may be a spurious detection of (**D**) or contaminated by (**d**) a diffraction spike from a nearby bright star on the same image
d	= 18774	
H	= 11182	**H,h** - Halo. Source may be a spurious detection of (**H**) or contaminated by (**h**) the scattered light halo surrounding a nearby bright source
h	= 9286	
O	= 23099	**O,o (letter "o")** - Optical ghost. Source may be a spurious detection of (**O**) or contaminated by (o) an optical ghost image caused by a nearby bright source
o	= 744	

We work outside of the plane to avoid confusion with Galactic sources

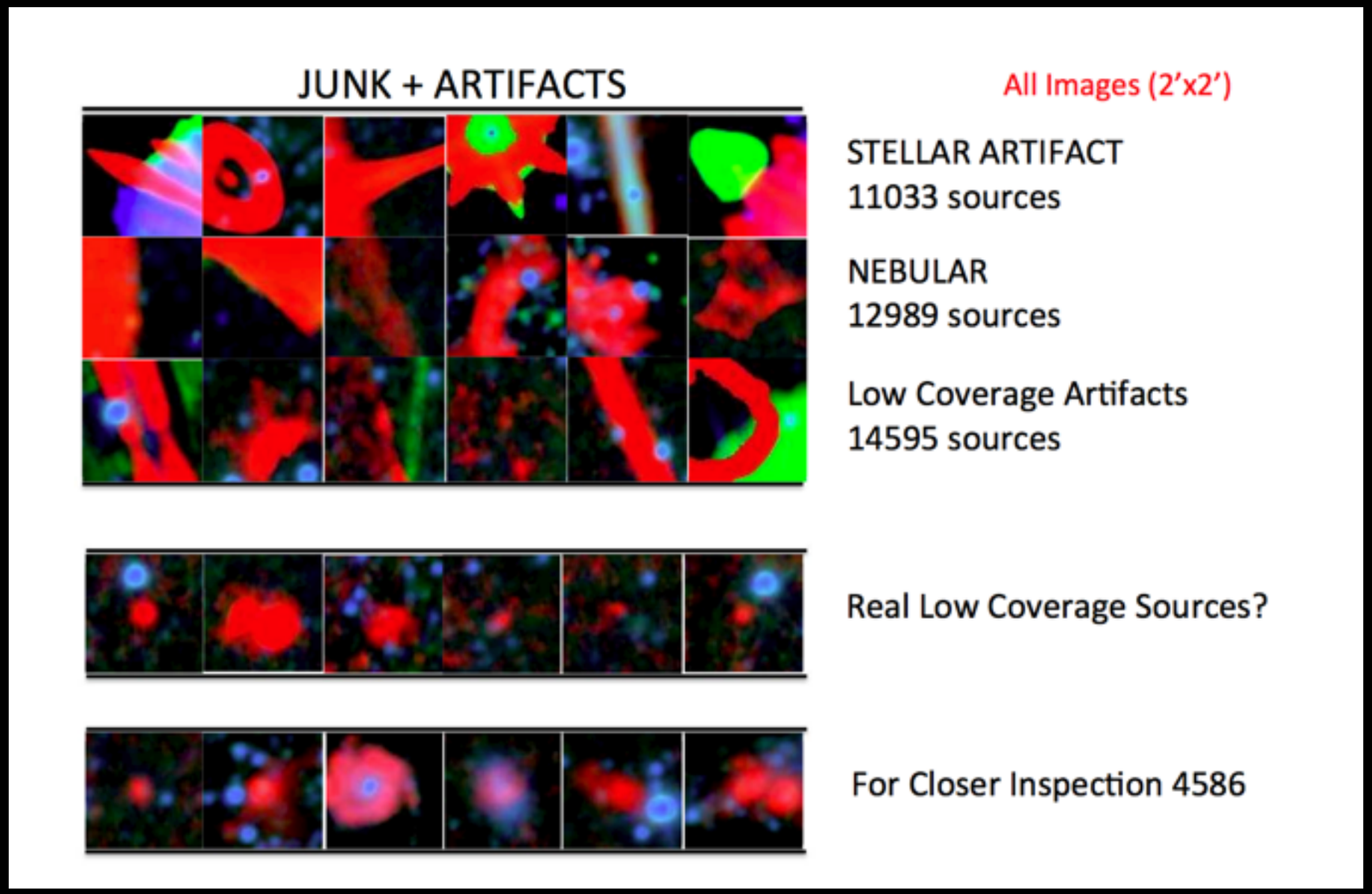


(We also avoid high source-density regions of the LMC and Orion)

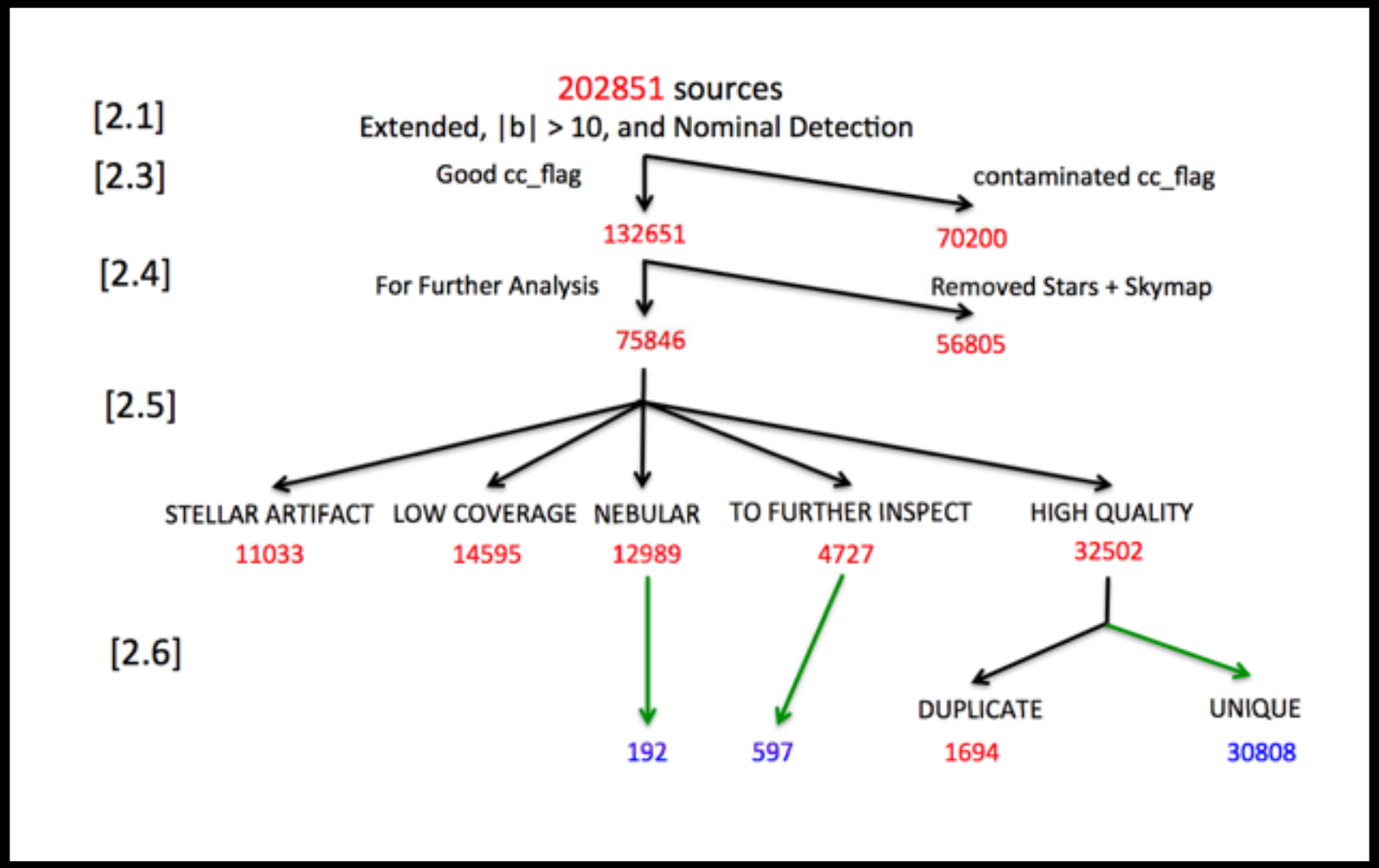
Rejecting blue sources removes most stellar artifacts



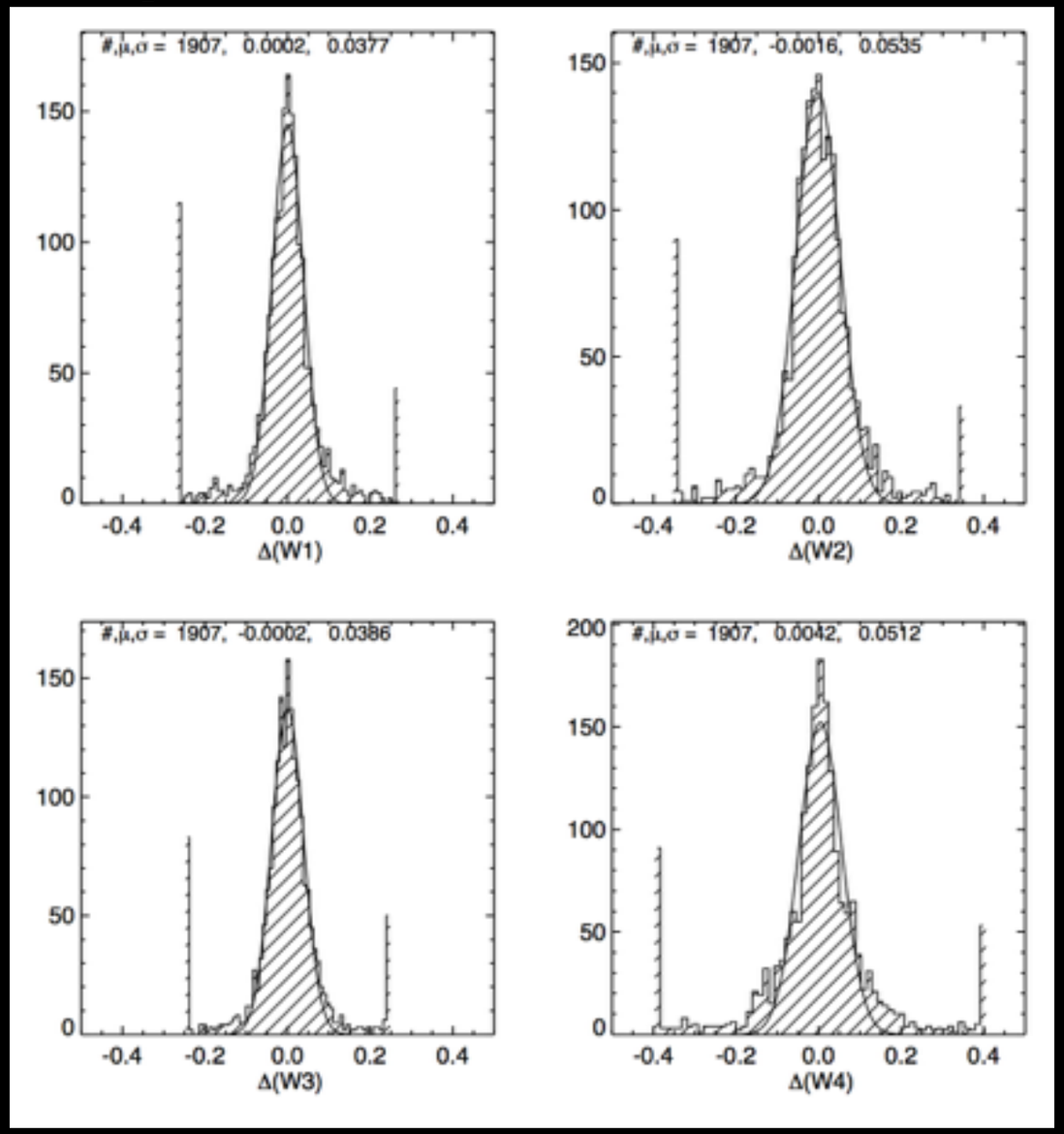
We visually inspect all apparently red objects



We have a clean catalog of 31,000 real, extended, red sources

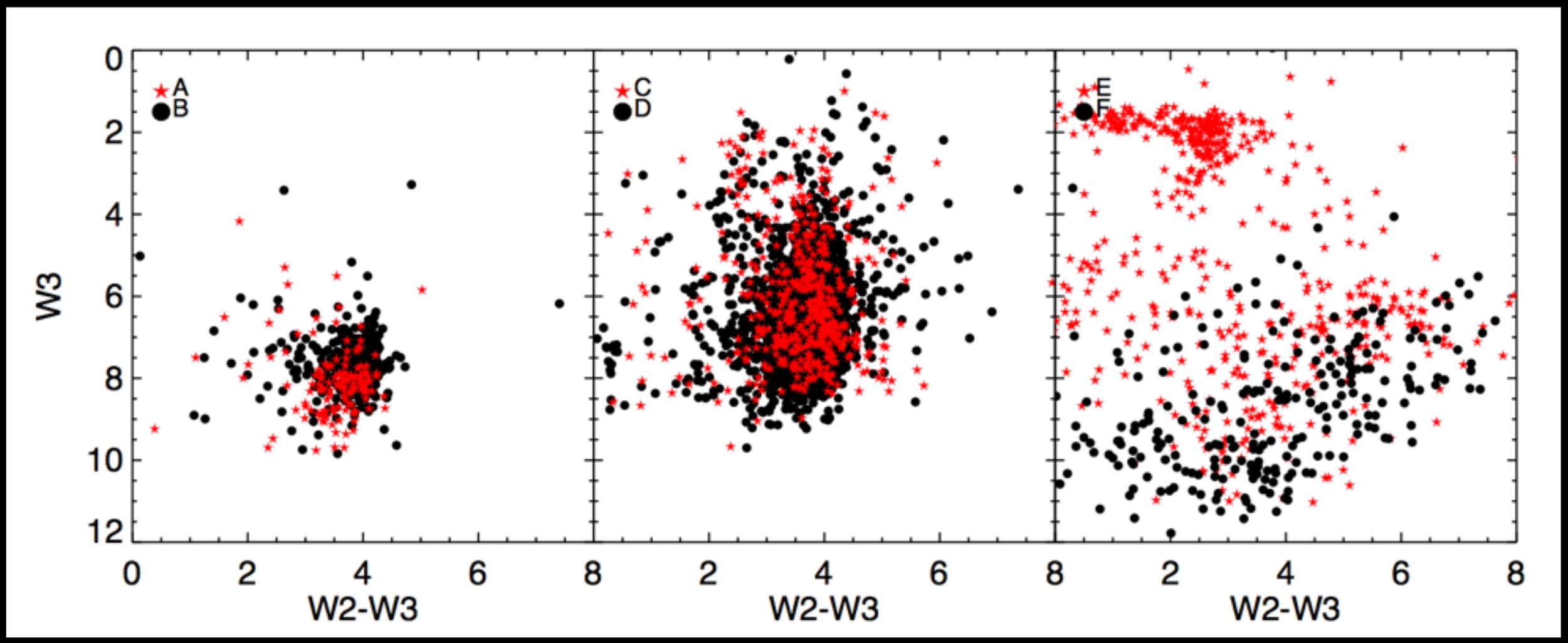


We correct the default photometry to match careful extended source photometry of the South Galactic Cap



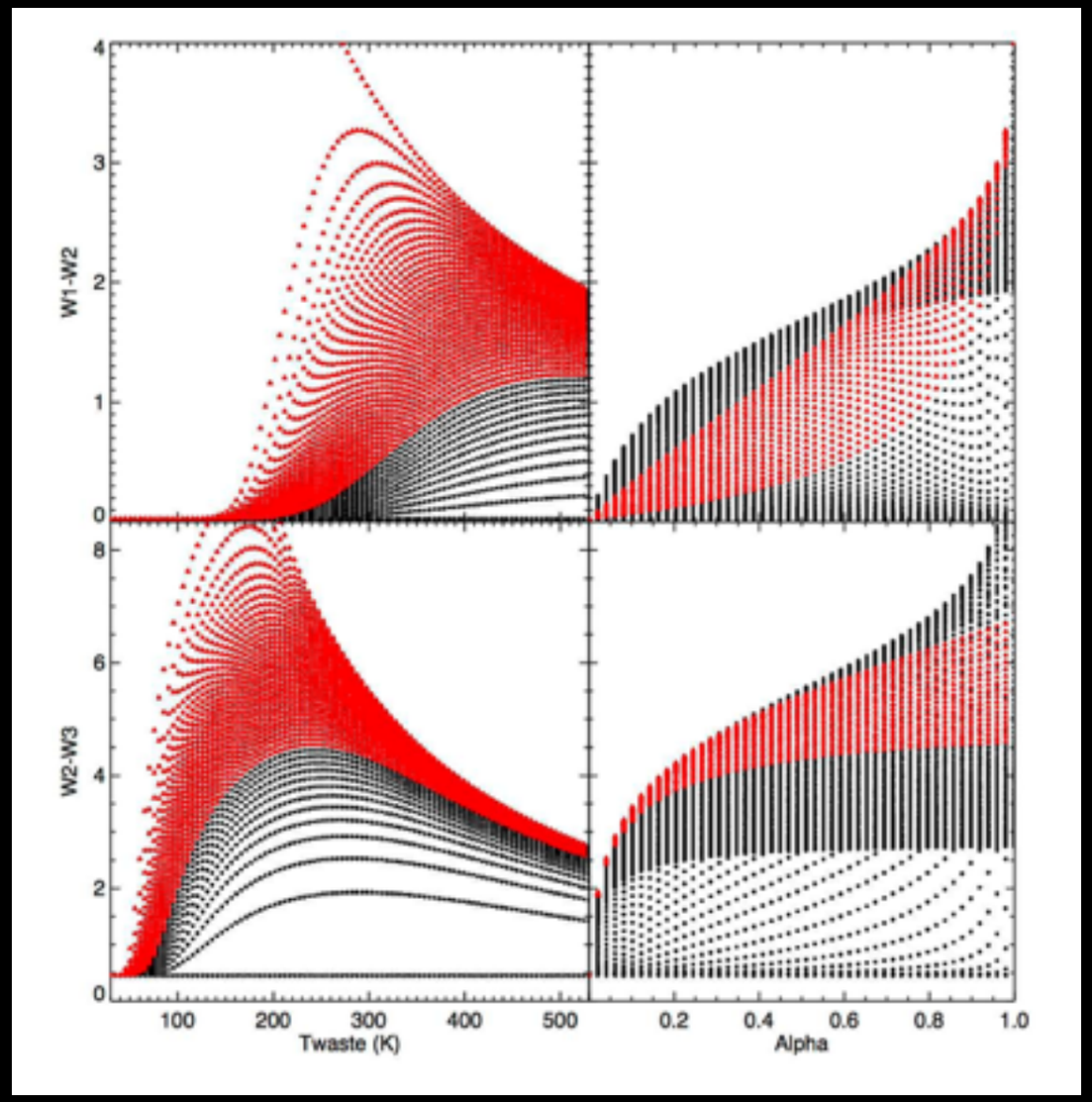
kindly provided by Tom Jarrett

We search for any very red sources new to science



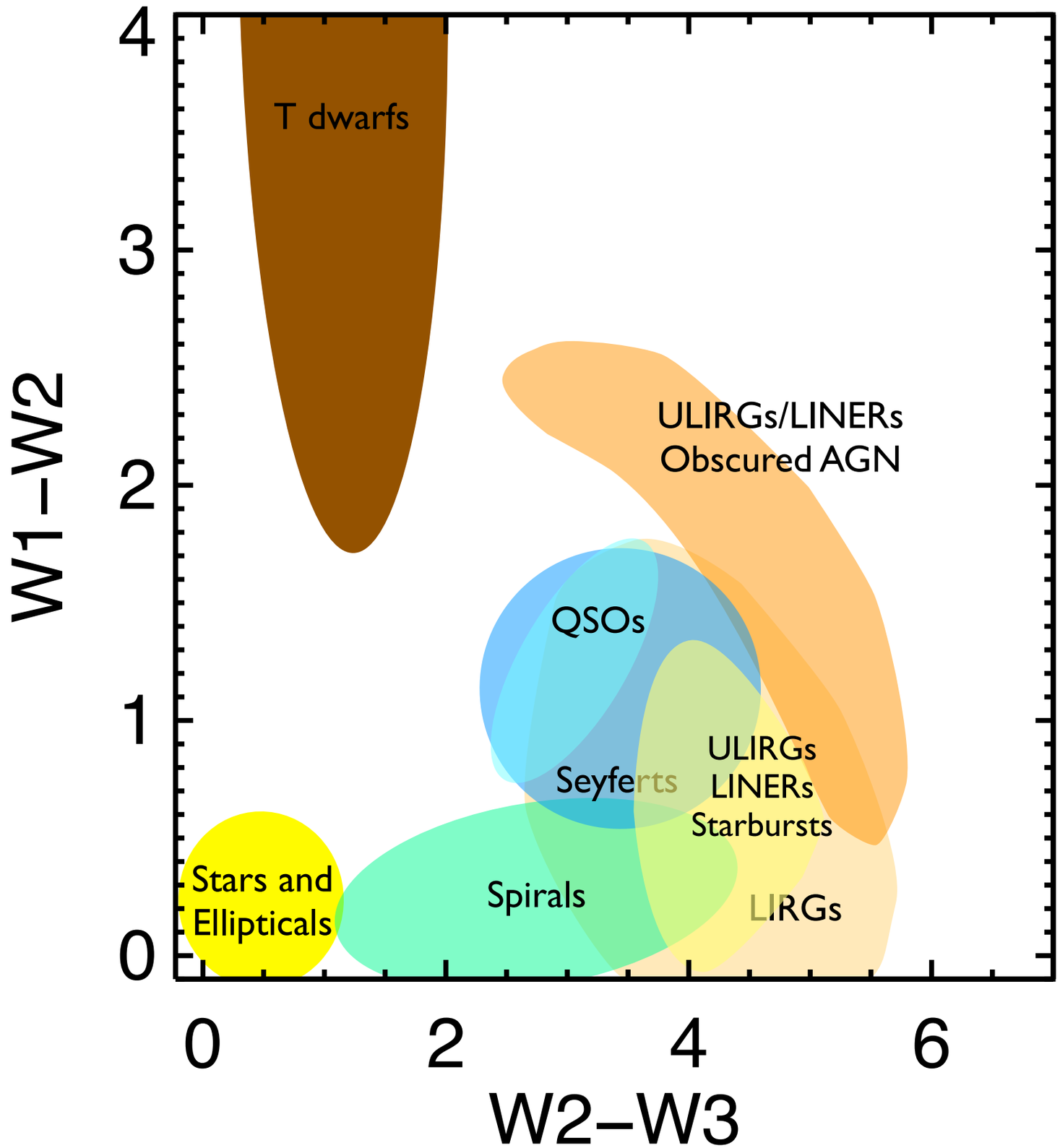
We also classify the "reddest" well-known sources, non-discrete sources (maxima in diffuse nebular emission), and artifacts

We generate a mock catalog of sources to determine which K3's we have ruled out

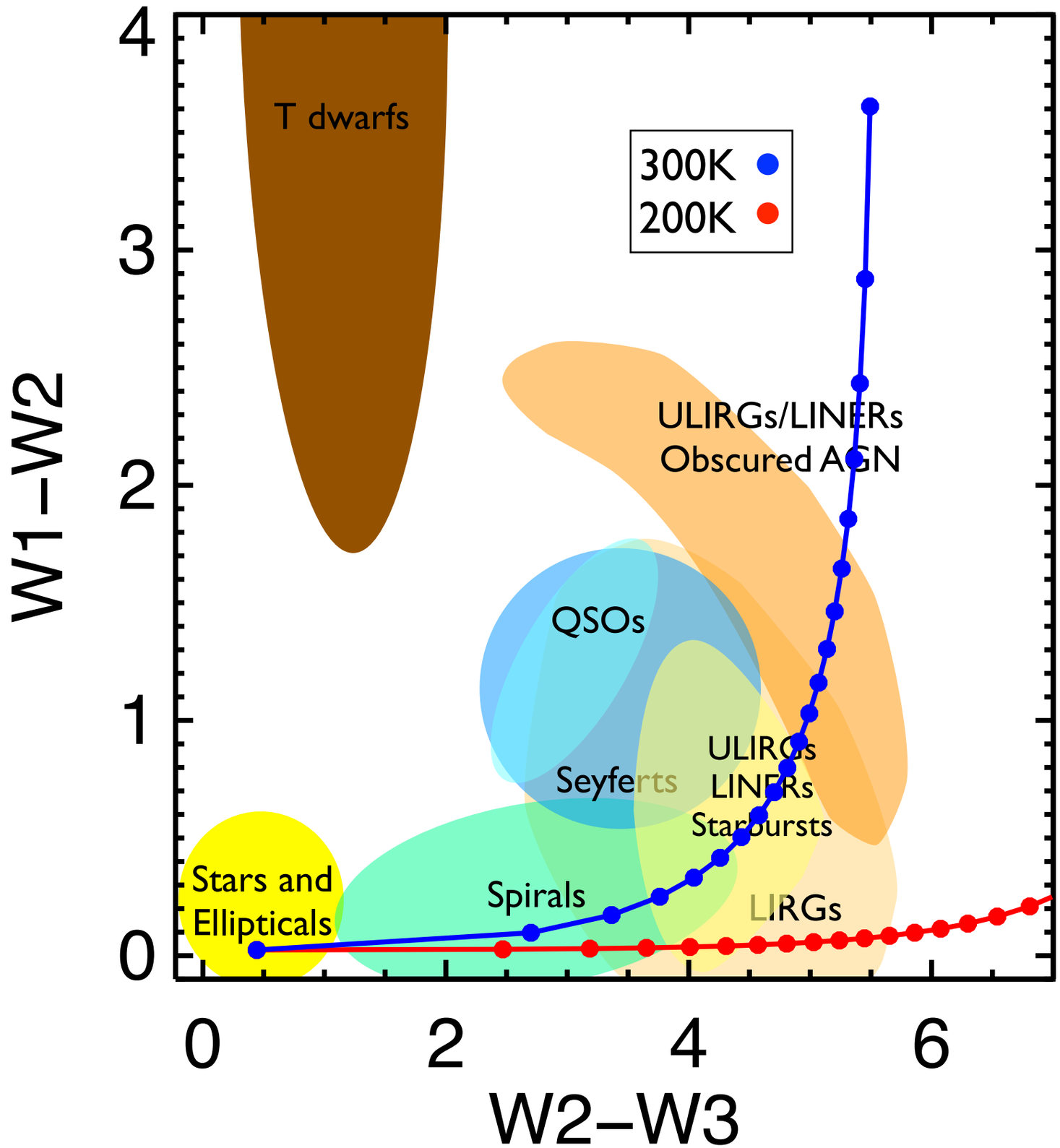


Left: Red points have $\alpha < 0.25$

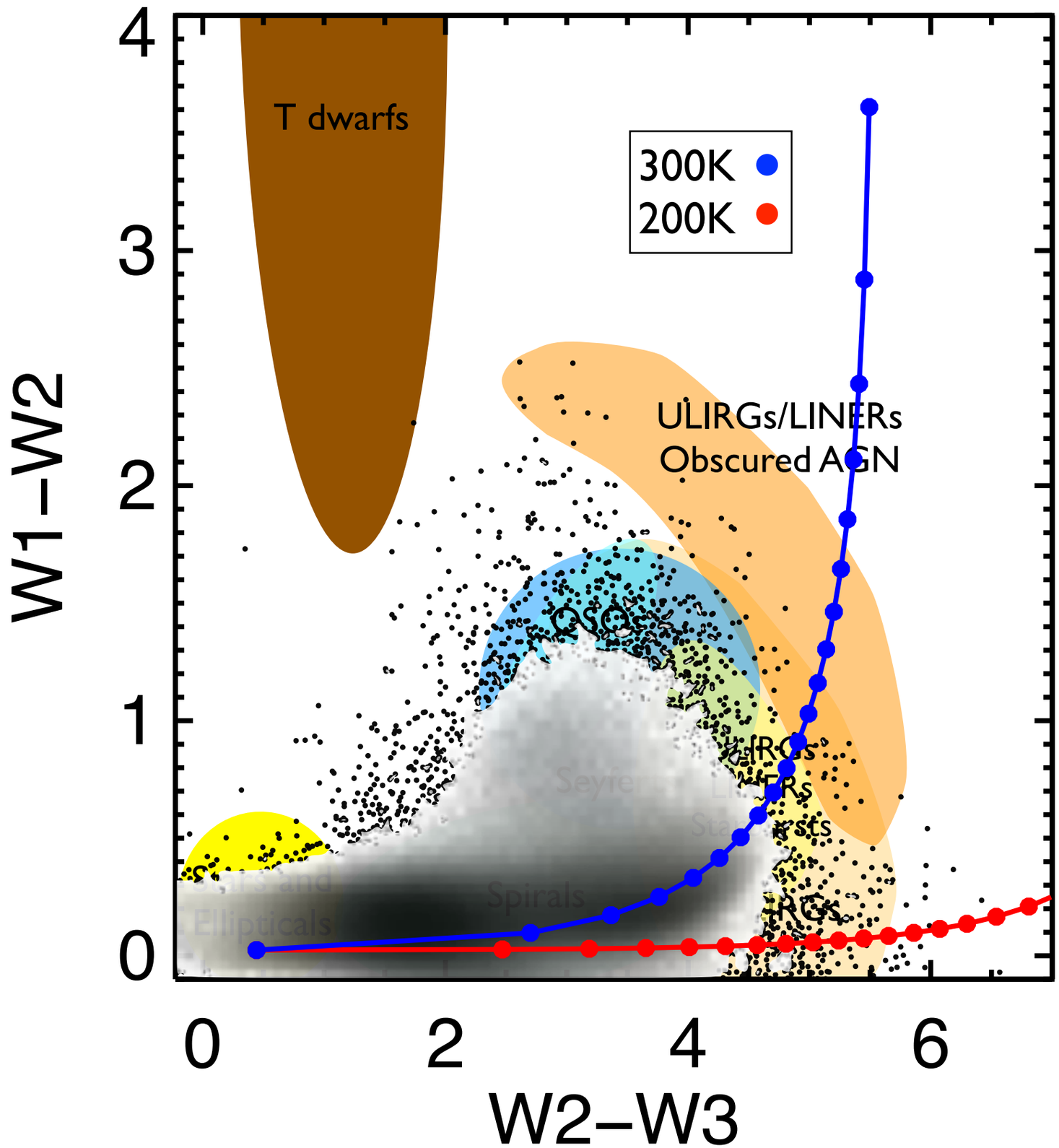
Right: Red points have $250\ K < T_{waste} < 350\ K$



Underlying figure reproduced from Lake et al. (2012) and Jarrett et al. (2011)



Underlying figure reproduced from Lake et al. (2012) and Jarrett et al. (2011)



Underlying figure reproduced from Lake et al. (2012) and Jarrett et al. (2011)

0th order result

- MIR-bright K3's are very rare among ~100,000 resolved galaxies in WISE catalog
- Only ~25 candidates with $\gamma > 0.5$, ~1000 with $\gamma > 0.25$
- This result is newly enabled by *WISE*

Referee comment on Davis (1955) (First upper limit on Solar neutrino production)

Any experiment such as this, which does not have the requisite sensitivity, really has no bearing on the question of the existence of neutrinos. To illustrate my point, one would not write a scientific paper describing an experiment in which an experimenter stood on a mountain and reached for the moon, and concluded that the moon was more than eight feet from the top of the mountain.

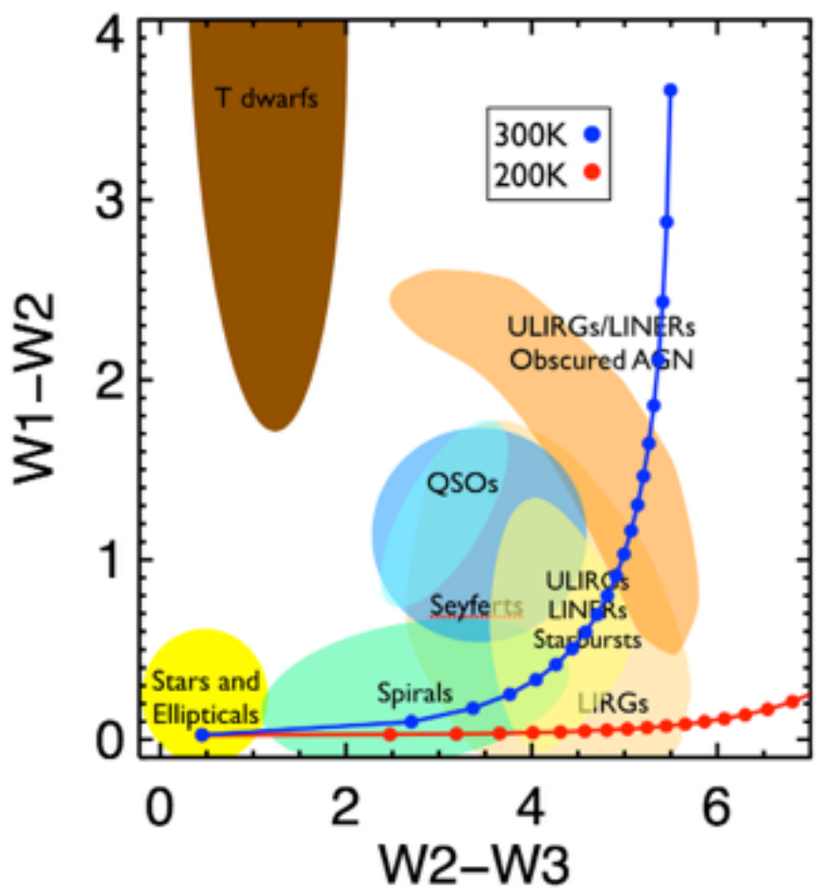
Our pilot program shows promise

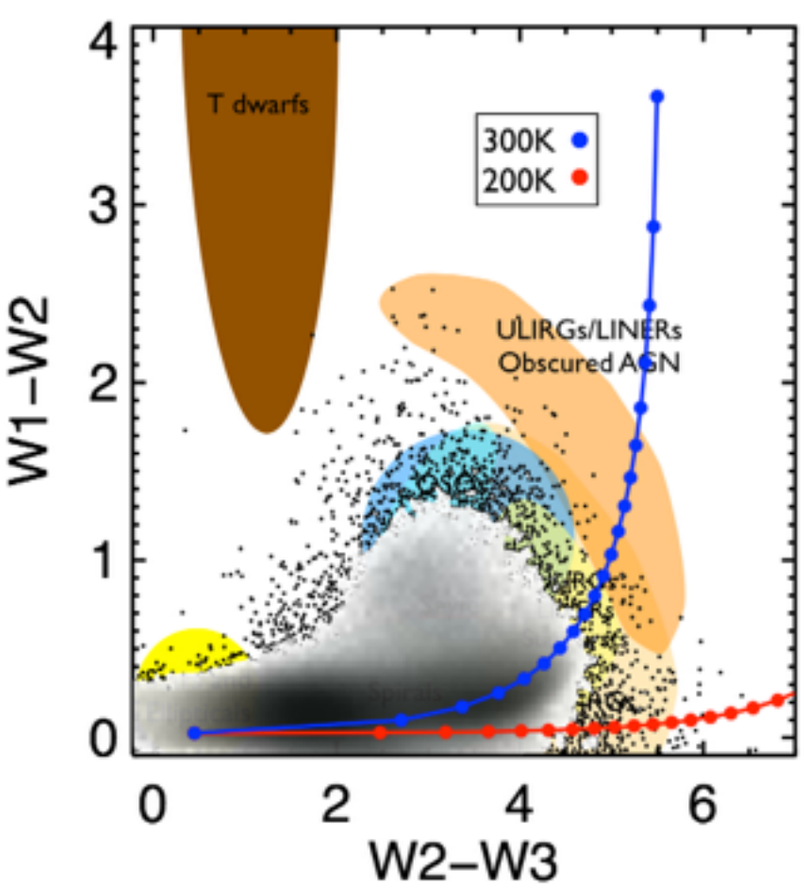
To push sensitivity to γ down:

Better model the dust

Identify and exclude giant stars, AGN

Focus on sources where sensitivity is high





Future Work

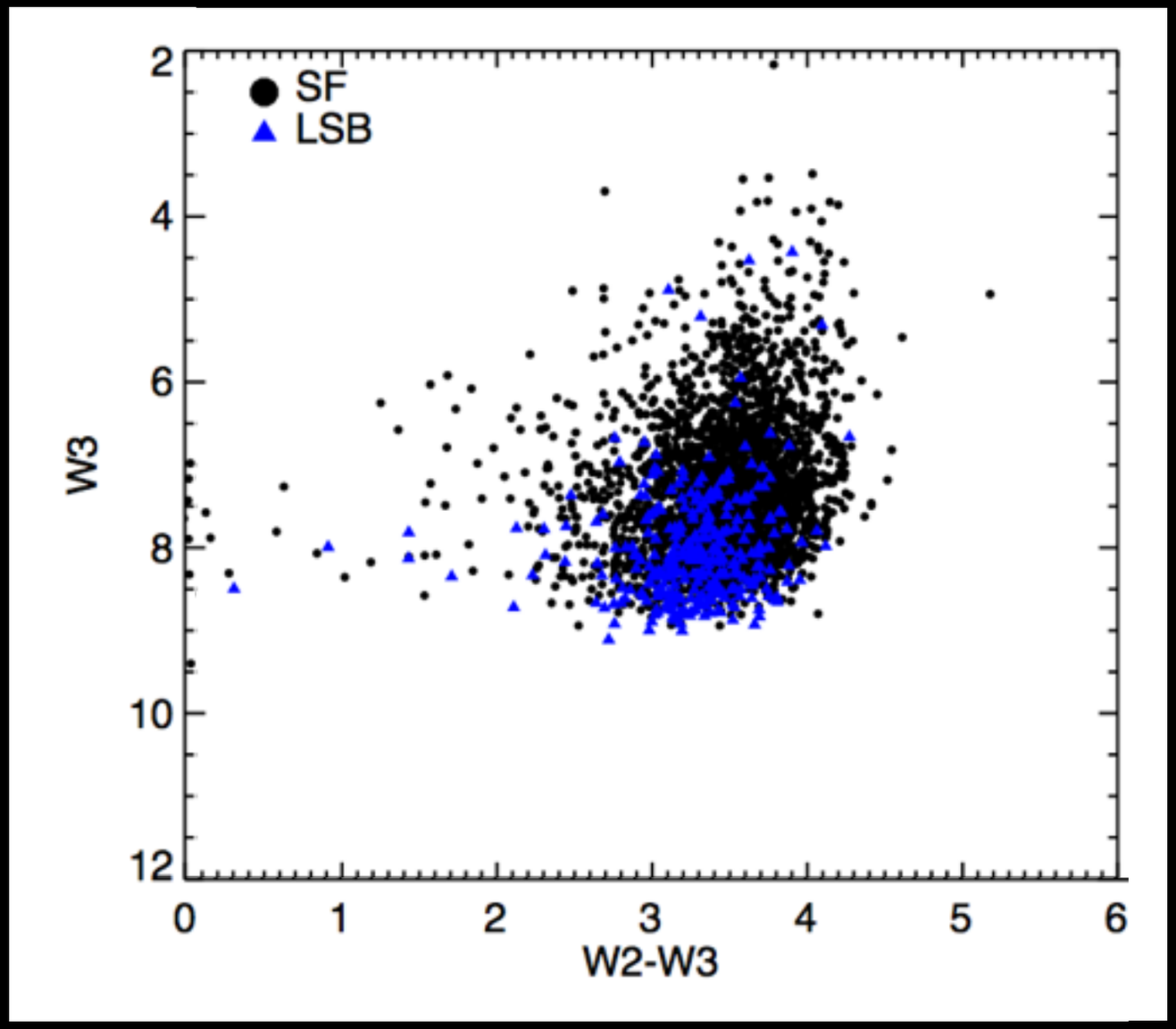
Galaxies:

- Thorough examination of ~2 dozen sources with $\gamma > 0.5$
- Broader photometric work (BVIJHKW1-4) to more thoroughly model dust in ~900 sources with $\gamma > 0.25$
- Identify *anomalously* MIR-bright galaxies, especially ellipticals where sensitivity to γ is good

Stars:

- Use optical-NIR colors to identify sources free from extinction by dust
- Prepare for *GAIA* parallaxes to identify MIR-bright, non-giant stars

We examine low surface brightness galaxies (lots of Dyson spheres?)



Curious…

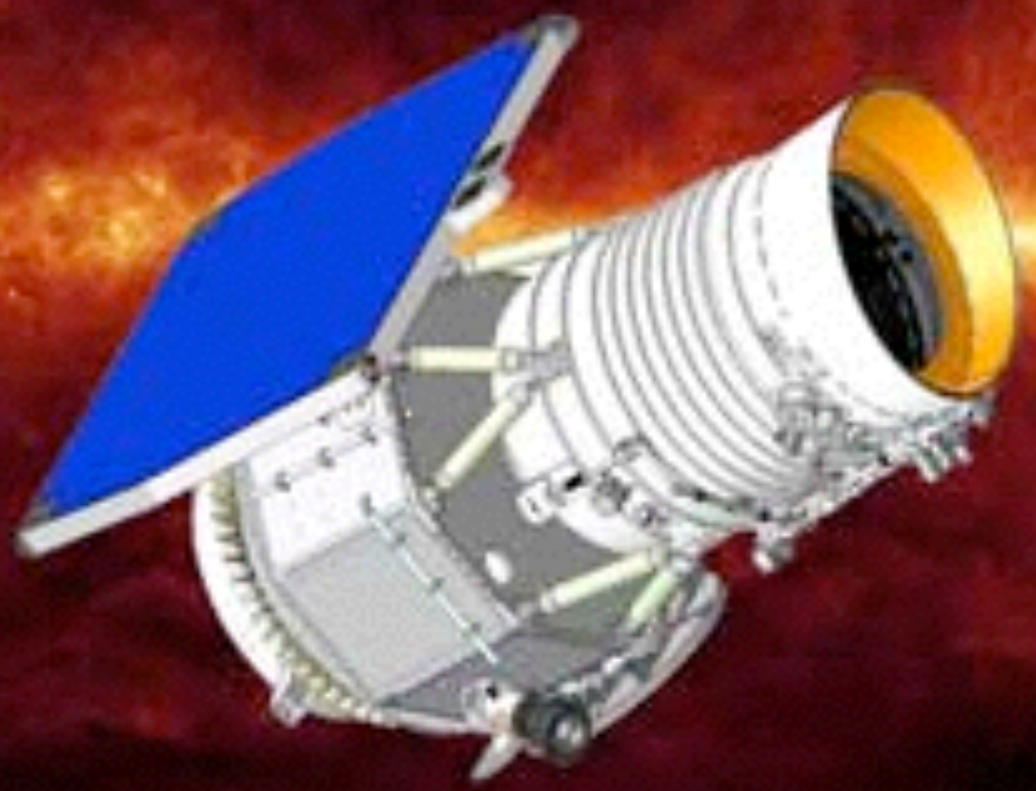
What does a null result imply?

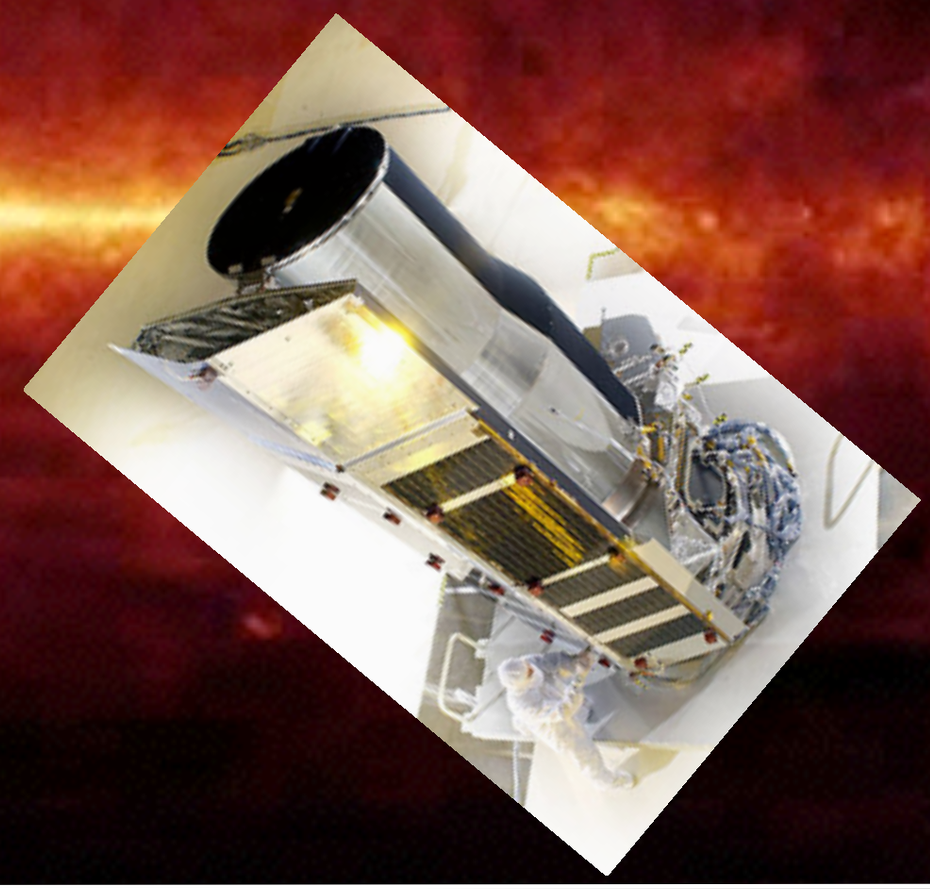
- Civilizations with MIR waste heat comparable to starlight do not exist
  - High values of $(\alpha + \varepsilon)$ are logistically impossible
  - … are physically impossible
  - They inevitably stop growing their energy supply
  - They are inevitably short lived
- New physics (violation of conservation of energy, laws of thermodynamics, FTL communication) is employed by all or most spacefaring civilizations
- Civilizations *inevitably* operate at low values of T_{waste} , or minimal values of γ, beyond our detection or confusion threshold

Conclusions

- Communication and Artifact SETI are complementary
- Hart's analysis argues a either a K2 or K3 search should eventually succeed
- Alien waste heat is likely emitted in the MIR
- 0th order result is that MIR-bright K3's are rare!
- Null result can imply new physics, or uniqueness of humanity.

The $\hat{G}$ Search for Extraterrestrial Civilizations





PENNSTATE

1855

Jason T. Wright
Roger Griffith, Steinn Sigurðsson
Matthew Povich (Cal Poly Pomona)