

SEDBYS: A python-based SED Builder for Young Stars

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ABSTRACT

Spectral energy distributions (SEDs) are useful primary and complementary tools in the analysis of observations of young stars. However, the process of collating, inspecting, and flux-converting archival photometry and spectroscopy to build spectral energy distributions for young stars can be time-consuming. Here, I present SEDBYS (Spectral Energy Distribution Builder for Young Stars), a python-based repository of command-line tools built to (i) query online photometric and spectroscopic catalogs and a distributed database of archival photometry, (ii) use a look-up table of zero points to flux-convert the acquired data, (iii) enable visual inspection of the SED and (iv) handle book-keeping to collate references in bibTeX format. The code is distributed via git and is equipped with additional tools to enable users to add existing or forthcoming catalogs to the list of sources queried, ensuring the longevity of SEDBYS as a tool for the star formation community.

1. Introduction

The shape of the spectral energy distribution (SED) of a star changes during its formation. Resembling a cool black body in the earliest stages of gravitational collapse, the initially spherical circumstellar envelope is flattened into a disk via the conservation of angular momentum and the stellar and circumstellar portions of the SED become more distinguished (Lada and Wilking, 1984; Beall, 1987; Wilking et al., 1989). In these latter stages, the SED resembles a stellar blackbody emission plus excess emission from UV to radio wavelengths, arising as a result of the accretion of circumstellar material onto the star, and through the re-processing and scattering of starlight by circumstellar dust and gas (Bertout, 1989; Fischer et al., 2011). Analysing the SED of a young stellar object (YSO) can thus reveal its evolutionary status (e.g. Furlan et al., 2016; Robitaille, 2017).

Moreover, studying different portions of the SED of a YSO can shed further light on the nature of the circumstellar material. For instance, the shape of the SED around the 10 μm silicate feature probes the level of dust grain growth, settling (e.g. D'Alessio et al., 2006), and processing into crystallised structures (e.g. Sargent et al., 2009); a relative dearth of near-infrared emission compared to far-infrared or submillimetre emission can reveal the presence of (potentially planet-carved) annular dust gaps and/or inner disk cavities (e.g. Espaillat et al., 2012); and the spectral index across the millimetre to radio portions of the SED can be used to distinguish thermal continuum from free-free emission (Wright and Barlow, 1975; Eisner et al., 2008), enabling the circumstellar dust mass to be estimated (e.g. Eisner et al., 2018). Information about the central star may also be inferred from the SED: stellar effective temperatures, luminosities, radii, and surface gravities are estimated by comparing the SED to stellar evolutionary models and/or model atmospheres (e.g. Leggett et al., 2001; Filippazzo et al., 2015; Pascual et al., 2016; Lodieu et al., 2018; Zhang and Tan, 2018).

SEDs are also used as complementary tools in the analysis of high angular resolution observations of YSOs. For instance, near- and mid-infrared interferometric studies of YSOs may use collated SEDs to provide an independent assessment of the stellar flux contribution which is otherwise degenerate with the characteristic size of the circumstellar emitting region (Lazareff et al., 2017). High contrast imaging (e.g. Rich et al., 2015) and interferometric studies (e.g. Davies et al., 2018) with limited wavelength coverage often also compare their models to SEDs to ensure their disk models are consistent with observations across all annuli.

YSO SEDs are typically compiled from archival data, sometimes supplemented with new photometric observations. Existing tools such as the VizieR Photometry Viewer¹ or the Virtual Observatory SED Analyser (VOSA; Bayo et al. 2008) are extremely useful in helping to collate data from surveys. However, they each suffer from at least one of the following caveats:

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- To be collated, photometry must exist in online catalogs. As such, potentially useful archival photometric data which was, for instance, published prior to the early 1990s or reported in the main body of a paper rather than being tabulated is completely missed. This particularly effects - but is by no means limited to - long wavelength (millimetre and radio) data. In addition, the converting of data tables in published journals to VizieR cataloged tables is by no means complete, further limiting the data that is retrieved.
- Data collation is based on target coordinates rather than individual object identifiers. As such, data for a number of individual stars in a multiple system (or otherwise crowded field) may be collated and combined with blended photometry obtained on telescopes with a wider field of view.
- Details of the observation date and effective telescope resolution or interferometric beam size are not collated, both of which are useful to assess when data for a specific target need to be cleaned due to e.g. a vertical spread in magnitude or flux at any given wavelength.
- While the direct source of the data is retained to aid book-keeping and referencing, some catalogs also contain data which has been sourced from a pre-existing catalog or study. Other catalogs are simply collations of many different individual sources of photometry. In these cases, the original references are not retained and extra time and effort must be spent on ensuring the work of the original authors is acknowledged.

Thus, even with these existing tools, collating and inspecting data to build an SED for an individual YSO can often be a time-consuming process.

Herein, I present the Spectral Energy Distribution Builder for Young Stars (SEDBYS), a python-based git repository² of command-line tools designed for the collation of archival photometric and spectroscopic data and the building and inspecting of SEDs. The aims of SEDBYS were to address the caveats outlined above. In particular:

- To create a searchable repository of published photometry and flux measurements which do not already exist in online catalogs, thereby increasing the legacy value of existing photometric survey data. The intent was not to ensure that this repository was complete. Instead, the aim was to design a relatively easy way for individuals to add new and existing published data to the repository to enable it to grow with time.
- As YSOs are intrinsically variable at optical and infrared wavelengths (see, for example [Cody and Hillenbrand, 2018](#), and references therein), the observation date should be collated alongside the photometry, where possible. This would allow the user to select (semi-)contemporaneous photometry and/or a bright epoch when inspecting their SED.
- To retain a record of the telescope resolution or extent of the interferometric beam alongside the photometry and flux measurements. This information is useful when a target is located in a crowded field or is a component of (or conversely comprises multiple members of) a binary or multiple system. Also, for longer wavelength observations, the resolution of the observations is important to consider whether any surrounding nebulosity may contaminate the flux measurement or has instead been resolved-out.
- To provide an interactive plotting tool which remains synchronous with the data collated for a particular target so that a record could be kept of any data rejected by the user, aiding reproducibility of results.
- To equip the user with a tool to create LaTeX format, fully referenced data tables and corresponding bibTeX files from the collated data.

This paper describes the different functions of SEDBYS. Details of how to use the tools are reserved for the ReadMe file distributed with the code. Section 2 covers the database query tool: Section 2.1 details which online photometry catalogs are queried and how; Section 2.2 details the procedure followed to automatically query specific online atlases of reduced and flux-calibrated infrared spectroscopy; Section 2.3 describes the SEDBYS photometry database and outlines the manner in which this is queried. Section 3 details the data inspection tool. Finally, Section 4 outlines how individual users may contribute to the continued expansion of SEDBYS through robust features designed to allow new or existing catalogs to be added to the online and local databases.

²<https://gitlab.com/clairedavies/sedbys>

Table 1
Catalogs queried using `astroquery.vizier`

Instrument or Survey	Catalog Reference(s)
XMM-OM	Page et al. (2012)
GALEX	Bianchi et al. (2011)
Gaia	Gaia Collaboration et al. (2018)
Tycho-2	Høg et al. (2000)
SDSS	Abazajian et al. (2009); Ahn et al. (2012); Alam et al. (2015)
APASS	Henden et al. (2015)
2MASS	Cutri et al. (2003)
MSX	Egan et al. (2003)
AKARI	Ishihara et al. (2010); Yamamura et al. (2010)
SPITZER	Evans et al. (2003); Caulet et al. (2008); Luhman et al. (2008); Gutermuth et al. (2009)
WISE	Cutri et al. (2012)
IRAS	Joint Iras Science (1994)
Herschel	Benedettini et al. (2018)
CSO	Andrews and Williams (2007)
SCUBA	Di Francesco et al. (2008); Andrews and Williams (2007)
LABOCA	Belloche et al. (2011)
ALMA	Pascucci et al. (2016); Ansdell et al. (2016); Cazzoletti et al. (2019)
VLA	Dzib et al. (2013)

2. DATABASE QUERIES

SEDBYS script `queryDB.py` is designed to query:

1. the online VizieR catalog database, operated by the CDS;
2. the SEDBYS database of photometry.

The SEDBYS photometry database has been compiled from extant publications which have not been cataloged in VizieR. `queryDB.py` is also equipped with an optional argument which the user can choose to use to automatically search for and retrieve fully processed, flux-calibrated low-resolution Spitzer and ISO SWS infrared spectra from online atlases. Further details of these procedures are outlined below.

2.1. Integration with VizieR and SIMBAD

`queryDB.py` utilises `astroquery` (Ginsburg et al., 2019), an affiliated package of `Astropy`³ (Astropy Collaboration et al., 2013; Price-Whelan et al., 2018), to retrieve photometry at UV to radio wavelengths for a user-specified target. The search is restricted to the surveys and catalogs listed in Table 1 as their format makes it simple to automate the retrieval of tabulated magnitudes (or fluxes) and their associated measurement uncertainties in a consistent manner.

Firstly, the user-specified target name is parsed to `astroquery.simbad` to retrieve JHK_s photometry from the 2MASS All-Sky Catalog of Point Sources (Cutri et al., 2003). Then, `astroquery.vizier` function `query_region` is used to iteratively query the other catalogs in Table 1. The `query_region` function recovers the sky coordinates for the specified target and uses these, together with a user-defined cone search radius, to find matches in catalogs. The SEDBYS user can specify the cone search radius using `queryDB.py` optional argument `rad` (which defaults to 10").

In some cases, multiple entries in a given catalog may be found within the defined cone search radius around the target position. By default, `queryDB.py` operates in interactive mode and, in such an instance, all potential matches are printed to screen alongside the positional offset⁴, `_r`, and a message prompting the user to specify which entry corresponds to their target by entering the corresponding `_r` value. Alternatively, the user can switch on `queryDB.py` optional argument `closest` which will automatically retrieve the data for the catalog entry with the smallest `_r`. This option is particularly useful when using `queryDB.py` in batch mode for a large number of YSOs.

³<http://www.astropy.org>

⁴The positional offset (in arcseconds) between each potential match in the given catalog and the input target sky coordinates is denoted as `_r` in VizieR. This symbol is retained in SEDBYS.

Table 2Catalog metadata stored in the python dictionaries within `cat_setup.py`

Entry number	Metadata
1	Catalog identifier (VizieR catalog) or path to file on local machine (local database)
2	Bibcode
3	Wavelengths (in m) for each photometric measurement
4	Effective resolution of each telescope or interferometric array
5	The column header for each photometric measurement
6	The column header for the error on each photometric measurement
7	The unit (mag, mJy, or Jy) for each photometric measurement
8	Filter name for each photometric measurement

Once a match is found in a catalog, the catalog metadata (see Table 2) are retrieved from the python dictionaries contained within SEDBYS file `cat_setup.py`. Photometric measurements, together with their uncertainties⁵, are retrieved from VizieR and saved to file alongside the catalog metadata.

2.2. Infrared spectra retrieval

If `queryDB.py` optional argument `getSpect` is switched on, the Cornell Atlas of Spitzer/IRS Sources (CASSIS; Leboutteiller et al. 2011) and Gregory C. Sloan's Atlas of full-scan AOT1 spectra (Sloan et al., 2003) are then queried for low-resolution Spitzer spectra and Infrared Space Observatory Short Wavelength Spectrometer (ISO/SWS) spectra, respectively. The sky coordinates of the target, retrieved from SIMBAD using `astroquery.simbad`, are used when querying CASSIS. In particular, the coordinates retrieved from SIMBAD are converted to decimal degrees using the `coordinates` package of Astropy and concatenated, alongside the cone search radius, into a string matching the format of the CASSIS *Query form*⁶ output. The `urlopen` and `urlretrieve` functions of the `urllib.request` python package are then used to (i) scrape the page source to identify the name of any files found by CASSIS which contain low-resolution Spitzer spectra and (ii) download a copy of these files to the user's local machine.

To retrieve the ISO SWS spectra, the `urlopen` function is used to scrape the full page source⁷. The sky coordinates of the user-specified search target are compared to those of each target in the atlas until a match within the user-defined cone search radius is found. The `urlretrieve` function is then used to download the corresponding file to the user's local machine. In case an object has been observed multiple times, this search for matches continues until the end of the page source is reached.

To aid book-keeping and referencing, the suggested acknowledgements for CASSIS and Gregory C. Sloan's SWS Atlas are hard-coded into SEDBYS. If data for a target is retrieved from these sources, a bibTeX file is created for the target which includes these acknowledgements.

2.3. The SEDBYS photometric database

SEDBYS is equipped with a database of previously published photometry which are either not available in VizieR or that are in VizieR but in a format that is not possible to query using the process outlined in Section 2.1. I have manually retrieved the data in the SEDBYS photometric database from individual publications and re-shaped them into a consistent format comprising:

- SIMBAD-compatible target identifiers;
- photometric measurements;
- measurement errors;
- the observation date, when known.

⁵The catalog metadata is flexible to some of the different ways measurement uncertainties are presented in VizieR. For instance, instead of providing individual measurement uncertainties, Di Francesco et al. (2008) provide a percentage flux uncertainty. The `queryDB.py` script contains a catch to look for instances of floats rather than strings in the measurement uncertainty catalog metadata entry. Floats are treated as percentage errors and `queryDB.py` combines these with the flux measurement to estimate the uncertainty.

⁶<https://cassis.sirtf.com/atlas/query.shtml>

⁷<https://users.physics.unc.edu/~gcsloan/library/swsatlas/aot1.html>

Metadata for each catalog in the photometric database (see Table 2) is saved to a python dictionary in SEDBYS file `cat_setup.py`.

The `queryDB.py` script iteratively searches through all catalogs in the SEDBYS photometric database for data corresponding to the user-specified target. In contrast to the online queries (Sections 2.1 and 2.2), matches are identified based purely on the target name and its aliases, retrieved from SIMBAD. The user-specified cone search radius is not used here.

2.3.1. Target identifiers and integration with SIMBAD

The procedures outlined above rely on integration with SIMBAD. As such, the user-specified target name must be identifiable by SIMBAD to enable the target sky coordinates and aliases to be retrieved by the `astroquery` functions. Some commonly adopted shorthand aliases for YSOs (e.g. SR 21) are not recognised by SIMBAD and the user must parse the full alias to `queryDB.py` when conducting the search (e.g. EM* SR 21 in this case).

The exception to the rules regarding target names concerns binary or multiple YSOs as these are known to often lack separate SIMBAD entries. If photometry is sought for a single component of a binary or multiple system, the user may parse a target identifier which comprises a SIMBAD-compatible name plus an alphabetic suffix to denote the primary or secondary (etc) status of the object in the system. For instance, if photometry was sought for the secondary component of the XZ Tau system, the user should parse V* XZ Tau B to `queryDB.py`. In such a case, the online queries outlined in Sections 2.1 and 2.2 are skipped, as an entry in SIMBAD will not be found, and `queryDB.py` limits its search to finding matches in the SEDBYS photometric database.

Requiring that the first part of the name of the binary or multiple system component remains SIMBAD-compatible is important. This portion of the target name is used to retrieve aliases from SIMBAD, which are then each appended with the suffix (i.e. “B” in our example case above) and used to identify matches in the SEDBYS photometric database. Furthermore, if a user searches for photometry for the combined system (i.e. XZ Tau in this case), `queryDB.py` will print a message to screen alerting the user to the fact that individual component photometry exists in the database.

2.3.2. Notes on individual sources of data

Some of the sources of data which I have compiled into the SEDBYS photometric database used object identifiers which are not SIMBAD-compatible. In these cases, I used the coordinates provided for targets in the source paper to link the data to a SIMBAD-compatible identifier. This also served as a cross-check of previous matching between sky coordinates and object identifiers. It is noted that table 15 in Ribas et al. (2017) presents a naming error for three YSOs in Chamaeleon (namely Hn 11, WY Cha, and T45a; Á. Ribas, private communication), which were associated an incorrect name. In SEDBYS, the Herschel fluxes provided in table 15 of Ribas et al. (2017) have been re-matched to their respective target identifiers. Similarly, in Tripathi et al. (2017), the SMA data for target RX J1633.9-2442 are incorrectly attributed to a target with name RX J1633.9-2422, which has no match in the ROSAT catalog. This has been corrected in the SEDBYS database.

3. DATA INSPECTION

The SEDBYS script `inspectSED.py` allows the user to visually inspect the collated spectroscopic and photometric data. This step is interactive and provides the user with a method to flag any unwanted data while retaining a record of the original search results to aid reproducibility of results. This is particularly useful for instances where, for example, the source may be confused, the data are saturated, or where upper limits are superseded by more sensitive observations.

The photometric data are converted to flux densities using zero points retrieved from the literature. With the exception of GALEX FUV and NUV and SDSS ugriz data, all measurements are in the Vega system. Python event handling is utilised to provide an interactive plot of the compiled SED. When the data are displayed, the user is prompted to click on any photometric data points they wish to flag for removal. The remaining data (or all the data if none were flagged) are then saved to a separate file containing the flux-converted values. The format of this file is also readable by `inspectSED.py`, enabling the user to repeat this step if necessary.

The SEDBYS script `toLaTeX.py` can then be used to reformat this file into a LaTeX table (see Appendix Table 3 for an example) with corresponding bibTeX file for easy referencing.

3.1. Example: MWC 297

Fig 1 shows the SED compiled using SEDBYS for the YSO MWC 297. This was generated using the following command sequence:

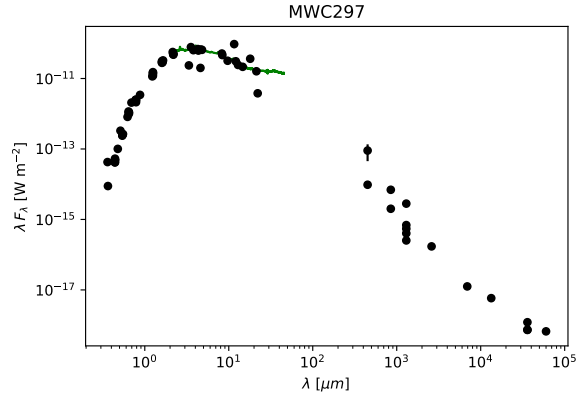


Figure 1: SED of MWC 297, built using SEDBYS using a cone search radius of $10''$ with optional arguments `getSpect` and `closest` switched on. The ISO/SWS spectrum is shown in green while the photometric data are overlaid as black filled circles. In most cases, photometric measurement errors are smaller than the data points.

```
python3 queryDB.py --obj=MWC297 --rad=10s --closest=True --getSpect=True;
```

```
python3 inspectSED.py --savePlt=True --phot=MWC297/MWC297_phot.dat
--spec=MWC297/70800234_sws.fit
```

The first command indicates that a cone search radius of $10''$ has been used and that optional arguments `getSpect` and `closest` were both switched on. `queryDB.py` created a new directory using the object name provided (i.e. the string parsed to the `obj` argument). A total of 102 photometric data points were retrieved and saved to newly created file `MWC297_phot.dat`. In contrast, using the VizieR photometry viewer provides no data at wavelengths longer than $850 \mu\text{m}$. An ISO/SWS spectrum was also retrieved and saved to the same directory. The original name of this file is retained.

The second command dictates that both the photometry and the spectroscopy retrieved by SEDBYS should be plotted and that the plot should be saved to file. None of the data retrieved by SEDBYS have been flagged for removal.

The full list of photometry is provided, with individual references, in Table 3. This was created using command:

```
python3 toLaTeX.py --phot=MWC297/MWC297_phot.dat
```

This also created a corresponding bibliographic reference file.

4. FUTURE DEVELOPMENT

The aim of this first release of SEDBYS has not been to ensure that the local database is complete. Instead, the idea that SEDBYS would be distributed via a git repository has been fed into its development and helps to ensure its growth and longevity. SEDBYS comes equipped with scripts (`addLocal.py` and `addVizCat.py`) which can be used to expand the SEDBYS photometric database and the list of VizieR catalogs to be queried, respectively. Any updates can then be pushed by the user to the git repository to grow the resource.

Using `addLocal.py` relies on the user first making a comma-separated photometric data file which matches the format of existing entries in the SEDBYS photometric database. The new file is tested to ensure:

- The target identifier is SIMBAD-compatible and must be provided as it appears within the SIMBAD database (exceptions apply for individual components of binary or multiple systems - see Section 2.3.1). For example, the canonical T Tauri star T Tau must be listed in full as $V^* \text{ T Tau}$, as it appears in SIMBAD, even though the shorthand name T Tau is SIMBAD-compatible.
- The observing date must be in YYYYMMMDD (e.g. 2020Jun10) or YYYYMMM format.

Then, the metadata (see Table 2) is parsed to `addLocal.py` to add the new entry to the SEDBYS photometric database. For example, using the following command would add the file called `herschel_phot.csv`, created from table 2 of Pascual et al. (2016) to the SEDBYS photometry database:

```
python3 addLocal.py --nam=HERSCHEL1 --fil=herschel_phot.csv
--ref='2016A&A...586A...6P' --wav=70e-6,100e-6,160e-6 --res=5.033,7.190,11.504
--fna=F70,F100,F160 --ena=eF70,eF100,eF160 --una=Jy,Jy,Jy
--bna=Herschel:PACS:F70,Herschel:PACS:F100, Herschel:PACS:F160
```

In contrast, a user wishing to add a new VizieR catalog to the list of queried catalogs is only required to parse the catalog metadata to `addVizCat.py`. Both scripts inspect the format of the catalog metadata parsed to them, ensuring:

- The catalog or the file exists.
- The bibliographic reference is compliant with NASA ADS formatting.
- The column headers provided appear in the catalog or the file being added.
- The measurement units are one of “mag”, “mJy”, or “Jy”.
- If the measurement unit is “mag”, the filter keyword must match one of the entries in SEDBYS file `zero_points.dat` to ensure it can be correctly converted to a flux density. Otherwise, it simply needs to be descriptive (e.g. ALMA:F1300). If the filter is not recognised, the user is prompted to add the filter zero point and central wavelength to the `zero_points.dat` file.

For example, the following command would ensure VizieR catalog I/259/tyc2 (Høg et al., 2000) is added to the list of online catalogs to be queried:

```
python3 addVizCat.py --nam=TYCH02 --cat='I/259/tyc2' --ref='2000A&A...355L...27H'
--wav=426e-9,532e-9 --res=0.37,0.462 --fna=BTmag,VTmag --ena=e_BTmag,e_VTmag
--una=mag,mag --bna=HIP:BT,HIP:VT
```

5. SUMMARY

In writing SEDBYS, I aimed to dramatically speed up and improve the process of collating archival spectrophotometric data to build SEDs for YSOs. The main advancements come in two parts: (i) the collation of a photometry database containing previously published archival data that is not catalogued by VizieR; (ii) an interactive plotting tool which remains synced to the collated data. In addition, by including scripts which allow individual users to expand the database with new and existing catalogs and/or data ensures that SEDBYS remains useful to the community for years to come.

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A. MWC 297 PHOTOMETRY

The data used to build the SED of MWC 297 in Fig. 1 are presented in Table 3. This table, including references, was produced using the SEDBYS script `toLaTeX.py`.

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Table 3

Photometry retrieved for MWC 297 using `queryDB.py`, flux-converted using `inspectSED.py` and tabulated using `toLaTeX.py`. Observation dates and flux density measurement uncertainties are provided where available.

Wavelength μm	λF_{λ} $10^{-13} \text{ W m}^{-2}$	Date	Reference
0.36	0.425	–	Hillenbrand et al. (1992)
0.36	0.089	–	Lazareff et al. (2017)
0.44	0.416	–	Hillenbrand et al. (1992)
0.44	0.480 ± 0.040	2006Jun09	Tannirkulam et al. (2008)
0.44	0.418	–	Lazareff et al. (2017)
0.44	0.489 ± 0.011	–	Henden et al. (2015)
0.44	0.532 ± 0.044	2006Aug27	Tannirkulam et al. (2008)
0.48	1.006 ± 0.045	–	Henden et al. (2015)
0.51	3.301 ± 0.035	–	Gaia Collaboration et al. (2018)
0.54	2.383 ± 0.202	–	Henden et al. (2015)
0.54	2.491 ± 0.184	2006Jun09	Tannirkulam et al. (2008)
0.54	2.561 ± 0.189	2006Aug27	Tannirkulam et al. (2008)
0.54	2.561	–	Lazareff et al. (2017)
0.55	2.657	–	Hillenbrand et al. (1992)
0.62	8.141 ± 0.817	–	Henden et al. (2015)
0.64	11.591 ± 0.041	–	Gaia Collaboration et al. (2018)
0.65	10.826 ± 0.897	2006Aug27	Tannirkulam et al. (2008)
0.65	9.965	–	Lazareff et al. (2017)
0.65	10.926 ± 0.906	2006Jun09	Tannirkulam et al. (2008)
0.69	20.725	–	Hillenbrand et al. (1992)
0.78	24.881 ± 0.277	–	Gaia Collaboration et al. (2018)
0.79	21.244 ± 1.370	2006Jun09	Tannirkulam et al. (2008)
0.79	25.075 ± 1.617	2006Aug27	Tannirkulam et al. (2008)
0.79	23.946	–	Lazareff et al. (2017)
0.88	34.297	–	Hillenbrand et al. (1992)
1.23	114.860	1989Apr	Berrilli et al. (1992)
1.25	151.556	–	Hillenbrand et al. (1992)
1.25	135.394 ± 2.369	–	Cutri et al. (2003)
1.25	120.385	–	Lazareff et al. (2017)
1.25	144.735 ± 10.664	2006Jun04	Tannirkulam et al. (2008)
1.60	311.187	–	Lazareff et al. (2017)
1.60	278.626	–	Hillenbrand et al. (1992)
1.60	289.083 ± 18.638	2006Jun04	Tannirkulam et al. (2008)
1.63	288.601	1989Apr	Berrilli et al. (1992)
1.65	326.315 ± 63.115	–	Cutri et al. (2003)
2.15	565.429 ± 124.987	–	Cutri et al. (2003)
2.18	507.814	–	Hillenbrand et al. (1992)
2.18	517.255	–	Lazareff et al. (2017)
2.18	489.446 ± 36.064	2006Jun04	Tannirkulam et al. (2008)
2.19	473.467	1989Apr	Berrilli et al. (1992)
3.35	235.555 ± 24.733	–	Cutri et al. (2012)
3.54	778.413	–	Hillenbrand et al. (1992)
3.79	636.974	1989Apr	Berrilli et al. (1992)
4.29	684.072 ± 60.797	–	Egan et al. (2003)
4.35	620.536 ± 61.337	–	Egan et al. (2003)
4.60	199.646 ± 3.310	–	Cutri et al. (2012)
4.64	662.736	1989Apr	Berrilli et al. (1992)
4.80	651.671	–	Hillenbrand et al. (1992)
8.28	511.240 ± 14.845	–	Egan et al. (2003)

Table 4Table. 3 *continued.*

Wavelength (μm)	λF_{λ} ($10^{-13} \text{ W m}^{-2}$)	Date	References
8.38	462.494	1989Apr	Berrilli et al. (1992)
9.69	319.010	1989Apr	Berrilli et al. (1992)
11.60	946.876 ± 216.282	–	Cutri et al. (2012)
12.13	308.196 ± 12.357	–	Egan et al. (2003)
12.89	242.680	1989Apr	Berrilli et al. (1992)
14.65	214.459 ± 12.483	–	Egan et al. (2003)
18.00	363.582 ± 0.691	–	Ishihara et al. (2010)
21.34	160.433 ± 8.429	–	Egan et al. (2003)
22.10	38.031 ± 0.035	–	Cutri et al. (2012)
450	0.903 ± 0.451	–	Di Francesco et al. (2008)
450	0.097 ± 0.013	–	Sandell et al. (2011)
850	0.069 ± 0.014	–	Di Francesco et al. (2008)
850	0.020 ± 0.001	–	Sandell et al. (2011)
1300	0.028	1995Feb	Henning et al. (1998)
1300	0.003	–	Hillenbrand et al. (1992)
1300	0.0040 ± 0.0001	2006Feb	Alonso-Albi et al. (2009)
1300	0.007	2006Aug28	Manoj et al. (2007)
1300	0.0055 ± 0.0003	–	Henning et al. (1994)
2600	0.00172 ± 0.00006	2006Feb	Alonso-Albi et al. (2009)
6917	0.0001	2005Dec	Alonso-Albi et al. (2009)
13350	0.00006	2005Dec	Alonso-Albi et al. (2009)
36000	0.0000074 ± 0.0000001	1990Feb11	Skinner et al. (1993)
36000	0.0000073 ± 0.0000001	1990Feb11	Skinner et al. (1993)
36000	0.0000121 ± 0.0000001	1991Feb07	Skinner et al. (1993)
60000	0.000007	1991Feb07	Skinner et al. (1993)