European University Cyprus

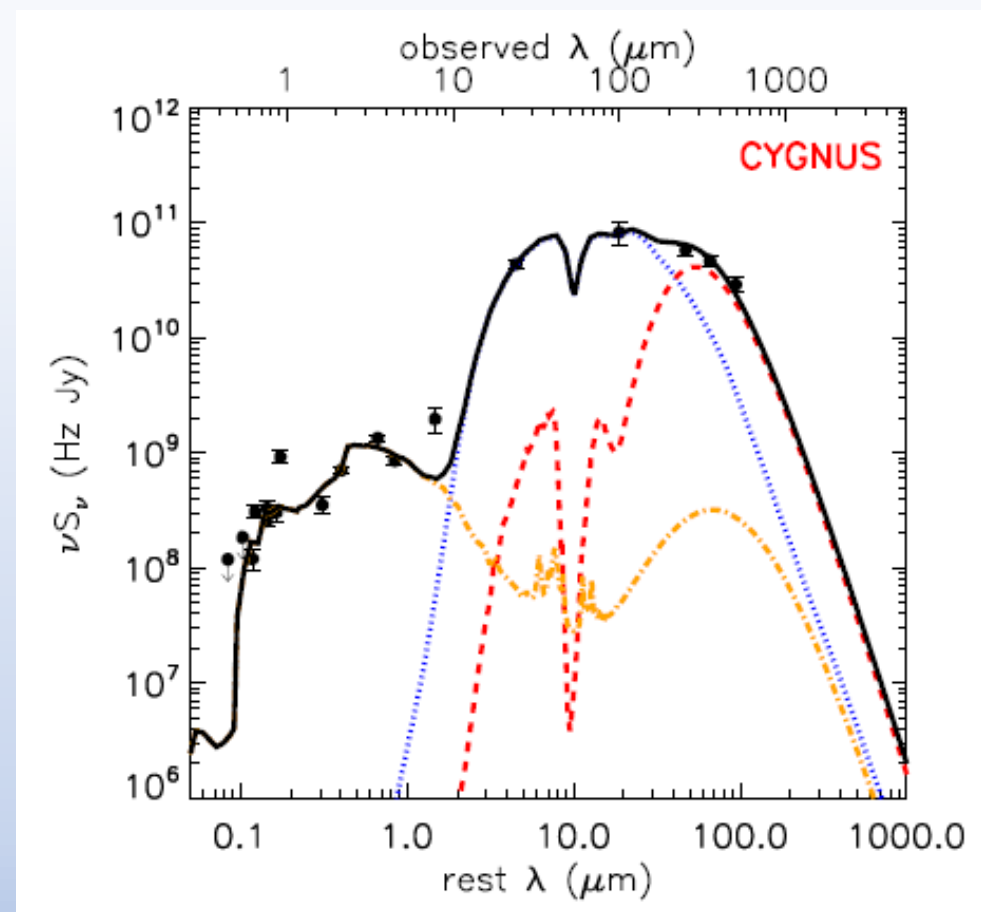ARC. Aristarchus Research Center

SMART

Charalambia Varnava

Two complementary ways of looking at galaxies: Images (left) and Spectral Energy Distributions or SEDs (right)

Nearby radio galaxy Centaurus A

SED of an obscured hyperluminous quasar at z~4.3 (Efstathiou et al. 2021)

SMART: Spectral energy distributions Markov chain Analysis with Radiative Transfer models

- Developed a new (Markov chain Monte Carlo (MCMC) SED fitting code, **SMART**, which fits SEDs *exclusively* with radiative transfer models. Available at: **https://github.com/ch-var/SMART**

- Takes comparable time to popular SED fitting methods based on energy balance (e.g. CIGALE, Noll et al. 2009; Boquien et al. 2019)

- Can be used to fit the SED of a galaxy at any redshift

- Promises to be very useful for analysing multi-wavelength SEDs of galaxies and obscured active galactic nucleus (AGN) from a number of ground-based and spaceborn facilities, such as:

SPITZER
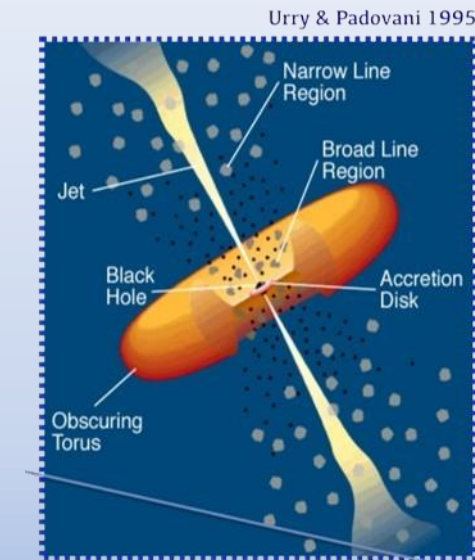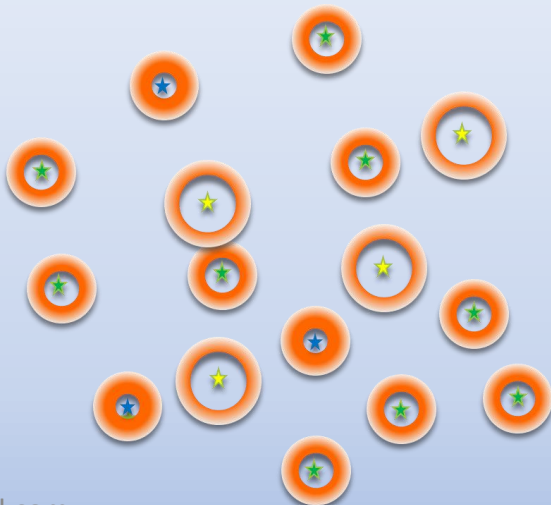(IR)

HERSCHEL
(FIR to submillimetre)

JWST
(optical to MIR)

Novel Features of SMART

1. More physically motivated and versatile compared to popular energy balance methods, such as CIGALE (Noll et al. 2009; Boquien et al. 2019) and MAGPHYS (da Cunha et al. 2008), that do not take properly into account the effects of dust in a realistic geometry

2. The code is parallelized and considerably faster than other MCMC codes, such as SATMC

3. Makes use of four different types of pre-computed AGN torus libraries, as in Efstathiou et al. (2022)

4. As in Efstathiou et al. (2022), can optionally add a component of polar dust in the fitting

5. Designed to fit an SED in comparable time with a spheroidal or disc host galaxy model

6. Can fit part of a galaxy and, if necessary, switch off any of the four components (AGN torus, starburst, spheroidal/disc, polar dust)
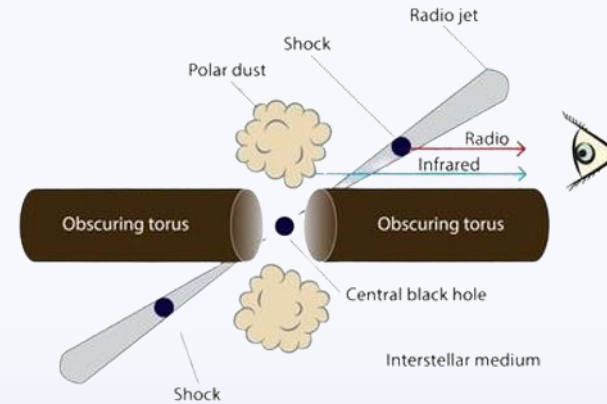
7. Can fix any of the model parameters

Description of SMART

- Developed a new method for fitting radiative transfer models to data, using an MCMC code

- As an MCMC sampler it utilizes the publicly available *emcee* code (Foreman-Mackey et al. 2013)

- Fits the ultraviolet to submillimetre SEDs *exclusively* with radiative transfer models that currently constitute four types of pre-computed libraries:

  - Starburst (Efstathiou et al. 2000,

    Efstathiou & Siebenmorgen 2009)

    – independent of redshift

  - AGN torus

    – independent of redshift

Urry & Padovani 1995

Description of SMART

o AGN polar dust (Efstathiou et al. 1995)

– independent of redshift

– optionally incorporated in **SMART**

o Spheroidal (Efstathiou et al. 2021)
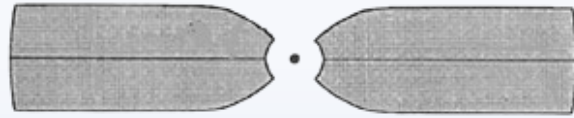
– dependent on redshift

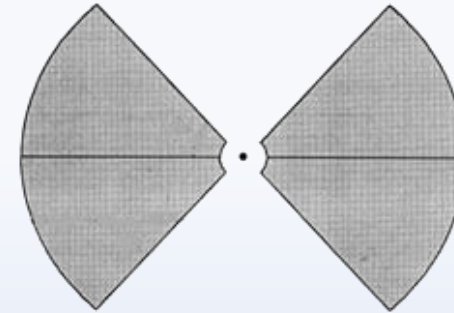o Disc (Efstathiou et al., in preparation)
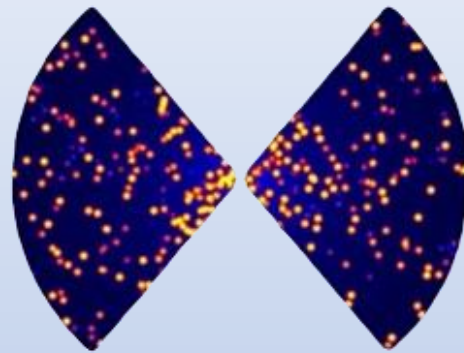
– dependent on redshift
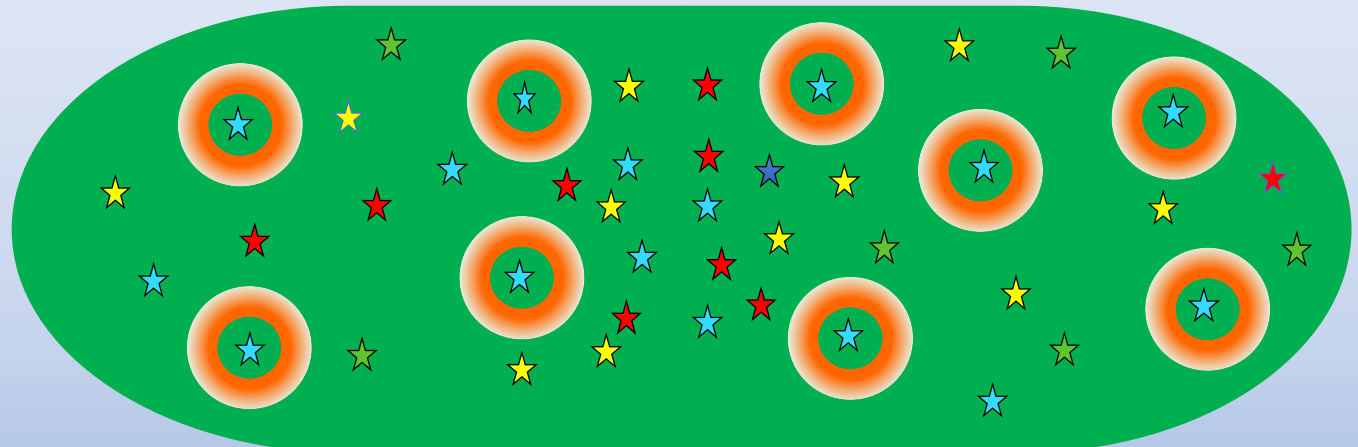
Description of SMART

- Allows us to explore the impact of four different AGN torus models and therefore constrain the properties of the obscuring torus:
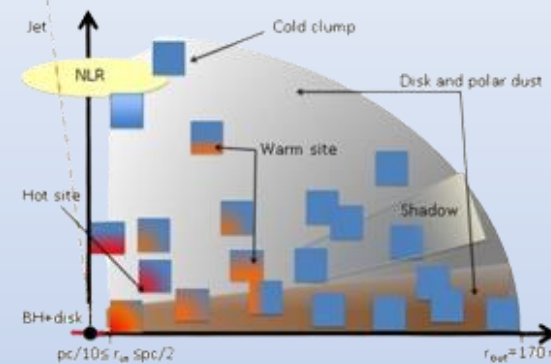

CYGNUS
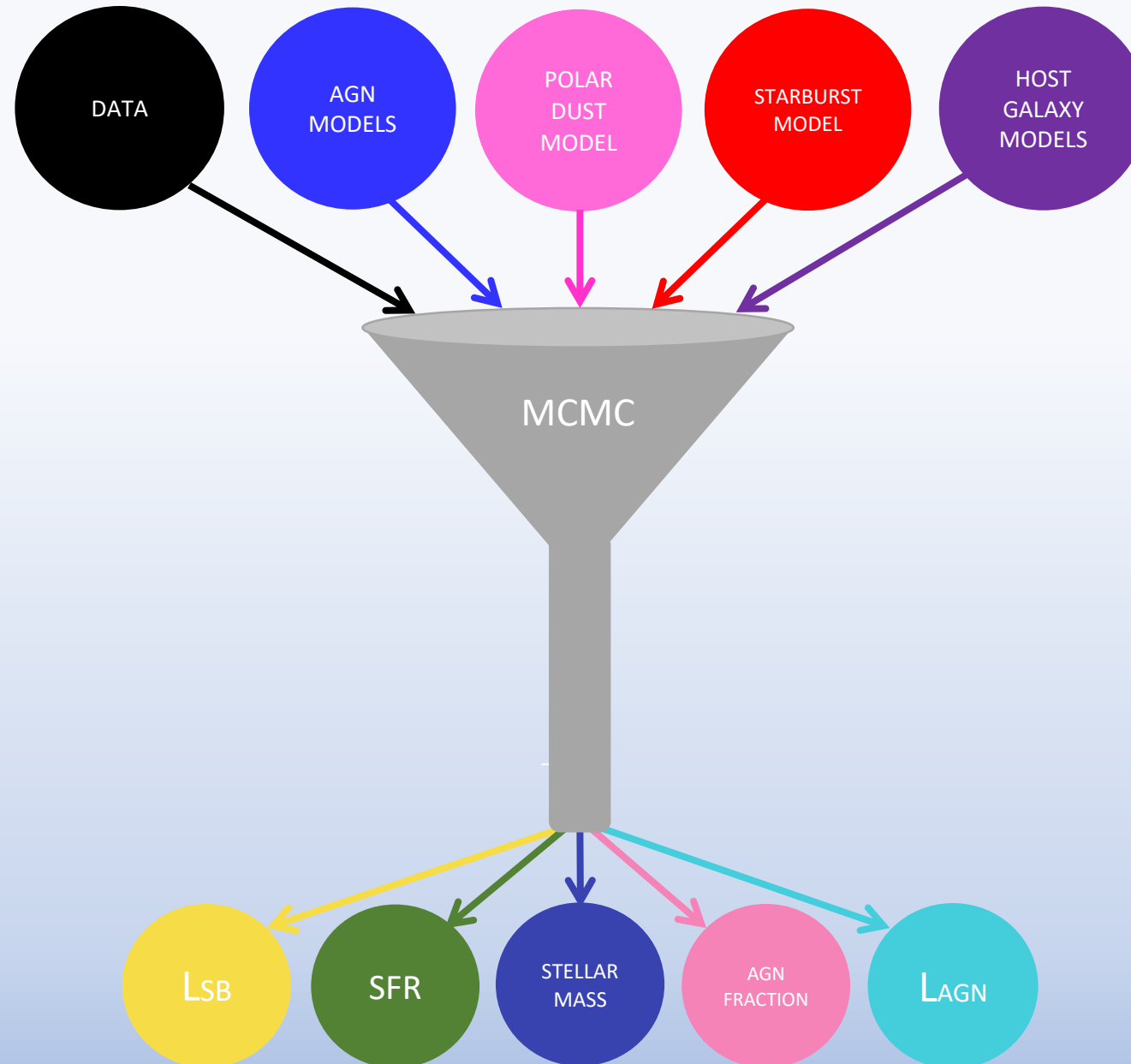(Efstathiou & Rowan-Robinson, 1995)
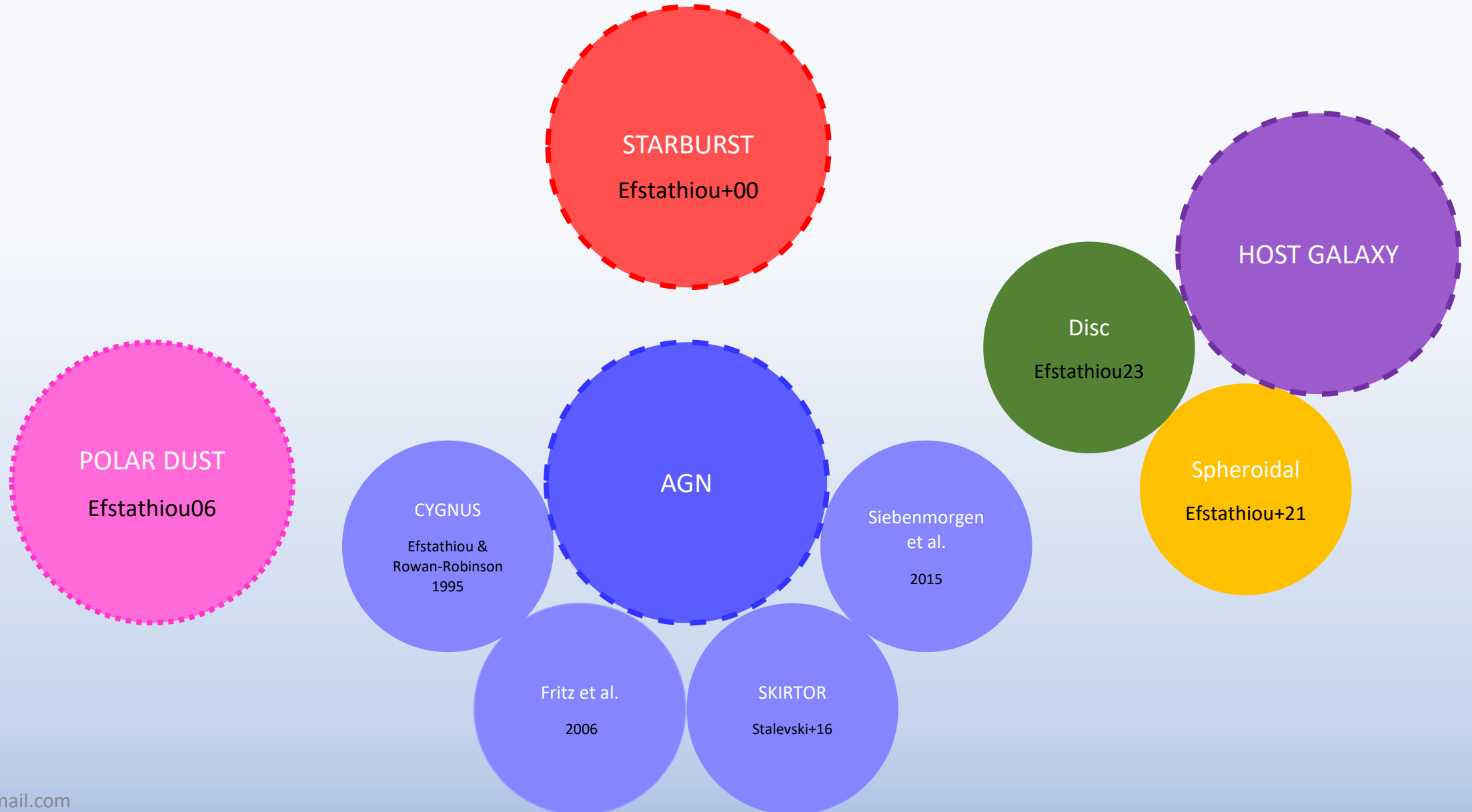

Fritz et al. (2006)

SKIRTOR
(Stalevski et al., 2016)


Siebenmorgen et al. (2015)

The SMART Method

Models used by SMART

STARBURST
Efstathiou+00

HOST GALAXY

Disc
Efstathiou23

POLAR DUST
Efstathiou06

AGN

CYGNUS
Efstathiou &
Rowan-Robinson
1995

Siebenmorgen
et al.
2015

Spheroidal
Efstathiou+21

Fritz et al.
2006

SKIRTOR
Stalevski+16

Comparison SED fit plots of the deeply obscured ultraluminous infrared galaxy (ULIRG) IRAS 08572+3915 (Efstathiou et al. 2014)
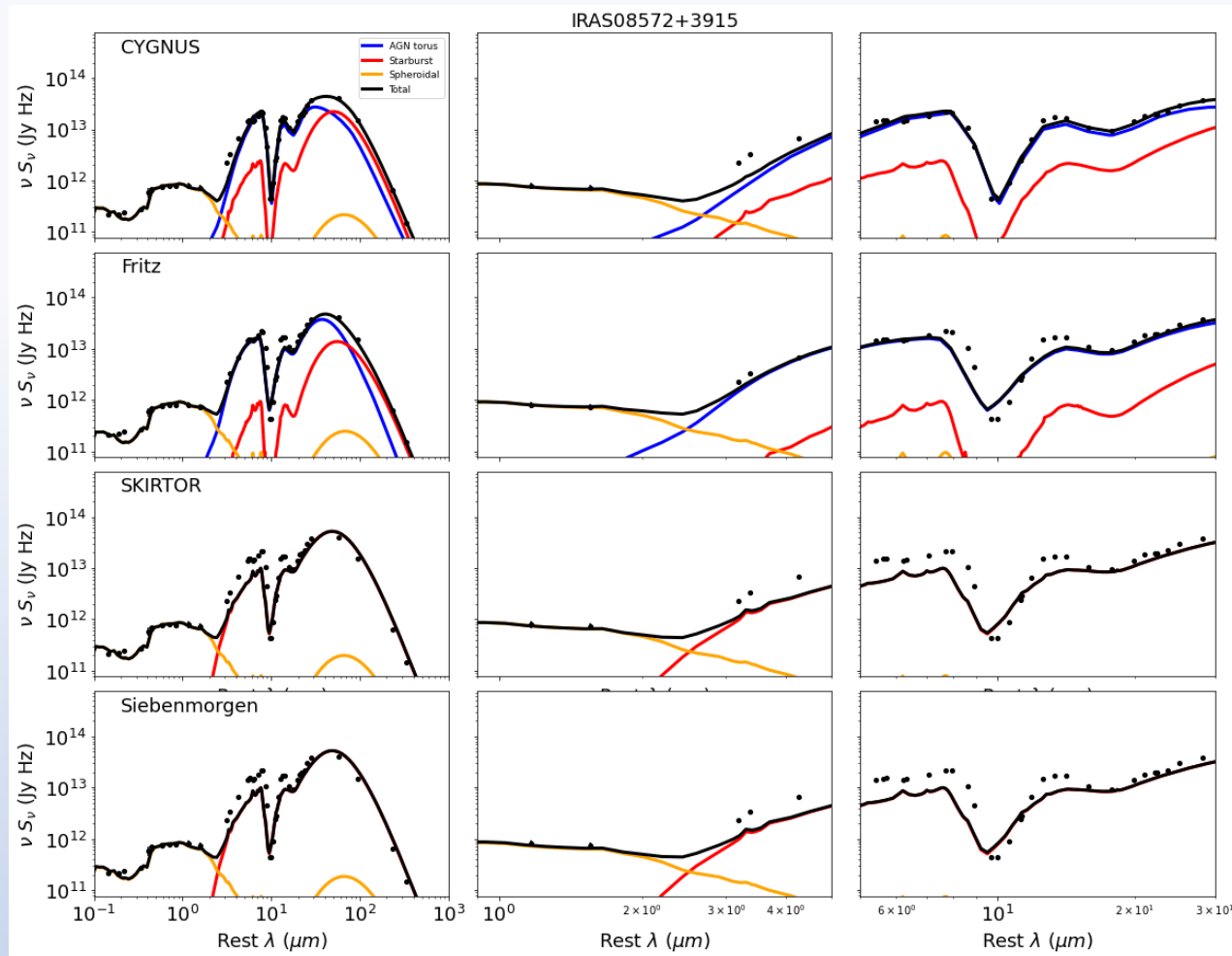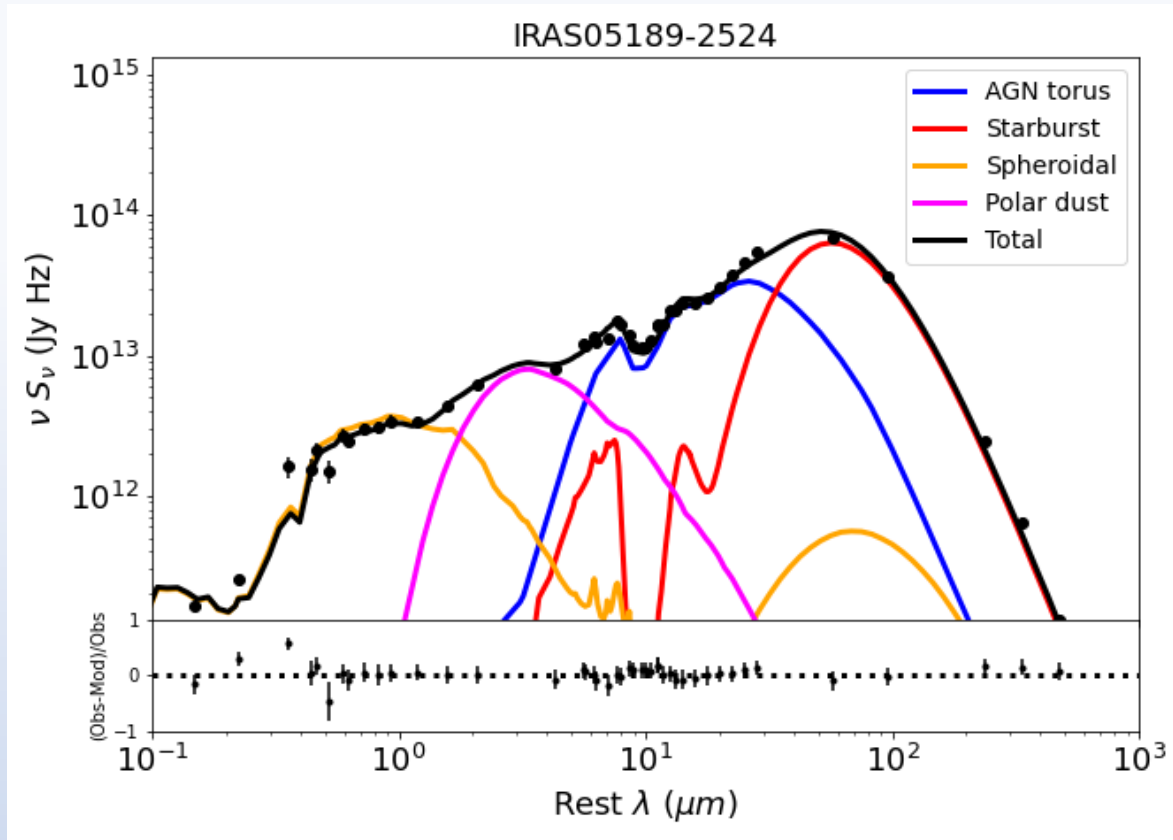

Comparison SED fit plots of IRAS 08572+3915: AGN torus (blue), starburst (red), spheroidal host (orange), total (black)
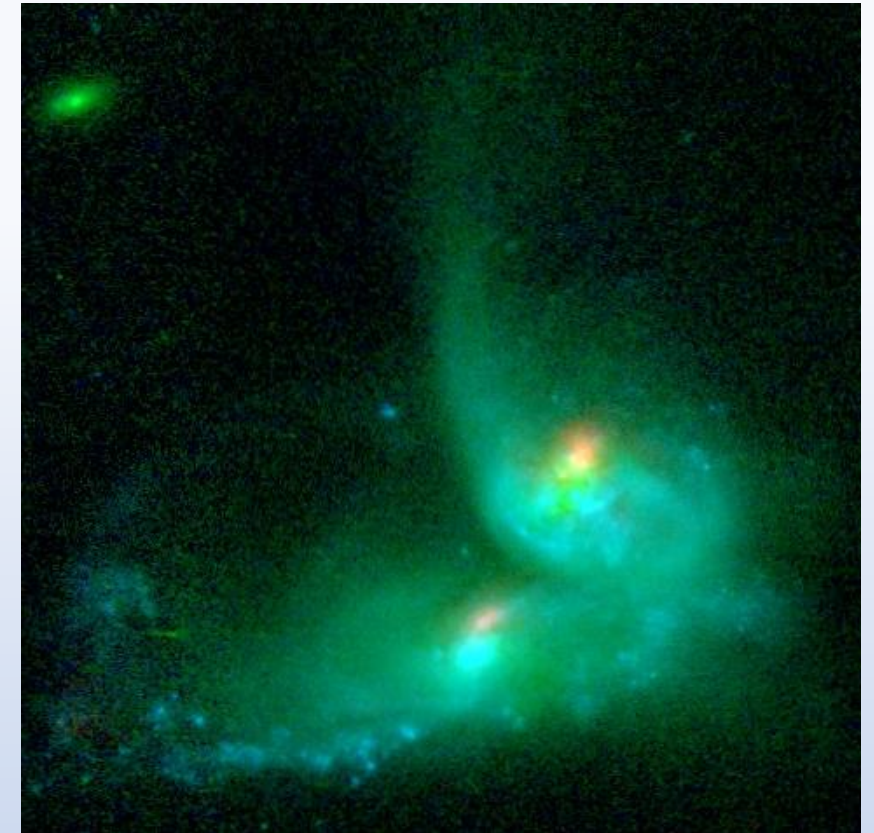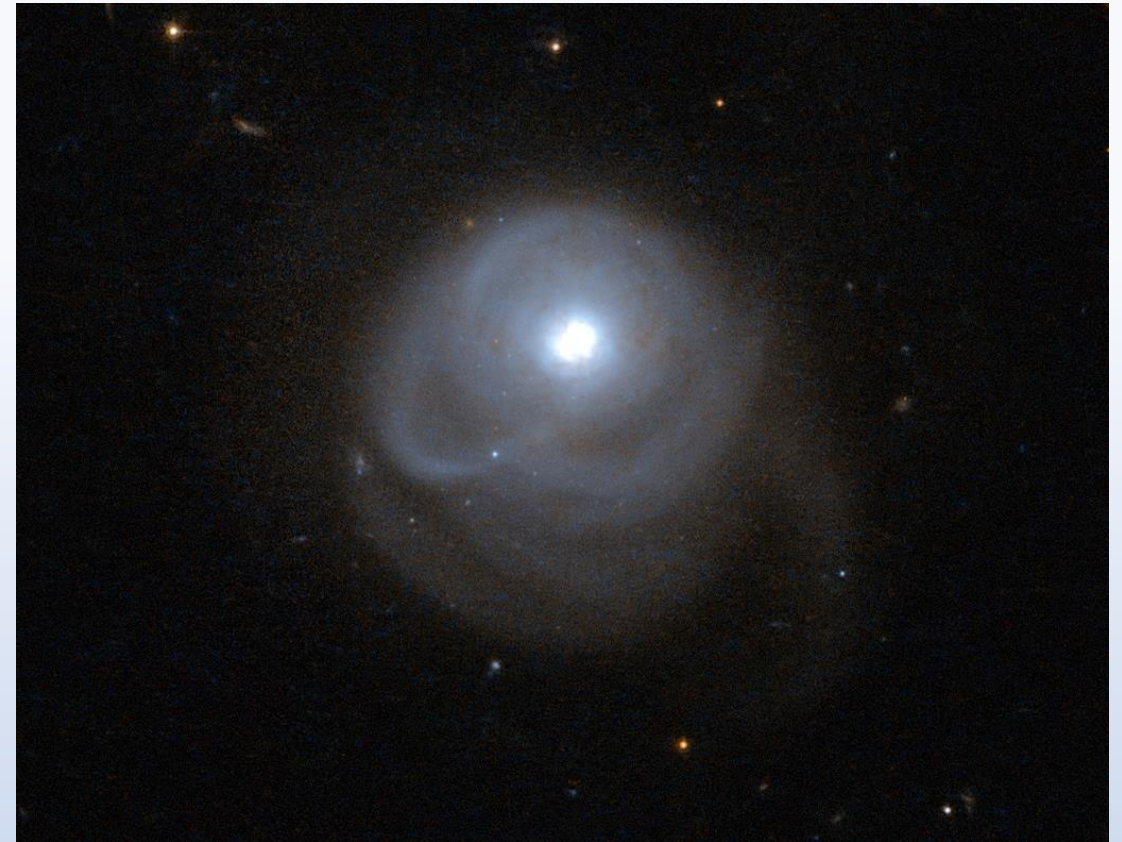
Optical Hubble Space Telescope image of IRAS 08572+3915

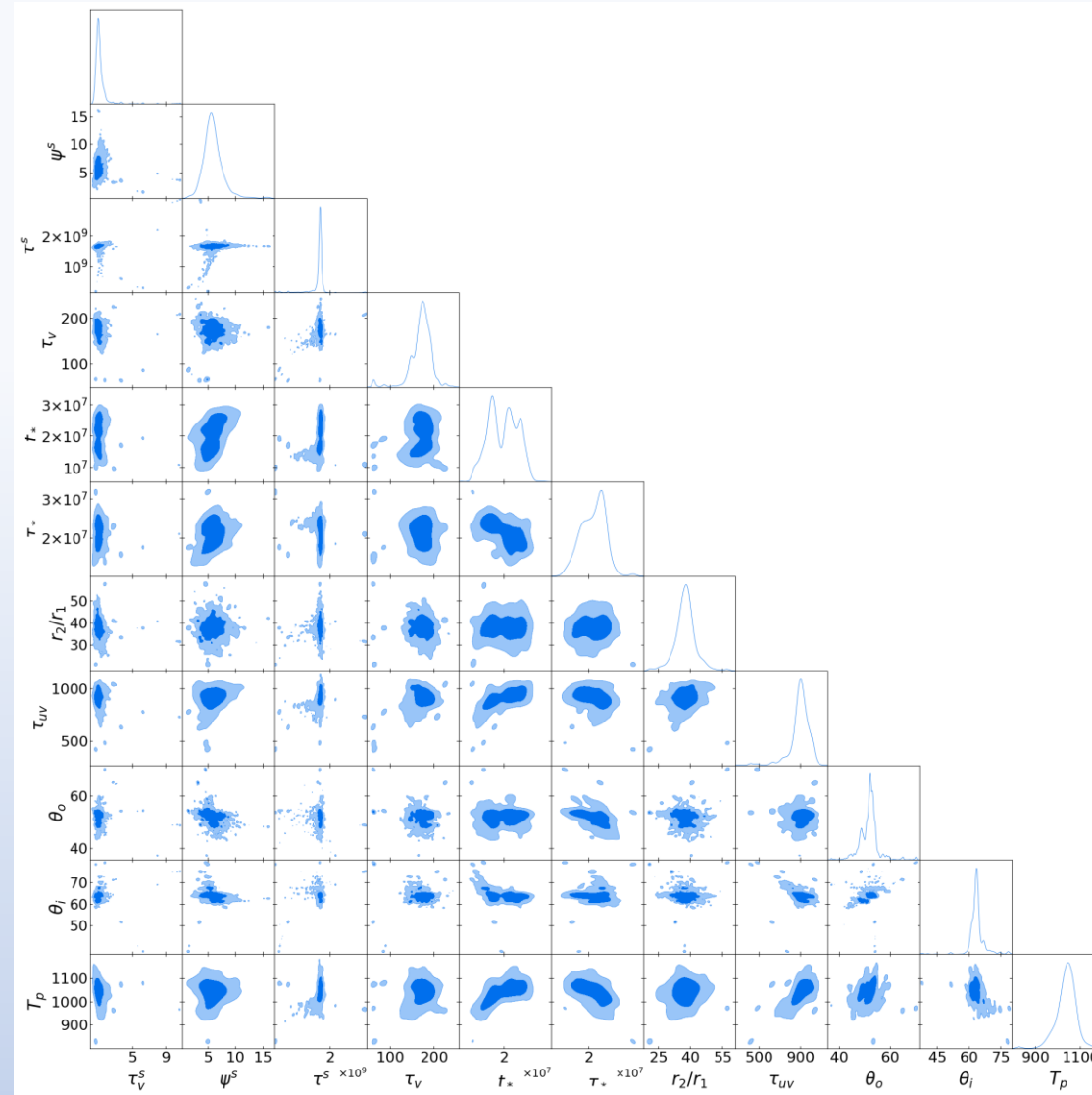# SED fit plot of a ULIRG associated with polar dust, IRAS 05189-2524

SED fit plot of IRAS 05189-2524: AGN torus (blue), starburst (red), spheroidal host (orange), polar dust (magenta), total (black)
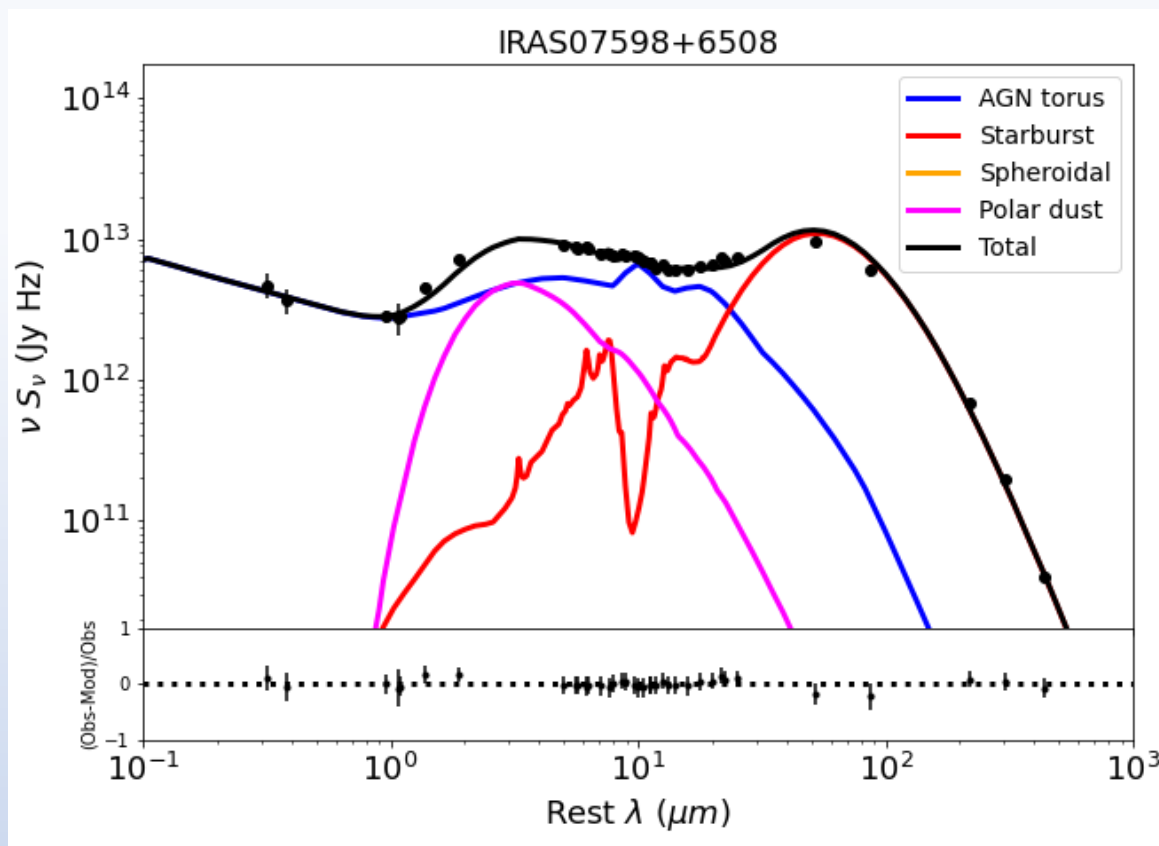

Optical Hubble Space Telescope image of IRAS 05189-2524
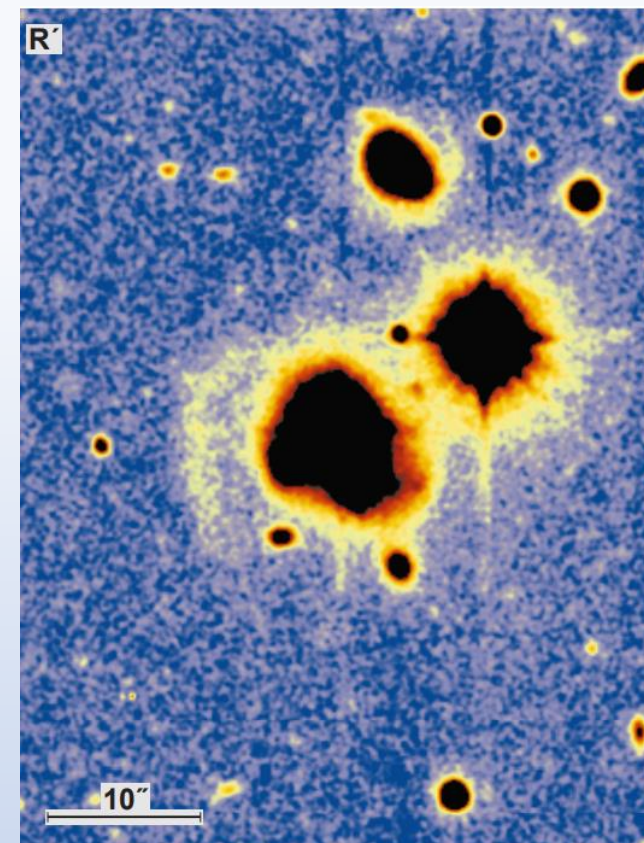
Corner plot of the galaxy IRAS 05189-2524

Corner plot of IRAS 05189-2524

SED fit plot of a ULIRG with an unobscured quasar and also associated with polar dust, IRAS 07598+6508
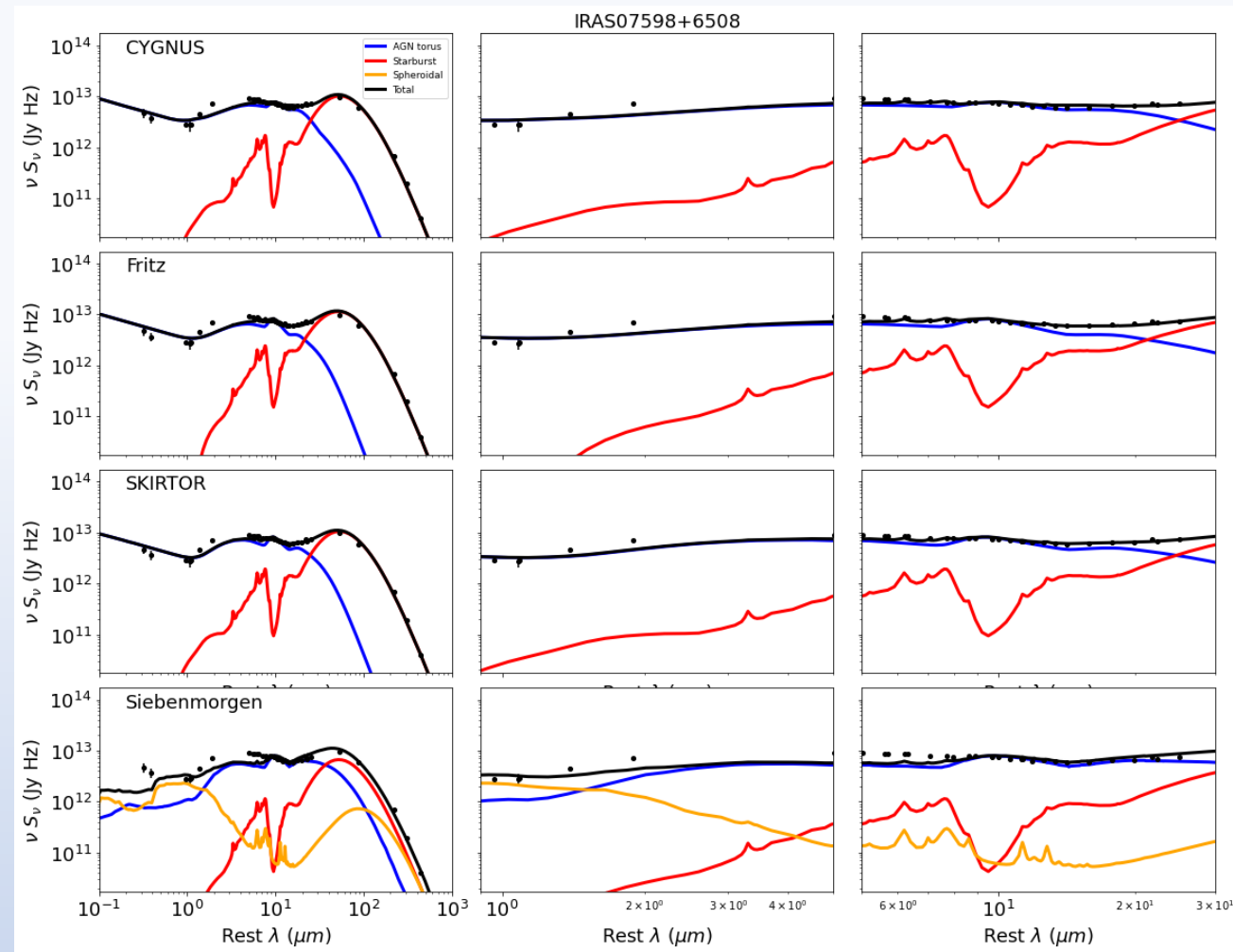

SED fit plot of IRAS 07598+6508: AGN torus (blue), starburst (red), spheroidal host (orange), polar dust (magenta), total (black)


R' image of IRAS 07598+6508 (Canalizo & Stockton 2000)

# Comparison SED fit plots of the galaxy IRAS 07598+6508 without using the polar dust component

Comparison SED fit plots of IRAS 07598+6508 without using the polar dust component: AGN torus (blue), starburst (red), spheroidal host (orange), total (black)

Examples of selected extracted physical quantities for the HERschel Ultraluminous Infrared Galaxy Survey (HERUS) sample, using the CYGNUS combination of models
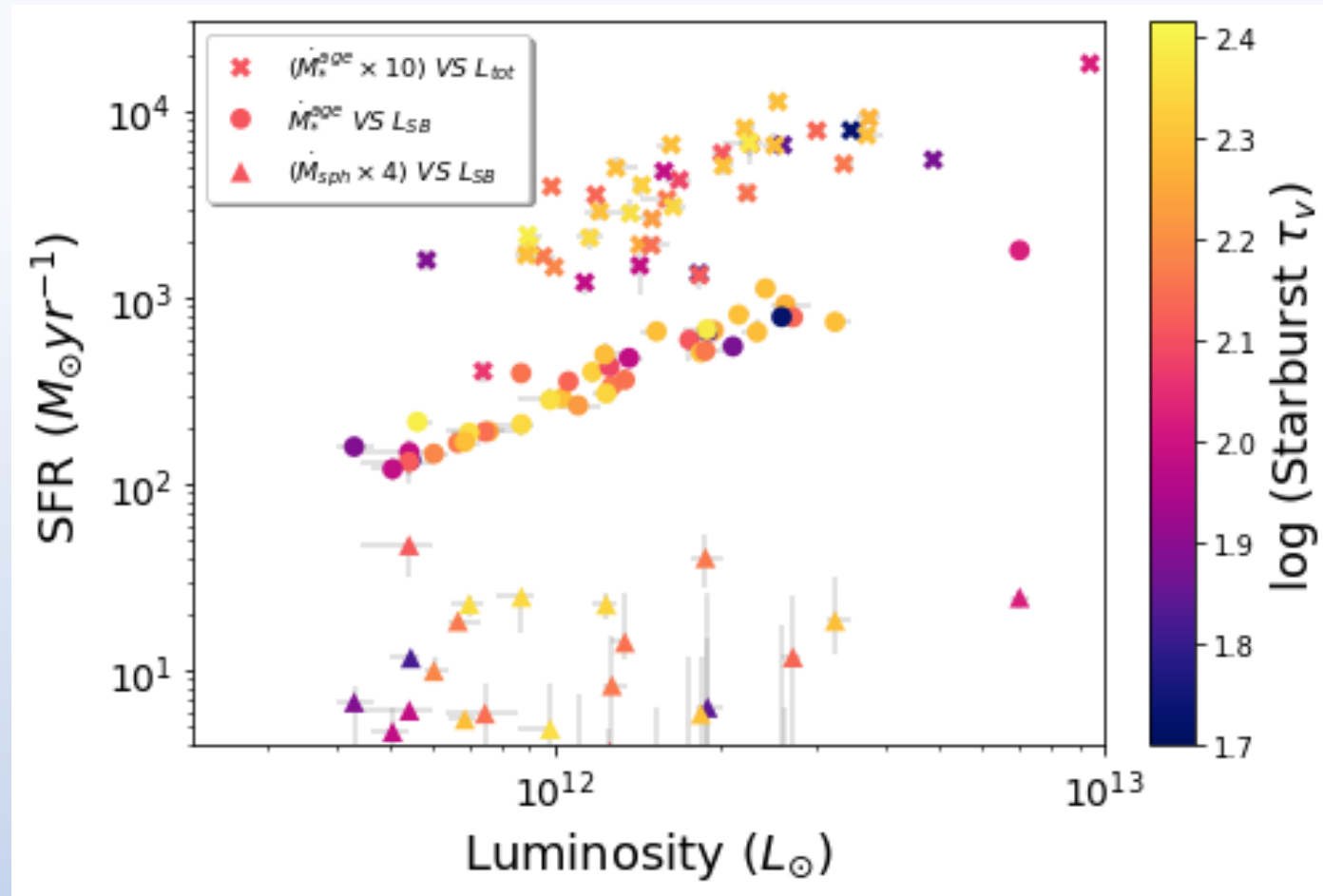
Star formation rate (SFR) against infrared (IR) luminosities (starburst or total)

Examples of selected extracted physical quantities for the HERUS sample, using the CYGNUS combination of models
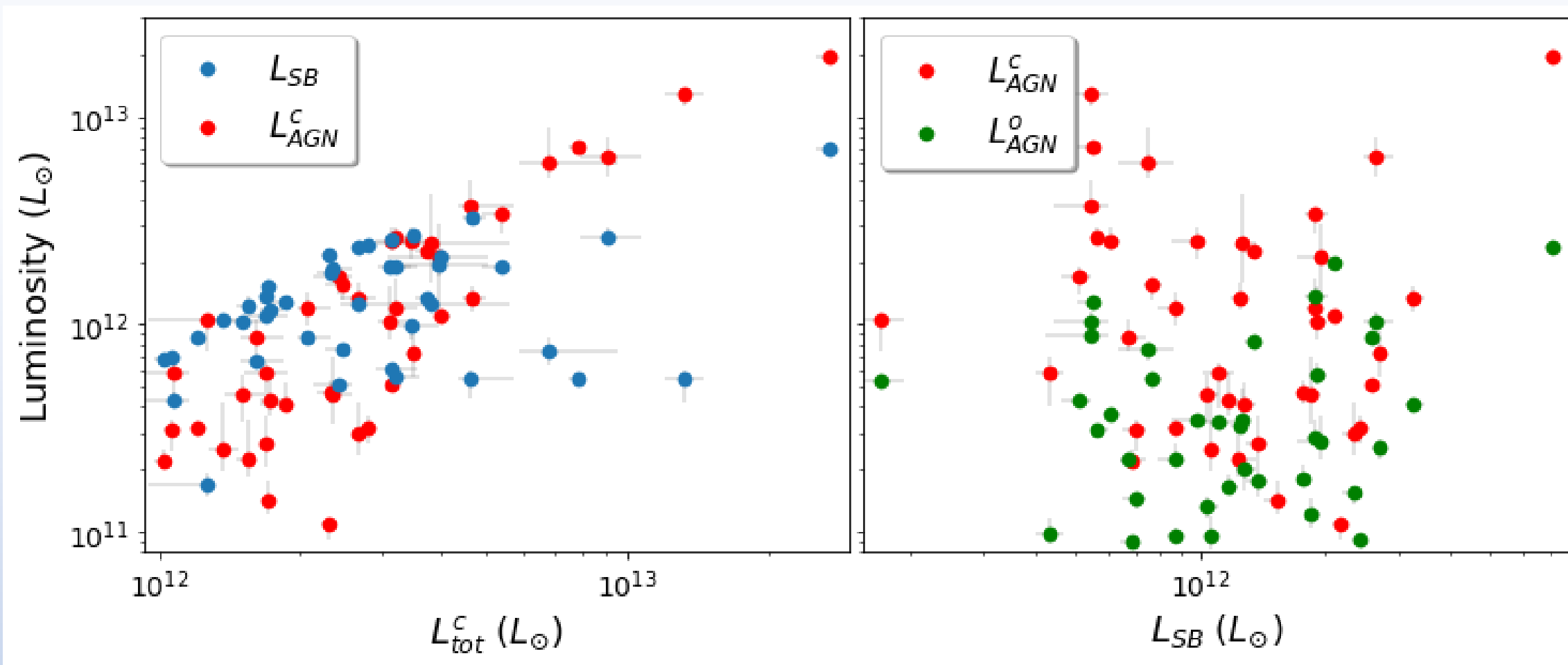
Left: Starburst and anisotropy-corrected AGN luminosity against total corrected IR luminosity
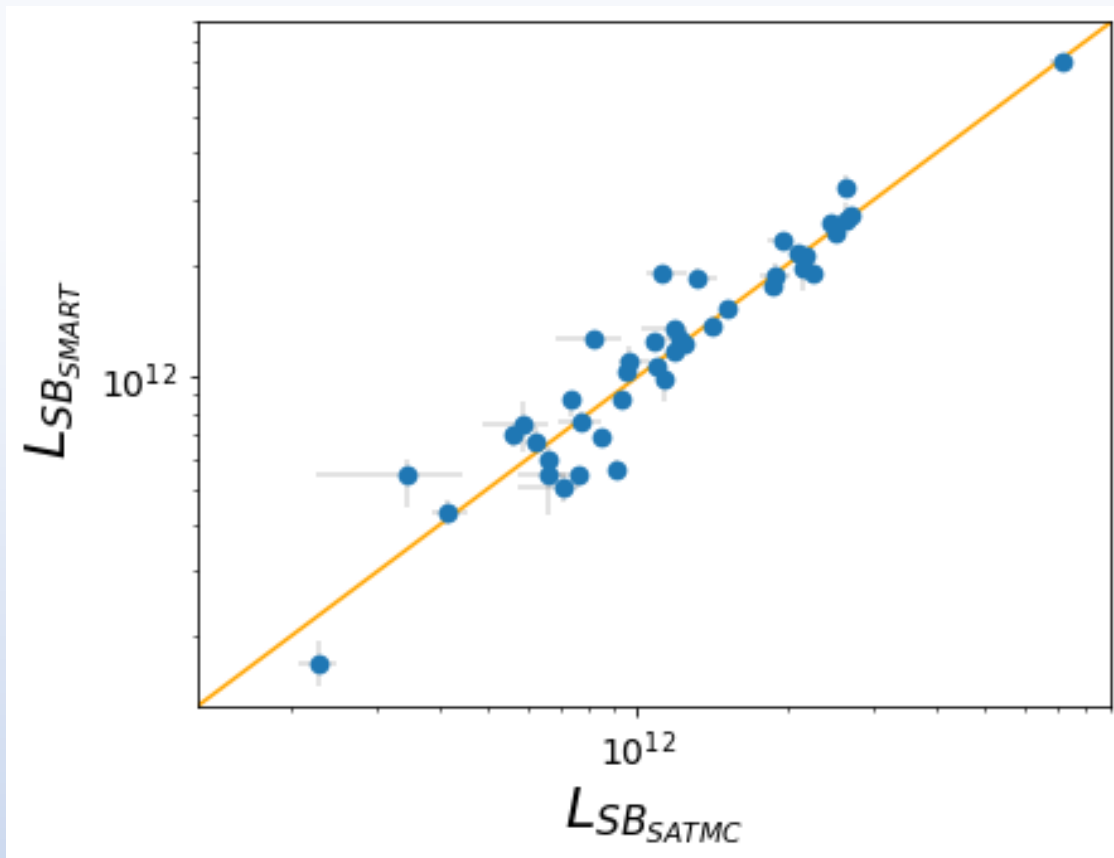
Right: Observed and anisotropy-corrected AGN luminosity against starburst luminosity

Examples of selected extracted physical quantities for the HERUS sample, using the CYGNUS combination of models
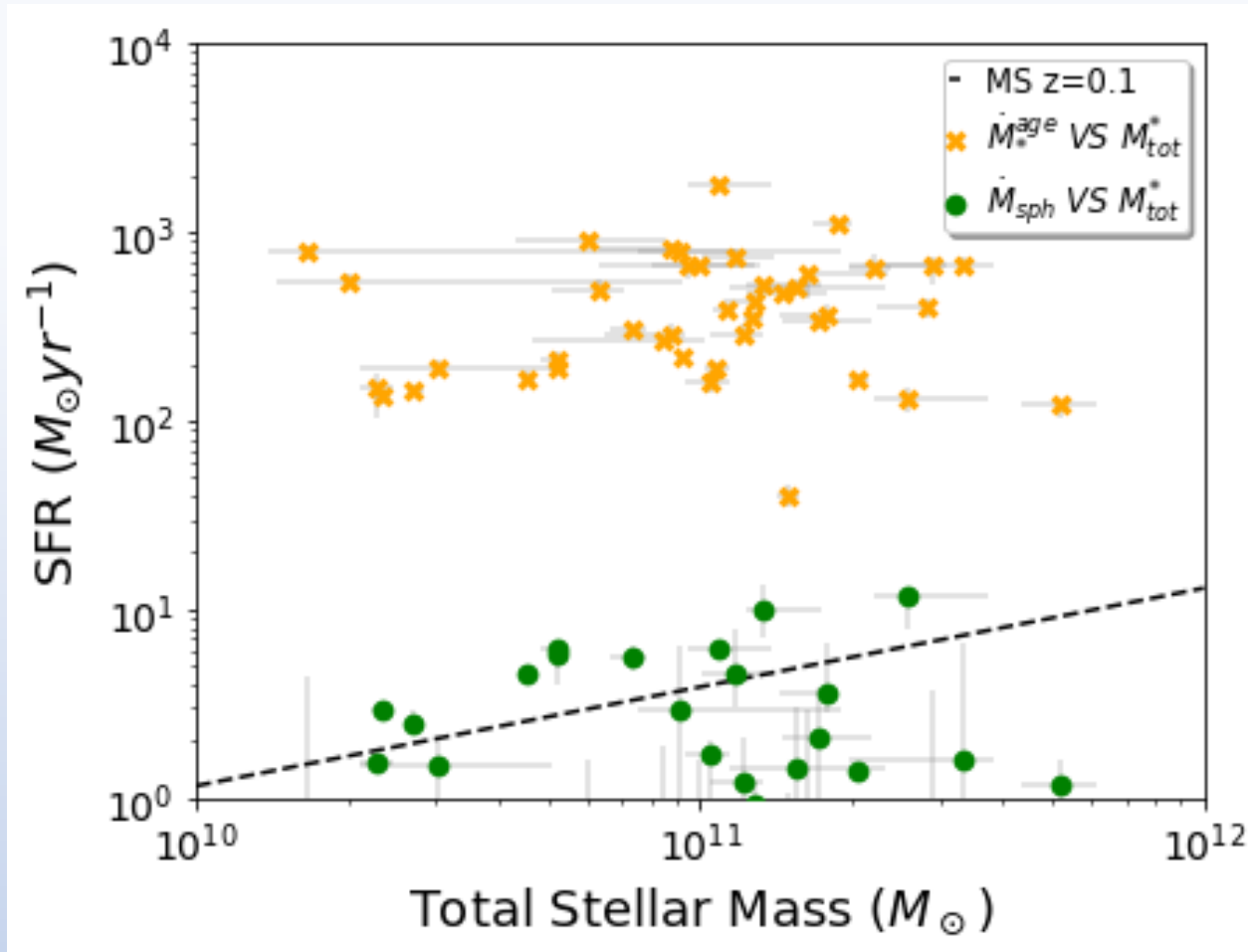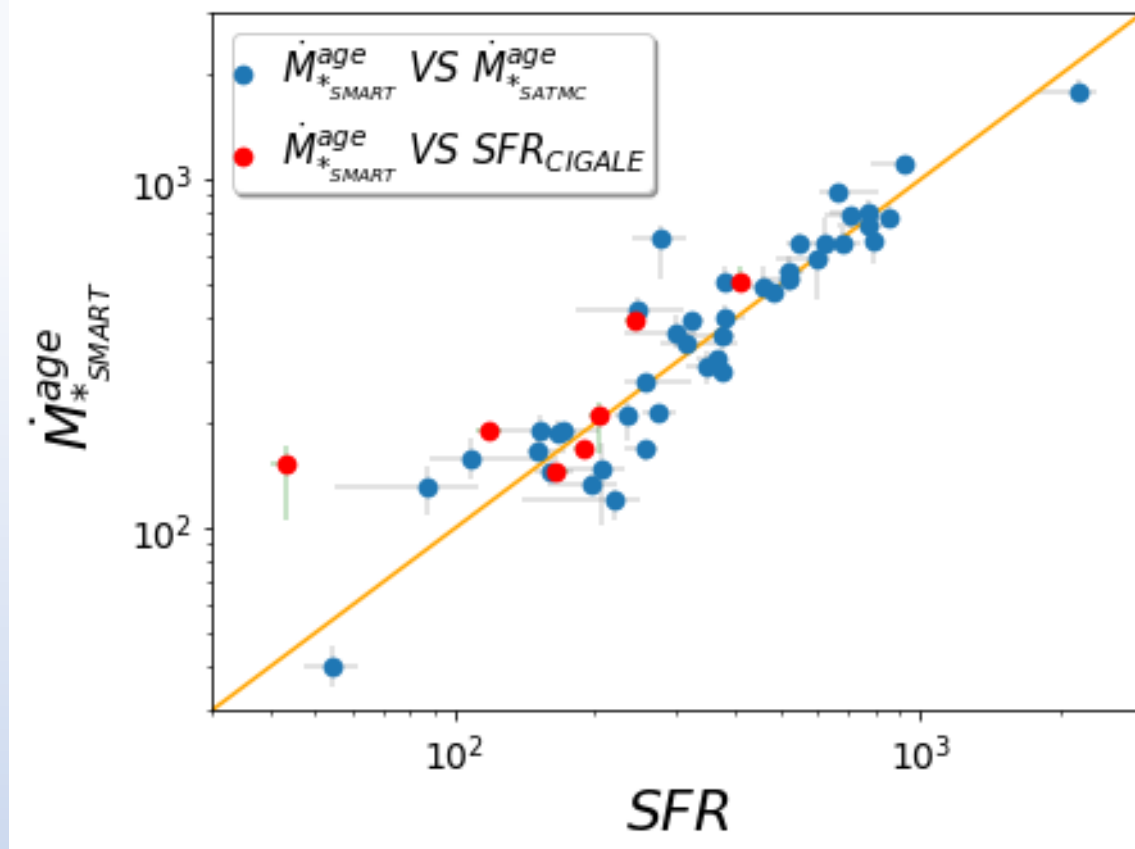

Starburst or host SFR against total stellar mass

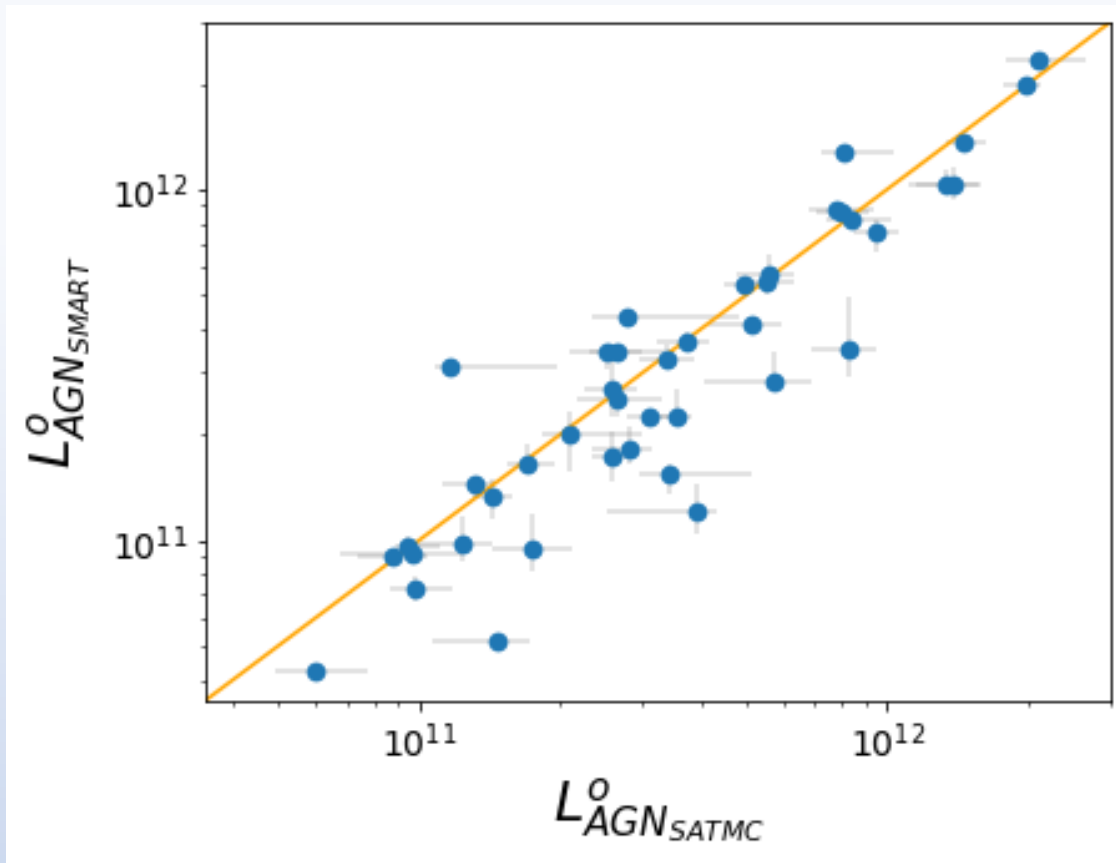# Comparison with results from other approaches for the HERUS sample

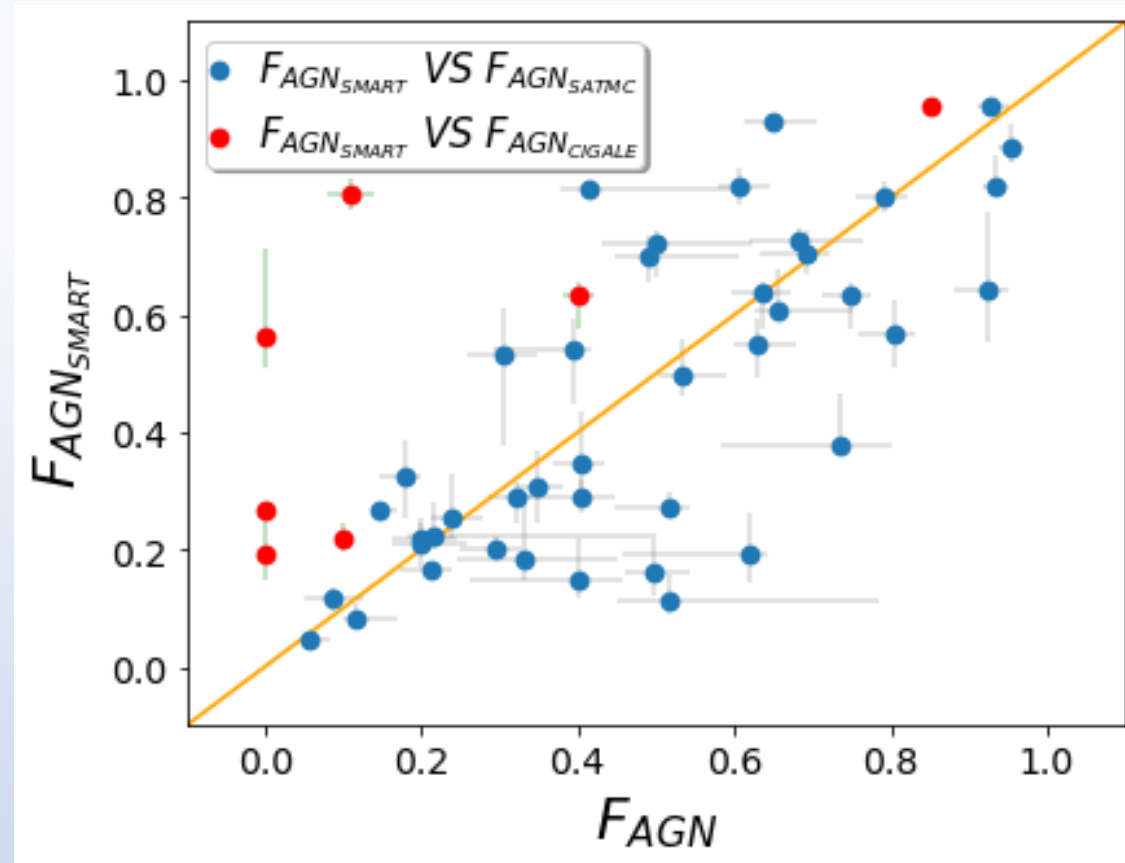Plot of the starburst luminosity extracted by **SMART** against the same quantity extracted by SATMC

Plot of the starburst SFR extracted by **SMART** against the same quantity extracted by SATMC and CIGALE

Comparison with results from other approaches for the HERUS sample
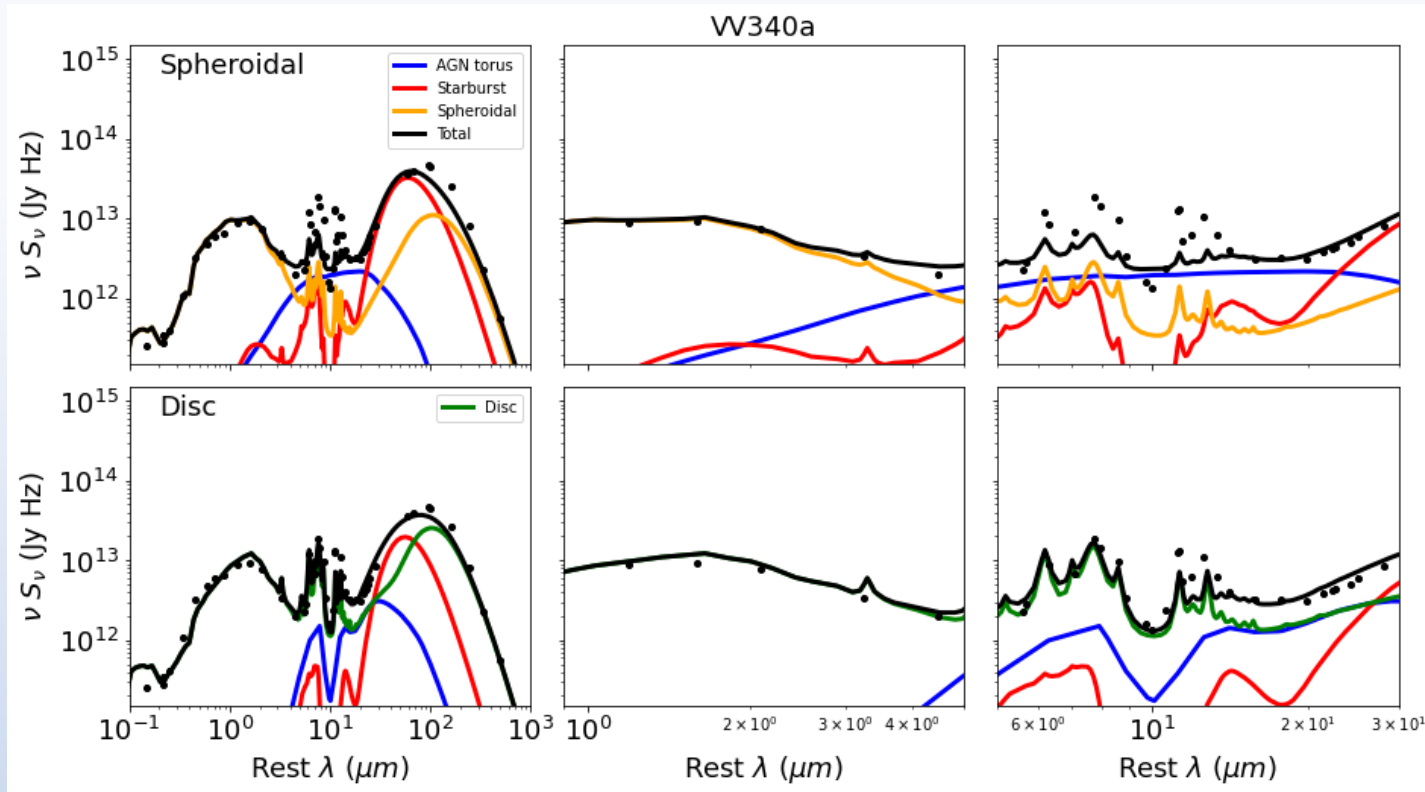

Plot of the observed AGN torus luminosity extracted by **SMART** against the same quantity extracted by SATMC

Plot of the AGN fraction extracted by **SMART** against the same quantity extracted by SATMC and CIGALE

Comparison of the two different host galaxy models used by SMART for a luminous infrared galaxy associated with a spiral galaxy


*Comparison SED fit plots of the galaxy VV 340a that **SMART** predicts it has a spiral morphology: AGN torus (blue), starburst (red), spheroidal host (orange), disc host (green), total (black)*

Composite image of X-ray data from Chandra (purple) and optical data from Hubble Space Telescope (red, green, blue) of VV 340

Comparison SED fit plots of the hyperluminous obscured quasar HELP_J100156.75+022344.7 at z~4.3 (Efstathiou et al. 2021)
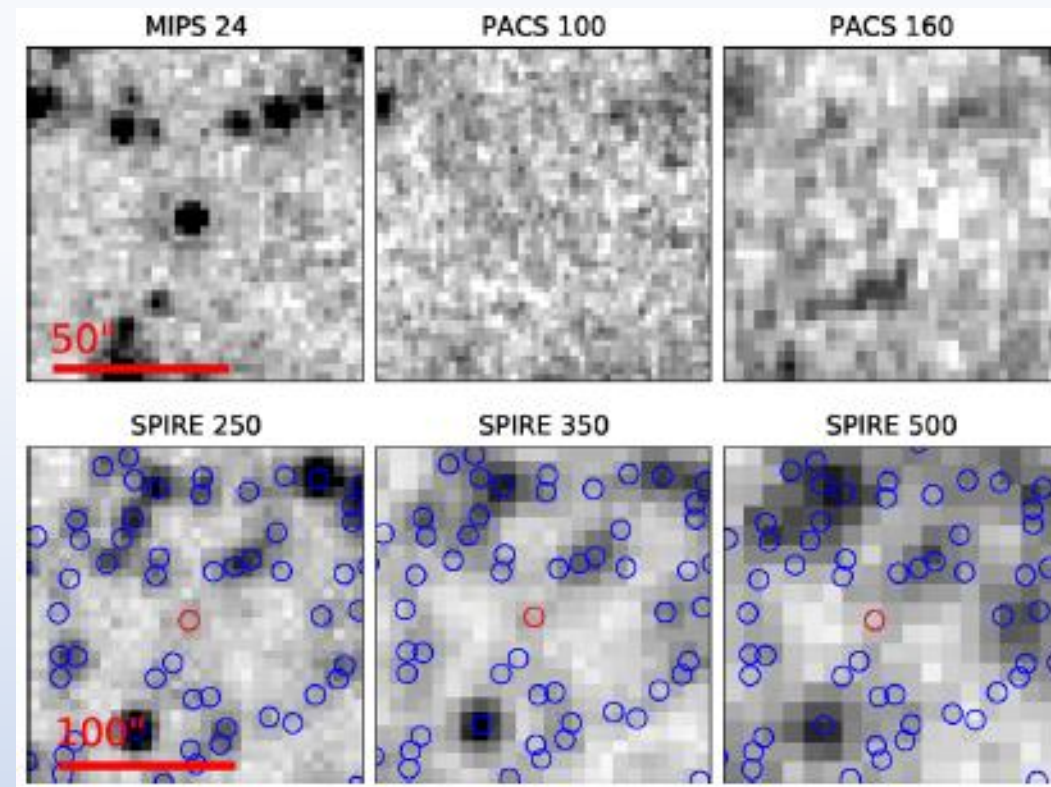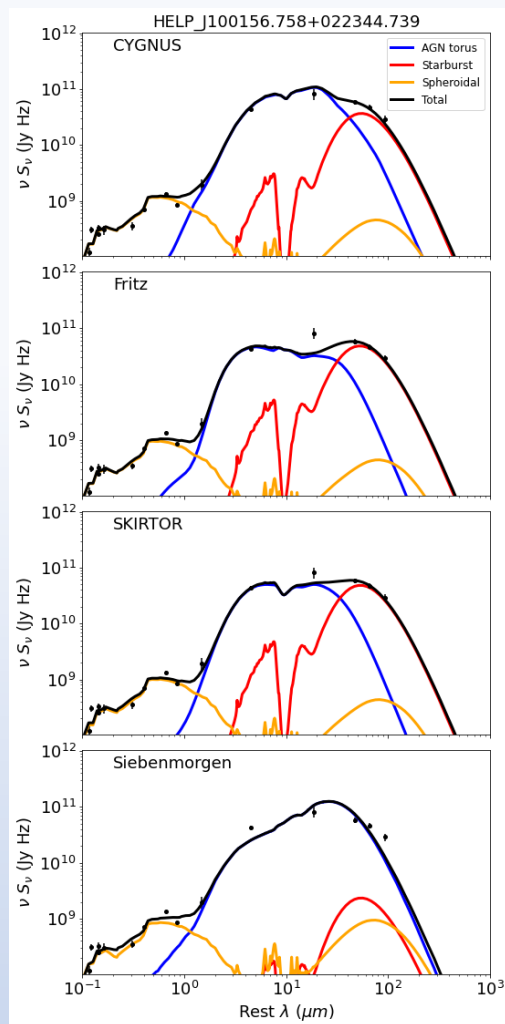

Postage stamps in various filters (Efstathiou et al. 2021)

Comparison SED fit plots of HELP_J100156.75+022344.7: AGN torus (blue), starburst (red), spheroidal host (orange), total (black)

Conclusions

- Developed a new fast MCMC SED fitting code, which uses *exclusively* radiative transfer models

- Takes comparable time to energy balance codes like CIGALE and MAGPHYS

- Tested with a range of obscured AGN in the redshift range ~0-7

- As **SMART** can fit with four different AGN torus models, it allows us to constrain the properties of the obscuring torus in AGN and quantify the uncertainties in AGN fraction and SFR

- Promises to be very useful for understanding galaxies and AGN at any redshift in the *JWST* era, as well as galaxy formation and evolution in general
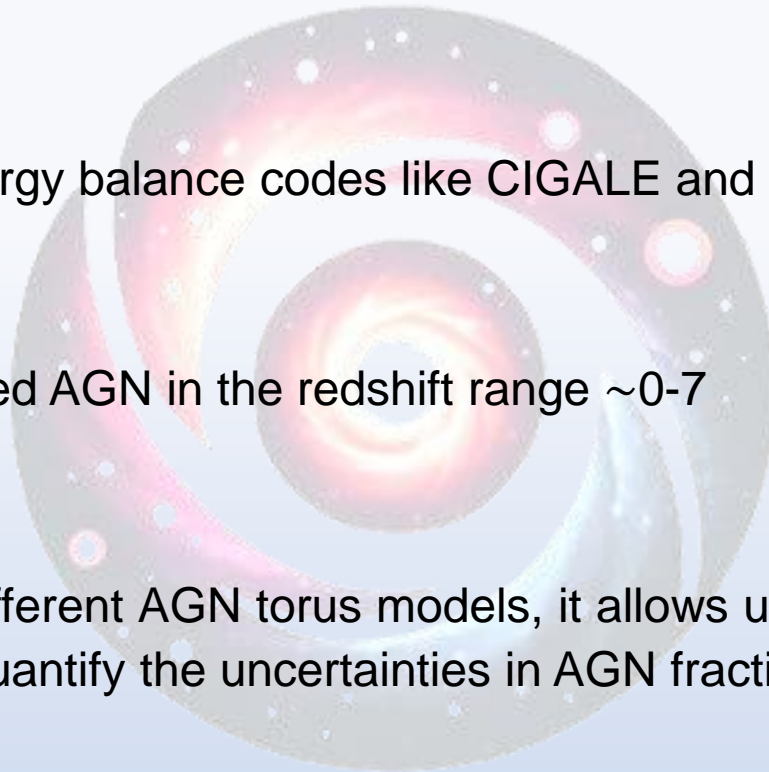
List of Publications

- Varnava C. & Efstathiou A., 2024. SMART: Spectral energy distributions Markov chain Analysis with Radiative Transfer models, MNRAS, 531(2), pp. 2304–2329

- Varnava C. & Efstathiou A., 2024. Exploring the properties of the obscured quasar COS-87259 at z=6.853, MNRAS: Letters, in preparation

- Varnava C. & Efstathiou A., 2024. Constraints on the starburst and active galactic nucleus activity of local ultraluminous infrared galaxies from a broad range of torus models, MNRAS, in preparation

- Efstathiou A., Lonsdale C. J. and Varnava C., 2024. Constraints on the starburst and active galactic nucleus activity of heavily obscured quasars at redshifts z~0.3–3. MNRAS, in preparation

SMART

can be found at:

https://doi.org/10.1093/mnras/stae1141
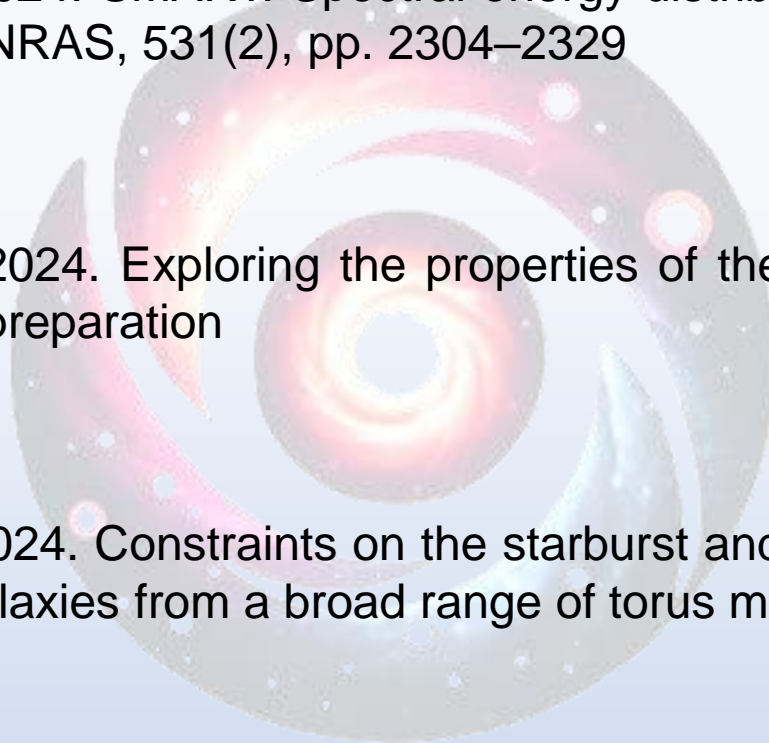
The code is available at:

https://github.com/ch-var/SMART

Thank you!

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