

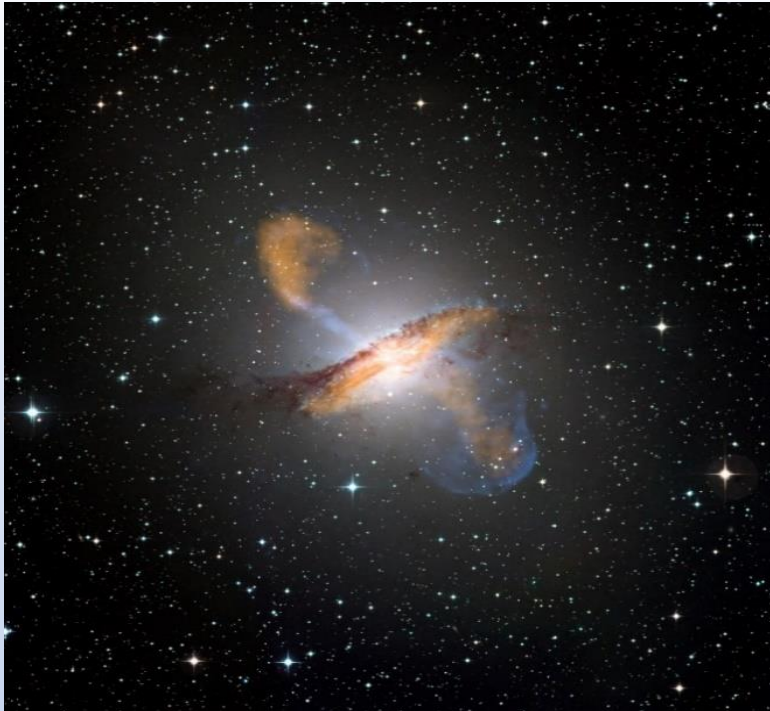


# SMART

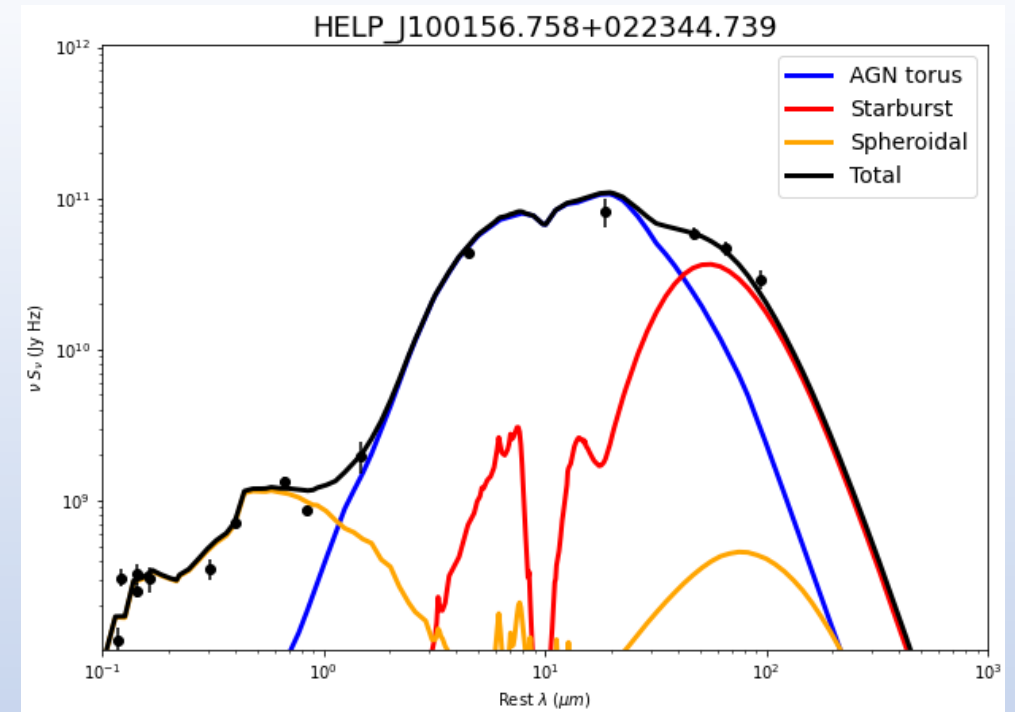
Charalambia Varnava

# 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  $z \sim 4.3$  (Varnava & Efstathiou, 2024)



# 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)



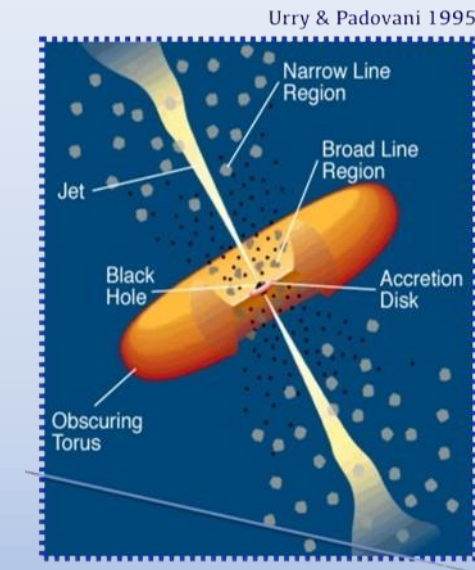
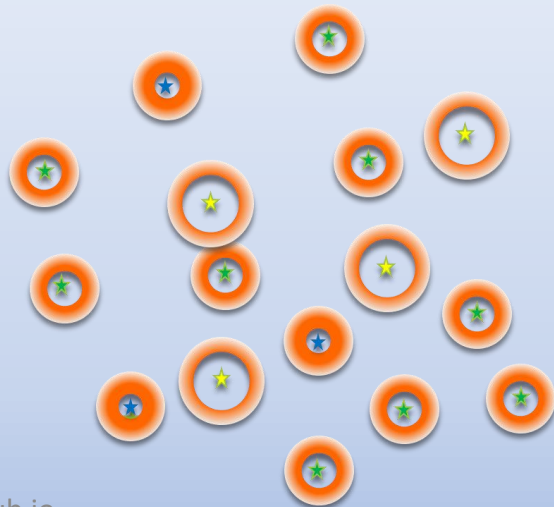
*JWST*  
(optical to MIR)

# 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





# Description of SMART

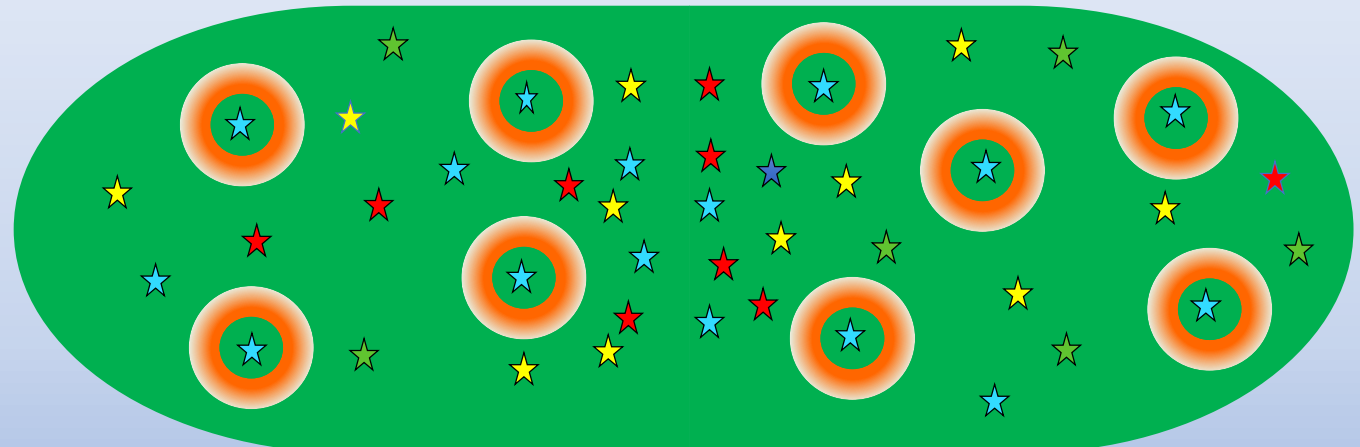
- AGN polar dust (Efstathiou et al., 1995)
  - independent of redshift
  - optionally incorporated in **SMART**



- Spheroidal (Efstathiou et al., 2021)
  - dependent on redshift

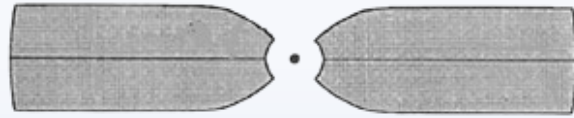


- Disc (Efstathiou et al., in preparation)
  - dependent on redshift

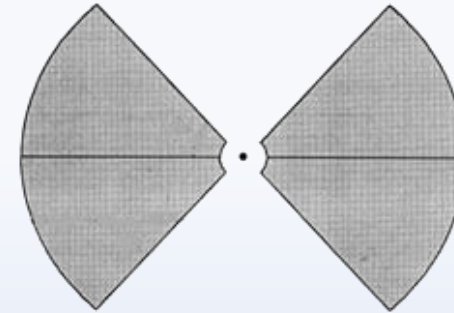


# Description of SMART

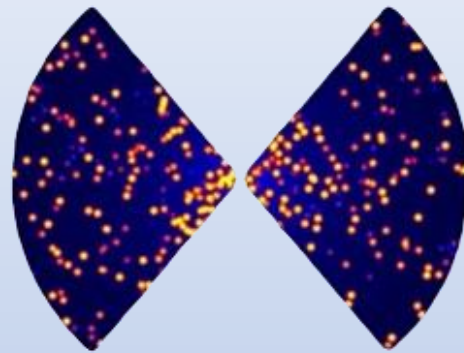
- Allows us to explore the impact of four different AGN torus models and therefore constrain the properties of the obscuring torus:



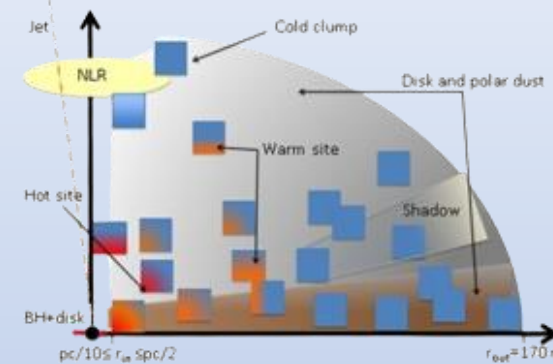
CYGNUS  
(Efstathiou & Rowan-Robinson, 1995)



Fritz et al. (2006)

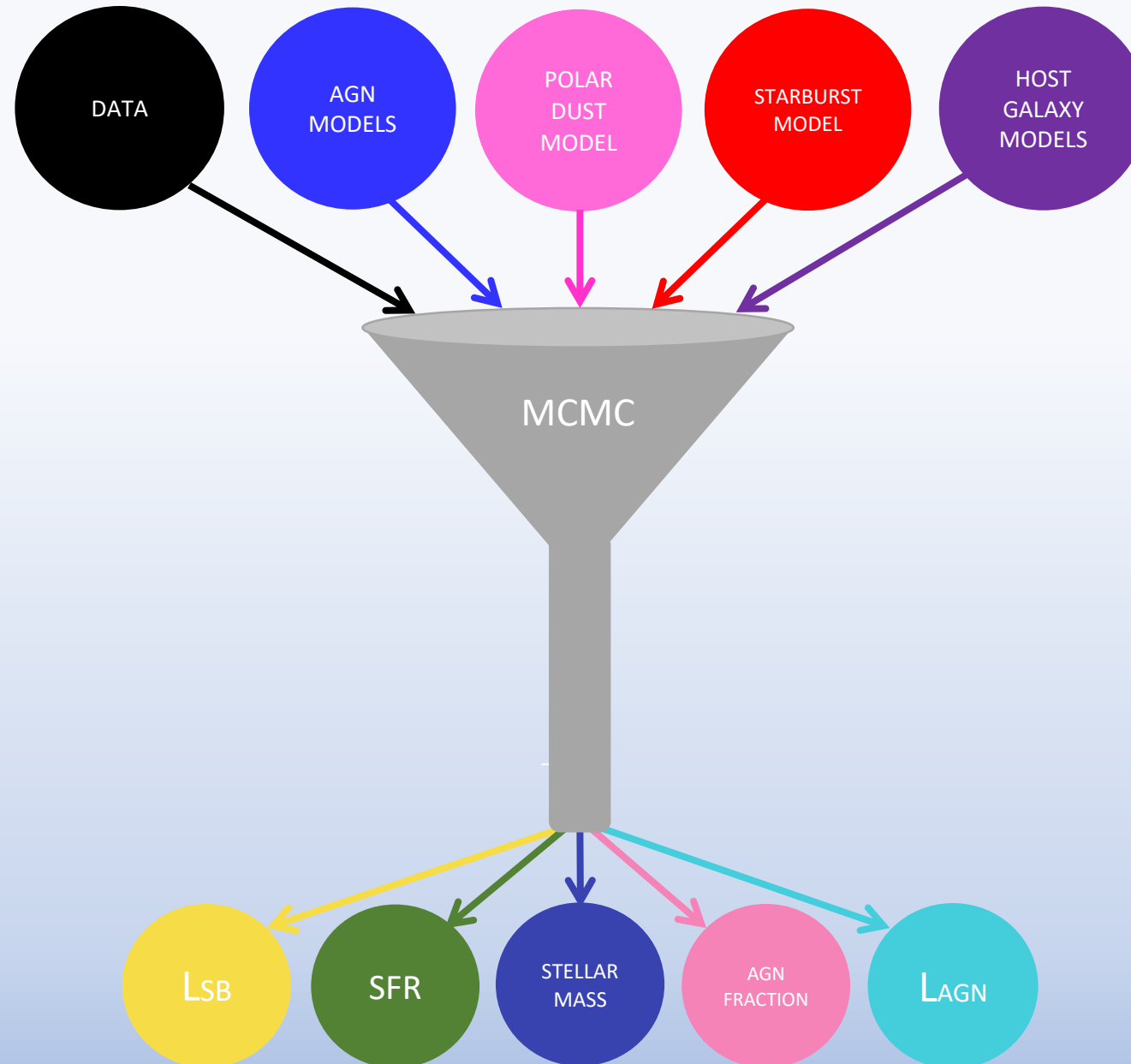


SKIRTOR  
(Stalevski et al., 2016)



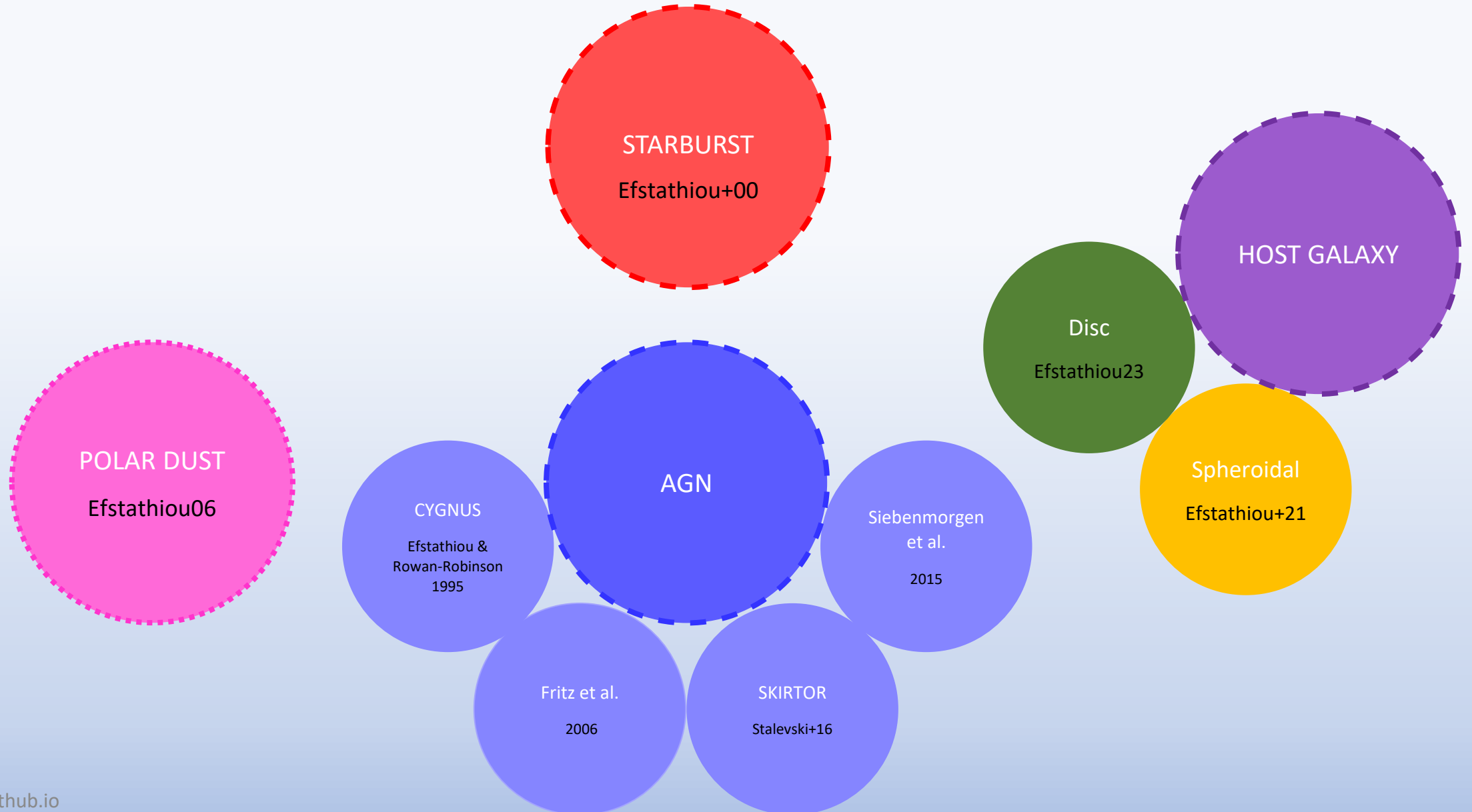
Siebenmorgen et al. (2015)

# The SMART Method

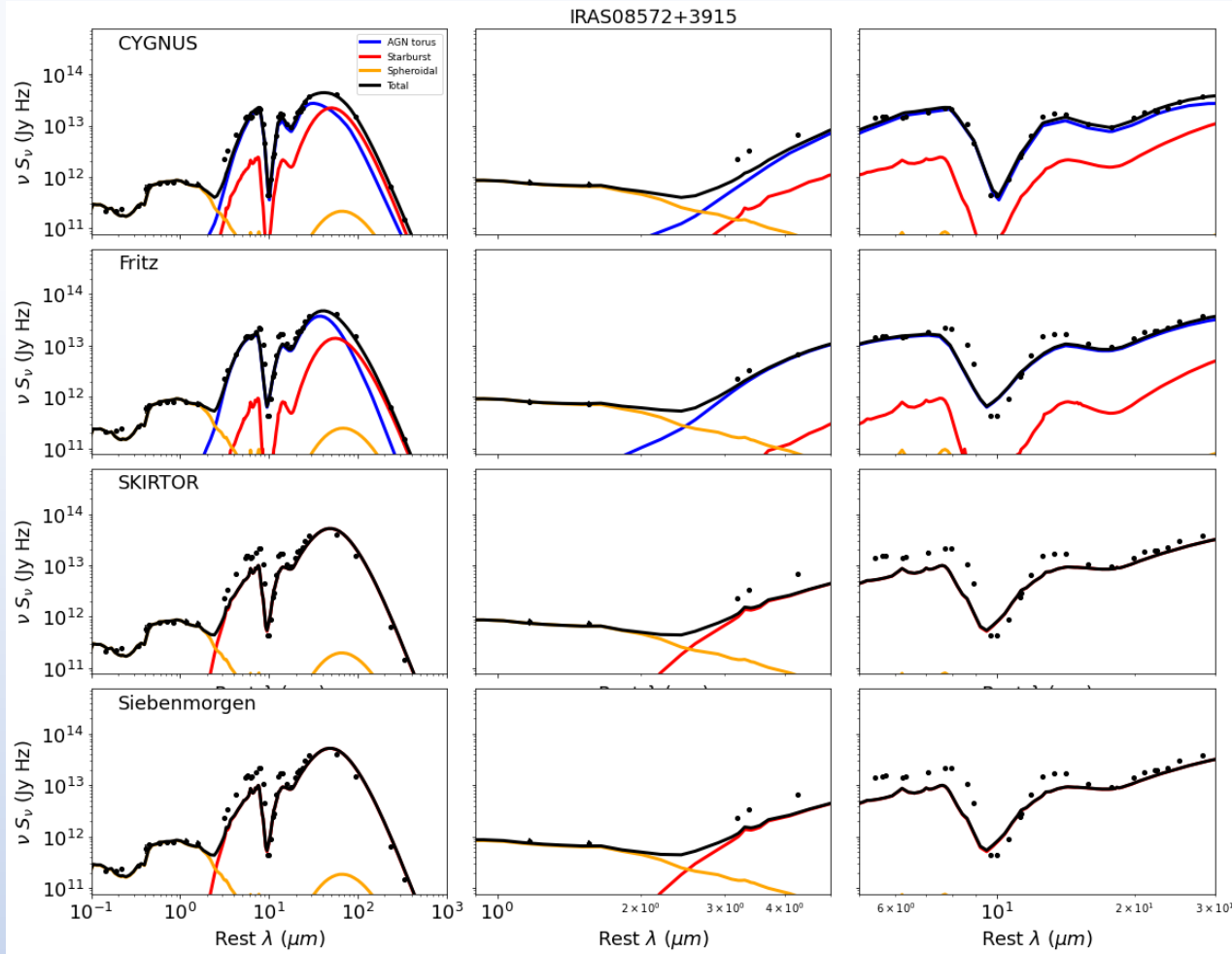




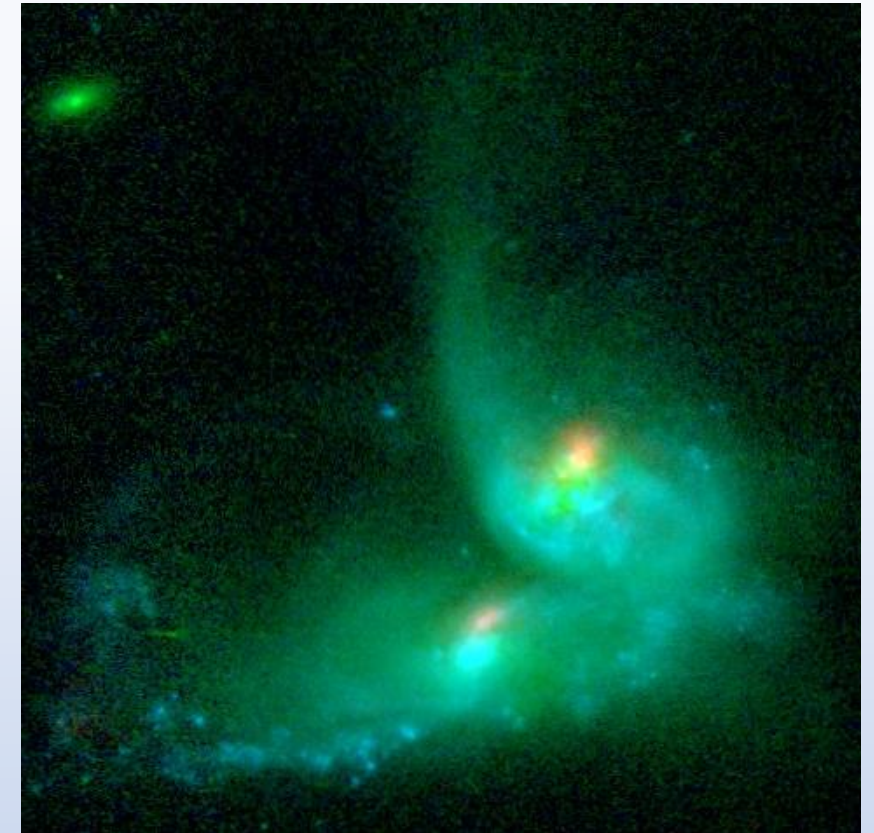
# Models used by SMART



# Comparison SED fit plots of the deeply obscured ultraluminous infrared galaxy (ULIRG) IRAS 08572+3915 (Varnava & Efsthathiou, 2024)

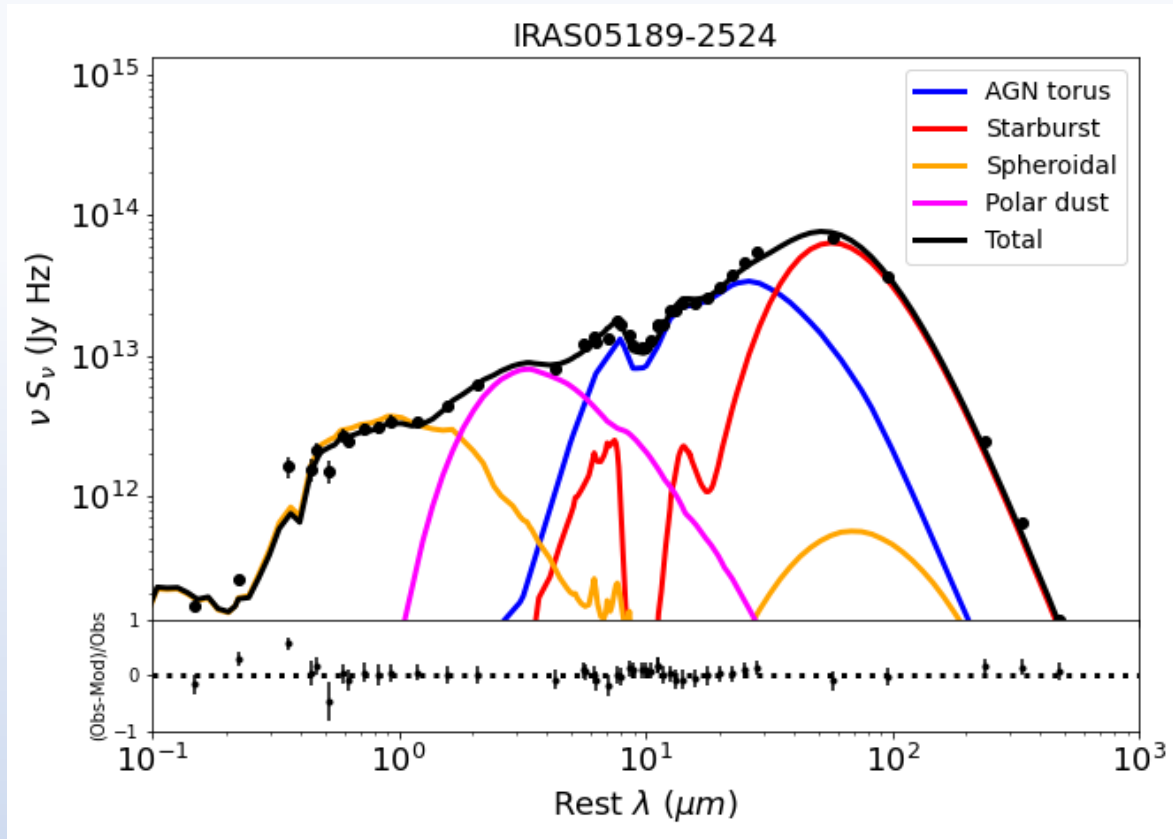


Comparison SED fit plots of IRAS 08572+3915: AGN torus (blue), starburst (red), spheroidal host (orange), total (black)

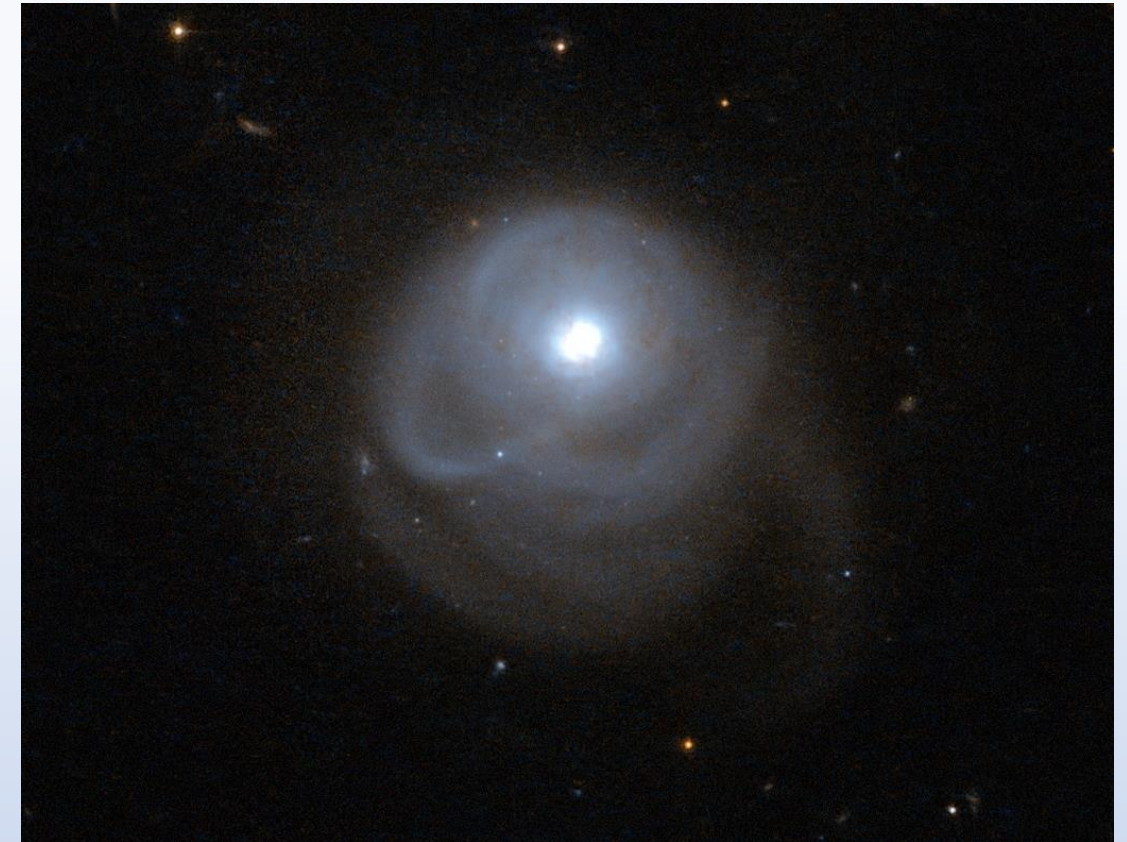


Optical Hubble Space Telescope image of IRAS 08572+3915

# SED fit plot of a ULIRG associated with polar dust, IRAS 05189-2524 (Varnava & Efsthathiou, 2024)

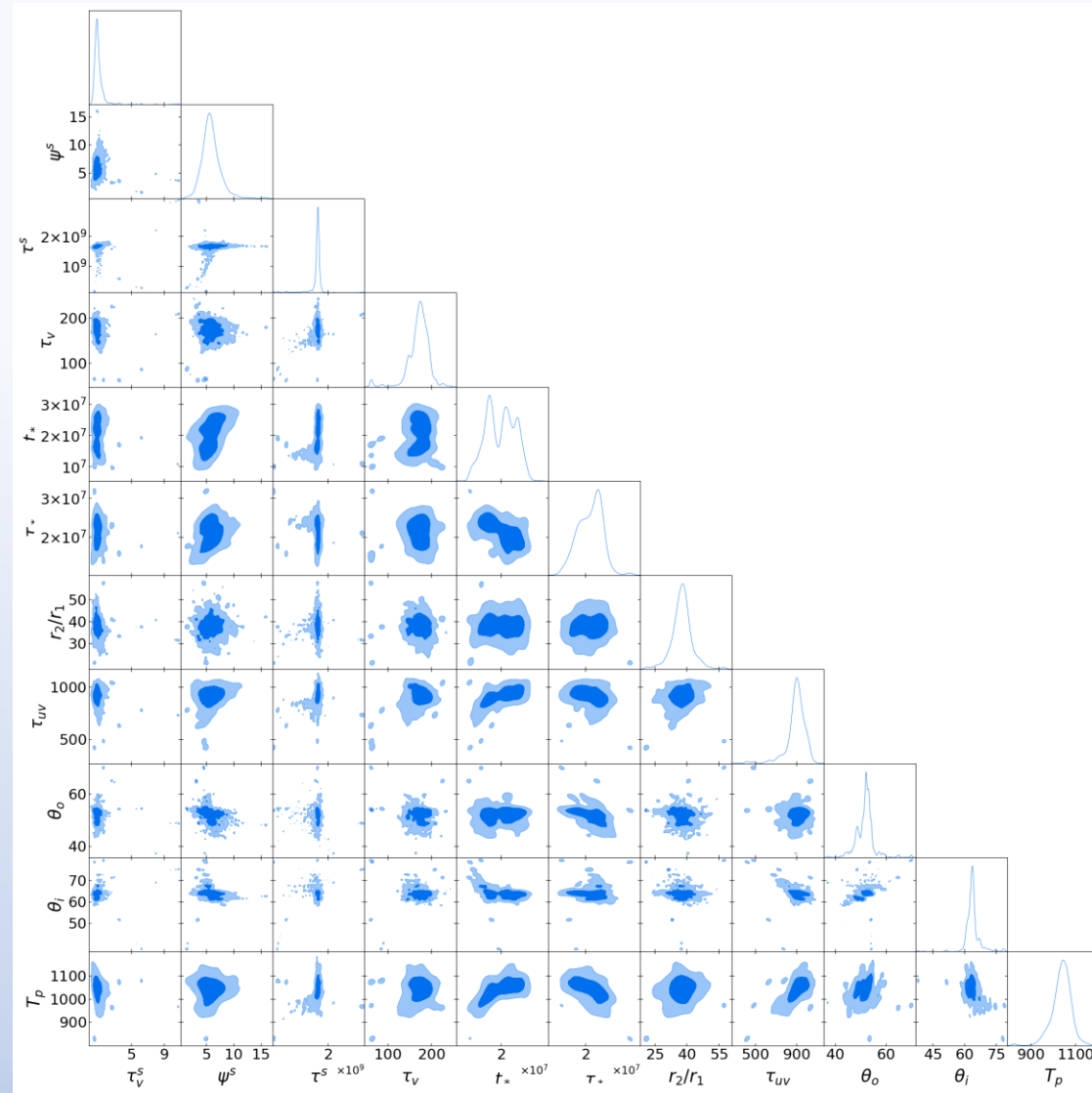


*SED fit plot of IRAS 05189-2524: AGN torus (blue), starburst (red), spheroidal host (orange), polar dust (magenta), total (black)*



*Optical Hubble Space Telescope image of IRAS 05189-2524*

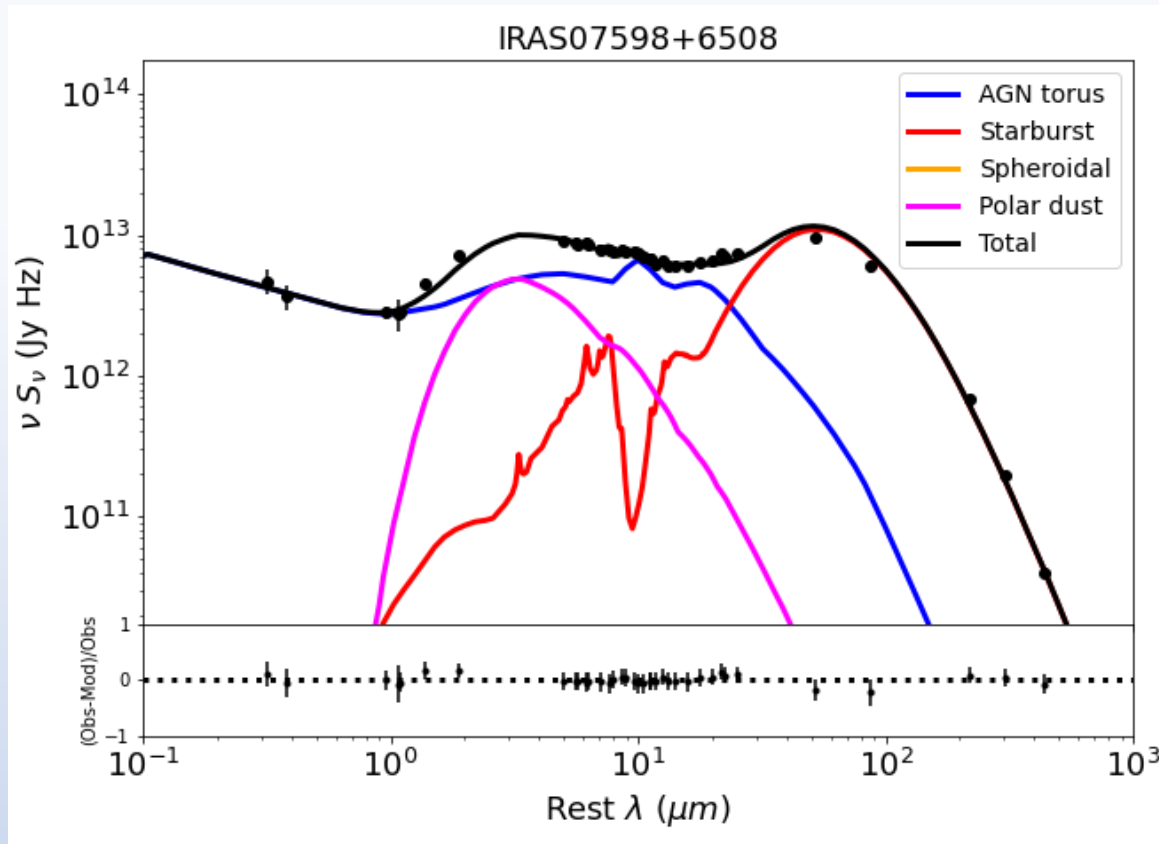
# Corner plot of the galaxy IRAS 05189-2524 (Varnava & Efstathiou, 2024)



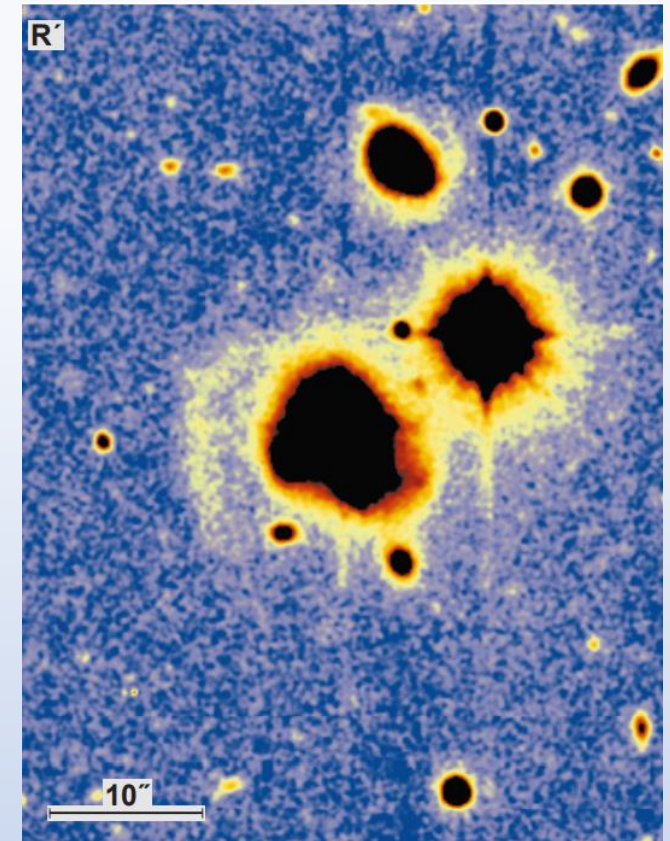
Corner plot of IRAS 05189-2524



# SED fit plot of a ULIRG with an unobscured quasar and also associated with polar dust, IRAS 07598+6508 (Varnava & Efstathiou, 2024)

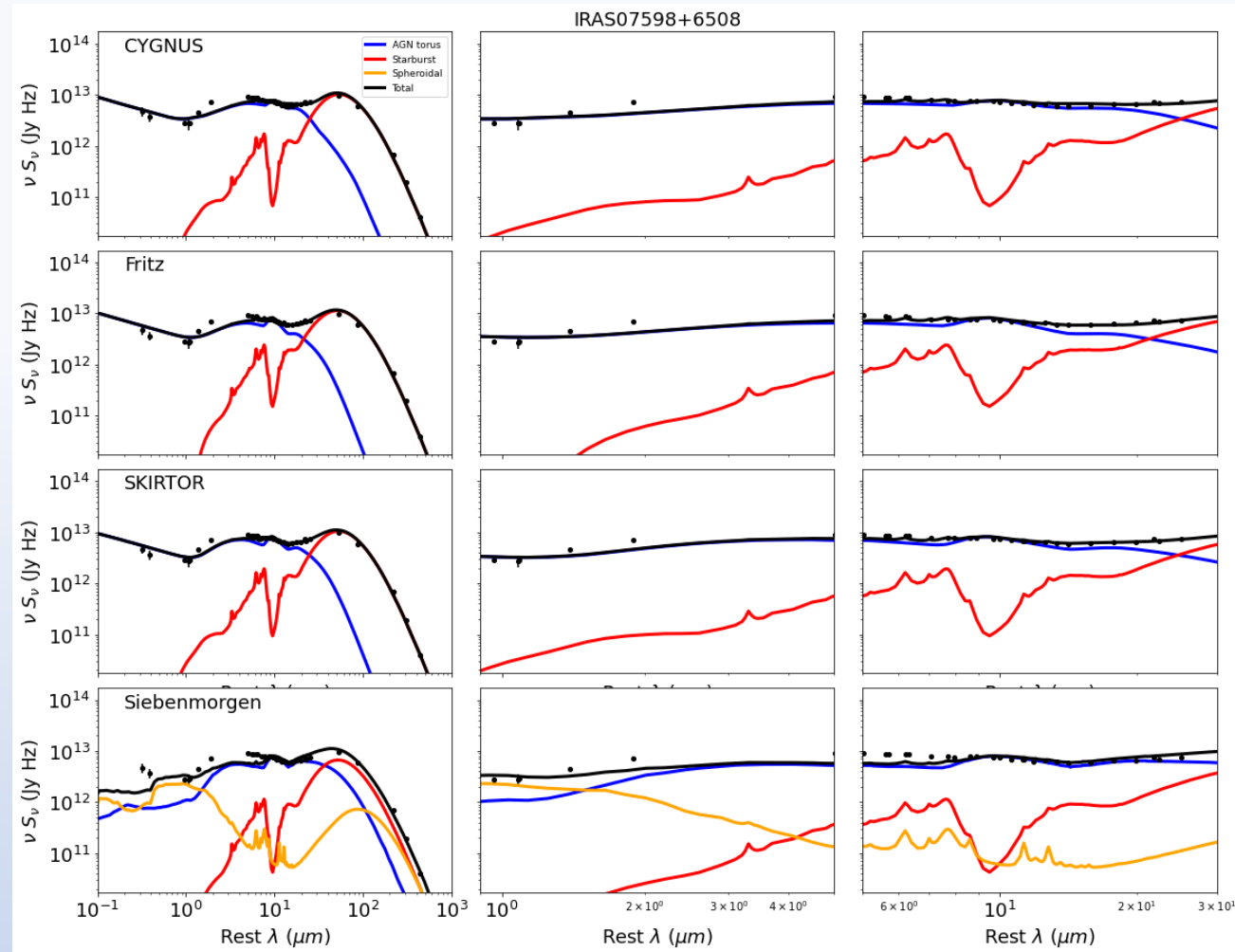


*SED fit plot of IRAS 07598+6508: AGN torus (blue), starburst (red), spheroidal host (orange), polar dust (magenta), total (black)*



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

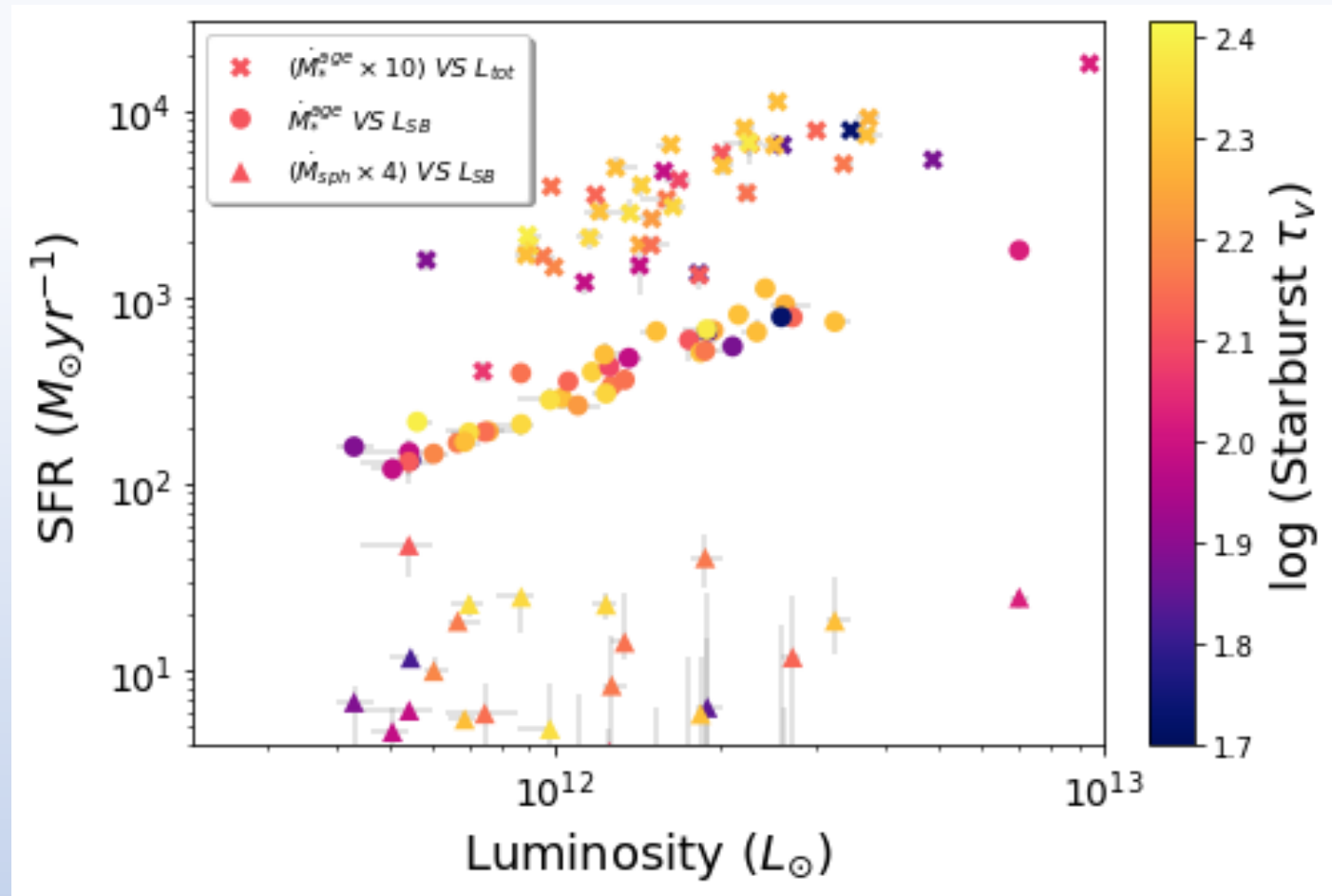
# Comparison SED fit plots of the galaxy IRAS 07598+6508 without using the polar dust component (Varnava & Efsthathiou, 2024)



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

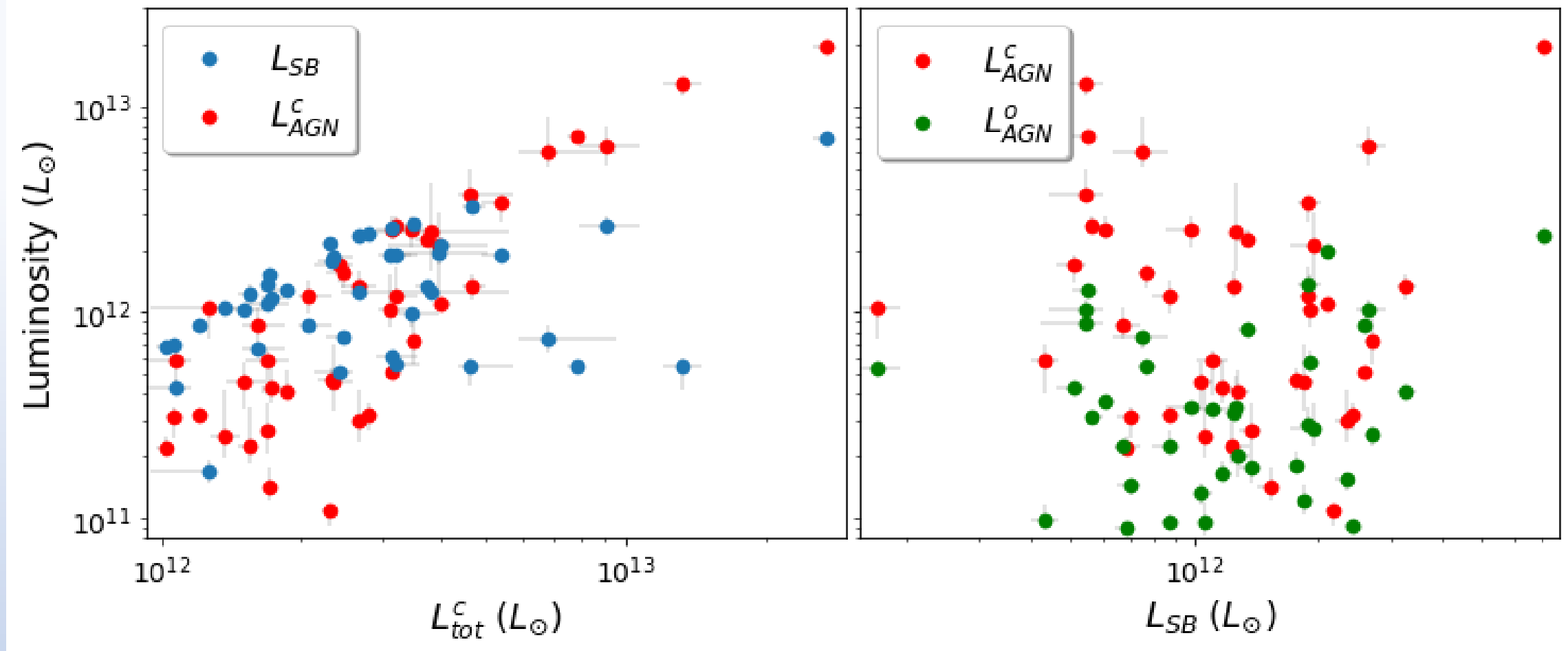


# Examples of selected extracted physical quantities for the HERschel Ultraluminous Infrared Galaxy Survey (HERUS) sample, using the CYGNUS combination of models (Varnava & Efstathiou, 2024)



*Star formation rate (SFR) against infrared (IR) luminosities (starburst or total)*

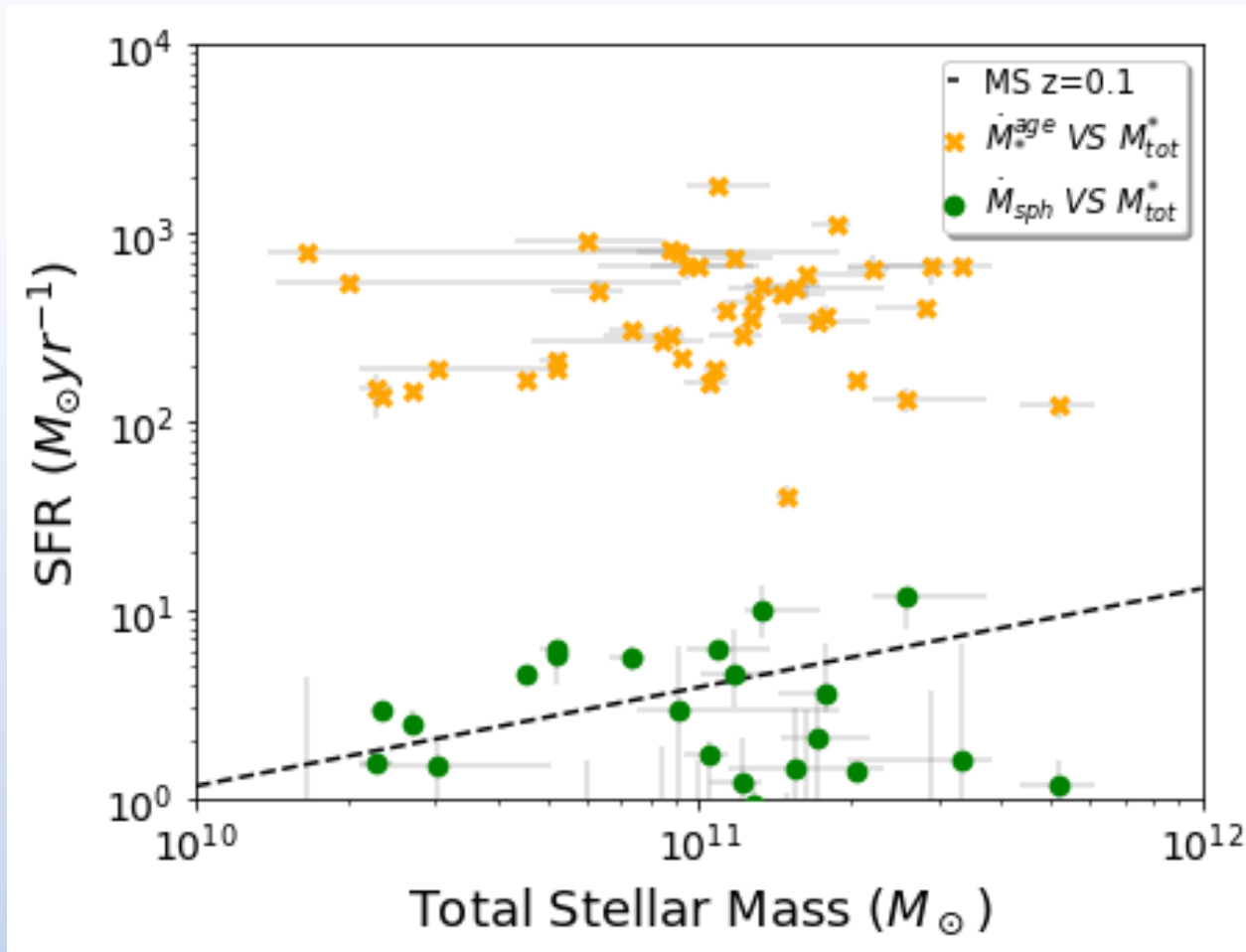
# Examples of selected extracted physical quantities for the HERUS sample, using the CYGNUS combination of models (Varnava & Efstathiou, 2024)



*Left: Starburst and anisotropy-corrected AGN luminosity against total corrected IR luminosity*

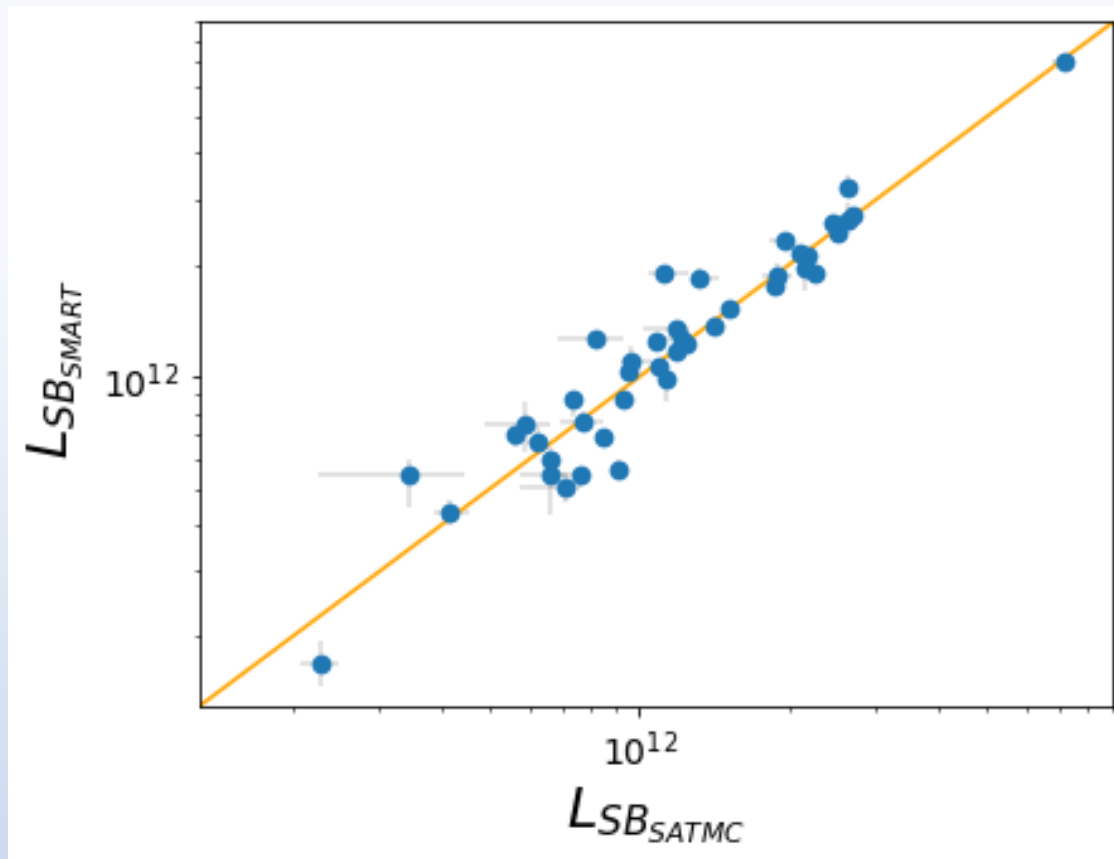
*Right: Observed and anisotropy-corrected AGN luminosity against starburst luminosity*

# Examples of selected extracted physical quantities for the HERUS sample, using the CYGNUS combination of models (Varnava & Efstathiou, 2024)

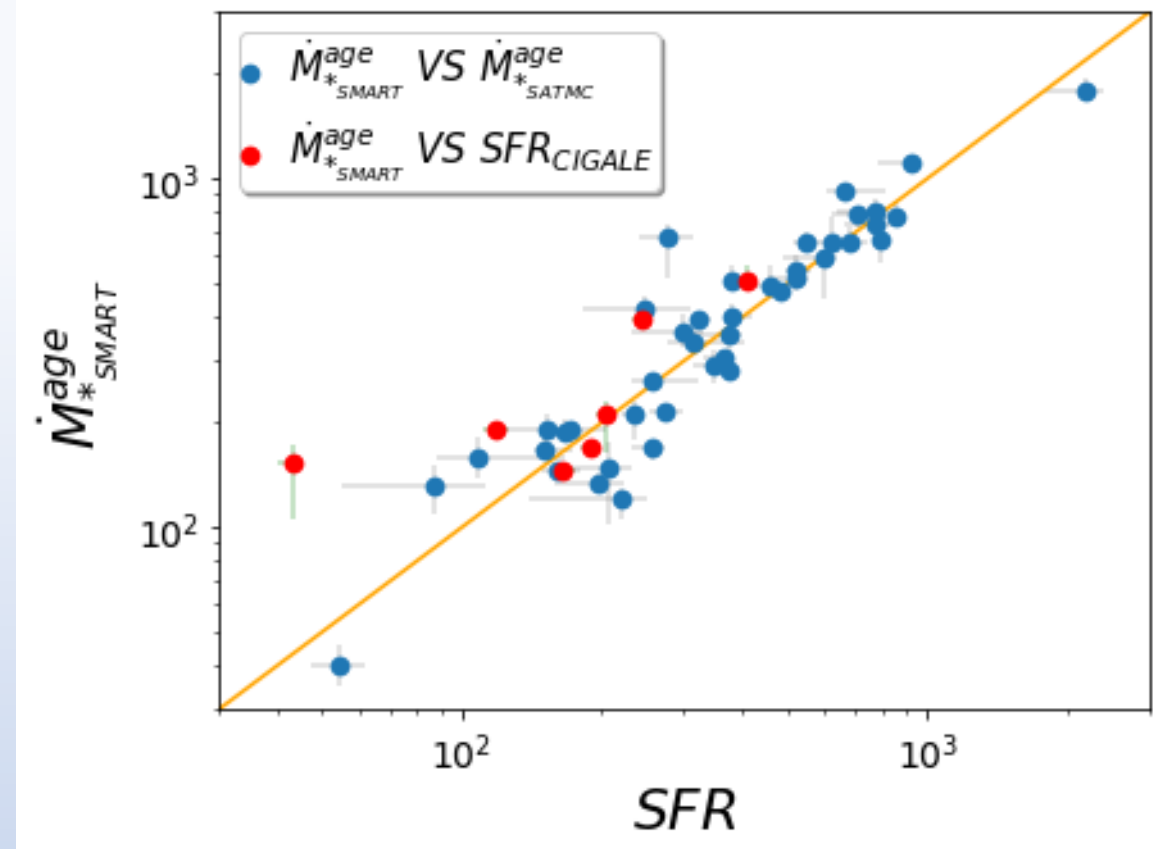


*Starburst or host SFR against total stellar mass*

# Comparison with results from other approaches for the HERUS sample (Varnava & Efsthathiou, 2024)

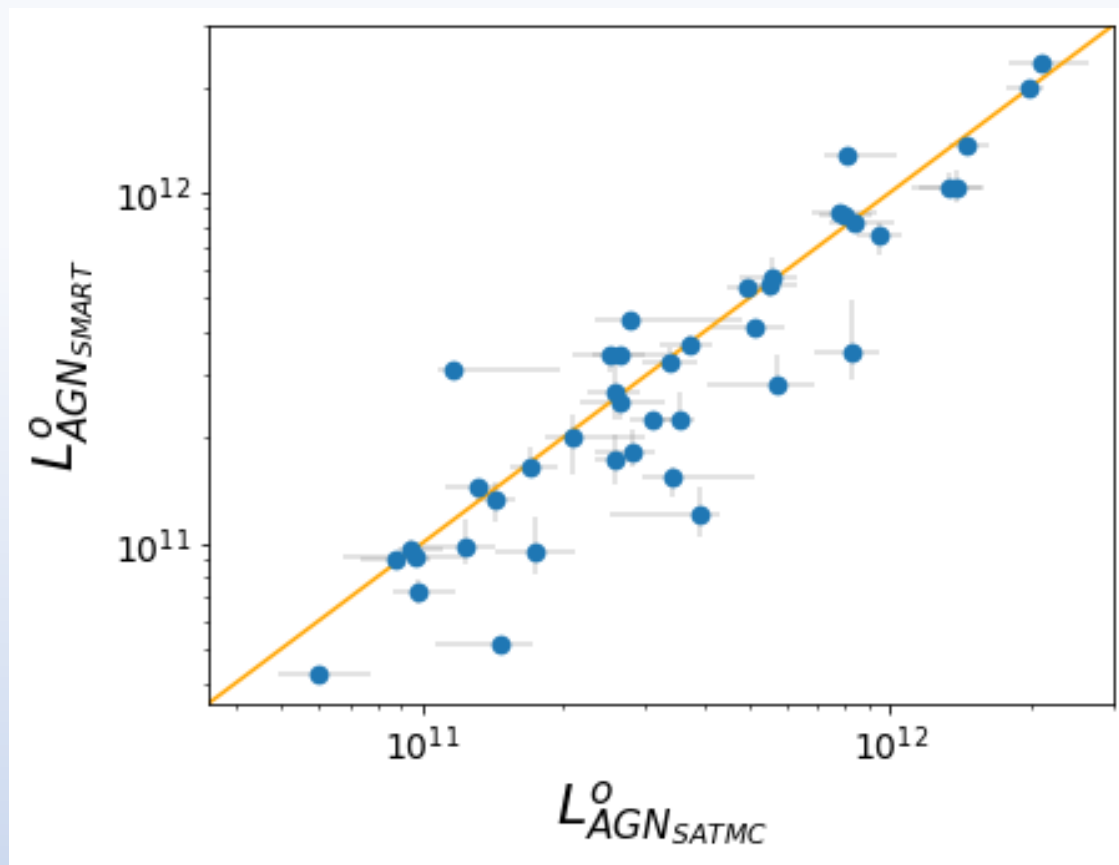


Plot of the starburst luminosity extracted by **SMART** against the same quantity extracted by SATMC

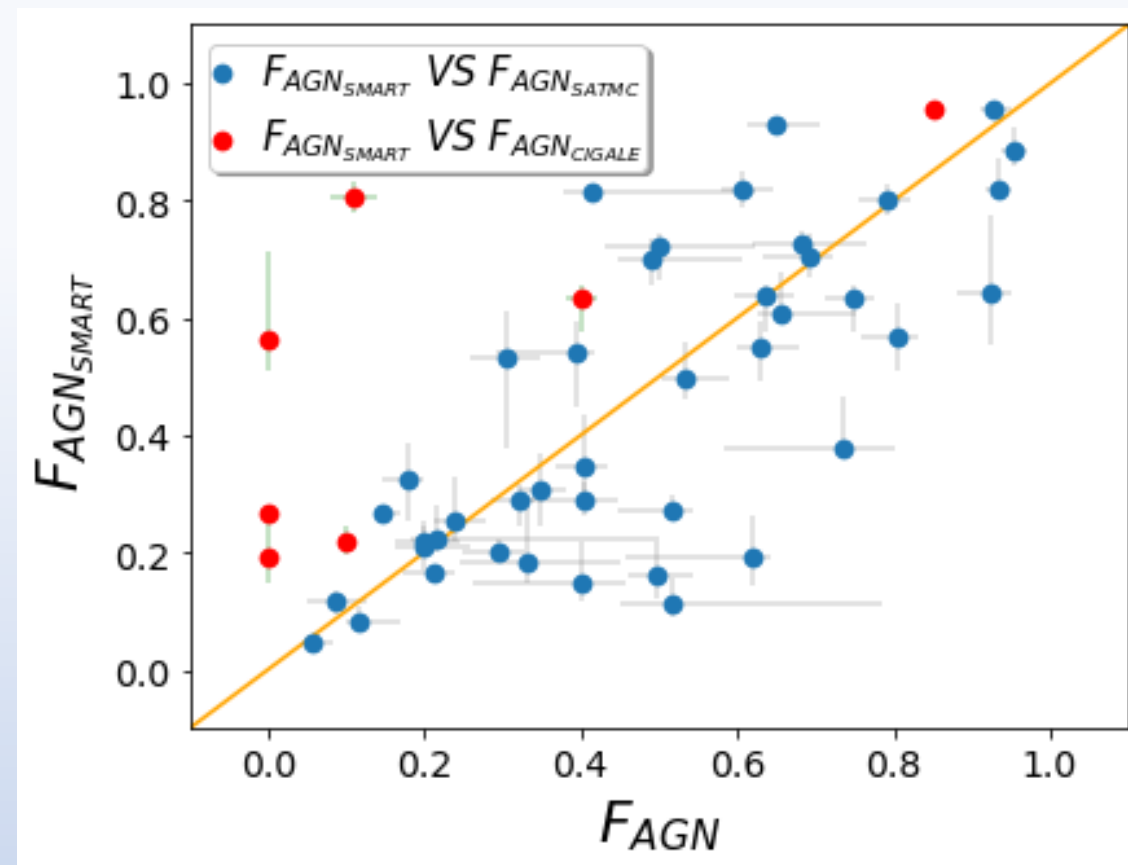


Plot of the starburst SFR extracted by **SMART** against the same quantity extracted by SATMC and CIGALE

# Comparison with results from other approaches for the HERUS sample (Varnava & Efsthathiou, 2024)

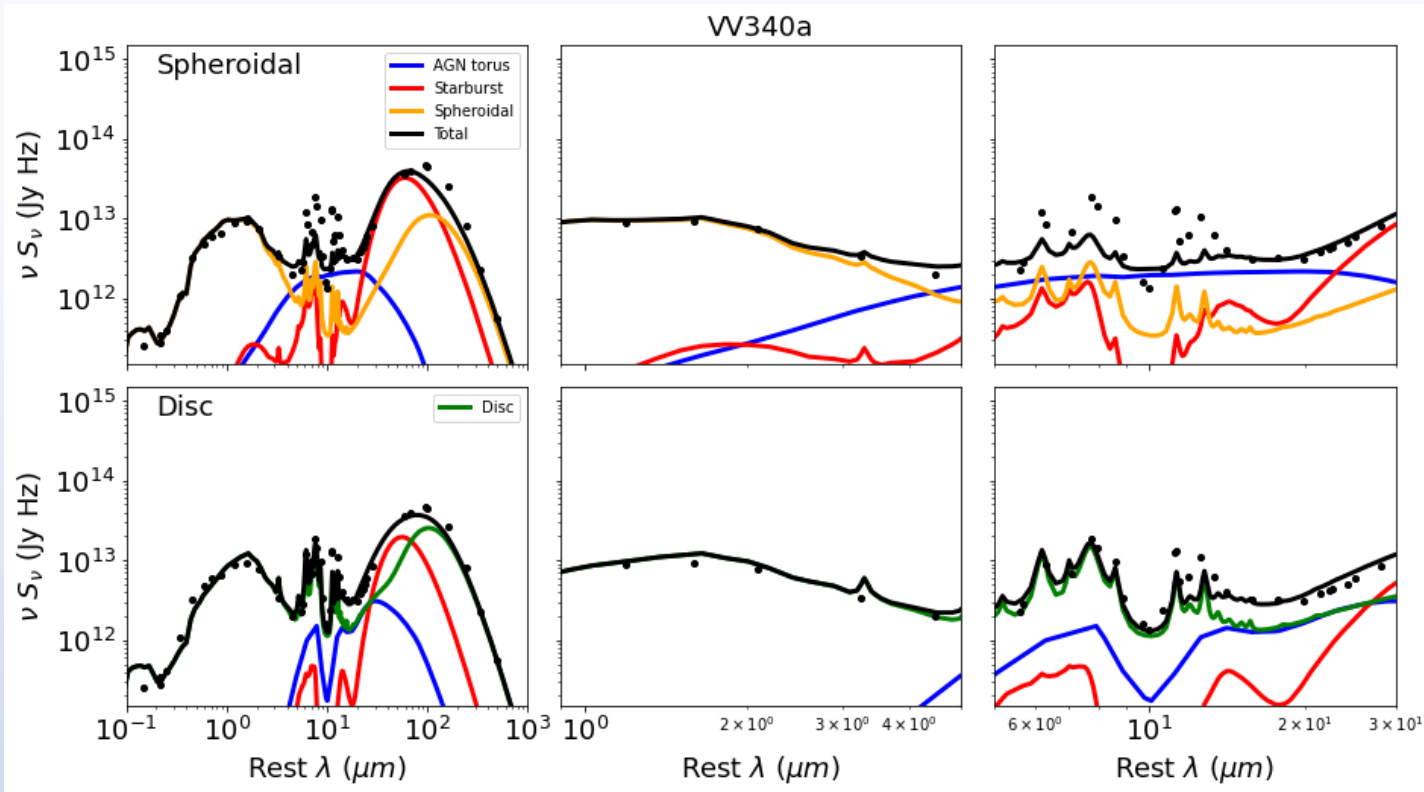


Plot of the observed AGN torus luminosity extracted by **SMART** against the same quantity extracted by SATMC



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 (Varnava & Efstathiou, 2024)



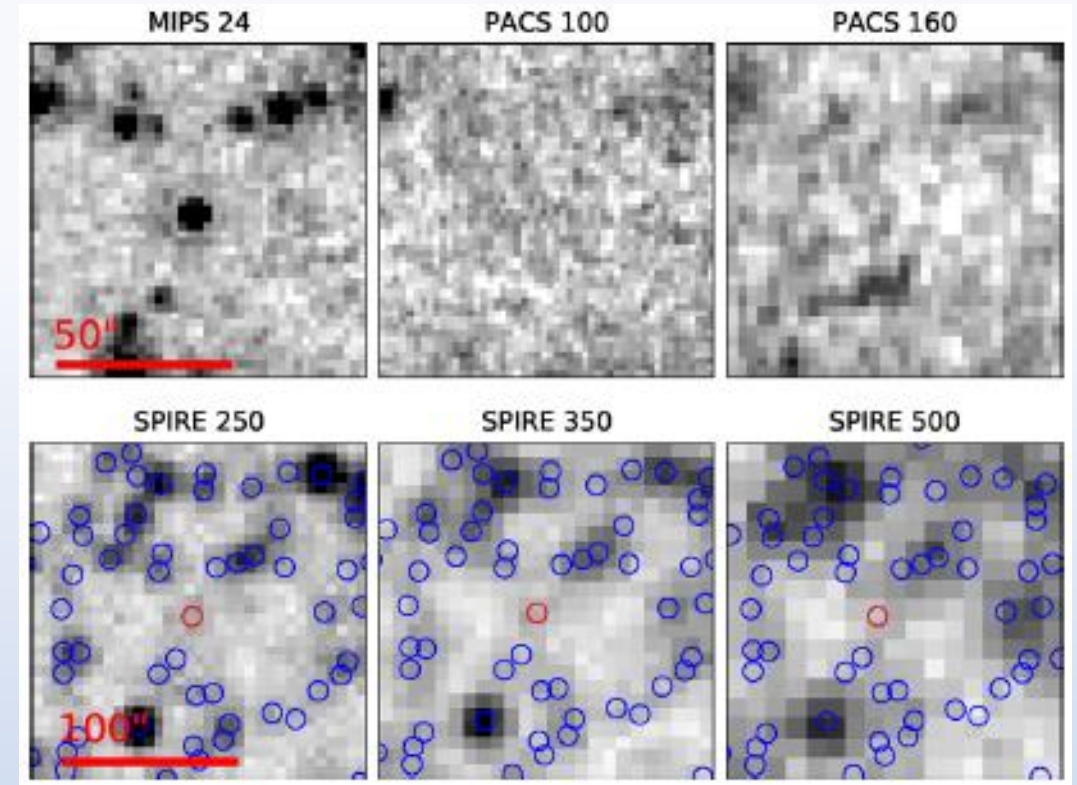
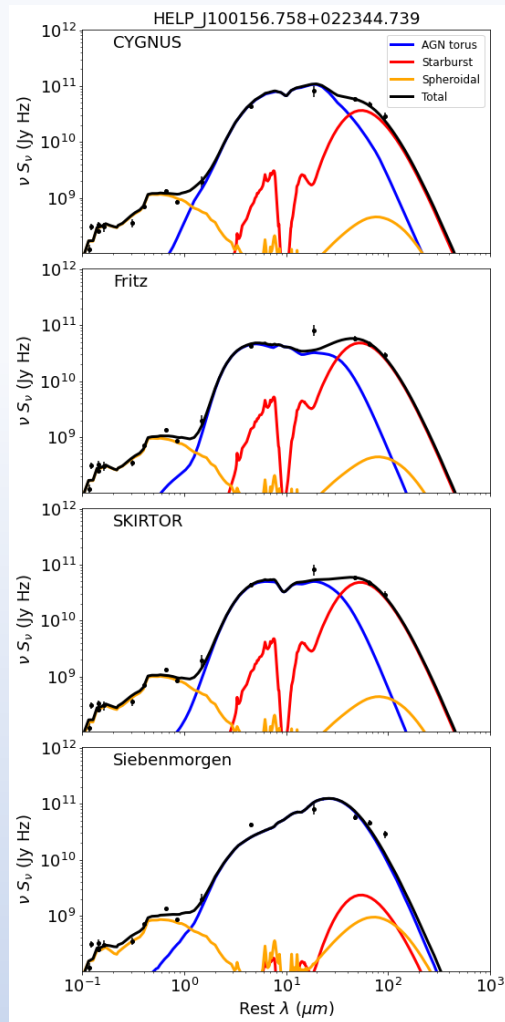
Comparison SED fit plots of the galaxy VV 340a that **SMART** predicts it has a spiral morphology: AGN torus (blue), starburst (red), spheroidal host (orange), disc host (green), total (black)



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 $z \sim 4.3$ (Varnava & Efstathiou, 2024)



*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  $\sim 0-7$
- 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  $z\sim 0.3\text{--}3$ . 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!

**Charalambia Varnava**

<https://ch-var.github.io>