The nuclear and extended mid-infrared emission of Seyfert Galaxies

The central engines of Active Galactic Nuclei (AGN)

- Unified Model (Antonucci 1993)
  The AGN type depends on orientation
- Seyfert torus size ~ few pc
  (Burtscher et al. 2013; García-Burillo et al. 2016)
- The torus absorbs the intrinsic AGN radiation and re-emits it in the IR, peaking in the MIR

Credit: W. Steffen (UNAM)
The central engines of Active Galactic Nuclei (AGN)

- Unified Model (Antonucci 1993)
  The AGN type depends on orientation
- Seyfert torus size ~ few pc
  (Burtscher et al. 2013; García-Burillo et al. 2016)
- The torus absorbs the intrinsic AGN radiation and re-emits it in the IR, peaking in the MIR
The central engines of Active Galactic Nuclei (AGN)

- Unified Model (Antonucci 1993)
  The AGN type depends on orientation
- Seyfert torus size ~ few pc
  (Burtscher et al. 2013; García-Burillo et al. 2016)
- The torus absorbs the intrinsic AGN radiation and re-emits it in the IR, peaking in the MIR
The central engines of Active Galactic Nuclei (AGN)

- Unified Model (Antonucci 1993)
  The AGN type depends on orientation
- Seyfert torus size ~ few pc
  (Burtscher et al. 2013; García-Burillo et al. 2016)
- The torus absorbs the intrinsic AGN radiation and re-emits it in the IR, peaking in the MIR
Mid-IR imaging: space (Spitzer/IRAC) vs. ground (Gemini/T-ReCS) observations

Díaz-Santos (2009, PhD)
Mid-IR imaging: space (Spitzer/IRAC) vs. ground (Gemini/T-ReCS) observations

Díaz-Santos (2009, PhD)
Sample selection

- 9 Month Swift/BAT AGN catalog
  - Very hard 14-195 keV band
  - One of the most complete to date
Sample selection

- 9 Month Swift/BAT AGN catalog
  - Very hard 14-195 keV band
  - One of the most complete to date
- Seyferts and distance limit
  - 8-10 m-class ground-based telescopes
  - N-band: resolution ~0.3"
  - DL<40 Mpc → resolution< 50 pc

IRAC 8 micron

Gemini/MICHELLE
Sample selection

- 9 Month Swift/BAT AGN catalog
  - Very hard 14-195 keV band
  - One of the most complete to date
- Seyferts and distance limit
  - 8-10 m-class ground-based telescopes
    - N-band: resolution ~0.3"
    - DL<40 Mpc → resolution< 50 pc
  - 24 Seyfert galaxies
  - Statistically significant results

IRAC 8 micron

NGC4051

Gemini/MICHELLE

Log $L_{14-195 \text{ keV}}$ [erg s$^{-1}$]

Number of objects

Distance (Mpc)

Number of objects
Nuclear and circumnuclear MIR emission

Nuclear & circumnuclear fluxes
- Nuclear fluxes (inner ~70 pc) → PSF subtraction
- **Nuclear fluxes** at 8 micron

Nuclear & circumnuclear fluxes

Compactness factor
(nuclear/total flux ratio)

The sample is dominated by circumnuclear MIR emission with low surface brightness.

The extended emission is ~30% of the total emission
- ~25% Sy 1 and ~30% Sy 2

It is important to perform visual classification to take into account this emission.

Circumnuclear emission = total – nuclear emission

**Visual classification**
Parsec-scale morphologies

**MIR morphologies classification**
(visual & quantitative)

- MIR morphologies on scales of ~400 pc
- Visual classification (by eye)
- Quantitative classification:
  - Compactness factor and PSF-sub residuals
- 75-79% of the sample show extended morphologies

**Comparison**
subarcsecond vs arcsecond res. data

- Only few galaxies have similar structures
- For the majority of the galaxies, the IRAC PSF is larger than the HR extended emission
  - The HR data is important to characterize the circumnuclear MIR emission
Parsec-scale morphologies

Are the MIR morphologies related to galaxy inclination and/or luminosity?

- Point-like MIR morphologies found in face-on or moderately-inclined galaxies
- Extended MIR morphologies found in galaxies at different inclinations
- We do not find a dependence of the MIR morphologies on X-ray luminosity
Kpc-scale morphologies

Arcsecond res. data
Kpc-scale morphologies

Galaxies with high S/N extended emission

- Similar structures and orientations
- Origin of the heating source of the MIR extended emission
  - Spitzer/IRS spectra

Arcsecond res. data vs subarcsecond res. data
Kpc-scale morphologies

Galaxies with high S/N extended emission

- Similar structures and orientations
- Origin of the heating source of the MIR extended emission
  - Spitzer/IRS spectra
- AGN-dominated systems have more compact MIR emission (300±100 pc) than SF dominated systems (600±700 pc)

Arcsecond vs subarcsecond res. data

N-band     Q-band
Kpc-scale morphologies

Galaxies with high S/N extended emission

- Similar structures and orientations
- Origin of the heating source of the MIR extended emission
  - Spitzer/IRS spectra
- AGN-dominated systems have more compact MIR emission (300±100 pc) than SF dominated systems (600±700 pc)

Comparison with normal galaxies

- Using IRAC data
- 70 nearby normal galaxies (SINGs sample)
- The total MIR luminosity of Seyfert galaxies is higher than in normal galaxies
  - Subtracting the nuclear emission remains larger than normal galaxies
  - Extra-contribution of AGN-heated dust
MIR correlations with AGN and SF indicators

- **Nuclear emission**
  - 2-10 keV
    - $R = 0.801$
    - $y = 0.75x + 10.89$
  - 14-195 keV
    - $R = 0.926$
    - $y = 0.62x + 16.41$

- **Circumnuclear emission**
  - 2-10 keV
    - $R = 0.926$
    - $y = 0.75x + 10.89$
  - 14-195 keV
    - $R = 0.926$
    - $y = 0.62x + 16.41$

- **Key Points**
  - Nuclear and circumnuclear MIR emission: tight correlation with X-rays → AGN activity
  - Sy 1 and Sy 2 are consistent with each other → 8 micron nuclear fluxes are nearly isotropic
MIR correlations with AGN and SF indicators

- Nuclear emission
- Circumnuclear emission

- Tight correlation with X-rays and [O IV], and weak correlation with [Ne II]SF → nuclear and circumnuclear MIR emission are AGN-dominated
Conclusions

- The majority of the galaxies (75-59%) show extended morphologies
- This extended emission has low surface brightness → (~30% of the total)
- AGN-dominated systems have more compact extended MIR emission than SF-dominated systems
- Tight correlations with X-rays and [O IV], and weak correlation with [Ne II]SF →
  8 micron nuclear fluxes (~70 pc) in our sample are AGN-dominated
- Practically the same correlations with larger scatter for the circumnuclear emission →
  AGN dominates the MIR emission in the inner ~ 400 pc (with some contribution of SF)


Email: igarcia@iac.es
Study of the torus properties of this complete sample of Seyfert galaxies

Nuclear IR fluxes and high angular resolution MIR spectra

NGC 2992

Are the covering factors of Sy1 and Sy2 ≠ ?

García-Bernete et al. (2015)

Ramos Almeida et al. (2014)

Email: igarcia@iac.es
Nuclear MIR emission

Nuclear fluxes

- Nuclear fluxes (inner ~70 pc) → PSF subtraction
  - **Nuclear fluxes** at 8 micron

1) Match the PSF star to the galaxy peak
   100% *(oversubtracted)*

2) Subtract different percentages of the galaxy peak emission

3) Find **non-oversubtracted** residuals
   1-D profile
   Subtraction residuals
Nuclear MIR emission

Nuclear fluxes

- Nuclear fluxes (inner ~70 pc) → PSF subtraction (HR observations with ≠ filters)

- Spitzer/IRS spectral decomposition
  - Nuclear fluxes as priors

Homogeneous nuclear fluxes at 8 micron