Super-resolving Herschel imaging: a proof of concept using Deep Neural Networks

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Why super-resolve Herschel SPIRE images?

- JCMT SCUBA-2 provides data with vastly improved PSF FWHM and confusion noise
- Herschel SPIRE covers a much larger area of the sky

Lim et al. 2020, Oliver et al. 2012

| Characteristic         | Herschel SPIRE | JCMT SCUBA-2 |
|------------------------|----------------|--------------|
| Wavelength (μm)        | 250            | 350          | 500          | 450           |
| PSF FWHM (")           | 18.1           | 24.9         | 36.6         | 7.9           |
| Confusion noise (σ, mJy/beam) | 5.8 ± 0.3   | 6.3 ± 0.4    | 6.8 ± 0.4    | 1             |
| Pixel scale (")        | 6              | 8.33         | 12           | 1             |
How did we build the network?

- The network is an autoencoder in a UNET configuration.
- Architecture based on the GalaxyGAN generator (Schawinski et al. 2017).
- Sigmoid activation function is used to suppress noise in the output images.
- Training is done on an alternating set of simulated and real data.
Training the Network – Simulated Data

• The simulated data is simulated using the Empirical Galaxy Generator

• Custom loss function combining
  • L1-loss
  • Mean flux difference
  • Median flux difference
  • Aperture flux differences based on sources identified in the simulated target data
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  - Aperture flux differences based on sources identified in the simulated target data

- The aperture loss identifies source locations in the simulated data and compare aperture fluxes at these coordinates between the simulated and generated data.

\[ L_{Aperture} = \frac{1}{N_s^{\text{target}}} \times \sum_{i=1}^{N_s^{\text{target}}} |f_{i}^{\text{target}} - f_{i}^{\text{generated}}| \]
Training the Network – Real Data

• The real data is from the Herschel SPIRE HerMES and the JCMT SCUBA-2 STUDIES surveys

• Custom loss function combining
  • L1-loss
  • Mean flux difference
  • Median flux difference
  • Aperture flux differences based on sources identified in the real target data
  • Aperture flux differences based on sources identified in the generated data

• The aperture loss identifies source locations in both the real generated data and cross-compare aperture fluxes at these coordinates between the real and generated data.

\[
L_{Aperture} = \frac{1}{N_s^{\text{target}}} \times \sum_{i=1}^{N_s^{\text{target}}} |f_i^{\text{target}} - f_i^{\text{generated}}| + \frac{1}{N_s^{\text{generated}}} \times \sum_{i=1}^{N_s^{\text{generated}}} |f_i^{\text{target}} - f_i^{\text{generated}}|
\]
Network output I

- The network is designed to not recreate a realistic noise profile in the image.

- Many recreated galaxies can be found in the Herschel SPIRE 250 µm image but their relative brightness is adjusted to reflect the 450 µm wavelength.
Network output I

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Many recreated galaxies can be found in the Herschel SPIRE 250 µm image but their relative brightness is adjusted to reflect the 450 µm wavelength.
Network output II

• The output achieves a PSF FWHM comparable to that of the JCMT SCUBA-2 450 µm images

• The generated PSF is more regular due to reduced noise
Network output III

- Positional reconstruction is generally inside ~12 arcsec
- A few generated sources are more than 20 arcsec from a real source, these are likely artefacts from the generator
Network output IV

• The network achieves a good flux reconstruction in galaxies brighter than 9 mJy

• The network overestimates the flux of the faintest galaxies
Network output V

- Completeness (Recall) = \[ \frac{TP}{TP + FN} \]
- Purity (Precision) = \[ \frac{TP}{TP + FP} \]
- Network Completeness plateaus about 95% for sources brighter than 15 mJy
- High Purity of the Network as the Purity never drops below 87%
Future work

- Super-resolve all the Herschel SPIRE imaging from the COSMOS field and make a source catalogue
- Super-resolve the fields used in the JCMT SCUBA-2 RAGERS project
- Cross-correlate super-resolved sources with existing catalogues

Thank you for listening

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