Secondary Flux Density Calibrators for Herschel

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Background

- Based on a report prepared for HCalSG (**FIR Secondary Calibrators for HAWC, PACS & SPIRE v3.0, 01/31/2006**), which gives a list of more than 50 objects potentially suitable as secondary calibrators
- **Work still on-going to identify additional sources and data needed to model their SEDs, and some of the sources still completely lack sub-millimeter data.**
- **SED modeling required to predict flux densities in PACS and SPIRE bands**

Secondary calibrators

- Calibrators, for which the flux densities cannot be prediced using basic physical properties, but which have to measured using a primary flux calibrator
- Can provide a substantial source of moderately bright calibrators (for us they fill in a gap between bright planets, asteroids and fiducial stars)
- At least a sub-set should be usable for both PACS and SPIRE and for cross-calibration with other observatories

Characteristics of a good flux calibrator

- Compact (preferably point-source)
- Non-variable (or variable in a completely predictable manner)
- No nearby sources or confusing background emission
- Bright, SNR of ~100 in a reasonable time, say 10 min
- Calibrators need to cover flux densities spanning from faint to bright

Faint Flux density limits for SPIRE & PACS

- SPIRE (250, 350, & 500 μm) (S/N of 100 in ~10 min for all bands):
  - S ≥ 130 mJy at 500 μm
  - S ≥ 140 mJy at 250 μm
- PACS (60-85 μm, 85-130 μm, 130-210 μm)
  - S ≥ 320 mJy in the 130 - 210 μm band
  - S ≥ 290 mJy in the 60 - 85 μm band

Secondary calibrators in the sub-mm

- Early sub-mm photometers had poor sensitivity requiring very bright calibrators, see e.g. Sandell (1994; NMRAS, 271,71)
  - mostly Ultra Compact HII regions
  - Young protostellar objects
  - AGB-stars
  - Protoplanetaries
- Almost all of these unsuitable as secondary calibrators. UCHII regions and Protostars are always surrounded by extended cloud emission, AGB-stars are variable even in the sub-mm !!

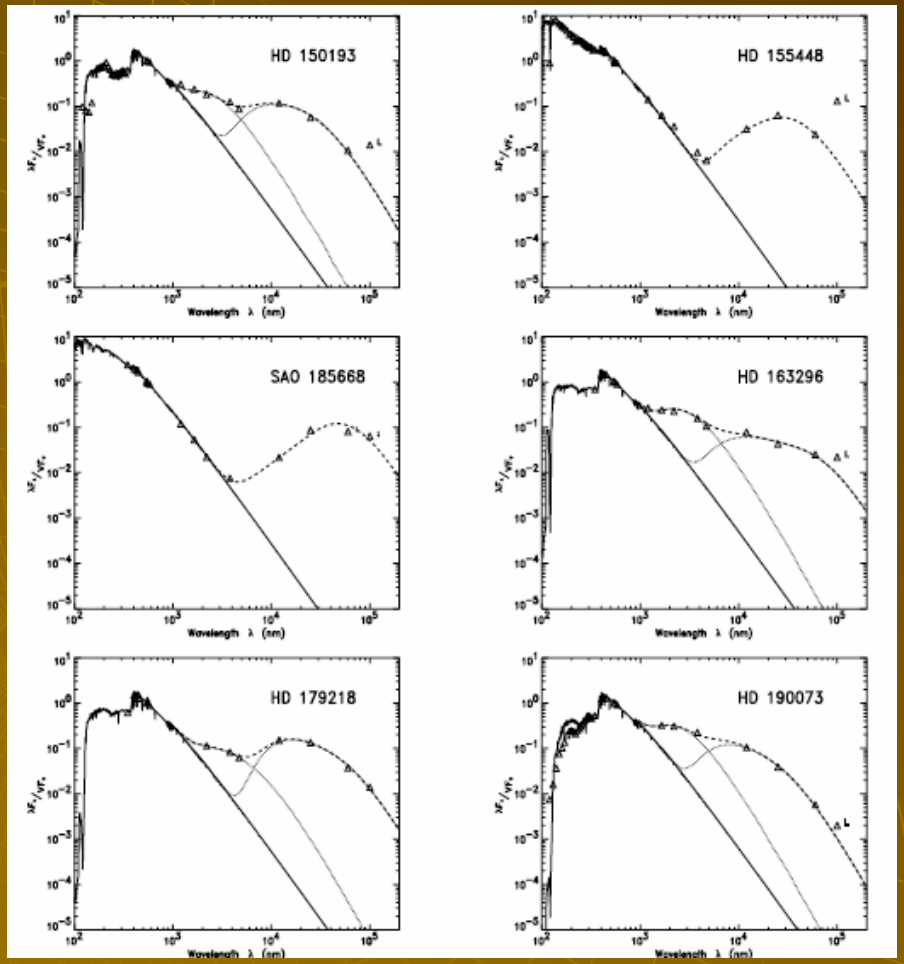
New target selection

- Isolated Herbig Ae/Be stars & Vega (debris disk) stars
  - Both groups have FIR excess due to dust disks
  - Disks are gas poor (especially debris disks), no strong emission or absorption lines
- Ulirgs and Lirgs (late mergers or relaxed systems
  - Dominated by emission from the nuclear region, hence point-like for SPIRE and PACS
- Post AGB stars:
  - Protoplanetaries and young planetary nebulae (SPIRE only)
    - Strong emission lines, outflows
  - Red supergiants (RSGs) (α Ori)
  - Evolved giants, variable?

HAEBE & Vega stars (~40), some too faint for SPIRE

- Isolated HAEBE stars are known to vary in the near- and mid-IR. Possibly still variable in the short wavelengths PACS bands
- Although care has been taken to select only isolated stars, some may still be surrounded by cloud emission
- Vega stars without sub-mm confirmation could be miss identifications (exclude fabulous 4; all extended)
- Typical examples: HD 163296 (8.7 Jy @450 μm),HD 169142 (3.3 Jy @ 450 μm), HD123160(Vega-type; 150 mJy @ 450 μm)

Typical SEDs of HAEBE and Vega-type stars (Malfait et al. 1998; A&A, 331,211)



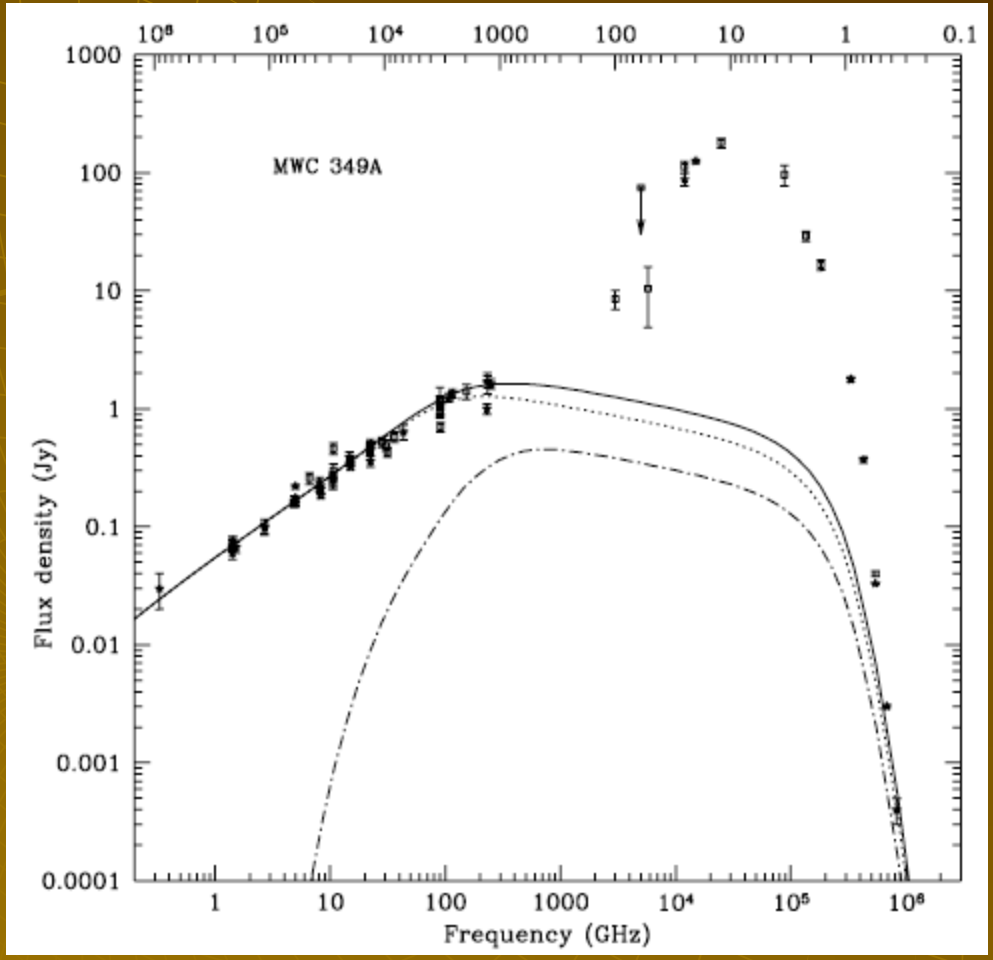
And two T Tauri stars (TW Hya & HL Tau)

- Both have well determined SEDs in the sub-mm
- HL Tau used as secondary calibrator for SCUBA and for SHARC II, expected to work well for SPIRE, but
  - Surrounded by reflection nebulosity, drives an optical jet and XZ Tau ~20” away
  - not a good calibrator for PACS, especially at short wavelengths !!

MWC 349

- Young Be star with gaseous disk, frequently used as a calibrator at cm and mm-wavelengths
- Strongest radio continuum star at cm wavelengths with a classical $\nu^{0.67}$ frequency dependence. Appears to be slowly fading, 1.4%/decade (Tafoya et al 2004, ApJ 610, 827)
- Some dust excess in the FIR
- Should be a good calibrator for both PACS and SPIRE (~ 5.5 Jy a5 450 μm)

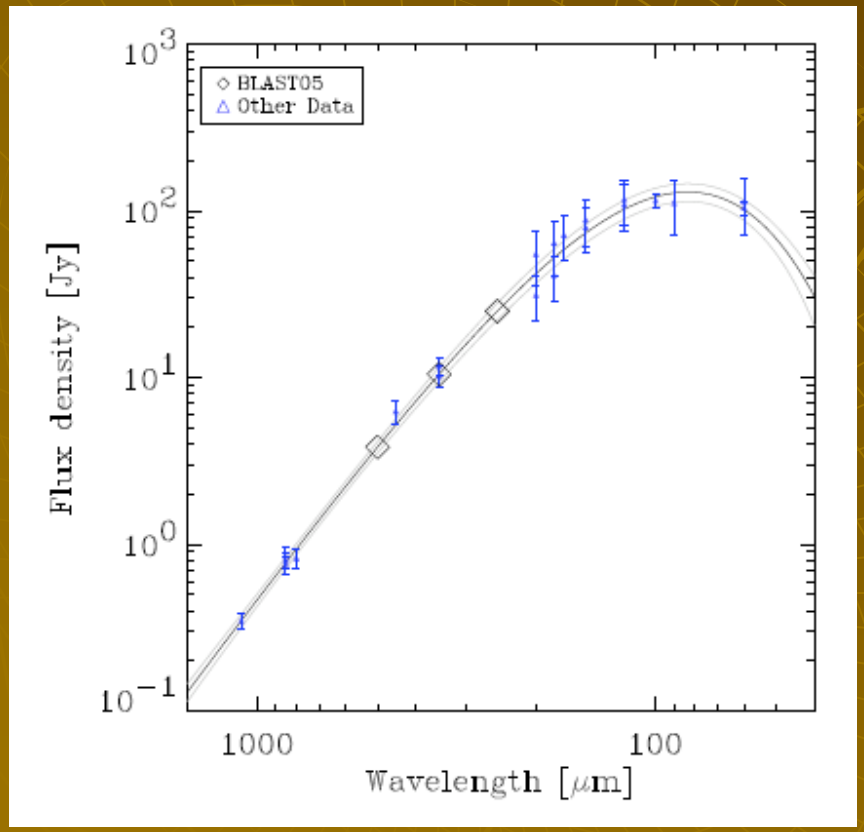
SED of MWC349 (Lugo et al. 2004; ApJ 614, 807)



ULIRGS and LIRGS (15)

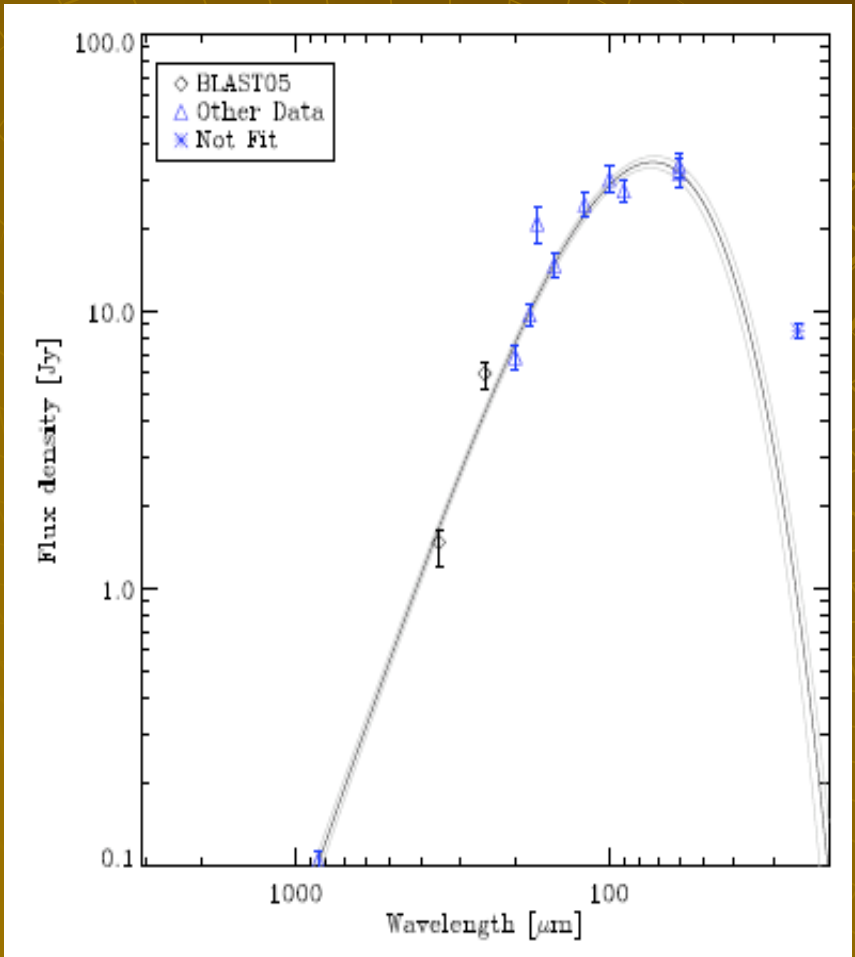
- Late mergers and relaxed systems, luminosity dominated by starburst activity, although some contribution from AGN activity (could be variable)
- Only systems which appear compact (≤ 5”) in the near-, mid-IR, but they could be surrounded by fainter extended emission in the FIR
- Faint emission lines, well behaved SEDs
- Some too faint for SPIRE
- Typical examples: Arp 220, Mrk 231
  - Both successfully used as calibrators by BLAST
    Arp220 was primary calibrator for their 2005 flight

Arp 220



- Primary calibrator for BLAST (Truch et al. 2008, preprint)
- Model predictions
  - S(500) = 3.9 Jy (8%)
  - S(350) = 9.8 Jy (10%)
  - S(250) =24.2 Jy (11%)
- CSO (SHARCII) S(350) =10.2 (1.0) Jy

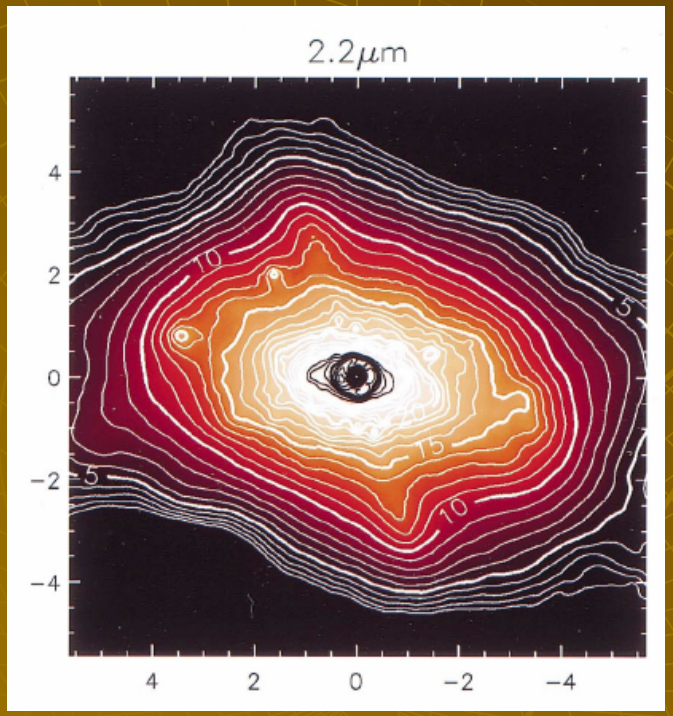
Mrk 231- SED fit from BLAST



S(250) = 6.0 (0.8) Jy
S(350) = 1.5 (0.3) Jy
S(500) = not detected

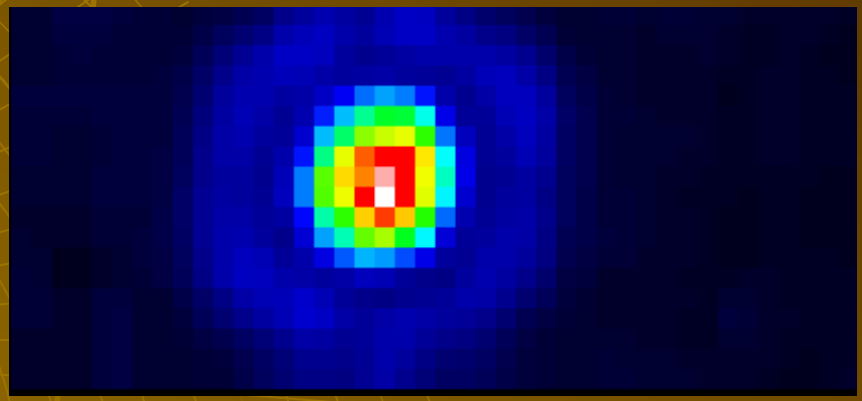
Dowell SHARCII
S(350) = 1.92 (0.26) Jy

Are ULIRGS compact enough for Herschel ?



Scoville et al (2000)

UGC5101 MIPS 160 μm

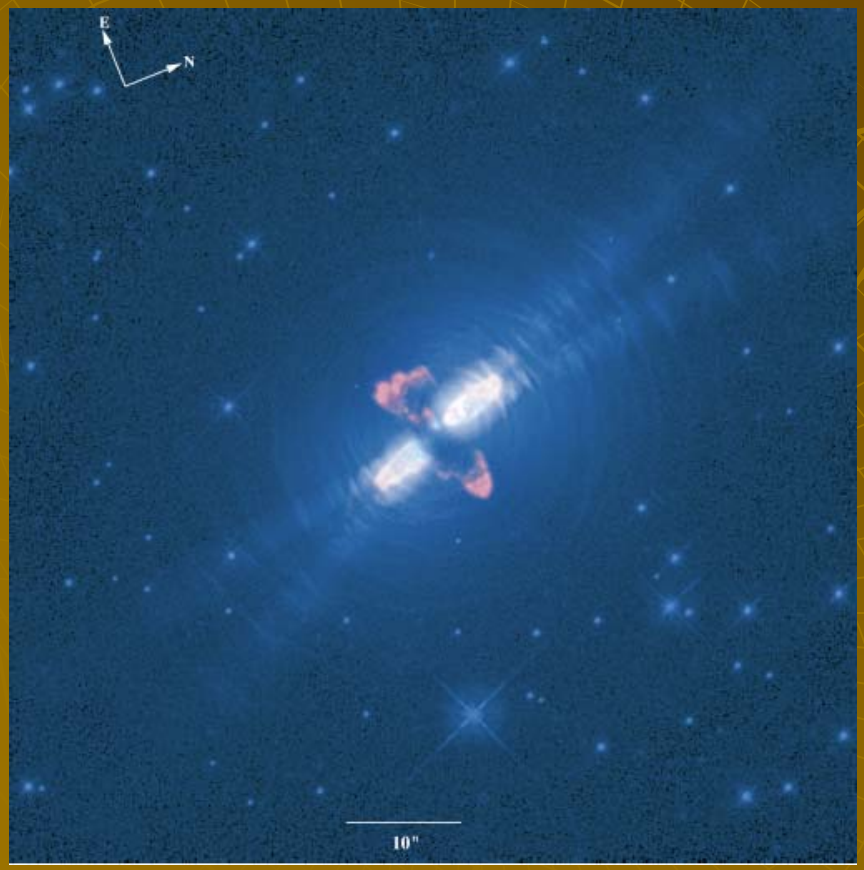


- UGC5101 appears extended at 2.2 μm, but still appears point like in a MIPS 160 μm image.

Post AGB stars

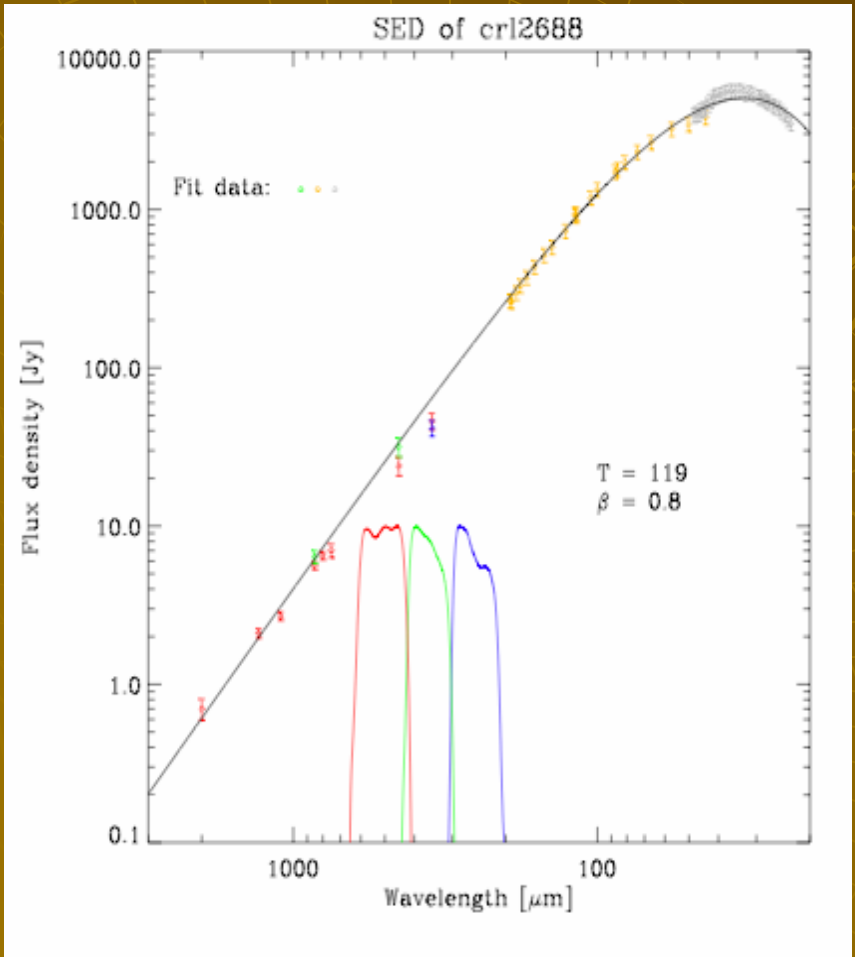
- Protoplanetary or Pre-planetary nebulae
  - Very good secondary calibrators in the sub-mm (CRL 618 & CRL2688, the latter also used for BLAST)
    - Sub-mm emission dominated by disk or torus surrounding the central star, compact in the sub-mm
    - Drive hot outflows, will be extended in the PACS bands
    - Non-variable, but strong emission lines, which will affect the flux, especially in narrow-band filters
  - About 30 known; many of them potential calibrators for SPIRE (especially since they can also be used for wavelengths/line calibration)
  - Young Planetary Nebulae, perhaps too extended (NGC 7027 ~ 10” in size)

CRL2688



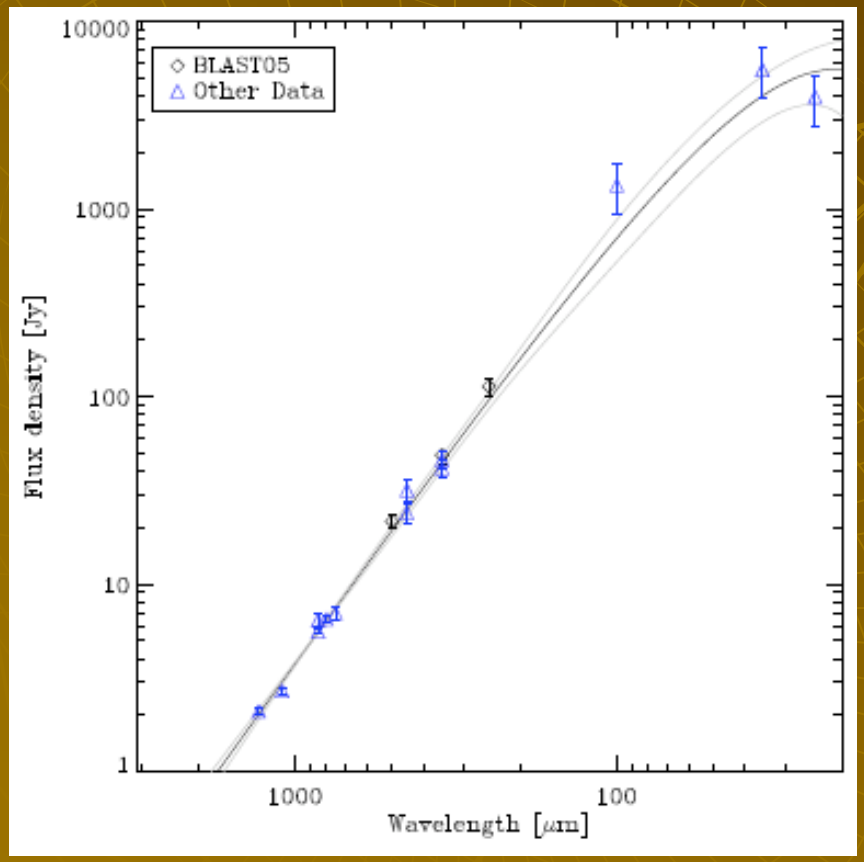
- Near-IR view of CRL2688 (Sahai et al 1998)
- Typical for most protoplanetaries
- Yet point-like in the sub-mm (FWHM ~ 5”)
- BLAST used CRL2688 to measure PSF (Truch et al. 2008), confirming it is still usable at 250 μm

CRL2688 SED



- Early model fit by the BLAST group
  - Clear discrepancy between the sub-mm and FIR (as defined by ISO LWS)
  - To me this highlights the fact that we pick up another emission component and shorter wavelengths

CRL2688 - BLAST SED



- BLAST 2005 flight (Truch et al 2008)
  - S(500) = 21.6 (1.7) Jy
  - S(350) = 49 (5) Jy
  - S(250) = 113 (14) Jy
- Dowell (SHARCII)
  - S(350) = 41.6 (4.2) Jy

To do

- Retrieve and analyze MIPS 70 μm data
- SED fitting (for desirable and well-characterized sources) to predict flux densities for SPIRE and PACS
- Continue to obtain more ‘crucial’ (= sub-mm) data (more for SOFIA than for Herschel)
- Confirm and refine predicted fluxes in flight