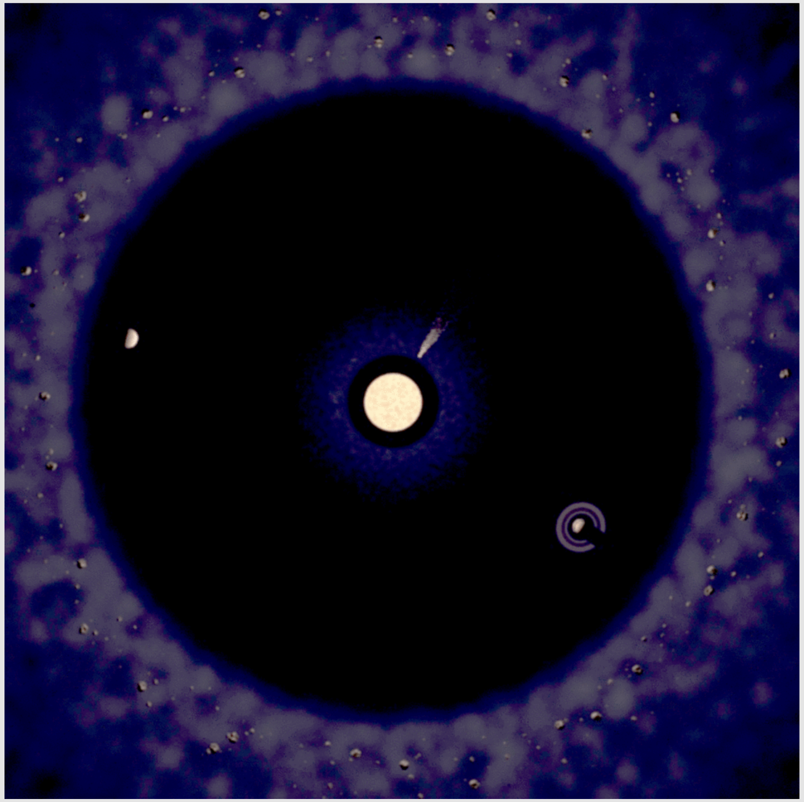
PACS Images of a Kuiper-Like Belt around the Planet-Host Star q^1 Eri

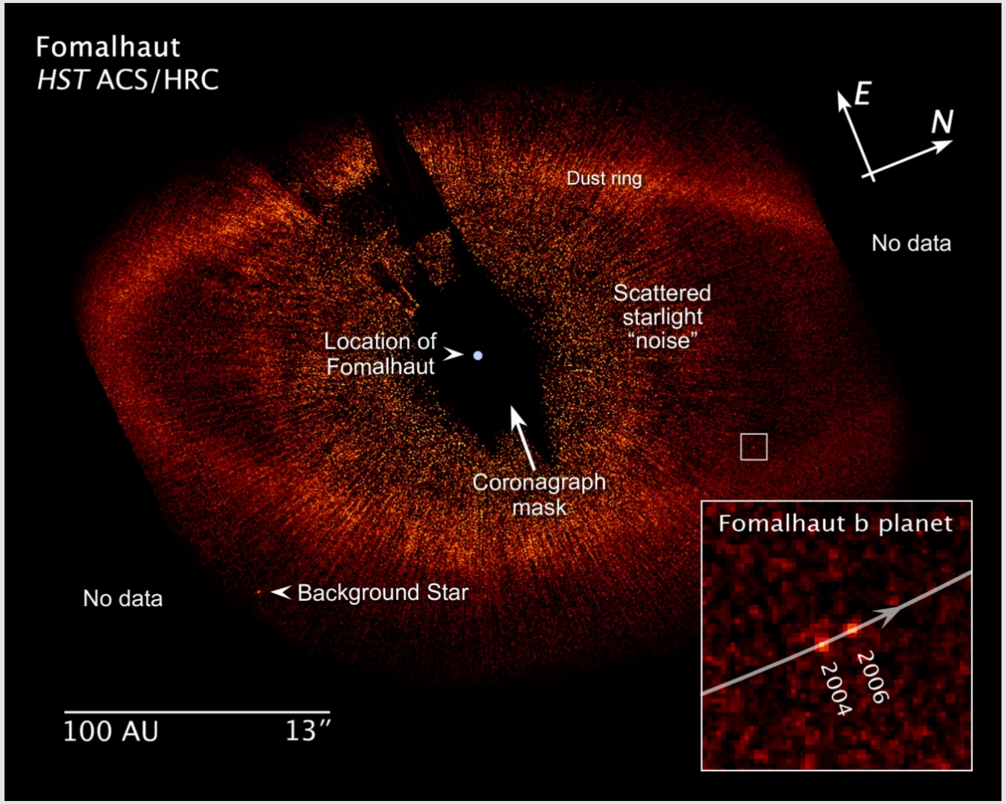
Analyzed with the DUNES Modeling Toolbox

Jean-Charles Augereau & Alexander Krivov
& the DUNES team

Debris disks in planetary systems

Debris dust tell us much about planetesimals and planets
and sheds light to formation and evolution of planetary systems





KALAS et al. 2008

The q^1 Eri planetary system

pre-Herschel understanding

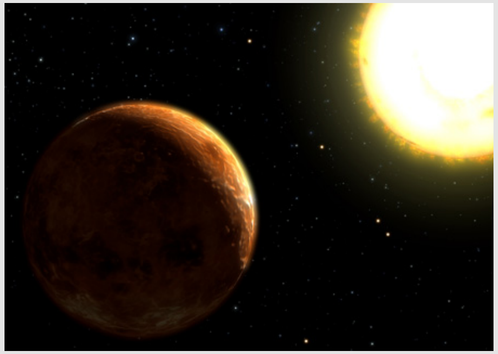
THE STAR

- Spectral type: F8
- Distance : 17.4 pc
- Age : ~ 2 Gyr

A JUPITER-MASS PLANET

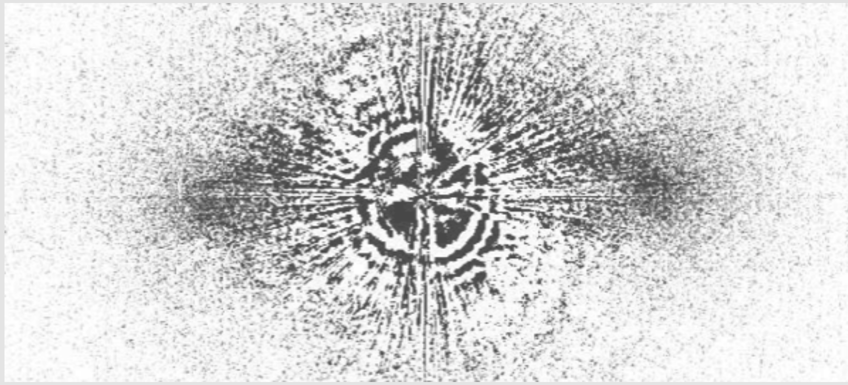
- M sin i: 0.93 $M_{Jupiter}$
- Semi-major axis: 2.03 AU
- Eccentricity : 0.1

MAYOR et al. 2003, BUTLER et al. 2006

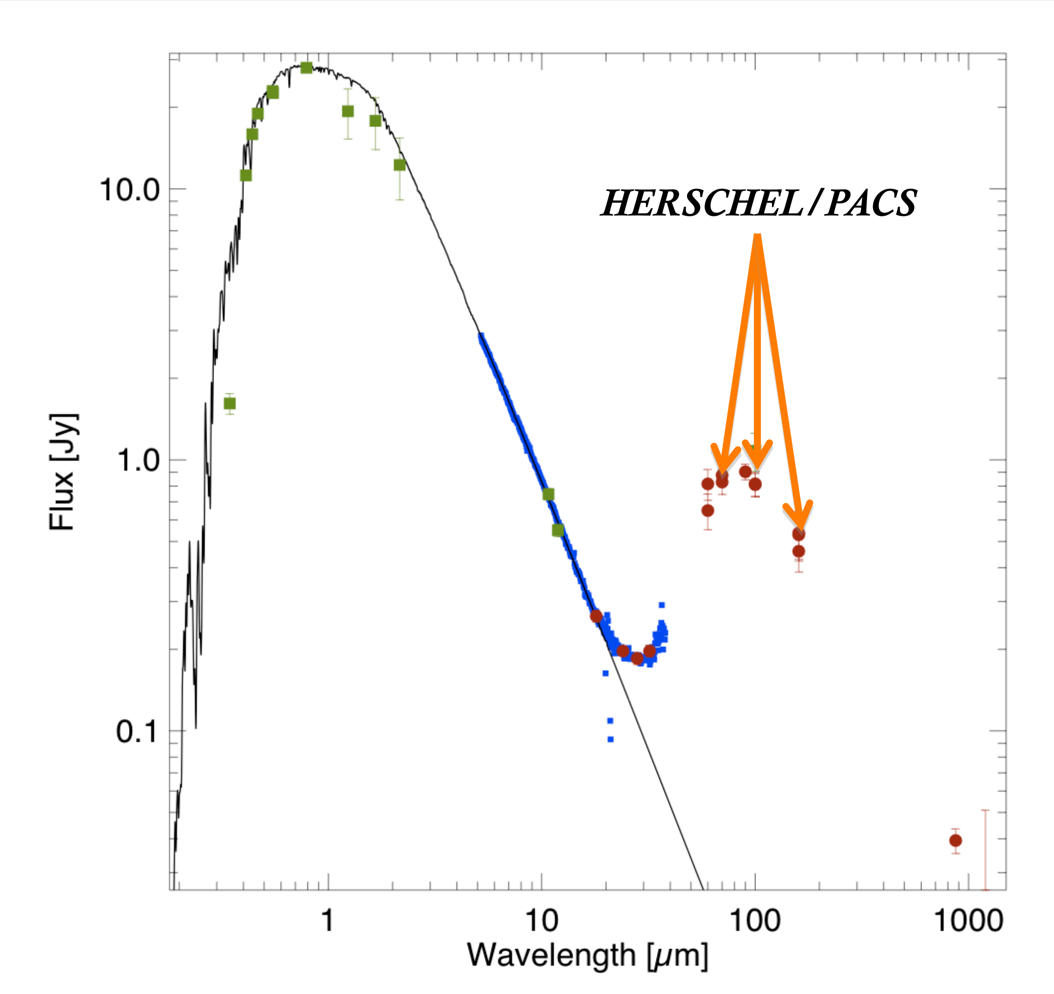


A KUIPER-LIKE BELT

- IRAS, ISO and Spitzer: cold dust, with a luminosity 1000 times that of the Kuiper Belt
- Sub-mm APEX/LABOCA images: disk extent is up to several tens of arcsec (*LISEAU et al. 2008*)
- HST images suggest a peak at 83AU (4.8", *STAPELFELDT et al., in prep.*)



PACS observations of q^1 Eri

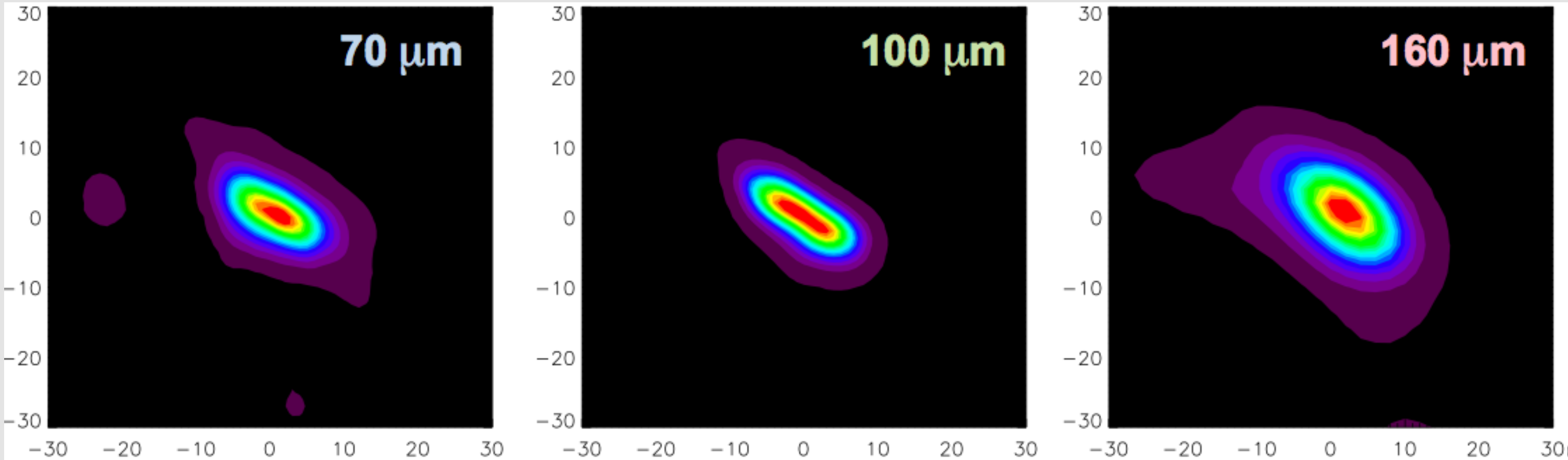


*See A&A Letter and poster by **LISEAU** et al.*

- New PACS photometric measurements at 70, 100 and 160 μm, consistent with previous observations
- SED fitting : known degeneracy between dust properties and disk structure
- ***Images required to break the degeneracy***

PACS observations of q¹ Eri

*See A&A Letter and poster by **LISEAU** et al.*

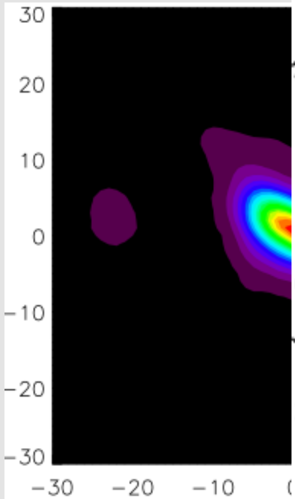


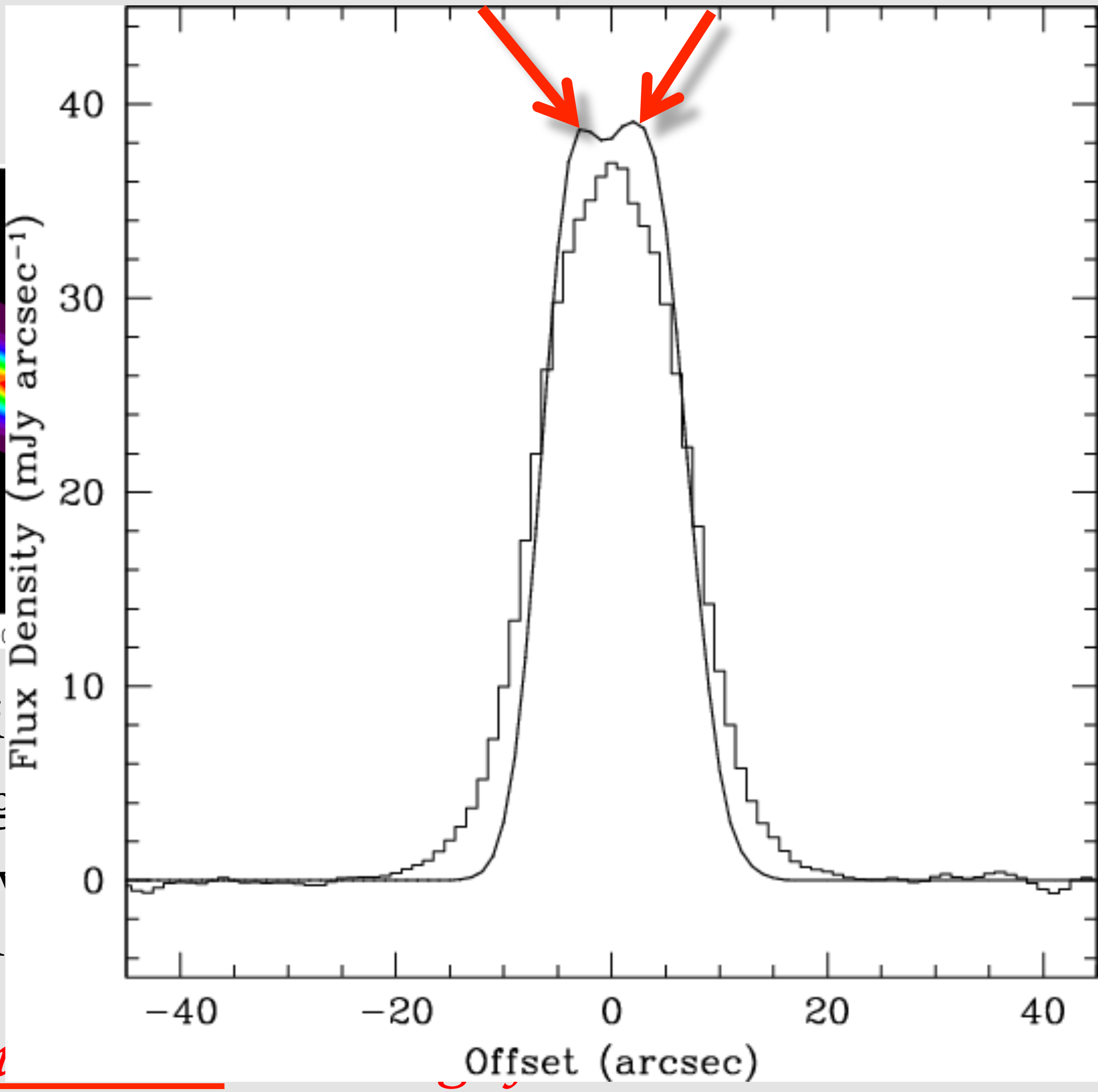
- Disk spatially resolved at all PACS wavelengths
- Disk marginally resolved along the minor axis: inclination > 55 deg
- Deconvolved images suggest a ~40AU wide ring at ~ 85AU, and inclination > 63 deg

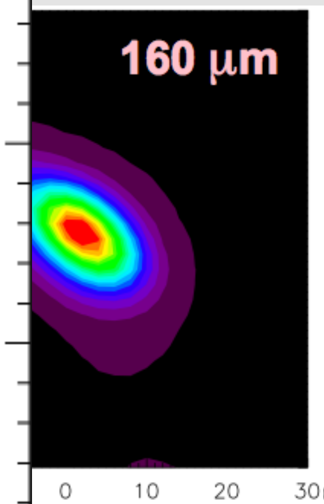
Detailed simultaneous modeling of the SED and PACS images required to unveil the disk structure, dust properties and dynamical history

PACS observations of q^1 Eri

A Letter and
***SEAU** et al.*







- Disk spati
- Disk marg … > 55 deg
- Deconvol … U,
  and inclin

Detailed simu … nages required to unveil the disk structure, dust properties and dynamical history

The DUNES modeling toolbox

Two modeling approaches, Three fitting strategies, Five codes

- **Classical**:
  - Radiative transfer, assuming power laws for the surface density and size distribution
  - Two radiative transfer codes, with different fitting strategies:
    - **GRATER (GRENOBLE)** : bayesian statistical analysis
    - **SAND (KIEL)** : simulated annealing minimization scheme
- **Collisional**:
  - Radiative transfer, fed by results from collisional code ACE that generates and evolves the disk "from the sources"
  - **ACE, SEDUCE** and **SUBITO** codes **(JENA)**

Advantages & limitations of the codes

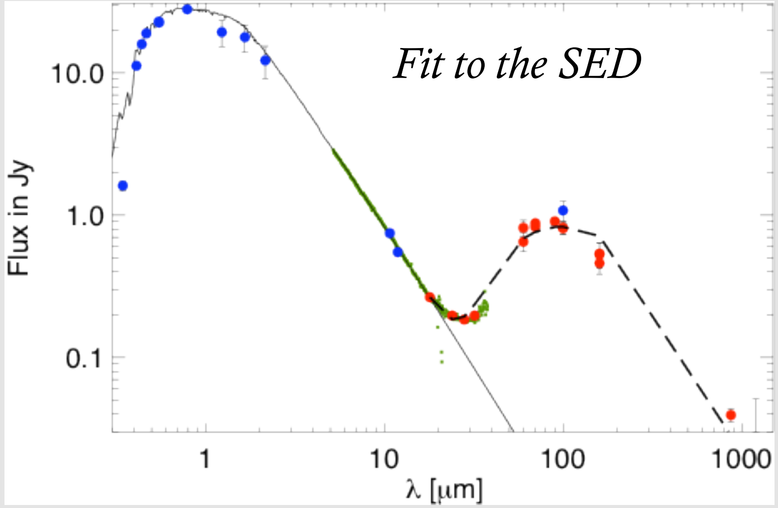
- **GRATER** [Grenoble, **J.-C. AUGEREAU & J. LEBRETON**]
  - ☺ Fast exploration of large parameter spaces
  - ☺ Stored grid for statistical analysis (24 million models for q^1 Eri)
  - ☺ Post-processing easy *(e.g. re-computation of χ^2 with different weights)*
  - ☹ Simplistic description of the disk properties
  - ☹ No direct link to parent bodies

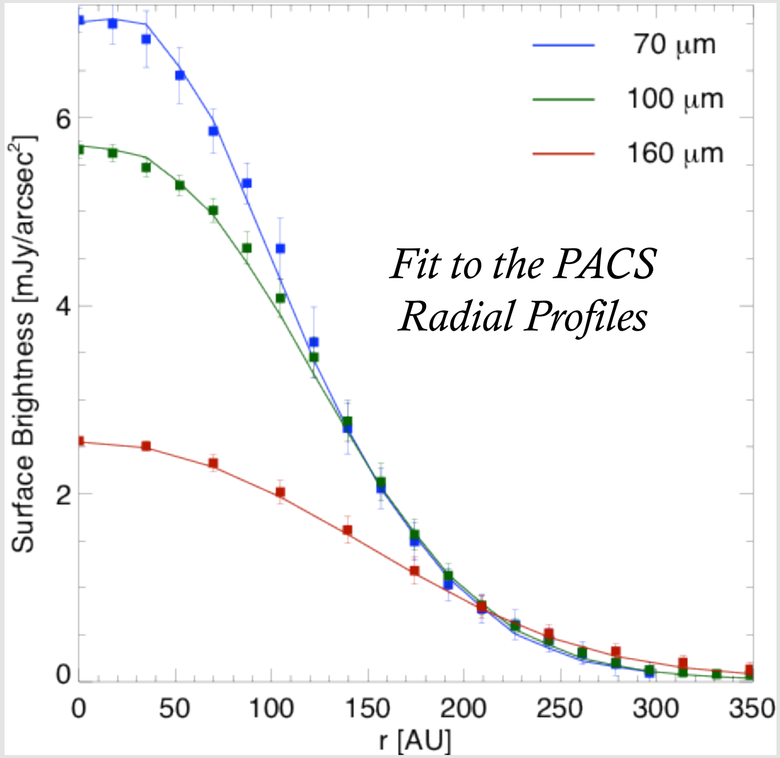
- **SAND** [Kiel, **S. ERTEL & S. WOLF**]
  - ☺ Fast: finds fit among ~10^{11} models in ~70 hours
  - ☺ Large number of free parameters possible
  - ☺ Limited initial constraints on disk physics
  - ☹ Simplistic description of the disk properties
  - ☹ No direct link to parent bodies

- **ACE + SEDUCE + SUBITO** [Jena, **A. KRIVOV, T. LÖHNE, S. MÜLLER**]
  - ☺ Deep physical modeling of the disk from the sources
  - ☺ Realistic description of disk properties
  - ☺ Mass and dynamical excitation of unseen parent bodies
  - ☹ CPU-demanding : 20 models in 3 months

Classical Approach

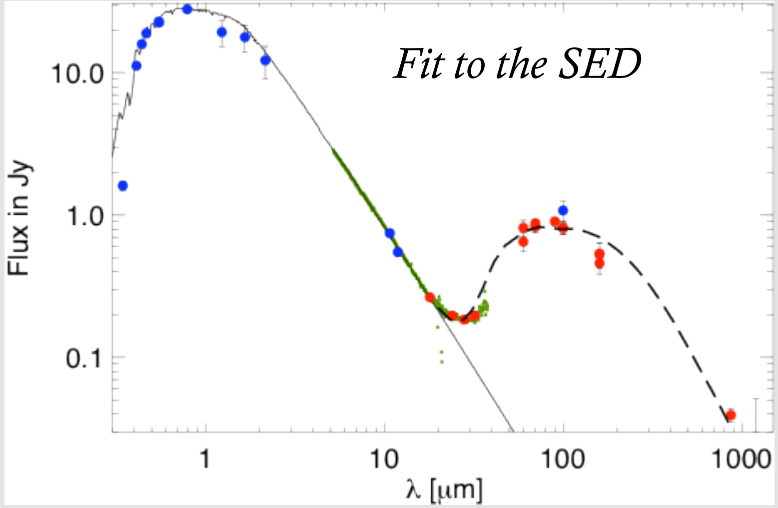
- *No initial constraints on outer disk radius*
- Best fit ($\chi_r^2 = 1.24$):
  - Dust disk :
    - Mass : 0.05 M_{Earth}
    - **Surface density: $r^{+0.9}$**
    - **Disk extent: 17-210AU**
  - Grain properties:
    - 50-50 silicate-ice mixture
    - Minimum grain size ~ 0.7 μm
    - Size distribution: -3.3 power law index

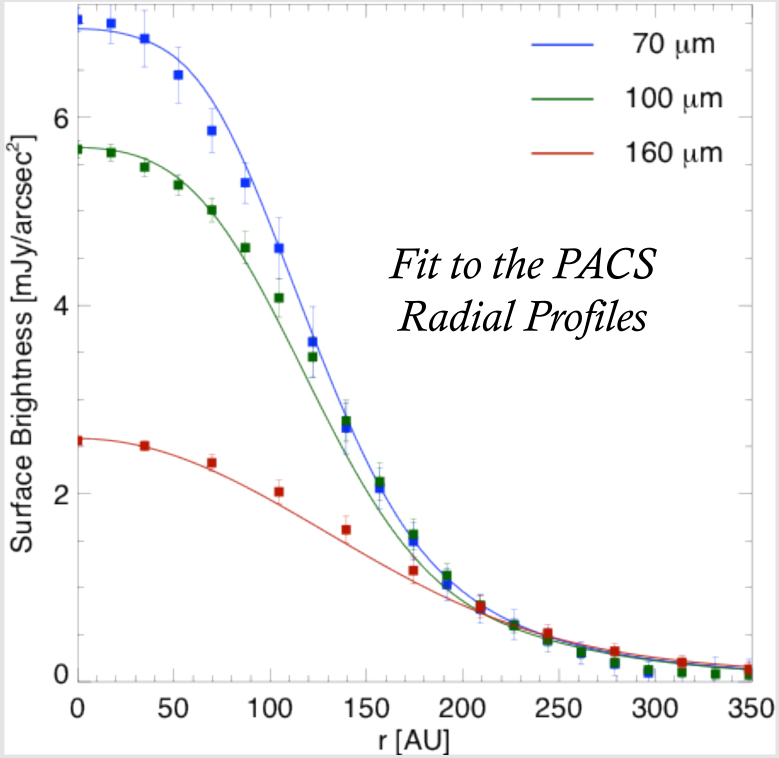




Classical Approach

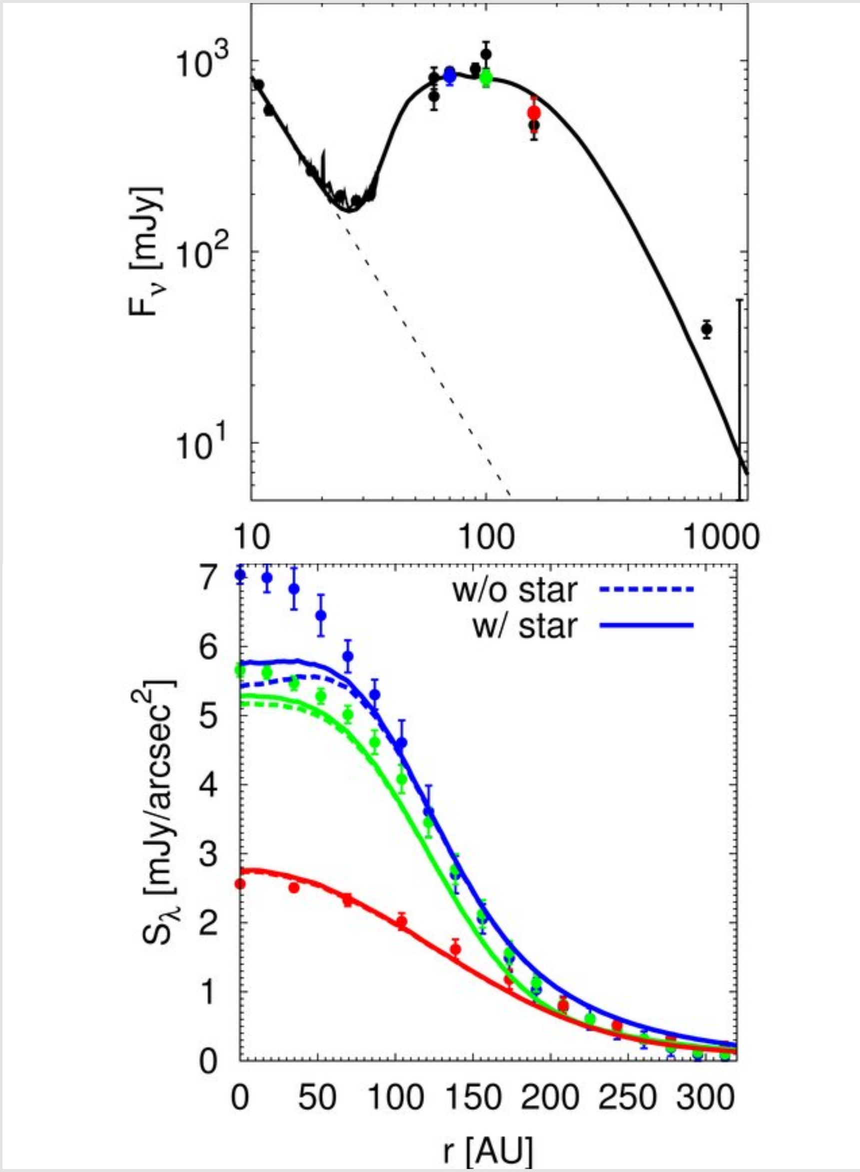
- *Constraint: fixed outer disk radius to sufficiently large value (600AU)*
- Best fit ($\chi_r^2 = 1.4$):
  - Dust disk :
    - Mass : 0.055 M_{Earth}
    - **Surface density: r^{-2}**
    - **Belt peak position: 75-80AU**
  - Grain properties:
    - 50-50 silicate-ice mixture
    - Minimum grain size ~ 0.4 μm
    - Size distribution: -3.3 power law index





Collisional Approach

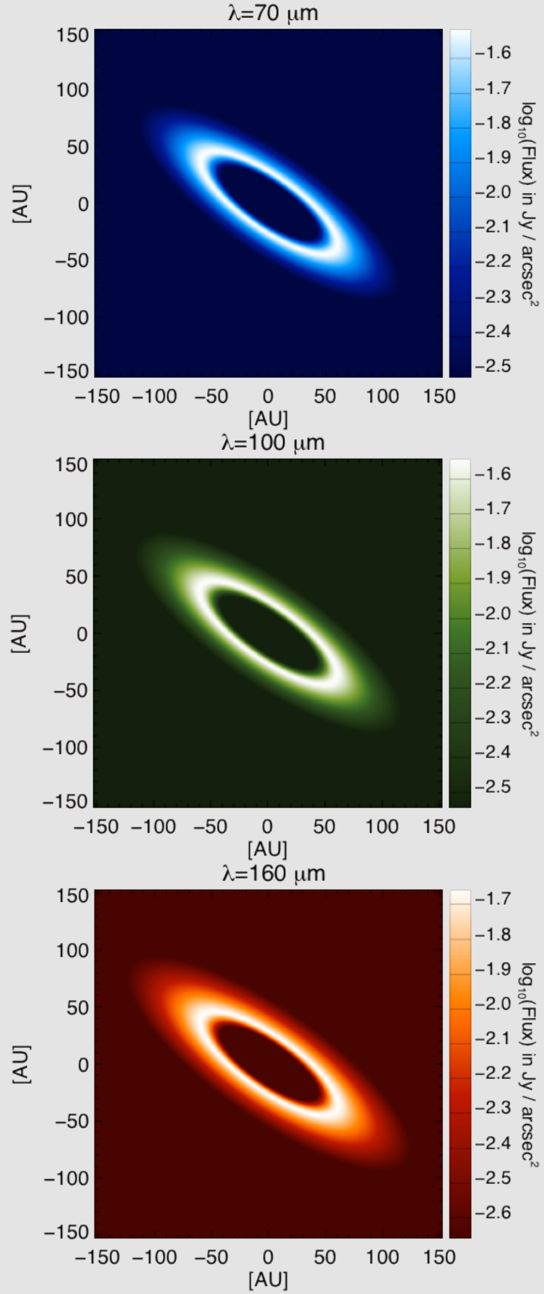
- Best fit:
  - Dust disk & grain properties:
    - Mass : 0.02 M_{earth}
    - 50-50 silicate-ice mixture
    - Coupled radial-size distribution
    - Weaker dust (Q_D*~10^7erg/g)
  - Parent belt:
    - Location: 75-125 AU
    - Eccentricities: 0.0…0.1
    - Mass : ~1000 M_{earth} (if 2 Gyr), but ~ 100 M_{earth} (if 0.5Gyr) (delayed stirring)



Summary of model results

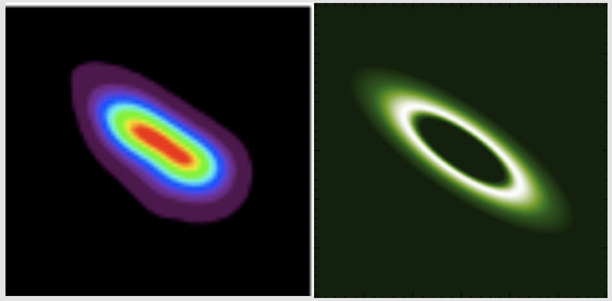
- Consistent results between the three codes:
  - Dust mass
  - Grain size distribution
  - Dust composition (ice likely)
  - Parent belt position at ~ 80AU
  - Dust surface density consistent with a collisionally active debris disk
- Open questions:
  - Lacking inner (<5”) 70µm emission (ACE)
  - SAnD also finds an alternative fit

Our unconvolved view of the q^1 Eri Kuiper Belt at PACS wavelengths



Conclusions

- **OBSERVATIONS**
  - Images of the exosolar Kuiper belt with unprecedented resolution and sensitivity
  - Inner gap seen in thermal emission at <100μm for the first time (after deconvolution)



- **MODELS:**
  - Degeneracy between dust properties and disk structure broken thanks to the PACS images
  - Probing dust composition: silicate-ice mixture likely (F8V!)
  - Probing collisional history: support to delayed stirring (self-stirring by Plutos. or stirring by q^1Eri c, or even by q^1Eri b)
  - Rough constraints on material strength: weaker dust
- **DUNES "toolbox" works fine, we are ready for more data**

- *More about q^1 Eri: poster by LISEAU*
- *More about OTKP DUNES: talk by EIROA*