since 1558

Debris Disks and Their Dust

Sebastian Müller

Collaborators

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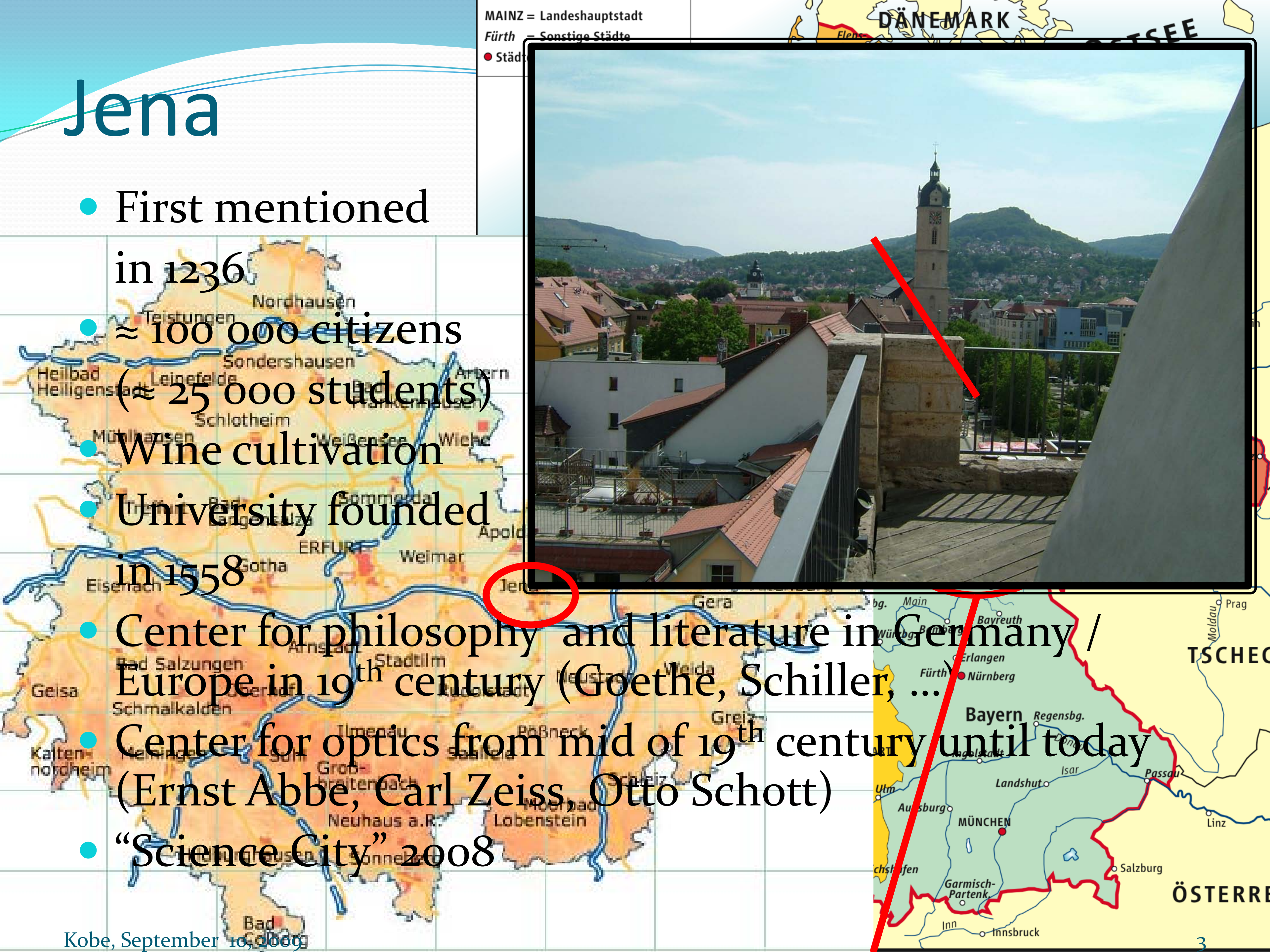
Germany

Before Starting…

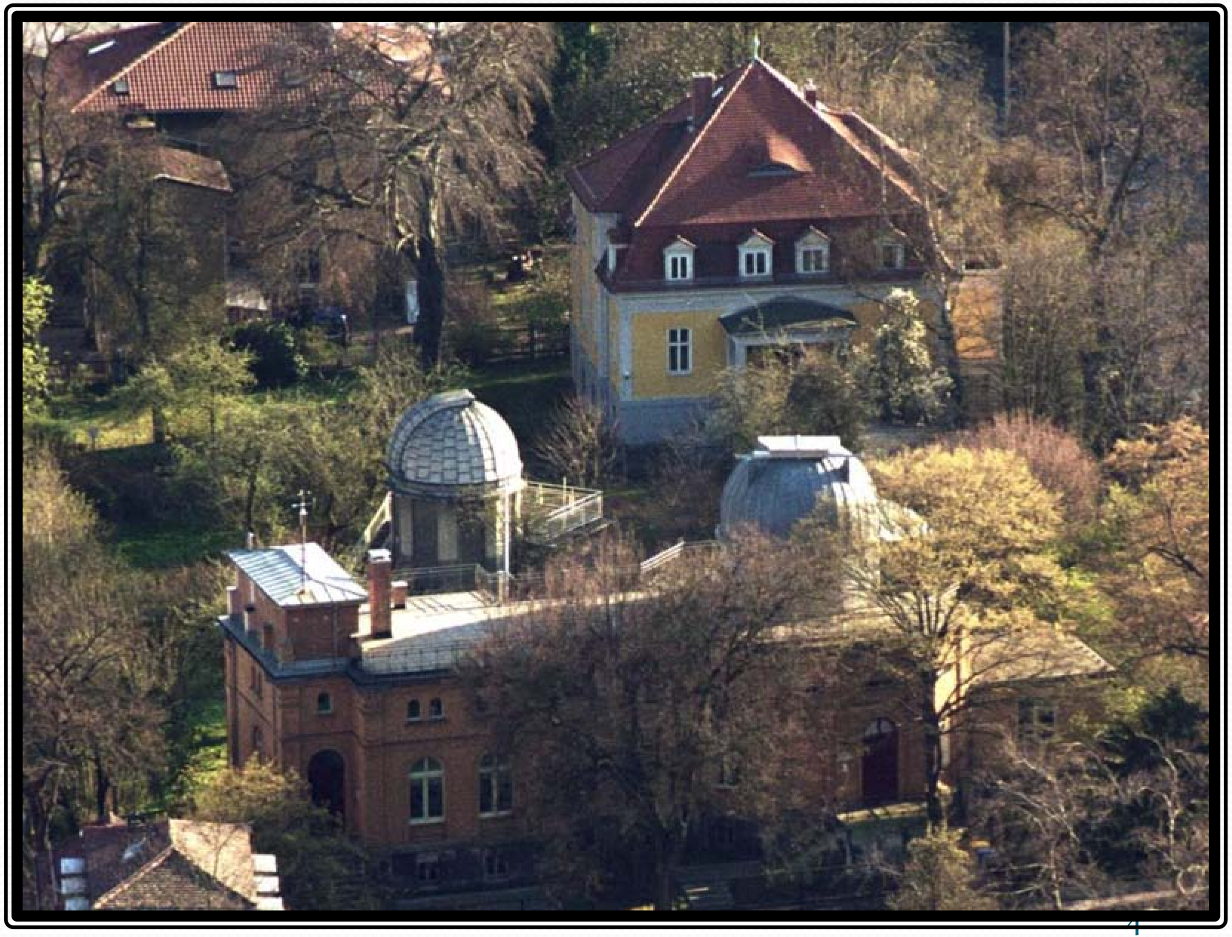
… let me introduce myself.

Jena



- First mentioned in 1236
- ≈ 100 000 citizens (≈ 25 000 students)
- Wine cultivation
- University founded in 1558
- Center for philosophy and literature in Germany / Europe in 19th century (Goethe, Schiller, ...)
- Center for optics from mid of 19th century until today (Ernst Abbe, Carl Zeiss, Otto Schott)
- "Science City" 2008

The Astrophysical Institute



The Astrophysical Institute

The observer group: Prof. R. Neuhäuser

- Search for exoplantes
- Neutron stars

The Astrophysical Institute

The laboratory group: Dr. H Mutschke

- Spectroscopy on dust from UV to mid-IR

The Astrophysical Institute

The theory group: Prof. A. V. Krivov

- Protoplanetary disk modeling
- Giant planet formation
- Debris disk modeling

Now let‘s get started!

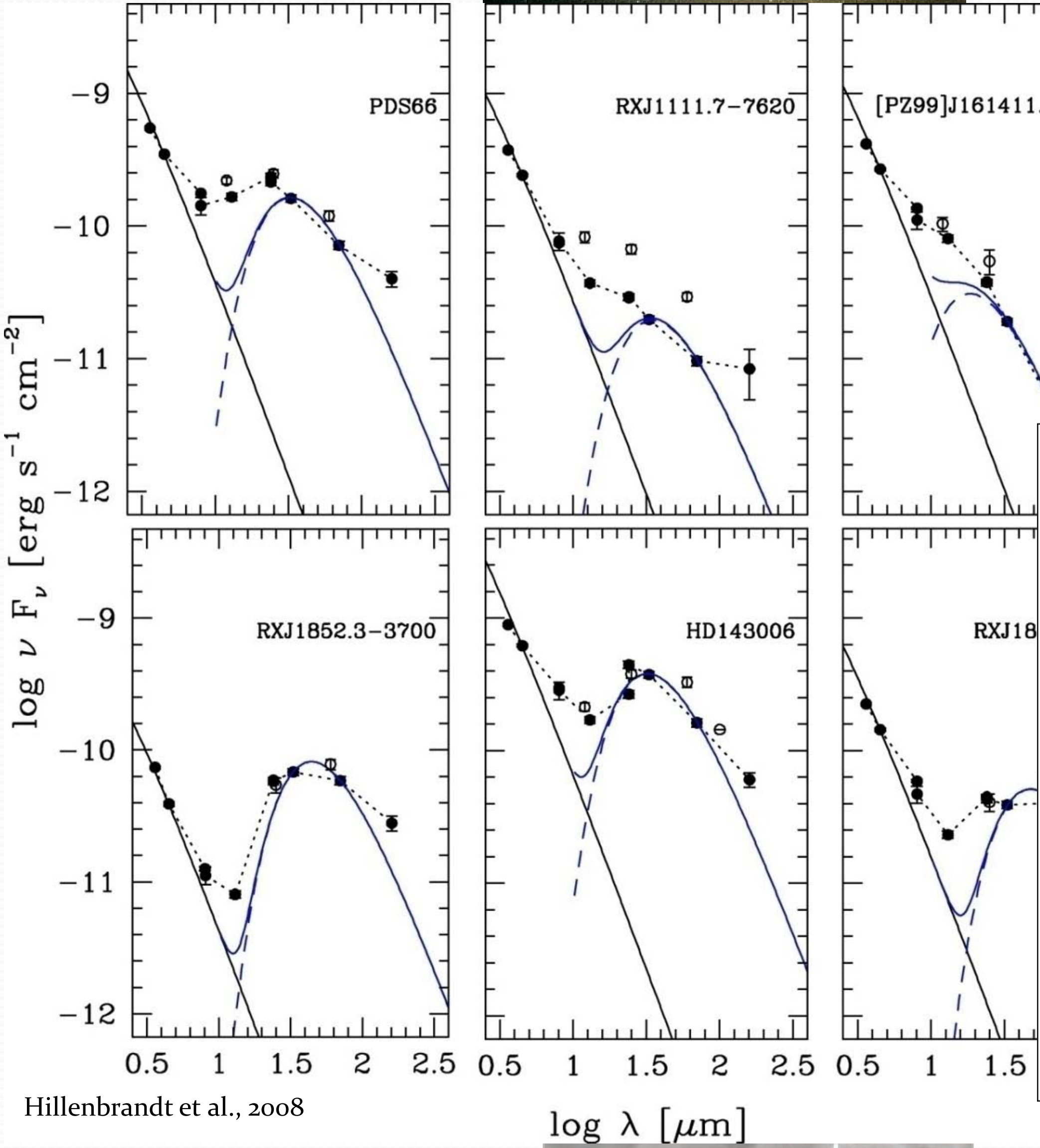
Outline

- Definition of debris disks
- Modeling of debris disks
  - Classical Approach
  - New Approach
- Outlook
- Summary

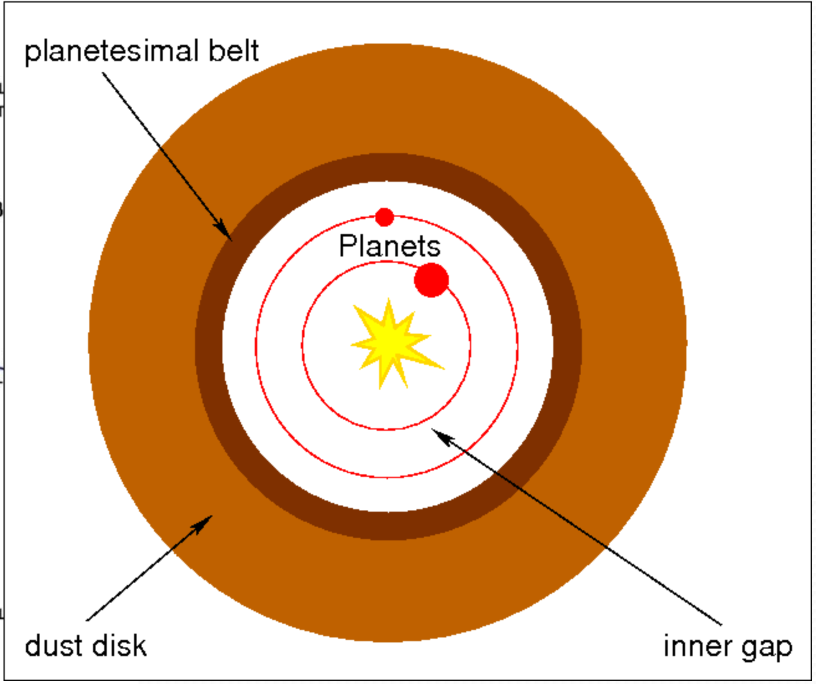
Debris Disks

An introduction

Definitio



Hillenbrandt et al., 2008



Information Sources

- Scattered stellar light: visual to near-IR
  - → Photometry
  - → Imaging
- Thermal emission of dust: mid-IR to radio
  - → Photometry
  - → Spectroscopy
  - → Imaging

Findings:

- ~ 15 % of MS stars host debris disks
  → Similar frequencies for AFGK stars
  (earlier types my be slightly favored)
  (e.g. Trilling et al., 2007, 2008; Hillenbrand et al., 2008)
- Strength of excess decreases with age
  (Zuckerman & Song, 2004; Moór et al., 2006)
- No correlation with metalicity
  (Greaves et al. ,2006; Beichman et al., 2006)

Debris Disk Modeling

It‘s all about dust!

Classical Approach

TABLE 2

Spitzer PHOTOMETRY IN mJy

Source	3.6 μm	4.5 μm	8.0 μm	13 μm[a]	24 μm	33 μm[a]	70 μm	160 μm
HD 105	1022.7 ± 22.0	645.4 ± 14.8	[illegible]	[illegible]	28.3 ± 1.2	20.5 ± 1.6	141.2 ± [illegible].3	110.1 ± 16.7
HD 377[b]	1029.1 ± 22.1	648.6 ± 14.9	234.7 ± 5.0	81.6 ± 5.0	36.6 ± 1.5	37.8 ± 2.7	162.0 ± [illegible]9	187.5 ± 50.4

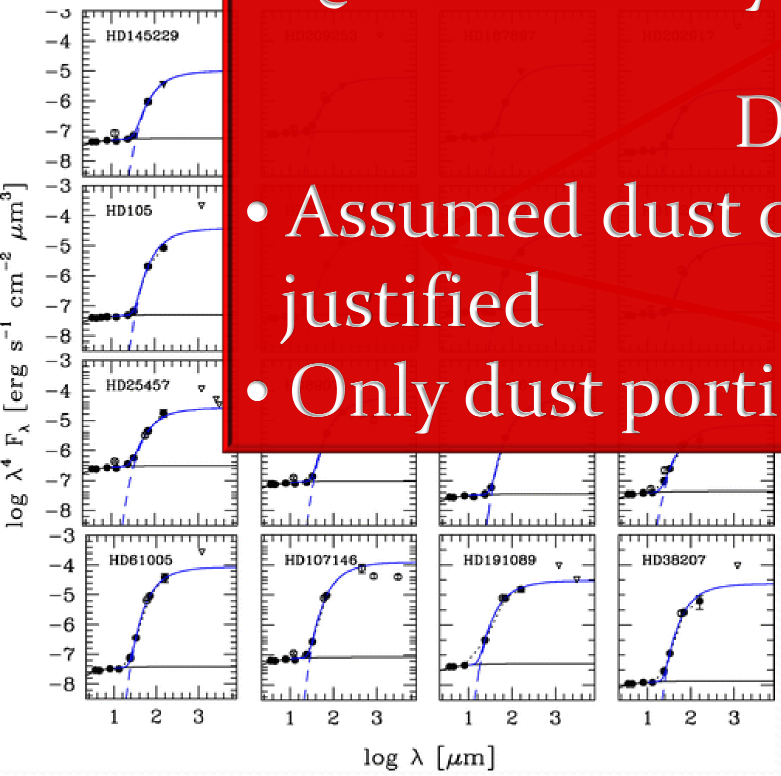
Hillenbrand et al.

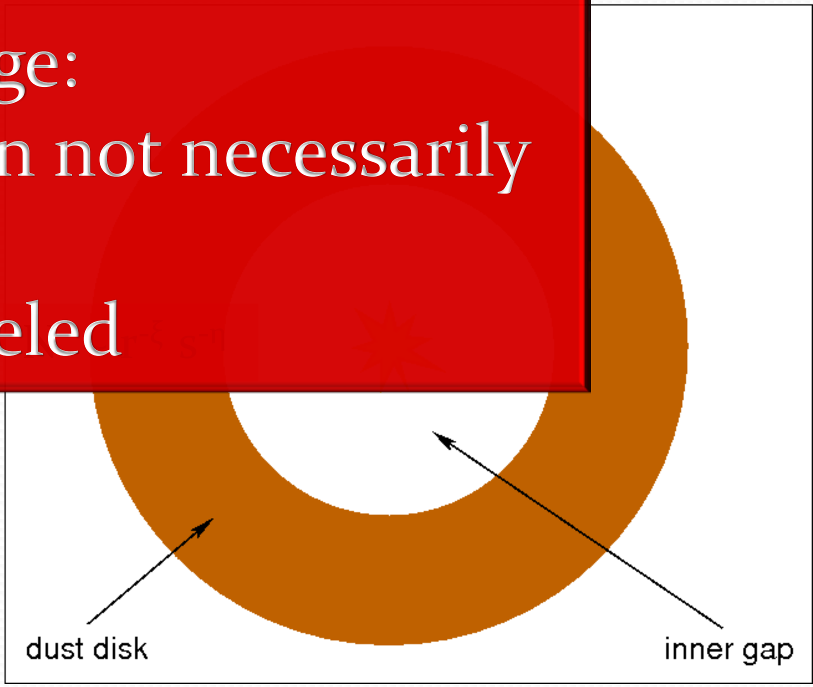
Advantage:

- Quick and easy to use

Disadvantage:

- Assumed dust distribution not necessarily justified
- Only dust portion is modeled

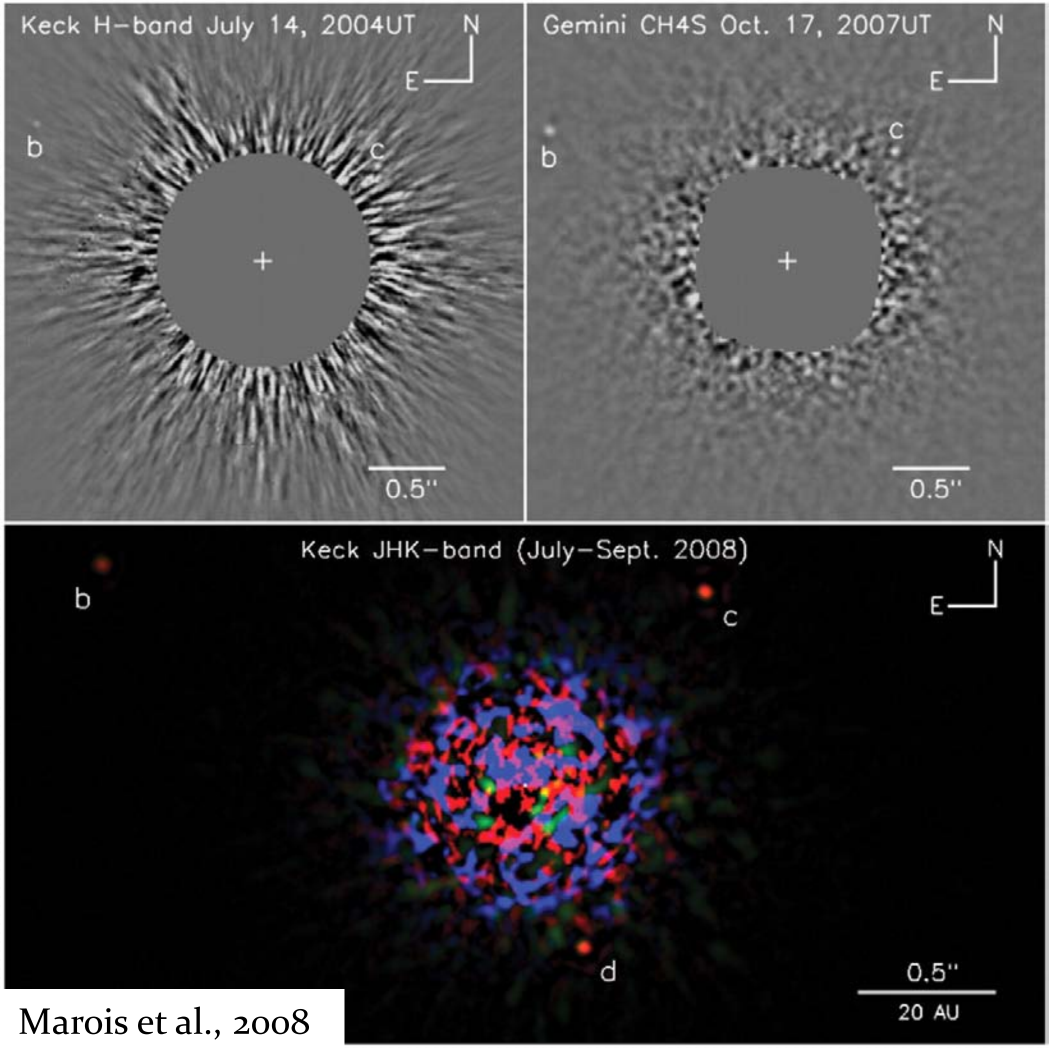




Classical Approach - Application

Investigation of the system HR 8799

- A5 V star at 40 pc
- IR-excess long known
- Special:
  3 planets discovered!

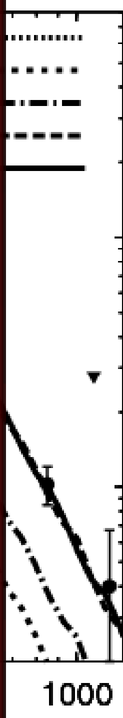


Marois et al., 2008

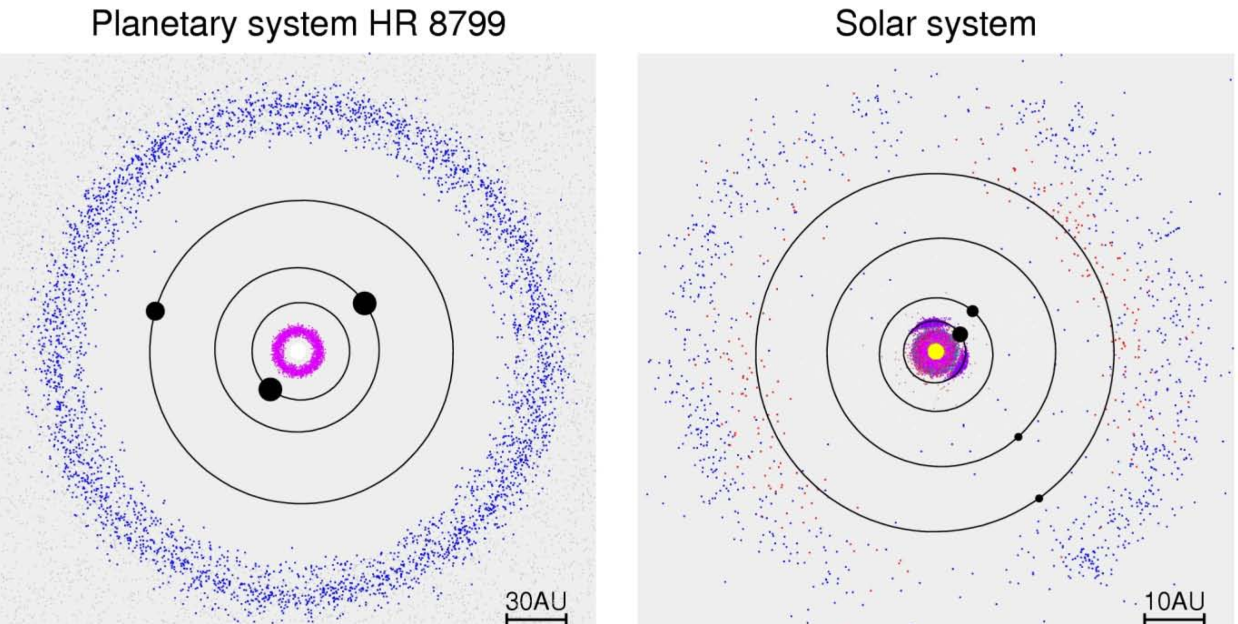
Reidemeister, Krivov, Schmidt, Fiedler, Müller, Löhne, Neuhäuser, A&A, 2009

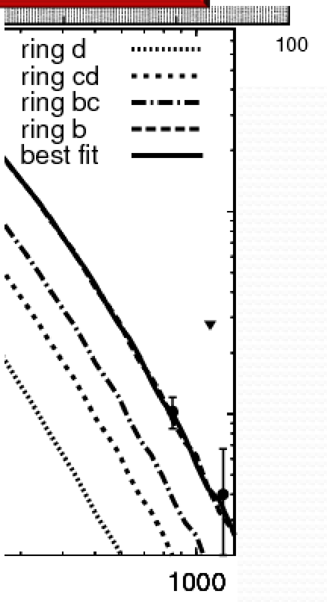
Results:

- Favor a rather younger age (≤ 50Myr)
- Nearly pole-on (20 – 30°)
- Evolutionary models suggest masses ≤ 7 - 10 M_{Jup}
- Planets stable for 5 - 13 M_{Jup} depending on systems orientation
  → higher masses require 2 : 1 resonance
- Planetesimal belts stable
- SED consistent with modeled planetesimal location
  → dust masses of $1\cdot10^{-5}$ and $4\cdot10^{-2}$ M_{Earth}



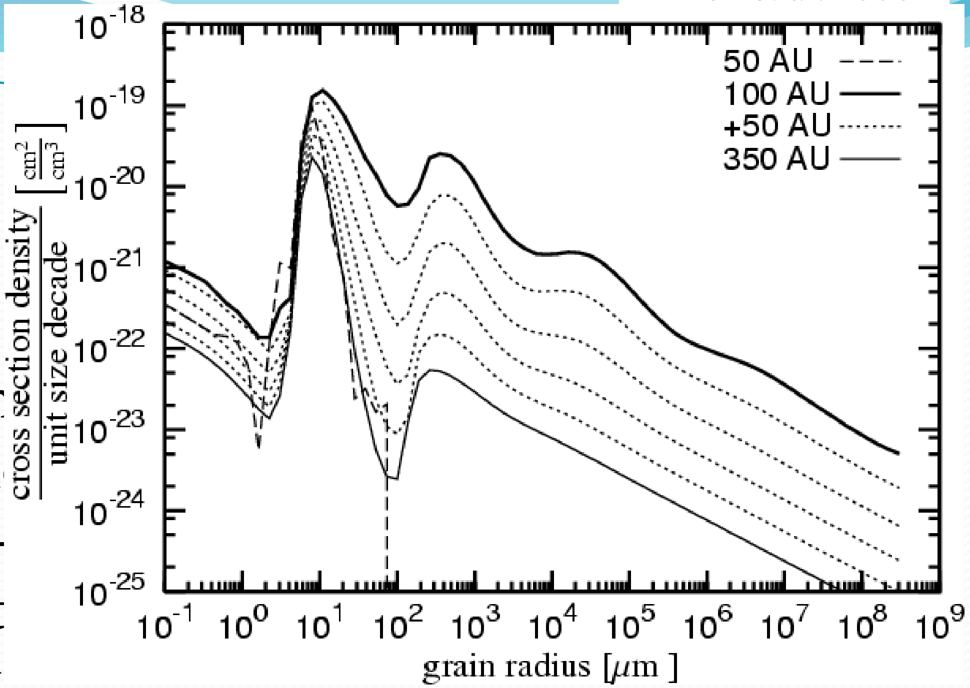
- Dust
- Plane
  - Ma
  - Sta
- Stabi





New Approach

Krivov et al. 2006



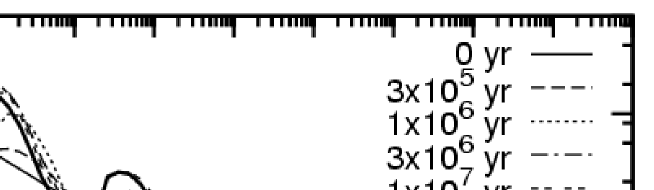
Collisional model: ACE (Ar

Typical ACE result:

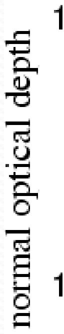
- Solving Boltzmann-Smoluch
- Assumptions: - steady-
  - azimut
- Acting mechanisms: - gravity
  - collisions

    * fragmentation (e.g. Takagi et al. 1983, Arakawa et al. ???)

    * cratering (e.g.)
  - direct radiation forces
  - Poynting-Robertson drag
  - wind drag



Krivov et al., 2006



New Approach

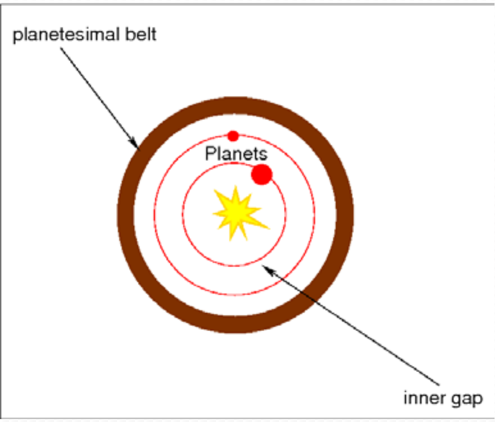
Information

Choose initial planetesimal belt

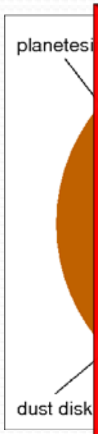
Modeled debris disk

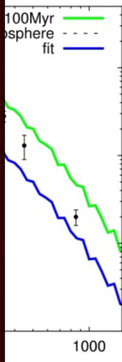
Fitting

Compare to observational data



Collisional Model





Attention:

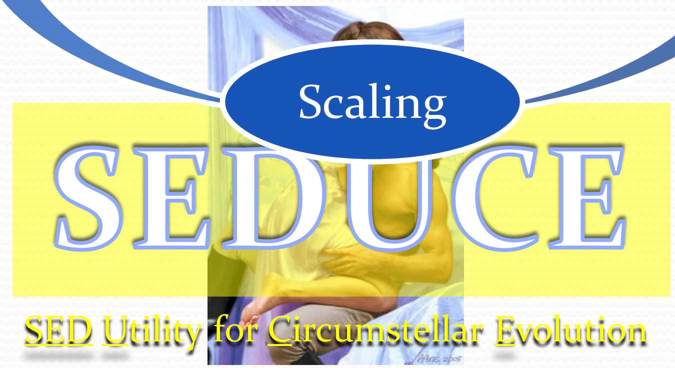
Fitting only possible if no transport mechansism are included!

(Löhne, Krivov & Rodmann, A&A, 2008; Krivov, Müller, Löhne &, Mutschke, ApJ, 2008)

ACE

Analysis of Collisional Evolution

Scaling



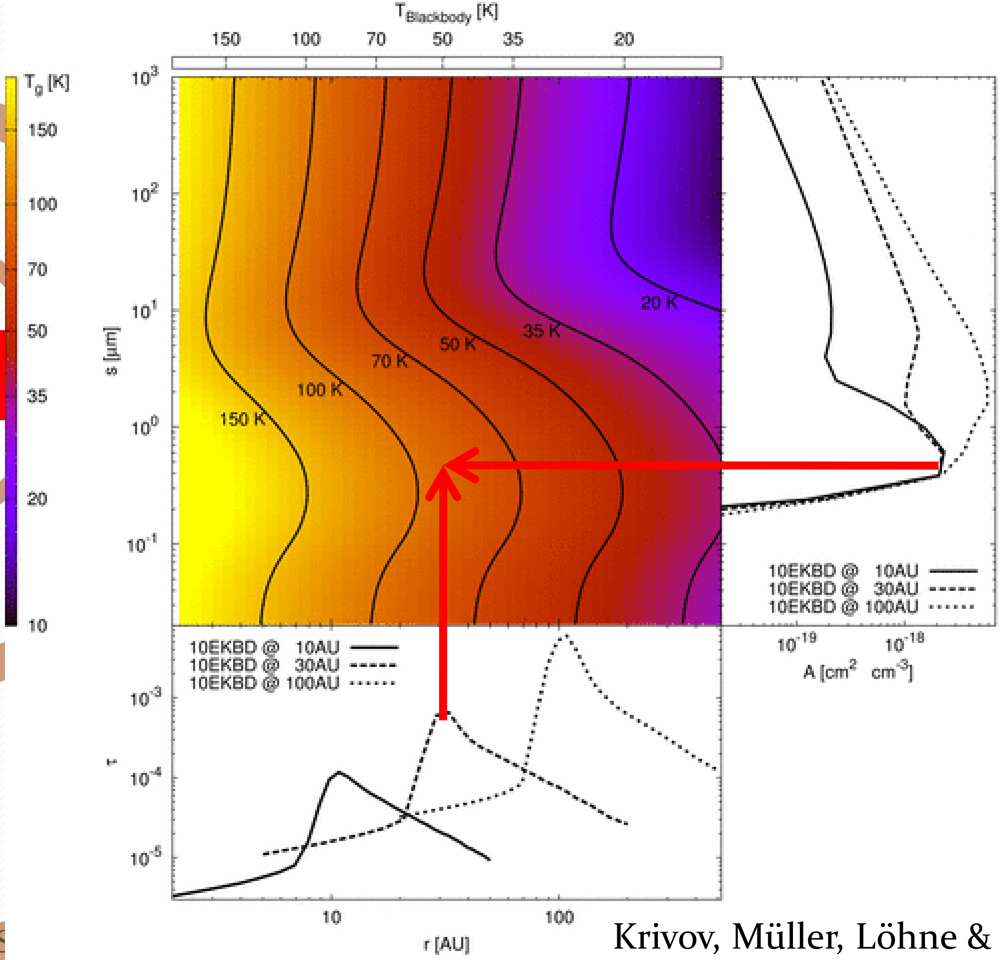
SEDUCE

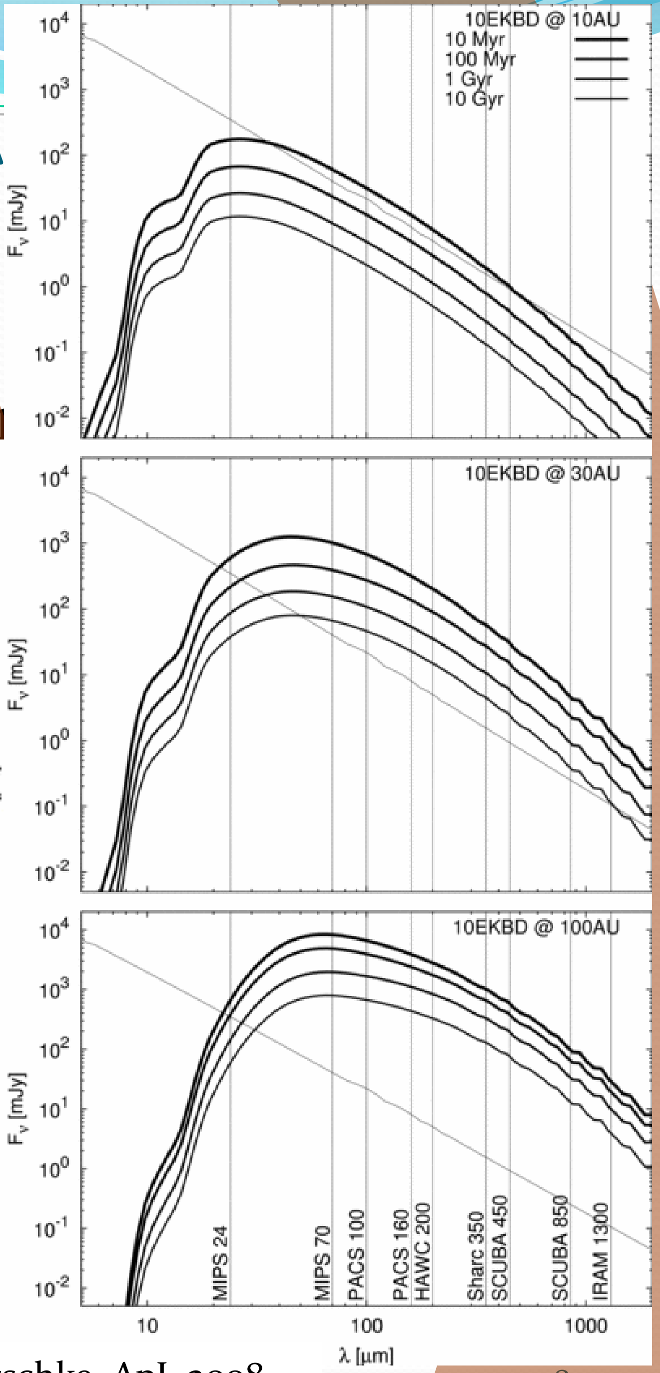
SED Utility for Circumstellar Evolution

New Approach – 1st A

10EKBD
@
100AU

Grid of reference disks for Sun-like sta



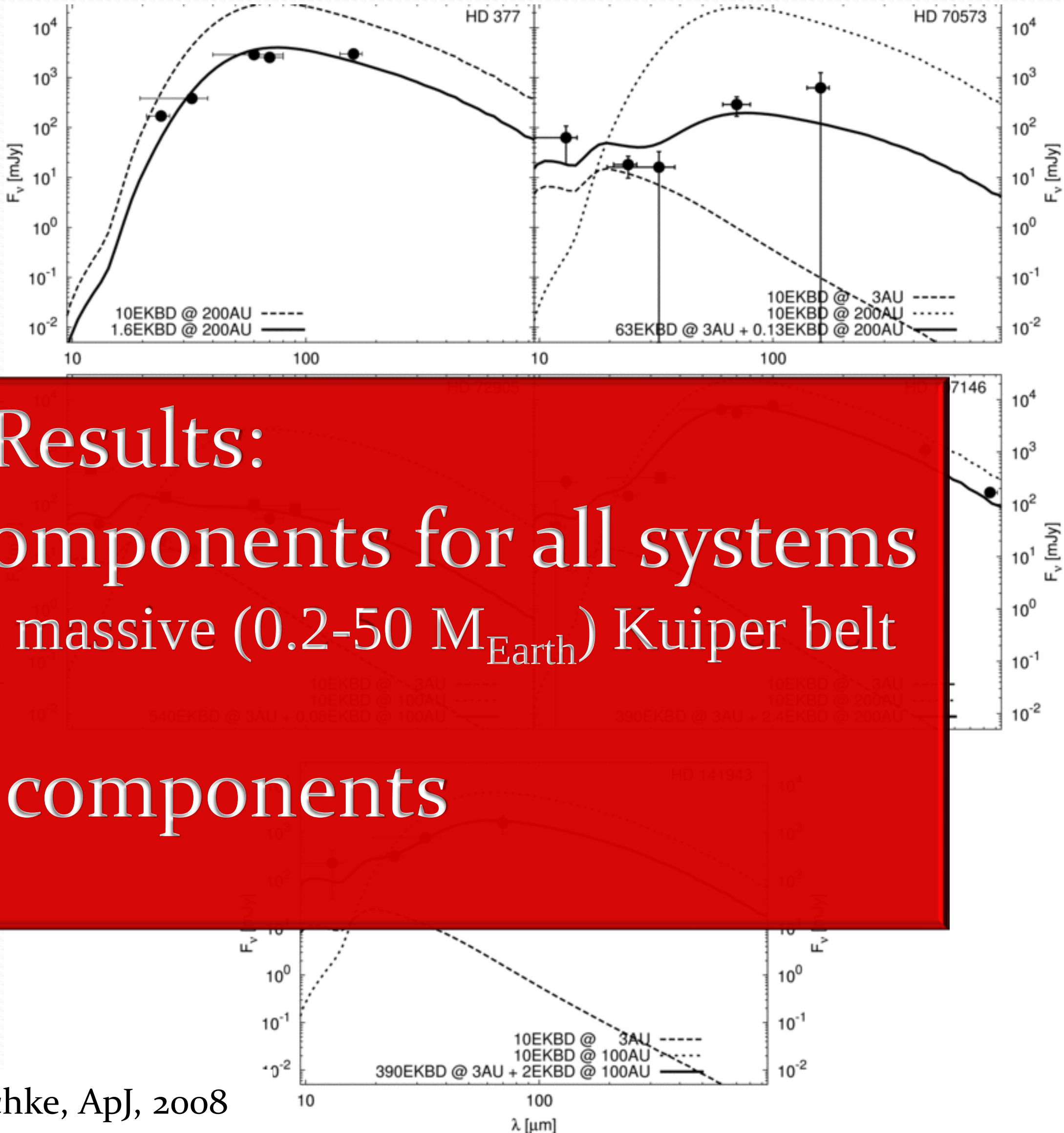


Krivov, Müller, Löhne & Mutschke, ApJ, 2008

New Approach – 1st Approach

5 well observed disk systems around G2 V stars:

Star
HD 377
HD 705
HD 729
HD 107
HD 141



Results:

Cold dust / outer components for all systems

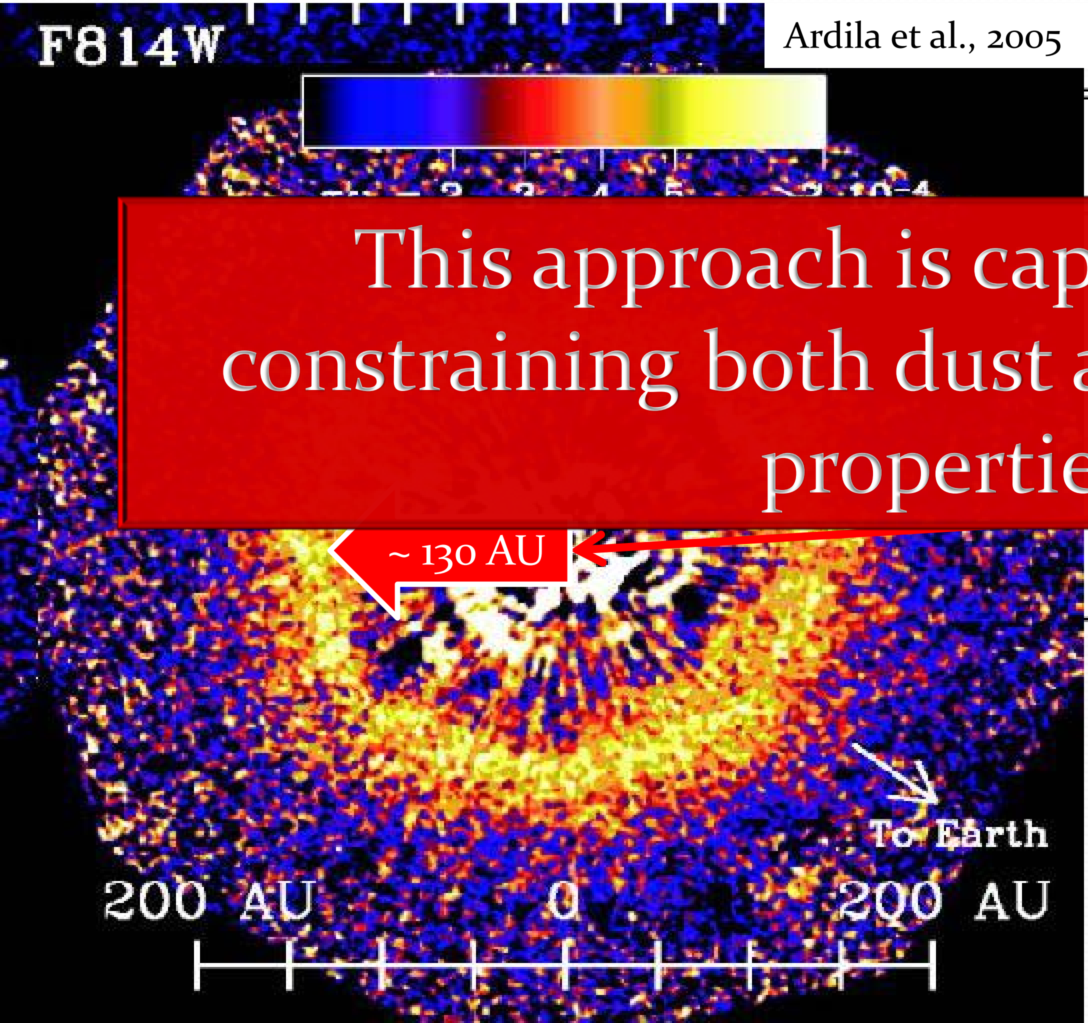
→ large (100-200 AU) and massive (0.2-50 M_{Earth}) Kuiper belt analogs

Warm dust / inner components

→ asteroid belt analogs?

Krivov , Müller, Löhne & Mutschke, ApJ, 2008

New Approach – 1^{st} Approach



Ardila et al., 2005

M_{disk}[a] ($M_\oplus$)	R_{belt}[b] (AU)	M_{dust}[c] ($M_\oplus$)	T_{dust}[d] (K)
[illegible]	200	3.1×10^{-2}	40
(0.0063) 0.0046	3	1.4×10^{-7}	200
(2.6) 2.5	200	2.0×10^{-3}	40
[illegible]	[illegible]	[illegible]	200
(0.23) 0.23	100	2.1×10^{-4}	50
(0.039) 0.023	3	4.9×10^{-7}	200
(47) 47	200	[illegible]	40
(0.039) 0.027	3	8.0×10^{-7}	200
(6.1) 6.1	100	5.5×10^{-3}	50

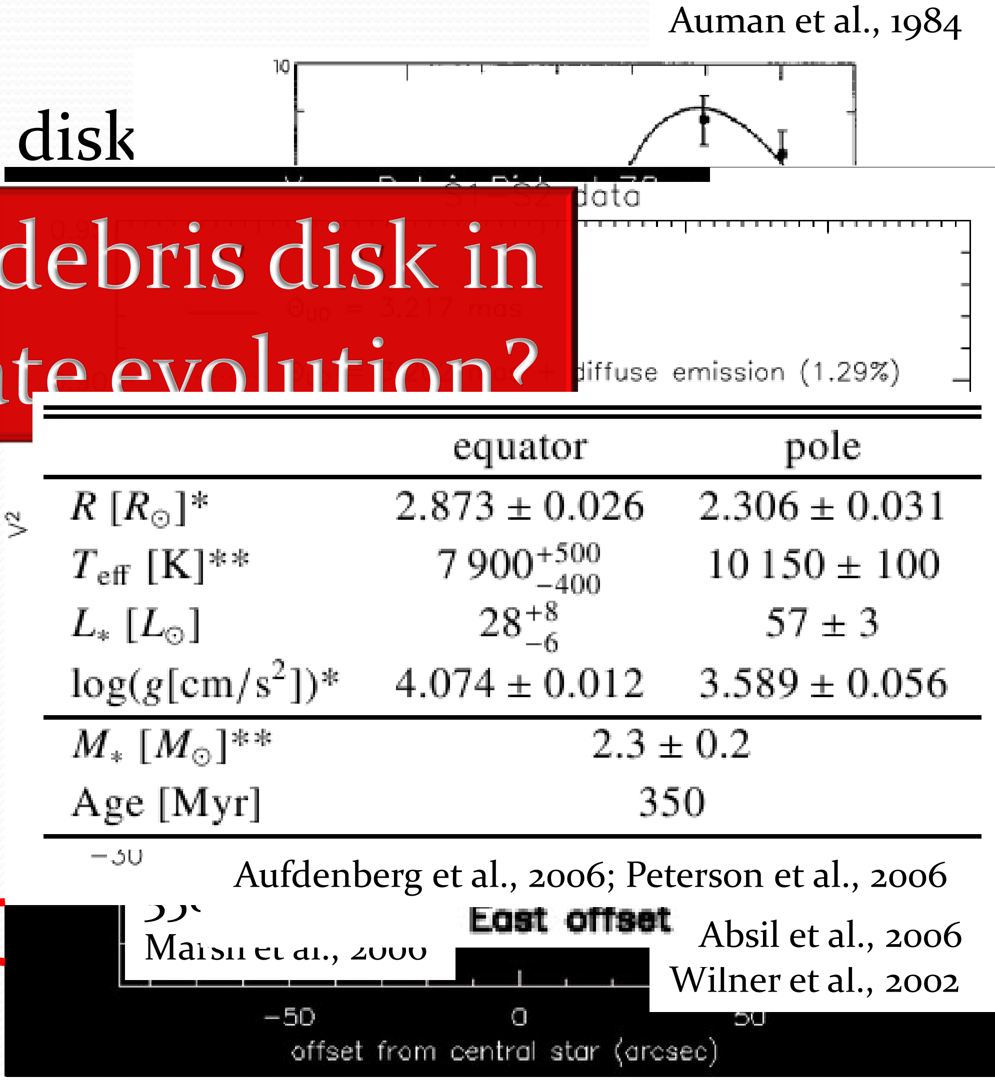
This approach is capable of easily constraining both dust and planetesimal properties!

New Approach – 2nd Application

Modeling of the Vega debris disk

- A0 V star at 7.76 pc
- Age of ~ 350 Myr
- Archetypal system
- Many curiosities:
  - Fast rotator
  - Very massive dust disk
  - Disk structure in longer wavelengths' images
  - ~~First discovered 'exozodi'~~

Is the Vega debris disk in a steady-state evolution?



Auman et al., 1984

	equator	pole
$R\ [R_\odot]$*	2.873 ± 0.026	2.306 ± 0.031
$T_{\rm eff}$ [K]**	$7\,900^{+500}_{-400}$	$10\,150 \pm 100$
$L_*\ [L_\odot]$	28^{+8}_{-6}	57 ± 3
$\log(g[\rm cm/s^2])$*	4.074 ± 0.012	3.589 ± 0.056
$M_*\ [M_\odot]$**	2.3 ± 0.2	
Age [Myr]	350	

Aufdenberg et al., 2006; Peterson et al., 2006

Marsh et al., 2006

Absil et al., 2006

Wilner et al., 2002

New Approach – 2nd Application

Model	L_* [$L_\odot$]	T [Myr]	$a_{\rm inner}$ [AU]	$a_{\rm outer}$ [AU]	$e_{\max}$	$i_{\max}$	composition	collisions	$Q_{D,s}$ [erg/g]	b_s	η
										0.37	1.833
										—	1.95
										—	—
										—	—
										—	—
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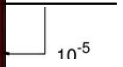
										—	—
										0.2	—
										0.45	—
										—	1.6
										—	1.95



Result:

General Agreement with observations

→ Vega disk observations not contradictious to steady-state dust production

→ model constraints:

- – disk older than several 10 Myr
- – Intermediate luminosity required
- – cratering collisions essential

- Combine to best fit

Müller, Löhne & Krivov, ApJ, subm.

Outlook

If you want to make God laugh, tell him your future plans.

(Woody Allen)

Waiting for Herschel

- Largest IR telescope to date
- Launched on May 14
- 3 year mission in Lagrange point L2
- First tests successful
- Open Time Key Project DUNES
  - → use PACS and SPIRE
  - → valuable information in far IR and submm

Apply new modeling approach:

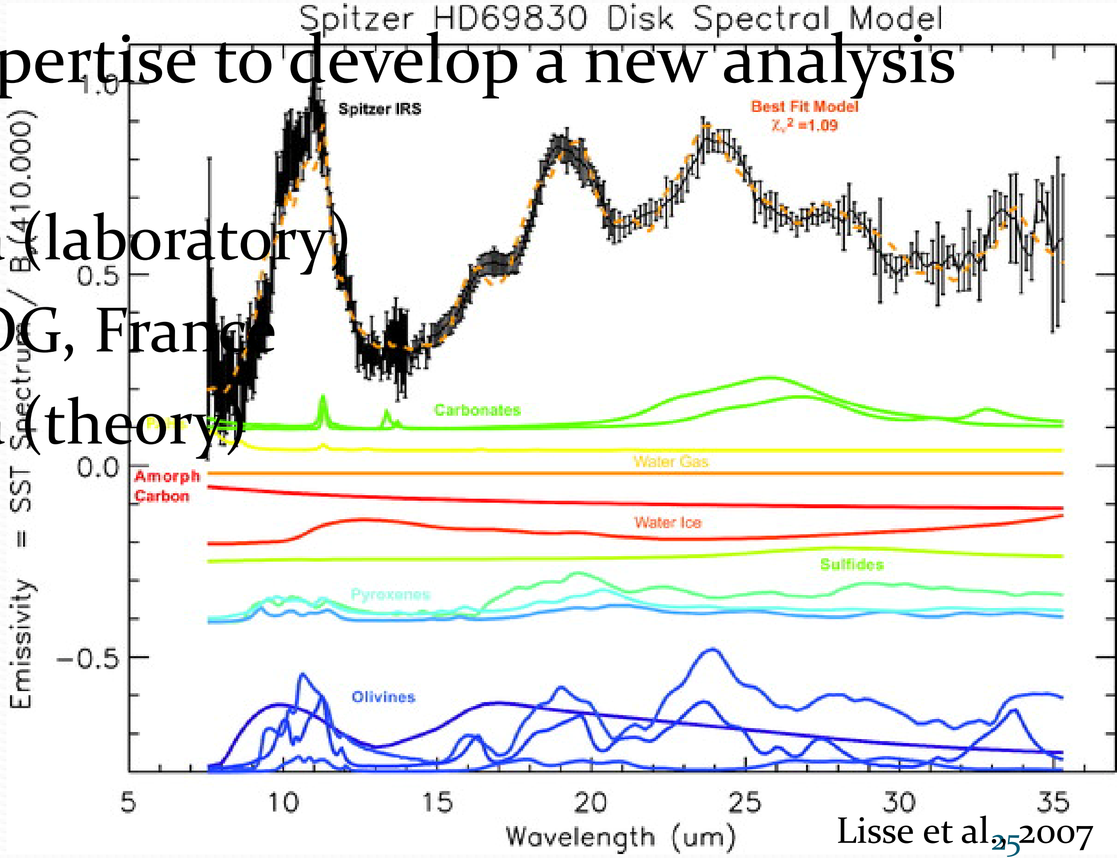
- Covers interesting wavelength region
- Several systems expected to be resolved

Improve new modeling approach:

- Unknown sensitivity
  → other mechanisms need to be included

Coming to disk chemistry

- High resolution spectra in mid-IR provide insight in composition of disks (e.g. silicate features)
- Combine different expertise to develop a new analysis approach:
  - Mineralogy: Jena (laboratory)
  - Observations: LAOG, France
  - Dynamics: Jena (theory)



Lisse et al. 2007

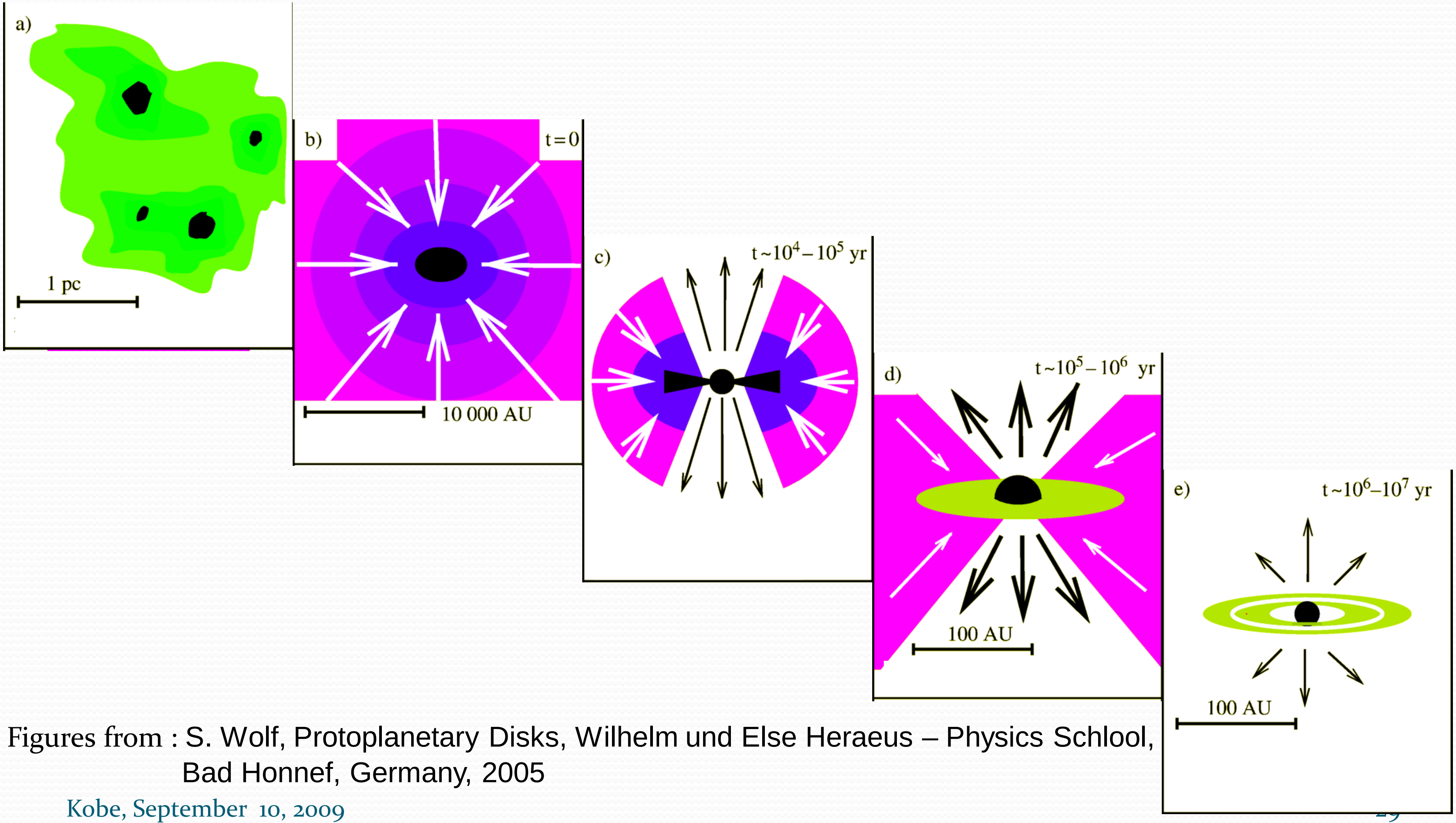
Summary

- Debris disks comprise dust and planetesimals but are observable only by the dust's (thermal) emission
- The classical way of modeling debris disks assumes simple analytical expressions for the dust distribution
  - Applied to the planetary system HR 8799 we could show that the SED supports our results from dynamical investigations
- We proposed a new way of modeling based on our collisional code ACE
  - A grid of thus modeled reference disks can be used to constrain both dust and planetesimal properties by "fitting" observed SEDs
  - Applied to the Vega system we could show that a steady-state collisional dust production is in agreement with the observations

Thanks for your attention!

ご清聴ありがとうございました。

Formation



Figures from : S. Wolf, Protoplanetary Disks, Wilhelm und Else Heraeus – Physics Schlool, Bad Honnef, Germany, 2005