Probing the NIR excess of Transitional disks with the Keck Interferometer

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Close companion or circumbinary disk material?

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“Disks in Garching”

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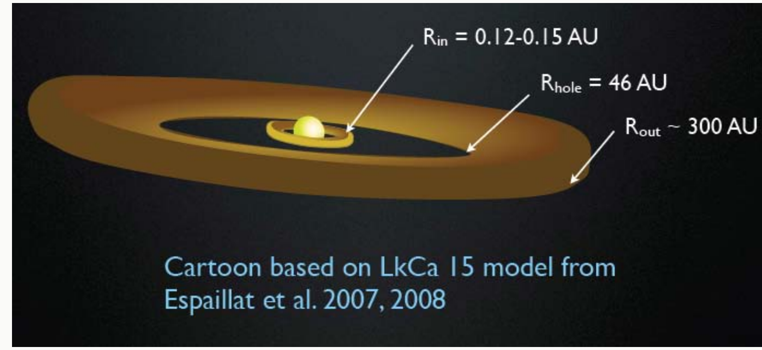
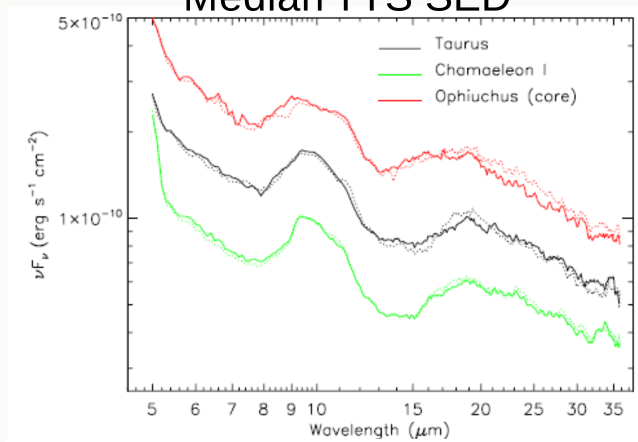
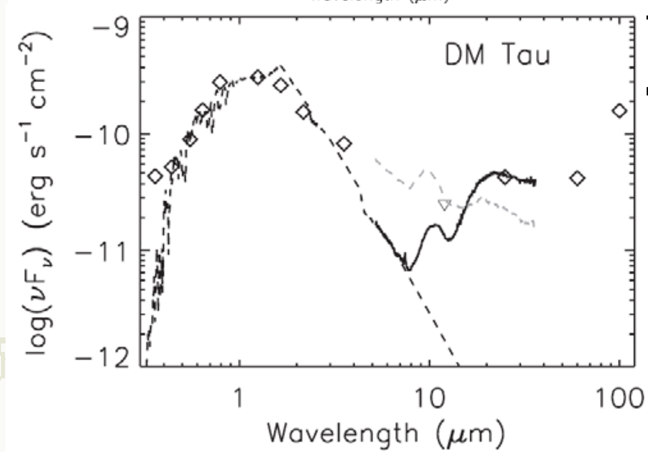
Overview

- **Transitional disks appear to be partially depleted of inner dust at (sub-) AU scales (several talks at this conference)**
- **Steep rise of mid-IR excess radiation (> 8um) is characteristic and is explained by an inner hole**
- **Small fractional abundance (few %) of transitional disks among TTS hints to a short (<Myr) phase of disk dissipation**
- **Disk evolution and dissipation from inside out would favour such a hole**



Median TTS SED





[Furlan + 06, 09]

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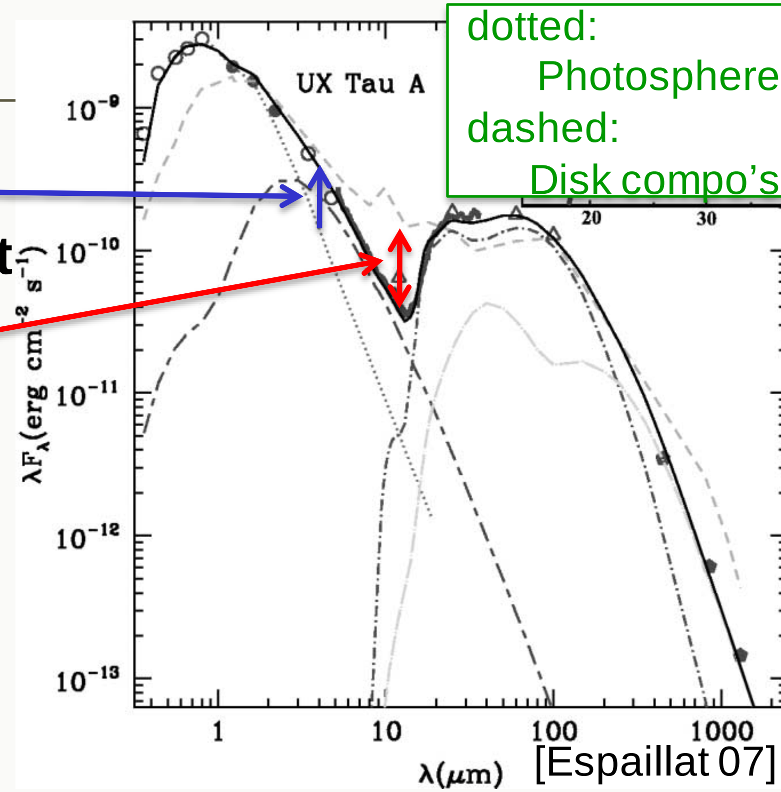
Overview

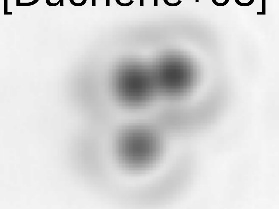
- **Sometimes NIR excess has been found as well. A significant amount of dust ($10^{-10..-9}$ $M_\odot$) has remained, and a planet might have opened the gap, instead of MRI or photoevaporation**
- **Missing angular resolution can lead to misinterpreting the SED: high resol. imaging reveals close companions in various cases**
- **There is enough YSO binaries around to populate the transitional disks [Ghez+93,97 Leinert+93; Simon+95, Mathieu92, Melo03]**

-> disks might be less "transitional" as thought



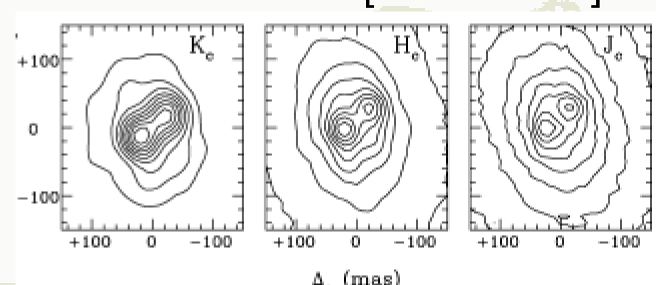
[Espaillat 07]

V773 Tau [Duchene+03]



3.8um, 1" across

CoKu Tau/4 [Ireland+ 08]



(talk by A. Kraus about aperture masking interferometry)

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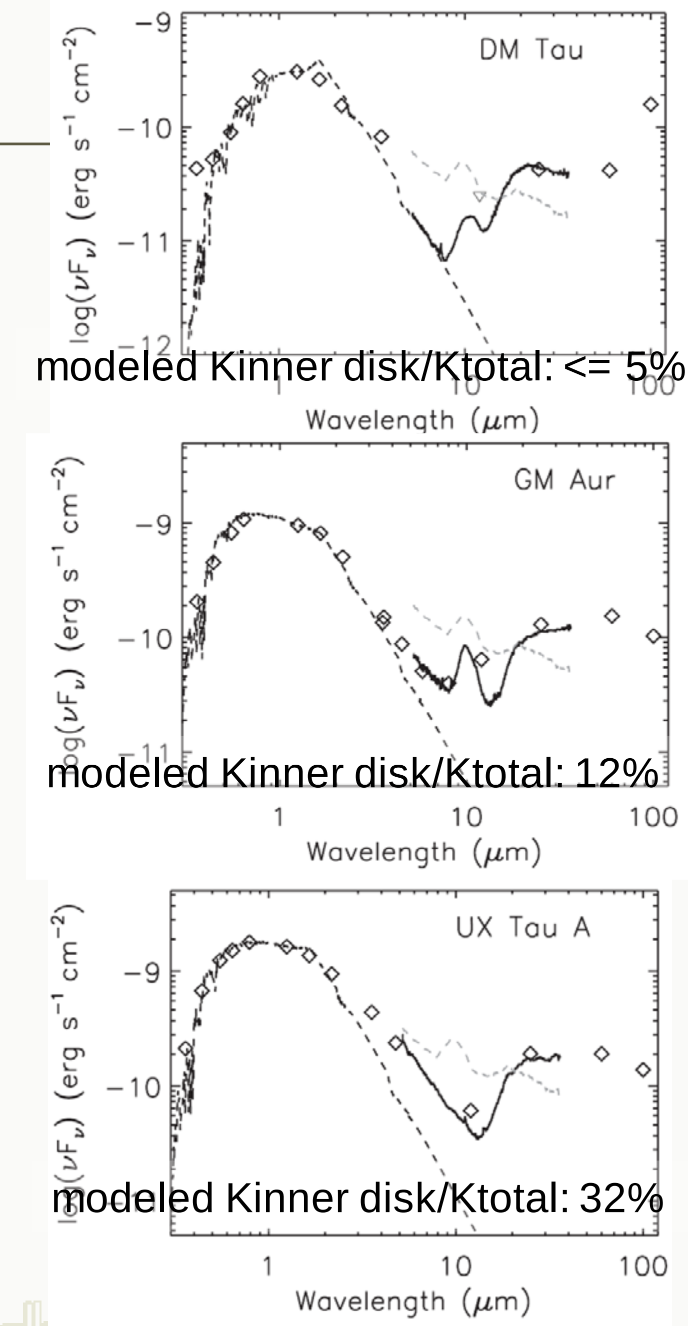
Overview

- **We observed five targets in the 1-2Myr young star-forming Taurus / Auriga and three stars in Ophiuchus**
- **Varius NIR excess and SED shapes**



[SED from Furlan +09]

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Overview

- **All our targets are accreting TTS (H-recomb. lines), in contrast to CoKu Tau/4**
- **Hole sizes are comparable**

	DM Tau[a]	GM Aur[a]	LkCa 15[b]	UX Tau A[b]	RY Tau[c]	CoKu Tau/4[f]
M_* ($M_\odot$)	0.65	1.2	1.1	1.5	2.0	0.5
R_* ($R_\odot$)	1.2	1.5	1.7	2.0	3.6	1.9 [h]
T_* (K)	3720	4730	4350	4900	5945 [d]	3720
L_* ($L_\odot$)	0.25	1.03	0.96	2.18	12.8	0.61 [h]
$\dot{M}$ ($M_\odot\,yr^{-1}$)	$2.0{\cdot}10^{-9}$	$1.0{\cdot}10^{-8}$	$2.4{\cdot}10^{-9}$	$9.6{\cdot}10^{-9}$	$2.5{\cdot}10^{-7}$	–
Spectral type	M1	K5	K5	K2	G1 [d]	M1.5
A_V	0.5	1.2	1.2	1.3	2.1	3.0 [g]
K_s mag. [e]	9.5	8.3	8.2	7.5	5.4	8.3 [g]
Inclination (deg)	40	55	42	60	25	50 – 75 [i]
R_{hole} [l] (AU)	3	24	46	56	[k]	10
$K_{inner\,dust}/K_{total}$	$\lesssim 0.05$	0.12	0.23	0.32	0.73	$\lesssim 0.05$
$R_{inner\,dust}$ [l] (AU)	–	< 5	0.13	0.17	0.25	–

Models and values from:
Calvet et al. (2005), Espaillat et al. (2007b), Akeson et al. (2005a), Calvet et al. (2004), Skrutskie et al. (2006), D'Alessio et al. (2005).

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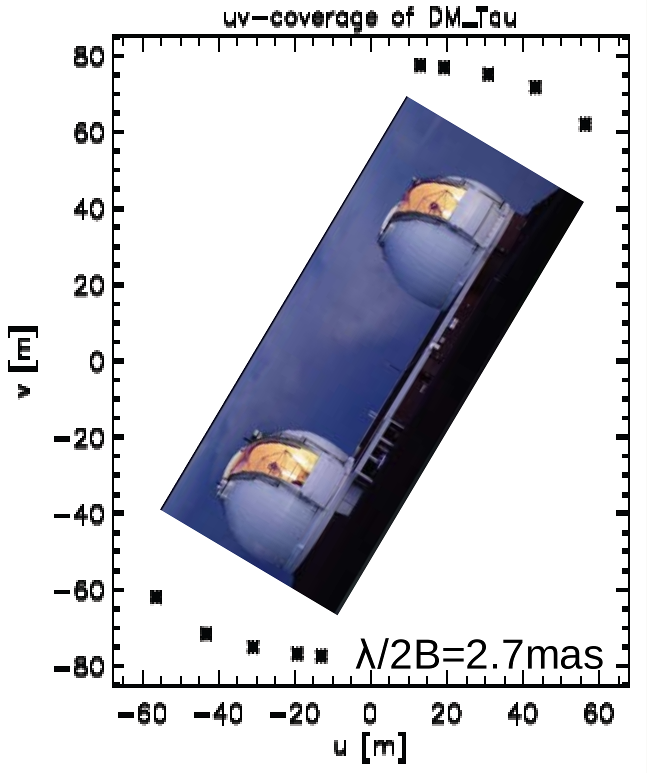
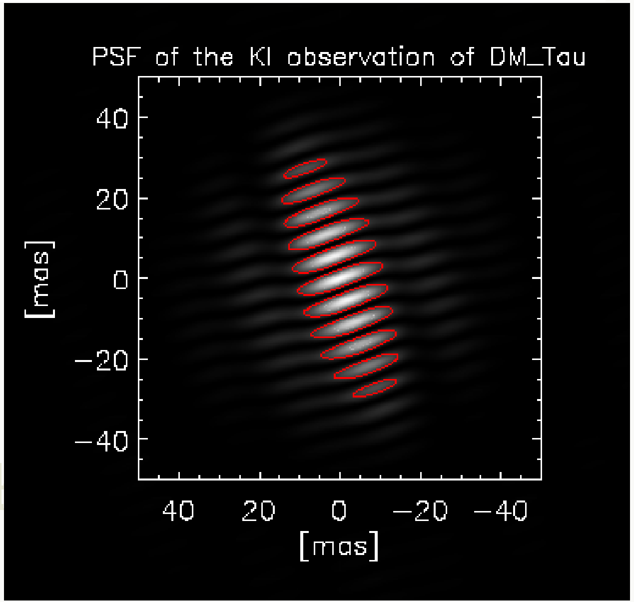
Overview

- **Our tool is the Keck Interferometer: 2.2um broad-band V^2-amplitudes at 85m results in 2.7mas resolution**
- **Excellent seeing (< 0.5”), and large apertures give high differential V2-precision (1-2%) down to K~10mag.**
- **Aperture synthesis due to earth’s rotation**





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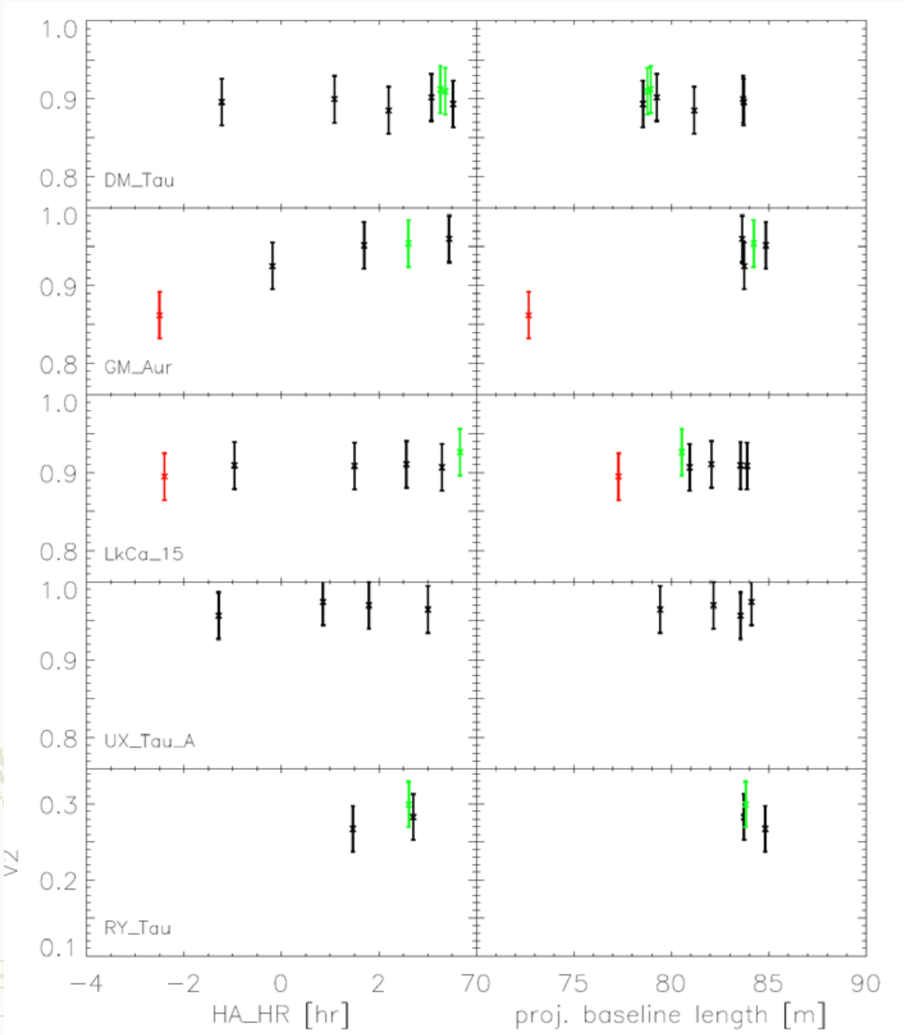
Resolving the stellar emission - Results

- **Binary range probed:**
  - Flux ratio: 1 – 0.05 (companion / primary)
    - Mass ratios down to 0.15 at 1 Myr (Palla & Stahler '99)
  - Separation 2.5 – 30 mas
    - 0.4-4 AU (projected)
  - Position angles: 0 – 360 deg
    - KI data is PA and Pri/Sec ambiguous
- **Complementary to previous single telescope aperture masking, which is sensitive down to 25~mas (Ireland&Kraus08)**
- **Quick look reveals:**
  - all targets are resolved
  - no V2-variation >= 0.2



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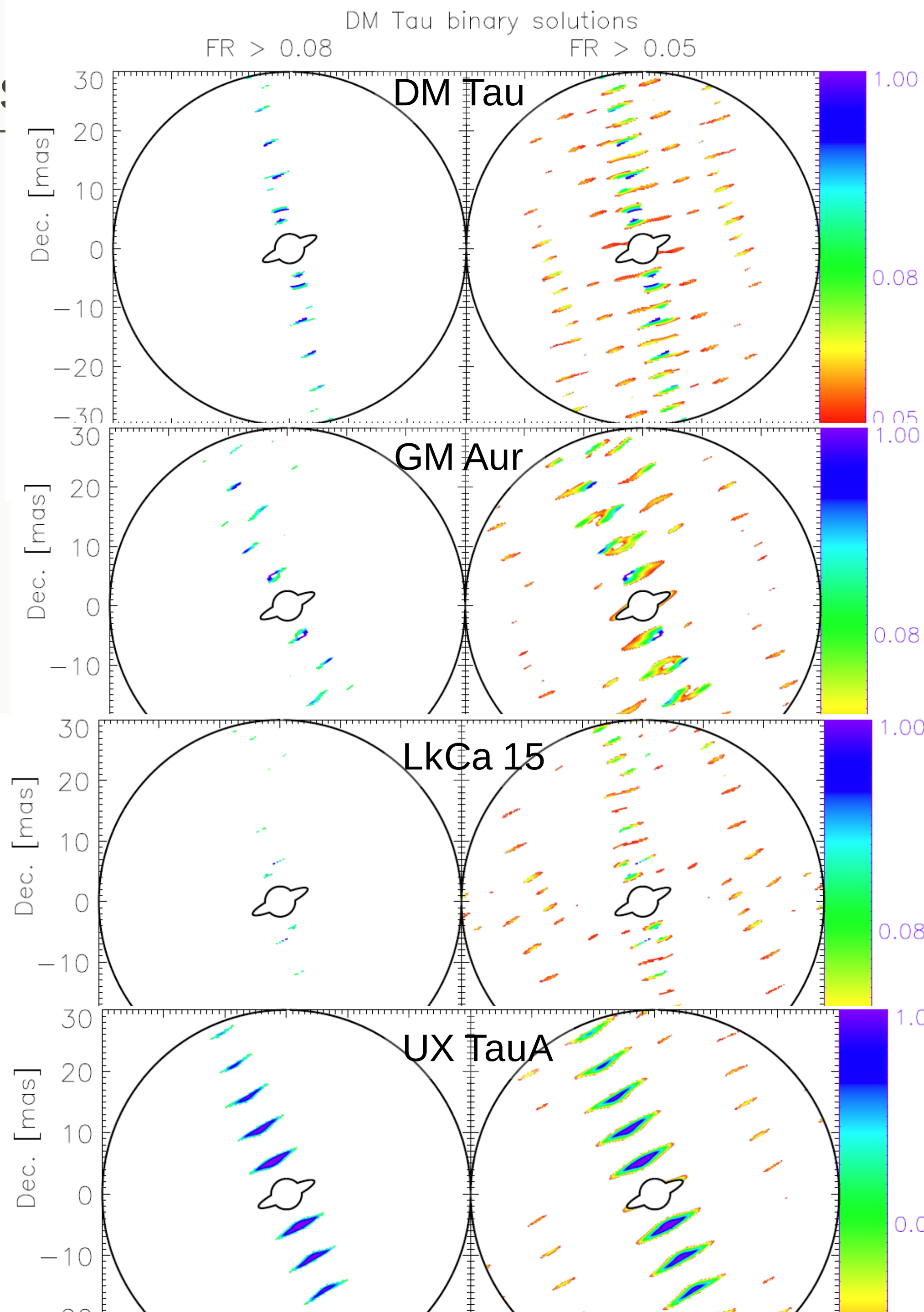
Resolving the stellar emis

- **At 99.7% confidence level ≥ 99 % (95 %) of the field-of-view are rejected**
- **Brighter companion solutions appear to be co-aligned with each other and with the KI baseline -> probably artificial solutions**
- **RY Tau has no solutions due to the addition of PTI data (different baselines)**



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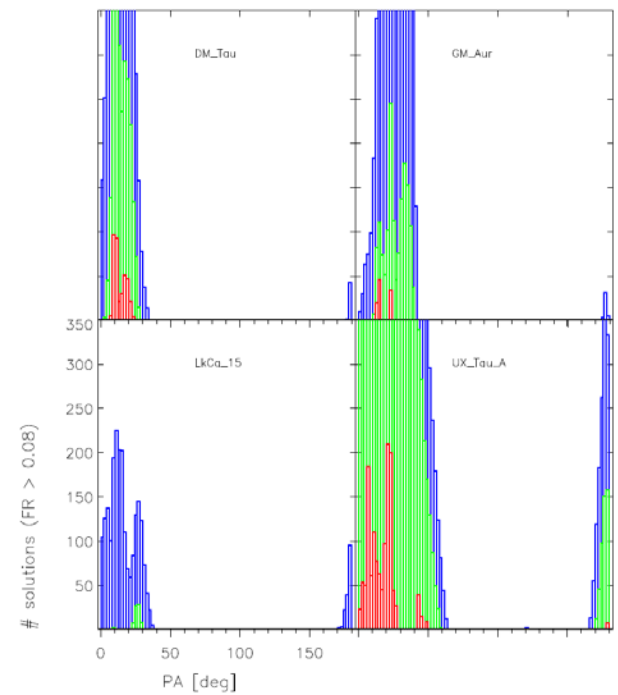
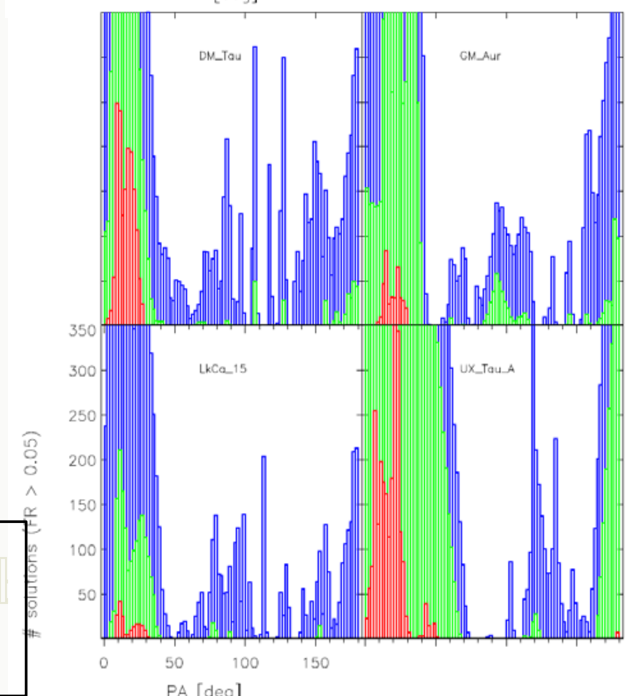
Resolving the stellar emission - Resul

- **Statistical analysis of the position angle of the solutions**
- **At the 3σ (1σ)-rejection level, there is no solution with FR ≥ 0.08 (0.05) outside a PA: 20±20 deg**
- **The probability of having two (three) co-aligned binaries in our five-target sample is 3% (0.4%)
  -> more than half of the sample does not harbor a binary**





Blue: 3σ-rejection
Green: 2σ-rejection
Red: 1σ-rejection

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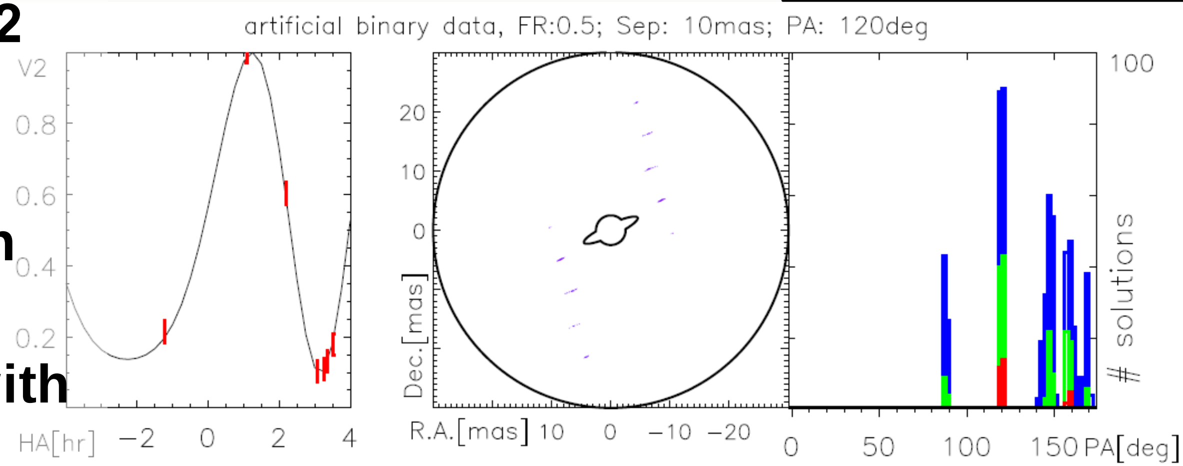
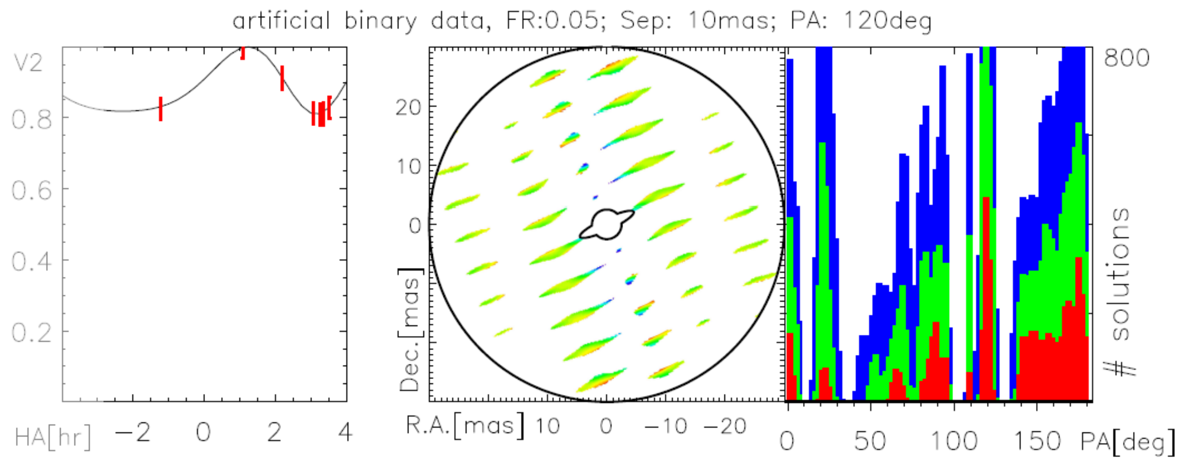
Resolving the stellar emission - Results

- **Probe sensitivity and analysis with mock data sets**
- **V2-variation ≥ 0.2**
- **Sampling is adequate**
- **Solutions peak in histograms**
- **No alignement with the KI baseline**

Blue: 3σ-rejection
Green: 2σ-rejection
Red: 1σ-rejection





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Resolving the stellar emission - Results

Summarizing the binary analysis

- **are sensitive to binary companions with flux ratios comparable to the near-IR excess fraction observed for these sources**
- **exclude almost all of the probed binary parameter range, down to companion flux ratios of 0.05 and 2.5 mas (3.5 AU) separations; this flux ratio limit translates into a companion mass limit of 0.1 $M_{\odot}$ for our target stars**
- **reject stellar binarity as the dominant mechanism in creating a transitional disk appearance**

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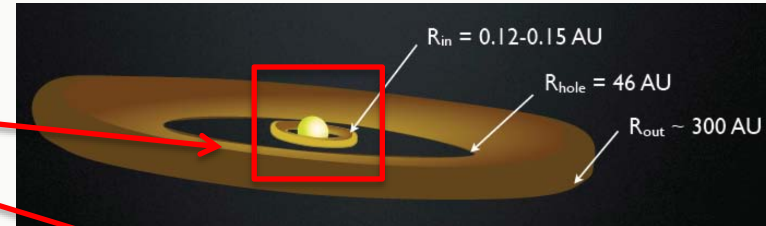
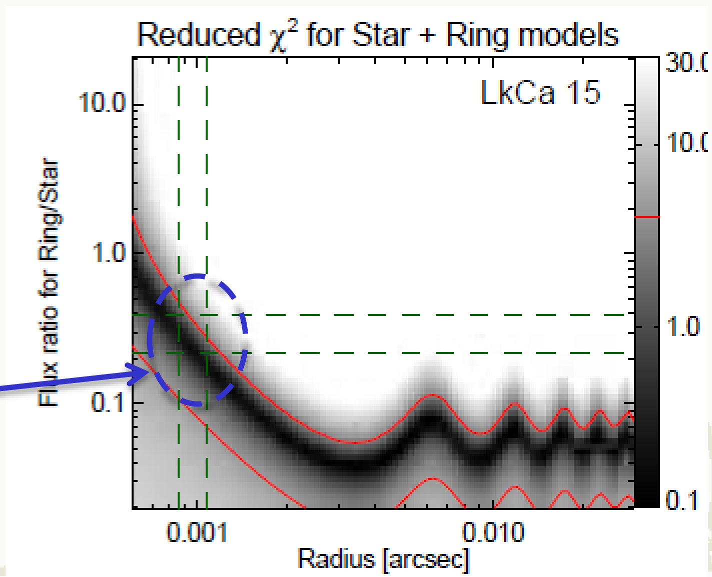
Resolving the inner disk emission

- **Simple star+ring model constrains the emission size**
- **Inclination cannot be fitted reliably with one baseline, but targets are ≤ 60 degr**
- **Prior estimation of NIR-excess is required (and limits) the precision of the size constraint**



We zoom into the innermost disk

- **For GM Aur, LkCa15, RY Tau, the derived ring radius is 0.1-0.2 AU**
- **UX Tau A is marginally resolved, with radius < 0.1AU**
- **4 of 5 targets show NIR excess emission at radii consistent with the gap SED models**



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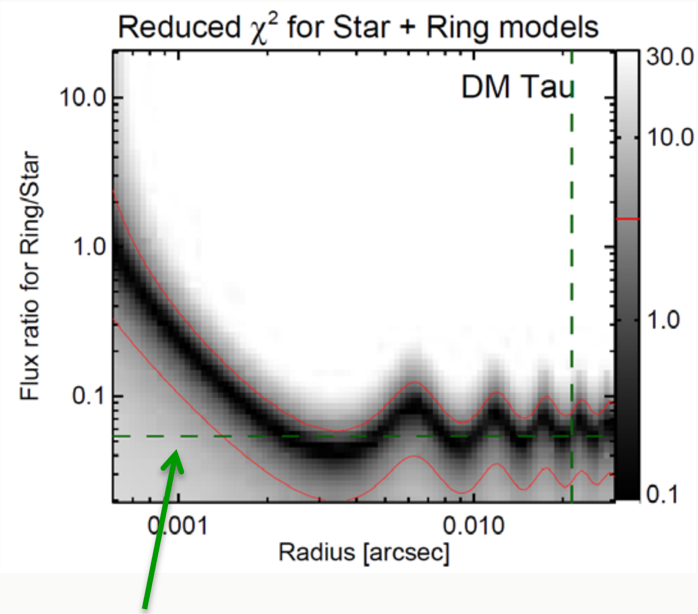
Resolving the inner disk emission

- **For DM Tau, the fifth target, we derive a lower limit: ≥ 0.2 AU**
- **KI data proves that there is extended emission, but the target could be overresolved**
- **The SED is consistent with no NIR excess (≤ 5%)**
  -> the extended emission could be scattered star light or hot dust emission below the detection precision of SED models
- **The lower limit is still consistent with the gap model, but a fully cleared hole and advanced disk dissipation is equally likely**
- **Interferometer is very sensitive to extended emission**



Upper FR limit, which translates into a lower radius limit of > 0.2 AU

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Summary

- **In general, close binaries do not create the transitional disk SED, thus the conception of catching disk dissipation "in the act" seems to be true**

- **Systems like CoKu Tau/4 appear to be the exception not the rule**

- **Four out of five targets show emission at radii < 0.2 AU, in addition to the colder MIR-disk, confined to radii of 10 AU and larger. This supports the gap-scenario, and planet formation as reason for the dust depletion**

- **Outlook: the here presented data and results are soon online in Pott et al. 09 (ApJ in press); the new data on three Ophiuchus transitional disks seem to confirm this result, but this is still work in progress…**

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