Mid-infrared variability of low-mass young stars studied with VLTI/MIDI: The cases of V1647 Ori and DG Tau

L. Mosoni[1], N. Sipos[2], K. É. Gabányi[1], A. Juhász[3], P. Ábrahám[1], Th. Henning[4], W. Jaffe[3], Á. Kóspál[5], M. Kun[1], Ch. Leinert[4], A. Moór[1], A. Müller[6], S.P. Quanz[2], Th. Ratzka[7], A.A. Schegerer[4], R. van Boekel[4], S. Wolf[8]

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Abstract Low-mass young stellar objects (YSOs) show variability not just at optical and near-infrared wavelengths, but also in the mid-infrared. The amplitude and time-scale of the brightness variations depend on the underlying physical mechanisms (e.g., dust processing, grain growth) and the structure of the circumstellar material. Variability studies can therefore provide us information on the structure and evolution of circumstellar material and can help to understand the initial conditions for planet formation. We studied the structure of the circumstellar material at a several AU scale around two low-mass YSOs, V1647 Ori and DG Tau. For both objects, we obtained multi-epoch mid-infrared interferometric observations with MIDI (Leinert et al. 2003), the mid-infrared instrument on the Very Large Telescope Interferometer (ESO/VLTI).

V1647 Ori **Background** Although many young stars exhibit temporal brightenings possibly caused by fluctuating accretion, the eruptions of the FU Orionis- and EX Lupi-type classes of variable stars (**FUors and EXors**) may represent the most intense bursts (e.g., Hartmann & Kenyon 1996). Such outbursts are characterized by an optical brightening of 2-6 magnitude. FUor eruptions can last from some years to several decades, while EXor-outbursts are usually considered as shorter counterparts of those of FUors (i.e., some months long). The triggering mechanism (thermal and/or gravitational instability) and the difference between the physics of FUor and EXor-outbursts are unclear. **It is hypothesized that all low-mass pre-main sequence stars undergo FUor and/or EXor phases.** Thus understanding the physics of the outbursts will shed light on fundamental processes of the early evolution of Sun-like stars and their circumstellar disks (structure, dust composition) and in turn on the changes of the conditions in the disks that govern the formation of planetary systems. One of the best-documented and most-studied outbursts in the history of eruptive low-mass young stars is that of V1647 Ori in 2003-2006 (see the references collected by Aspin & Reipurth 2009). V1647 Ori was observed with MIDI at two epochs during its 2003-2006 outburst to investigate the temporal evolution of its circumstellar structure and physical processes related to the eruption (Mosoni et al. 2013).

Modeling Optical-infrared SEDs at five epochs were compiled. For modeling we used the *MC3D* radiative transfer code (Wolf et al. 1999, Schegerer et al. 2008). First, we created a reference model for the 2005 March, and later on modified it to fit the data of other epochs. Our modeling, with a smoothly decreasing accretion rate as a major varying parameter, provided good fits of the SEDs at different stages of the outburst. It is important to note that the inner radii of the dust disk and envelope also had to increase during the transition from quiescence to the outburst peak. The latter finding is clear evidence of dynamical variations in the inner circumstellar environment of V1647 Ori. This dust clearing is likely caused by the evaporation of the dust grains due to the outburst heat.

VLTI/MIDI data obtained during both the slow and rapid fading stages indicate a considerable change of the circumstellar structure. In constrast to our expectations, based on our model sequence, the object looked more resolved at the second epoch. Our attempts of changing the disk parameters failed the reproduce the data.The **increase of the inner radius of the dusty envelope**, i.e., rapid removal of dust from the inner 3 AU of the envelope can be due to wind or outflow processes. Two possible scenarios are:

1. *A blown-up sperical cavity scenario* is produced at the end of the outburst phase.
2. *A warm dust halo disappeared* by 2005 September. The cavity was created at the beginning of the outburst and was continuously filled with dust, but was cleared as the wind started to wane. We may also see V1647 Ori in a non-equilibrium situation in 2005 September, when the sudden fading of the central source was not yet followed by the fading of the optically thick circumstellar material. The exact study of such an event would require time-dependent radiative transfer modeling.

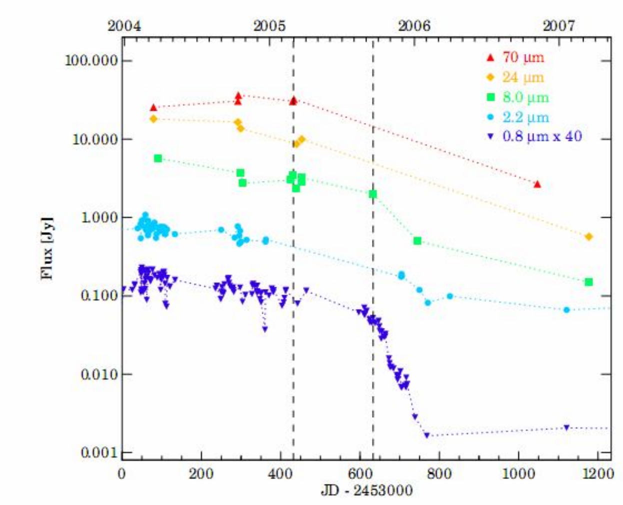


Fig. 1. Light curves of V1647 Ori. Epochs of MIDI observations are indicated.

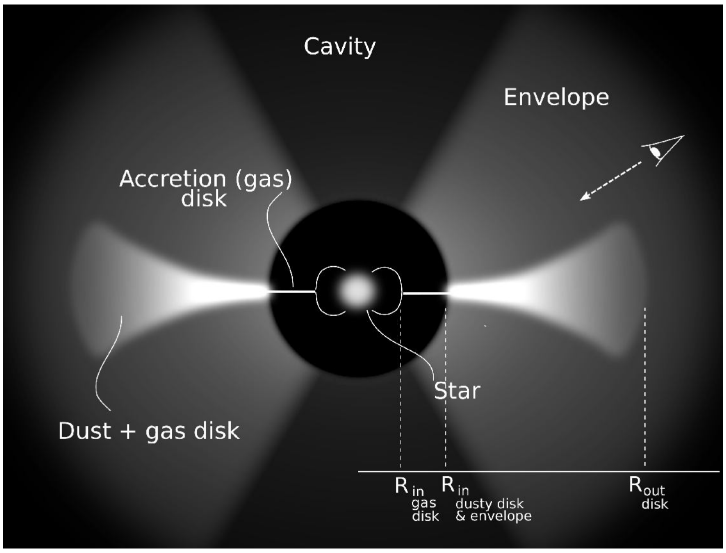


Fig. 2. Schematic picture of the model geometry of the object (not to scale). The line of sight crosses through the envelope. The inclination of the disk is ~60 degree, the opening angle of the conical cavity is ~50 degree.

Parameters	Final model
Stellar parameters	
Temperature (T_{star})	3800 K
Mass (M_{star})	0.8 $M_\odot$
Radius (R_{star})	3.25 $R_\odot$
Interstellar visual extinction (A_V)	0 mag
Circumstellar disk parameters	
Inner radius of dusty disk ($R_{in,disk}$)	0.7 AU
Outer radius of dusty disk ($R_{out,disk}$)	500 AU
Scale height at 100 AU (H_0)	15 AU
Flaring index (β)	1.2
Exponent of radial density profile (α_{disk})	−1.75
Total mass of disk and envelope (M)	0.045 $M_\odot$
Distance (d)	400 pc
Inclination (ϑ)	60 °
Circumstellar envelope parameters	
Inner radius of dusty envelope ($R_{in,env}$)	0.7 AU
Outer radius of dusty envelope ($R_{out,env}$)	3000 AU
Exponent of radial density profile (α_{env})	−1.5
Parameters for the accretion	
Accretion rate ($\dot{M}$)	3.5×10^{-6} $M_\odot yr^{-1}$
Magnetic truncation radius (R_{trunc})	5 R_{star}
Temperature of the hot spot (T_{spot})	6500 K

Parameters of the best model for 2005 March reference epoch. Fitted parameters shown in *italics*.

Parameters	2004		2005		2003/06
	Mar	Oct	Mar	Sept	quiescent
$\dot{M}$ ($M_\odot yr^{-1} \times 10^{-6}$)	7.0	5.5	3.5	1.6	0.3
$R_{in,disk}$ (AU)	0.7	0.7	0.7	0.7	0.5
$R_{in,env}$ (AU)	0.7	0.7	0.7	3.0	0.5
A_V (mag)	18.9	18.9	18.9	11.5	23.4

Model parameters changed for different epochs. Note the change of the inner dust radius between quiescence and outburst. During the outburst the accretion rate decreased continuously. The inner radius of the envelope changed between the epochs of MIDI observations.

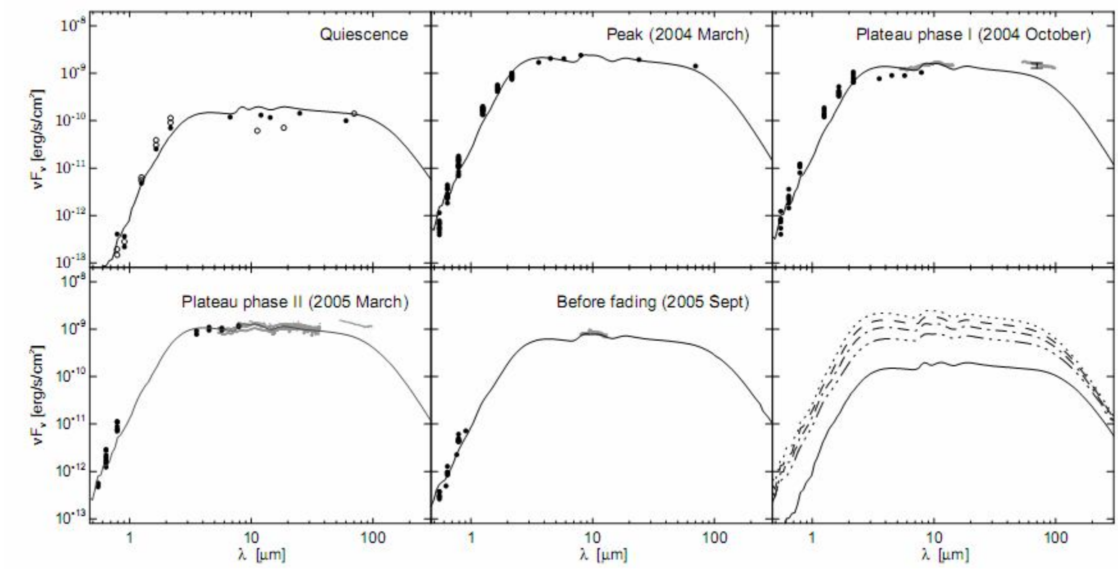


Fig. 3. Spectral energy distributions of V1647 Ori at five different epochs. Between the outburst epochs only the accretion rate was changed here. Note that the model for 2005 September shown here does not fit the MIDI data. The last panel shows all models. The decrease of the brightness of the object with time, from peak (top) to quiescence (bottom) is continuous.

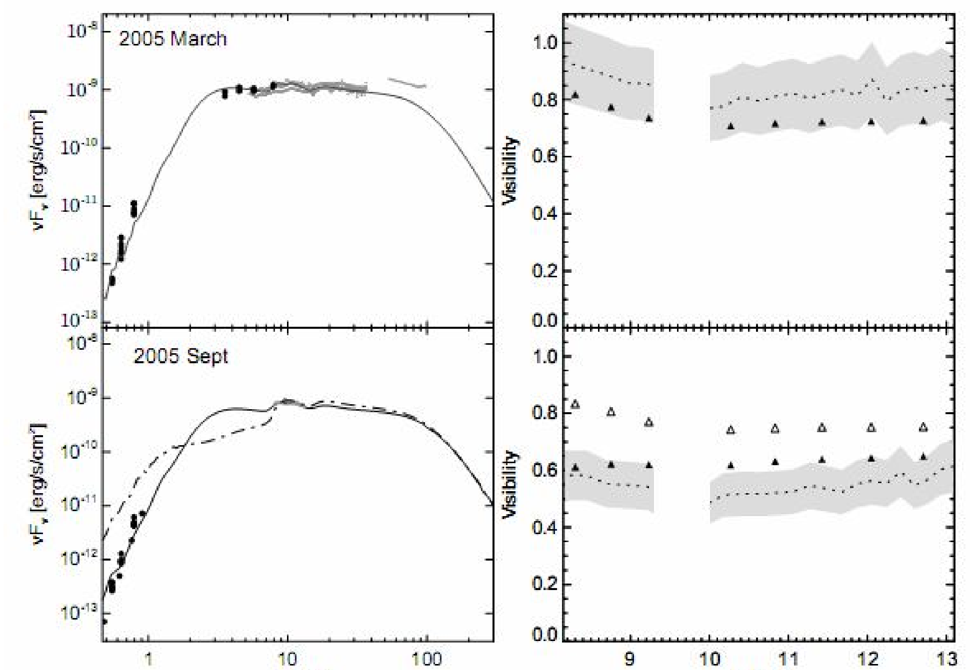
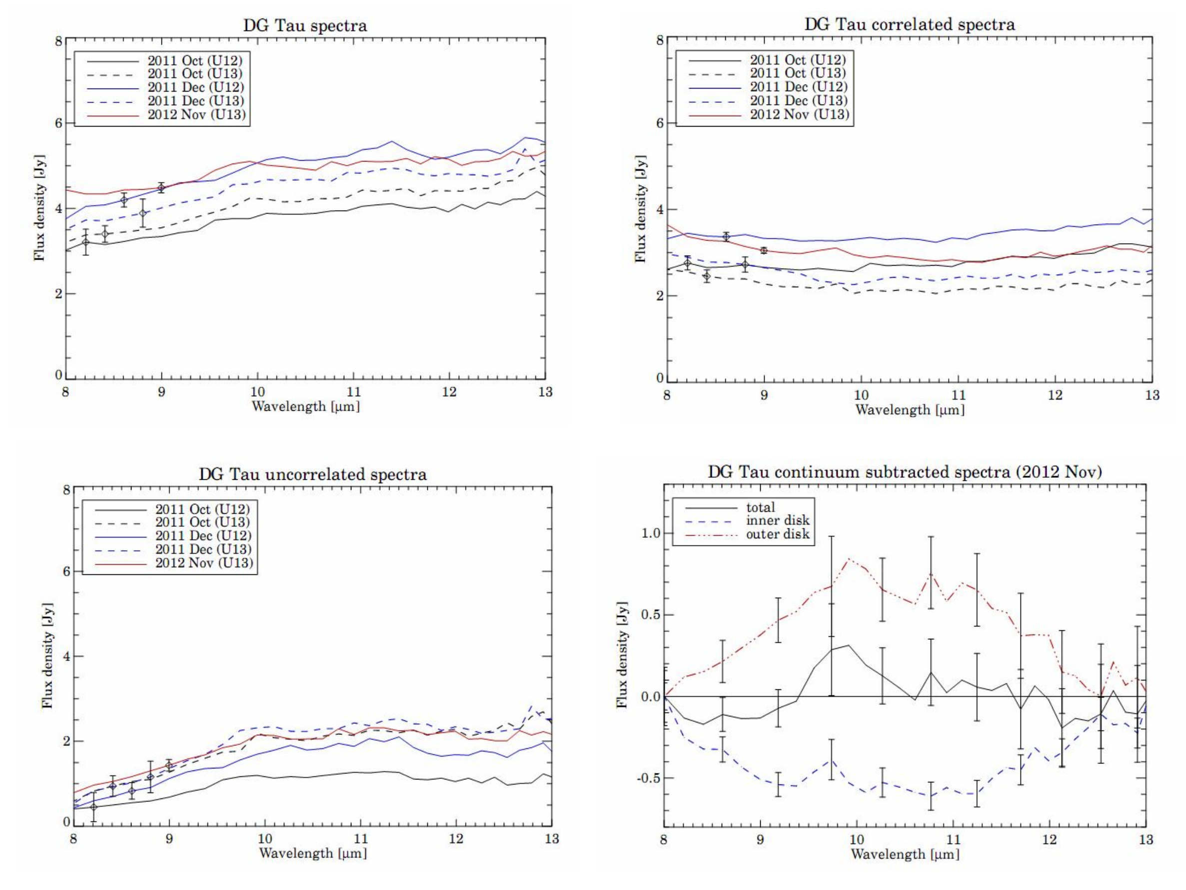


Fig. 4. Fits of SEDs and MIDI data. In the *bottom left* panel the solid line, in the *bottom right* panel the open triangles show the model where only the accretion rate was decreased relative to the reference model. The dash-dotted line (*bottom left* panel) and the filled triangles (*bottom middle* panel) show the model where the inner radius of the envelope was also increased. In general, our modeling showed that the circumstellar environment of V1647 Ori can be described by a disk and envelope system with parameters that are typical for embedded low-mass YSOs. This finding supports the hypothesis that eruptive YSOs are not peculiar objects, but represent a phase in the evolution of all low-mass YSOs.

DG Tau The 10 micron silicate feature is known to show temporal variations in DG Tau. The change could be caused by the variation of the height of the inner rim of the disk. Such variation, via the changing shadowing, should affect the silicate emission of the disk outwards the rim. Dust lifted above the disk by wind can also cause changes, i.e., the silicate emission increases in the inner and decreases in the outer regions. MIDI data allows us to study the mid-infrared emission of DG Tau at different spatial scales, i.e., providing spectra of the inner and outer disk regions. The border between inner and outer regions is defined by the resolution of the observations, i.e., the length of the baselines. DG Tau was observed with MIDI on UT1-UT2 (U12) and UT1-UT3 (U13) baselines with resolutions of a few AUs, at five epochs. Three kinds of spectra were obtained: that of the whole system (total, *top left*), the inner disk (correlated, *top right*) and the outer disk (uncorrelated, *bottom left*).The spectra show slight variations but no strong silicate feature. The total and uncorrelated (outer disk) spectra show weak emission, the correlated (inner disk) spectra absorption. This is consistent with a typical disk system. Variations might be proven by detailed data analysis. However, the continuum subtraction will be difficult. The best quality spectra are shown in the *bottom right* panel. Errors are shown only at a few wavelength values for clarity. The errors are typically twice higher at the long wavelength end of the N-band in all cases.



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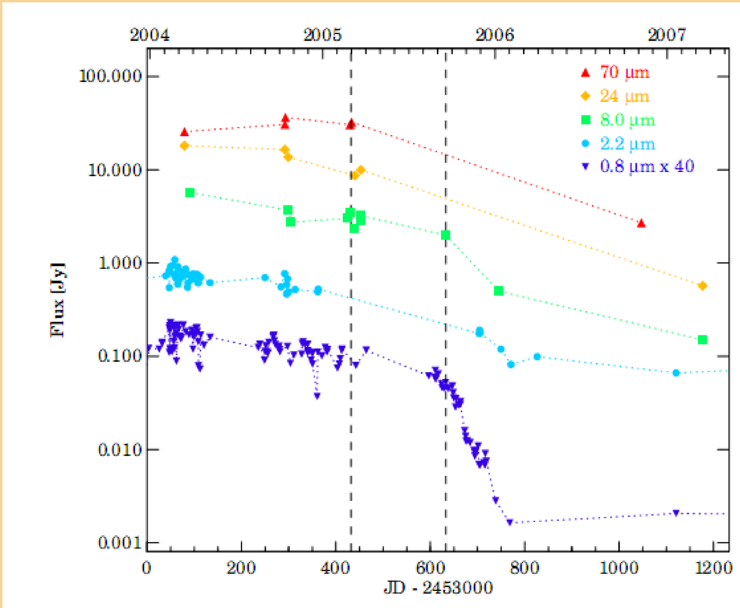

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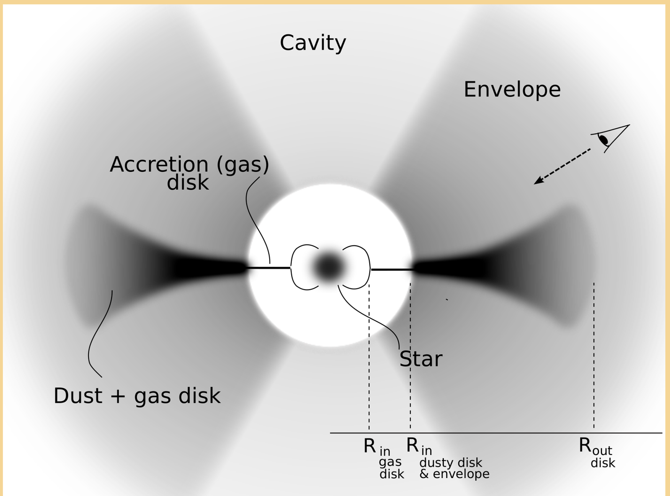

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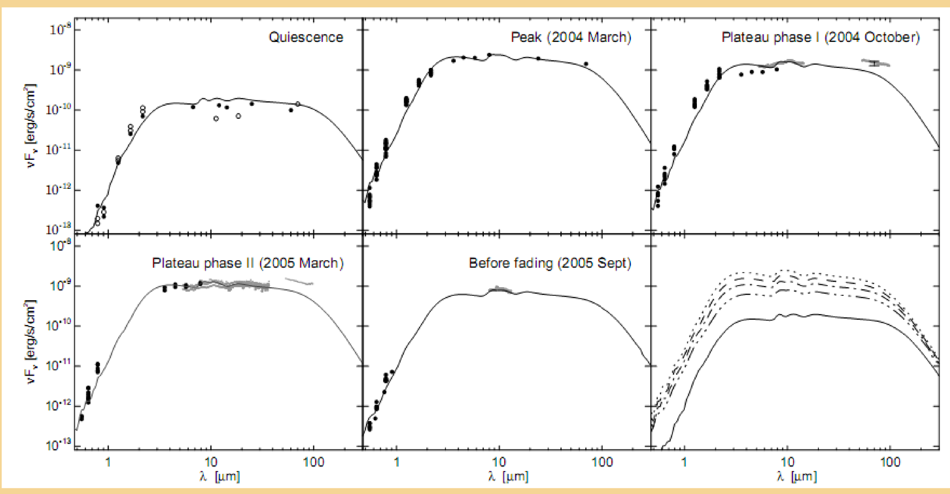

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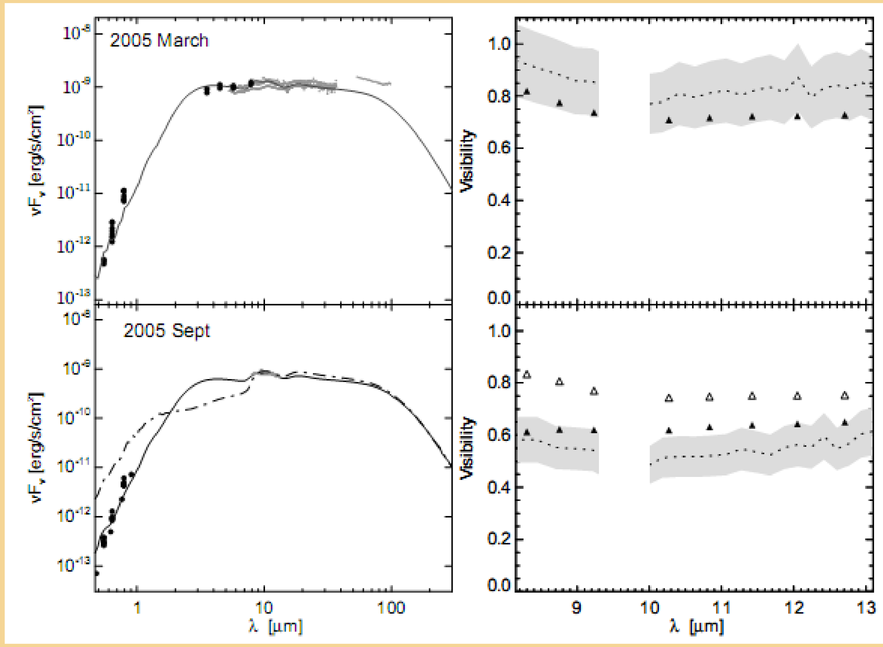

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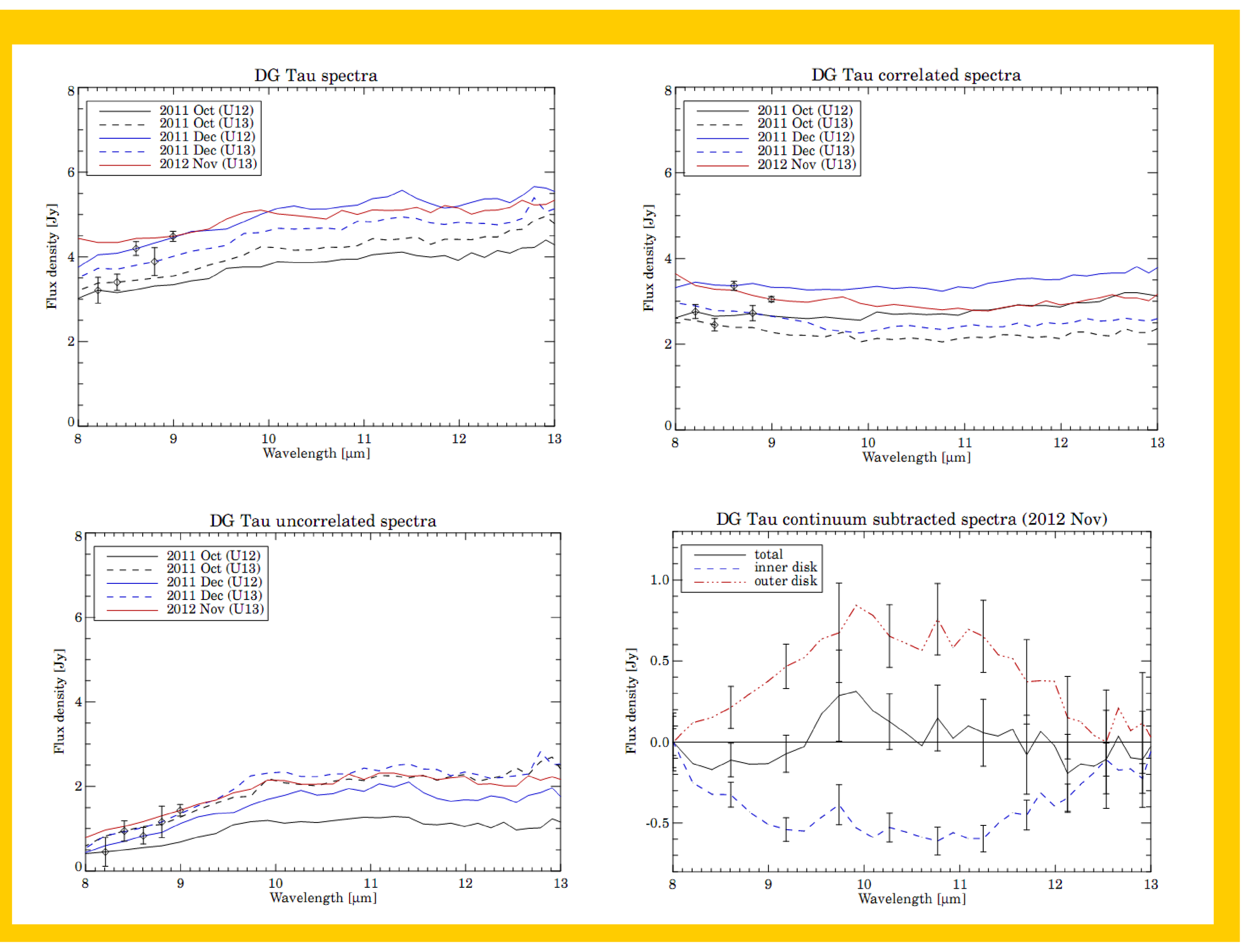

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Contact

Comments? Questions? I am somewhere close. Thank you.

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