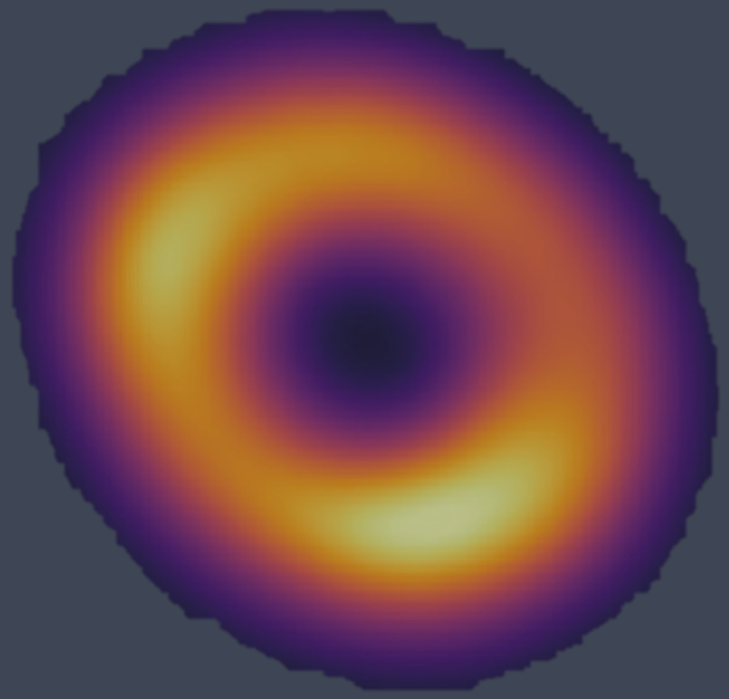
The gas and dust disk around the **CQ Tau** pre-main-sequence star



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Collaborators: A.Miotello, S. Facchini, E. Ragusa, G. Lodato, L. Testi et al.

Protoplanetary discs formation:

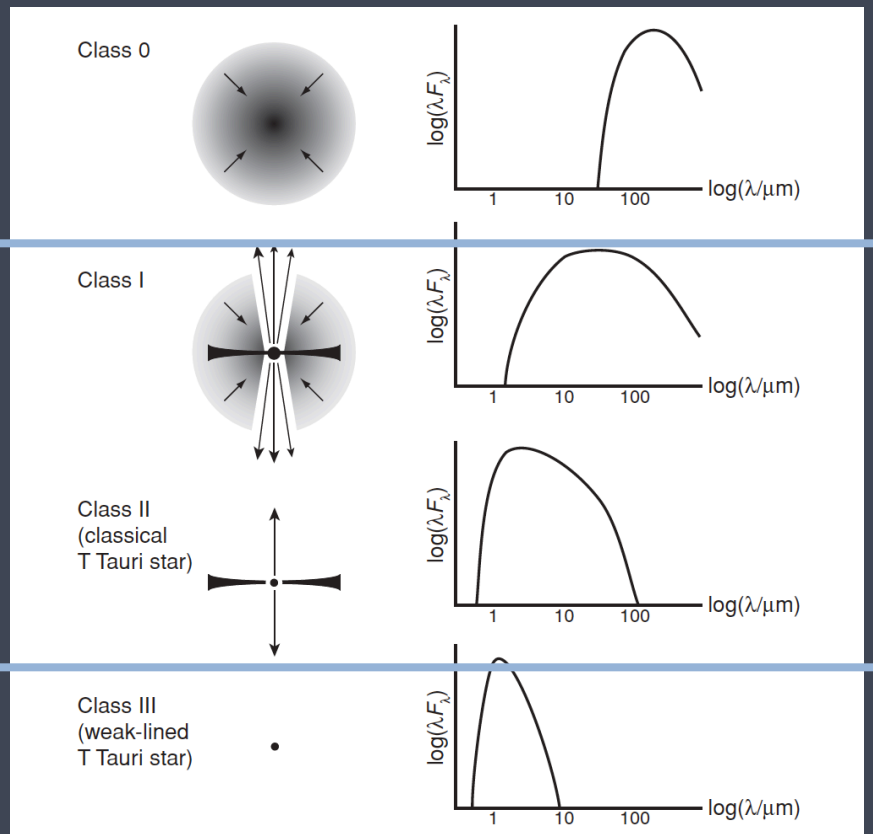

Fig. 2.1. Classification scheme for Young Stellar Objects.

- A dense molecular cloud collapses under its own gravity
- Due to its initial rotation, forms a disk which carries most of the angular momentum of the primordial nebula
- The disk slowly accretes onto the central star and forms eventually planets.
- **Transitional disks (TDs)** are a particularly interesting class of protoplanetary disks, where the inner regions present a cavity, possibly cleared out by massive planets.

I. TARGET PROPERTIES: CQ Tau

Presence of **an inner cavity** in the disk dust and gas distribution in the new **new ALMA** (Atacama Large Millimeter Array) **observations** (PI: L. Perez, L. Testi).

- young (5Myr)
- nearby (d =162 pc)
- intermediate mass (M_* = 1.5 M_{sun})
- L_* = 10 L_{sun}
- T_*= 6900 K

What are the dust and gas profiles? Can a planet be responsible to clear the distribution of gas and dust in such a way?

Our **goal** is to find the **best model's parameters** to describe the high angular resolution **ALMA observations** and to constrain the **properties** (mass and location) **of the planet candidate.**

We employed the chemical-physical code DALI to describe these profiles and hydrodynamic simulations (PHANTOM) to address if the presence of a planet.

Our data include:

- the Spectral Energy Distribution (SED) used to probe the small grains distribution;
- the thermal continuum produced by cold dust to probe the large grains distribution;
- the line emission maps in different isotopologues of the CO molecule (^{12}CO, ^{13}CO and $C\,^{18}O$) to probe the gas content and temperature.

1) Spectral Energy Distribution (SED)

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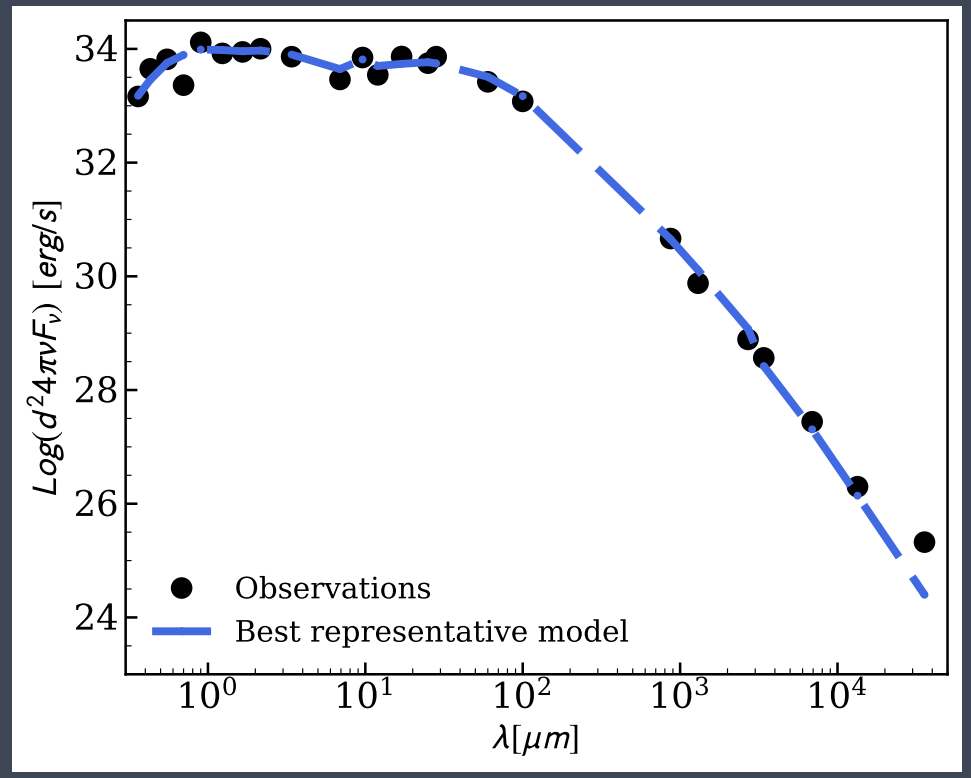

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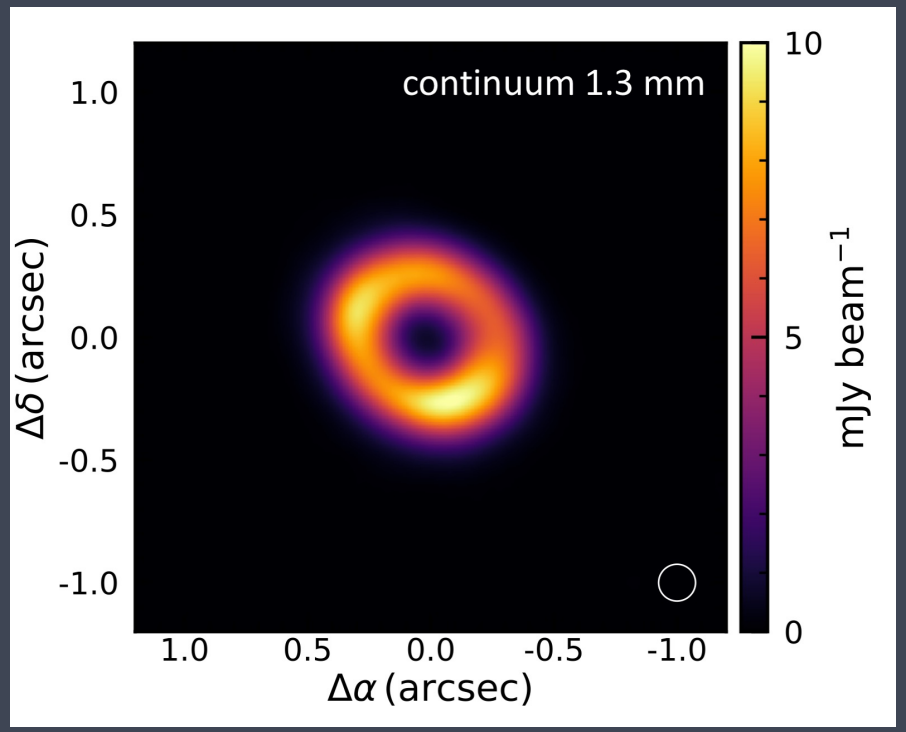
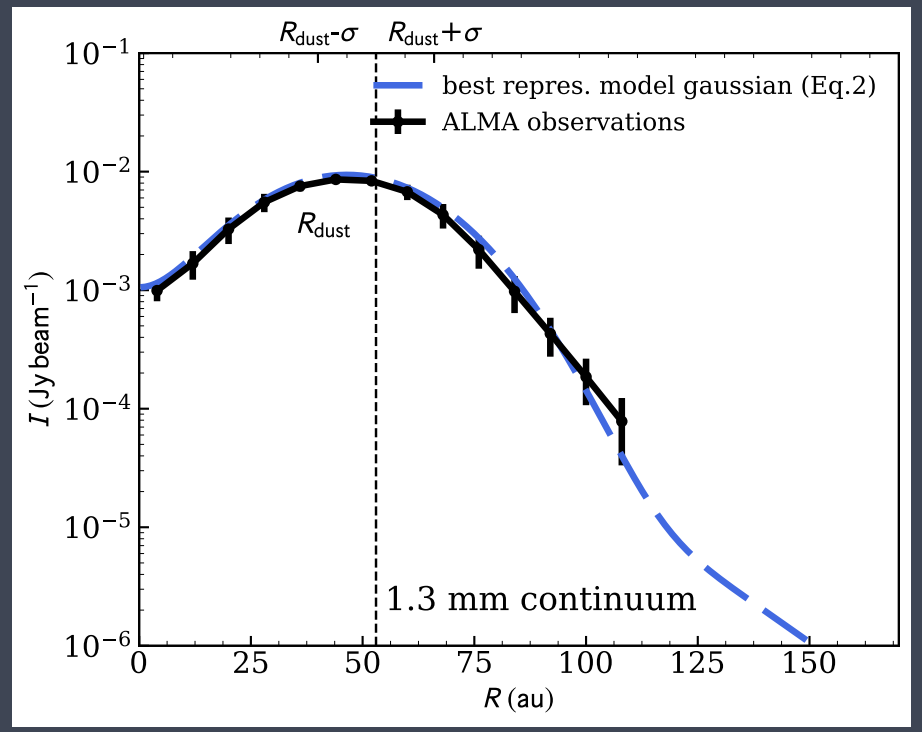
2) Dust Continuum at 1.3 mm





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3) ^{12}CO ($J = 2 - 1$): main isotopologue, only traces the surfaces of protoplanetary disks (optically thick at low column densities)

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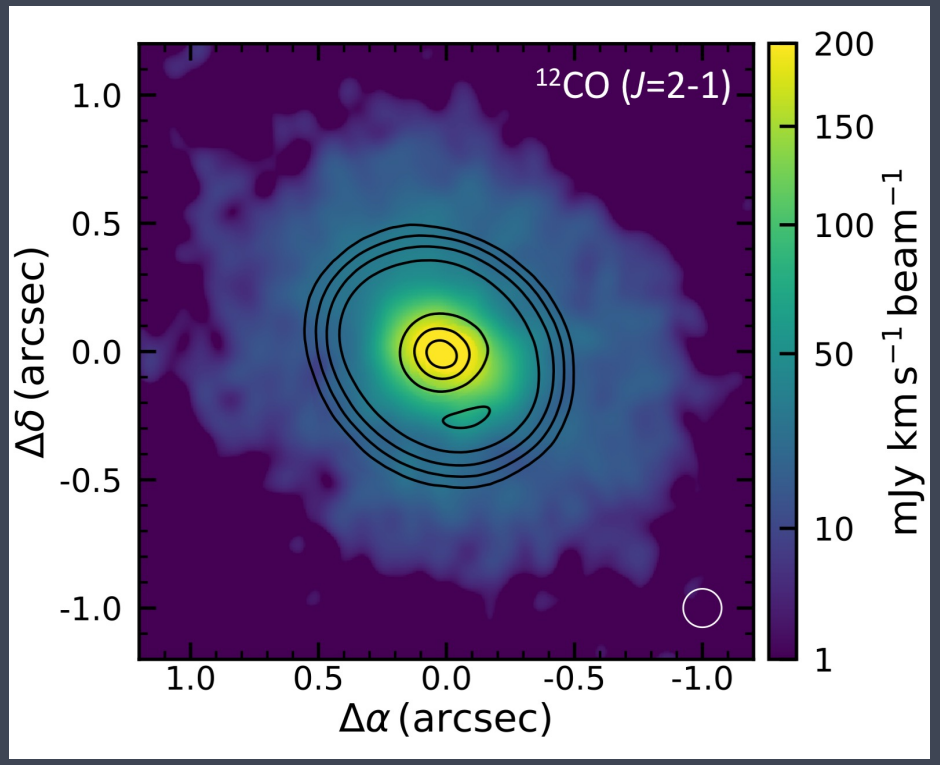

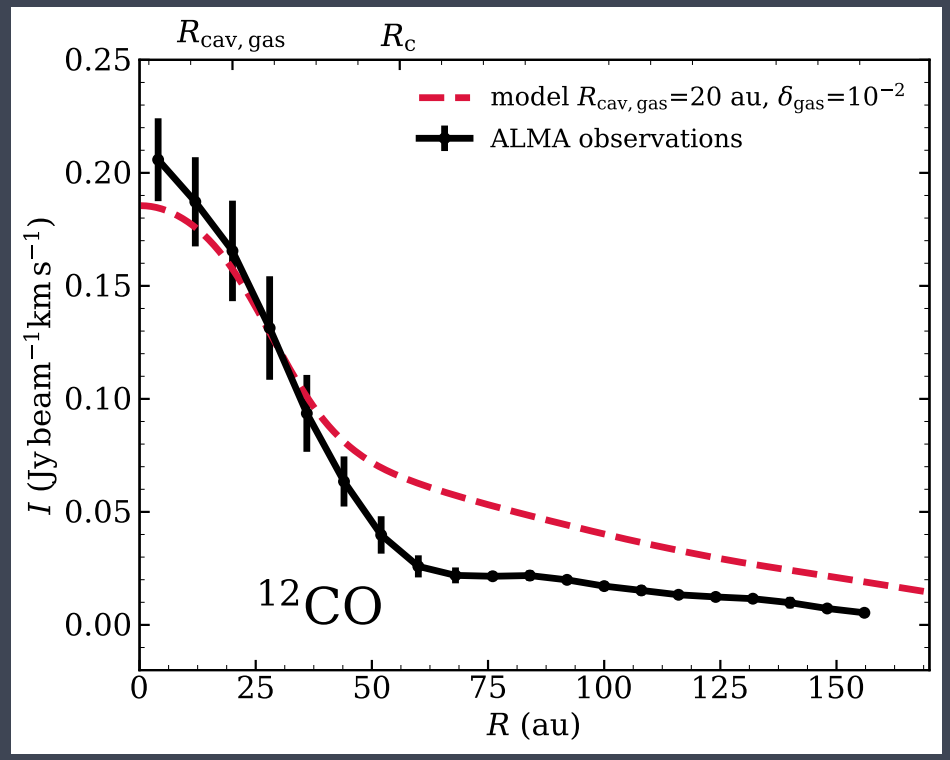

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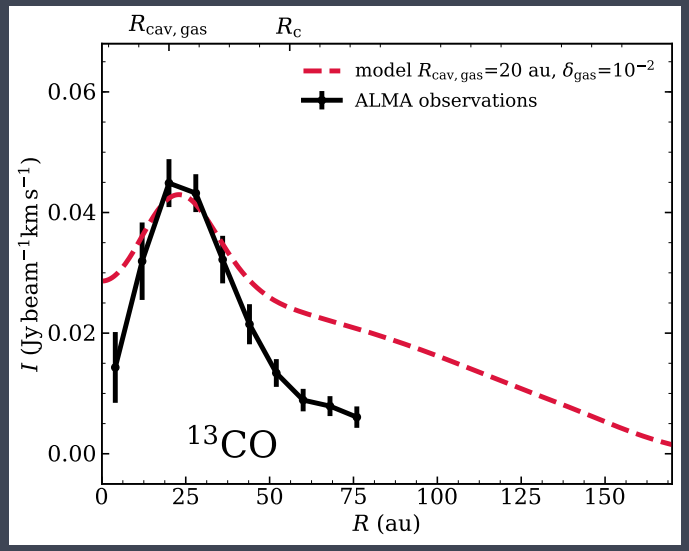
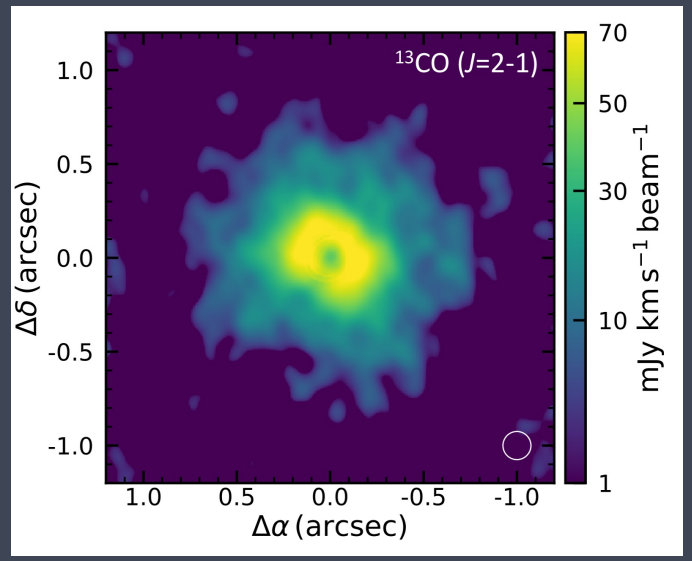
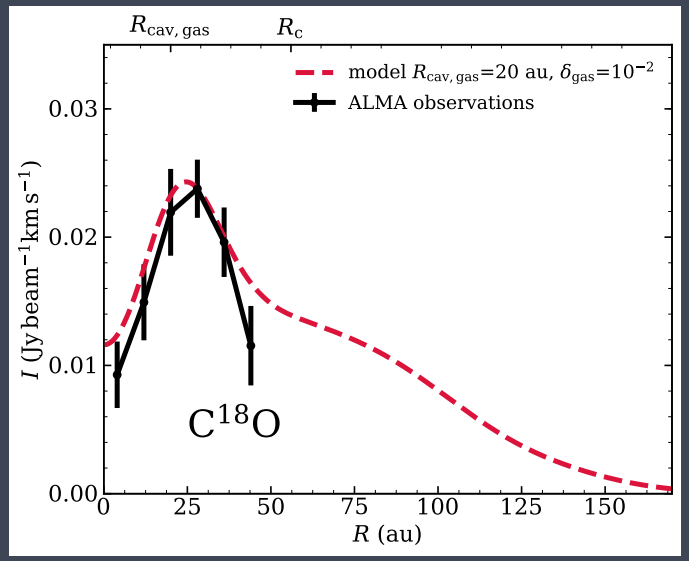


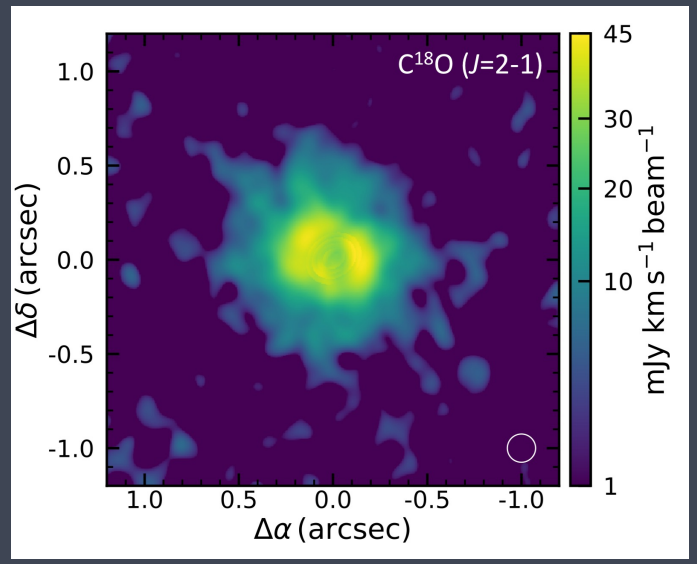
^{13}CO



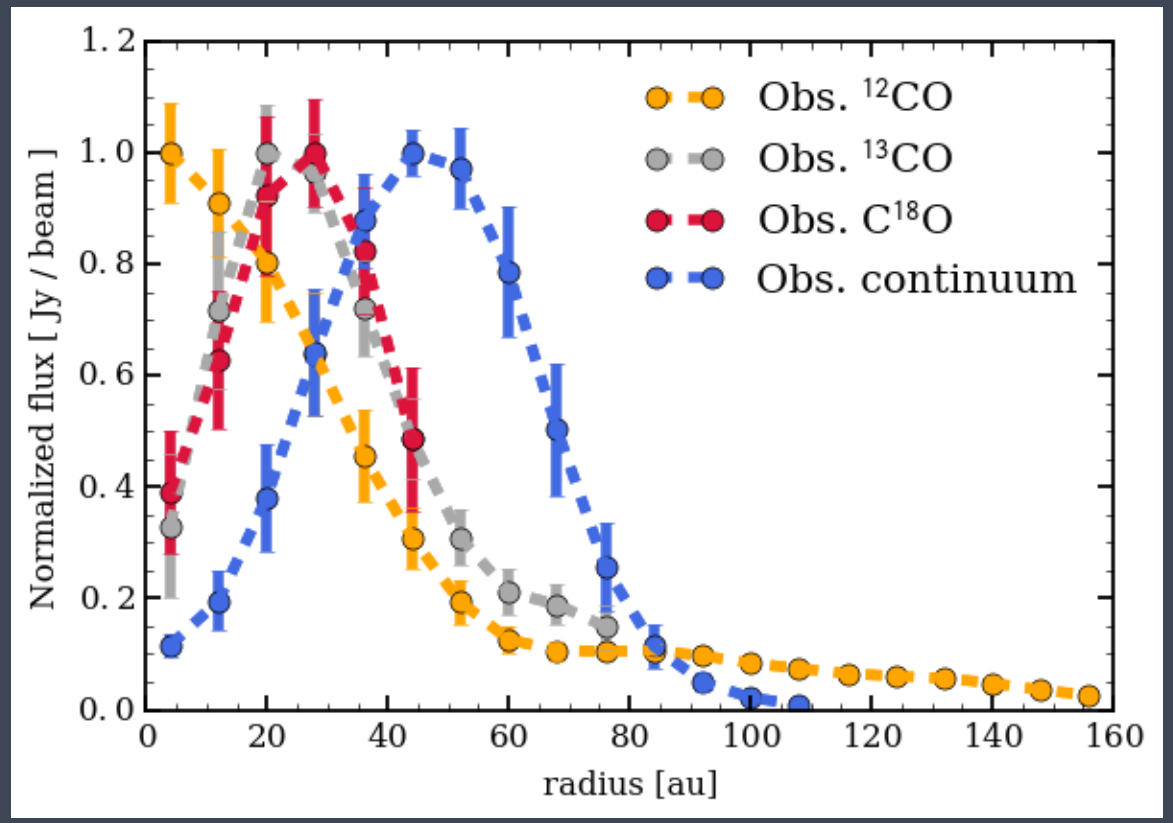
3) ^{13}CO and C ^{18}O ($J = 2 - 1$): less-abundant CO isotopologues, optically thick much deeper and trace the gas down to the midplane of the disk



C ^{18}O



Comparing the radial profiles



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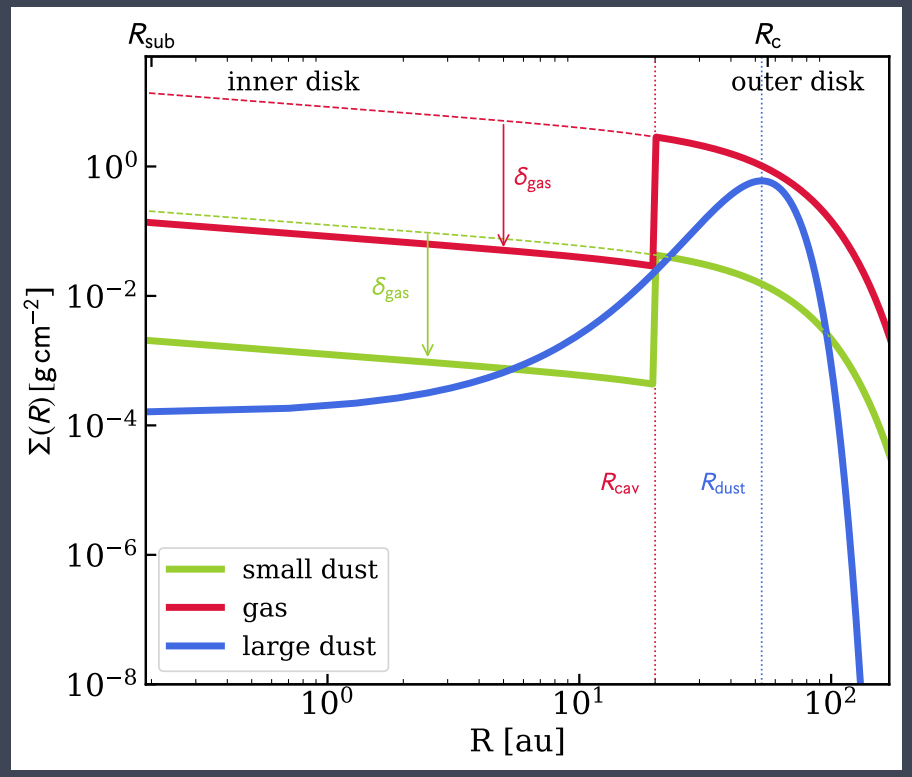
- **Continuum** peaks at larger radii than the gas
- **^{12}CO** do not show a cavity
- **^{13}CO** and **C ^{18}O** have a similar radial profile
- **Dust peak is at larger radii than the gas one**

Results:

- We modelled CQ tau as a disk where there is a sharp ring of dust (just outside the supposed planetary orbit) and a broader extent of the gas.
- There is clear evidence of the presence of an **inner cavity in both dust and gas distribution.**
- The **dust-to-gas ratio** is not uniform over the whole radial extent and the global dust-to-gas ratio is found to be 0.09, higher than the typical values assumed, most likely because of carbon depletion.

LARGE DUST: GAUSSIAN

h_C = 0.125 rad
ψ = 0.05
Σ_{dust} =0.6 g/cm^2
σ = 13 au
R_{cav} = 53 au



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GAS: SELF-SIMILAR PROFILE

R_C = 56 AU
h_C = 0.125 rad
ψ = 0.05
Σ_{gas} = 2.5 g/cm^2
γ = 0.3
R_{cav} = 15-25 AU
Δ_{GAS} = 10^{-1}-10^{-3}

SMALL DUST

$\Sigma_{s\,d}$ =0.0375 g/cm^2

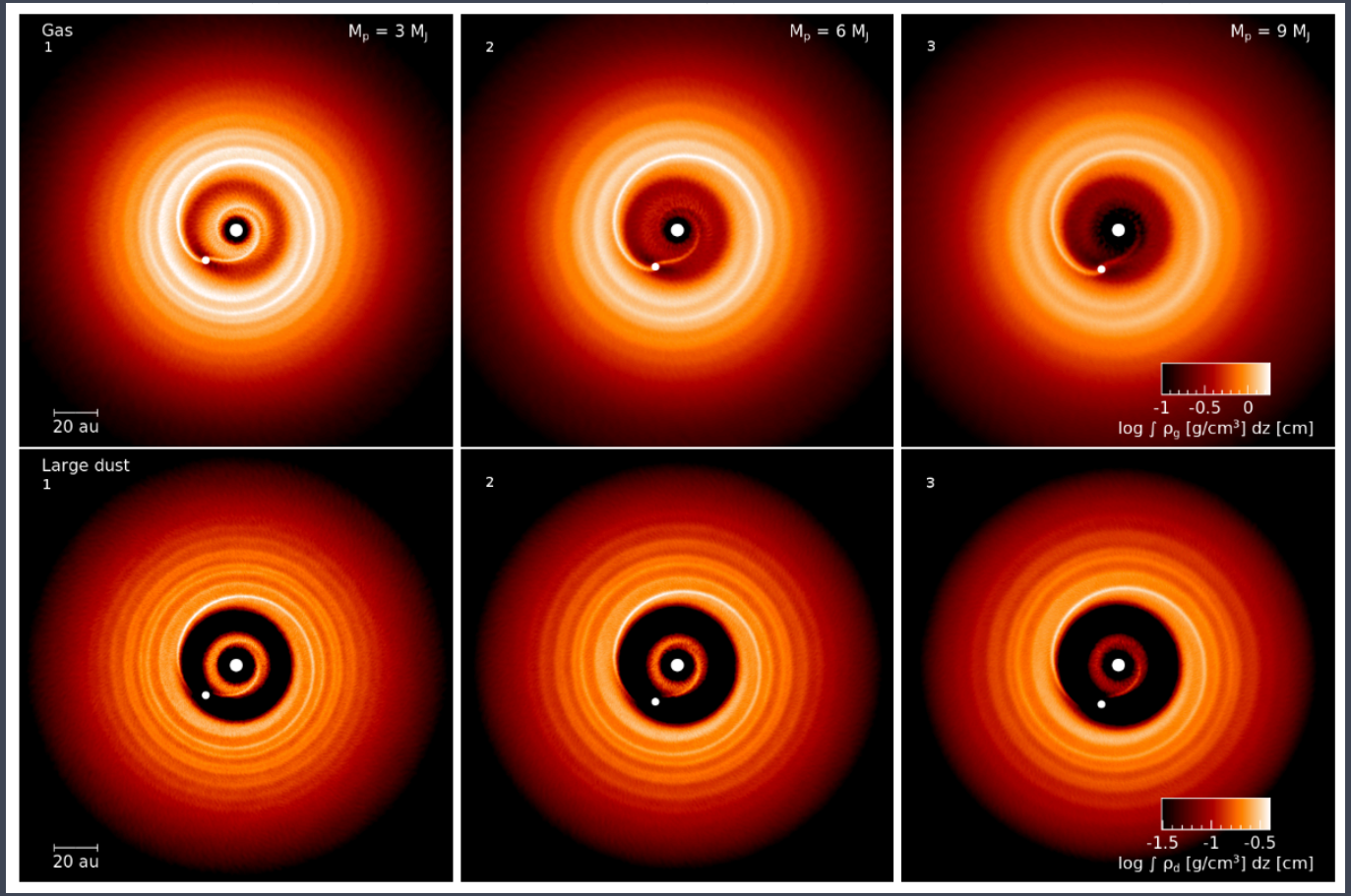
Results:

We have run SPH **hydrodynamic simulations** (PHANTOM) to address if the presence of a planet can reproduce the ALMA data and we found good agreement with the DALI profiles.

The planet should have $M_P \sim 6 - 9 M_{Jup}$; $R_P \sim 20\ AU$.

Gas

Dust



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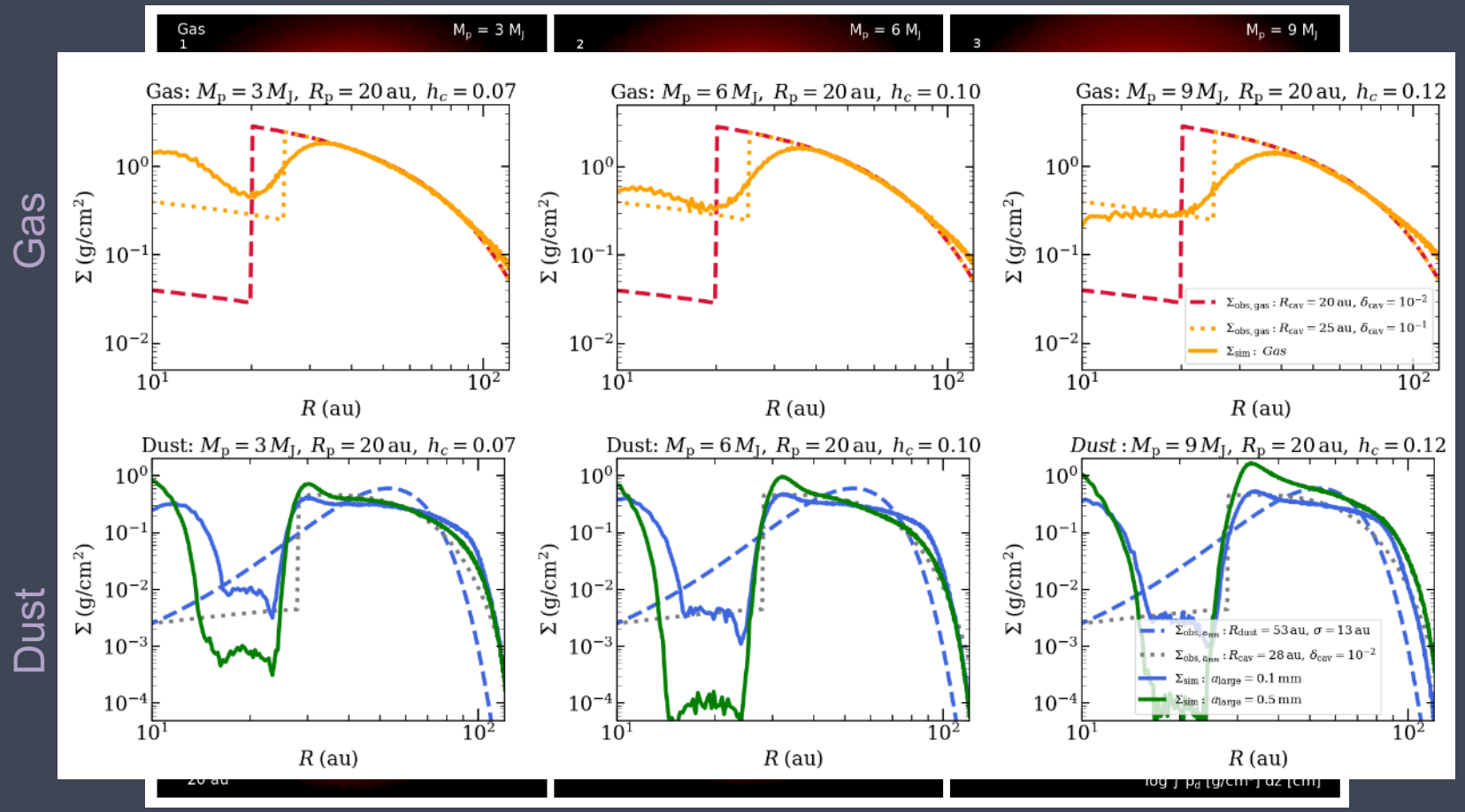

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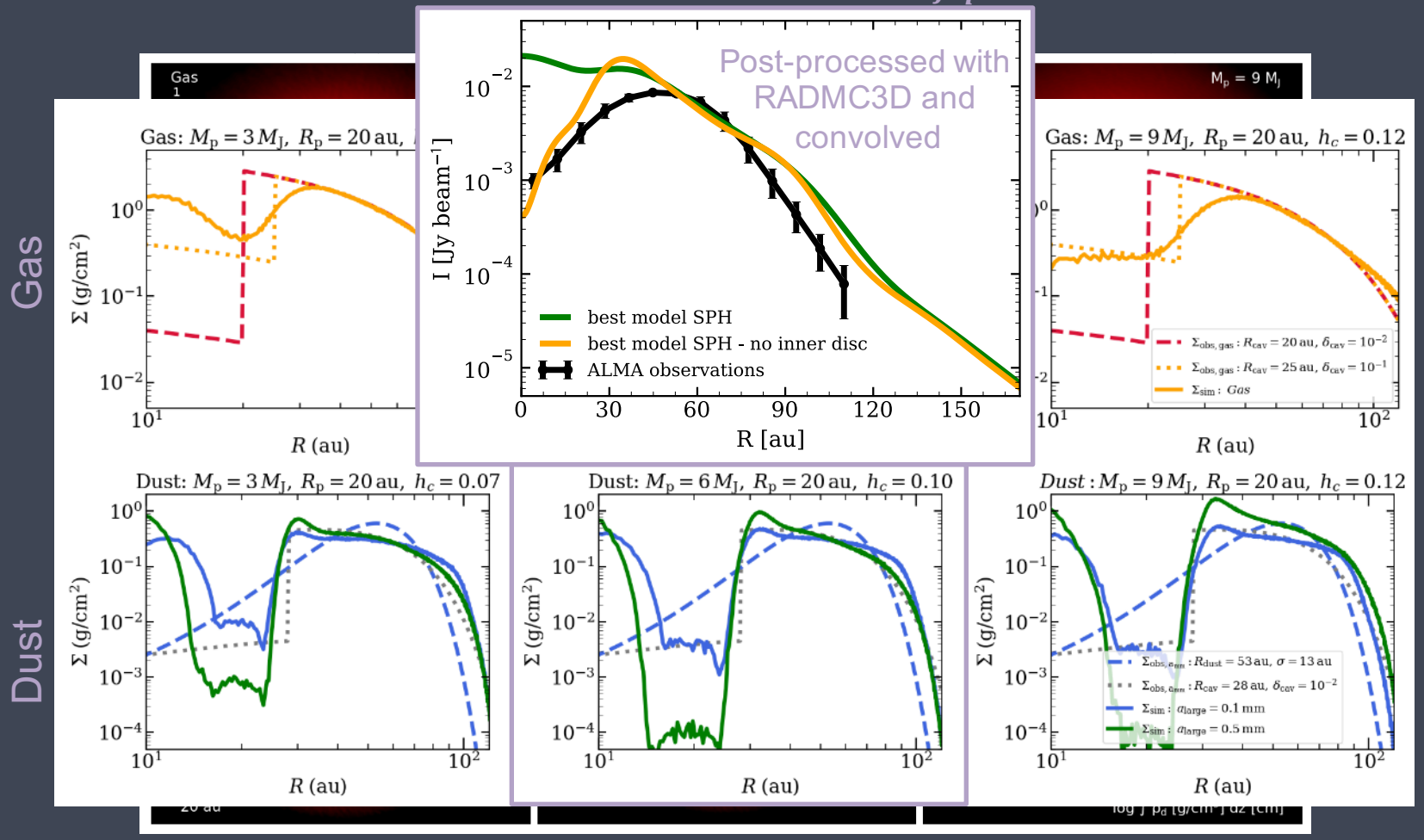

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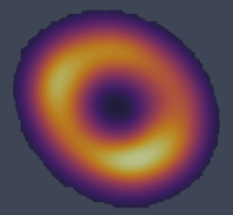
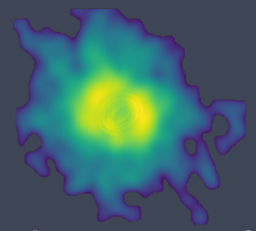


Take home messages



- We have studied the spatially resolved ALMA observations of the dust continuum and of three CO isotopologues, ^{13}**CO**, ^{13}**CO** and ^{13}**CO** , together with the observed SED of CQ Tau. We employed the chemical-physical code DALI to describe these profiles.

- In the CQ Tau disc the gas radial extent is a factor of two broader than that one of the large dust grains.

- CQ Tau shows a clear cavity in both gas and dust: gas inner cavity with size between 15 and 25 au and a density depletion factor between 10^{-1} and 10^{-3}. The radial profile of the distinct cavity in the dust continuum is described by a Gaussian ring centered at R_{dust} = 53 au and with a width of = 13 au.

- The computed dust-to-gas ratio is not radially constant throughout the disc. Moreover, the global dust-to-gas ratio is found to be 0.09.

- We find that a massive planet with a mass of at least M_p = 6 - 9M_J located at R_p = 20 au from the central star can reproduce well the ring feature at 50 au but not the dust distribution in the inner cavity region of the best representative density model predicted using DALI.

Thank you!

Further material

Stellar properties

[1]SpT	[5]L_* ($L_\odot$)	[5]M_* ($M_\odot$)	[5]age Myr	[2]$T_{\rm eff}$ (K)	[3]d (pc)	[4]σ_d (pc)	[6]A_V (mag)
F2	10	1.67	10	6900	162	2	1.9

Disk model with DALI

	Species	Parameter	Range
Vertical structure		h_c [rad]	0.05; 0.07; 0.075; 0.1; **0.125**; 0.15; 0.2
		ψ	0; **0.05**; 0.1; 0.15; 0.2; 0.25; 0.3
Radial structure		R_0 [au]	20; 15; 25; 30; 35; 40; **56**; 60; 100; 200
		$R_{\rm sub}$ [au]	**0.2**
Self similar density profile (Eq. 1)	gas	$\Sigma_{0,\rm gas}$ [g cm^{-2}]	1; 2; **2.5**; 5; 7.5; 10; 12.5; 15; 20; 25; 30; 38; 50; 60
Self similar density profile (Eq. 1)	small dust	$\Sigma_{0,\rm small}$ [g cm^{-2}]	0.375; **0.0375**; 0.00375
	gas,small dust	$R_{\rm cav}$ [au]	5; 10; 15; **20**; 25
	gas,small dust	$\gamma_{\rm gas}$	0; **0.3**; 0.5; 0.7; 1.; 1.5
	gas,small dust	$\delta_{\rm gas}$	10^{-4}; 10^{-3}; $\mathbf{10^{-2}}$; $5{\cdot}10^{-2}$; 10^{-1}; 1; 10^{1}
Gaussian ring (Eq. 2)	large dust	$R_{\rm dust}$ [au]	52; **53**; 55; 60
	large dust	σ [au]	10; 11; 12; **13**; 14; 15; 20; 25
	large dust	$\Sigma_{0,\rm dust}$ [au]	**0.6**
Dust properties		Size small grains	**0.005μm - 1μm**
		Size large grains	**1μm - 1cm**
		$q_{\rm small}$	**3.5**
		$q_{\rm large}$	**3**
		χ	**0.2**