Dissecting Galaxies Near and Far:
High Resolution Views of Star Formation and the ISM
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Molecular gas at the center of the Galaxy

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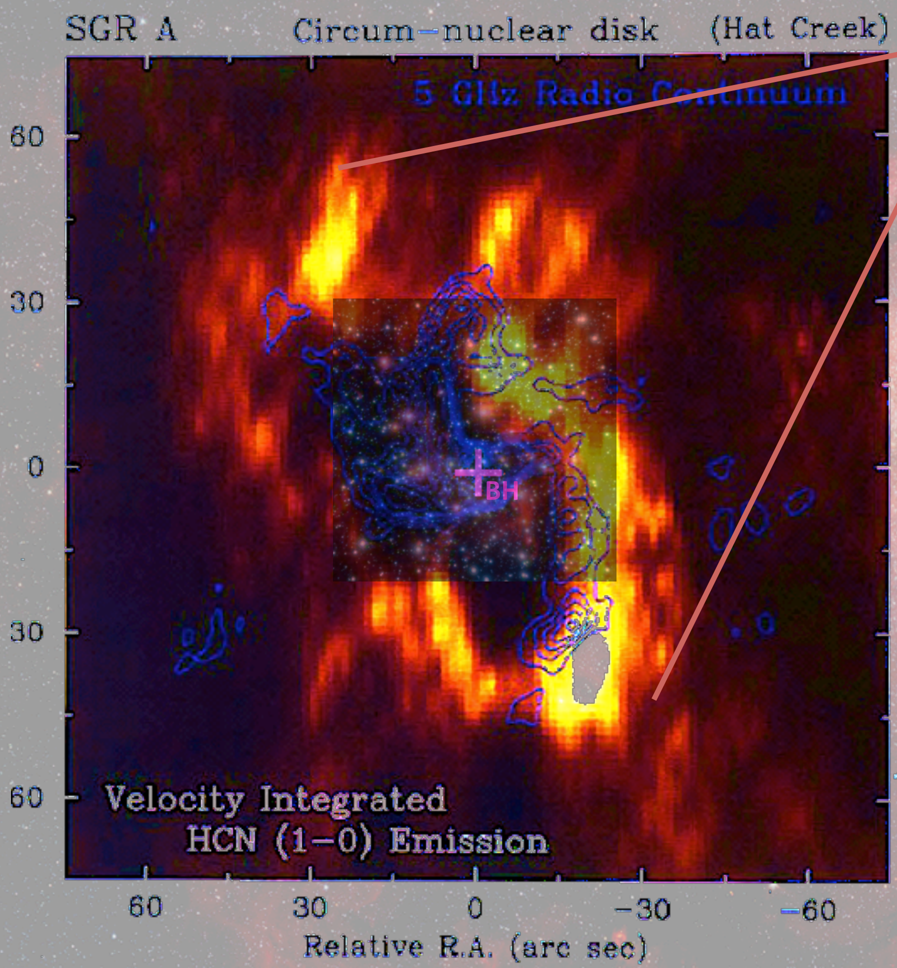
grant agreement 312430
for supporting this contribution

Outline

- Introduction
- Regularized 3D fitting
- Gas distribution and dynamics
- Gas excitation
- Conclusion

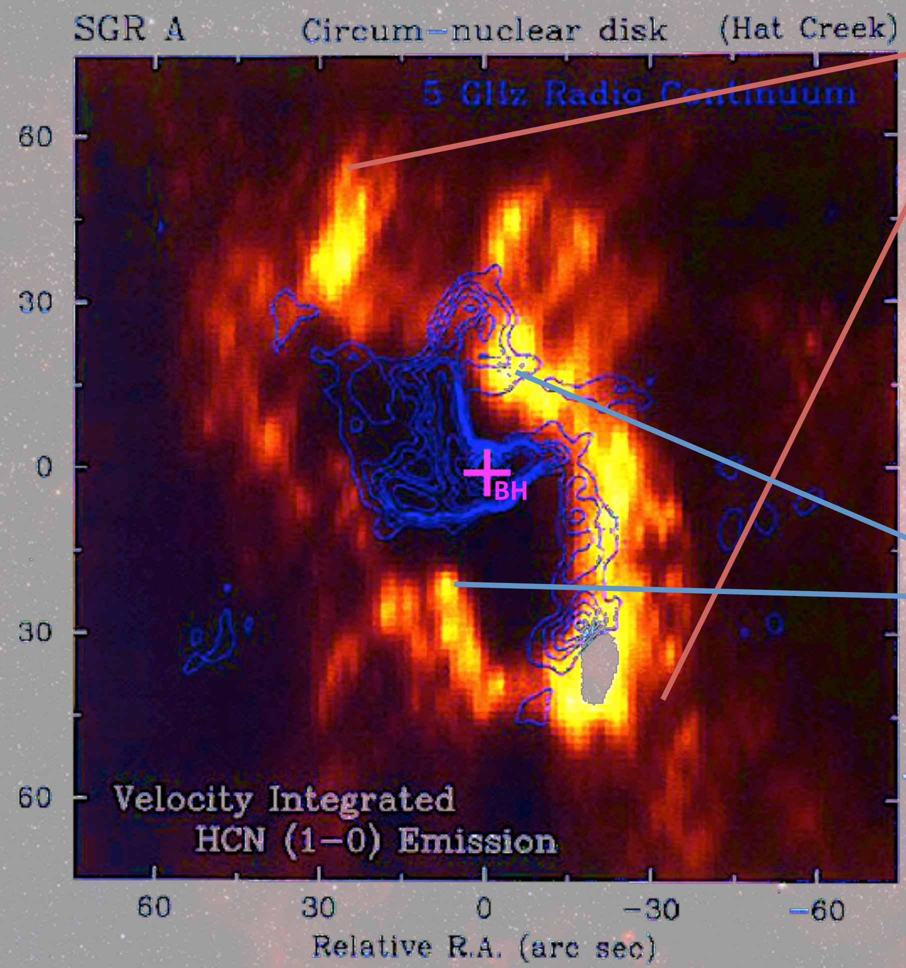
Gas structure of the central parsec



Circumnuclear disk (CND)

- Asymmetrical ring 1 pc inner radius
- warm and turbulent
- clumpy: clouds of dust and molecular gas
- mass ≈ $10^4 - 10^6$ $M_{\odot}$
- T ≈ 200 – 300 K
- ionized central cavity

Gas structure of the central parsec



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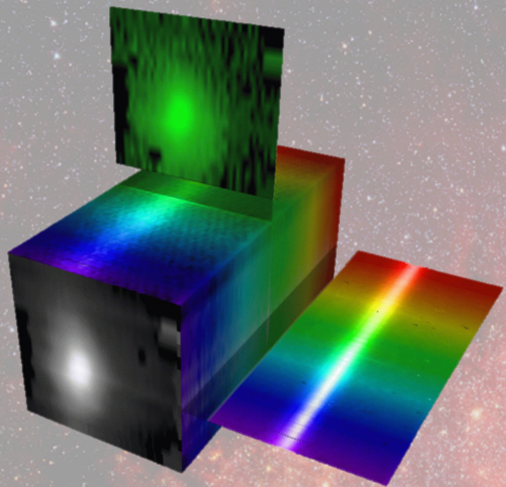
Minispiral

- Clouds of atomic and ionized gas
- intense UV radiation
- ionized boundary of atomic gas clouds falling towards the center

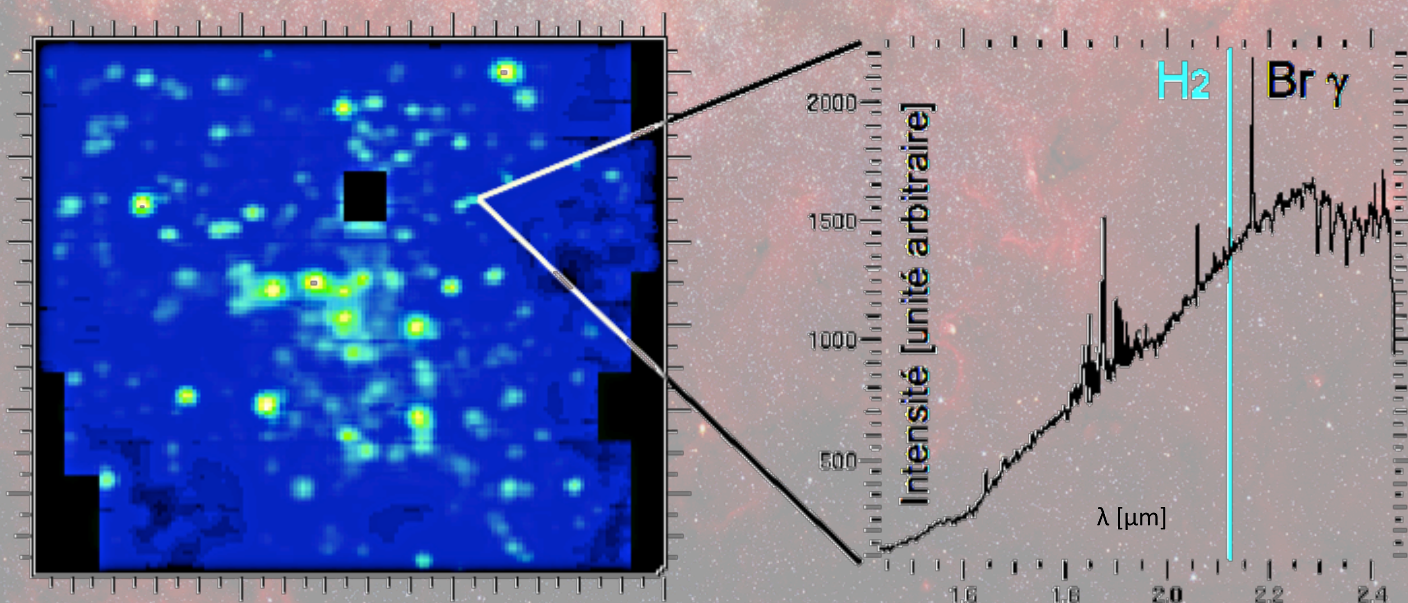
Dataset



SPIFFI

VLT near-infrared integral field spectrograph

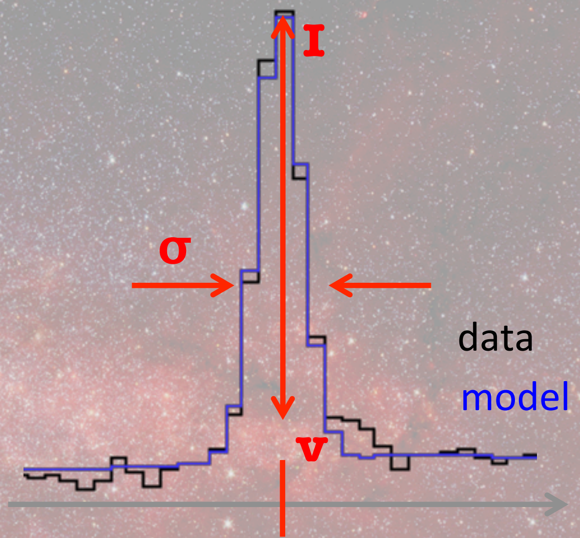
- VLT/SINFONI without adaptive optic
- 39“x29“ central cavity mosaic
- Spectral resolution R=1500 (in H+K)
- Spectra for every pixel of the field



Analysis

H_2 analysis:

maps of each parameter of the Gaussian fit:
intensity / velocity / width



fit pixel by pixel ⇨ **but** low signal-to-noise

⇩

spatial smoothing: - edge effects
- degrades spatial resolution

T. Paumard (Paumard *et al.* in prep.) ⇨ New line fitting method: regularised 3D fitting

Method

$$\varepsilon(a_1, ..., a_n) = \sum_{\alpha,\delta,\lambda} ((D - M_3) \cdot W)^2) + \sum_{i=1}^{n} R_i(a_i)$$

Estimator = **χ2** + Regularisation

L1L2 algorithm

$$\mathcal{J}_{L1L2}(O(x)) = \mu \sum_x \left[\frac{\Delta O(x)}{\delta} - \ln(1 + \frac{\Delta O(x)}{\delta}) \right]$$

Mugnier *et al.* 2004 (MISTRAL) and Gratadour (Yoda)

\+

- low signal-to-noise pixels disfavoured
- Spectral resolution conserved
- No edge effects
- random variations of the maps disfavoured

Method

$$\varepsilon(a_1, ..., a_n) = \sum_{\alpha,\delta,\lambda} ((D - M_3) \cdot W)^2) + \sum_{i=1}^{n} R_i(a_i)$$

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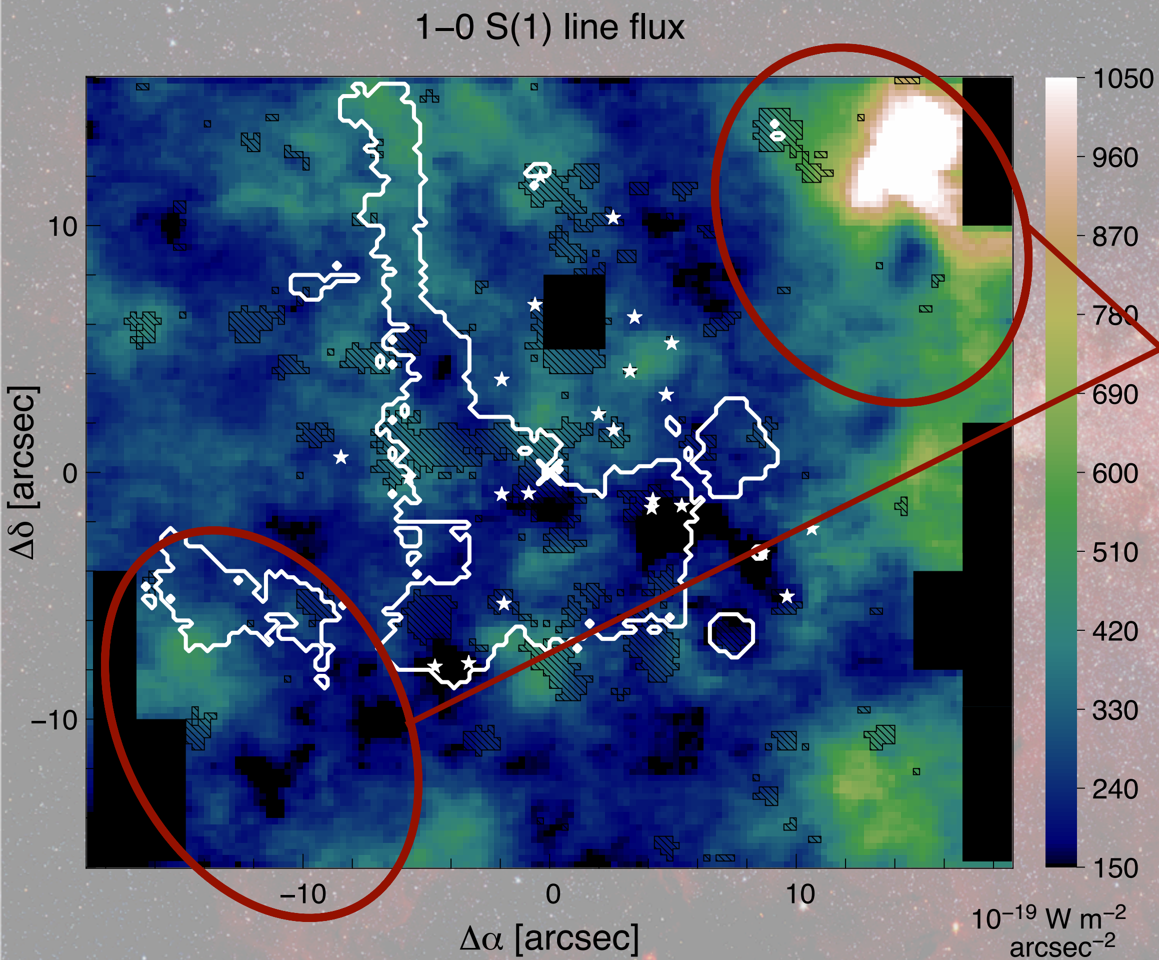
Mugnier *et al.* 2004 (MISTRAL) and Gratadour (Yoda)

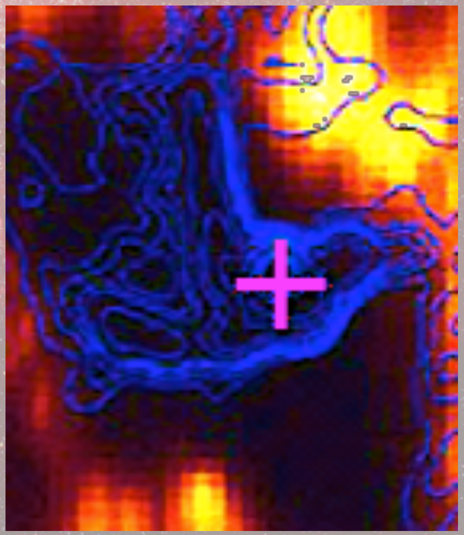
- hyper-parameters tuning
- no objective criteria

- individual spectra fitting
- error bars

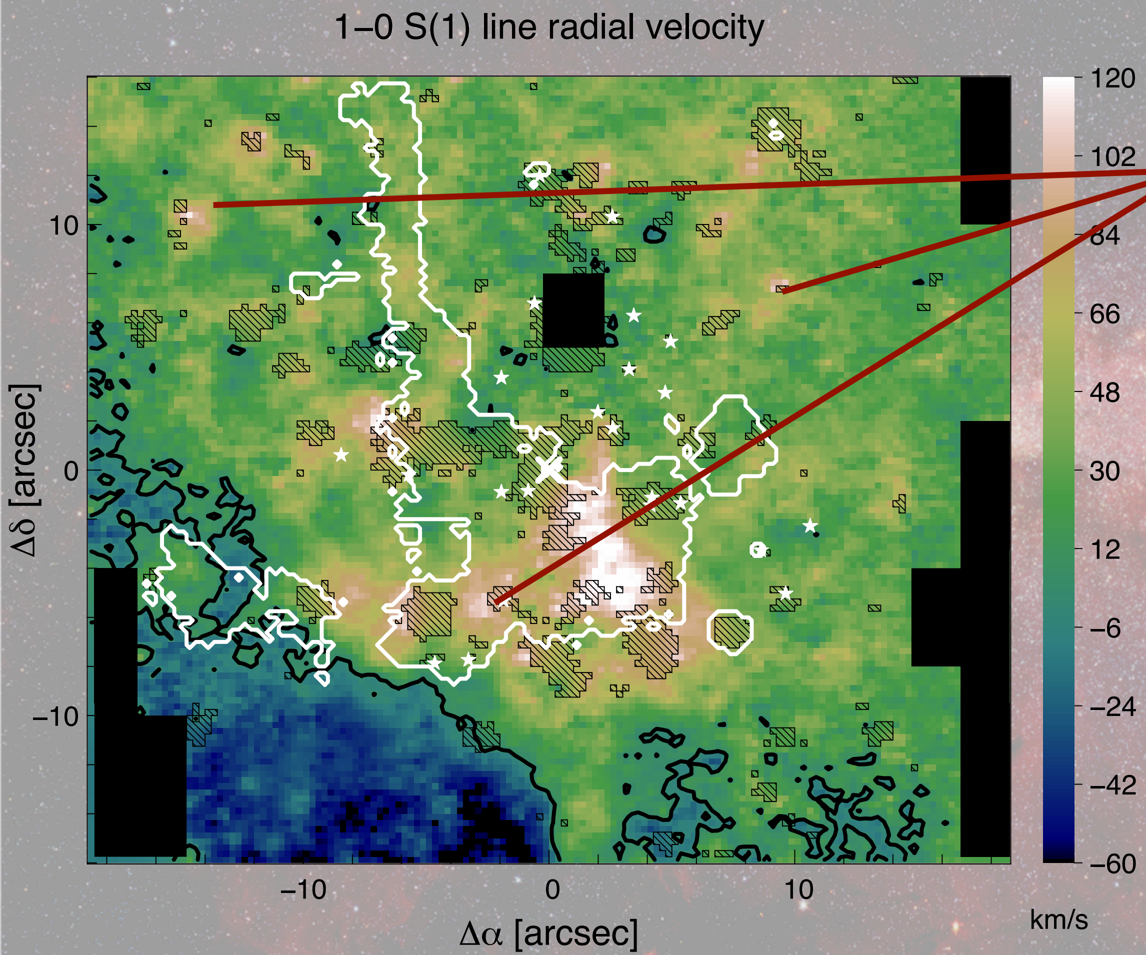
1-0 S(1) line flux



- H_2 everywhere
- fluxes compatible with previous results ()
- CND emission

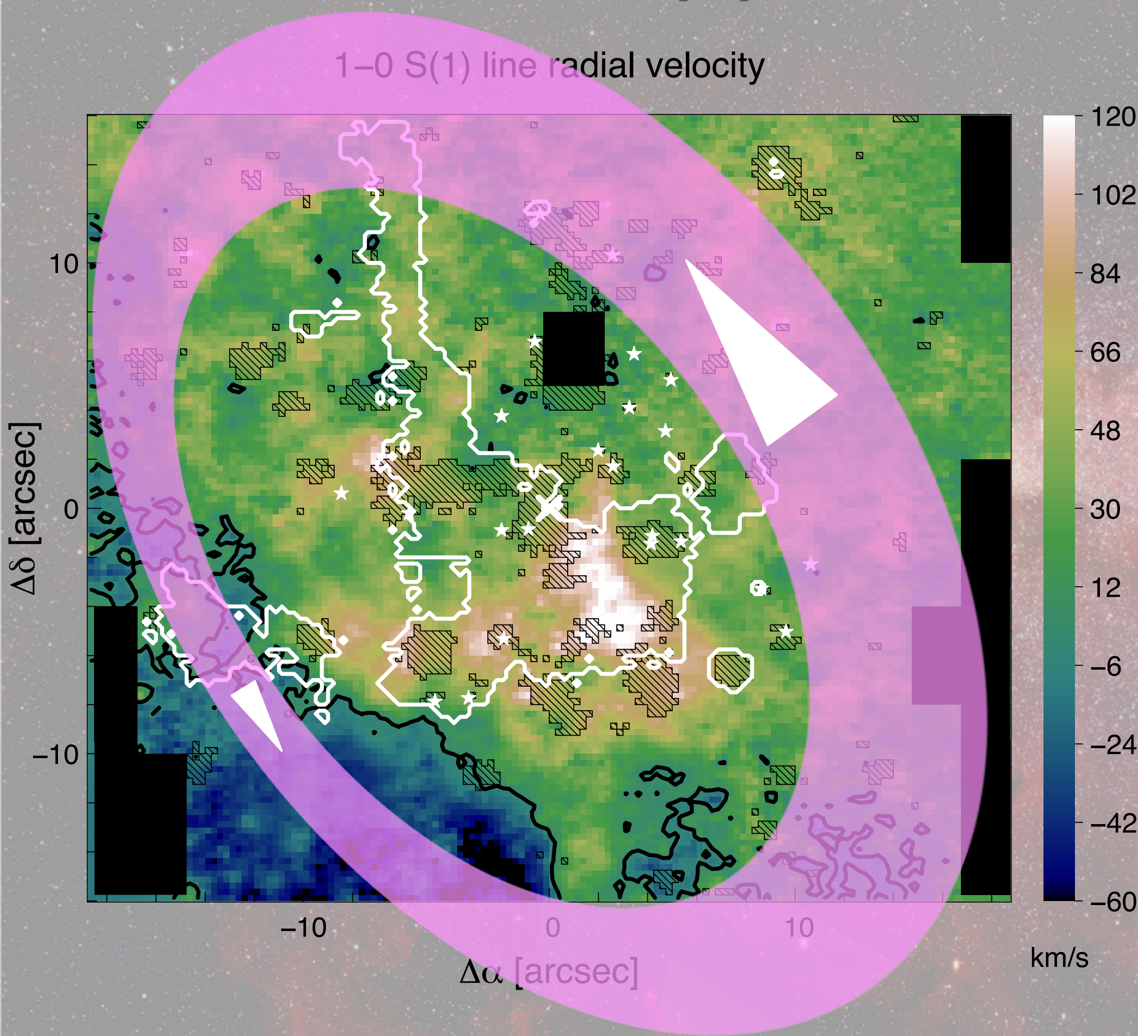


1-0 S(1) line radial velocity



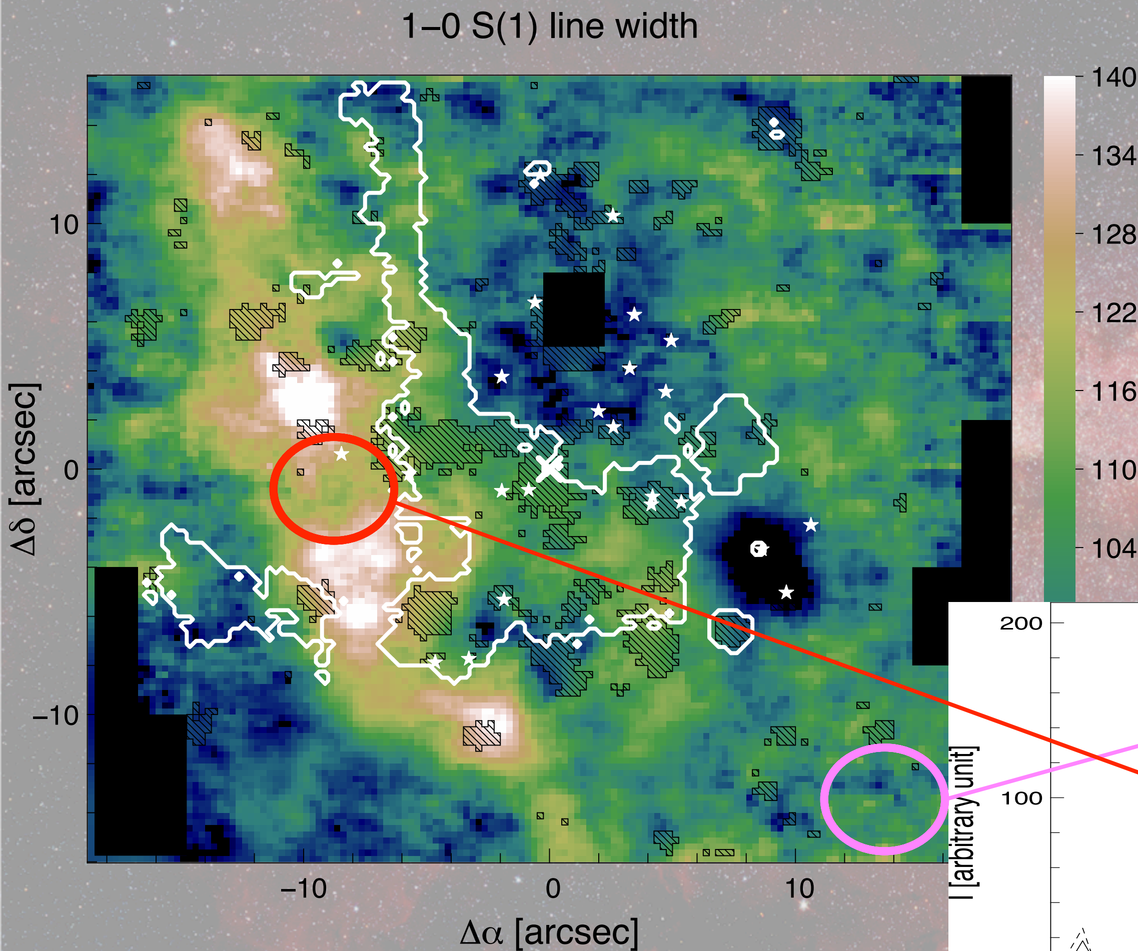
- CND motion
- peaks -> stars

1-0 S(1) line radial velocity

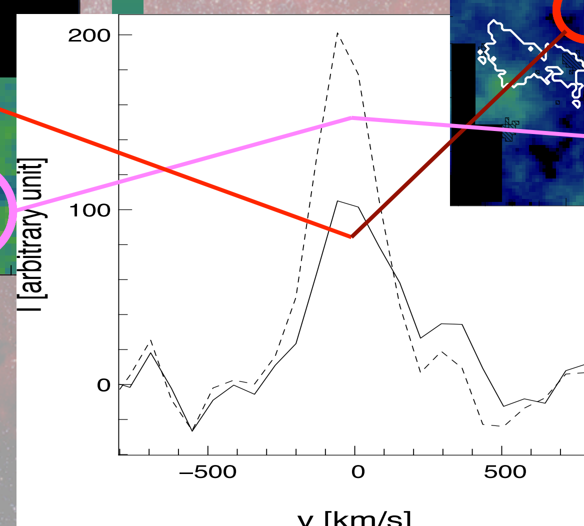


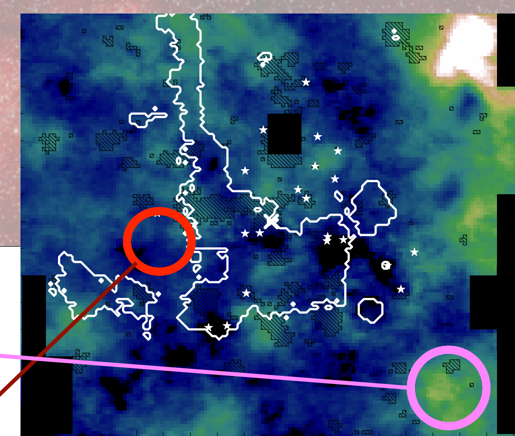
- CND motion

1-0 S(1) line width



- Wide and weak line near the Northern Arm
- Narrow and intense line elsewhere





Others lines maps with 3D method

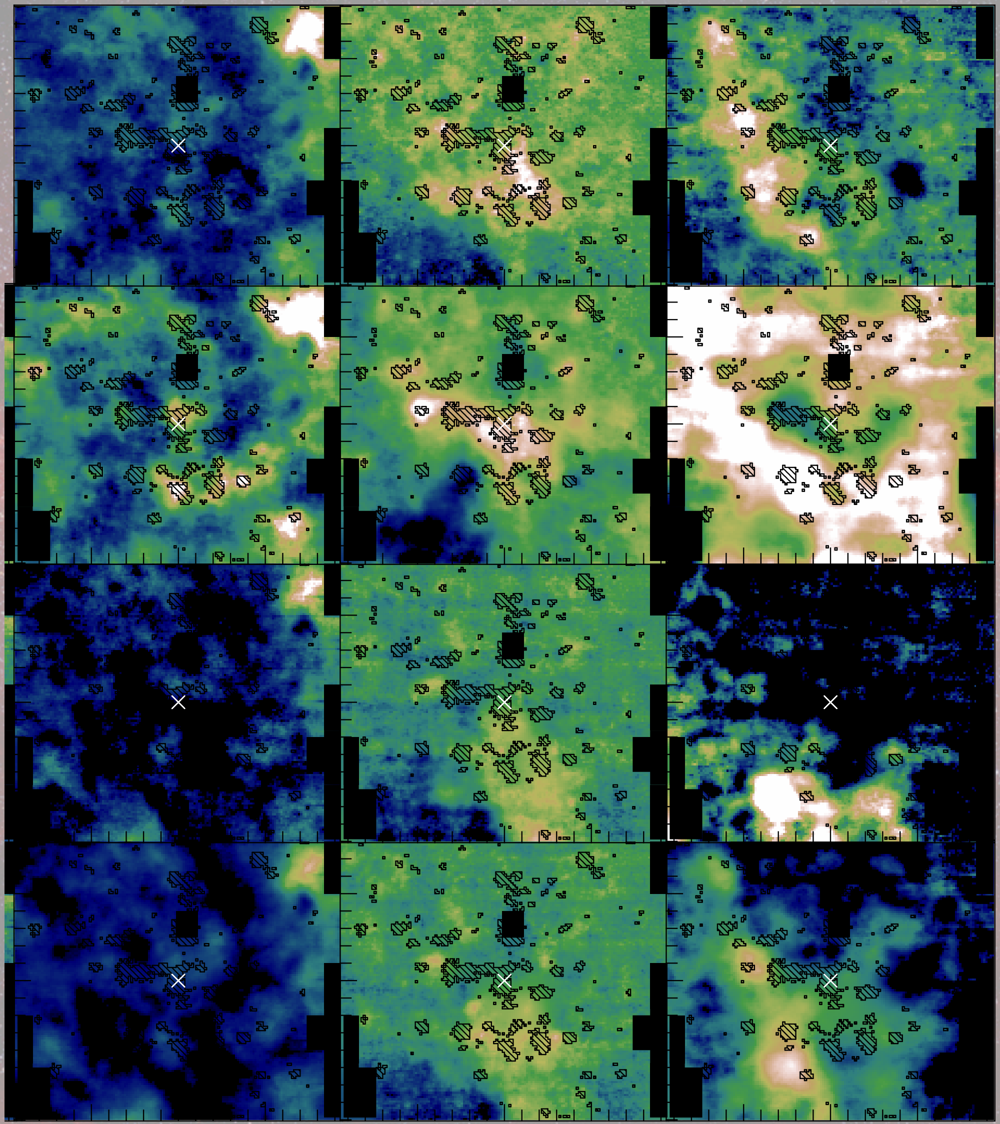
Line flux radial velocity line width

1-0 S(1)
λ = 2.1218 μm

1-0 S(3)
λ = 1.9575 μm

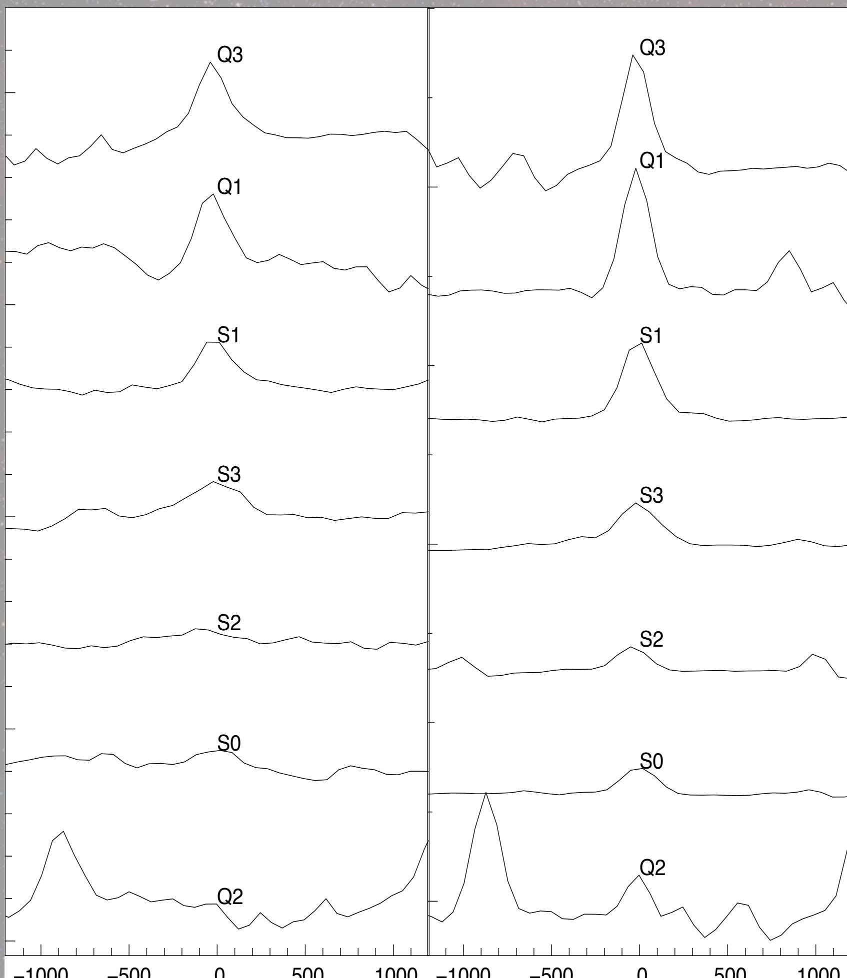
1-0 Q(1)
λ = 2.4075 μm

1-0 Q(3)
λ = 2.4236 μm



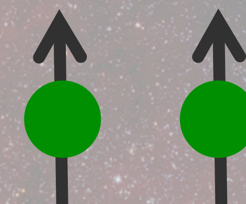
H_2 lines

Average spectrum Highest intensity region



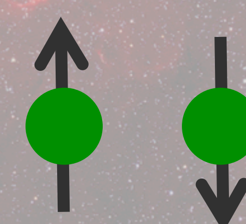
Ortho

1-0 S(3) λ = 1.9575 µm
1-0 S(1) λ = 2.1217 µm
3-2 S(3) λ = 2.2013 µm
2-1 S(1) λ = 2.2477 µm
1-0 Q(1) λ = 2.4065 µm
1-0 Q(2) λ = 2.4133 µm
1-0 Q(3) λ = 2.4236 µm

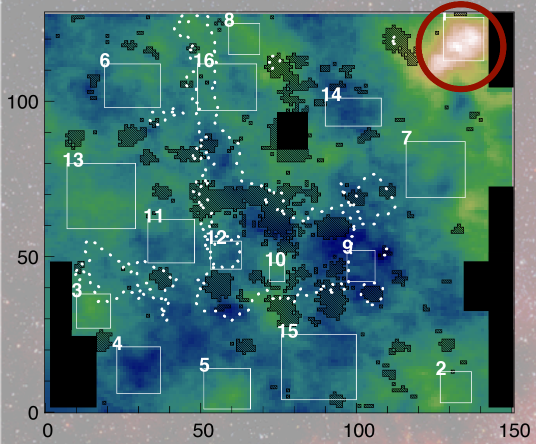


Para

1-0 S(2) λ = 2.0338 µm
1-0 S(0) λ = 2.2233 µm
3-2 S(2) λ = 2.2869 µm
1-0 Q(2) λ = 2.4134 µm



Zone analysis



Column density of molecules in state [*v*, *j*]

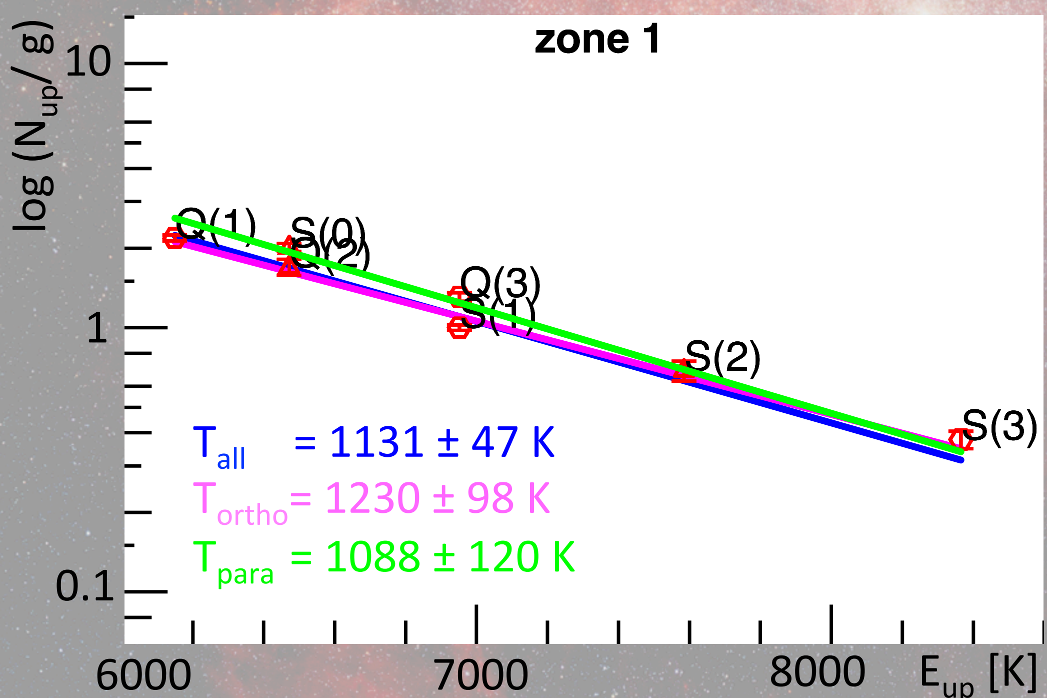
$$N_{vj}/g_{vj} = 4\pi f / A\Omega$$

for thermalized populations

$$\frac{N_{vj}}{N_{tot}} = \frac{g_{vj} e^{-E_{vj}/T_e}}{\sum_i g_i e^{-E_i/T_e}}$$

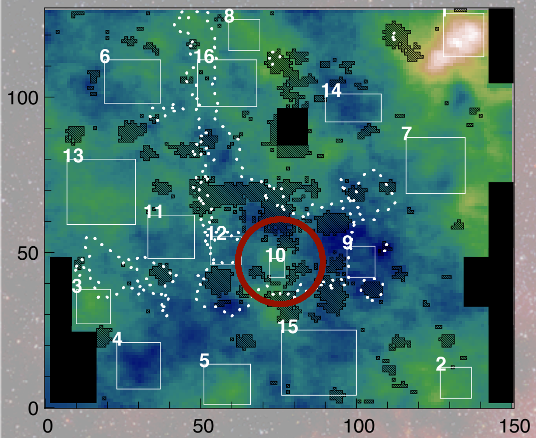
Excitation diagram fitting function

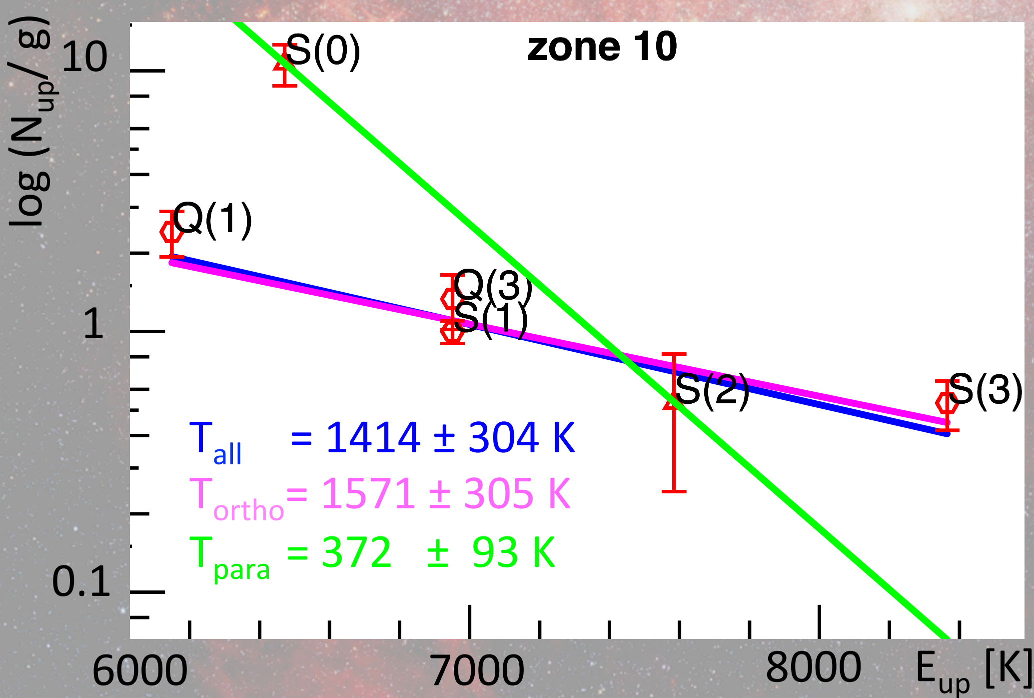
$$\frac{N_{vj}/g_{vj}}{N_{13}/g_{13}} = A e^{-(E_{vj}-E_{13})/T_e}$$



→ thermalization is the rule

Zone analysis





higher density of UV radiation

↓

H_2 more rapidly destroyed

↓

shorter mean life during

↓

thermalization cannot fully occur

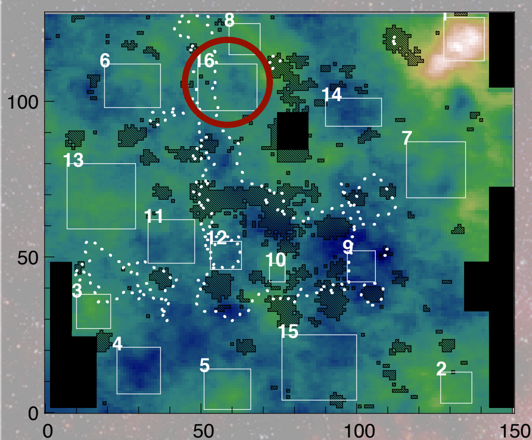
↓

recently formed H_2 may form mainly as para

↙ emission has to be in the central cavity

↘ constraints on H_2 formation/excitation models **!**

Zone analysis



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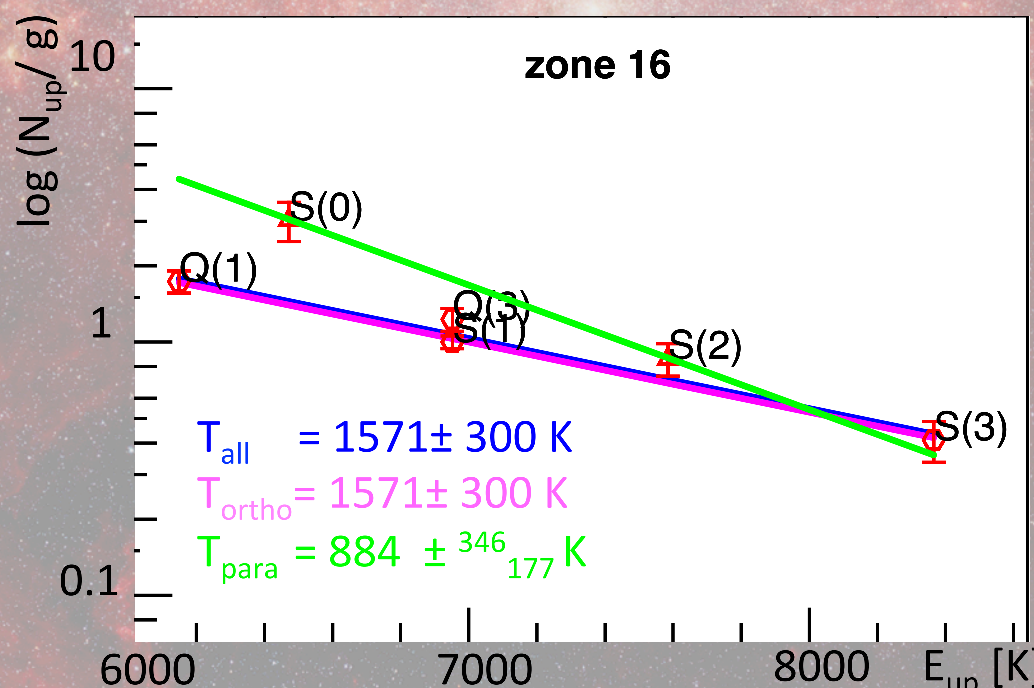


If thermodynamic equilibrium valid:

		Previous measurements (CO)		
CND:	T ~ 1200 K (inner cavity > 1500 K for ortho ~ 800 K for para)	< 400 K	→	High temperatures
	$N_{tot} \simeq 0.02 - 5 \cdot 10^{24}\ m^{-2}$	$10^{26}\ m^{-2}$	→	Low total column density
	M (500 *arcsec*^{2}) $\simeq 0.4 \pm 0.1\ M_\odot$	$> 10^3\ M_\odot$	→	Low masses

No contradiction: we are looking different things → the more excited and hot H_2

✧ **Regularized 3D fitting method** → High resolution picture of the central parsec

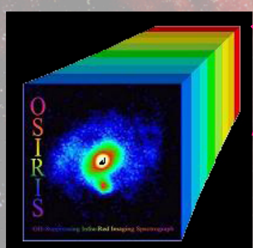
Different components of the emission

CND (bright and narrow line) — Inner cavity (wide and weak line)

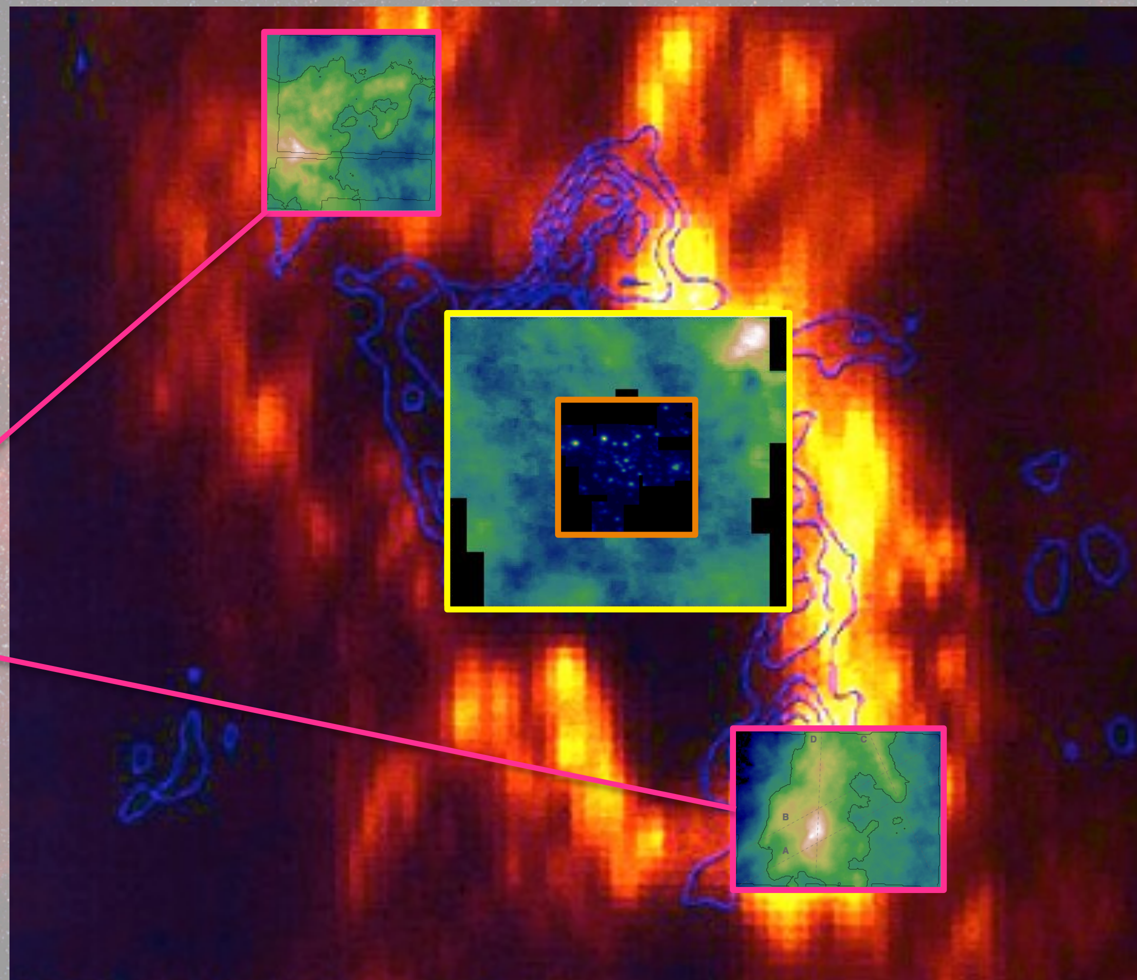
✧ **Multi-lines analysis**

- high T → UV pumping as main excitation mechanism
- **CND:** hot H_2 in a thin layer (0.01 – 1%) at the surface of the CND (Le Bourlot, private communication)
- **Central cavity***:* less dense, UV radiation penetrates and heats (higher T), more clouds on the line of sight (large velocity dispersion)
- Departure from thermodynamcal equilibrium : recently formed H2, in a short timescale formation/destruction cycle

Perspectives



OSIRIS data
Paumard *et al.*
in prep.

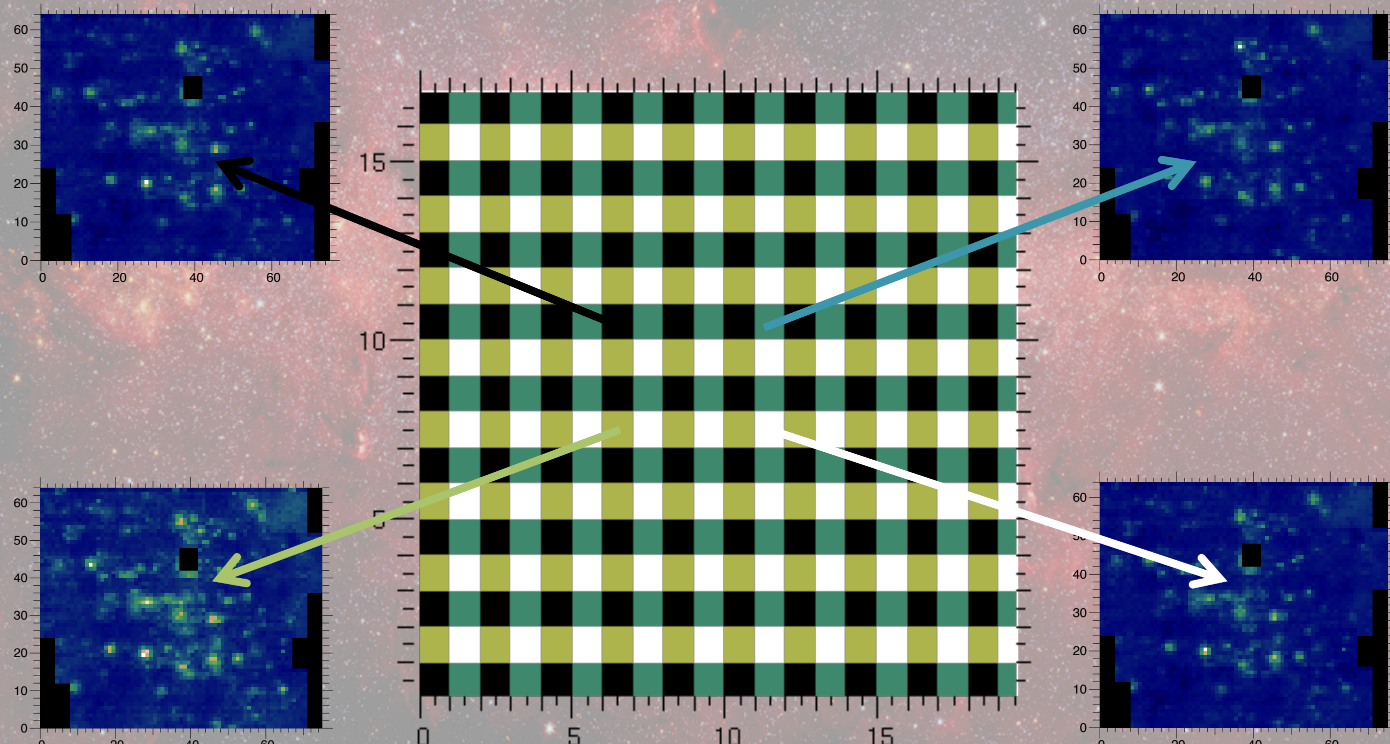


Thank you for your attention

Uncertainties estimation

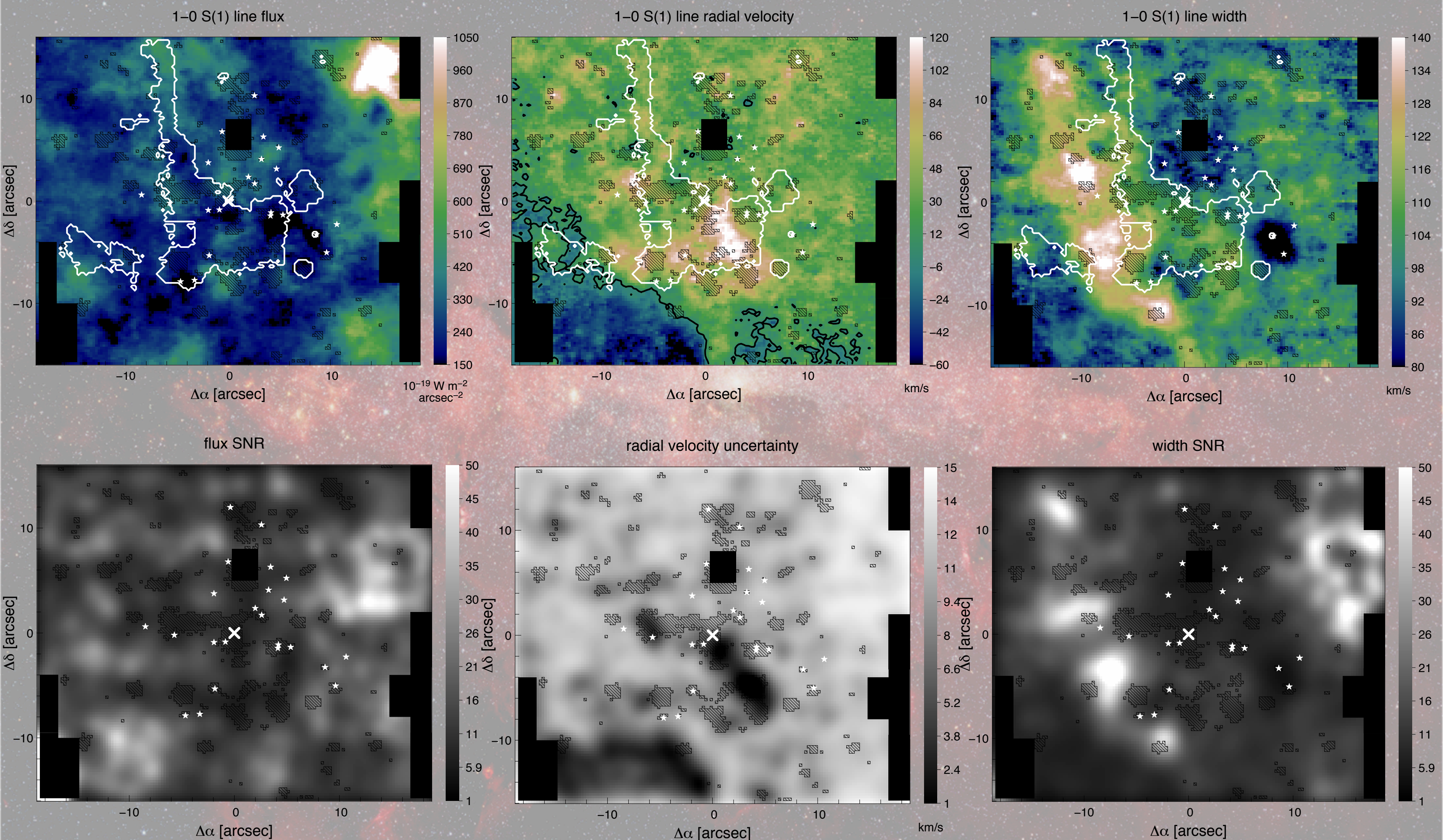
1 pixel over 4 → (interpolated) → New cube of the same size

↳ 4 times → 4 new Independent cubes



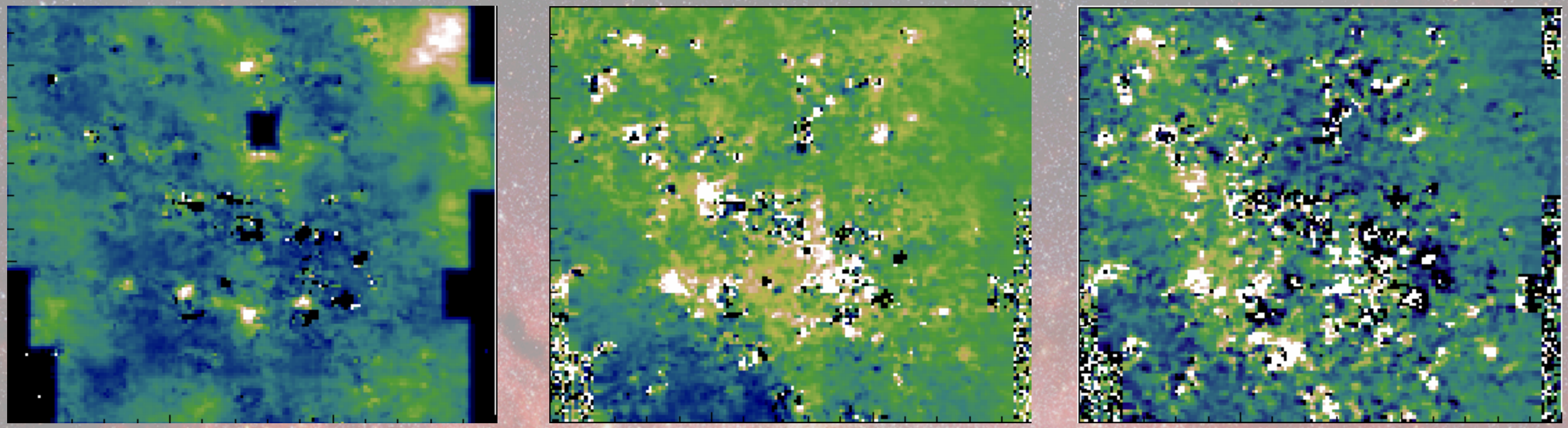
4 maps for each parameter → standard deviation (divided by 2)

Uncertainties estimation

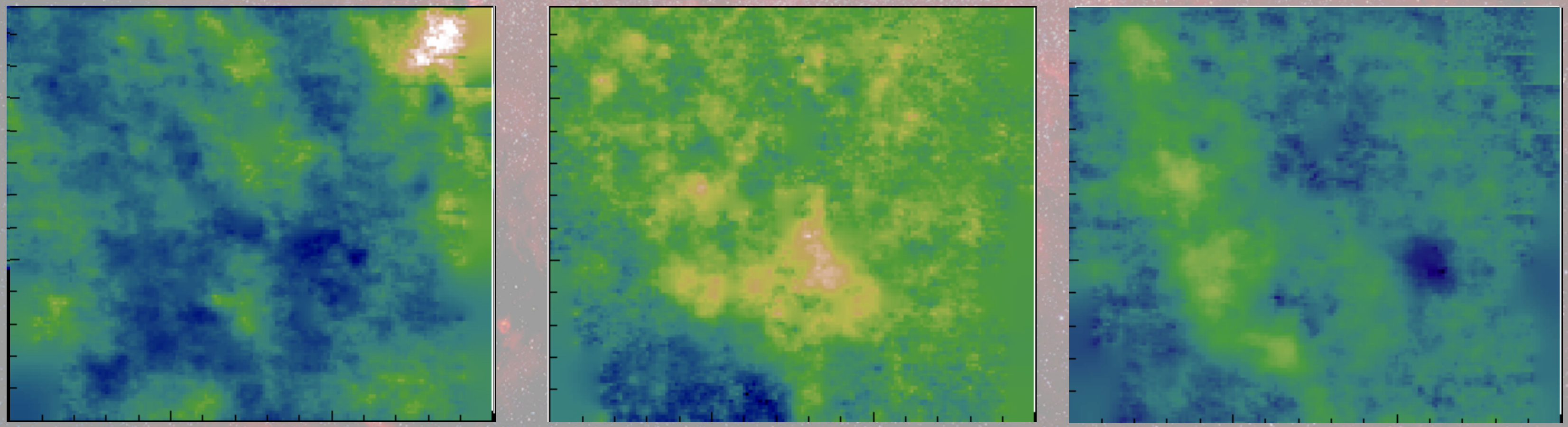


Pixel by pixel VS regularized 3D fitting

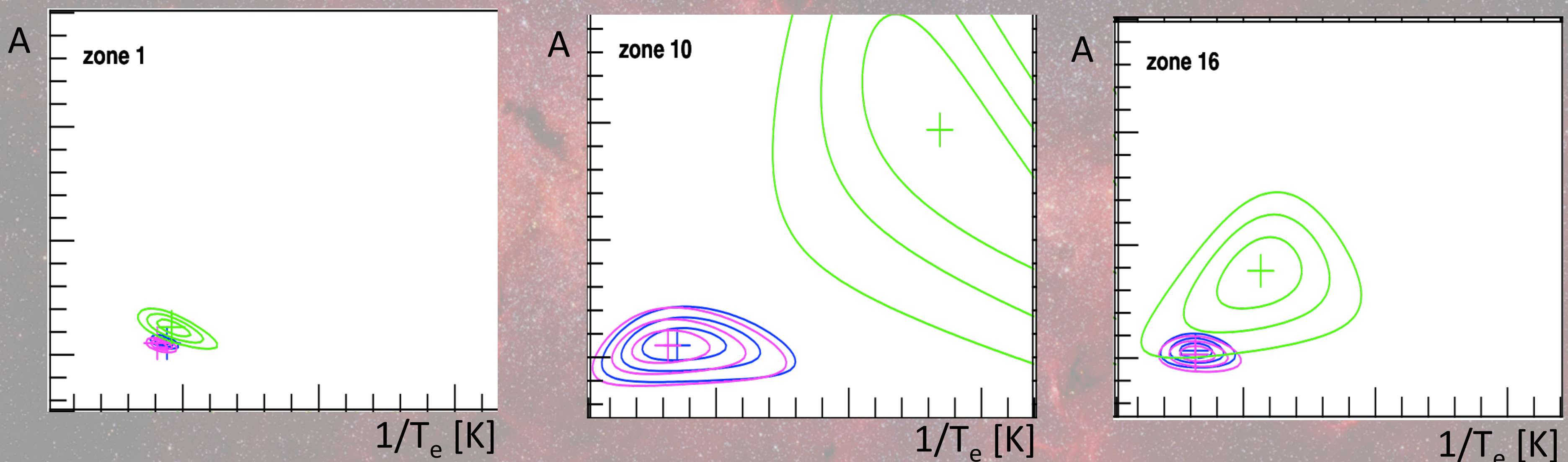
Pixel by pixel fitting

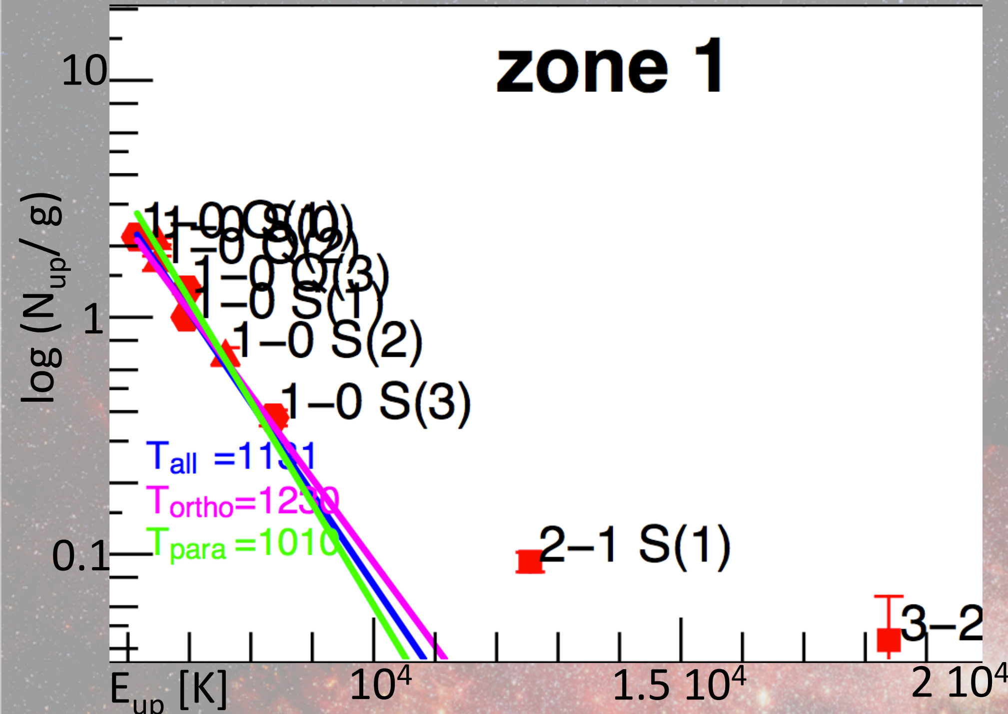


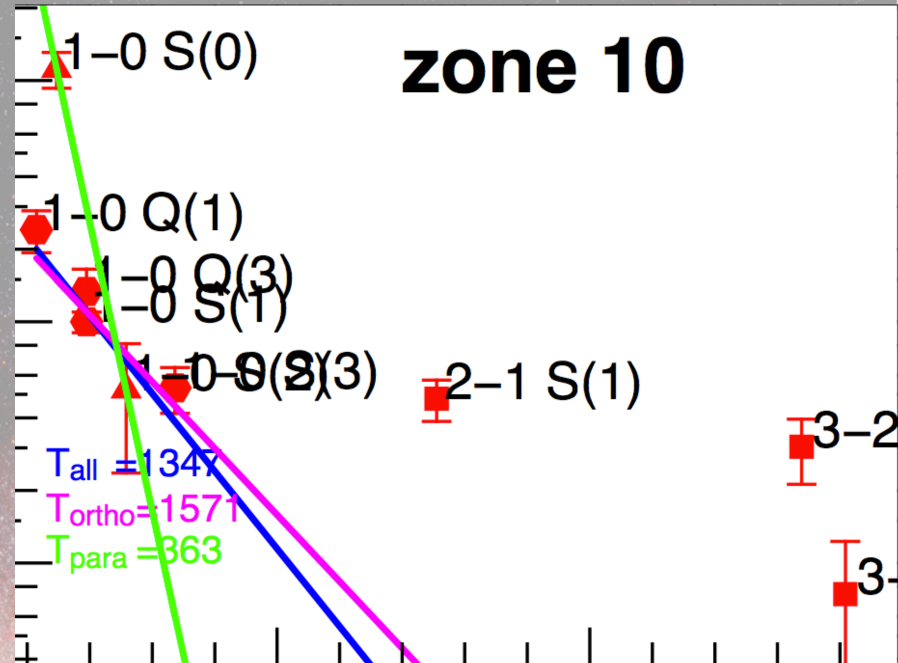
Regularised 3D fitting

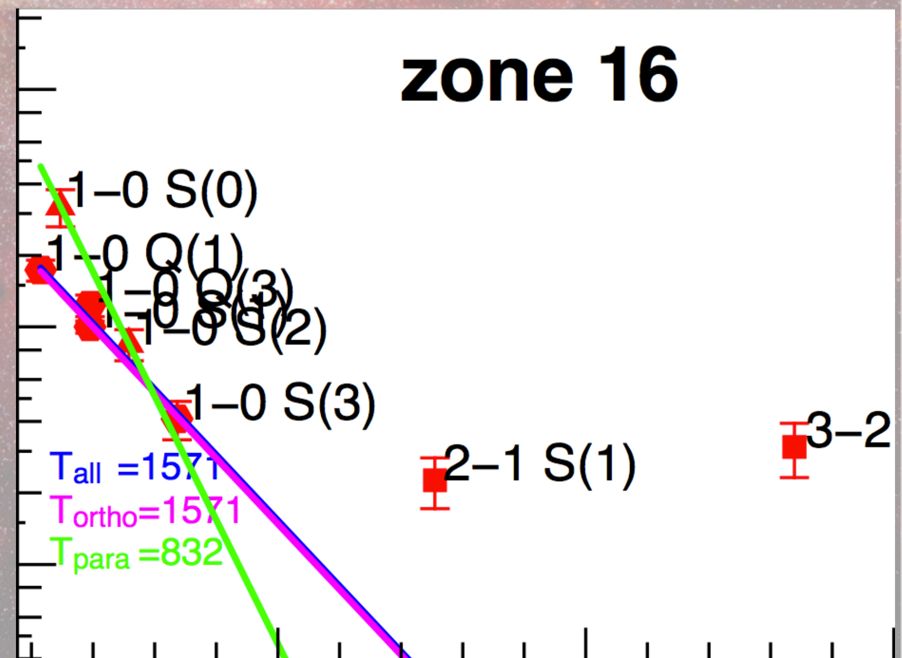


Chi-squared maps









Excitation diagrams v=1,2,3

Le Bourlot simulation