OBSERVED CHEMISTRY IN THE GG TAU A GAS AND DUST DISK:
The first detection of H_2S in a protoplanetary disk

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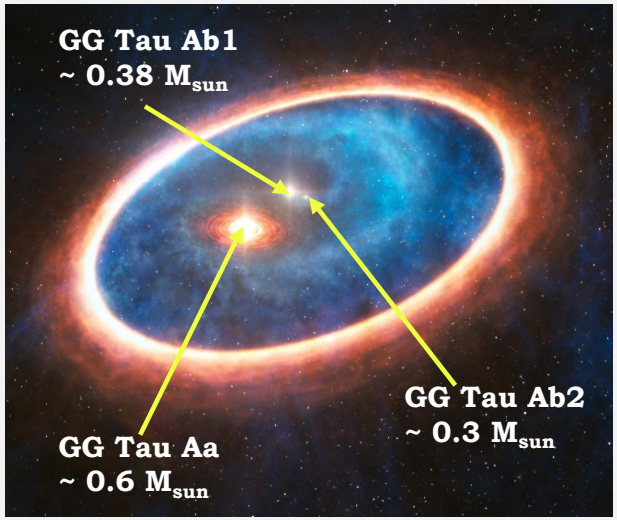

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CONTENTS

Introduction

GG TAU A , a typical T Tauri star

Taurus-Auriga star forming region

140 pc, 2-3 Myr

A triple system,

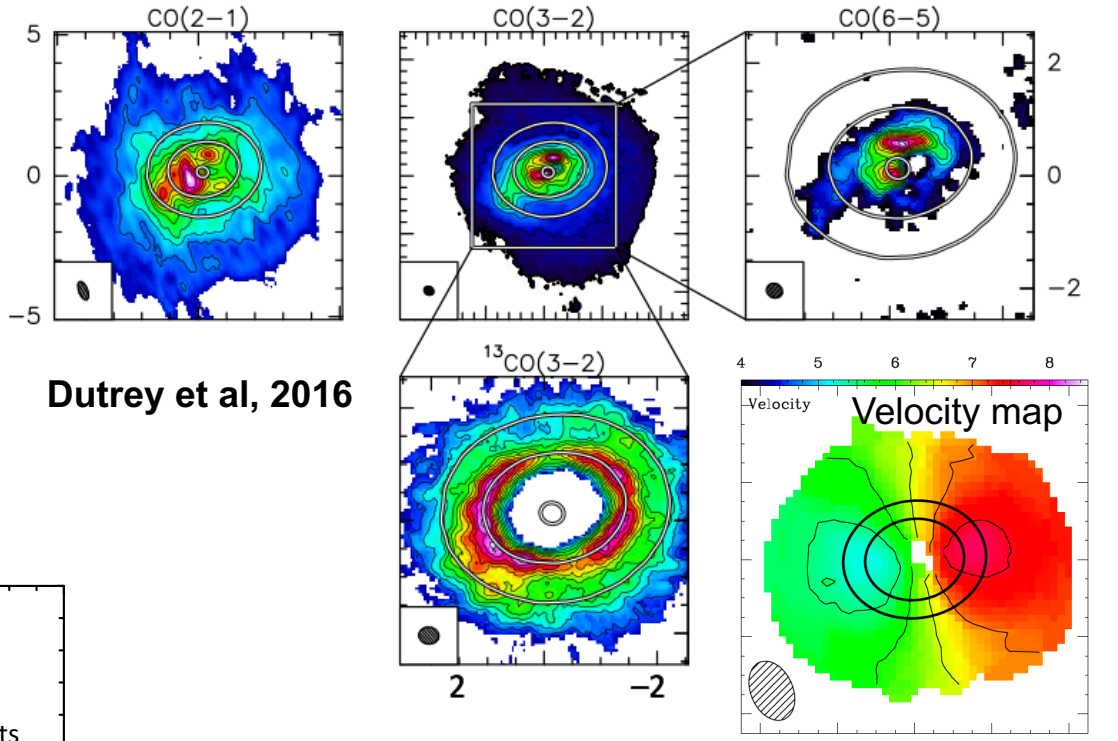
Cavity of 180 au, i~ 37^o, PA ~8^o

$M_{\star}$=1.3 $M_{\odot}$, M_{disk} = 0.12 $M_{\odot}$

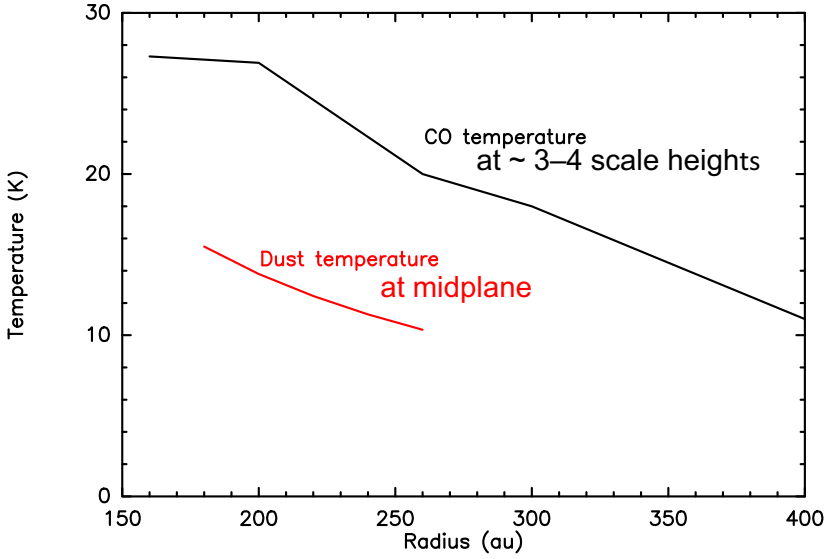
Gas + dust disk out to 800 au

Dust ring of 180 – 260 au

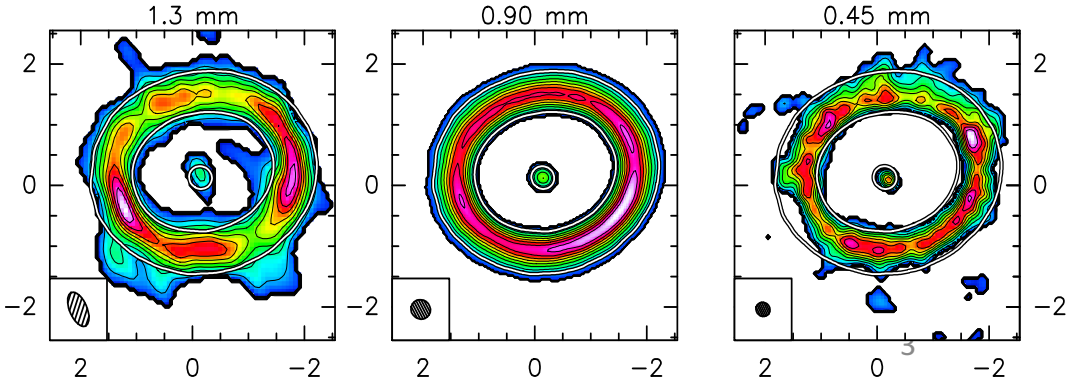
Observed molecular lines in GG Tau A



Dutrey et al, 2016

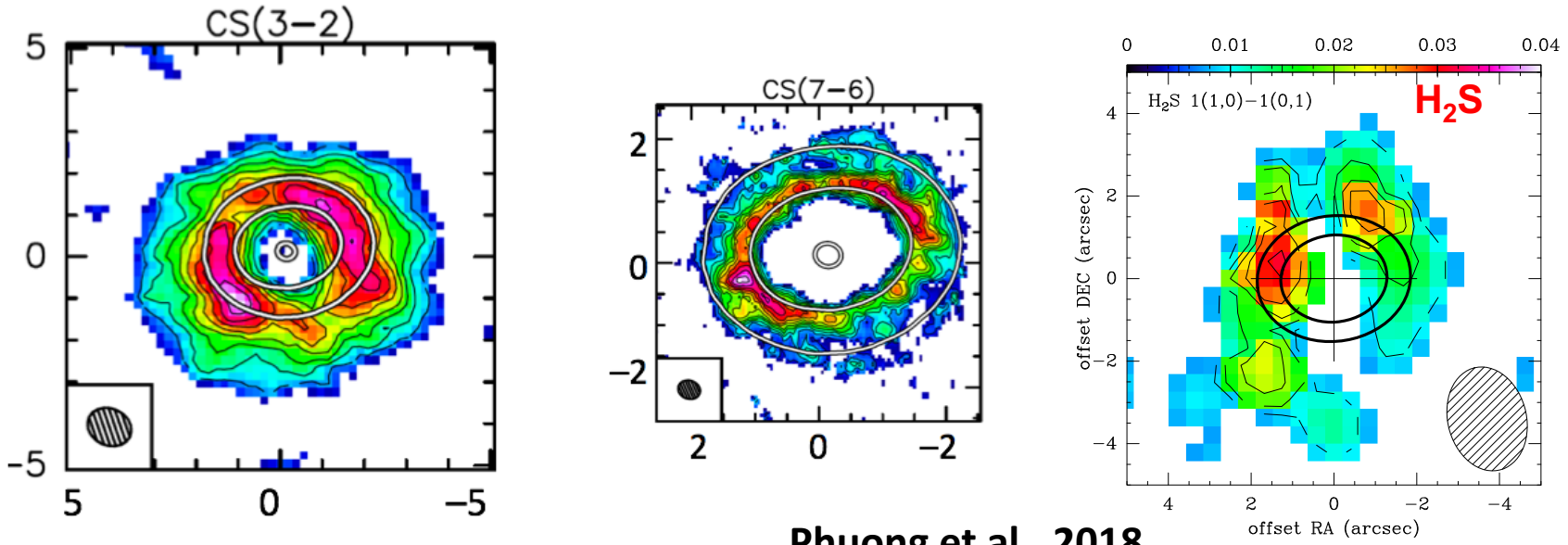


Observed continuum emission in GG Tau A



Observations and results (S-bearing species)

In recent attempt to study molecular chemistry with focus on Sulfur-bearing species, we observed CS, H_2S, SO, SO_2 and CCS in the GG Tau A disk.



Phuong et al., 2018

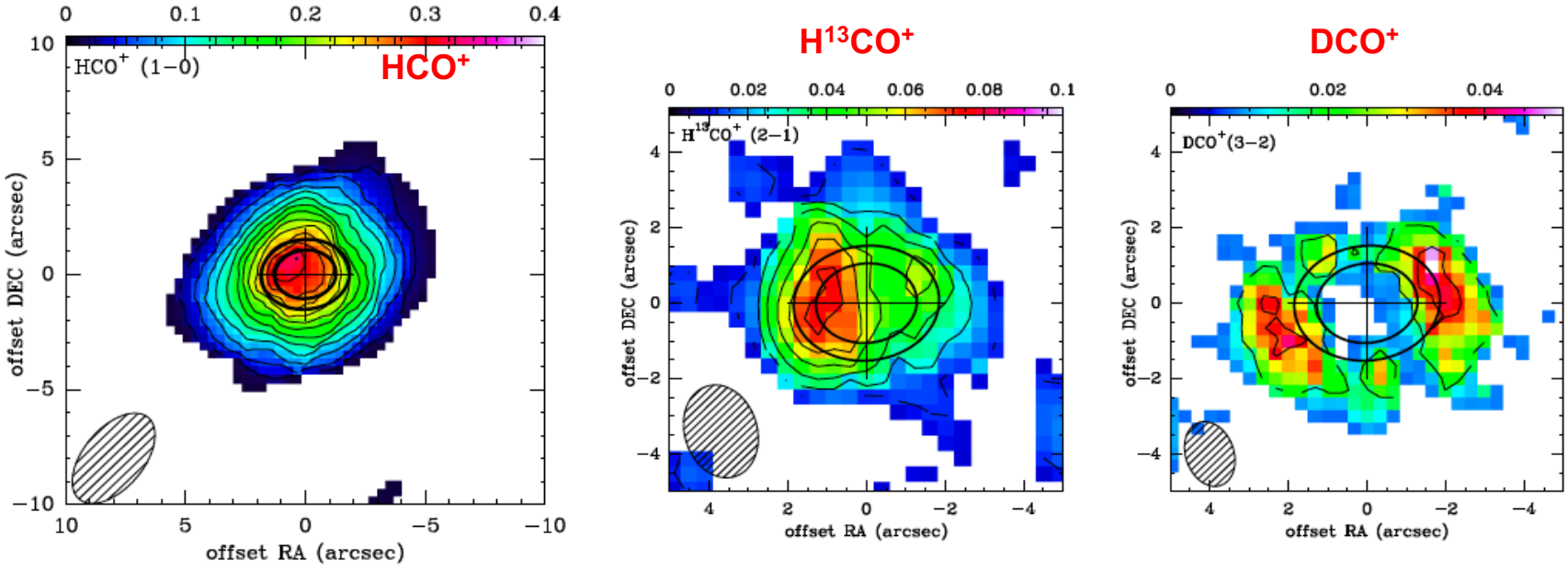
CS (3-2) and CS (7-6) are observed in the disk, with CS (3-2) is more extended and CS(7-6) mostly present in the dense ring region.

Most of the H_2S 1(1,0) –1(0,1) emission originates from the dense ring between 180 and 260 au (T ~25 K) and extends up to ~500 au.

Other Sulfur-bearing species SO, SO_2, which are expected to be in the warmer region of the disk and C_2S are not detected.

Observations and results (C-bearing species)

Some Carbon-bearing molecules were also observed.
HCO^+(1–0) is as extended as the CO emission out ~800 au
$H^{13}CO^+$(2–1) isotopologe emission peaks in the eastern part of the ring.
DCO^+ (3–2) emission peaks outside of the dense ring.



Phuong et al., 2018

The measured $HCO^+/H^{13}CO^+$ ratio is ~30, suggesting partially optically thick emission for HCO^+(1–0) line.

Observations and results (C-bearing species)

Precursors of DCO^+ and HCO^+ are H_2D^+, H_3^+ and CO

$$H_2D^+ + CO \rightarrow DCO^+ + H_2$$

$$H_3^+ + CO \rightarrow HCO^+ + H_2$$

H_2D^+ formed in the gas phase at low temperature, easily destroyed by CO, N_2

$$H_3^+ + HD \leftrightarrows H_2D^+ + H_2 + 232K$$

→ H_2D^+ should be abundant in cold disk mid-plane and studing DCO^+ may give evidence for the CO snow line in disk mid-plane.

The measured DCO^+/HCO^+ ratio in disks:

0.03 over the GG Tau A disk – This work

0.04 in the disk of TW Hydra (0.06 $M_\odot$) – van Dishoeck et al. 2003

0.024 in the disk of LkCa 15 (0.028 $M_\odot$) – Huang et al. 2017

→ This is consistent with other disks and gives clear evidence of ongoing deuterium enrichment in the GG Tau A disk.

Observations and results

We use three-phase (i.e., gas phase, grain surface, and grain mantle, along with possible exchanges between the different phases) chemical model **Nautilus** to model the chemistry in the dense and cold ring of GG Tau A in order to explain the observations.

– **C/O ratio** affects the abundances of SO, SO_2: Their column densities drop by factors of 100 and 500, respectively, when C/O changes from 0.46 to 1.2 (Semenov et al. 2018)
– **UV field** has a negligible impact on the H_2S desorption and mild affects to the SO/H_2S ratio and small affects to the DCO^+/HCO^+ ratio.
– **2 grain size** model produces much higher H_2S than observed.

Final compromised parameters

One grain size model of 0.1 μm
Stellar UV flux of $f_{UV200AU} = 375\chi_0$
The standard C/O ratio of 0.7
Sulfur abundance of $8\ 10^{-8}$

For CS:

$$CD_{(Observed)}/CD_{(Predicted)} \sim 2$$

For DCO^+ and HCO^+:

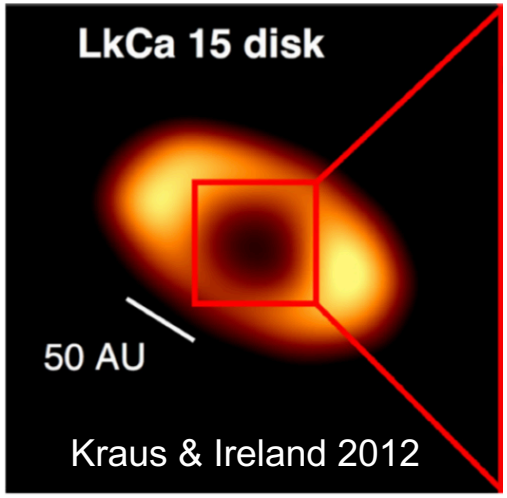
$$CD_{(Observed)}/CD_{(Predicted)} \sim 5 - 7$$

But over-predicted for H_2S (grain surface formation species) :

$$CD_{(Observed)}/CD_{(Predicted)} \sim 26$$

Discussion

Comparison with other sources



Molecular abundance relative to ^{13}CO ($X_{[mol]}/X_{[^{13}CO]} \times 10^5$)

	TMC-1[a]	LkCa 15	GG Tau
HCO^+	$600 \pm 180^{(1)}$	$150 \pm 35^{(3)}$	130 ± 12
H_2S	$<45^{(1)}$	$<7^{(4)}$	11 ± 3
$H^{13}CO^+$	$15 \pm 4^{(2)}$	$5 \pm 1.5^{(4)}$	4.7 ± 0.3
DCO^+	$30 \pm 9^{(2)}$	$4.5 \pm 1.4^{(4)}$	3.5 ± 0.15

Notes. [(a)] ^{13}CO abundance is derived from CO abundance in Ohishi et al. (1992), [(1)] Omont (2007), [(2)] Butner et al. (1995), [(3)] Punzi et al. (2015), [(4)] Dutrey et al. (2011), [(5)] Huang et al. (2017).

The disks appear to have very similar relative abundances, suggesting similar chemical processes at play, while the dense core differs significantly.

The H_2S column density is about **3 times greater** than the upper limits for DMTau, MWC480, GOTau, and LkCa 15 (Dutrey+2011), probably reflecting the larger disk mass of GG Tau A.

The **CS to H_2S abundance ratio of 20** in GG Tau A may still be similar in all sources.

Summary

- We report the first detection of H_2S in a protoplanetary disk and the detections of HCO^+, $H^{13}CO^+$, DCO^+.
- Our three-phase chemical model fails to reproduce the observed column densities of S-bearing molecules, except for CS, suggesting that our understanding of Sulfur chemistry is still incomplete.
- Comparisons with other disks indicate that the detection of H_2S appears to be facilitated by the large disk mass, but that the relative abundance ratios remain similar. This indicates that GG Tau A could be a good test bed for chemistry in disks.

Thank you for your attention!