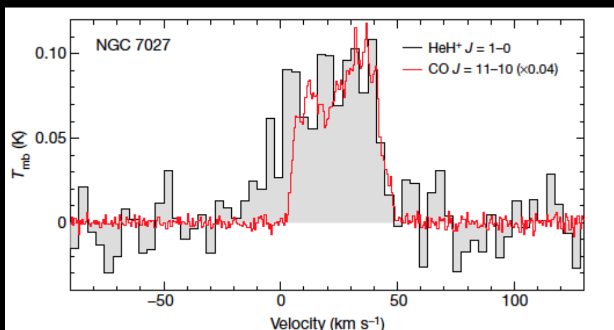
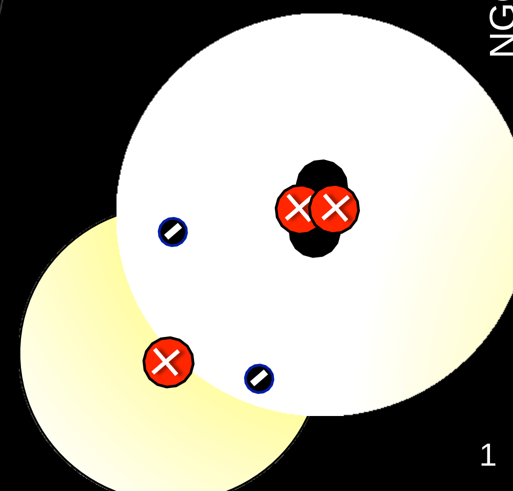
First astrophysical detection of the helium hydride ion (HeH^+)



NGC 7027 image: Latter (SSC/Caltech) and NASA/ESA

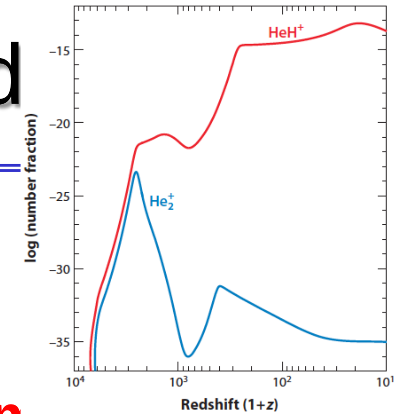
Rolf Güsten
MPI für Radioastronomie

· on behalf of ·



Güsten, Wiesemeyer, Neufeld, Menten, Graf, Jacobs, Klein, Ricken, Risacher & Stutzki 2019, *Nature 568, 357* (arXiv:1904.09581)

Searching for Helium Hydrid



Galli & Palla 2013,ARAA

What is special about HeH^+ ?

The chemistry of the universe began with the helium hydride ion

HeH^+: first molecular bond formed during recombination (z ~7000)

- by (slow) radiative association $He + H^+ \rightarrow HeH^+ + h\nu$
- with progressing recombination, first path to H_2: $HeH^+ + H \rightarrow He + H_2^+$
- marking the beginning of the *molecular age*: $H_2^+ + H \rightarrow H_2 + H^+$

Where is the mystery ?

Despite obvious relevance to our understanding of the Early Universe the molecule has escaped unequivocal detection in interstellar space

- in the laboratory, discovered in 1925 (Hogness & Lunn) by mass spectroscopy
- predicted “detectable” in local plasmas [➡planetary nebulae] (late 1970s)
- but all attempts to detect HeH^+ in interstellar space have been unsuccessful

Searching for Helium Hydride

Conditions in planetary nebulae predicted to be suitable for HeH^+

[Drabowsky & Herzberg '77, Black '78, Flower & Roueff '79, Roberge & Dalgarno '82]

- hard UV field from central white dwarf drives Strömgren spheres with the He^+ zone slightly extending beyond the H^+ sphere
- in this thin overlap layer HeH^+ is formed by radiative association of $He^+ + H \rightarrow HeH^+ + h\nu$ ($\neq$ early universe)

model predictions identified NGC7027 as a most promising target

[Cecchi-Pestellini & Dalgarno '93]

Searching for Helium Hydride

All attempts to detect HeH^+ have been unsuccessful (NGC7027)

from the ground

unsuccessful search for ro-vibrational IR lines

- v=1-0 R(0) at 3.364 µm, no detection [Moorhead et al. 1988)
- v=1-0 P(2) at 3.609 µm upper limit (blend with H20-6) [Dinerstein et al. 2001]

from space

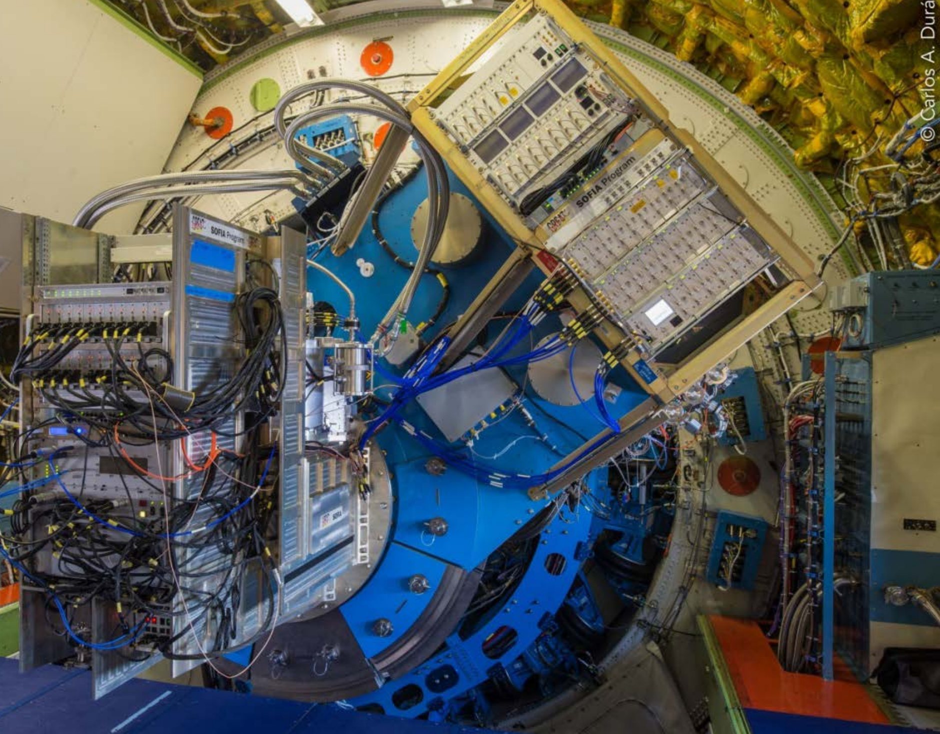
ground-state J=1-0 at 149.1 µm with ISO /LWS (Liu et al. 1997)

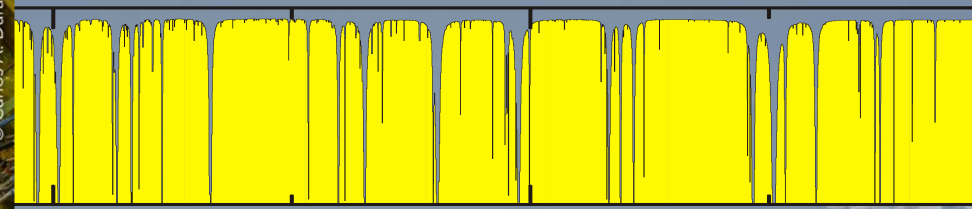
- LWS resolving power (0.6µm) insufficient to separate from nearby CH doublet

[CH separated from HeH^+(1-0) by -90 km/s]

⇒ upper limit on HeH^+ brightness (1.26 10^{-13} erg $s^{-1}cm^{-2}$)

But, in 2016, with a new high-frequency LO the HeH^+ J=1-0 line (2.01 THz) became accessible for observations with upGREAT onboard SOFIA





quencies

GREAT

Receiver	Channel	#	Frequency
4GREAT	4G-1	1	492- 627
	4G-2	1	893-1073
	4G-3	1	1239-1515
	4G-4	1	2495-2690
upGREAT HFA	HFA-V	7	4745
upGREAT LFA	LFA-V	7	1810-1950
	LFA-H	7	1830-2070

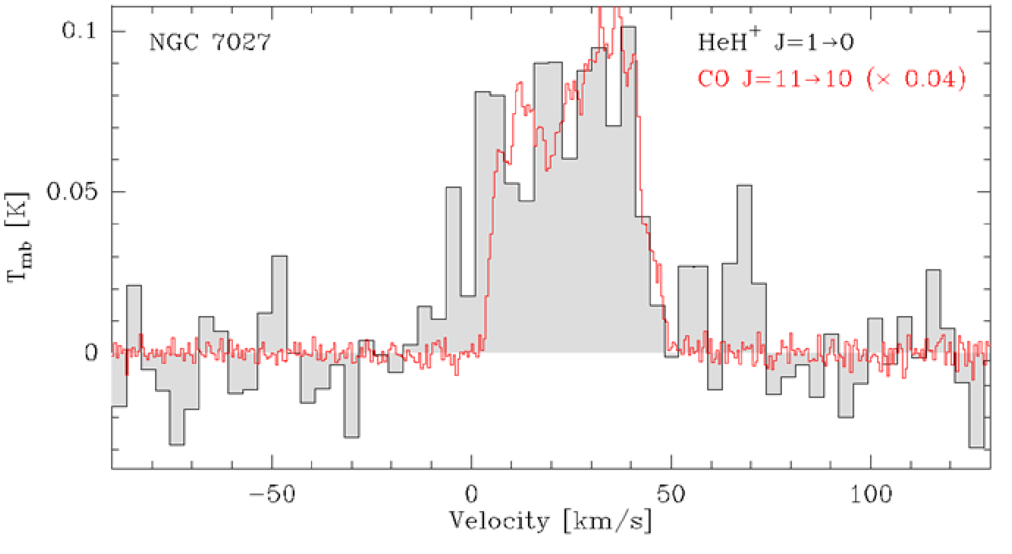
Modular dual-chan

for high-resolution s

First Dectection of Helium Hydride

Observations with upGREAT/LFA-H ($\lambda/\Delta\lambda \sim 10^7$)

- NGC7027 was observed during 3 legs in May 2016, total on source: 71min
- HeH^+ has been clearly detected, well separated from nearby CH doublet
- Integrated line brightness: 3.6 ±0.7 K km/s (1.63 10^{-13} erg $s^{-1}cm^{-2}$)



Modelling Helium Hydride

We have revisited the predictions for NGC7027

Using the CLOUDY photoionization code (Ferland et al.)

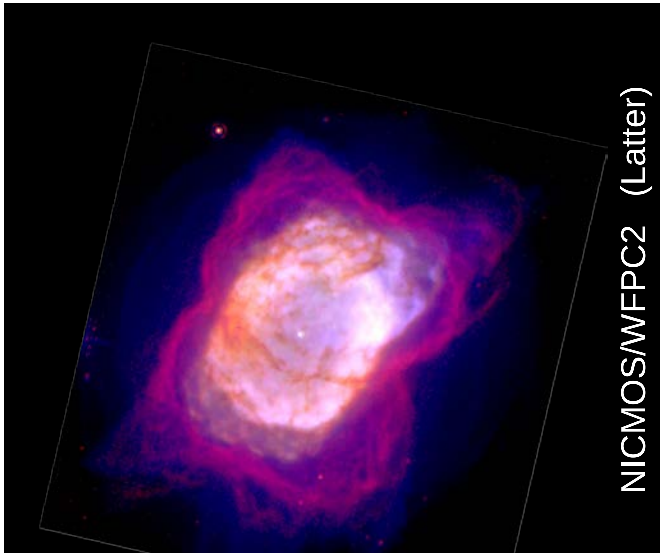
- to calculate the radial dependence of temperature and relevant abundances

Parameters:

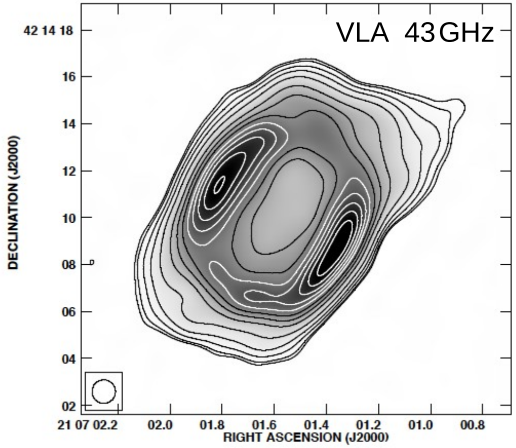
- Adopted distance 980 pc
- Stellar effective temperature $T_{eff} = 1.9 \times 10^5$ K
- Luminosity of white dwarf $1 \times 10^4 L_\odot$
- <radius> of ionized gas shell 3.1 × 4.6”

Assumptions:

- constant pressure (set to match radius)
- spherical symmetry



NICMOS/WFPC2 (Latter)



Zijlstra et al. 2008

Modelling Helium Hydride

Chemical network

Main formation mechanism

$He^+ + H \rightarrow HeH^+ + h\nu$

k_{RA} = 1.4 x 10^{-16} cm^3 s^{-1} (Vranckx et al. 2013*)

2.5 x 10^{-16} cm^3 s $^{-1}$ (Zygleman & Dalgarno '90*)

*after factor 4 correction for "approach factor"

Minor formation pathway

$H^+ + H \rightarrow H_2^+ + h\nu$

$H_2^+ + He \rightarrow HeH^+ + H$ -0.6ev

Main destruction mechanisms

$HeH^+ + e^- \rightarrow He + H$

$HeH^+ + H \rightarrow He + H_2^+$

k_{DR} = 3.0 x 10^{-10} cm^3 s^{-1} (Stromholm et al. 1996)**

k_{PT} = 1.2 x 10^{-9} cm^3 s^{-1} (Bovino et al. 2012)

**next VG: latest finding: 4.3 x 10^{-10} Novotny et al. 2019

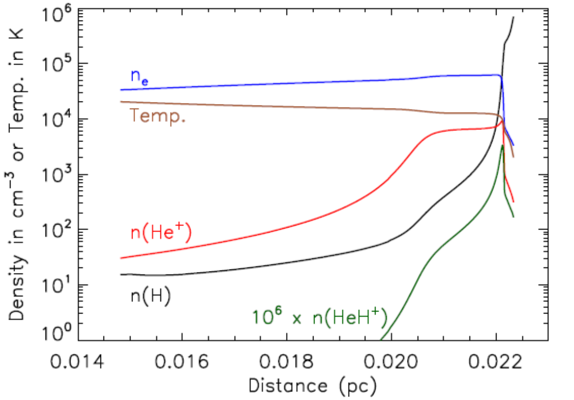
Minor destruction mechanism

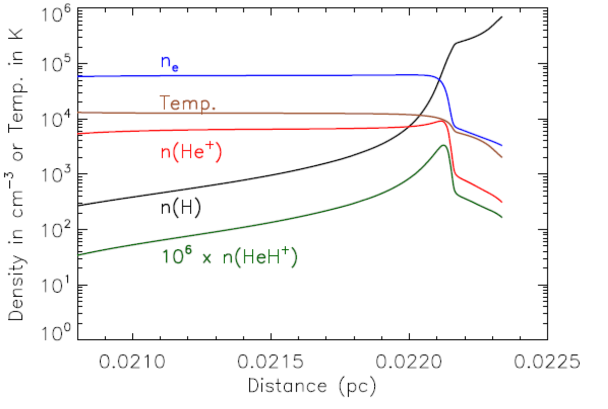
$HeH^+ + h\nu \rightarrow He + H^+$

Modelling Helium Hydride

NGC7027 model predictions (03/19):

- HeH^+ peaks sharply in He^+/H overlap
  with peak fract. abundance 4×10^{-8}
- predicted line intensities
  - fall short of observed J=1-0 by factor 4
  - ro-vib lines: consistent with upper limits





Since, destruction rates R2 & R3 **have been revised (increased!)**

- resulting now in factor ~8 discrepancy wrt to the observed flux
- [similar findings for the IR ro-vib transitions that we have detected recently]

Conclusions

- unambiguous detection brings decade-long search to happy end

but HeH^+ observations appear not in line with current model for NGC7027. A concern might be our simplified source model, but model predicts well the newly observed IR H/He recombination lines. So, the

- biggest challenge might be in the uncertain reaction rates

As the main destruction channels seem confirmed now by independent groups the questions are:

- could the radiative association rate be heavily underestimated ?
- has some important formation mechanism been overlooked ?

The answers are obviously highly relevant to primordial chemistry and the role of HeH^+ in creating a first path to the formation of molecular hydrogen H_2