Searching for Diatomic Hydrides in the Winds of Evolved Stars

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DIATOMIC HYDRIDES IN THE ISM

- Underpin much of interstellar chemistry
- Swings & Rosenfeld (1937) – First identification of methylidyne (CH) in space
- Neutrals: CH, OH, NH, HCl, HF, SH
- Ions: CH⁺, OH⁺, SH⁺, HCl⁺, ArH⁺, HeH⁺
- Hydrogen → most abundant reactant in ISM
- Precursors to more complex species like ammonia (NH₃), methane (CH₄)

Diatomic hydrides offer a way for us to track the dominant chemical processes in any given interstellar environment.
Three main gas phase pathways for diatomic hydrides

In general, neutral hydrides are difficult to form directly. Instead, CR and UV ionization drives hydride chemistry in most environments.

- Diffuse clouds, PDRs

Neutral hydrides thus require dissociative recombination of heavier ions

\[ \text{e.g. } CH_3^+ + e^- \rightarrow CH + H_2 \]

Requires high temperature, high density, source of atoms.
ENVELOPES OF EVOLVED STARS

- Inner wind conditions allow reactions to reach **equilibrium** before traveling outward
- Parent molecules and dust form near stellar surface
- Processed into **daughter molecules** in outer regions
- Hydrides detected toward evolved stars
  
  $\text{HCl, HF, OH, SH, NH}_3, \text{PH}_3, \text{H}_2\text{O, H}_2\text{S, CH}_4, \text{SiH}_4$

Silane ($\text{SiH}_4$), phosphine ($\text{PH}_3$), ammonia ($\text{NH}_3$), and water ($\text{H}_2\text{O}$) have been observed to be much more abundant than equilibrium models predict.
SOFIA - SEARCHING FOR LIGHT HYDRIDES IN CSES

- SOFIA GREAT – German Receiver for Astronomy at Terahertz Frequencies
  - 4GREAT upgrade
  - Similar frequency coverage and spatial resolution as Herschel HIFI

- Targeted transitions of three neutral hydrides:

  SiH \(^{(2Π_{1/2})}\) \(J = 3/2 \rightarrow 1/2\) 624.925 GHz  
  \(J = 5/2 \rightarrow 3/2\) 1043.918 GHz

  PH \(^{(3Σ^-)}\) \(N = 3 \rightarrow 2\), \(J = 4 \rightarrow 3\) 1507.640 GHz

  FeH \(^{(4Δ)}\) \(Ω = 5/2\), \(J = 7/2 \rightarrow 5/2\) 1324.771 GHz

\(E_{up} \sim 30 – 300\) K
Placing Upper Limits

Assume:
1. SiH, PH, and FeH are in local thermodynamic equilibrium (LTE)
2. Described by a single excitation temperature, $T_{\text{ex}}$
3. Spherically symmetric
4. Optically thin

SOFIA DDT 75_0058: “Further Investigation of FeH Toward IRC+10216”

2 additional hours of observing time on this transition
SUMMARY OF RESULTS

- Searched for SiH, PH, and FeH toward the envelopes of IRC+10216 and VY CMa using SOFIA GREAT
- Though none of the target hydrides were clearly detected, we were able to place strict upper limits on their abundances
  - Siebert et al. 2020 + Keady & Ridgeway 1993 + Agúndez et al. 2014b:
    \[
    \frac{[\text{SiH}]}{[\text{SiH}_4]} < 1.4, \quad \frac{[\text{PH}]}{[\text{PH}_3]} < 4 \quad \text{observed}
    \]
  - Agúndez et al. 2020:
    \[
    \frac{[\text{SiH}]}{[\text{SiH}_4]} \sim 1 \times 10^6, \quad \frac{[\text{PH}]}{[\text{PH}_3]} \sim 1 \times 10^4 \quad \text{under TE}
    \]
- In CSEs, growth of hydride molecules occurs much faster than predicted by equilibrium
- H-addition on grain surfaces is likely very important
- Further modeling and observational efforts are needed to fully understand this
- FeH could be a daughter molecule formed in the outer regions of IRC+10216, but confirmation is needed
THANK YOU!

References:

Ziurys, L. 2006, PNAS, 103, 12274