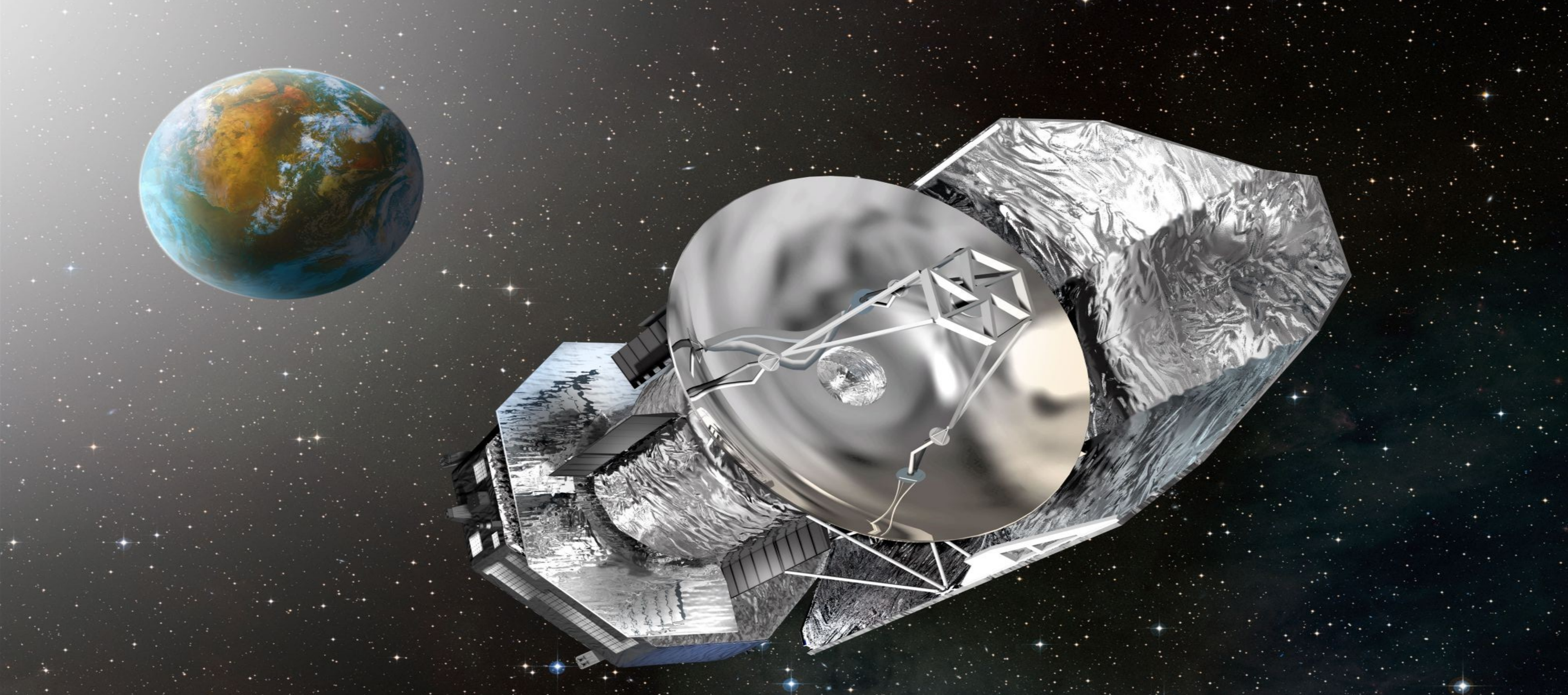
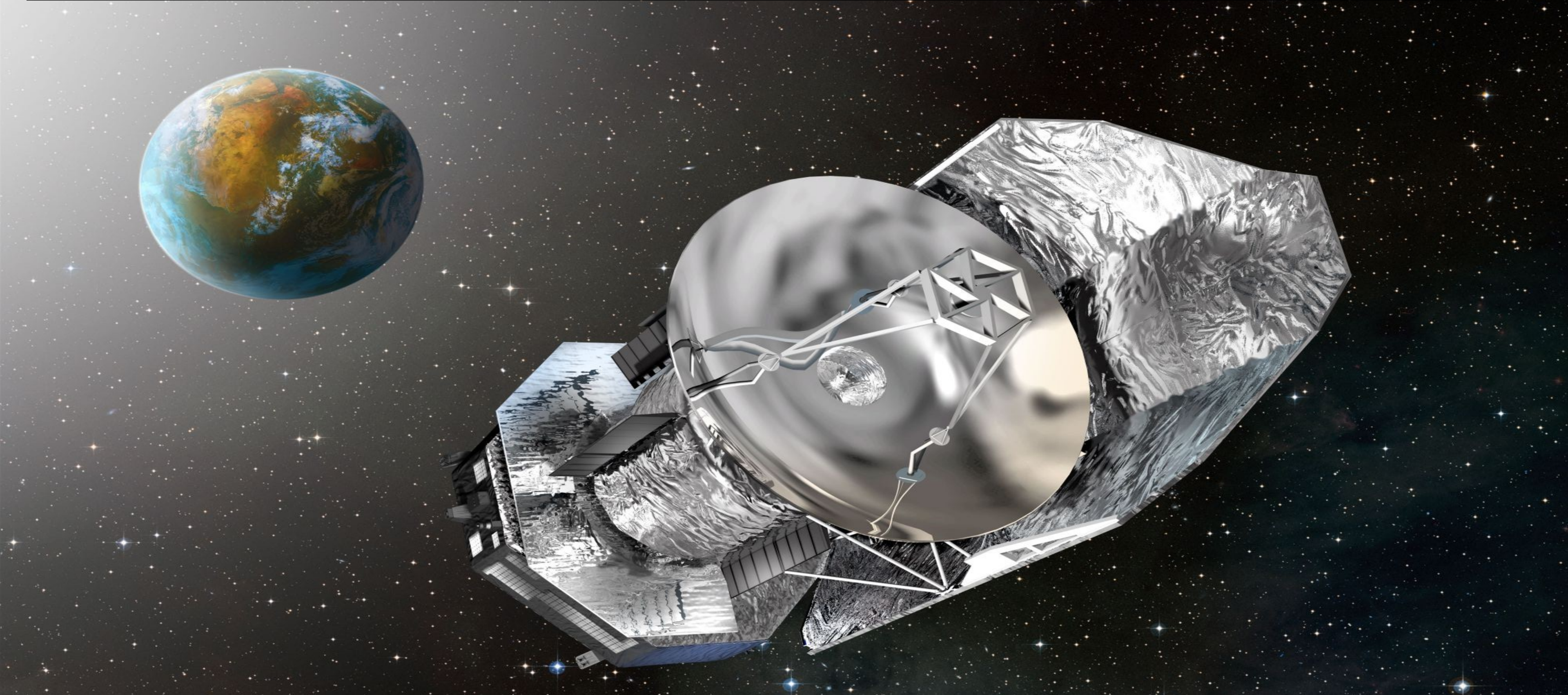
Nitrogen hydrides in interstellar gas: ortho-to-para ratios & deep searches for new species

Carina Persson
Chalmers University of Technology



A.O.H. Olofsson, M. Gerin, M. Hajigholi, J. H. Black, M. De Luca, E. Herbst, J.R. Goicoechea, G.E. Hassel, H.S.P. Muller, D. Lis, E.S. Wirström, M. Olberg, T.A. Bell, J. Cernicharo, B. Mookerjea, Å. Hjalmarson, A. Coutens, B. Godard, P. Hily-Blant, K.M. Menten, J.C. Pearson, M. Schmidt, F. Wyrowski, S. Yu



Nitrogen hydrides in interstellar gas

- Major nitrogen reservoir probably in N or N2, but over 55 N-molecules have been detected in space.

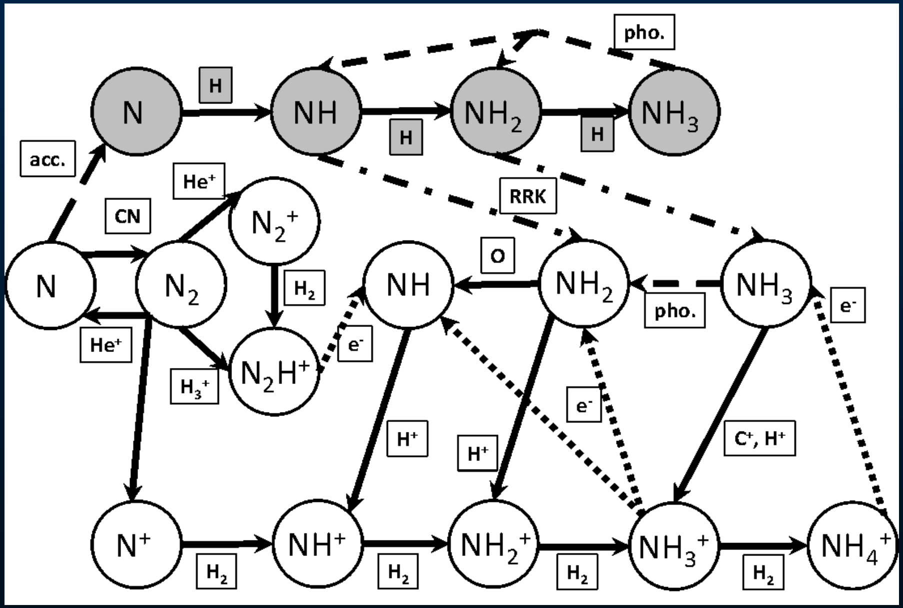


Figure by George Hassel, Siena College.
Grey = dust chemistry.
White = gas phase chemistry.
Solid lines = gas phase reactions as labeled.
Dashed lines = photodissociation.
Dotted lines = dissociative recombination.

Nitrogen hydrides, e.g. NH+, NH, NH2, and NH3, are key species in the nitrogen chemistry and at the root of the chemical network leading to more complex species.

High critical densities ~ 10^8 cm^-3.

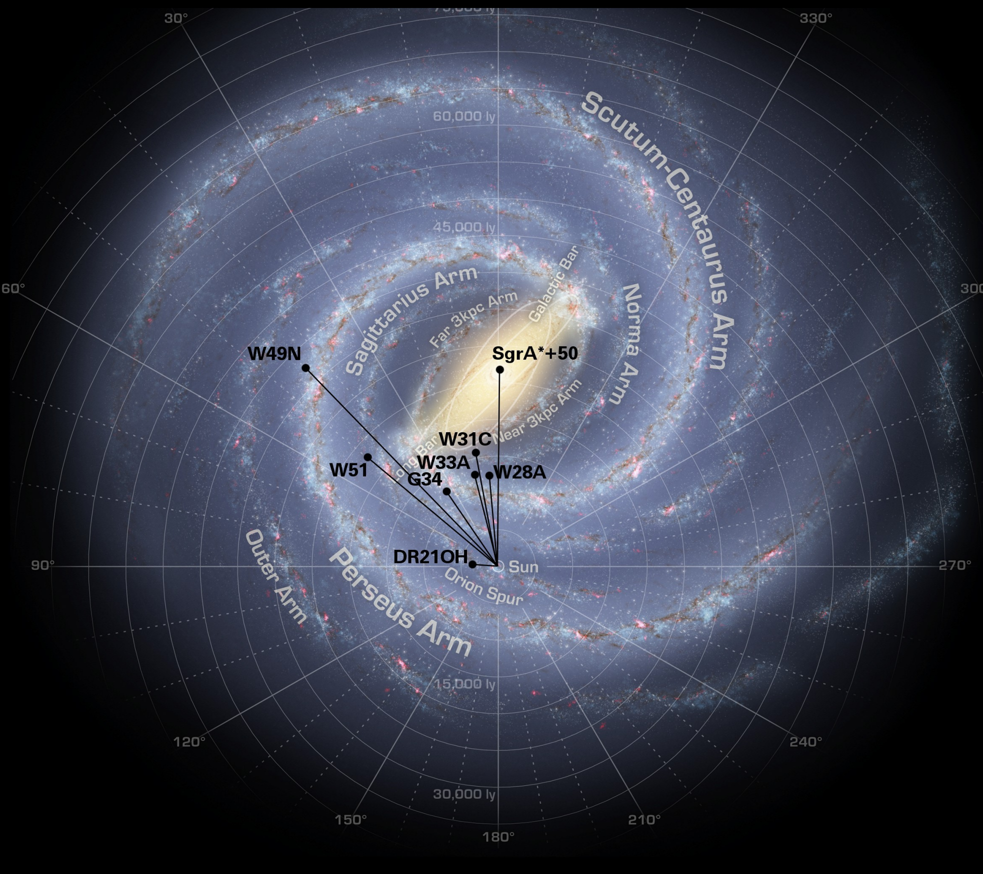
Nitrogen hydrides in interstellar gas

- The lowest rotational transitions lie at sub-mm and THz frequencies and must therefore be observed from space with a few exceptions (lowest NH2 lie at 461 GHz).
- Before Herschel – only a few observations in interstellar space of NH (first discovered 1991, Meyer & Roth) and NH2 (first discovered 1993, van Dishoeck et al.). Still no detection of NH+.
- The nitrogen hydrides have hyperfine structure (hfs) components.
- NH2 and NH3 have ortho and para spin symmetry states:
  - NH3 mainly observed in its para symmetry form (inversion lines). Few ortho-to-para ratio (OPR) estimates especially in cold gas (0_0 ortho level has no splitting).
  - NH2 OPR – one previous estimate by Goicoechea et al. 2004 (ISO data).

PRISMAS

Probing InterStellar Molecules with Absorption line Studies (GT Herschel Key Programme)

PI: Maryvonne Gerin, CNRS/LERMA



Annotated Roadmap to the Milky Way
(artist's concept)
NASA / JPL-Caltech / R. Hurt (SSC-Caltech) ssc2008-10b

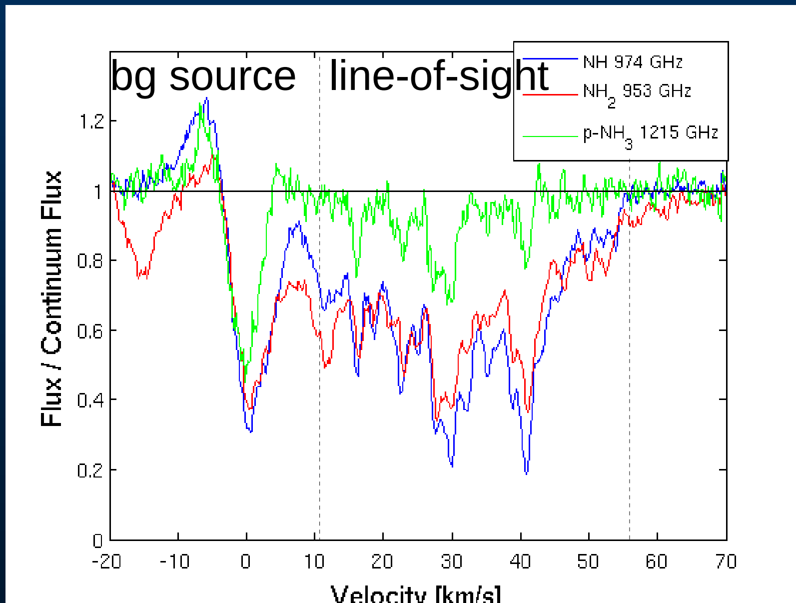
Observations of eight Galactic Plane targets show absorption against their bright far-IR continuum. Different lines of sight are sampled and also give info on the very chemically rich background sources.

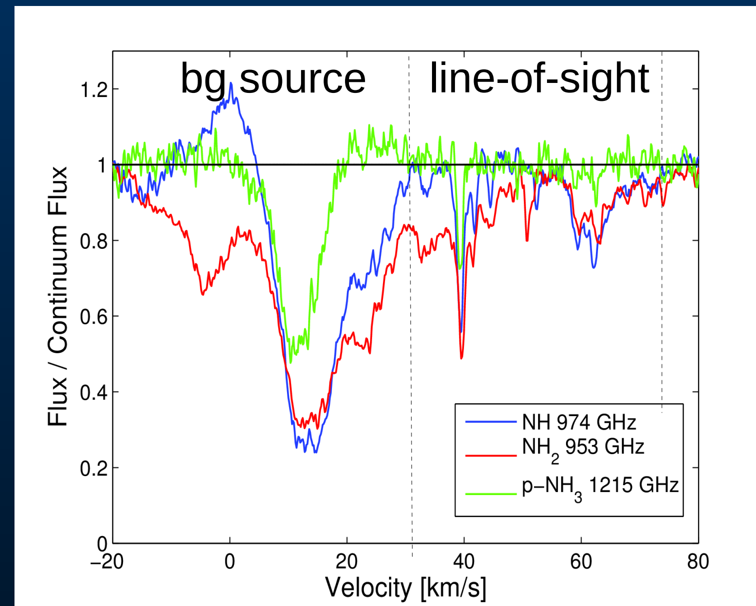
The bright background sources are high-mass star-forming regions containing compact HII regions.

All molecules in the ground state → very simple analysis.

N-hydrides towards G10.6-0.4 (W31C) and W49N

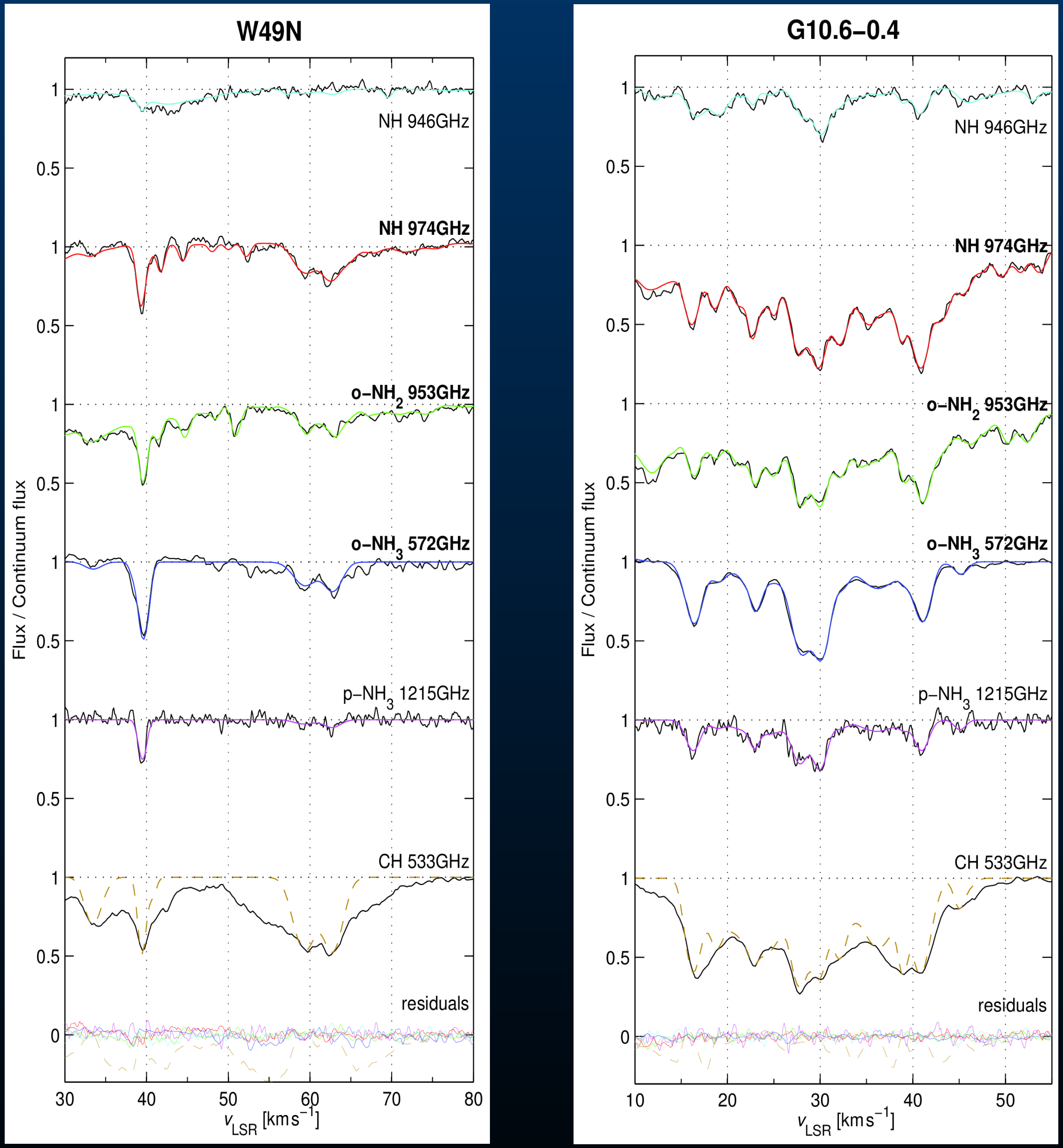
Persson et al. 2010, A&A





First results similar abundances of all three species in the l-o-s: $NH/NH_3 \sim 2$, $NH_2/NH_3 \sim 1$, using τ = -log(Ta/Tc) and RADEX (non equilibrium radiative transfer code) assuming n(H2) = 500 cm-3 and Tk = 30 K.

Mean abundance relative to total amount of hydrogen in the l-o-s: $X(NH) \sim$ 6e-9, $X(NH_2) \sim$ 3e-9, $X(NH_3) \sim$ 3e-9
assuming high temperature limits OPR(NH3) = 1 and OPR(NH2) = 3.



Line-of-sight:

Simultaneous fitting assuming Gaussian optical depth profiles of NH, NH2, NH3 – including all hyperfine structure (hfs) components.

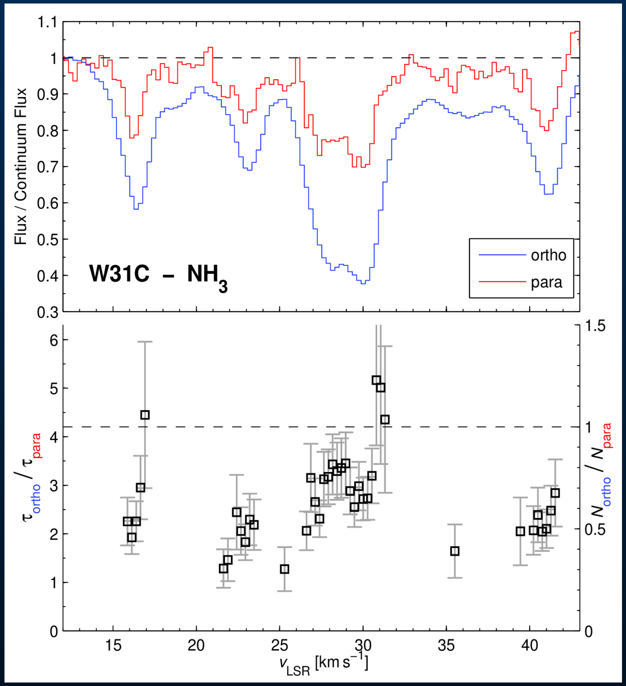
Relative opacities of the hfs components scale as *A*ul**g*u.

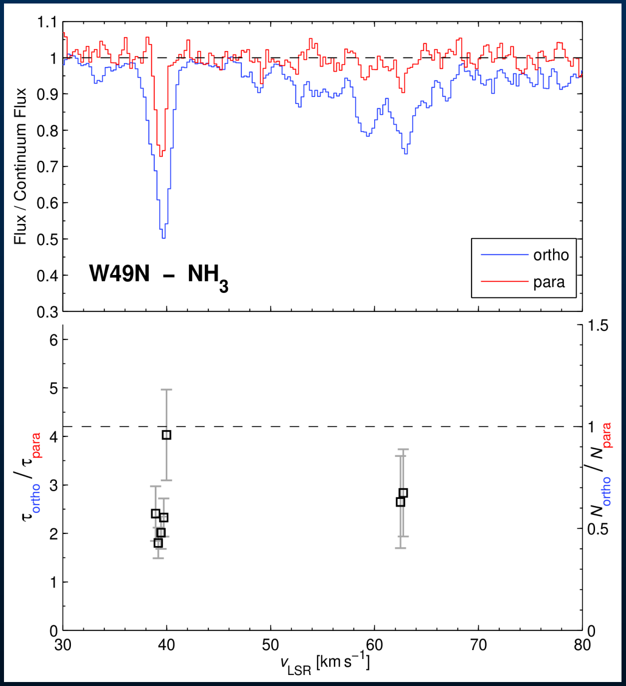
We required that the V_{LSR} and line width of each velocity component must be the same for all transitions and species.

Used minimum no of velocity components.

NH3 Ortho-to-para ratio in the *sight-lines (translucent/diffuse gas)*

Persson et al. 2012, A&A

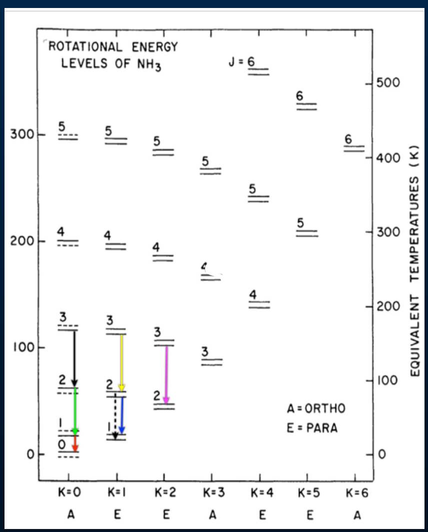




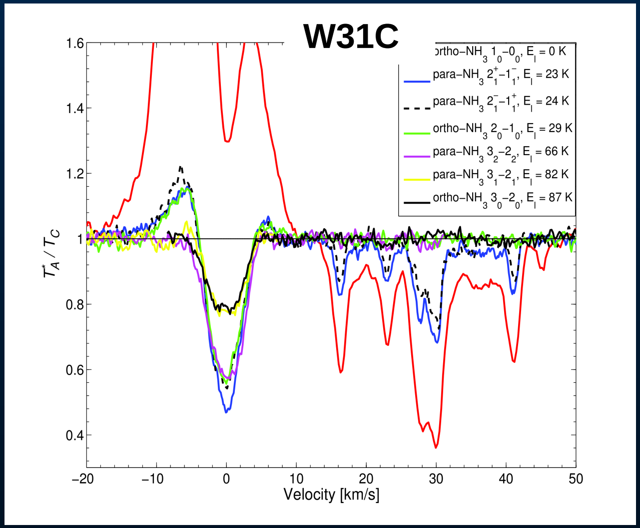
We have found an OPR of ~ 0.5 – 0.7 in the l-o-s towards W31C, W49N and SgrB2(M) which was surprising since we were expecting to find a value of unity (the high temperature limit) or higher.

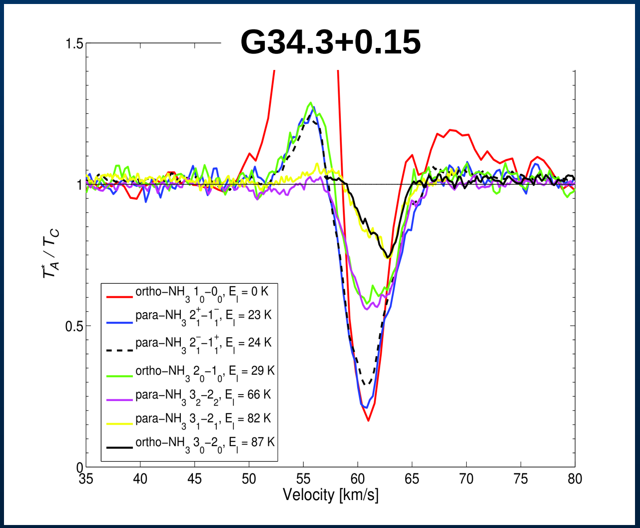
Ratios from the ground state transitions: ortho-NH_3 1_0-0_0 and para-NH_3 2_1-1_1 (assuming $J(T_{ex}) \ll T_C$) for Tex<10 K and f=572 and 1215 GHz.

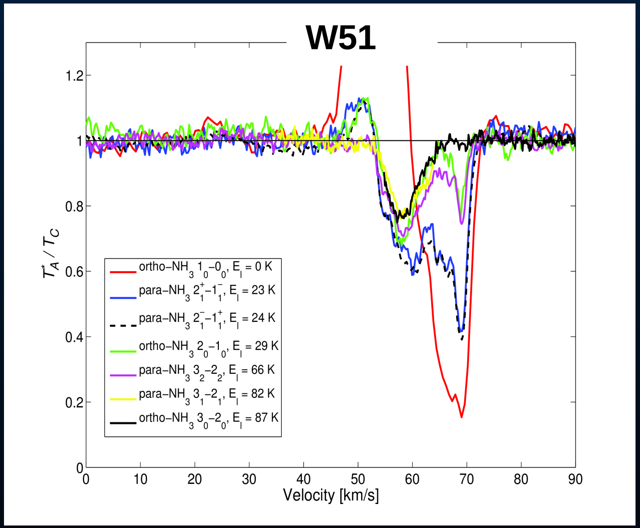
NH3 Ortho-to-para ratio in *dense(r) gas – combining PRISMAS with our OT1 data*



Persson et al. in prep







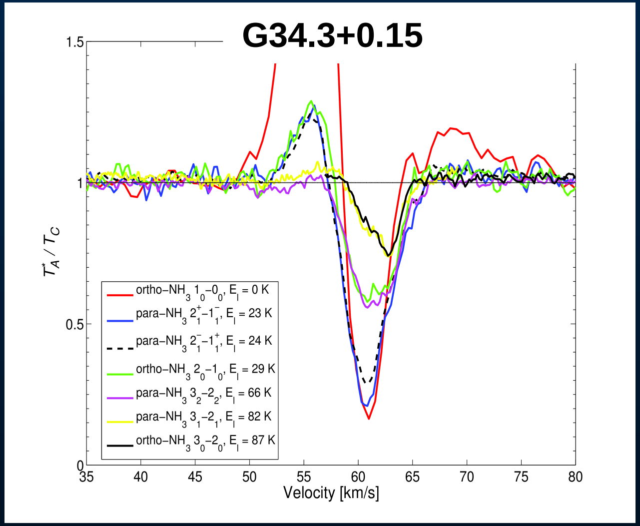
The excitation strongly depend on the radiation field which can change line ratios.

n(H2) ~1e3-1e5 cm^{-3} and T_k~20-50 K in the absorbing layer.

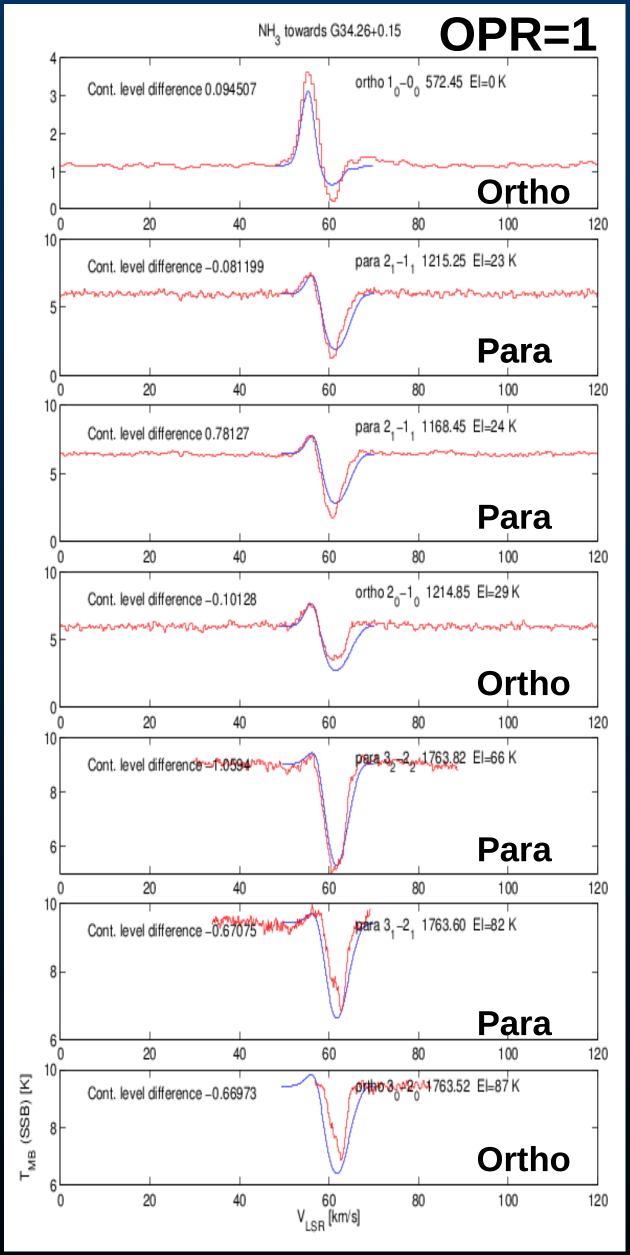
NH3 as a tracer of dynamics in star-forming regions

Poster session B # 45 (17-18 Oct)

"Observations of THz ammonia absorption tracing infall in high-mass star forming region G34.26+0.15" M. Hajigholi et al.

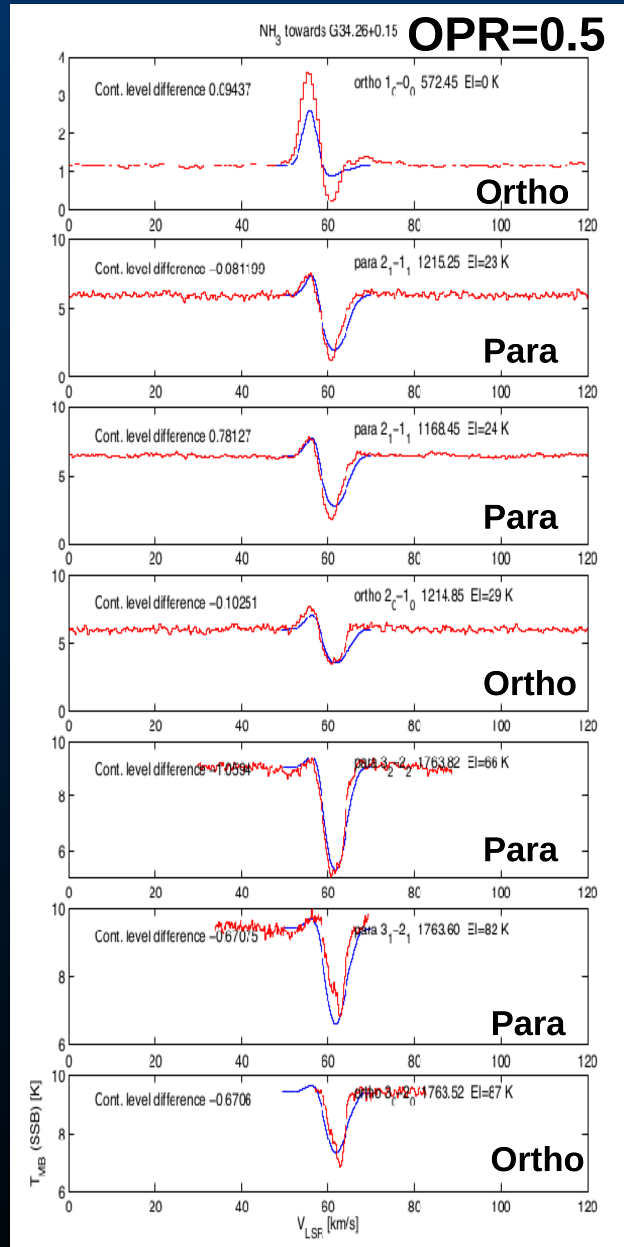


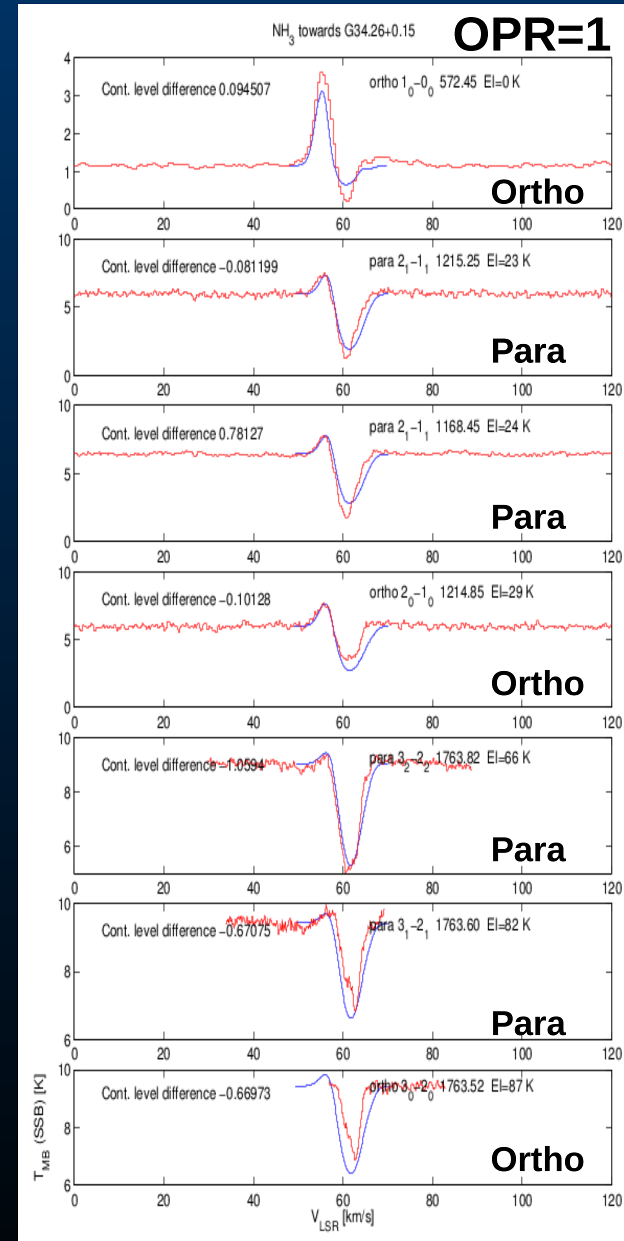
M. Hajigholi et al. in prep



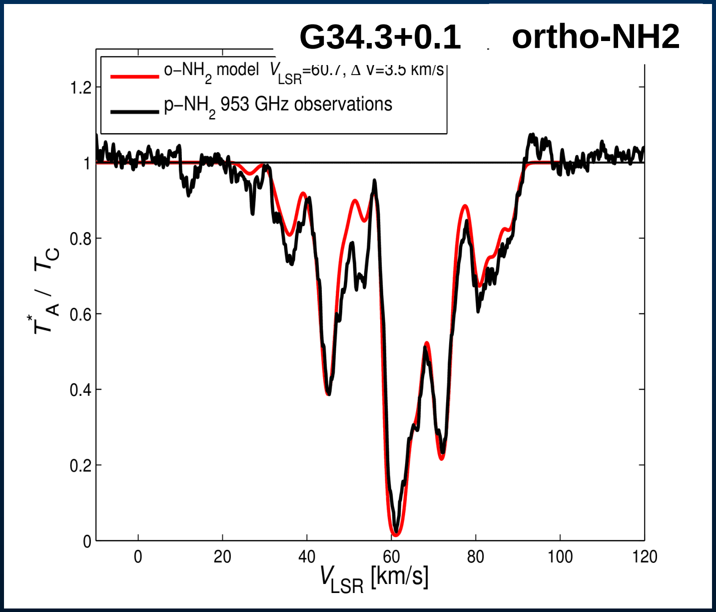
Example of on-going radiative transfer modelling of NH3 spectral lines using a spherically symmetric accelerated lambda iteration code (P. Bergman, Onsala space observatory).

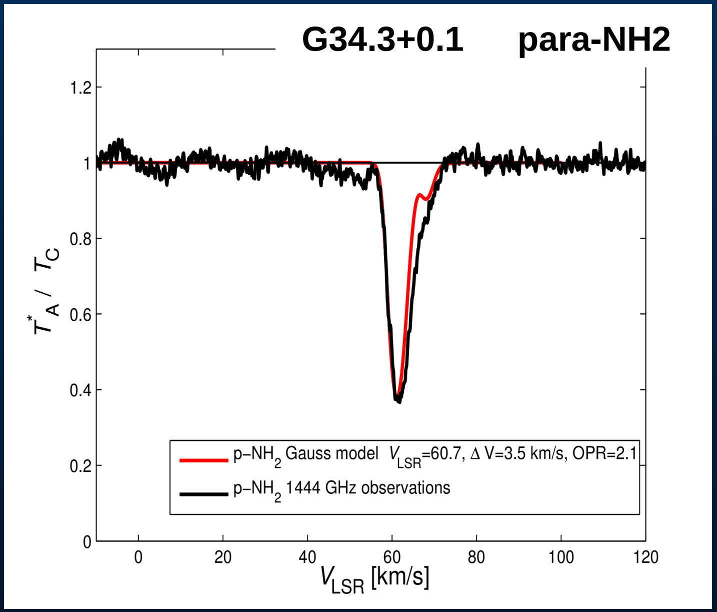
So far we have found an OPR-NH3 of 0.5-1 in the source molecular clouds. Further modelling can hopefully improve this value.





The complex structure of NH2



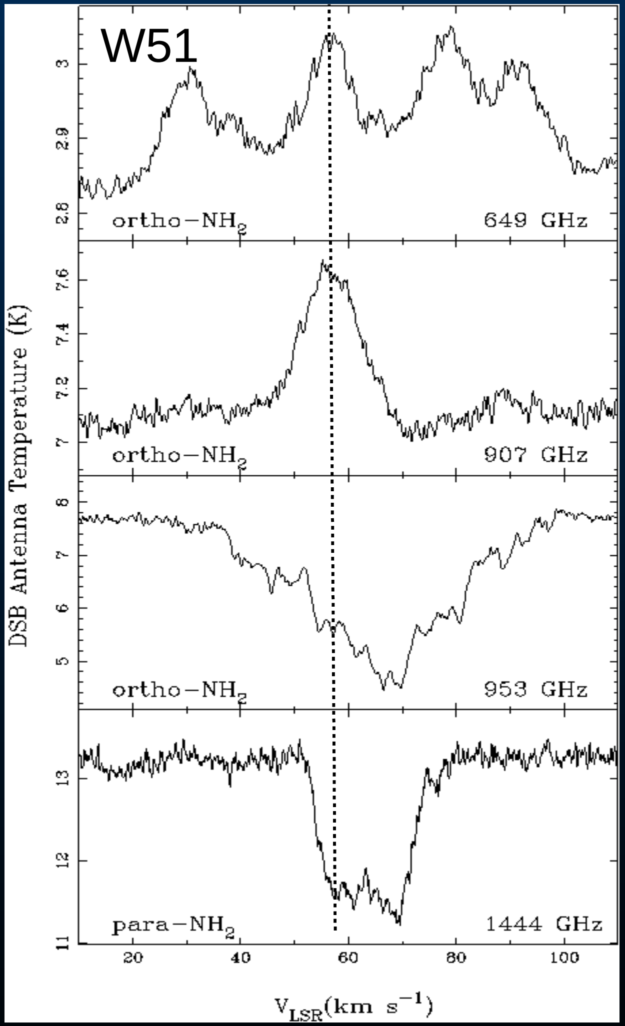


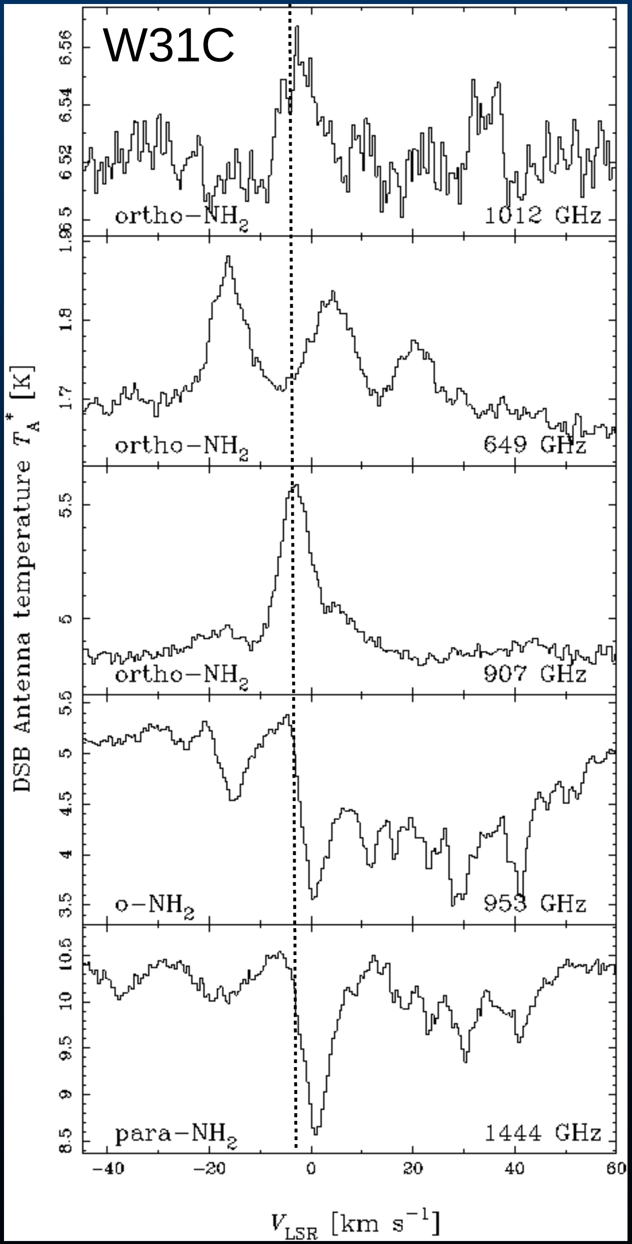
NH2 at 953 GHz has 24 (strong) hyperfine structure components (V_{LSR} *from -16 to +28 km/s w.r.t. the strongest hfs).*

NH2 at 1444 GHz has 5 (strong) hyperfine structure components (at V_{LSR} *= 0 - 8 km/s w.r.t the strongest hfs).*

One velocity component is modelled assuming that all hfs components have Gaussian optical depth profiles and are scaled with *A*ul**g*u.
Using Radex to convert opacities to N we get an OPR ~ 3.5 not including the background radiation.
Including the bg radiation we get OPR ~ 2.7.

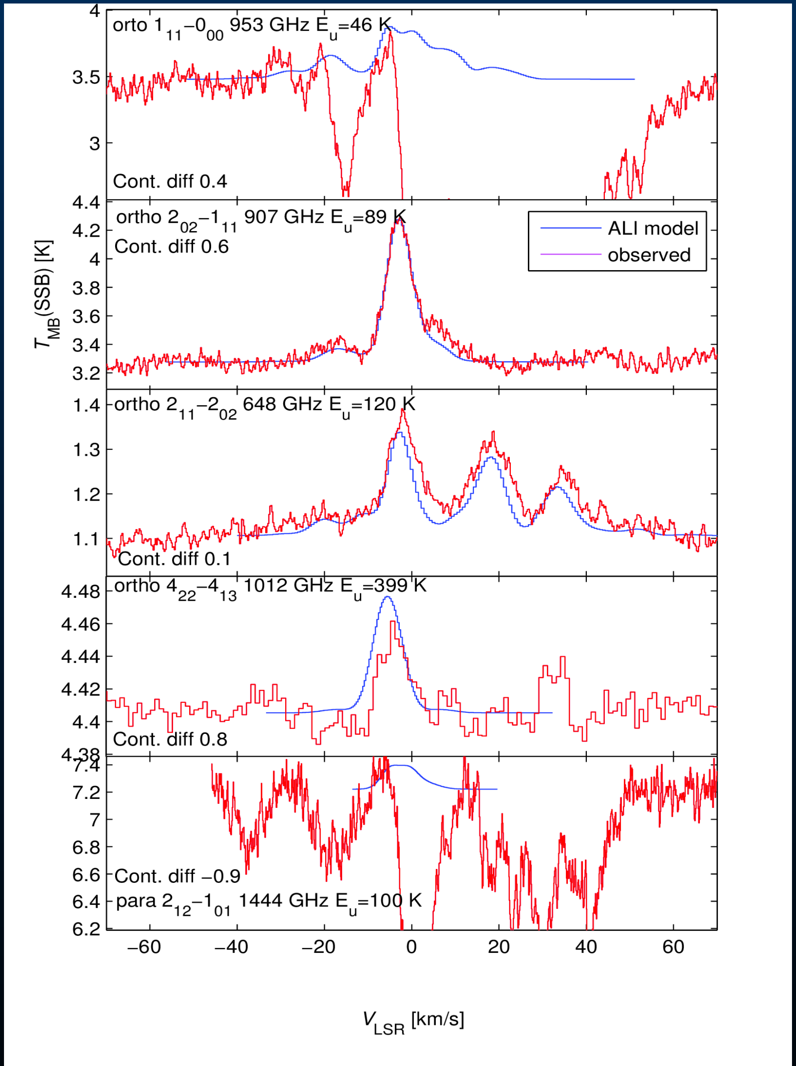
NH2





Persson et al. in prep

ALI modelling of NH2 emission in W31C



Ortho-to-para ratio of NH2

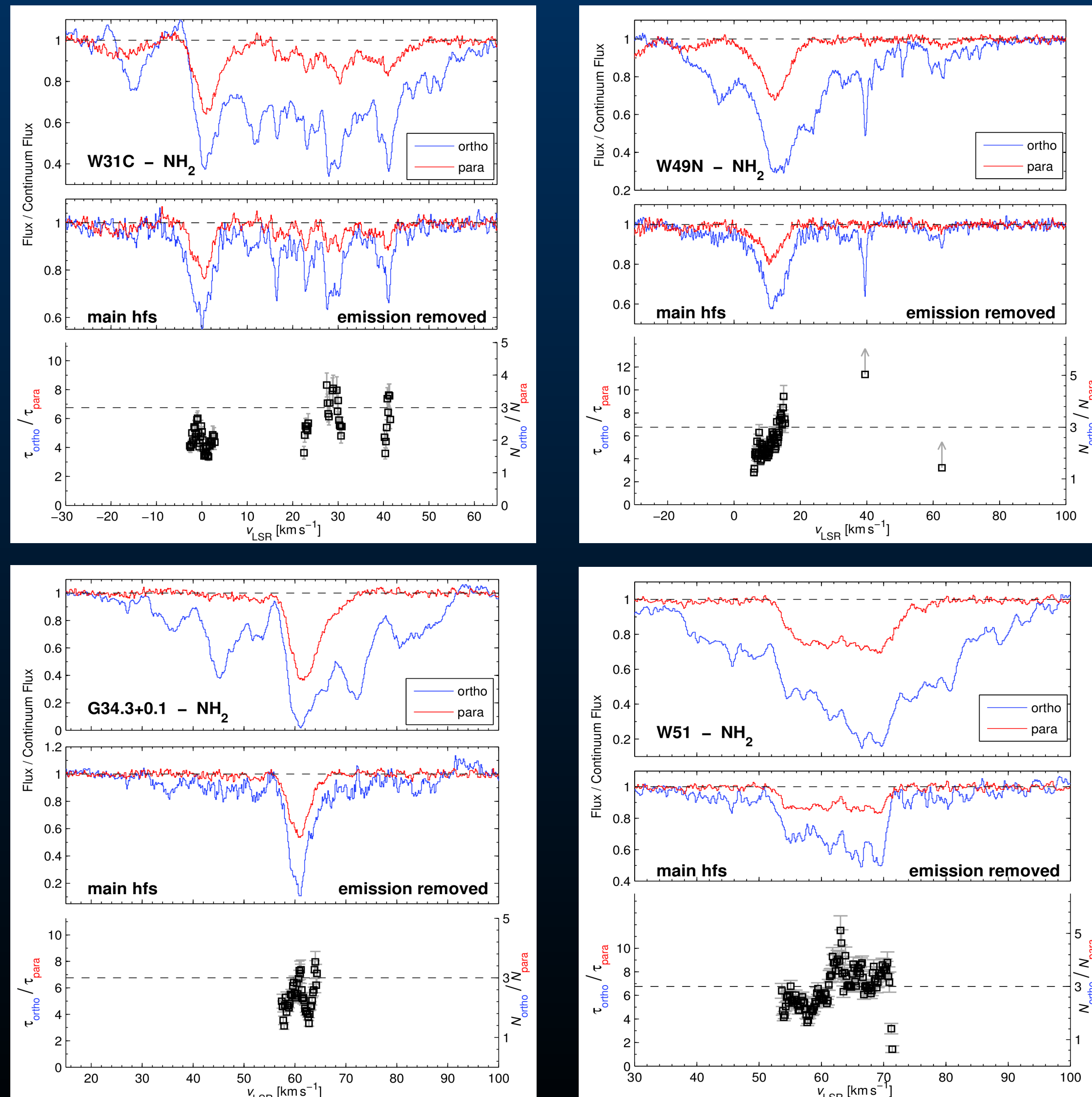
N(o-NH2) / *N*(p-NH2) vs. v_{LSR}

Emission in the sources is removed.

High temperature limit OPR(NH2) is 3.

Ortho-NH_2 1_{11}-0_{00} J = 3/2 – 1/2 at 953 GHz and para-NH_2 1_{10}-1_{01} J = 5/2 – 3/2 at 1444 GHz.

$\tau = -\log(Ta/Tc)$ assumes $J(T_{ex}) \ll T_C$



Why so low ortho-to-para ratios?

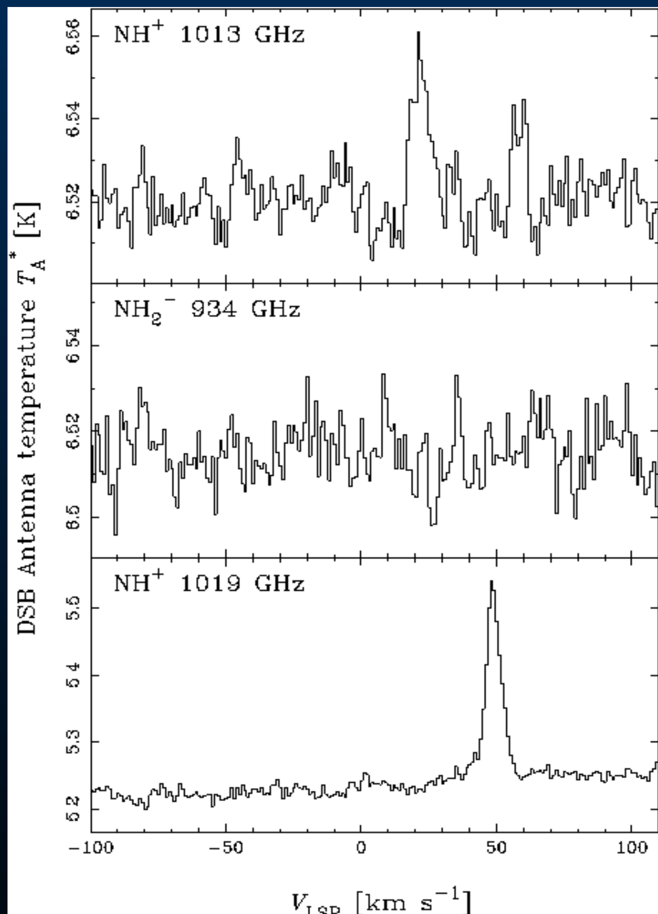
- A. Faure et al., ApJ, 2013, 770,2: The low OPR of NH3 and NH2 is consistent with nuclear spin selection rules in a para-enriched H2 gas independent of temperature in the range 5-30 K. *A low OPR of H2 naturally drives the OPR of nitrogen hydrides to below their statistical values*.

- A. Faure et al. predict OPR(NH3) ~ 0.7 & OPR(NH2) ~ 2.3 (but cannot predict higher opr than 1 and 3). (Talk about collisional excitation of interstellar hydrides session 8b.)

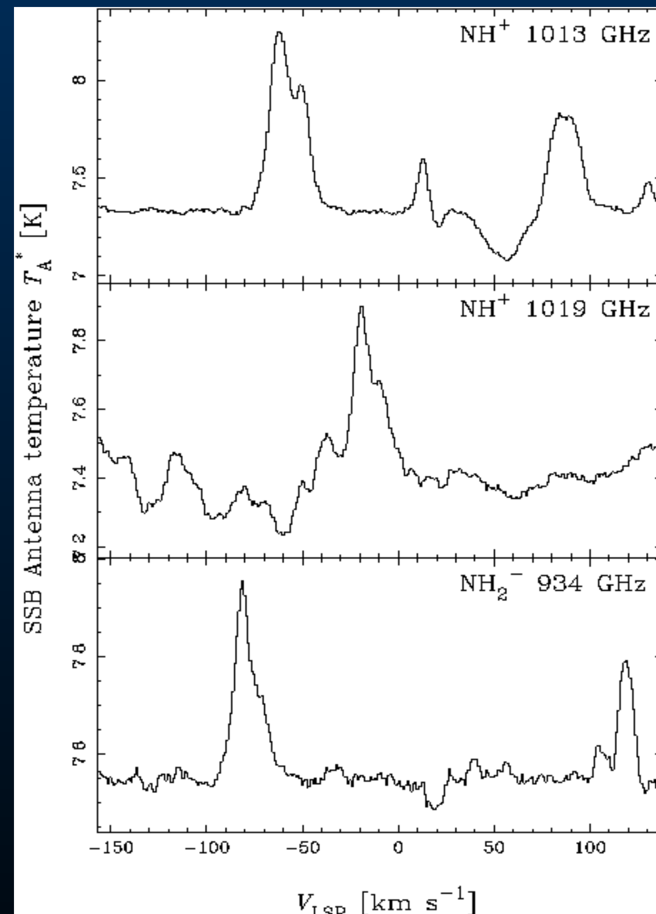
- Poster session A no 68: Chemistry of Interstellar Nitrogen revisited with the Herschel Space Observatory, R. Le Gal.
- Poster session B: nr 42 Nitrogen Hydrides in IRDCs: Exploring the Initial Conditions of IRDC Core Formation, Jimenez-Serra.

Searches for NH+ and p-NH2-

G10.6-0.4 (W31C)



SgrB2 (M)



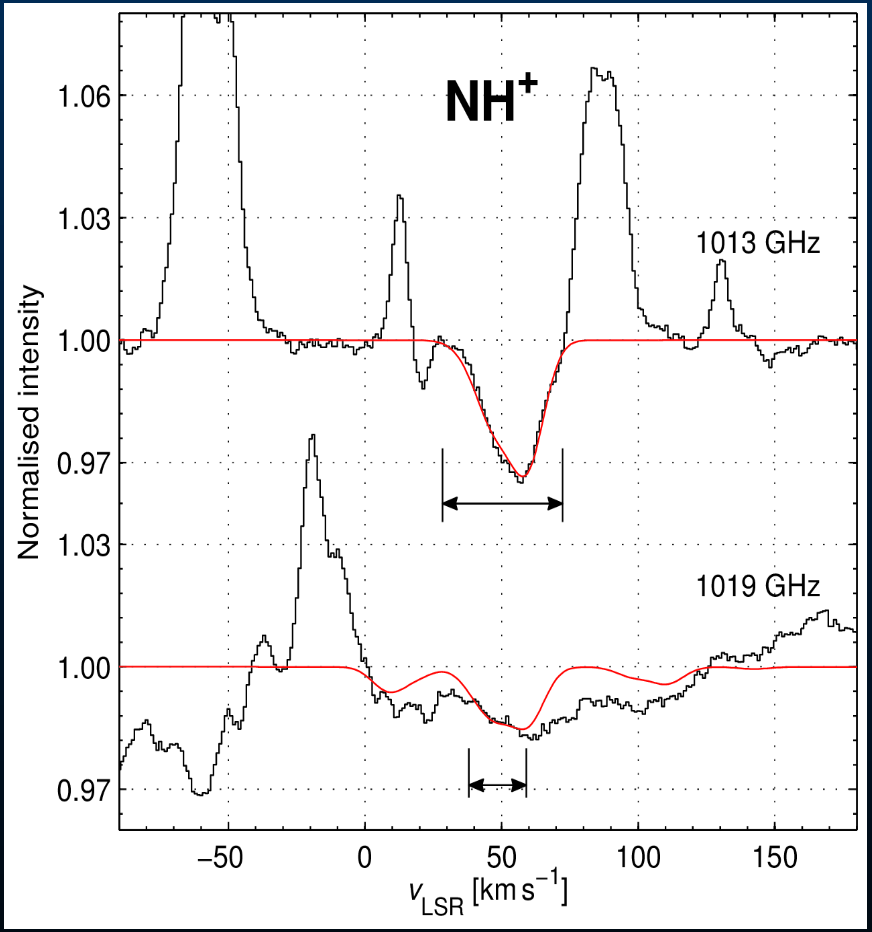
No clear NH+ detection in W31C. 1σ/*T*c=0.2% and 0.4% in W31C and SgrB2(M), respectively.

If detected – the rest frequency of NH2- is 933.996 GHz (141 MHz off-set from the predicted frequency).

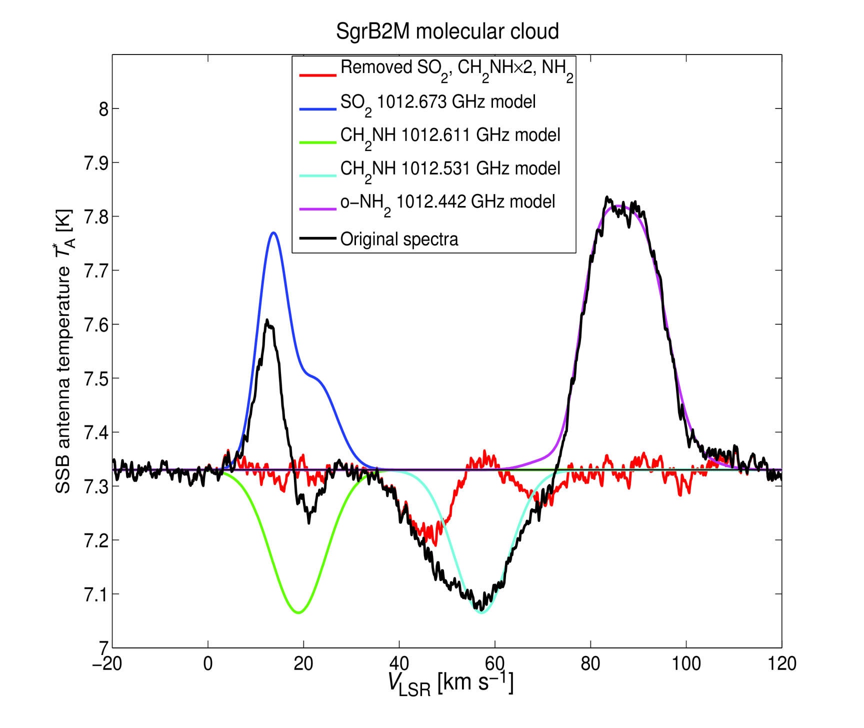
NH+ in SgrB2 (M) molecular cloud?

Simultaneous Gaussian fits to both NH+ ground state rotational transitions at 1013 and 1019 GHz =>

v_{LSR} = 59 km/s
width = 11.5 km/s



NH+ in SgrB2 (M) molecular cloud?



CH2NH

One blend with NH+ and one with SO2.

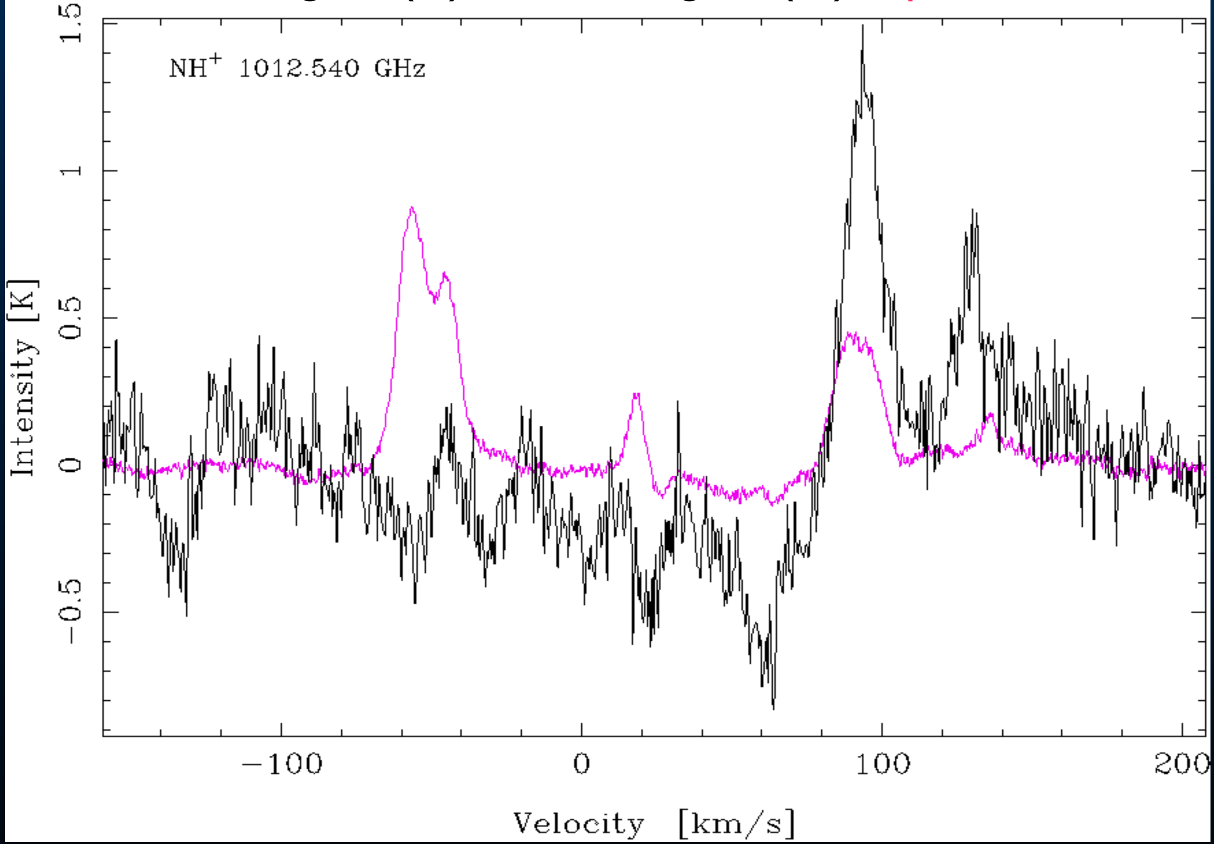
So most likely (almost) no NH+ absorption.

NH+ in SgrB2 (N) molecular cloud? (HEXOS data)

Seems to be less CH2NH than in SgrB2(M) and very little SO2.

So part of the absorption at ~60 km/s could come from NH+.

SgrB2(N)=black SgrB2(M) = pink



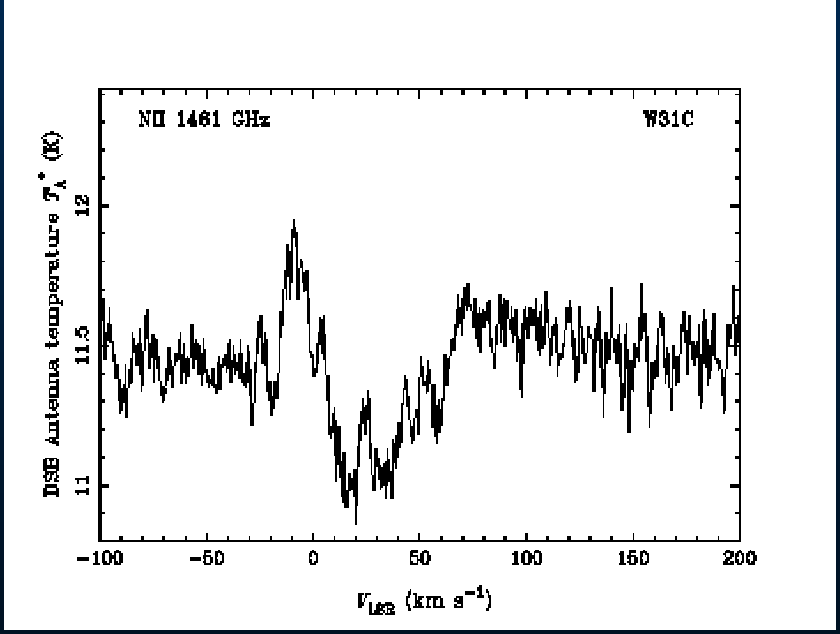
NH+ and p-NH2- upper limits towards SgrB2(M) and G10.6-0.4 (W31C)

- N(NH+)/N(NH) $\lesssim$ 1 % in the l-o-s.

  In contrast to CH+ and OH+ relative to CH and OH, [CH+]/[CH] ~ 1 and [OH+]/[OH] ~ 3% in visible data (e.g. Crane et al. 1995, Krelowski et al. 2010, Wyrowski et al. 2010, Gerin et al. 2010).
- Chemical models predicts abundances:
  X(NH+) ~ 1e-13 – 1e-14 (Persson et al. 2010).
- In respective line-of-sight:
  N(NH+)/N_H $\lesssim$ 2e-10 and 7e-11.
  N(p-NH2-)/N_H $\lesssim$ 2e-11 and 4e-11.
- In respective source molecular cloud:
  X(NH+) $\lesssim$ 1e-12 and 3e-12.
  X(p-NH2-) $\lesssim$ 7e-14 and 9e-13.

N+ absorption towards W31C

PI: Maryvonne Gerin (OT1 programme *Diffuse ISM phases in the inner Galaxy*)



N(N+) ~ 1.5e17 cm^{-2} in the total line of sight (10-60 km/s) → N(N+)/N(NH+) ≳ 1e5.

Comparing with NH → N(N+) / N(NH) ~ 1e3.

Most N+ probably comes from WIM (Warm Ionized Medium) and not the same gas as NH, NH2 and NH3.

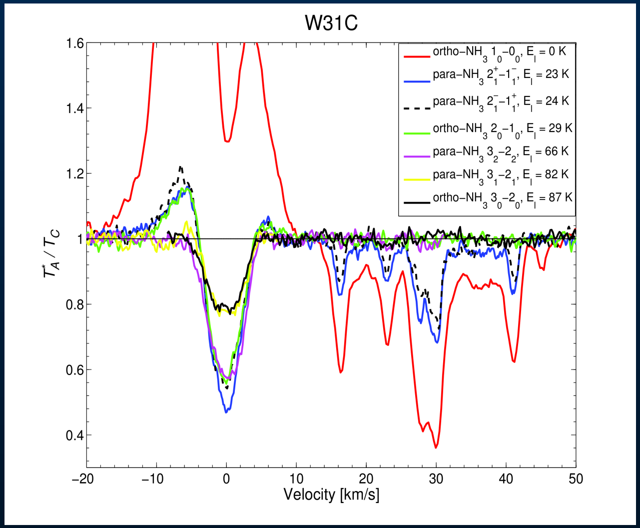
Summary

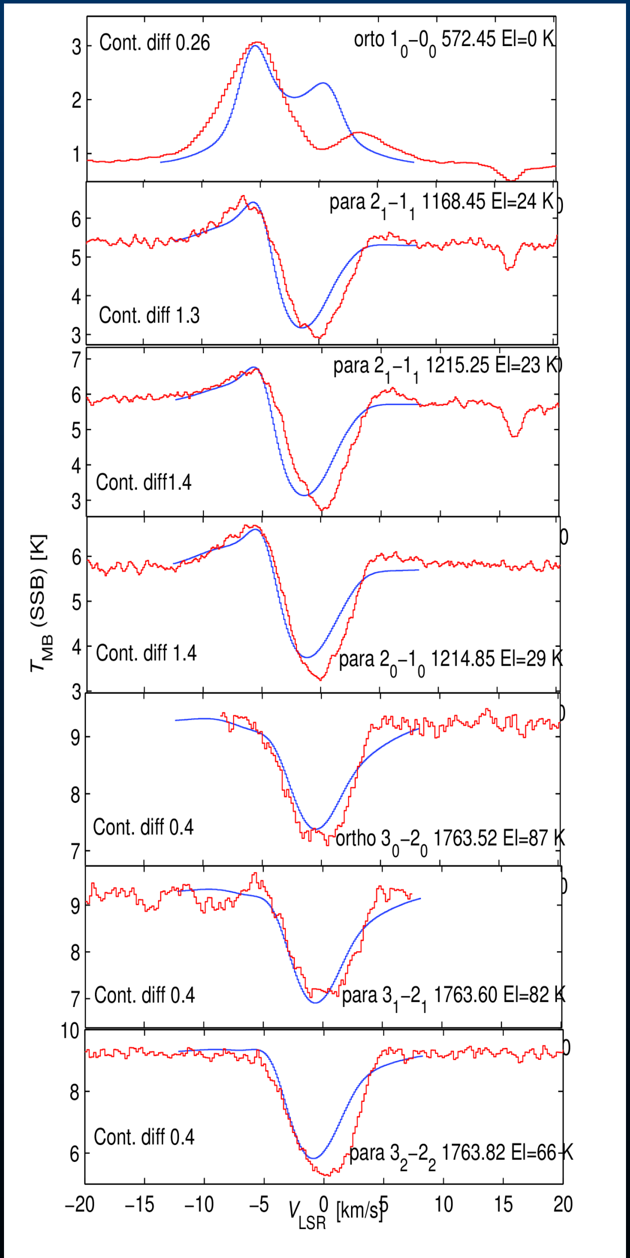
- Similar abundances of all NH, NH2 and NH3 in diffuse/translucent gas: *N*(NH)/*N*(NH3) ~ 1-2, *N*(NH2)/*N*(NH3) ~ 1 (using OPR-NH2 = 2.3 and OPR-NH3 = 0.7).
- Abundance relative to molecular hydrogen in the l-o-s: *X*(NH3) ~ 6e-9. Similar abundances in the denser gas associated with the star-forming regions traced by absorption lines.
- Upper limits of *X*(NH+) < 1e-11 w.r.t. hydrogen in the diffuse gas and $\lesssim$ 1e-12 – 1e-13 in W31C and SgrB2(M).
  N(NH+)/*N*(NH) <~ 1 % in the l-o-s towards W31C.
- A very tentative detection of NH2- : *X*(NH2-) <~7e-14 in SgrB2(M).
- Ortho-to-para ratio of NH3 ~ 0.5 – 0.7 (high temperature limit is 1).
- Ortho-to-para ratio of NH2 ~ 2.3 (high temperature limit is 3).
- N+ detected in absorption in the sight-line towards G10.6-0.4 (W31C). N+/NH+ $\gtrsim$ 1e5. Most of the column is probably from the WIM.

NH3 Ortho-to-para ratio in *dense(r) gas*

W31C

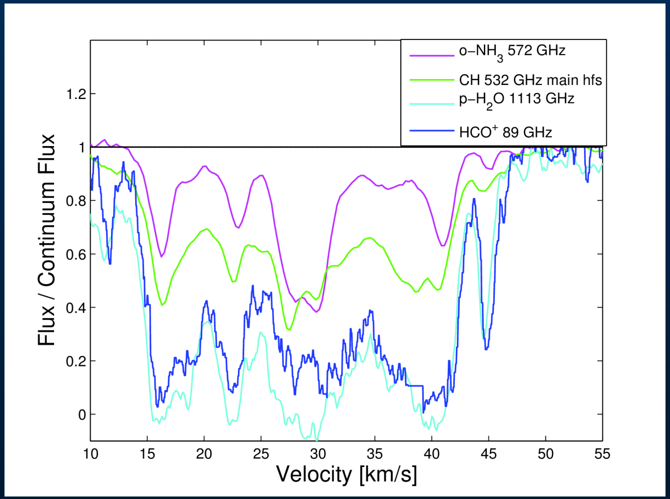
OPR(NH3) ~ 0.5-1 in the gas associated with the sources; *n*(H2) ~1e3-1e5 cm^{-3} and T_k~20-50 K) depending on model.

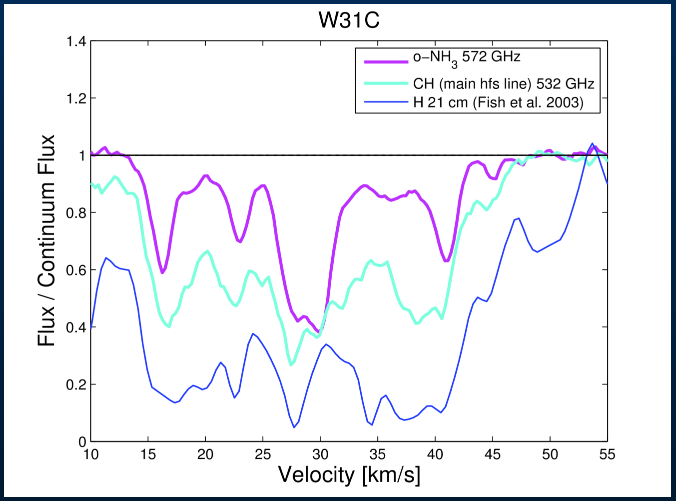


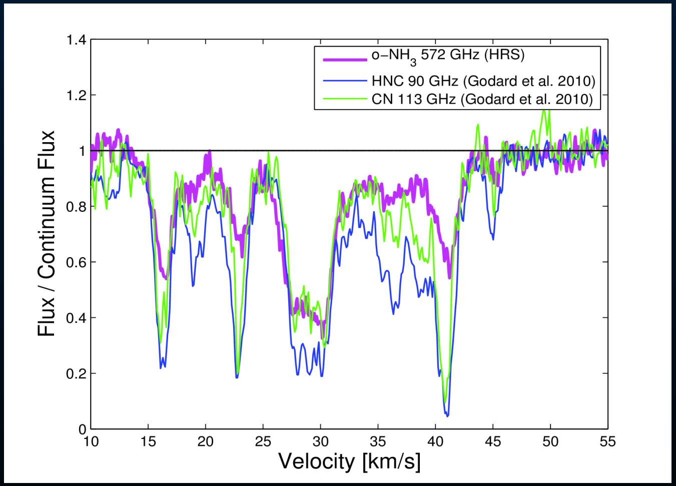


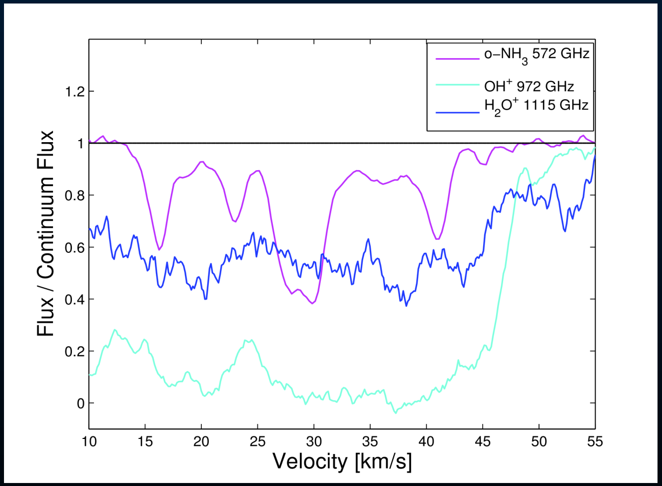
Example of on-going modelling of NH3 spectral lines using a spherically symmetric accelerated lambda iteration code (P. Bergman, Onsala space observatory).

Comparison of nitrogen hydrides in the l-o-s towards W31C with species tracing both high and low molecular fractions









NH3 OPR

Example of model dependence:

The only difference in the two models are small changes in the velocity field.