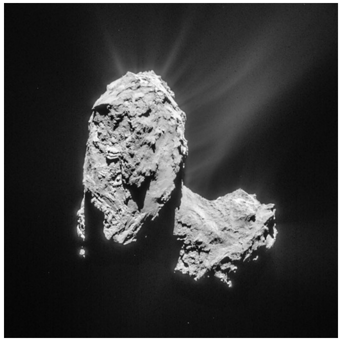
Contribution of HIRES to cometary science

Philippe Rousselot
UTINAM Institute/OSU THETA, Besançon

Emmanuel Jehin
STAR Institute, Univ. of Liège

Back to basics for comets...

Nucleus ~ 10 km



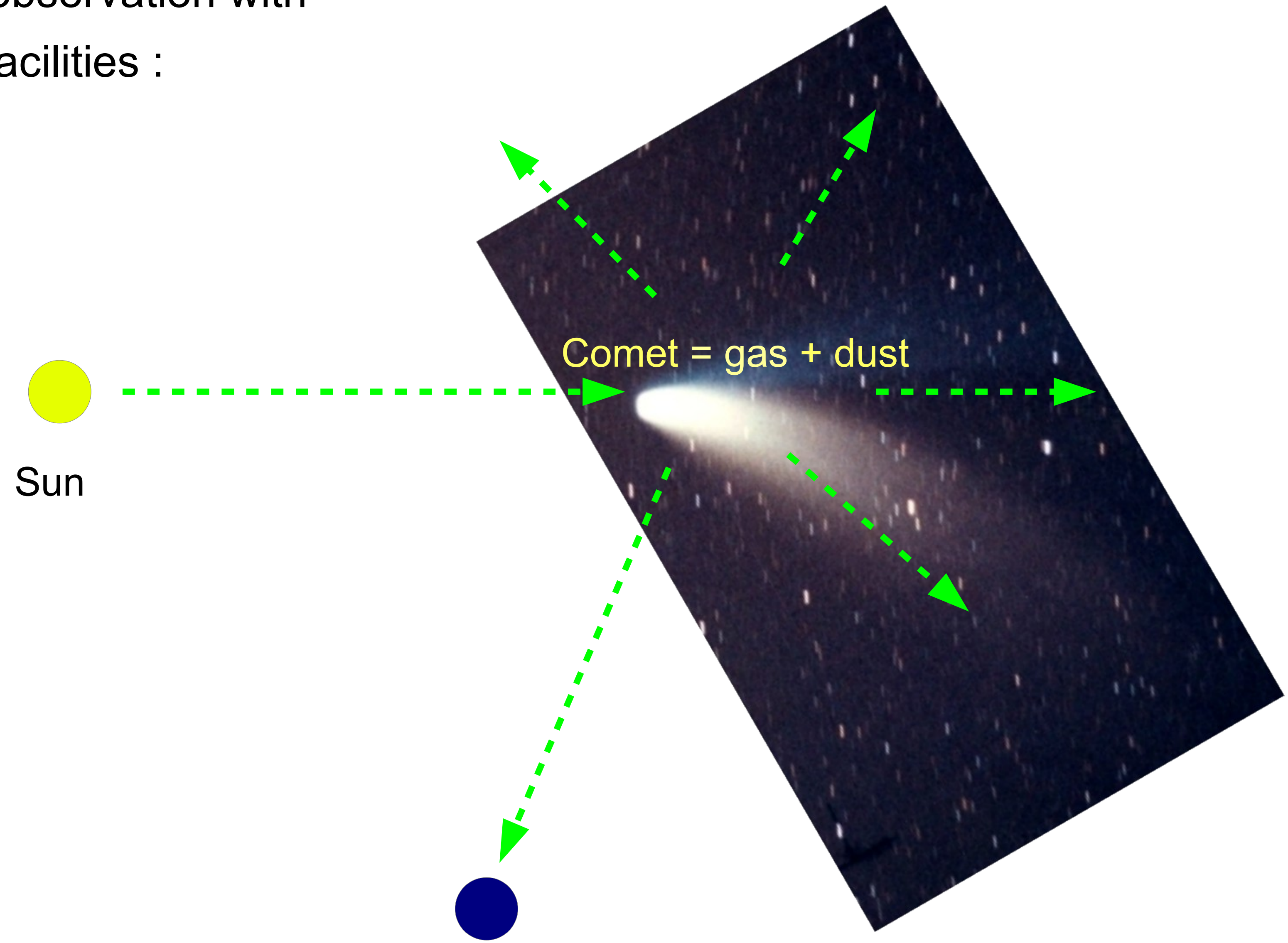
Coma ~ 10 000 – 100 000 km

Dust tail
~ a few millions km

Plasma tail ~ a few millions km

Chemical composition known by spectroscopic investigation with ground-based facilities / space mission and in situ analysis.

Spectroscopic observation with ground-based facilities :

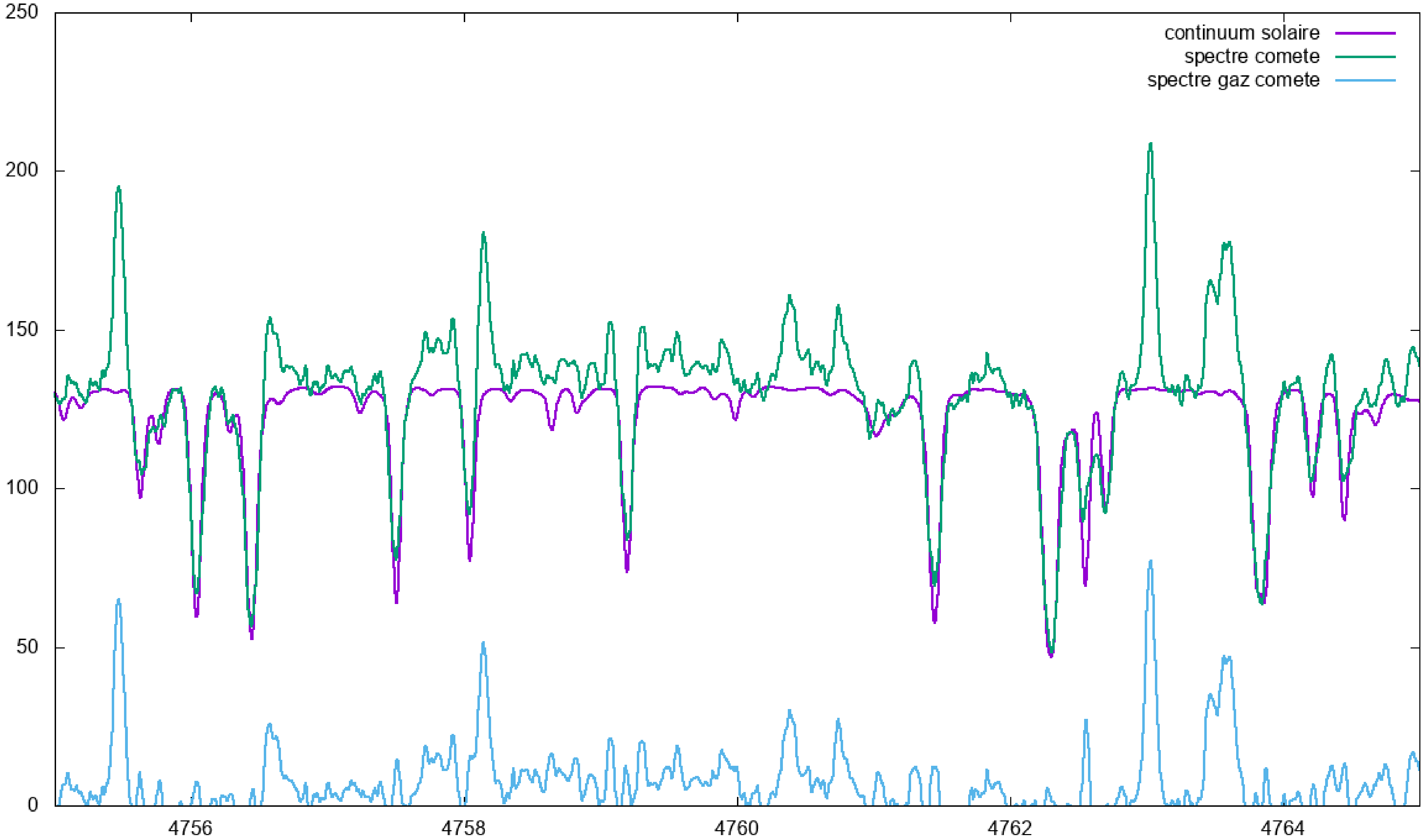


Earth : emision spectrum (gas) + solar continuum (dust)

The spectrum observed in a cometary coma includes two elements :

→ a **continuum** coming from the solar lights scattered by the dust grains (Mie scattering that creates a reddening)

→ some **emission lines** created by the fluorescence mechanism of chemical species in the coma.



Parent molecules visible with ground based facilities (% / eau) :

water	H_2O	100	IR, radio
carbon monoxide	CO	0,2-23	radio, IR, UV
carbon dioxide	CO_2	2.5-30	IR
Hydrocarbons (≈ 2%) :			
methane	CH_4	0.12-1.5	IR
acetylene	C_2H_2	0.04-1.5	IR
ethane	C_2H_6	0.14-2	IR
CHO-bearing molecules (≈ 4%) :			
methanol	CH_3OH	0.6-6.2	radio, IR
formaldehyde	H_2CO	0.13-1.4	radio, IR
ethylene glycol	$HOCH_2CH_2OH$	0.07-0.35	radio
formic acid	$HCOOH$	0.028-0.18	radio
ethanal	CH_3CHO	0.047-0.08	radio
methyl formate	$HCOOCH_3$	0.07-0.08	radio
ethanol	C_2H_5OH	0.12	radio
glycolaldehyde	CH_2OHCHO	0.016	radio
Nitrogen-bearing molecules (≈ 1%) :			
ammonia	NH_3	0.3-0.7	radio, IR
hydrogen cyanide	HCN	0.085-0.25	radio, IR
hydrogen isocyanide	HNC	0.002-0.035	radio
acetonitrile	CH_3CN	0.008-0.035	radio
methyl cyanide	HC_3N	0.002-0.068	radio
isocyanic acid	$HNCO$	0.009-0.08	radio
formamide	NH_2CHO	0.008-0.021	radio
Sulfur-bearing molecules (≈ 1,5 %) :			
hydrogen sulfide	H_2S	0.13-1.5	radio
sulfur monoxide	SO	0.04-0.3	radio
sulfur dioxide	SO_2	0.2	radio
carbonyl sulfide	OCS	0.03-0.4	radio, IR
disulfure de carbone	CS_2	0.2	UV, radio
thioformaldehyde	H_2CS	0.009-0.09	radio
disulfur	S_2	0.001-0.25	UV

+ **dissociation products / ions** (ex : CN, C_2, C_3, NH_2, NH, CH, CO^+, N_2^+…) + **isotopologs** + **Na, Ca$^+$**

HIRES:

→ **Wavelength range** (0.35-1.8 μm) adapted mainly to **dissociation products or ions** (CN, C_2, C_3, NH_2, NH, CH, CO^+, N_2^+…).

→ Measurement of absolute and relative abundancies, **even for low abundancies** (e.g **N_2^+** for most of the comets).

→ Measurement of **isotopic ratios** in dissociation products.

Detection of species with low abundance:

→ Important for **interstellar comets** coming inside the solar system: case of **2I/Borisov**, 2 such comets expected to be detected / year with LSST, most of them will probably be faint and with a short period of visibility. **Unique opportunity to have information about the composition of other planetary systems**.

→ Important for **Main Belt Comets** to detect gazeous species and infer their composition.

→ Important for **distant comets**: source of activity ?

Isotopic ratios:

The following isotopic ratios have now been measured in comets:
D/H, $^{12}C/^{13}C$, $^{14}N/^{15}N$, $^{16}O/^{18}O$,$^{16}O/^{17}O$, $^{32}S/^{34}S$, $^{32}S/^{33}S$

Among them **$^{12}C/^{13}C$, $^{14}N/^{15}N$, $^{16}O/^{18}O$** can be measured in radicals having emission lines in the spectral range covered by HIRES:

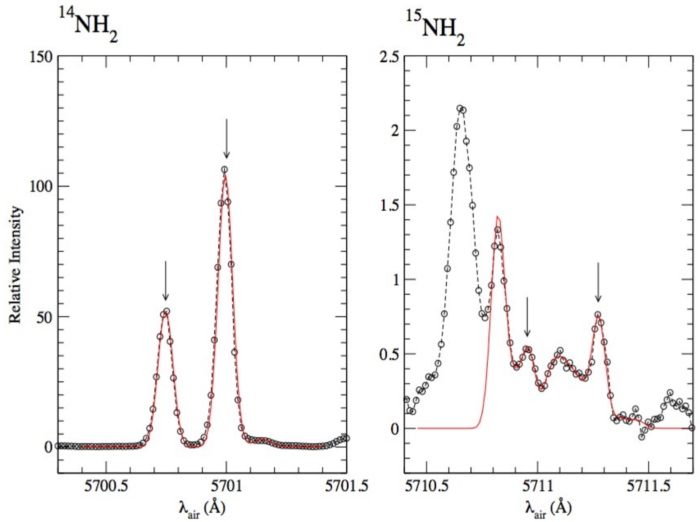
$NH_2 \rightarrow {}^{14}N/^{15}N$
$C_2 \rightarrow {}^{12}C/^{13}C$
$CN \rightarrow {}^{12}C/^{13}C$ and $^{14}N/^{15}N$
$N_2^+ \rightarrow {}^{14}N/^{15}N$
$CO^+ \rightarrow {}^{12}C/^{13}C$ and $^{16}O/^{18}O$

Case of $^{14}N/^{15}N$:

→ Terrestrial value = 272

→ Measurements done in comets with :

→ **HCN** (sub-mm range)
→ **CN** (388 nm with **UVES at VLT**)
→ **NH_2** (570 nm with **UVES at VLT**)



Rousselot et al. (2014)

→ **Attempts to measure it with N_2^+** in comet C/2016 R2 with UVES at VLT.

→ **Rosetta** (ROSINA in situ mass spectrometer) in comet 67P: **NH_3** and **N_2** (results announced for paper in preparation, not so obvious to measure because of some other species with similar mass).

→ **Dust grains** with **Stardust**.

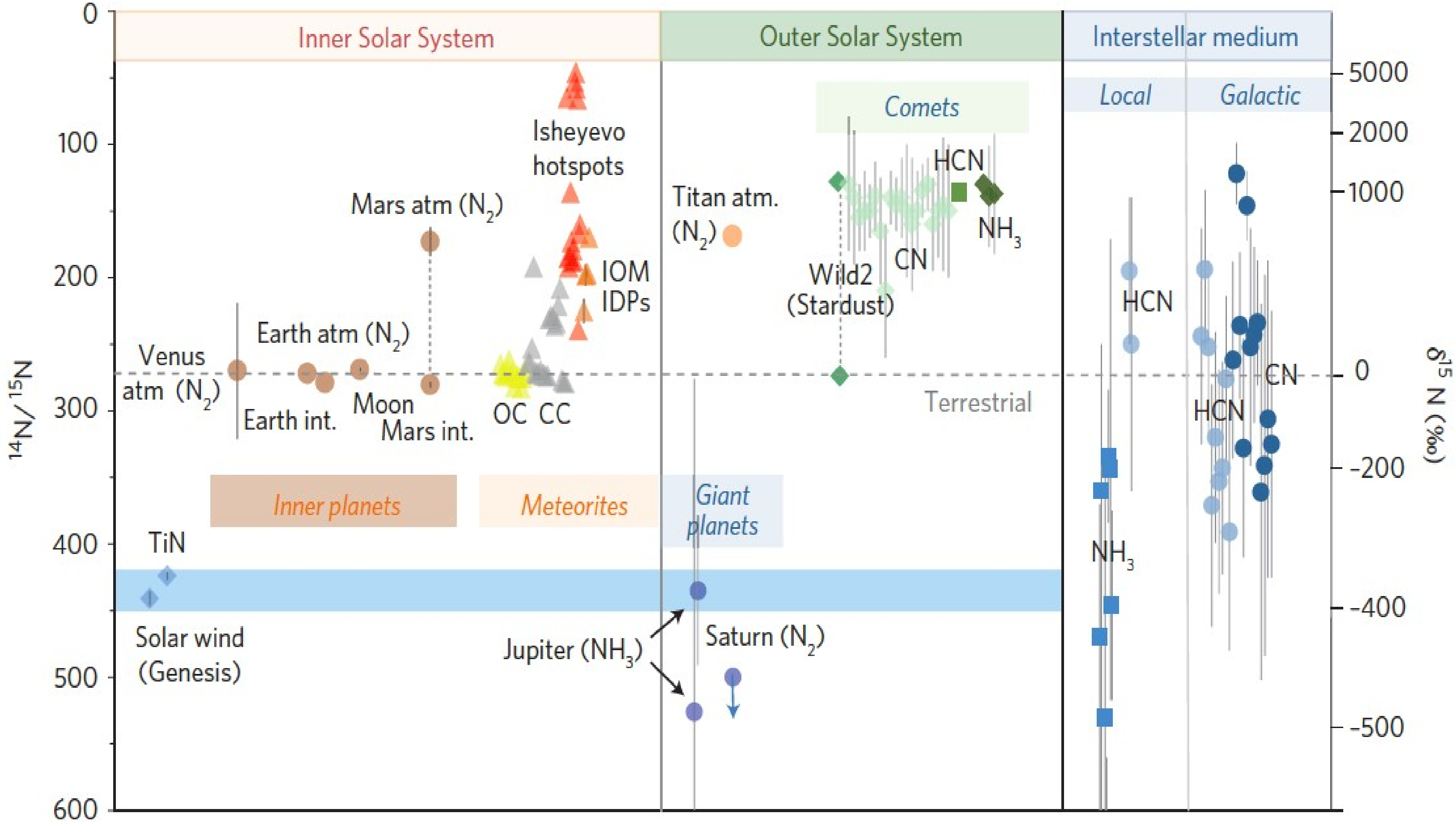
→ At least **3 isotopic reservoirs** in the solar system:

→ **PSN poor** in ^{15}N ($^{14}N/^{15}N$=441)

→ **inner solar system** (planets + bulk meteorites) enriched by a factor of 1.6 / PSN ($^{14}N/^{15}N$=272)

→ **cometary ices** enriched by a factor of 3 / PSN ($^{14}N/^{15}N$~140)

→ ratios ≈ consistent with an **increase of ^{15}N with heliocentric distance** (qualitative agreement with D/H)

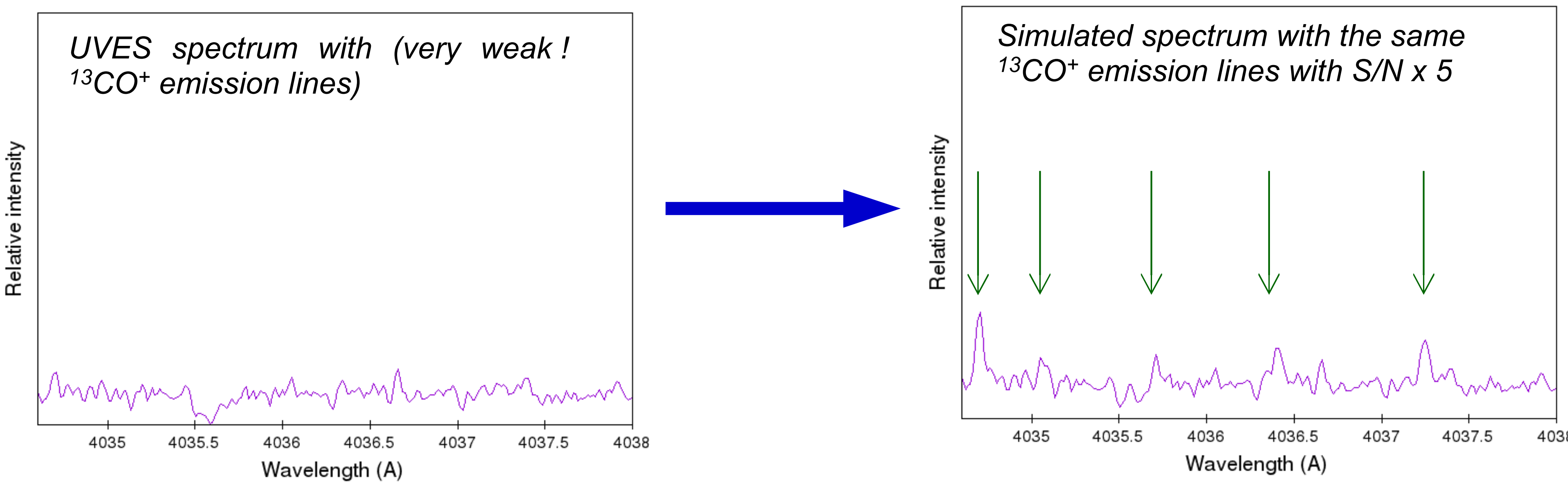


Füri (2015)

What HIRES could do:

→ **Gain for S/N ~ 5 / VLT** (UVES)

Example with $^{13}CO^+$ emission lines simulated from an UVES spectrum of comet C/2016 R2:



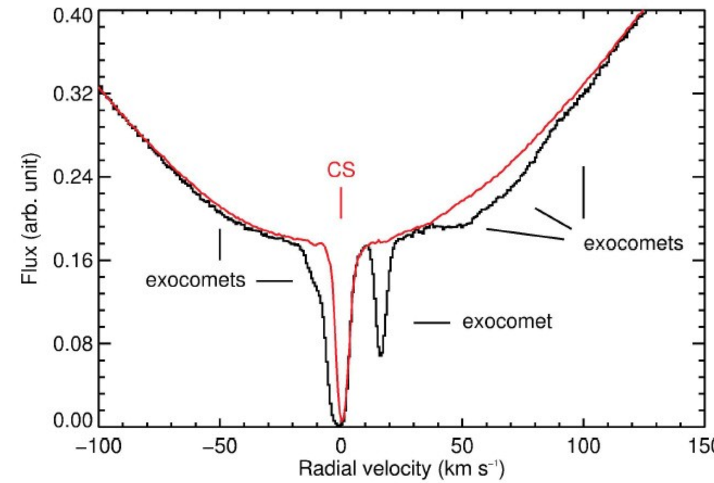
→ **Measurement of $^{14}N/^{15}N$ in N_2^+** (not enough S/N with UVES even with C/2016 R2)

→ **Reduce error bars to detect $^{14}N/^{15}N$ variations in NH_2 or CN with the type of comet** (not yet detected but large errorbars).

→ Measurements of **isotopic ratios in interstellar comets** (2I/Borisov with NH_2 emission lines)

… and, maybe, measurement of relative abundances in exocomets:

→ **Absorption lines (Ca II and Na I) due to exocomets** detected in **β Pic** and more than 20 other stars.

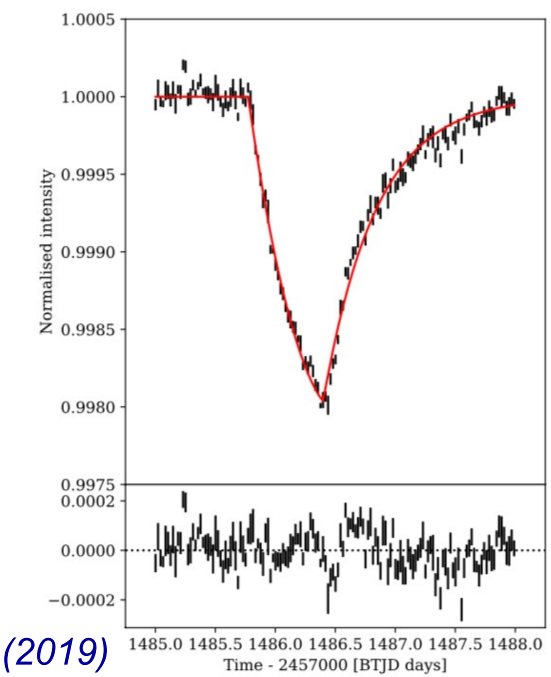


Kiefer et al. (2014)

→ **Ca II K absorption lines** observed at 393.4 nm around β Pic by HARPS:

→ **Doppler shift allows dynamical studies**
(for β Pic : two families of comets, one of them being in MMR with a massive planet and the other one being fragments of one of a few parent bodies).

→ First « **exocomet transit** » observed by TESS on β Pictoris:



Zieba et al. (2019)

Thanks for your attention !