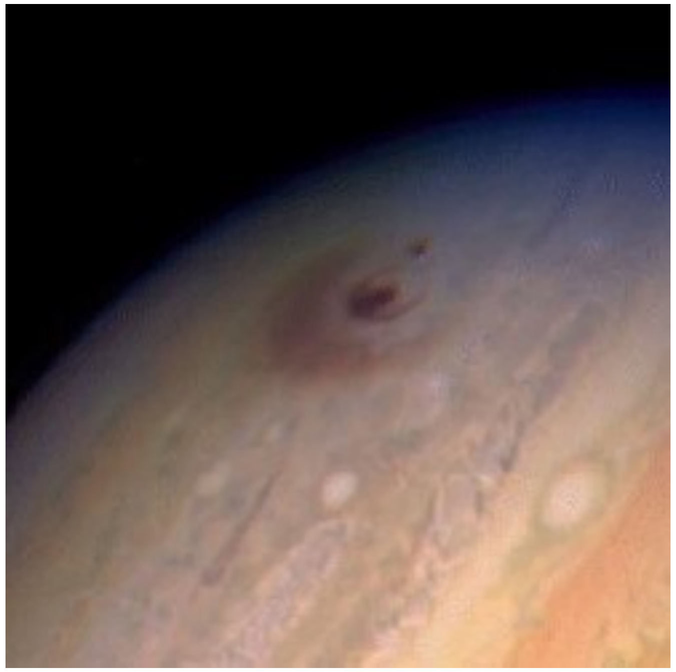
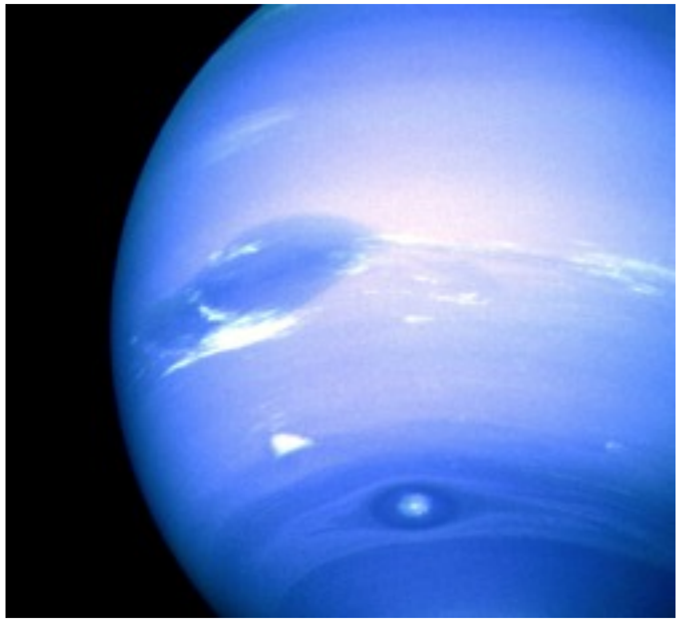
ALMAとの連携による、ガス惑星大気の高空間分解能・低分散中間赤外分光観測





東京農工大学 特任助教

飯野孝浩

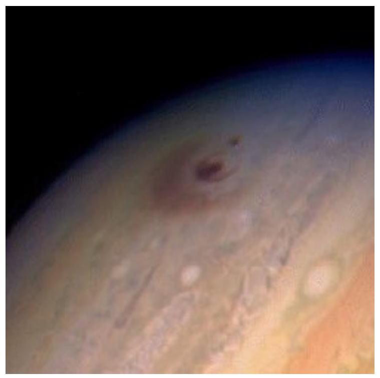
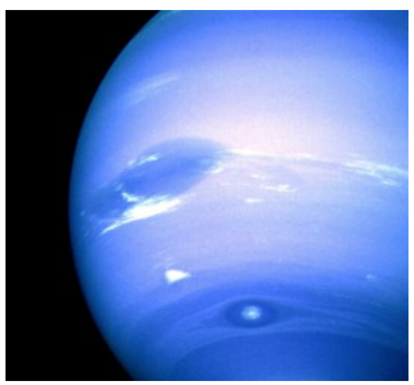
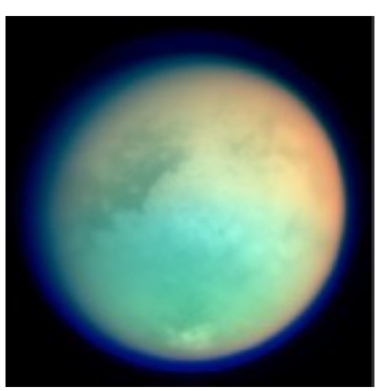

アルマ望遠鏡
ビッグデータ
天文学と
気象学の
融合
×
地球衛星観測
大気リトリーバル
波長・時間・空間ドメインに膨大(60TB超)
実績ある最尤解自動探索アルゴリズム
地球センシング技術による惑星リモートセンシング
地球環境の特異性と普遍性を解明
「比較惑星気象学」の創出
地球型天体群・木星衛星群：生命の存在形態は？
天王星型天体群：古太陽系環境は？
隣接研究分野へのシナジー
【天文学】
ビッグデータ電波天文学
原始惑星系円盤HL Tau
【地球気象学】
地球観測モデルの高精度化
南極オゾンホール
【宇宙生物学】
地球外での生命環境
地球生物DNAモデル

Contents

1. ミリ波・サブミリ波でのガス惑星観測
2. 中間赤外でのガス惑星大気観測
3. ガス惑星大気のサイエンス
4. 近年の観測的動向
5. MIR/サブミリの将来計画

Problems of previous researches:

A beam dilution effect caused by the small diameter of the planet

apparent diameter of planets		spatial resolution of radio observatories	
	~40”	7~11”	
	~2”.3	10~20”	
	~0”.7	10~20”	

Mapping observation of planets is hardly available!

これまでのミリ波・サブミリ波でのガス惑星観測

大気組成に着目して

Neptune成層圏のHCN、CO検出

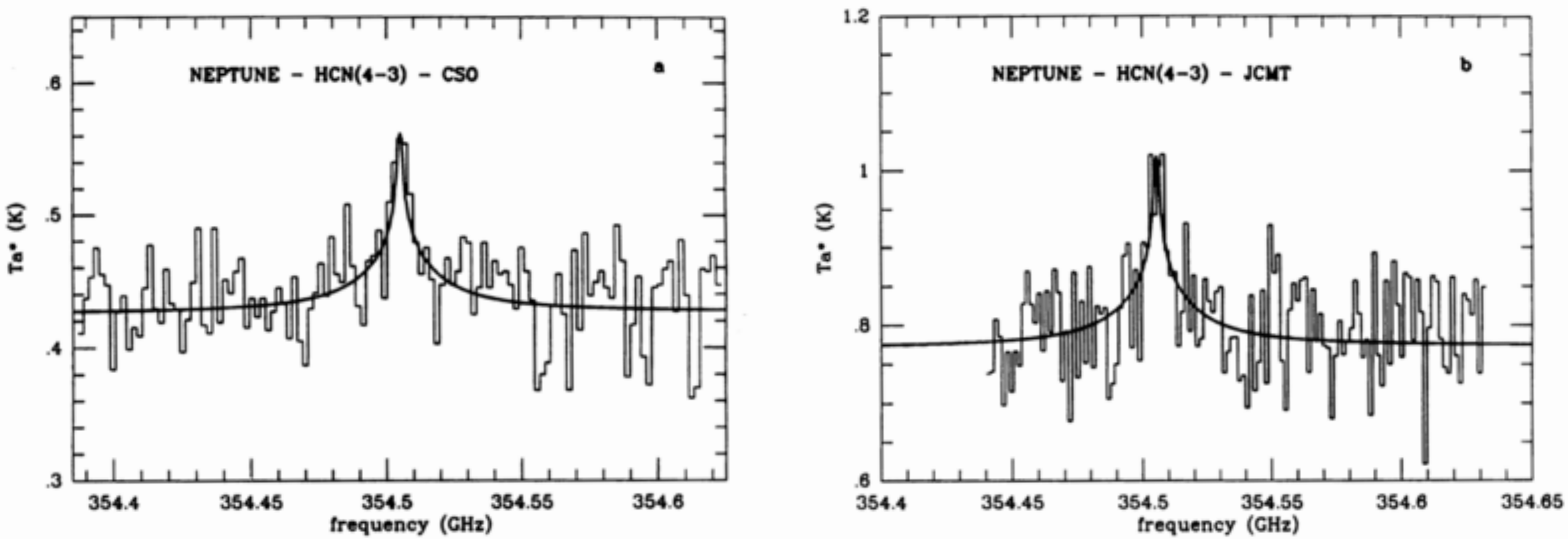


FIG. 5.—(*a*) Comparison of the antenna temperature spectrum of the (4–3) line of HCN on Neptune observed at the CSO with the synthetic spectrum calculated from the HCN vertical distribution shown in Fig. 4. The spectral resolution is 2 MHz. (*b*) Comparison of the antenna temperature spectrum of the (4–3) line of HCN on Neptune observed at the JCMT with the synthetic spectrum calculated from the same vertical HCN distribution. In this case, the spectral resolution is 1.5 MHz.

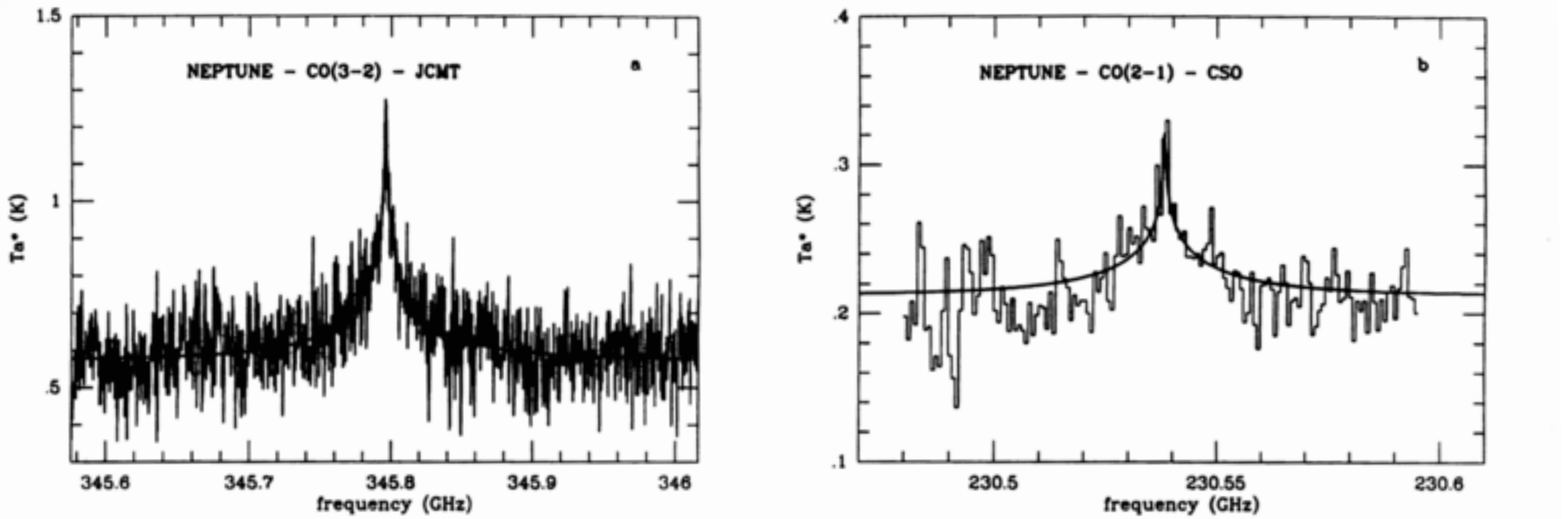
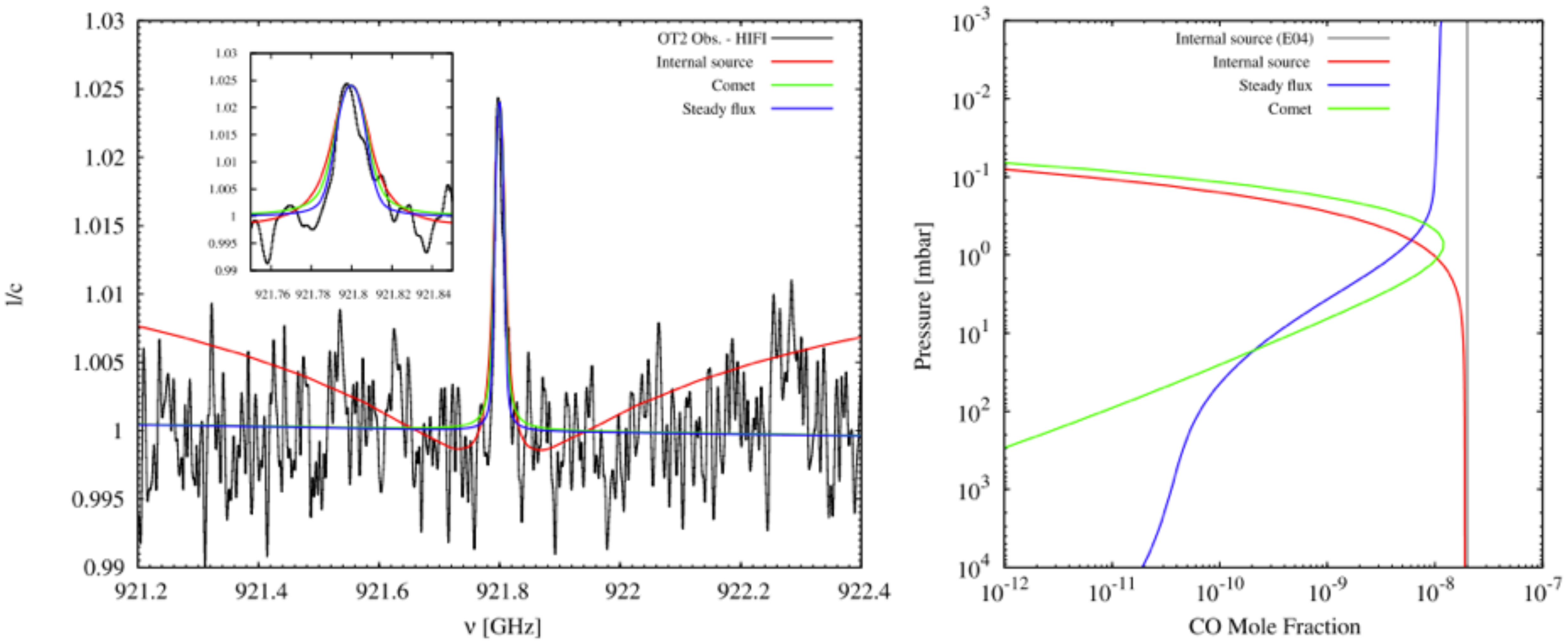


FIG. 6.—(*a*) Comparison of the antenna temperature spectrum of the (3–2) line of CO observed at the JCMT with the synthetic spectrum calculated from the CO vertical distribution shown in Fig. 4. The spectral resolution is 0.35 MHz. (*b*) Comparison of the antenna temperature spectrum of the (2–1) line of CO observed at the CSO with the synthetic spectrum calculated from the same CO vertical distribution. In this case, the spectral resolution is 0.5 MHz.

Marten+ 1992

Uranus成層圏COの高度分布導出



Herschel/HIFI, CO(J=8-7)

Cavalie+ 2014

木星成層圏でのSL9由来分子群観測

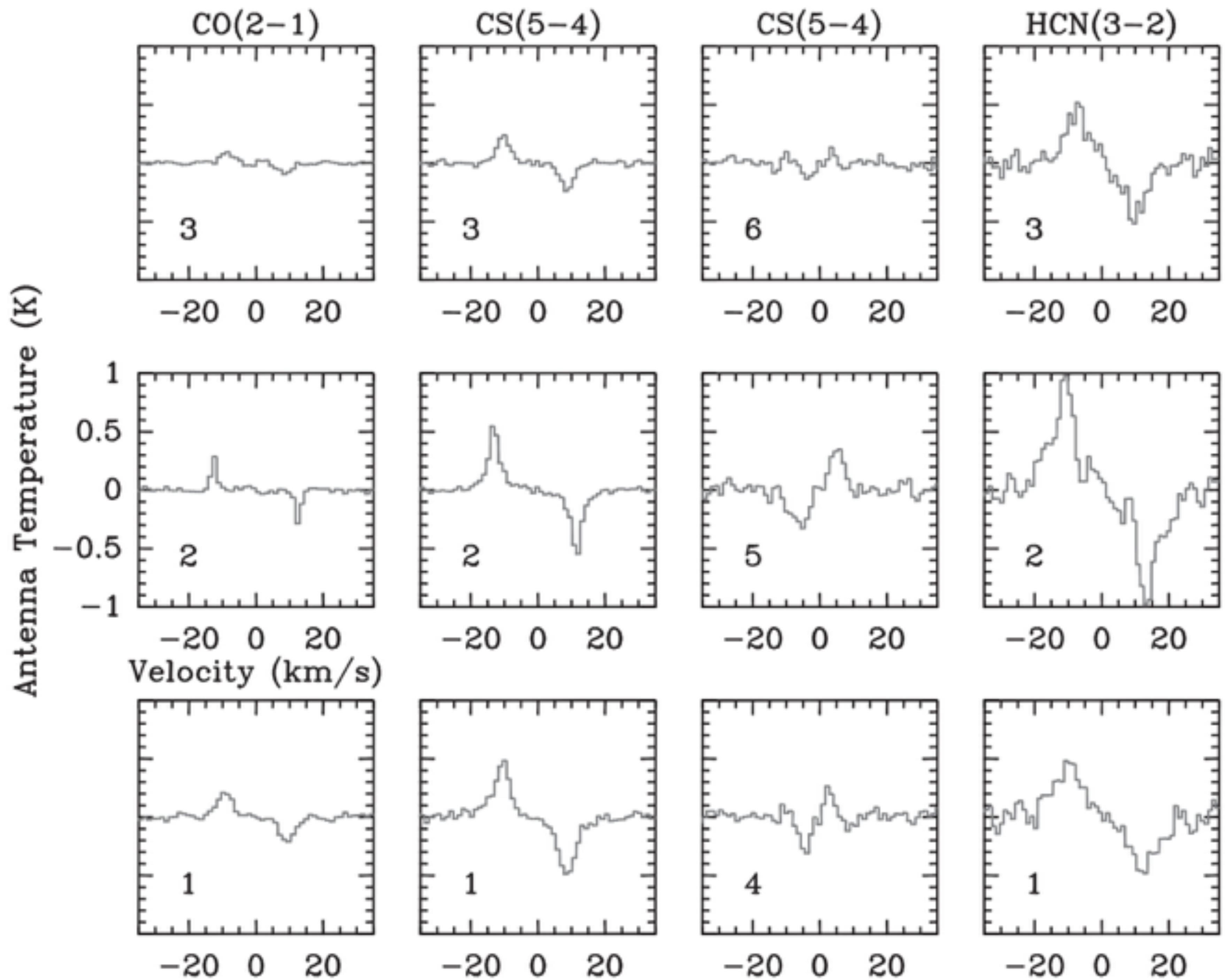
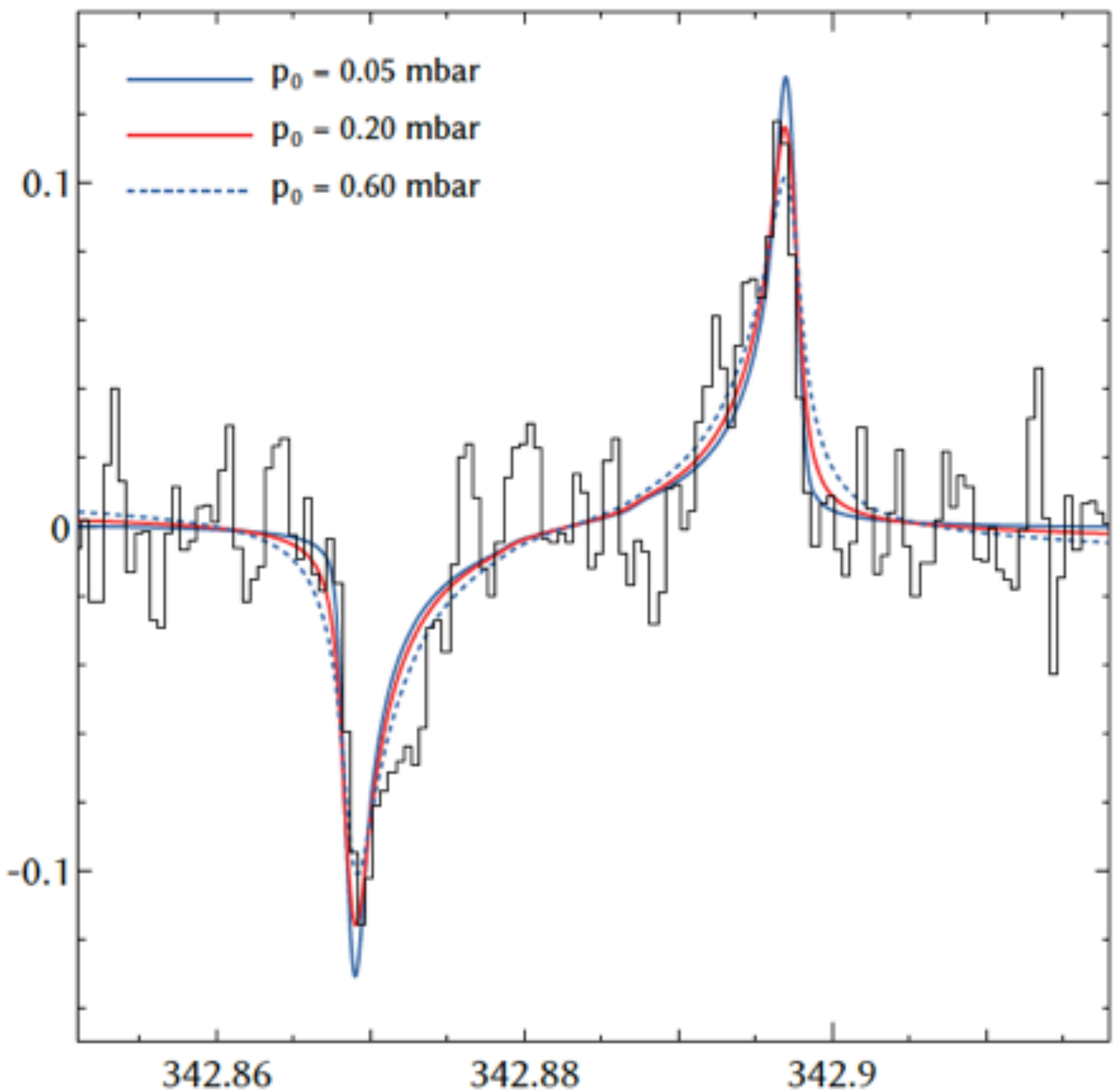
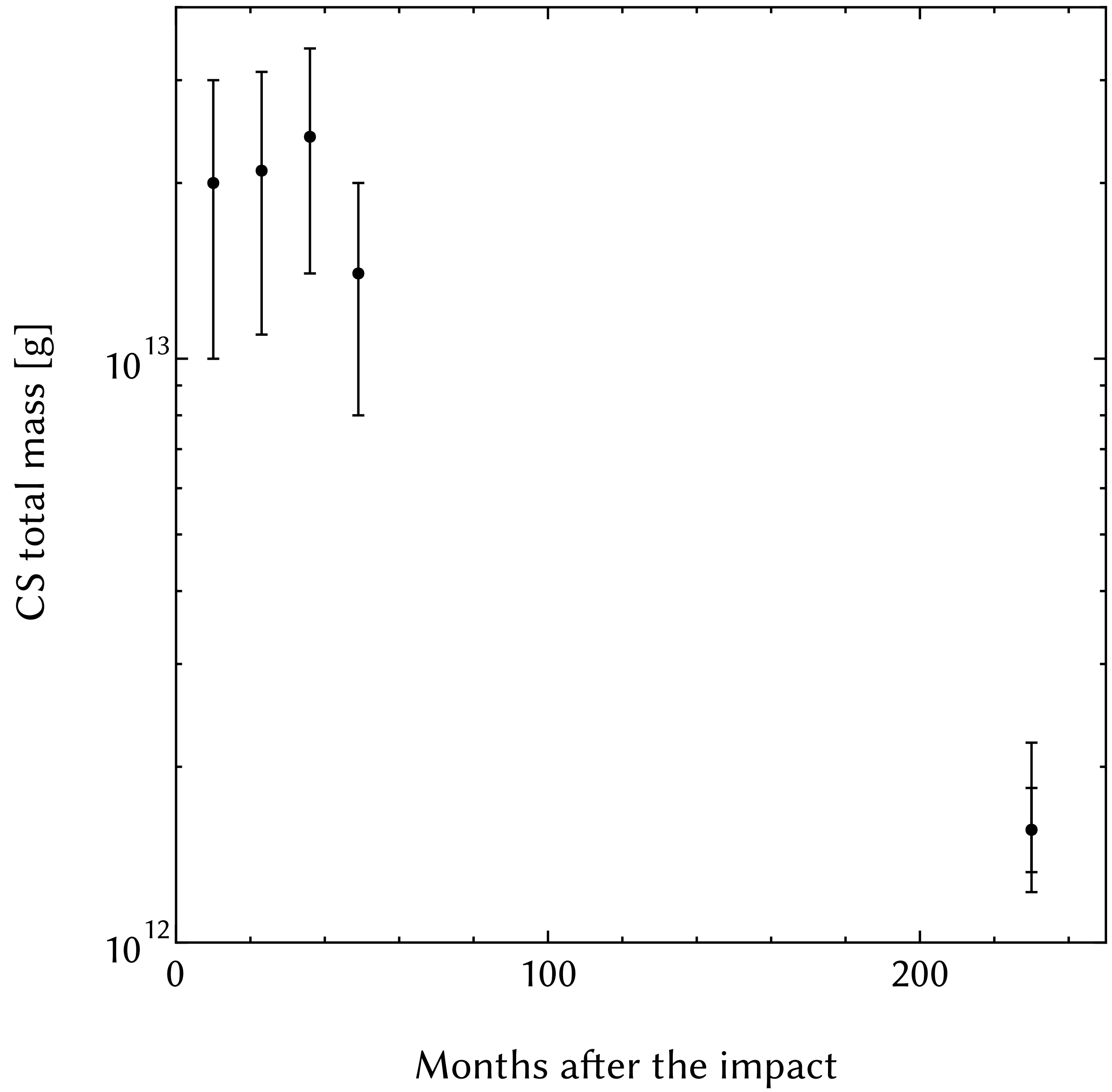


Fig. 7. CO, CS and HCN spectra obtained in July 1997 at IRAM. See Fig. 1 for labels identifying the observing positions.

Moreno+ 2003

木星成層圏でのSL9由来分子群観測





ASTE, CS(J=7-6)

Iino+ 2016b Accepted to AJ

My previous research 2:

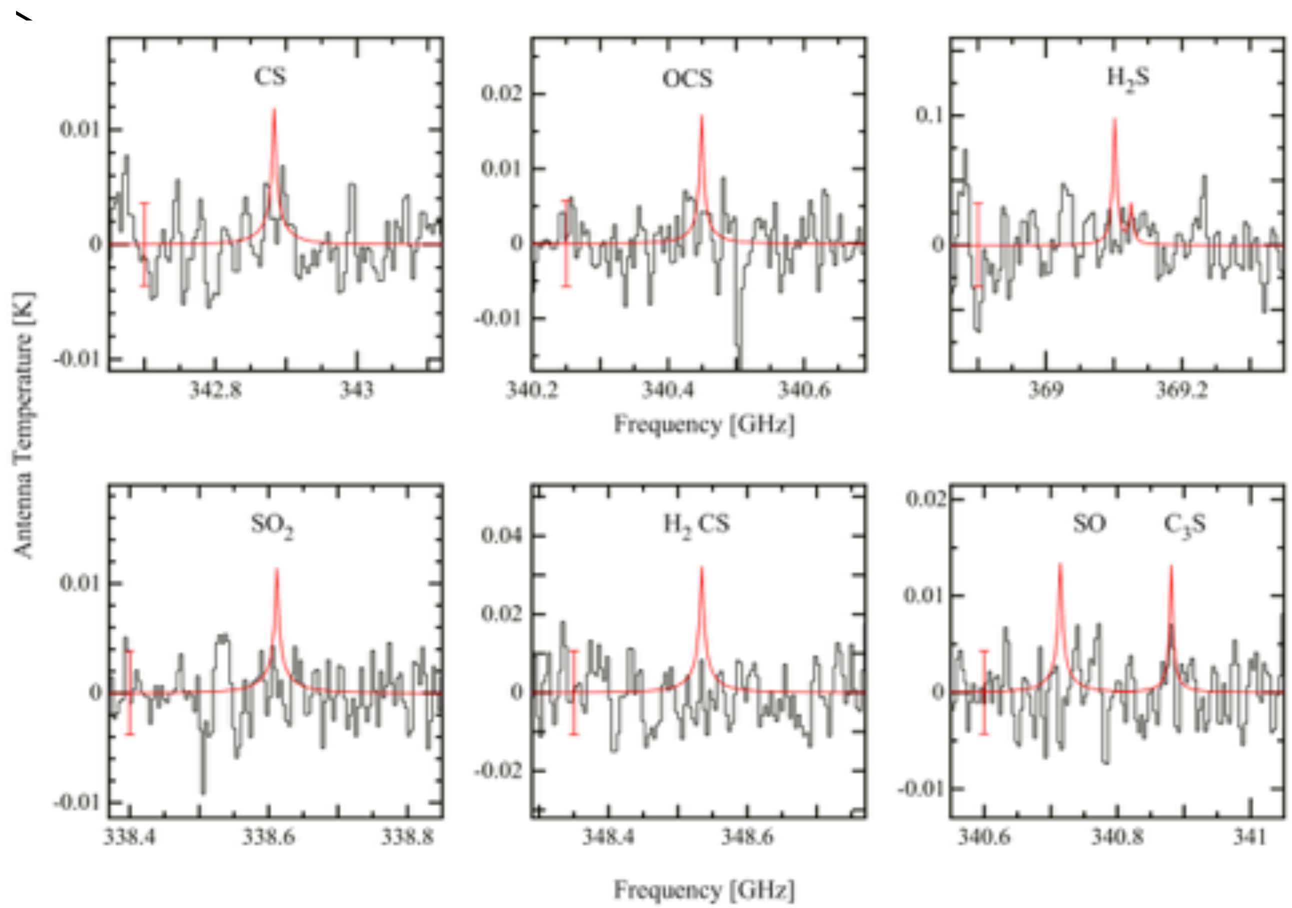
Absence of sulfur-bearing species on Neptune

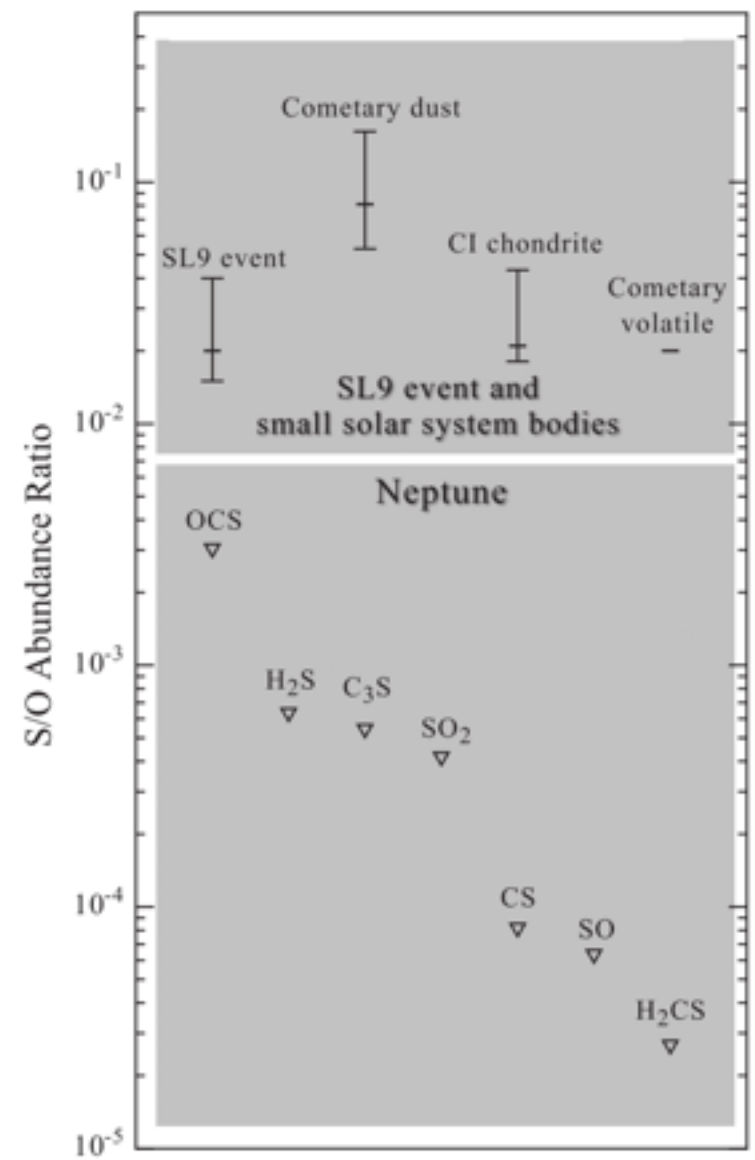
Aim:

A new constraint on the origin of stratospheric volatiles on Neptune such as CO, HCN and Hydrocarbons

Method:

New searches for Sulfur-bearing species with ASTE in 2009 and 2013 (Iino et al. 2014, P&SS)





Results:

CS and other S-bearing species was not found

Absence of S-bearing species <—> Jupiter's case

-> indicates the origin of volatiles are different from Jupiter's case

海王星成層圏COの広帯域分光

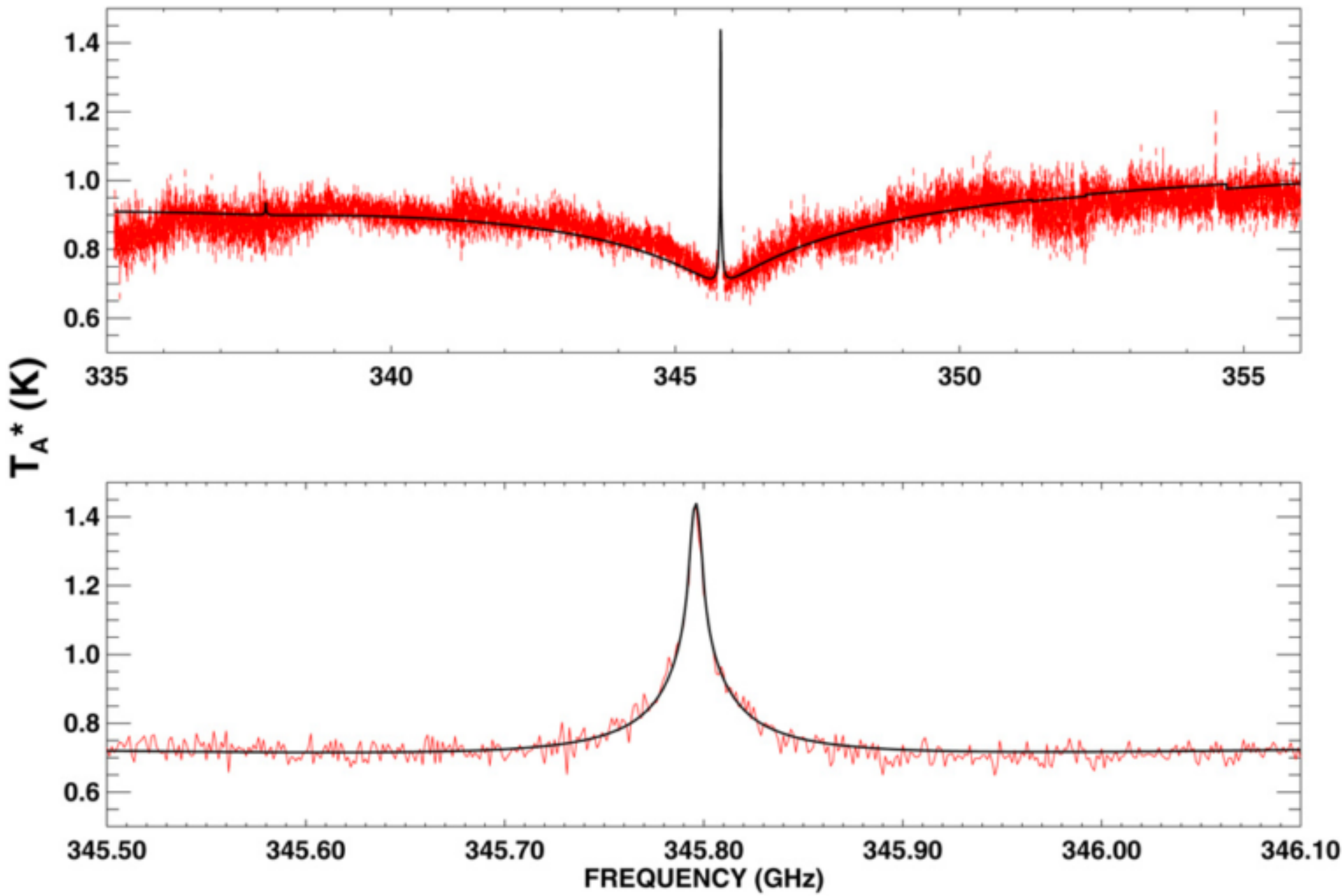


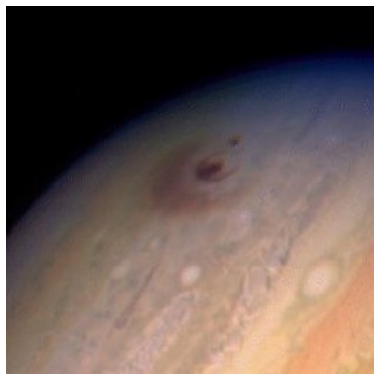
Fig. 5. The measured Neptune spectrum (red) overlaid with the best-fit model (black). This model was produced using the CO profile shown in Fig. 6

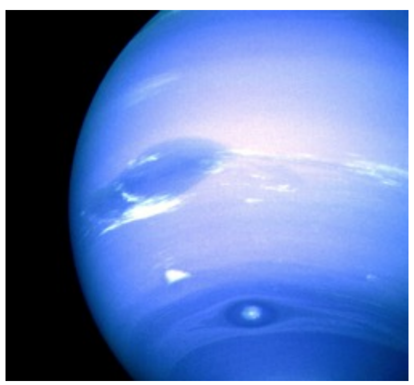
Hesman+ 2007, JCMT, CO(J=3-2)

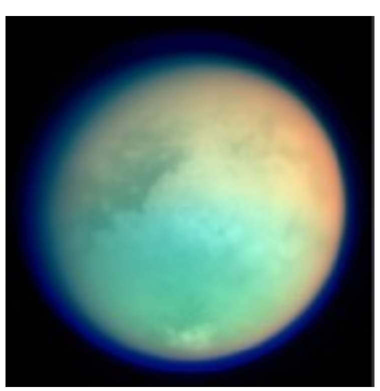
Problems of previous researches:

A beam dilution effect caused by the small diameter of the planet

apparent diameter of planets	spatial resolution of radio observatories
~40"	7~11"
~2".3	10~20"
~0".7	10~20"



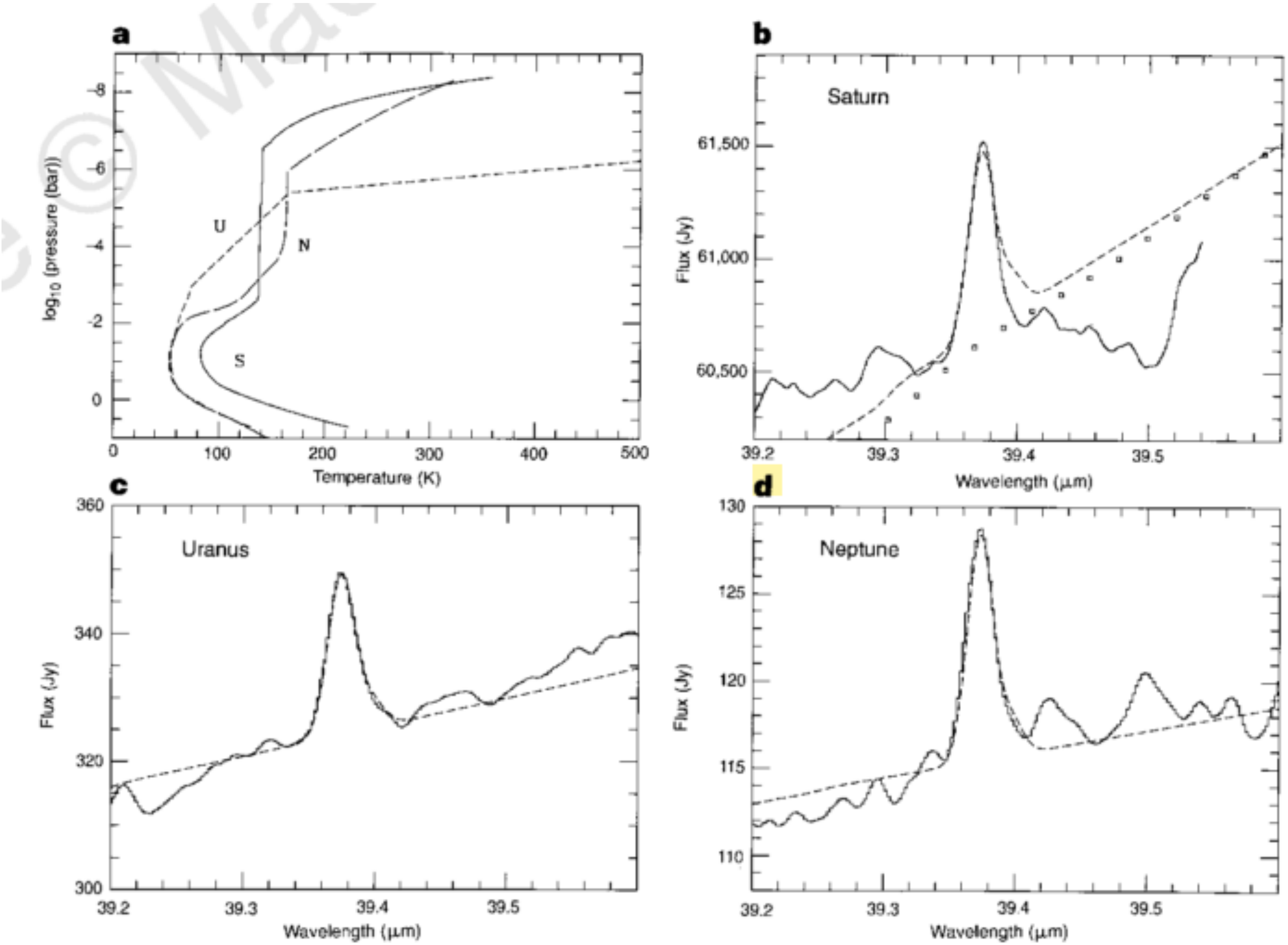




Mapping observation of planets is hardly available!

中間赤外での
ガス惑星大気観測

ガス惑星・タイタン成層圏H_2O, CO_2層の検出



惑星外からのOxygen fluxの示唆　ISO/SWS. Feuchtgruber+ 1999

彗星衝突由来木星成層圏H_2O空間分布

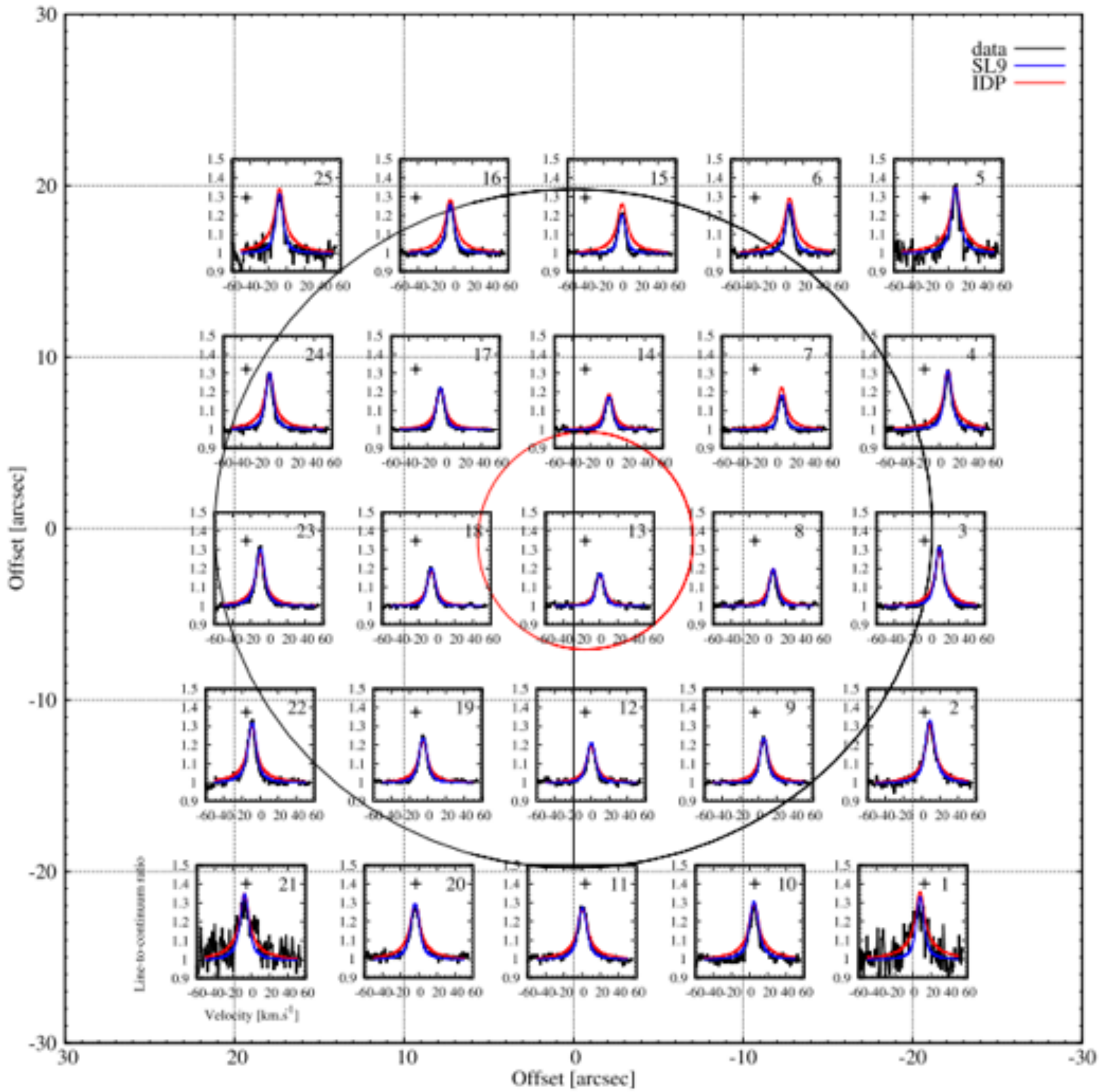
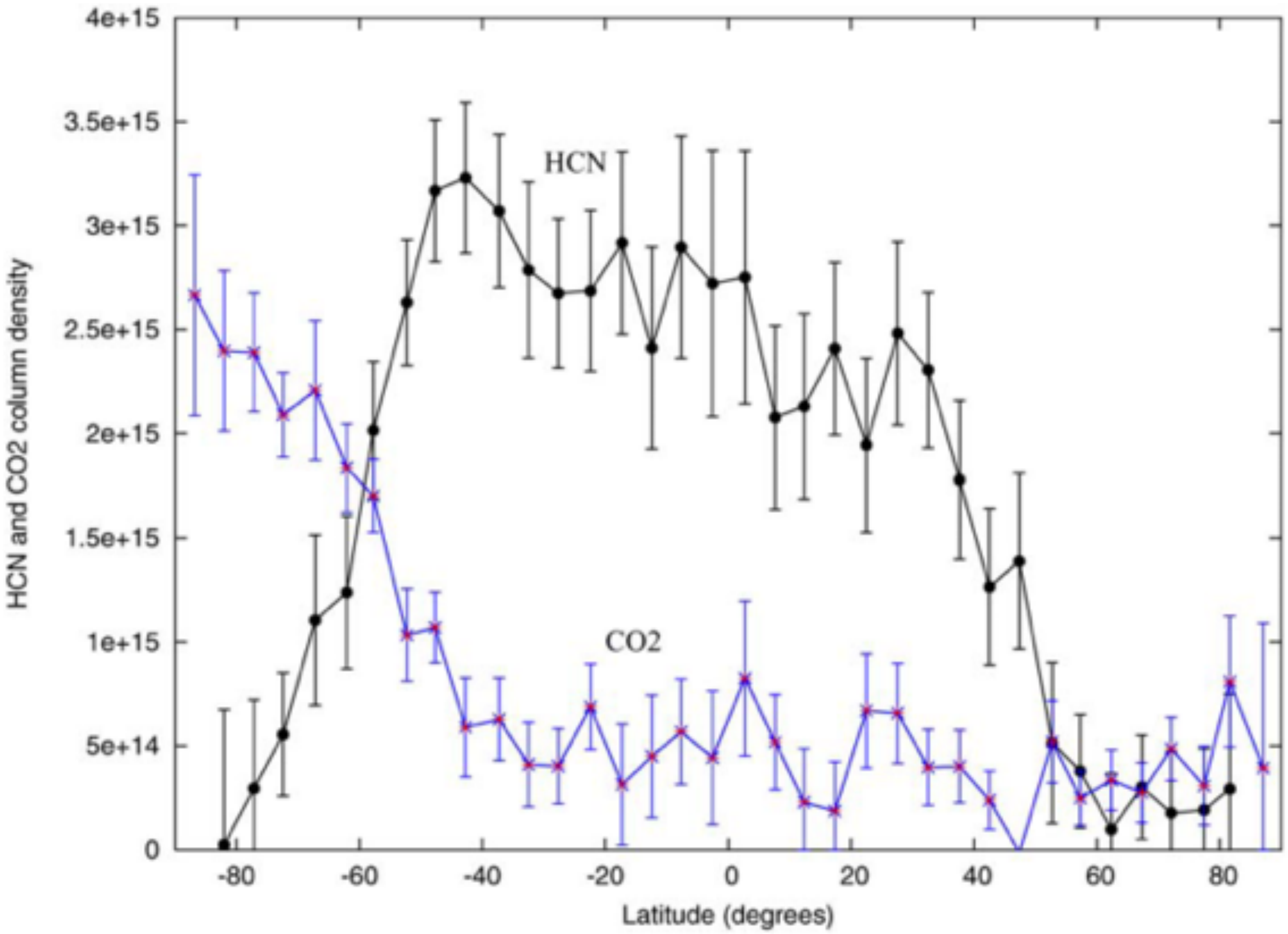
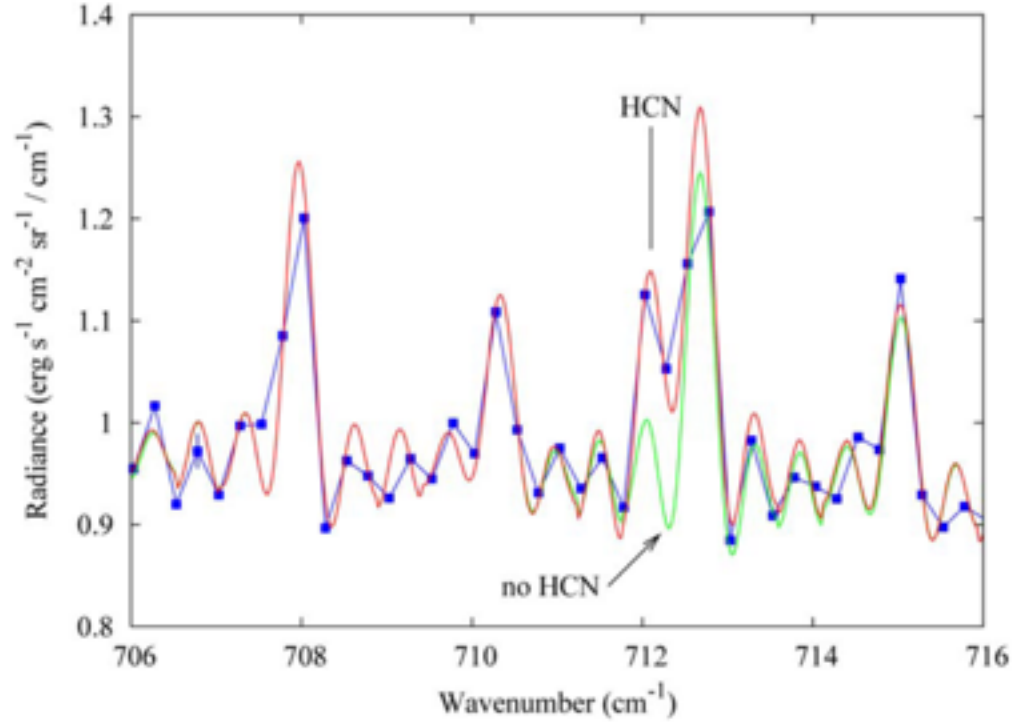


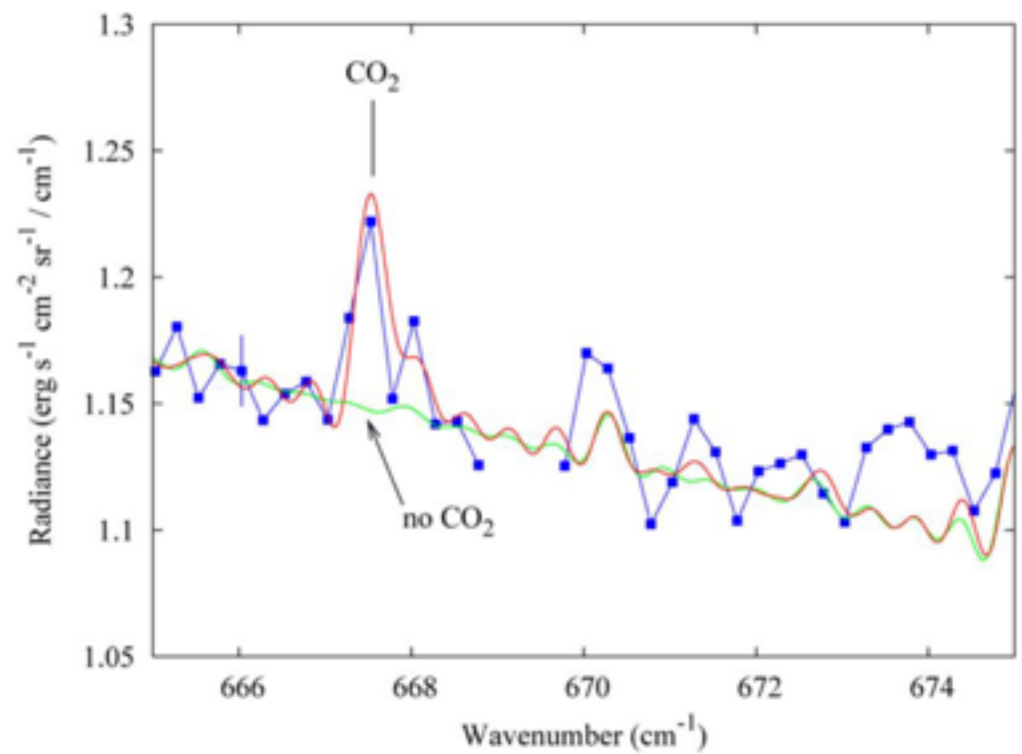
Fig. 11. Water 5 × 5 raster map at 1669.9 GHz obtained with *Herschel*/HIFI on July 7, 2010, expressed in terms of l/c and smoothed to a spectral resolution of 12 MHz (observation are plotted in black). Jupiter is represented with the red ellipse, and its rotation axis is also displayed. The black crosses indicate the center of the various pixels after averaging the H and V polarizations. The beam is represented for the central pixel by the red dotted circle.These high S/N observations rule out the IDP source model (red lines) because they result (i) in narrower lines than the ones produced by the IDP model; and (ii) in a non-uniform spatial distribution of water. Even if the flux in the northernmost pixels is adjusted to lower values to fit the l/c, the IDP model fails to reproduce the line wings (see Fig. 12). By adjusting the local water column density by rescaling the SL9 vertical profile, we find that an SL9 model (blue line), in which all water resides at pressures lower than 2 mbar, enables one to reproduce the observed map.

Herschel PACS, Cavalie+ 2014

木星成層圏のCO_2, HCN緯度分布

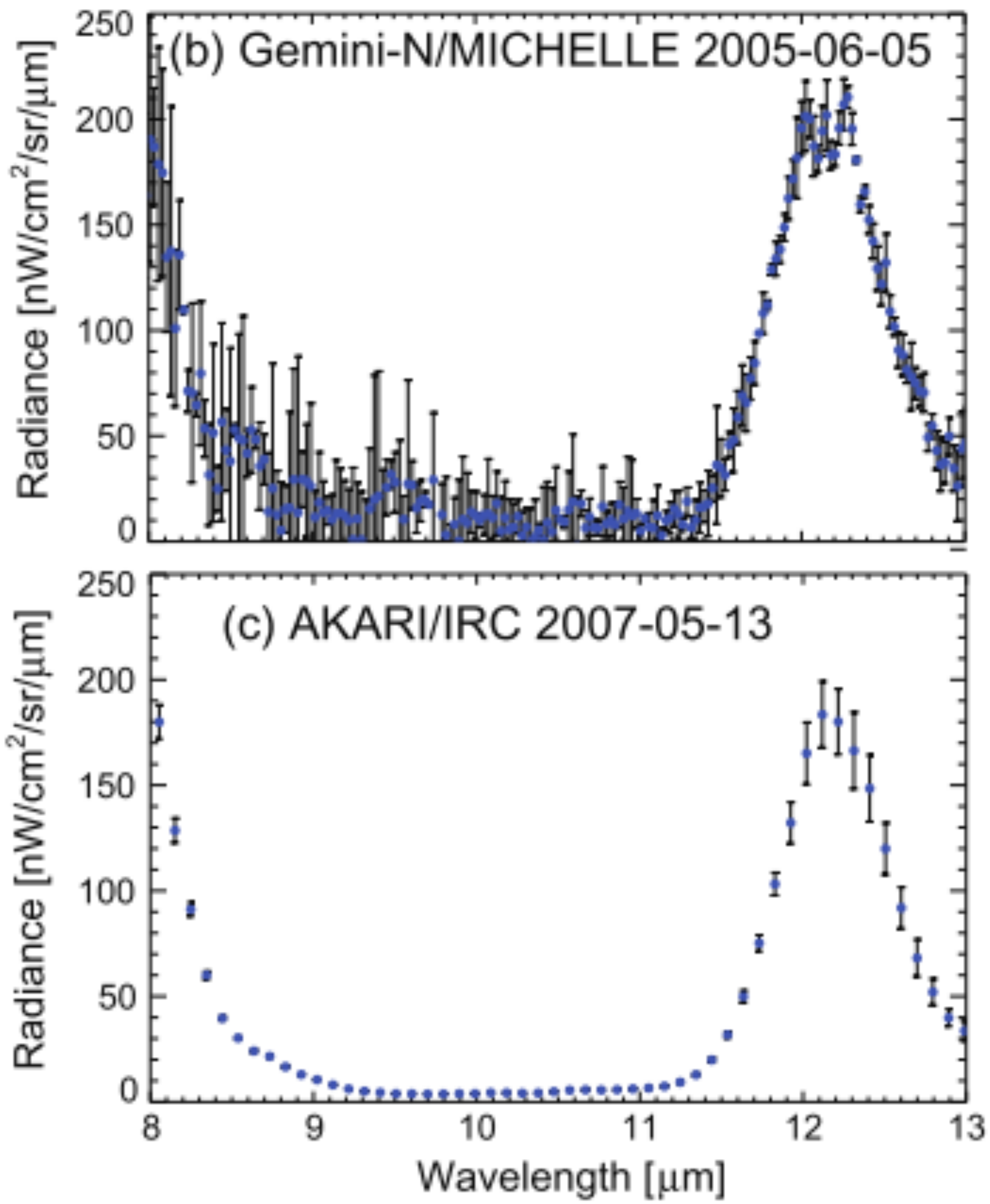




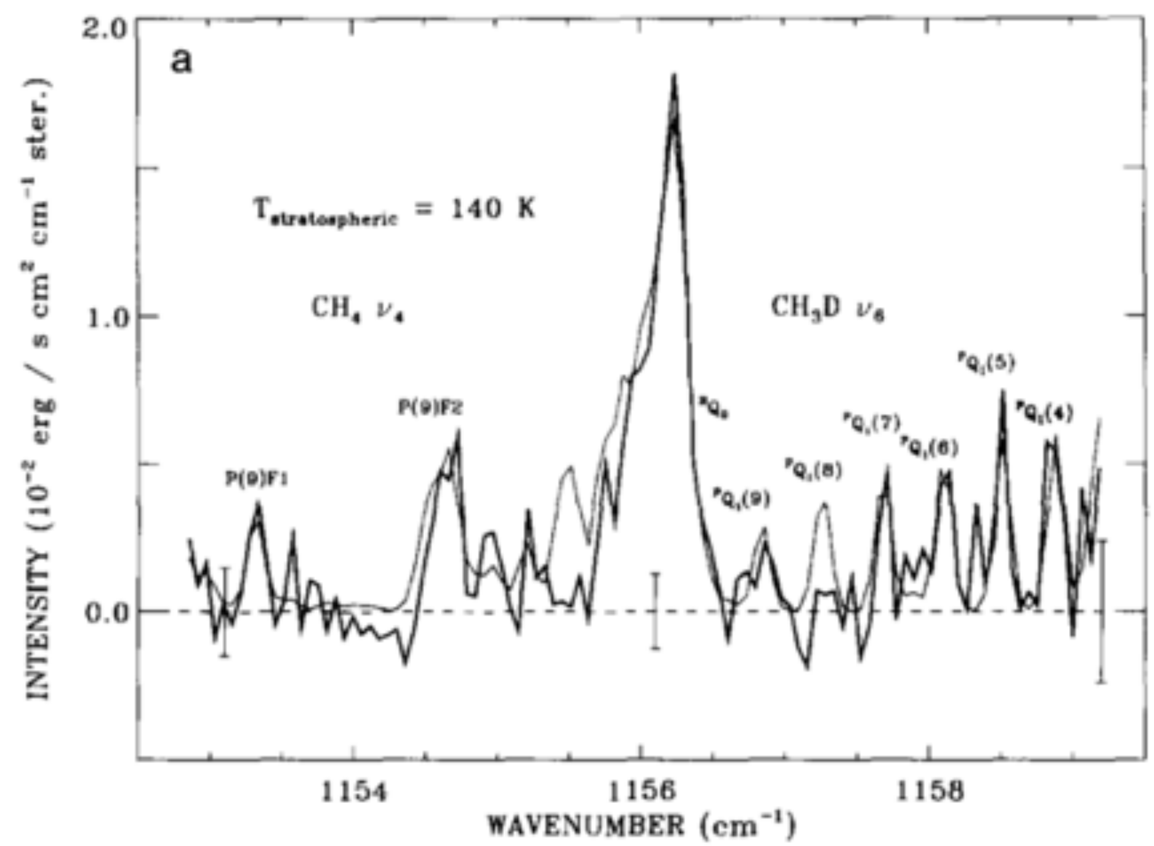


Cassini, Lellouch+ 2006

ガス惑星成層圏の分光観測



N-band spectroscopy,
Fletcher+ 2014



First derivation of D/H
Orton+ 1992

ガス惑星成層圏分光のサイエンス

1.成層圏分子の起源、化学

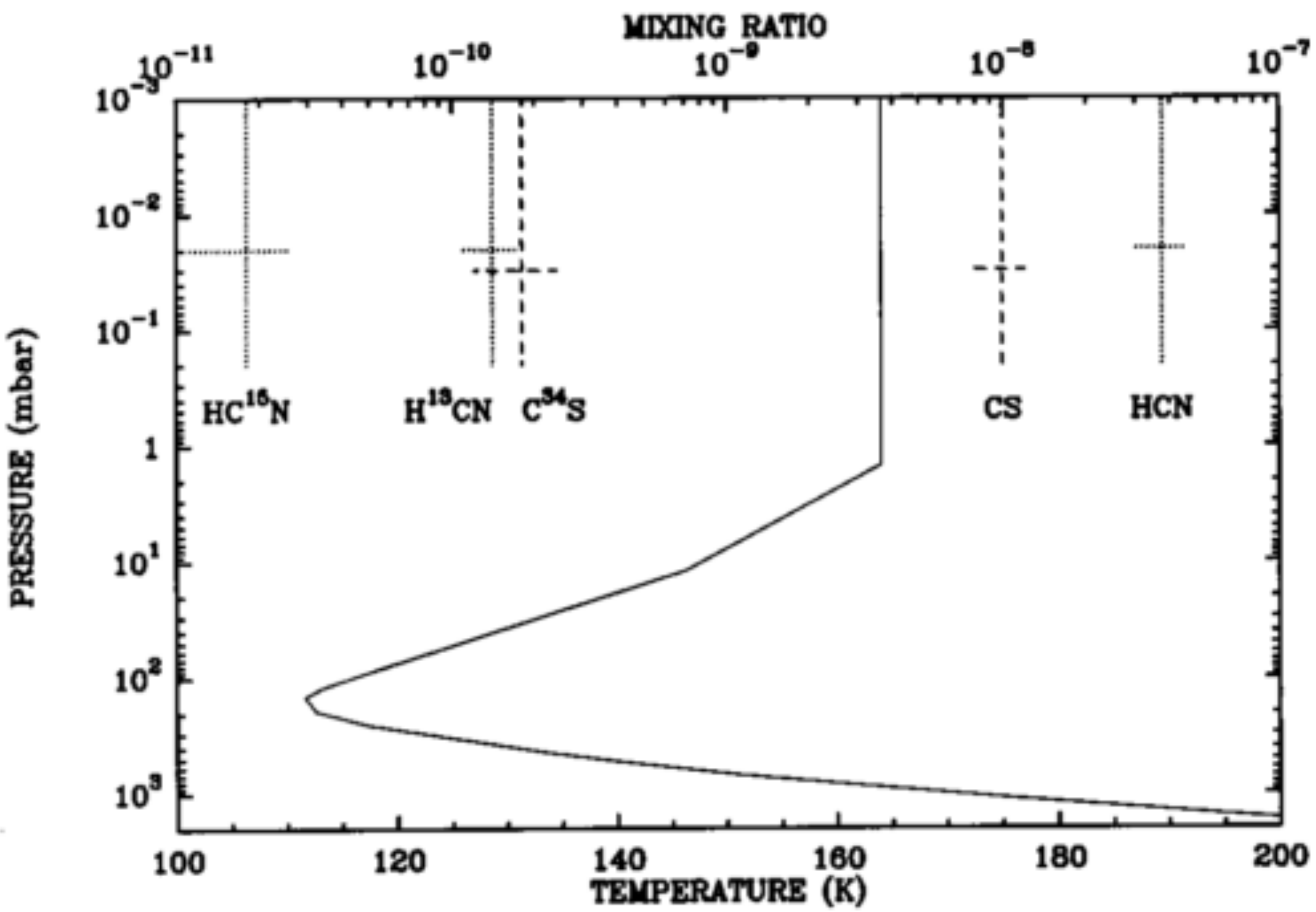
mm/sub-mm, MIRともにline contamination小さい

系外惑星大気分光でも期待（MIR)->ExoMol

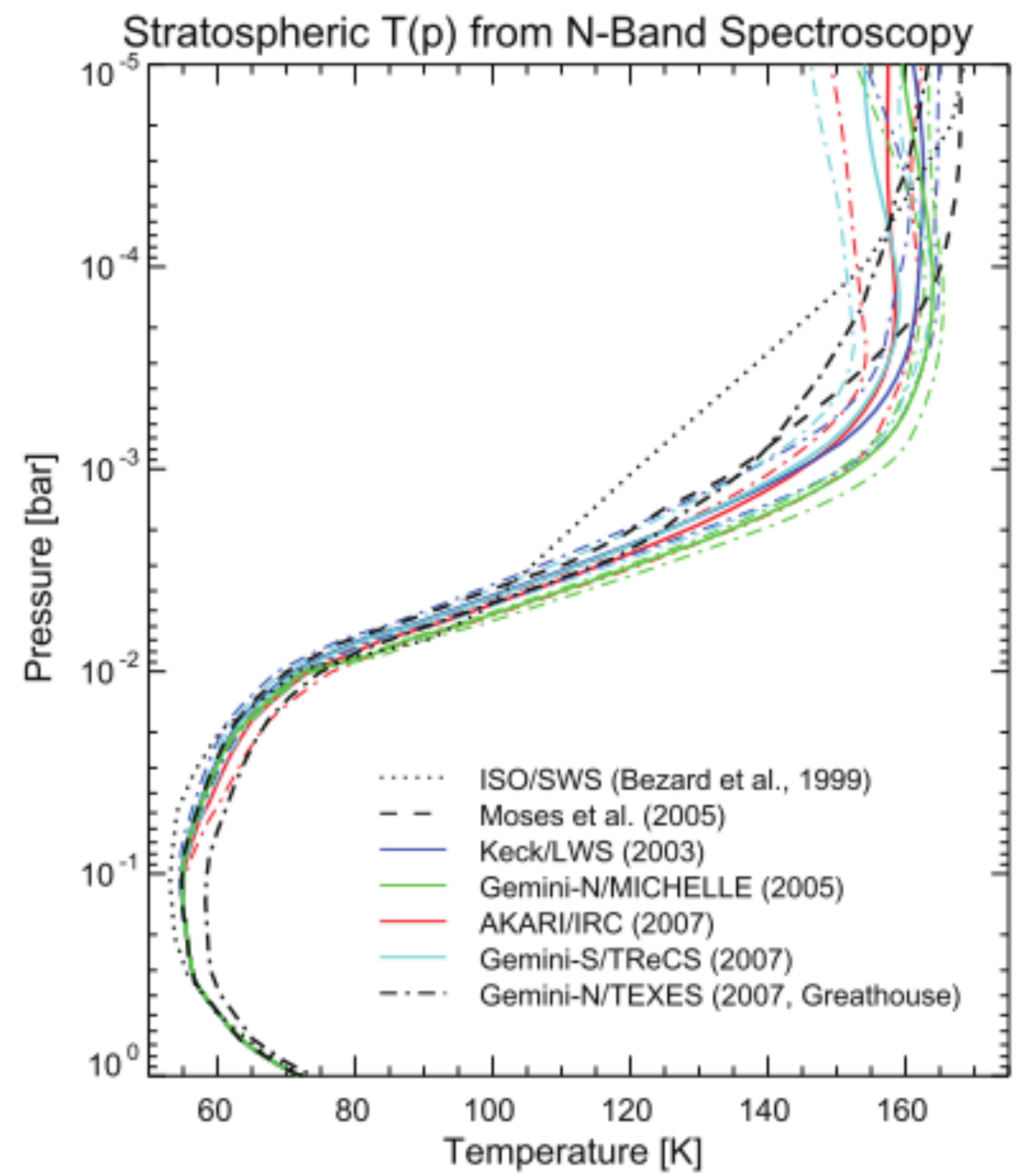
2.同位体比導出による惑星形成過程の制約

3.ダイナミクス

ガス惑星大気構造と成層圏分子の起源



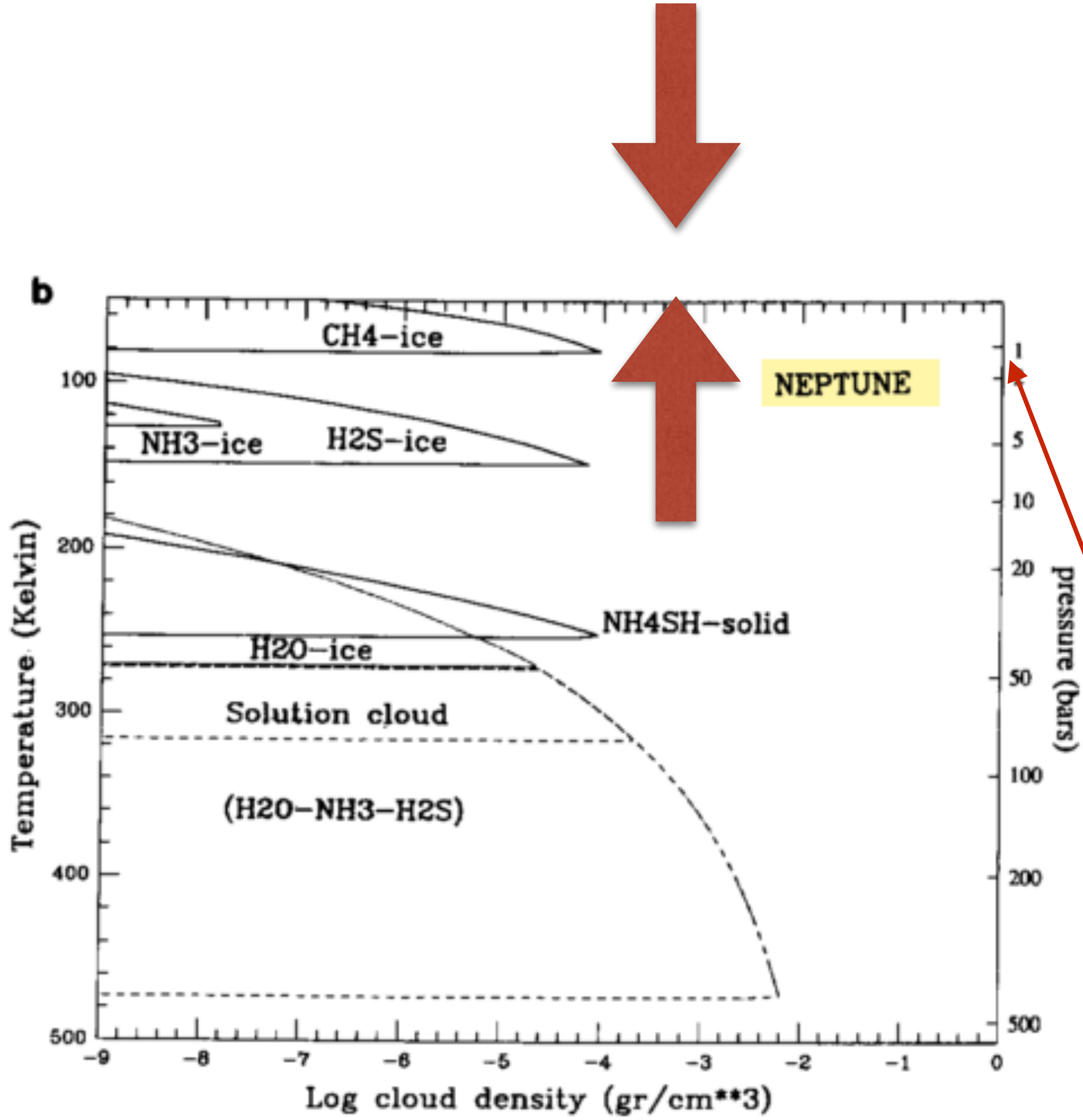
Matthews+ 2002

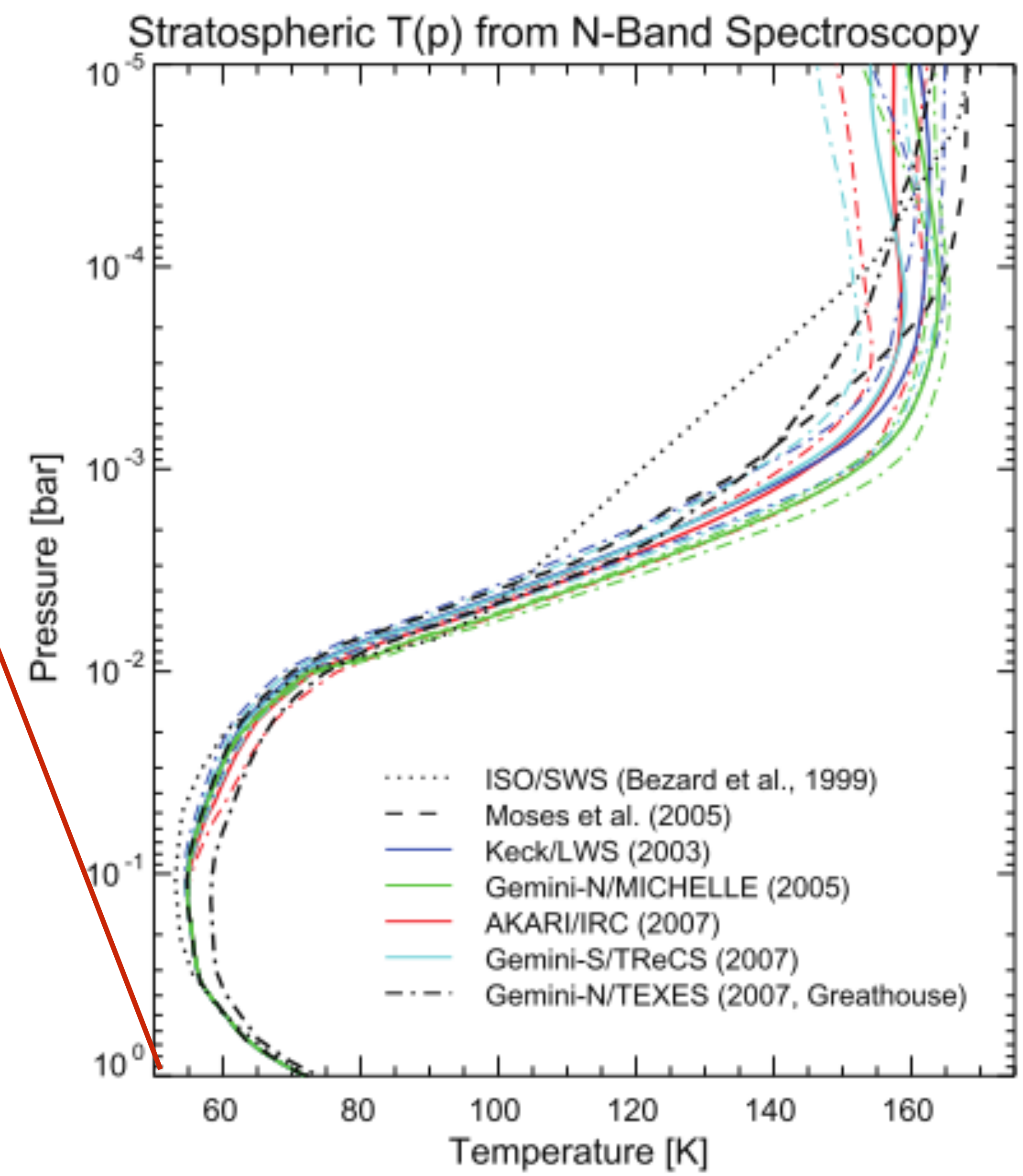


Fletcher+ 2014

未知の紫外吸収物質が成層圏を形成

成層圏分子の起源は？外部？内部？

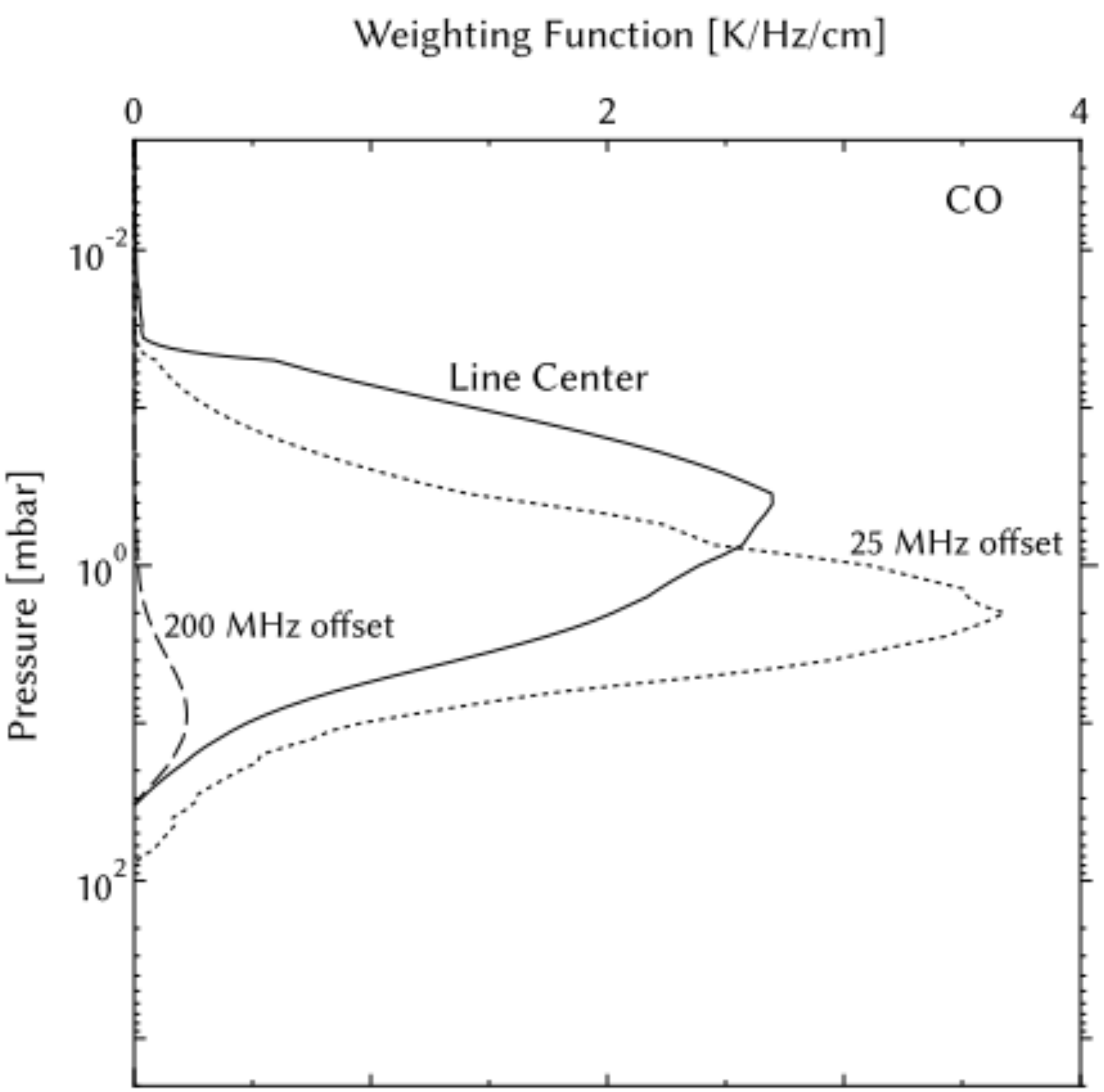




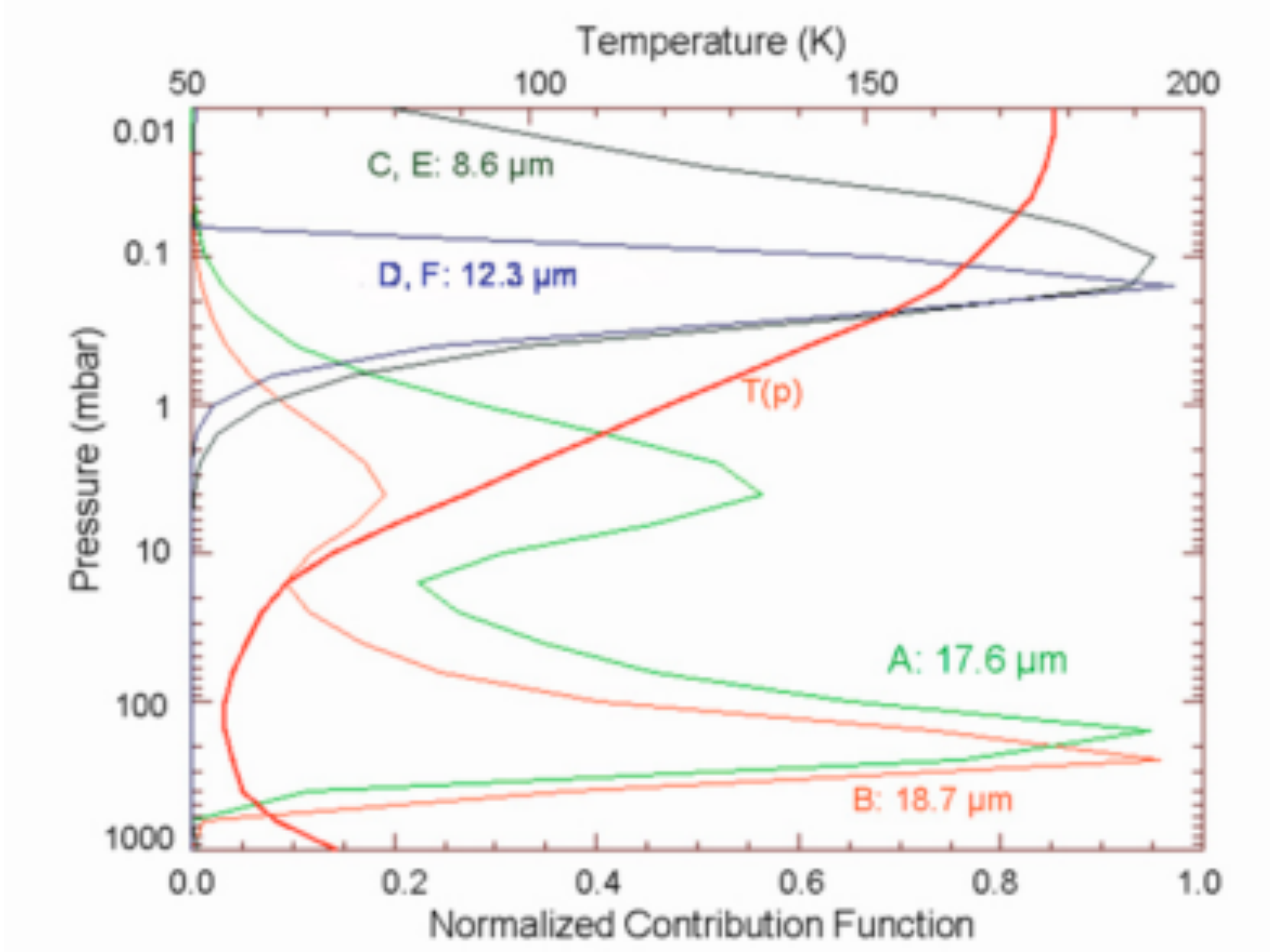
Cloud structure of Neptune
dePater+

Fletcher+ 2014

分子分光時の観測高度



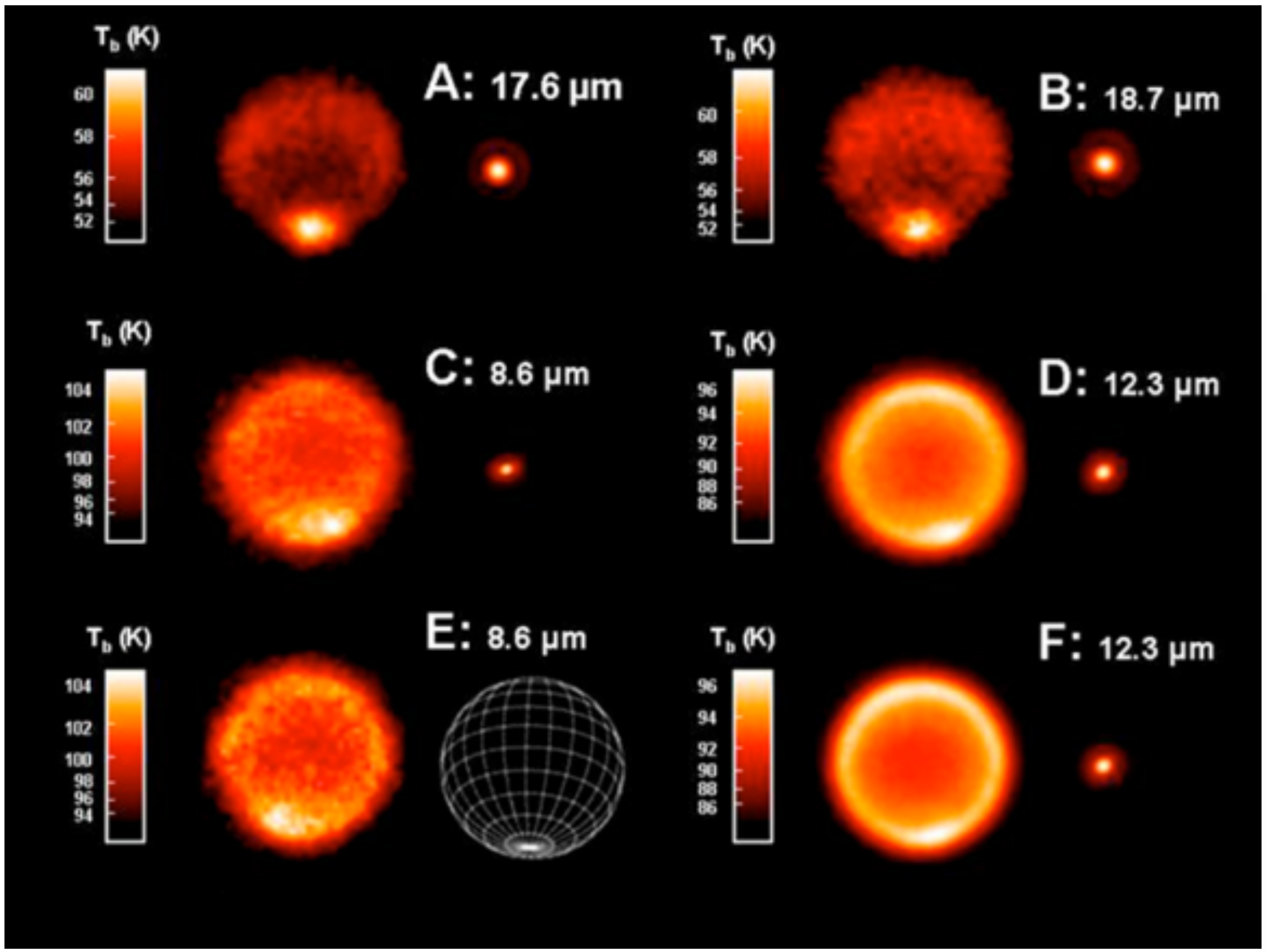
海王星COの高度別感度

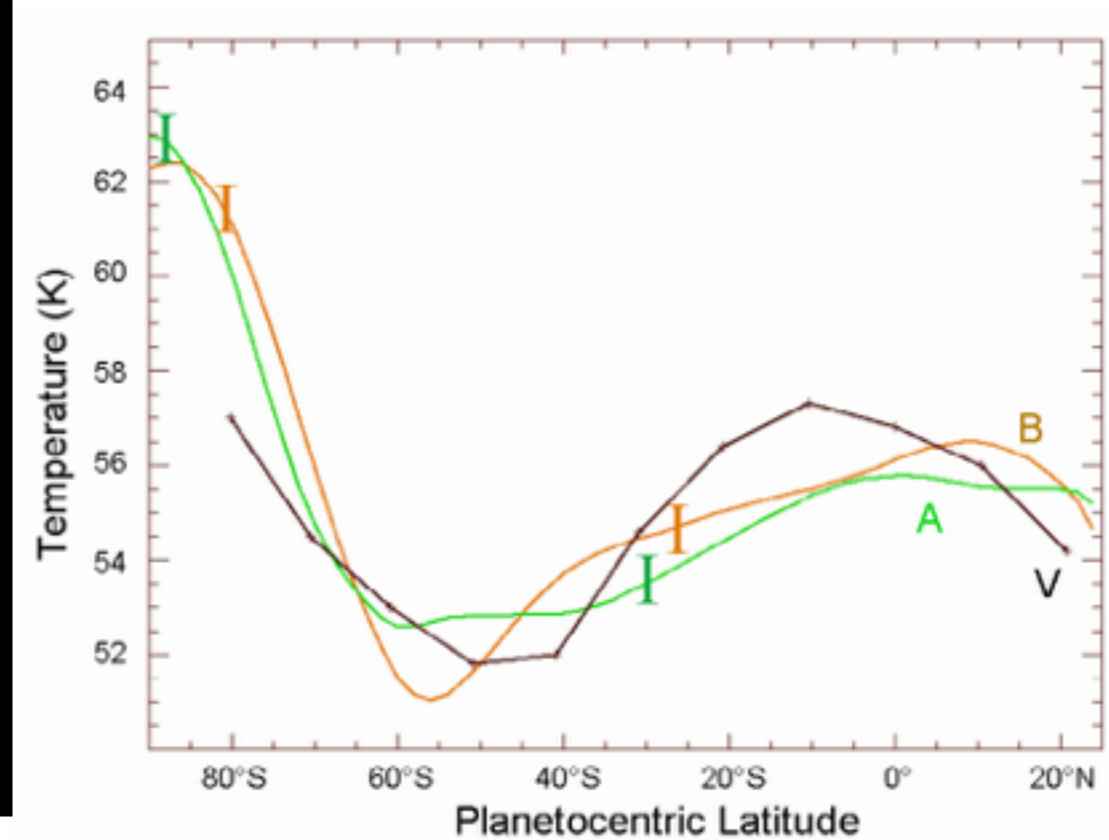


海王星MIRの高度別感度
Fletcher+ 2014

高空間分解能観測・モニタリングによる成層圏分子サイエンスの新展開

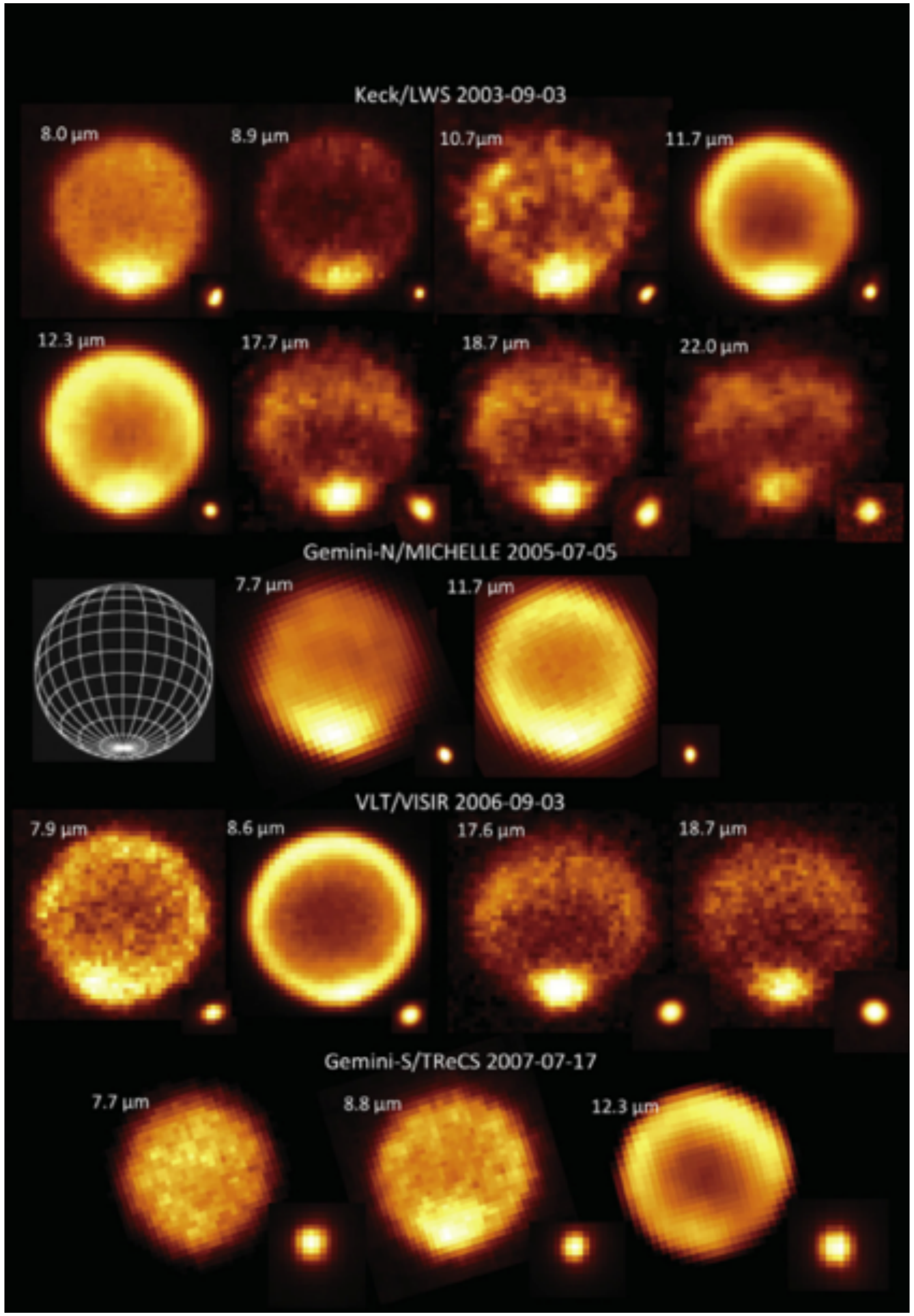
海王星成層圏MIR hot spotの検出





海王星MIR IMAGING Orton+ 2007, VLT

海王星成層圏MIR hot spotの検出



海王星MIR IMAGING Fletcher+ 2014

海王星成層圏メタン・エタンの時間変動

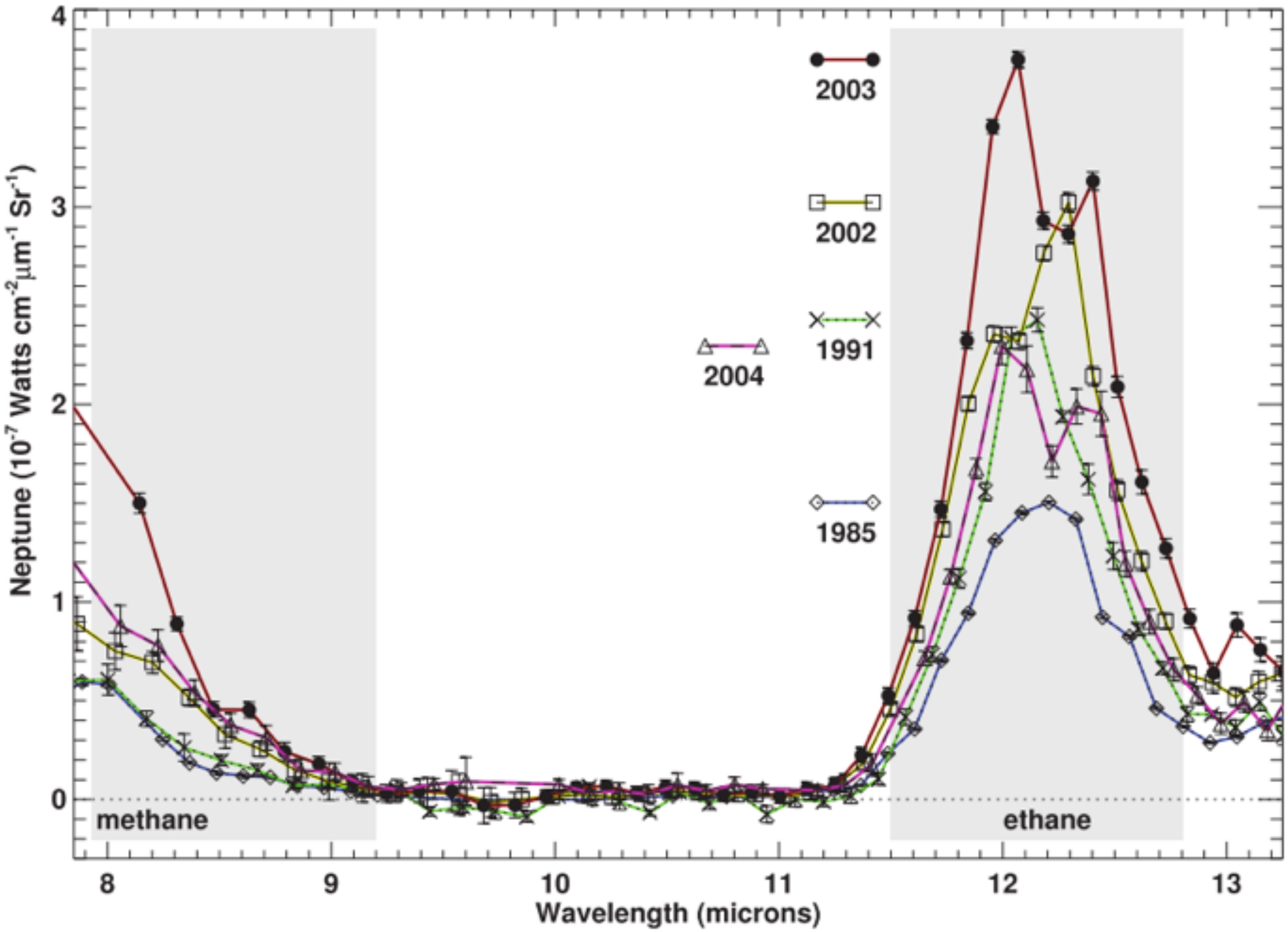
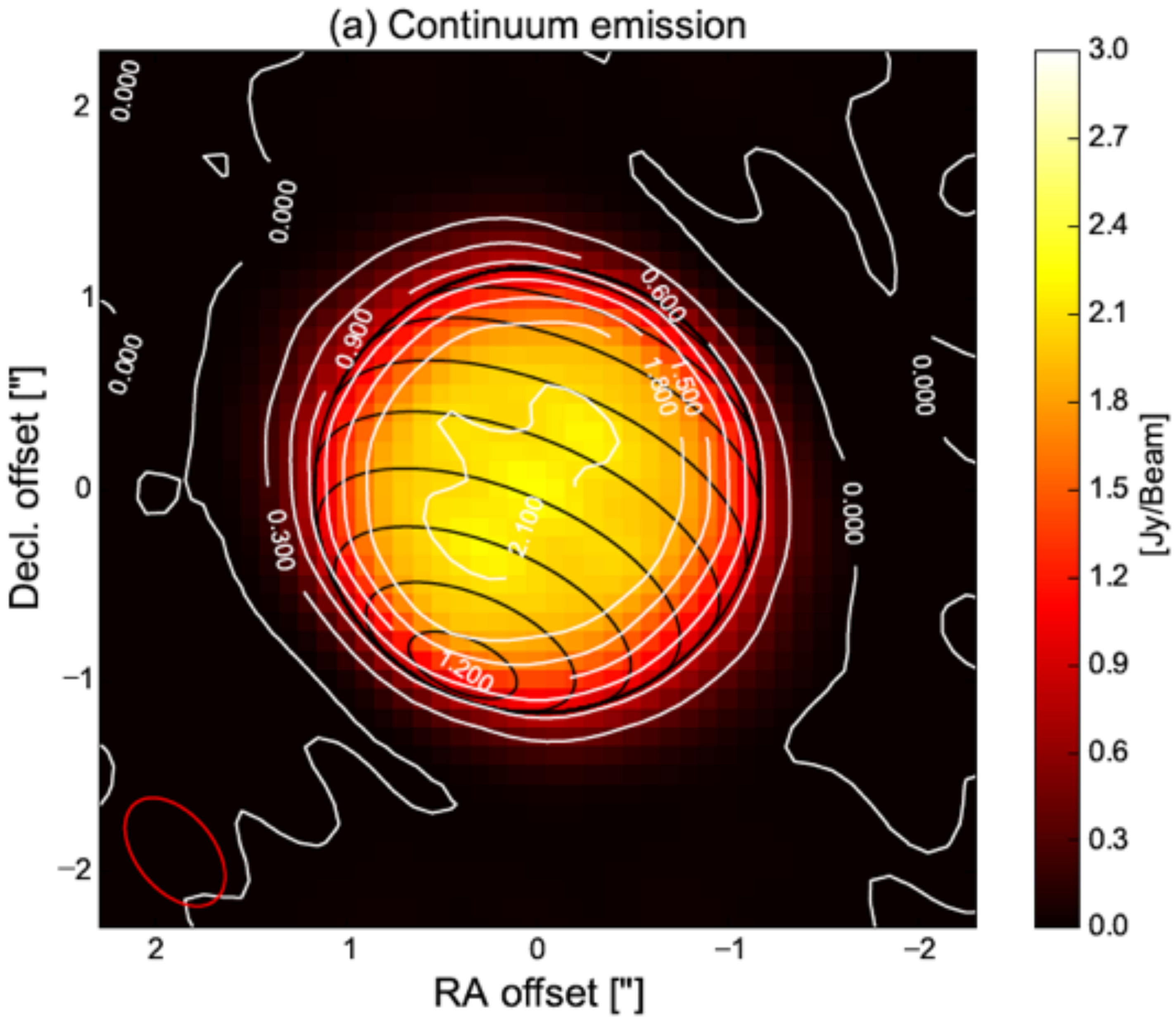


FIG. 3.—Spectra of Neptune at 8–13 μm. Observations of Neptune in 2002 (*yellow line*), 2003 (*red line*), and 2004 (*purple line*) are compared to data from 1991 (*green line*; Hammel et al. 1992) and 1985 (*blue line*; Orton et al. 1990, 1992). The 12.2 μm ethane emission brightened significantly from 1985 to 2003, returning to the 1991 level in 2004. The emission also changed shape during the past decade, indicating that another factor was operating in addition to temperature variations (temperature modifications scale only the amplitude of the emission). We see elevated methane emission near 8 μm in 2002–2004. The gray areas were used by Hammel et al. (1992) to calculate ethane/methane abundance ratios.

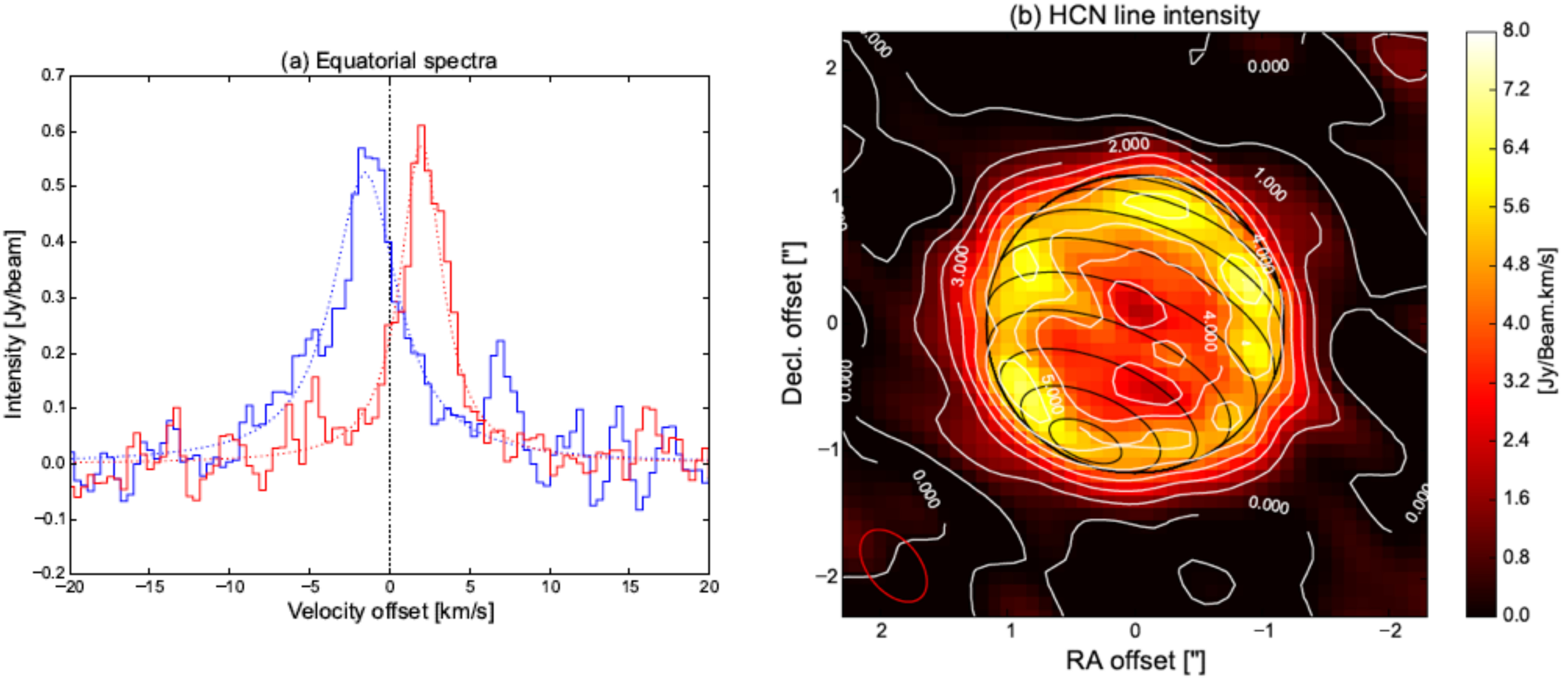
Hammel+ 2006

ALMAでの海王星HCN観測



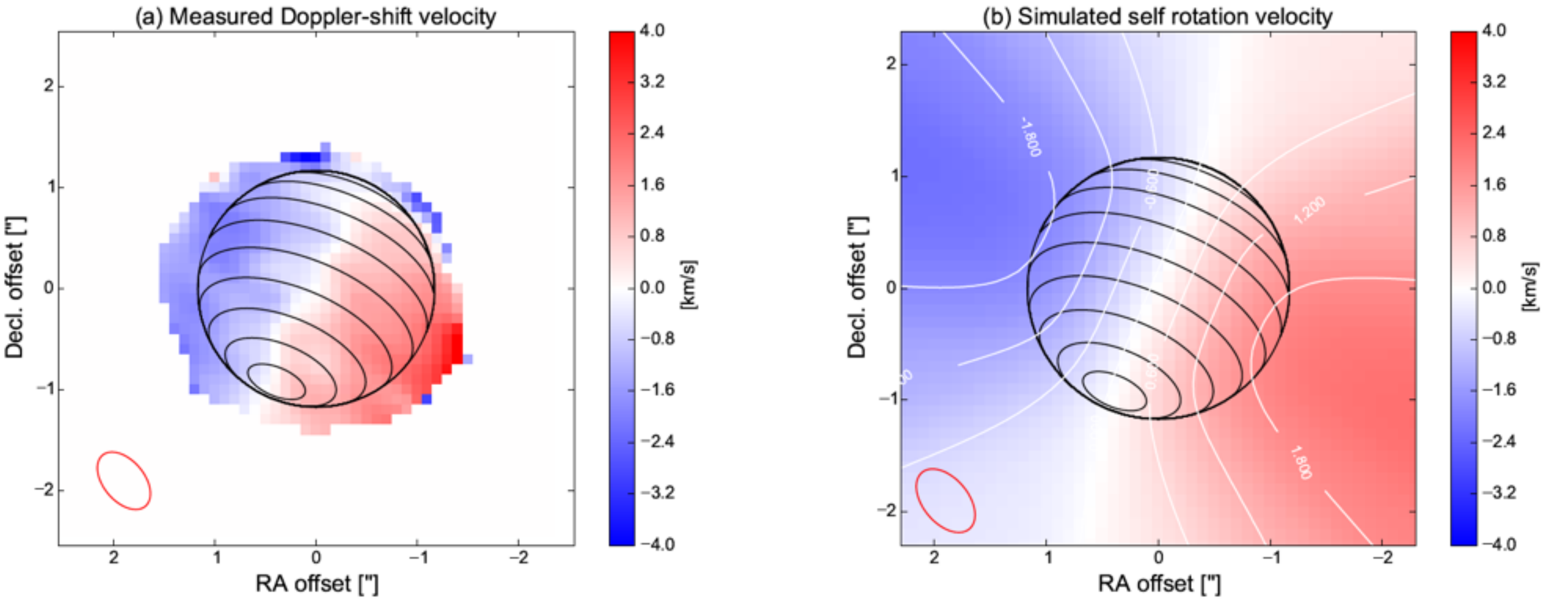
354GHz continuum, Iino+ 2016, Submitted to ApJL

ALMAでの海王星HCN観測



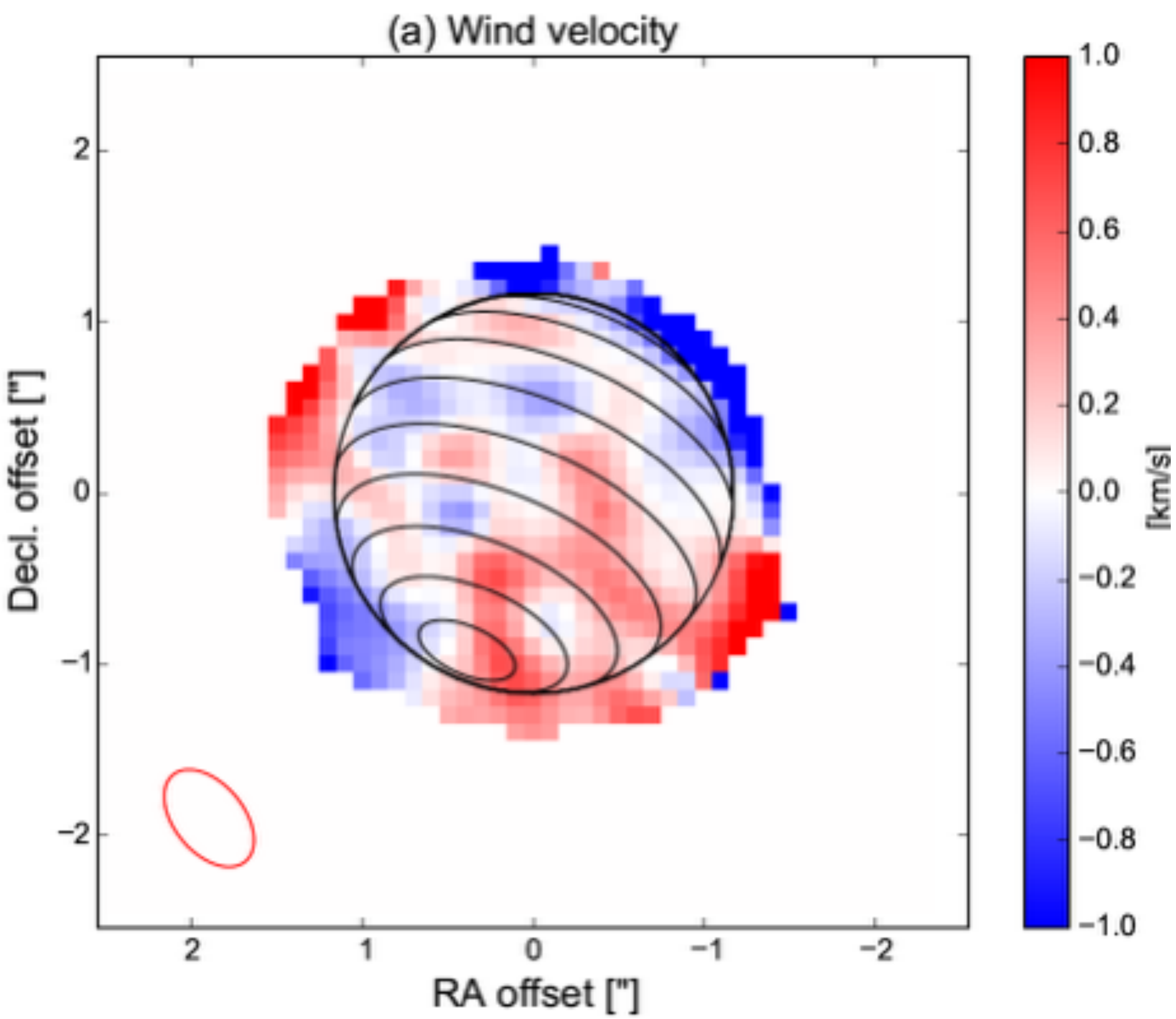
Iino+ 2016, Submitted to ApJL

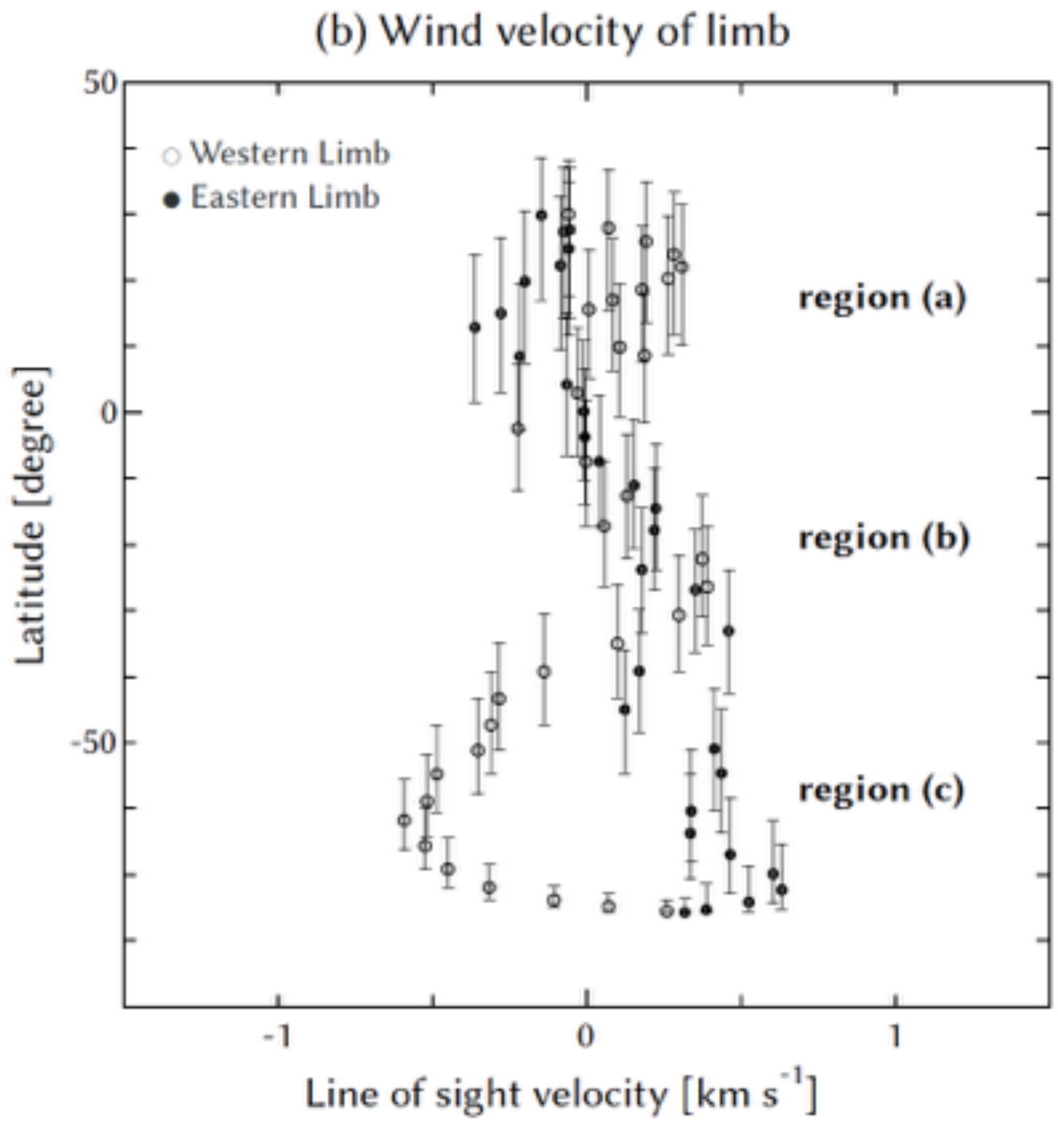
ALMAでの海王星HCN観測



Iino+ 2016c, Submitted to ApJL

海王星成層圏ダイナミクスの初検出





Iino+ 2016c, Submitted to ApJL

海王星MIR・サブミリ波モニタリング

1. 極域hot spotの時間変動は？
2. 分子群空間分布の時間変動は？

   (Hydrocarbon, H_2O?, HCN)

大気組成・同位体は？

1. N-bandより長波長での有機分子・H_2Oの観測可能性は?
   Hydrocarbon radical, Isotopes,,,
2. 高分散でのD/H, $^{18}O/O$…

まとめ

1.MIR/sub-mmでの分子・連続波イメージング＋モニタリング

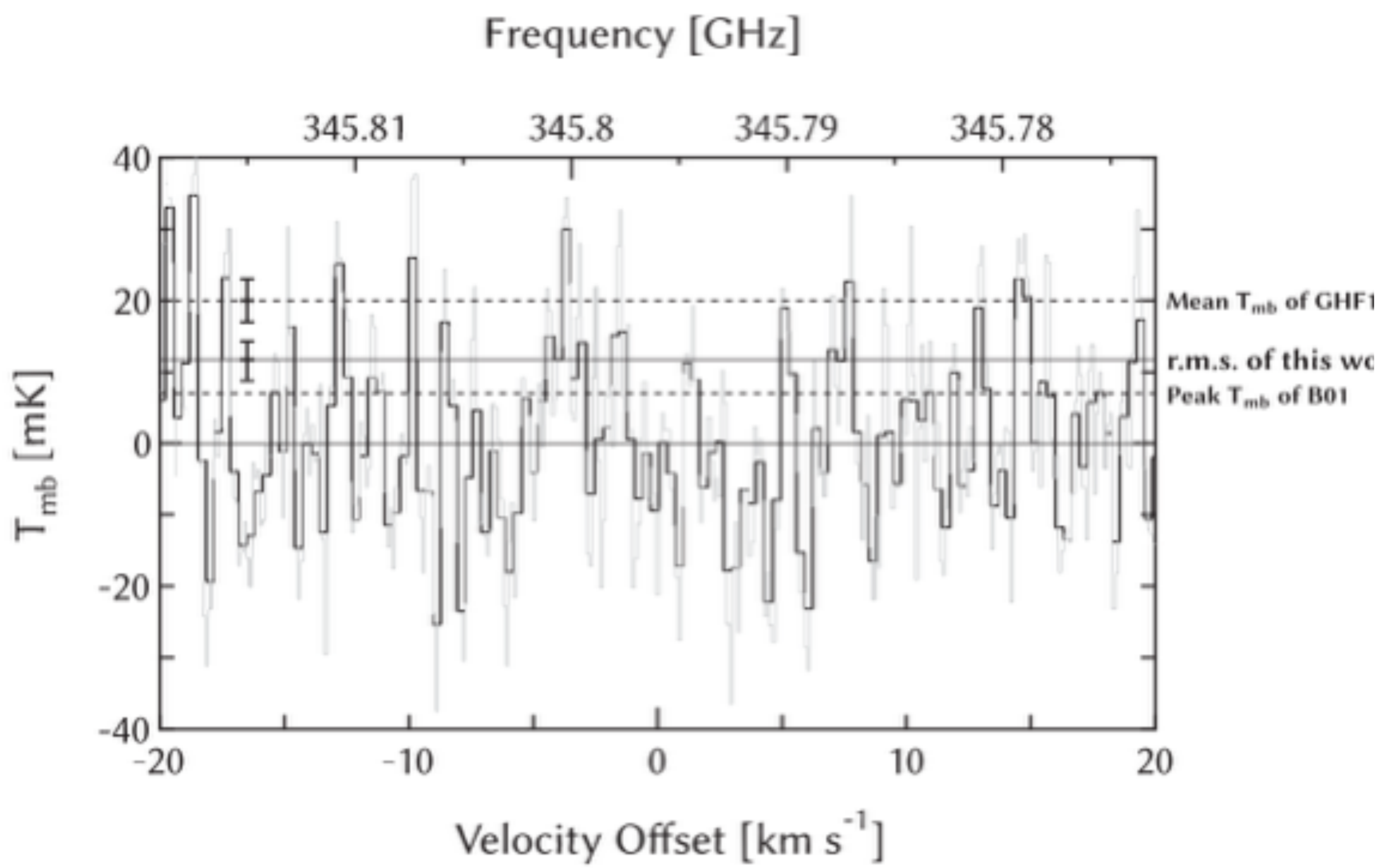
->成層圏揮発性分子群の起源を押さえる

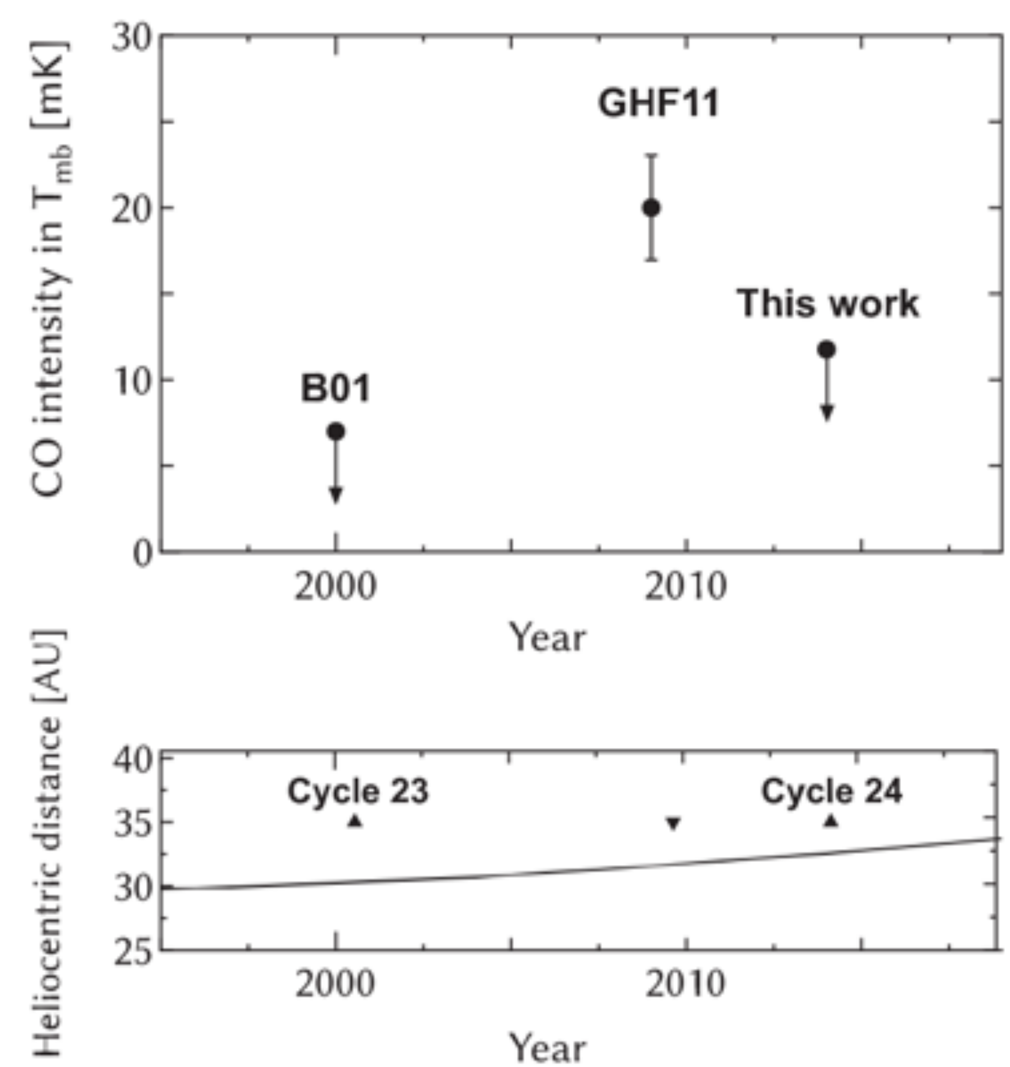
2.（できれば）高分散分光で新分子探索(含同位体)

My previous research 3:
Time-variation of CO on Pluto

Aim:
Confirmation of the presence of abundant CO on Pluto discovered with JCMT in 2009 (CO J=2-1)

Method：
A new and more sensitive observation of CO(J=3-2) with ASTE in 2014





Results:
The time variation of CO was found
-> does not relate to solar activity and heliocentric distance
(Iino et al. 2016, PASJ)