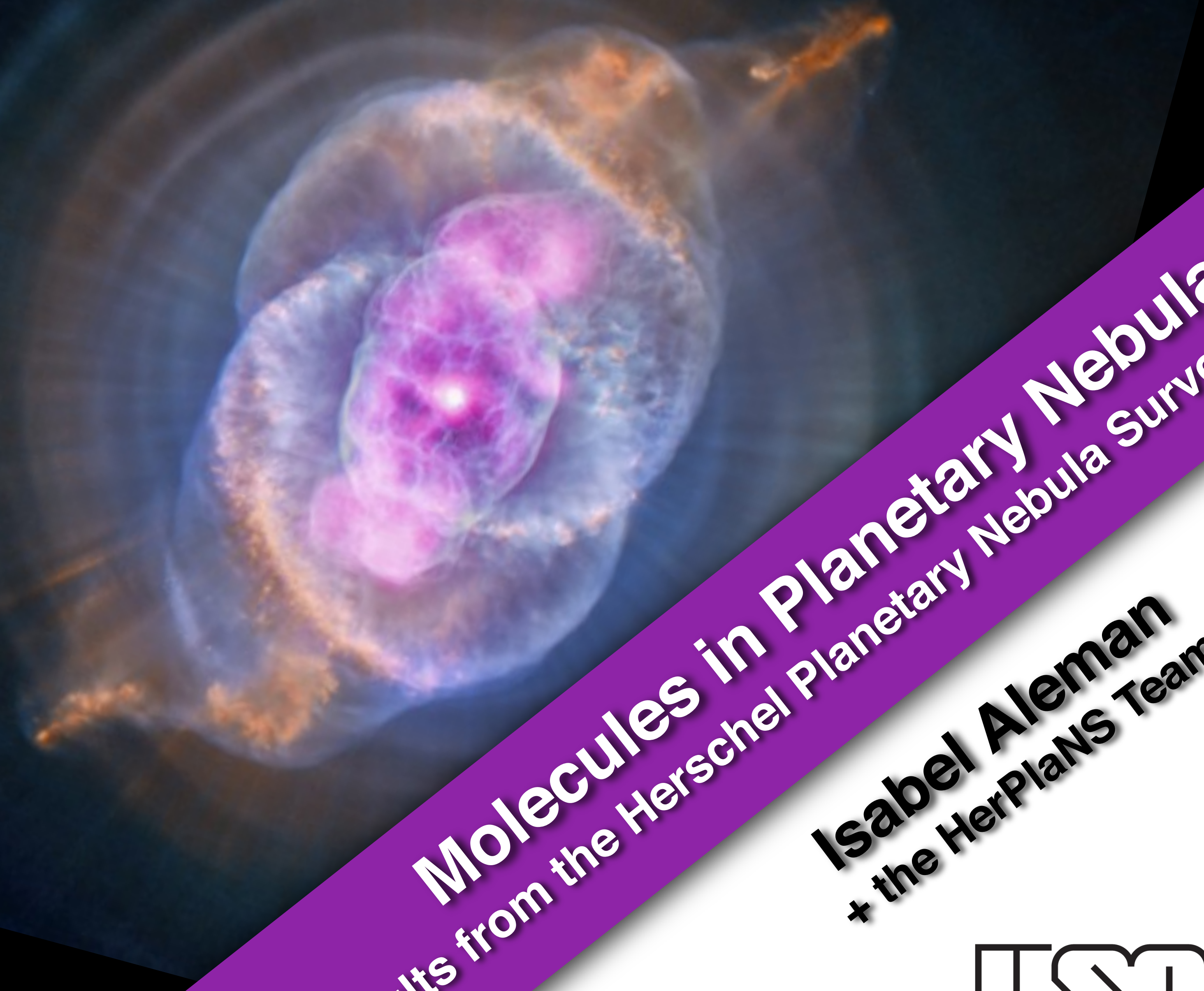


Molecules in Planetary Nebulae

Results from the Herschel Planetary Nebula Survey (HerPlaNS)

Isabel Aleman

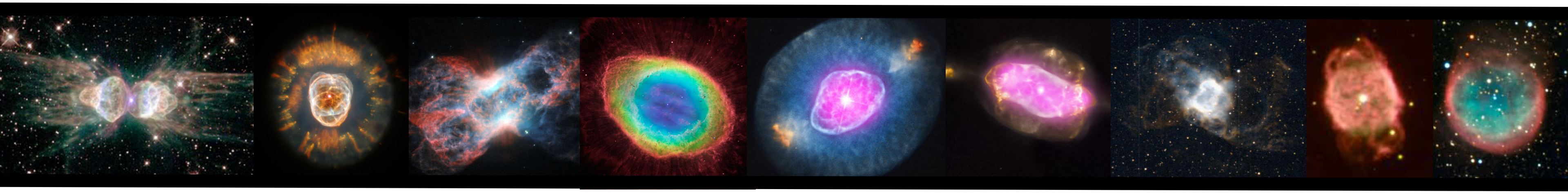
+ the HerPlaNS Team

UNIVERSIDADE DE SÃO PAULO

Universiteit Leiden

In this presentation...

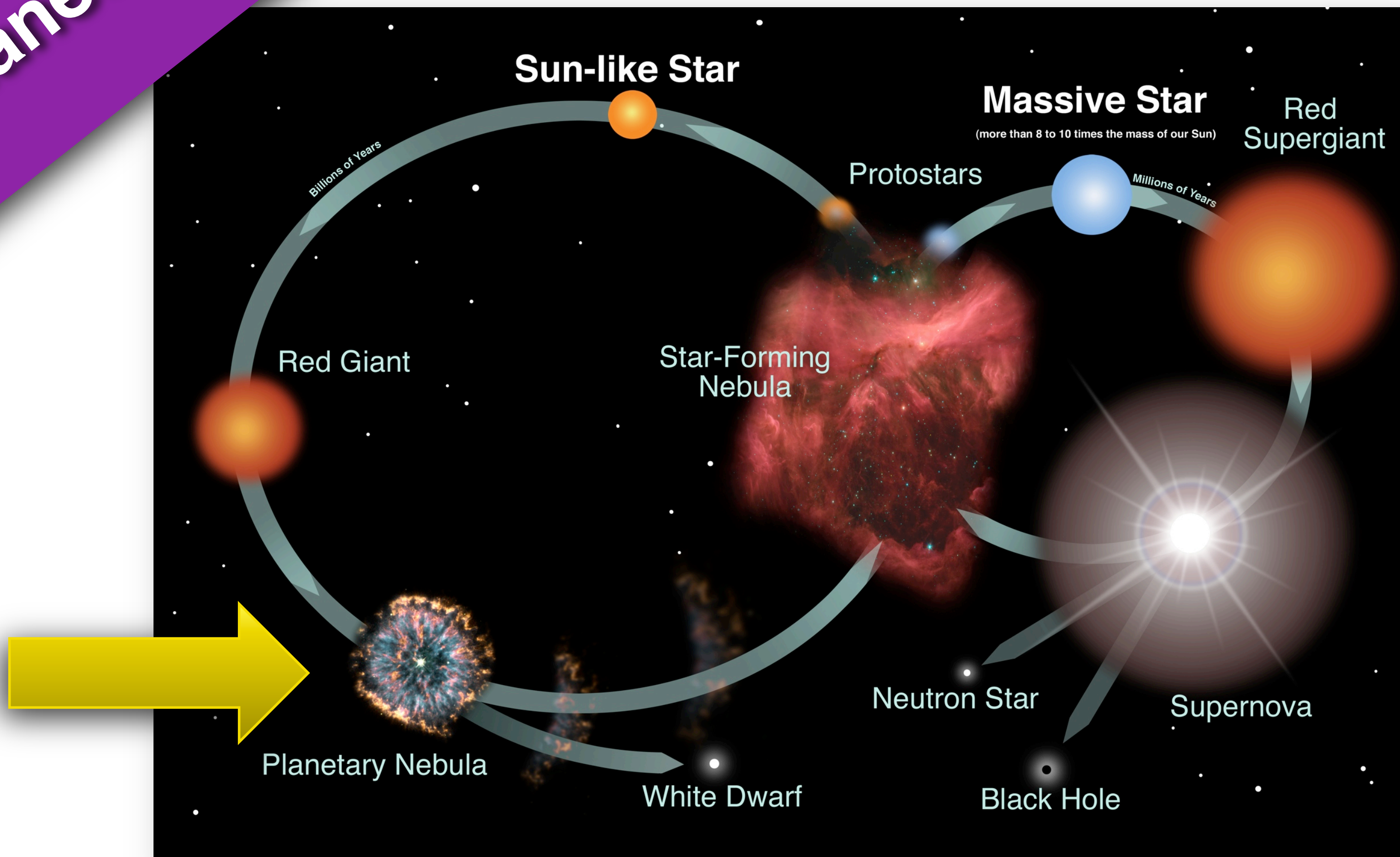
- ✓ First detection of OH^+ in Planetary Nebulae (PNe) with Herschel
- ✓ Characteristics of the emission
- ✓ Detection of OH, CH^+ and CO
- ✓ Possible influence of X-rays in the chemistry of PNe
- ✓ Planetary Nebulae (PNe) can be interesting Astrochemistry “Laboratories” for Hydrides



Why Planetary Nebulae?

PNe are the ionized ejecta of old low- to intermediate-mass stars

PNe are an important part of the cycle of matter in galaxies – “pollute” the ISM!

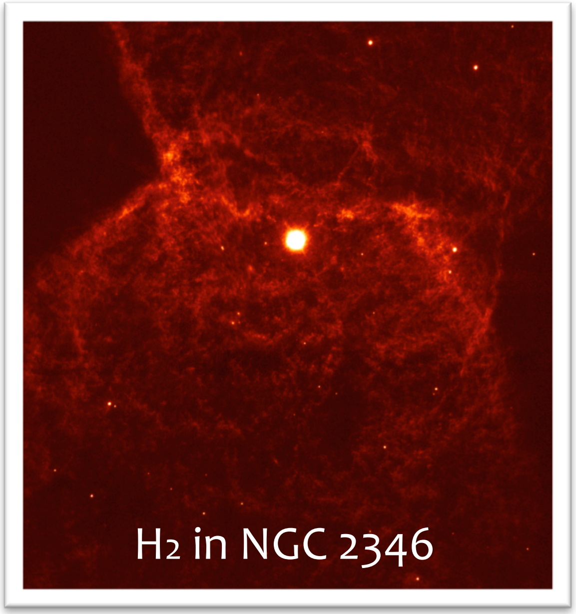


Credit: NASA and the Night Sky Network

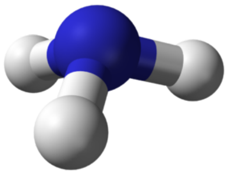
Why Planetary Nebulae?

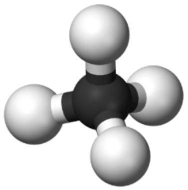
- ✓ Good ‘laboratories’ to test the chemistry in strong radiation fields
  - ✓ relatively simple systems
  - ✓ spatially resolved

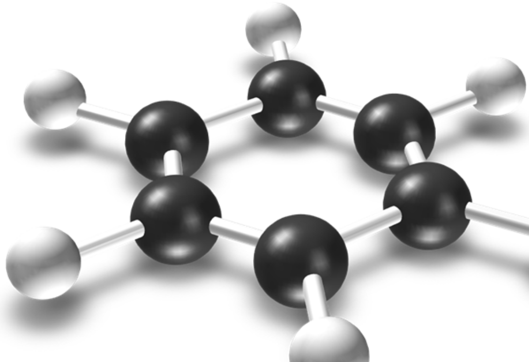
- ✓ Several molecules already detected in PNe



H_2 in NGC 2346





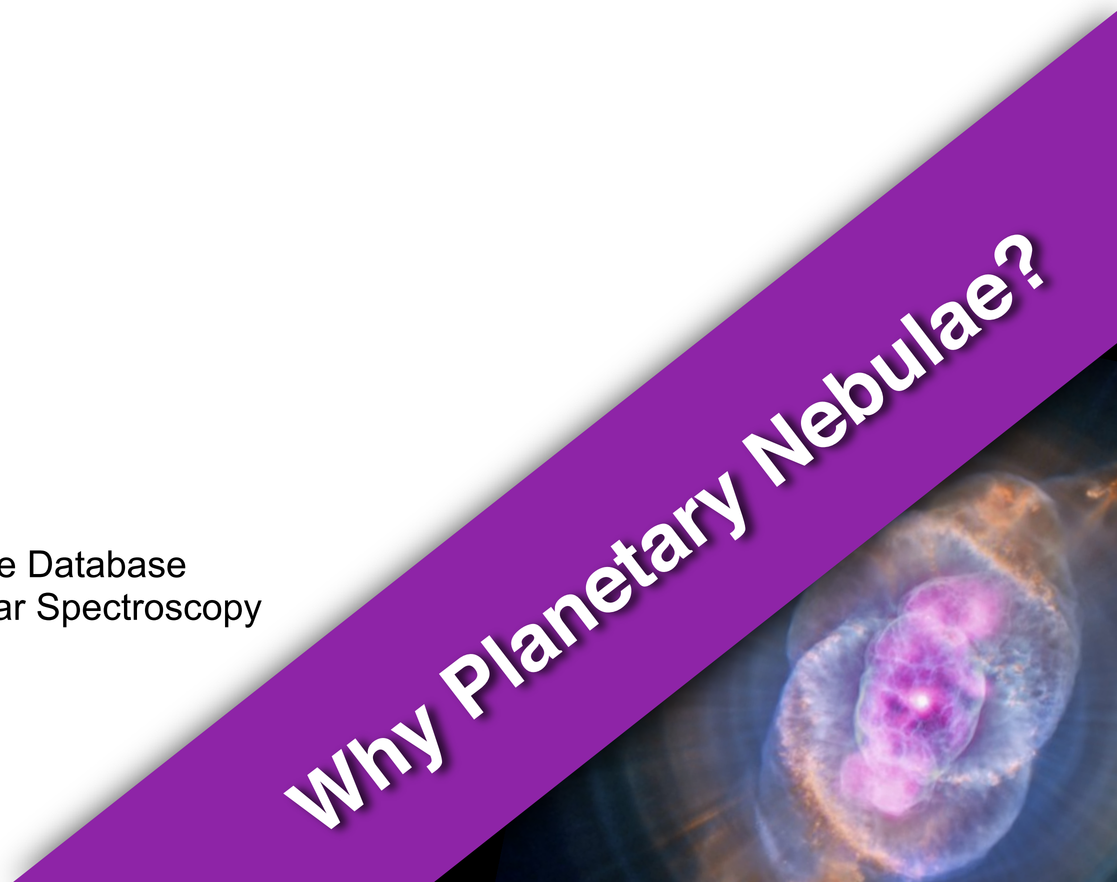


Molecules Detected in the Interstellar and Circumstellar Medium (PNe in Blue)

2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	9 atoms	10 atoms	11 atoms	12 atoms	>12 atoms
H2	C3	c-C3H	C5	C5H	C6H	CH3C3N	CH3C4H	CH3C5N	HC9N	c-C6H6	HC11N
AlF	**C2H**	l-C3H	C4H	l-H2C4	CH2CHCN	HC(O)OCH3	CH3CH2CN	(CH3)2CO	CH3C6H	n-C3H7CN	**C60**
AlCl	C2O	C3N	C4Si	C2H4	CH3C2H	CH3COOH	(CH3)2O	(CH2OH)2	C2H5OCHO	i-C3H7CN	**C70**
C2	C2S	C3O	l-C3H2	CH3CN	HC5N	C7H	CH3CH2OH	CH3CH2CHO	CH3OC(O)CH3		C60+
CH	CH2	C3S	**c-C3H2**	CH3NC	CH3CHO	C6H2	**HC7N**				
CH+	**HCN**	C2H2	H2CCN	**CH3OH**	CH3NH2	CH2OHCHO	C8H				
CN	HCO	**NH3**	CH4	CH3SH	c-C2H4O	l-HC6H	CH3C(O)NH2				
CO	**HCO+**	HCCN	**HC3N**	HC3NH+	H2CCHOH	CH2CCHCN	C8H–				
CO+	HCS+	HCNH+	HC2NC	HC2CHO	C6H–	H2NCH2CN	C3H6				
CP	HOC+	HNCO	HCOOH	NH2CHO	CH3NCO	CH3CHNH					
SiC	**H2O**	HNCS	H2CNH	C5N							
HCl	H2S	HOCO+	H2C2O	l-HC4H							
KCl	**HNC**	**H2CO**	H2NCN	l-HC4N							
NH	HNO	H2CN	HNC3	c-H2C3O							
NO	MgCN	H2CS	SiH4	C5N–							
NS	MgNC	H3O+	H2COH+	HNCHCN							
NaCl	**N2H+**	c-SiC3	C4H–								
OH	N2O	CH3	HC(O)CN								
PN	NaCN	C3N–	HNCNH								
SO	OCS	PH3	CH3O								
SO+	**SO2**	HCNO	NH4+								
SiN	**c-SiC2**	HOCN	NCCNH+								
SiO	CO2	HSCN									
SiS	NH2	H2O2									
CS	H3+	C3H+									
HF	SiCN	HMgNC									
HD	AlNC	HCCO									
O2	SiNC										
CF+	HCP										
PO	CCP										
AlO	AlOH										
OH+	H2O+										
CN–	H2Cl+										
SH+	KCN										
SH	FeCN										
HCl+	HO2										
TiO	TiO2										
ArH+	C2N										
	Si2C										

+ PAHs...

Source: The Cologne Database
for Molecular Spectroscopy



HerPlaNS:
Herschel Planetary Nebula Survey

Open time
PI: Toshiya Ueta (Denver U.)

11 Planetary Nebulae (PNe)

Close → Distance < 1.5 kpc

- ✧ **Spatially resolved by PACS**

Well known

- ✧ **Observed other wavelengths**
- ✧ **Many previous studies**

PACS + SPIRE
Spectra + Photometry

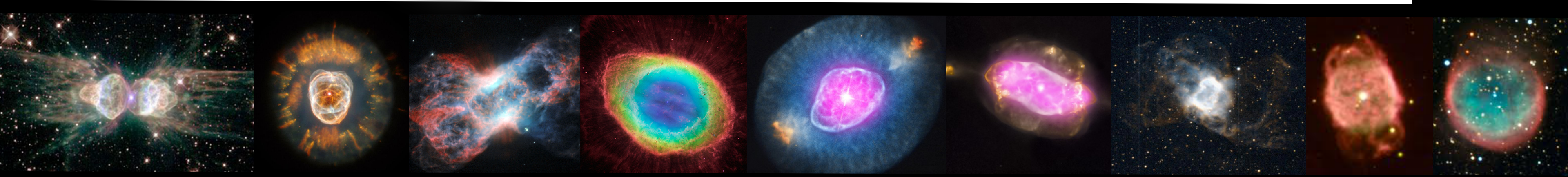
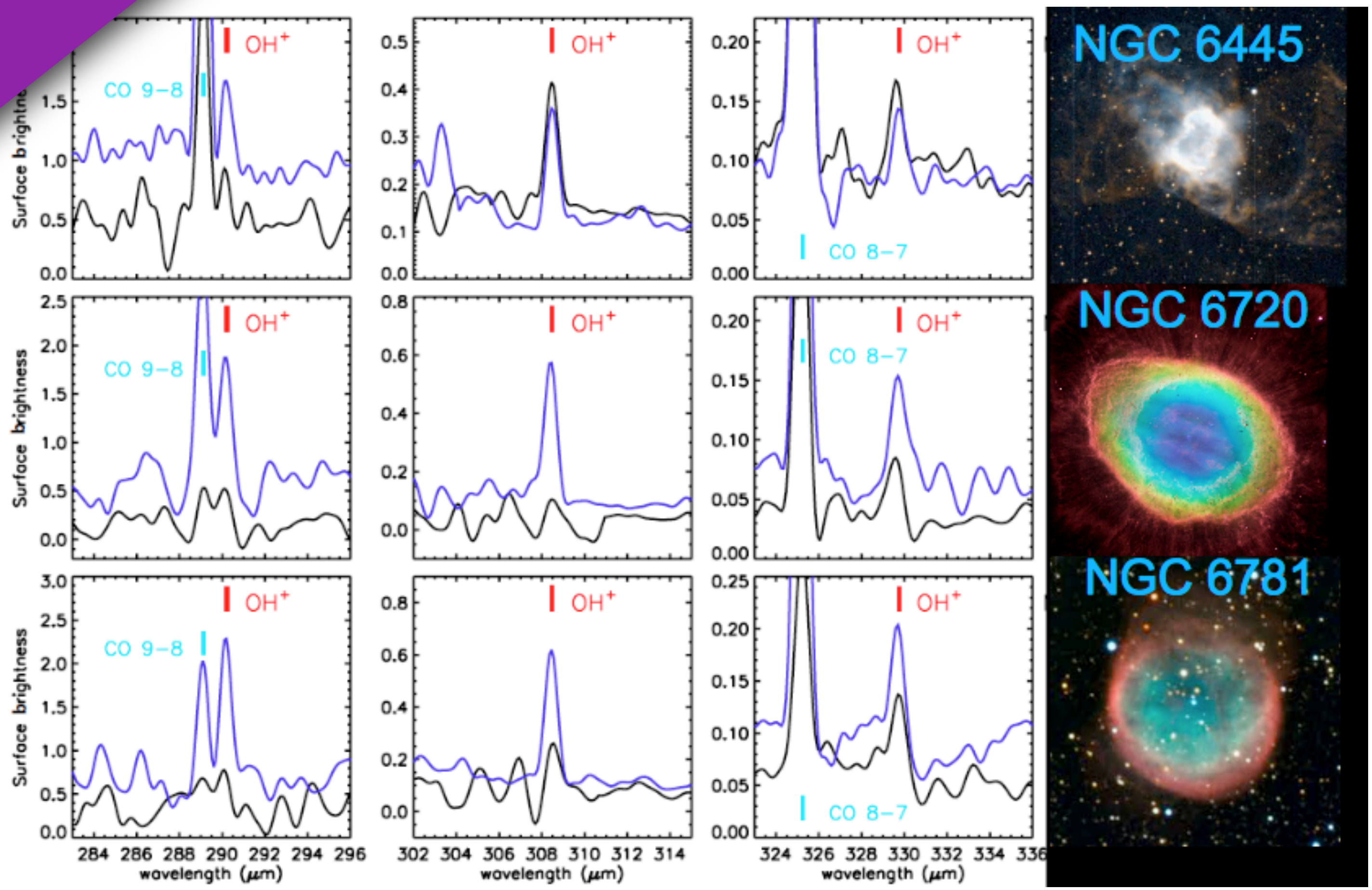


Image Credits: HST, Chandra, AAT, Herschel, ESA

First Detection of OH^+ in PNe

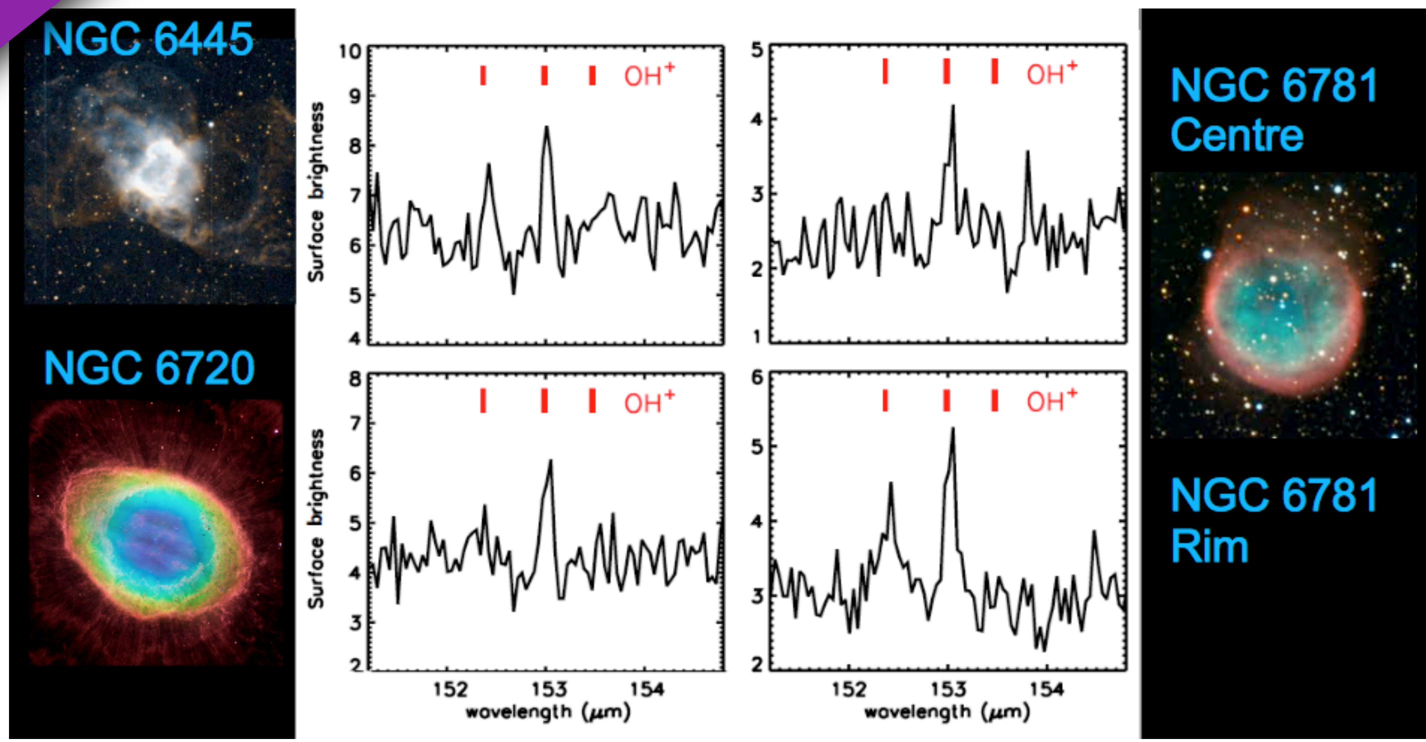
OH^+ Detection - SPIRE



Aleman et al. (2014), Etxaluze et al. (2014)

First Detection of OH^+ in PNe

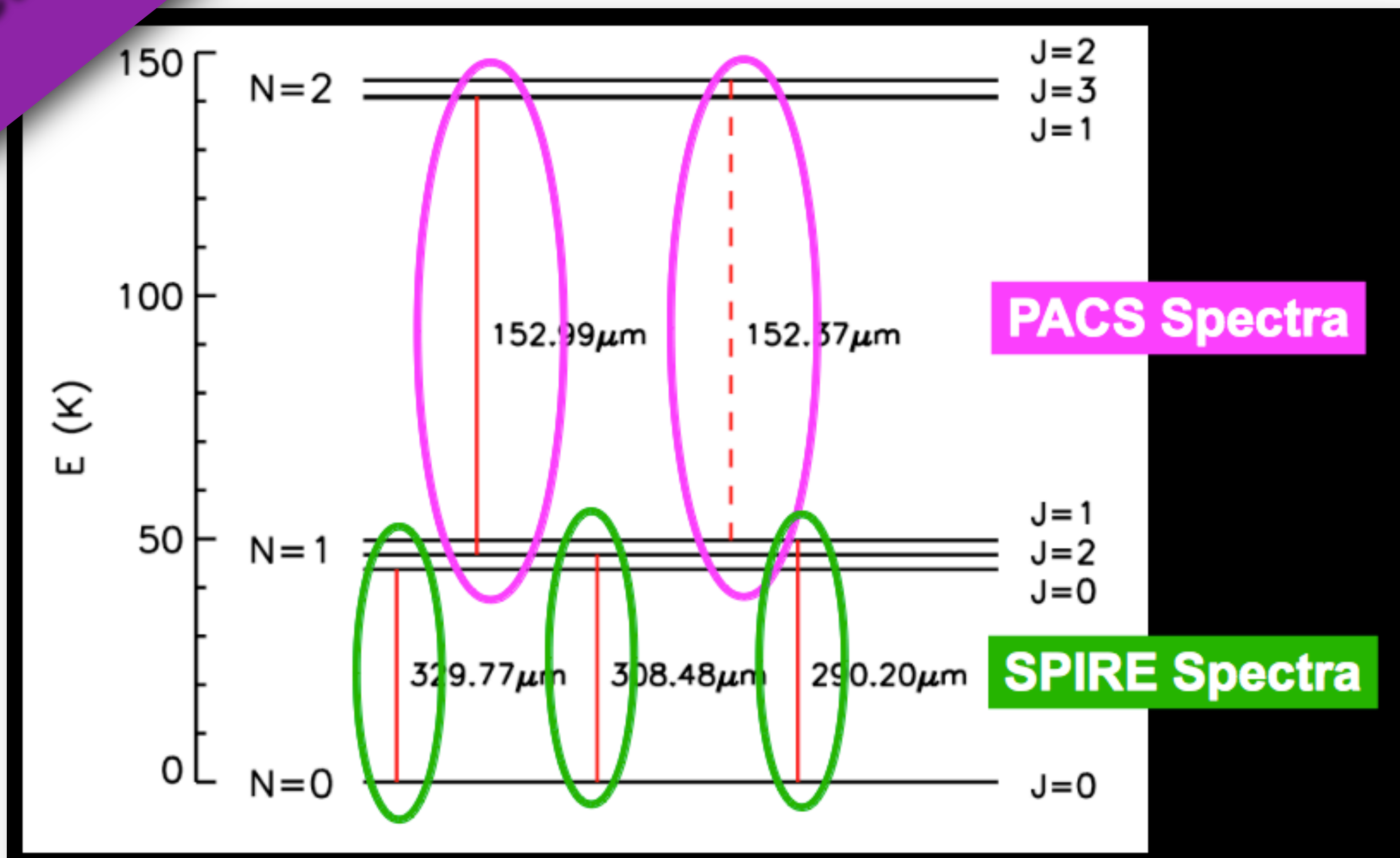
OH^+ Detection – PACS



Aleman et al. (2014), Etxaluze et al. (2014)

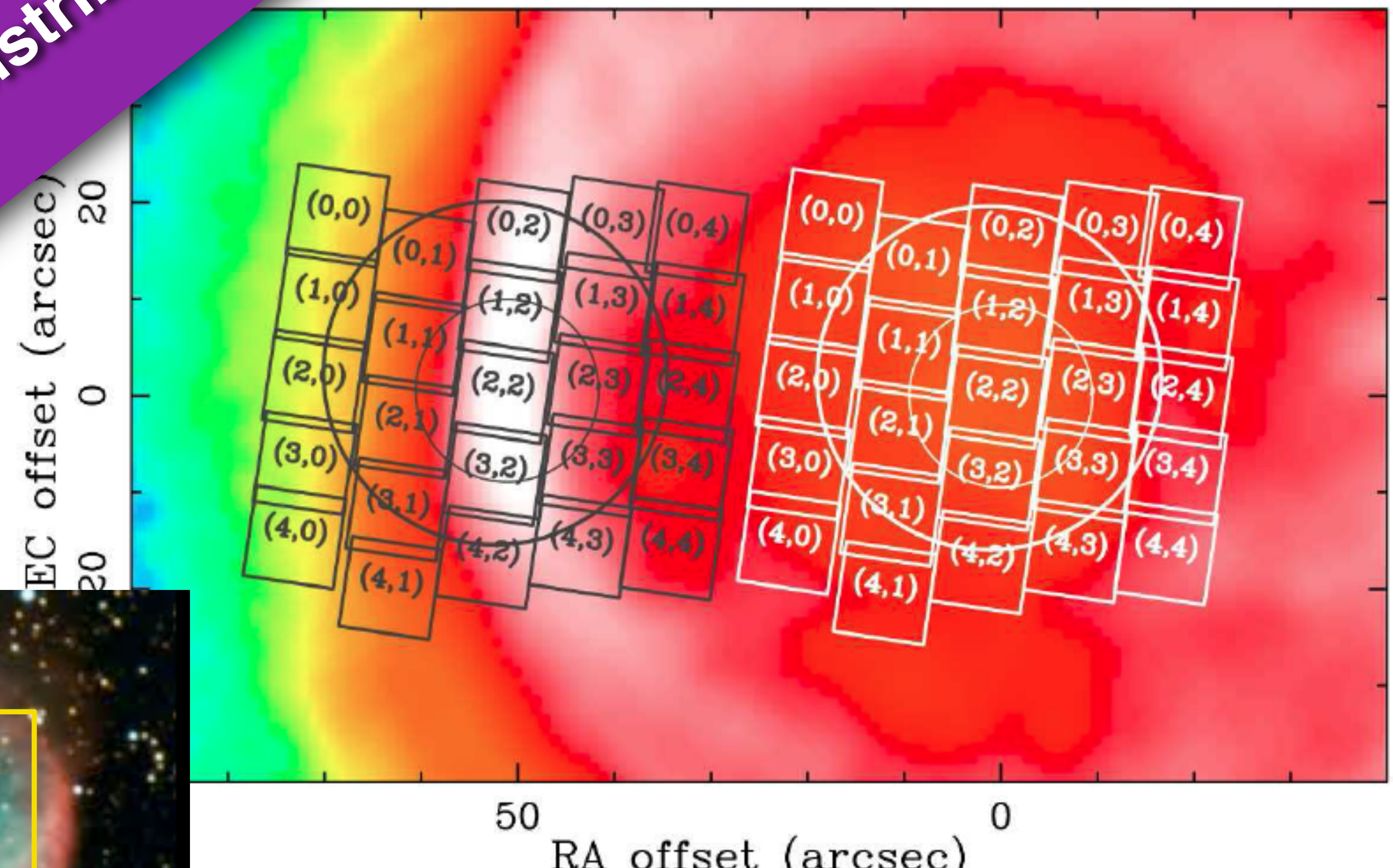
First Detection of OH^+ in PNe

OH^+ Rotational Level



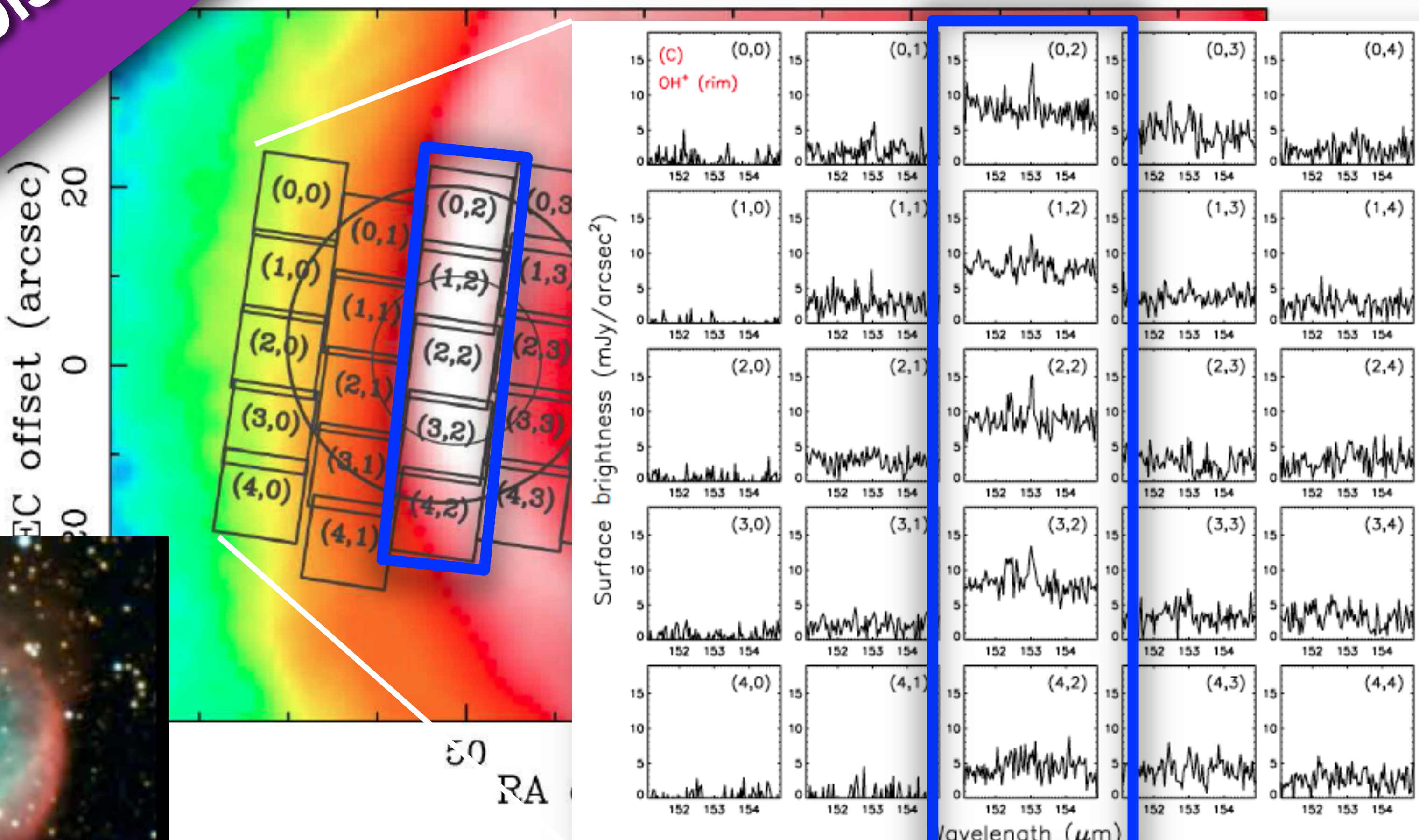
Spatial Distribution of OH^+

Aleman et al. (2014)



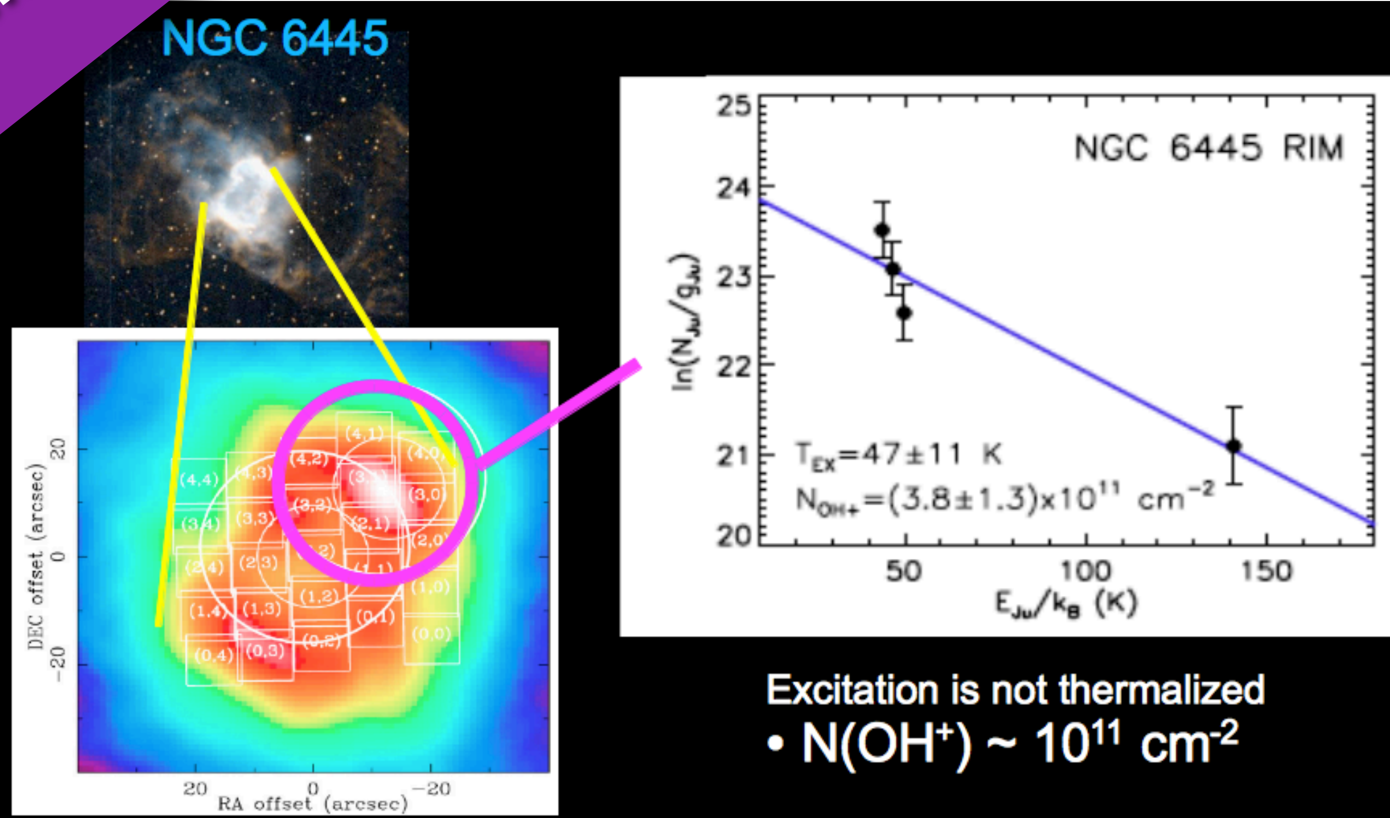
Spatial Distribution of OH^+

PDR, $\chi \sim 2\text{-}10$, $n \sim 10^4\ cm^{-3}$



Aleman et al. (2014)

Excitation and Column Densities



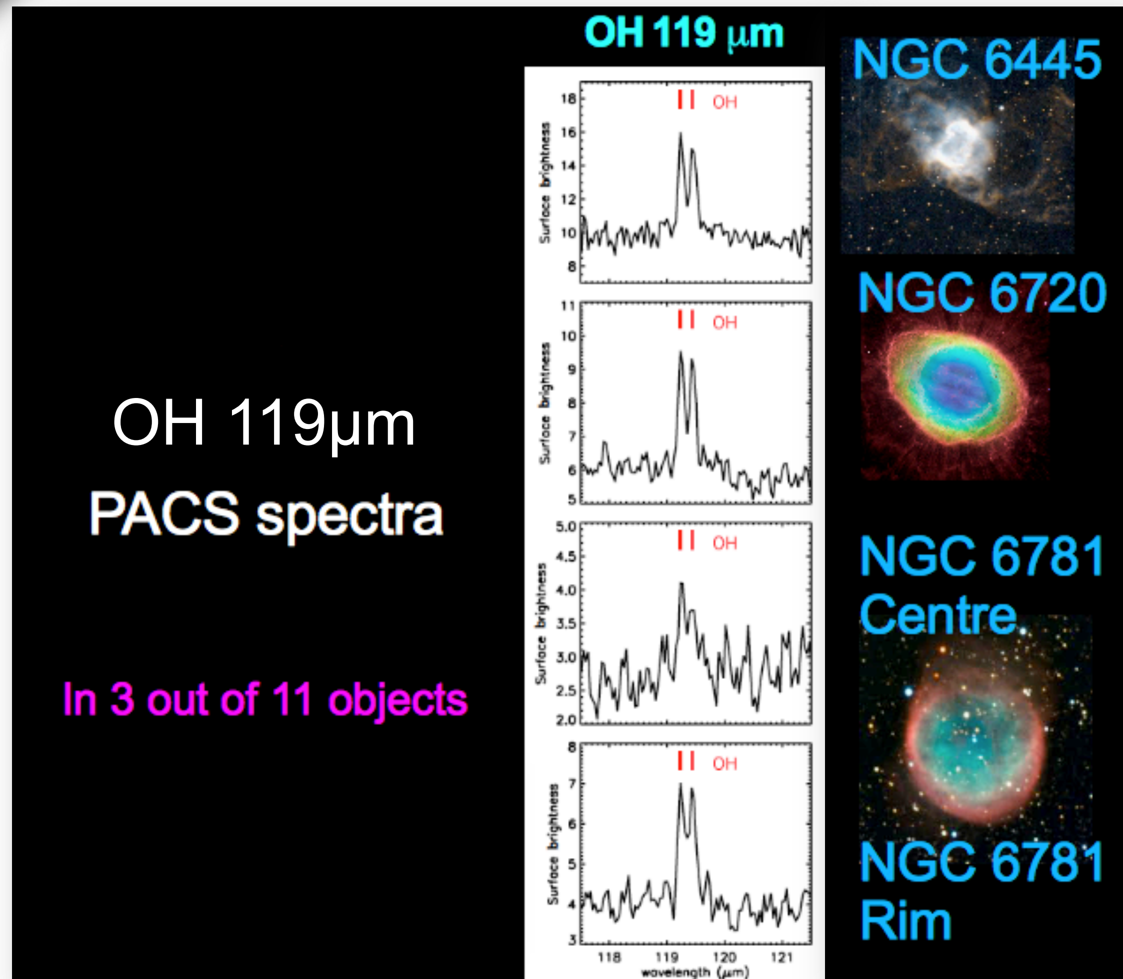
Excitation is not thermalized

- $N(OH^+) \sim 10^{11}$ cm^{-2}

Aleman et al. (2014)

More Molecules: OH

OH Detection - PACS

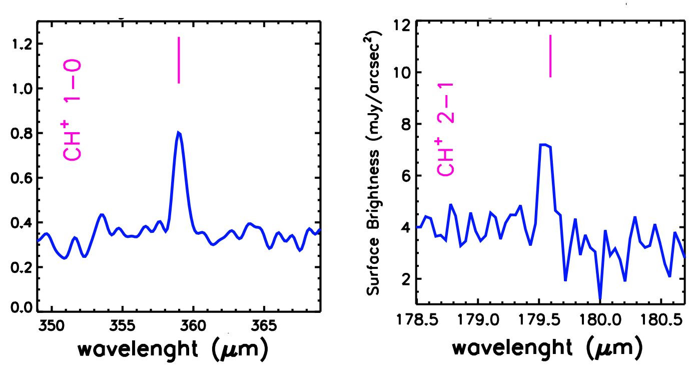


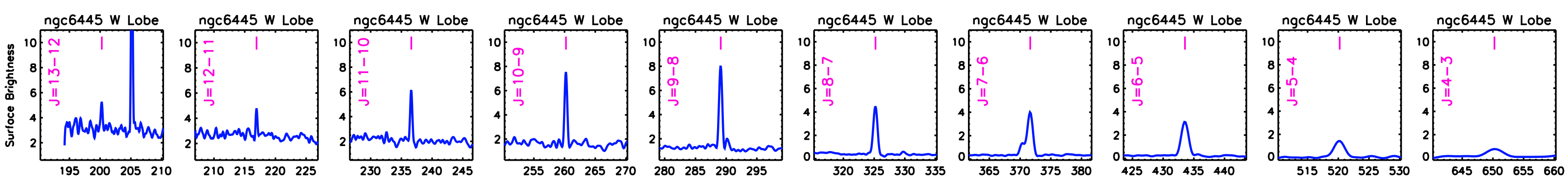
Aleman et al. (2014)

More Molecules: CH^+ and CO

CO and CH^+ detected in the same PNe we see OH and OH^+

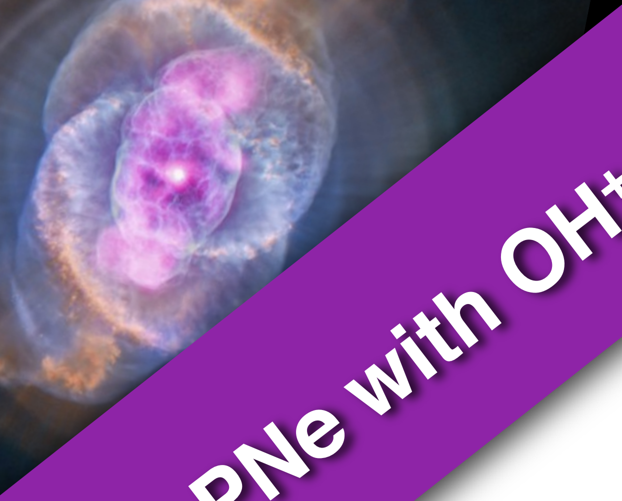
Ex: NGC 6445



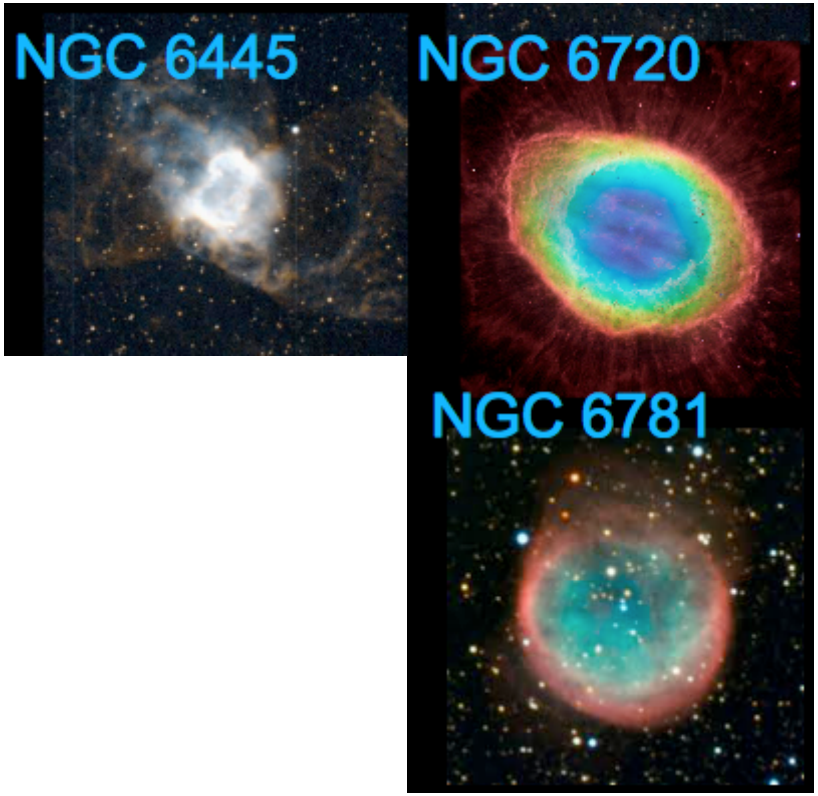


Aleman et al. (2016, in preparation)

PNe with OH^+



OH^+ Detections



HerPlaNS
Aleman et al. (2014)

Non Detections

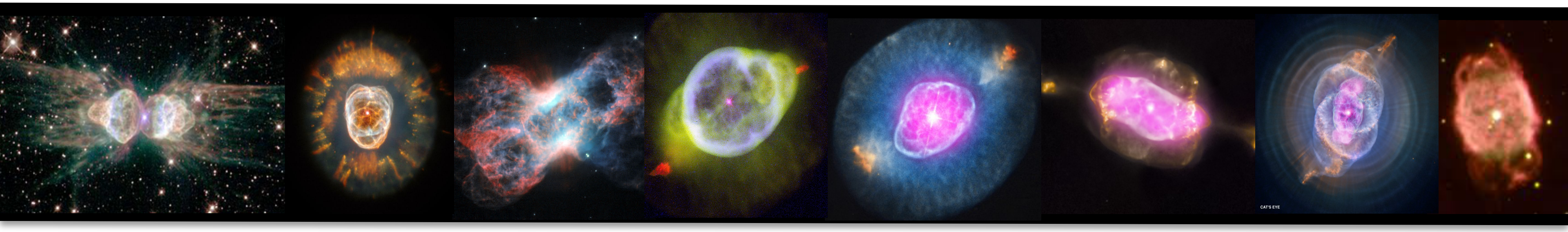
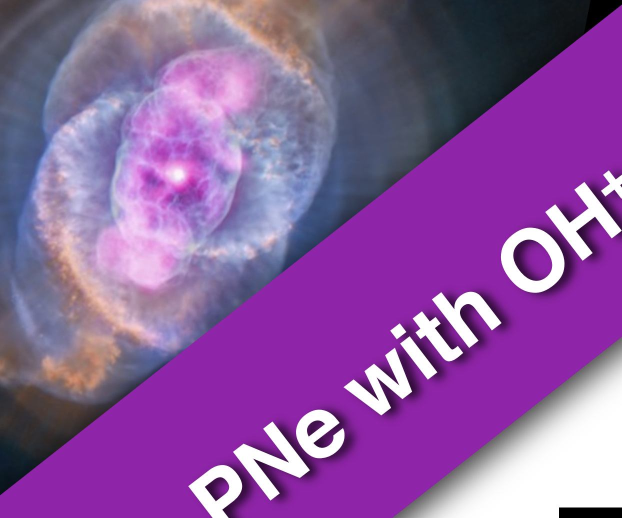
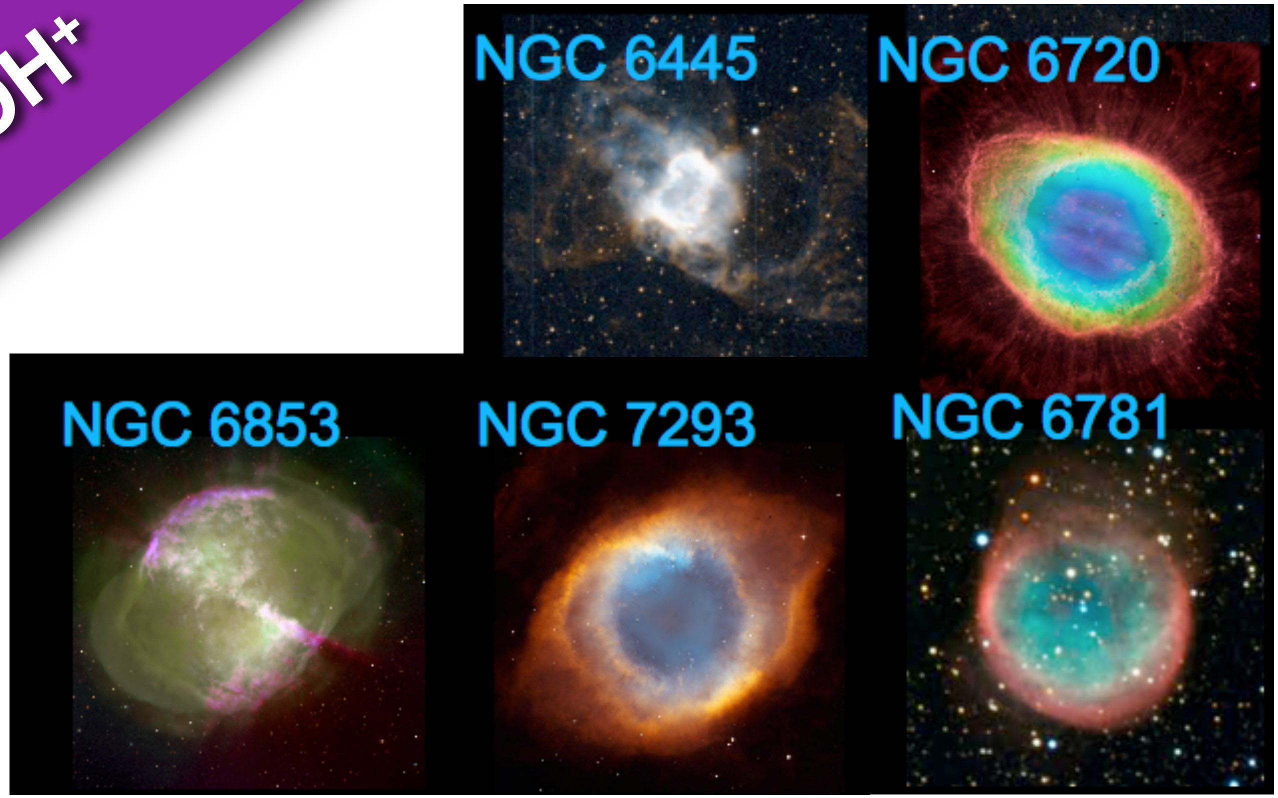


Image Credits: HST, Chandra, AAT, Herschel, ESA

PNe with OH^+



OH^+ Detections



HerPlaNS + MESS Sample
Aleman et al. (2014) + Etxaluze et al. (2014)

Non Detections

Image Credits: HST, Chandra, AAT, Herschel, ESA

Con

Observations

HerPlaNS + MESS:
→ 5 out of 14 molecule-rich

PN	T* (10^3 K)	X-Rays	C / O	H_2	PAHs	OH^+	OH	CH^+	CO	CO Lit
NGC 7027	175	D	2.29	Y	Y	N	N	Y	Y	Y
NGC 6445	**170**	**P**	**0.45**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
NGC 6720	**148**	**No Det.**	**0.62**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
NGC 6853	**135**	**P**	**--**	**Y**	**N**	**Y**	**--**	**--**	**--**	**Y**
NGC 6781	**112**	**No Det.**	**1.0**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
NGC 7293	**110**	**P**	**0.87**	**Y**	**N**	**Y**	**--**	**--**	**Y**	**Y**
Mz 3	30-107	D,P	0.83	N	N	N	N	N	N	Y
NGC 3242	89	D	--	N	N	N	N	N	N	N
NGC 7009	87	D,P	0.32	N	N	N	N	N	N	N
NGC 7026	83	D,P?	--	Y	Y	N	N	N	N	N
NGC 6826	50	D,P	0.87	N	N	N	N	N	N	N
NGC 40	48	D	1.41	Y	Y	N	N	N	N	N
NGC 6543	48	D,P	0.44	N	N	N	N	N	N	N
NGC 2392	47	D,P	1.14	Y	N	N	N	N	N	N

Aleman et al. (2016, in preparation)

Con Observations

HerPlaNS + MESS:
→ 5 out of 14 molecule-rich

PN	T* (10^3 K)	X-Rays	C / O	H_2	PAHs	OH^+	OH	CH^+	CO	CO Lit
NGC 7027	175	D	2.29	Y	Y	N	N	Y	Y	Y
NGC 6445	**170**	**P**	**0.45**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
NGC 6720										**Y**
NGC 6853										**Y**
NGC 6781										**Y**
NGC 7293										**Y**
Mz 3	3									Y
NGC 3242										N
NGC 7009										N
NGC 7026										N
NGC 6826										N
NGC 40										N
NGC 6543										N
NGC 2392	47	D,P	1.14	Y	N	N	N	N	N	N

Molecule-Rich PNe have:

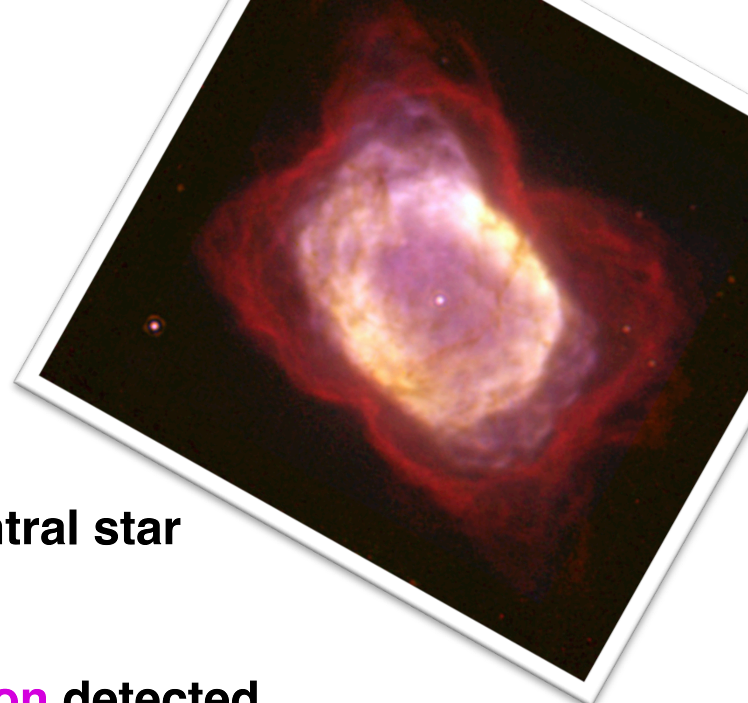
* Central Stars with High T_{eff}
(Some are soft X-rays point sources)

* No Diffuse X-Ray emission (hard X-rays)

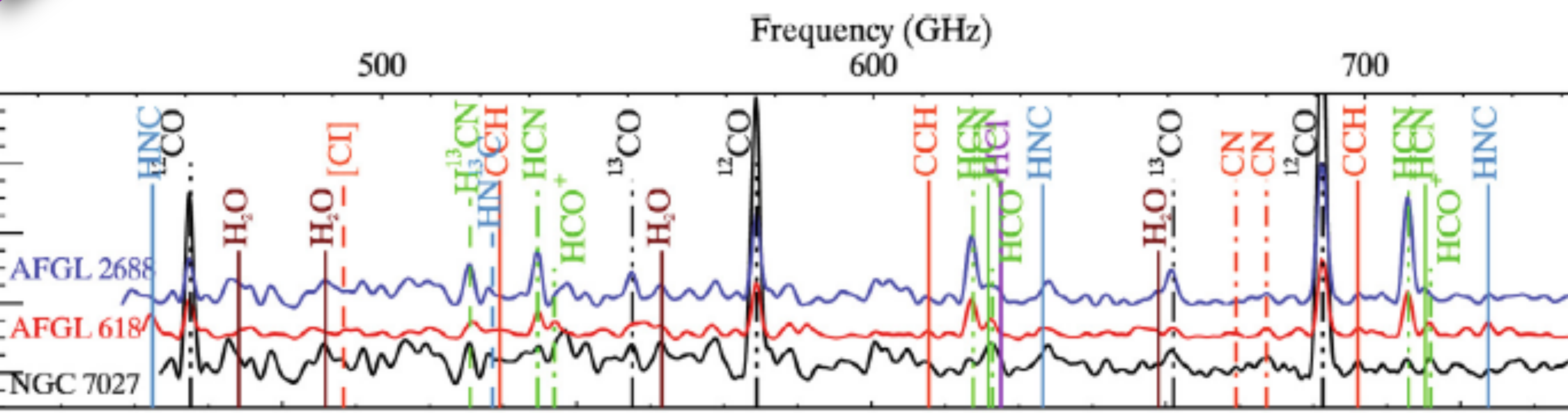
* C/O <~ 1

Aleman et al. (2016, in preparation)

Detection of OH^+



- ✓ NGC 7027 has a very hot central star
- ✓ But no OH^+ is detected
- ✓ C-rich: C/O ~ 3
- ✓ X-Ray: hard + diffuse emission detected (see Kastner et al. 2012)



Wesson et al. (2010)

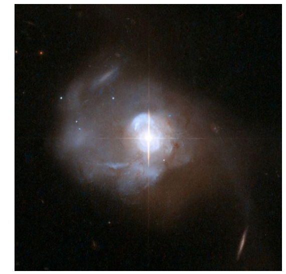
Constrains from Observations

Other objects with OH^+ emission

- **Active Galactic Nuclei**

  Mrk 231

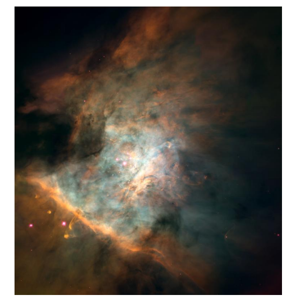
  (HIFI; van der Werf et al. 2010)



- **Orion Bar and Ridge**

  PDR prototype

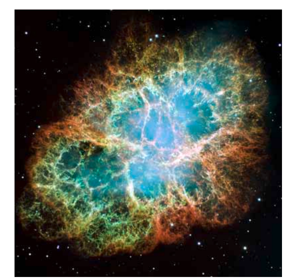
  (HIFI; van der Tak et al. 2013)



- **Crab Nebulae**

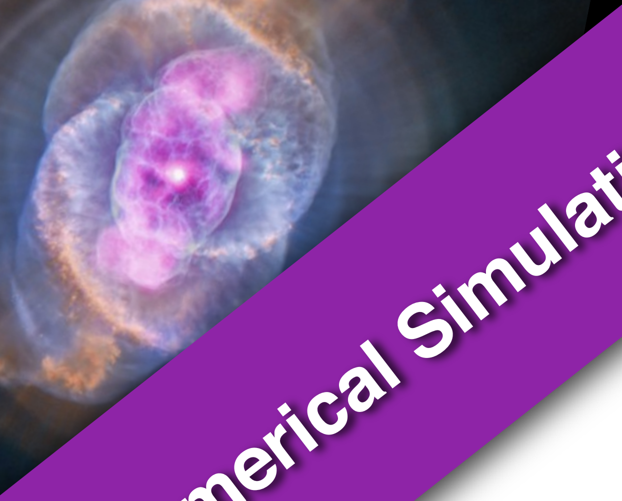
  Supernova Remnant

  (SPIRE; Barlow et al. 2013)



+ Absorption

ISM diffuse clouds

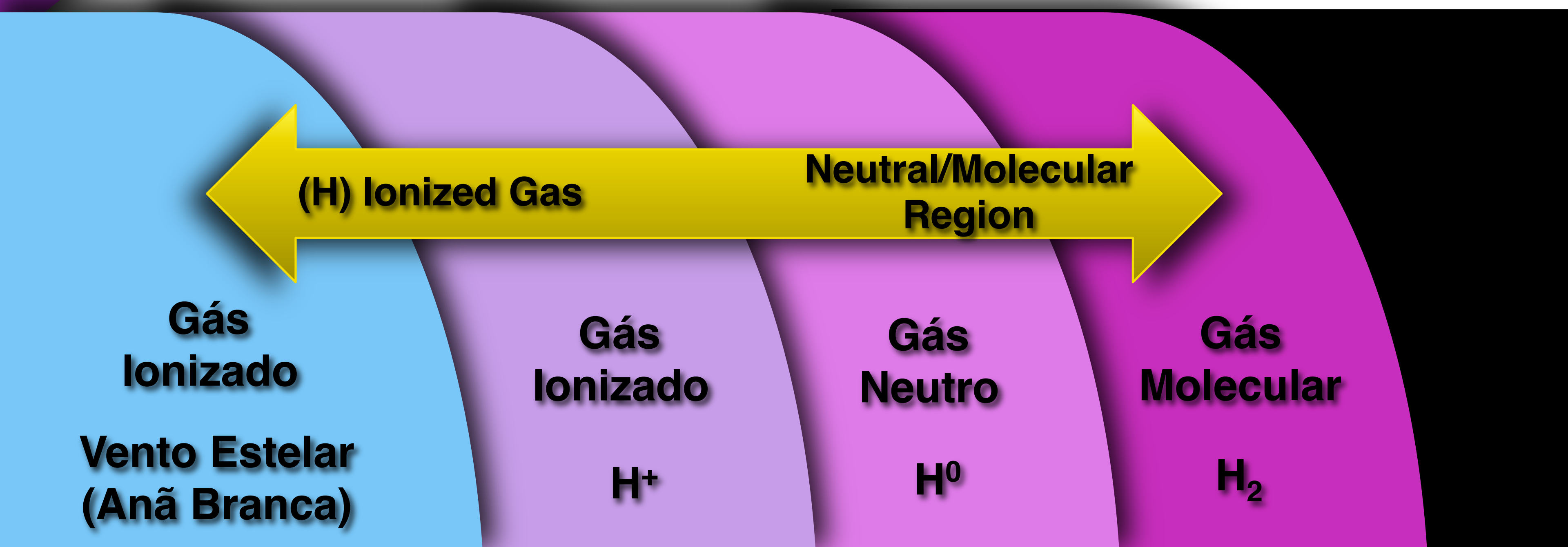


Numerical Simulations

- ✓ Next Step: Models

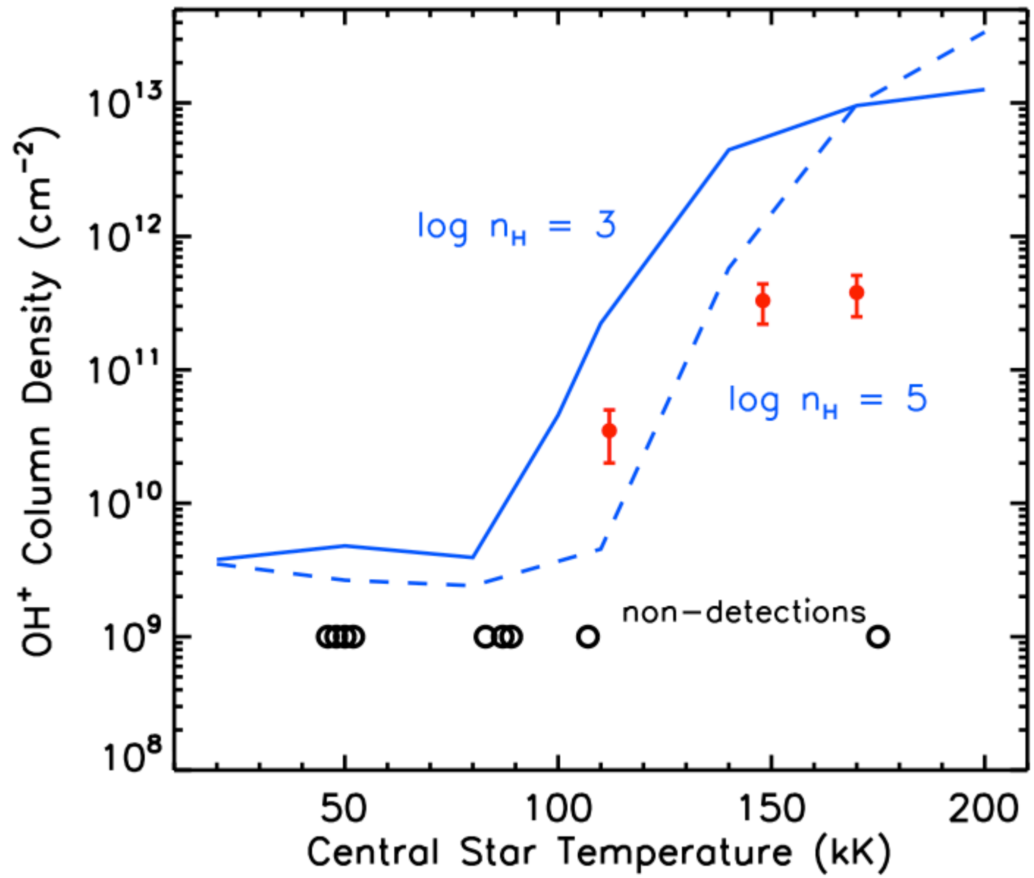
- ✓ Self-consistent
- ✓ Ionized Region + PDR
- ✓ Soft X-rays

- ✓ CLOUDY (Ferland et al. 2013)
  + AANGABA (Gruenwald & Viegas 1992)



Next Steps - Models

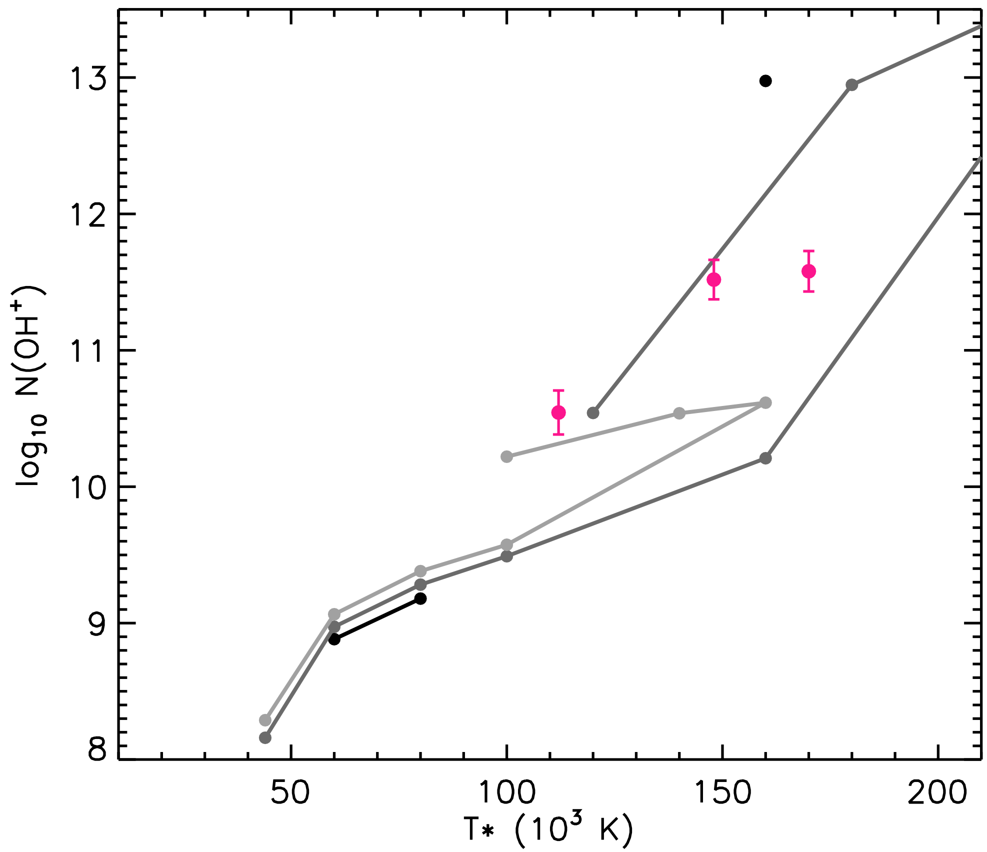
Preliminary Models - CLOUDY



Cloudy v.15 (beta version)
Ferland et al (2013)
+ Updates to be published

Next Steps - Models

Preliminary Models - AANGABA



Code described in Kimura et al. (2012) and references therein

Conclusions

- ✓ **1^{st} detection of OH^+ in PNe**
  - → **HerPlaNS + MESS teams**
- ✓ **OH^+ emission**
  - ✓ **detected from PNe that produce high-energy photons → T^* > 100 000 K**
  - ✓ **produced in the ring/torus-like structures → P/XDRs!**
- ✓ **Abundance and Excitation**
  - ✓ **$N(OH^+) \sim 10^{10} - 10^{11}$ cm^{-2} | $n(OH^+) \sim 10^4$ cm^{-2} | Non-thermal exc.**
- ✓ **Molecule Rich PNe:**
  - ✓ **High T* (soft X-rays)**
  - ✓ **No Diffuse Hard X-Rays**
  - ✓ **Chemistry depends on C/O ratio**

Aleman et al. (2014) + Aleman et al. (2017, in preparation)

Thank you!

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herschel

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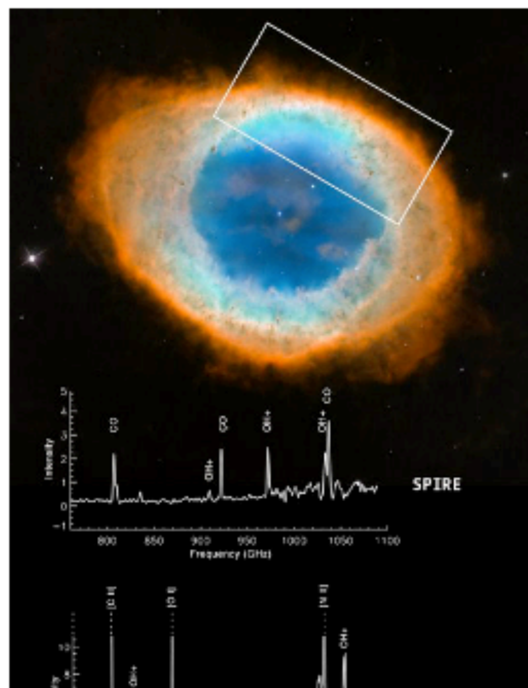
NEW MOLECULES AROUND OLD STARS

17 June 2014

Using ESA's Herschel space observatory, astronomers have discovered that a molecule vital for creating water exists in the burning embers of dying Sun-like stars.



When low- to middleweight stars like our Sun approach the end of their lives, they eventually become dense, white dwarf stars. In doing so, they cast off their outer layers of dust and gas into space, creating a kaleidoscope of intricate patterns known as planetary nebulas.

These actually have nothing to do with planets, but were named in the late 18th century by astronomer William Herschel, because they appeared as fuzzy circular objects through his telescope, somewhat like the planets in our Solar System.

Over two centuries later, planetary nebulas studied with William Herschel's namesake, the Herschel space observatory, have yielded a surprising discovery.

Like the dramatic supernova explosions of weightier stars, the death cries of the stars responsible for

Search here

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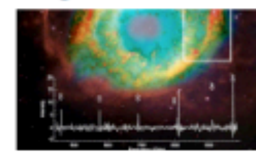
Shortcut URL

http://sci.esa.int/jump.cfm?oid=54158

Images And Videos



- Water-building molecule in Helix Nebula
- Water-building molecule in Ring Nebula
- Herschel observations of Helix Nebula

Related Publications
- Aleman, I., et al. [2014]