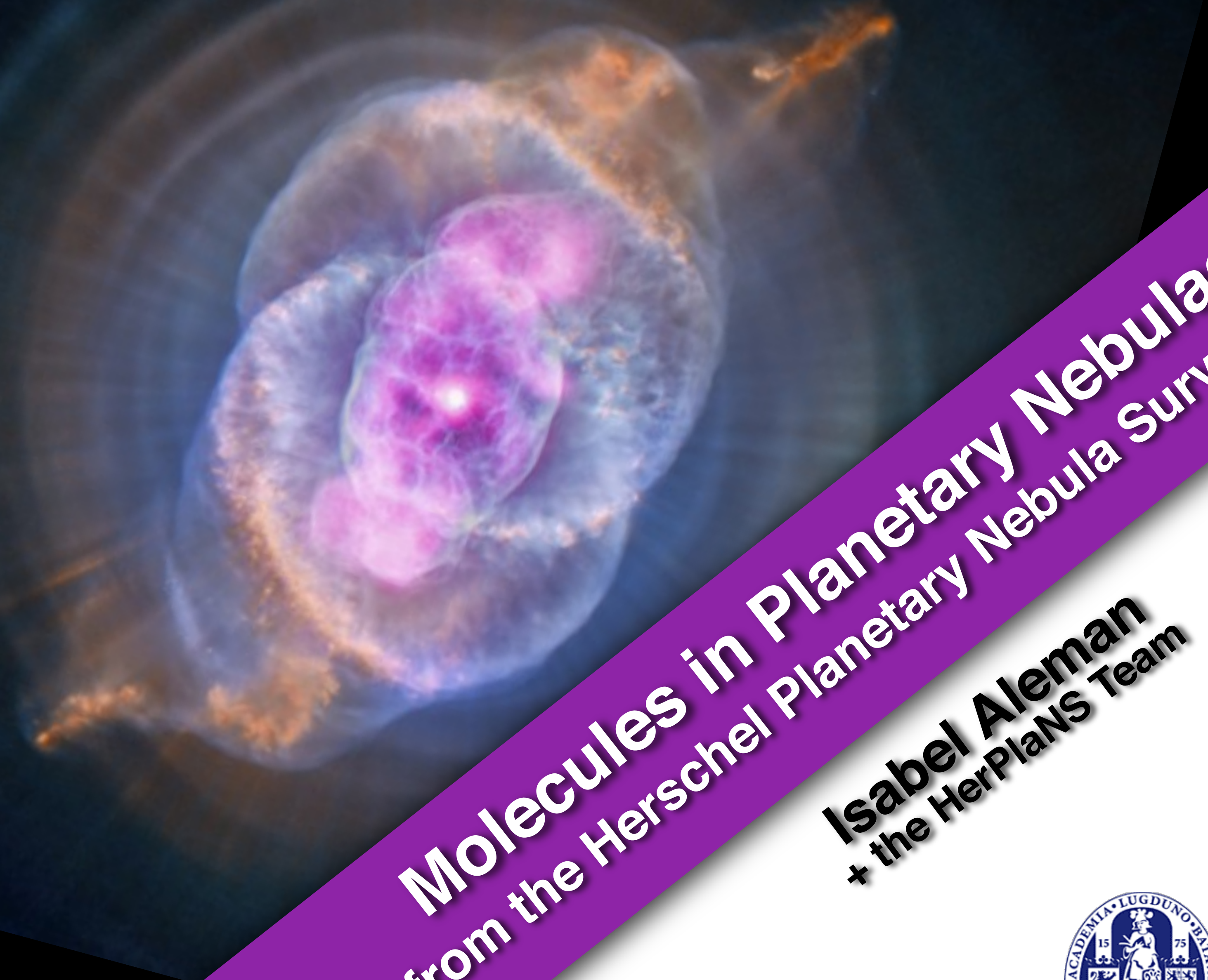


Molecules in Planetary Nebulae

Results from the Herschel Planetary Nebula Survey (HerPlaNS)

Isabel Aleman

+ the HerPlaNS Team

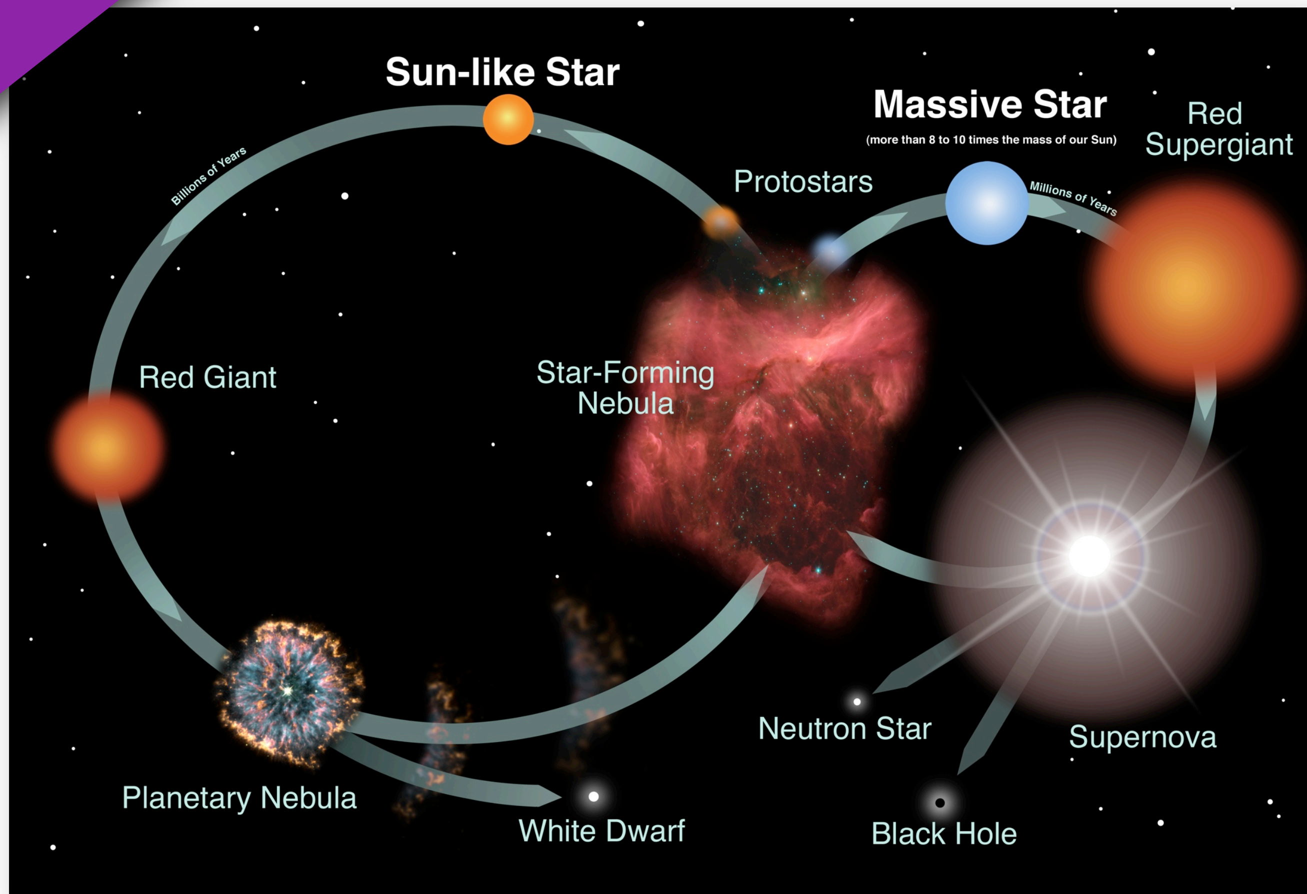
Universiteit Leiden

IAG - USP

Why Planetary Nebulae?

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

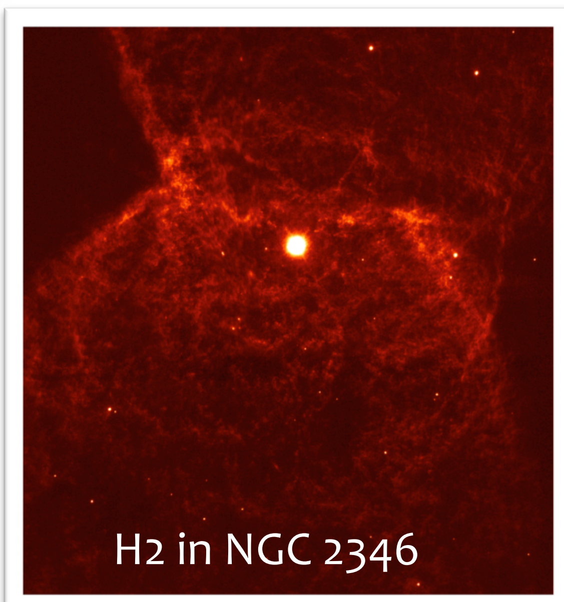
PNe are an important part of the cycle of matter in galaxies – “pollute” the ISM!



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**
- ✓ **Bunch of molecules already detected in PNe**



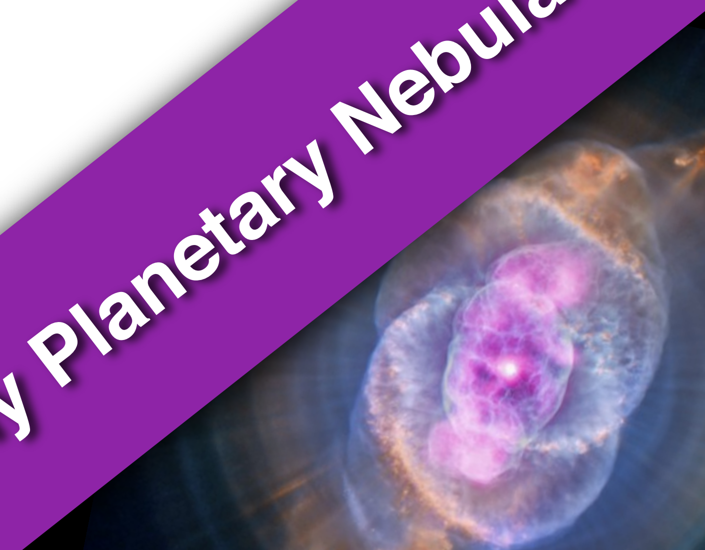
Molecules Detected in the Interstellar and Circumstellar Medium (PNe in Blue)

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

Why Planetary Nebulae?



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

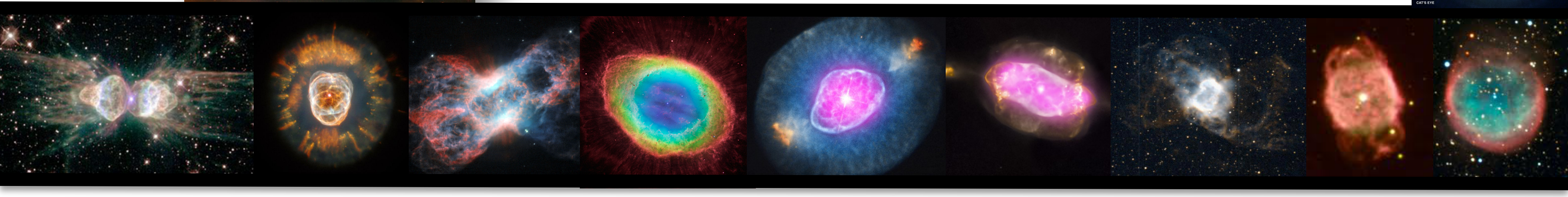
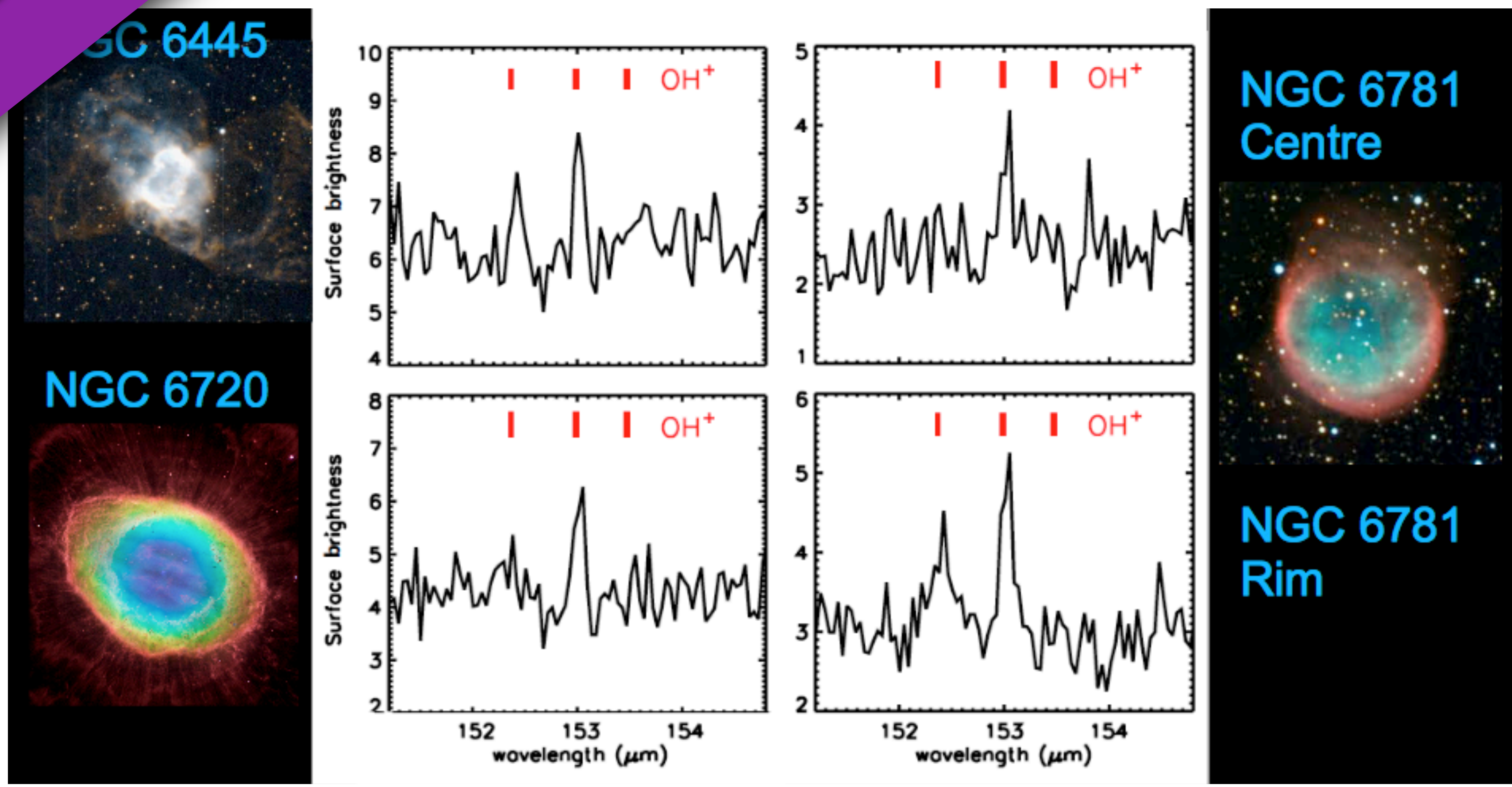


Image Credits: HST, Chandra, AAT, Herschel, ESA

First Detection of OH^+ in PNe

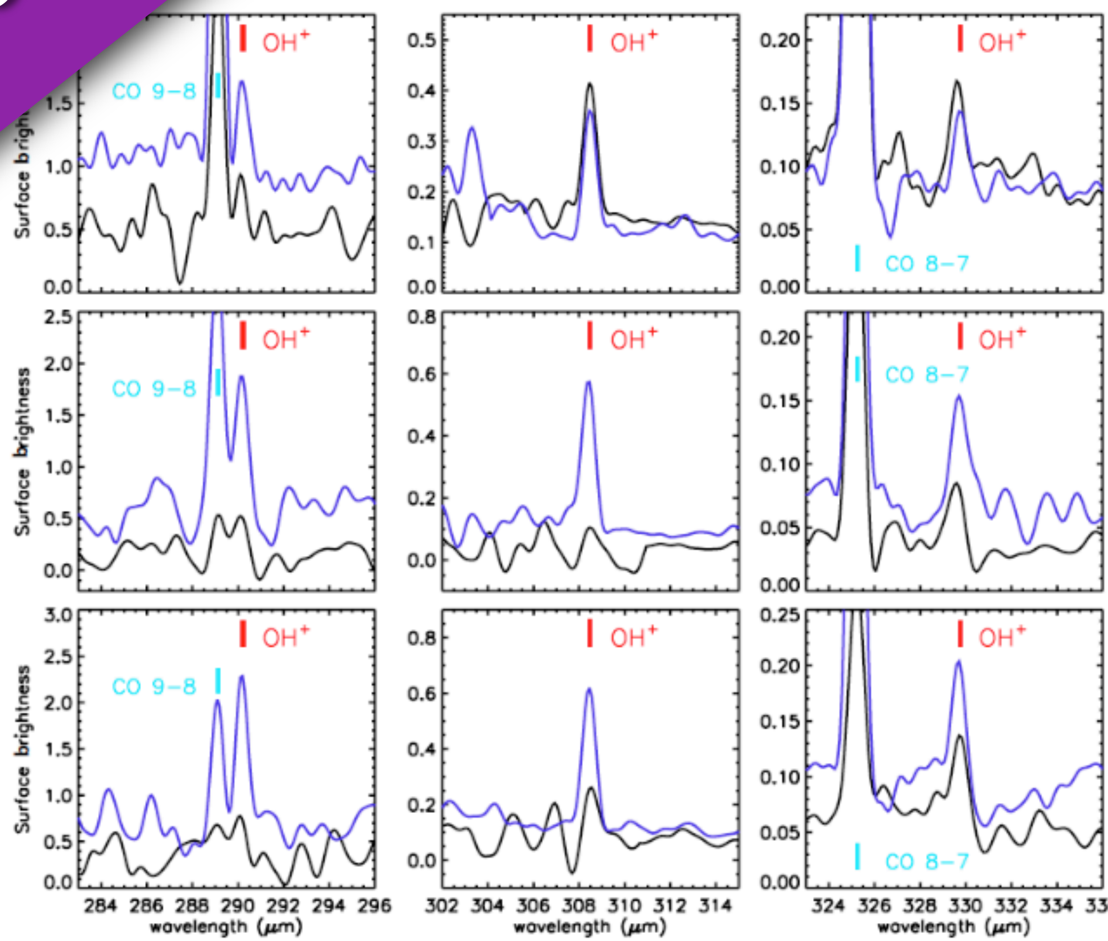
OH^+ Detection – PACS

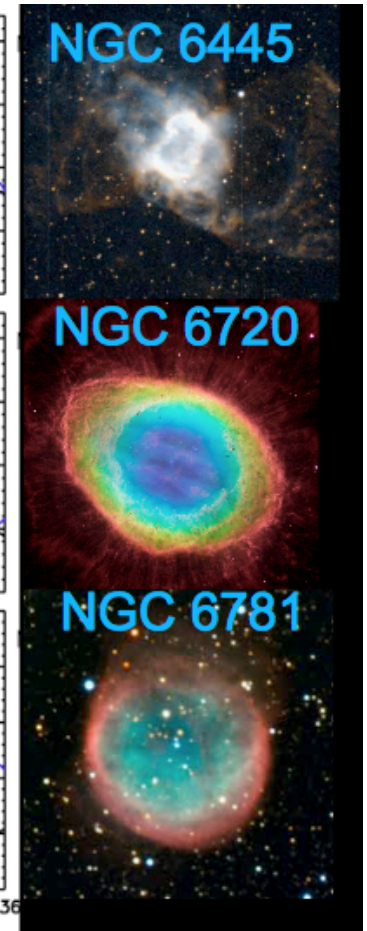


Aleman et al. (2014), Etxaluze et al. (2014)

First Detection of OH^+ in PNe

OH^+ Detection - SPIRE





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

herschel

esa

ESA | SCIENCE & TECHNOLOGY | HERSCHEL

Missions
- Show All Missions

Mission Home
- Summary
- Fact Sheet
- Objectives

Participants
- Mission Team
- Industrial Team

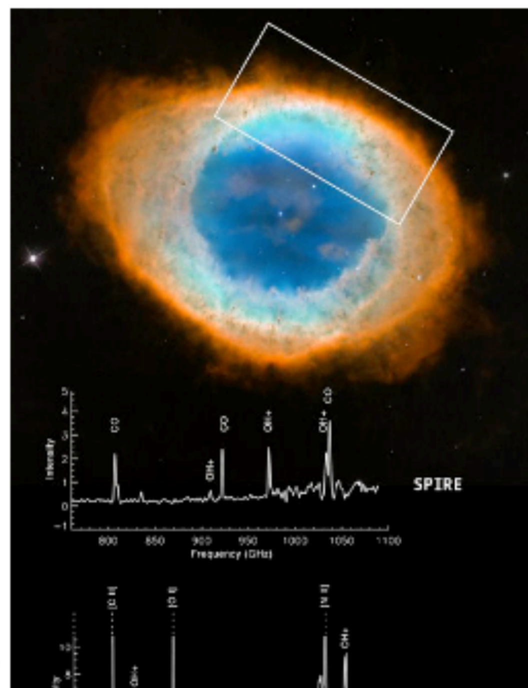
Spacecraft
- 3D Model
- Instruments
- Test Campaign

Mission Operations
- Launch Information
- Orbit/Navigation
- Launch Vehicle
- Launch Campaign
- Status Reports

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

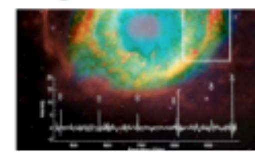
Search here

2-Sep-2014 20:11 UT

Shortcut URL

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

Images And Videos

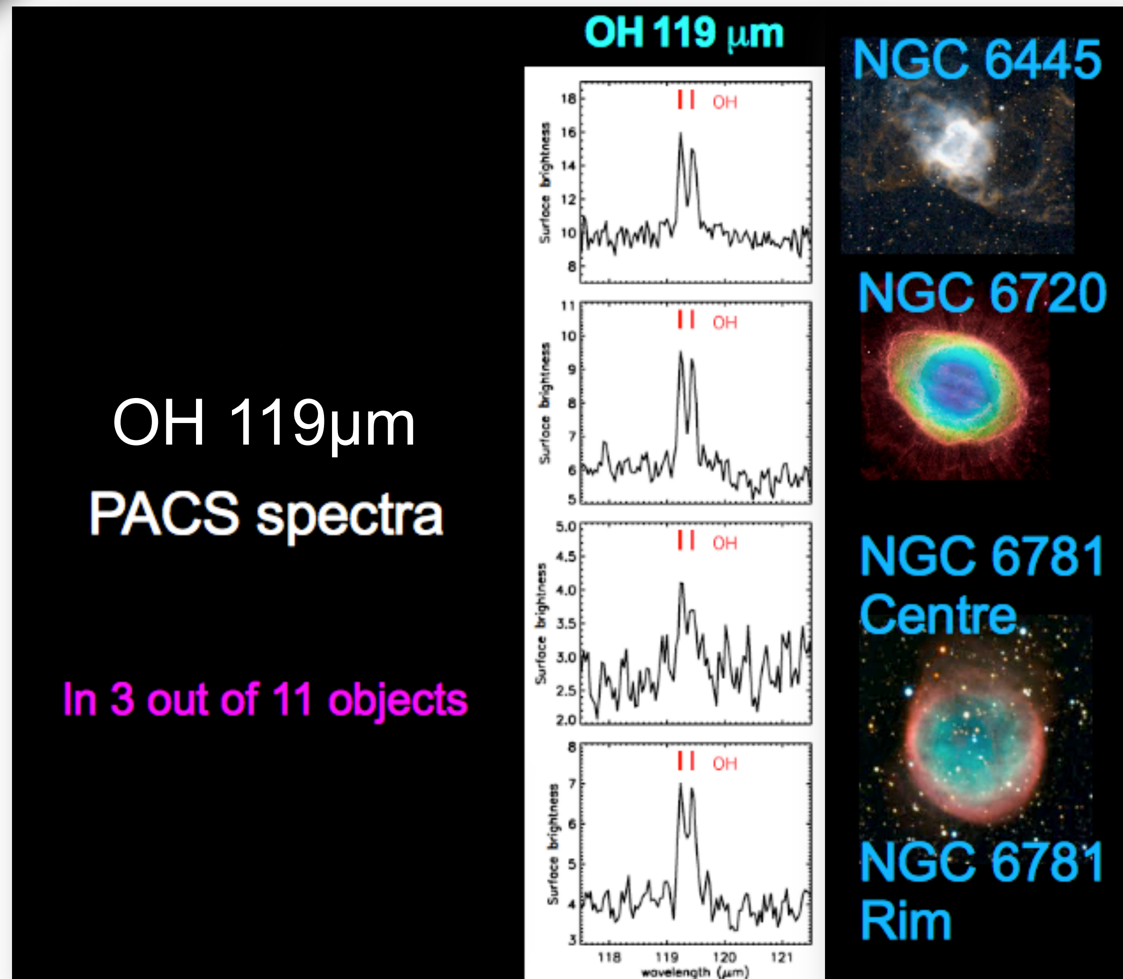


- Water-building molecule in Helix Nebula
- Water-building molecule in Ring Nebula
- Herschel observations of Helix Nebula

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

More Molecules: OH

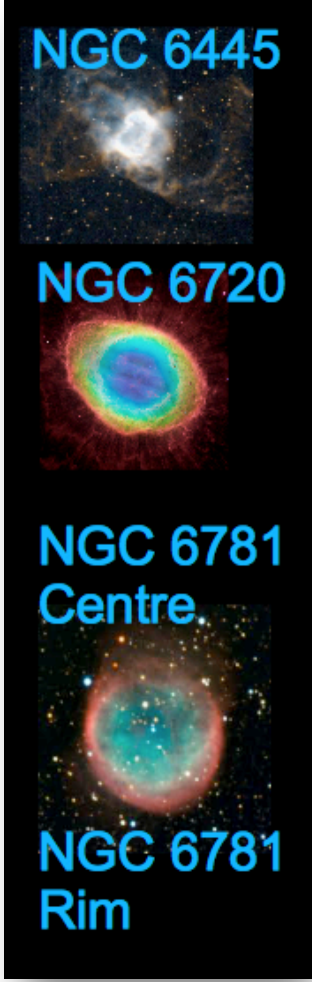
OH Detection - PACS



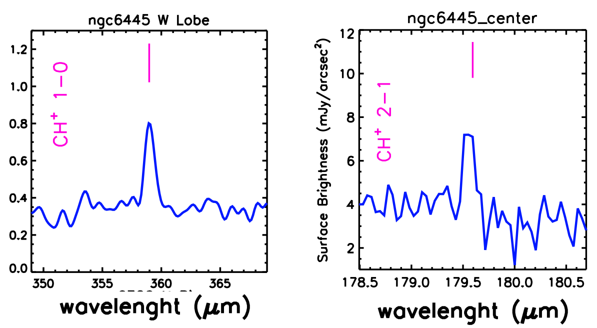
Aleman et al. (2014)

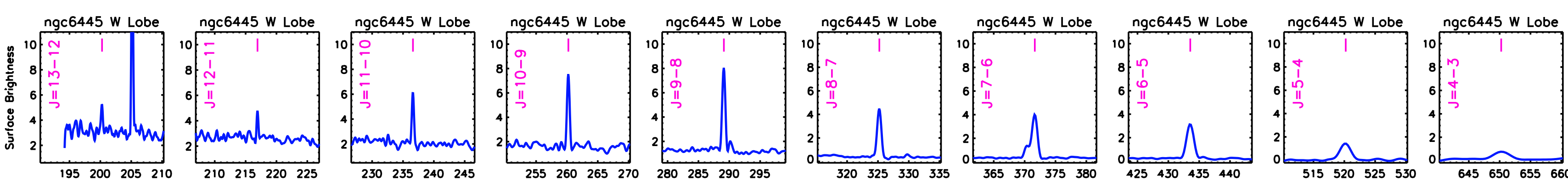
More Molecules: CH^+ and CO

✓ **CO and CH^+ detected in the same PNe as OH and OH^+**



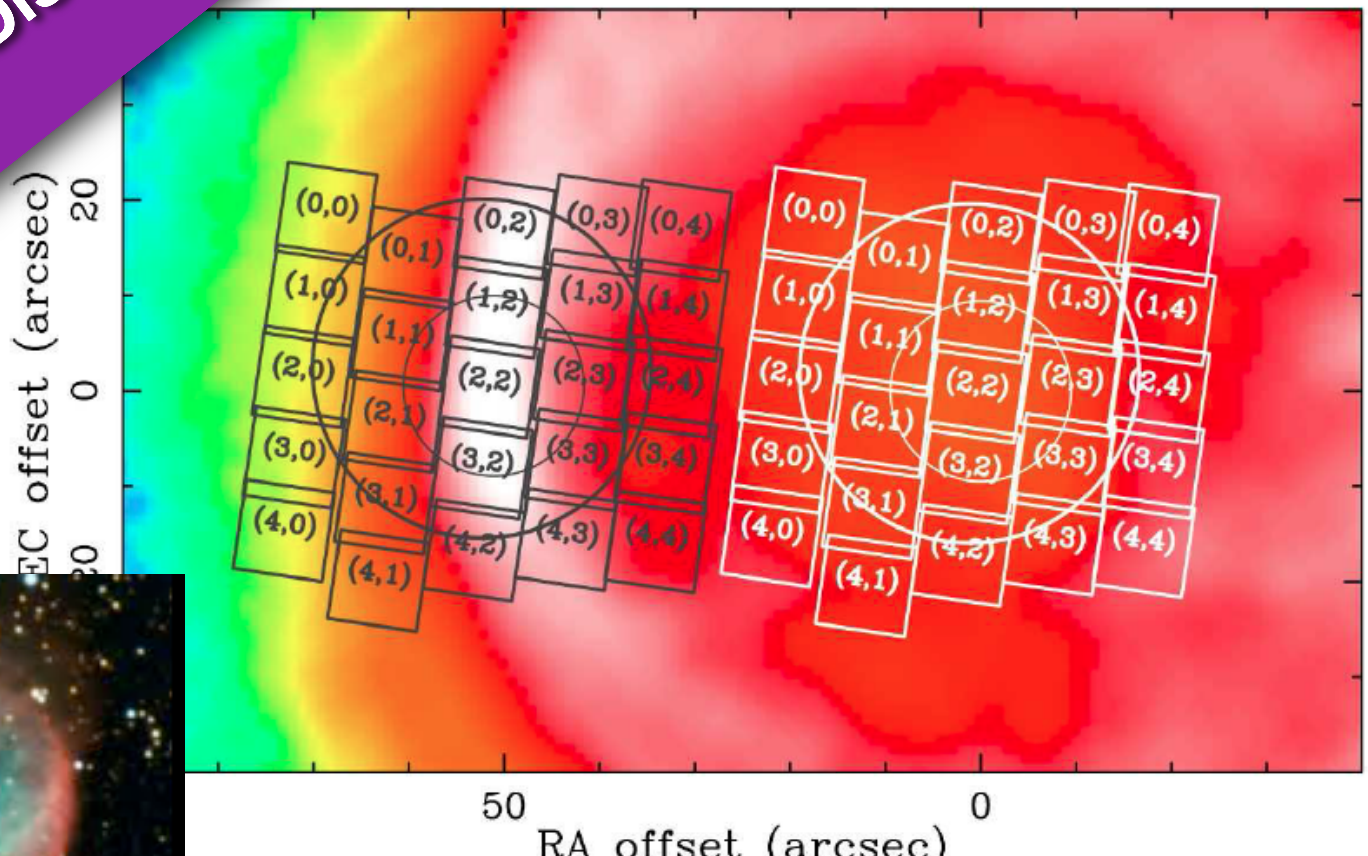
CH^+ and CO in NGC 6445





Aleman et al. (2016, in preparation)

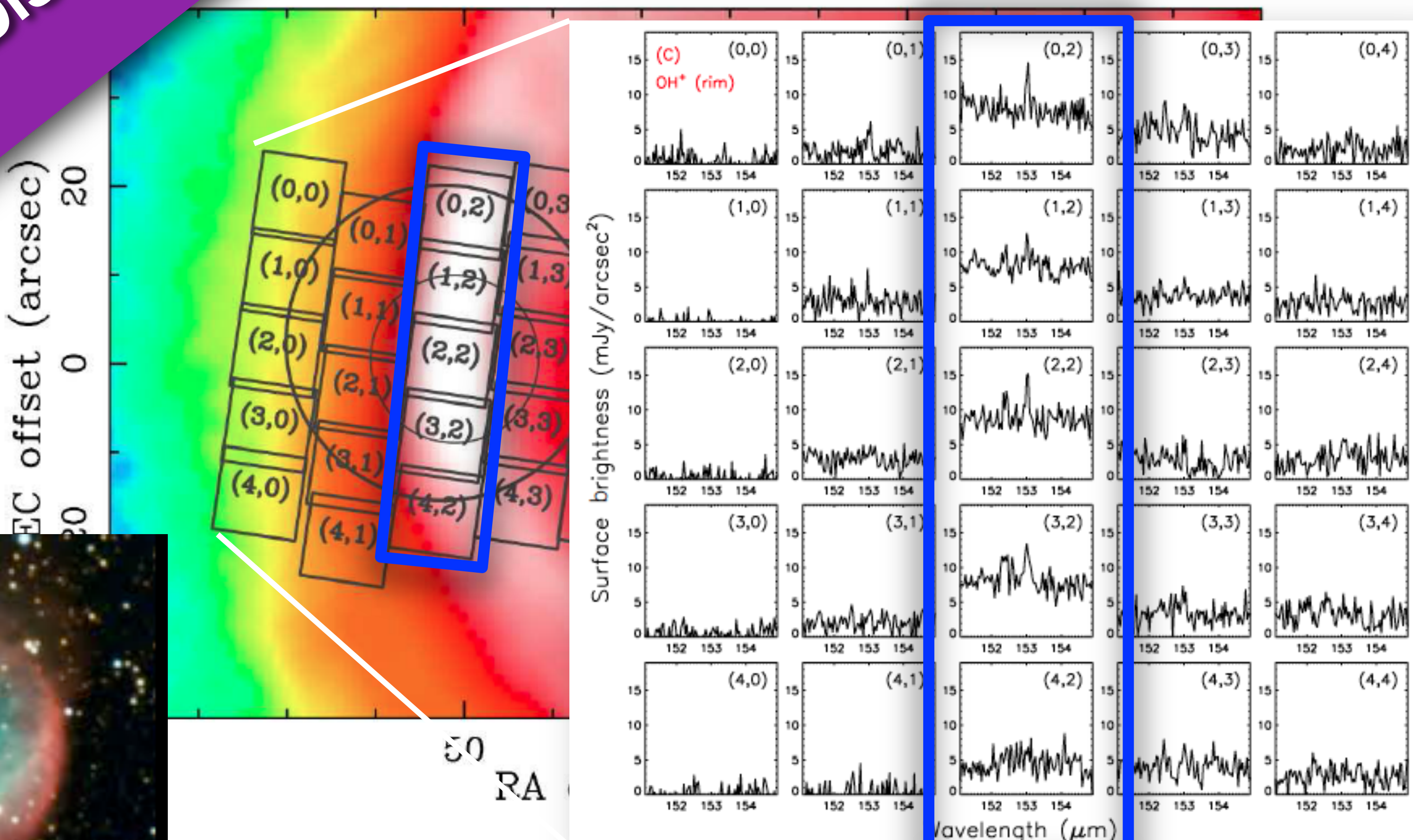
Spatial Distribution of OH^+



Aleman et al. (2014)

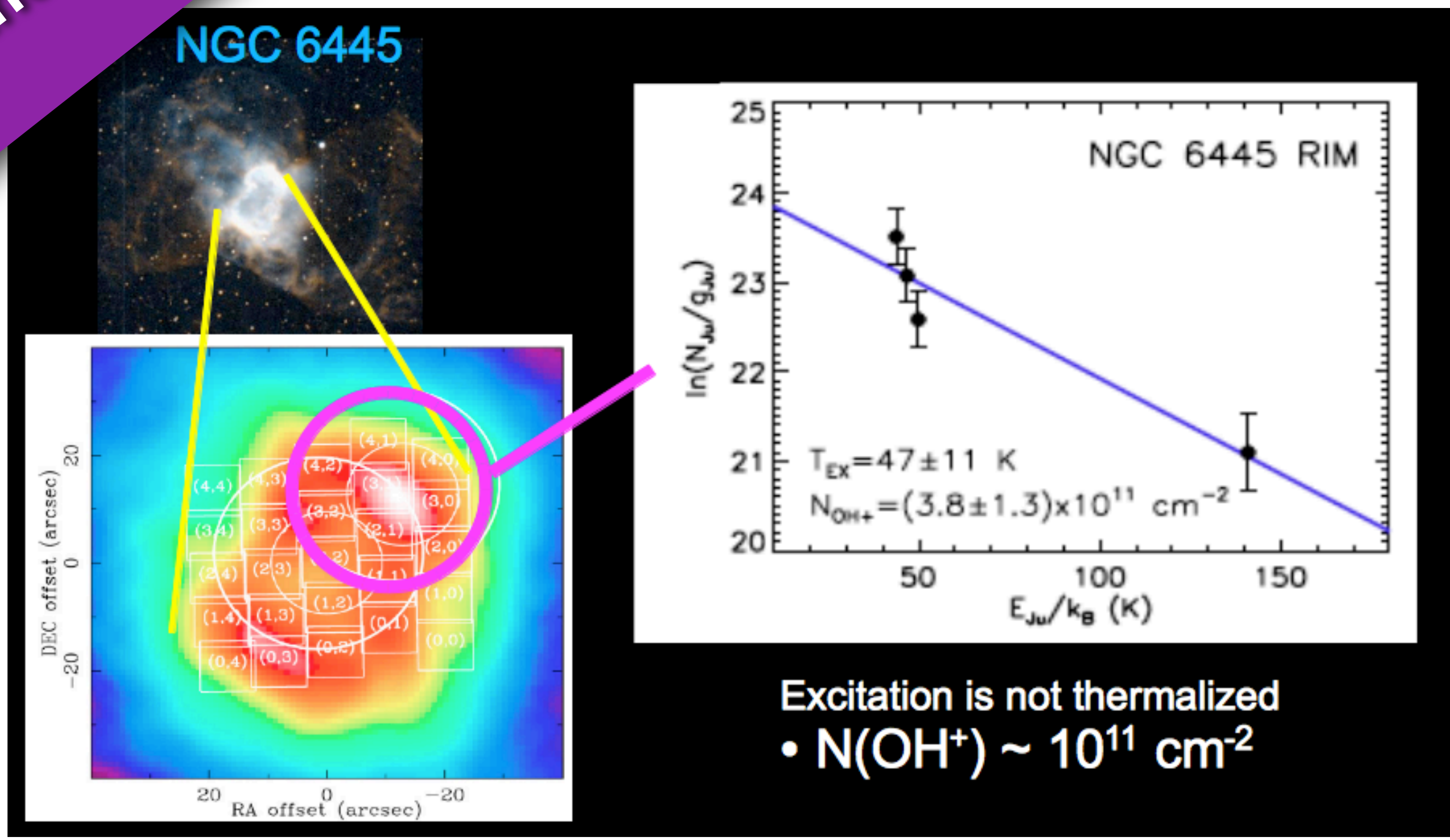
Spatial Distribution of OH^+

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



Aleman et al. (2014)

Excitation and Column Densities



Excitation is not thermalized

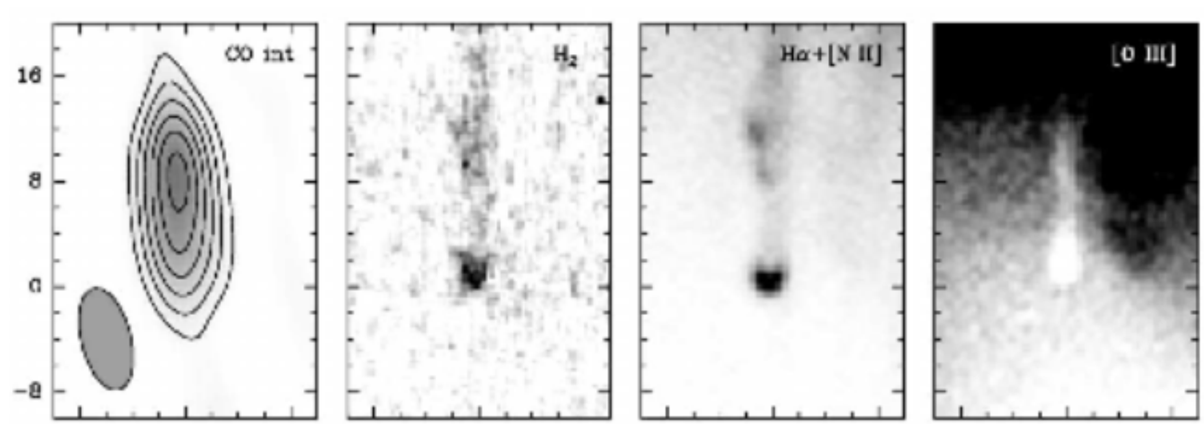
- N(OH$^+$) ~ 10^{11} cm^{-2}

Aleman et al. (2014)

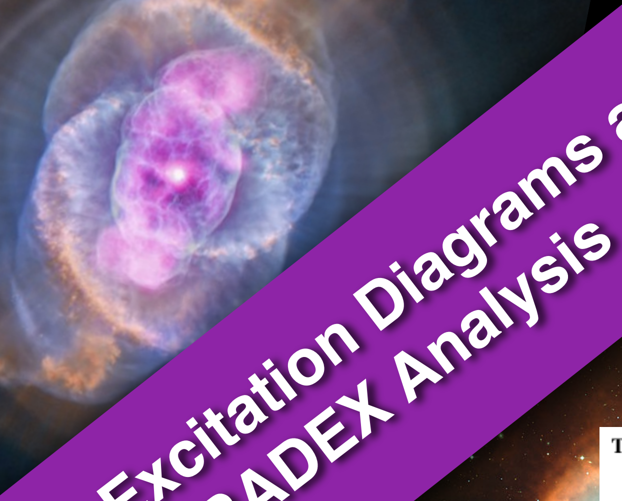
CO Excitation Diagrams and RADEX Analysis

Cometary Knots

NASA, NOAO, ESA, the Hubble Helix Nebula Team, M. Meixner (STScI), and T.A. Rector (NRAO)



Huggins et al. (2002)



CO Excitation Diagrams and RADEX Analysis

Cometary Knots

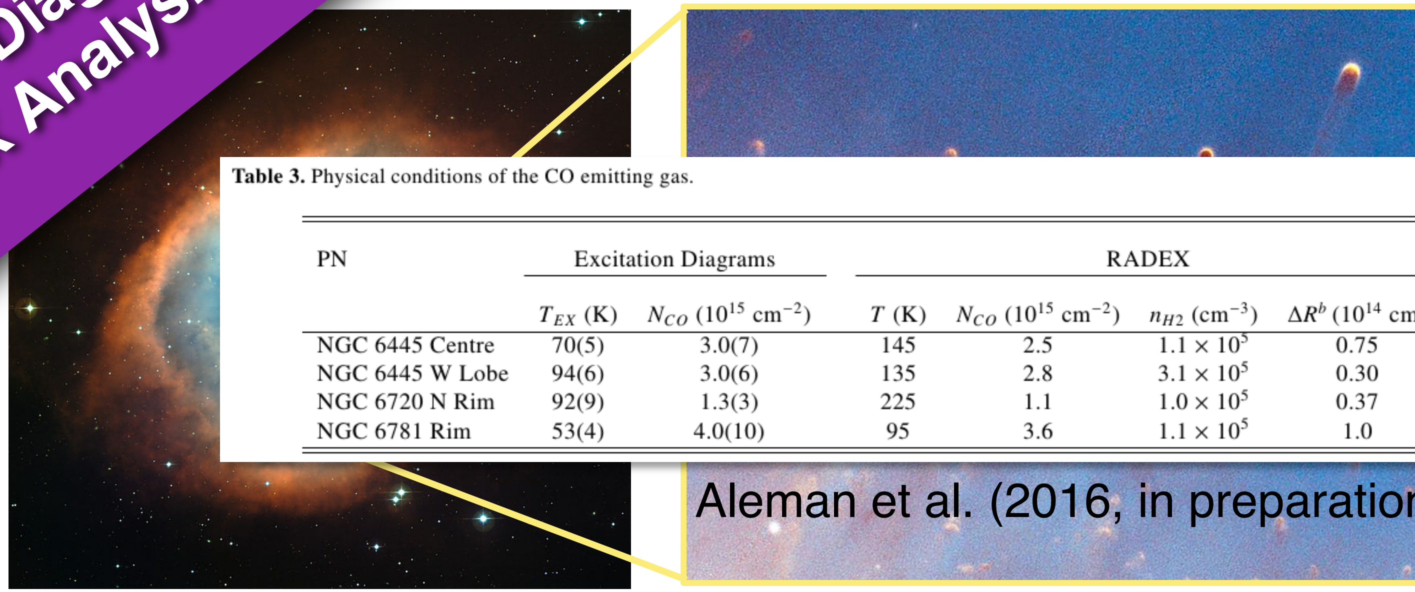
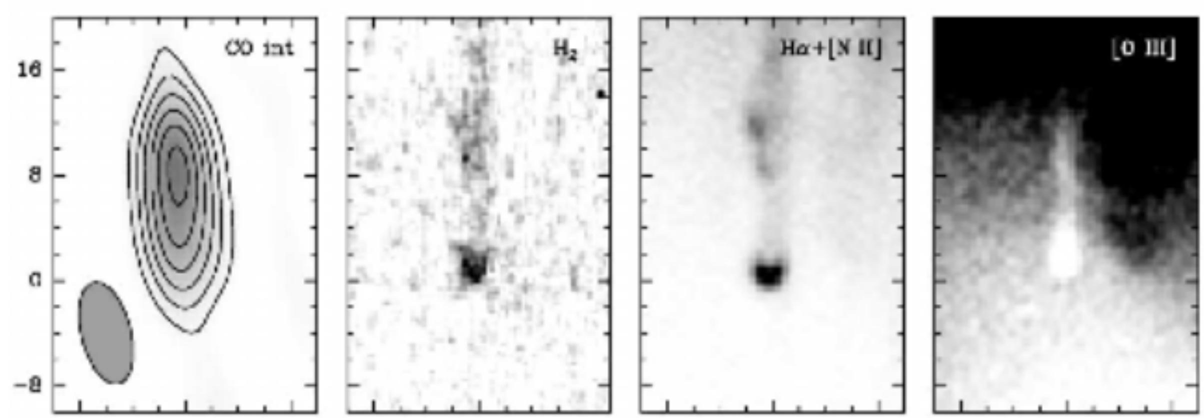


Table 3. Physical conditions of the CO emitting gas.

PN	Excitation Diagrams		RADEX			
	T_{EX} (K)	N_{CO} (10^{15} cm^{-2})	T (K)	N_{CO} (10^{15} cm^{-2})	n_{H2} (cm^{-3})	ΔR^{b} (10^{14} cm)
NGC 6445 Centre	70(5)	3.0(7)	145	2.5	1.1×10^5	0.75
NGC 6445 W Lobe	94(6)	3.0(6)	135	2.8	3.1×10^5	0.30
NGC 6720 N Rim	92(9)	1.3(3)	225	1.1	1.0×10^5	0.37
NGC 6781 Rim	53(4)	4.0(10)	95	3.6	1.1×10^5	1.0

Aleman et al. (2016, in preparation)

NASA, NOAO, ESA, the Hubble Helix Nebula Team, M. Meixner (STScI), and T.A. Rector (NRAO)



Huggins et al. (2002)

Constrai

Observations

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

PN	T* (10³ K)	X-Rays	C / O	H2	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.	1.0-1.5	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	N	N	N	N	N	N	N

Aleman et al. (2016, in preparation)

Constrai... Observations

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

PN	T* (10^3 K)	X-Rays	C / O	H2	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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y
NGC 6853	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y
NGC 6781	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y
NGC 7293	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y
Mz 3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y
NGC 3242	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N
NGC 7009	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N
NGC 7026	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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	N	N	N	N	N	N	N

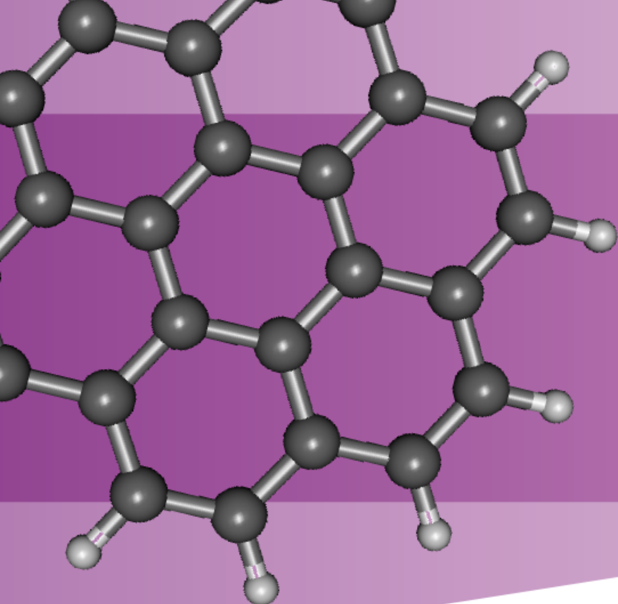
Molecule-Rich PNe:

- High T* (soft X-rays)
- No Diffuse Hard X-Rays
- Chemistry depends on C/O ratio.

Aleman et al. (2016, in preparation)

Conclusions

- ✓ 1^{st} detection of OH^+ in PNe
  - → HerPlaNS + MESS teams
- ✓ OH^+ emission is
  - ✓ detected from PNe that produce high-energy photons → $T^* > 100\,000$ K
  - ✓ produced in the ring/torus-like structures → P/XDRs!
- ✓ CO emission → cometary knots
- ✓ Densities
  - ✓ $N(OH^+) \sim 10^{10} - 10^{11}$ cm^{-2} | $n(OH^+) \sim 10^4$ cm^{-2} | Non-thermal exc.
  - ✓ $N(CO) \sim 10^{15}$ cm^{-2} | $n(CO) \sim 10^5$ cm^{-2} | Thermal exc.
- ✓ Molecule Rich PNe:
  - ✓ High T* (soft X-rays)
  - ✓ No Diffuse Hard X-Rays
  - ✓ Chemistry depends on C/O ratio



AstroPAH

A Newsletter on Astronomical PAHs

The Team (OH^+ Paper)

- PI: Toshiya Ueta (University of Denver/JAXA)
- A. G. G. M. Tielens (Leiden Observatory)
- D. Ladjal (University of Denver)
- K. M. Exter (KU Leuven)
- J. Kastner (Rochester Institute of Technology)
- R. Montez (Vanderbilt University)
- Y.-H. Chu (University of Illinois)
- H. Izumiura (National Astronomical Observatory of Japan)
- I. McDonald (University of Manchester)
- R. Sahai (JPL)
- R. Szczerba + N. Siódmiak (N. Copernicus Astronomical Center)
- P. A. M. van Hoof (Royal Observatory of Belgium)
- E. Villaver (Universidad Autónoma de Madrid)
- W. Vlemmings (Onsala Space Observatory)
- M. Wittkowski (ESO)
- A. A. Zijlstra (University of Manchester)

Thank you!

Universiteit Leiden

IAG - USP

NWO

CNPq

Conselho Nacional de Desenvolvimento Científico e Tecnológico