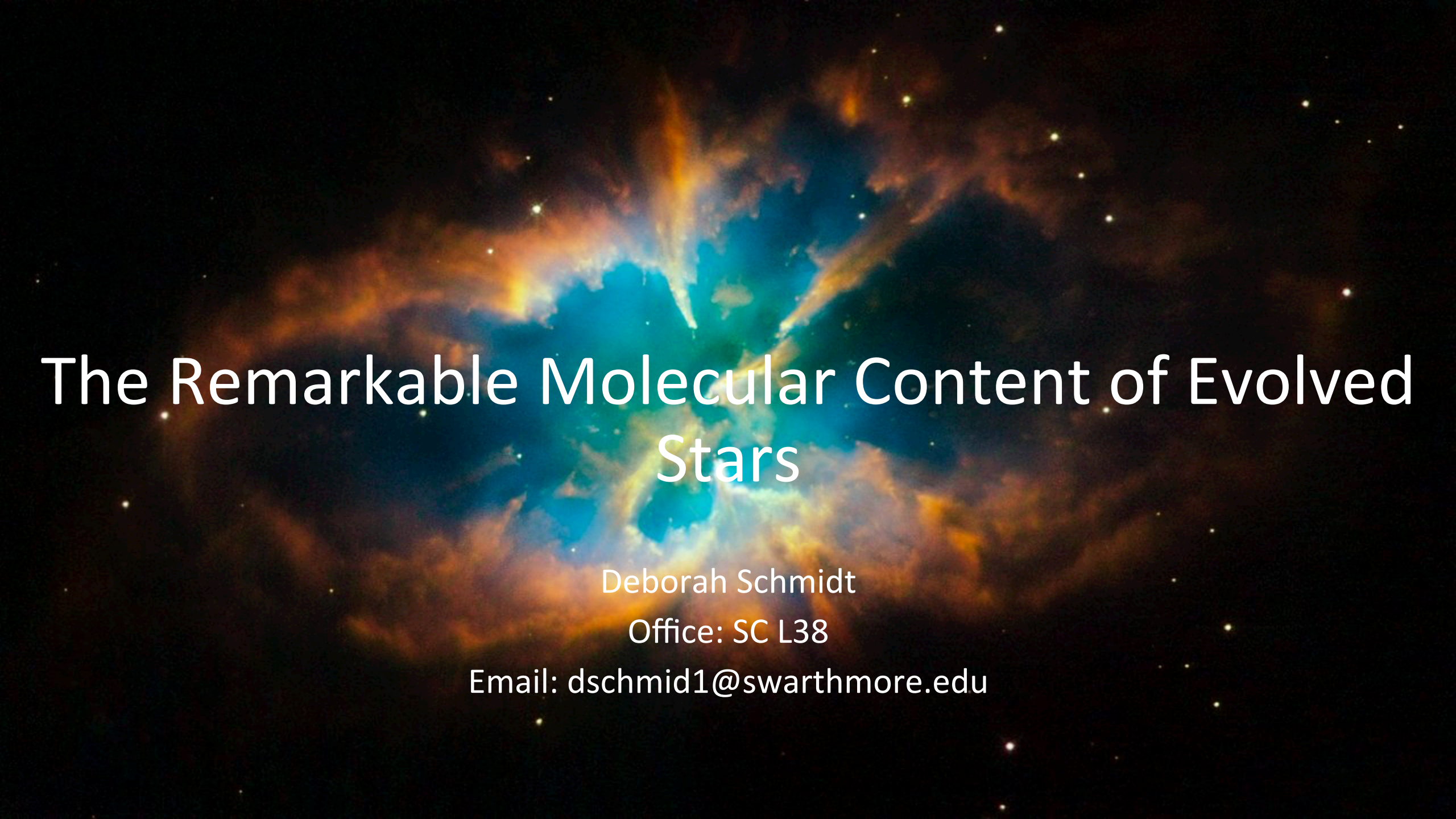


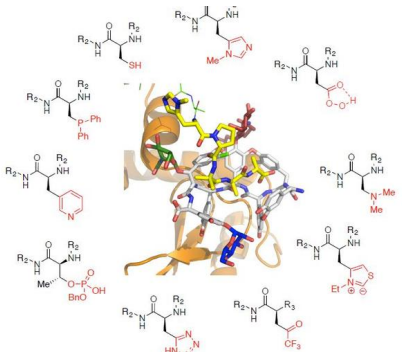
The Remarkable Molecular Content of Evolved Stars

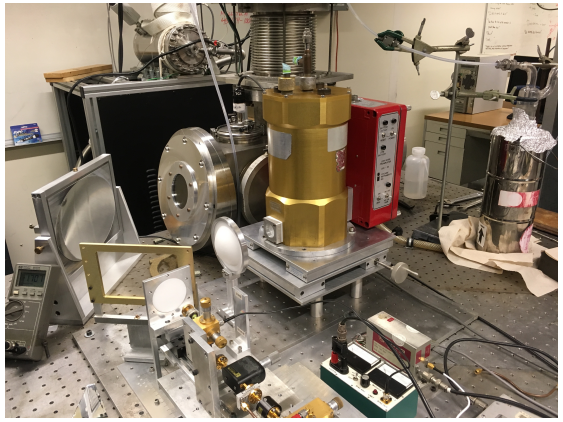
Deborah Schmidt
Office: SC L38
Email: dschmid1@swarthmore.edu

Astrochemistry: The Junction of Many Disciplines

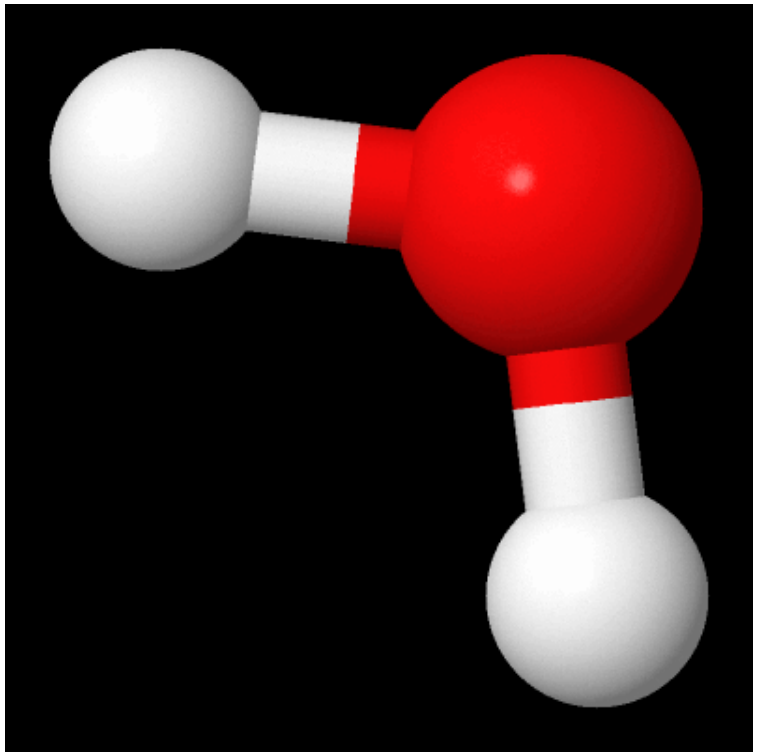
$$\hat{H}\,\Psi = E\,\Psi$$

Astrochemistry





How We Identify Molecules in Space



CO Pure Rotational Spectrum

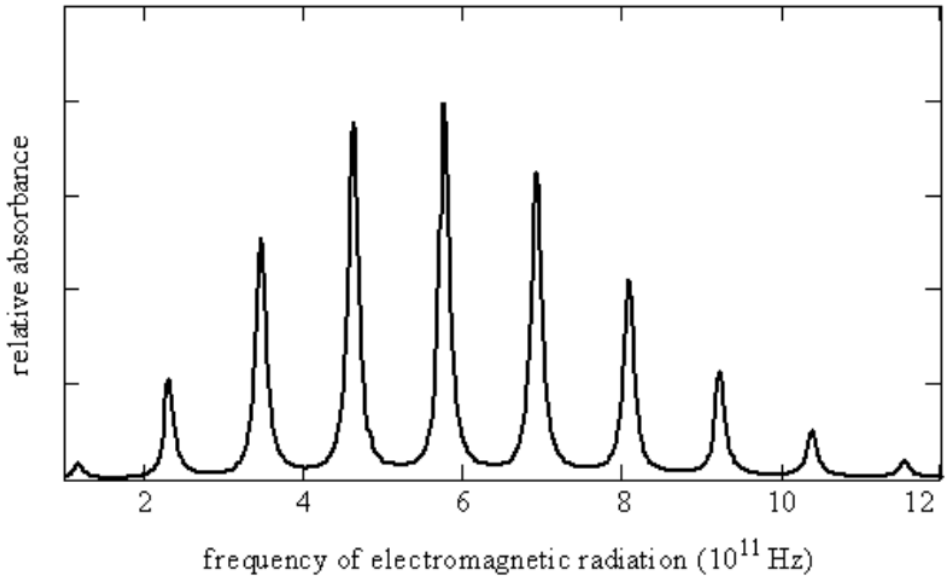


Image credits: Wikimedia Commons; Zielinski et al. 2005, *J. Chem. Educ.*, 82, 1880

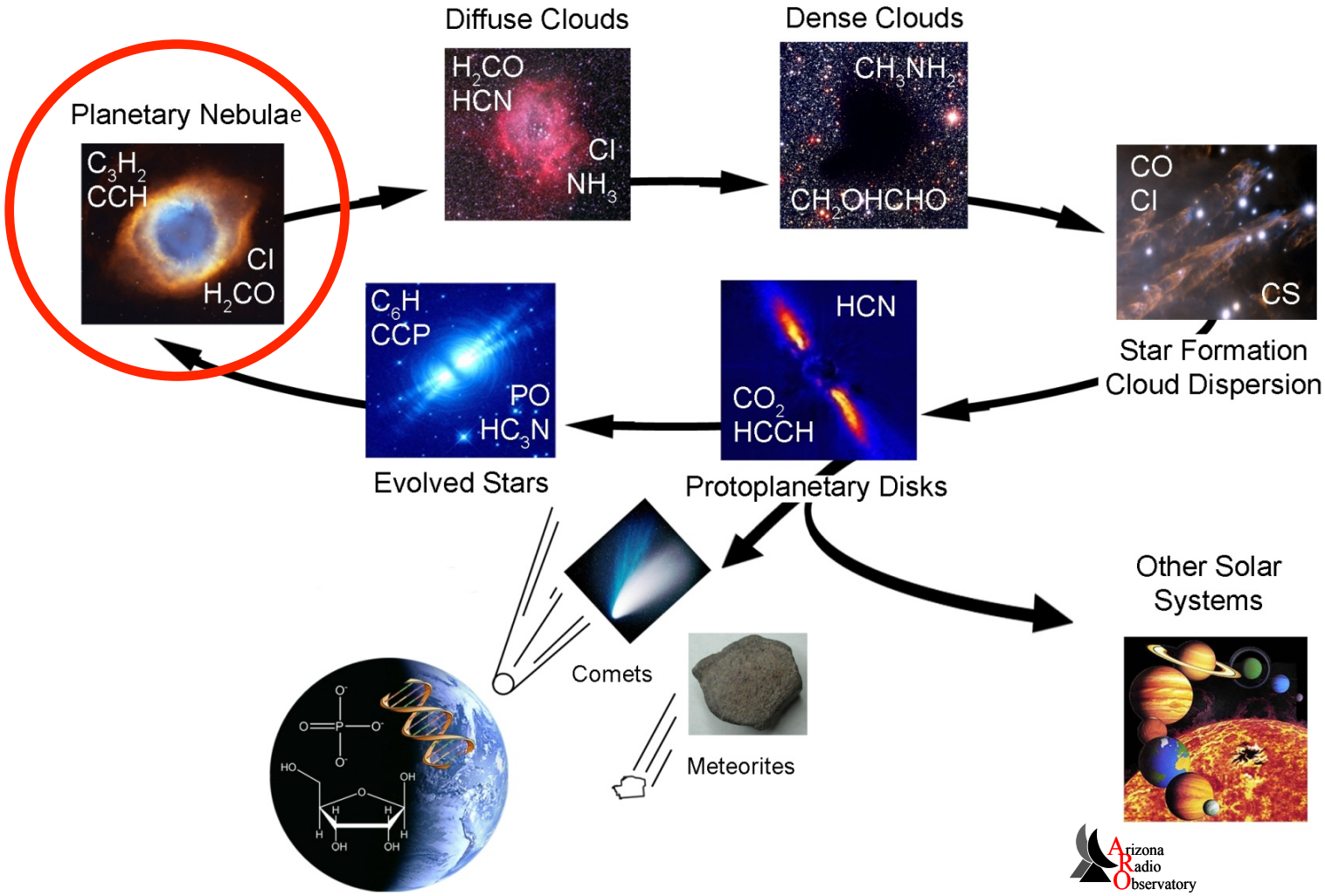
Searching the Cosmos for Molecular Fingerprints

Known Circumstellar and Interstellar Molecules

2	3	4	5	6	7	8	9	10+
AlCl	KCl	AlNC	HCS	CH_3	HNCO	NH_4^+	c-H_2C_3O	c-C_2H_4O	H_3CC_2CN	CH_3C_4H	$(CH_3)_2CO$
AlF	NH	AlOH	HCS^+	l-C_3H	HNCS	CH_4	E-HNCHCN	CH_3C_2H	$H_2COHCHO$	CH_3OCH_3	$(CH_2OH)_2$
AlO	N_2	C_3	HN_2^+	l-C_3H^+	NH_3	CH_3O	C_2H_4	H_3CNH_2	$HCOOCH_3$	CH_3CH_2CN	CH_3CH_2CHO
ArH^+	NO	C_2H	HNO	c-C_3H	HSCN	c-C_3H_2	CH_3CN	CH_2CHCN	CH_3COOH	CH_3CONH_2	CH_3OCH_2OH
C_2	NO^+	CCN	HOC+	C_3N	SiC_3	l-H_2C_3	CH_3NC	H_2CHCOH	H_2C_6	CH_3CH_2OH	CH_3C_5N
CF^+	NS	C_2O	HSC	C_3N^-	HMgNC	H_2CCN	CH_3OH	C_6H	CH_2CHCHO	C_8H	CH_3CHCH_2O
CH	NaCl	C_2S	KCN	C_3O		H_2C_2O	CH_3SH	C_6H^-	CH_2CCHCN	C_8H^-	HC_8CN
CH^+	MgH^+	C_2P	MgCN	C_3S		H_2CNH	l-H_2C_4	HC_4CN	CH_3CHNH	HC_7N	C_2H_5OCHO
CN	NaI	CO_2	MgNC	H_3O^+		HNCNH	HC_3NH^+	HC_5O	C_7H	CH_3CHCH_2	CH_3COOCH_3
CN^+	O_2	FeCN	NH_2	C_2H_2		H_2COH^+	$HCONH_2$	CH_3CHO	NH_2CH_2CN	CH_3CH_2SH	CH_3C_6H
CN^-	PN	H_3^+	N2O	H_2CN		C_4H	C_5H	CH_3NCO	$(NH_2)_2CO$		C_6H_6
CO	PO	H_2C	NaCN	H_2CN^+		C_4H^-	C_5N	$HOCH_2CN$			C_3H_7CN
CO^+	SH	H_2Cl^+	NaOH	H_2CO		HC_3N	HC_2CHO				$(CH_3)_2CHCN$
CP	SH^+	H_2O	OCS	H_2CS		HCC-NC	HC_4N				C_6H_5CN
CS	SO	H_2O^+	O_3	HCCN		HCOOH	CH_2CNH				$HC_{10}CN$
FeO	SO^+	HO_2	SO_2	HCCO		NH_2CN	C_5S				C_{60}
H_2	SiC	H_2S	C-SiC_2	$HCNH^+$		NCCNH$^+$					C_{70}
HCl	SiN	HCN	SiCSi	$HOCO^+$		HC(O)CN					
HCl^+	SiO	HNC	SiCN	HCNO		C_5					
HF	SiS	HCO	SiNC	HOCN		SiC_4					
HO	TiO	HCO^+	TiO_2	CNCN		SiH_4					
OH^+		HCP		HOOH							

The Cosmic Cycle

Provide **~80%** of their material to diffuse clouds!



Planetary Nebulae

Image credit: X-ray, NASA/CXC/SAO; Optical, NASA/STScI)

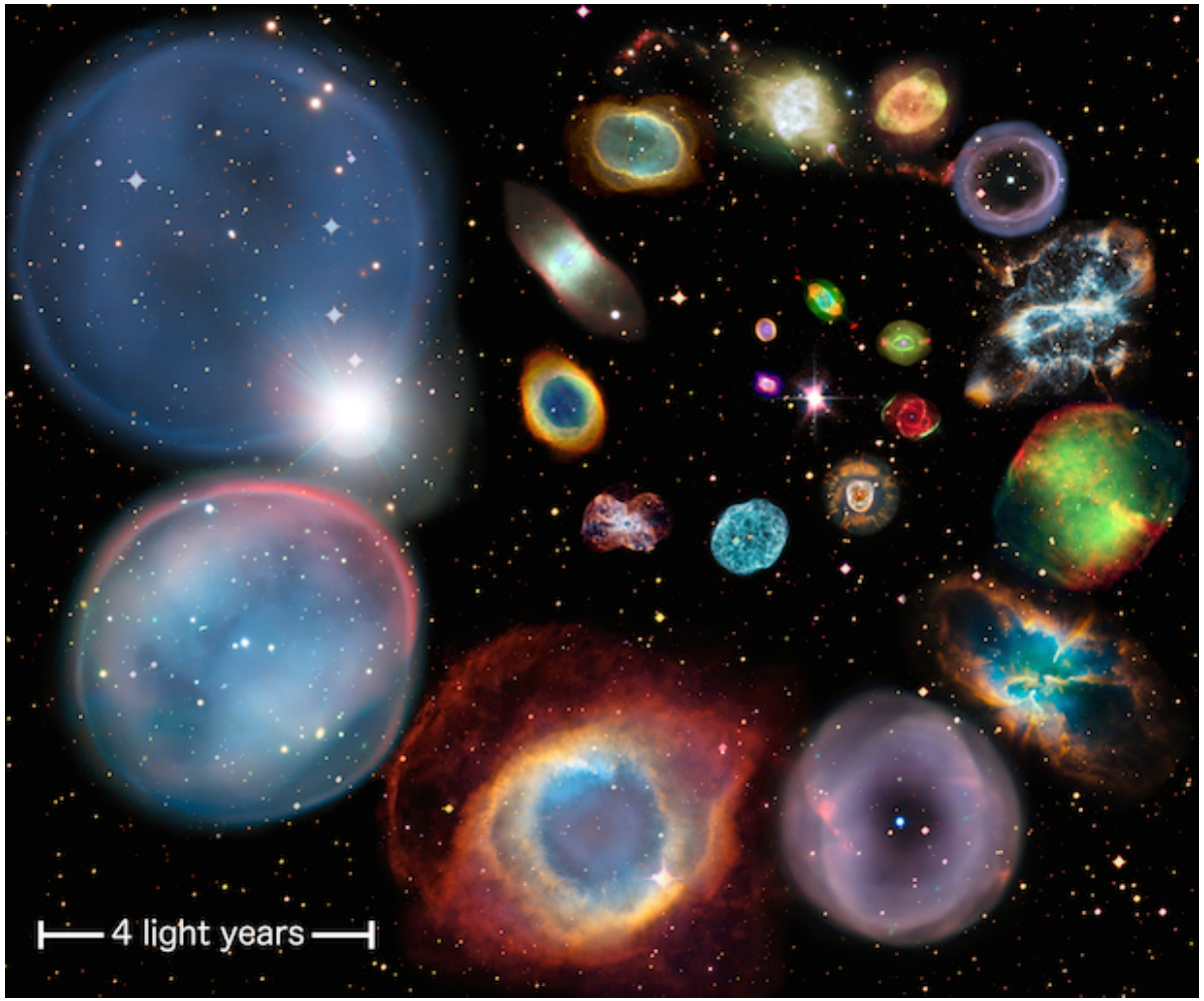


Image credit: ESA/Hubble/NASA/ESO/Ivan Bojicic/David Frew/ Quentin Parker

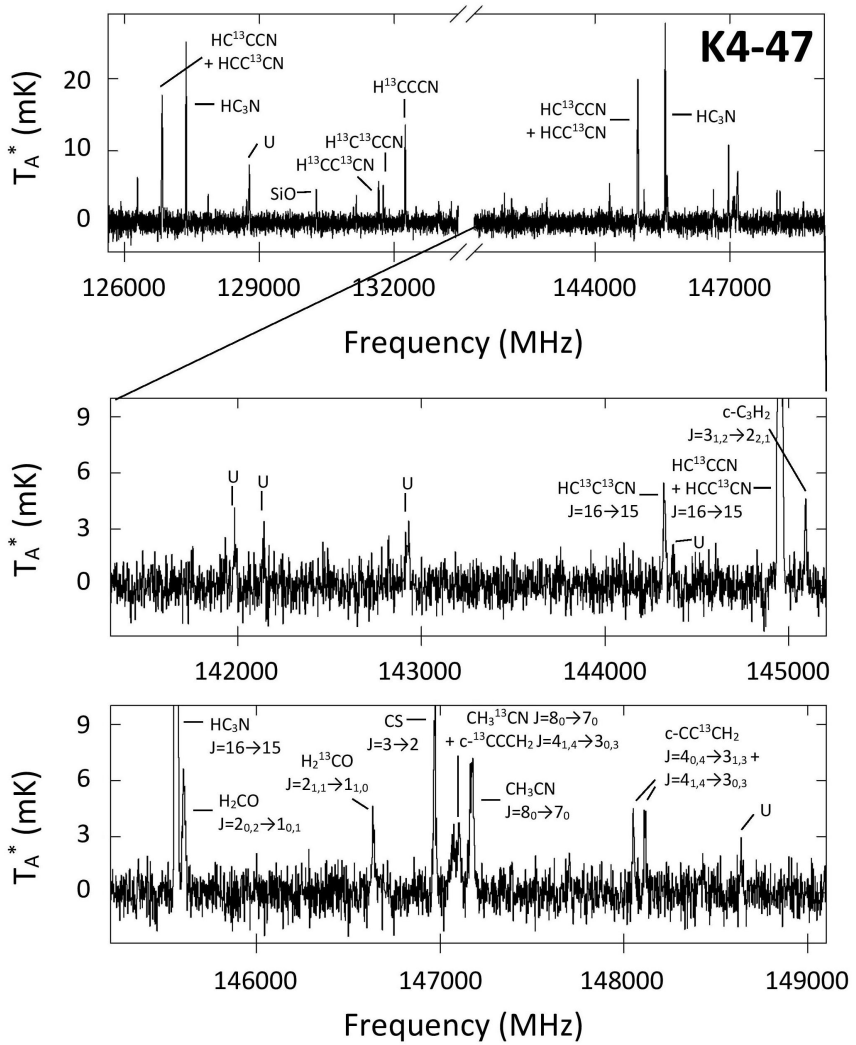
Observations

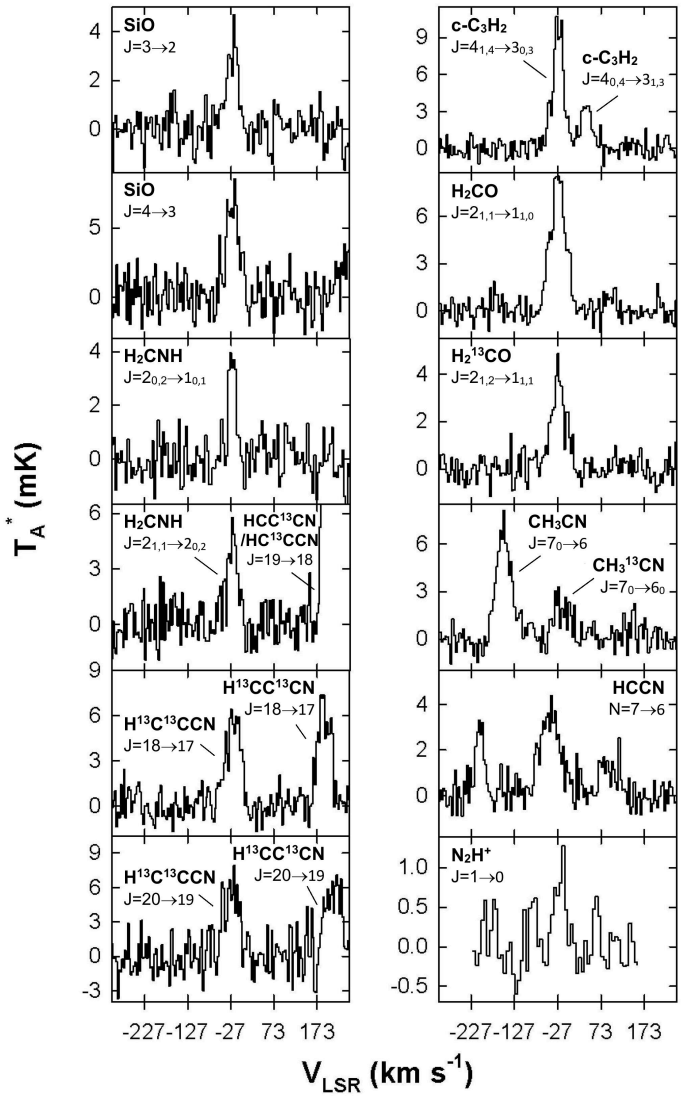
ARO 12-M Telescope
Kitt Peak, AZ

ARO Submillimeter Telescope
Mt. Graham, AZ

Image credits: Arizona Radio Observatory

Analysis


K4-47
HC13CCN + HCC13CN
HC3N
U
SiO
H13CCCN
H13C13CCN
H13CC13CN
HC13CCN + HCC13CN
HC3N
TA* (mK)
Frequency (MHz)
c-C3H2 J=31,2→22,1
HC13C13CN J=16→15
HC13CCN + HCC13CN J=16→15
HC3N J=16→15
H2CO J=20,2→10,1
H2 13CO J=21,1→10,0
CS J=3→2
CH3 13CN J=80→70 + c-13CCCH2 J=41,4→30,3
CH3CN J=80→70
c-CC13CH2 J=40,4→31,3 + J=41,4→30,3


SiO J=3→2
SiO J=4→3
H2CNH J=20,2→10,1
H2CNH J=21,1→20,2
HCC13CN /HC13CCN J=19→18
H13CC13CN J=18→17
H13C13CCN J=18→17
H13CC13CN J=20→19
H13C13CCN J=20→19
c-C3H2 J=41,4→30,3
c-C3H2 J=40,4→31,3
H2CO J=21,1→10,0
H2 13CO J=21,2→11,1
CH3CN J=70→6
CH3 13CN J=70→60
HCCN N=7→6
N2H+ J=1→0
TA* (mK)
-227 -127 -27 73 173
VLSR (km s-1)

Summer Research

- I'm aiming to take on two students for the summer.
- Even better if you can start early (spring semester)!
- Absolutely **no** experience in radio astronomy/data analysis necessary.
- Consider taking "Introduction to Radio Astronomy" in the spring to see what radio astronomy is all about!
- For more information, see me in **SC L38** or email me at **dschmid1@swarthmore.edu.**