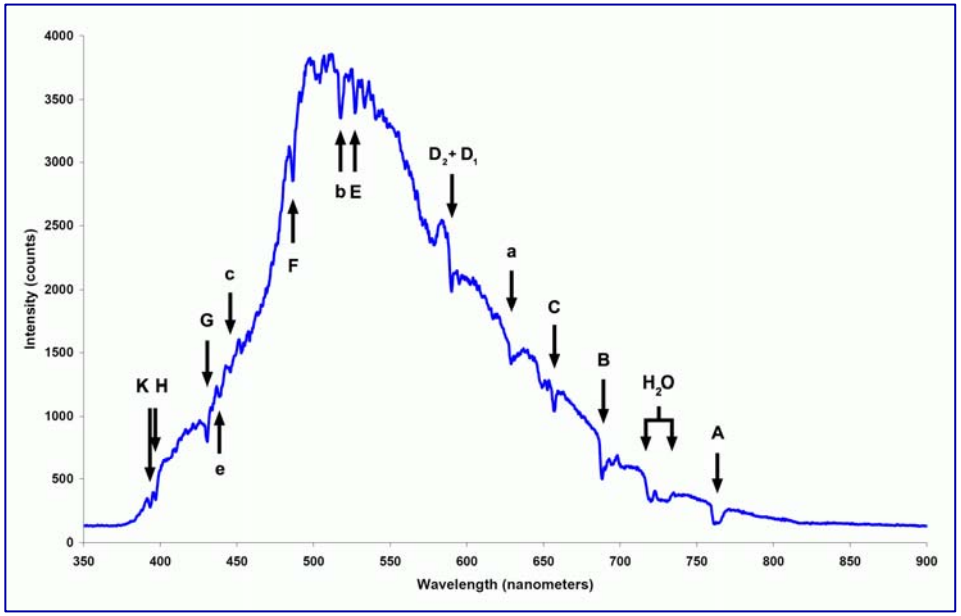
Atoms and Molecules in the Universe
the need for studying
spectroscopy

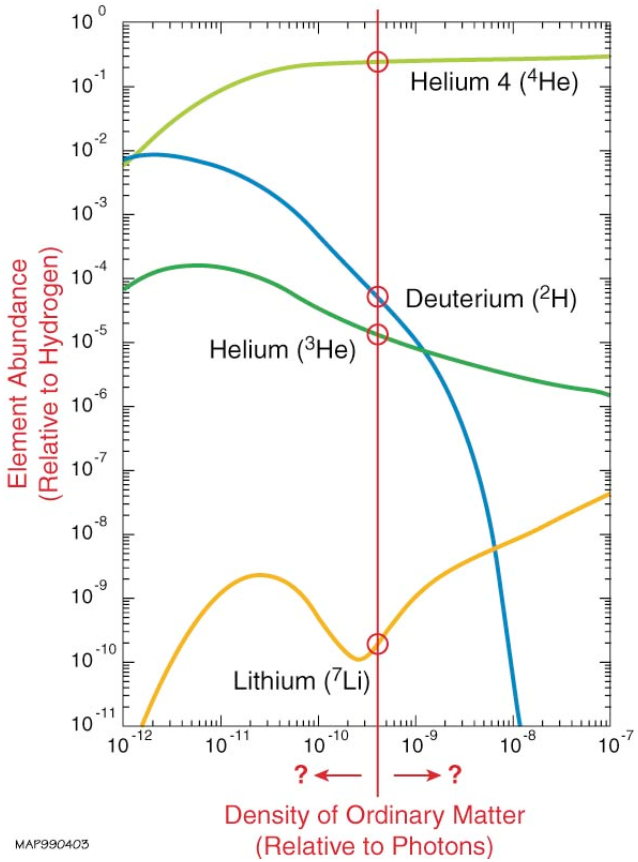
Joseph von Fraunhofer
(1787-1827)

A	O_2	759.370
B	O_2	686.719
C	Hα	656.281
a	O_2	627.661
D_1	Na	589.592
D_2	Na	588.995
D_3 (or d)	He	587.5618



Solar spectrum with Fraunhofer lines and
atmospheric water absorption band indicated.

First elements formed after Big Bang



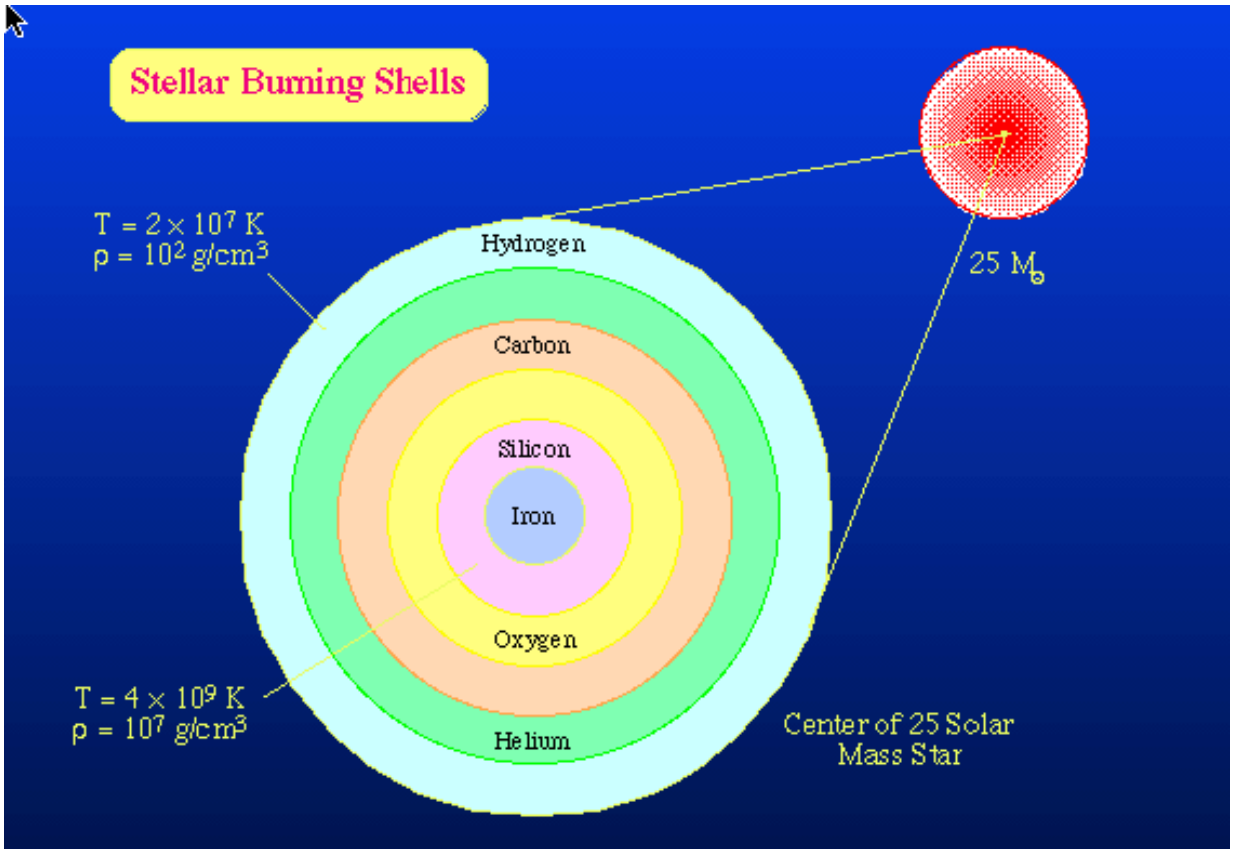
density of Baryons in universe

Primordial nucleosynthesis of elements:
only 3 minutes ! (limited lifetime of neutrons)

H, D,
^{4}He, ^{3}He (24%, ~all neutrons)
^{7}Li

Abundance ratio
is proof of Big Bang model

Heavy elements produced in death of stars: Supernovae



-massive stars (10 M_{sun}) lives only 10^7 years

-hydrogen at inside is exhausted and is burned into helium

-core contracts under gravity and starts fusion of He into Carbon and Oxygen

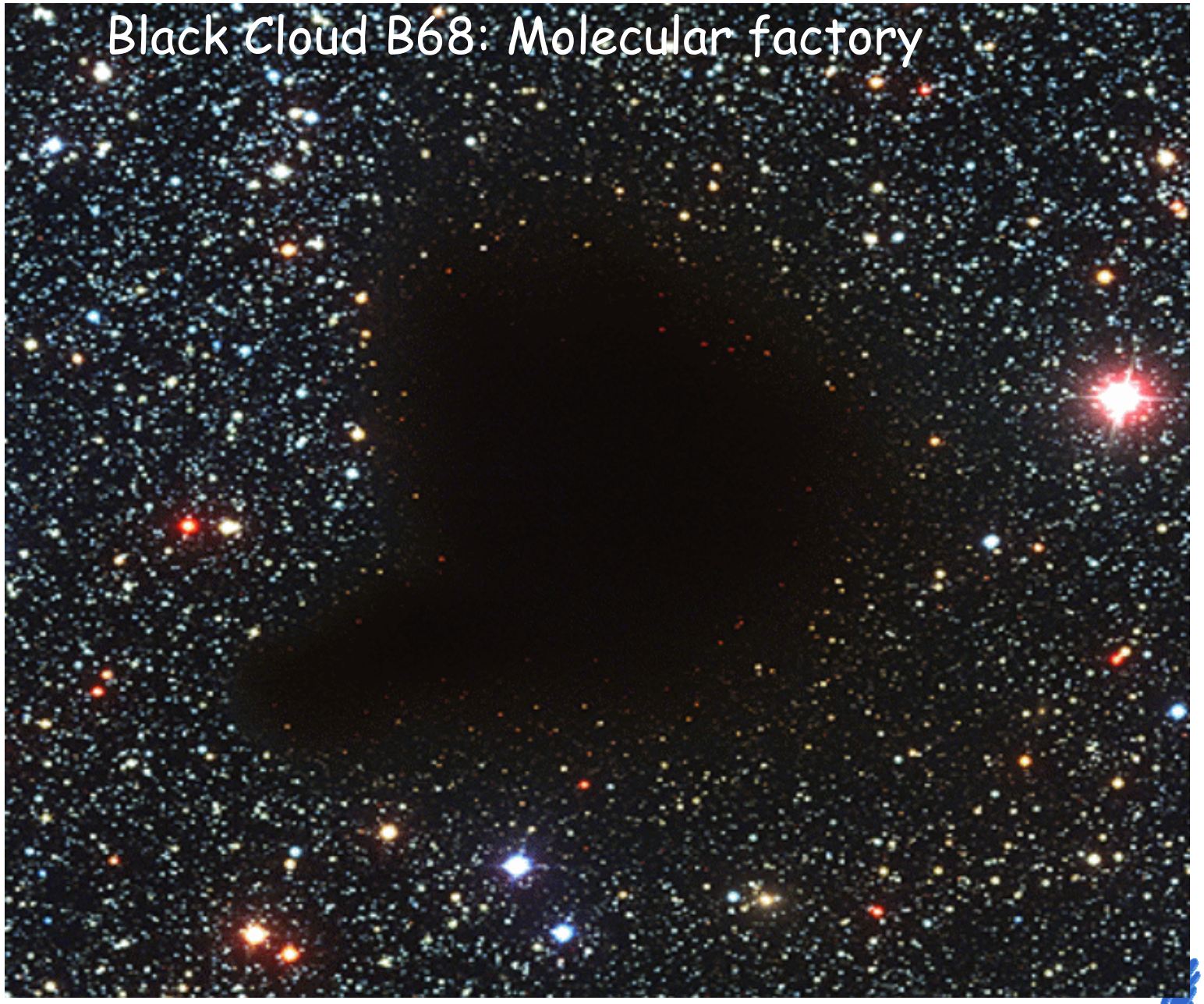
-repeated pattern of core collaps and subsequent fusion

-last stage: Si burns into Fe (takes one week)

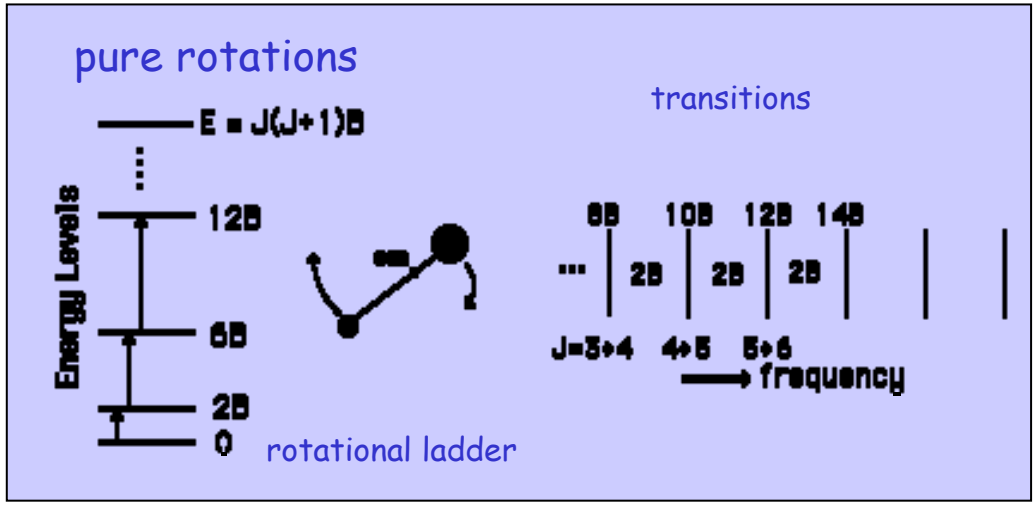
-gravitational collaps in 1s 10 km diameter, only neutrons

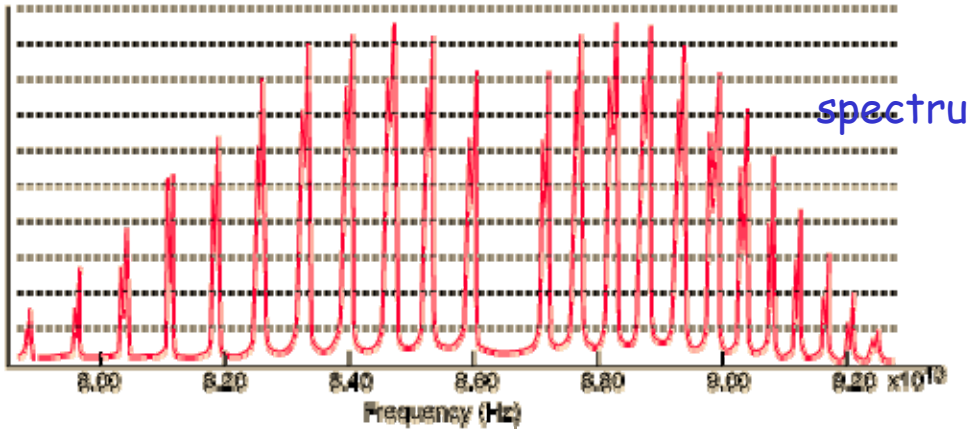
-potential energy causes a shock emission of energy (99% neutrinos)

Black Cloud B68: Molecular factory

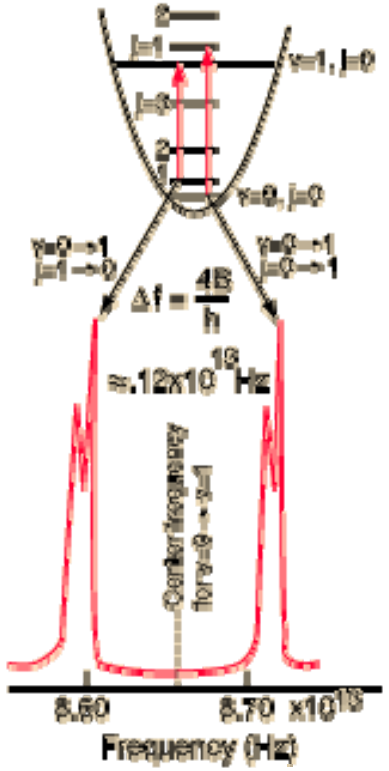


Structure of diatoms





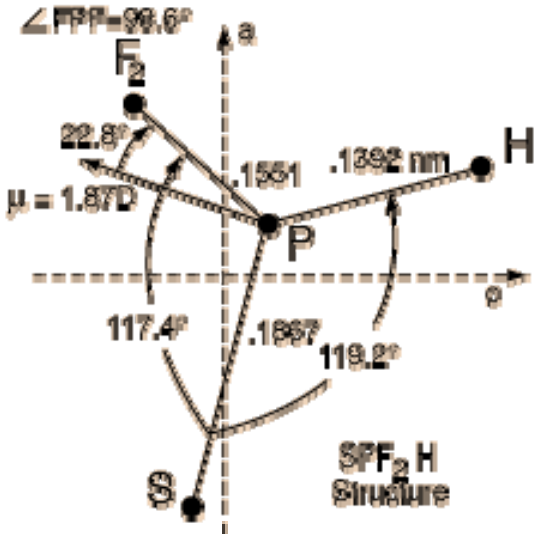
spectrum HCl



dipole moment required

Poly-atomic molecules

3 rotational axes



$$KE_{rotational} = \frac{1}{2} I\omega^2 = \frac{J^2}{2I}$$

$$KE_{rot} = \frac{1}{2} I_a \omega_a^2 + \frac{1}{2} I_b \omega_b^2 + \frac{1}{2} I_c \omega_c^2$$

in general 3 axes of rotation: 3 inertial moments

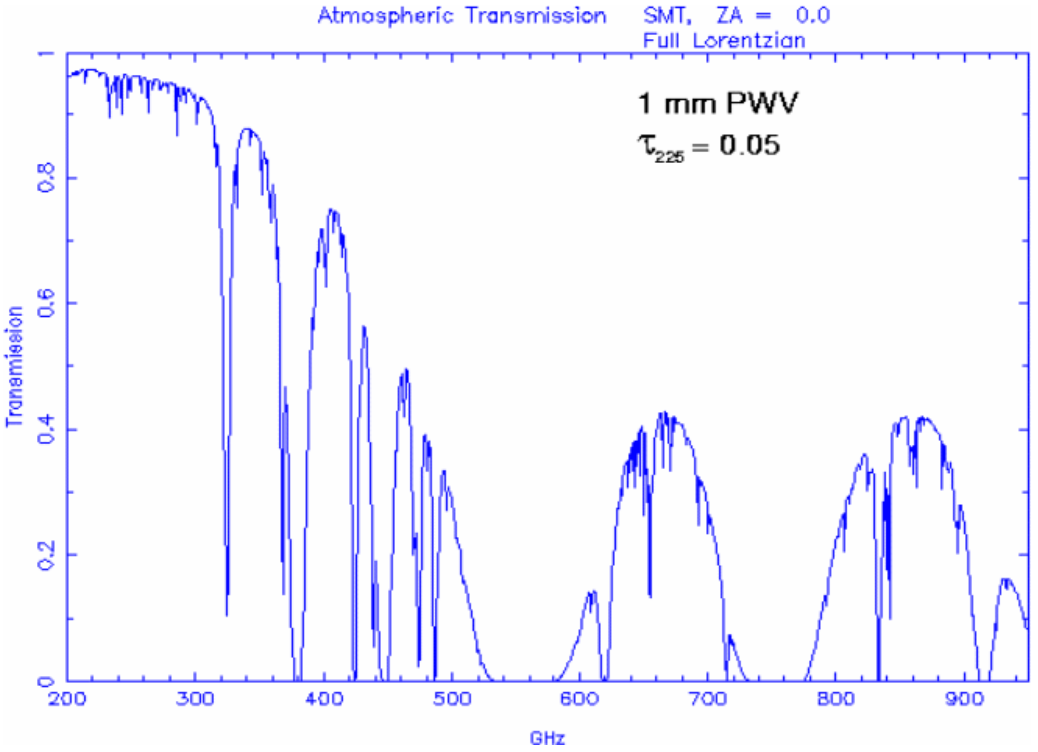
3 rotational quantum numbers:

J, K_a, K_c

Microwave spectroscopy gives I-moments directly

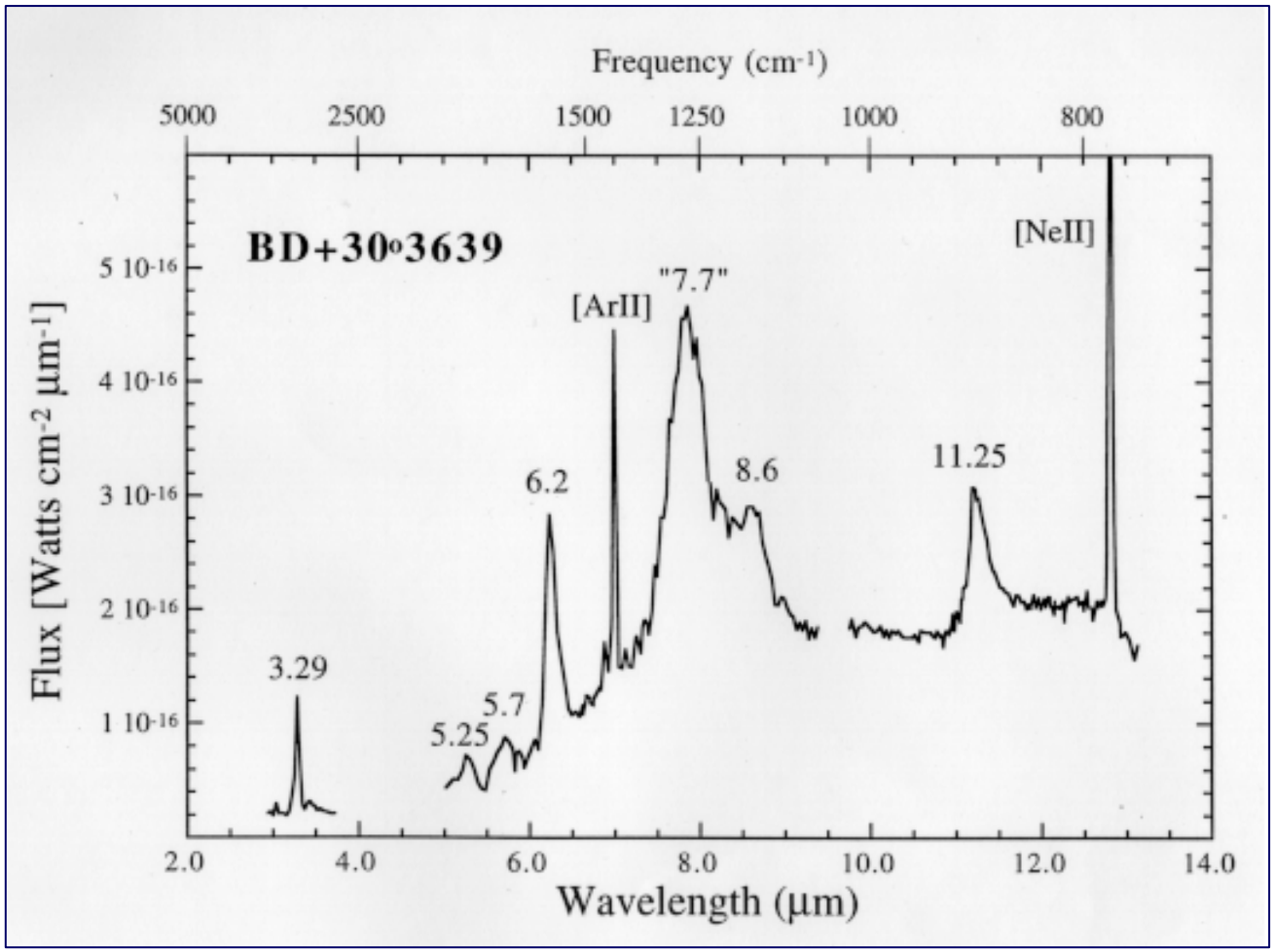
Observation of molecules mostly by Radio-Astronomy

Westerbork Telescope Array



Only in atmospheric "window

"The Unidentified Infrared (UIR) Bands and the PAH-hypothesis

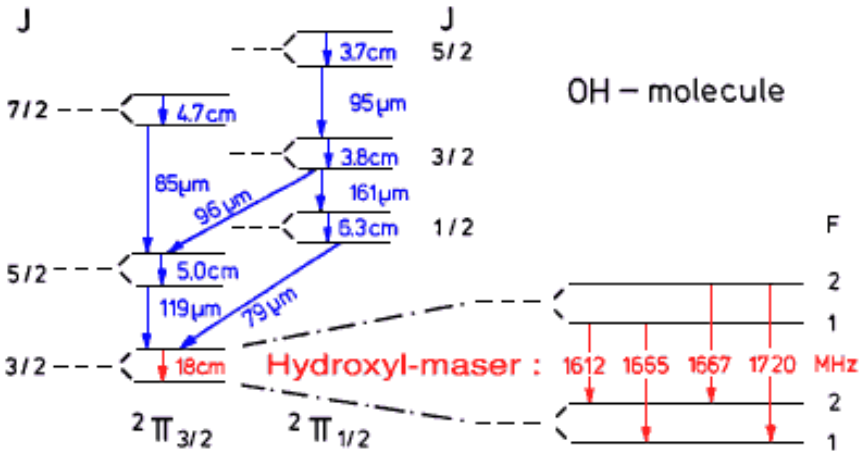


Infrared spectroscopic features observed, mostly from hot regions (dust exposed to UV radiation)

Interstellar Masers

Orion nebula

Hydroxyl radical - OH



Level scheme
OH molecule

$\nu = 1.6$ GHz

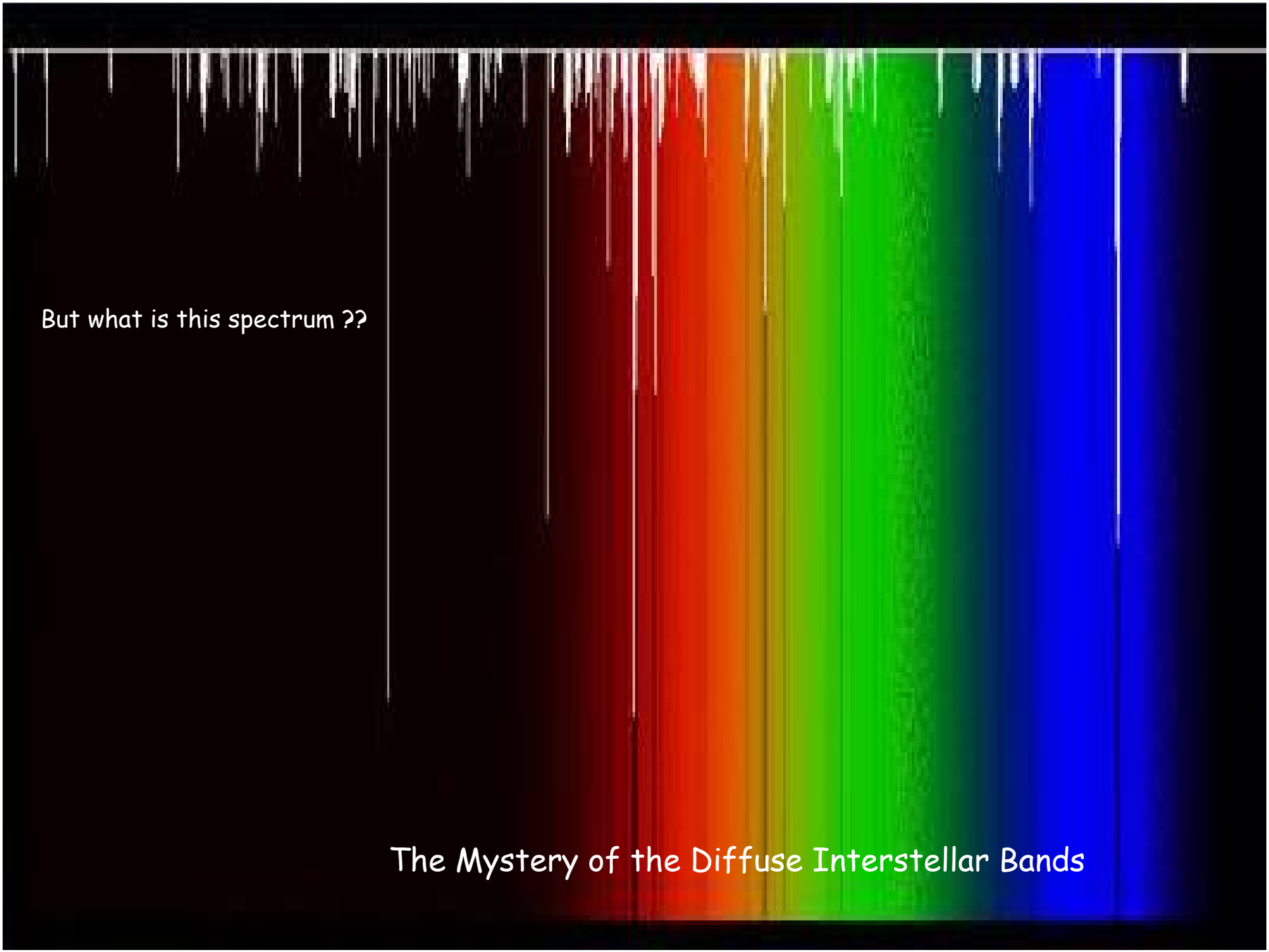
Also: H_2O, SiO, Methanol masers

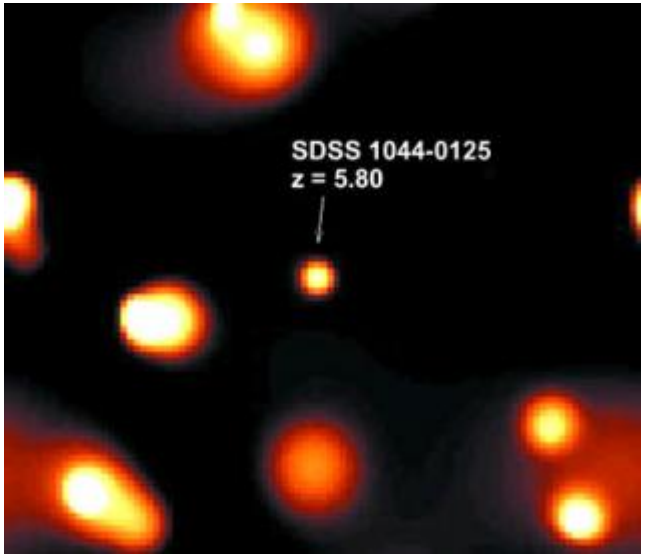
Molecules observed in Interstellar Space

Number of Atoms										
2	3	4	5	6	7	8	9	10	11	12+
H_2	C_3	c-C_3H	C_5	C_5H	C_6H	CH_3C_3N	CH_3C_4H	CH_3C_5N?	HC_9N	C_6H_6
AlF	C_2H	l-C_3H	C_4H	l-H_2C_4	CH_2CHCN	$HCOOCH_3$	CH_3CH_2CN	$(CH_3)_2CO$		$HC_{11}N$
AlCl	C_2O	C_3N	C_4Si	C_2H_4	CH_3C_2H	CH_3COOH?	$(CH_3)_2O$	NH_2CH_2COOH?		PAHs
C_2	C_2S	C_3O	l-C_3H_2	CH_3CN	HC_5N	C_7H	CH_3CH_2OH			C_{60}^+?
CH	CH_2	C_3S	c-C_3H_2	CH_3NC	$HCOCH_3$	H_2C_6	HC_7N			
CH^+	HCN	C_2H_2	CH_2CN	CH_3OH	NH_2CH_3		C_8H			
CN	HCO	CH_2D^+?	CH_4	CH_3SH	c-C_2H_4O					
CO	HCO^+	HCCN	HC_3N	HC_3NH^+						
CO^+	HCS^+	$HCNH^+$	HC_2NC	HC_2CHO						
CP	HOC^+	HNCO	HCOOH	NH_2CHO						
CSi	H_2O	HNCS	H_2CHN	C_5N						
HCl	H_2S	$HOCO^+$	H_2C_2O							
KCl	HNC	H_2CO	H_2NCN							
NH	HNO	H_2CN	HNC_3							
NO	MgCN	H_2CS	SiH_4							
NS	MgNC	H_3O^+	H_2COH^+							
NaCl	N_2H^+	NH_3								
OH	N_2O	SiC_3								
PN	NaCN	CH_3								
SO	OCS									
SO^+	SO_2									
SiN	c-SiC_2									
SiO	CO_2									
SiS	NH_2									
CS	H_3^+									
HF	H_2D^+									

Detection of amino acetonitrile in Sgr B2(N)

2008


But what is this spectrum ??
The Mystery of the Diffuse Interstellar Bands



VOLUME 82, NUMBER 5 PHYSICAL REVIEW LETTERS 1 FEBRUARY 1999

Search for Time Variation of the Fine Structure Constant

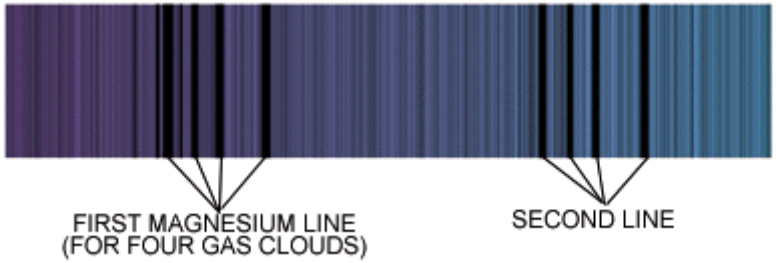
John K. Webb,[1] Victor V. Flambaum,[1] Christopher W. Churchill,[2] Michael J. Drinkwater,[1] and John D. Barrow[3]
[1]*School of Physics, University of New South Wales, Sydney, New South Wales 2052, Australia*
[2]*Department of Astronomy & Astrophysics, Pennsylvania State University, University Park, Pennsylvania 16802*
[3]*Astronomy Centre, University of Sussex, Brighton, BN1 9QJ, United Kingdom*
(Received 13 February 1998; revised manuscript received 9 July 1998)

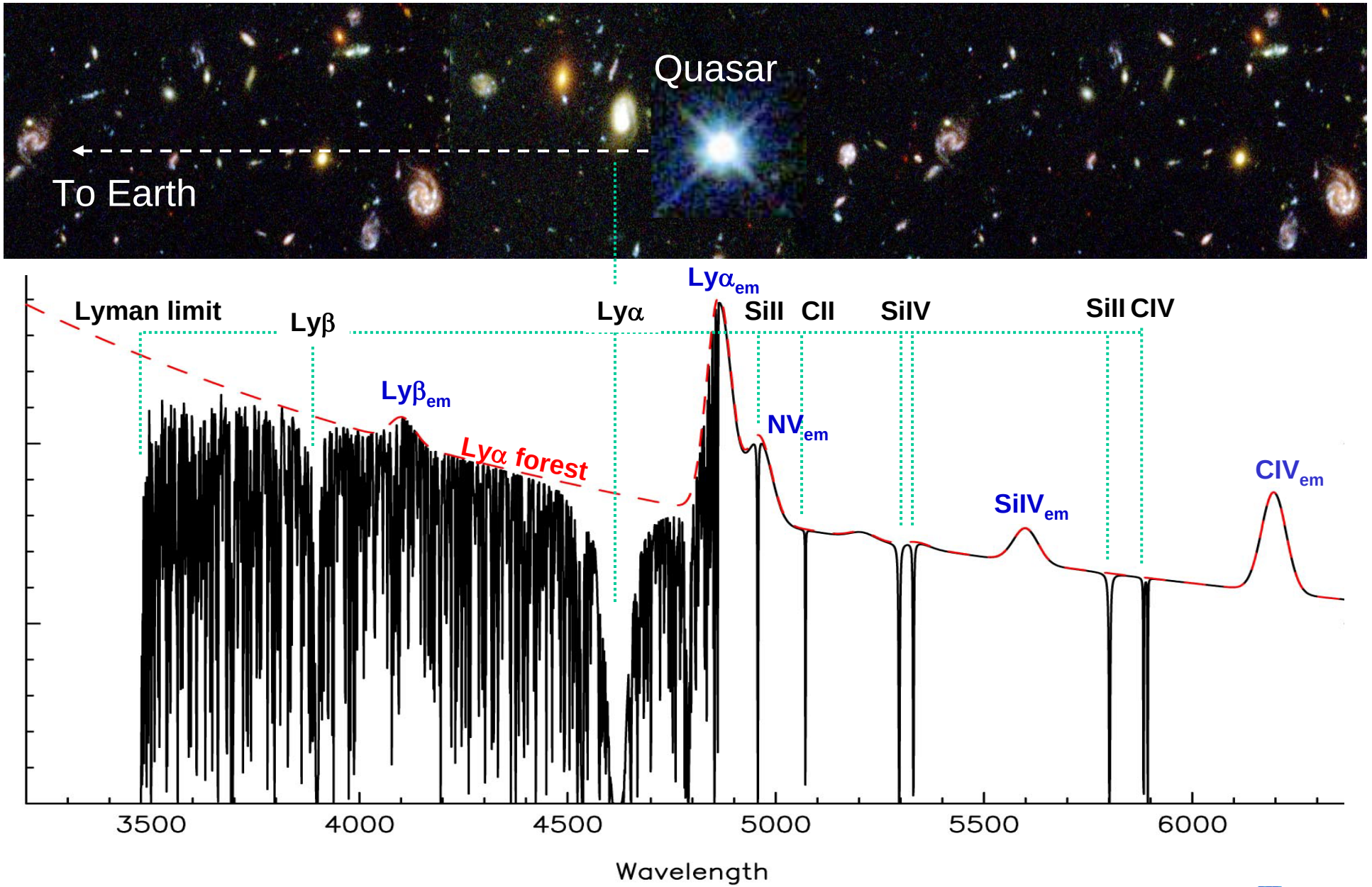
VOLUME 82, NUMBER 5 PHYSICAL REVIEW LETTERS 1 FEBRUARY 1999

Space-Time Variation of Physical Constants and Relativistic Corrections in Atoms

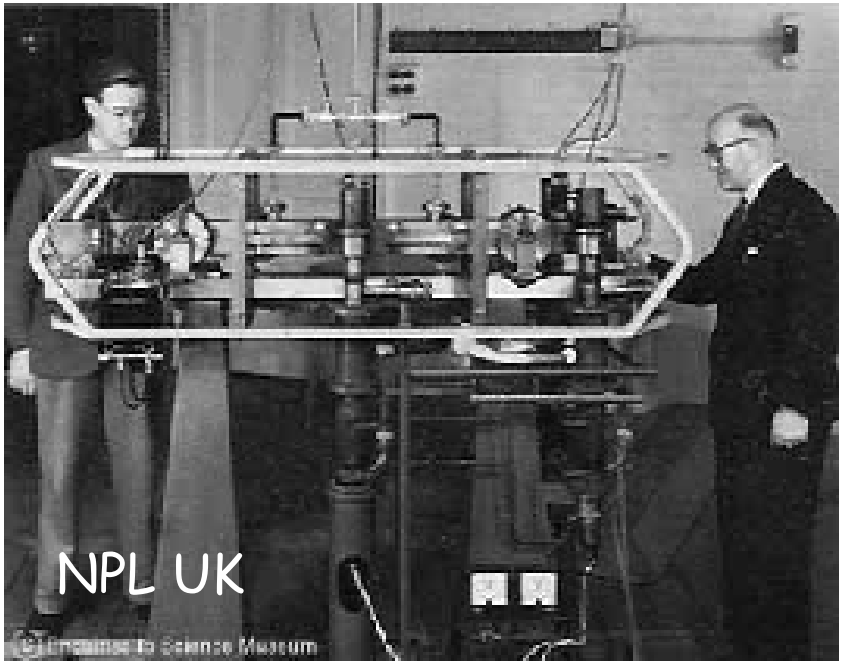
V. A. Dzuba,* V. V. Flambaum, and J. K. Webb
School of Physics, University of New South Wales, Sydney, New South Wales 2052, Australia
(Received 12 February 1998)

Quasars give us the opportunity to look back in time;
The *looking* is done by means of spectroscopy.

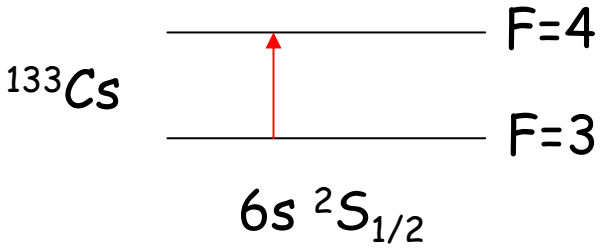



Quasar
To Earth
Lyman limit
Lyβ
Lyβem
Lyα forest
Lyα
Lyαem
SiII
CII
SiIV
SiII CIV
NVem
SiIVem
CIVem
3500
4000
4500
5000
5500
6000
Wavelength

Atoms and clocks



frequency / time standard
9,192,631,770 Herz



Nobelprijs 2005

Frequency combs: extreme precision

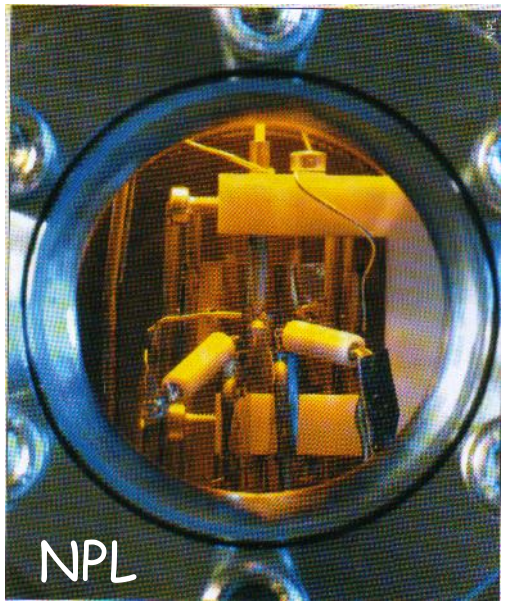
J. Hall

T.W. Hänsch

“for their contributions to the development of laser-based precision spectroscopy including the optical frequency comb technique”

Future atomic clocks: in the optical domain

Ion traps ?



Hg^+, Al^+, Sr^+, Yb^+ ?

NIST, NPL, PTB

Optical lattices ?