# Molecular Masers in Variable Stars

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# Late-type Variables

- Red giant stars, M ~ 1 to a few  $M_{\odot}$ , L ~ a few  $10^3 L_{\odot}$ ,
- Brightness varies at timescales of tens and hundreds of days, due to stellar pulsations.
- Subtypes: Miras (M), Semiregular (SR).
- Optical spectra: spectral types M, S, C.
  Strong molecular bands: TiO, VO (M), ZrO (S), CN, C<sub>2</sub>,... (C).

Sometimes atomic emission lines appear (Balmer series of hydrogen, iron, etc.) - probably

- Losing matter at a rate of  $10^{-6}$ - $10^{-5}M_{\odot}$  per year.
- The lost matter forms a circumstellar envelope, containing molecules and dust.

# Late-type Variables

- Circumstellar dust reradiates stellar light, hence large infrared excesses.
- Circumstellar molecules emit radio lines: thermal (CO, CN, ...) and masering (OH, H<sub>2</sub>O, SiO, HCN).

#### Light Curves of Mira stars Lockwood & Wing 1971

From visual to 1.05 µm

1.05 µm



### Light Curves of Mira stars at 1.05 µm

(Lockwood & Wing 1971)



#### Circumstellar Molecular Masers

- OH  $\lambda = 18$  cm (1612, 1665, 1667 MHz)
- $H_2O \lambda = 1.35 \text{ cm} (6_{16} 5_{23}, 22235 \text{ MHz})$
- SiO λ=7, 3.5, 1.7,... mm: *v*=0, 1, 2, 3, *J*=1-0, 2-1, 3-2,...
- HCN  $\lambda$ =3.4 mm:  $\nu$ =(0 2<sup>0</sup> 0), J=1-0;

 $\lambda = 1.1, 0.85 \text{ mm}: v = (0 \ 1^{1c} 0), J = 3-2, 4-3$ 

Level Diagram of H<sub>2</sub>O



# RS Virginis (Lekht et al. 2001) Visual light curve H<sub>2</sub>O line profiles





#### **RS Virginis**, H<sub>2</sub>O, 1981-2000 (Lekht et al. 2001) H<sub>2</sub>O flux correlates with the visual curve, H<sub>2</sub>O lags behind by 0.2-0.4*P*



#### RS Vir, $H_2O-m_{vis}$ correlation (Lekht et al. 2001) $R(\tau) = \langle F_{H2O}(t + \tau) F_{vis}(t) \rangle / \langle F_{H2O}(t + \tau) F_{vis}(t) \rangle_{max}$



#### U Orionis, H<sub>2</sub>O, 1980-2000 Rudnitskij et al. 2000





#### U Orionis, H<sub>2</sub>O, VLA, 1988 Dec 12 Bowers & Johnston, 1994



#### Pumping by a Spherical Shock (Rudnitskij & Chuprikov, 1990)



# R Leo

 $H_2O$ 

100 50

n

F., Jy

-6

### (Esipov et al., 1999) Optical spectrum





# R Leo (Esipov et al., 1999) Visual light curve, Hα flux, H<sub>2</sub>O flux, 1994-1999



# VX Sgr (M-type supergiant, SR variable) (Pashchenko & Rudnitskij, 1999) H<sub>2</sub>O Bipolar outflow model





### **Extra-solar Planets Catalog**

From the <u>Extrasolar Planets Encyclopaedia</u> http://www.obspm.fr/planets Global statistics (as of Nov 21, 2001):

66 planetary systems, 74 planets, 7 multiple planets systems

STAR	<b>M[.SIN<i>I</i>]</b> Jup. mass	Semimajor axis (AU)	<b>PERIOD</b> days	ECC.	INCL. (deg)
<u>HD 83443</u>	0.35 0.16	0.038 0.174	2.9861 29.83	0.08 0.42	- -
<u>HD 16141</u>	0.215	0.35	75.82	0.28	-
<u>HD 168746</u>	0.24	0.066	6.409	0.	-
<u>HD 46375</u>	0.249	0.041	3.024	0.	-
<u>HD 108147</u>	0.34	0.098	10.881	0.558	-
<u>HD 75289</u>	0.42	0.046	3.51	0.054	-
<u>51 Peg</u>	0.47	0.05	4.2293	0.0	-
<u>BD -10 3166</u>	0.48	0.046	3.487	0.	< 84.3°

Millimetre Science with the

Upgraded Australia Telescope

# Planet-driven shock

