Modelling non-thermal massive radio emitters

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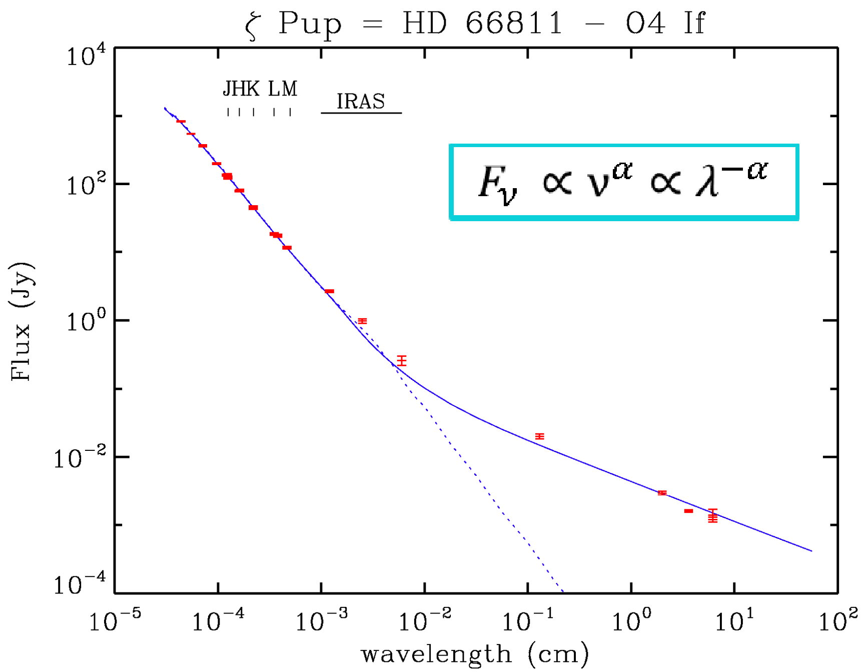
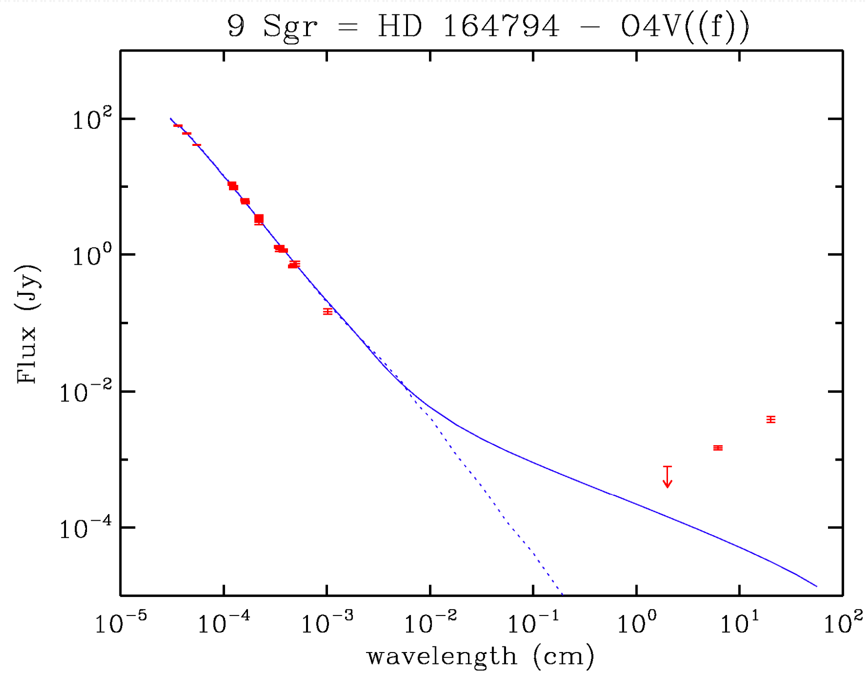
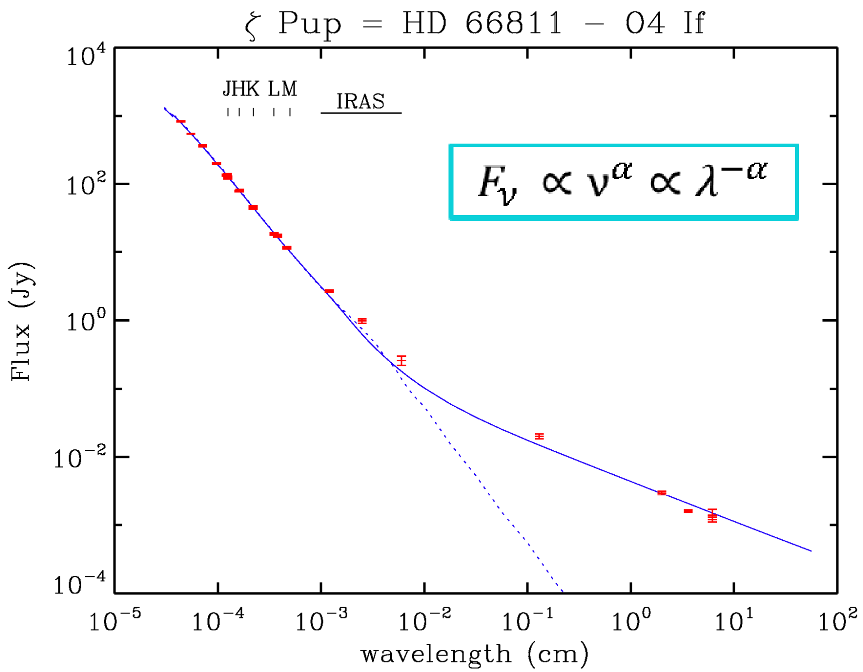
Thermal

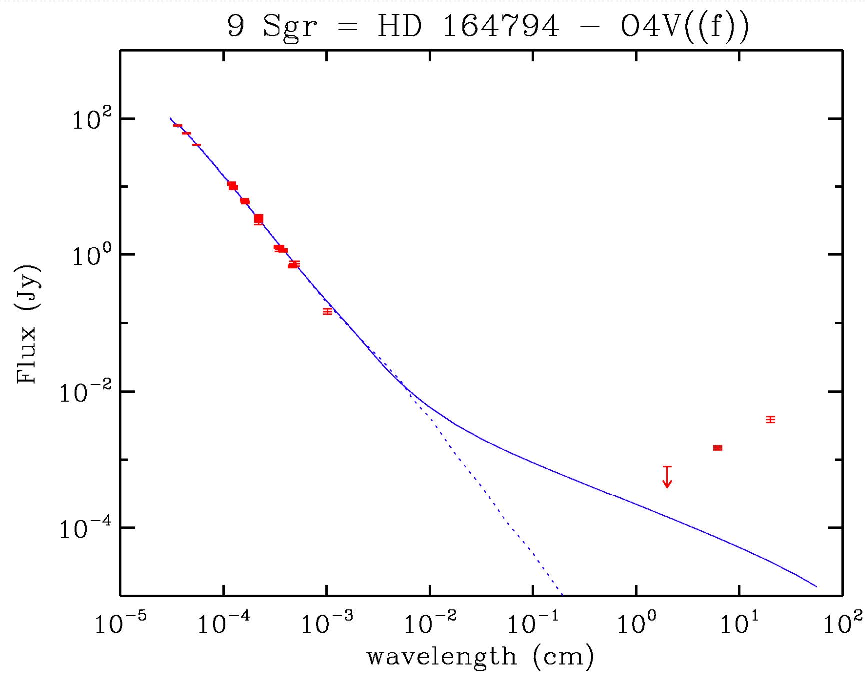




- OB-stars show thermal radio emission with spectral index $\alpha > 0$
- The radio thermal radiation is due to the free-free emission in the ionized material of the stellar wind

Thermal



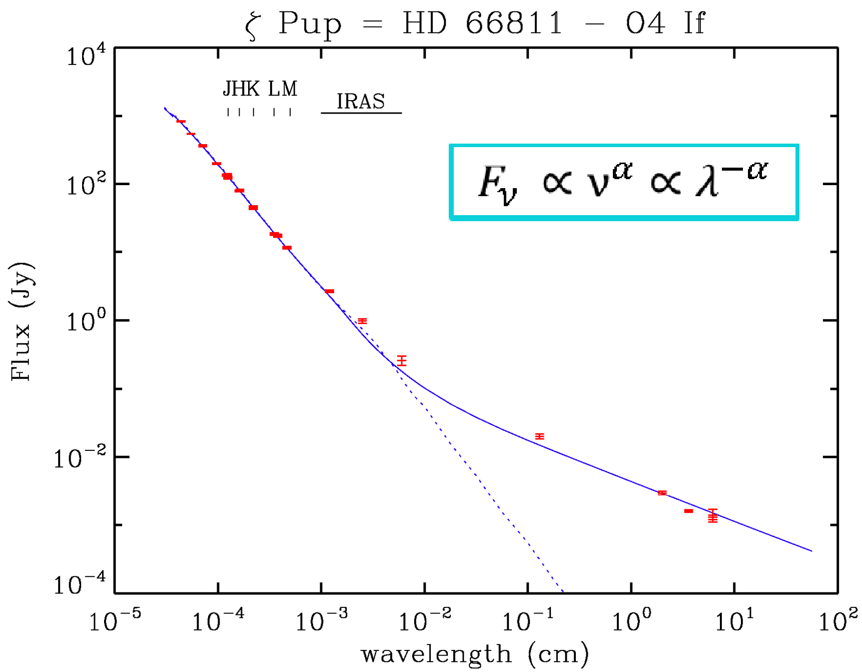


The radio flux F_ν is given by the Wright and Barlow (1975) formula:

$$F_\nu \propto \left(\frac{\dot{M}}{v_\infty}\right)^{4/3} \lambda^{-\alpha} \qquad \alpha = +0.6$$

$\dot{M}$ = mass-loss rate
v_∞ = terminal wind velocity

Thermal



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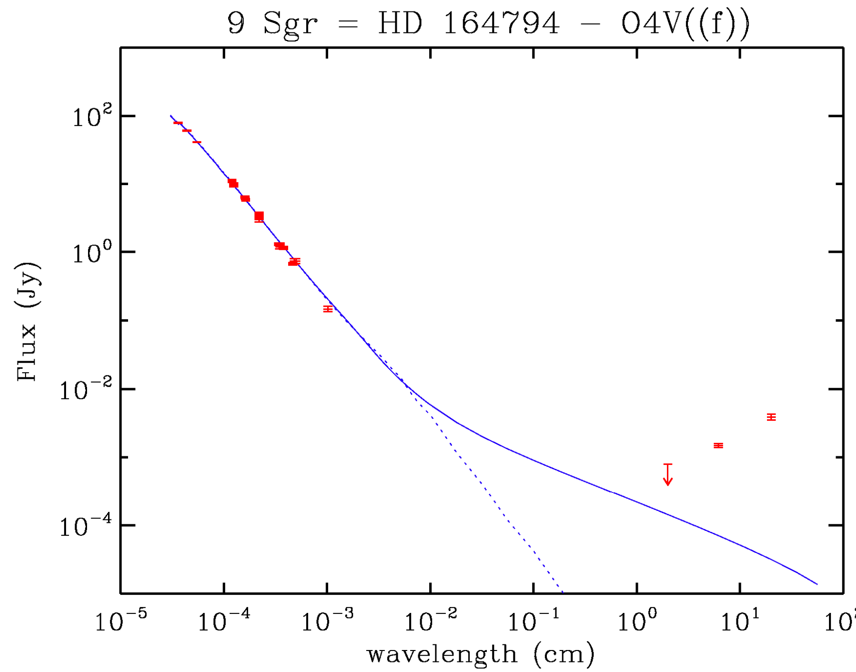
Non-thermal



Spectral index is $\alpha \leq 0$

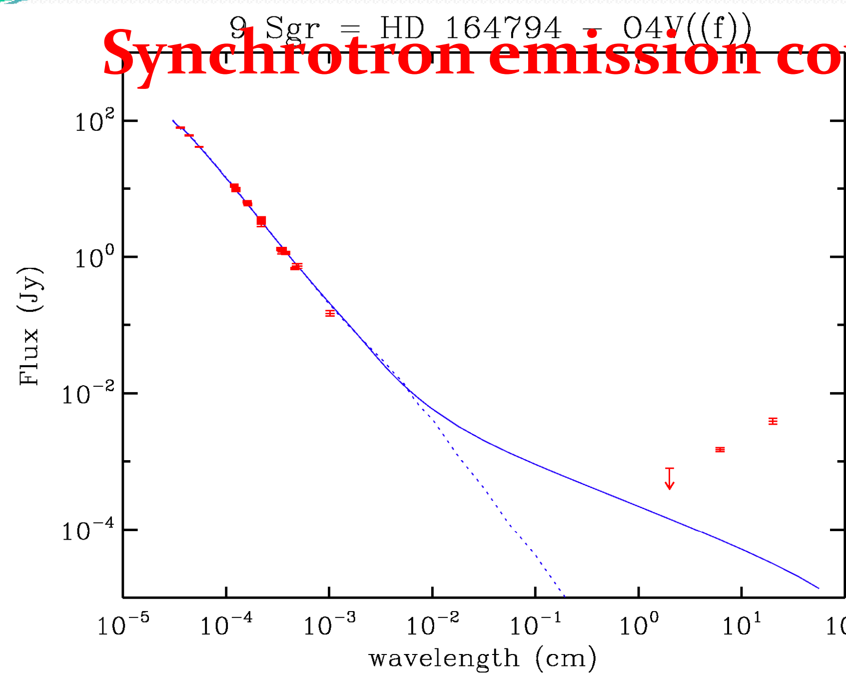
Flux variability

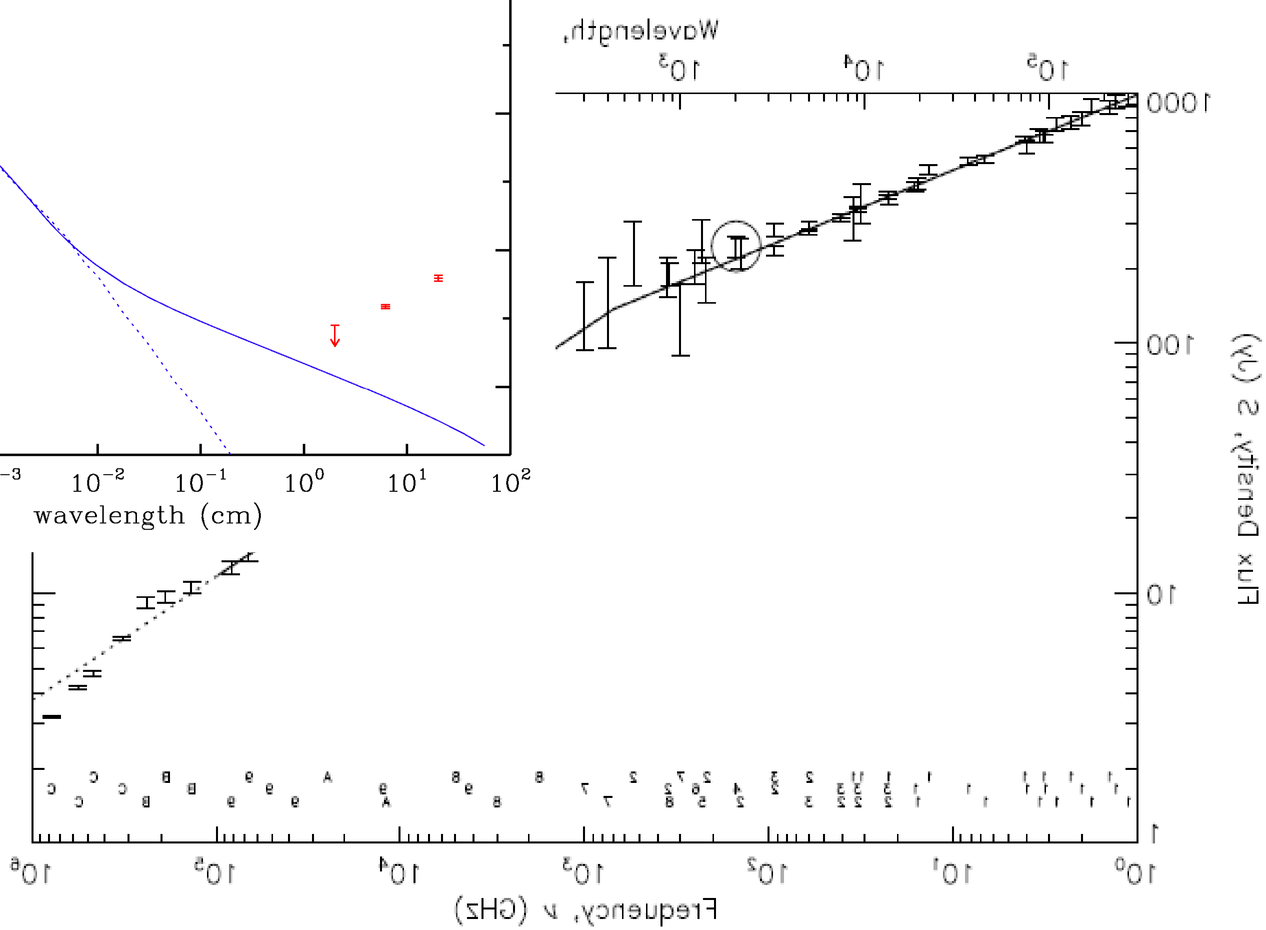
Mass-loss rate higher than in UV, H_α

Higher brightness T

25% OB stars are non-thermal
(Bieging et al. 1989)

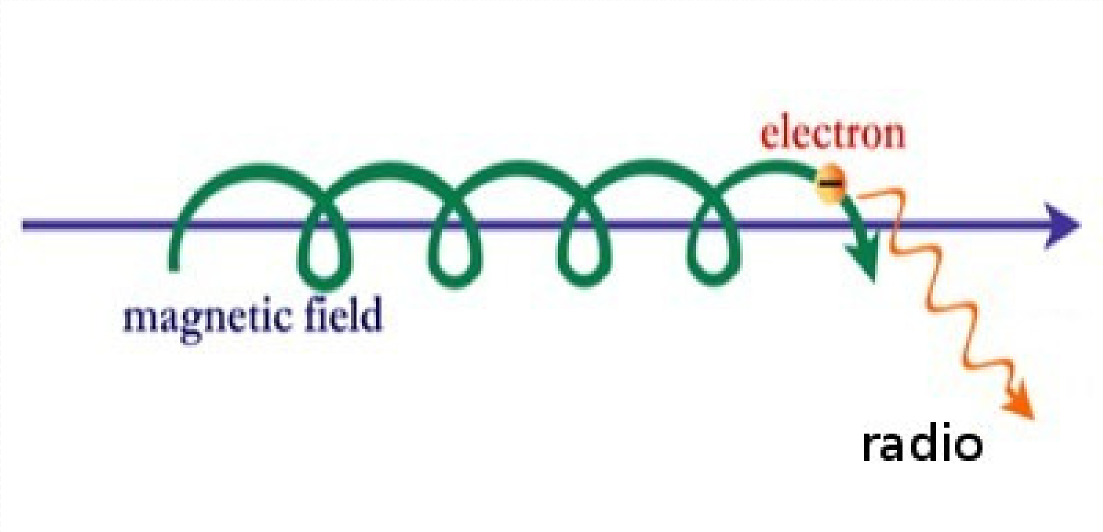
Synchrotron emission could be a possible explanation





Radio (ESO, WMAP) - optical spectrum of Crab Nebula (Arendt et al. 2011)

Synchrotron radiation



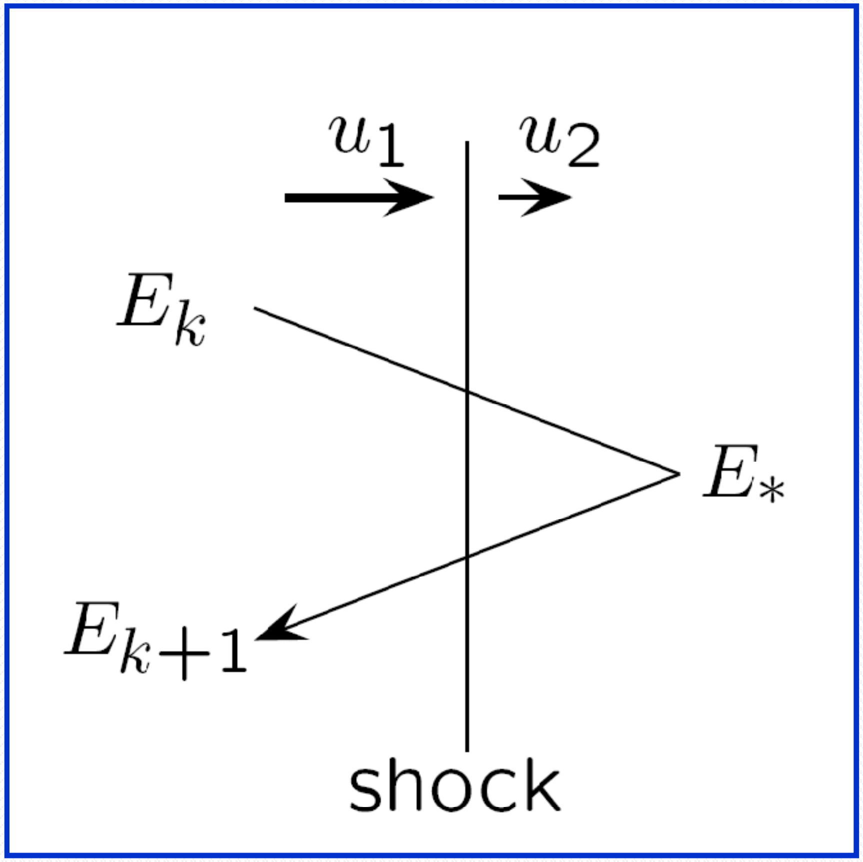
(http://www.astro.wisc.edu/~bank/index.html)

Where do the relativistic electrons come from?

They cannot be produced at T=40000K with a thermal mechanism

Particle acceleration

First-order Fermi acceleration mechanism at collisionless shocks



Distribution of particle momenta

- The particle momentum density distribution at the shock is a power-law:

$$N(p) \sim p^{-(\chi+2)/(\chi-1)}$$ (Bell 1978)

p = particle momentum

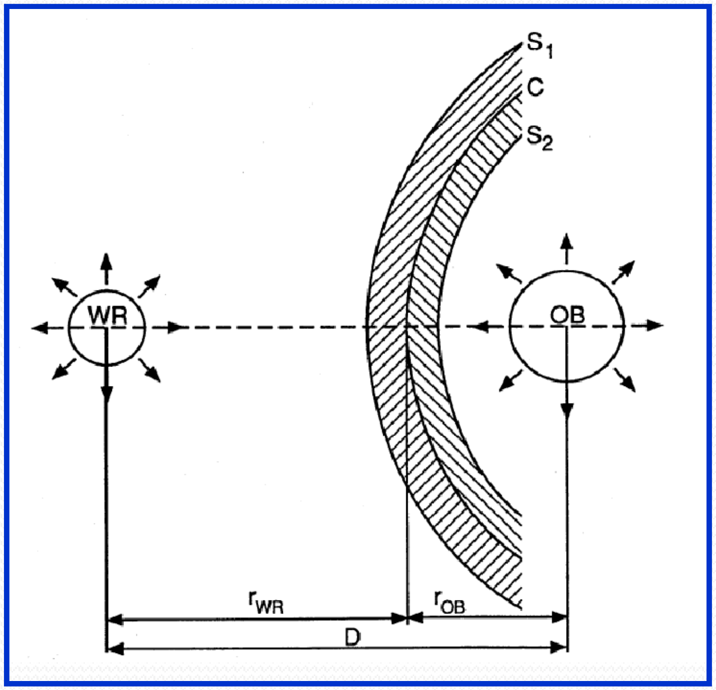
$\chi = u_1/u_2$ = shock compression ratio

- The spectral index of the synchrotron emission:

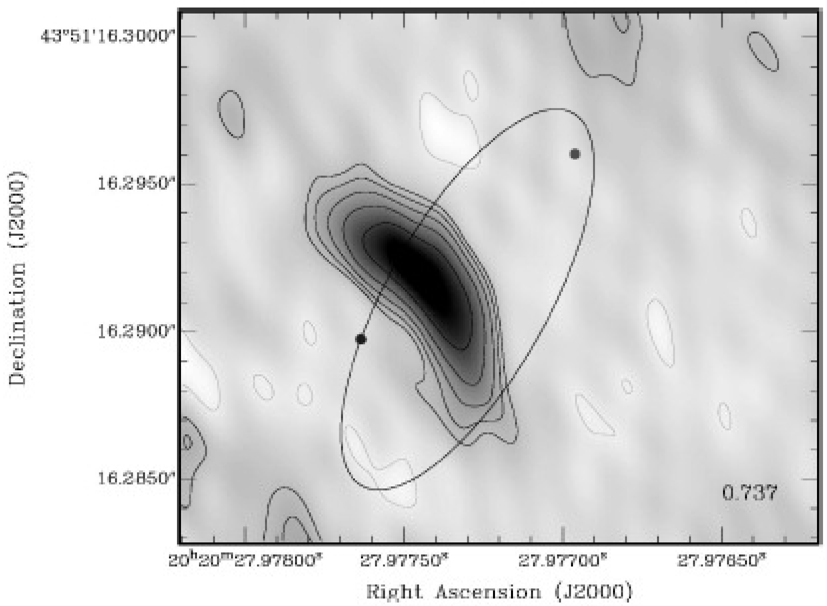
$$\alpha \approx -\frac{3}{2(\chi-1)}$$ (Rybicki & Lightman 1979)

Binary stars

Their colliding winds create the contact discontinuity and *bow-shaped* shocks

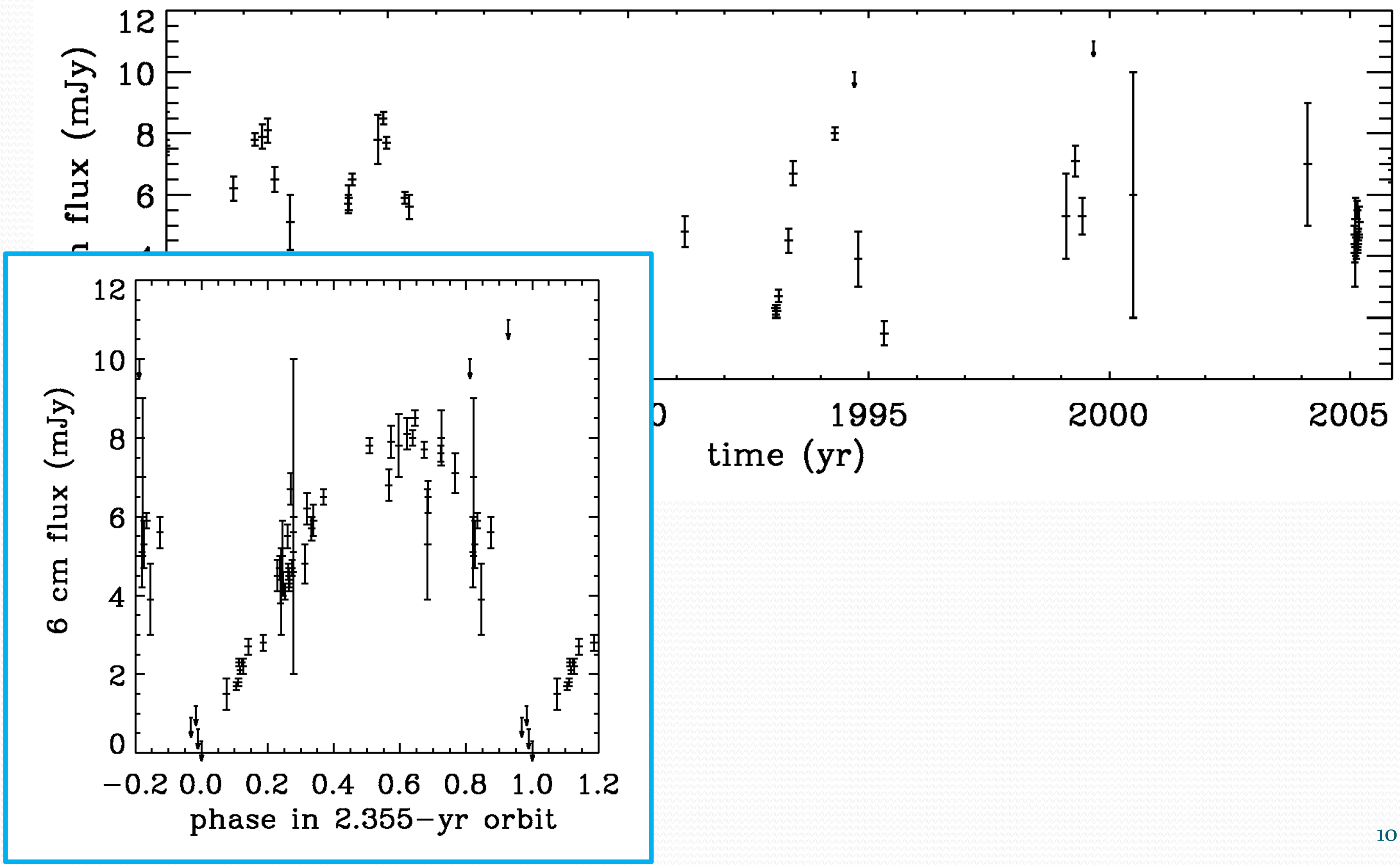


(Eichler & Usov 1993)



WR 140 (8.4 GHz VLBA, Dougherty et al. 2005)

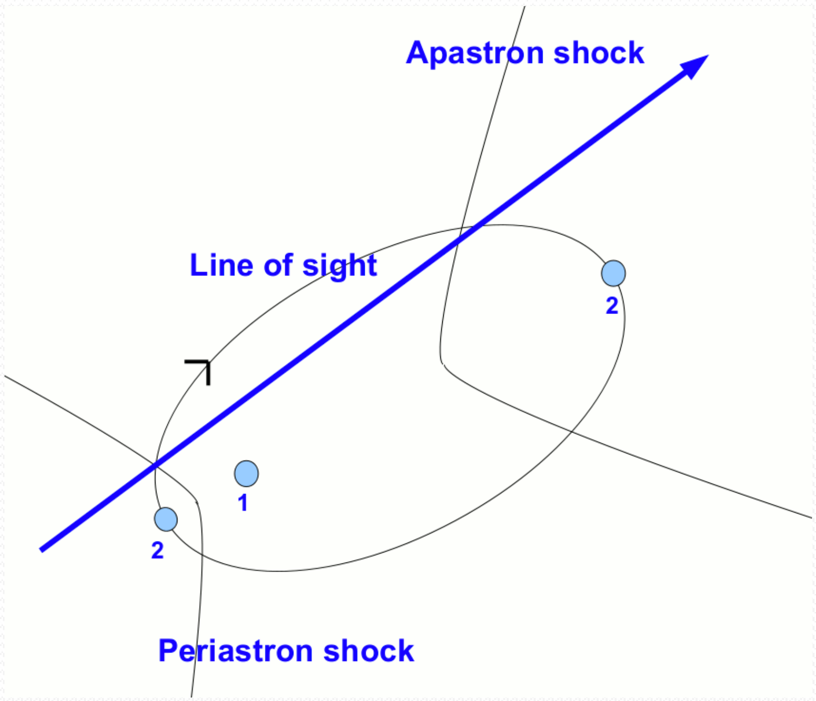
Cyg OB2 No. 9. (VLA, Van Loo et al. 2008)



How does binarity explain variability ?

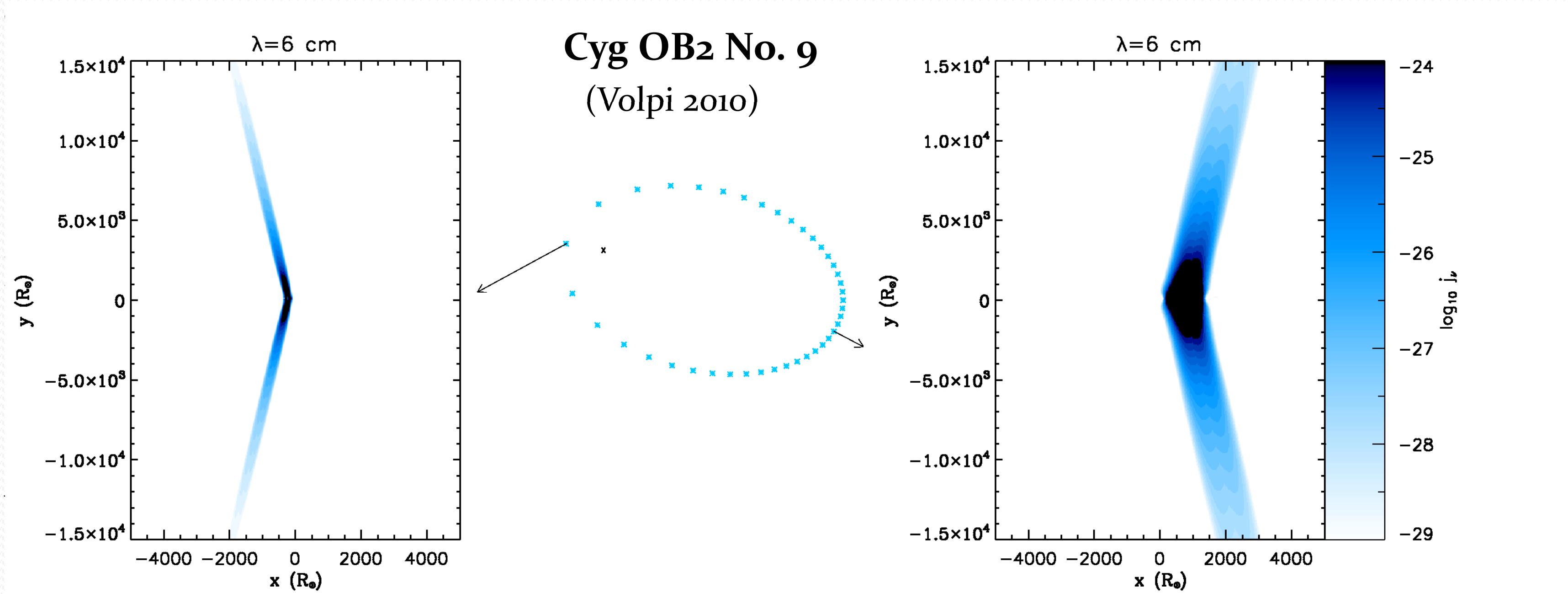
There are two contributions:

- Intrinsic synchrotron variations due to the changes in collision energy linked to orbital phase
- Changing free-free absorption along the sightline



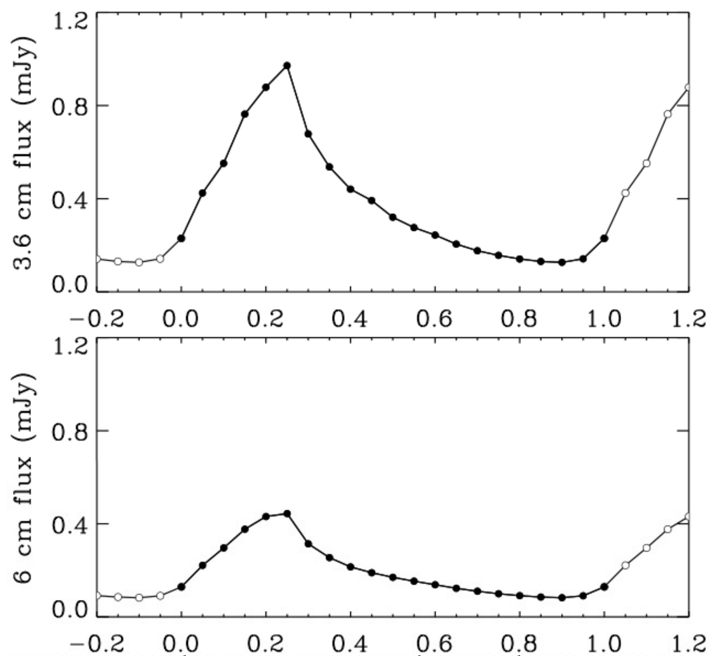
Theoretical model

- The two winds from the binary components collide and create shocks
- The electrons are accelerated at each shock

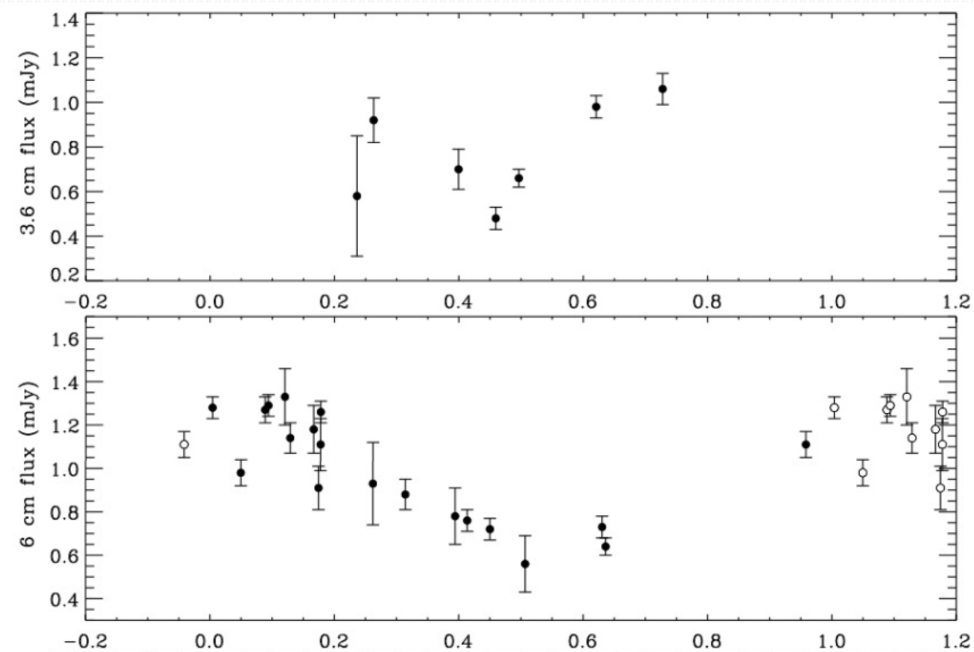


on

Cyg OB2 No. 8A: a 21.9-day binary (De Becker et al. 2004)



phase in 21.9-day orbit



phase in 21.9-day orbit

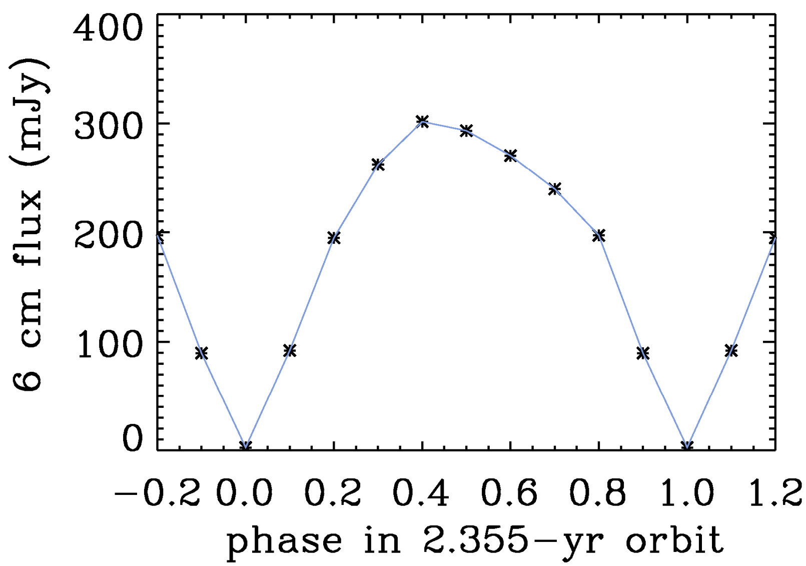
(Blomme et al. 2010)

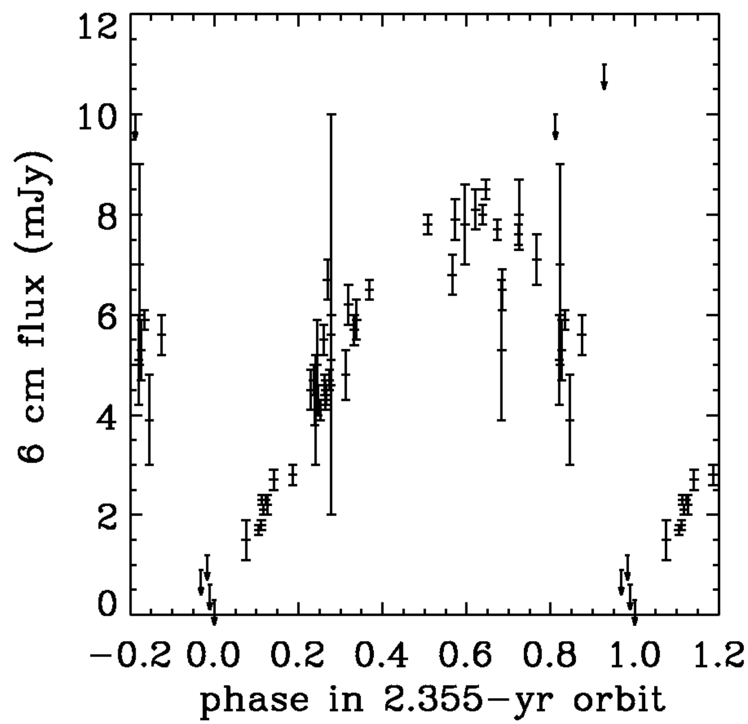
Theoretical model Cyg OB2 No. 8A **VLA data**

☺ Orbital phase-locked variability

☹ Phase of maximum and minimum flux. Add orbital motion to hydrodynamics?

Cyg OB2 No. 9: a 2.355-year binary (Van Loo et al. 2008, Nazé et al. 2008)





☺ Orbital phase-locked variability

☹ The fluxes are too high

☹ The maximum occurs too early
(Volpi 2010)

Changing from analytical hydrodynamical quantities to true hydrodynamics

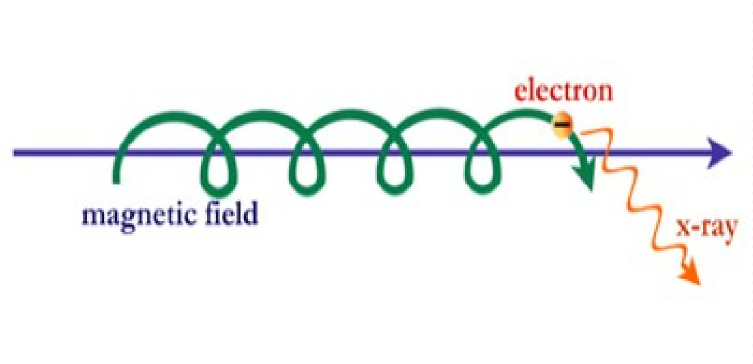
Conclusions

- A negative spectral index, variability, higher brightness T and wrong higher mass loss-rates indicate non-thermal emission
- Colliding wind binary, shocks, relativistic electrons + magnetic field = synchrotron emission explains the non-thermal radiation
- The variability is due to changing synchrotron emission and free-free absorption
- Our model explains qualitatively the variability linked to the orbital period but quantitatively, improvements are still needed

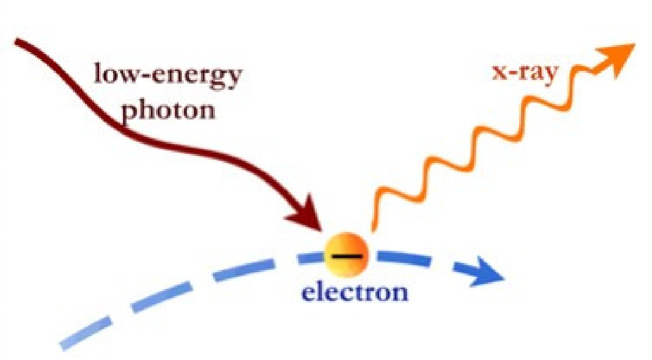
THANKS!

- **Synchrotron radiation:**

(**http://www.astro.wisc.edu/~bank/index.html**, Abbott et al. 1986, Bieging et al 1989):



- **Inverse Compton radiation** (**http://www.astro.wisc.edu/~bank/index.html**):



Introduction

- Non-thermal radiation in the radio band is present in binary systems
  - First observation of non-thermal emission in a binary system by Moran et al. 1989 (MERLIN)
  - Theoretical explanation by Eichler & Usov 1993:

    The colliding winds in the binary create a contact discontinuity and two shocks

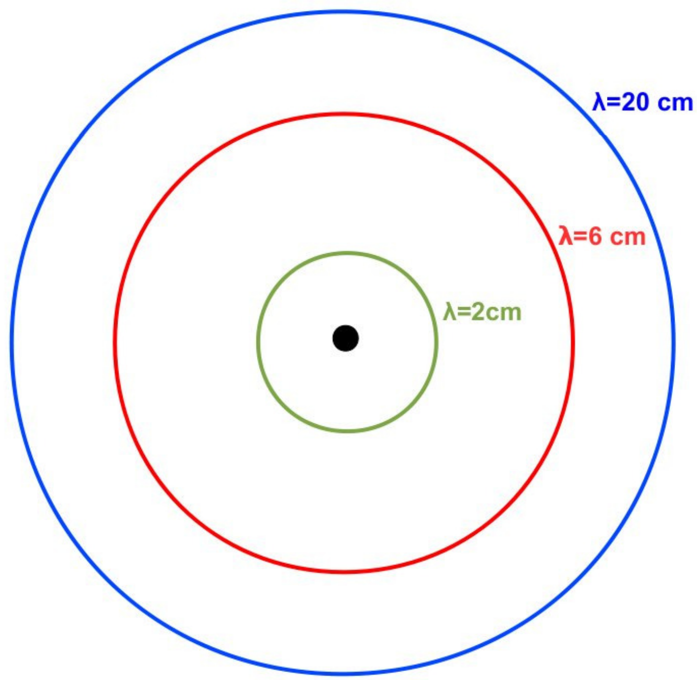
    The electrons are accelerated by the shocks up to relativistic energies

    Ultrarelativistic electrons + B create non-thermal emission called synchrotron radiation

- Non-thermal radiation shows variation linked to the binary period and free-free absorption

Thermal emitters

- $\dot{M}$ is obtained easily from F_ν
- The optical depth for free-free absorption is $\tau \propto \lambda^2$



Anomalies in radio observations of O-type stars

- 25% OB stars show anomalies in the radio continuum
  (Bieging et al. 1989)

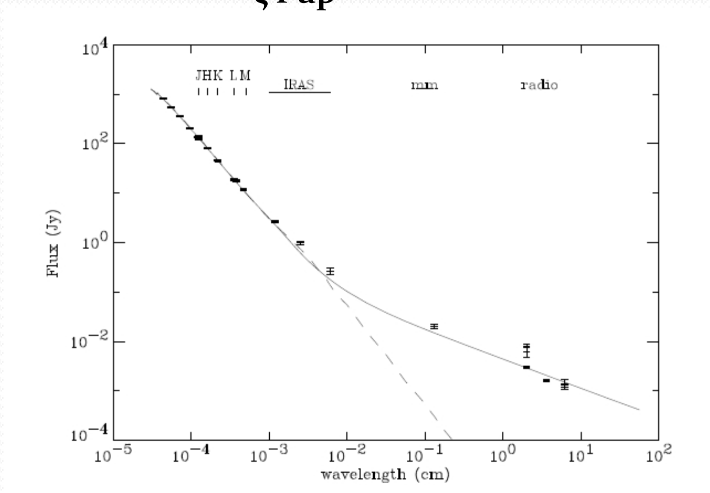
- The radio mass-loss rate is higher than in UV or H_{α}
  (9 Sgr, Abbott et al. 1980)

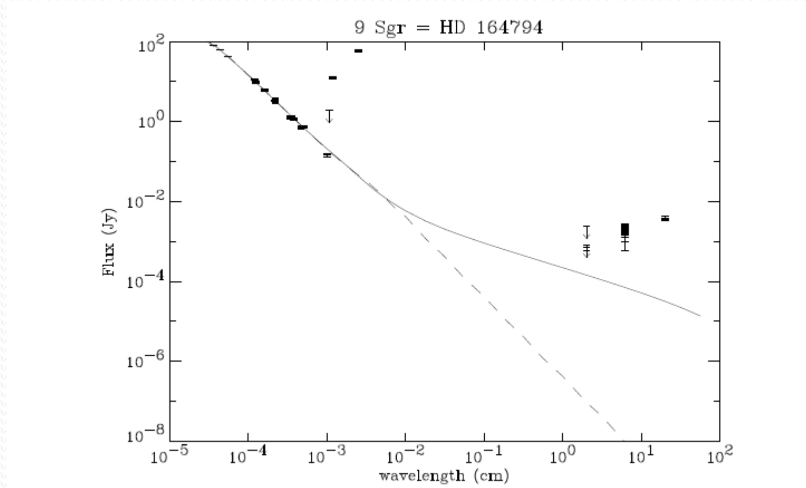
- Brightness T too high to be produced by free-free emission electrons and ions (Cyg OB2 No.9 White & Becker 1983)

Anomalies in radio observations of O-type stars

- Spectral index in radio fluxes is $\alpha \leq 0.0$ (Bieging et al. 1989)

ζ Pup



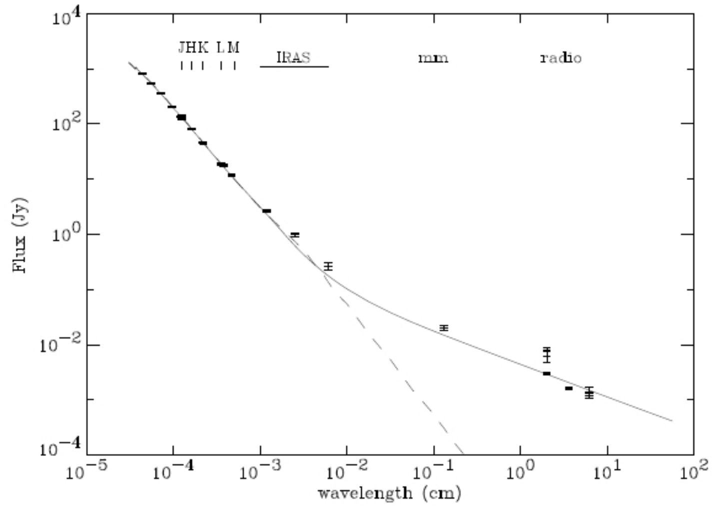


Dashed line=black body radiation
Solid line=thermal emission with α=+0.6 fit the data
(http://www.ast.leeds.ac.uk/~svenvl/journals/JAD.pdf)

Dashed line=black body radiation
Solid line=thermal emission with α=+0.6 does not fit the data
(http://www.ast.leeds.ac.uk/~svenvl/journals/JAD.pdf)

Thermal emitters

- OB-stars show thermal radio emission with spectral index α=+0.6



ζ Pup
Dashed line=black body radiation
Solid line=thermal emission with α=+0.6
(http://www.ast.leeds.ac.uk/~svenvl/journals/JAD.pdf)

Thermal emitters

- The radio thermal radiation is due to the free-free emission in the ionized material of the stellar winds
(Seaquist & Gregory 1973, Olnon 1975, Palagia & Felli 1975, Wright & Barlow 1975)

- The radio flux F_ν is given by the Wright and Barlow (1975)'s formula:

$$F_\nu \propto \left(\frac{\dot{M}}{v_\infty}\right)^{4/3} \left(\frac{1}{\lambda}\right)^{\alpha}$$

$\dot{M}$ = mass-loss rate (in $M_\odot \mathrm{yr}^{-1}$)

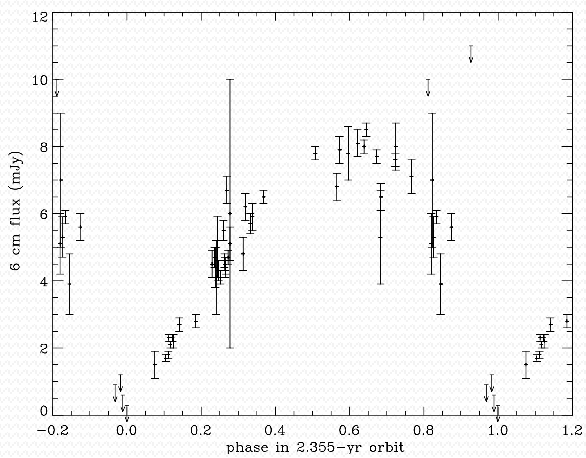
v_∞ = terminal wind velocity (km s^{-1})

λ = radio wavelength (cm)

α=+0.6

Anomalies in radio observations of O-type stars

- Flux variability too high to be due to changes in stellar wind parameters (9 SGr, Cyg OB2 No.9, Abbott et al. 1984)



Cyg OB2 No. 9. Observed VLA 6 cm radio emission (from Van Loo et al. 2008)

Hot massive stars

- Wolf Rayet and **OB early-type**
- First radio detected O-type star: ζ Pup (Morton & Wright 1978)

ζ Pup
(http://www.southern-astro.com.au/gallery.php?PhotoID=10)

- Bieging et al. (1989) surveyed 18 OB-stars with VLA