Betelgeuse – Challenging our Understanding for more than 2000 years

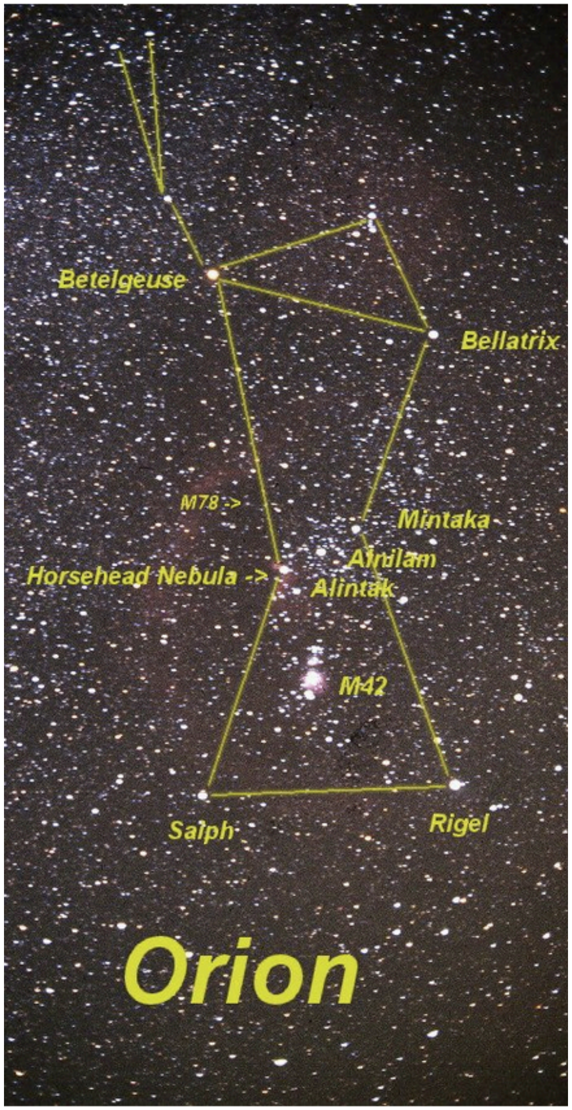
Stephen Ridgway

Betelgeuse Workshop 2012

Nov 26, 2012

30000 BC

The Geissenklosterle carving – a paleolithic star map?



Calendars, Symbols and Orientations: Legacies of Astronomy in Culture, M. Rappenglück, Uppsala Astro. Obs. Report No. 59 (2003).

~ 950

Betelgeuse - Origin of the name

10th Century Book of Constellations,
By Abd al-Rahman al-Sufi.

يد الجوزا   yad al-jauza = hand of the giant

بد الجوزا   bad al-jauza = misspelling

A Dictionary of Modern Star Names, by Paul Kunitzsch and Tim Smart, Sky Publishing, 2006.

2009-11

Public interest also….

- “The Incredible Shrinking Star” (New Scientist)
- “Betelgeuse to explode … or has it exploded already?” (BBC)
- “Will its Violent Death Impact Earth?” (Daily Galaxy)

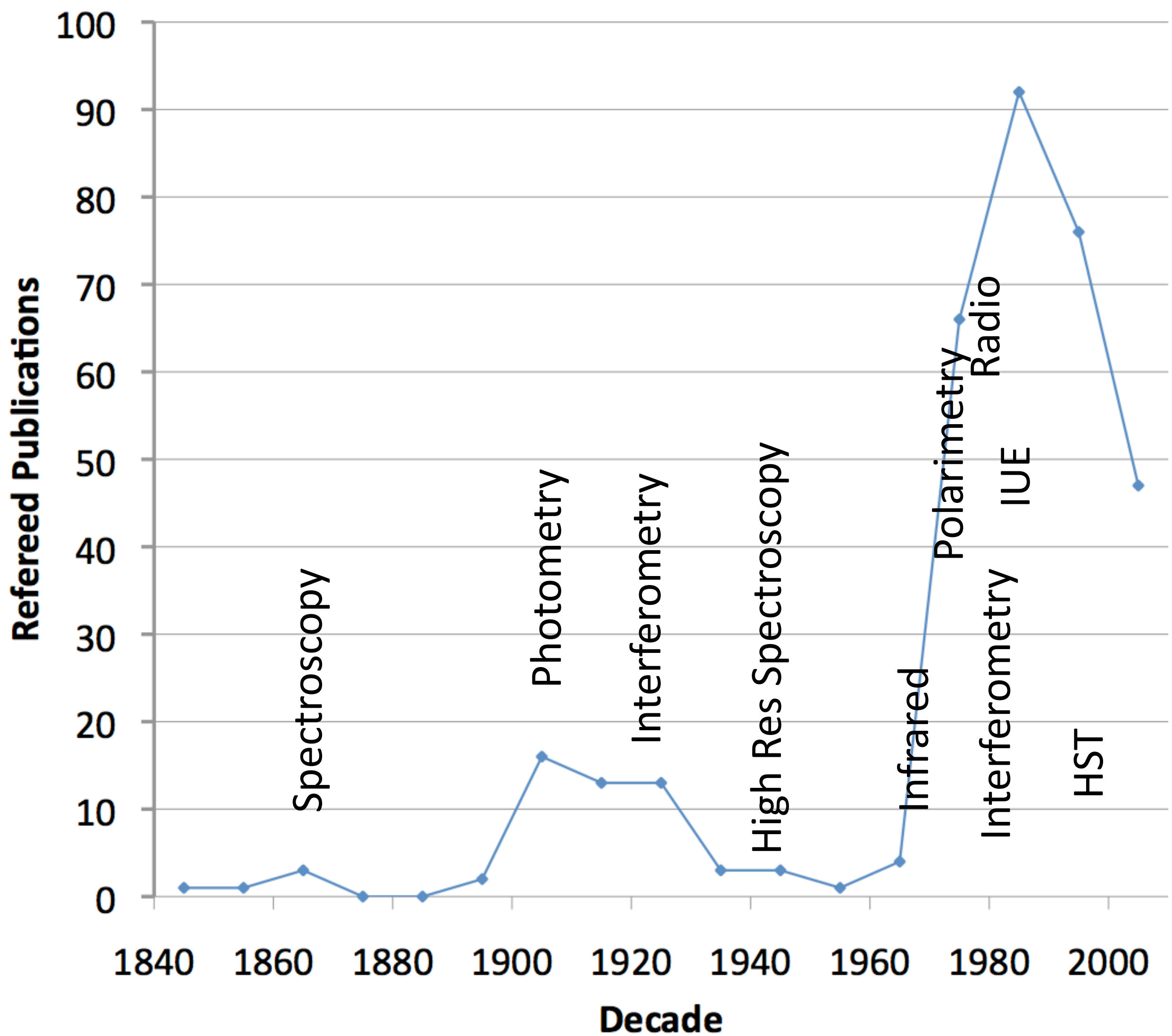
2012

COSMIC PREDICTION
James Kotsybar

Betelgeuse is gonna blow!
It's just a matter of time
It's only ten million years old
But already well past its prime.
Betelgeuse is gonna blow:
Its hydrogen fuel is spent,
And though it's switched its diet,
And decreased by fifteen percent,
Betelgeuse is gonna blow,
And it's gonna happen soon --
Within a hundred thousand years
It will seem as bright as the
moon.
When exactly, we don't know,
But Betelgeuse is gonna blow!

2012

Number of refereed publications on Betelgeuse per decade



12000 BC – 200 AD

Mythological evidence for knowledge of variable stars

- α Ori and α Sco are the only two recognizably variable bright stars
- Myths concerning "variability" of the personalities ascribed to the Orion constellation world-wide: Greece, Hungry, Brazil, North America
- Association of Orion and Scorpio in Greek and Chinese mythology –

Stephen R. Wilk, JAAVSO 27, 1999.

Color of Betelgeuse

- Yellow – early Chinese records
- Ruddy – Ptolemy
- Orange-red – Angelo Secchi

140 BC – 1839 AD

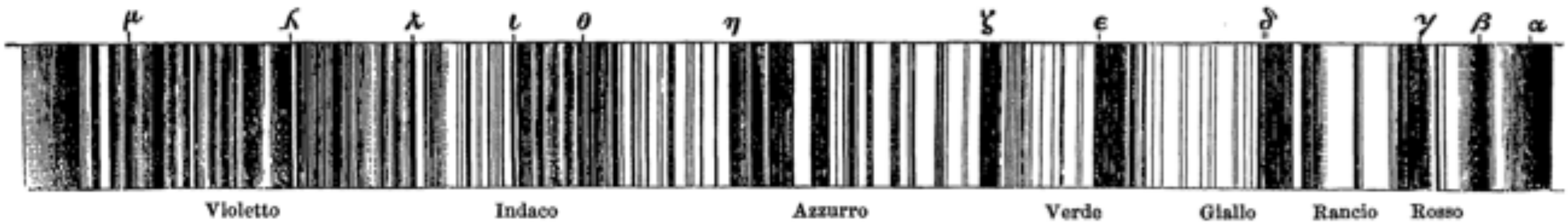
Brightness

- Hipparchus/Ptolemy – the magnitude system
- Brahe/Bayer – the naming convention

- Alpha Ori – V= 0.42
- Beta Ori – V= 0.12

1866 - 1911

Early spectroscopy

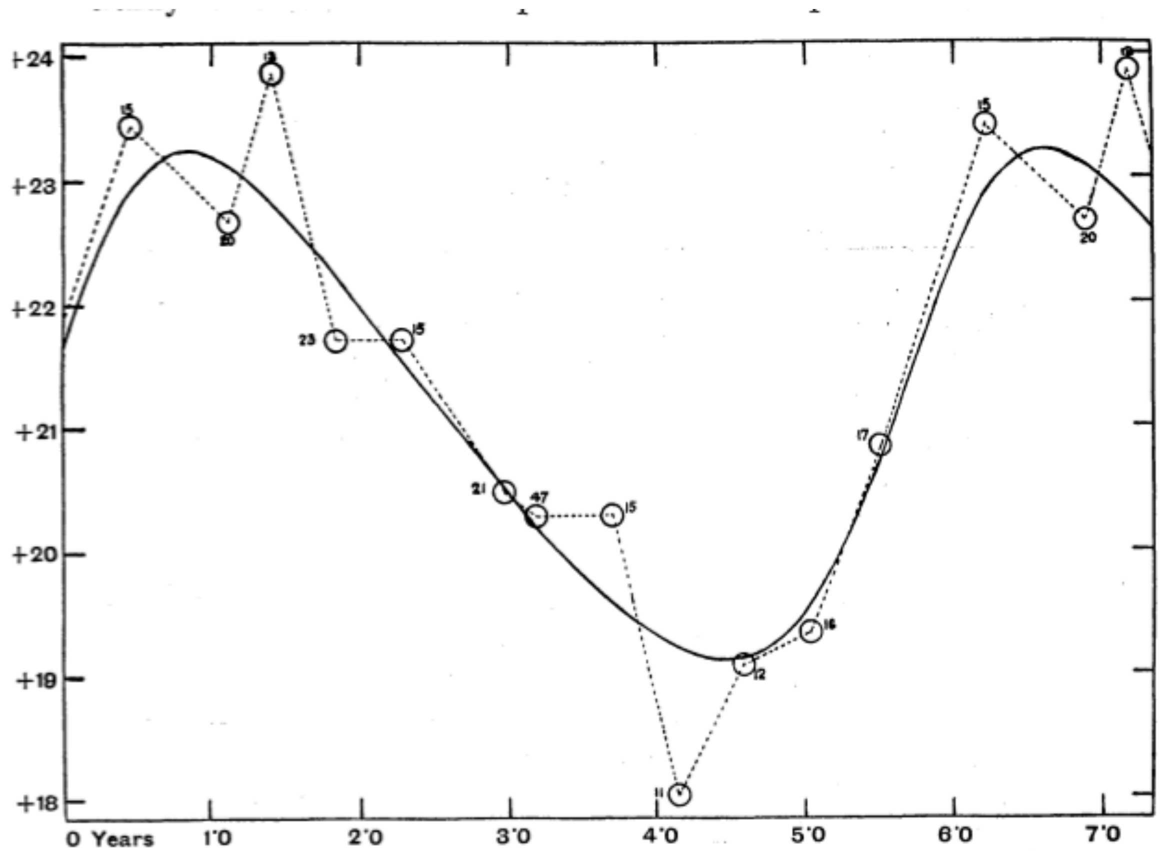


Rev. Father Secchi, Royal Astronomical Society, 1866.

1866: Betelgeuse spectrum is variable - Secchi
1899: no it isn't – Harrer
1907: Bands ascribed to TiO
1911: possible 6yr binary period – objective measurements!

1896 - 1926

Periodic variation of RV ~5.8 yr
Cape and Lick Spectroscopy



Spencer Jones, MNRAS 88, 660 (1928)

Selenium and Photoelectric Photometry – 5.4 yr period

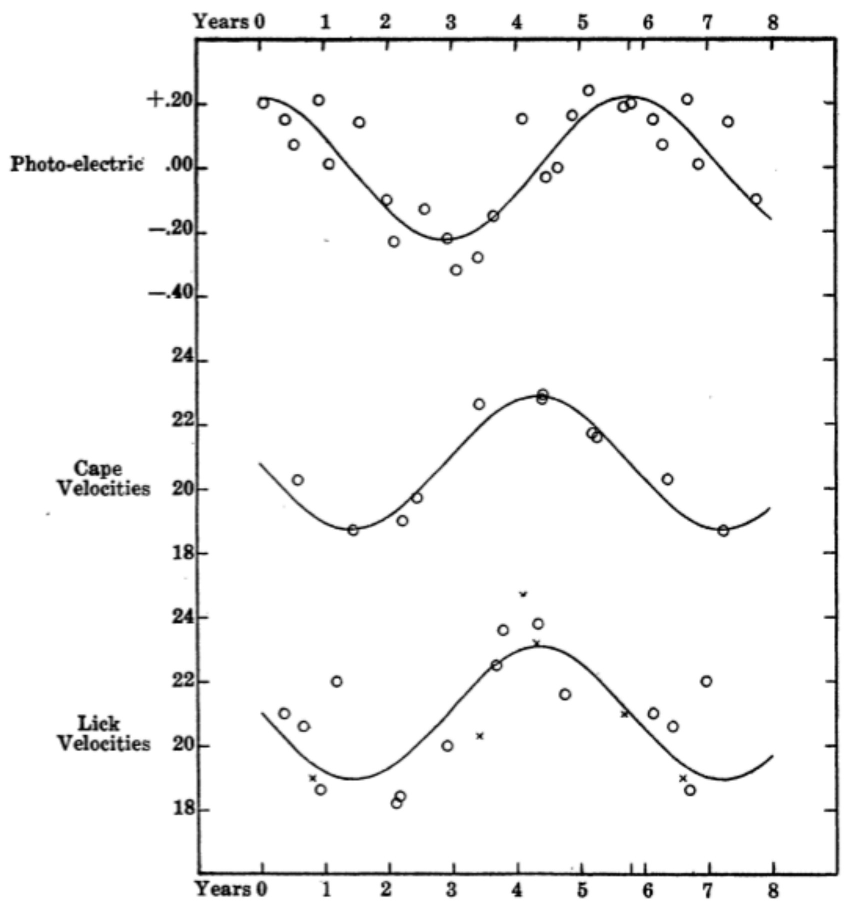


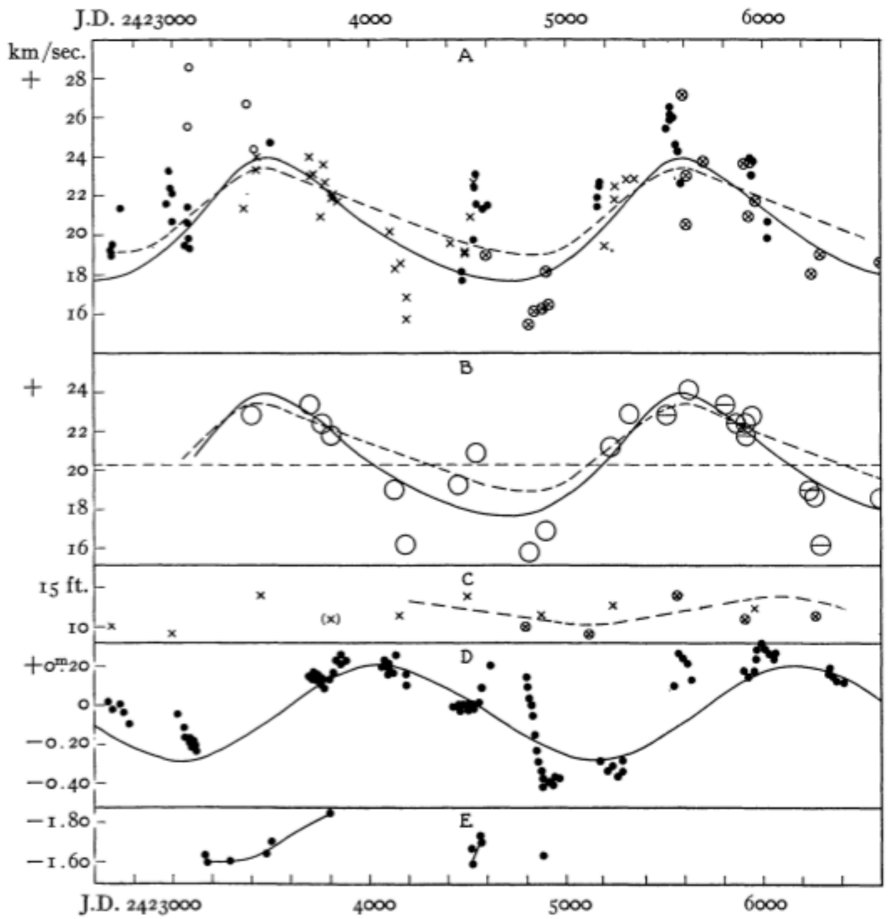
FIGURE 2—The Light-Curve and Velocity-Curves of α Orionis

A pulsation model implies that maximum light occurs at minimum diameter, with a diameter change of ~30%.

Stebbins, PubWashObs 15, 1775 (1928)

1933

Mt Wilson Spectroscopy



RV

RV

Folded and averaged

Vmag

Stebbins

Mbol

Nicholson & Petit

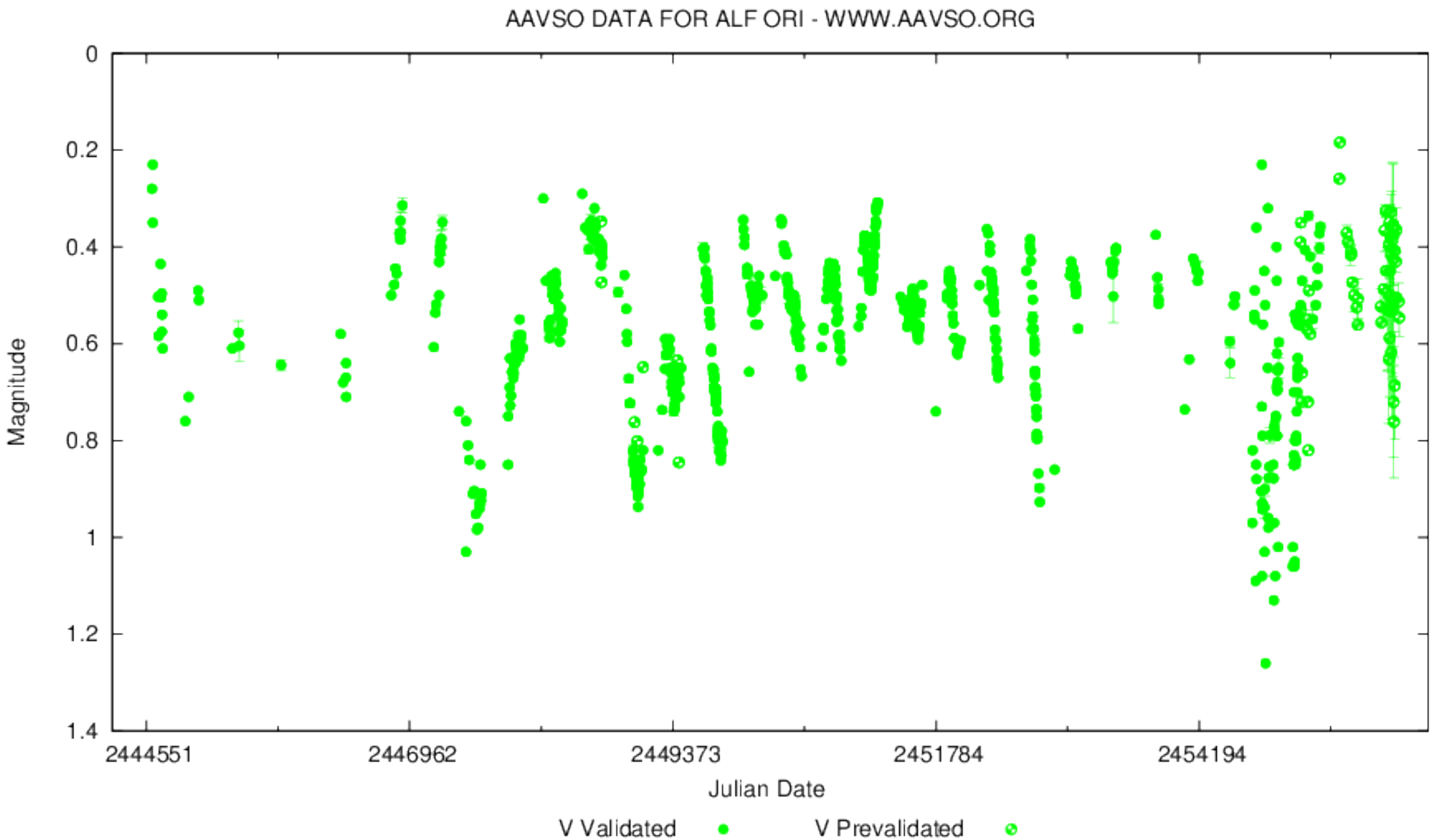
1920

1931

Sanford, ApJ 77, 110 (1933)

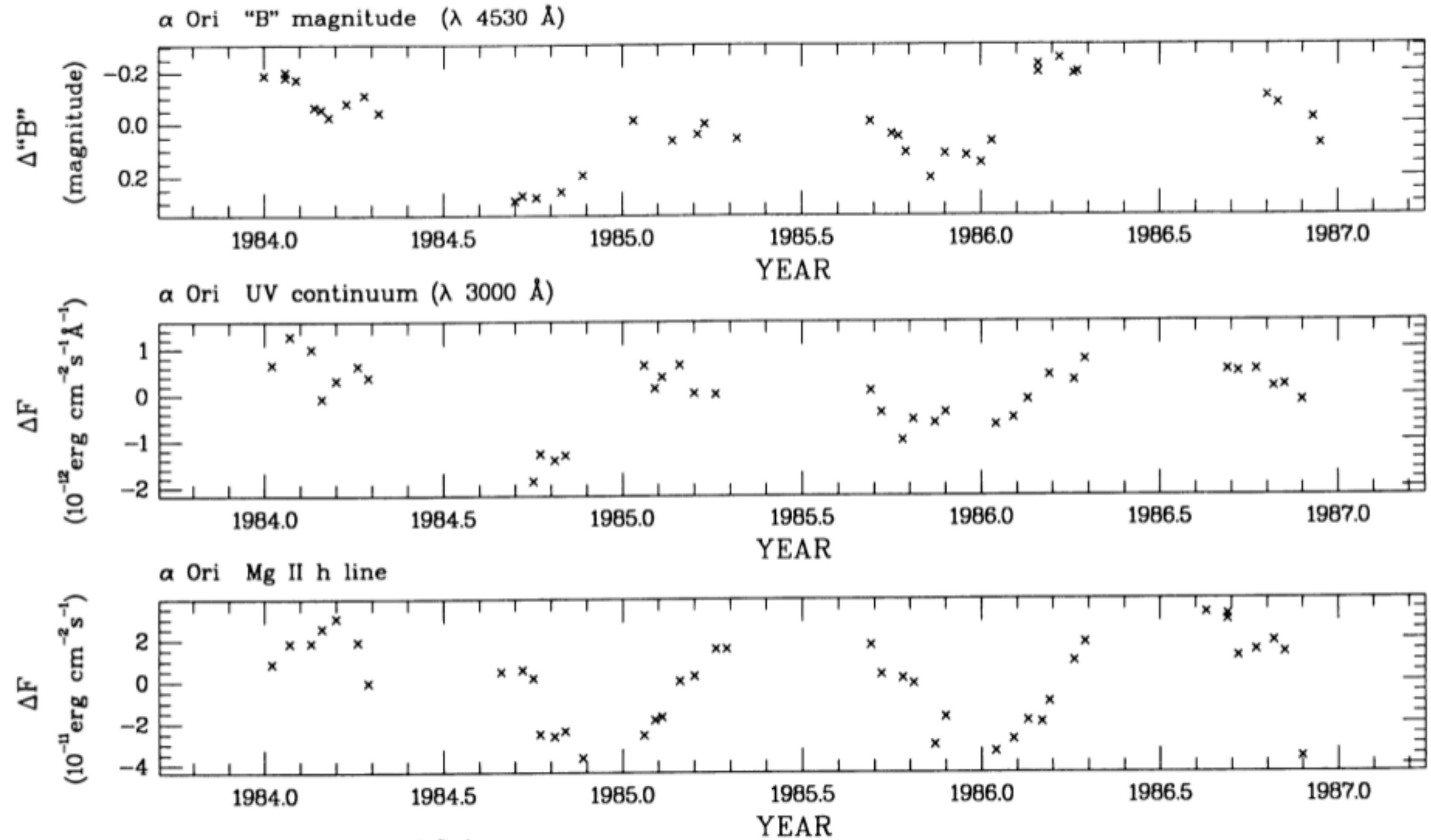
1980 - 2010

Variability – V band



1984 - 1987

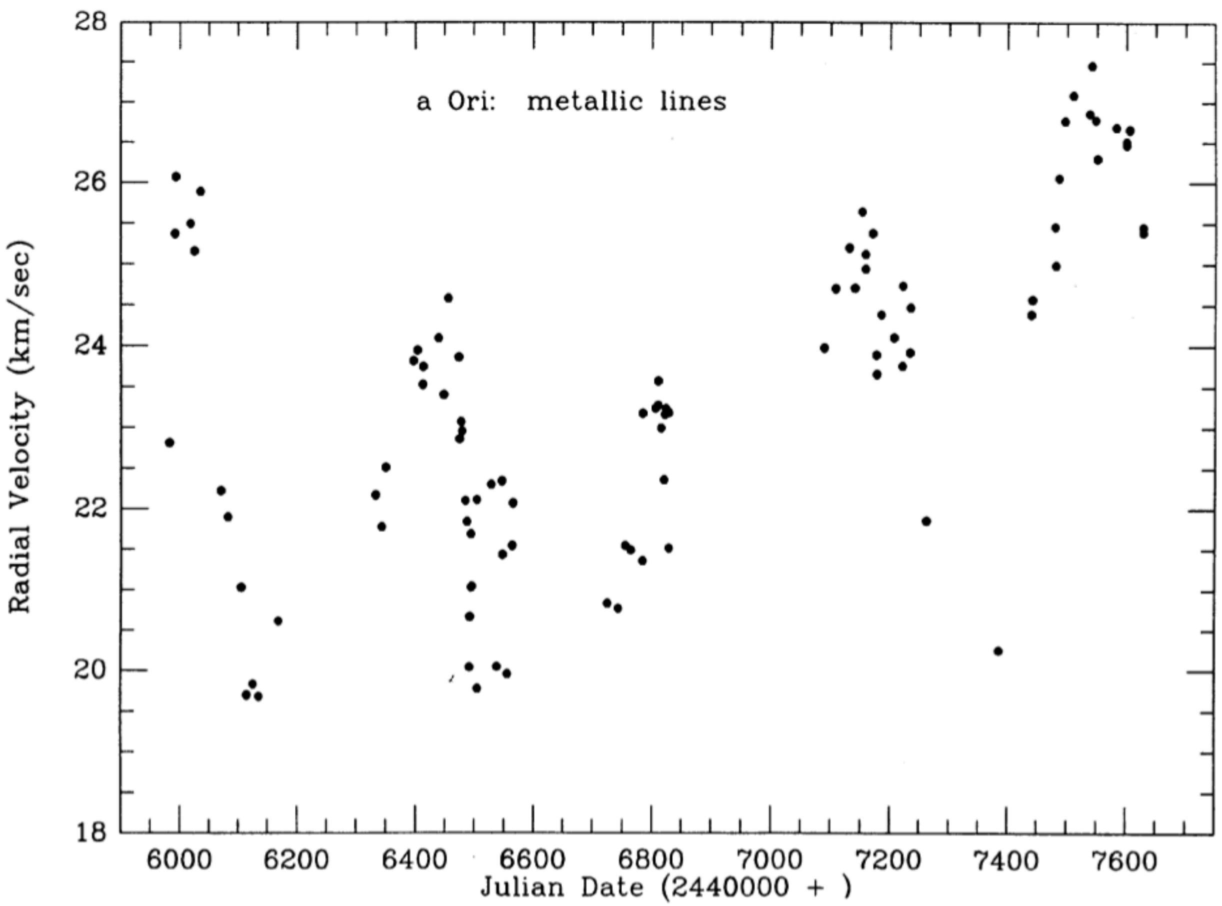
Blue-UV pulsations – 420 day period



Dupree et al, ApJ 317, L85 (1987)

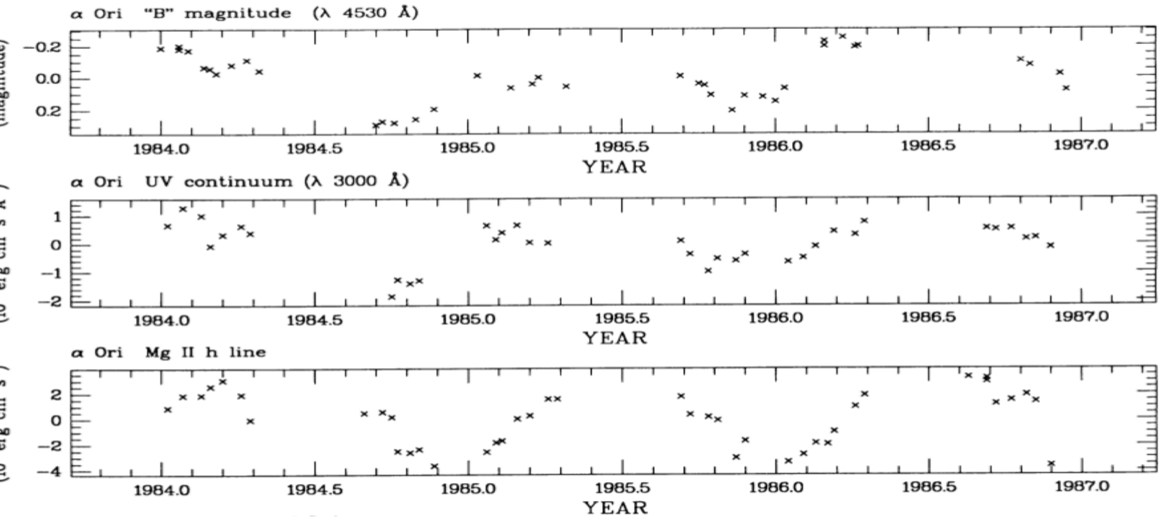
1989

RV Monitoring



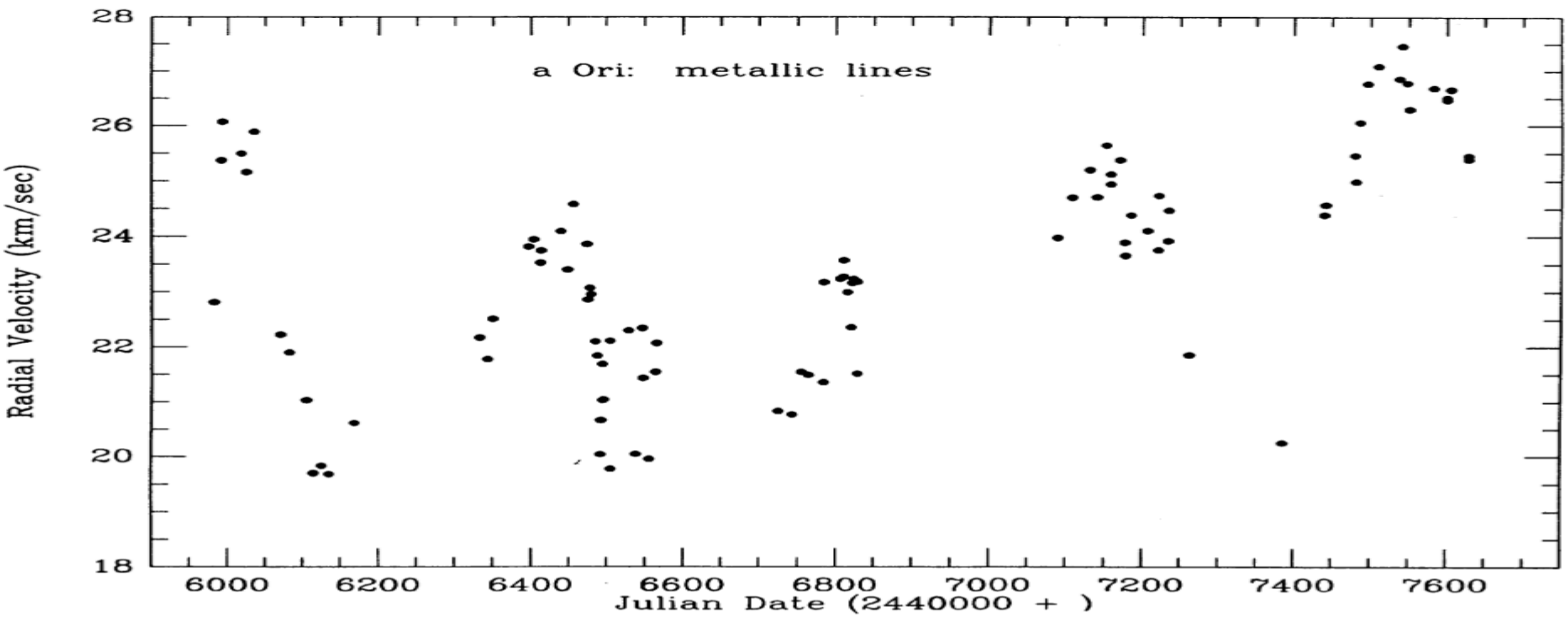
1984 1989

- Period ~ 400 days
- Smith et al, AJ 98, 2233 (1989)



Compare Blue flux with RV

Minimum brightness corresponds to in-falling photosphere



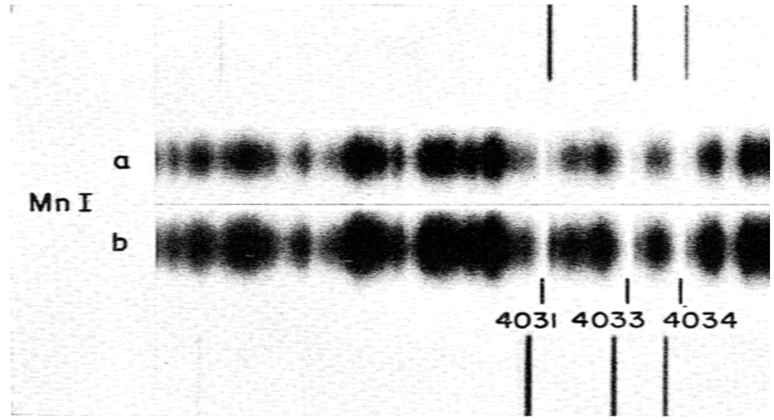
1984

Summary of variability

- During activity, long term variation hidden – during quiescence, long term period seen.
- Major disturbances in the atmosphere are likely to occur 1-2 years following the minimum in the 6-year RV curve.
- Rapid photometric changes are not global
- Observed events: large, rapid decrease in RV followed by 0.5 mag decrease in brightness – tend to occur just after pulsation RV minimum – speculate that mass is levitated and decoupled at these events.

Goldberg, PASP 96, 366 (1984)

Line profiles



- Adams, PASP 49, 156 (1937)
  - Mt Wilson 100”, 1 Å/mm
  - Some lines double due to central emission core
  - Most lines diffuse
  - K7665 and 7699 are narrow and displaced 0.3Å to the violet
  - No evidence of spectral change with RV variation.
  - Hypothesis of convection and turbulence stronger than in other stellar types.
- Spitzer, ApJ 90, 494 (1939)
  - Interpretation as expanding shell

P. Wellman – stellar wind

- Multiple components in Ca II.
- Chromospheric temperature inversion
- Mass motion 10 km/sec outward of 10^{-4} of the atmosphere

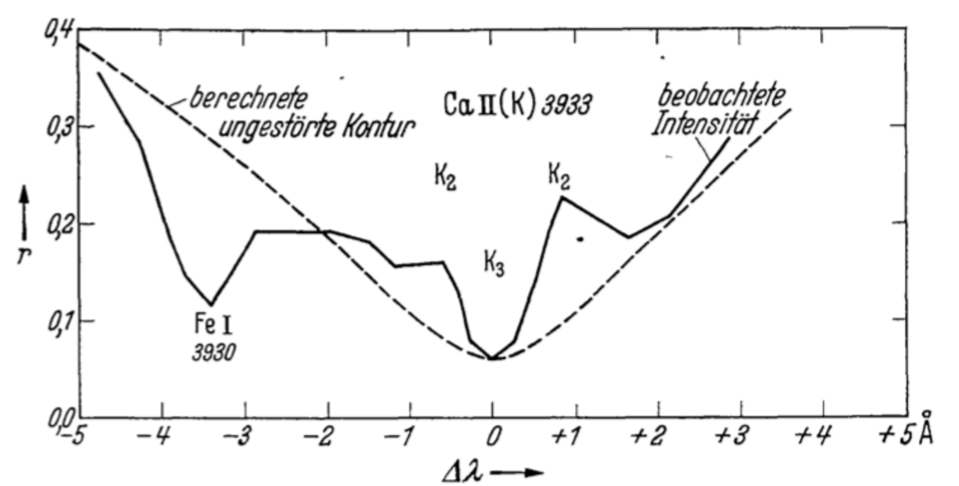


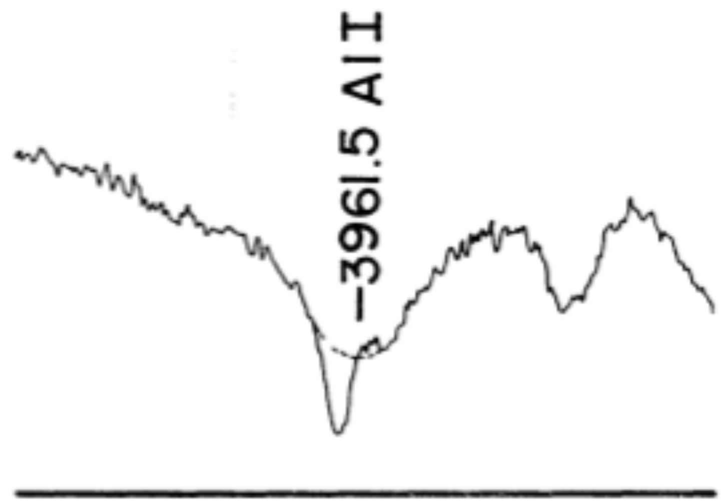
Abb. 2. Die doppelte Umkehr der Linie *K* im Spektrum von α Orionis (Ausschnitt aus Abb. 1).

ZSAstro 20, 214 (1941)

1960-62

Ray Weymann, mass loss rate

- Assume symmetric photospheric lines – in order to define a pseudo continuum.
- Curve of growth analysis of circumstellar metal lines.
- Expansion ~10 km/sec
- T ~ 1000K
- $4x10^{-6}$ Msolar/yr



Abstract: AJ 65, 503 (1960); article: ApJ 136, 844 (1962)

1979

Multi-component Chromosphere – Boesgaard I

- FeII emission lines trace motions above the photosphere
- Lines are broad ~85 km/sec
- Higher excitation lines are in-falling by 5-6 km/sec *relative to the photosphere*
- Lower excitation lines are outflowing consistent with lower shell

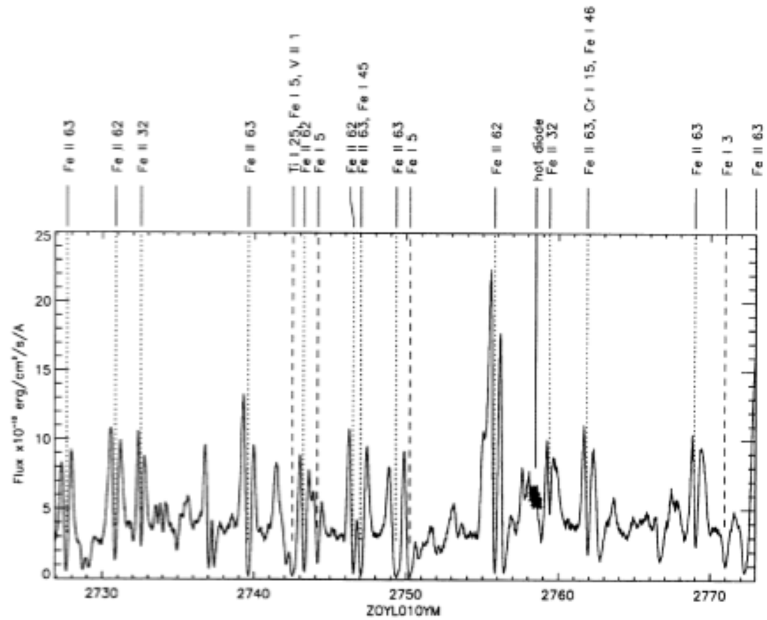


FIG. 18. Medium resolution (G270M) spectrum Z0YL010YM.

Brandt et al, ApJ 109, 2706 (1995)

Boesgaard, ApJ 232, 485 (1979)

1979

Multi-component Chromosphere – Boesgaard II

The photosphere and chromosphere are extended. Upwelling material is driven by photospheric convection, giant fountaining or prominences, radiative pressure on molecules, etc. Some of this material returns to the star at high velocity. There are large turbulent motions in the medium of both large and small scale. Other material continues to move outward, possibly becoming supersonic at the base of the corona, and driving mass loss through the hydrodynamic expansion of the hot corona.

Boesgaard, ApJ 232, 485 (1979)

1921 - 2008

Distance

- Schlesinger, AJ 33, 130 (1921)
  - 77 +- 40 pc
- Seagrave, AJ 33, 146 (1921)
  - 59 +- 25 pc

- Hipparcos
  - 131 +- 30 pc
- VLA/Hipparcos
  - 197 +- 45 pc

Petit & Nicholson - Infrared Radiation,

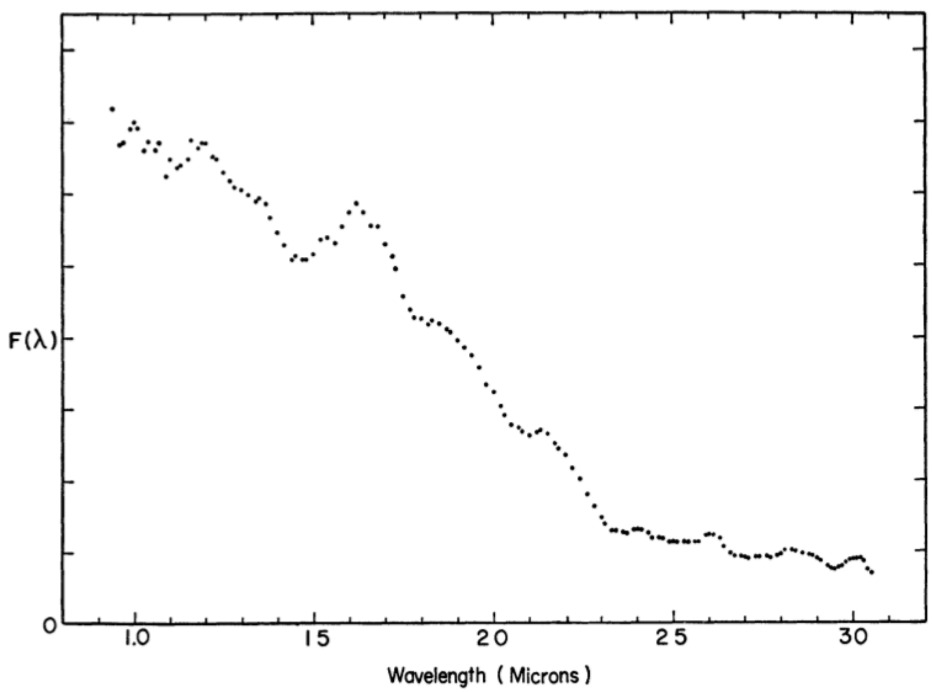
- Thermocouple with IR transmitting optics
  - Described extended IR sensitivity measure as "radiometric"
  - Cool stars have a larger flux at wavelengths beyond 1 micron than shortward of 1 micron (1922)
  - Temperature calibration – M2 corresponds to 3050K (1928)

Edison Petit & Seth Nicholson, ApJ 68, 279 (1928)

1964 - 2000

Water vapor bands – Stratoscope

- Balloon-borne telescope at 80,000 feet
- Infrared spectra, 1-3 microns
- H2O at 1.4, 1.9 microns

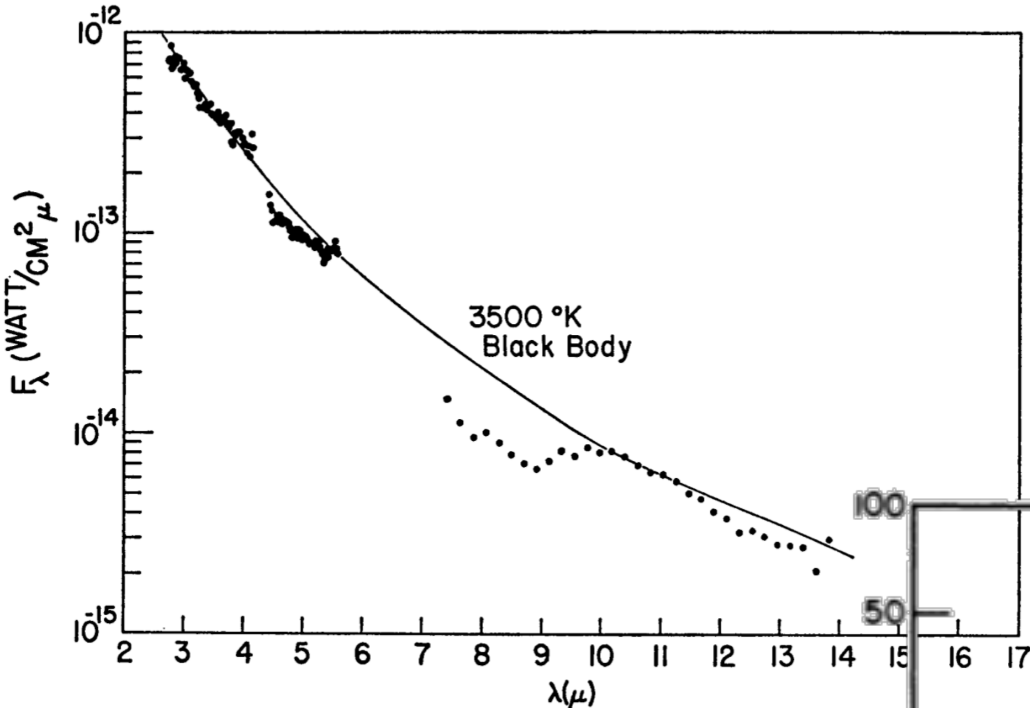


Woolf et al., ApJ 140, 833 (1964)

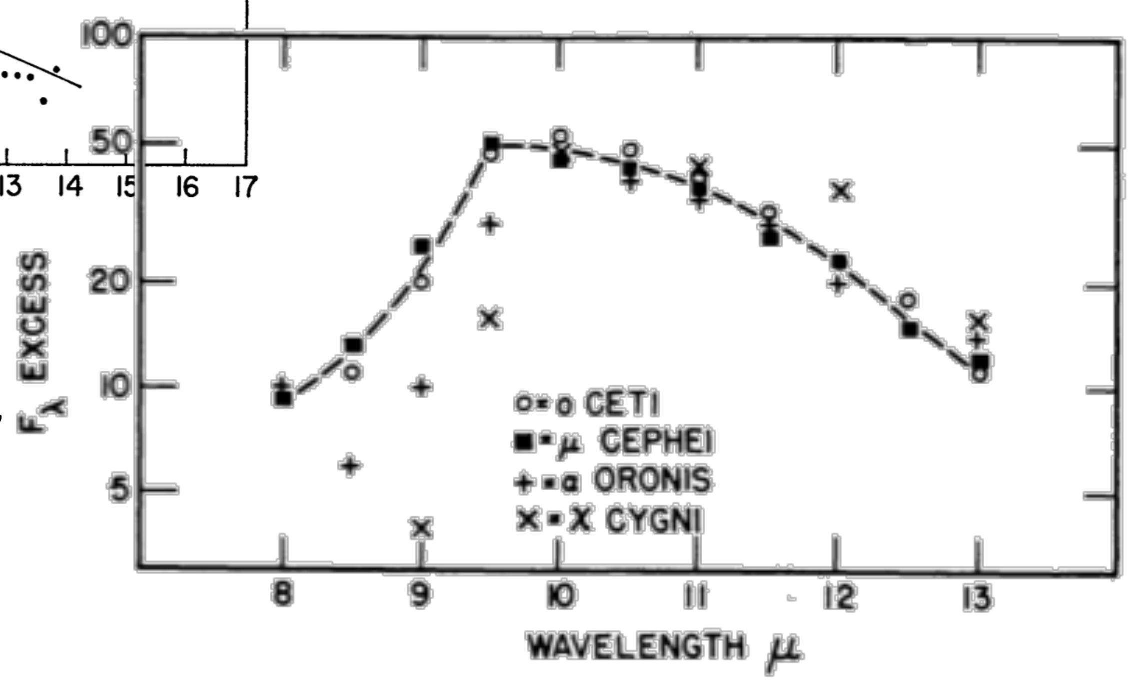
- Re-analysis by Tsuji in 2000
    - ApJ 538, 801 (2000)
- H2O confirmed
- Texc ~ 1500K

1968 - 1969

Mid-Infrared and Dust



- Correct interpretation
  - Woolf & Ney, ApJ 155L, 181 (1969)
  - Emission, predicted for mineral grains

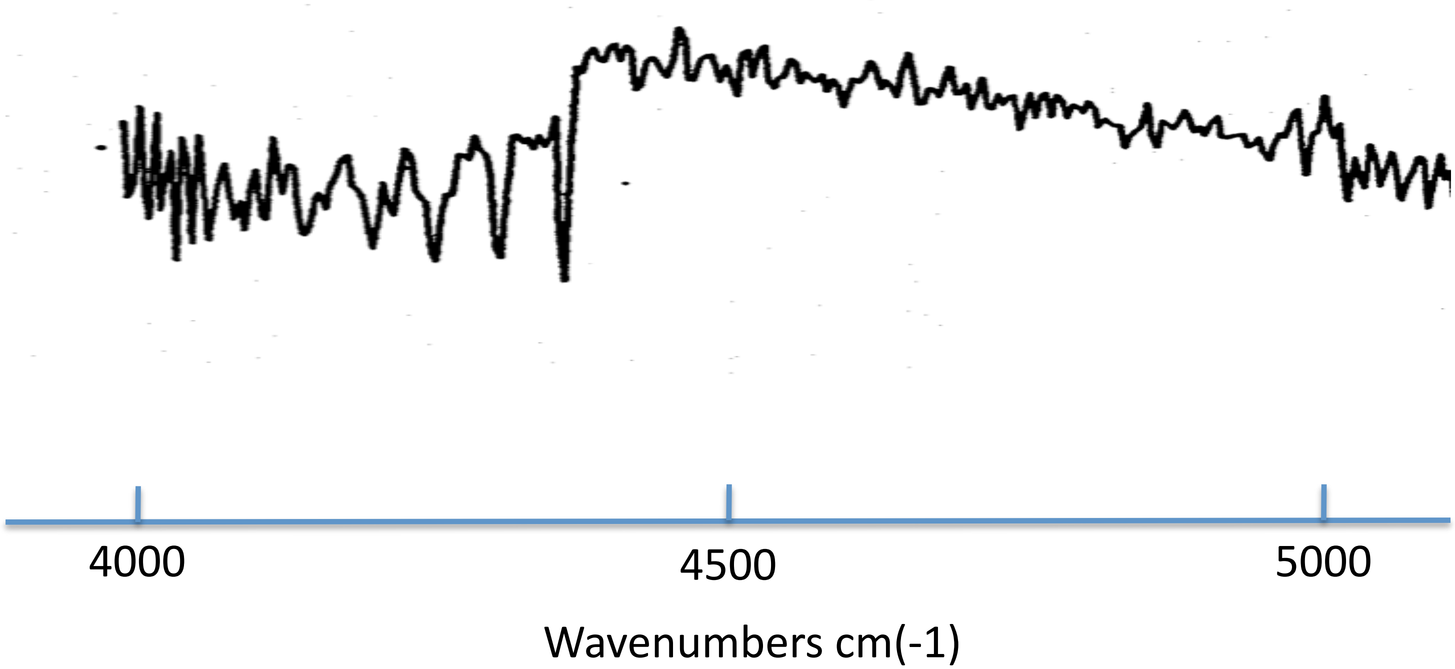


- Discovery spectrum
  - Gillett, Low & Stein, ApJ 154, 677 (1968)
  - "Absorption feature"

1970

Medium resolution IR spectroscopy

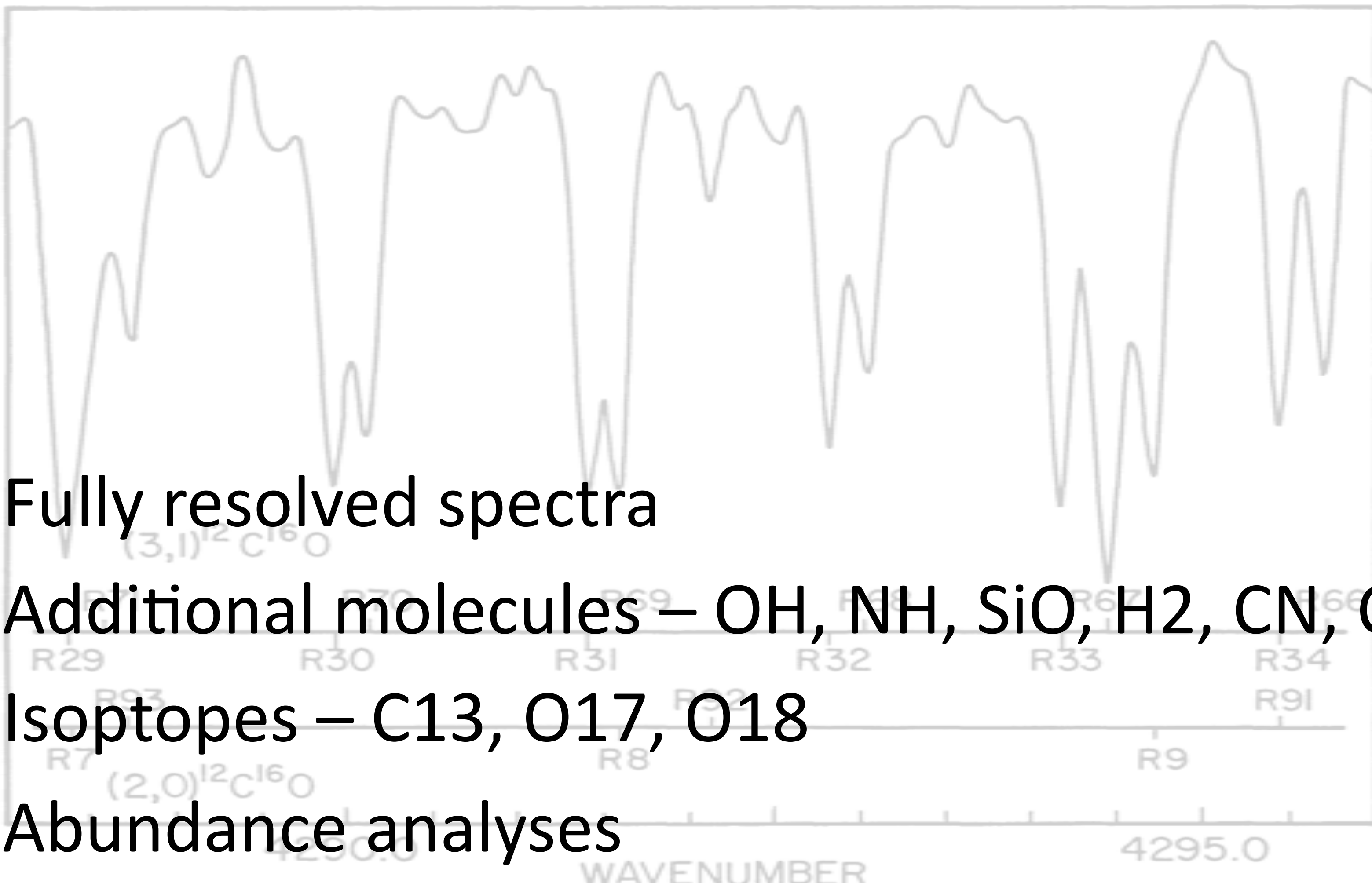
- Fourier transform spectroscopy
- 1-3 microns
- CO 1st overtone vibration-rotation



Johnson, AJ 75, 785 (1970)

FTS-IR spectroscopy – 1970->

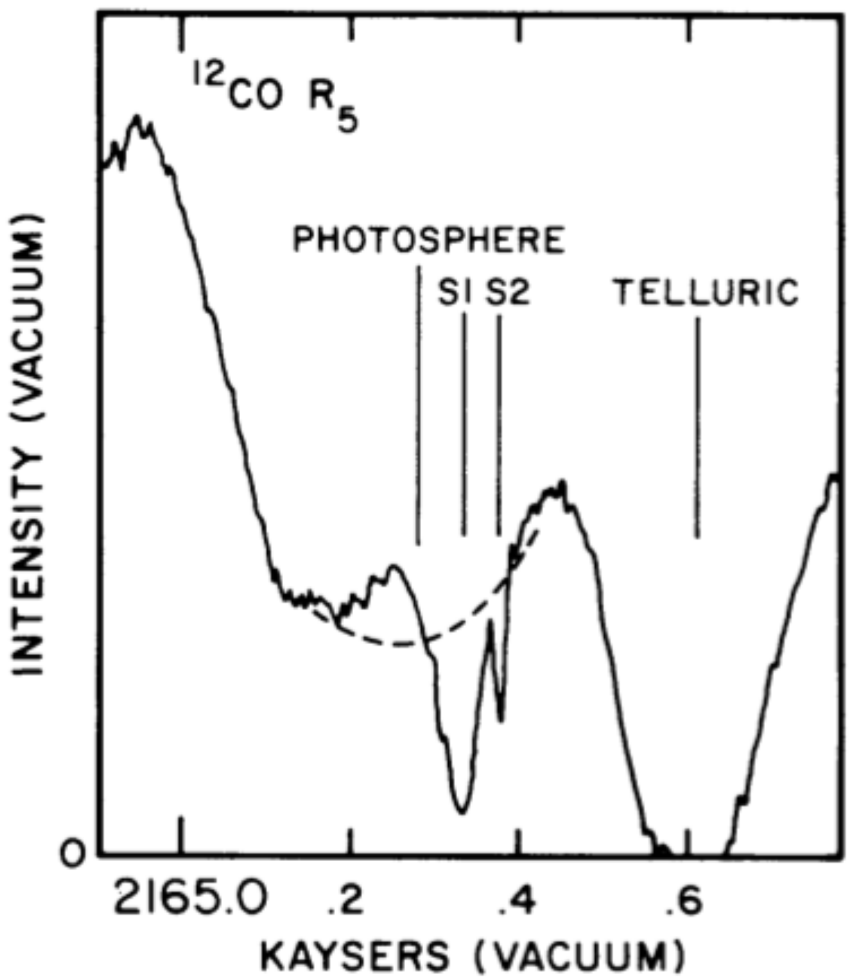
1970 - 2000



- Fully resolved spectra
- Additional molecules – OH, NH, SiO, H2, CN, C2
- Isoptopes – C13, O17, O18
- Abundance analyses
  - Lambert, Maillard, Tsuji and others

1979

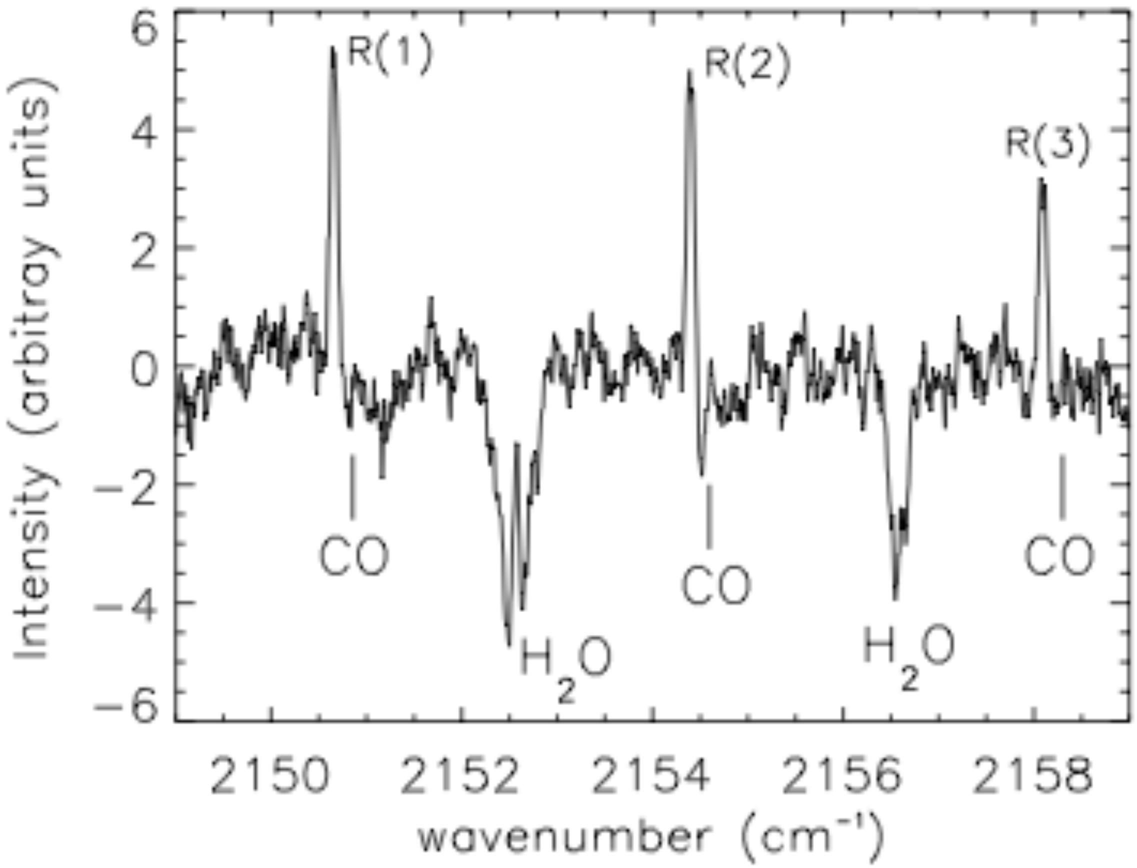
A molecular shell



- In the CO fundamental vibration-rotation band
- Two components:
  - S1: -6.3 km/sec, Texc = 200K
  - S2: -12 km.sec, Texc = 70K
- Bernat et al, ApJ 233L, 135 (1979)

The Molecular Shell at High Spectral Resolution

1999

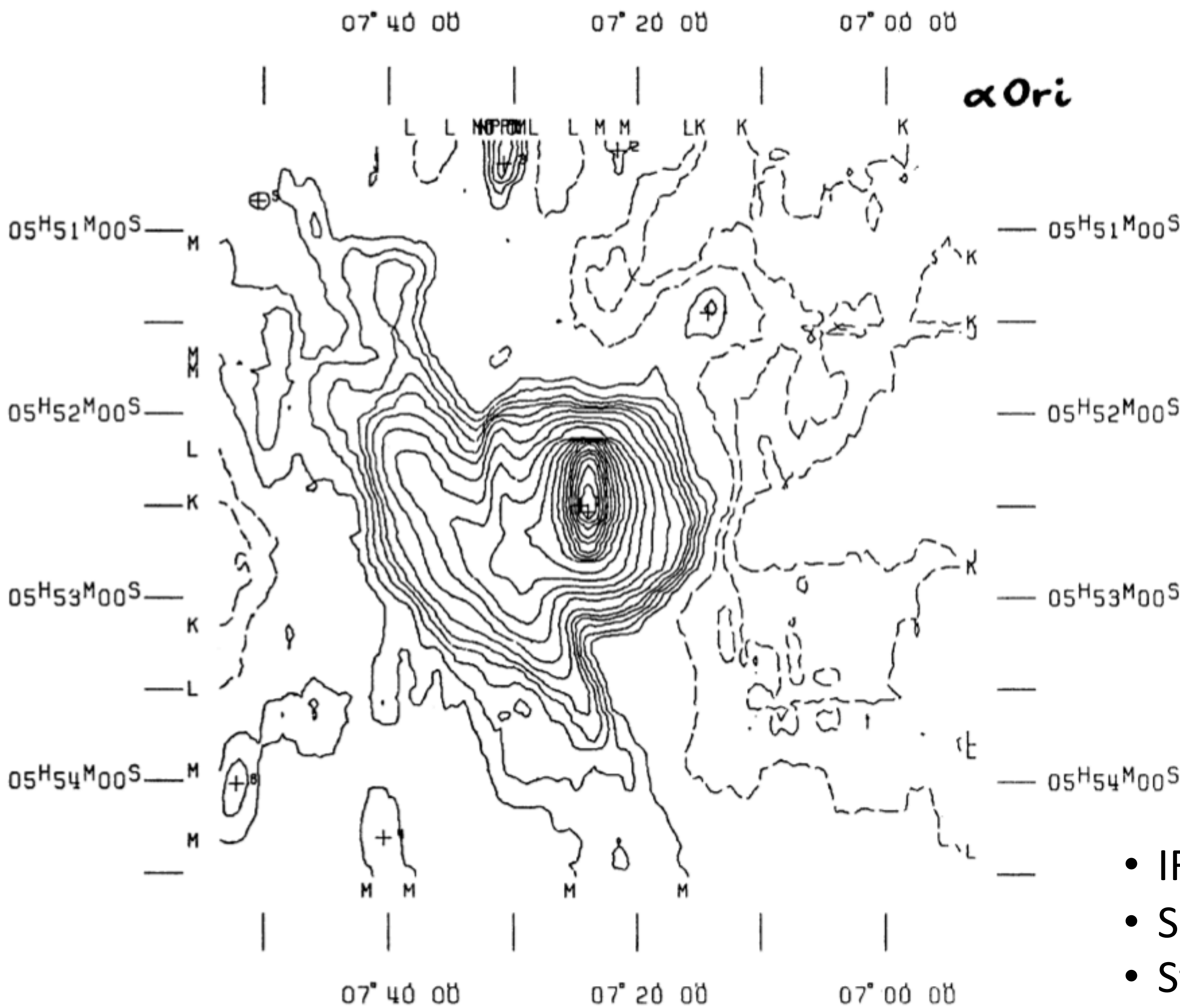


- CO 4.6 fluorescent emission
- T = 38+5-6 at
- 4” offset

Ryde et al, A&A 347, L35 (1999)

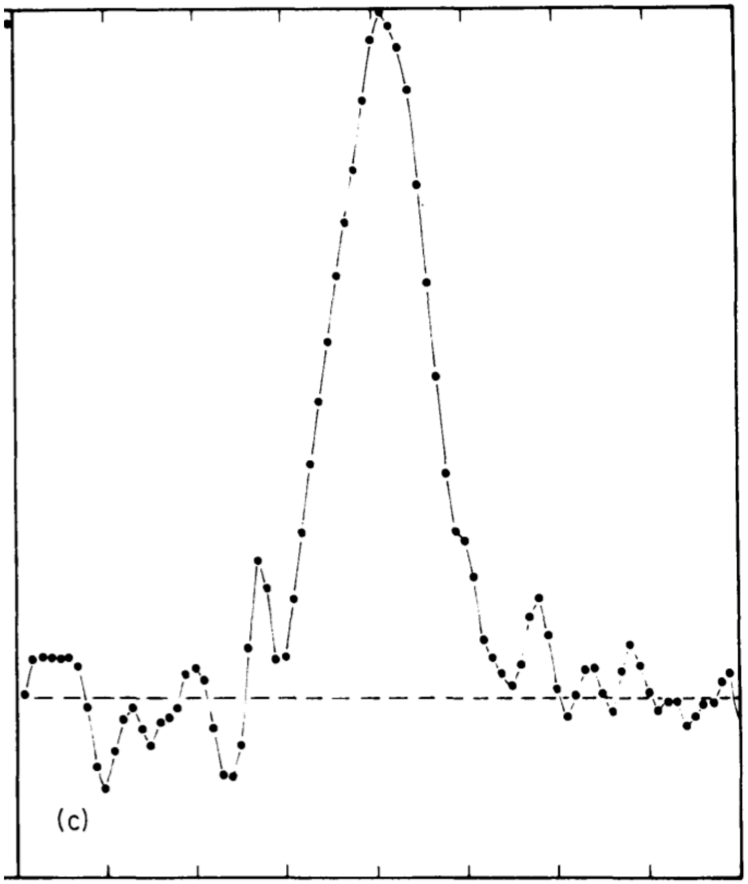
1988

The Extended Dust Shell

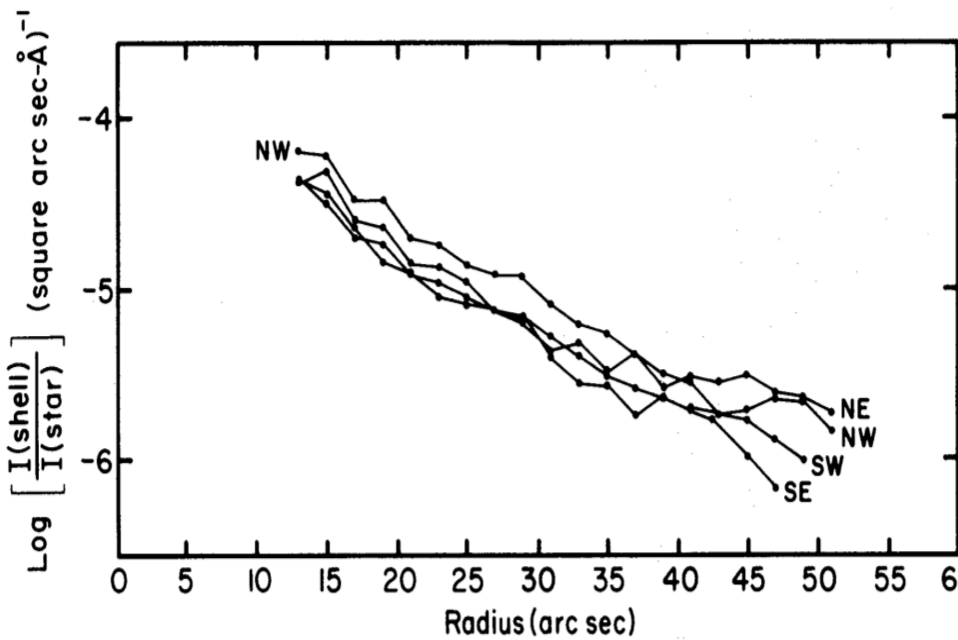


- IRAS – 60 micron scans
- Shell diam 20 arc-min
- Stencel et al, AJ 95, 141 (1988)

An atomic shell

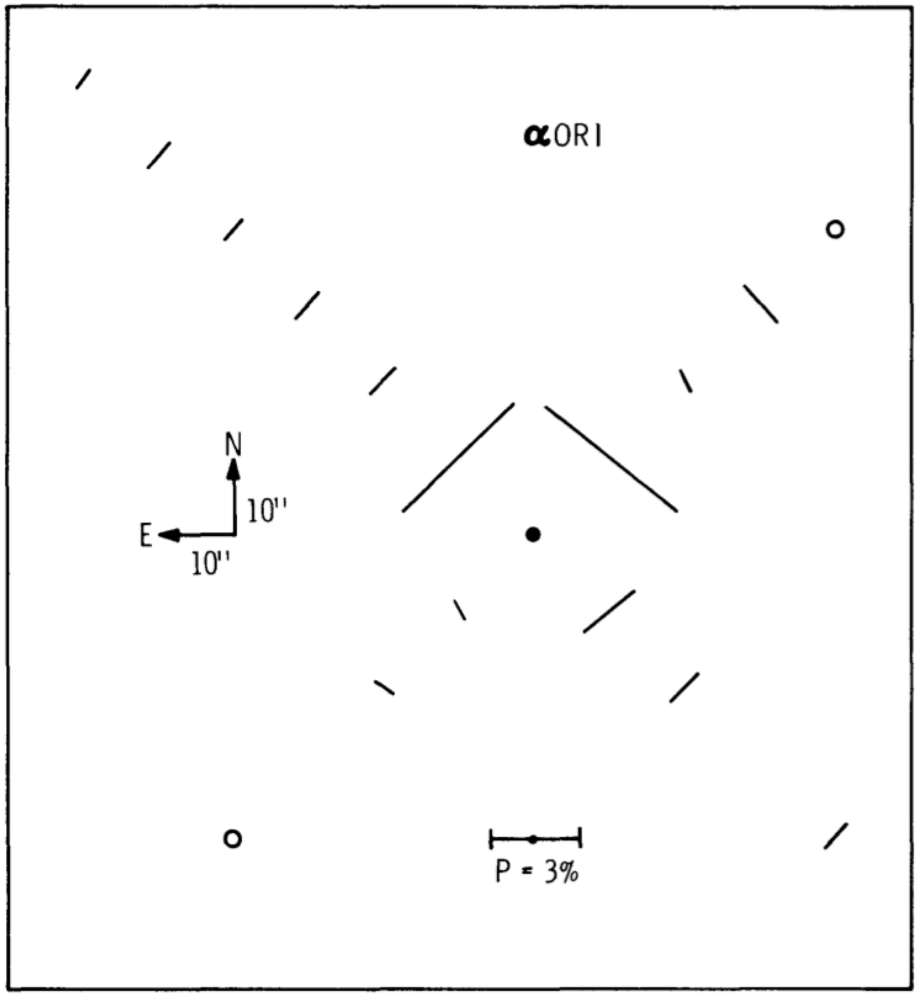


- KI 7699Å
- 2” off star
- Bernat & Lambert, ApJ 201L, 153 (1975)



- Extended to >50” off star
- NW more intense
- Expansion time ~4500 yr
- Honeycutt et al, ApJ 239, 565 (1980)

The Extended Shell - Polarization



- Polarization in blue light from scattering on dust
- Polarization extends to >90"
- McMillan et al, ApJ 226L, 87 (1978)

1981

Goldberg, in Physcial Processes in Red Giants, (Reidel), 301 (1981)

- Stellar CM RV 21 km/sec heliocentric
- Photospheric RV -7 to +3 km/sec
- K I lines and CO (two velocities)
  - Warm component: -10 km/sec -> -7.5 km/sec
  - Cold component: -16 km/sec
- Na D (two velocities)
  - -8.7
  - -14.5 km/sec
- HI
  - Line center -5 km/sec
  - Line wings 0 km/sec
- Terminal velocity achieved beyond region of photospheric pulsation
- Further acceleration of outer shell – grain formation?
- Expansion age ~ 500 years

Early spatial measurements

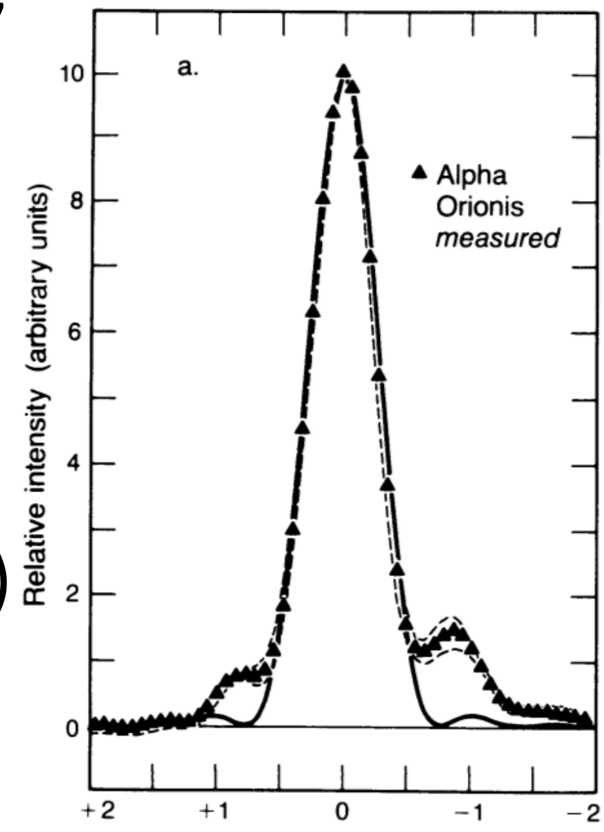
- 1921: 47 marcsec+-10% - Michelson & Pease
- 1922: diameter variations and correlated RV changes

Michelson & Pease, ApJ 13, 249 (1921)

1977-1984

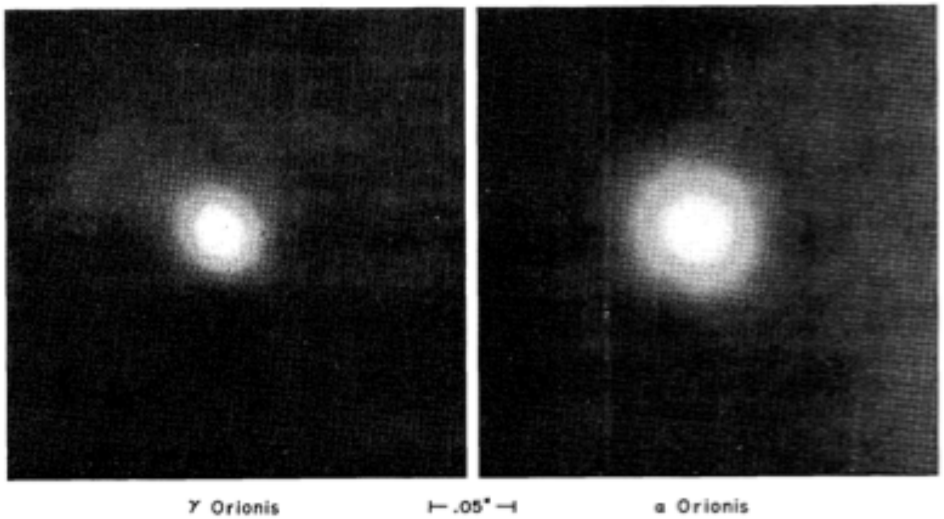
Mid-IR Spatial Measurements

- Interferometry at 11.1 microns
  - 25% of the flux emitted from a shell >1.5”
  - McCarthy et al., ApJ 214L, 85 (1977
- Spatial scanning at 10 microns
  - Asymmetric dust distribution
  - Peaking 0.9 arcsec from star
  - Bloemhof et al, ApJ 276, L21 (1984)

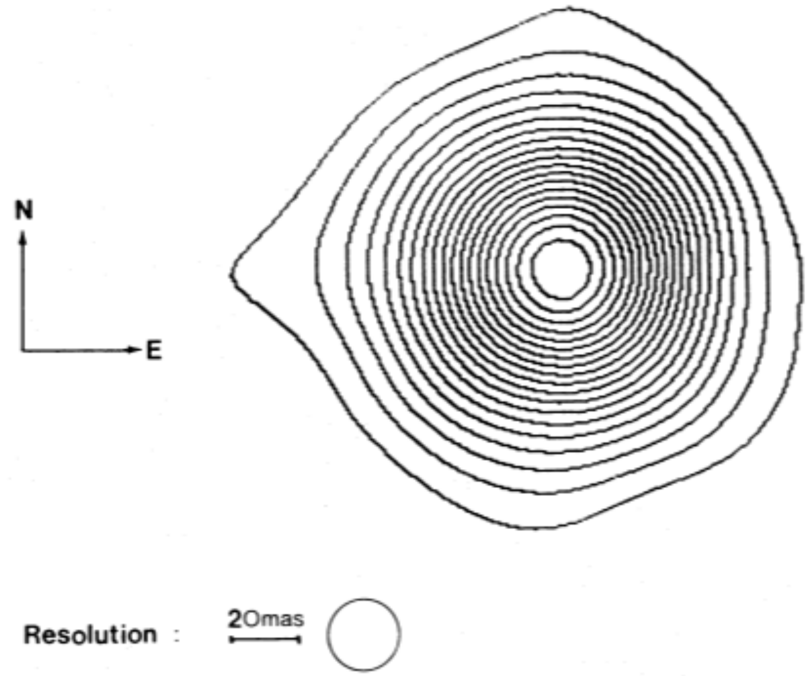


1976 - 1987

Speckle Interferometry



Worden et al, J Opt Soc Am 66, 1243 (1976)



- H-alpha emission to 4.5 R*
- NW-SE elongation
- Hebden et al, ApJ 314, 690 (1987)

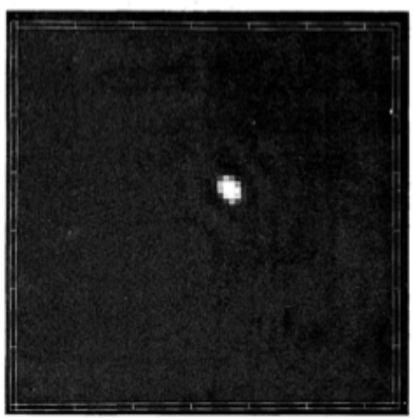


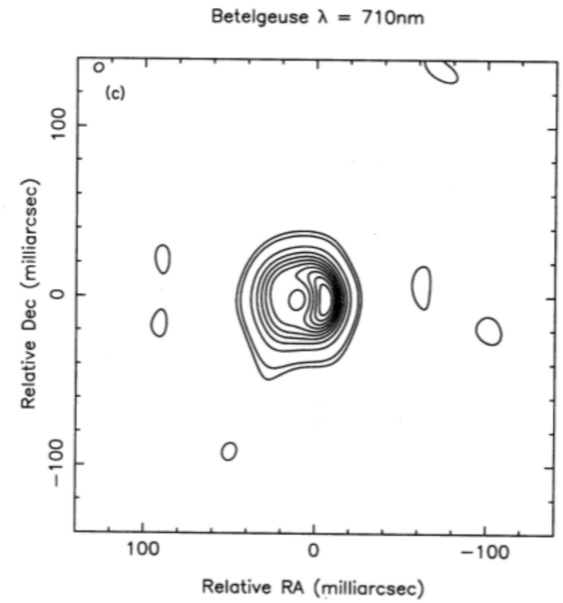
Fig. 20. Differential speckle image of the unresolved source γ Ori showing the nearly diffraction-limited 15-msec of arc (FWHM) point spread function of the full 6.86-m aperture. Scale: 5 msec/pixel.

Fig. 21. Differential speckle image of α Ori (Betelgeuse) showing a significant resolved structure at diameters to 100 msec of arc. The photon and atmospheric statistics in this preliminary sample of ~1000 frames of data limit this result to an effective signal maximum to a rms background noise ratio of ~10:1. Scale: 5 msec of arc/pixel (compare with Fig. 20).

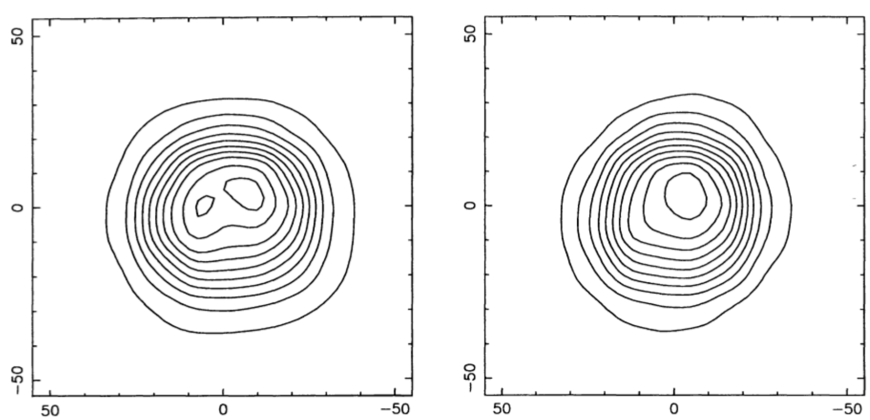
H-alpha emission to 2 R* - Hege et al AplOpt 24, 2565 (1985)

Aperture masking images of the Surface

1990 - 1998



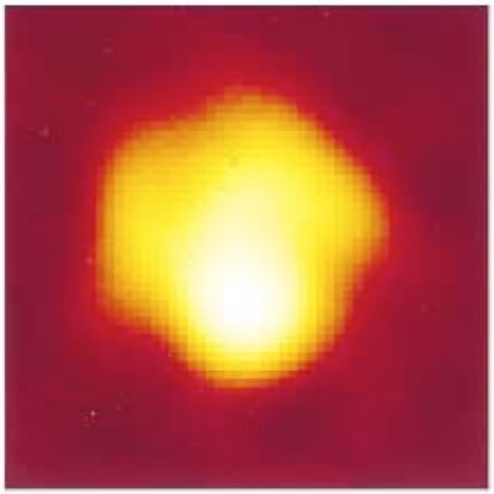
710 nm: Buscher et al, MNRAS 245, 78 (1990)



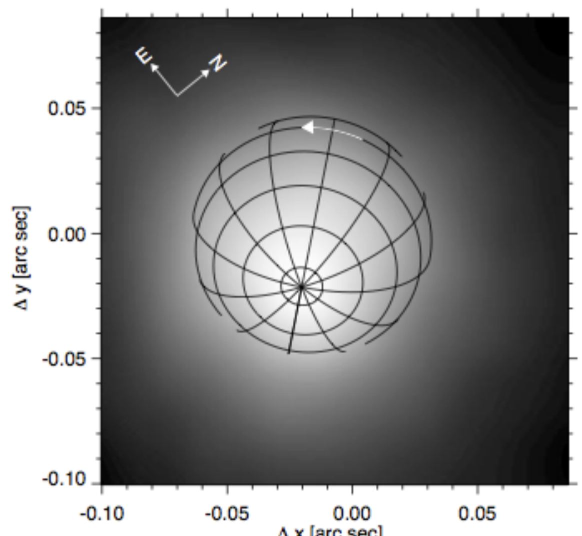
- 700 nm: Tuthill et al, MNRAS 285, 529 (1997)

- Photosphere dominated by a small number of spots

HST imaging of the Surface



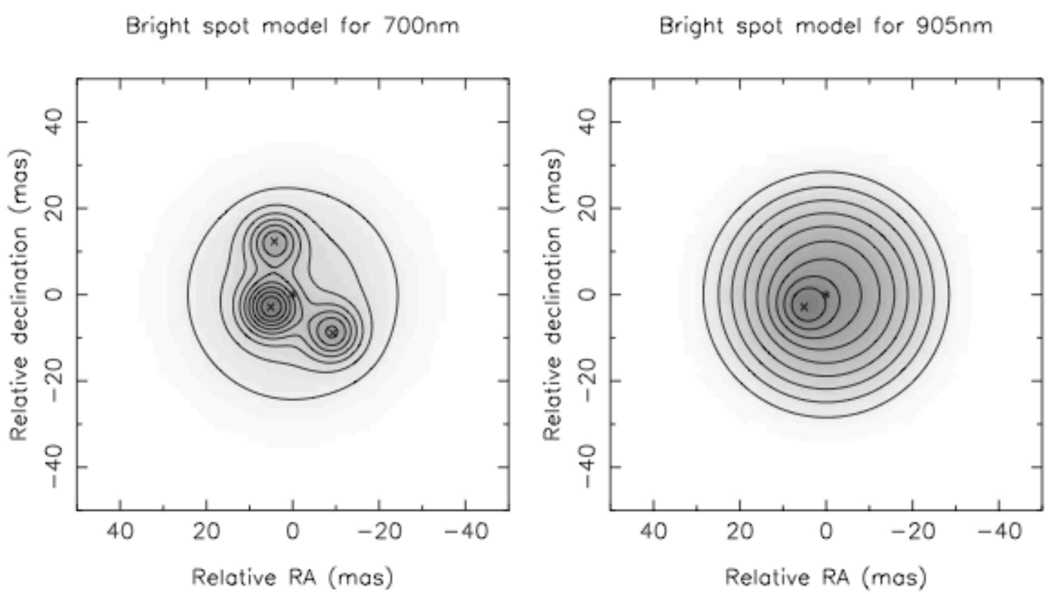
280 nm: Gilliland & Dupree, ApJ 463, L29 (1996)



280 nm: Uitenbroek et al, AJ 116, 2501 (1998)

- Chromosphere extended 2-5X
- Difficult to reconcile spot observations with convective origin
- Bright spot may have a shock origin
- Differential velocity shift consistent with rotation => 17 yr period

Interferometric images of the Surface



700, 905 nm: Young et al, MNRAS 315, 635 (2000) – bright feature solution

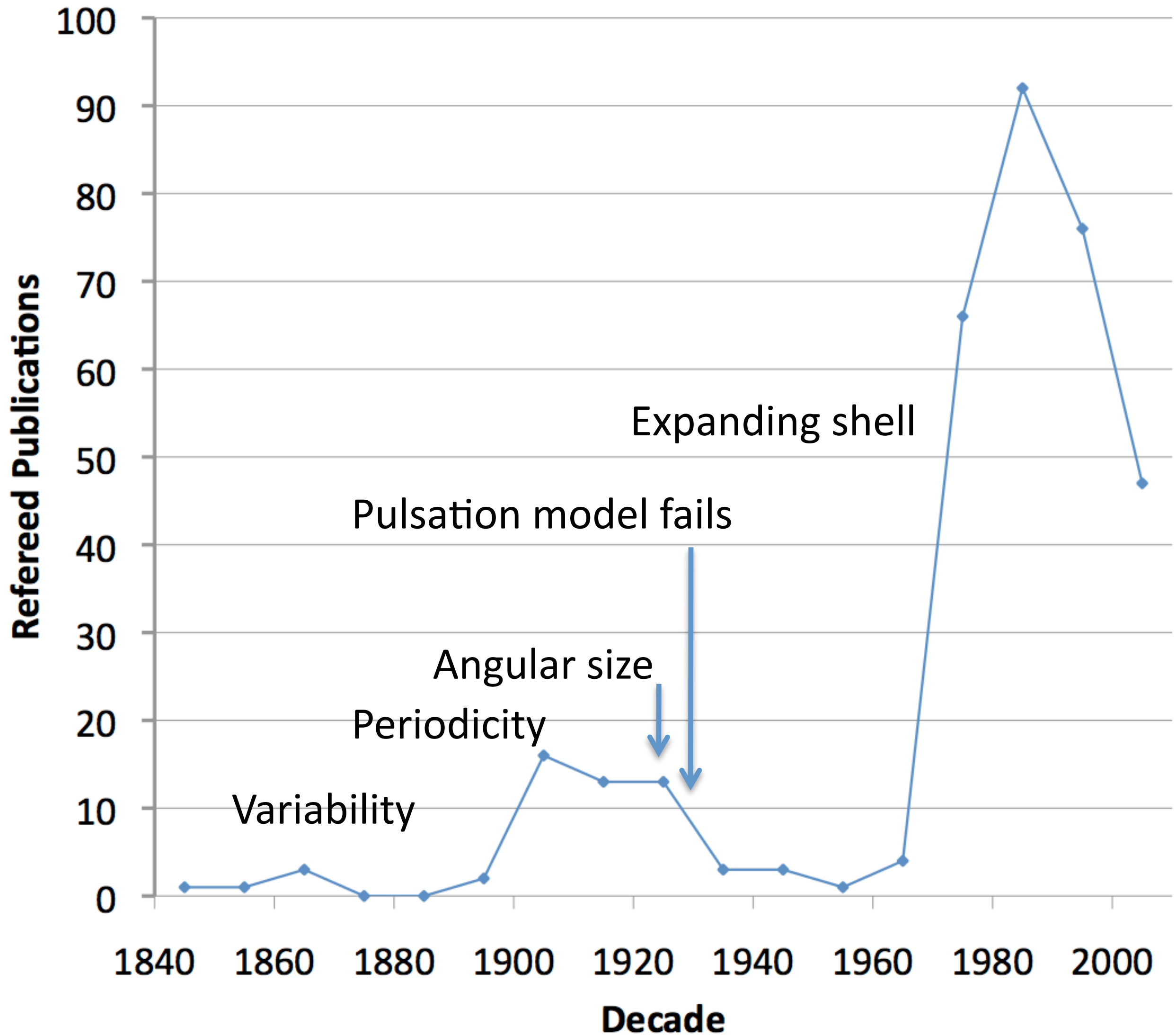
- Feature contrast decreasing with wavelength
- Featureless at 1290 nm
- Favor opacity variation over temperature differential across photosphere

Schwarzschild, ApJ 195, 137 (1975)

- In a red giant, the pressure scale hight is a ~50% the stellar radius (vs 0.1% for solar granulation).
- Predict brightness variations ~150 days

Schwarzschild, ApJ 195, 137 (1975)

Number of refereed publications on Betelgeuse per decade



Nov 25, 2012

What is left to know?

- There are several time scales in the brightness and RV variations – what is the origin of each and how are they linked?
- Is mass loss localized and where?
- Can any observed surface structure be identified with convection?
- Is evidence of rotation confirmed?
- How does the discrete RV structure of the shell arise (ie. how is mass loss accerated?)
- What observations can constrain the physics of 3-d models?
- Can we look forward to an observer's silver bullet?