COLLEGE OF NATURAL SCIENCES AND MATHEMATICS
THE UNIVERSITY OF TOLEDO

Starlit Nights: Adventures in Exploring the Universe

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University of Toledo

Distinguished University Professor Lecture
University of Toledo
19 April 2016

Image Credit: Wally Pacholka, TWAN

Discovering an Early Model
of the Universe

Astronomy is an obsession that can strike at a very young age…

“A long time ago in a galaxy far, far away…”

Astrophysics is a branch of space science that applies the laws of physics and chemistry to explain the birth, life and death of stars, planets, galaxies, nebulae and other objects in the universe. It has two sibling sciences, astronomy and cosmology, and the lines between them blur.

Astronomer?
or Astrophysicist?

Yes!

How many?

- American Astronomical Society (AAS) ~7,000 members (not all are professional astronomers)
- International Astronomical Union (IAU) ~ 11,000 members (some overlap w/ AAS membership, not all are professional astronomers)
- Estimated ~12,000 professional astronomers world-wide (universities and colleges, observatories, NASA, industry, government labs, national facilities, museums and planetariums, etc.)
- Astronomers really are ~1 in a million!

Why I love being an astronomer:

Astronomy provides perspective…

the universe

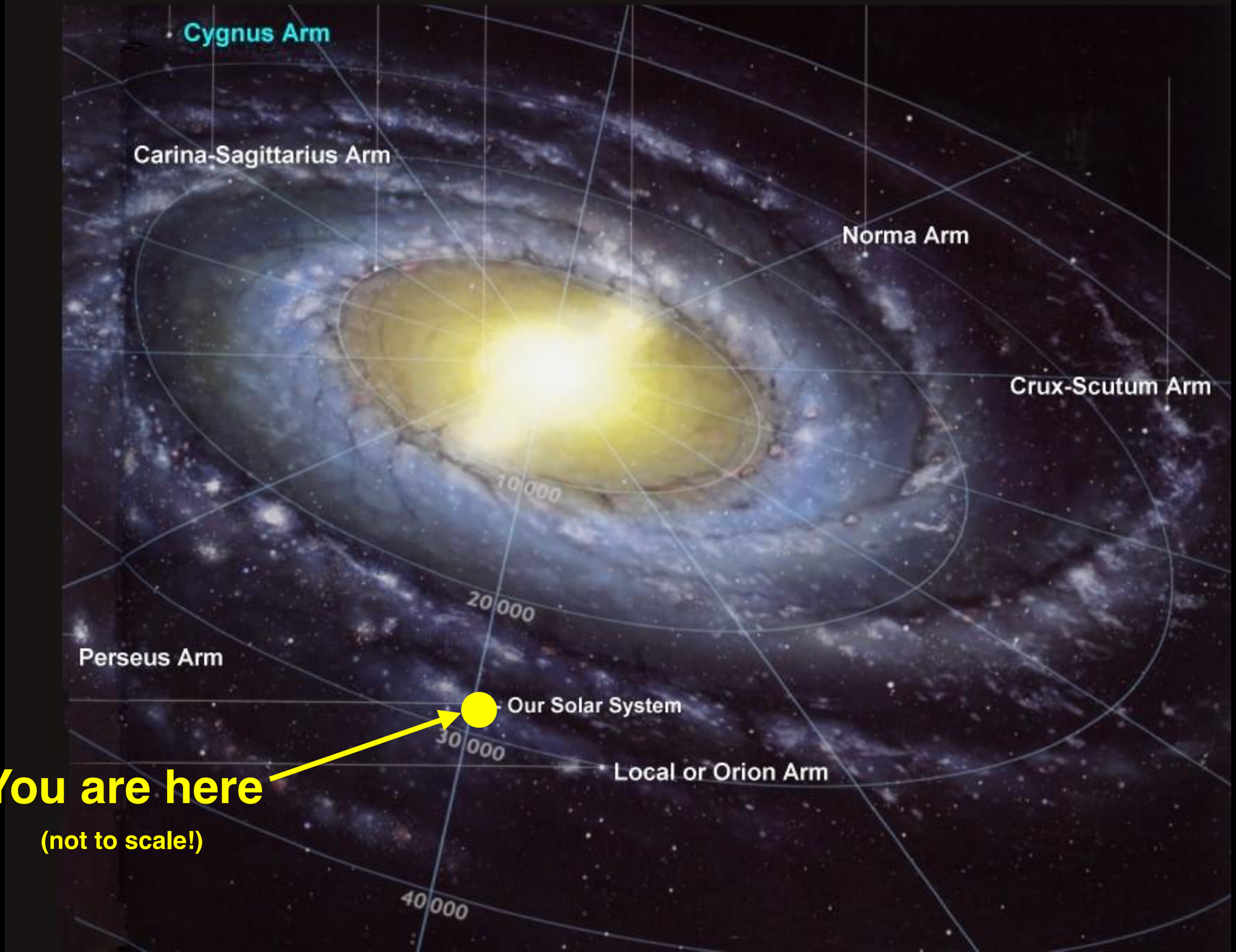
the Local Supercluster

the Local Group

the Milky Way Galaxy

Earth

the solar system (not to scale)


Cygnus Arm
Carina-Sagittarius Arm
Norma Arm
Crux-Scutum Arm
10 000
20 000
Perseus Arm
Our Solar System
30 000
Local or Orion Arm
You are here
(not to scale!)
40 000

...but still keeps you centered.

I LOVE THESE SUMMER EVENING REALITY CHECKS FROM OLIVER!

HOLD OUT A SPECK OF SAND AT ARM'S LENGTH...

opus 8-5-07 ©

THAT'S THE PORTION OF THE NIGHT SKY AT WHICH THEY POINTED THE HUBBLE TELESCOPE FOR A WEEK.

IT WAS THERE-- DEEP WITHIN THAT DOT OF DARK NOTHINGNESS TEN BILLION LIGHT YEARS DISTANT-- THAT THEY FOUND THE UNEXPECTED:

GALAXIES! THOUSANDS! **THOUSANDS!**

...WITH **BILLIONS** OF STARS! ... AND **TRILLIONS** OF NEW WORLDS.

AND BEYOND THOSE... **MORE!**

ALL IN THE SPACE OF A SINGLE GRAIN OF SAND ON THE VAST BEACH OF THE COSMOS.

WHICH NICELY FRAMES THE QUESTION MAN HAS BEEN ASKING FOR MILLENNIA.

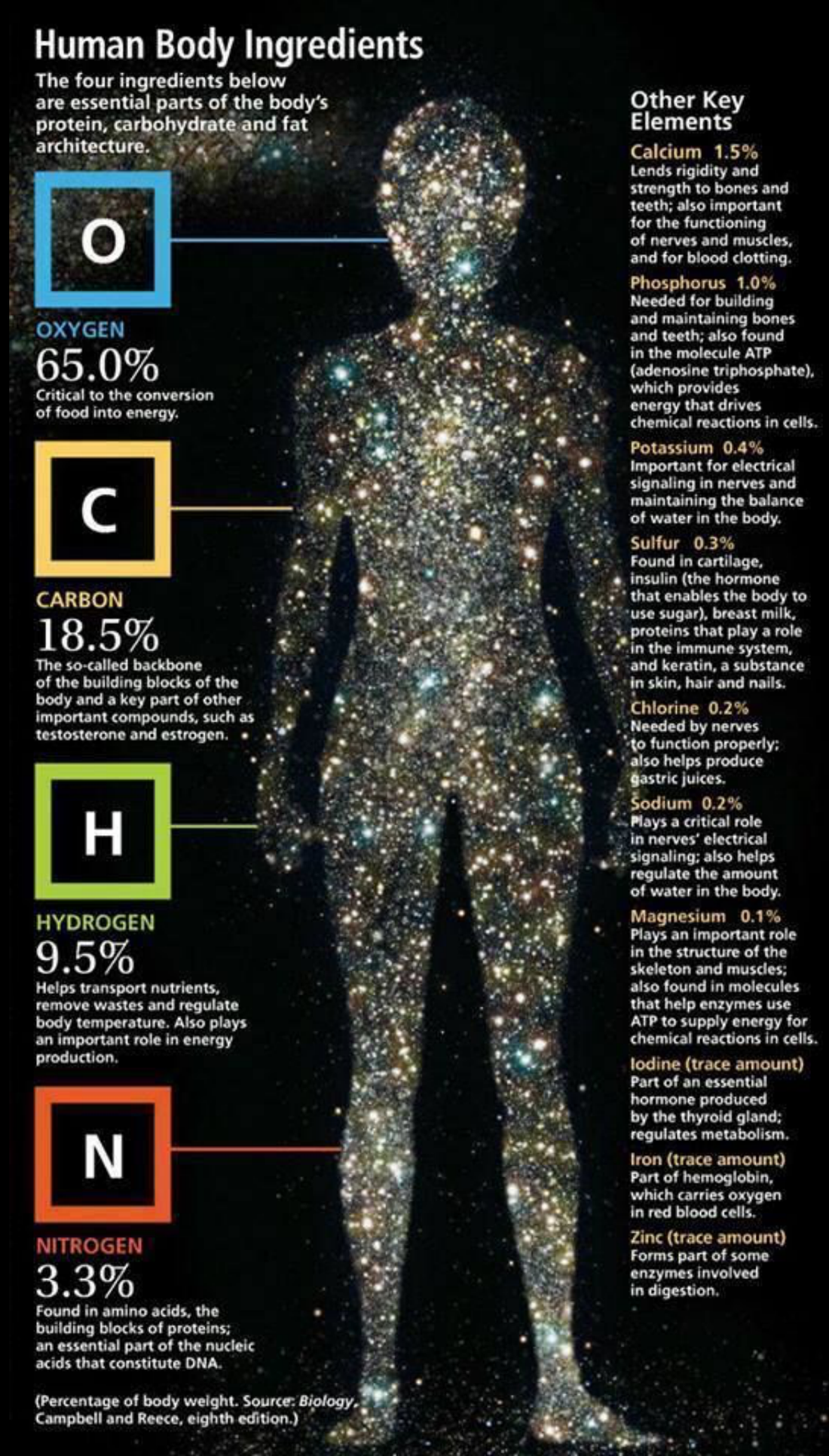
WHAT QUESTION?

WHAT'S THE CENTER OF IT ALL?

ME.

ME, BABY.

We are all stardust.



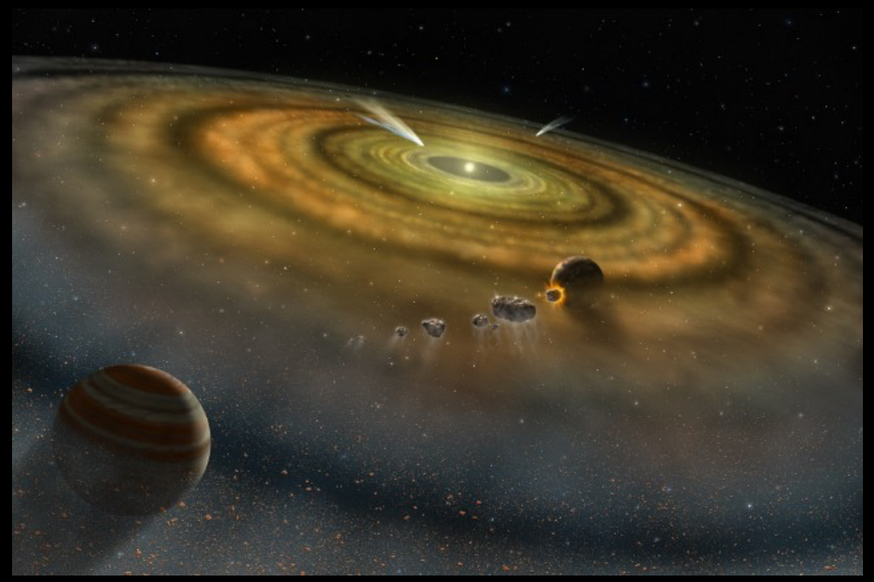
Astronomy is a bit of a different kind of science

It is OBSERVATIONAL

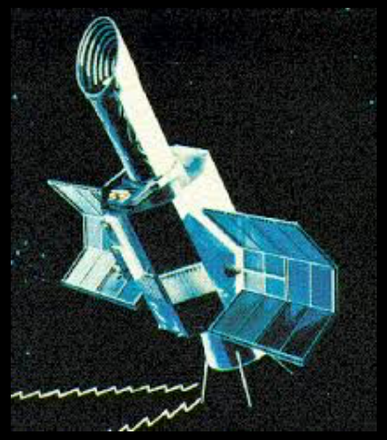
In most cases, the experiment has already been run

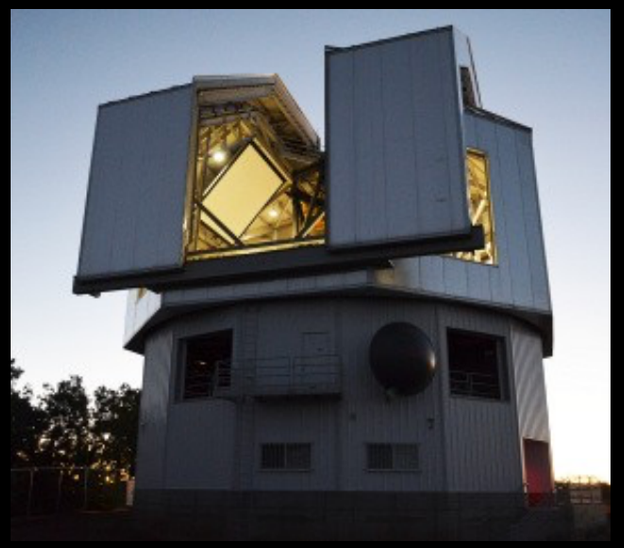
You can only observe the results

A Selection of “Experiments”



My Lab Equipment





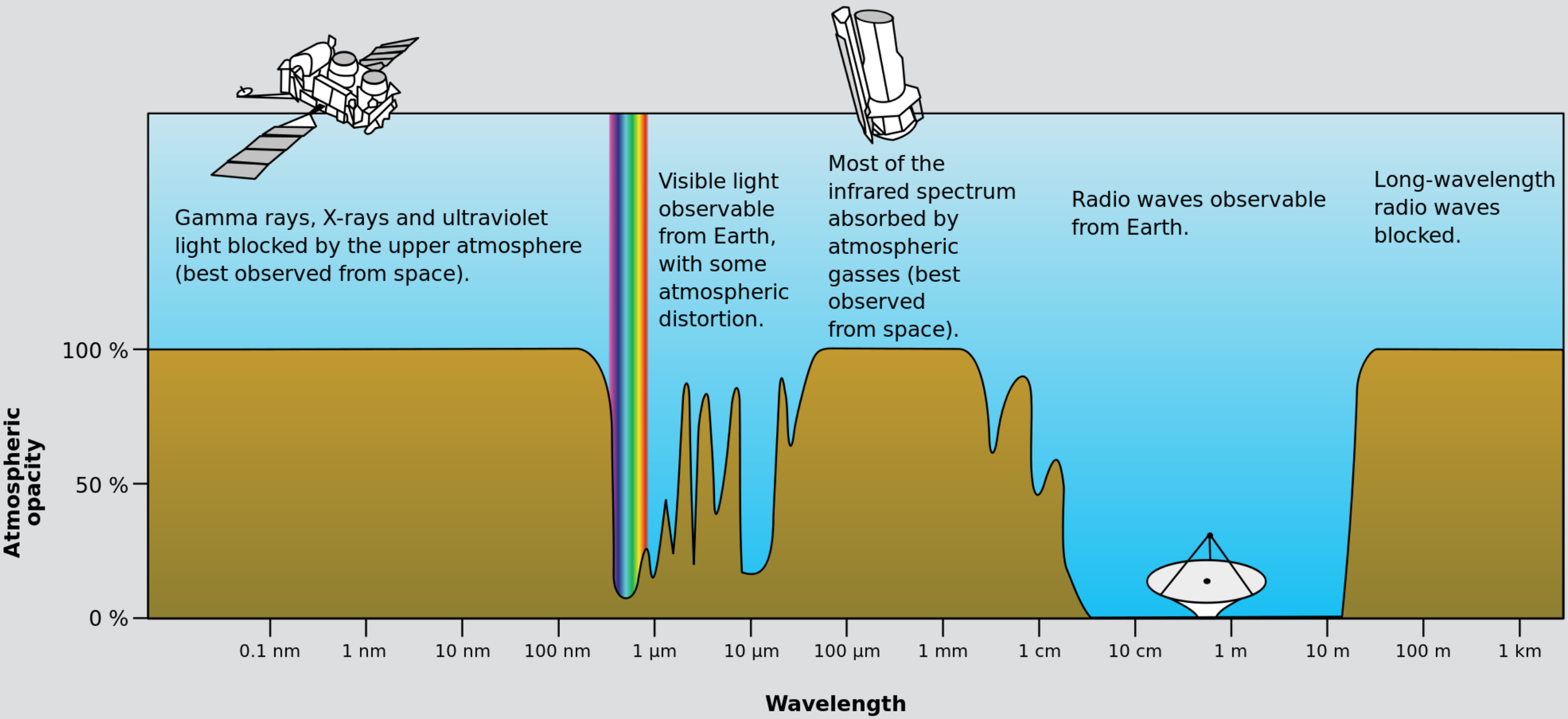
All the information we get comes to us in various forms of light*.

We have to decipher the information that the light provides.

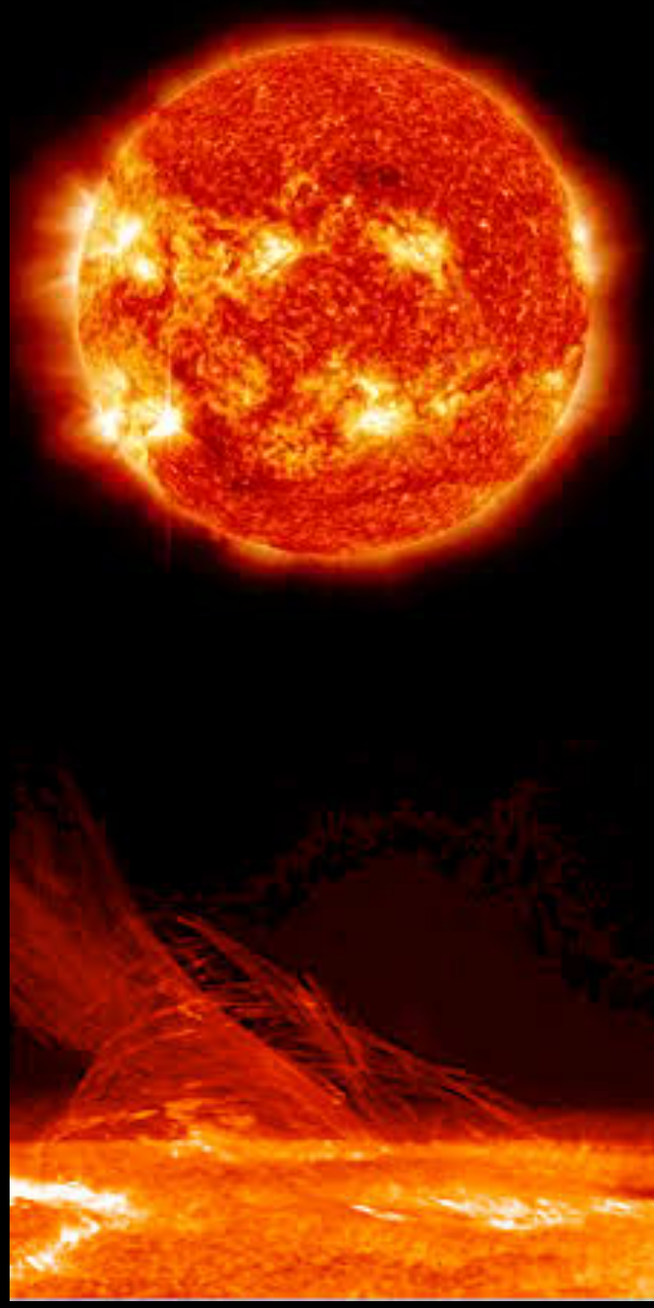
We also have to wait for the light to get to us (astronomy = “time travel”).

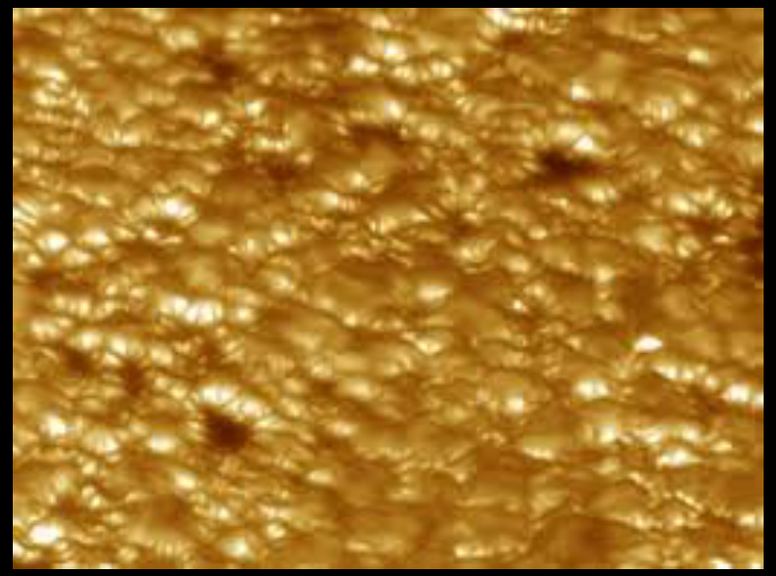
except now we have gravitational waves, too!

Electromagnetic Spectrum and Observation Limits

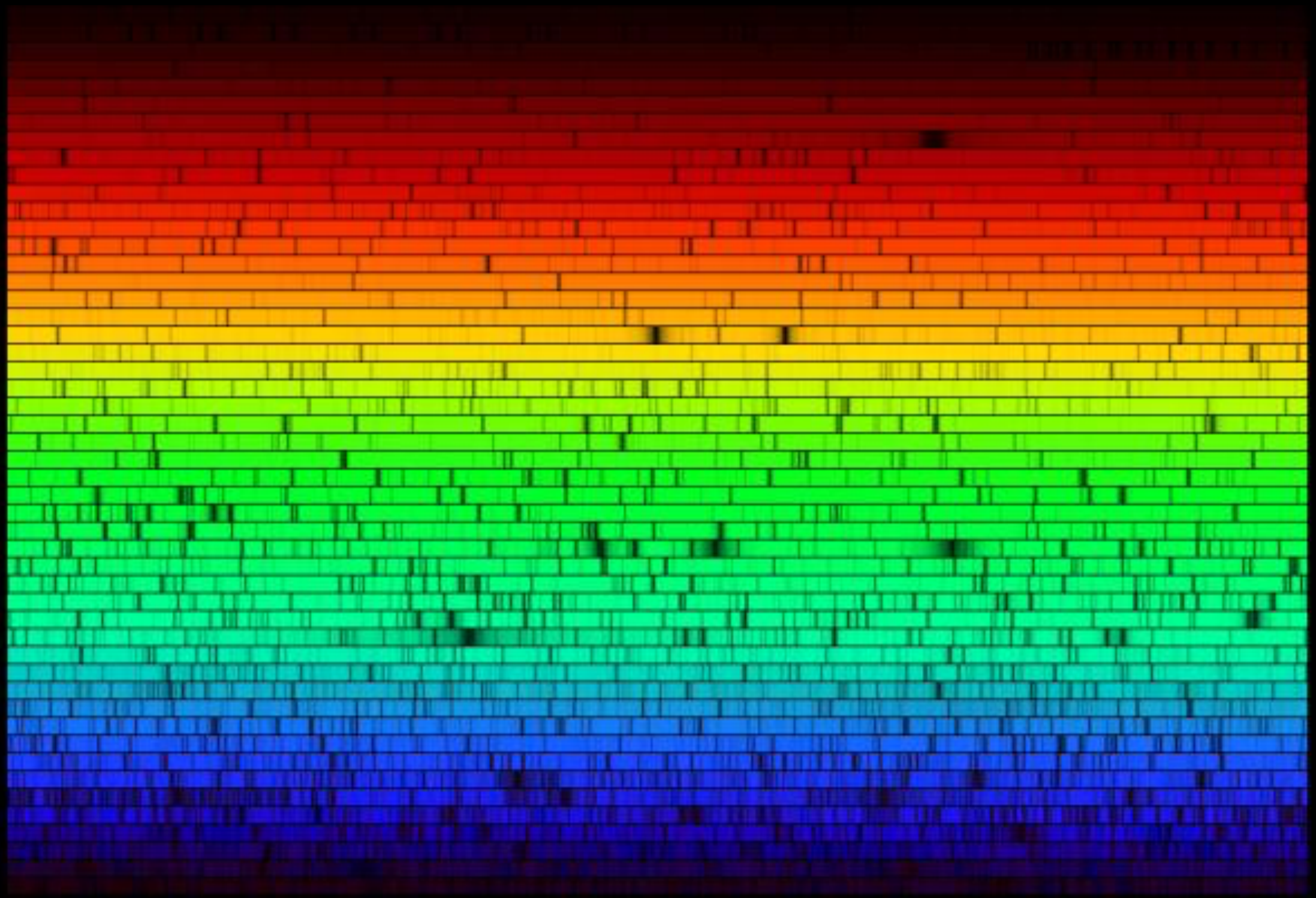


Images of a nearby star (the Sun)



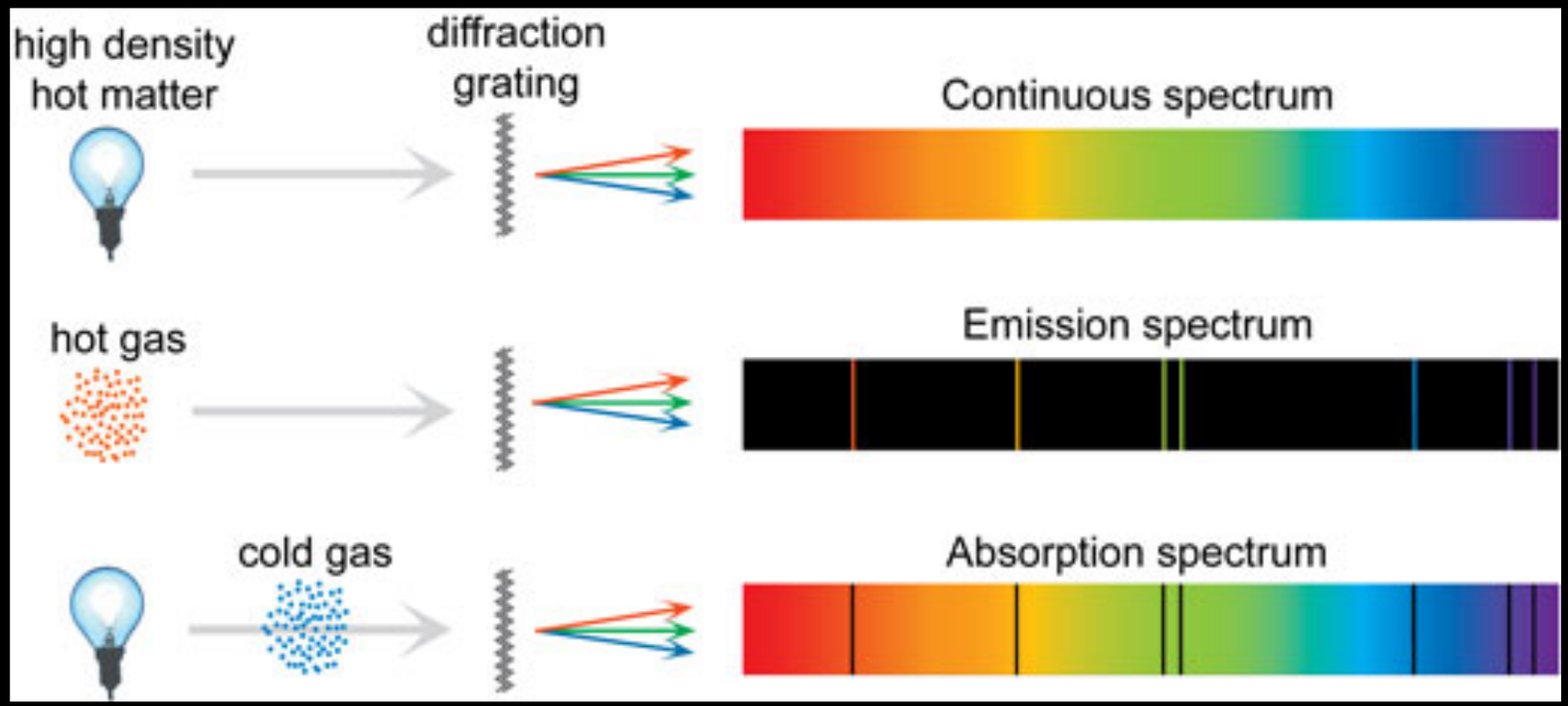


Spectrum of a nearby star (the Sun)

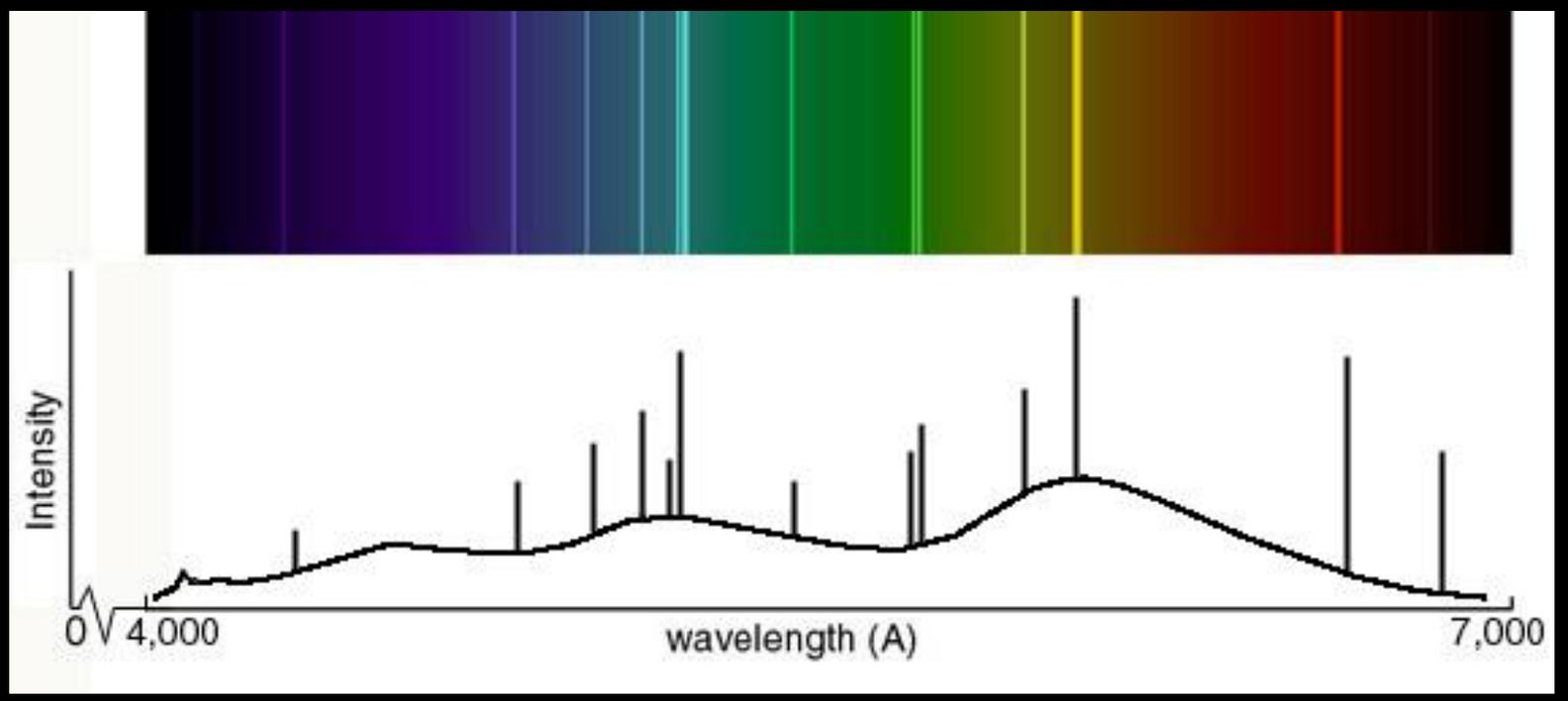


Credit: N. Sharp/KPNO/NSO/NOAO/AURA/NSF

Types of spectra



Emission Line Spectrum



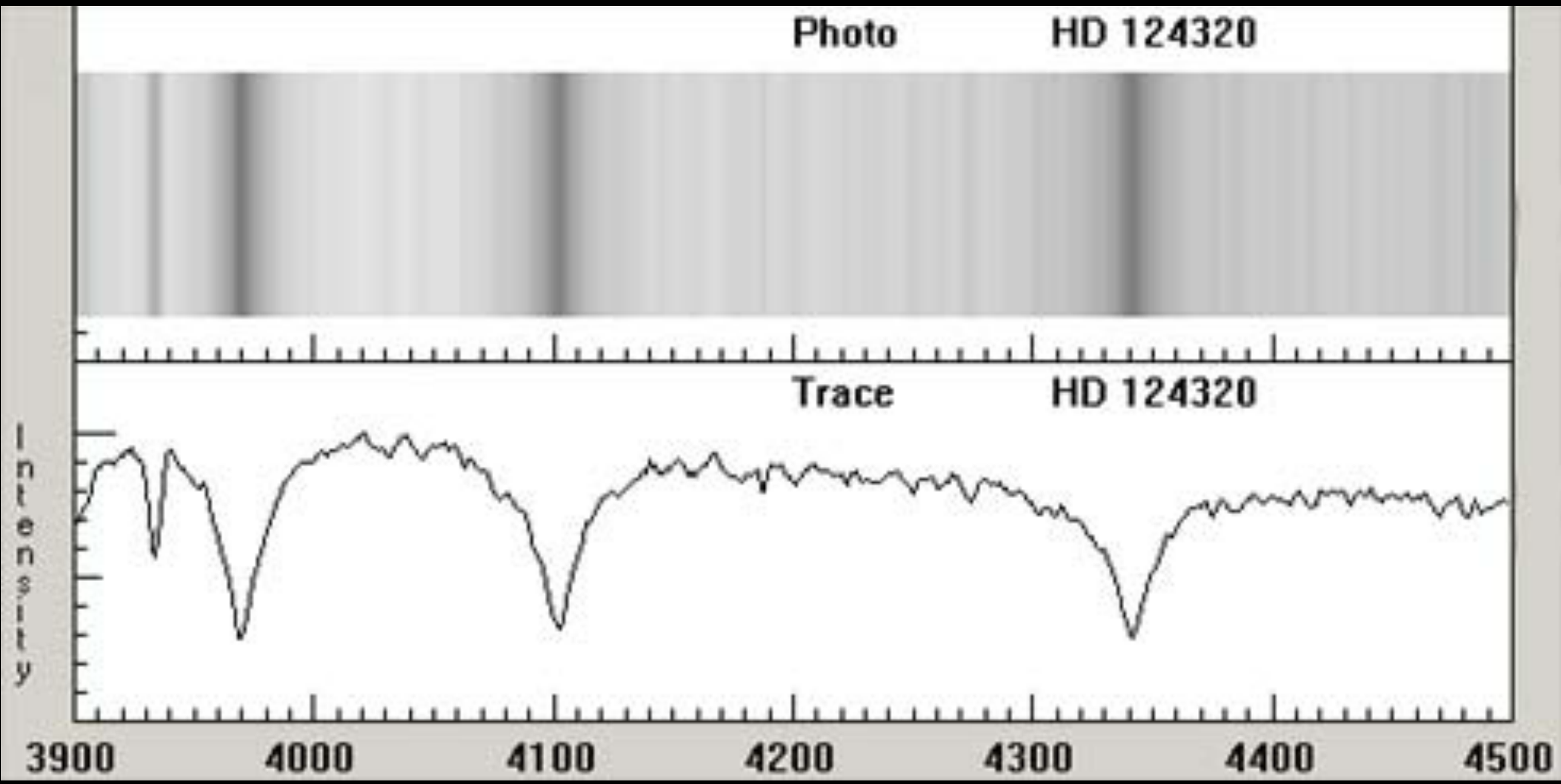
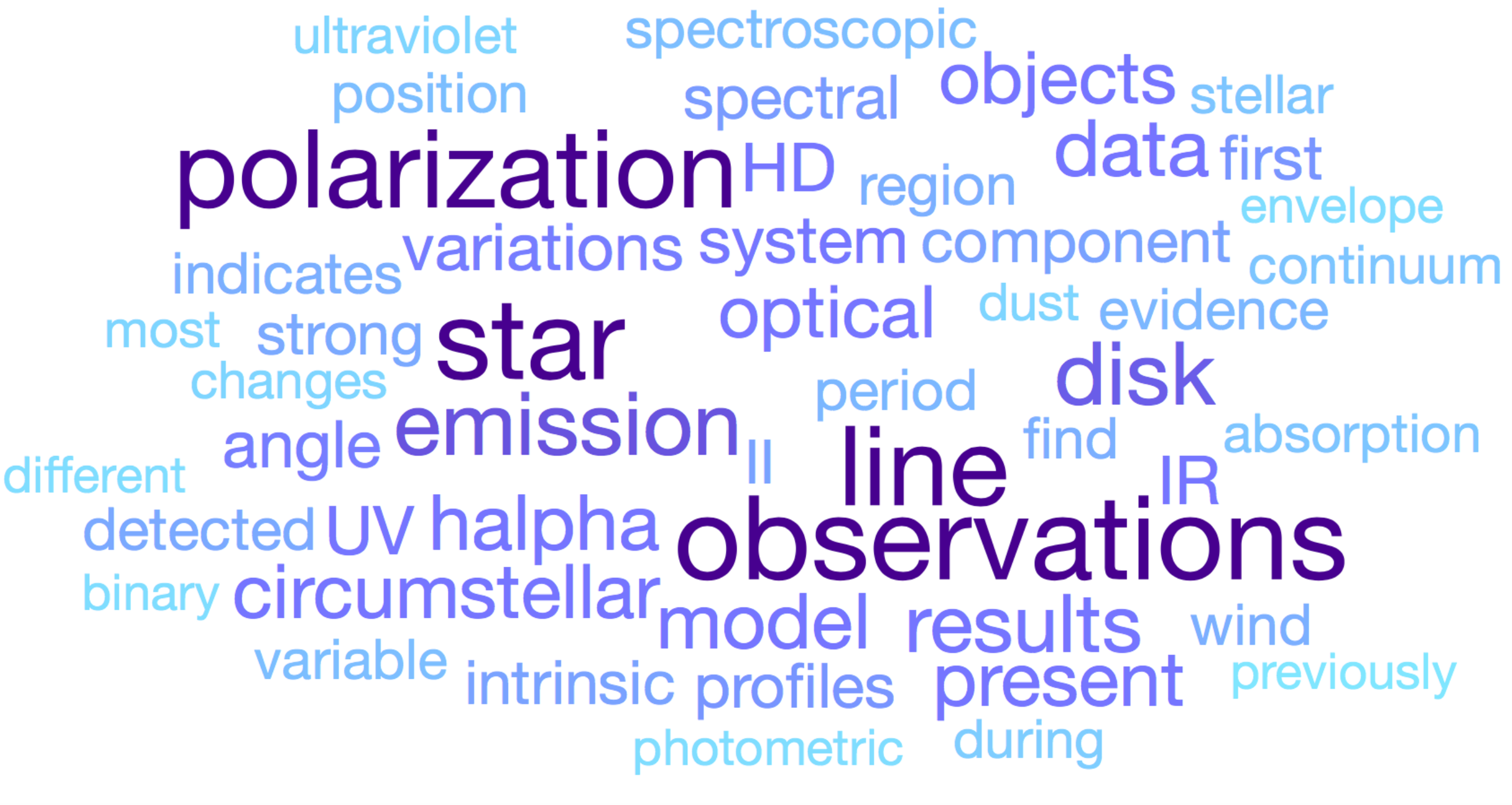


Photo
HD 124320
Trace
HD 124320
Intensity
3900
4000
4100
4200
4300
4400
4500

Frequently Used Word Cloud
(*my refereed publications*)



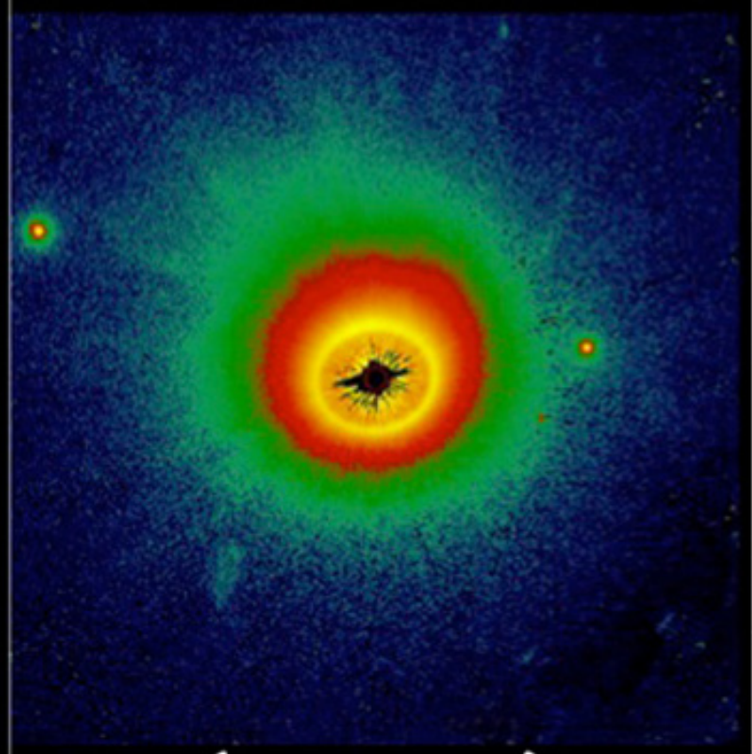
Credit: NASA ADS Bumblebee

Fun with Stars

- **Circumstellar disks** (young, intermediate, old)
- Stellar winds and envelopes (hot massive stars)
- Ultraviolet (UV), optical, infrared (IR)
  - sometimes radio, x-ray
- Spectroscopy, **spectropolarimetry**, photometry, imaging
- Space- and ground-based observations

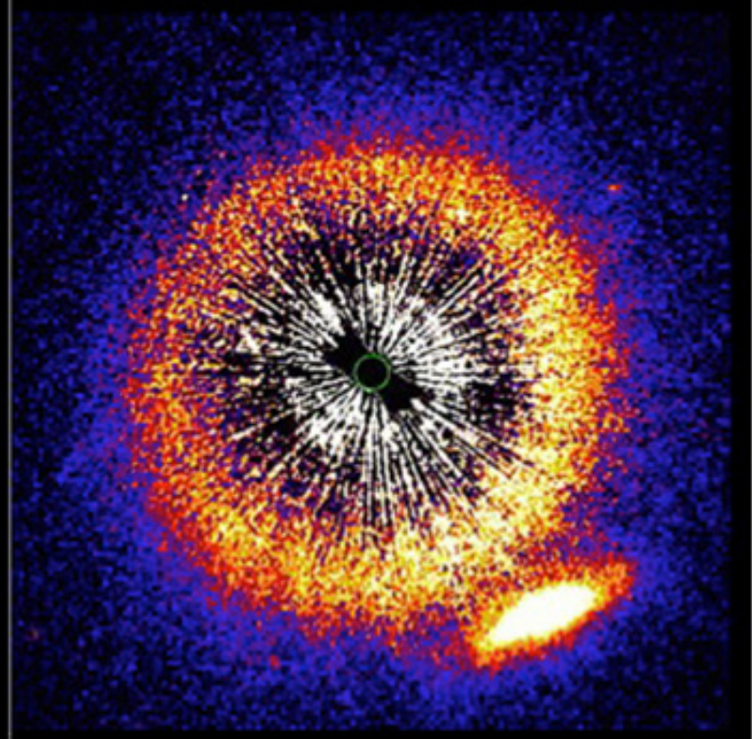
The Hubble GO/12228 Program Debris Disk Sample

HD 181327 (F6V)



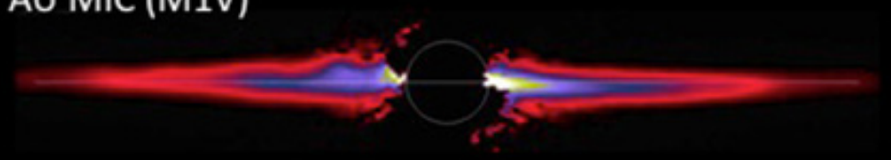
530 AU (10.2″)

HD 107146 (G2V)



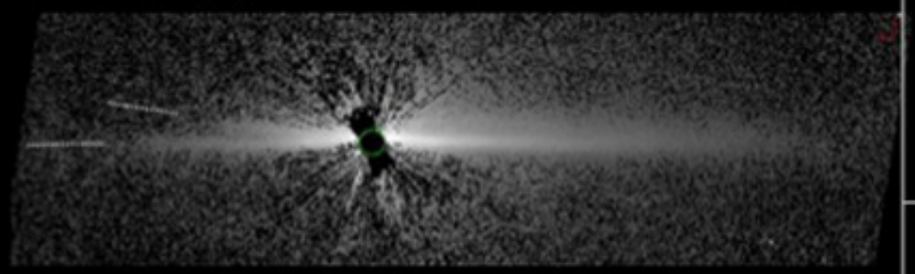
290 AU (10.6″)

AU MIC (M1V)



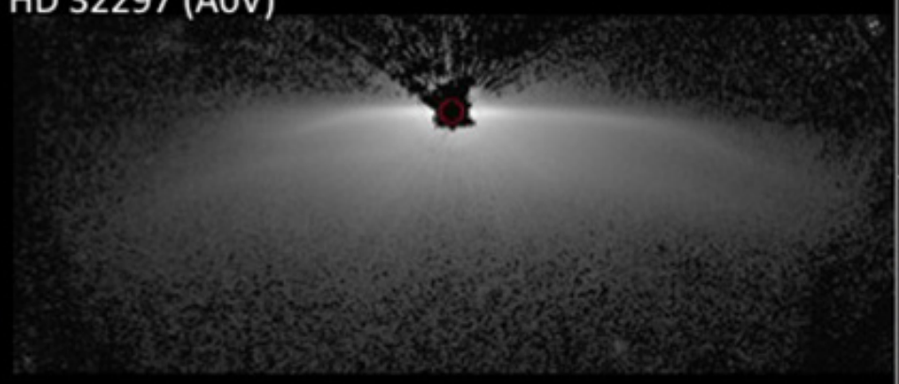
100 AU (10.1″)

HD 15115 (F2)



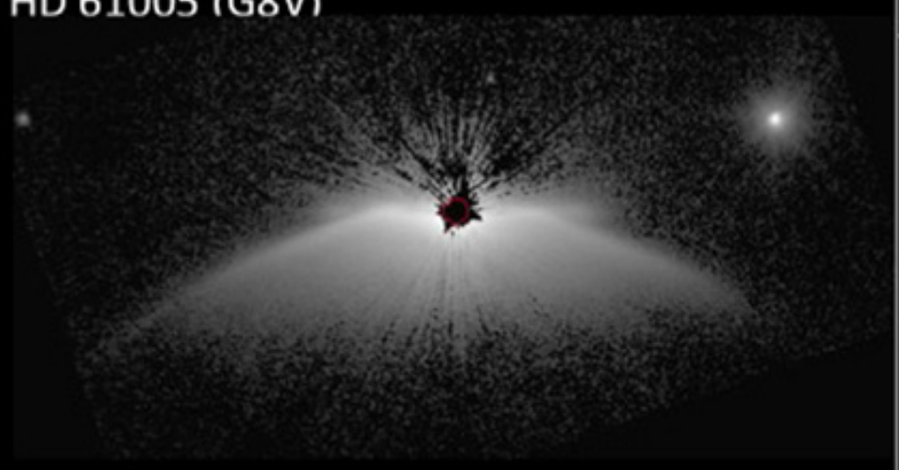
890 AU (19.7″)

HD 32297 (A0V)



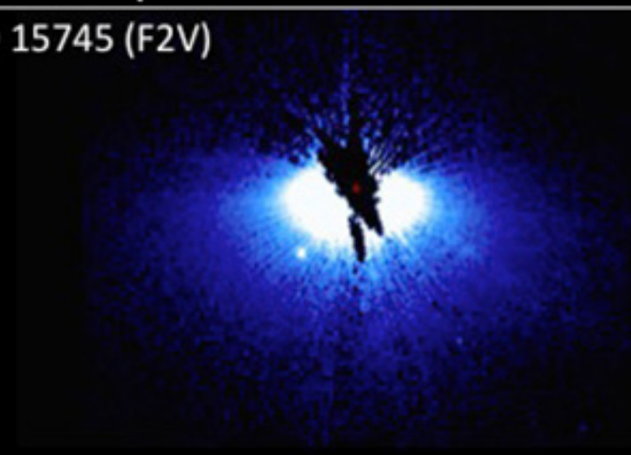
2390 AU (21.3″)

HD 61005 (G8V)



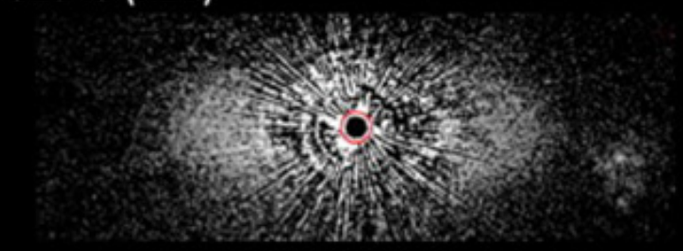
550 AU (12.1″)

HD 15745 (F2V)



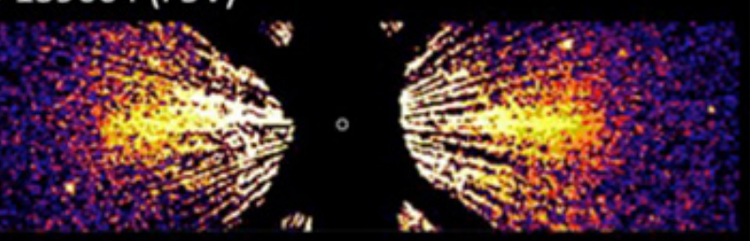
700 AU (11″)

HD 92945 (K1V)



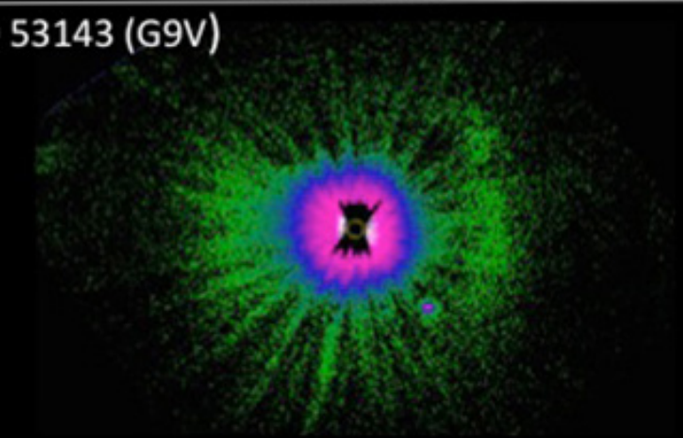
230 AU (10.7″)

HD 139664 (F5V)



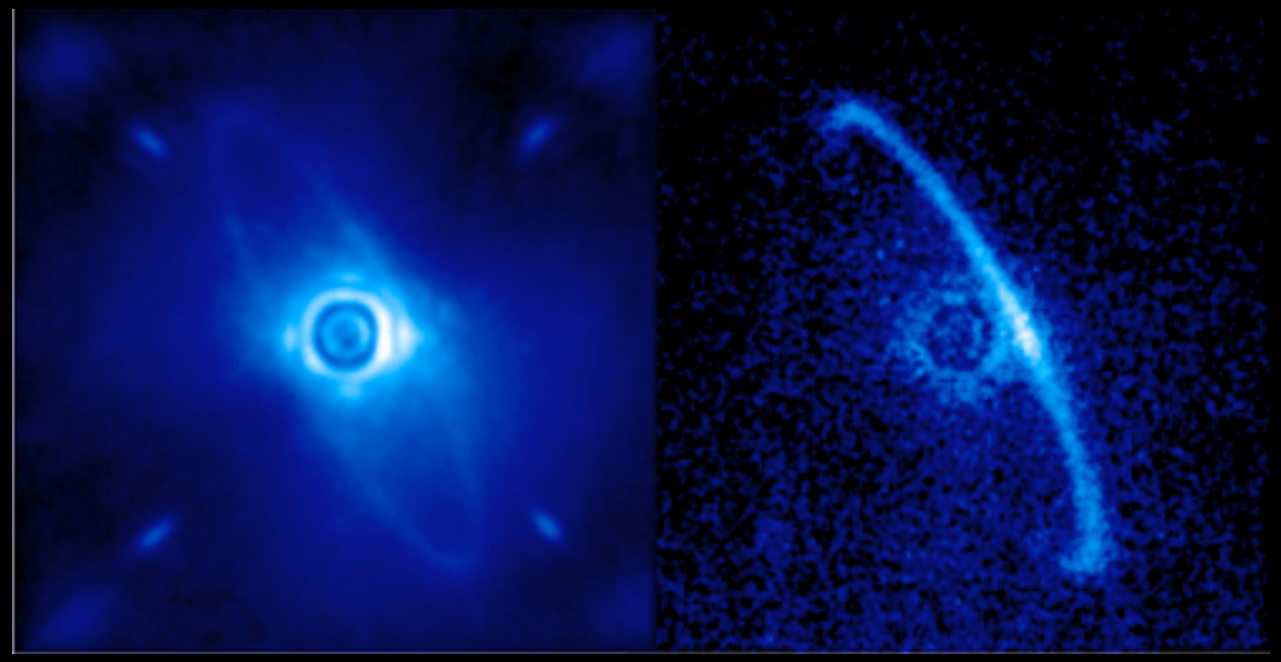
160 AU (9.2″)

HD 53143 (G9V)



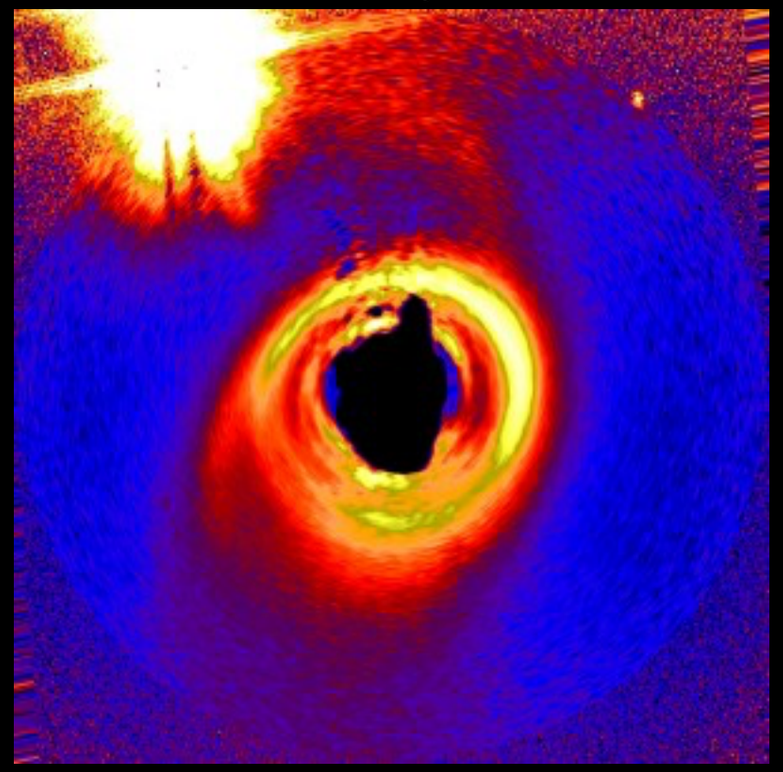
250 AU (13.6″)

HR 4796A



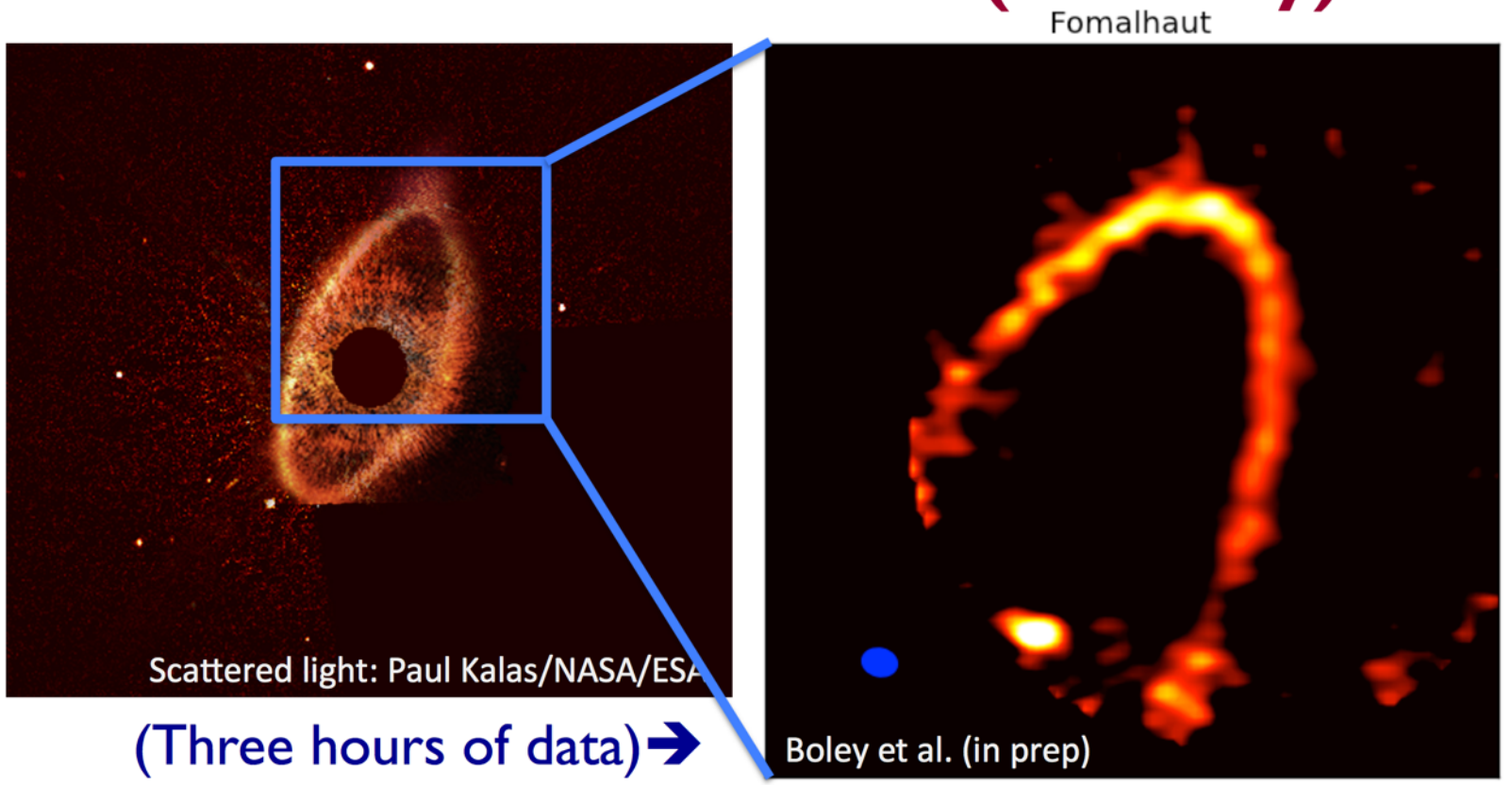
Credit: Kalas

TW Hya



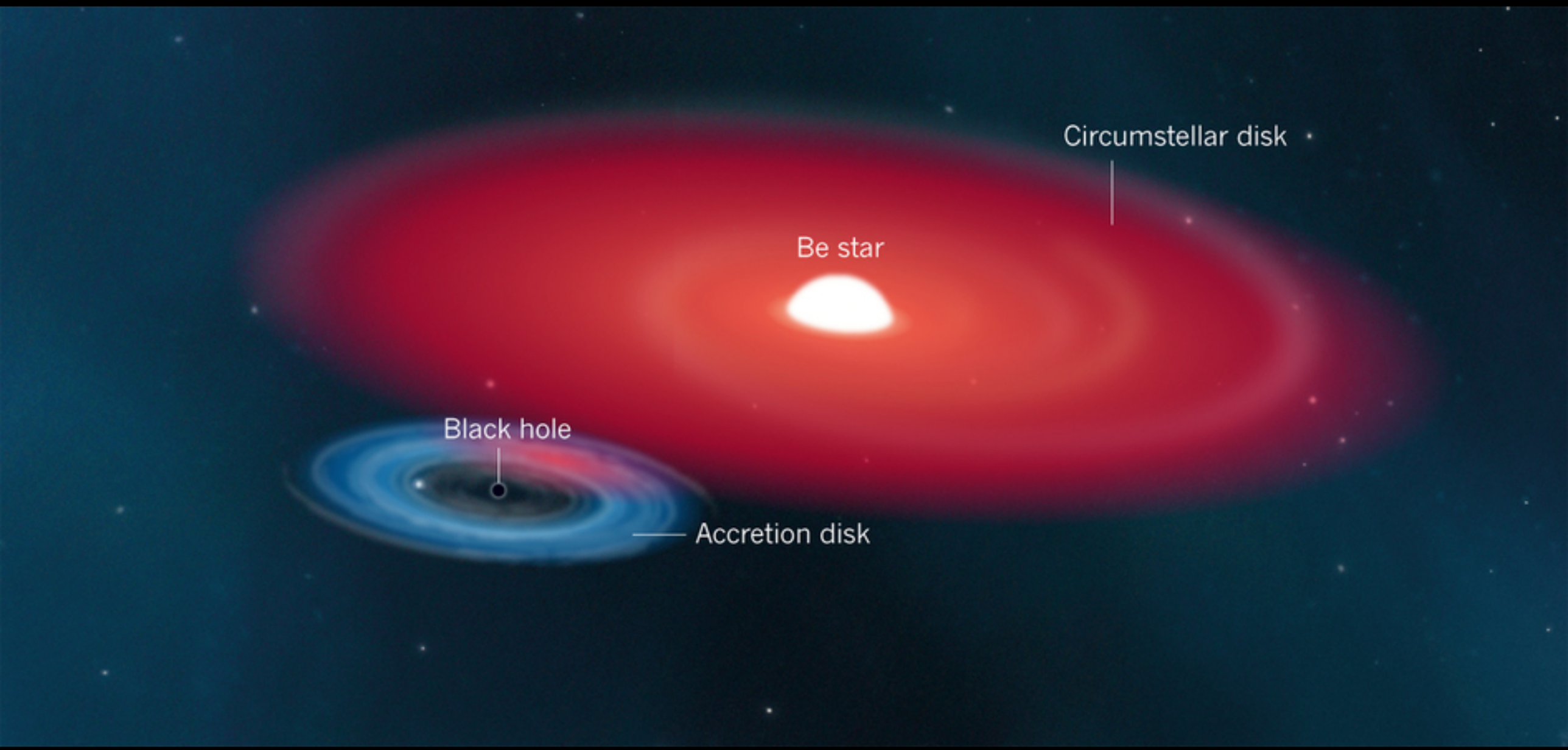
Credit: Rosenfield et al.

Fomalhaut Observations (PI: Boley)

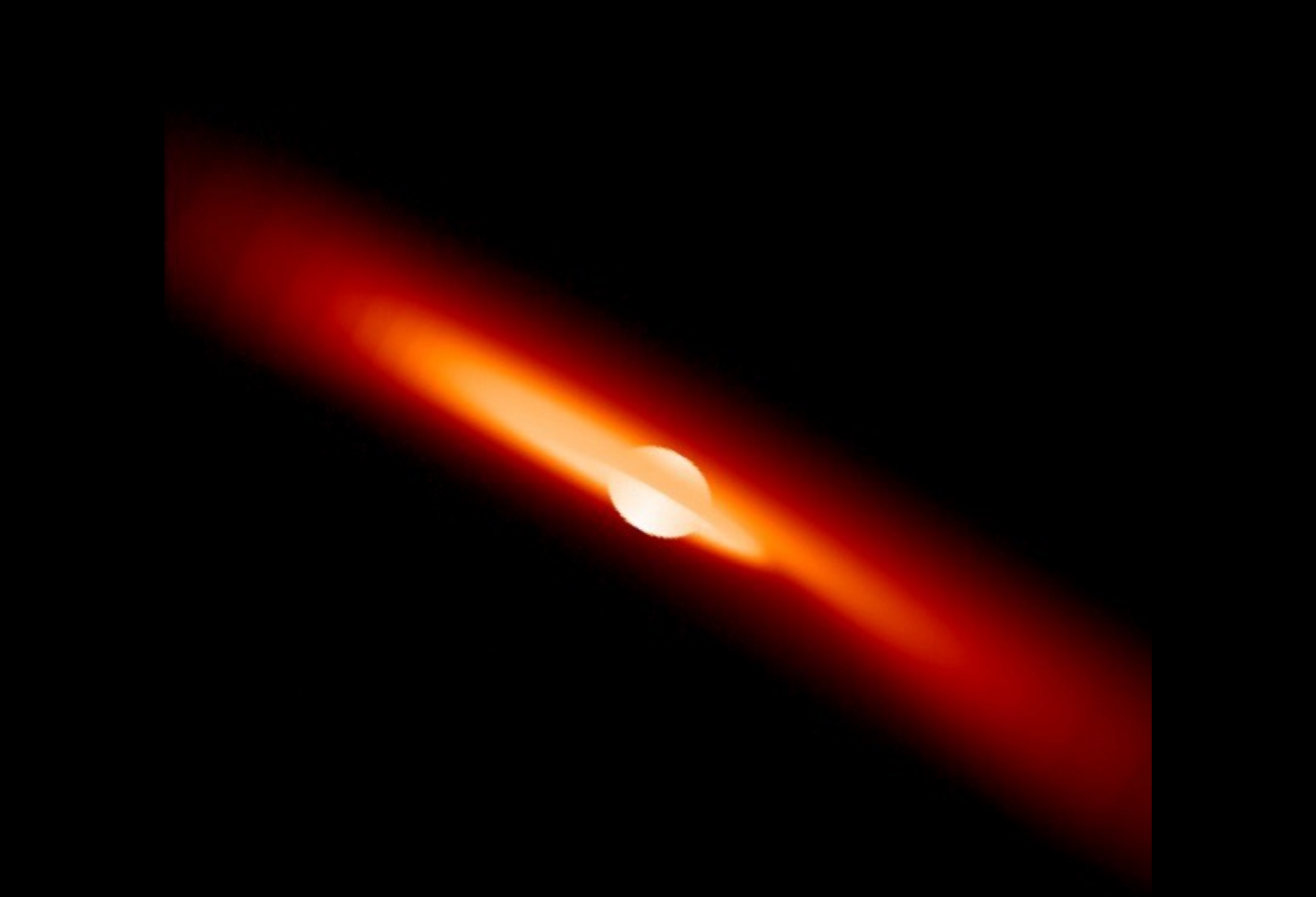


Simpler Case: Be Stars with Gas Disks

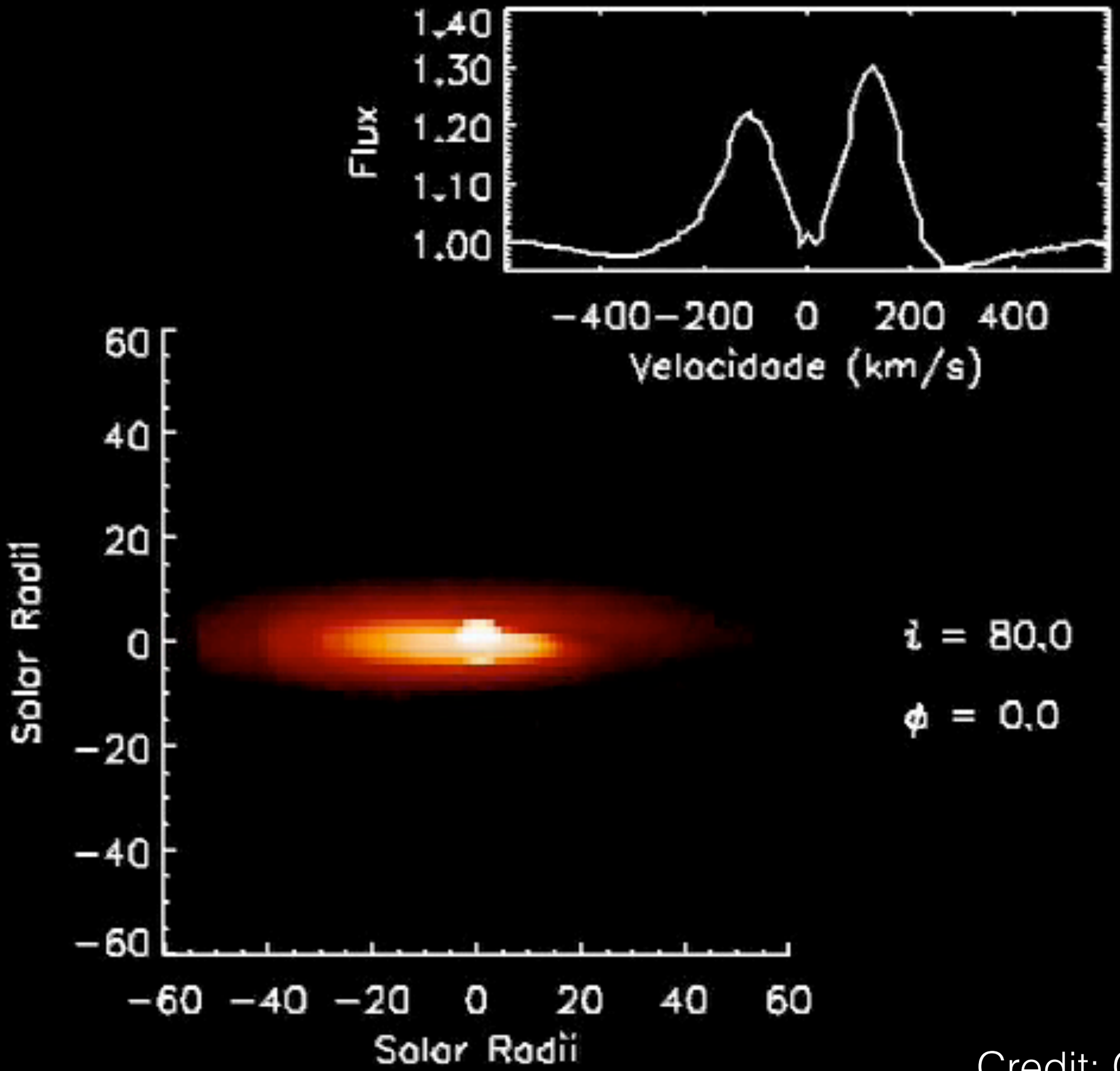
Be star with a black-hole companion



Credit: McSwain (2014) Nature 505, 296



Carciofi et al. 2009

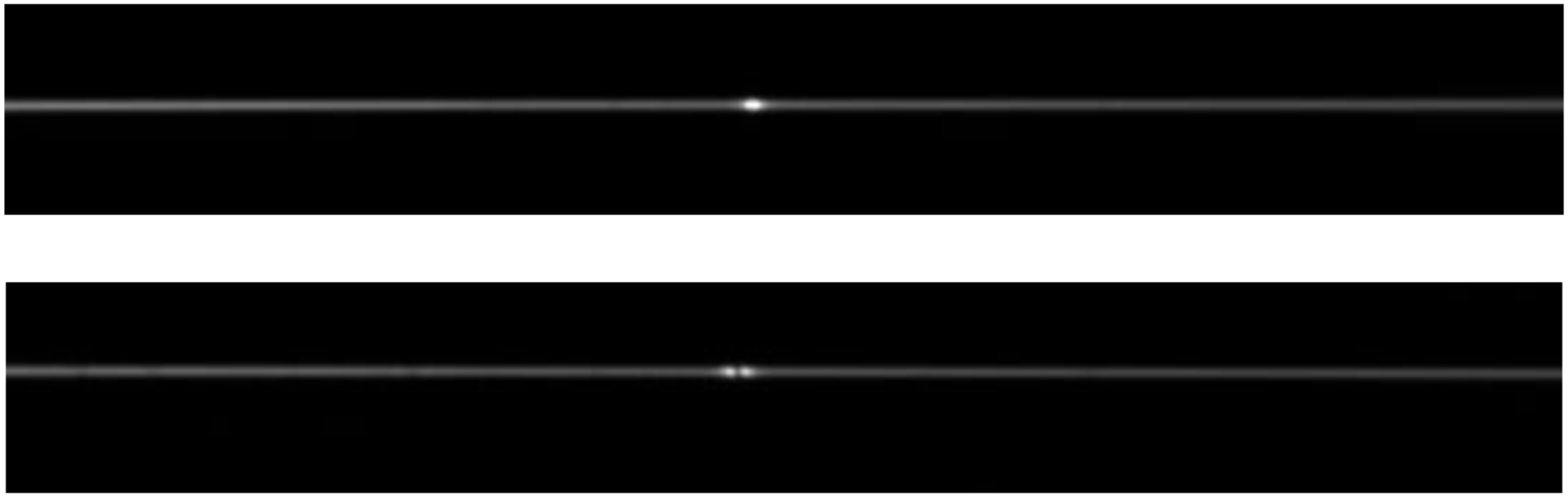


Credit: Carciofi

Ritter Observatory

on the University of Toledo Main Campus

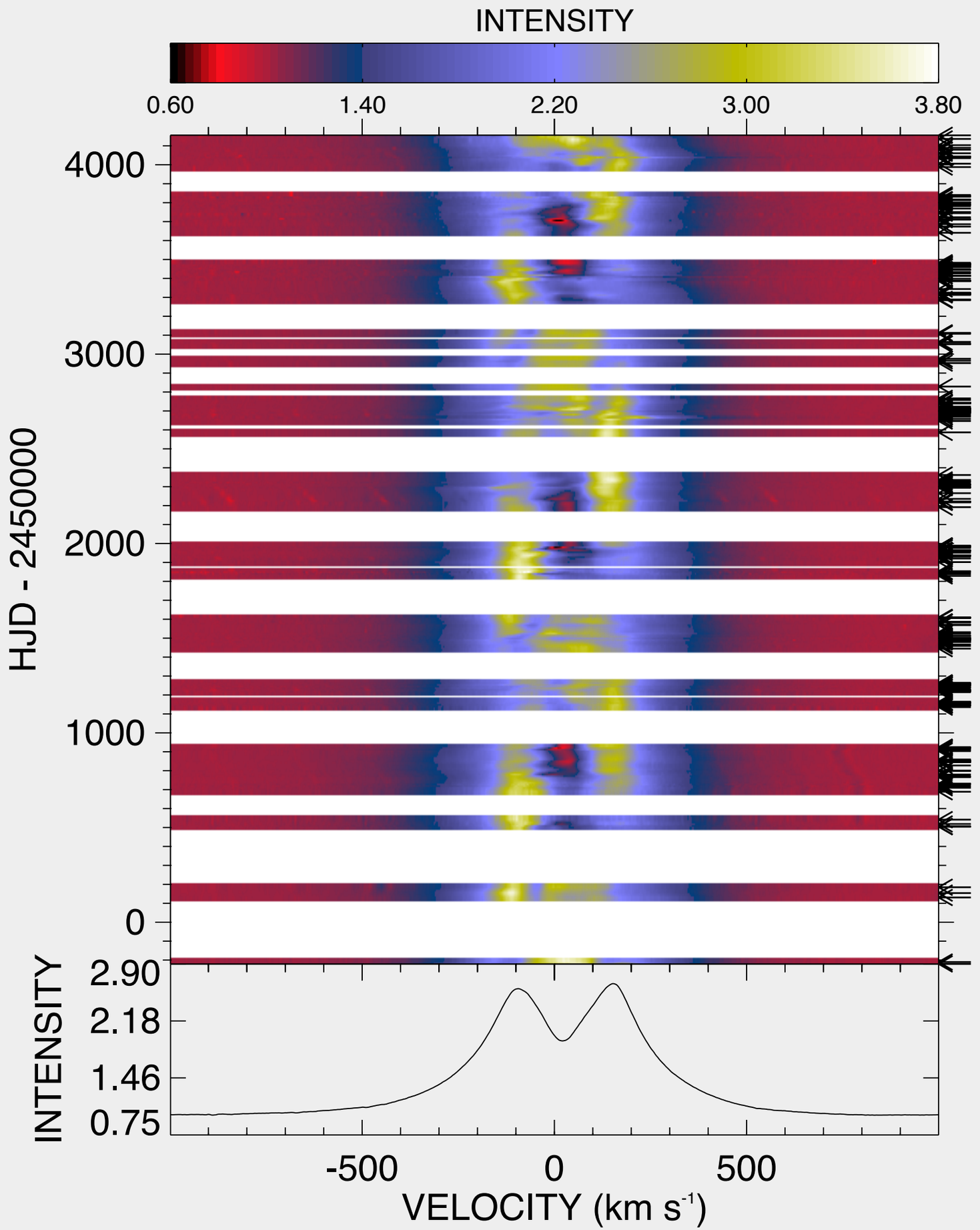
Home of the Ritter Astrophysical Research Center & Ritter Planetarium



Two examples of Be stars spectra around H-Alpha (R=3000 spectrograph). Up: 31 Peg. Down: HD193182.

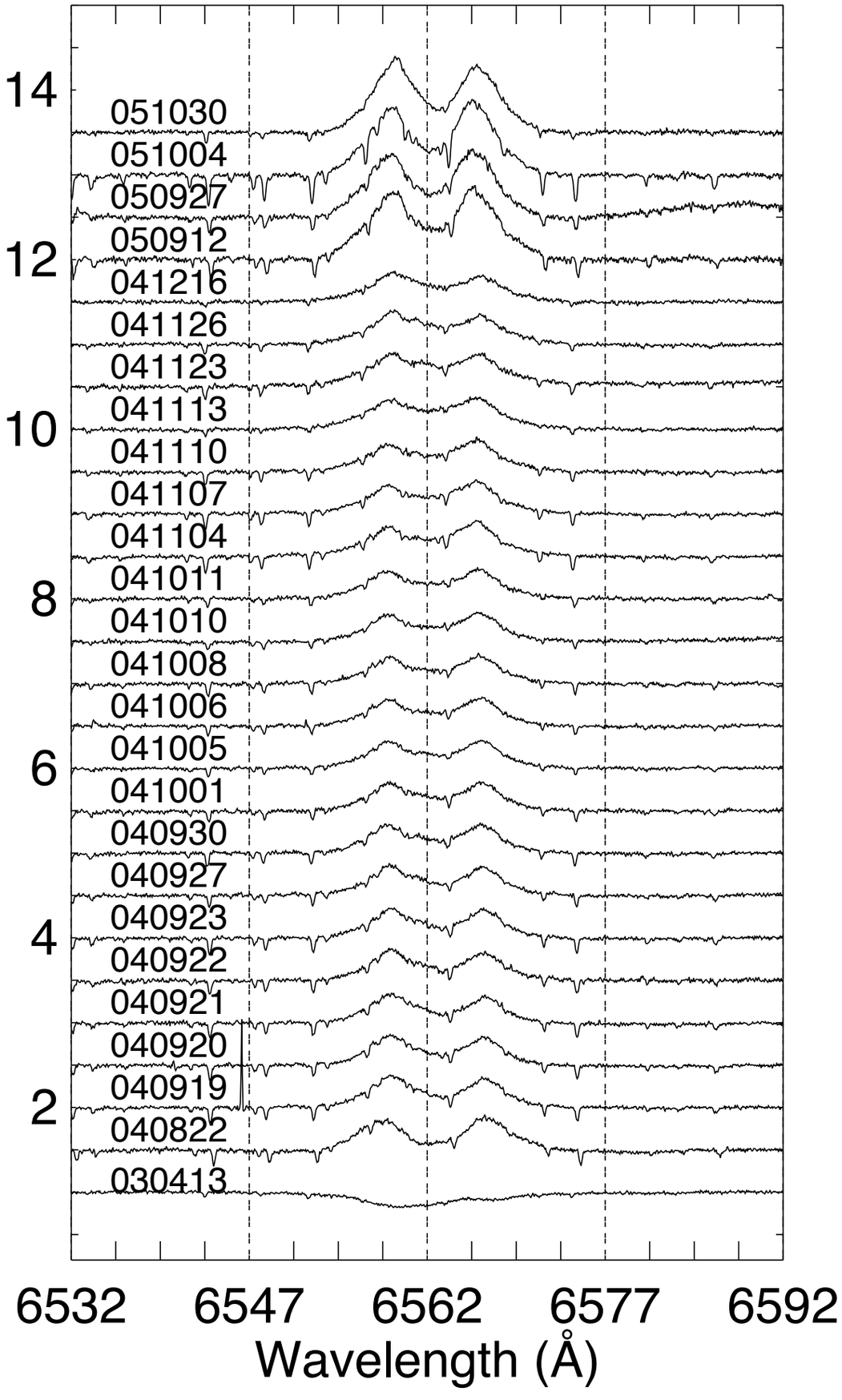
Credit: Buil

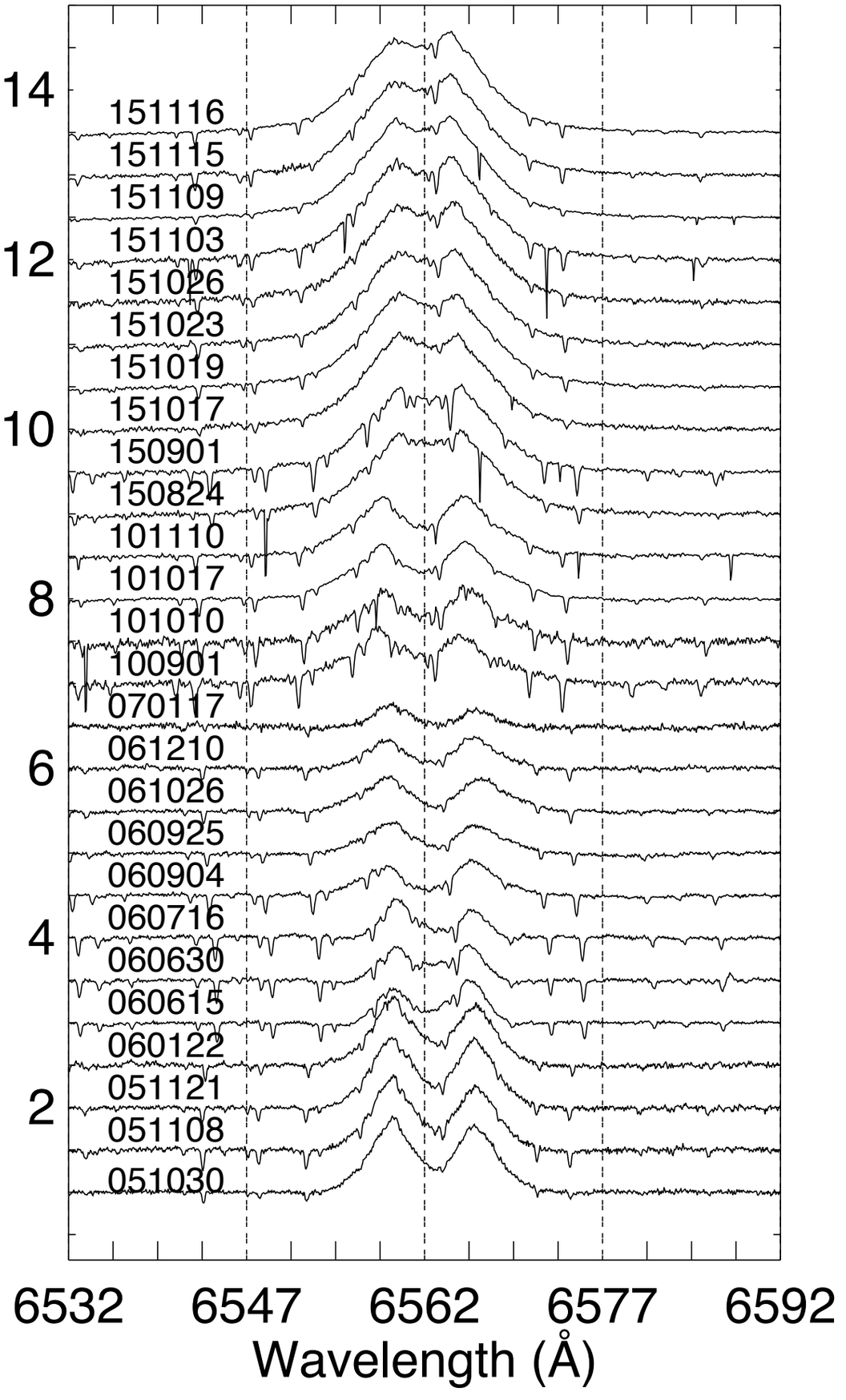
Dynamical Spectrum of zeta Tau



Credit: N. Richardson

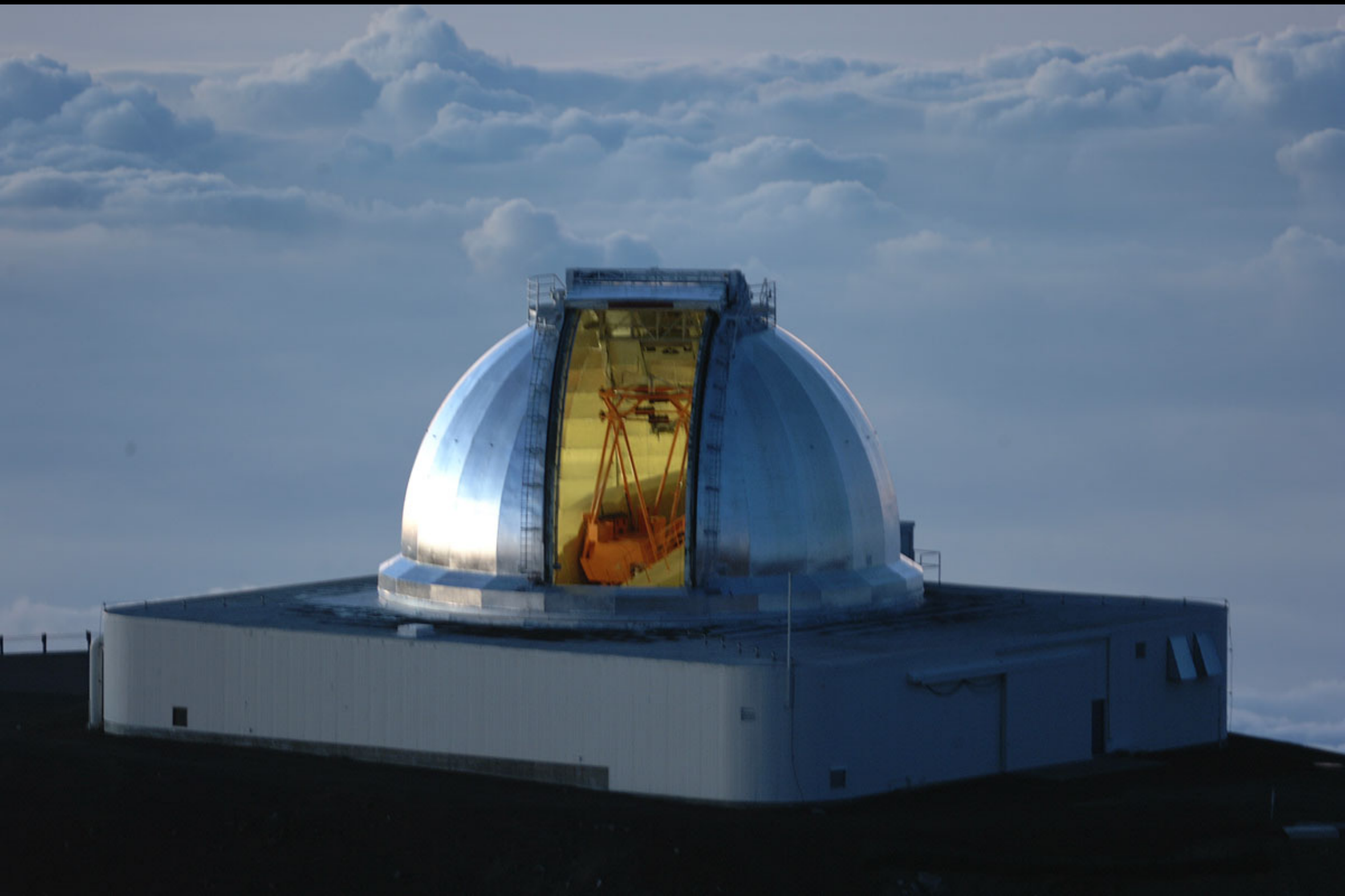
π Aqr Hydrogen α Profiles



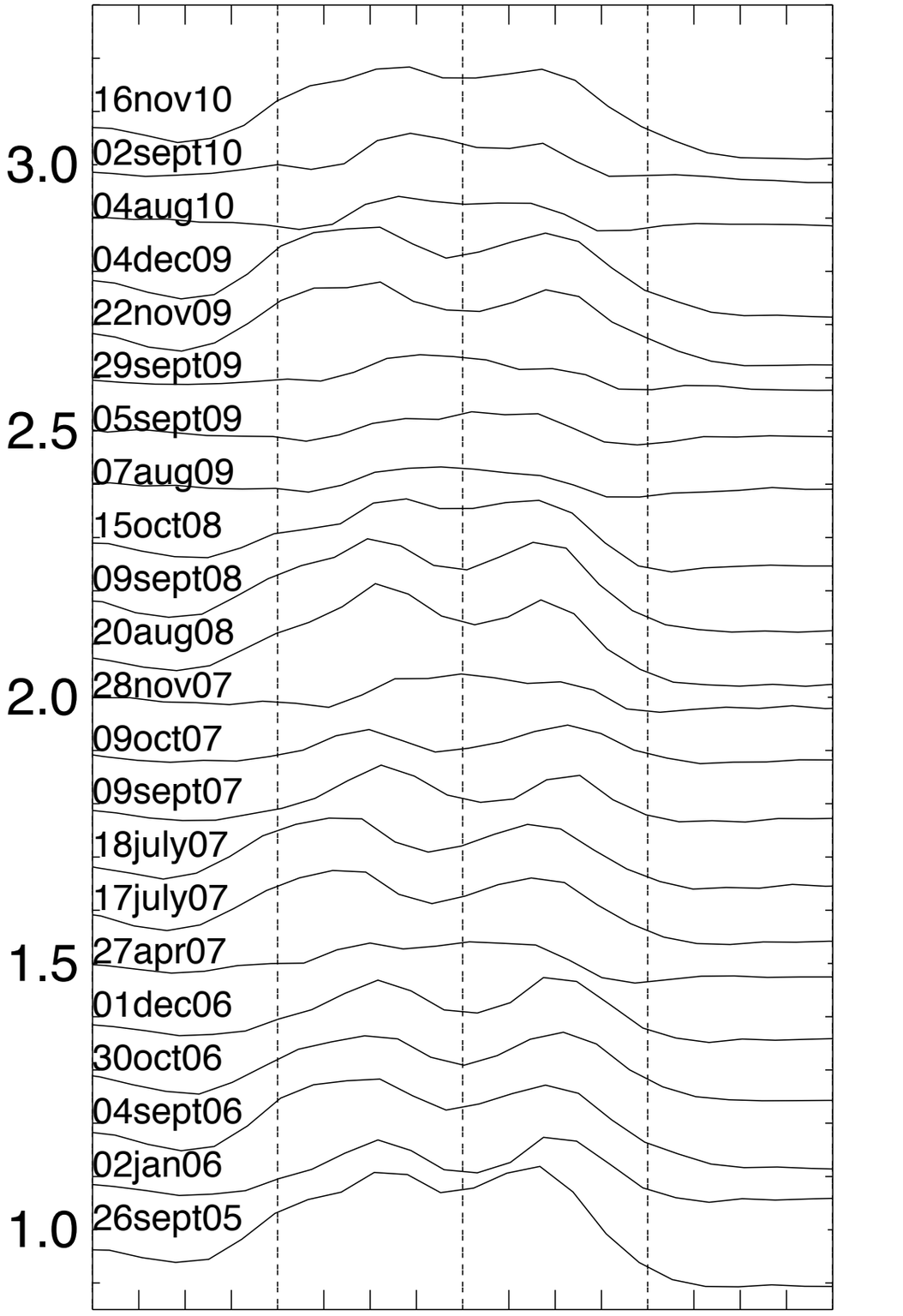


Mauna Kea Observatory, Hawaii

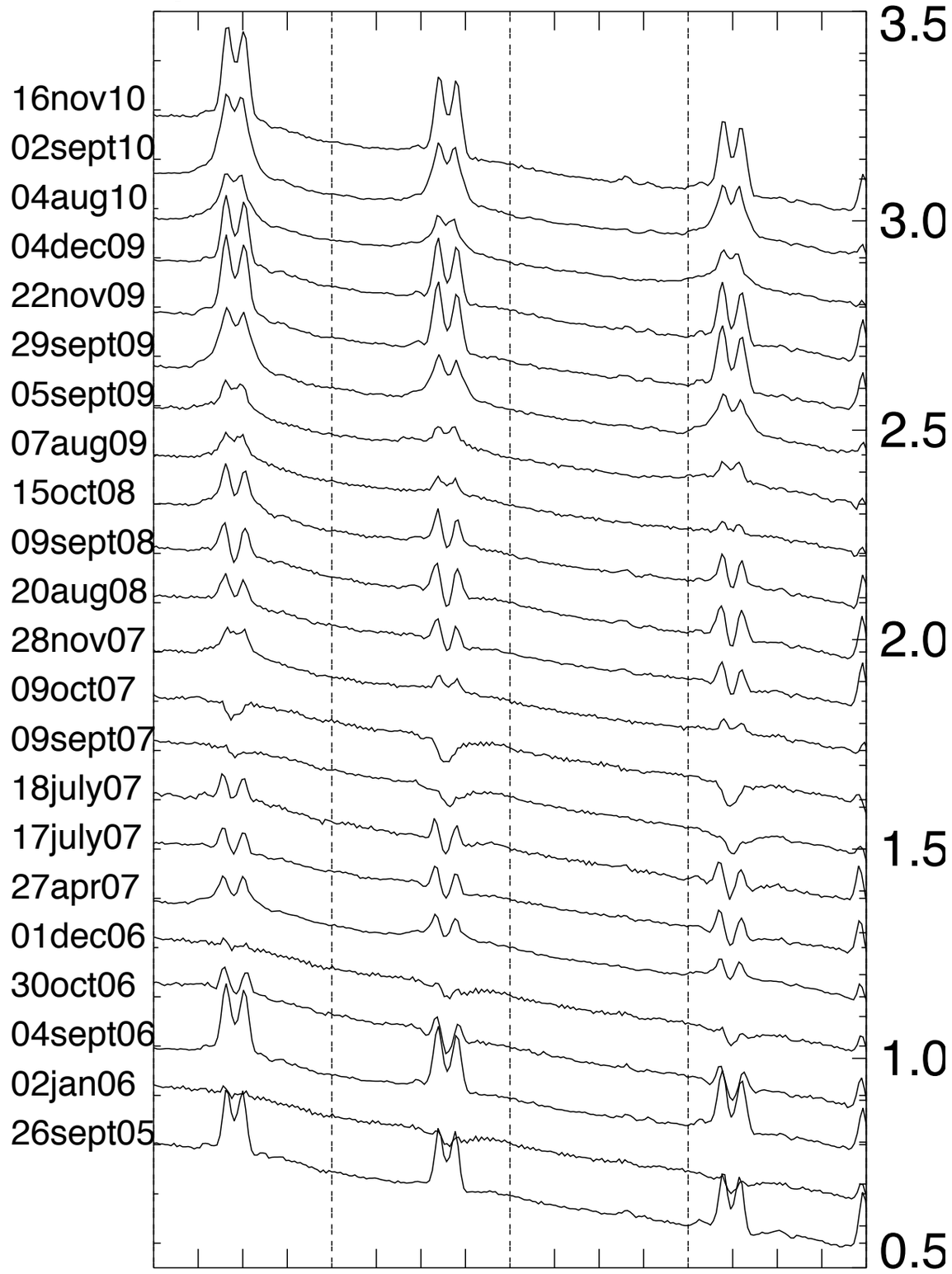
NASA IRTF (Mauna Kea, Hawaii)



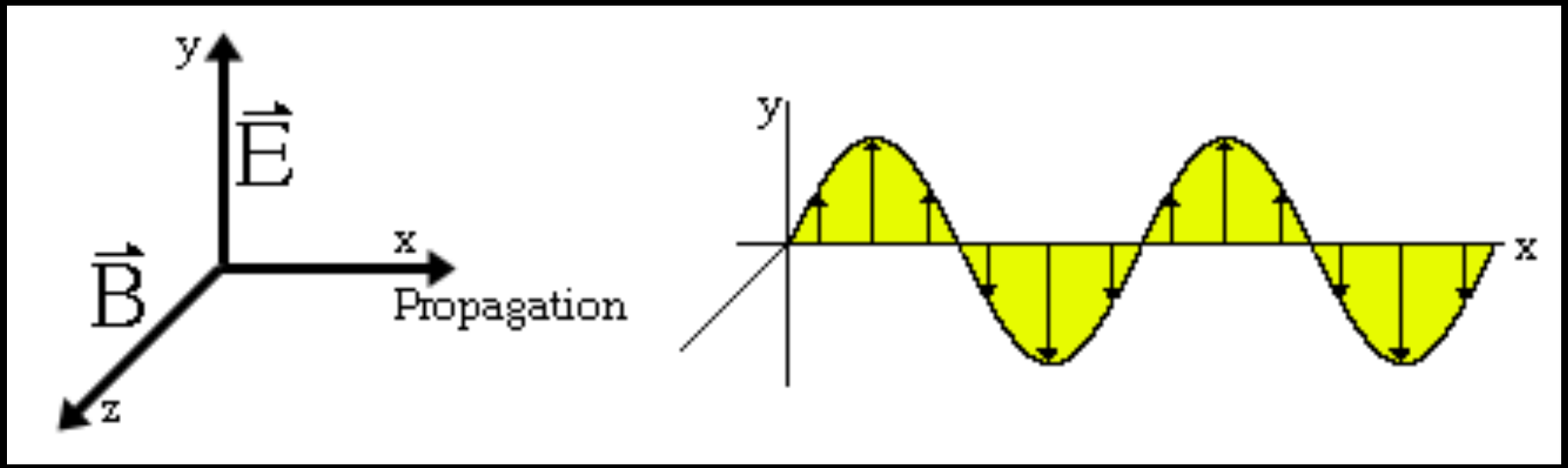
π Aqr Brackett γ Profiles

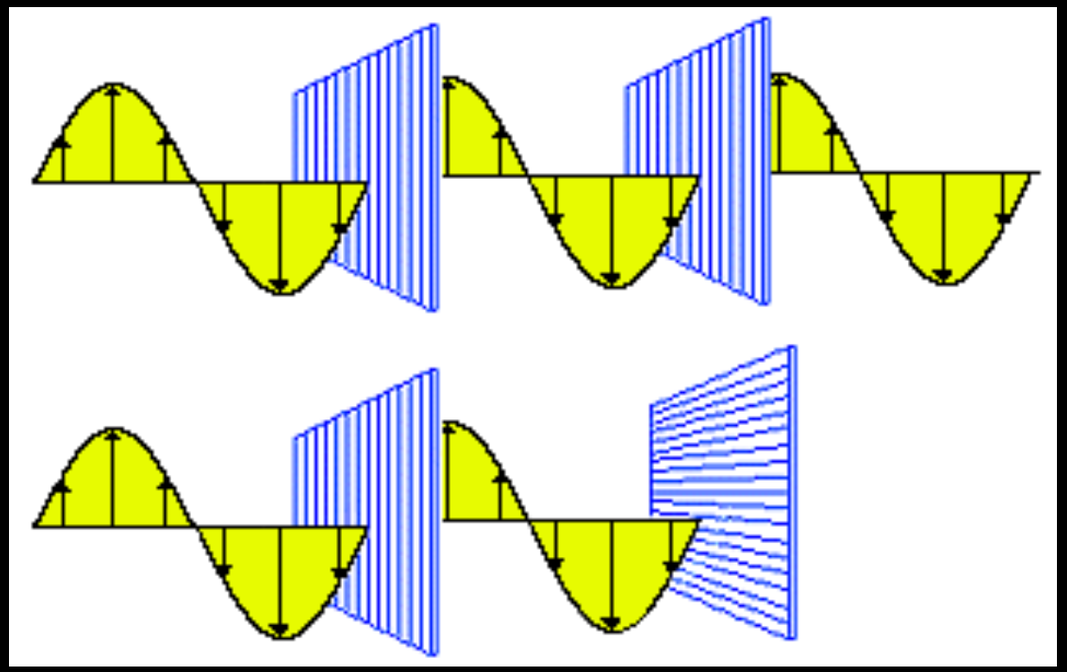


π Aqr Brackett 11–13 Profiles



Basic Physics of Polarization





Use polarization analyzers to determine degree of polarization & position angle

Polarizing Mechanisms

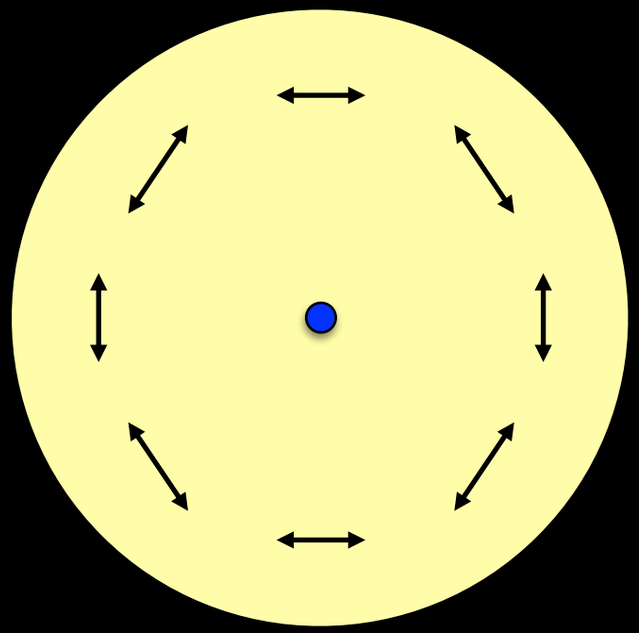
- electron scattering
- dust scattering
- interstellar dichroic extinction*
- thermal emission by aligned elongated dust grains (important in IR)
- magnetic fields (circular polarization)
- line scattering

Polarization in Hot Stars

- Dominated by electron scattering in circumstellar envelope (CSE)
- Polarization is in a direction perpendicular to scattering plane
- Envelope not resolved, so observed polarization is the co-added net polarization

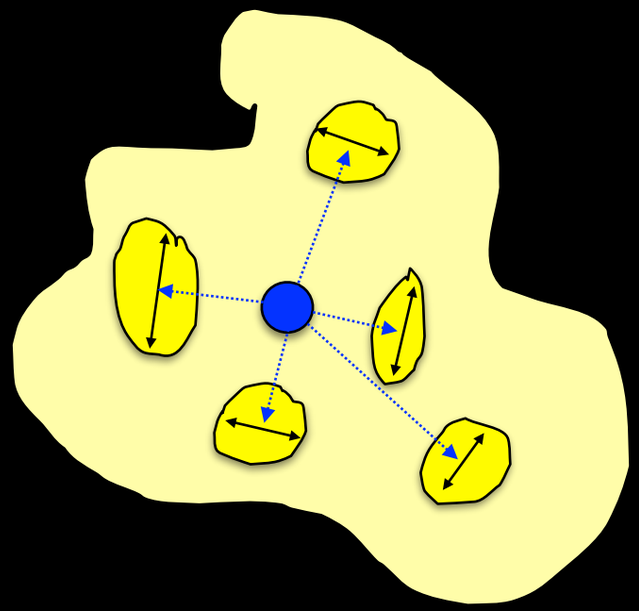
Effect of Asymmetries (Unresolved case)

Polarization at each point is perpendicular to the radius vector



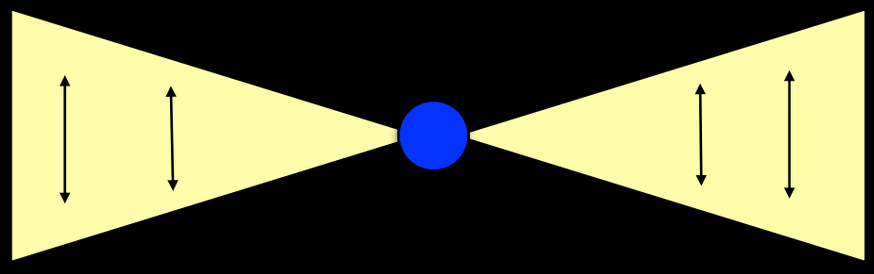
SPHERICAL

Vectors co-add:
Total Polarization = 0



BLOBS

Net polarization depends on relative contributions from individual blobs

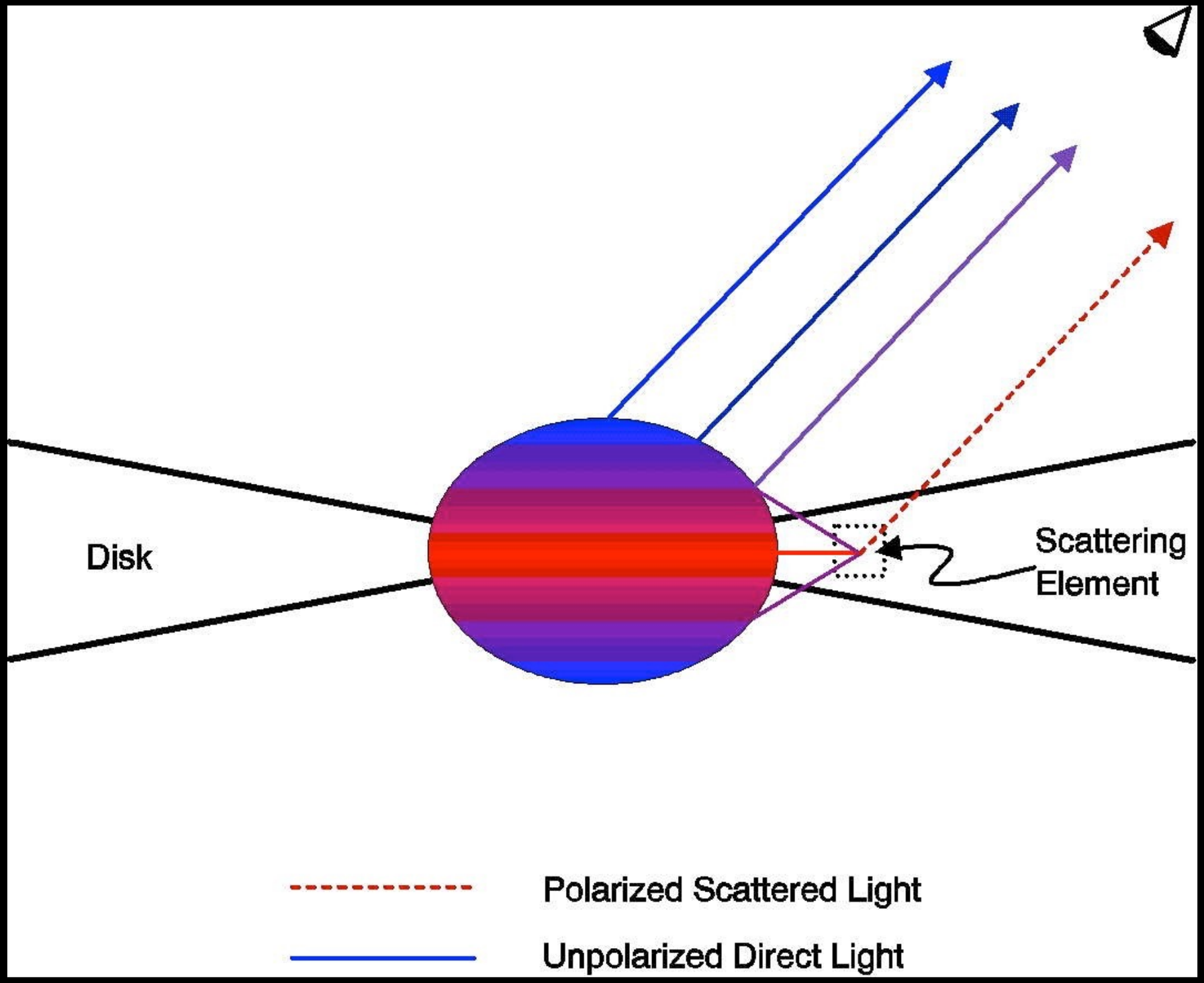


DISK (or JET)

Polarization perpendicular to disk/jet (No cancellation from polar material)

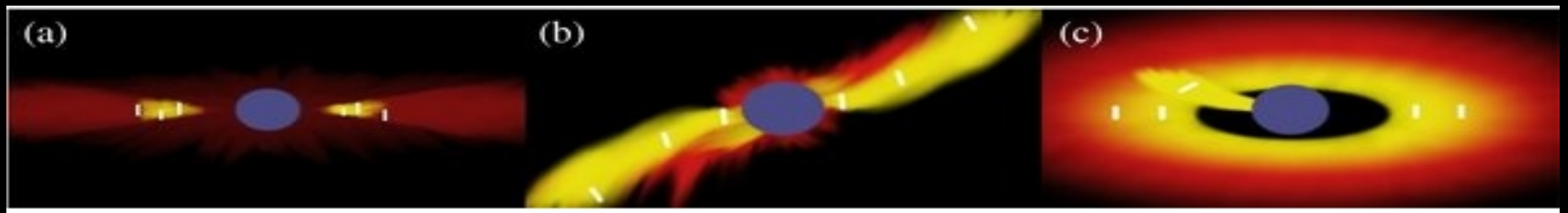
Note: can “flip” with wavelength if pole dominates at one wave-length and disk dominates at another

Polarization from Disk Scattering



Polarimetry Probes Disk Geometry

Axisymmetric edge-on simple disk | Departure from axisymmetry (inner warped disk) | Injection of non-equatorial clumps



Region producing polarization

Region producing hydrogen emission

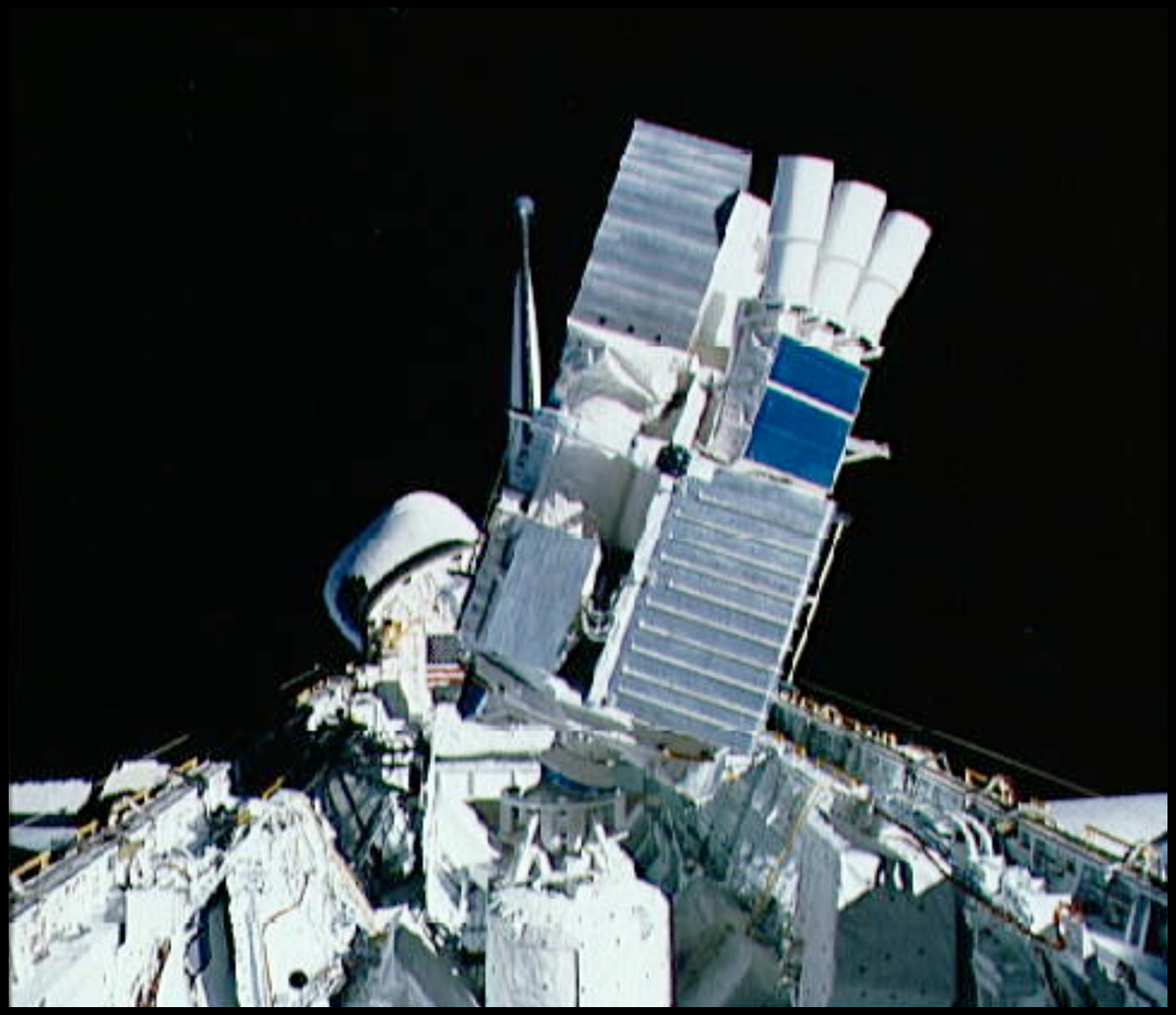
Wisniewski et al. 2010 ApJ 709 1306

Why Spectropolarimetry?

- Polarized light produced when starlight scatters off electrons in disk
- Polarized light then passes through disk before arriving at telescope
- Disk opacity (hydrogen etc.) imprints wavelength dependence on polarized light
- Polarization level gives geometry info


BRAND HOFFMAN LOUNGE PARKER GARDNER
DURRANCE ASTRO 1 PARISE


NASA
WUPPE HUT UIT BBXRT
UV/X-RAY Astro-1 ASTRONOMY



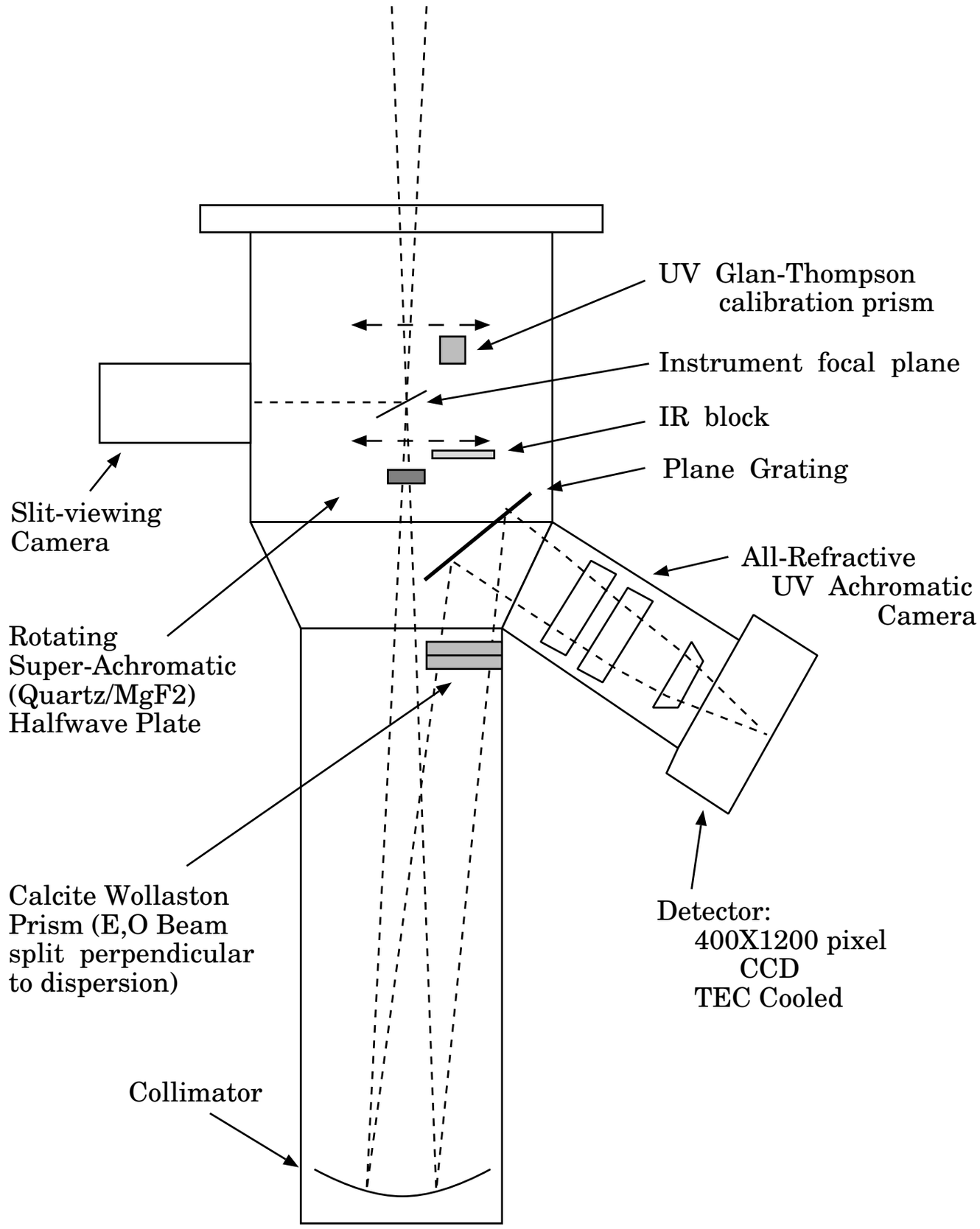

GRUNSFELD JERNIGAN OSWALD GREGORY LAWRENCE
ASTRO 2
PARISE DURRANCE


ASTRO-2
HUT
UIT
WUPPE

HPOL at Ritter Obs

James Davidson
UT PhD 2013
(now at U. Virginia)

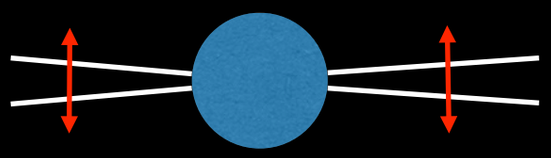
HPOL Spectropolarimeter

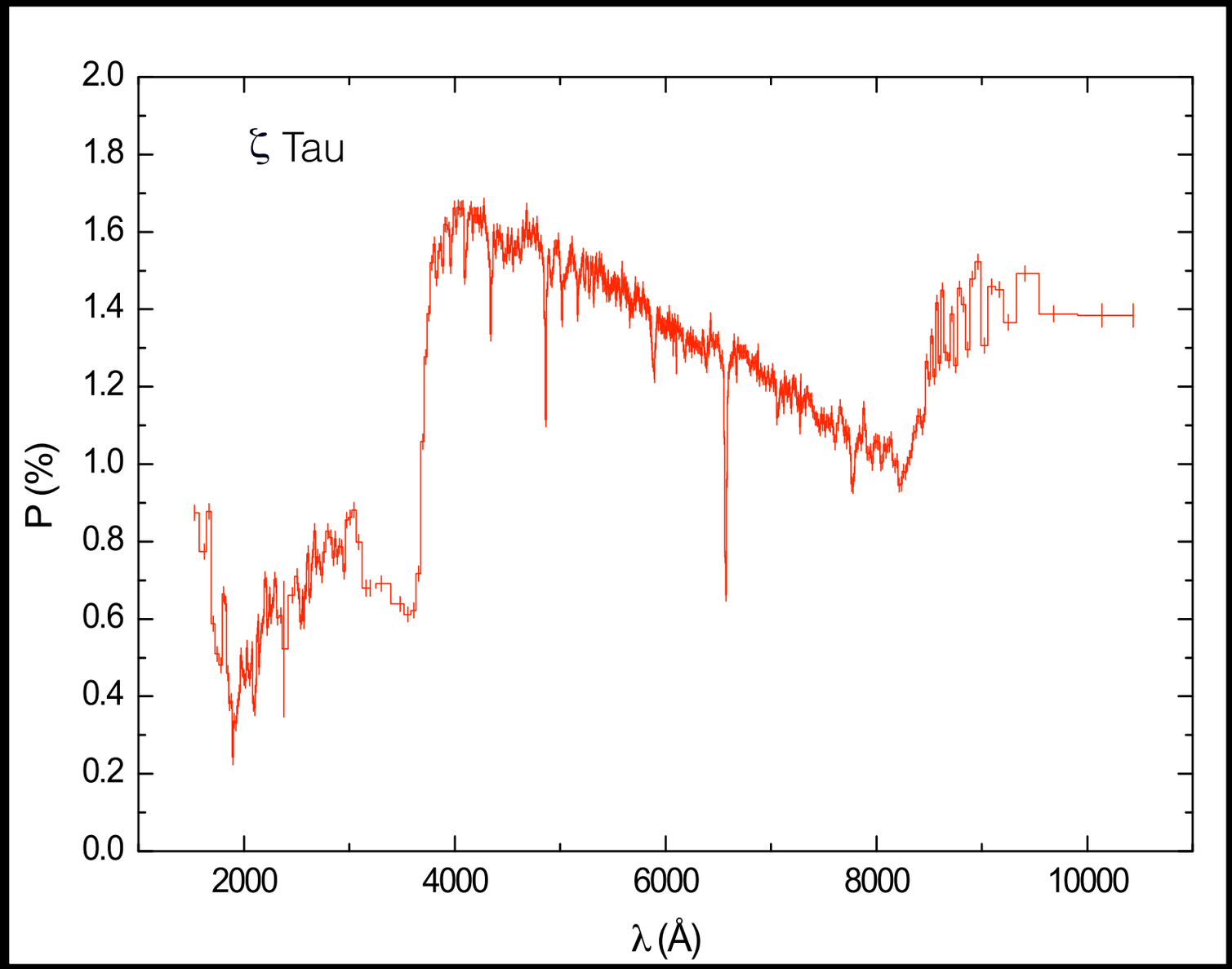


Credit:
K.H. Nordsieck

Spectropolarimetry

- Photons scattered by free electrons in disk
- Scattered light is polarized
- Degree of polarization depends on disk geometry



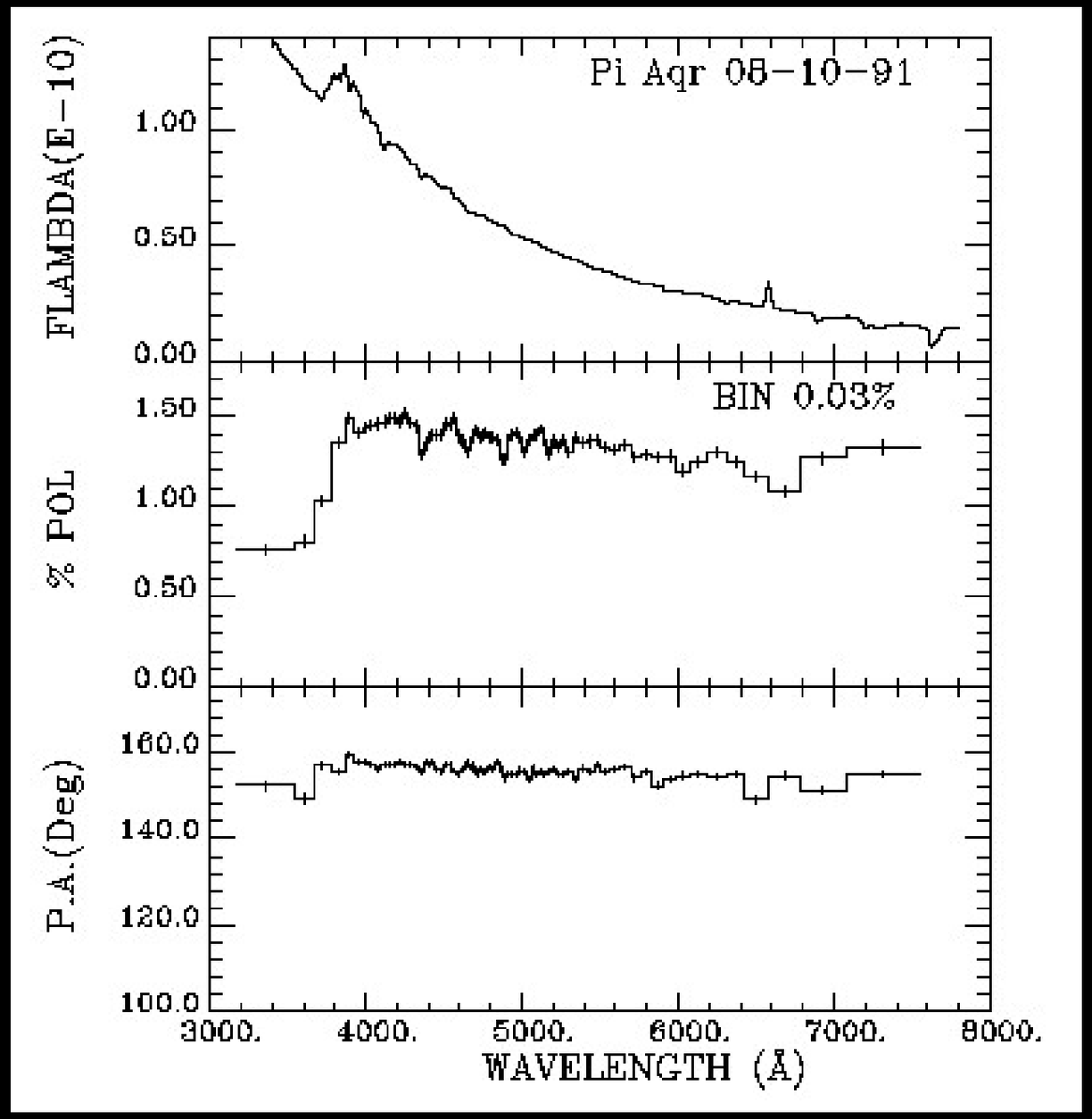


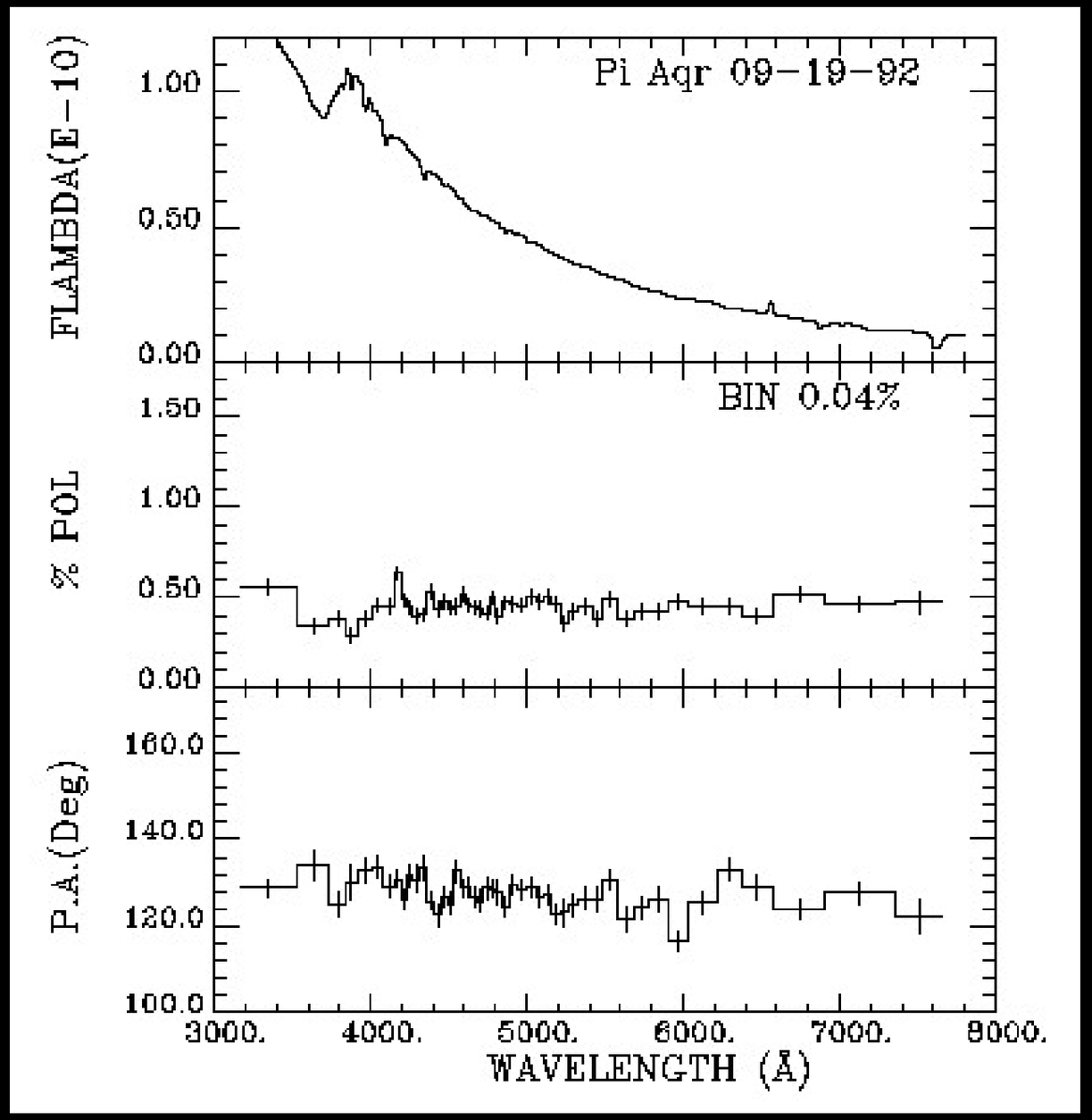
Wood, Bjorkman, & Bjorkman 1997

Case of the Disappearing Disk of Pi Aqr

- Spectropolarimetric monitoring for 15+ yrs at Pine Bluff Observatory (U. Wisconsin)
- Spectroscopic monitoring at Ritter Observatory (U. Toledo)
- Additional spectroscopic and photometric monitoring elsewhere (published)
- Significant changes observed over last 20 yrs; most striking changes from 1989-1995
- Disk began to rebuild ~2005, still weak

Example Extremes





Low State

High State

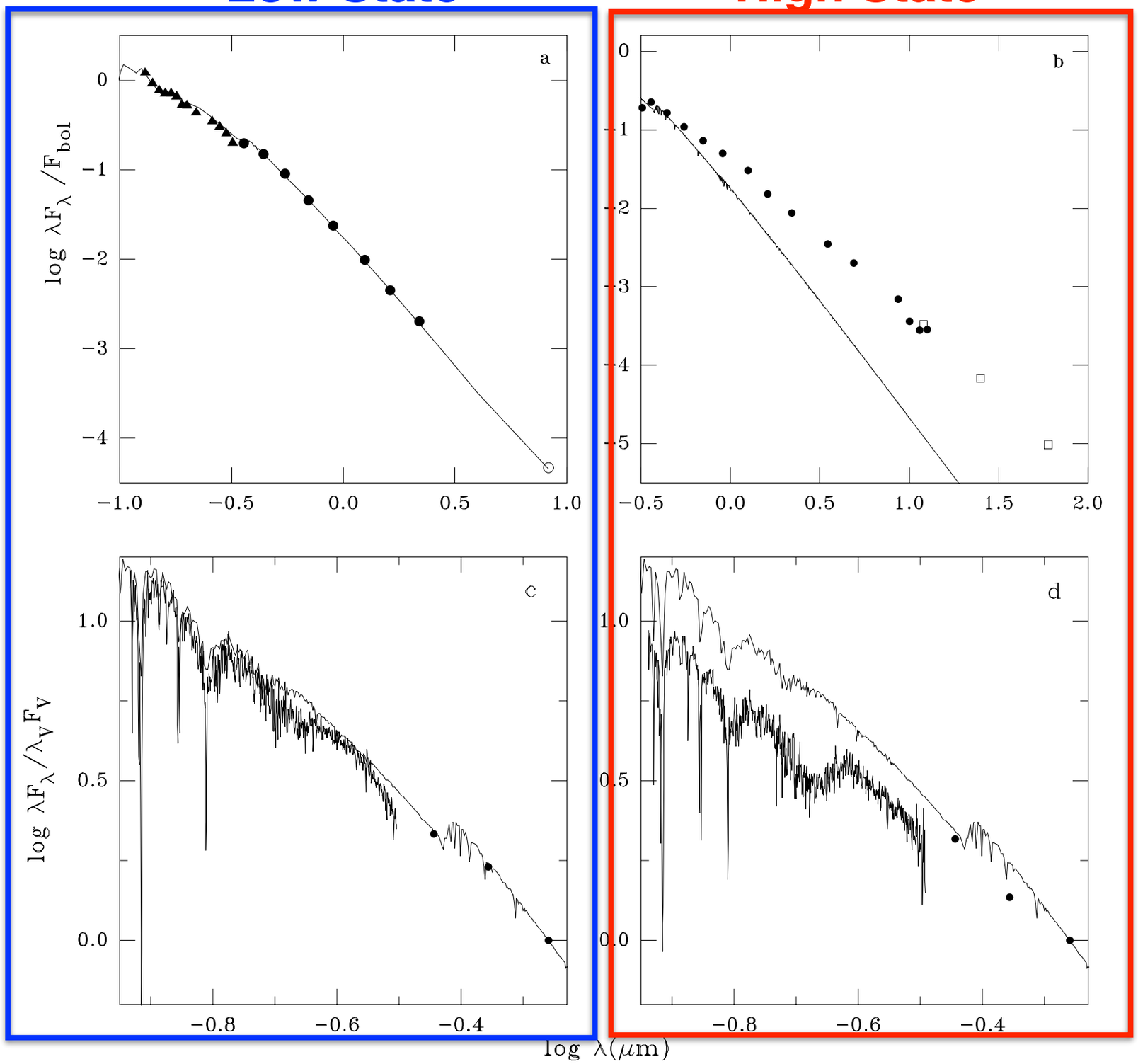
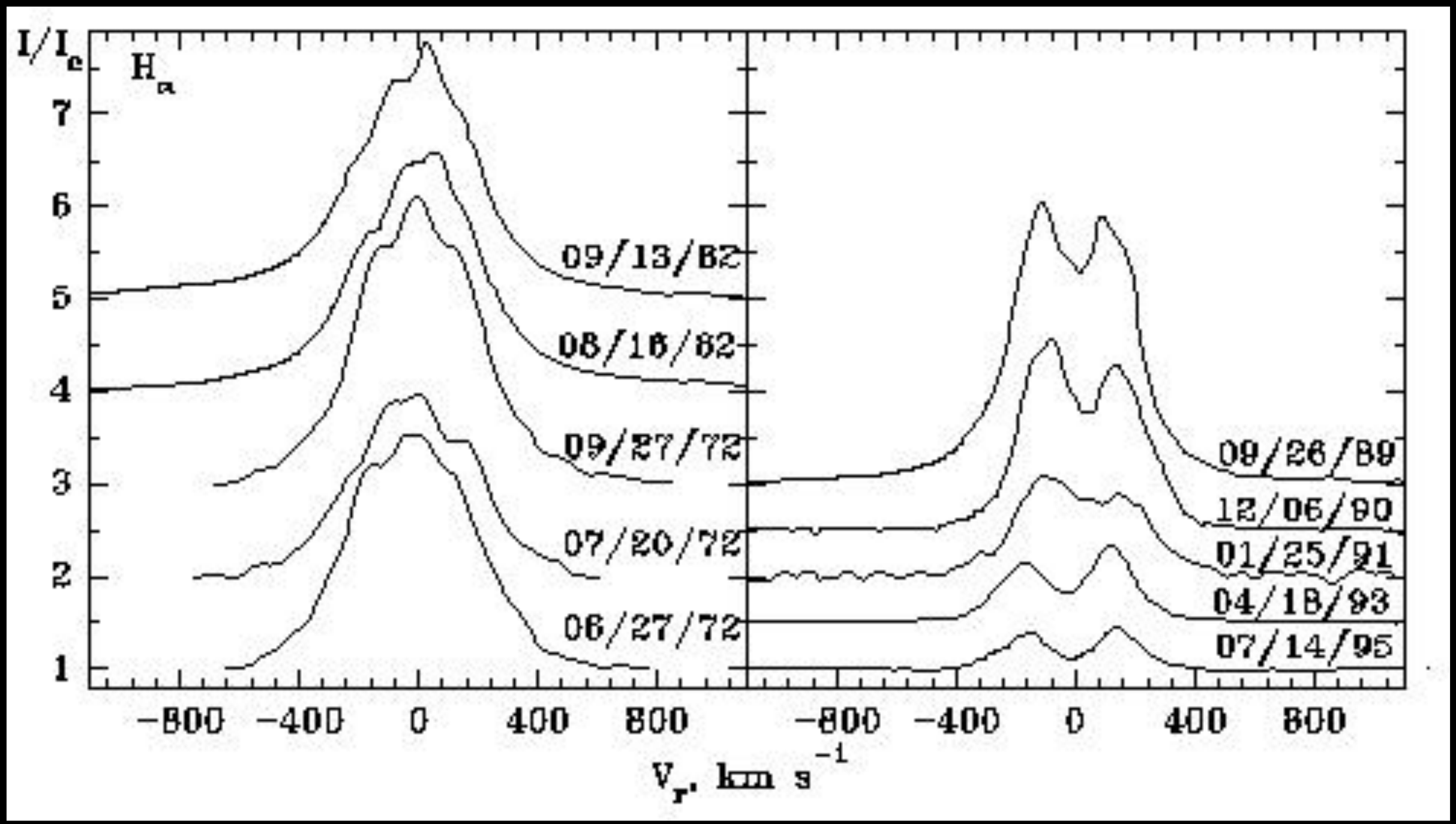


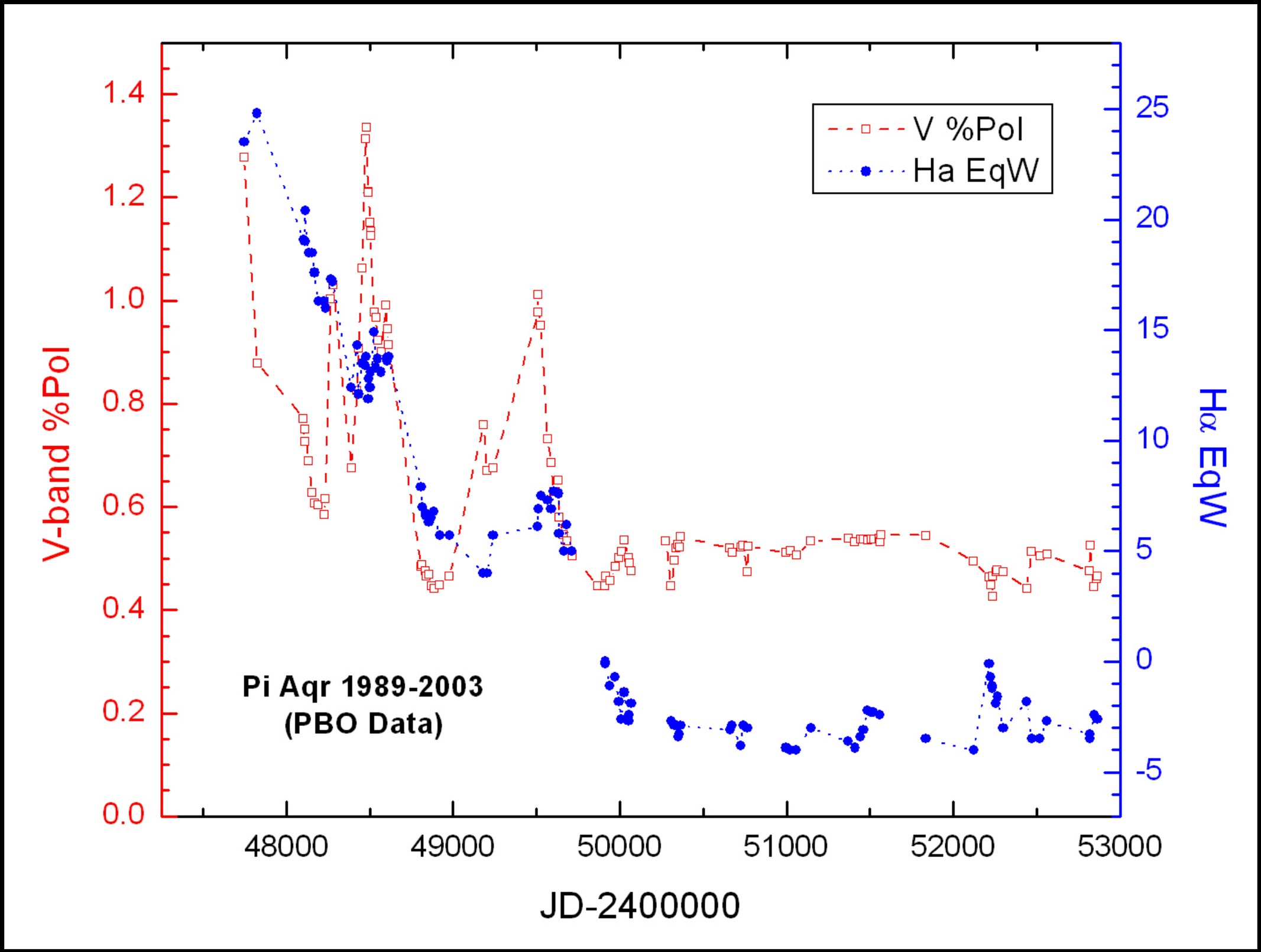
FIG. 2.—Dereddened spectral energy distributions of π Aqr in the active Be (panels *b* and *d*) and quasi-normal star (panels *a* and *c*) phases. Ground-based photometric data are shown by filled circles, the *MSX* (panel *a*) and *IRAS* (panel *b*) data by open circles and squares, respectively, and UV continuum fluxes from the *IUE* spectrum LWP 30769 by triangles. The Kurucz model atmosphere for $T_{\rm eff} = 25,000$ K and $\log g = 4.0$ is shown by solid lines in all panels. The *IUE* spectra of π Aqr supplemented with the *UBV* photometric data in the corresponding phases are shown in panels *c* and *d*.

Bjorkman et al. 2002

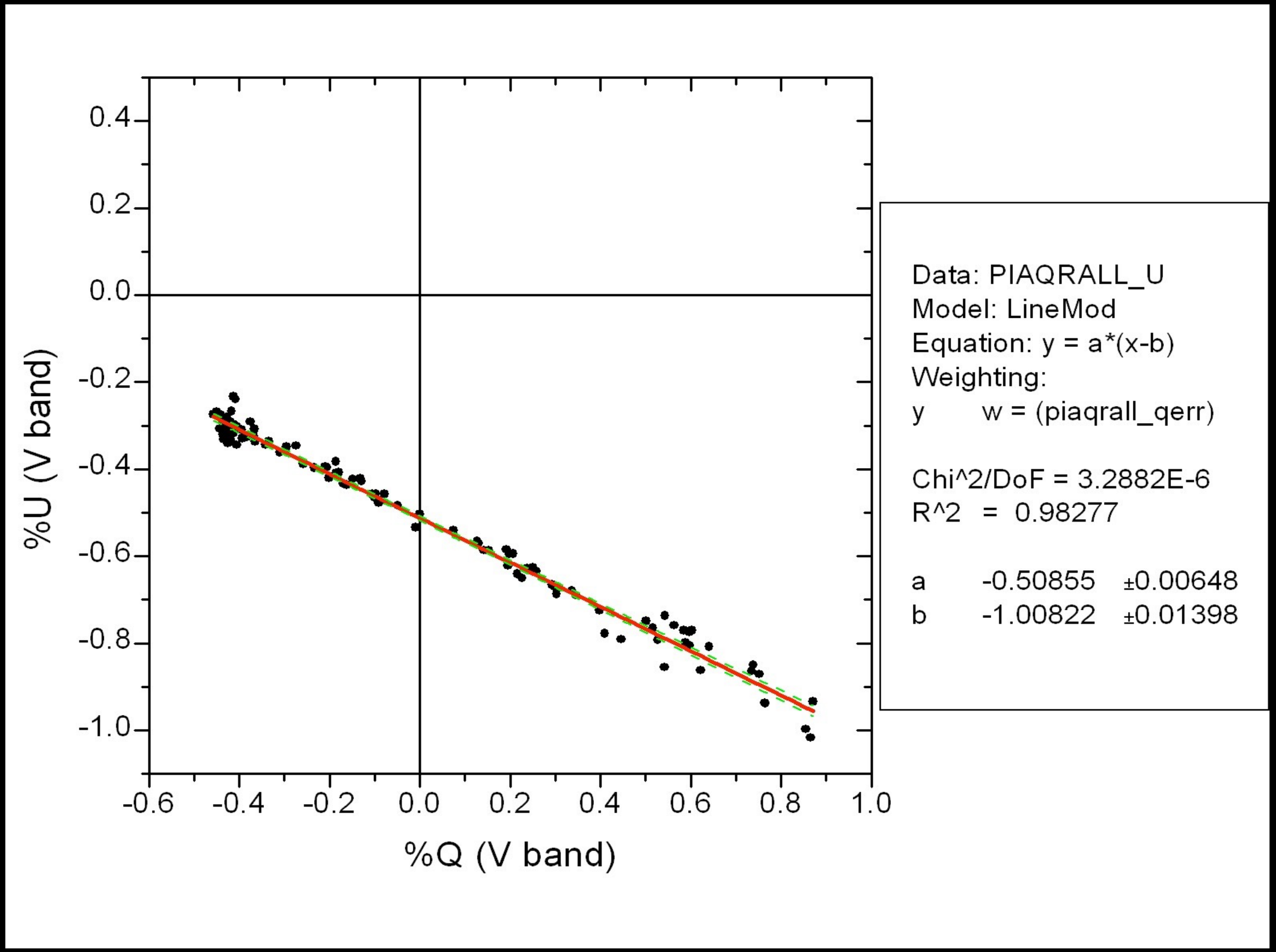
Watching a Disk Disappear (pi Aqr)



Watching a Disk Disappear (pi Aqr)



Pi Aqr QU Plot



Studying individual stars
one at a time is useful, but…

We would like to have a larger number of examples
for statistical purposes

We can do this by looking at clusters of stars
(many at once)

Variable Circumstellar Disks

- A few (~10) examples well studied (pi Aqr, 60 Cyg)
- Timescales differ (small sample)
- Need better statistics and larger sample
- Combine cluster studies (photometry) with monitoring of individual stars (polarimetry + spectroscopy)
- Goal: Determine physical mechanisms

Cerro Tololo Inter-American Observatory (CTIO), Chile

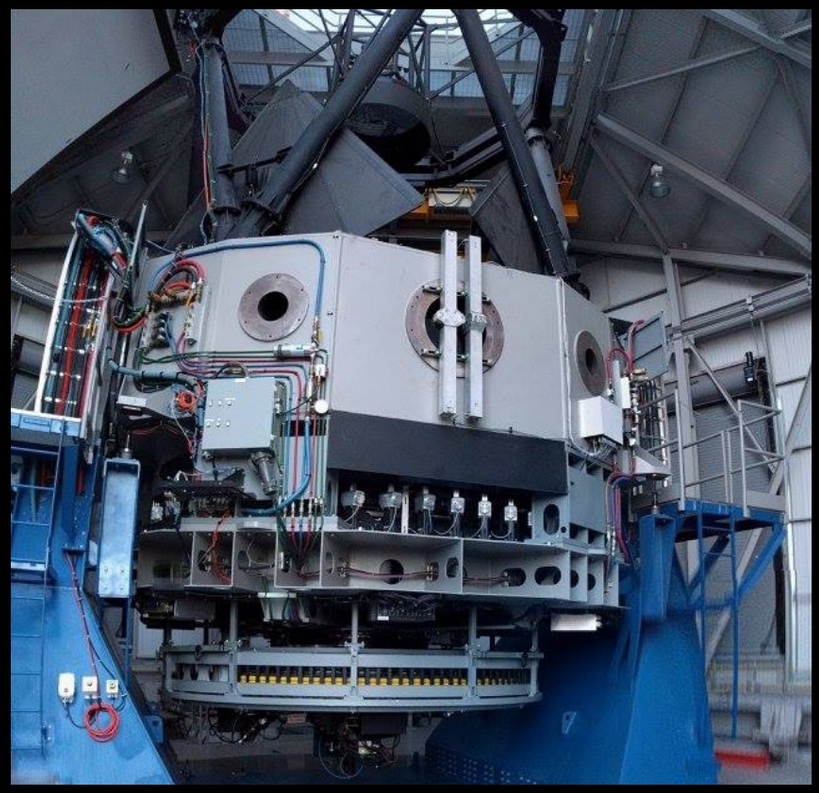
Tarantula Nebula

RMC 136

NGC 2100

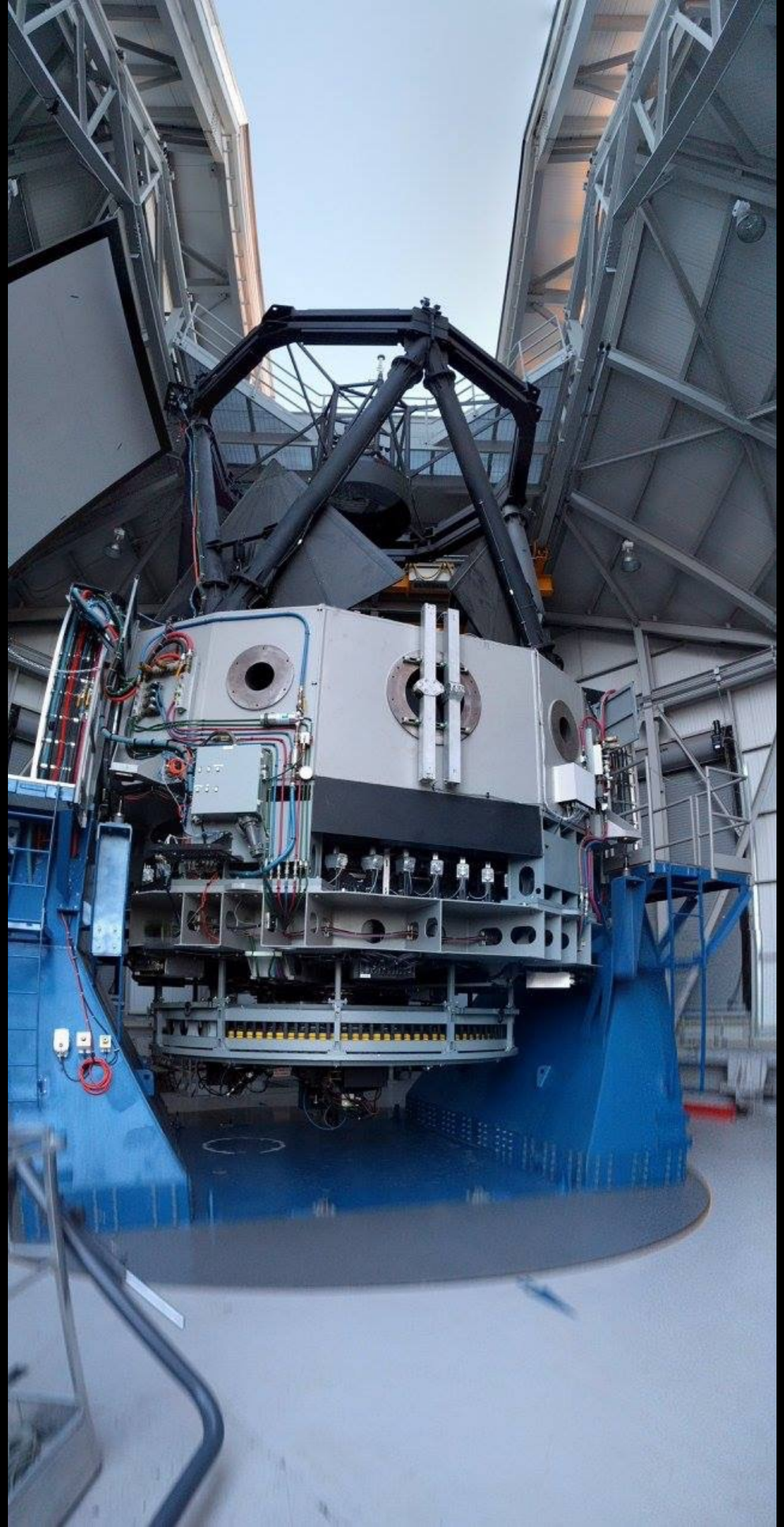
Discovery Channel Telescope

Image Credit: Lowell Observatory

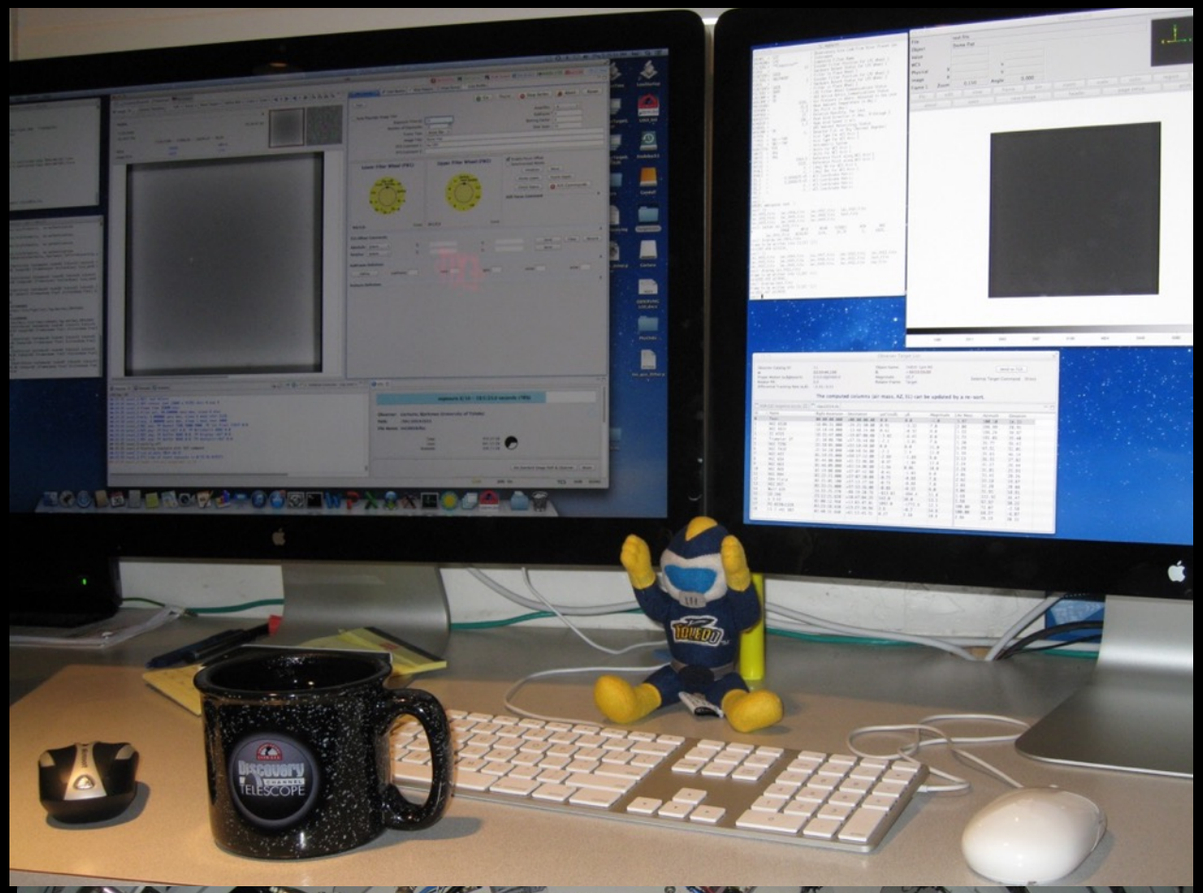


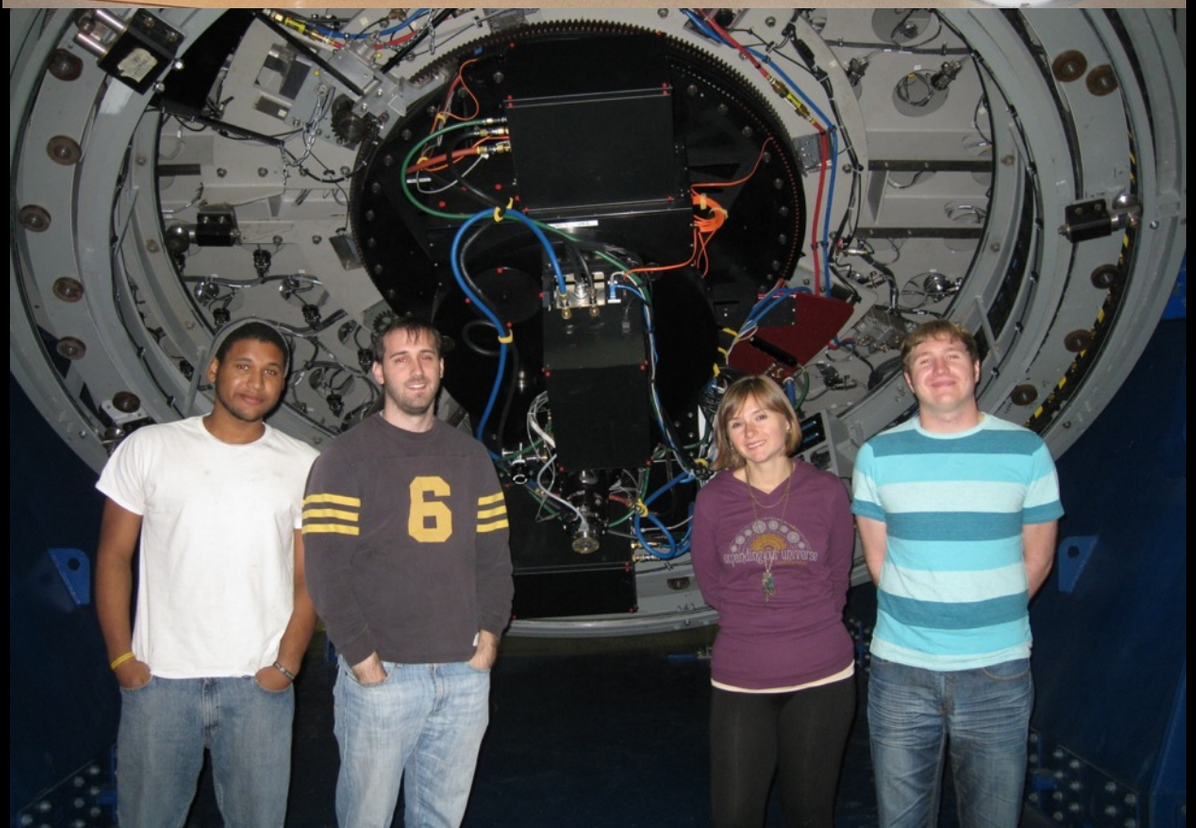
DCT SITE AND INSTRUMENTS

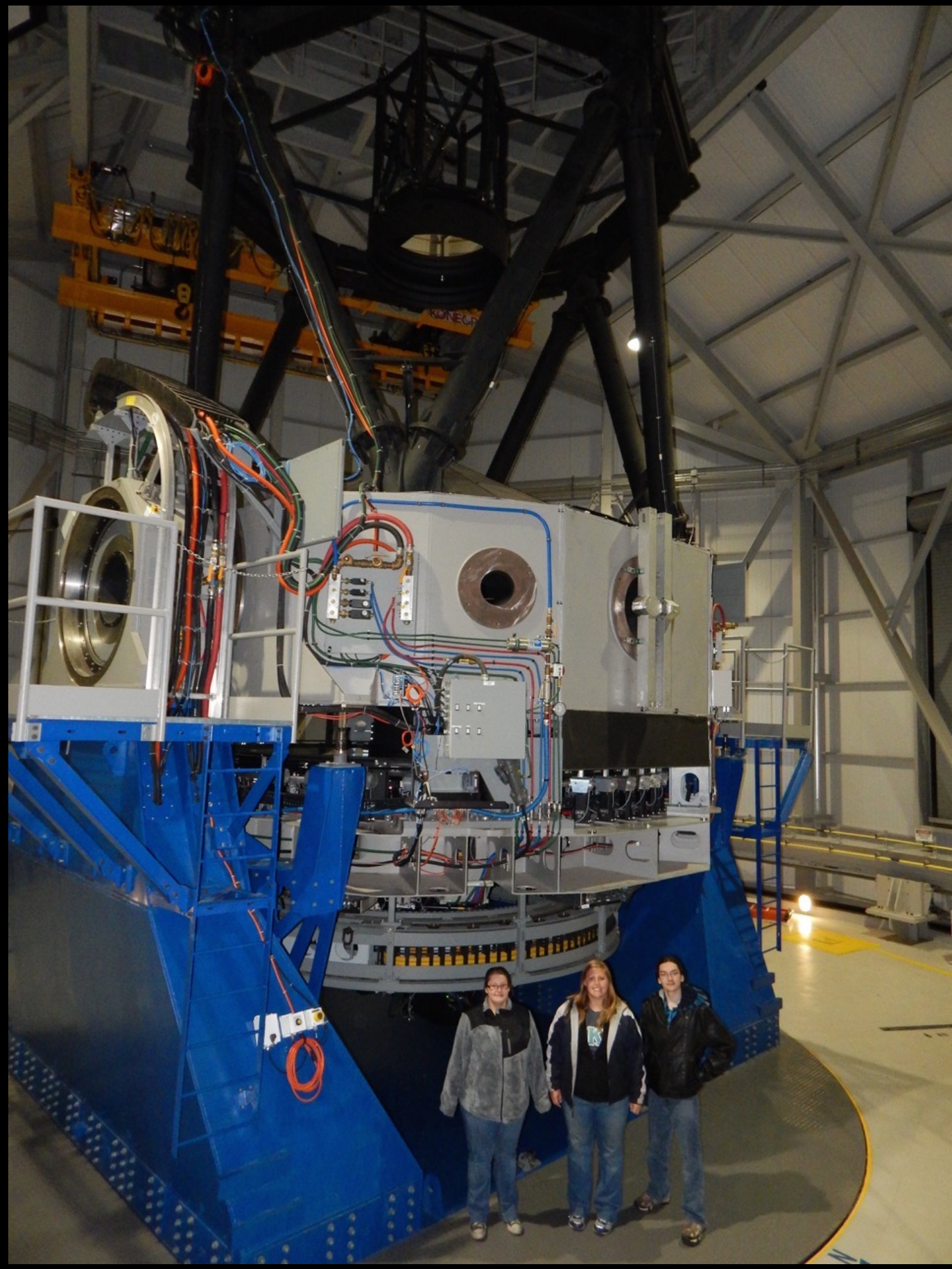
COCONINO NATIONAL FOREST (~40 MILES SE OF FLAGSTAFF, AZ)



UT Students at the DCT








Credit: C. Gerhartz

NGC 6611
&
Eagle Nebula

Image Credit: Cody Gerhartz
Univ. of Toledo
LMI/DCT

More to come on the cluster project - stay tuned!

Just don’t forget to always look up!

When I Heard the Learn’d Astronomer

When I heard the learn'd astronomer,
When the proofs, the figures, were ranged in columns before me,
When I was shown the charts and diagrams, to add, divide, and measure them,
When I sitting heard the astronomer where he lectured with much applause in the lecture-room,
How soon unaccountable I became tired and sick,
Till rising and gliding out I wander'd off by myself,
In the mystical moist night-air, and from time to time,
Look'd up in perfect silence at the stars.

W. Whitman (1865)

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Lowell/DCT
Ritter Observatory
Pine Bluff Observatory
WUPPE/Astro
HPOL

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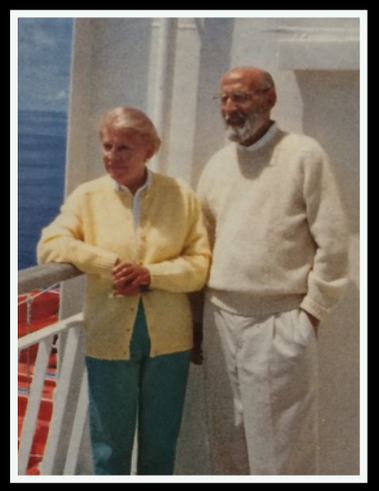

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APS physics

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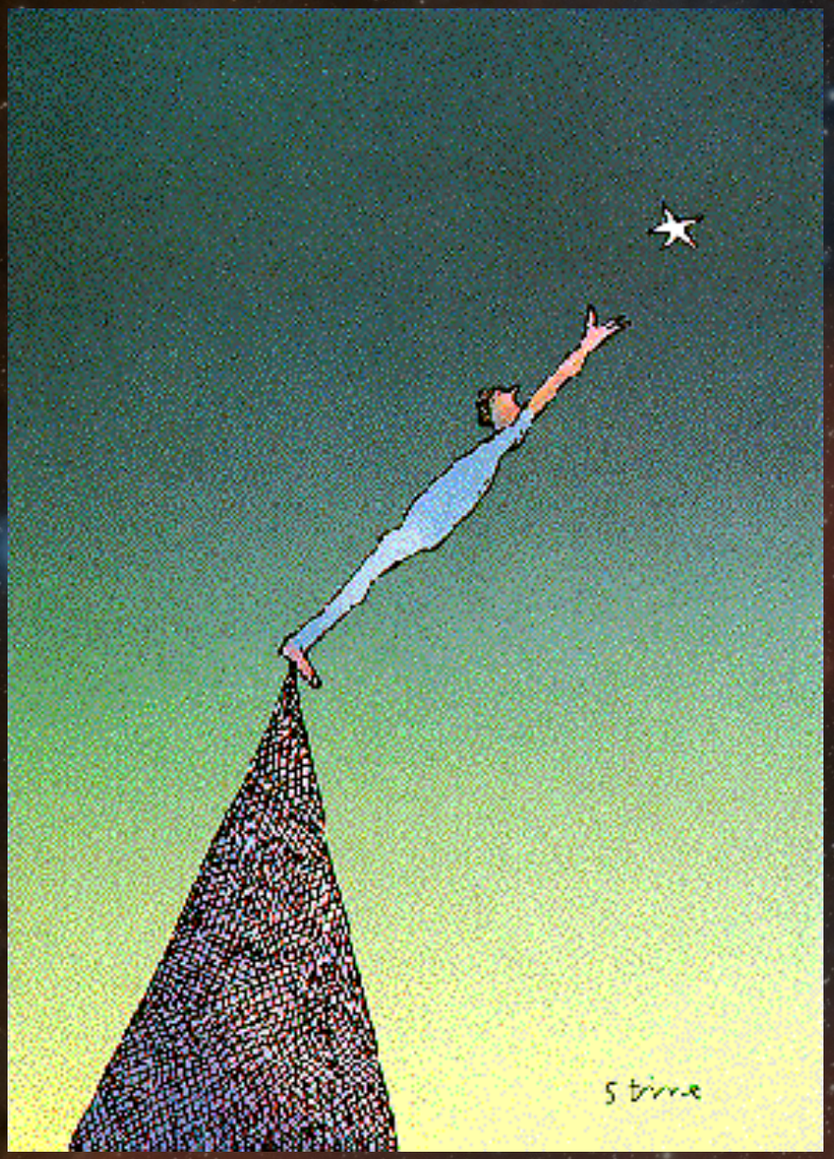
Thanks for Listening!

Any questions?



Ritter Observatory
University of Toledo