RFI Response Summaries

5 Rapid Science Summaries

Topic: Stars

Tom Madura (Gull)

Ian Roederer (Lawler)

Myron Smith (Neiner)

Rico Ignace

Ken Carpenter

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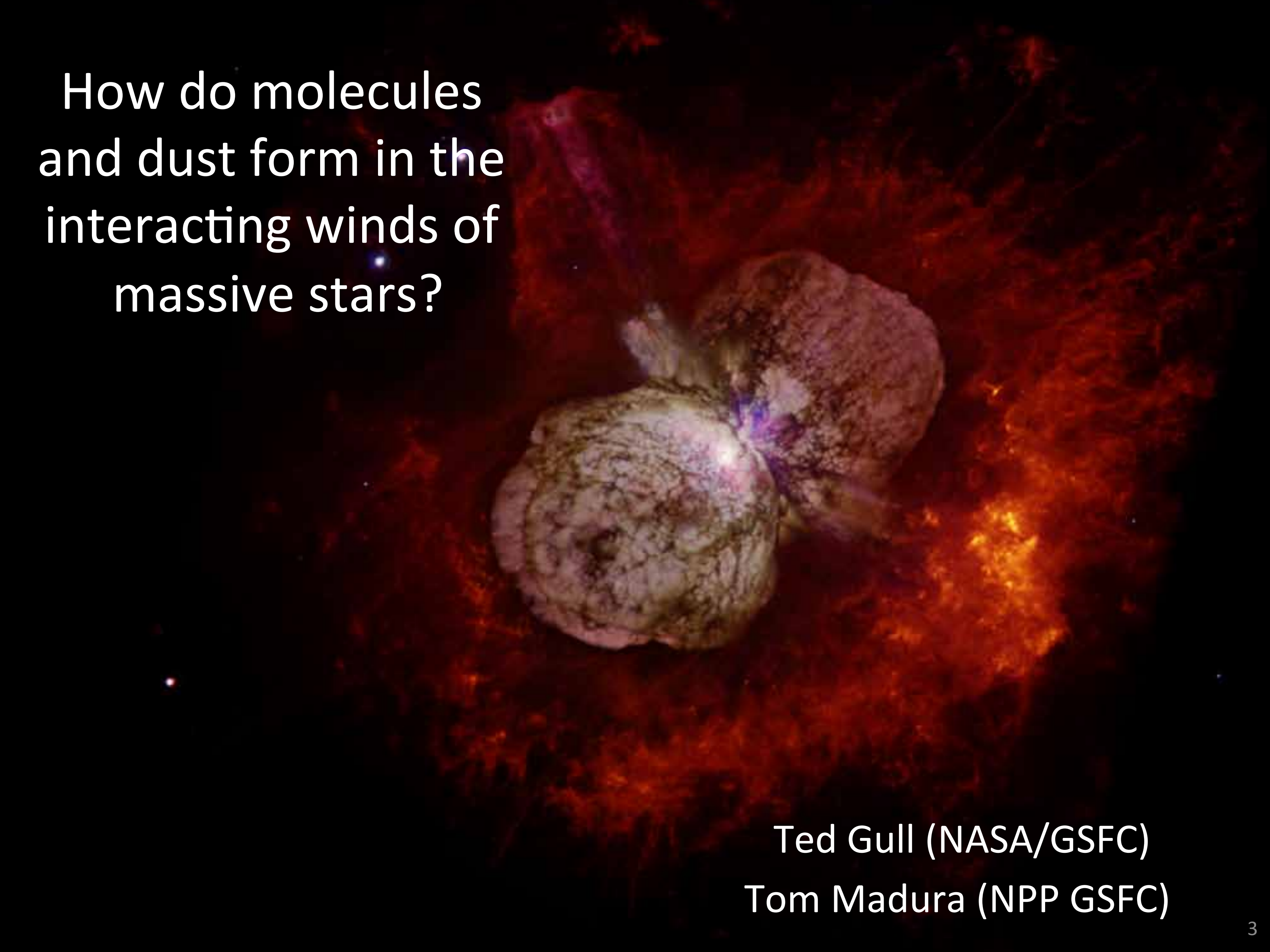
How do molecules and dust form in the interacting winds of massive stars?



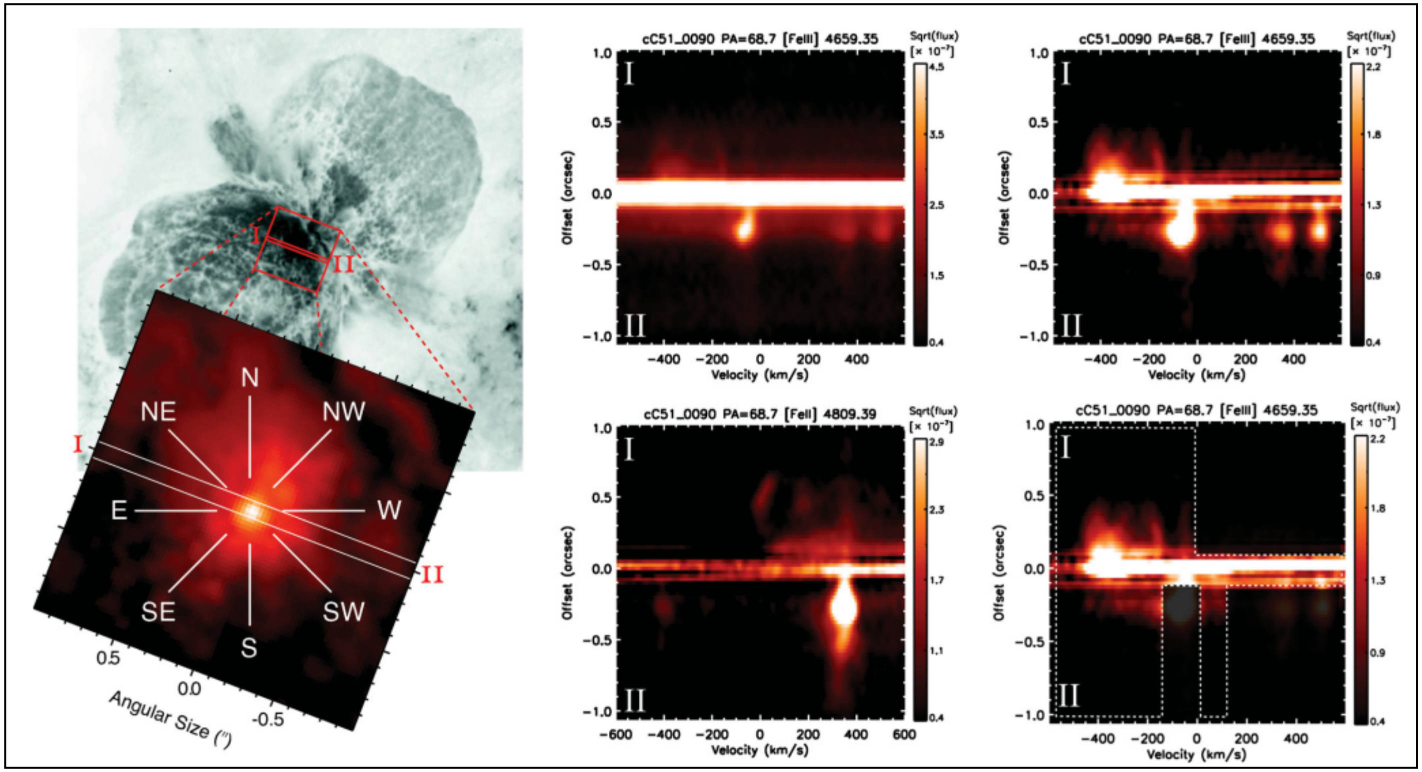
Ted Gull (NASA/GSFC)

Tom Madura (NPP GSFC)

Dust Formation

- Big picture
  - Dust nuclei and molecules are expelled in the winds and ejecta of massive stars. What are the conditions leading to this dust/molecule formation?
  - Dust plays an intrinsic role even at high redshifts where massive stars are the source..
- Example of what has been done up to now?
  - HST/STIS studies of Eta Car's interacting winds via forbidden emission lines in visible region

Figure 1, Madura et al. 2012, MNRAS 420, 2064



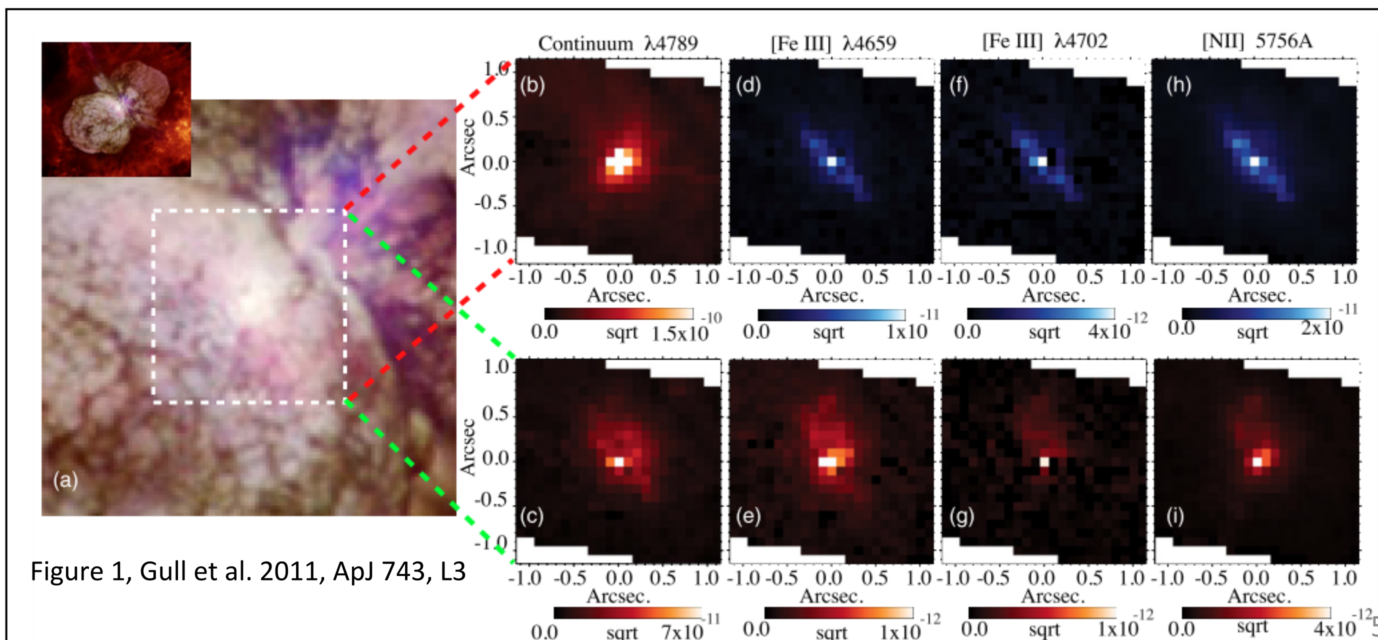


Figure 1, Gull et al. 2011, ApJ 743, L3

Dust Formation

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  - HST/STIS studies of Eta Car's interacting winds via forbidden emission lines in visible region
  - 3-D time-dependent hydro and radiative transfer models; obs. w/ models led to 3-D orientation of binary orbit

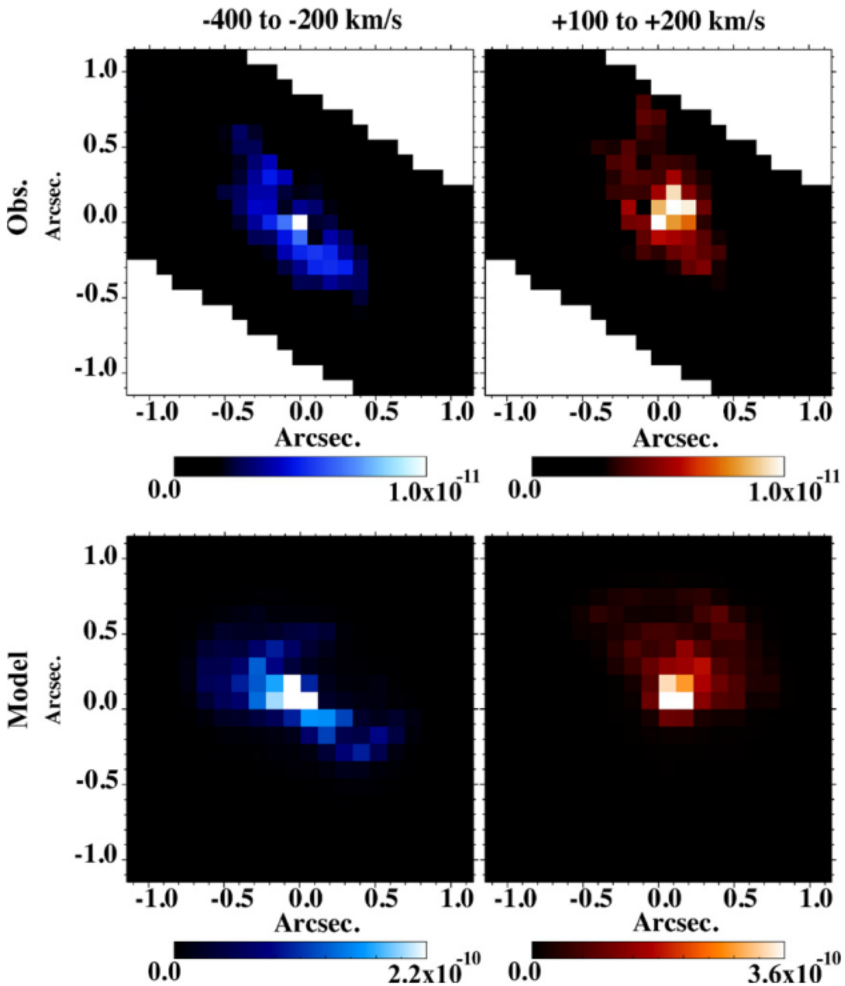


Figure 3, Gull et al. 2011, ApJ 743, L3

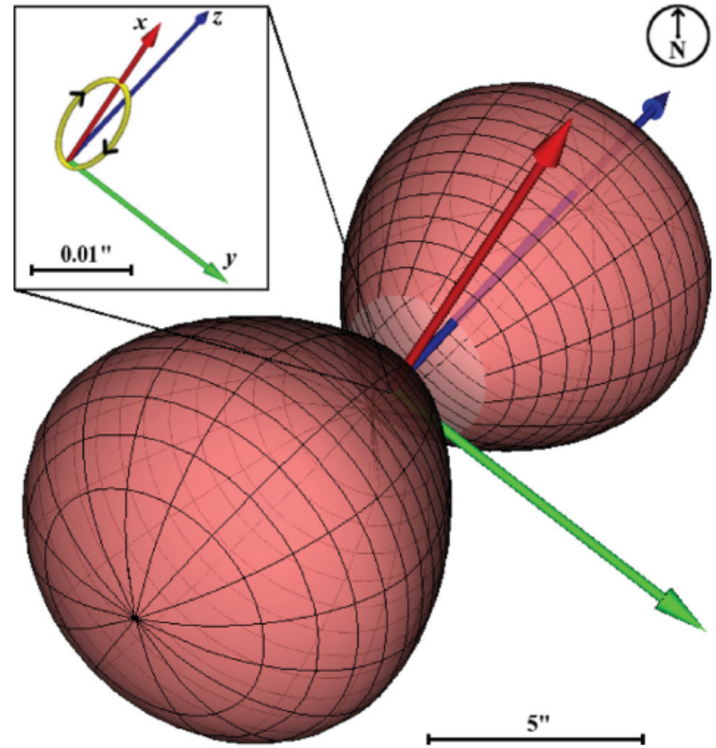


Figure 12. Illustration of η Car's binary orbit (inset, yellow) on the sky relative to the Homunculus nebula for a binary orientation with $i = 138°$, $\theta = 7°$ and $PA_z = 317°$, which lies near the centre of our best-fitting range of orbital parameters. The $+z$ orbital axis (blue) is closely aligned with the Homunculus polar axis in 3D. η_B orbits clockwise on the sky relative to η_A (black arrows in inset), and apastron is on the observer's side of the system. The semimajor axis ($+x$-axis, red) runs from NW to SE on the sky, while the semiminor axis ($+y$-axis, green) runs from SW to NE. North is up.

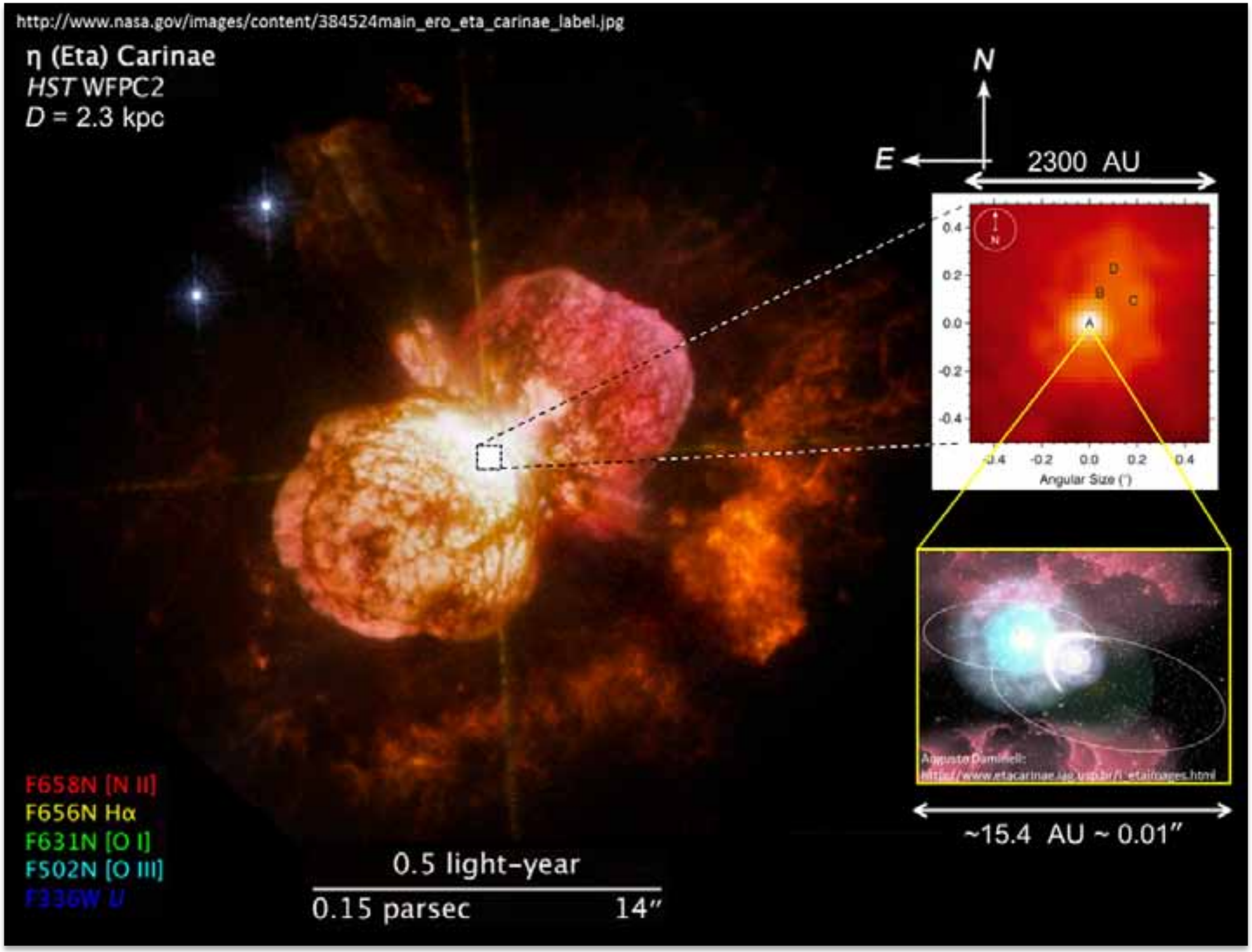
Figure 12, Madura et al. 2012, MNRAS 420, 2064

Dust Formation

- Big picture
  - Dust nuclei and molecules are expelled in the winds and ejecta of massive stars. What are the conditions leading to this dust/molecule formation?
  - Dust plays an intrinsic role even at high redshifts where massive stars are the source..
- Example of what has been done up to now?
  - HST/STIS studies of Eta Car's interacting winds via forbidden emission lines in visible region
  - 3-D time-dependent hydro and radiative transfer models; obs. w/ models led to 3-D orientation of binary orbit
  - Herschel evidence for molecules, despite C & O depletion

We need to resolve the binary orbit.

– Limitations of angular resolution combined with spectral resolving power ~10,000.



Investigate physical conditions in massive star winds, especially wind-wind collisions.

What are next steps needed?

- Larger aperture telescope w/imaging spectroscopy, improved throughput by new optical designs: detector, optics, photonics?
- More detailed 3-D modeling of wind-wind interactions w/radiative transfer

Science Requirements

- Imaging 0.01"/ Spectroscopy R = 10^4 visible / Time Domain sample across decade (5.5-year binary period)
- Field(s) of View <2"
- Angular resolution:
  - Required 0.03" / Desired 0.005"
- Spectral resolution
  - Required: R = 10^4
- Wavelength band(s)
  - Required Visible / Desired NIR
- Sensitivity
  - System throughput > 50% including detector quantum efficiency
- Dynamic Range
  - Single photon counting w/ high dynamic range in counting rate & contrast
- Other requirement(s)
  - Multiple visits for time variability

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The Origin of the Elements Heavier Than Iron

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Understanding the origin of the elements is one of the major challenges of modern astrophysics.

<u>Cosmic Origins science goals related to this science:</u>

How did the first stars influence their environment?

How were the chemical elements dispersed through the circum-galactic medium?

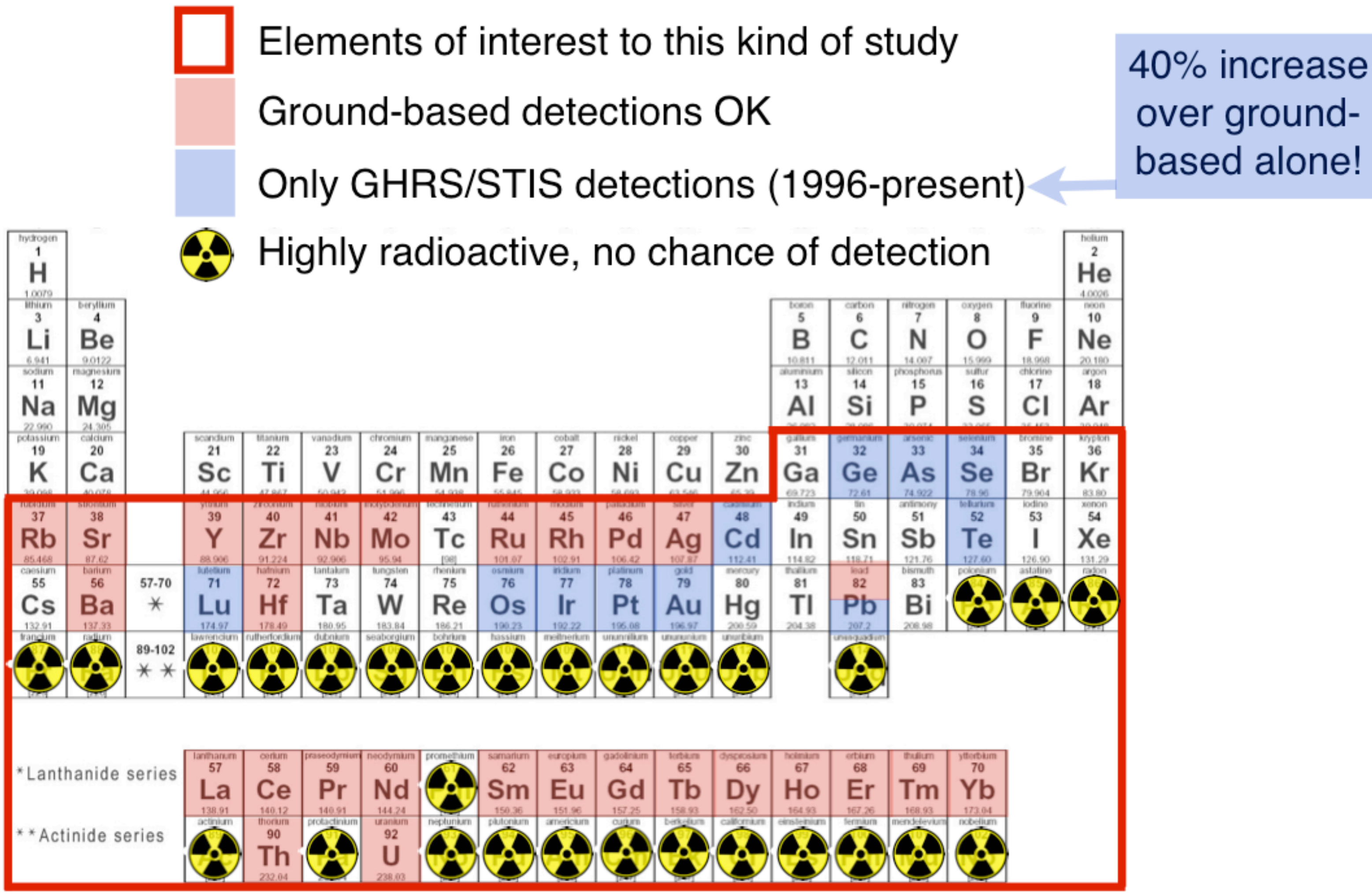
How did galaxies (and their stars) form and evolve?

<u>Our goal:</u>

Detect (and measure) as many heavy* elements as possible in stars whose atmospheres retain a fossil record of the evolving composition of the ISM. This constrains the physical conditions of nucleosynthesis and the frequency of the astrophysical sites producing these elements. A major, unsolved problem is the definitive identification of the site(s) of the r-process.

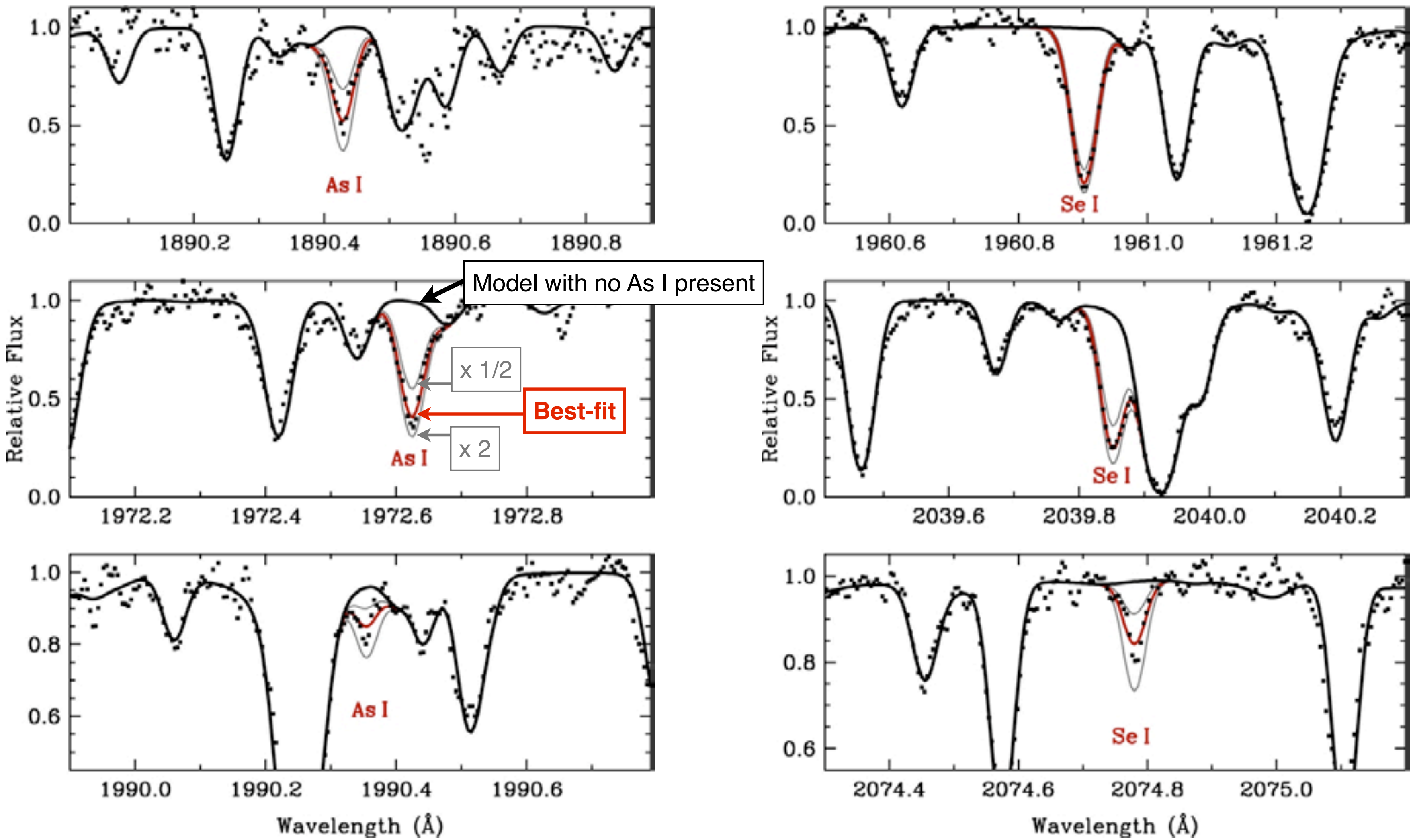
* Elements heavier than the iron-group, i.e., $Z > 30$

UV spectroscopy enables the detection of elements that cannot be detected in optical or NIR stellar spectra.



This is what successful UV detections look like.

The spectra show one metal-poor star, HD 160617, observed at
R ~ 110,000 and S/N ~ 20-40 in 13 hours with HST+STIS.



Roederer, I.U. & Lawler, J.E., Astrophys. J., **750**, 76, (2012) Other than overall efficiency, STIS is nearly ideal for this kind of work, but the need for high spectral resolution and high S/N limits HST+STIS to only the brightest metal-poor stars in the sky (V < 9 or so). There are many more interesting stars fainter than this limit that are inaccessible to HST+STIS.

Requirements for future improvement:

(1) Wavelength coverage from 1900 Å $< \lambda <$ 3100 Å (or ≧1/2 of that) in a single exposure.

(2) Spectral resolution R ~ 60,000 is sufficient. Lower (R ~ 30,000) and higher- (R ~ 100,000) resolution settings would be helpful.

(3) An improvement in sensitivity over HST+STIS by ~10 or more would push the frontier. Sensitivity comparable to HST+STIS would still allow investigations that cannot be done by any other facility.

(4) Multiplexing offers little advantage (but ~10' x 10' for ~10+ stars could be of limited use).

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Stellar physics with UV and visible spectropolarimetry

Presented by Myron Smith (STScI)

PI Coralie Neiner (LESIA, Paris Observatory, France)

with over 30 other scientists from the USA, France, Canada, Belgium, Germany, Ireland, Brazil, Sweden, Switzerland, The Netherlands and ESO

http://lesia.obspm.fr/UVMag

Stellar physics

Goal: formation, structure, evolution and environment of all types of stars

Why:
- to understand how the building blocks of our Universe work together
- to understand how first stars formed, evolved and influenced their environment leading to new generations of stars
- to understand the mechanisms giving rise to stellar systems
- to understand how stars influence their planets and life

How:
- through the measurement of stellar magnetospheres, winds, activity and environments in various types of stars (PMS, solar-like, O stars, Be stars, Ap stars, pulsating stars, late stages,...) over time (rotation, orbit, stellar cycles,...)
- with spectroscopy in the UV (wind-sensitive lines, most of the hot stars' energy,...) and visible (stellar surface, rotation, spots, pulsations,...)
- with spectropolarimetry in the UV (activity, polarization in the confined wind, chromospheres,...) and visible (activity, magnetic fields, disks,...)

Science status

What has been done up to now:

- Space UV spectroscopy by the USA and Europe (IUE, FUSE, HST,...)
→ information on stellar winds and hot stars
- High-resolution ground-based spectropolarimetry by France and Sweden (ESPaDOnS, Narval, HARPSpol)
→ information on stellar magnetic fields, environment, and indirect information on wind confinement

What has never been done:

- Space high-resolution spectropolarimetry in the visible → continuous time series to cover the full stellar rotation period and obtain complete 3D maps
- High-resolution UV spectropolarimetry (only WUPPE with R~500)
→ general purpose survey, polarization in the wind
- Simultaneous UV+visible spectropolarimetry → integrated picture, contrasts, statistics and incidence rates, evolutionary view

→ We want to obtain a global but detailed picture of the stars and their environments along their formation and evolution

Technical status

What is being done now:

- Ideas have been proposed by France (LESIA+IRAP), the Netherlands (F. Snik et al.) and the USA (W. Sparks et al.) on how to build a space UV+visible spectropolarimeter
- a R&D program has started at CNES (French Space Agency) to study these ideas and build a prototype

We do not know yet how to build a space high-resolution spectropolarimeter:

→ it is mandatory to keep the instrumental polarization at a low level (due to mechanical stress, temperature effects, crosstalk,...)

→ we have never tested high-resolution spectropolarimetry in the UV

We propose:

- to build a prototype to test the level of instrumental polarization
- either a dedicated mission (~1m telescope) or an instrument for a LUVO
- monitoring of specific stars + survey of a large sample

Science requirements

Specification	Requirement	Goal
Spectral range	117-320 + 390-870 nm	90-1000 nm
UV resolution	25000	100000 and 2000
Optical resolution	35000	80000
UV S/N	100	200
Optical S/N	100	300
Polarization	V in lines	QUV in lines + continuum
Instrumental polarization	3%	1%
Accuracy in radial velocity	1 km s^{-1}	0.3 km s^{-1}
Target magnitude	V=3-10	V=2-15
Targeted stars	50	100
Time per targeted star	4 weeks	6 weeks (4+1+1)
Survey stars	4000	8000
Time per survey star	20 min	30 min
Mission duration	4 years	12 years

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Time Series and Polarimetric Data

Richard Ignace
Physics & Astronomy
East Tennessee State University

Broad Science Context

- **Axisymmetric geometries, stochastically structured flows, and magnetism represent many of the current challenges to our understanding of stellar astrophysics.**
- **Polarimetry as a Tool**
  – *Probe of geometry*: net polarization of unresolved sources immediately implies non-sphericity
  – *Probe of opacity*: for example, electron scattering is gray
  – *Probe of magnetic fields*: Zeeman in lines
- **The Importance of Time Series Data**
  – Surveys like those for microlensing and Kepler
  – Importance of not penalizing constrained observations, but actually encouraging them

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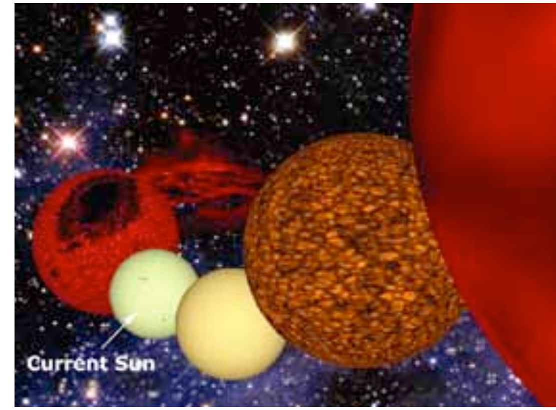
Mass Transport Processes and their Roles in the Formation, Structure, and Evolution of Stars and Stellar Systems

Kenneth G. Carpenter (NASA-GSFC), Margarita Karovska (CfA),
Carolus J. Schrijver (LMATC), Carol A. Grady (Eureka Scientific),
Ronald J. Allen (STScI), Alexander Brown (UColo), Steven R. Cranmer (CfA),
Andrea K. Dupree (CfA), Nancy R. Evans (CfA),
Edward F. Guinan (Villanova U.), Graham Harper (TCD-IE),
Antoine Labeyrie (College de France), Jeffrey Linsky (UColo),
Geraldine J. Peters (USC), Aki Roberge (NASA-GSFC), Steven H. Saar (CfA),
George Sonneborn (NASA-GSFC), and Frederick M. Walter (SUNY)

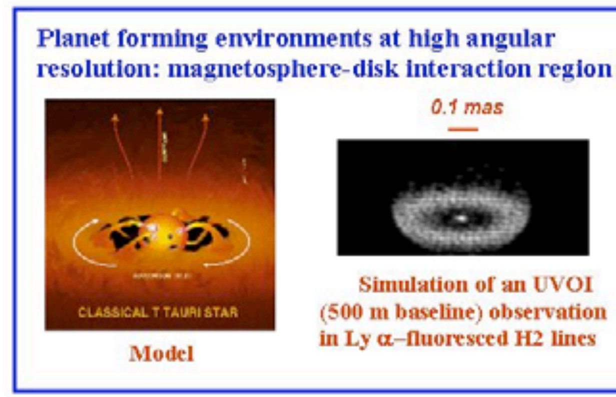
Presented at the UVIS COR RFI Workshop at STScI, 18 September, 2012

Science Context

- Science Driver: Advance our understanding of the formation, structure, and evolution of stars and stellar systems
  - The evolution of structure and transport of matter within, from, and between stars are controlled by dynamic processes, such as variable magnetic fields (and variable magnetic activity), accretion, convection, shocks, pulsations, winds, and jets.
  - These dynamic processes can be studied in detail only with a dramatic increase in angular resolution over that currently available, to the sub-mas level – comparable to the leap from Galileo's telescope to HST.
  - These investigations are a pre-requisite to understanding similar physical processes on much larger scales throughout the Universe.



Evolution of the Sun in time

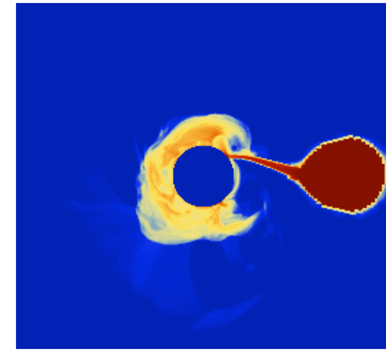


Environs of Young Stars

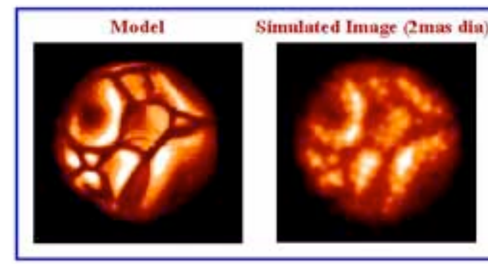
- Previous work:
  - Investigators using both ground-based and space-based facilities have made significant progress, but the next quantum leap in our understanding requires spectral imaging which resolves stellar disks and the surface manifestations of magnetic activity in their atmospheres and the mass flows to, from, around, and between stars

Proposed Science Investigation

- What cannot be done now?
  - The relevant spatial structures cannot be resolved with telescope diameters and hi-res techniques in our arsenal.
  - Our current understanding is thus mostly based on inferences from integrated-light spectral studies, for example using only disk-integrated light from stars.
- Proposed Science
  - Obtain sub-mas UV/Optical spectral imaging observations to resolve stellar surfaces and their environs and reveal the details of the many dynamic processes that affect the formation, structure, and evolution of stars and stellar systems, including: variable magnetic fields (& associated stellar activity), accretion, convection, shocks, pulsations, winds, and jets



Simulation of Mass transfer in Algol System (Richards/Ratliff 1998)

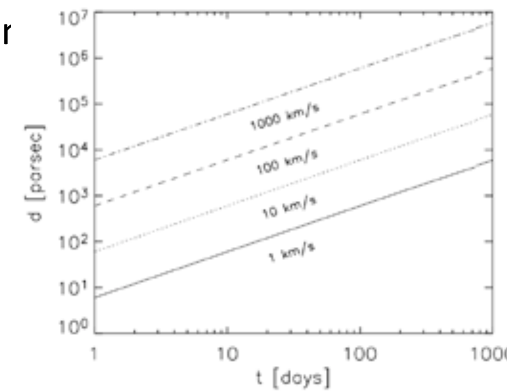


Large convective cells on M-supergiant

- What are next steps needed?
  - Develop the technologies needed to enable future large diameter (0.5-1.0 km) multi-element sparse aperture telescopes and interferometers, capable of UV/ Optical spectral imaging observations with angular resolutions at the sub-mas level, including:
    - Precision formation-flying of 6 – 30 spacecraft
    - Autonomous wavefront sensing and control of a many-element sparse arrays
    - Methodologies for ground-based validation of large-baseline, many element systems

Science Requirements

- UV/Optical Spectral Imaging
  - In the light of emission lines formed over a range of temperatures, e.g.. CII 1335 Å, C IV 1550 Å, Mg II 2800 Å, etc., with cadence ranging from a few hours to a year or more, depending on the motion/evolution of the object in question (see figure to right)
  - In broader band NUV/Optical light with 1 min cadence
- Field of View: > 4 x 4 mas
- Angular resolution required: ~ 0.1 mas (outer primary mirror array diameters of at least 500m)
- Spectral resolution required: 10 Å (UV lines), 100 Å (NUV/Optical continuum)
- Wavelength bands
  - UV/Optical: 1200-6600 Å
  - Narrow bands (10 Å wide) around important emission features, incl. C II 1335 Å, C IV 1550 Å, Mg II 2800 Å, etc.
  - Broad band NUV or optical (100 Å wide) for high temporal resolution asteroseismology (1 min cadence)
- Sensitivity: minimum detectable flux of at least 5.0×10^{-14} ergs/cm^2/s integrated over C IV 1550 Å lines



Minimum time interval between successive images required to resolve the motion of a feature moving at different speeds, as a function of the object's distance.

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Open Discussion