An Imaging Survey of Red Supergiants with CHARA-MIRC (updates)

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Our Goals

What do the surfaces of red supergiants look like?

We will construct the highest resolution images of the surfaces of red supergiants yet produced

Do RSG surface features relate to variability and convection?

We will image these stars over time scales ranging from months to years.

Are models of red supergiants correct?

We will confront models with our interferometric and spectroscopic data

Our Project

OBSERVING

- High resolution imaging of ~21 Red Supergiants (2-7 mas) with MIRC 6-T (H band)
- Complementary Spectroscopy & Photometry
- Follow up observations of select targets →variability of convective features on surfaces
- So far: Aug 17-23, 2015
  Oct 24-27, 2015
- Now with 3 additional targets

  with Miguel Montargès

IMAGING AND MODELLING

- Reconstruct Images: HARD!
- Get stellar parameters
  - MARCS & SATLAS models
- Compare observations to convection as predicted by 3D hydrodynamic models

1 night completely lost
3 ended early due to haze, smoke, or clouds
2 nights with 'good' seeing

Challenges

- OBSERVING
  - Need telescope time
  - Weather!
- MODELING & IMAGING
  - Reconstructing Images
    - Correlated errors in data
    - Artifacts from image reconstruction
    - What's the best way to recover an image?
  - Models
    - 1D model atmospheres don't treat convection realistically
    - Few 3D hydrodynamical models exist
      - Long computing time

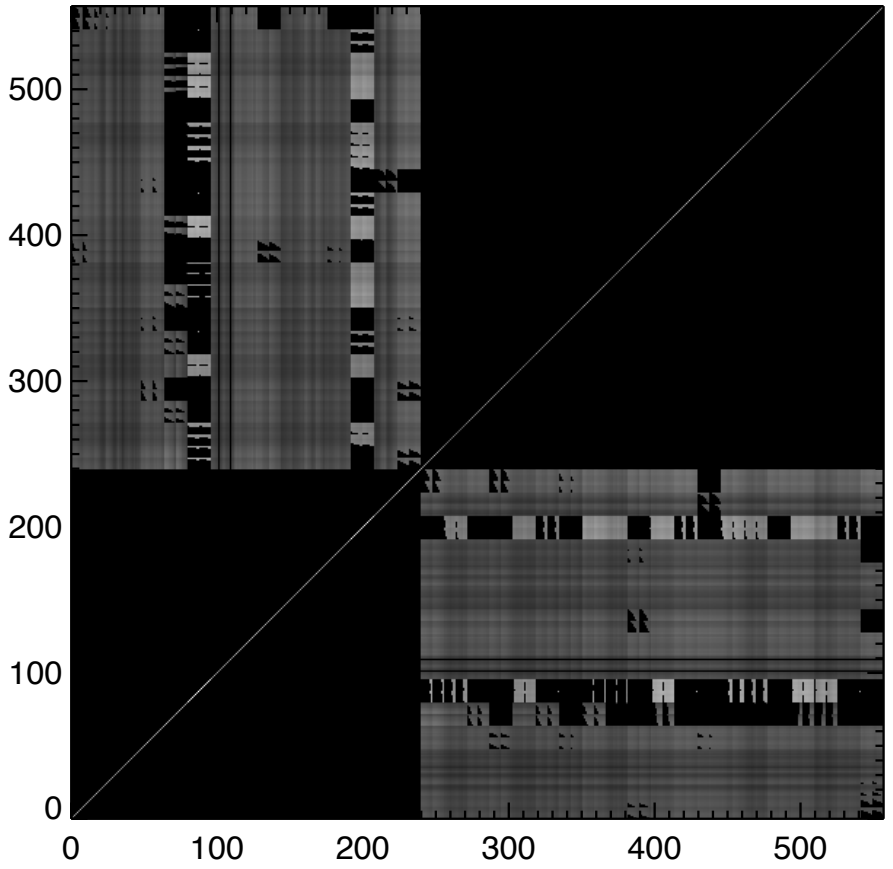
Early results

Name	UD diameter (mas)	Error (mas) (don't believe these!)
41 Cyg	1.14	0.02
AD Per	2.44	0.02
AZ Cyg	3.74	0.01
BU Per	2.50	0.15
FZ Per	1.85	0.01
KK Per	3.04	0.82
Ksi Cyg	9.15	0.90
PP Per	1.48	0.02
RW Cyg	6.00	0.06
S Per	4.71	0.04
SU Per	3.24	0.01
W Per	2.71	0.18
XX Per	2.91	0.03

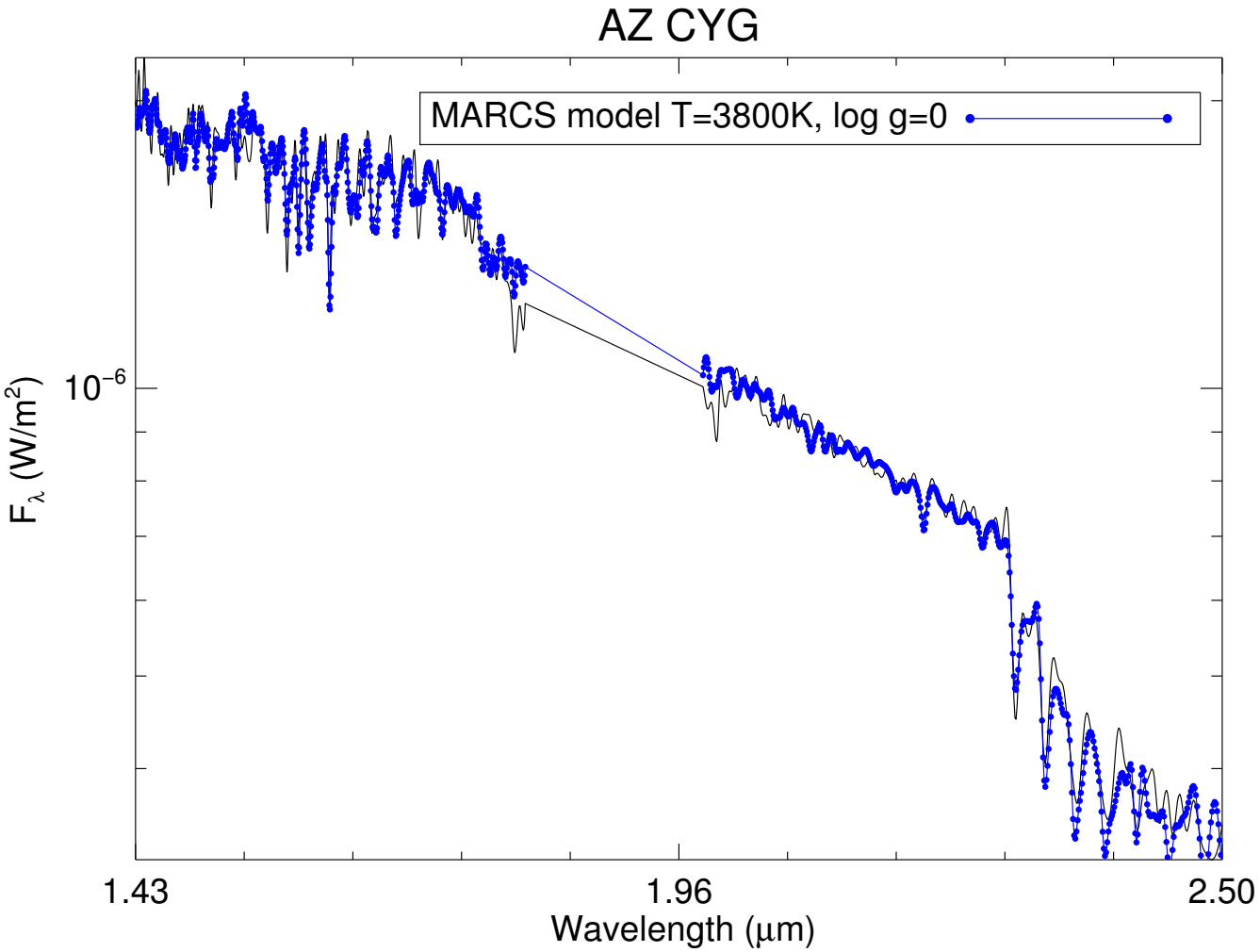
Correlation in the data

- Currently: We can calculate post-reduction pipeline
- Goal: Implement into pipeline

Covariance between V^2 And T3

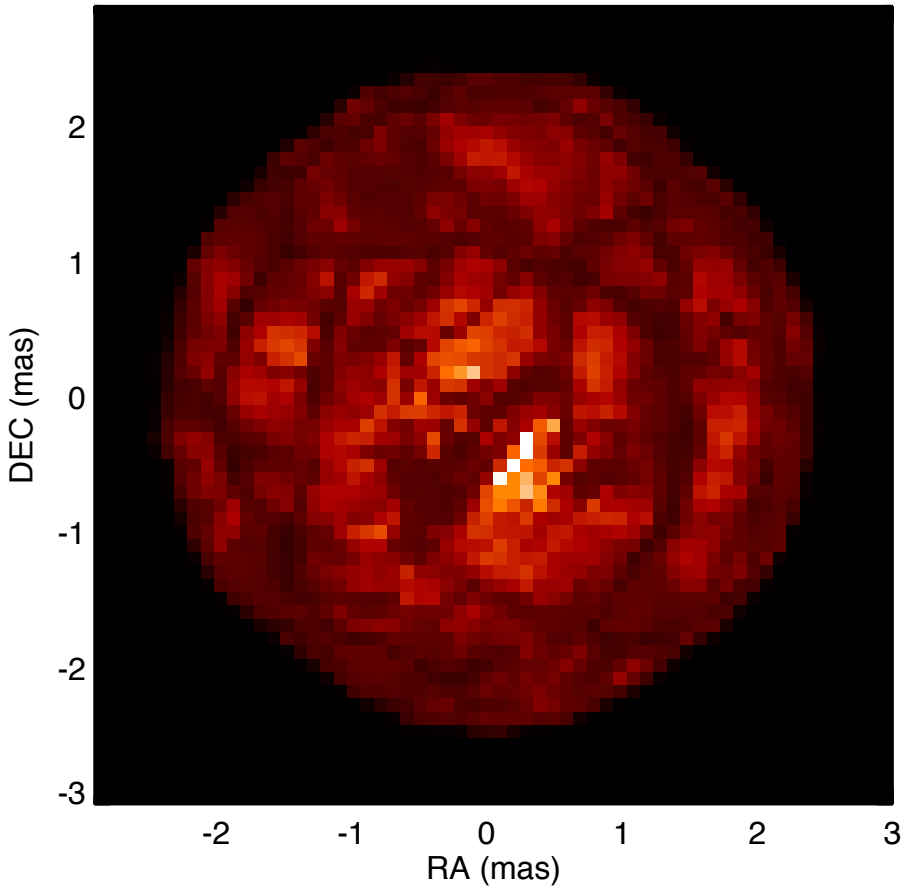


Ongoing work …



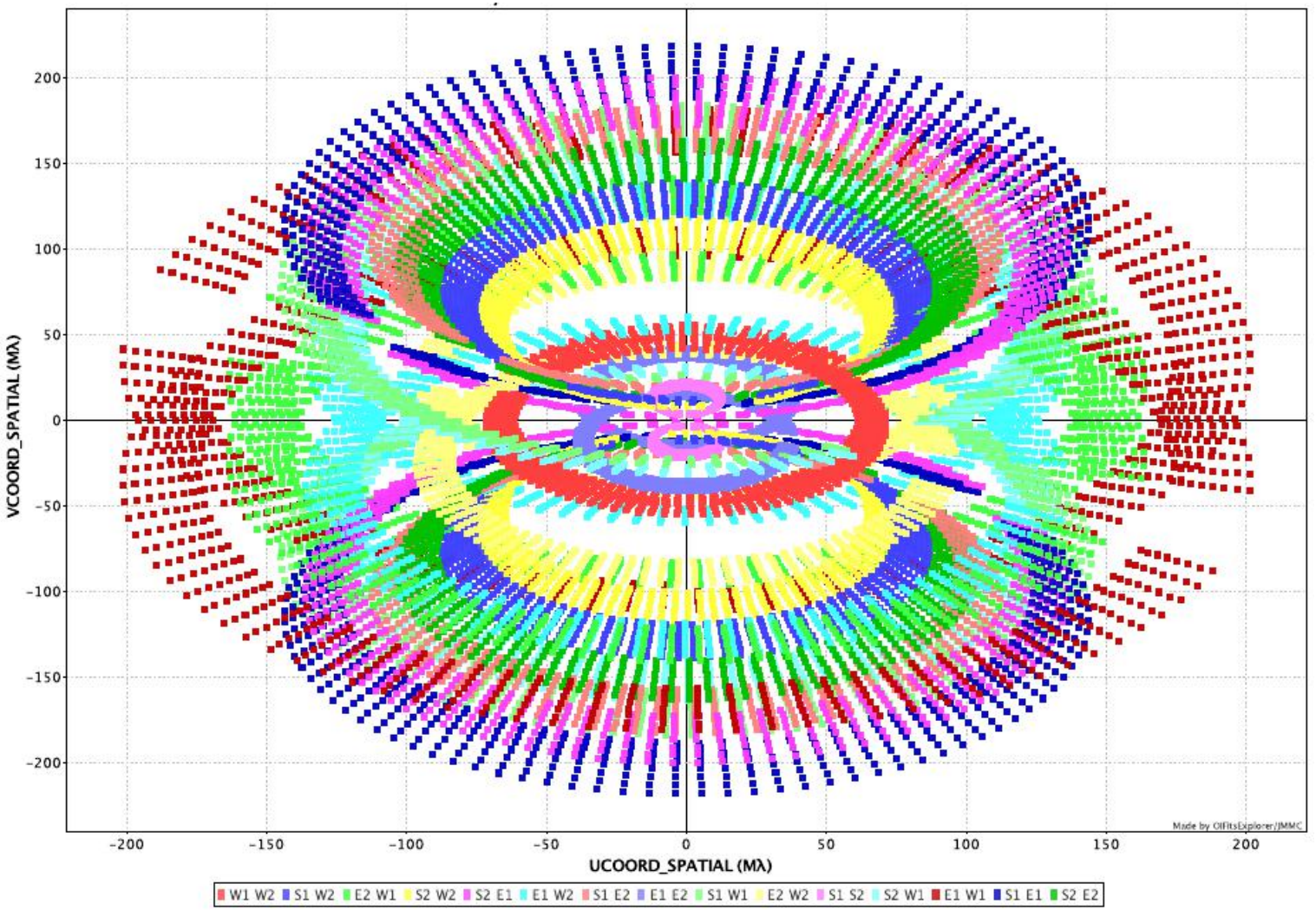
Spectral data from Lançon and Rocca-Volmerange 1992

What might we see?

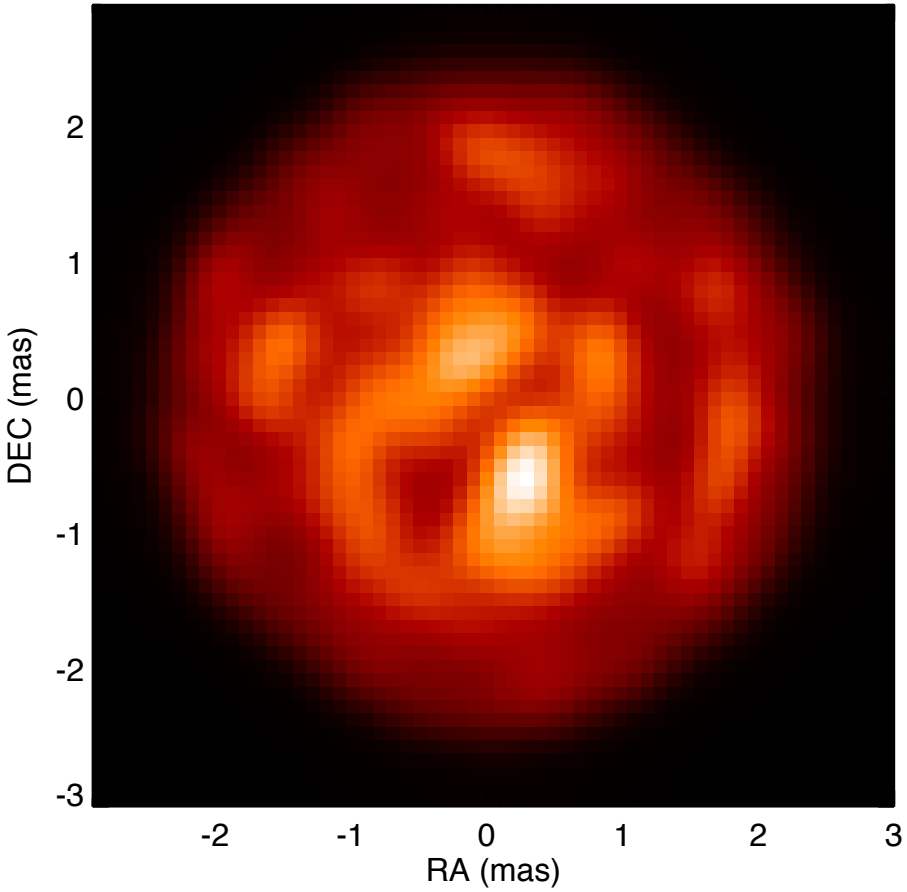


Chiavassa et al. 2010

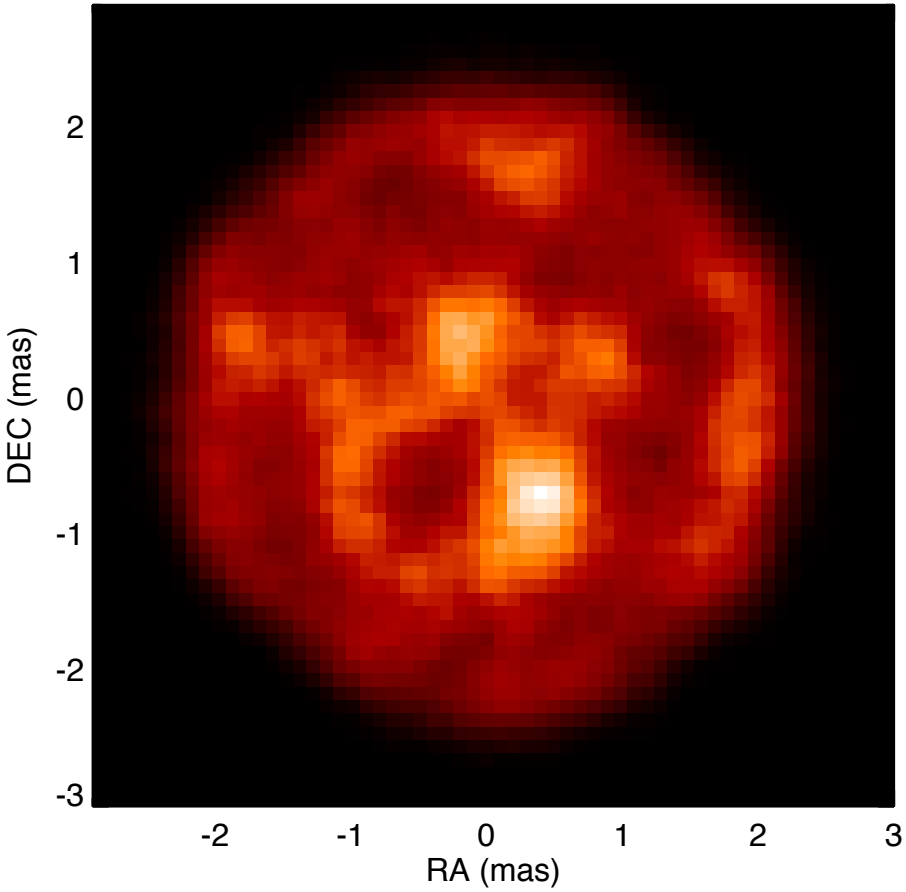
A dream …


VCOORD_SPATIAL (Mλ)
UCOORD_SPATIAL (Mλ)
200
150
100
50
0
-50
-100
-150
-200
Made by OIFitsExplorer/JMMC
W1 W2 S1 W2 E2 W1 S2 W2 S2 E1 E1 W2 S1 E2 E1 E2 S1 W1 E2 W2 S1 S2 S2 W1 E1 W1 S1 E1 S2 E2

Current results

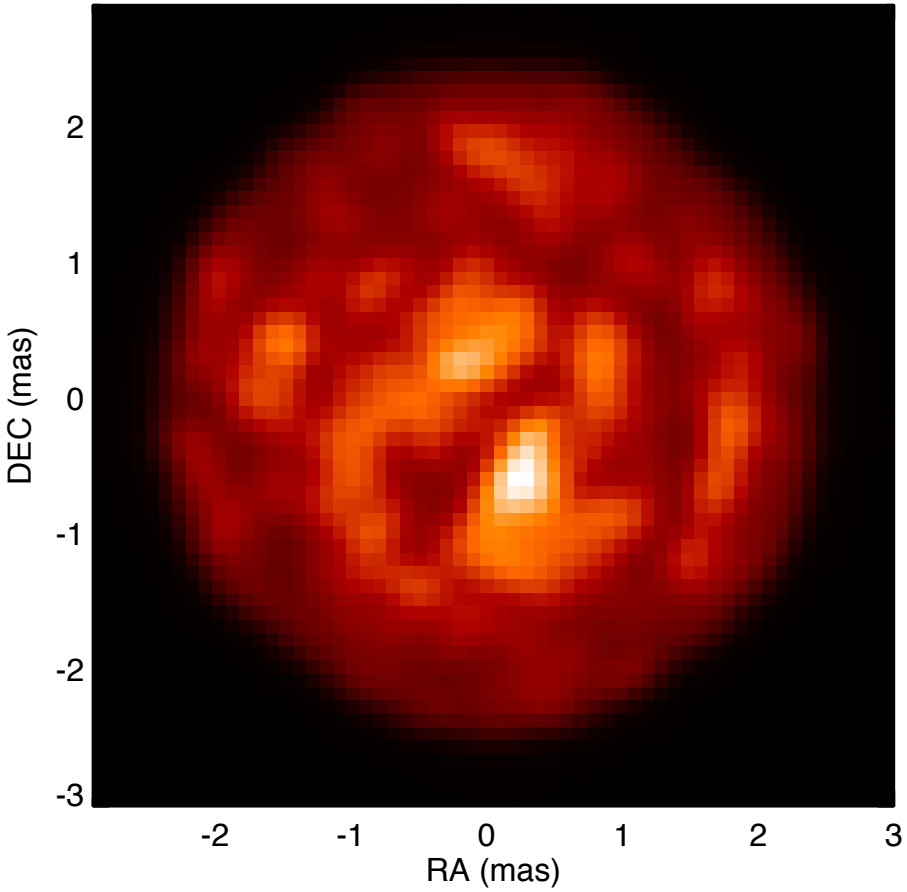


Original Convolved to 330m telescope

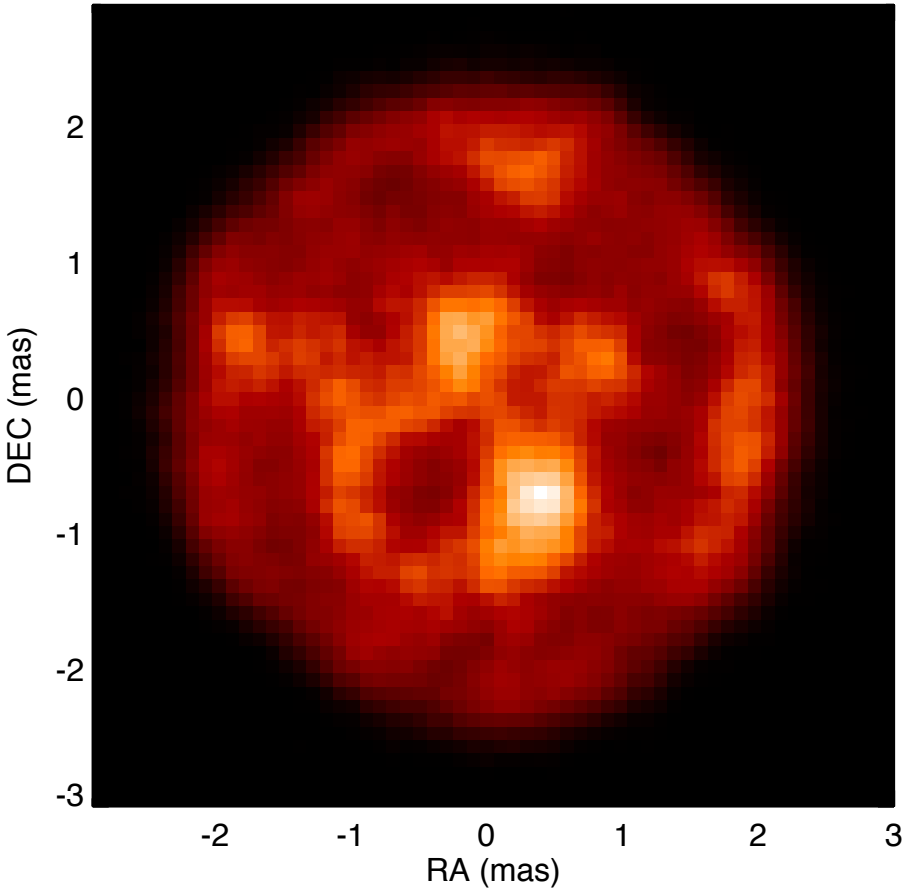


Reconstruction

Current results



Original Convolved to 500m telescope

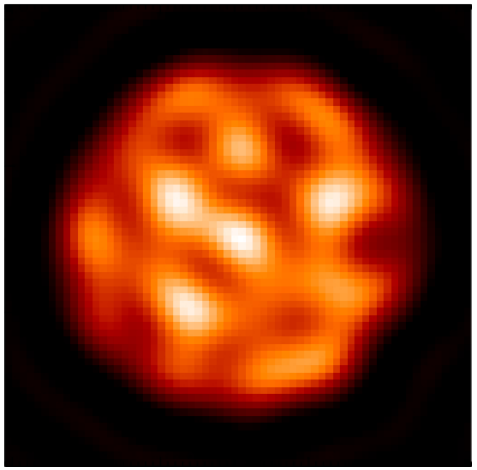


Reconstruction

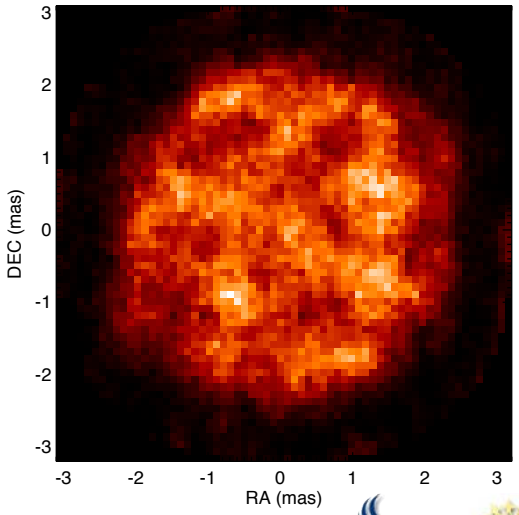
Finding the best regularization for a known object

- To find best regularizers
  - Compare results for simulated data to the source image
  - Human eye is good at this…image metrics attempt to recreate this

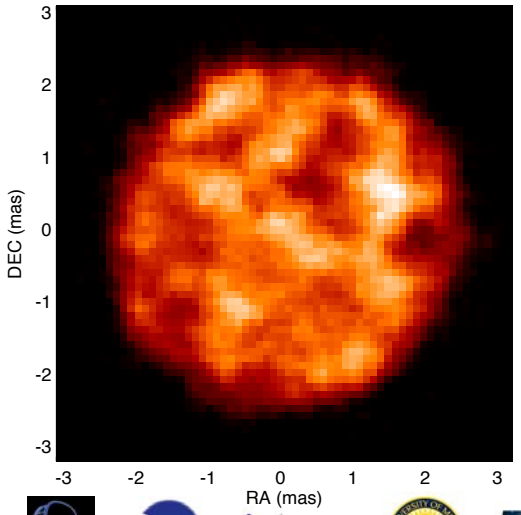
"Best possible" image



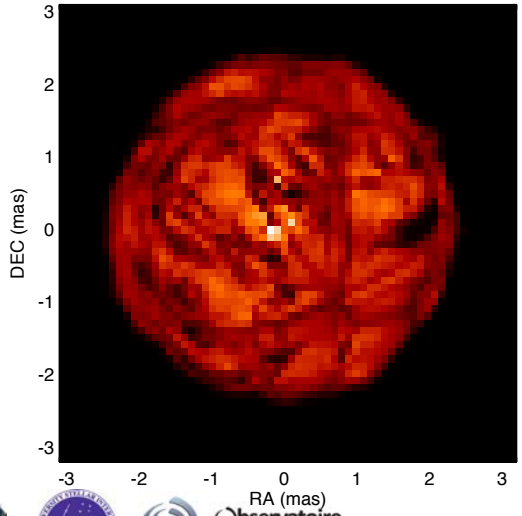
Mean Square Error



Structural Similarity



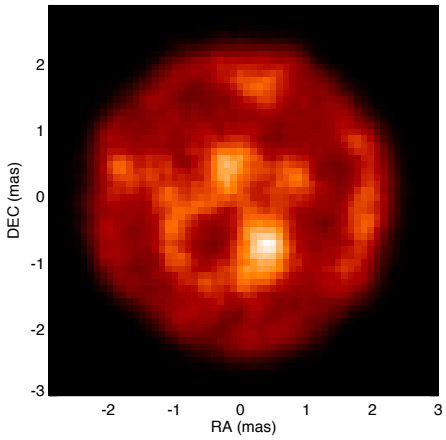
Original Image

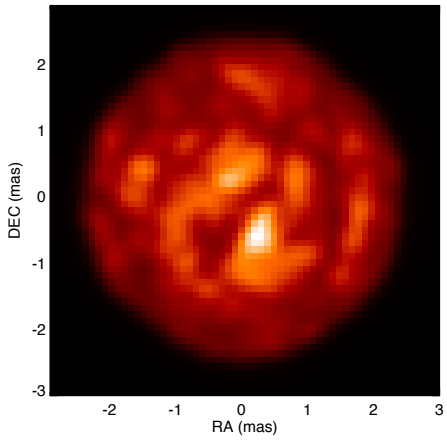


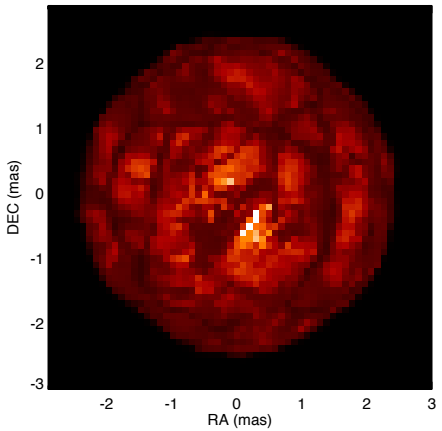
Chiavassa 2009

A New Regularizer?

- Goal: Move beyond bright spots to well defined cells in images
  - Idea: Get darker cell boundaries in our reconstruction
    - Flux lower than image average (excluding area outside star)
    - Surrounded by regions of steep flux change but rather constant flux in neighbors
    - SUGGESTIONS WELCOME!

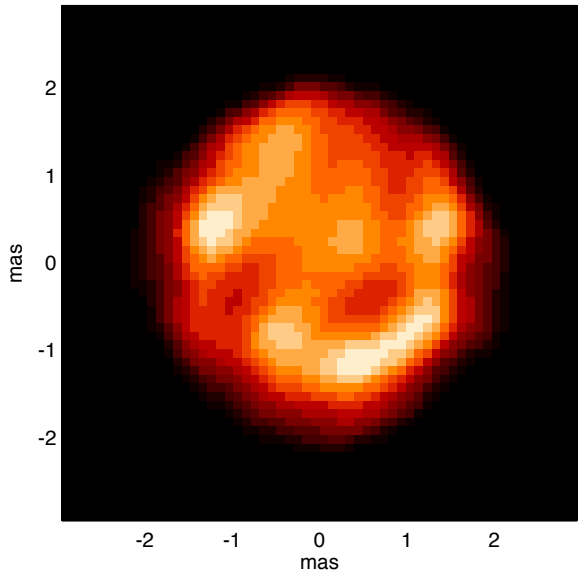




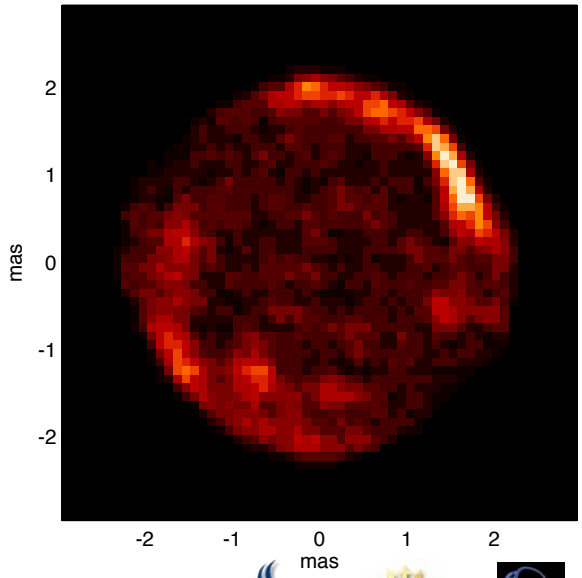


Detecting artifacts

mean of images



standard deviation of images



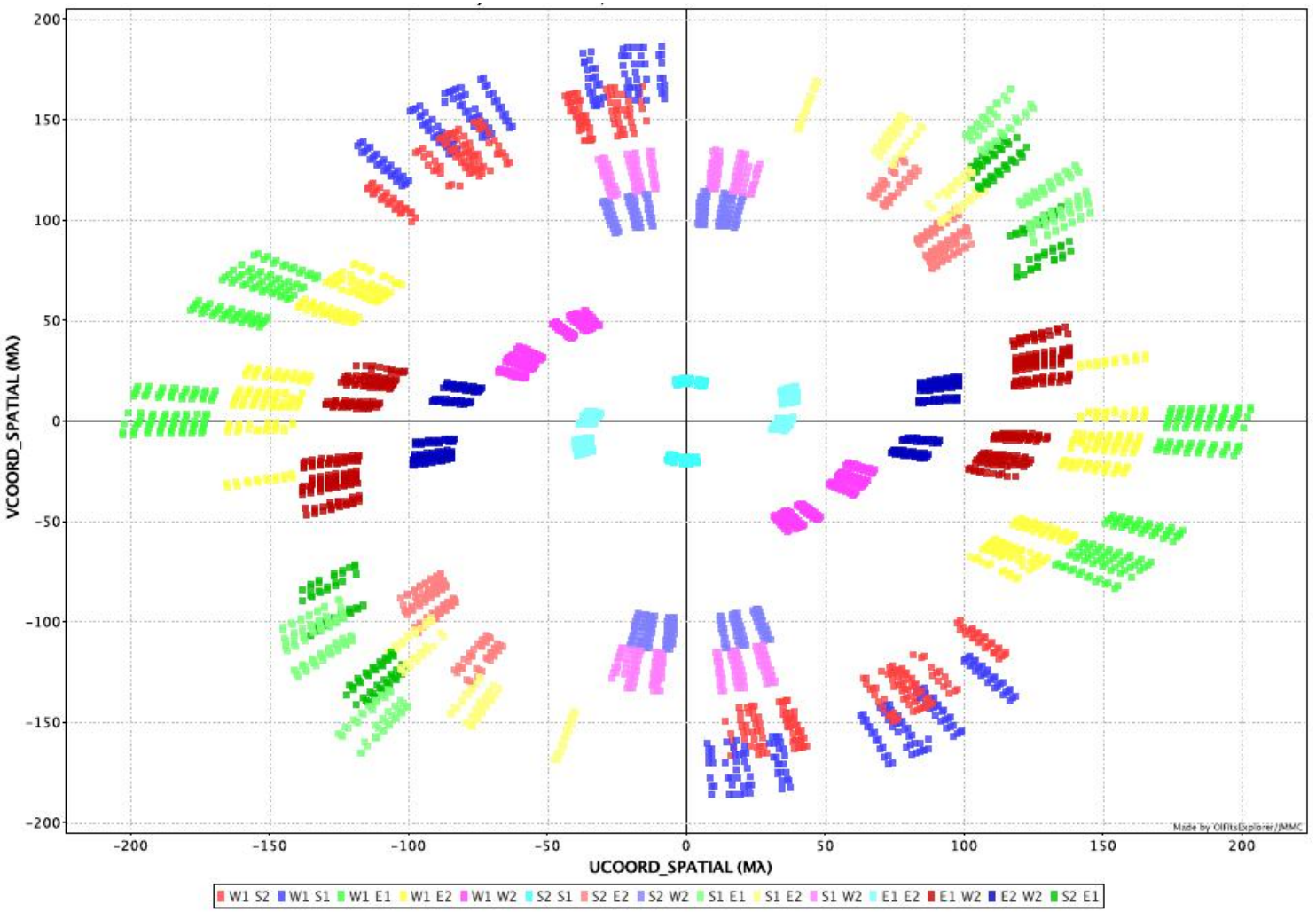
To identify artifact **due to the reconstruction process:**

1) Reconstruct many images using independent Markov Monte Carlo chains

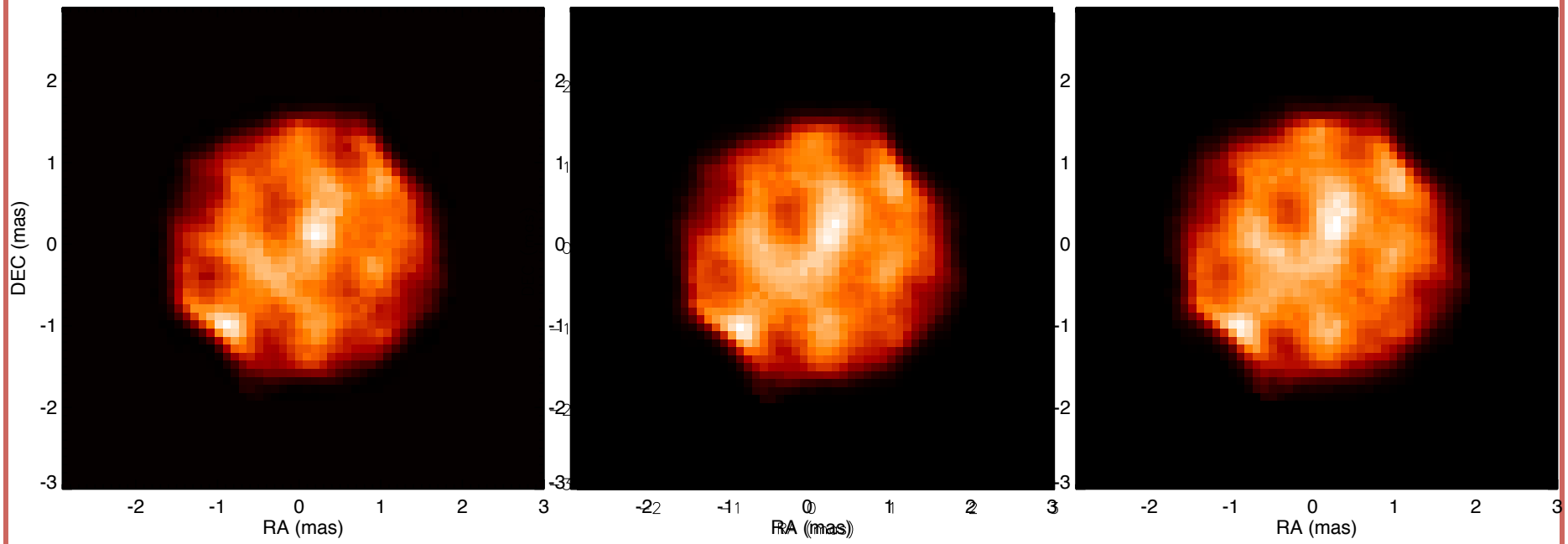
2) Co-align resulting images based on given metric

3) Compute statistics on the stack (mean, mode, median, standard deviation = error map)

The SU Per supergiant



First Images of SU Per… much work to be done



mean-σ

Su Per (mean)

mean+σ