Stars and Their Environments: Mirrors to the Universe

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ngVLA 2016 Workshop
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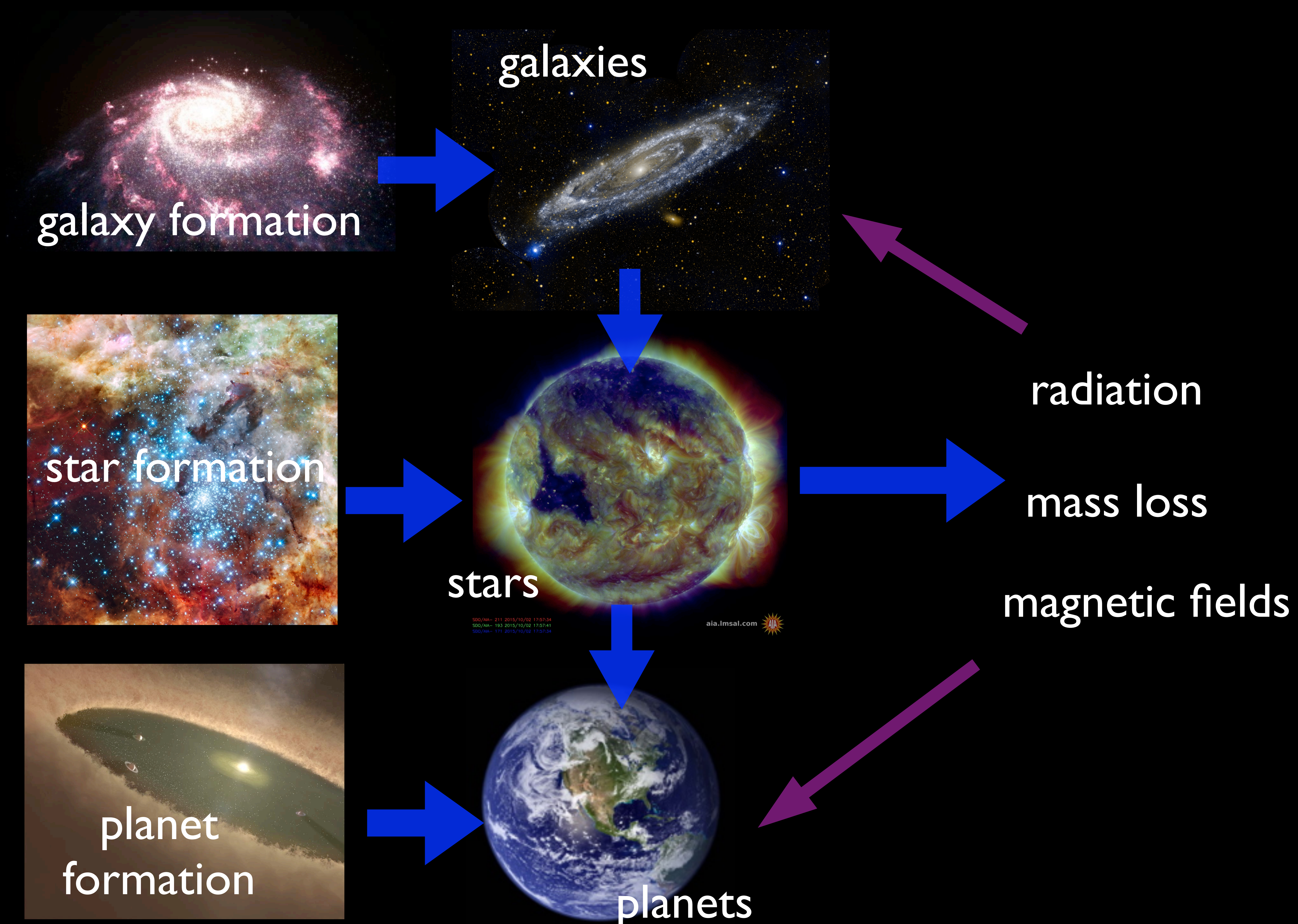

galaxy formation
galaxies
star formation
stars
aia.lmsal.com
radiation
mass loss
magnetic fields
planet formation
planets

Gaia (2013)

eROSITA (2016)

TESS (2017)

JWST (2018)

LSST (2023)

SKA (2023)

WFIRST (2024)

GMT/TMT/
E-ELT (mid 2020s)

CHEOPS (2017)

PLATO (2024)

Athena (2027)

possible recommendations from next decadal for future flagship space mission

ATLAST/LUVOIR/
HDST

FIR Surveyor

HabEx

X-ray Surveyor

Big Questions*

- how do stars form?
- how do circumstellar disks evolve, form planetary systems?
- how diverse are planetary systems?
- do habitable worlds exist around other stars?
- how do rotation and magnetic fields affect stars?

✔ radio wavelengths inform each of these topics, are vital for understanding how stars work and how they interact with their environment

✔ Observations with the next generation VLA will be key to advancing these areas; require large collecting area coupled with access to large frequency space, high spatial resolution

*as informed by the Decadal Survey and more recent results

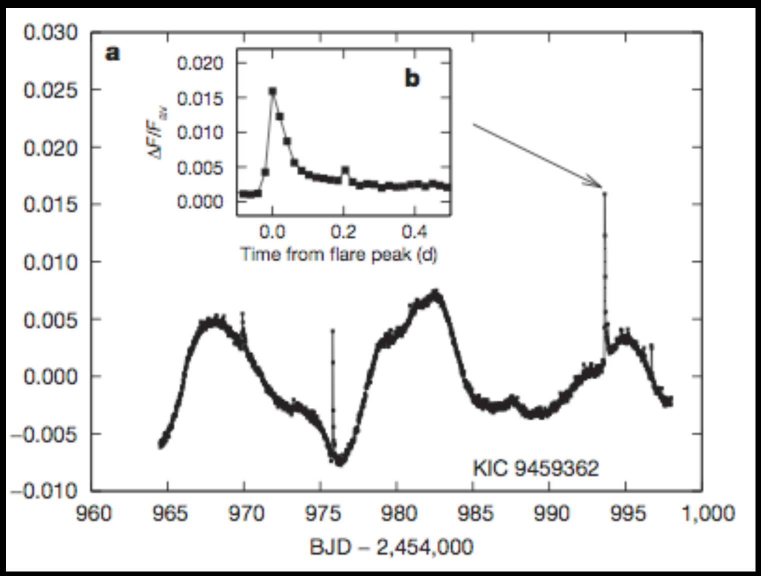
Areas where an ngVLA can make unique and powerful contributions

- Time domain studies of stellar dynamos in action
- Fundamental properties of stars
- Stars as planet hosts

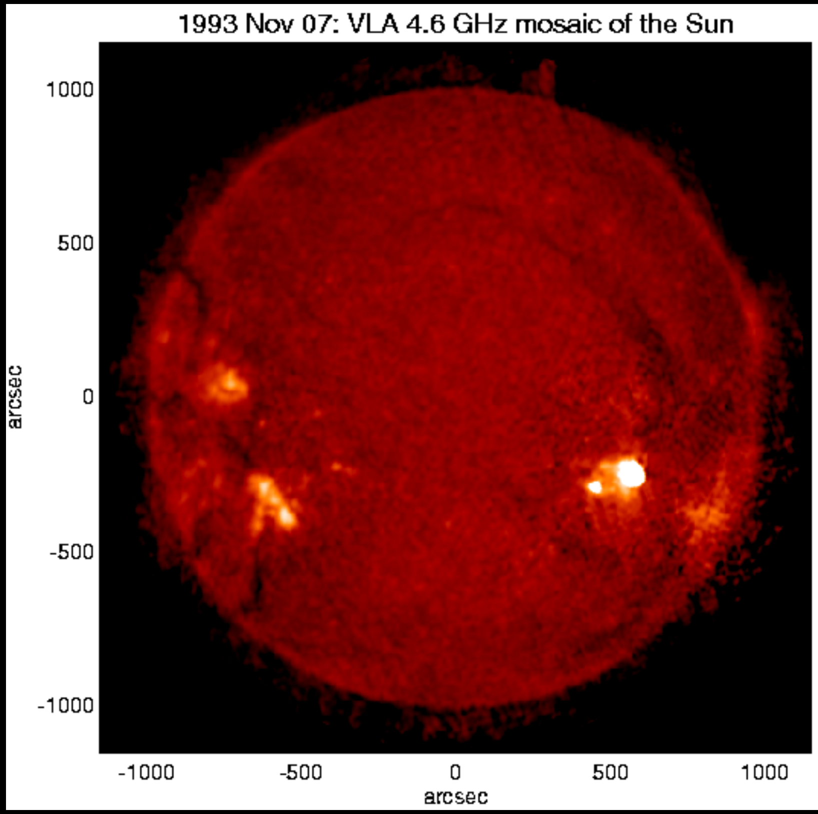
Time Domain Revolution

- Continuous monitoring of nearby stars (to find exoplanets) has rich spinoff for stellar science
  - asteroseismology: stellar masses, radii, ages
  - eclipses, changing starspot configurations
  - stellar rotation periods
  - short time-scale signatures of magnetic activity (flaring)
- 3D space motion constraints on a billion stars from Gaia
- Transient monitoring finds unanticipated results
- Time-varying stellar signals: understanding creation, destruction of magnetic fields in stellar atmospheres

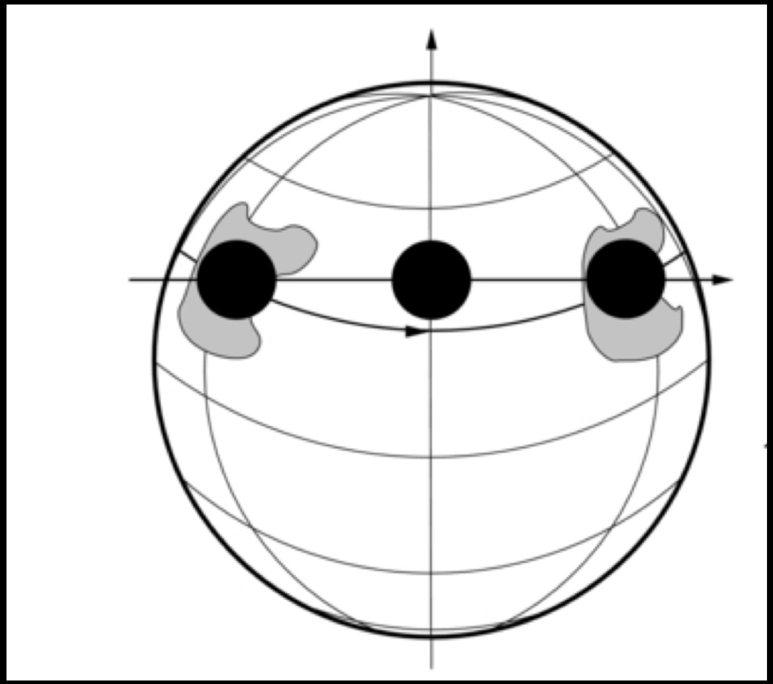
Time Domain



Maehara et al. (2012)



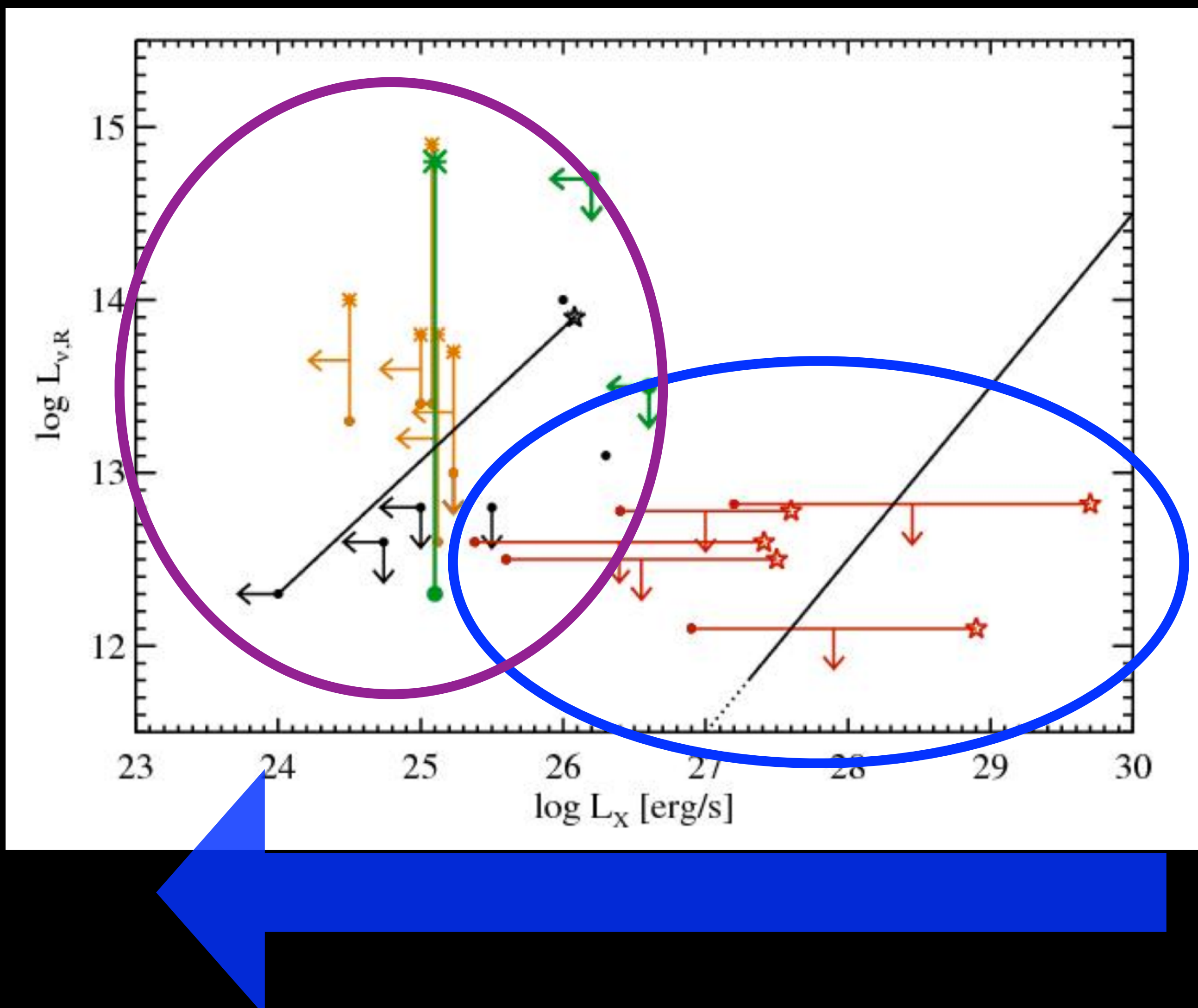
the solar disk at 5 GHz; courtesy of Stephen White



Nutzman et al. 2011)

- Multi-month stellar light curves from transiting planet-hunting missions (e.g. TESS) find planets, starspots, flares, oscillations. ..
- Starspot properties from transits of exoplanets with JWST
- For nearby stars, ngVLA can trace changes in radio luminosity (for L_r~10^{13} erg/s/Hz, d=10 pc) to 20% over timescales of 5 minutes over 500 MHz, determine how observed accelerated electron population changes, constrain particle environment near star

Time Domain Studies Reveal Dynamos at the End of the Main Sequence



At 10x sensitivity of VLA, ngVLA will have $L_{R,min}=10^{12}$ (d/75pc)^2 erg/s/Hz

Osten et al. (2015) most sensitive upper limits to radio emission from nearby ultracool dwarfs: 7×10^{10} erg/s/Hz

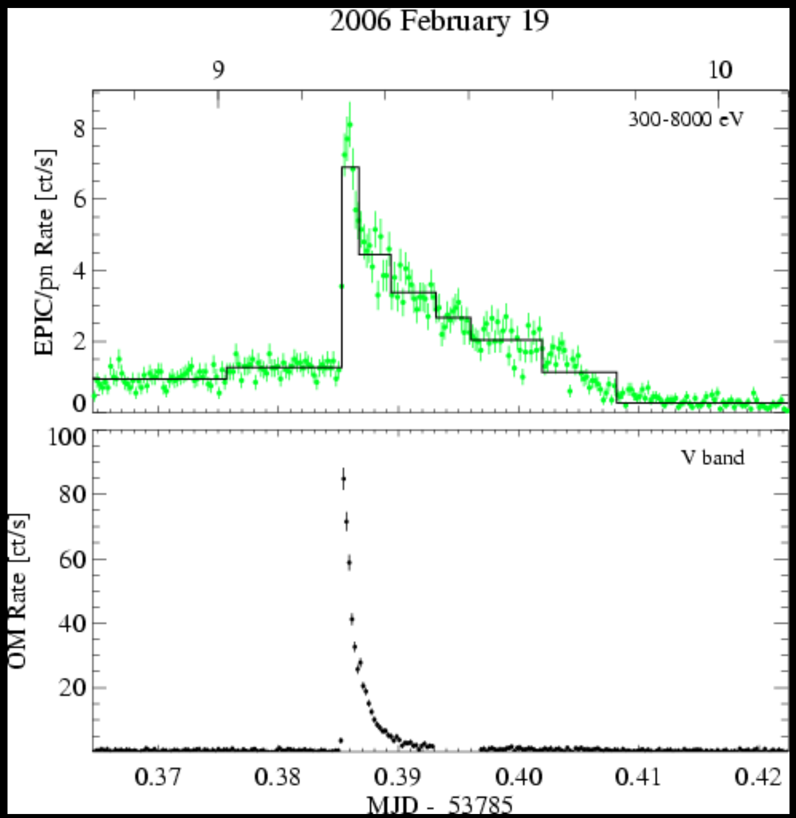
Stelzer et al. (2012)

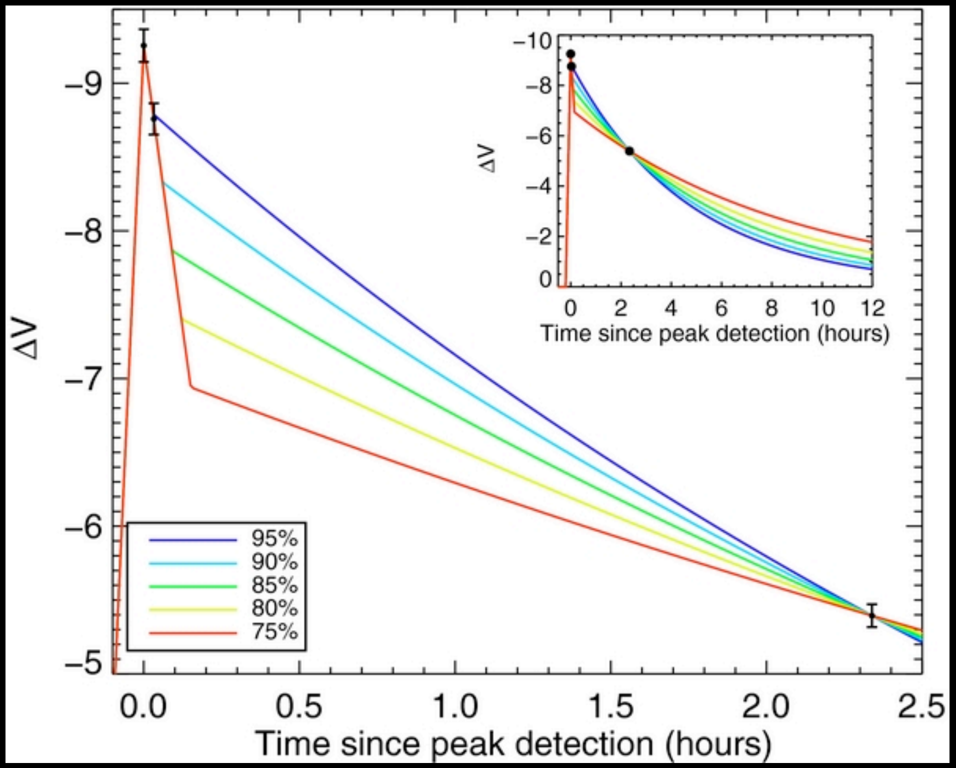
"X-ray loud" = detections of handfuls of photons

"radio-loud" = tens -100s of microJy flux detections

Time Domain Studies Reveal Dynamos at the End of the Main Sequence

coronal flaring, spectacular optical flaring





ΔV=6 magnitudes in the optical!

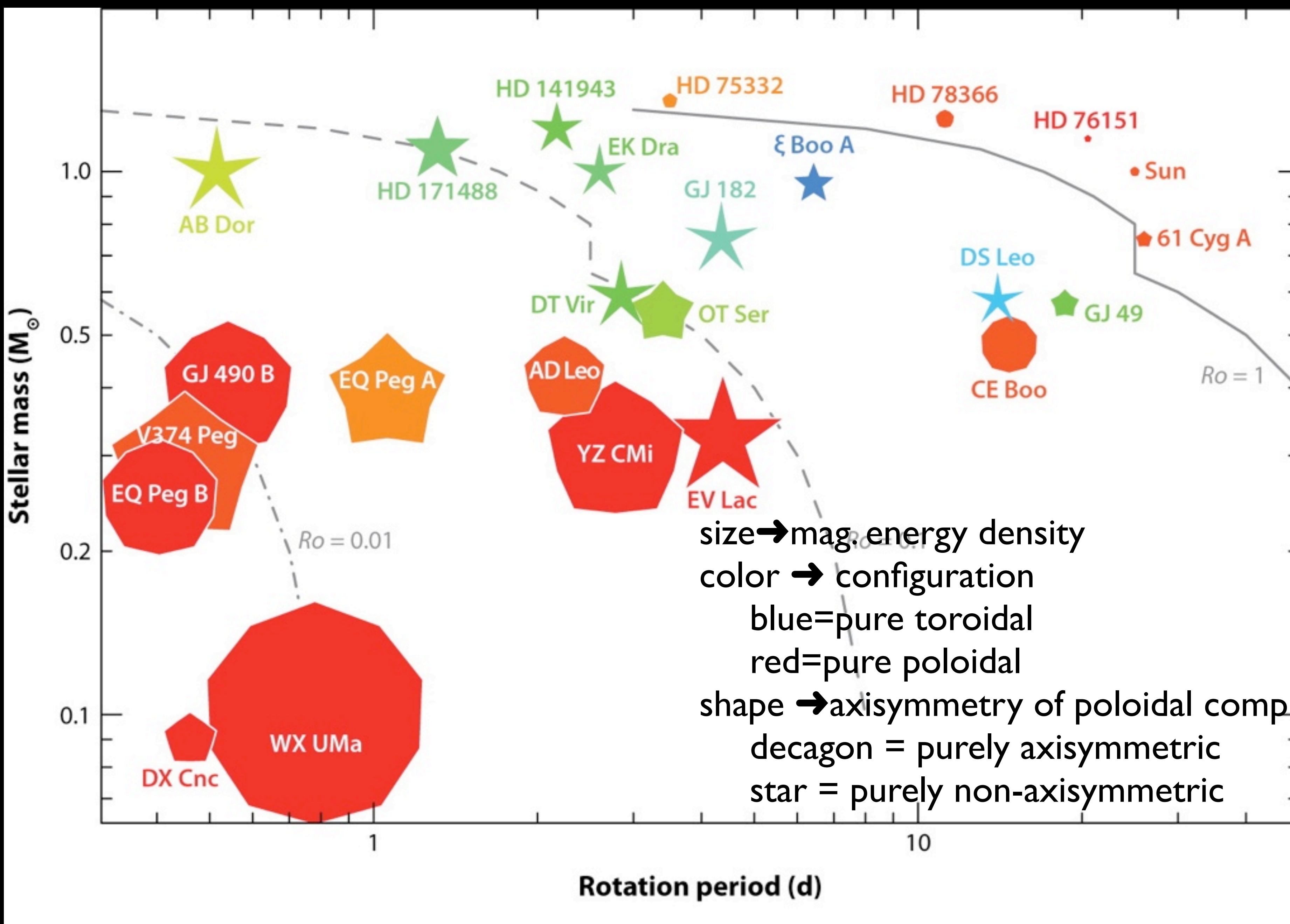
$E_x=10^{32}$ ergs, equivalent to the largest solar flares

Schmidt et al. (2014)
M8V caught by ASAS-SN survey; ΔV=9.25

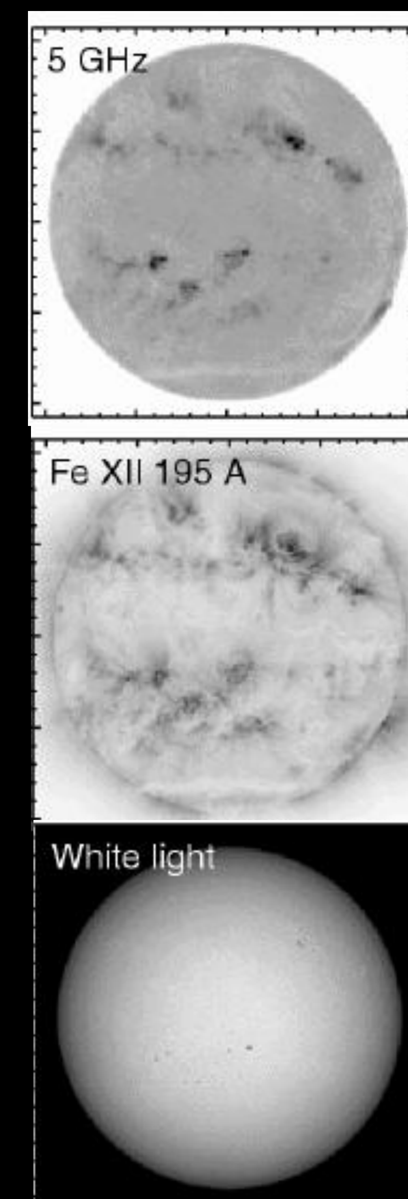
M8V caught in a giant X-ray/optical flare:
Stelzer et al. (2006)
temperature, VEM evolution suggests coronal flare activity, with loop length scale ~R_*

Beyond B Field Detections to Characterization of Geometry

Radio Zeeman Imaging: chart changing magnetic field configuration, effect on radio flux



Donati J.-F, Landstreet JD. 2009.

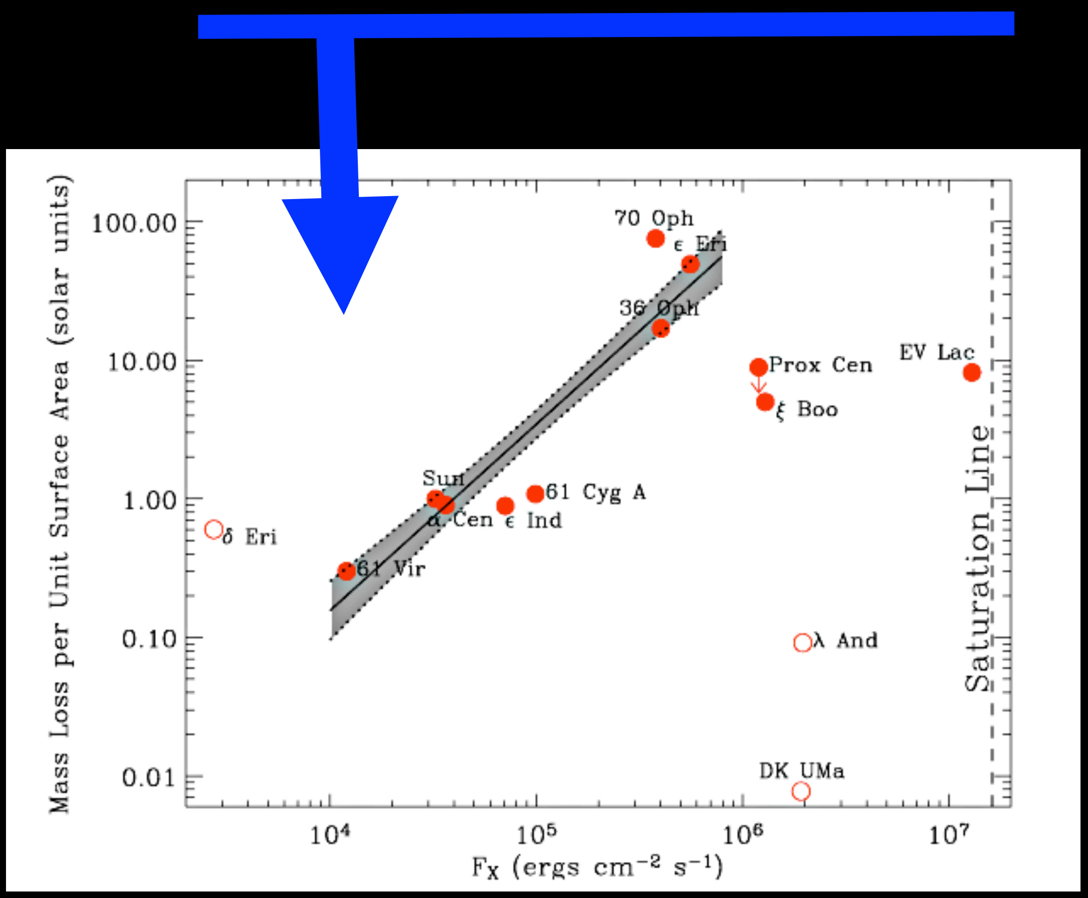


White (1999)

Fundamental Properties of Stars

- How do stars lose mass? Need constraints on winds of MS stars
- Direct measurements at $\nu > 10$ GHz of ionized winds can give constraints on $\dot{M}$ down to about 20 $\dot{M}_\odot$
- Measurements of mass loss on the main sequence limited to the highest masses; inferences from astrospheric effects require high resolution UV spectroscopy, which is an endangered resource

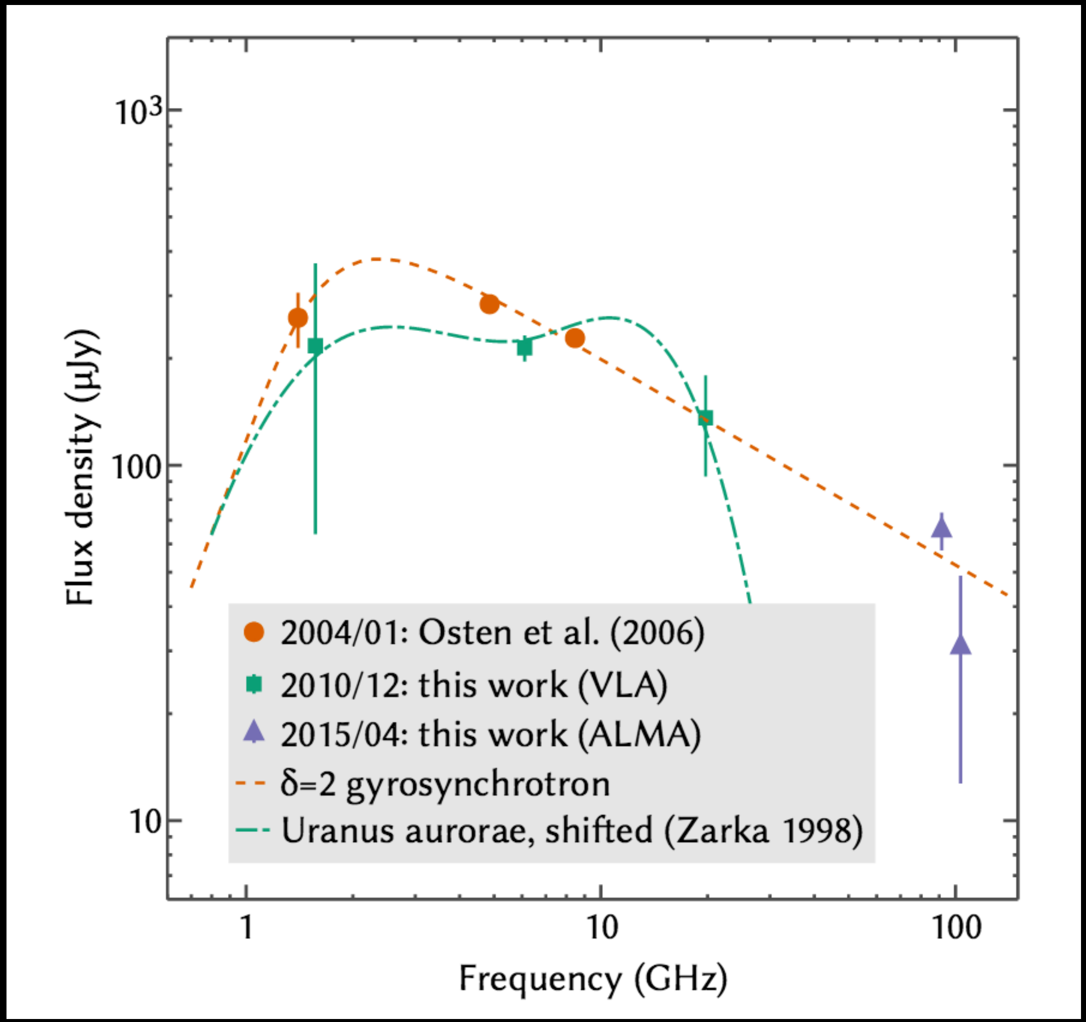
previous attempts at direct detection at radio wavelengths have led to upper limits 2-3 orders of magnitude higher than the Sun's present-day mass loss



Wood et al. (2005) indirect measures of mass loss from Lyman alpha absorption

Fundamental Properties of Stars

- Stellar atmospheres: properties of accelerated electrons
- Need sensitivity ($L_{r,min}$ = 10^{12} $(d/75pc)^2$ erg/s/Hz simultaneous access to wide swath of frequency space (factors of several). Peak frequency is typically in the few GHz-10 GHz range, need higher frequencies to probe optically thin conditions



Williams et al. 2015

mm detection with ALMA of coronal emission from a nearby, nonaccreting ultracool dwarf

Fundamental Properties of Stars

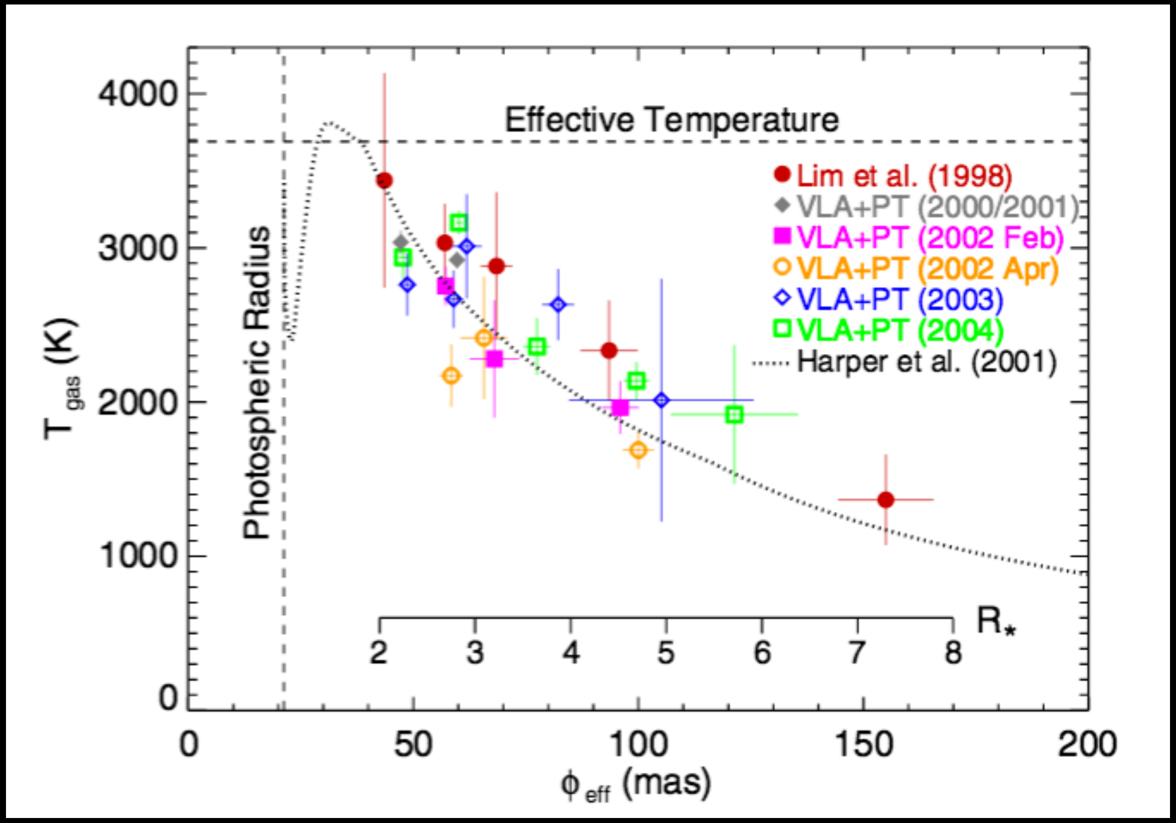
- Mass loss in early red supergiants needs spatially resolved observations on scale of chromosphere, wind acceleration region
- Intermingling of hot & cold gas? UV hot spots (Gilliland & Dupree 1996), radio pockets cooler than mean global temperature (O'Gorman et al. 2015)

mass loss in action?

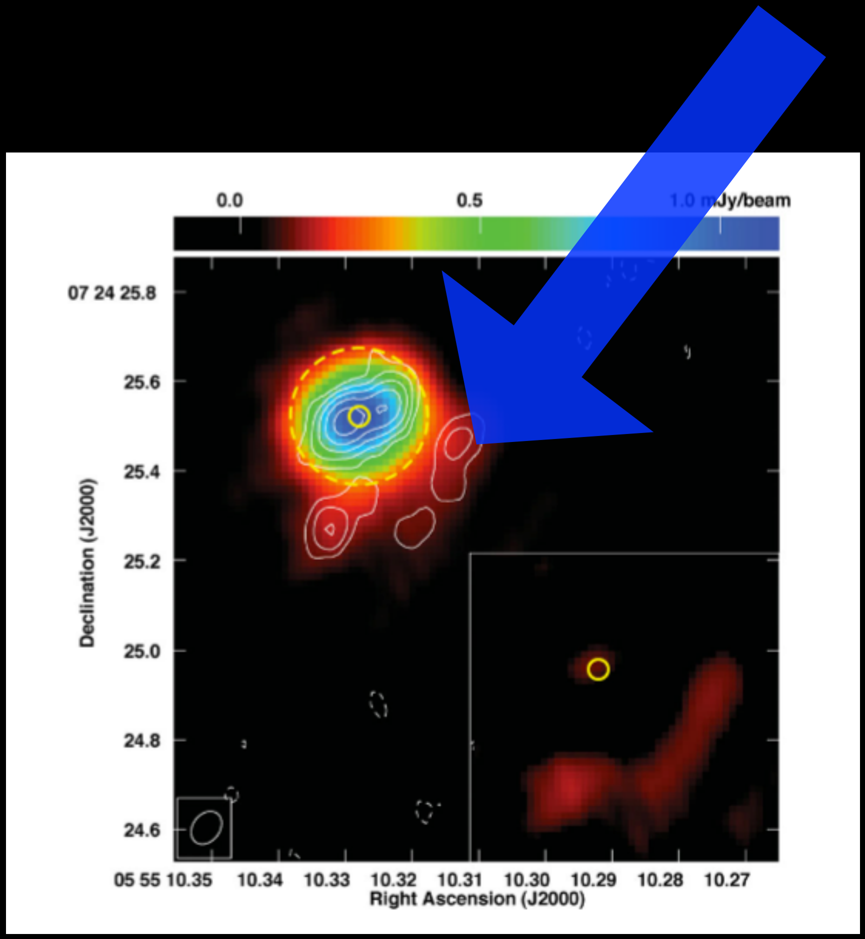
M of 2×10^{-6} $M_{\odot}$

$\dot{M}$ of 10^{-6} $M_{\odot}$ yr^{-1}

t~few yrs



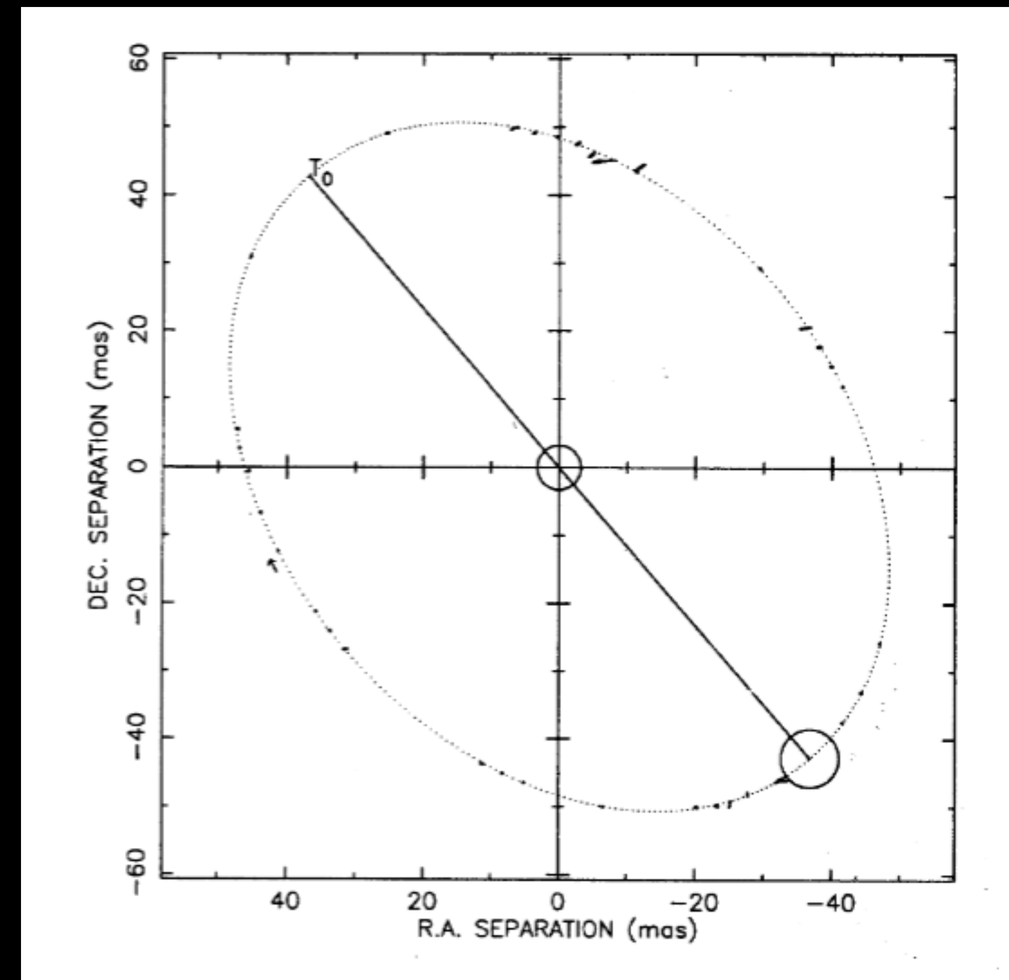
O'Gorman et al. 2015



Richards et al. (2013)

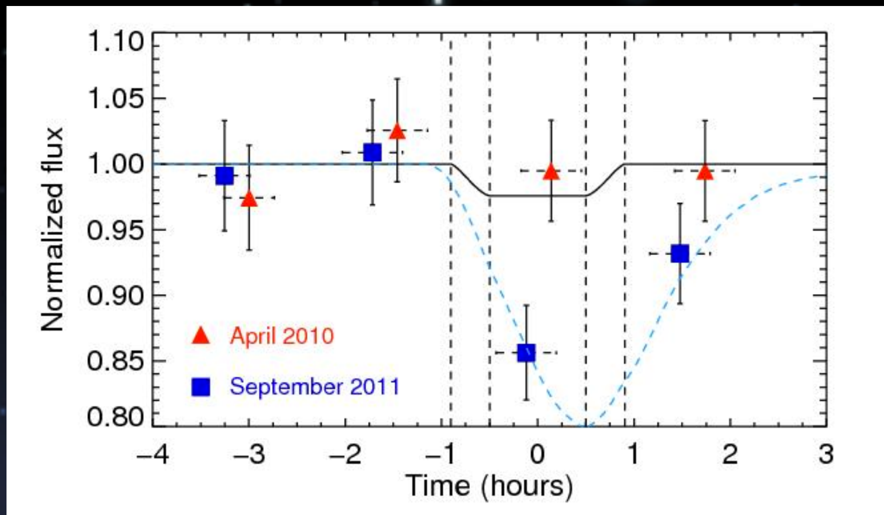
Fundamental Properties of Stars

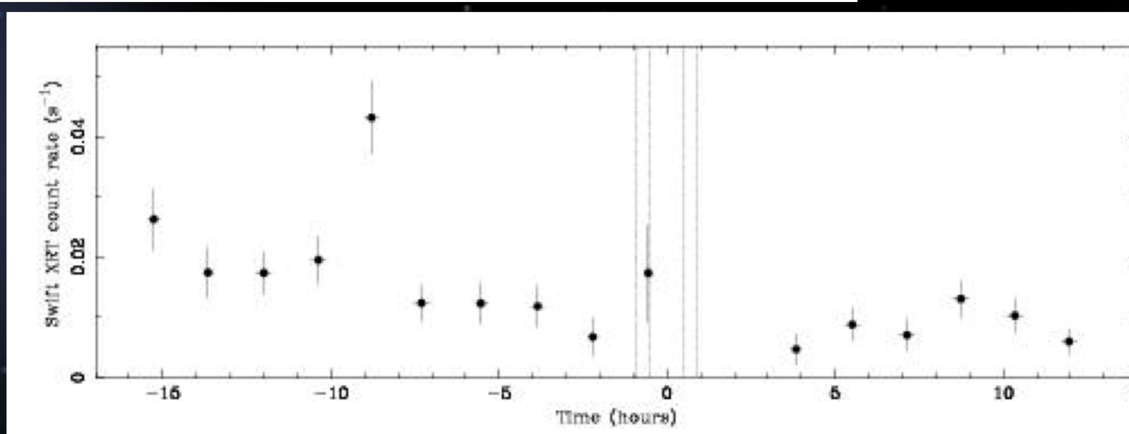
- Resolving stellar coronae
- Capella (G8III+G1III, d=12.9 pc) weak radio source detected by Drake & Linsky 1986) cm-wavelength radio emission consistent with thermal bremsstrahlung
- Coronal densities, temperatures well-constrained by X-ray spectra, but no spatial resolution
- ngVLA can probe evidence for magnetically-induced disk inhomogeneities (hints at variations of coronal lines)



Capella orbit; Hummel et al. (1994)
each star is resolvable (6-8 mas) with the ngVLA

Stars as Planet Hosts





- Impact of stellar particle & radiative environment on close-in planets
- Temporal variations in Lyman α reveal an evaporating atmosphere (Lecavelier des Etangs et al. (2012))
- Stellar energetic input to planet & atmosphere's response.
- Need to be able to see small changes in stellar radio flux during transits, correlate with stellar activity.

Conclusions

- Still much to learn about the details of how stars work
- There are good nearby examples which can be mined for astrophysics of mass loss, magnetic field creation & destruction, magnetic processes
- The next 10-15 years will see an increasing amount of collaboration/interaction between stellar, planetary communities to understand the ecosystems of other solar systems

A ngVLA provides powerful, unique diagnostics to studies of stars and their environments