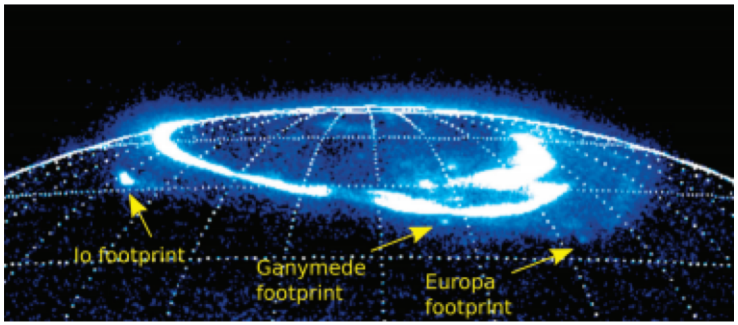
# Searching for Low-Frequency Radio Emissions from Young Stars and Exoplanets

Jason Ling
Rice University
NRSM URSI Meeting
10 January 2019

# Exoplanetary Radio Emission

Cyclotron Maser Instability

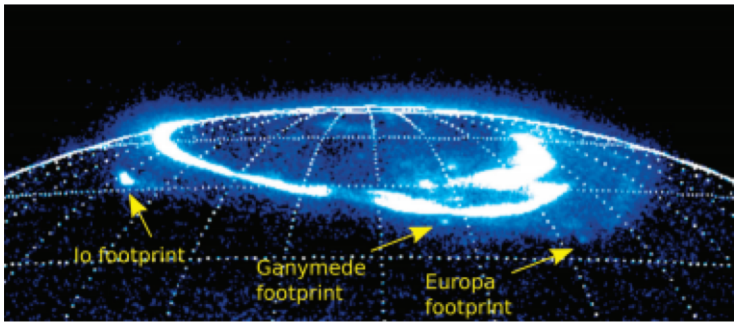


# Exoplanetary Radio Emission

Cyclotron Maser Instability

Peak frequency scales with planetary magnetic field

Flux *may* scale with physical conditions

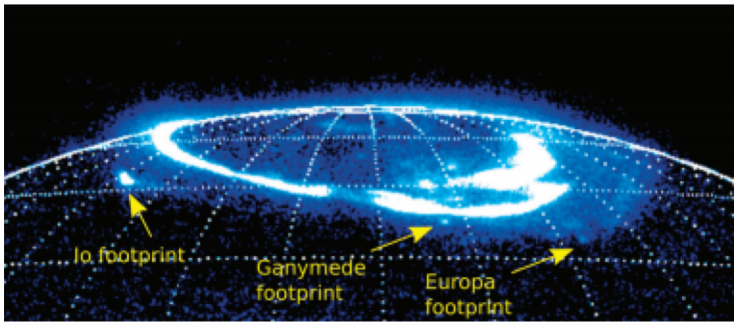


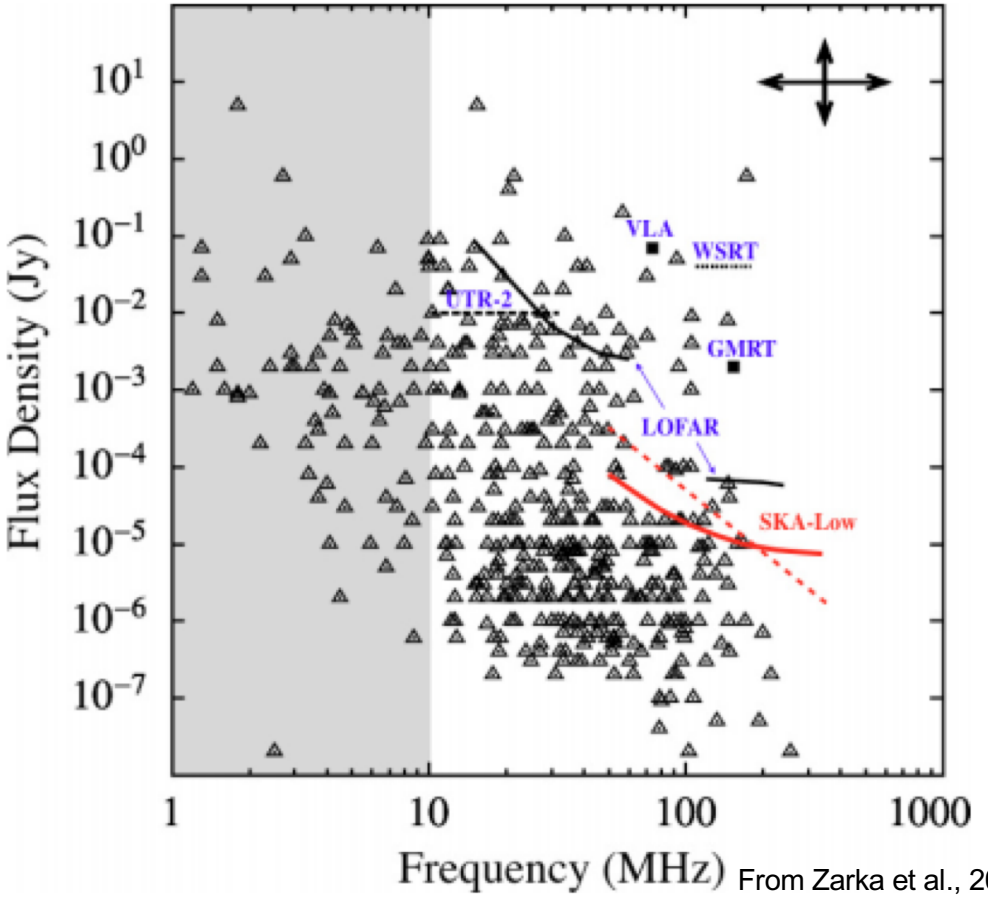
# Exoplanetary Radio Emission

Cyclotron Maser Instability

Peak frequency scales with planetary magnetic field

Flux *may* scale with physical conditions



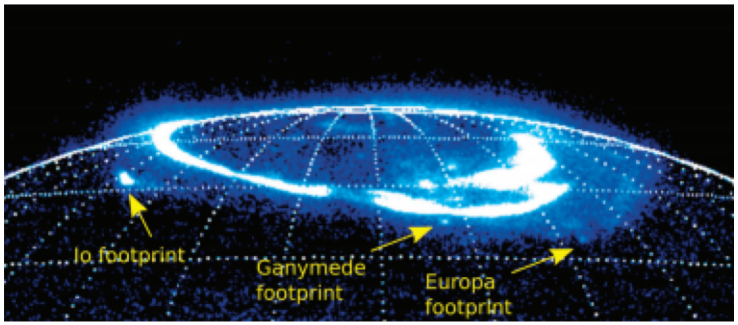

From Zarka et al., 2015

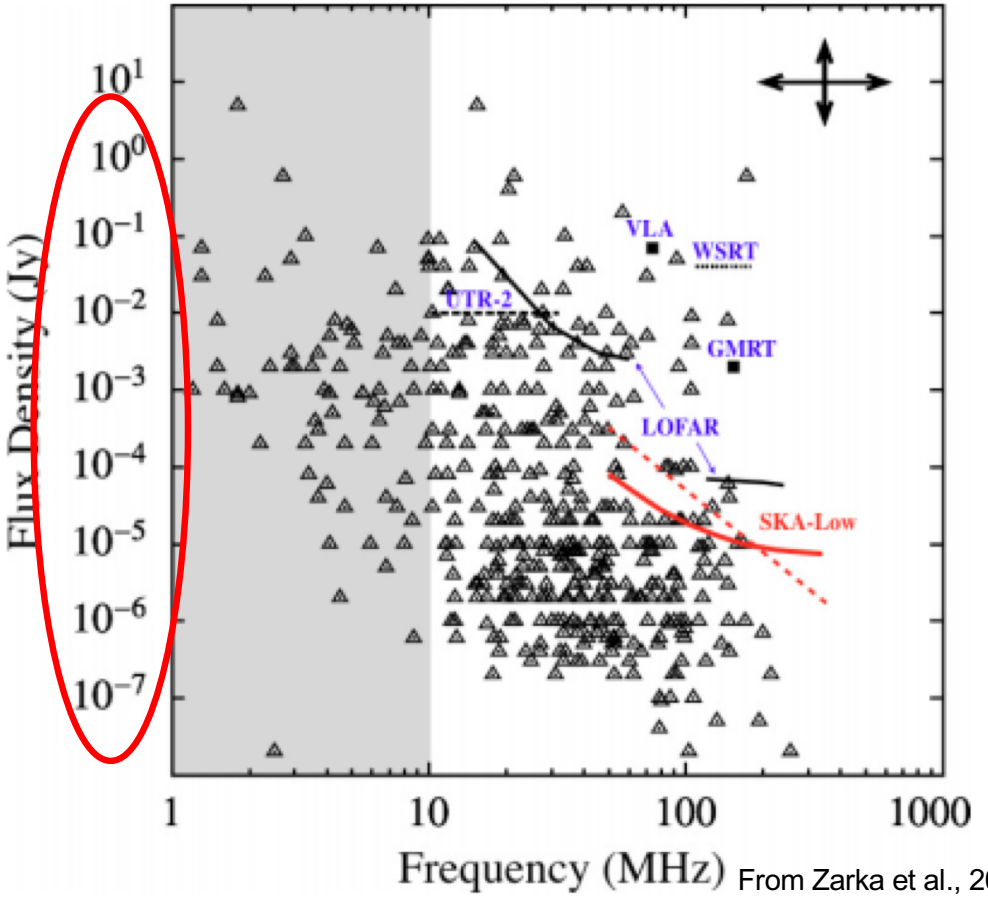
# Exoplanetary Radio Emission

Cyclotron Maser Instability

Peak frequency scales with planetary magnetic field

Flux *may* scale with physical conditions



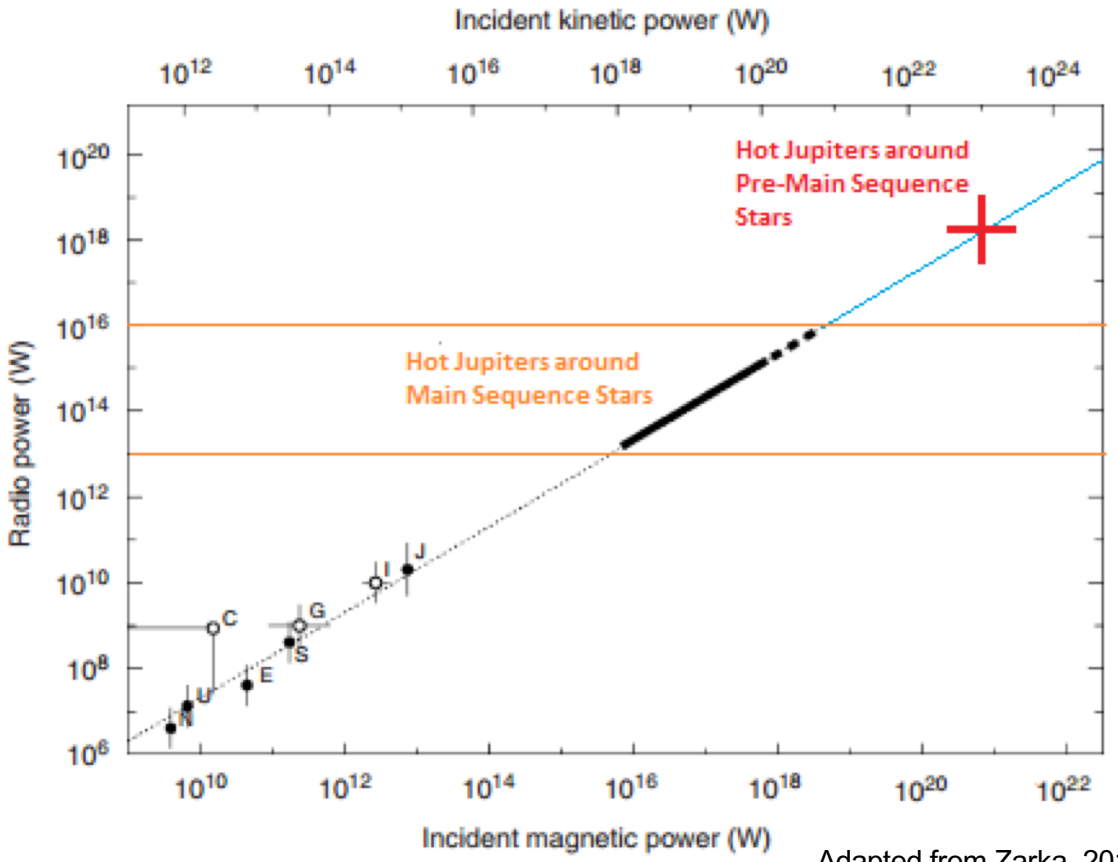

From Zarka et al., 2015

# Exoplanetary Radio Emission

Cyclotron Maser Instability

Peak frequency scales with planetary magnetic field

Flux *may* scale with physical conditions



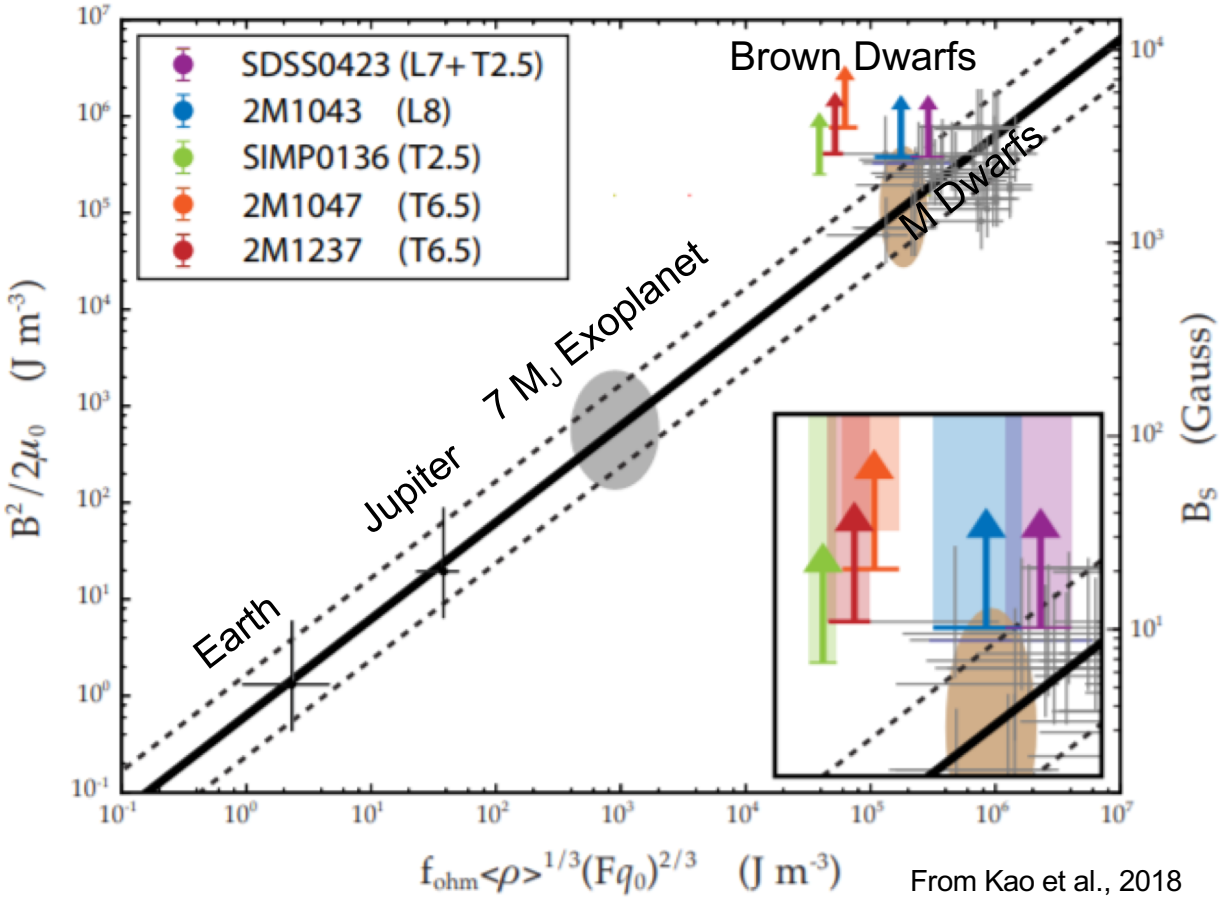

Adapted from Zarka, 2015

# Exoplanetary Radio Emission

Cyclotron Maser Instability

Peak frequency scales with planetary magnetic field

Flux *may* scale with physical conditions




From Kao et al., 2018

# Stellar Radio Emission

Gyromagnetic

Thermal Bremsstrahlung

Radio Flares

Youngers stars may be more active

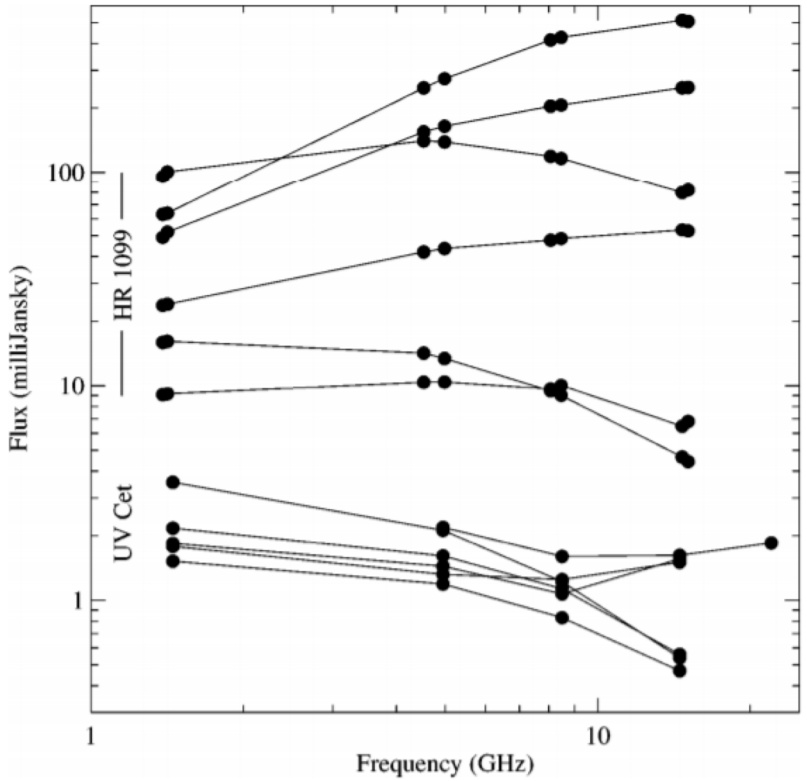



**Figure 3** Radio spectra of the RS CVn binary HR 1099 (*upper set*) and the dMe dwarf UV Cet (*lower set*) at different flux levels. The gently bent spectra are indicative of gyrosynchrotron emission, and the high-frequency part of the U-shaped spectra for UV Cet has been interpreted as a gyroresonance component (HR 1099 spectra: courtesy of S.M. White).

From Guedel, 2002

# Stellar Radio Emission

Gyromagnetic

Thermal Bremsstrahlung

Radio Flares

Youngers stars may be more active

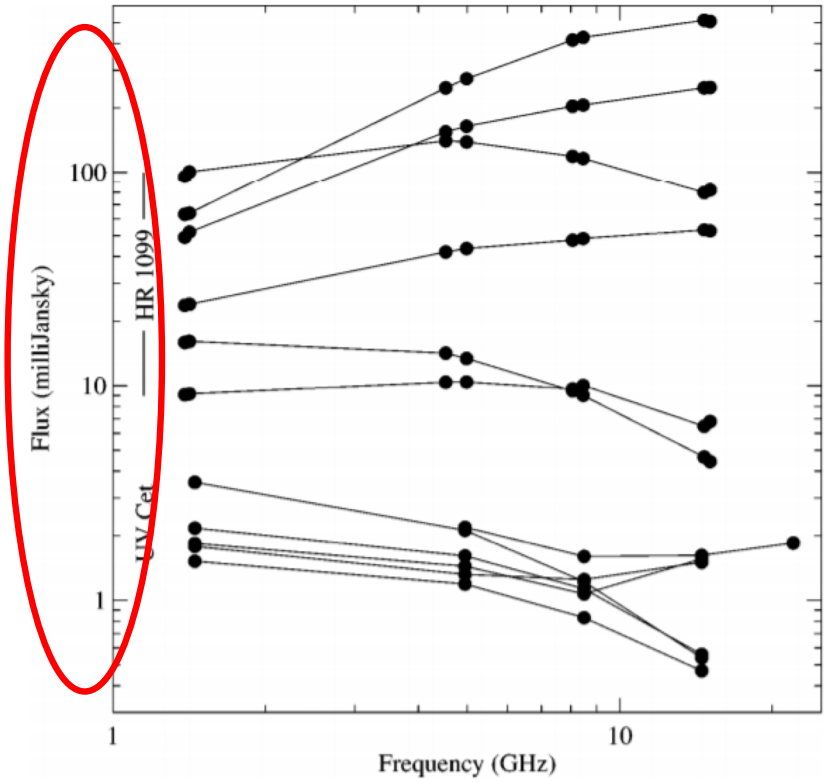


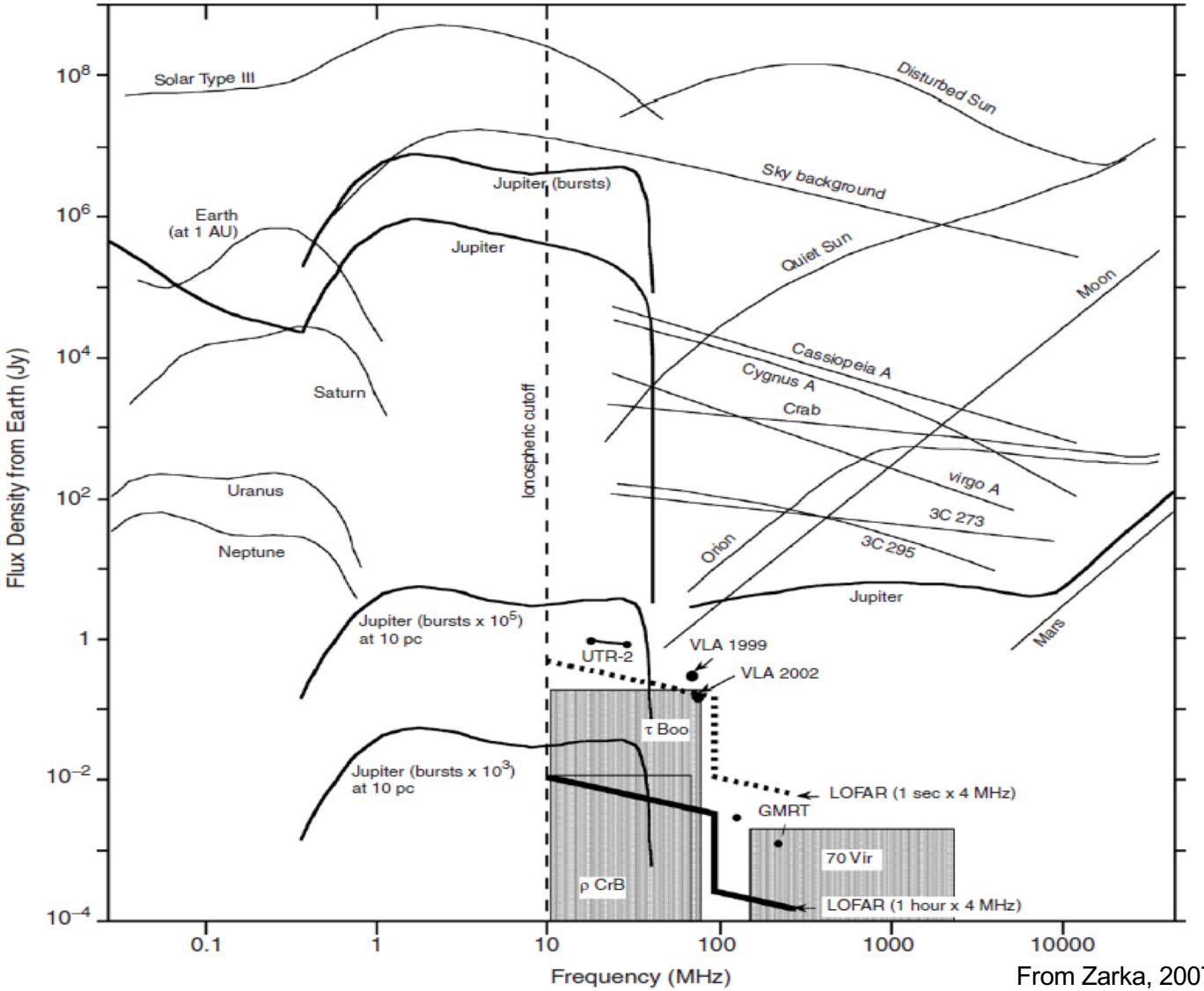

**Figure 3** Radio spectra of the RS CVn binary HR 1099 (*upper set*) and the dMe dwarf UV Cet (*lower set*) at different flux levels. The gently bent spectra are indicative of gyrosynchrotron emission, and the high-frequency part of the U-shaped spectra for UV Cet has been interpreted as a gyroresonance component (HR 1099 spectra: courtesy of S.M. White).

From Guedel, 2002

# Radio Spectra

Planetary emission comparable to stellar

Note bursts/flares compared to quiescent emission

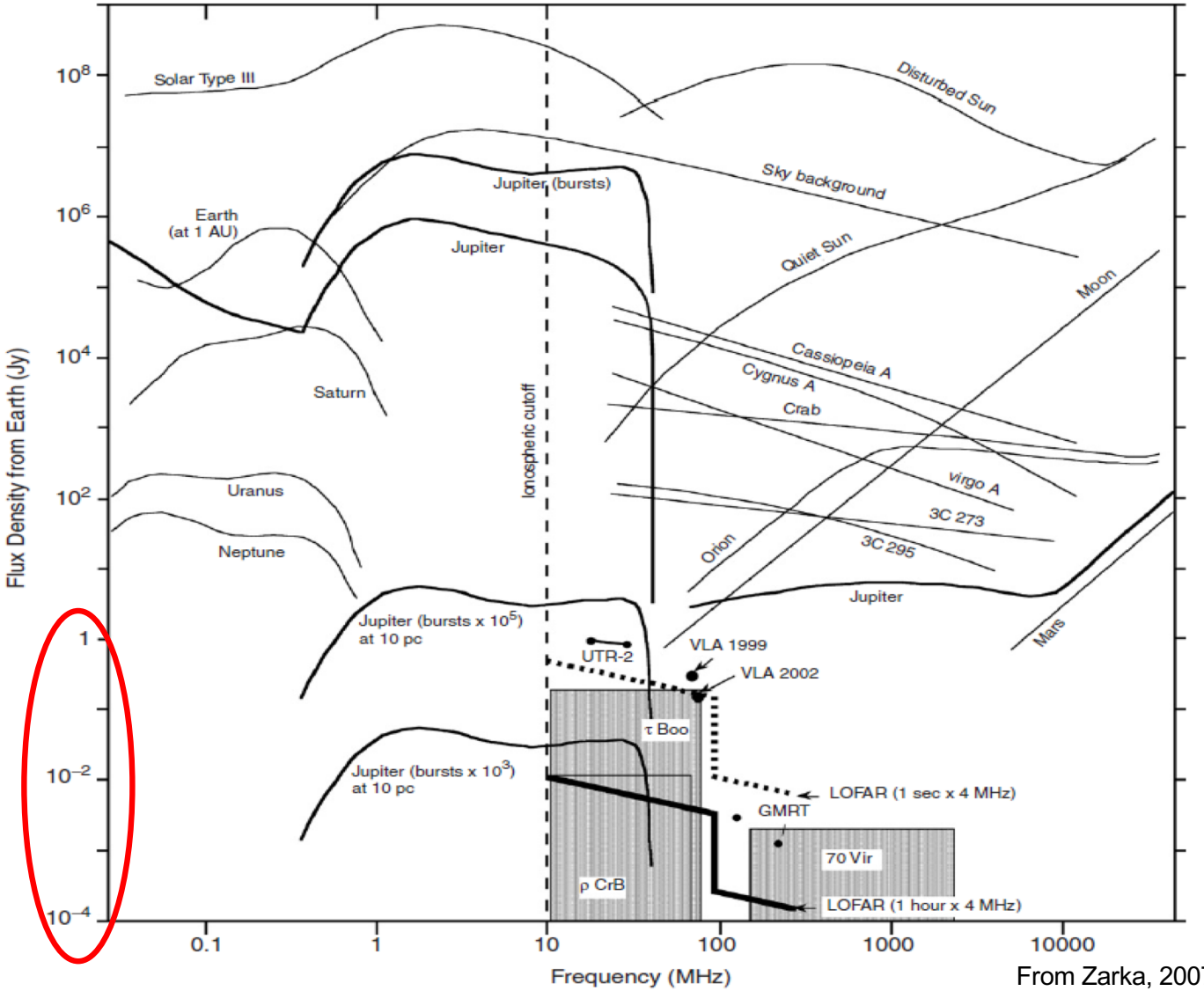



From Zarka, 2007

# Radio Spectra

Planetary emission comparable to stellar

Note bursts/flares compared to quiescent emission




From Zarka, 2007

# What are we looking for?

Low frequency (< 10 GHz) radio emissions

# What are we looking for?

Low frequency (< 10 GHz) radio emissions

Exoplanetary origin?

- Magnetic fields
- Independent detection method

# What are we looking for?

Low frequency (< 10 GHz) radio emissions

Exoplanetary origin?

- Magnetic fields
- Independent detection method

Stellar origin?

- Interplanetary radiation environment
- Stellar activity

Hard to disentangle

# What are we looking for?
# And why?

Low frequency (< 10 GHz) radio emissions

Exoplanetary origin?

- Magnetic fields
- Independent detection method

Stellar origin?

- Interplanetary radiation environment
- Stellar activity

Hard to disentangle

# What are we looking for?
## And why?

Low frequency (< 10 GHz) radio emissions

Exoplanetary origin?

- Magnetic fields
- Independent detection method

Stellar origin?

- Interplanetary radiation environment
- Stellar activity

Hard to disentangle

Habitability!

# A Multifrequency Approach

Range of peak emission frequencies and spectra

Employ 3 radio sky surveys to search for emission

Look at various (4) populations of interest

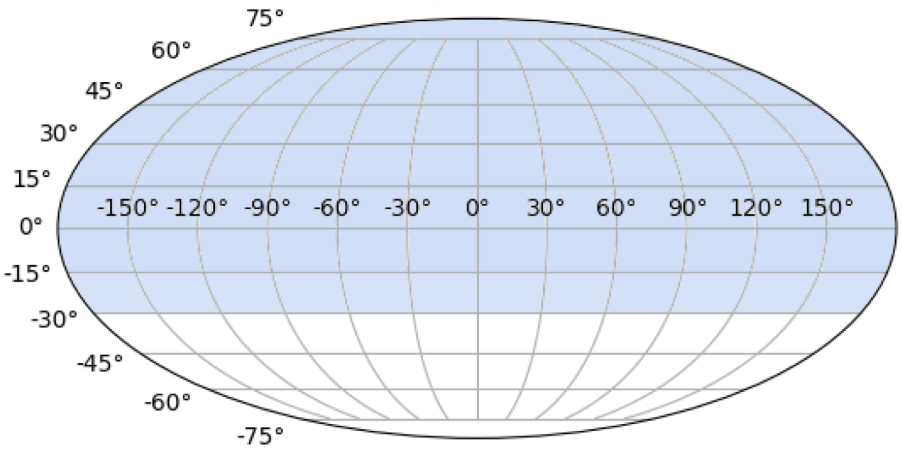
# A Multifrequency Approach

Range of peak emission frequencies and spectra

**Employ 3 radio sky surveys to search for emission**

Look at various (4) populations of interest

VLSSr




74 MHz
100 mJy/beam rms noise
75” resolution
90,000 radio sources detected
2001-2007

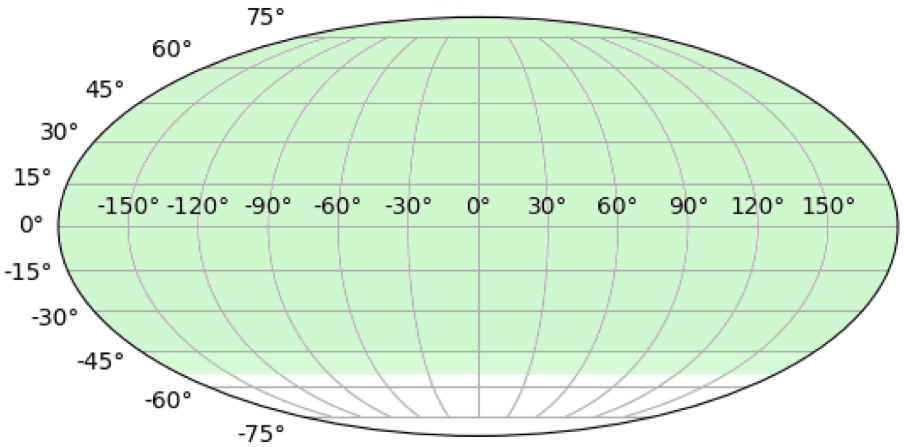
# A Multifrequency Approach

Range of peak emission frequencies and spectra

**Employ 3 radio sky surveys to search for emission**

Look at various (4) populations of interest

TGSS




150 MHz
3.5 mJy/beam rms noise
25” resolution
630,000 radio sources detected
2010-2012

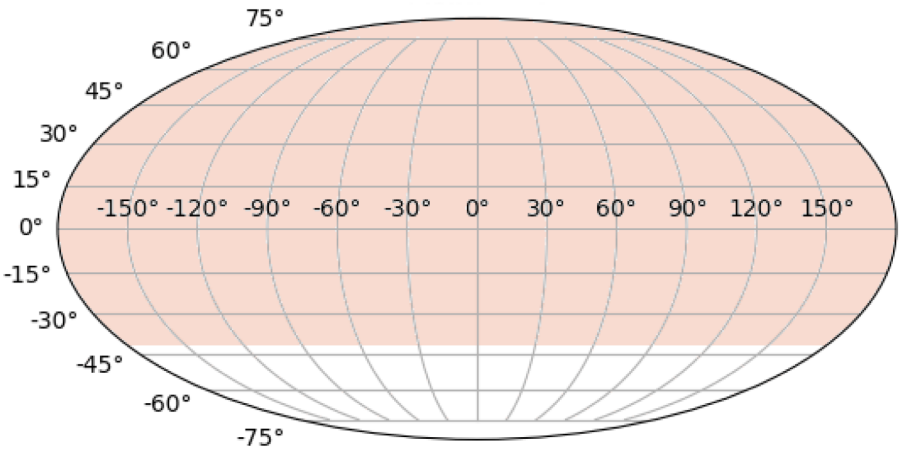
# A Multifrequency Approach

Range of peak emission frequencies and spectra

**Employ 3 radio sky surveys to search for emission**

Look at various (4) populations of interest

NVSS




1.4 GHz
0.45 mJy/beam rms noise
45” resolution
1,800,000 radio sources detected
1993-1996

# A Multifrequency Approach

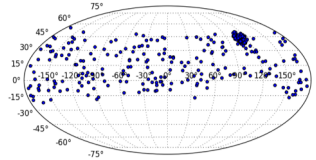
Range of peak emission frequencies and spectra

Employ 3 radio sky surveys to search for emission

**Look at various (4) populations of interest**

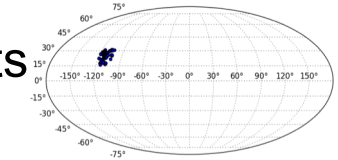
## Exoplanets

300 objects (<300 pc)
Dec limits



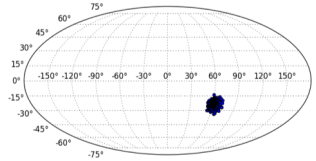
## Taurus Young Stellar Objects

346 objects



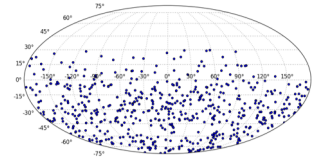
## Upper Scorpius YSOs

863 objects



## Nearby Stars (RECONS)

652 objects
90% complete within 10 pc



# What Can We Hope to Find?

- Flaring events
  - Transient bursts of higher emission
  - Greatest chance for direct detection?

- Quiescent emission
  - Observed during inactive times
  - Statistically different from other samples on the sky?

# Point-by-Point Matching

Direct detection method

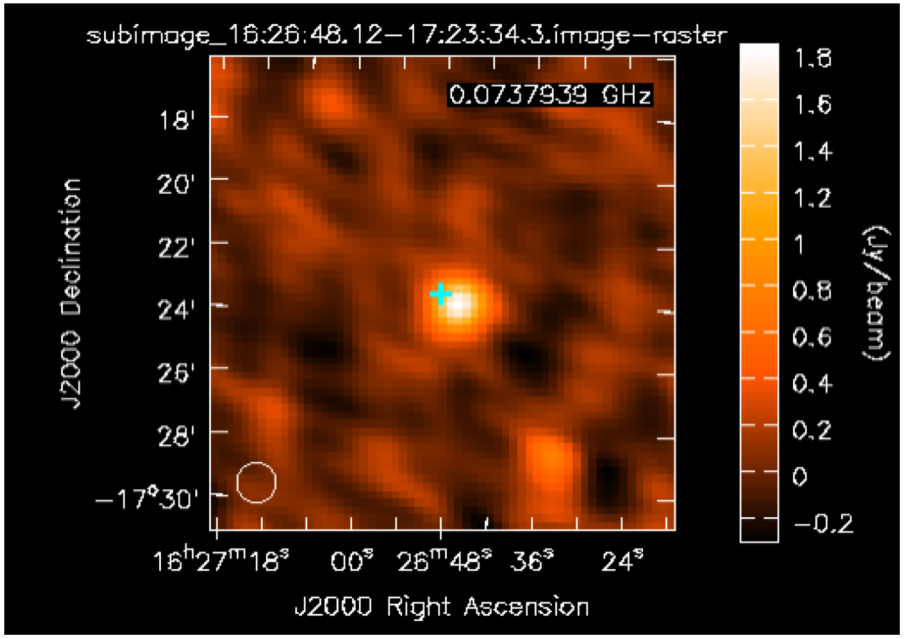
Check whether objects of interest are within a synthesized beam from a detected radio source

14 Tentative detections:

- 1 at 74 MHz
- 3 at 150 MHz
- 10 at 1.4 GHz

Follow up observations needed

GJ 3954



# Ensemble Detections

Cut out subimages centered on the objects of interest

Low resolution -> point sources -> pixel arithmetic/comparisons

2 methods:

- Image stacking
- Non parametric statistical tests

# Ensemble Detections - Stacking Analysis

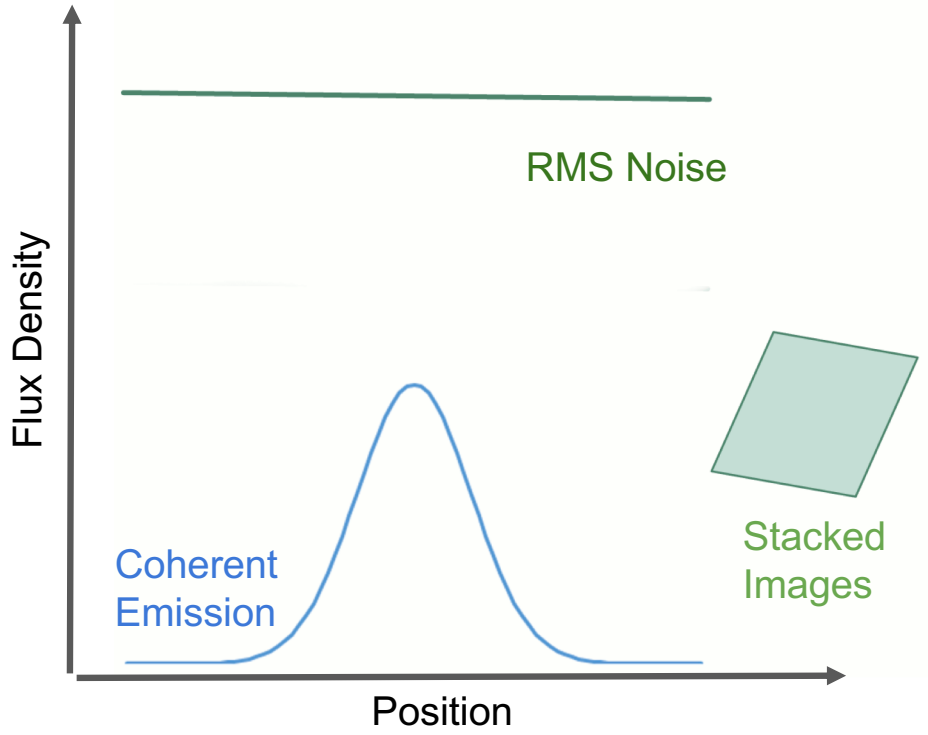
Add together images centered on the objects of interest to reduce rms noise and increase coherent signals.

Weighted stacking of each image:

$$IM_N = \frac{\Sigma\, w_i * IM_i}{\Sigma\, w_i}$$

Where:

$w_i = 1/(rms_i)^2$

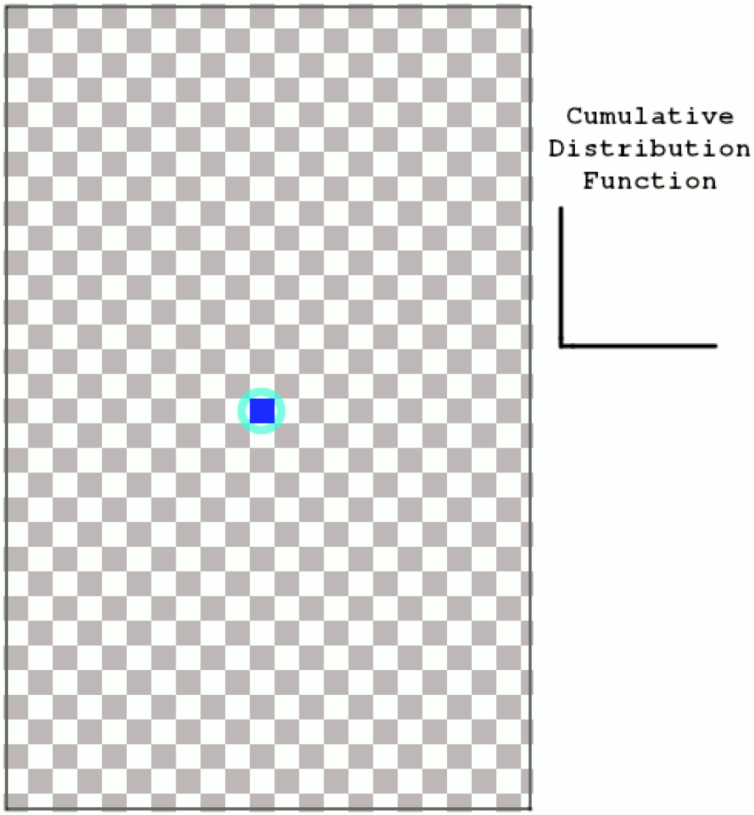


# Ensemble Detections - 2-Sample Statistical Tests

Compare the distributions of center pixel values to all other values

Anderson-Darling Test - are the samples drawn from different distributions?

Take median test significance of all pixel comparisons



# Ensemble Detections - Simulating Emission

At what flux level would these methods make a significant detection?

Simulate sources - impose a peak flux, convolve with synthesized beam, add to subimage

Repeat analysis techniques until the desired significance is met

Establish upper limits on emission

# Ensemble Detections - Simulating Emission

- 1 mJy to 100 mJy
- 74 MHz
- Exoplanet sample

| | **Stacking Analysis** | | **2-sample Statistical Test** |
|---|---|---|---|
| Injected Peak Flux | Resulting rms noise | Signal-to-Noise Ratio | Confidence Interval |
| 1 mJy | 7.03 mJy/beam | 0.46$\sigma$ | ~90% |
| 5 mJy | | 0.54$\sigma$ | 90% < x < 95% |
| 10 mJy | | 0.64$\sigma$ | |
| 50 mJy | 7.04 mJy/beam | 1.39$\sigma$ | 95% < x < 98% |
| 100 mJy | | 2.18$\sigma$ | > 99% |

# Future Directions

Follow up observations for the potential direct detections

Additional instruments and sky surveys including VLASS at 2-4 GHz

Targeted surveys

# Summary

Searching for radio emissions to tell us about exoplanets and exosolar systems

A few tentative direct detections

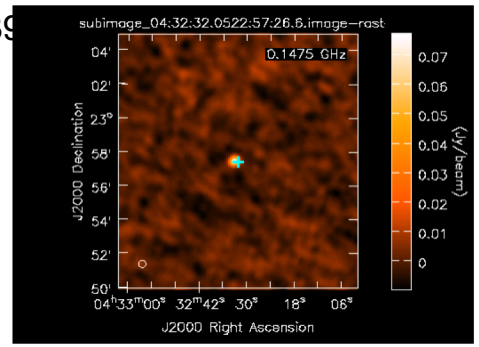
Combining images constrains quiescent/average emission

Still a few orders of magnitude to go, probably

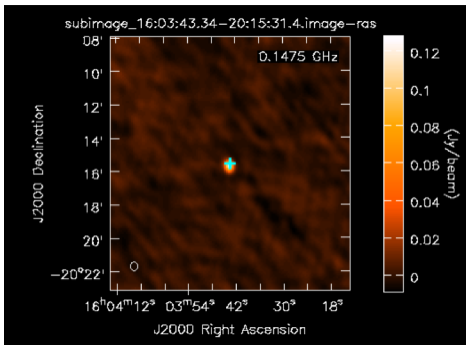
Thank you for your time!

# Point-by-Point Matching Results

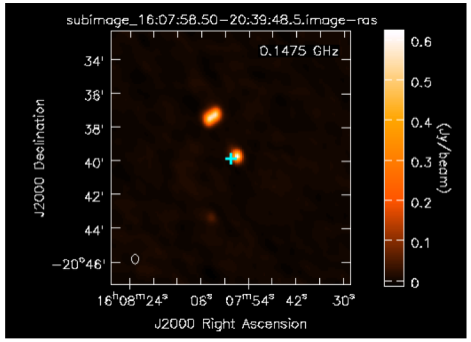
IRAS 04295+2251 (TGSS)



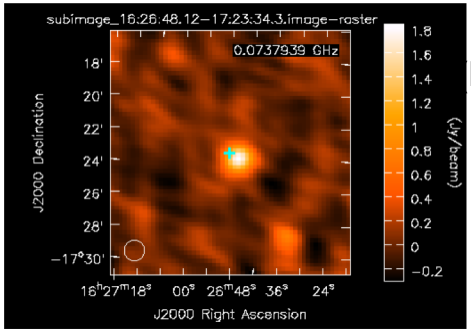

2MASS J16034334-2015314 (TGSS)

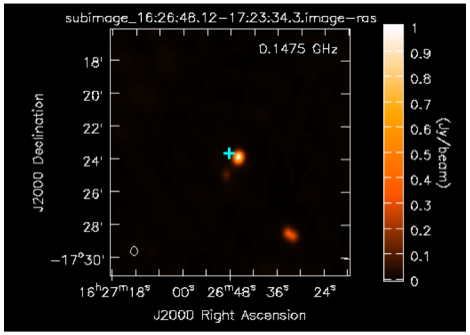



2MASS J16075850-

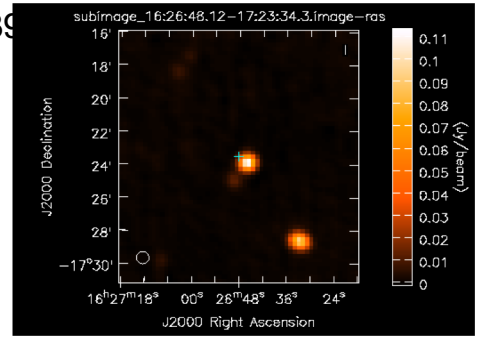



NVSS)



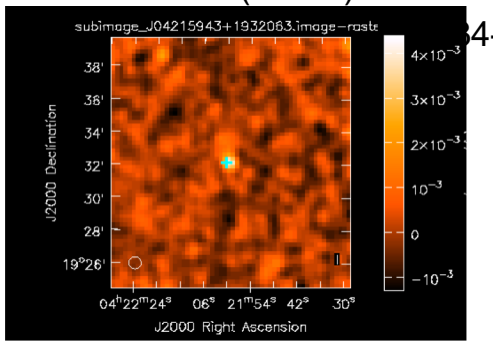




GJ 3

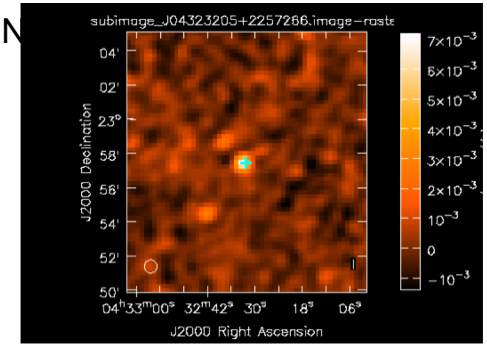


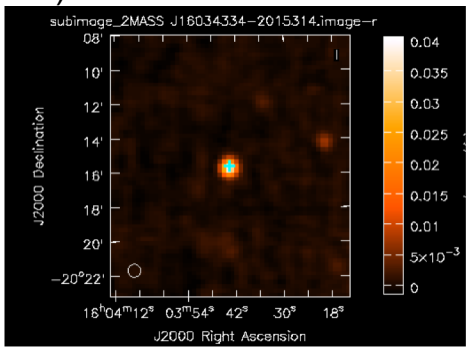
# Point-by-Point Matching Results

V* T Tau (NVSS)

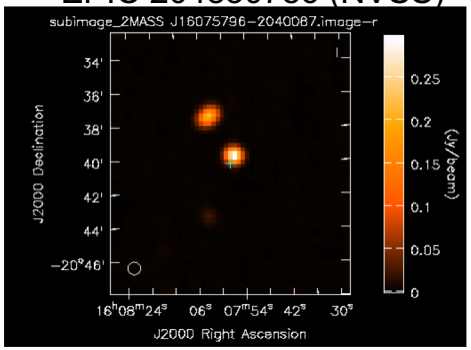



IRAS 04295+2251 (NVSS)

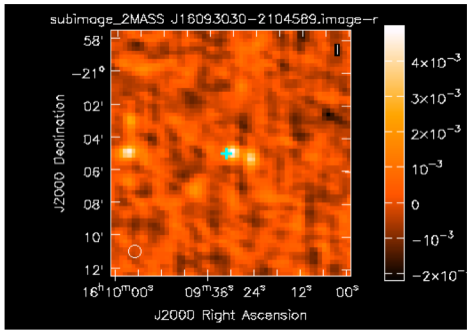


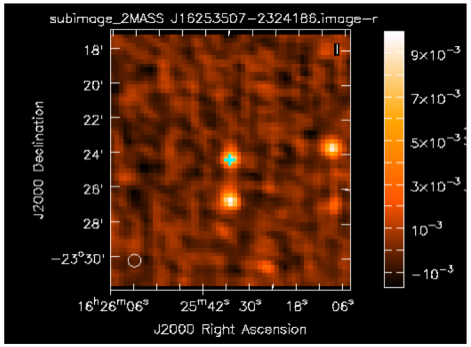




EPIC 204830786 (NVSS)



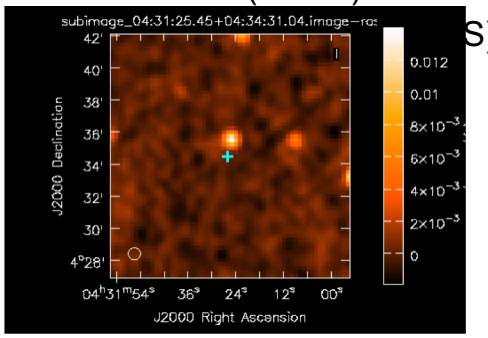

1RXS J160929.1-210524 (NVSS)



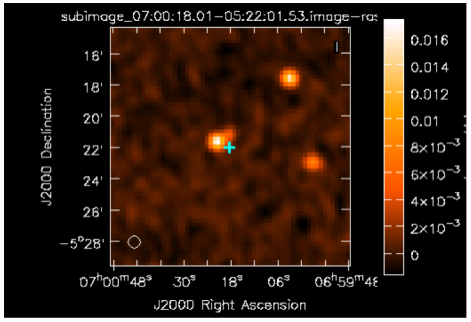
# Point-by-Point Matching Results

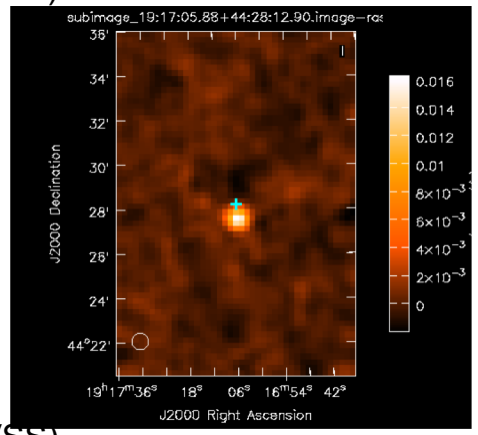
HD 28678 (NVSS)

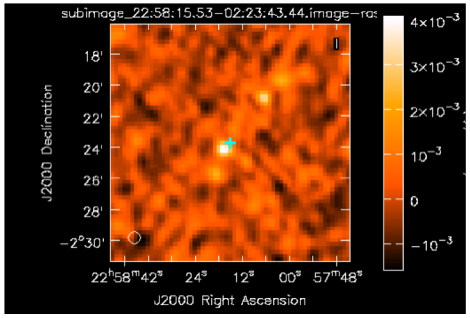



S)

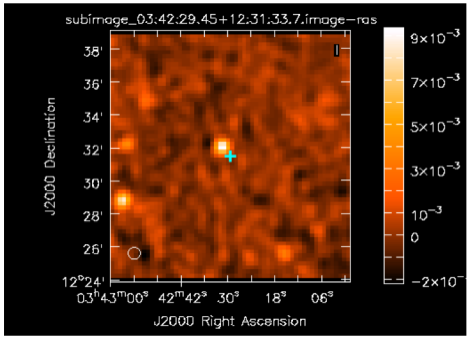
HD 52265 (NVSS)



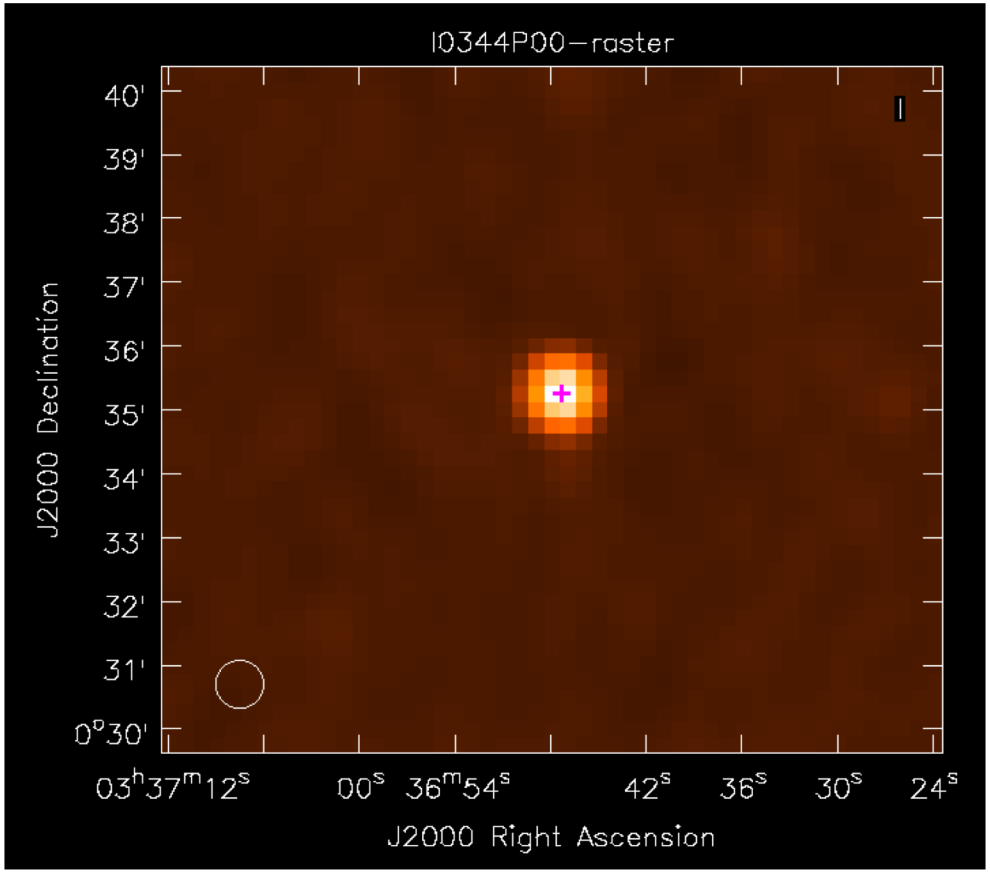




1057 (NVSS)



# HR 1099


I0344P00−raster
40'
39'
38'
37'
36'
35'
34'
33'
32'
31'
0°30'
J2000 Declination
03h37m12s
00s
36m54s
42s
36s
30s
24s
J2000 Right Ascension