LOOKING FOR BROWN DWARFS WITH LOFAR

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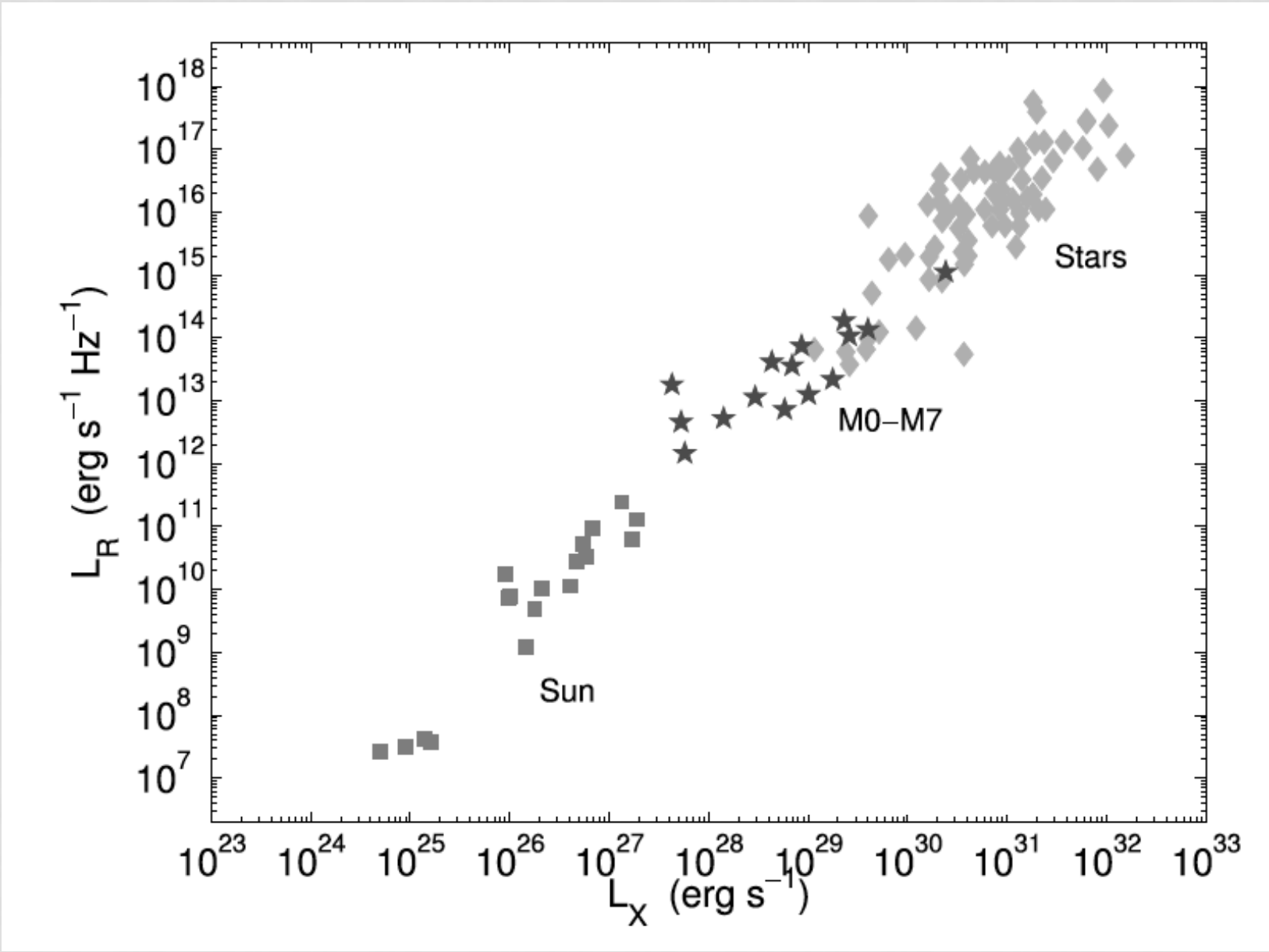
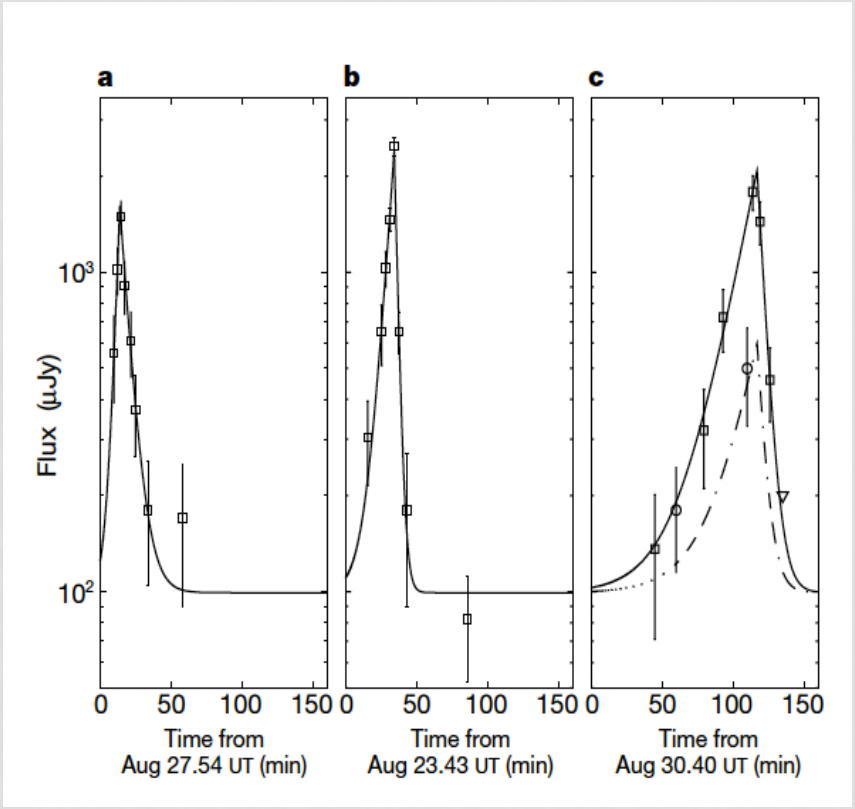


Berger, et. al. 2004

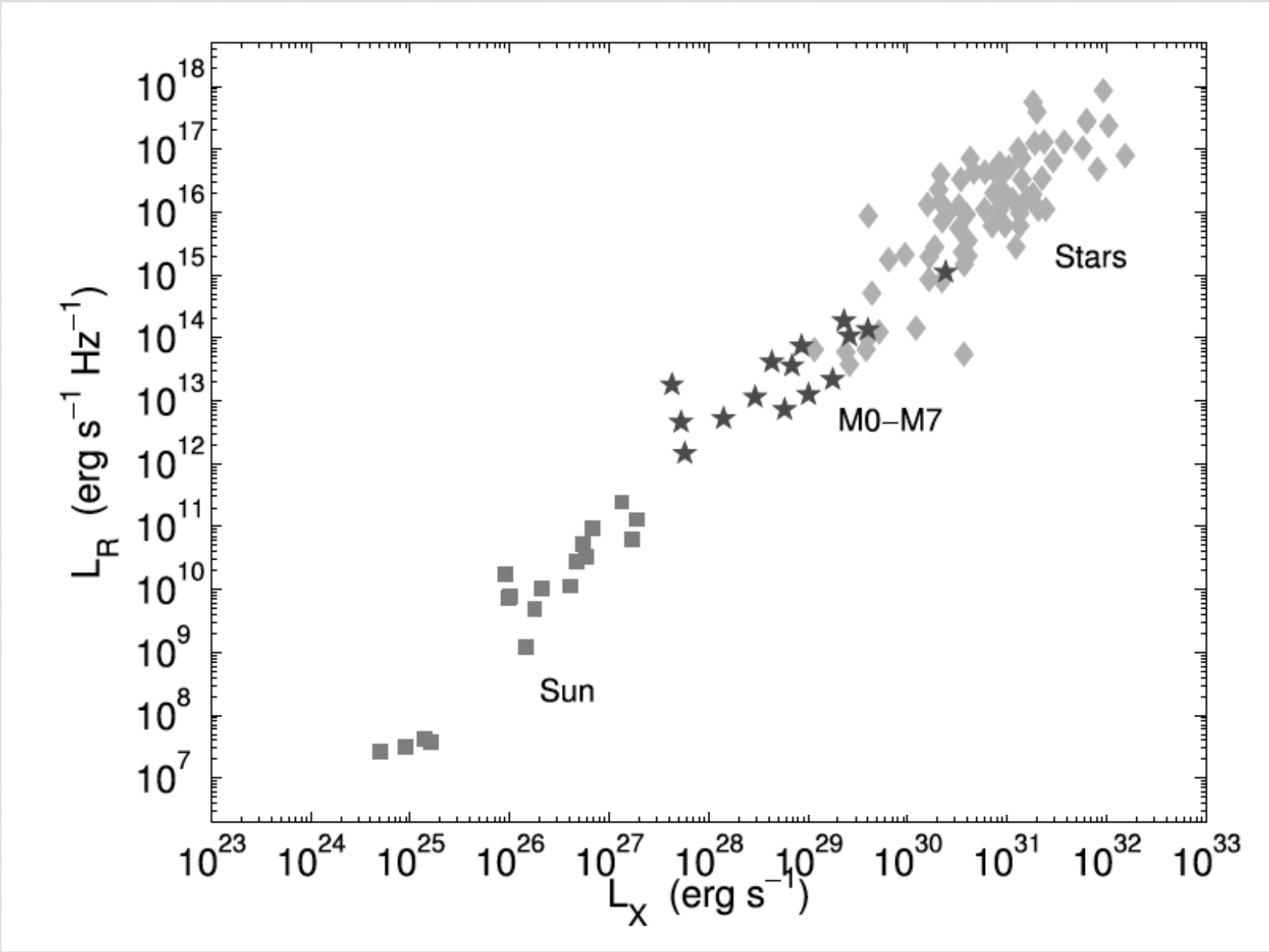
FIRST DETECTION



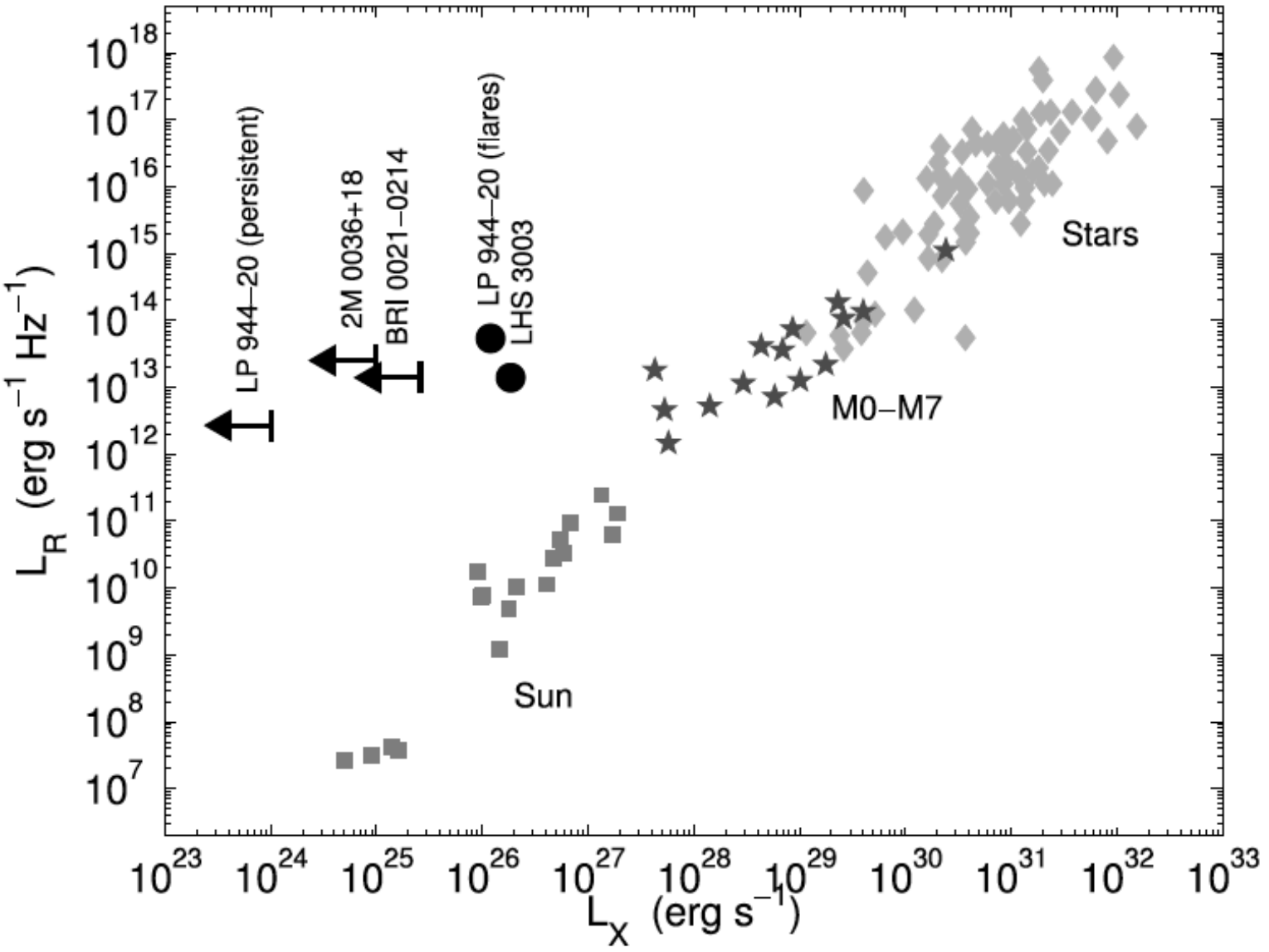
letters to nature

Discovery of radio emission from the brown dwarf LP944–20

E. Berger*, S. Ball†, K. M. Becker‡, M. Clarke§, D. A. Frail‖, T. A. Fukuda¶, I. M. Hoffman#, R. Mellon☆, E. Momjian**, N. W. Murphy††, S. H. Teng‡‡, T. Woodruff§§, B. A. Zauderer‖‖ & R. T. Zavala¶¶



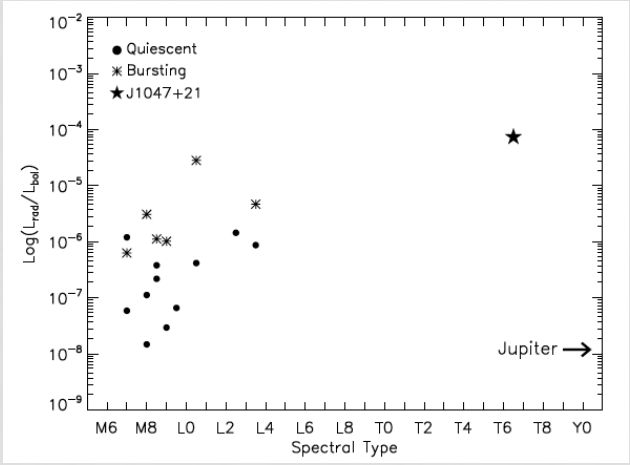
Berger, et. al. 2004



Berger, et. al. 2004

SUMMARY OF RADIO OBSERVATIONS

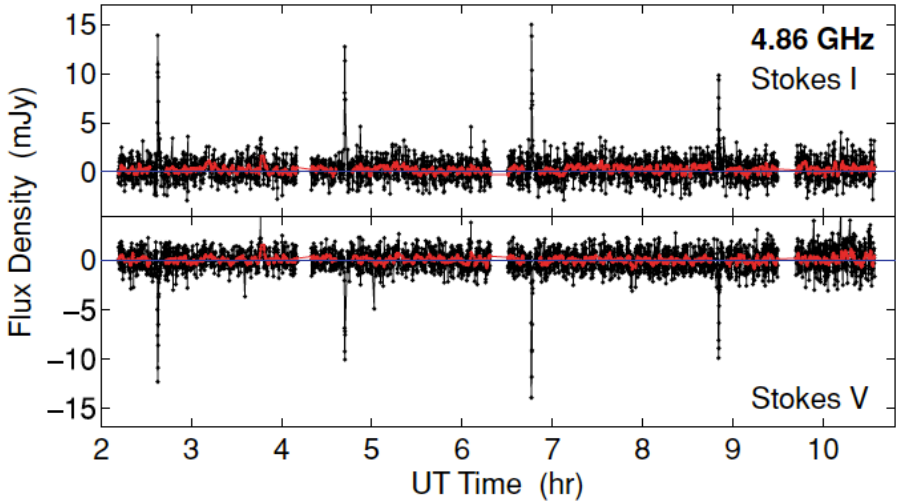
- Most observations done in GHz
- Only a dozen detected out of ~100 observed
- Detections show possible correlation with *vsin i*
  - Fast Rotation (~2-4 hrs)
  - Preferred inclinations (60-90°)
- Coolest (~900K) T6.5 Brown Dwarf



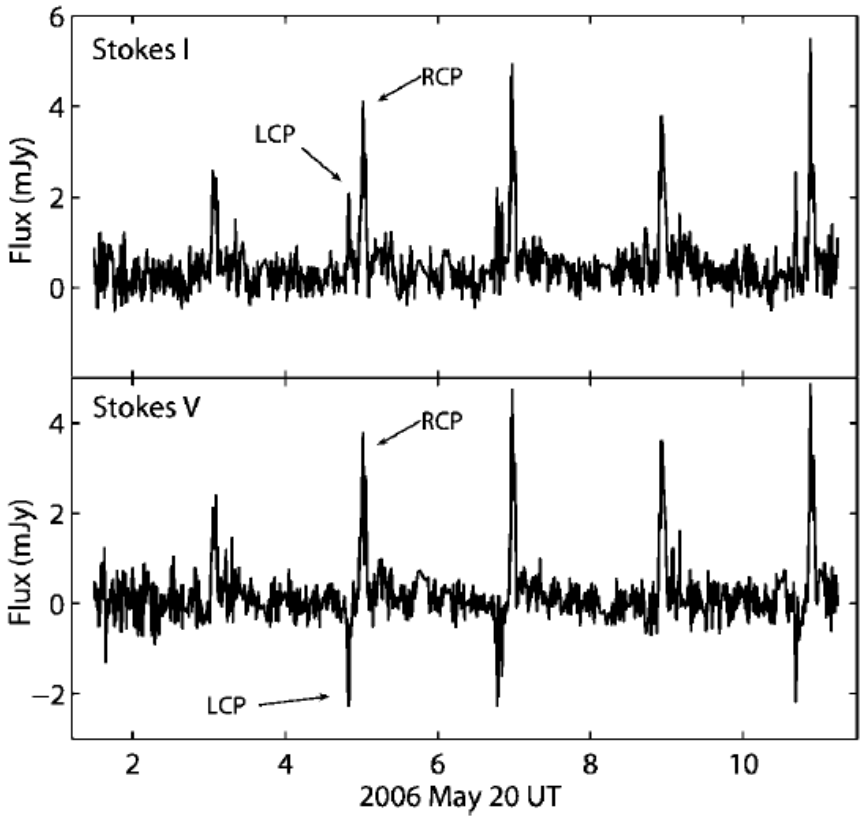
Route, et. al 2012

FLARES OR PULSES?

Berger, et. al. 2009



- 100 % circularly polarized
- ~10 min long
- 5-30 % duty cycle

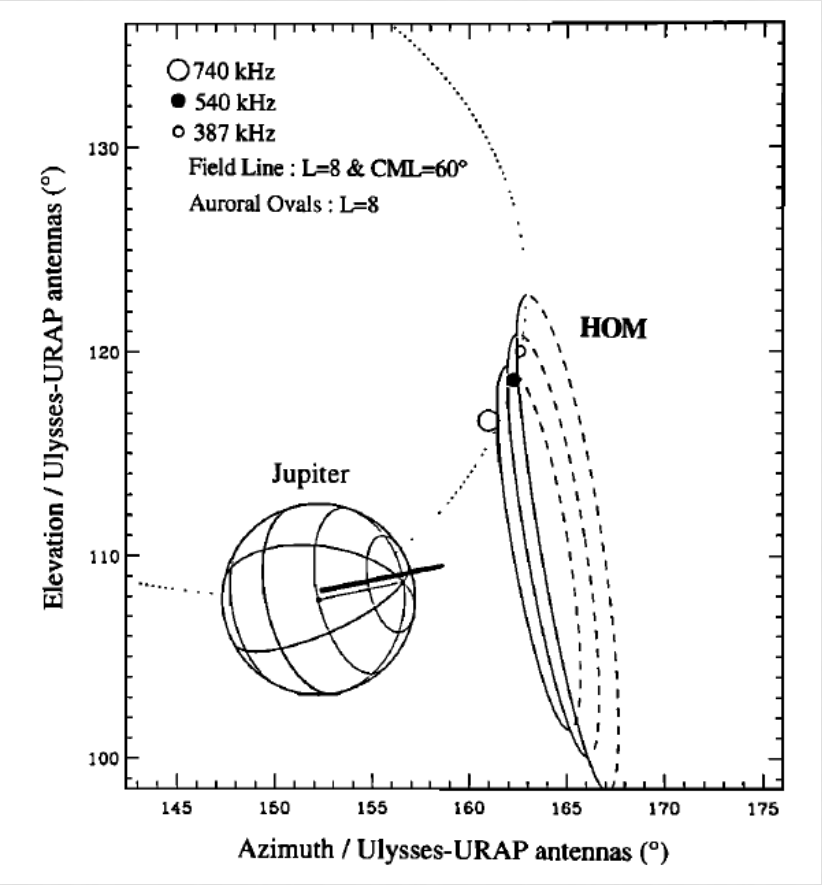


Hallinan, et. al. 2007

THE THEORY

Electron Cyclotron Maser Instability (ECMI)

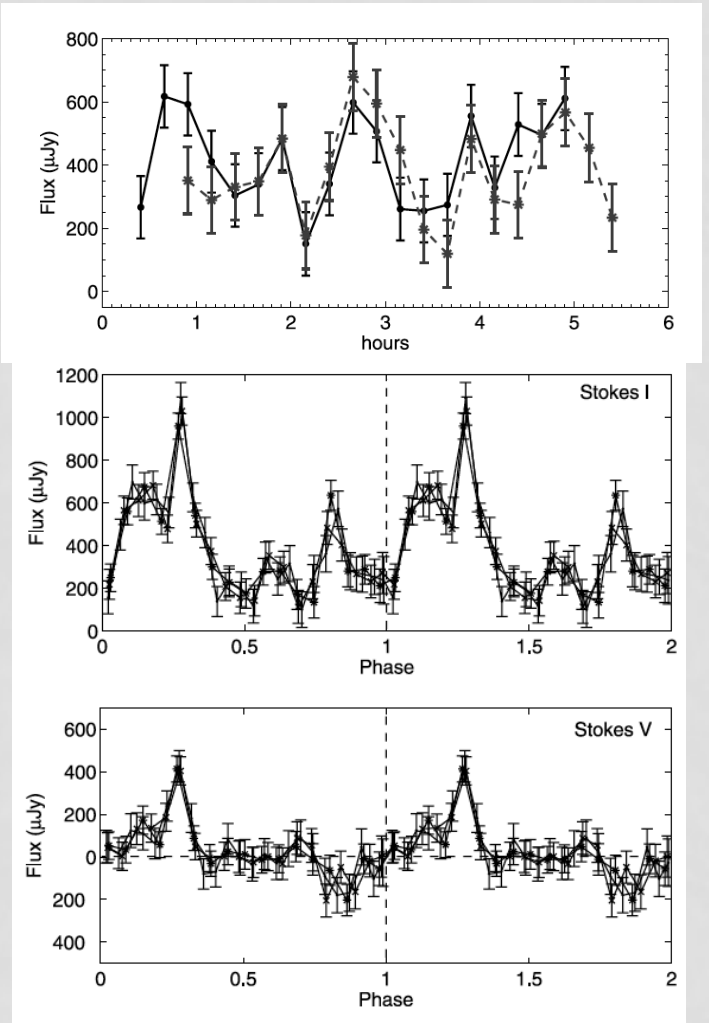
- Coherent Maser
- Resonate at Cyclotron frequency
  - ν_C ~ 2.8 * **B** [MHz]
  - kG Bs for detected UCDs
- Use to explain mainly the 100% circularly polarized pulses
- Originally seen for Solar Planets
- Also proposed for quiescence



Zarka, et. al. 1998

QUIESCENCE

- Range of spectral indexes, self-abortion?
- Large scale structure of **B**
- Modulated with rotation



Hallinan, et. al. 2006

Table 1: Spectral index of brown dwarfs

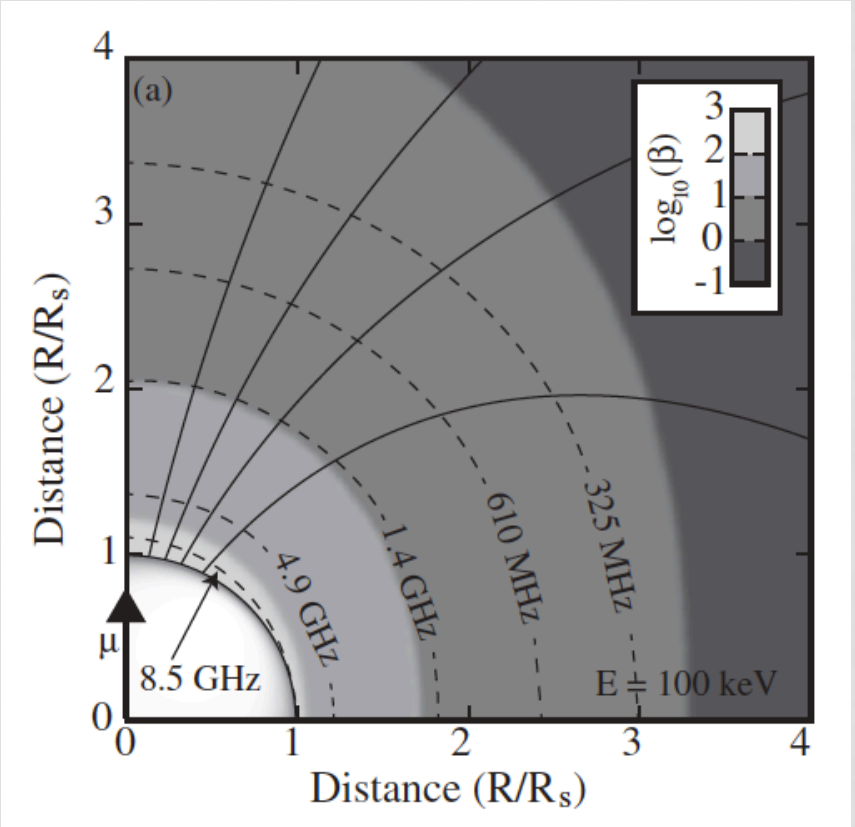
Name	Spectral Index	Frequency range	References
LP944-20	2.1(0.3)	4.9-8.5	Berger et al. (2001)
TVLM 513-46546	0.0(0.2)	4.88-8.44	Hallinan et al. (2006)
TVLM 513-46546	0.1(-0.2)	1.4-4.8	Osten et al. (2006)
	-0.4(-0.1)	4.8-8.4	
LHS2397aAB	-0.4(0.2)	5-7.1	Williams et al. (2013)
2MASSW J07464+2000	-0.7(0.3)	4.86-8.46	Berger et al. (2009)
2MASSW J0036+18	-1.2(0.3)	4.9-8.5	Berger et al. (2005)
2MASS J104753+21242	0.9(1.0)	5-6.7	Williams et al. (2013)

WHAT IS THE EMISSION LIKE AT LOFAR FREQUENCIES?

WHAT IS THE EMISSION LIKE AT LOFAR FREQUENCIES?

- Detection at MHz:
  - 40-70 G →112-196 MHz
  - Assuming dipole **B**

$$B \approx B_s \left(\frac{R_s}{R} \right)^3$$



Jaeger et. al. (2011)

LOFAR OBSERVATIONS

OBSERVING STRATEGY

- Interferometric data
  - Localization
- 2 rotational periods
  - Complete phase
- CS + RS stations
  - Greatest sensitivity

OBSERVATIONS

- **Cycle 2:** LC2_020, LC2_016
  - 2MASS [redacted] ✓
    - 6hrs
  - 2MASS [redacted] ✓
    - 4hrs x 2
- **Cycle 4:** LC4_031
  - [redacted] ❐
    - 4hrs
  - 2M[redacted] ❐
    - 12hrs

NAIVE VIEW

Have BD location at phase center.

Press the “black box” button.

Close your eyes!

Wait

Get science out.

PREPROCESSING AND CALIBRATION

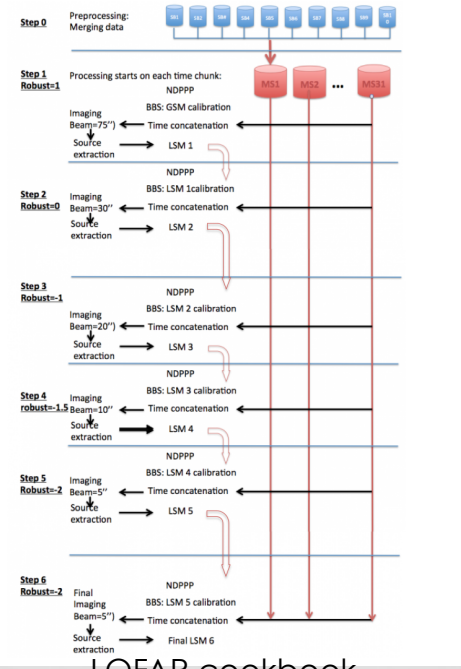
Preprocessing

- AOFlagger
- Average
  - 8 ch → 1 ch
  - 4 sec → 12 sec
- AOFlagger
- Calibrate
  (BBS - stand-alone)
- AOFlagger
- Merge subbands*
  - SB050_350
- (No Demixing)*

PREPROCESSING AND CALIBRATION

Automated Selfcal

- Steps: 120, 100, 80, 70, 60, 50, 45, 40, 35, 30, 25, 20”

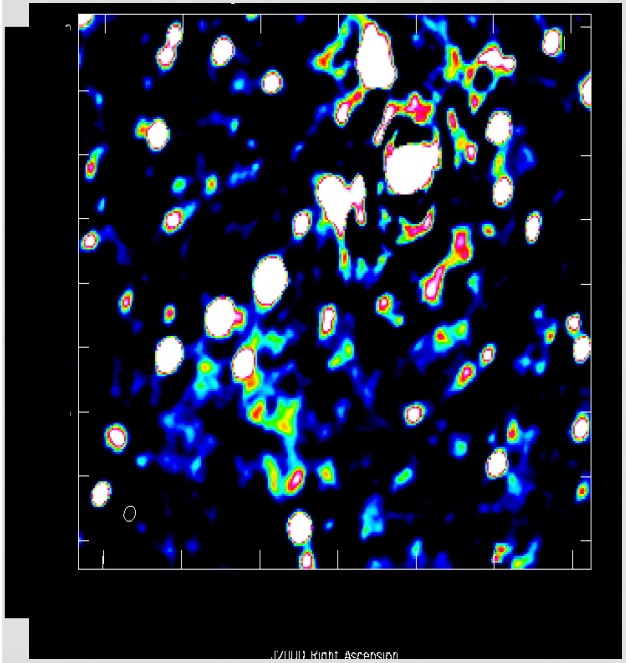


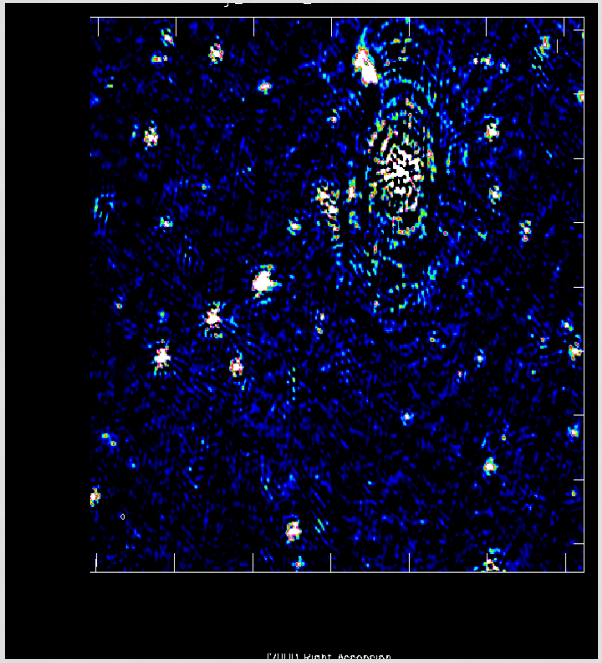
LOFAR cookbook

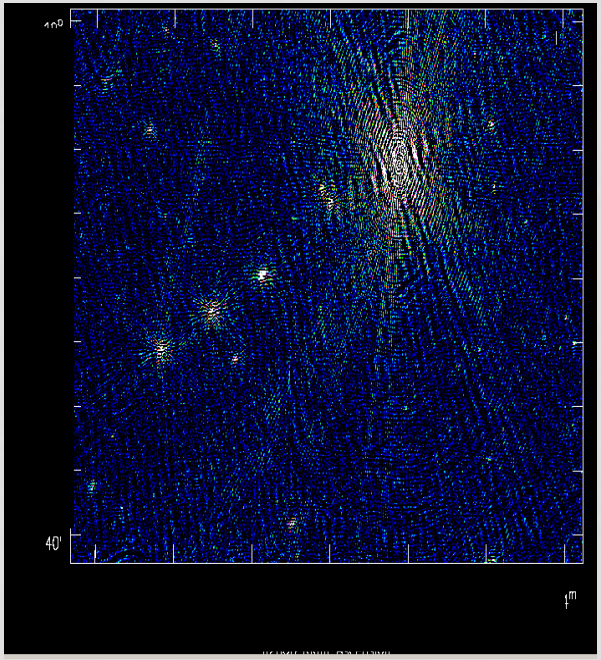
Manual Self-calibration

- CASAPY:
  - Phases -- 60 sec
  - Bandpass(B) – +30min
  - Phases – 60 sec
  - Phases – 10 sec
  - Amplitudes – 10min
- No DDC
  - No FACETS

AUTO-SELFCAL (2M [redacted])

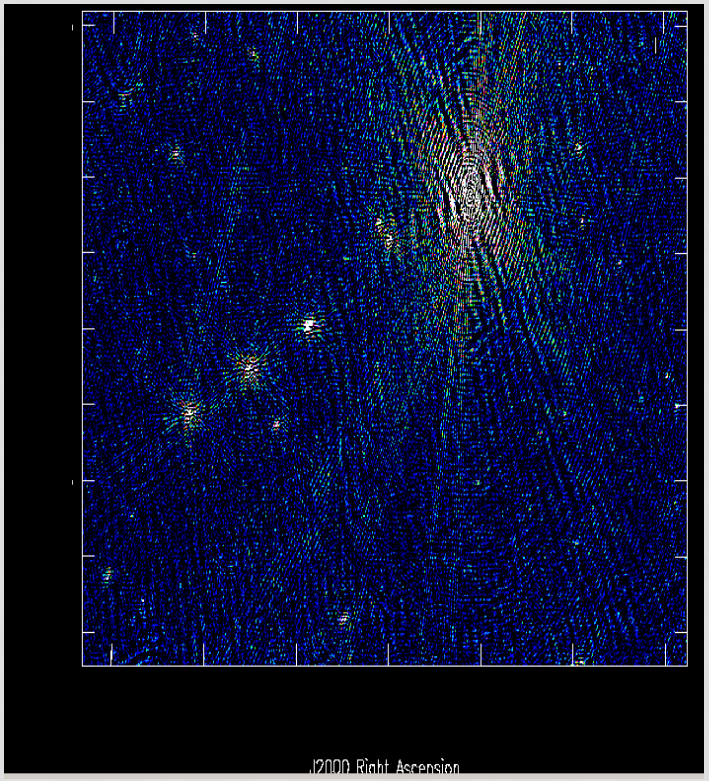




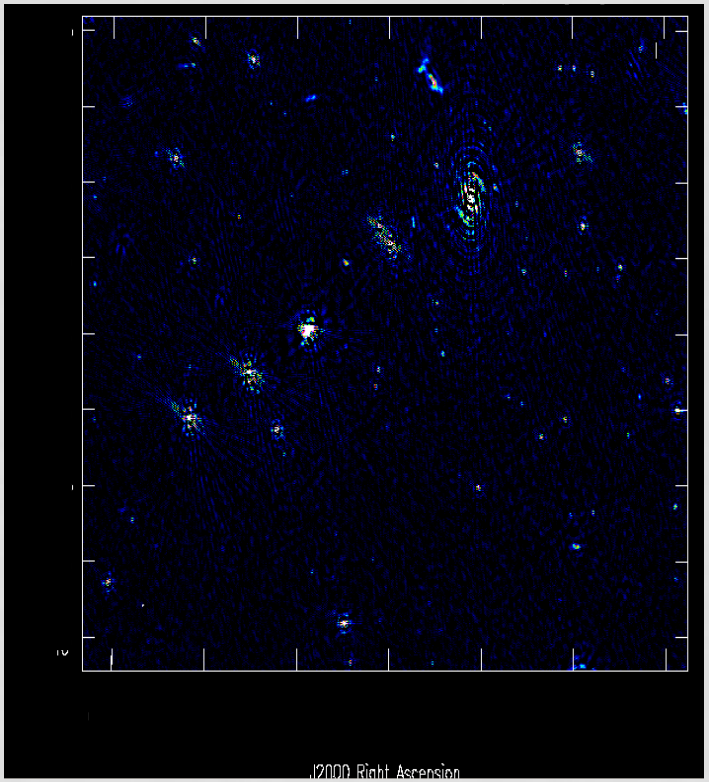


- 80'' → ~ 17mJy
- 40'' → ~ 9mJy
- 20'' → ~ 8mJy

AUTO VS MANUAL

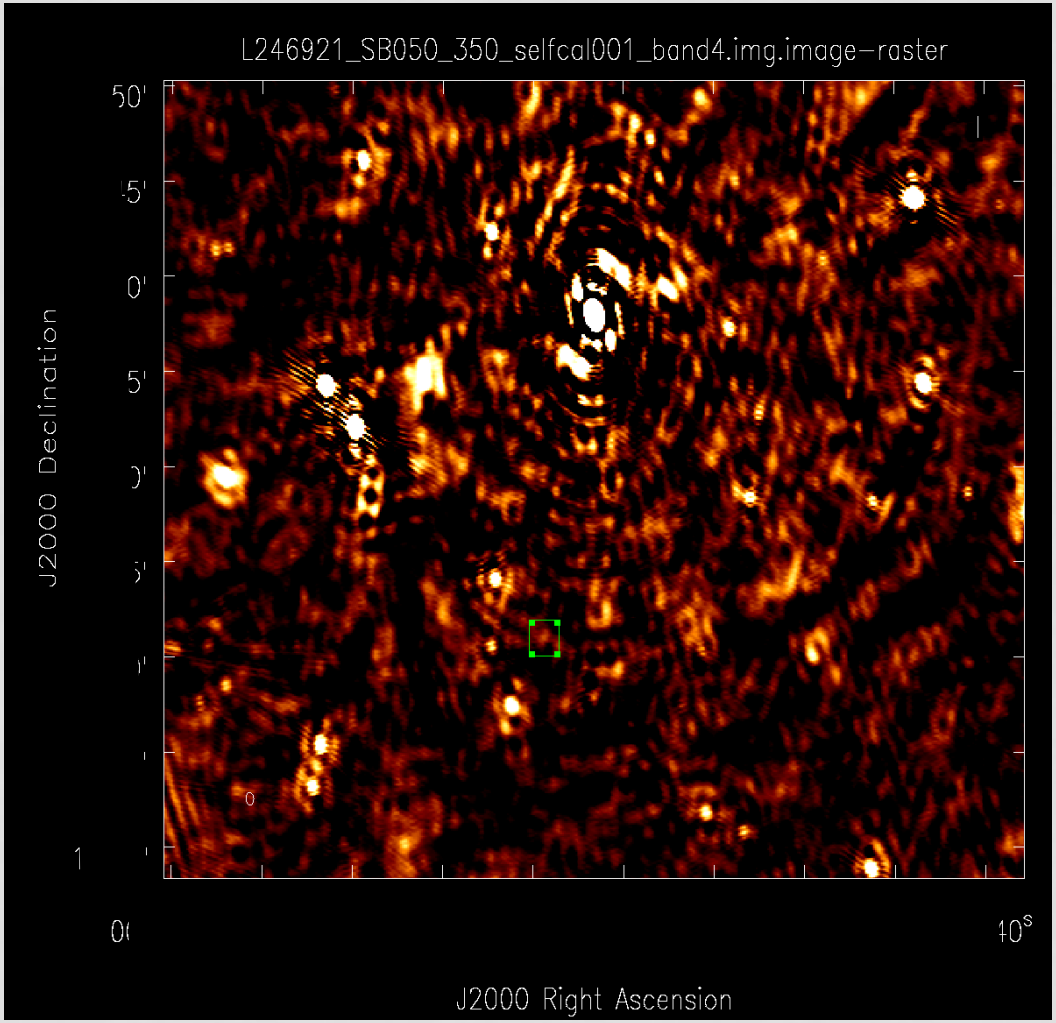


- 20'' → ~ 8mJy

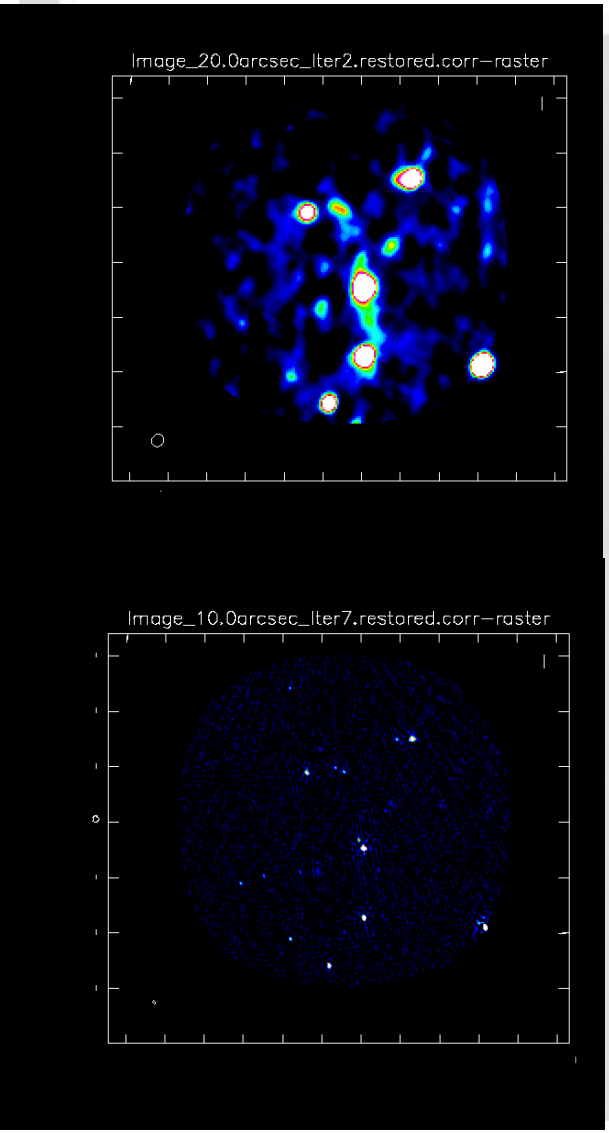


- 20'' → ~ 0.8mJy

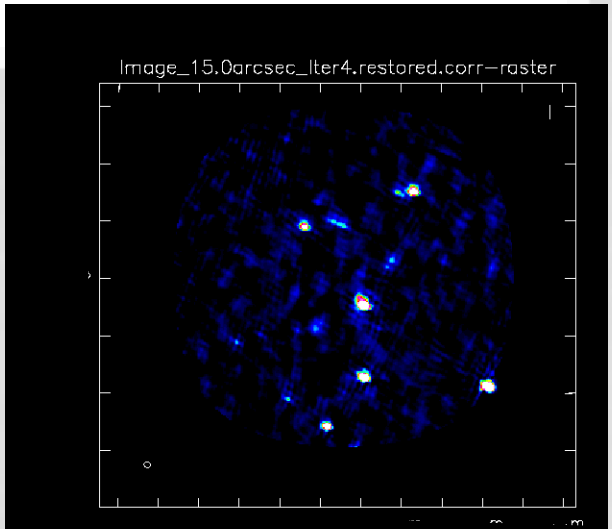
ONE ISSUE…


L246921_SB050_350_selfcal001_band4.img.image-raster
50'
5'
0'
5'
J2000 Declination
J2000 Right Ascension
10s

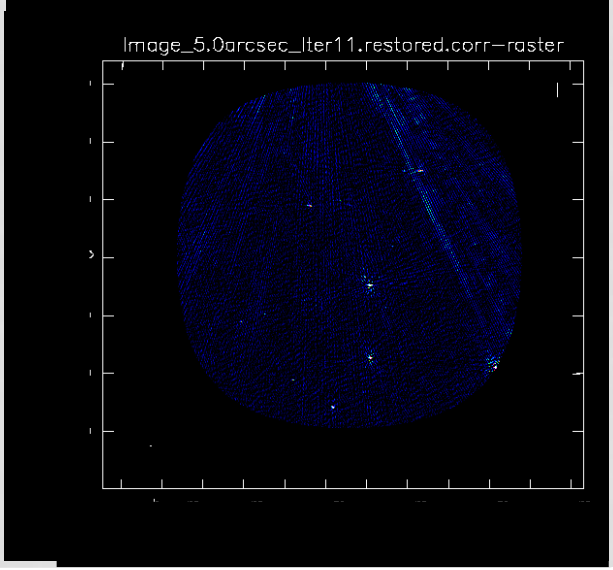
AUTO-SELFCAL (2M [redacted])



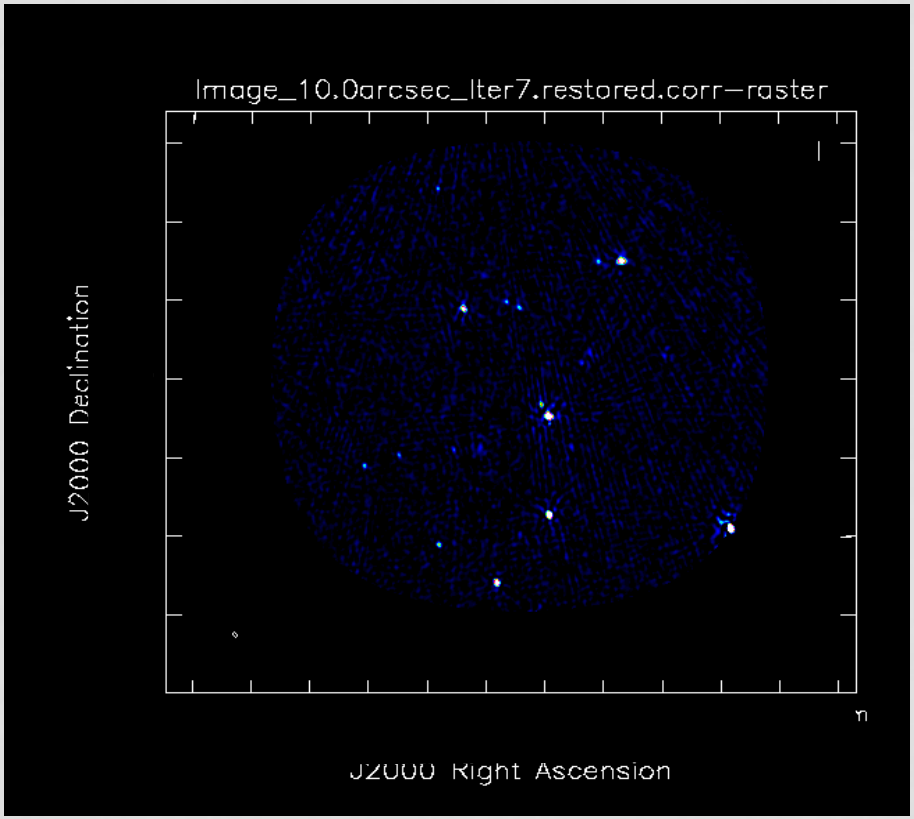
- 80” ← ~20mJ
- 60” → ~7mJ

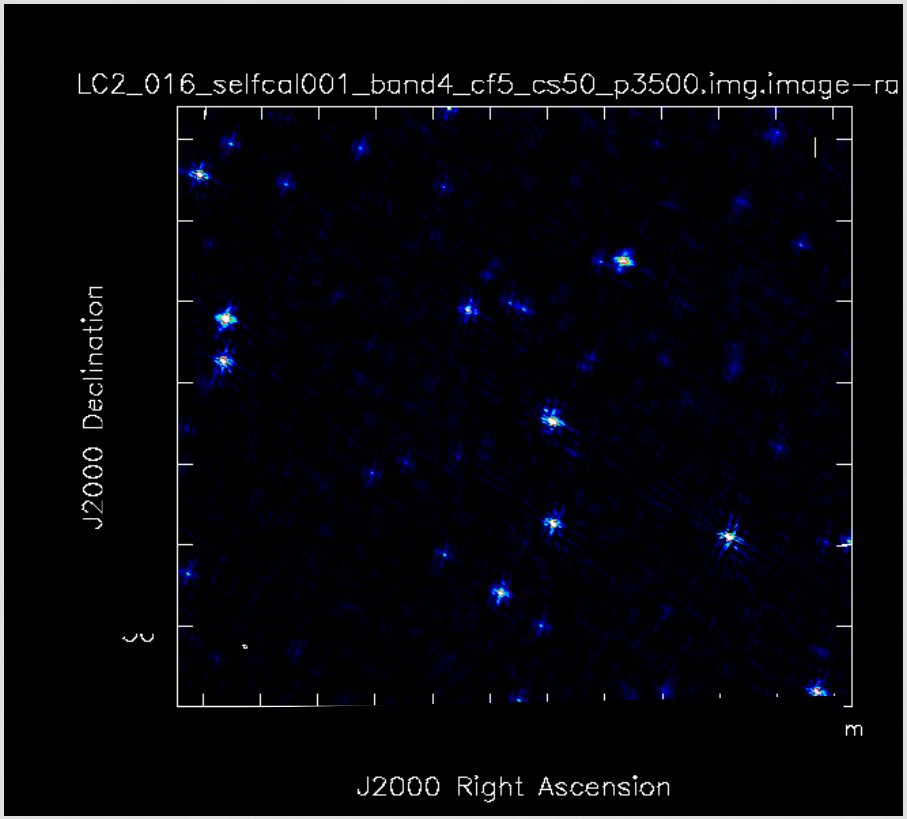


- 40” ← ~4mJy
- 20“ → ~8mJy



AUTO VS MANUAL





- 40'' ← ~4mJy
- 20'' ← ~1,2mJy

QUIESCENCE?

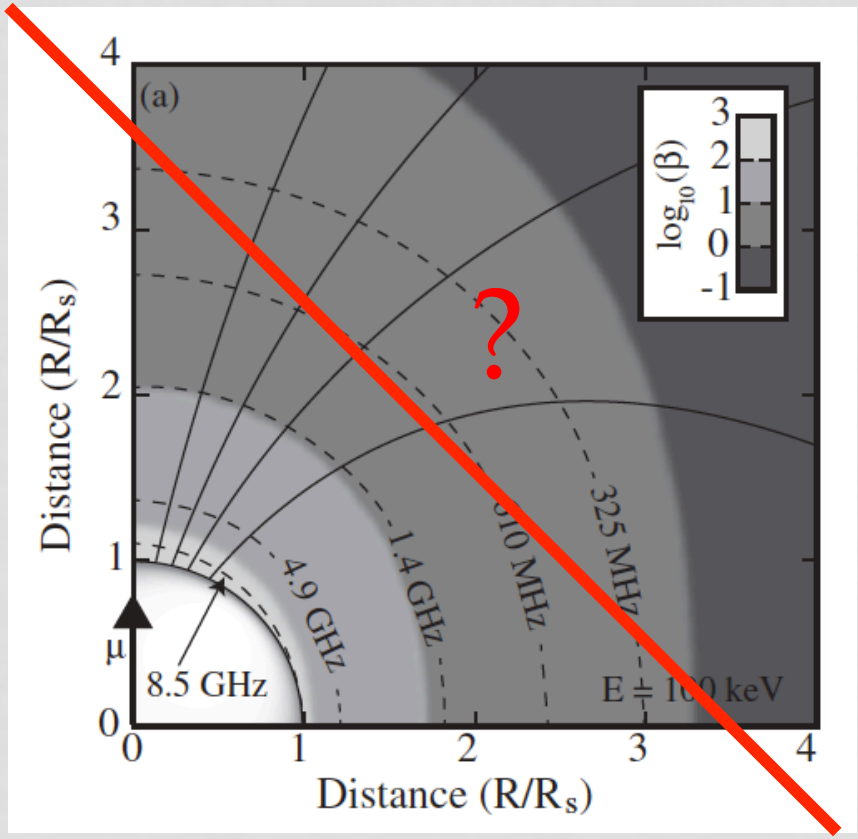
- The quiescent emission not strongly constrained, could use better calibration.

LOOKING FOR PULSES..

- Split visibilities
  - Rotational Period / 16
  - ~11min → 2MASSJ[redacted]
  - ~7 min → 2MASSJ[redacted]
- Image on Stokes V

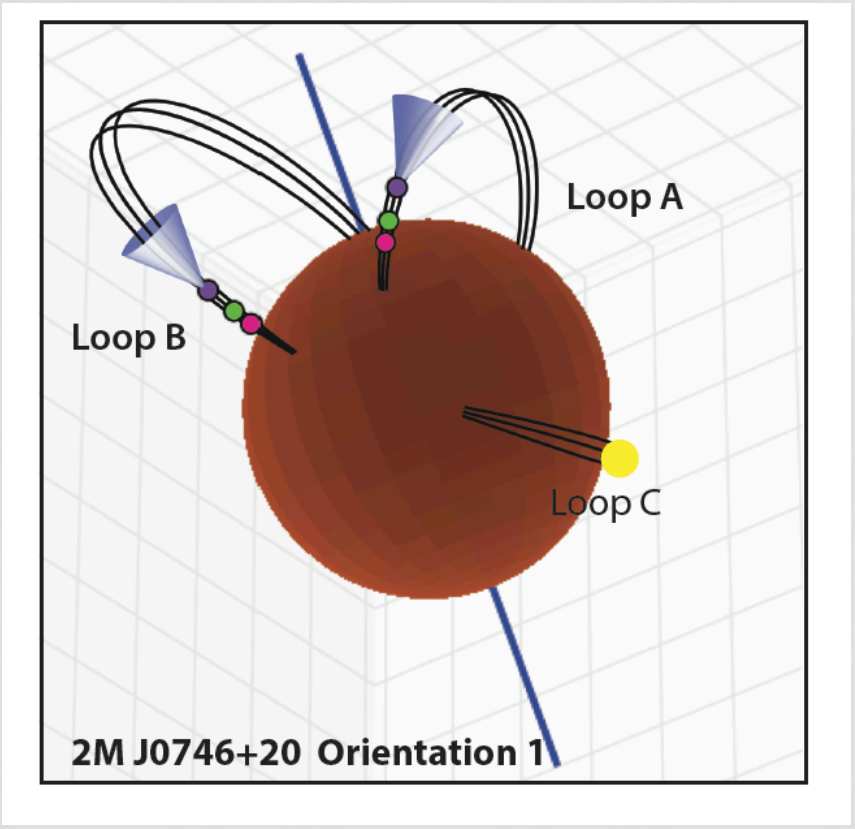
MAGNETIC FIELD STRUCTURE

Large scale B



Jaeger et. al. (2011)

Non-axisymmetric B



Lynch et al. (2015)

CONCLUDING

- The quiescent emission not strongly constrained, could use better calibration.
- Pulse emission seems absent, hinting for a small scale axisymmetric magnetic field.