Low frequency GMRT observations of ultra-cool dwarfs: new constraints on coronal properties

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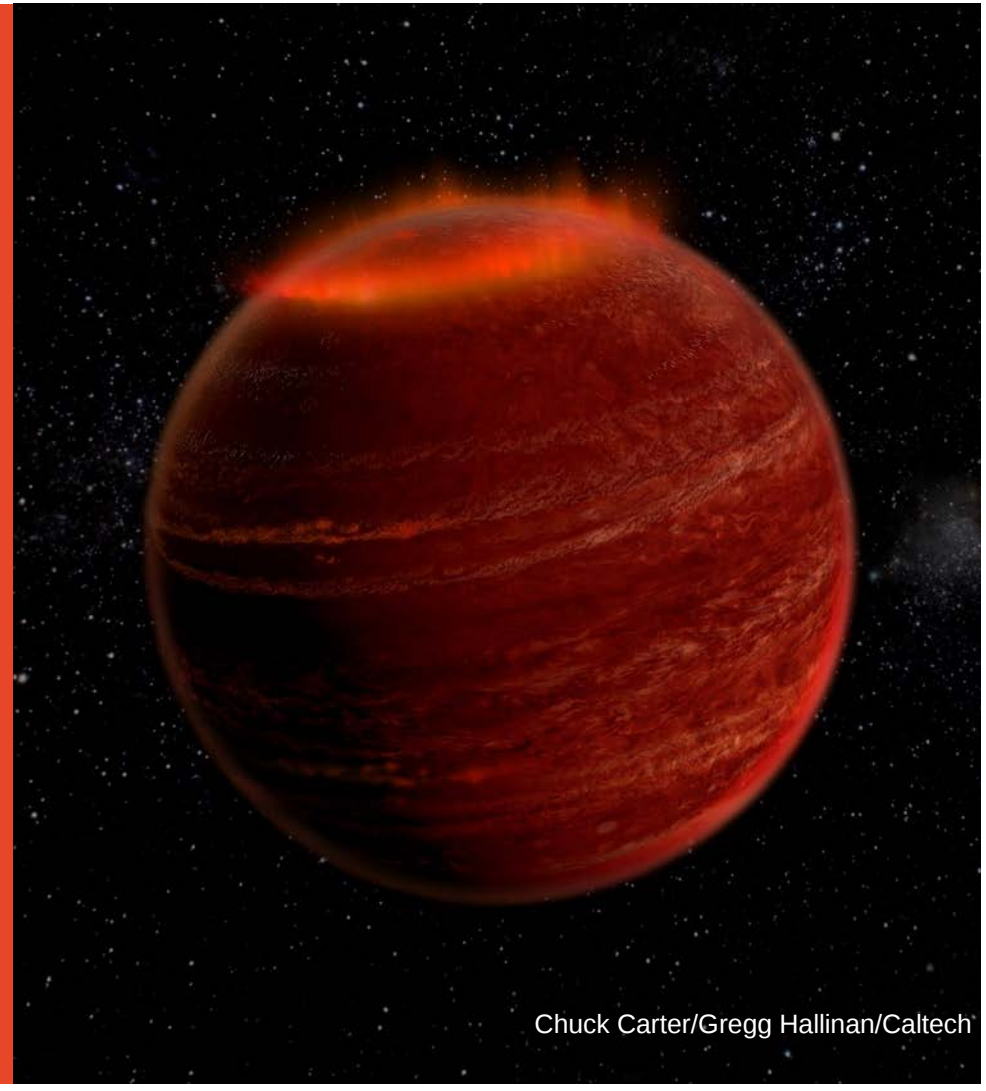


Chuck Carter/Gregg Hallinan/Caltech

1. **What is the nature of low-frequency radio emission of Ultra-Cool dwarfs?**

2. **Can we use this to place tighter constraints on their coronal properties?**

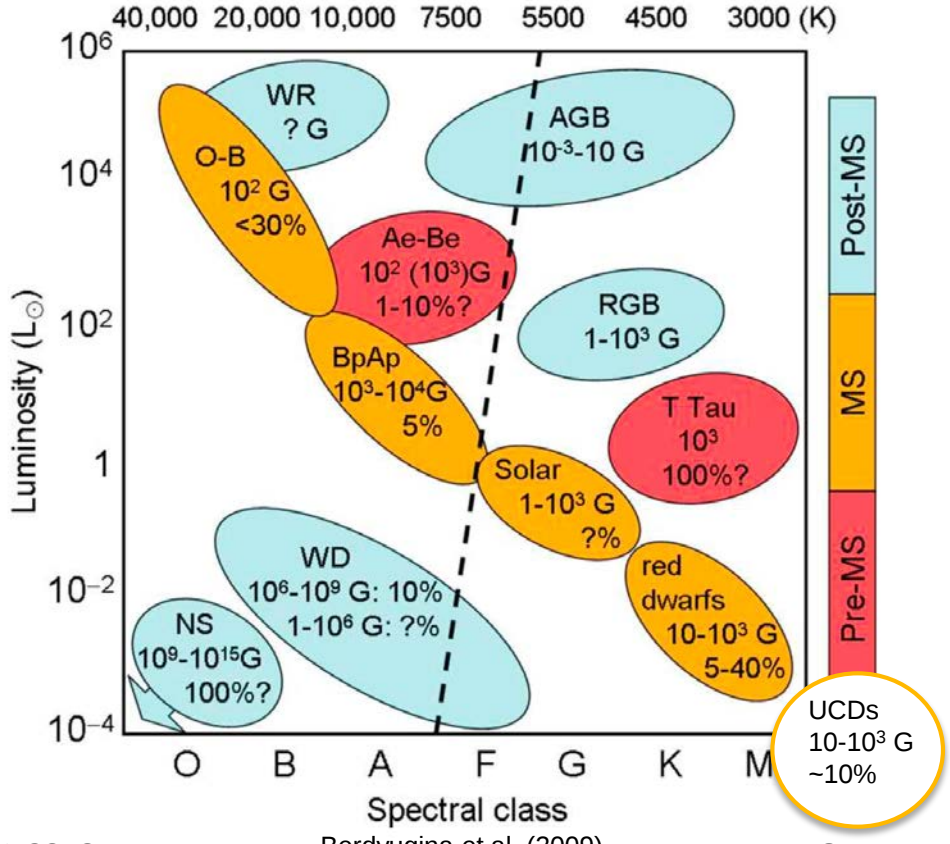
3. **What does this tell us about the physical mechanisms operating in their magnetosphere?**

The pervasiveness of stellar magnetism

Magnetic fields influence many stages of stellar life, e.g.

- Formation
- Mass loss
- Rotation
- Late stage evolution

Ultra-Cool Dwarfs (UCDs) span gap between low-mass stars and high-mass planets



Berdyugina et al. (2009)

What are ultra-cool dwarfs?

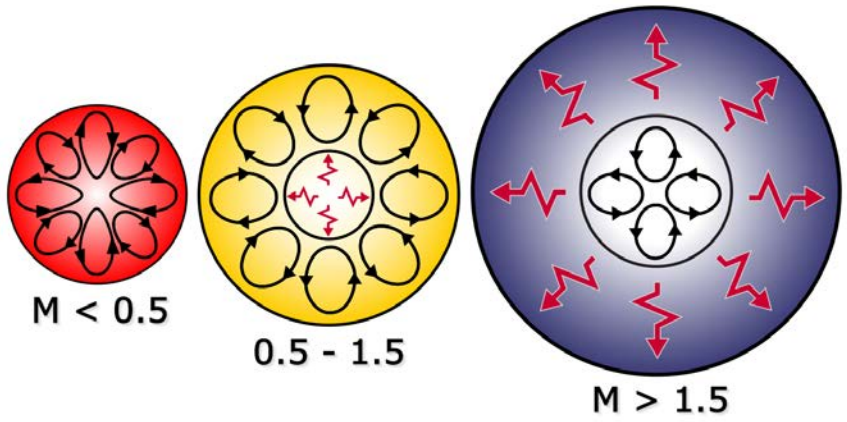
UCDs encompass edge of Hydrogen-burning limit, and beyond

Spectral class > M7; T_{eff} < 2700 K; M ≤ 0.1 $M_{\odot}$

UCDs are fully convective → α-Ω dynamo responsible for solar-type magnetic fields doesn't apply

Durney et al. (1993):

Fully convective dynamos can't sustain strong magnetic fields



https://commons.wikimedia.org/wiki/File:Star_types.svg

UCDs break trends

UCDs exhibit a sharp decline in Hα & X-ray luminosity

- Standard activity tracers of FGKM stars

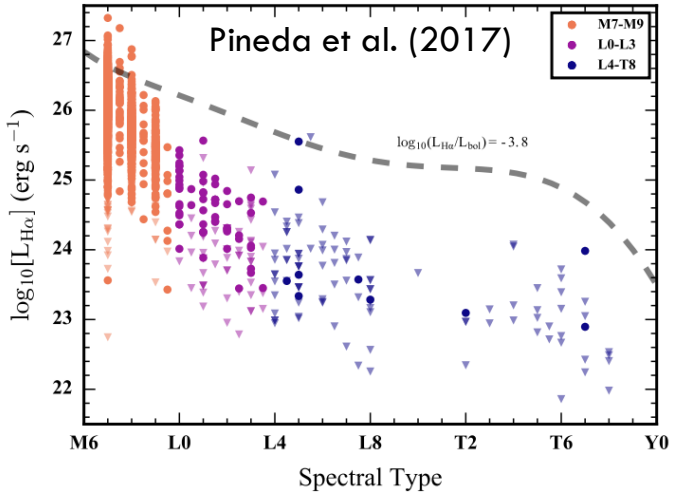
→ inability of UCDs to sustain hot corona

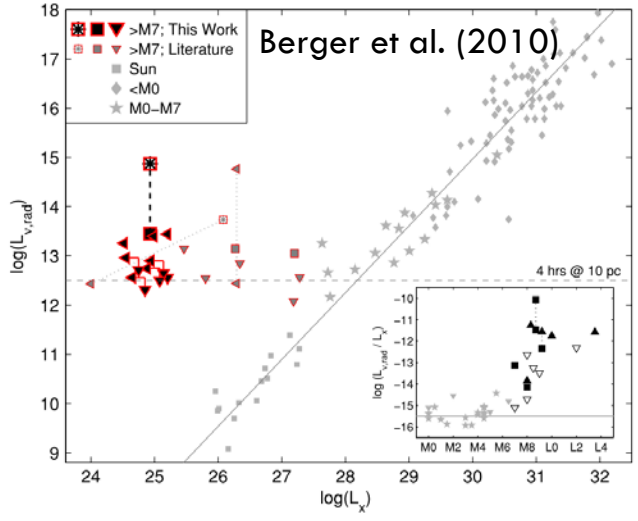
→ transition to cold neutral atmosphere

Güdel-Benz Relation: $L_X \sim L_{\nu,R}^{0.73}$

→ For UCDs: decline in L_X → negligible $L_{\nu,R}$

Berger et al. (2001): detection of strong non-thermal radio emission





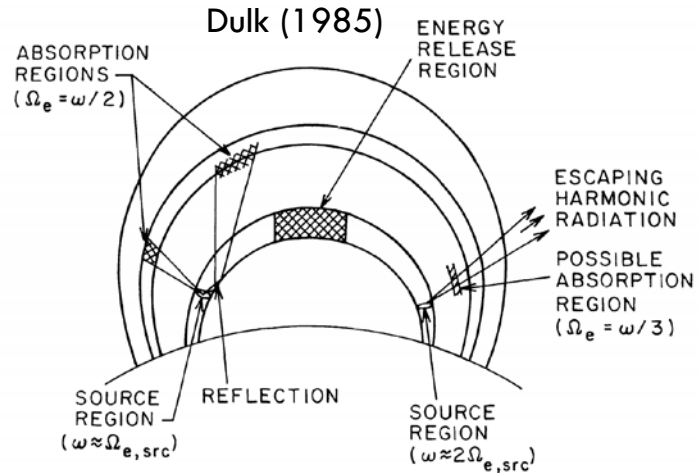
Radio emission mechanisms

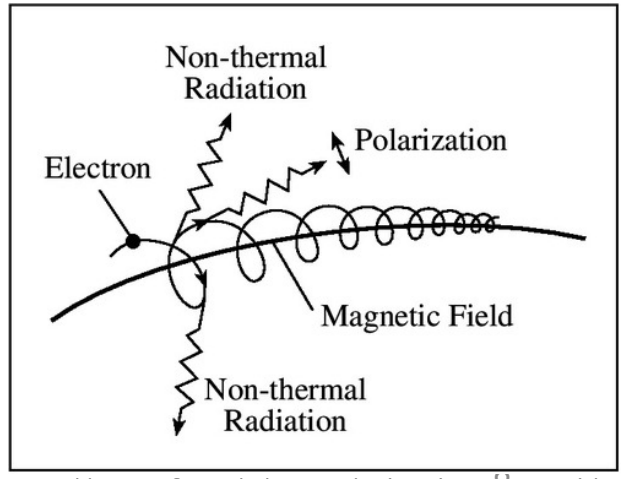
Electron cyclotron maser instability (ECMI):

- Bursty, flare-like emission
- Could be source of quiescent emission
- Emits close to local cyclotron frequency:
  $\Omega_e = eB/cm_e \approx 2.8 \times 10^6\ B$

Gyrosynchrotron radiation:

- Likely to be responsible for quiescent emission





https://ase.tufts.edu/cosmos/print_images.asp?id=50

Key questions

Presence of non-thermal radio emission indicates presence of strong magnetic fields (up to several kG)

- Unexpected, given early theoretical considerations & observed decline of activity tracers

How are these strong magnetic fields generated in UCDs? What is their topology, and does this evolve?

How is the stellar magnetosphere populated with non-thermal electrons responsible for radio emission?

Breaking degeneracies at low frequencies

Gyrosynchrotron emission can be used to constrain coronal electron density and magnetic field strength (N_e & B)

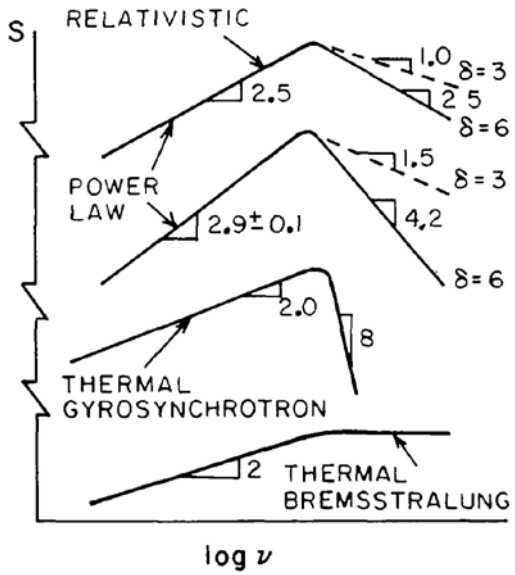
Previous works* find N_e and B are degenerate

Low frequency observations break degeneracy:

Probe optically thick emission → locate spectral turnover

Spectral turnover depends on N_e & B:

$$\nu_{peak} \approx 10^{3.41+0.27\delta} (N_e L)^{0.32-0.03\delta} B^{0.68+0.03\delta}$$



Dulk (1985)

*(e.g. Osten et al., 2006; Lynch et al., 2015)

Probing UCD magnetospheres with the GMRT

Observed 10 UCDs with the Giant Metrewave Radio Telescope (GMRT) at ~610 & 1300 MHz, to:

1. Determine location of spectral turnover
2. Determine existence of low-frequency counterpart to bursty emission observed at higher frequencies

First observations of UCDs at these frequencies to be published in the literature (Zic et al., in prep.)

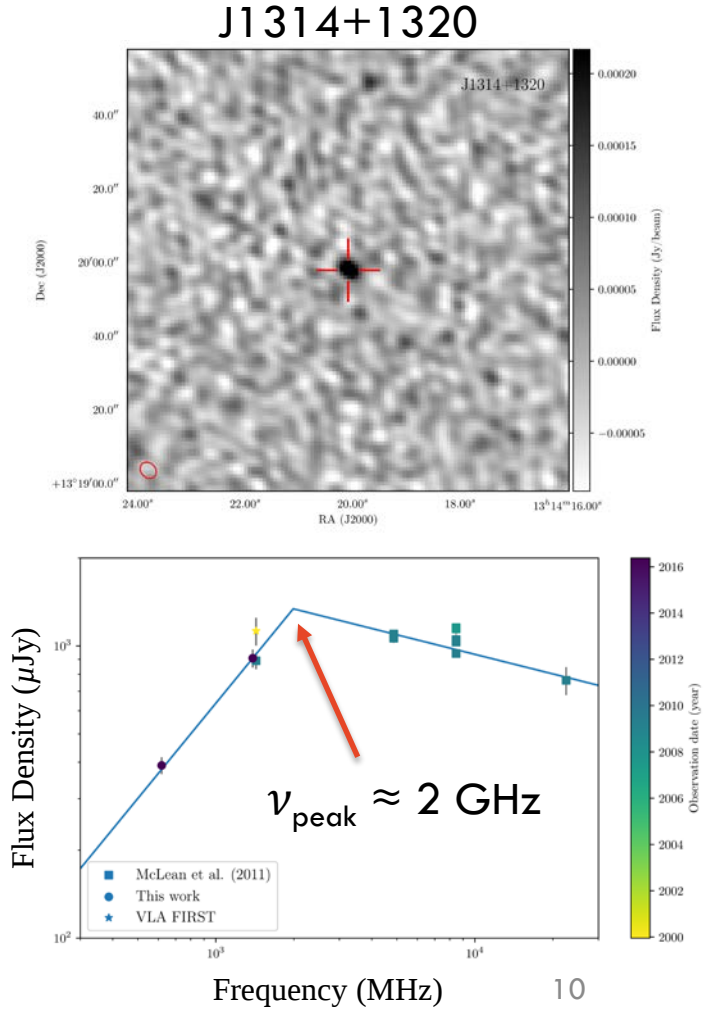
Detections… and non-detections

Name	S_{610} (μJy)	S_{1300} (μJy)	$T_{b,610}$ (10^{10}K)	$T_{b,1300}$ (10^{10}K)
2M 0034+05	< 245	< 243	< 3.8	< 0.83
2M 0036+18	< 800	< 1040	< 10	< 3.0
2M 0314+16	< 200	< 728	< 6.7	< 5.4
2M 0355+11	< 184	< 1020	< 2.0	< 2.5
2M 0423-04	< 150	< 1360	< 5.9	< 12
2M 0746+20	319 ± 58	355 ± 65	8.0 ± 1.5	2.0 ± 0.4
2M 0828-13	< 160	< 165	< 3.5	< 0.8
J1314+1320	390 ± 26	908 ± 65	19 ± 1	8.8 ± 0.6
TVLM 513-46	< 148 [a]	< 194 [b] < 201 [c]	< 2.8 [a]	< 0.85 [b] < 0.76 [c]

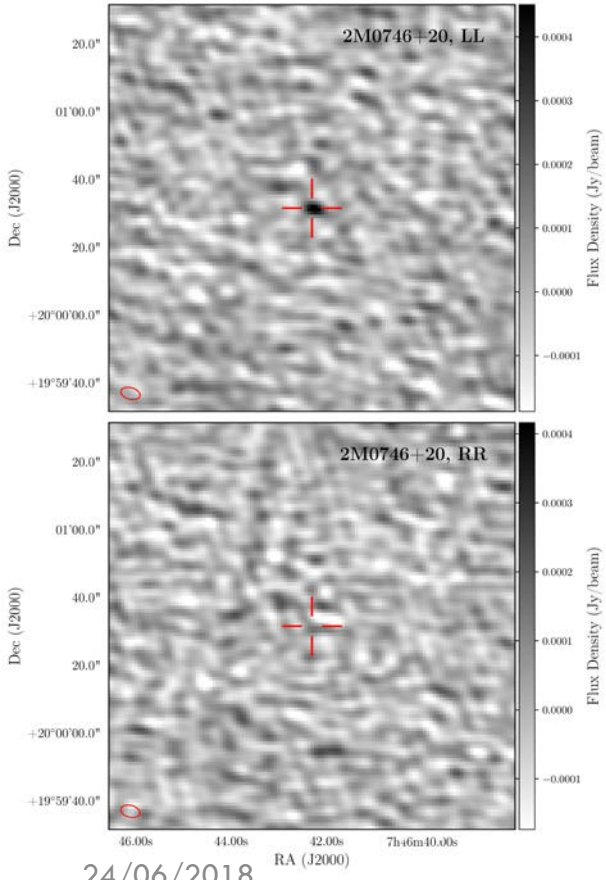
Table 3. Notes: (a): Epoch 2016-08-18; (b): Epoch 2008-01-19; (c): Epoch 2016-09-25

Zic et al. (in prep.)

J1314+1320



Interpreting 2M0746+20 is challenging…



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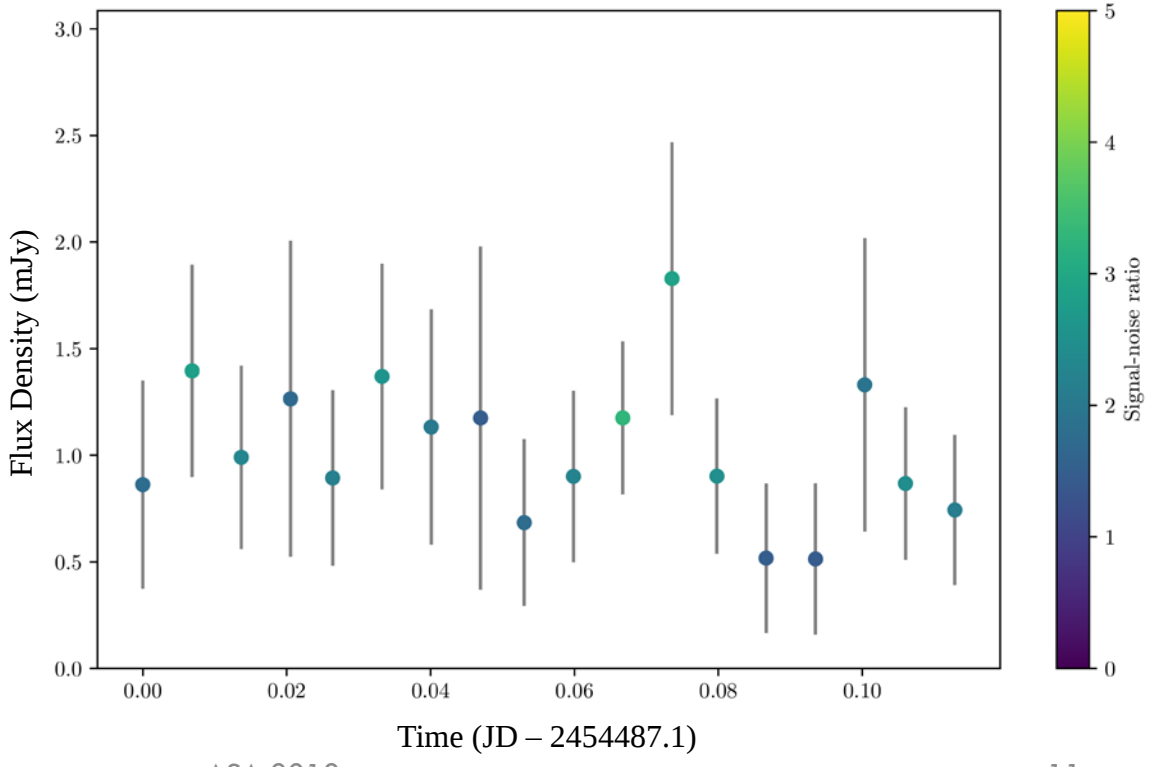

Summary

We have observed 10 UCDs at ~610 & 1300 MHz, to:

1) Determine coronal N_e & B by locating spectral turnover of emission
2) Determine existence of low-frequency bursting emission

J1314+1320 consistent with optically-thick gyrosynchrotron radiation, with a spectral turnover at ~2 GHz

Use this information to constrain coronal properties using coronal modelling

2M 0746+20 is difficult to characterise!

Future Work

Long-term variability adds uncertainty to the spectral shape and therefore coronal properties of UCDs

- Simultaneous observations with the GMRT and VLA/ATCA can provide instantaneous snapshot of the full radio SED → more accurate coronal constraints
- uGMRT now provides 300 MHz instantaneous bandwidth: 10x better than before

Follow-up observations at low frequencies will also assist in characterising the unusual behaviour of 2M0746+20