Recent cm-wave observations

Anita Richards, JBCA, Manchester
Decin, Etoka, Harper, Kervella, Lim, Garrington, Gray, McDonald,
***O'Gorman**, Wittkowski et al.*

Some VLA highlights *O'Gorman et al. 2015*
E-MERLIN 2012-2015 (and a correction)

RadioNet

ALMA

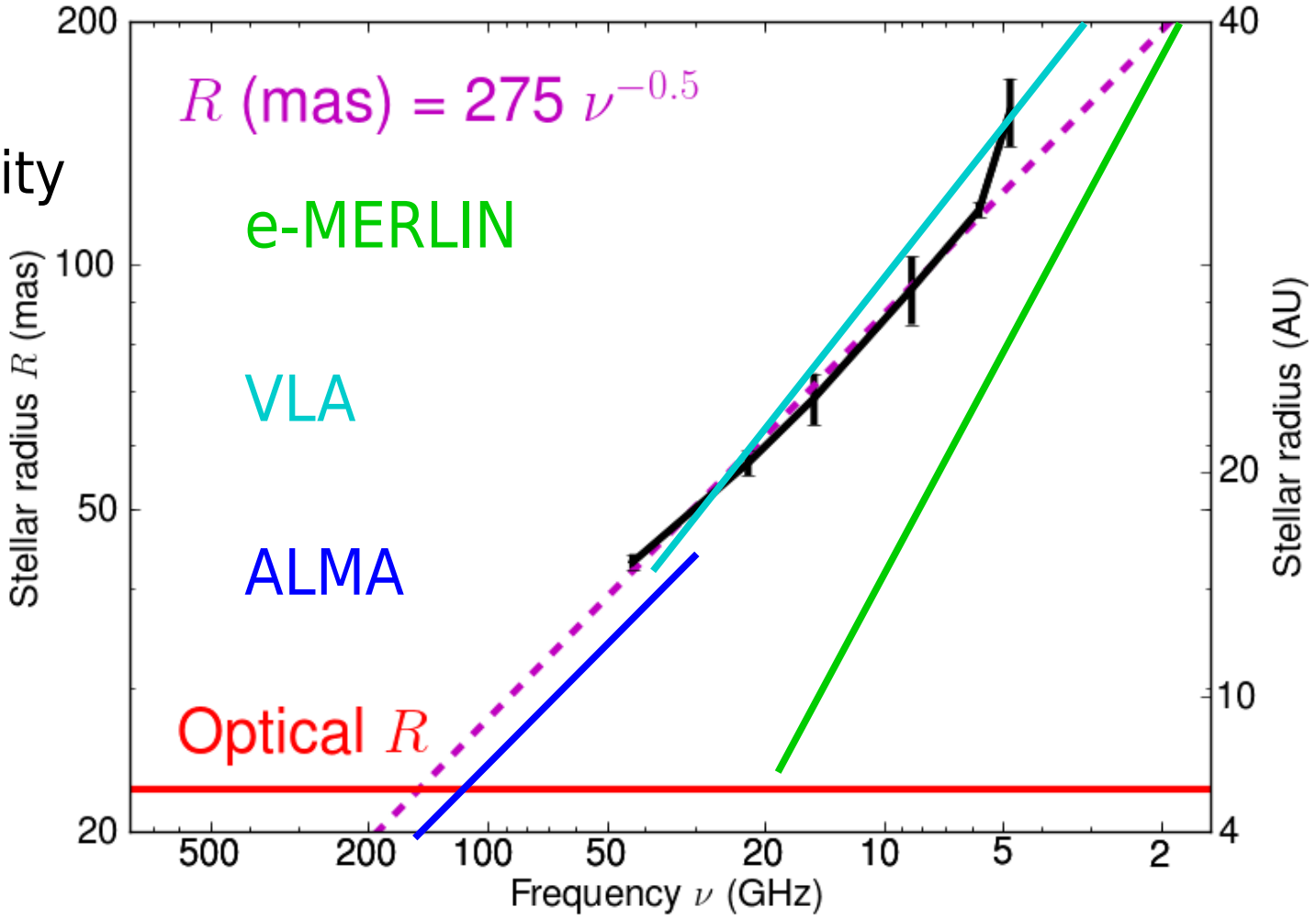
EUROPEAN ARC
ALMA Regional Centre || UK

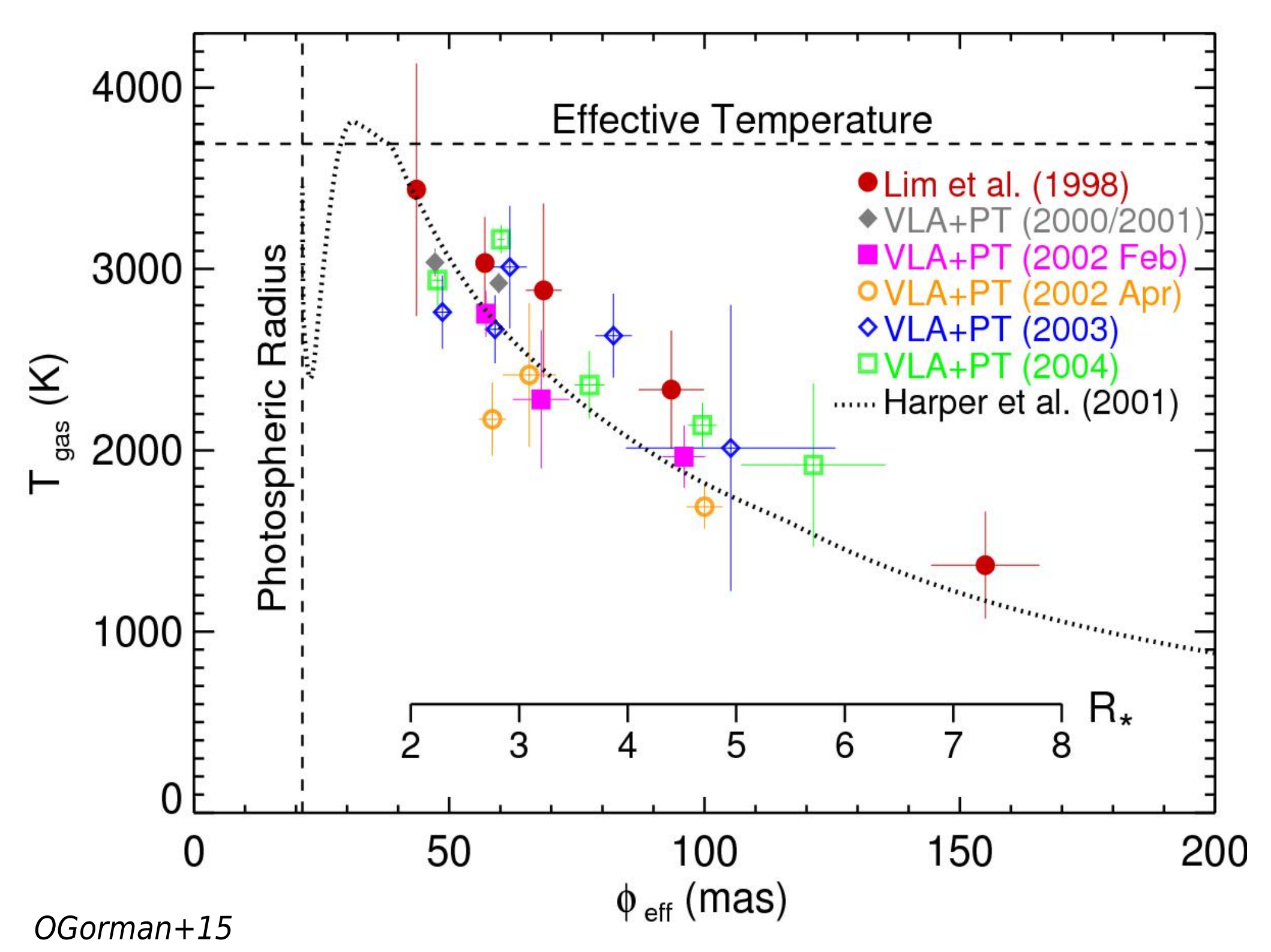
e-MERLIN
The University of Manchester
Jodrell Bank Observatory
MANCHESTER 1824
IVOA
EUROPEAN VLBI NETWORK

VLA+Pie Town monitoring

- 2000 - 2004, λ 0.7 - 20.5 cm, resolution 0”.04-1”.2
  - *OGorman+15*

- λ<7cm resolved
- λ<4cm eccentricity up to 0.7
- Tentative fits of –ive δ functions 3-10% of total, offset by up to half radius
- T_b profile agrees with *Lim+98, Harper+01*




Effective Temperature
Photospheric Radius
Lim et al. (1998)
VLA+PT (2000/2001)
VLA+PT (2002 Feb)
VLA+PT (2002 Apr)
VLA+PT (2003)
VLA+PT (2004)
Harper et al. (2001)
T gas (K)
ϕ eff (mas)
R*
0
1000
2000
3000
4000
50
100
150
200
2
3
4
5
6
7
8

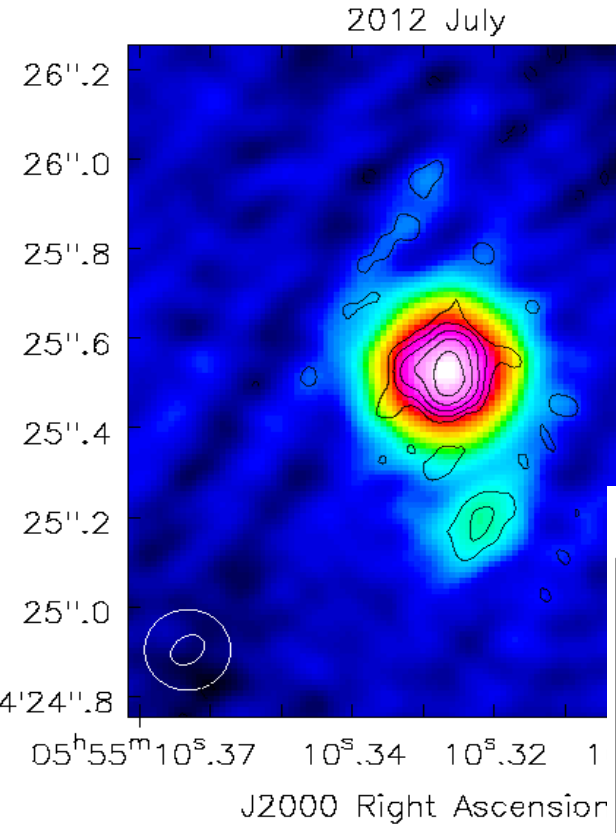
OGorman+15

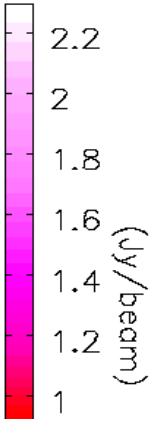
e-MERLIN at 5.75 GHz (5.2 cm)

- 2012 July, 2015 March, June
  - ~8 hr useful per epoch
  - 400 MHz effective b/w
    - 15-20 mas astrometry
      - Few mas relative accuracy
    - rms 15-20 μJy/bm
    - 10% flux scale accuracy
  - Re-reduced 2012 data with correct Cm axis offset
    - *Richards+13* ***incorrect***
- Image at 180-mas resolution
  - Measure whole star
    - Radius ~4.4 $R_\star$
- Image at 78x57 mas^2
  - Subtract peak, measure residuals

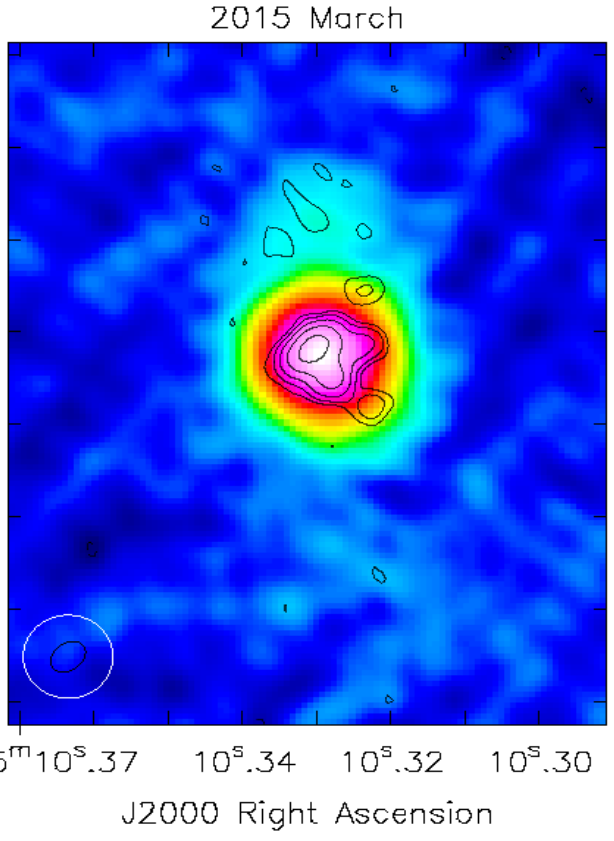
	2012 Jul	**2015 Mar**	**2015 Jun**
Tot. flux (mJy)	2.78	2.39	2.35
Area (mas^2)	204 x 195	212 x 198	201 x 189
T_b (K)	2650 (310)	2120 (225)	2300 (230)
Resid. min (mJy/bm)	-0.15	-0.25	-0.12
Resid. max (mJy/bm)	0.23	0.21	0.17

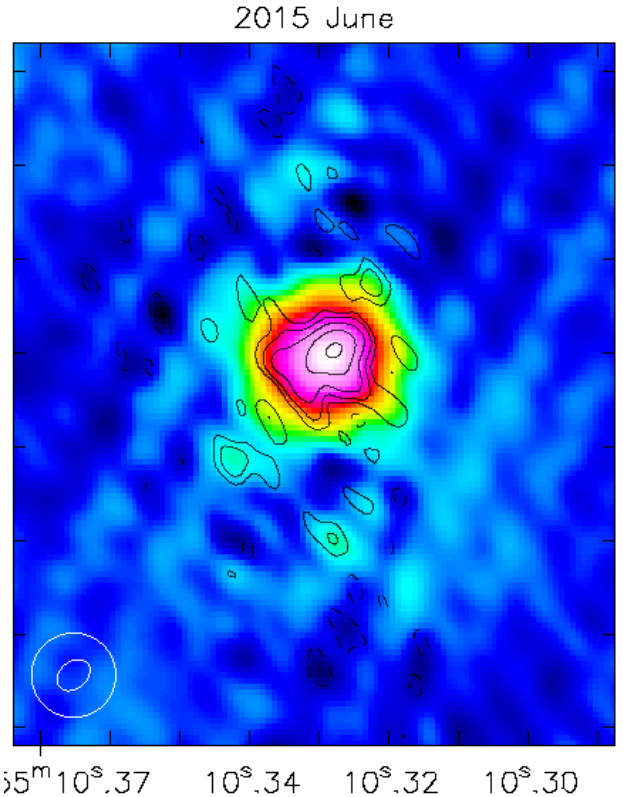
e-MERLIN

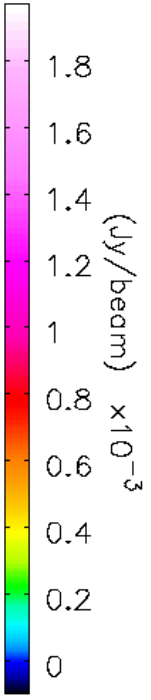




- Proper motions broadly consistent with *Harper+06* (25, 10 mas/yr) …. but
  - 35-mas Dec discrepancy in 2015
    - Changing hot spot positions
    - Phase transfer errors

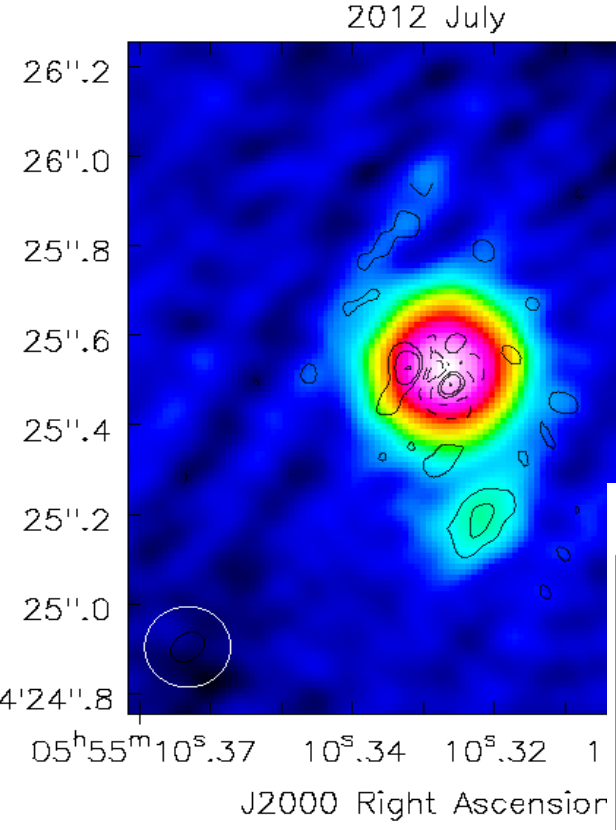


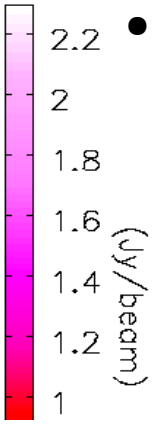




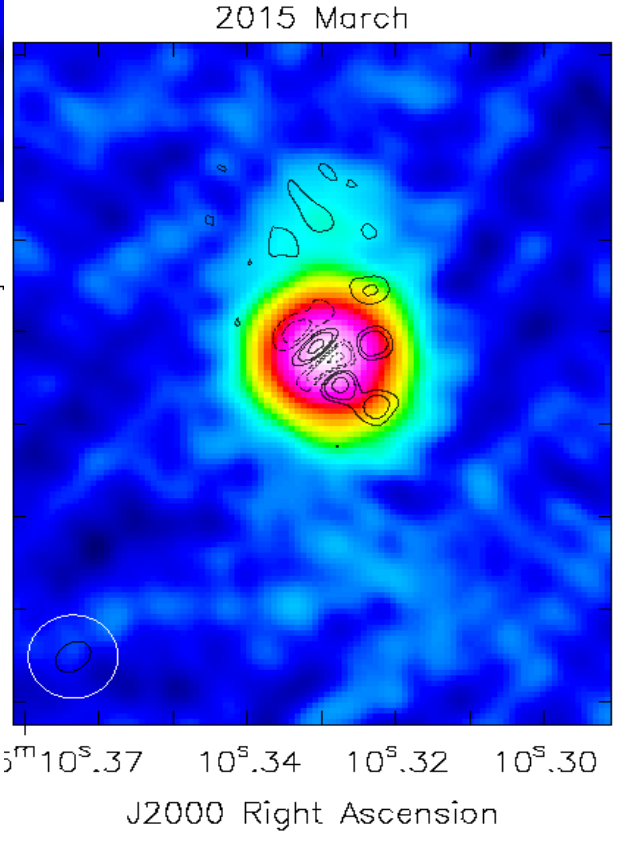
- 78x57 mas^2 contours (-1,1,2,4… x50 µJy/bm) over 180-mas resolution disc

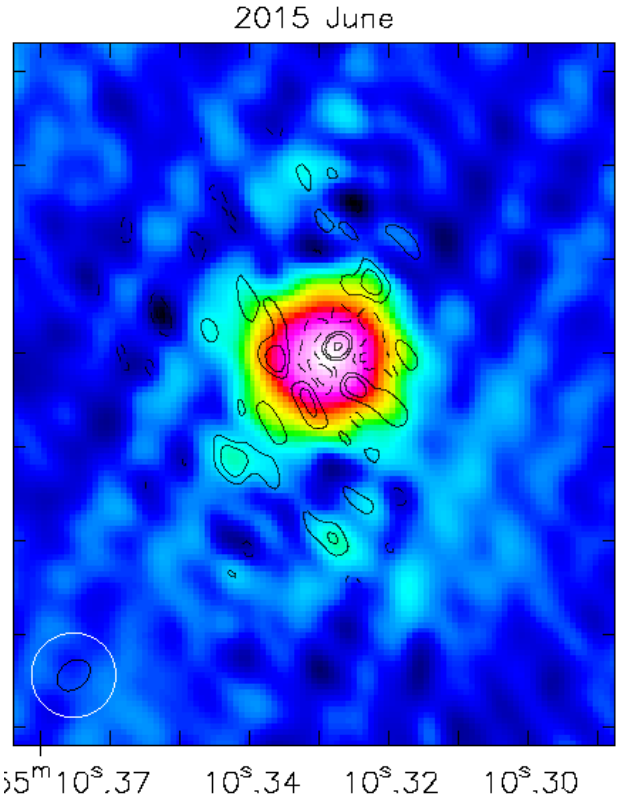
Residual hot/cold spots

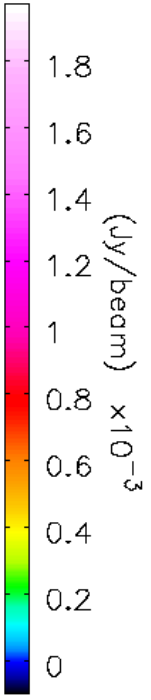




- Subtract high-resolution Gaussian
  - ~7 residuals >6σ within disc
    - Up to ±~10% flux density
    - Location errors ≳(10, 15) mas
    - Unresolved
      - Maybe clustered smaller comps



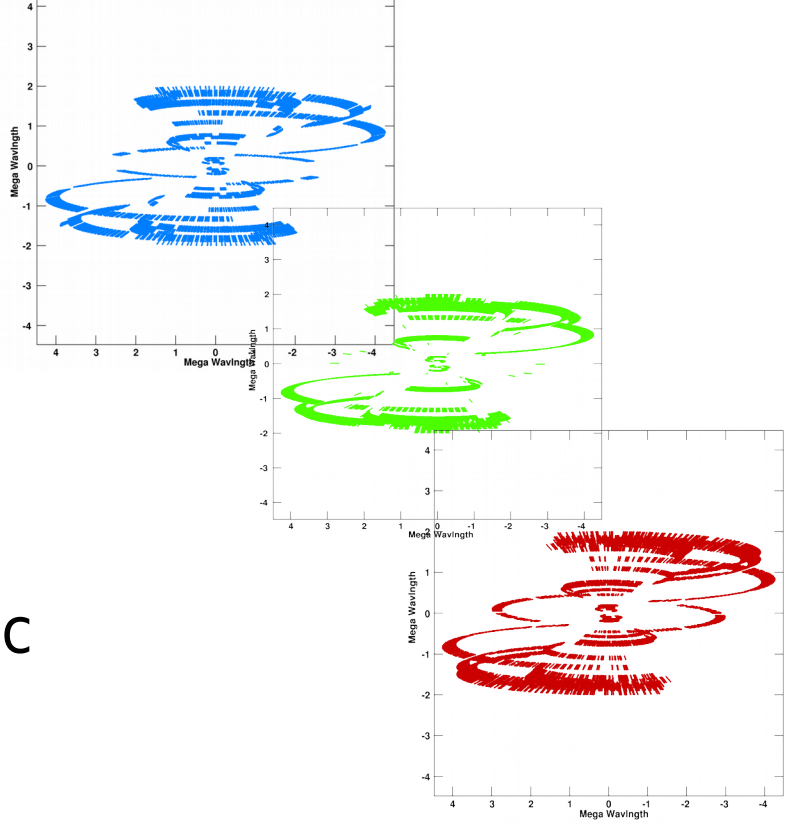




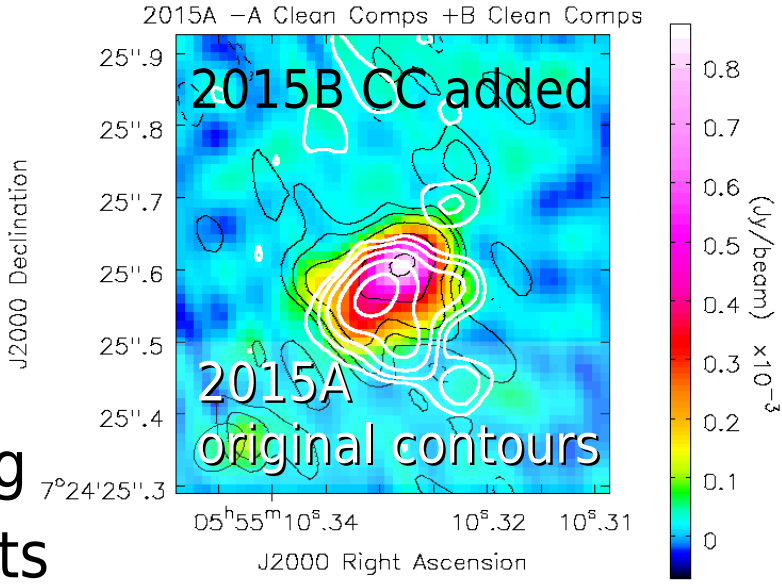
- Residual contours (-1,1,2,4... x50 μJy/bm) over 180-mas resolution disc

Hotspots believable?

- *uv* coverage similar all 3 epochs
  - Noise distribution Gaussian
- Subtracted CC from calibrated data
  - Added Gaussian model full stellar disc
    - Imaged, recovered similar
  - Added collection of δ functions
    - Recovered beam-size residuals
  - Added CC to 2015A from 2015B
- Flux scale errors
  - Attenuator setting issues in 2012
- Phase/amp referencing errors
  - Low elevation atmosphere
  - Attenuator and delay jumps, chunking
- Excess random errors, not major artefacts

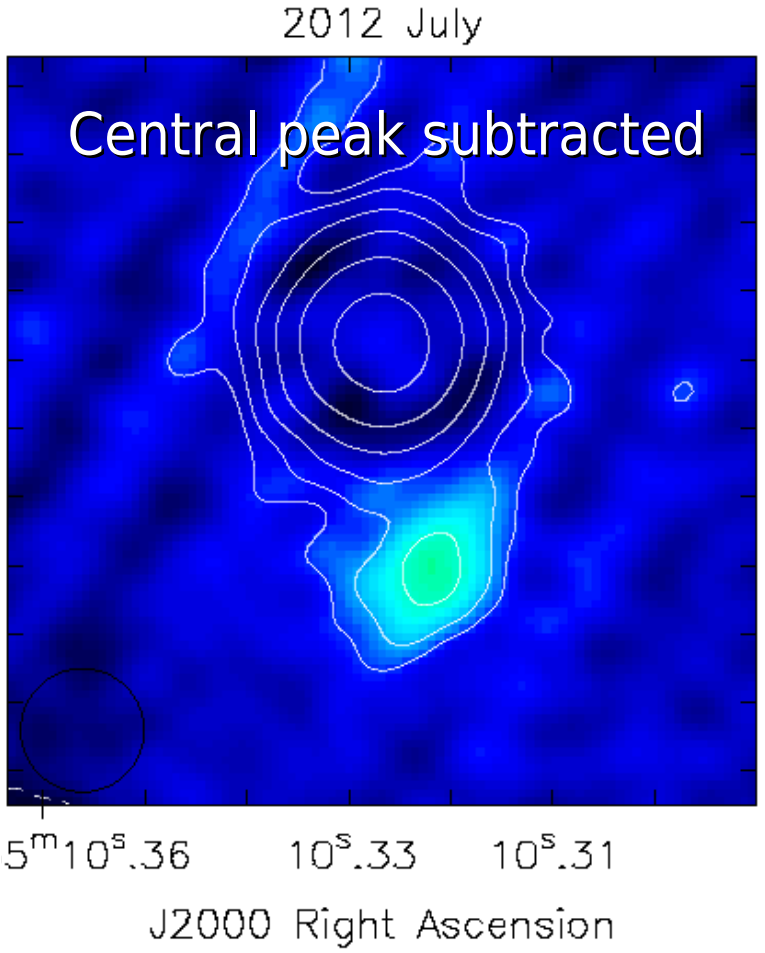


- Image looks like 2015B

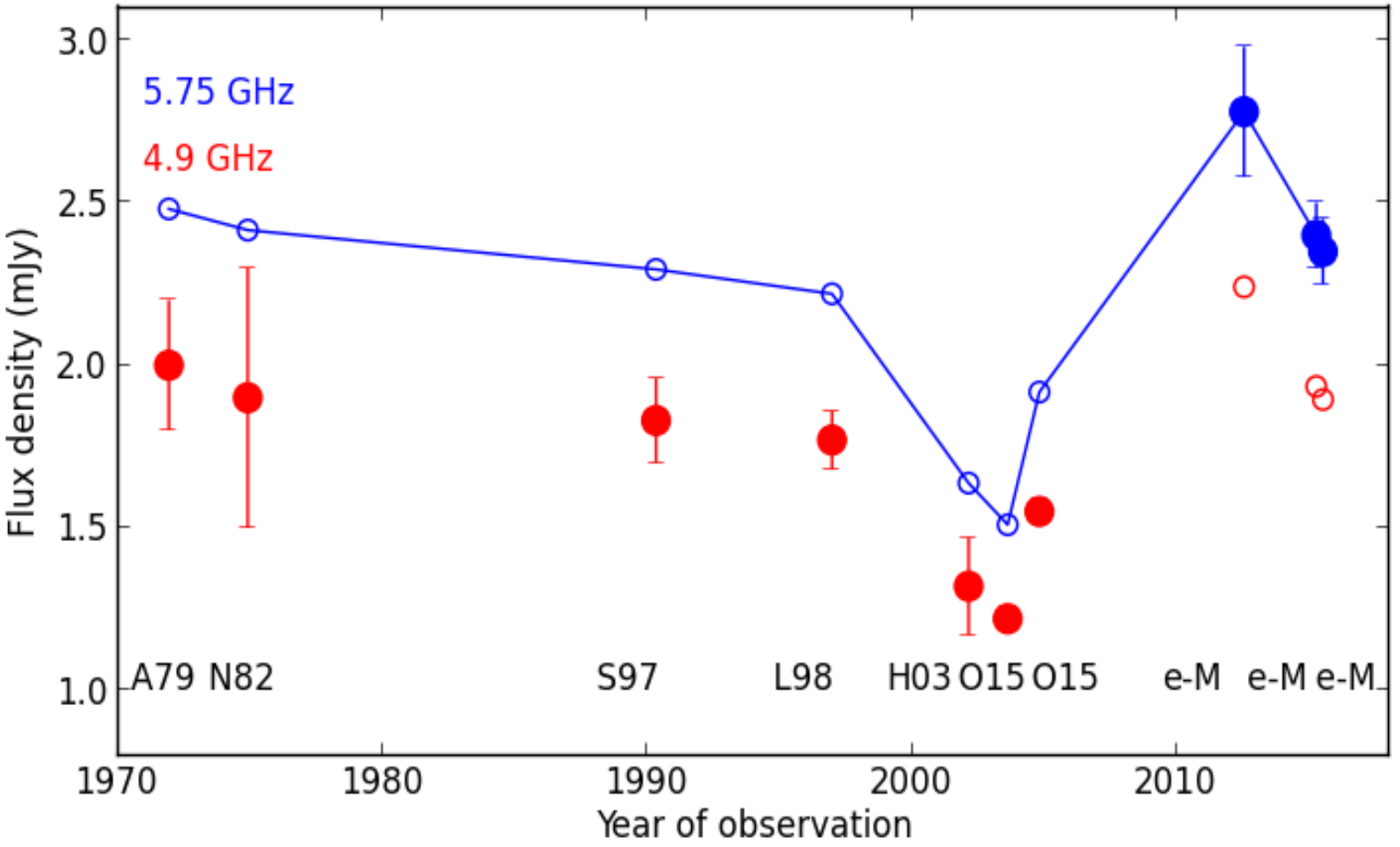


SW blob

- SW residual after subtracting Gaussian
  - Centre 0”.35 (15$R_\star$) from star
    - Total flux density 190 μJy in 0.063 asec^2
    - Blob T_B 125±40K
  - Approximately spherical?
    - Radius 125 mas ~25 au
- n_H~16x10^{12} m^{-3}, n_e~15x10^9 m^{-3}, T_e~525 K (*Harper+2001*)
    - Implies τ ~0.0025
    - H mass ~2.2x10^{-6} $M_\odot$
      - One such clump ejected every couple of years?
  - BUT not seen properly in 2015
    - However, noisier data



Long-term variability at λ 5-6cm



Solid:observed

Hollow: extrapolated, spectral index $\alpha = 1.33$

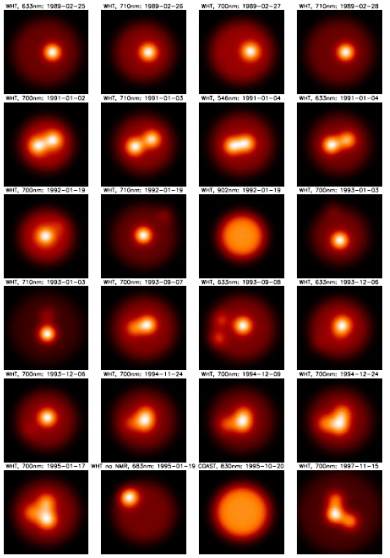
- Decline 1970 to 2003
- Recent increase

– *Altenhoff+79* (Efflesburg), *Newell+82*, *Skinner+97*, *Lim+98* (all VLA), *Harper+03*, *O'Gorman+15* (VLA+Pie Town), *e*-MERLIN

Radio variability

- ~25% variability in months at $\lambda > 1$cm
  - More stable at 0.7 cm *Drake+'92, OGorman+'15*
- No obvious correlation between λ or with $R_\star$
  - Too rapid for global pulsation/mass loss effects?
- Chemistry/ionisation threshold changes? *Harper & Linsky 2001*
- Observed 1.3-cm surface ~1.5-2.5 $R_\star$ (predicted 1.8$R_\star$)
  - Variability correlates w. V-band (400-d period) *OGorman+'15*
    - Pulsation shocks strongly damped within 2 $R_\star$
  - Heating > increased radiation field
    - Rapid recombination and photo-ionisation of metals
    - Ionising radiation shines through to 5-cm layer?
      - But not back to optically thicker 0.7-mm layer?

Starspots



- λ 5.2 cm radius ~100 mas
  - ~4.5 x optical $R_\star$
    - Optical: 1-3 compact spots, 1989-1997 (*Tuthill+97*)
- Same origin, expanding in more extended layers?
- Actual size 5-cm spots unclear, ≲60 mas, maybe ≪
- Probably ≲10% T_b fluctuations
- Appearance changes in months
  - Heating/cooling, imaging distortion
    - Not measurable proper motion
- Convection? Up/down draughts?
- You tell me!!???