



Aalto University  
School of Electrical  
Engineering

# Long-term solar monitoring at mm-wavelengths

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*1) Metsähovi Radio Observatory, Aalto University*

# Background – Solar observations at Metsähovi Radio Observatory

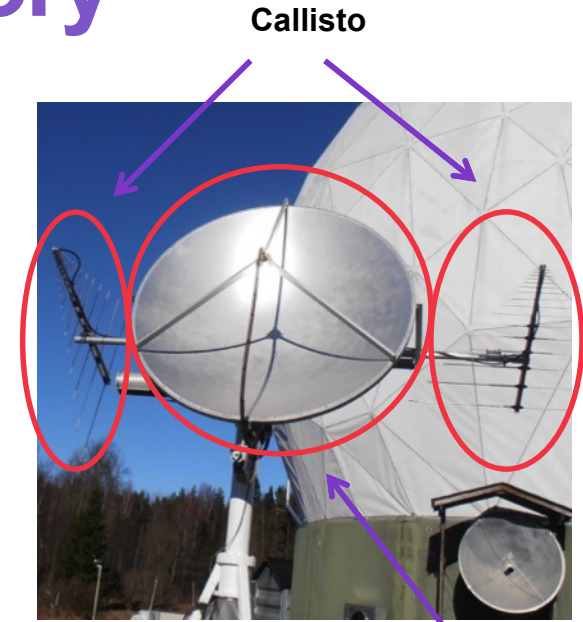
- **Solar observations at mm-wavelengths since 1978**
  - **Data set (radio maps) covers three full solar cycles !!!**
    - *Note: Nobeyama operated since 1992!*
  - Solar radio maps mainly at 37 GHz (+ and some at 86 GHz)
  - Permanent / static observation system
  - However, the data set is not perfect:
    - *the data has gaps (shown in later)*
    - *calibration is tricky: based on the statistical definition of Quiet Sun Level (QSL)*
    - *resolution is relatively low (2,4 arc min)*
- **Monitoring the total solar flux at 11,2 GHz since 2001**
- **Observations dm-wavelengths since 2009 (e-Callisto network)**

# Metsähovi Radio Observatory - instrumentation

- **Three different instruments:**
  - 14-meter radio telescope (solar radio maps, active area tracks,...) at 37 GHz (86 GHz)
    - *solar observation campaigns at summer*
    - *daily radio maps*
  - SunAnt (11,2 GHz) – continuous
  - Callisto (100 – 850 MHz, two polarization) – continuous <sup>(1)</sup>



MRO-14

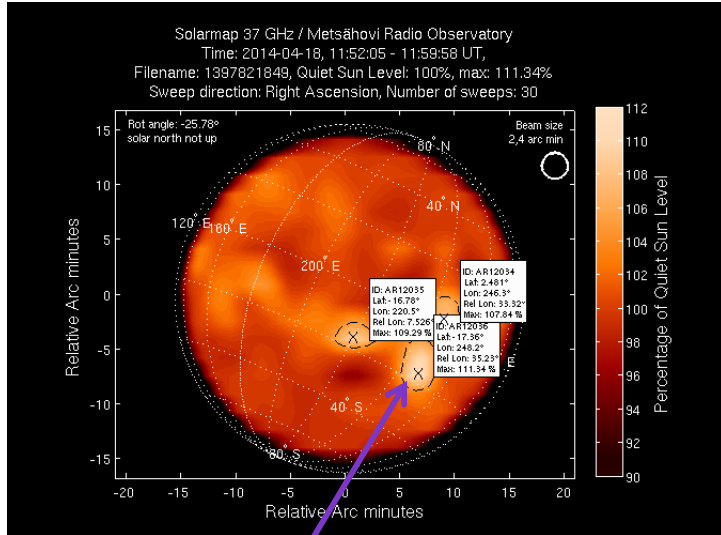


SunAnt and Callisto

SunAnt

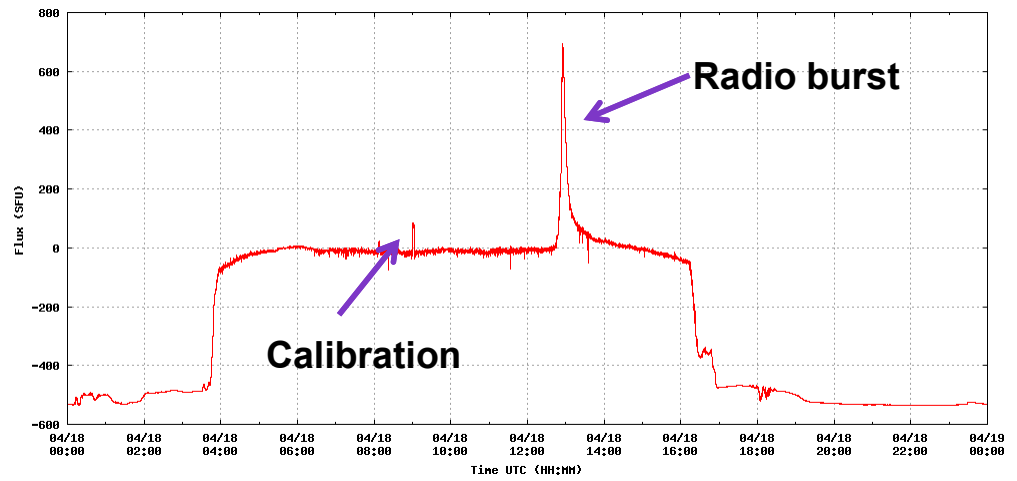
<sup>1)</sup> Node of the e-Callisto network (<http://www.e-callisto.org>)

# Data products

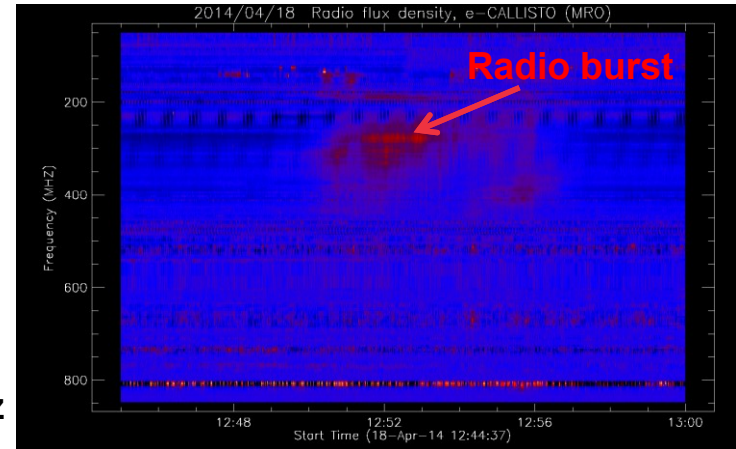


Solar radio map at 37 GHz

“Active radio brightening”

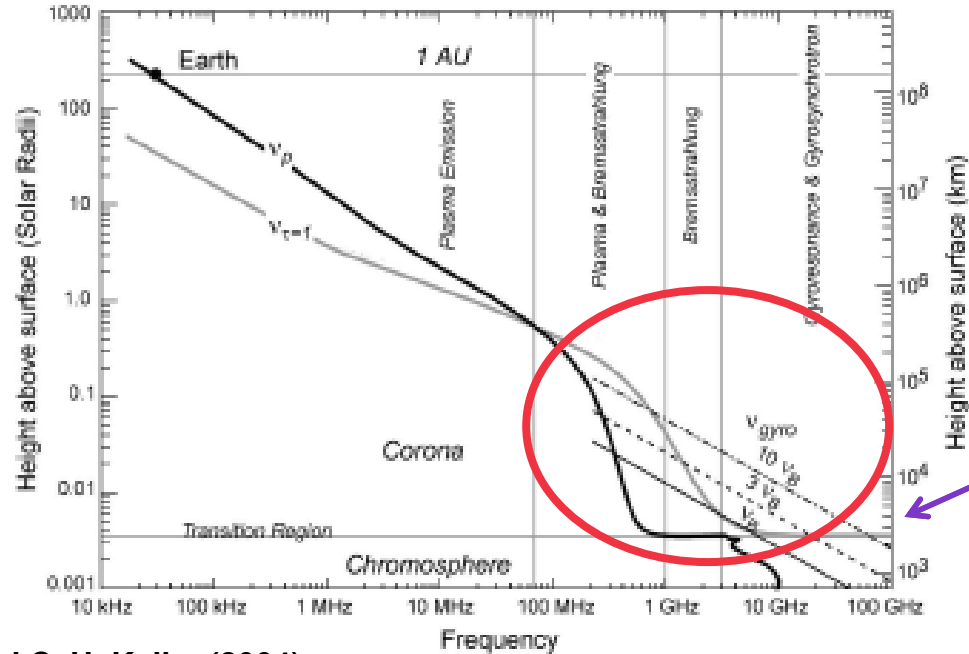


Total intensity at 11.2 GHz



Radio spectra at 50-850 MHz

# Solar atmosphere – origin of emission

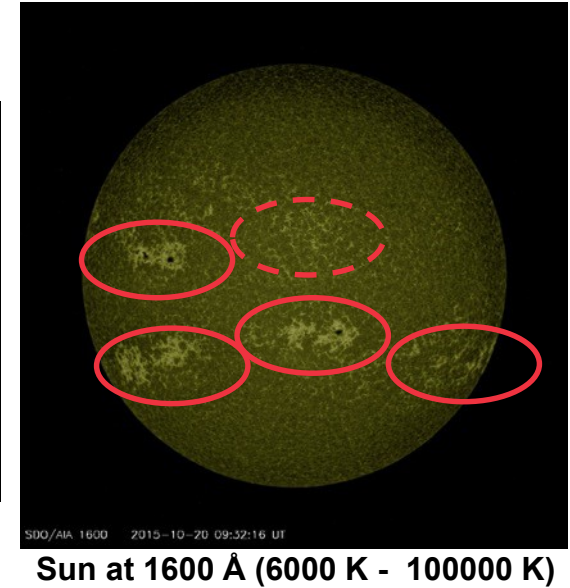
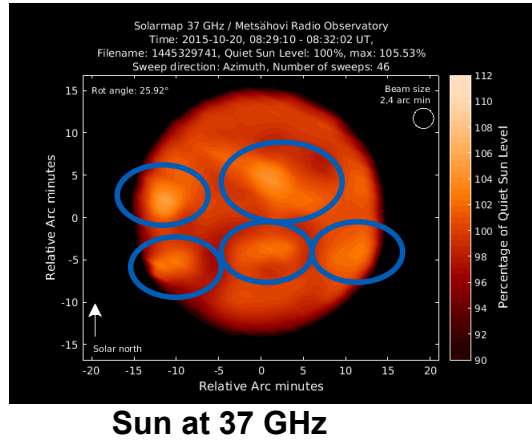
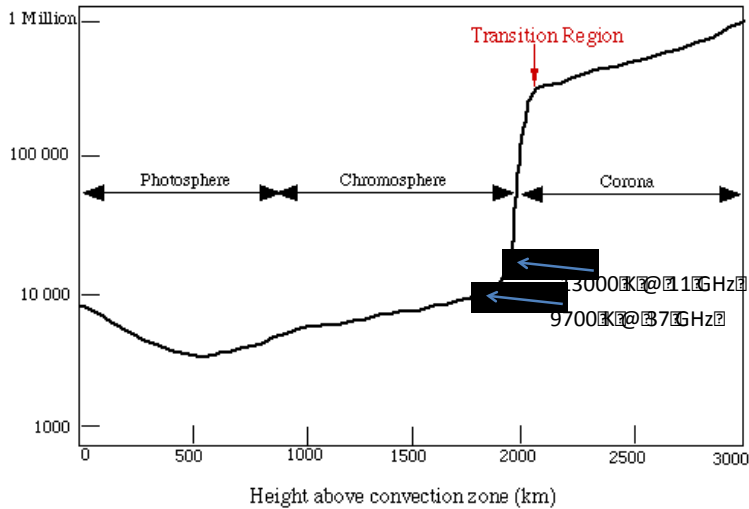


**Metsähovi**

- Chromosphere →
- Transition Region →
- Corona

ed. D.E. Gary and C. U. Keller (2004)

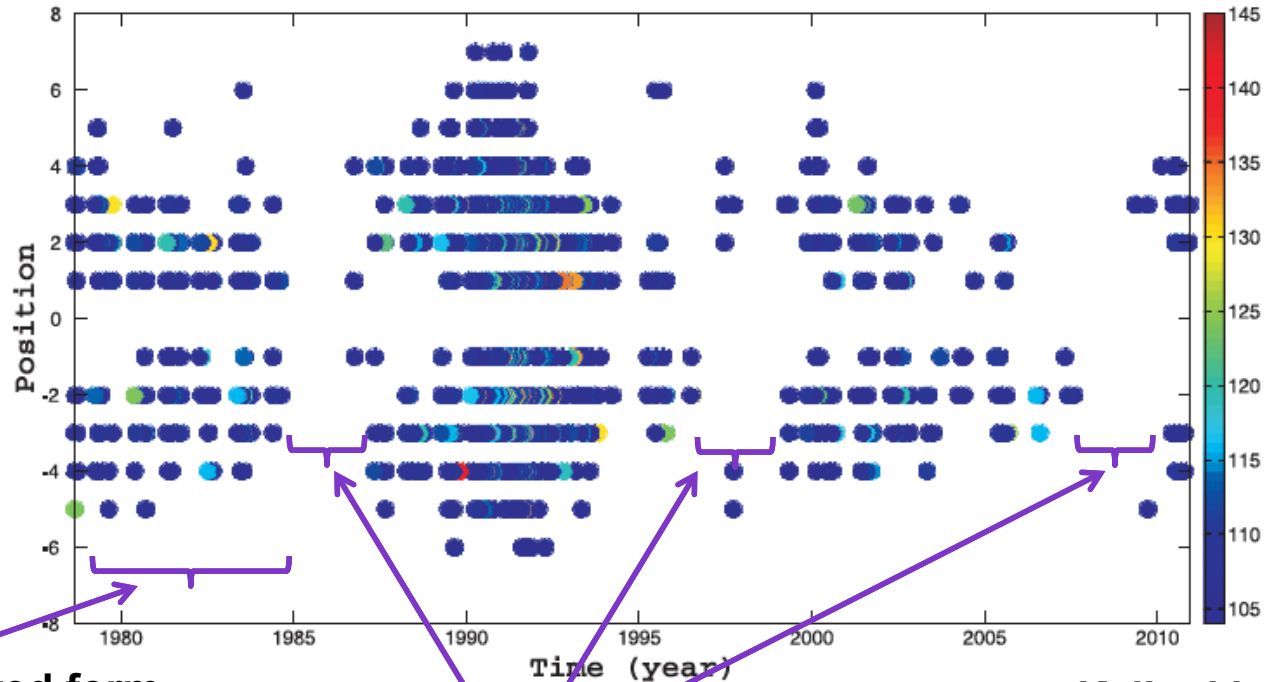
# Solar atmosphere - temperatures at mm-wavelengths



# Research done using MRO data

- **Enhanced temperature regions (ETR) in polar areas (Riehoainen et al., 2001, 2003)**
  - Radio brightening in polar areas are connected to polar faculae and coronal bright points
  - Polar faculae have own cycle?
- **Single event analysis (Pohjolainen et al., 2002)**
- **Short-term variability of active regions, oscillations in minute and hour scales (Smirnova et al., 2011, 2013, 2015)**
- **Statistical distribution of radio brightenings (RB) (Kallunki et al., 2012)**
  - Butterfly diagram
  - Preliminary comparison to sunspot cycle
- **Total solar flux at 11,2 GHz (Uunila and Kallunki, 2015)**
- **Active area (RB) sizes at 7 mm (in preparation)**

# Butterfly diagram at 37 GHz (all radio maps)

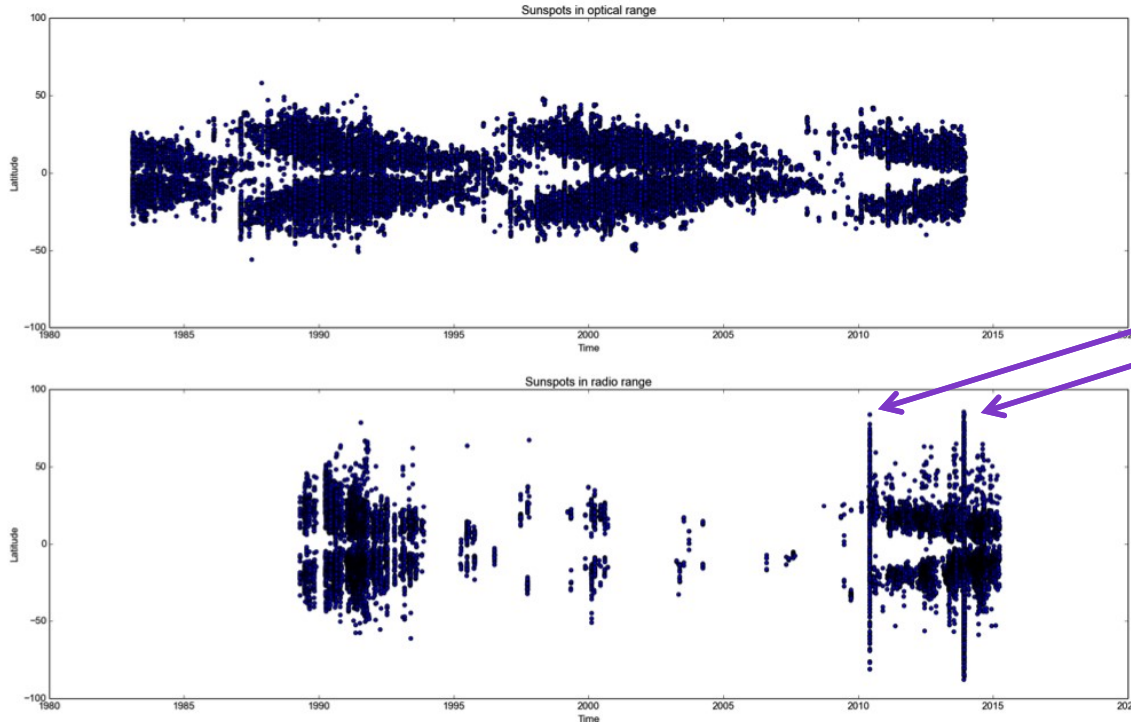


only in printed form

Kallunki et al., 2012.



# Butterfly diagram at 37 GHz (1989-)

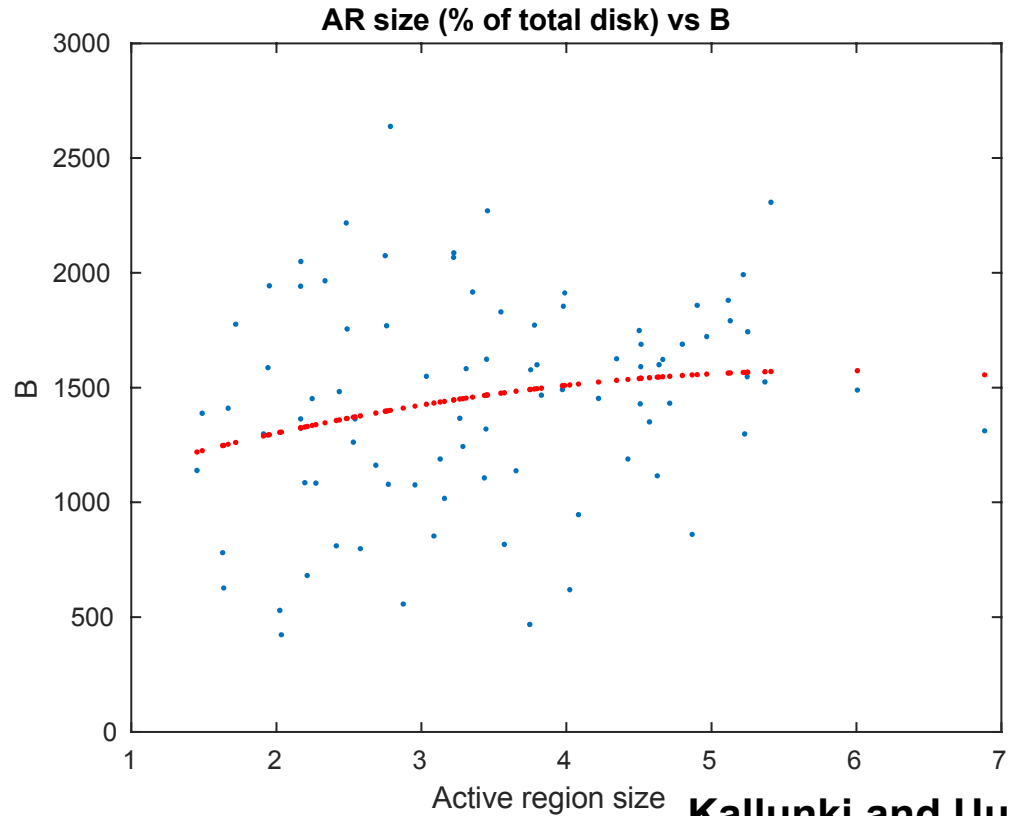


Data errors

Current special assignment project by Lukkari ja Homanen

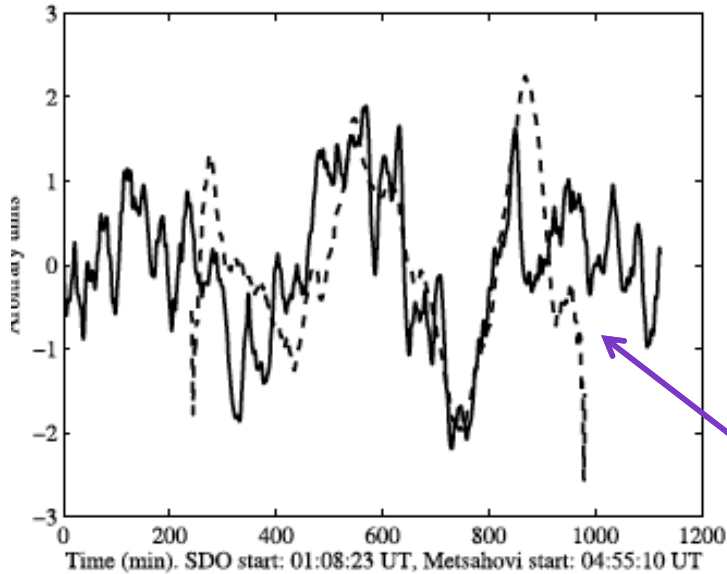
Optical data: Royal Observatory, Greenwich - USAF/NOAA Sunspot Data

# Active area (RB) sizes at 7 mm



Kallunki and Uunila, 2016 (in preparation)

# Quasi-periodic oscillations of active regions at 37 GHz



Solid line = SDO /HMI

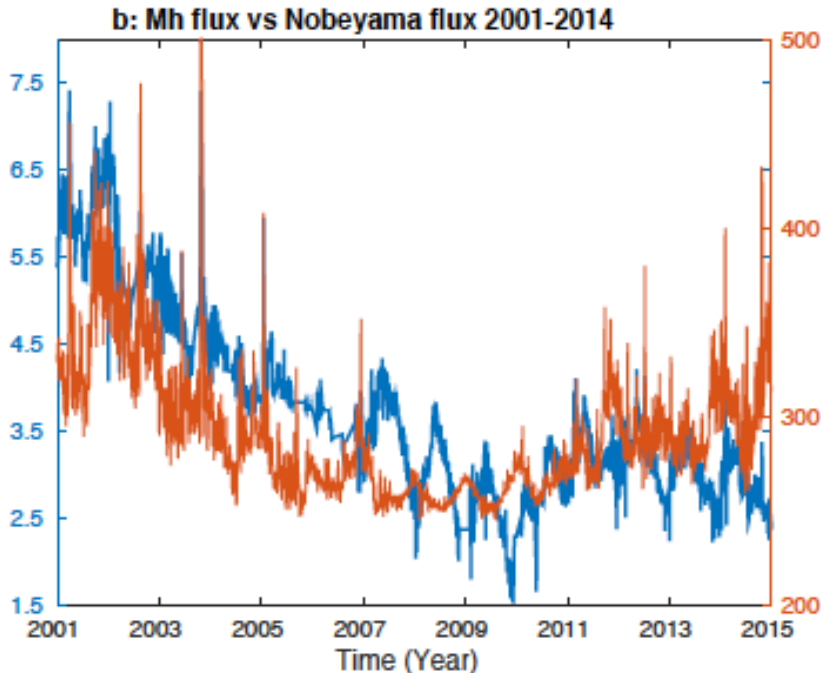
Dashed line = 37 GHz

Date	Active region	( $P$ , minutes)	$\Delta T_{corr}$	$\Delta T_{prop}$ (1)	$\Delta T_{prop}$ (2)	$\Delta T_{prop}$ (3)	$L$ (km)
2011/06/29	11242	200–250, 250–400	18	16.4	15.6	14.9	11300
2011/06/30	11243	200–400	16	20.0	19.01	18.3	13800
2011/07/21	11254	200–300	19	23.9	22.7	21.8	16500
2012/05/02	11471	200–250	23	22.6	21.5	20.6	15600
2012/05/23	11486	250–300	35	34.5	32.8	31.5	23800
2012/05/23	11484	200–250	30	26.7	25.3	24.3	18400
2012/06/20	11510	250–300	27	29.6	28.1	26.9	20400

Maximum temperature of AR at 37 GHz and maximum magnetic field strength of AR  
 → periodicity analysis is performed

Smirnova et al., 2015

# Solar flux at 11,2 GHz (Sunant radiotelescope)



**Blue = MRO at 11,2 GHz  
Red = Nobeyama at 9,4 GHz**

**Uunila and Kallunki, 2015.**

**Statistical distribution of detected  
solar radio events at 11,2 GHz,  
Kallunki and Uunila, 2014.**

# What else we could study?

- **Statistical distribution of radio brightenings → comparison with other wavelengths (magnetic fields etc.)**
- **Observing the upcoming solar minimum at mm-wavelengths**
- **Low temperature regions at mm-wavelengths**
  - Connection to e.g. coronal holes?
  - Cyclicity
  - Rotation
- **Modeling aspect by ReSoLVE team?**

# Additional information

- **The data are already available online:**
  - Solar radio maps at 37 GHz (<http://www.metsahovi/solar-gallery>)
  - Total solar flux at 11,2 GHz (<http://www.metsahovi/Sunant>)
  - Callisto data (<http://soleil.i4ds.ch/solarradio/callistoQuicklooks/>, MRO=Metsähovi)
- **To have access to raw (scientific) data, and for more information about observations or instrumentation, please contact Juha Kallunki ([juha.kallunki@aalto.fi](mailto:juha.kallunki@aalto.fi))**

# Thank you!

[http://metsahovi.aalto.fi/en/research/projects/solar\\_radio/](http://metsahovi.aalto.fi/en/research/projects/solar_radio/)

