Cosmic Masers

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What is a Maser?

- Microwave Amplification by Stimulated Emission of Radiation
- Microwave version of a LASER
- Occur astronomically in gas around young and evolved stars, the centre of AGN, supernova remnants, protoplanetary nebula and comets
Common Species

- OH
  - $\rightarrow$ 180mm: 1612, 1665, 1667, 1720 MHz
  - $\rightarrow$ 63mm: 4750 & 4765 MHz
  - $\rightarrow$ 50mm: 6035 & 6030 MHz

- H$_2$O
  - $\rightarrow$ 13mm: 22.235 GHz
  - $\rightarrow$ 3mm: 96.261 GHz
Common Species

• **CH$_3$OH**
  → 45mm: 6669 MHz
  → 25mm: 12179 MHz
  → 13-8mm: 23.1, 28.9, 37.7, 38.2 GHz
  → 3mm: 85.5, 86.6, 86.9, 93.1, 94.5 GHz
  → 3mm: 107.0, 108.8 GHz

• **SiO**
  → 7mm: 42.820 & 43.122 GHz
  → 3mm: 86.243 GHz

294 transitions from 800 MHz to 800 GHz
Uncommon Species

- **NH$_3$**
  → 16-12mm: 18.5 – 23.9 GHz
- **HCN**
  → 3mm: 88.631 GHz
- **H$_2$CO (formaldehyde)**
  → 62mm: 4830 MHz
- **Radio recombination lines**
  → 2mm-25µm: 147 GHz – 12 THz
Properties of a Maser

- The maser components are extremely small (mas) and narrow (fractions of a km/s)
  → Measure position and velocity of components with great accuracy
- Require long path length of velocity coherent gas
- Requires a mechanism to “pump” the gas into an excited state
Astronomical Tools

- Velocity probes
- Proper motions
- Geometric and statistical parallax → Distance estimates
- Zeeman splitting → Measure magnetic fields
- Interstellar scattering → Probes of ISM throughout Galaxy
Star Forming Regions

- OH, H$_2$O and methanol masers found towards massive star forming regions
  → SiO detected in 3 SFR
- Young massive stars highly embedded
  → Masers one of the few tools for study
- Many associated with UCH$_{II}$ regions
- Some probably associated with protostars
6.7-GHz methanol in G339.88-1.26
SiO masers in Orion BN/KL

Evolved Stars (OH/IR)

- SiO, H₂O & OH masers form in outer envelope of evolved (AGB) stars
SiO masers in TX Cam

Movie courtesy of Phil Diamond, Jodrell Bank
Other Galactic Masers

- SNR show OH emission 1720 MHz
- OH, H$_2$O and SiO masers are present in protoplanetary nebula
- 18 cm OH emission detected in many comets
Extragalactic OH Masers

- 1667 MHz (plus other 18 cm) OH masers detected towards IR luminous galaxies
- Isotropic luminosities $10^3$ – $10^6$ times larger than brightest Galactic masers
- Most distant $\sim z=0.3$
- “Diffuse” and compact component
Extragalactic H$_2$O Masers

- “Normal” H$_2$O masers detected in nearby galaxies
- Megamaser emission occurs in active galactic nuclei (AGNs)
  → in shocks driven by jets and winds
  → in accretion disks of supermassive black holes
Mass = $3.6 \times 10^7 \, M_\odot$
Dist = $7.2 \pm 0.3 \, \text{Mpc}$

Image courtesy of Lincoln Greenhill, CfA VLBI Group

See also:


Project VERA

- VLBI Exploration of Radio Astrometry
- Dedicated phase referencing VLBI network
  - Four 20-m antennas spread over Japan with dual-beam systems
  - Up to 2 degree separation
- Baselines 1000 – 2300 km
- 128 MHz bandwidth (1 Gbps)
Project VERA

- S/X, 22 & 43 GHz receivers
  - S/X for geodetic observations
  - Position & proper motion of H$_2$O & SiO masers
- 10µs relative positional accuracy
- Determine distances of D kpc with uncertainty D% (e.g. 10% at 10kpc)
  - Distance to GC, Galactic rotation at Sun, Outer rotation curve, Distribution of Dark Matter, Shape of Galaxy, Megamasers – proper motions
Analysis

• Model fit in the image cube
  → Super resolve!
  → Beware large scale structure

• “In beam” phase reference
  → Accurate relative positions

• Hanning smooth
New ATCA Possibilities

- Access to most of the Galactic plane
- 22 GHz water masers → SFR, evolved stars, megamasers → 96 GHz water maser
- 86 GHz SiO masers → stellar environment, Galactic rotation → YSO?
- mm methanol transitions → 107 GHz et al