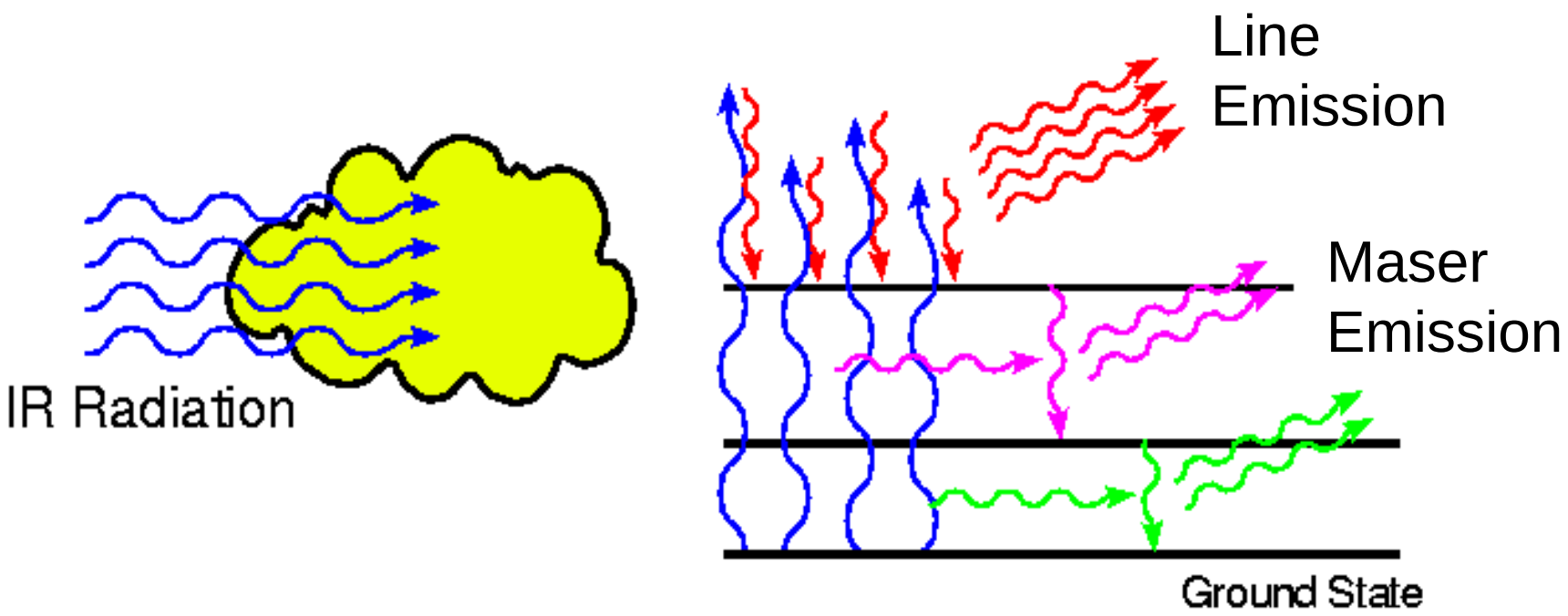
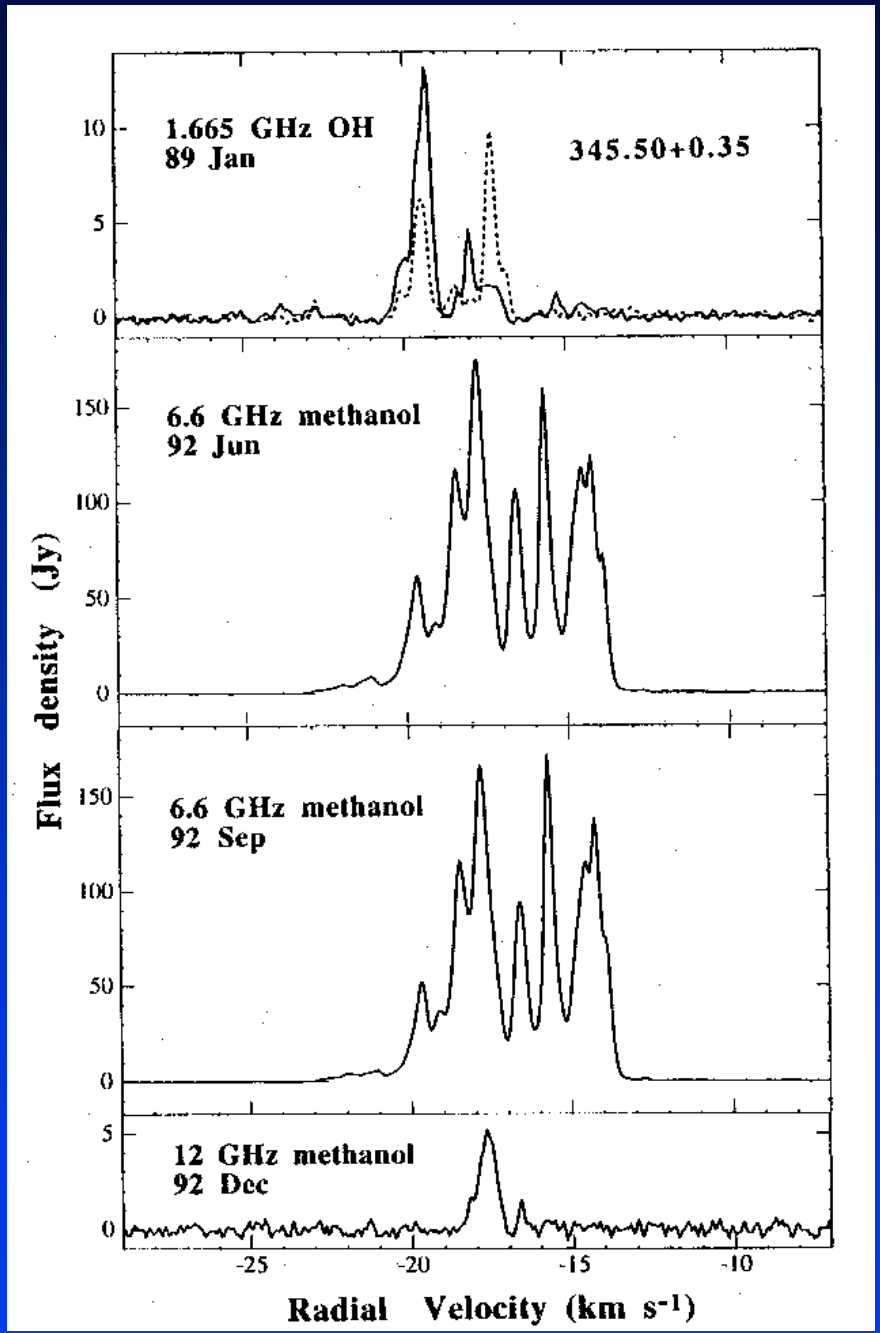
# *Cosmic Masers*

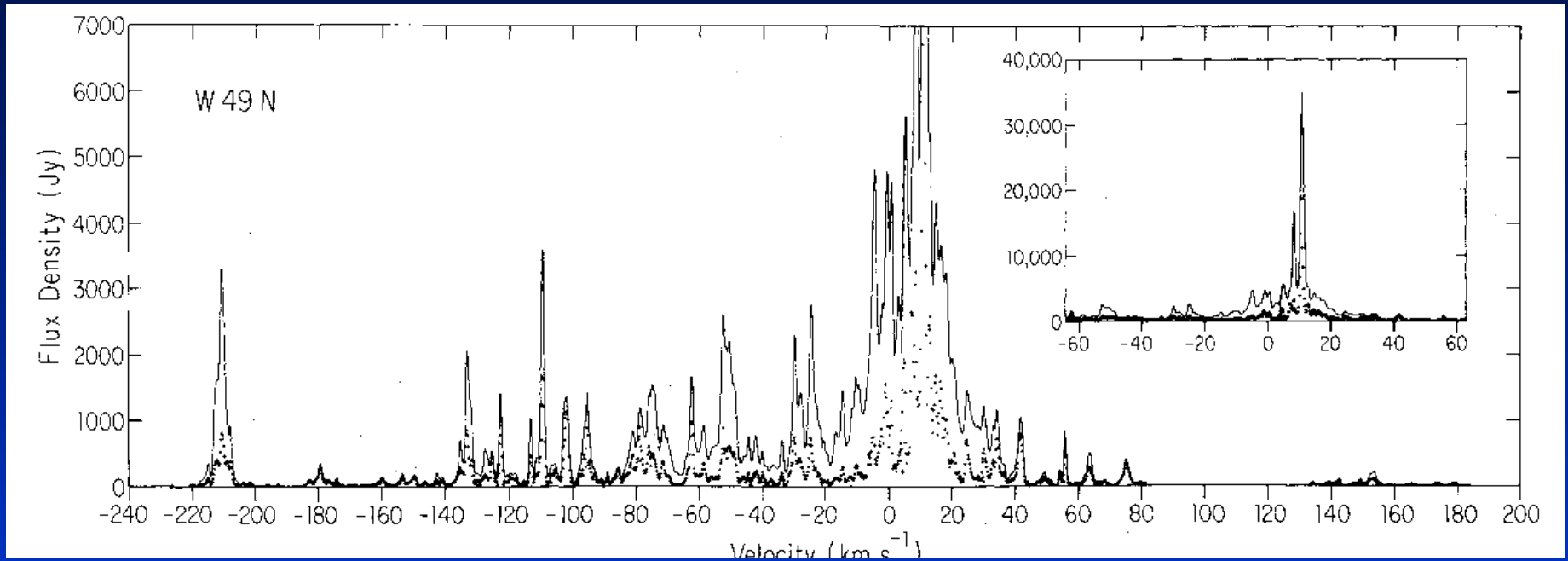
Chris Phillips
CSIRO / ATNF

# *What is a Maser?*



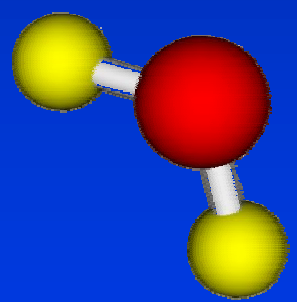



Caswell, et al 1995 MNRAS 272

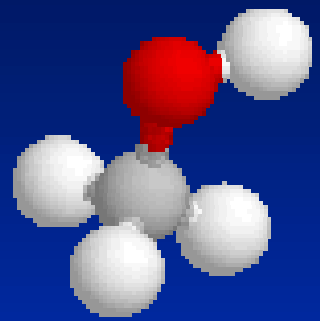

W 49 N
Flux Density (Jy)
7000
6000
5000
4000
3000
2000
1000
0
40,000
30,000
20,000
10,000
0
-60
-40
-20
0
20
40
60
-240 -220 -200 -180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120 140 160 180 200
Velocity (km s$^{-1}$)

# *Common Species*

- OH
  - → 180mm: 1612, 1665, 1667, 1720 MHz
  - → 63mm: 4750 & 4765 MHz
  - → 50mm: 6035 & 6030 MHz
- $H_2O$
  - → 13mm: 22.235 GHz
  - → 3mm: 96.261 GHz



# *Common Species*

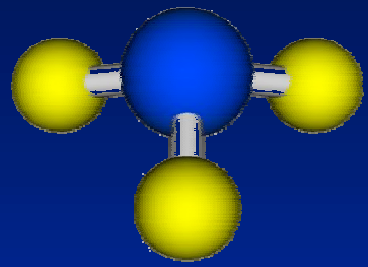


- $CH_3OH$
  - → 45mm: 6669 MHz
  - → 25mm: 12179 MHz
  - → 13-8mm: 23.1, 28.9, 37.7, 38.2 GHz
  - → 3mm: 85.5, 86.6, 86.9, 93.1, 94.5 GHz
  - → 3mm: 107.0, 108.8 GHz

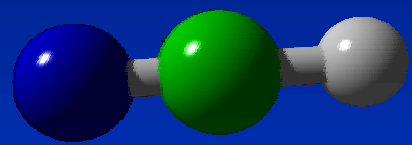
294 transitions from 800 MHz to 800 GHz

- SiO
  - → 7mm: 42.820 & 43.122 GHz
  - → 3mm: 86.243 GHz

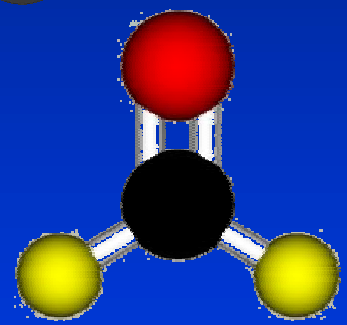
# *Uncommon Species*



- $NH_3$
  - → 16-12mm: 18.5 – 23.9 GHz
- HCN
  - → 3mm: 88.631 GHz



- $H_2CO$ (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

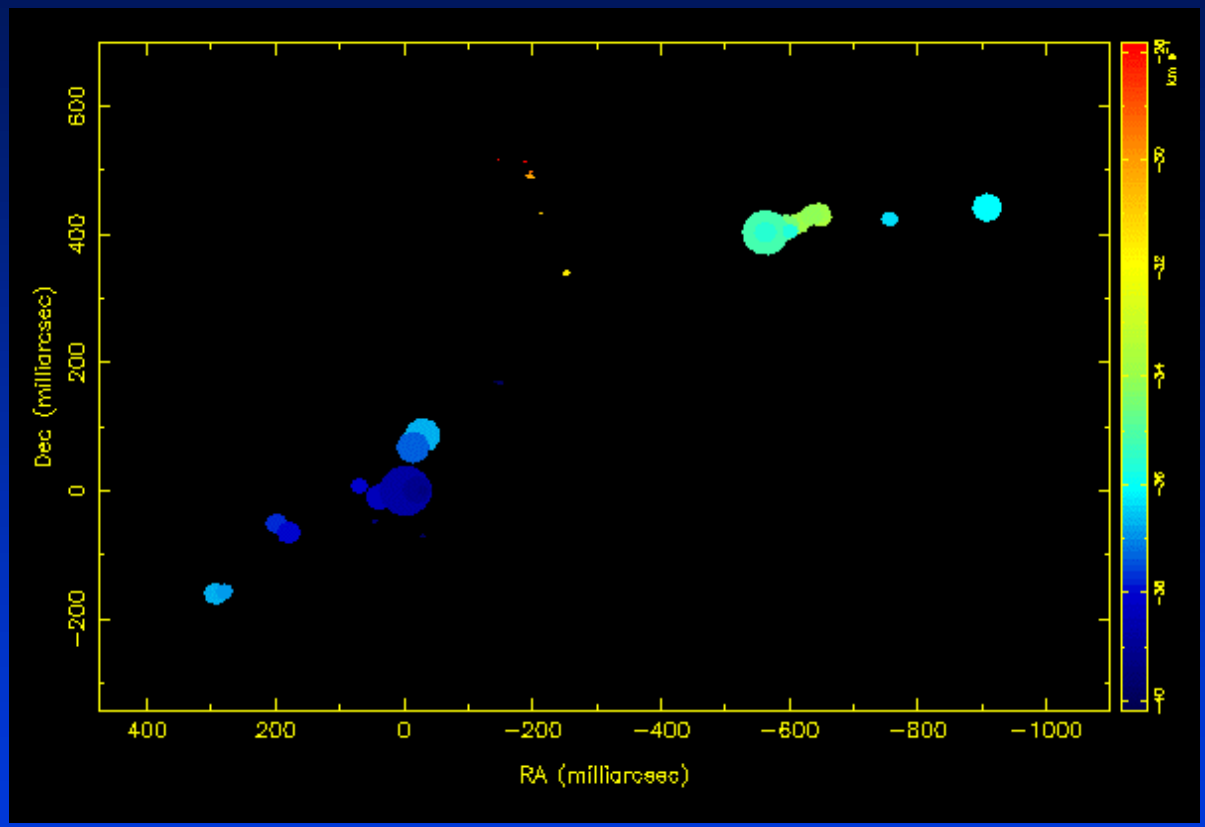
# *Astronomical Tools*

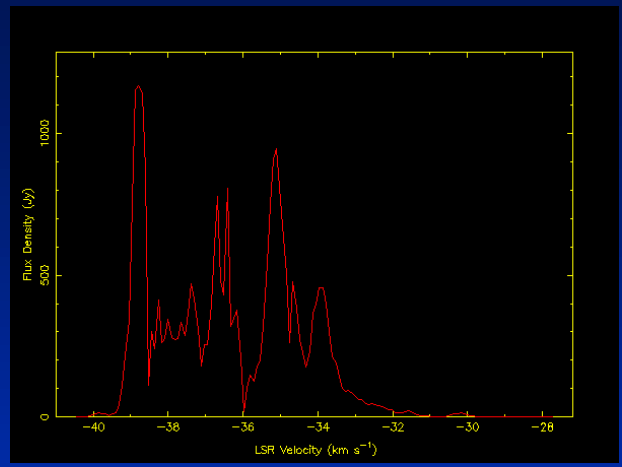
- Velocity probes
- Proper motions
- Geometric and statistical parallax
  $\rightarrow$ Distance estimates
- Zeeman splitting
  $\rightarrow$ Measure magnetic fields
- Interstellar scattering
  $\rightarrow$ Probes of ISM throughout Galaxy

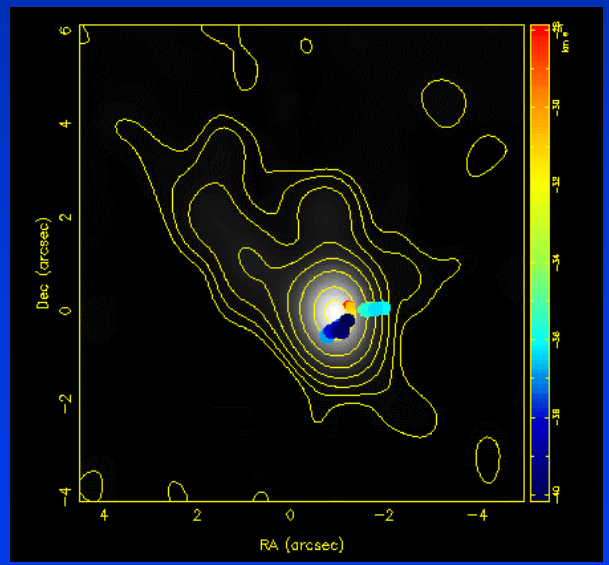
# *Star Forming Regions*

- OH, $H_2O$ and methanol masers found towards massive star forming regions
  - $\rightarrow$ SiO detected in 3 SFR
- Young massive stars highly embedded
  - $\rightarrow$ Masers one of the few tools for study
- Many associated with UCHII regions
- Some probably associated with protostars

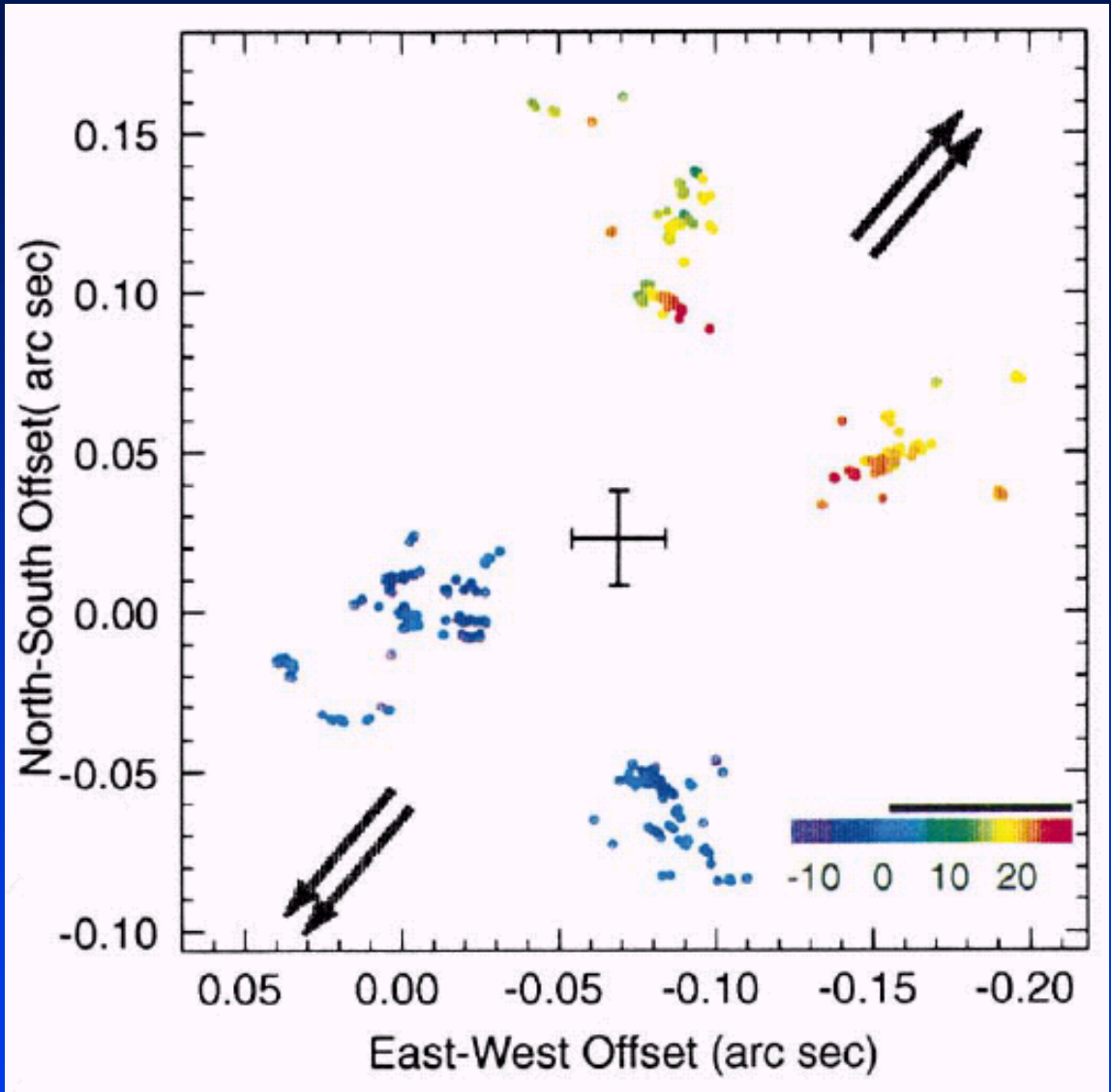
# 6.7-GHz methanol in G339.88-1.26



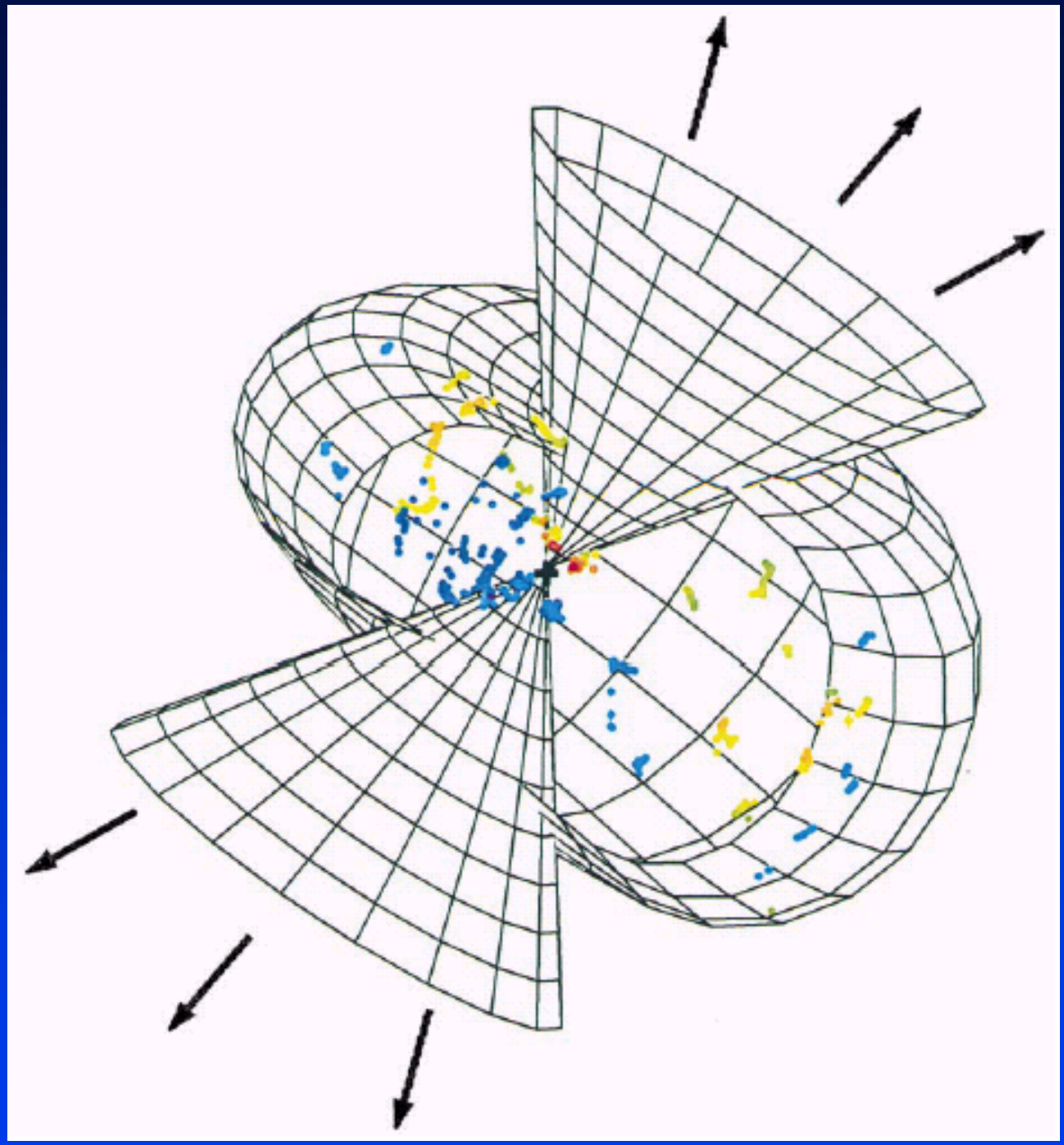



# SiO masers in Orion BN/KL




Greenhill etal, 1998, *Nature*, **396**, 650



# *Evolved Stars (OH/IR)*

- SiO,$H_2O$ & OH masers form in outer envelope of evolved (AGB) stars

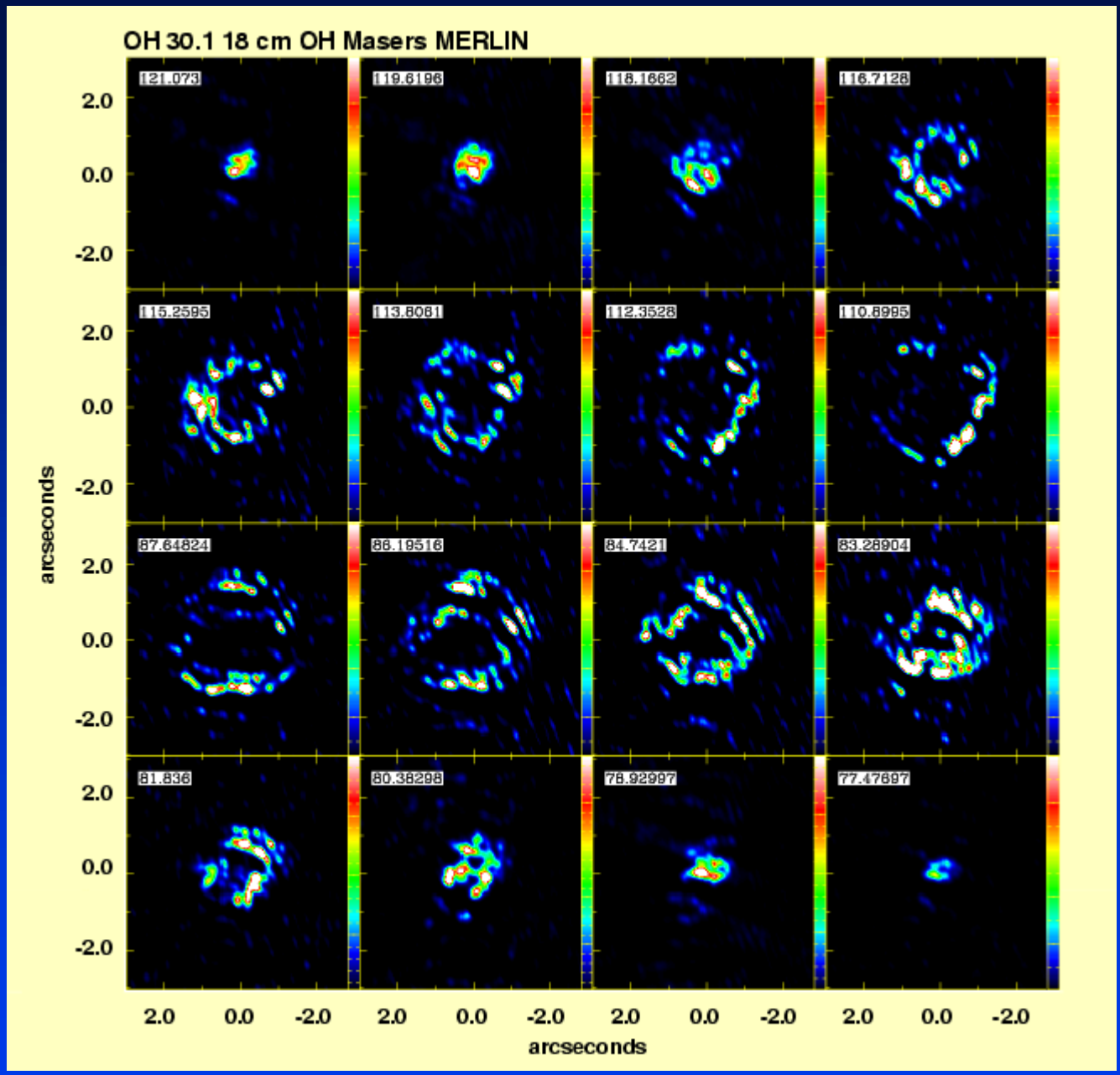



Image courtesy Jessica Chapman

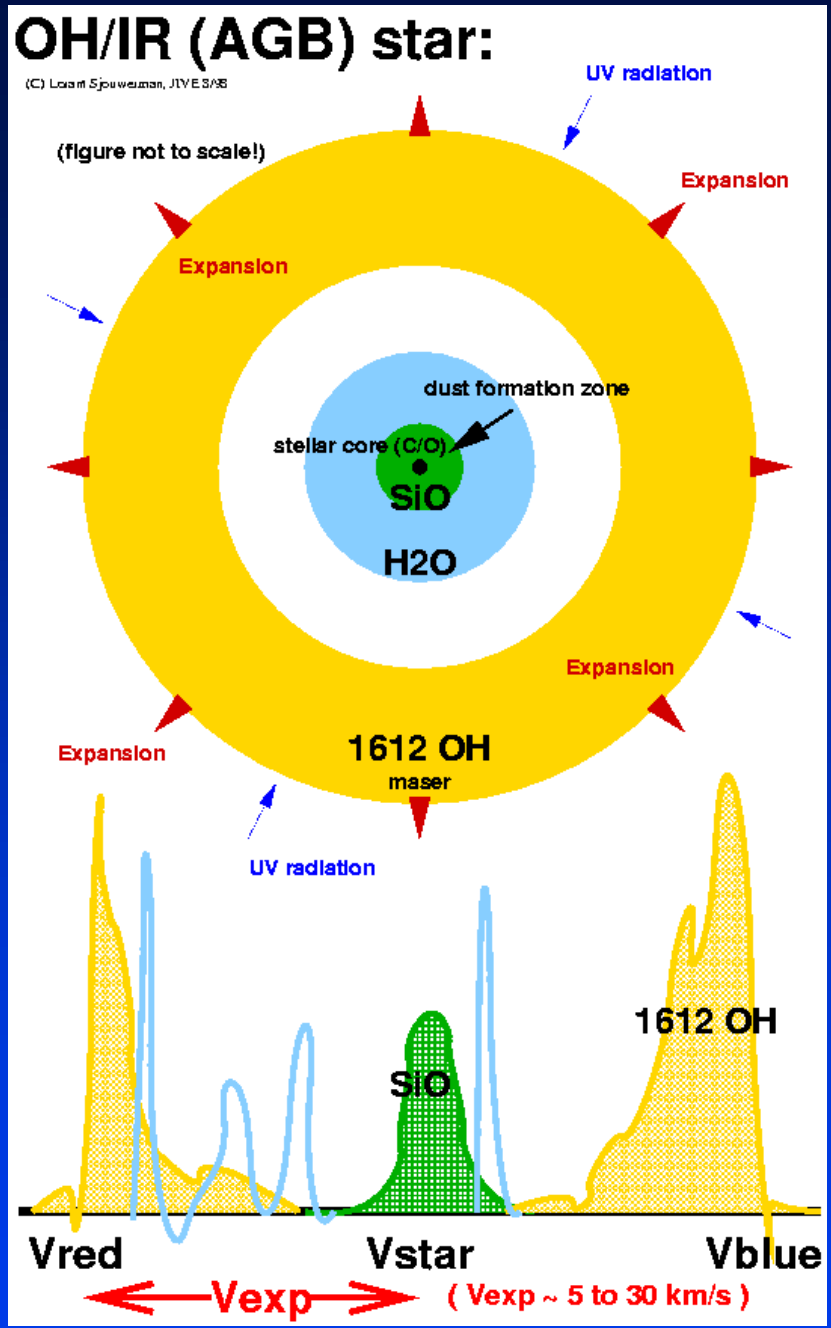
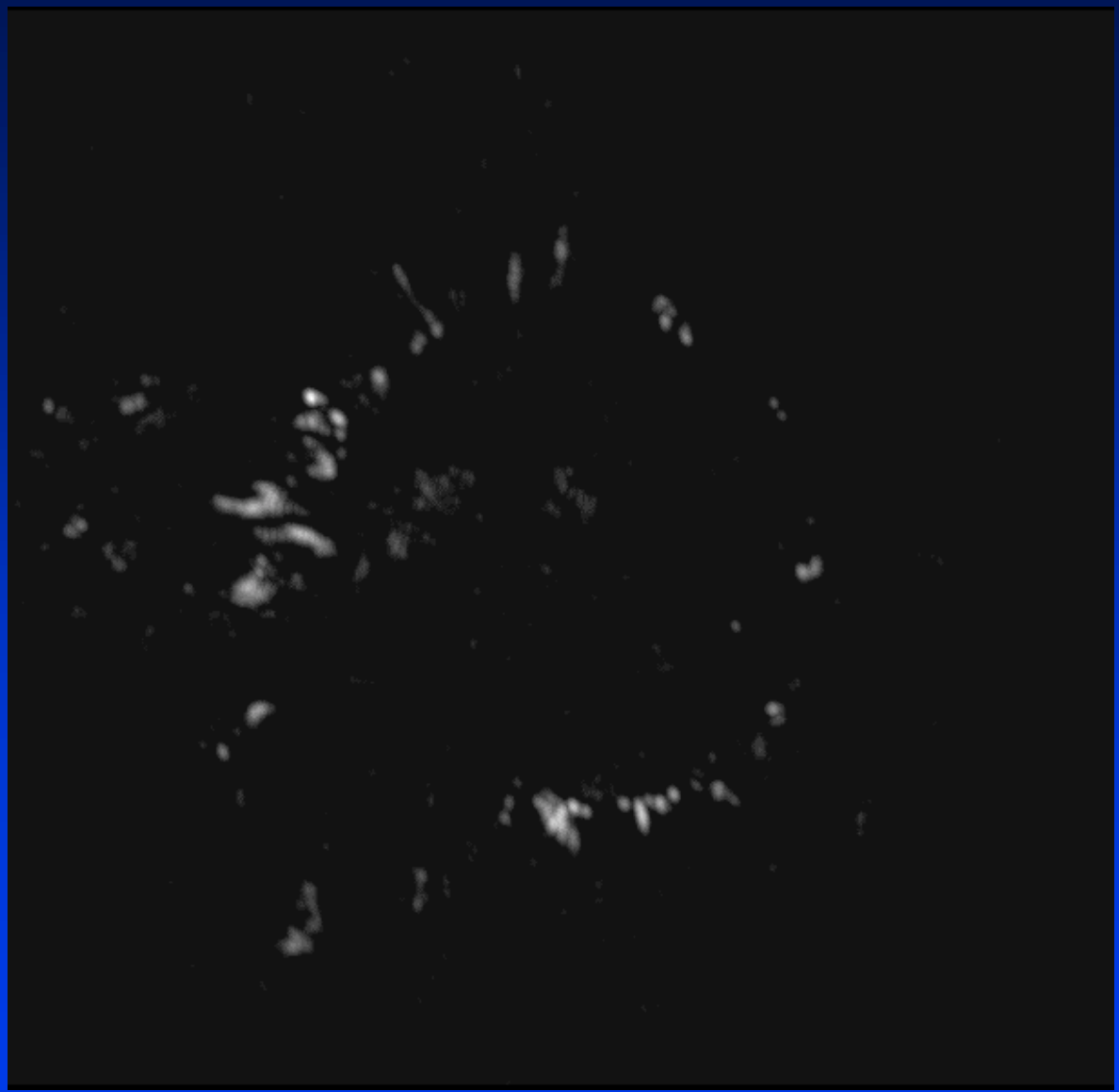



Image courtesy
Lorant Sjouwerman

# SiO masers in TX Cam



Movie courtesy of
Phil Diamond,
Jodrell Bank

# *Other Galactic Masers*

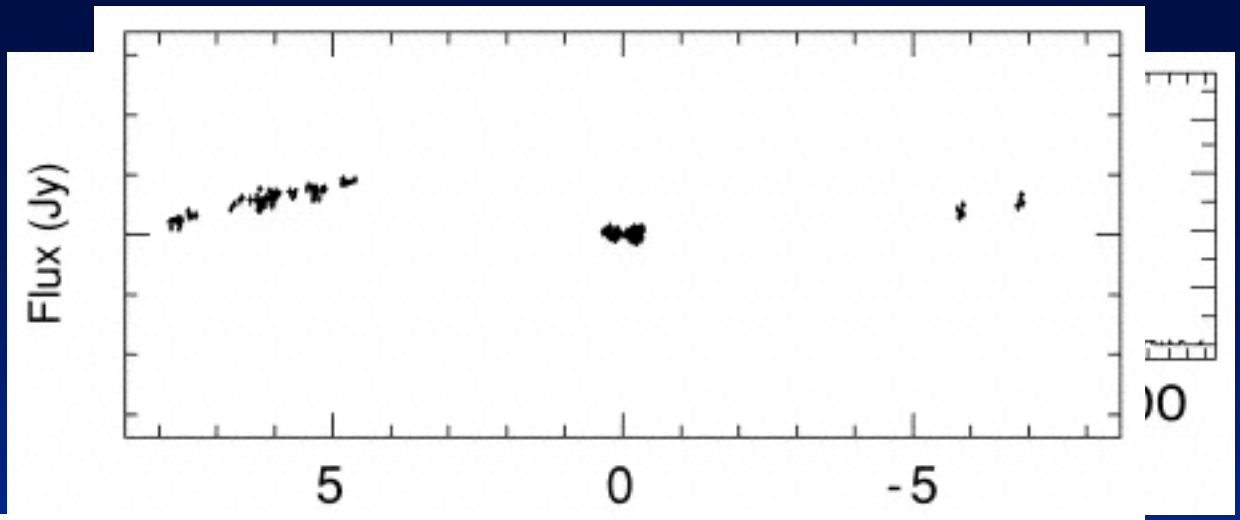
- SNR show OH emission 1720 MHz
- OH, $H_2O$ and SiO masers are present in protoplanetary nebula
- 18 cm OH emission detected in many comets

# *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 ~ z=0.3
- “Diffuse” and compact component

# *Extragalactic $H_2O$ Masers*

- "Normal" $H_2O$ masers detected in nearby galaxies
- Megamaser emission occurs in active galactic nuclei (AGNs)
  - $\rightarrow$ in shocks driven by jets and winds
  - $\rightarrow$ in accretion disks of supermassive black holes




Mass = $3.6 \times 10^7\ M_\odot$

Dist = $7.2 \pm 0.3$ Mpc

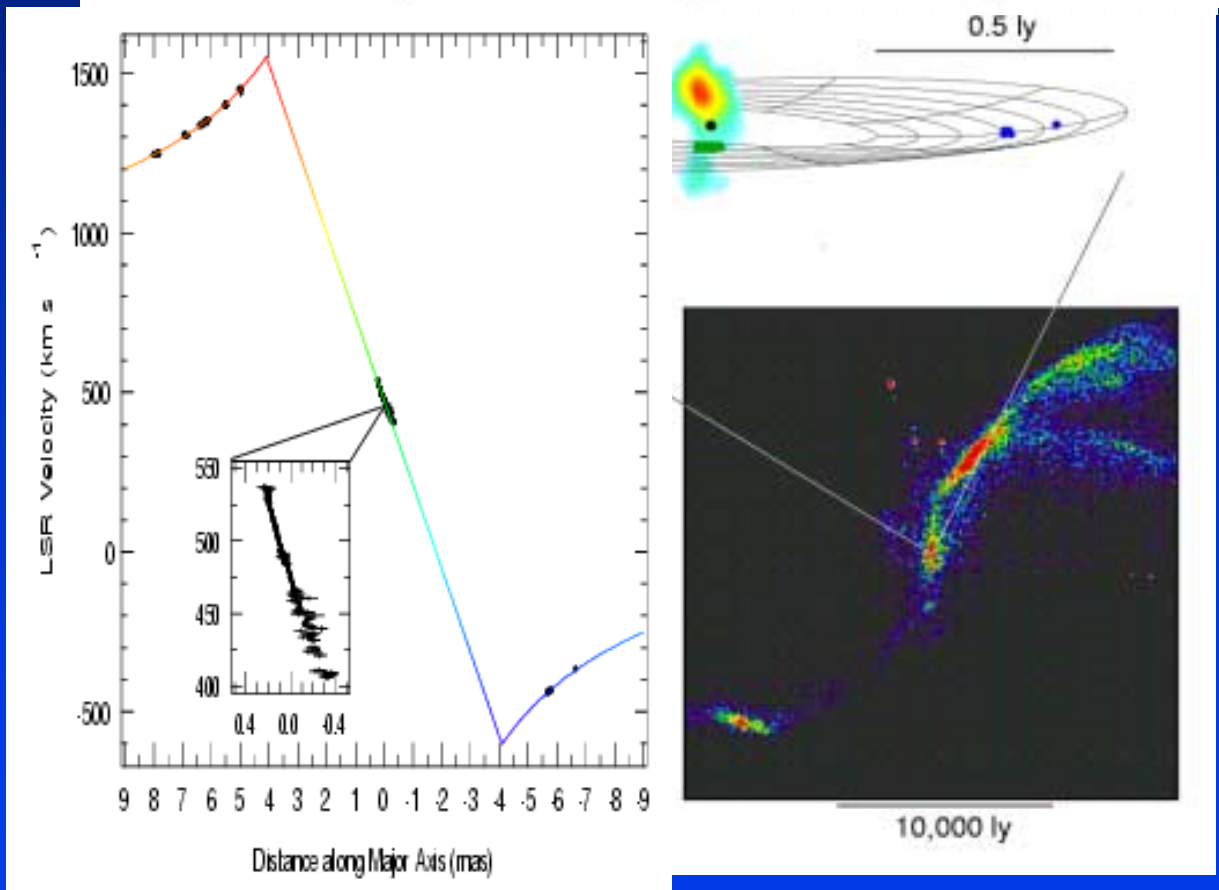



Image courtesy of Lincoln Greenhill, CfA VLBI Group

See also:

Hernstein etal, 1999, *Nature*, **400**, 539

Miyoshi etal, 1995, *Nature*, **373**, 127



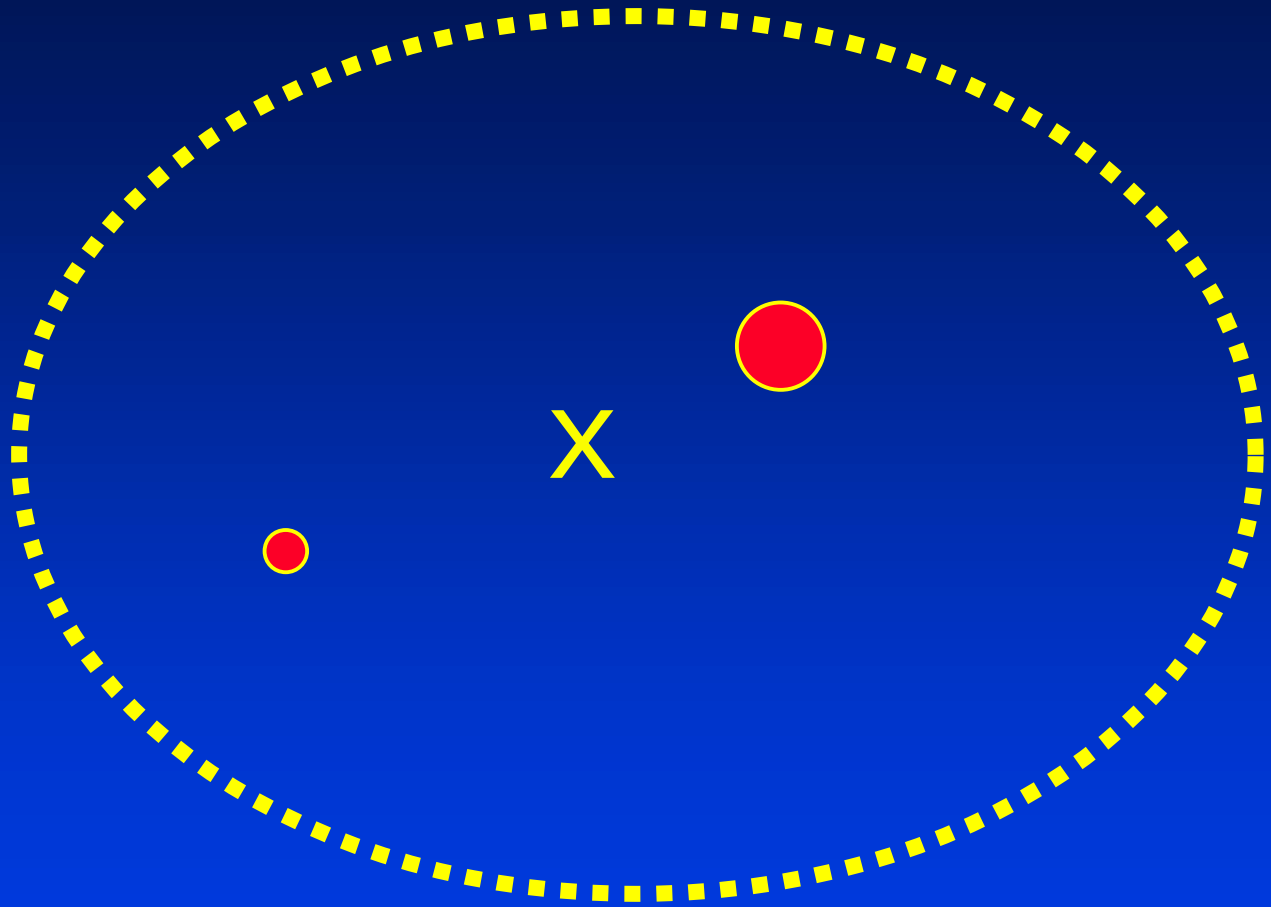

- V
- D
  r
- Fou ver Japan
  with dual beam systems
  → Up to 2 degree separation
- Baselines 1000 – 2300 km
- 128 MHz bandwidth (1 Gbps)

# *Project VERA*

- S/X, 22 & 43 GHz receivers
  - → S/X for geodetic observations
  - → Position & proper motion of $H_2O$ & 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


X

# *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