2MASS/D.Figer

Finding Red Supergiants in the Galaxy and Measuring their Distances

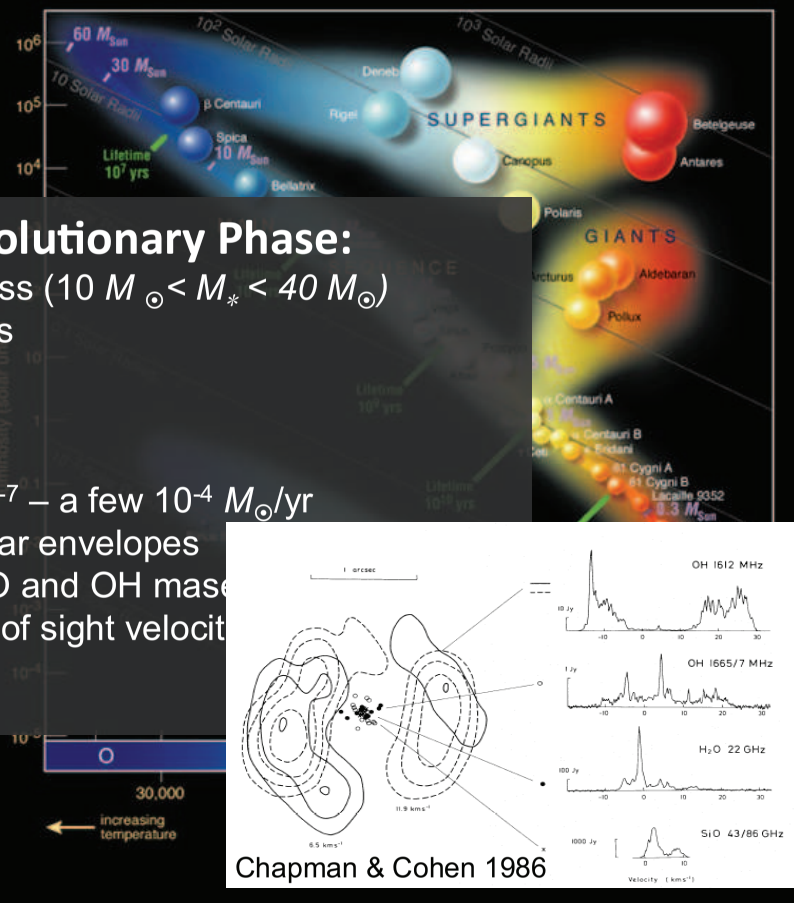
Karl Menten
MPI für Radioastronomie, Bonn

XXVIII IAU General Assembly Beijing

2012 August 24

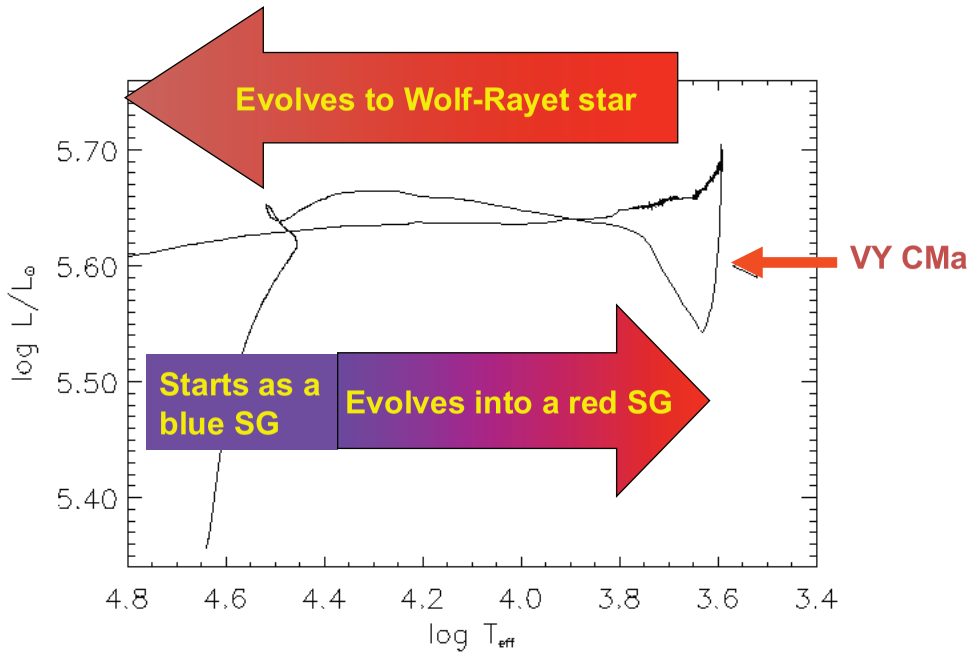
The Red Supergiant Evolutionary Phase:

- Stars of moderately high mass (10 $M_\odot < M_* < 40\ M_\odot$)
- near the end of their lifetimes
- Helium core burning
- $L = 10^4$ – a few $10^5\ L_\odot$
- $T_{eff} \sim 3000 - 4000$ K
- (Often heavy) mass loss: 10^{-7} – a few $10^{-4}\ M_\odot$/yr
  - Formation of circumstellar envelopes
    - sometimes SiO, H_2O and OH mase
      - yield stellar line of sight velocit



Chapman & Cohen 1986

Evolutionary track of a 40 solar mass star of solar metallicity



zero age main sequence → red supergiant → Wolf-Rayet star

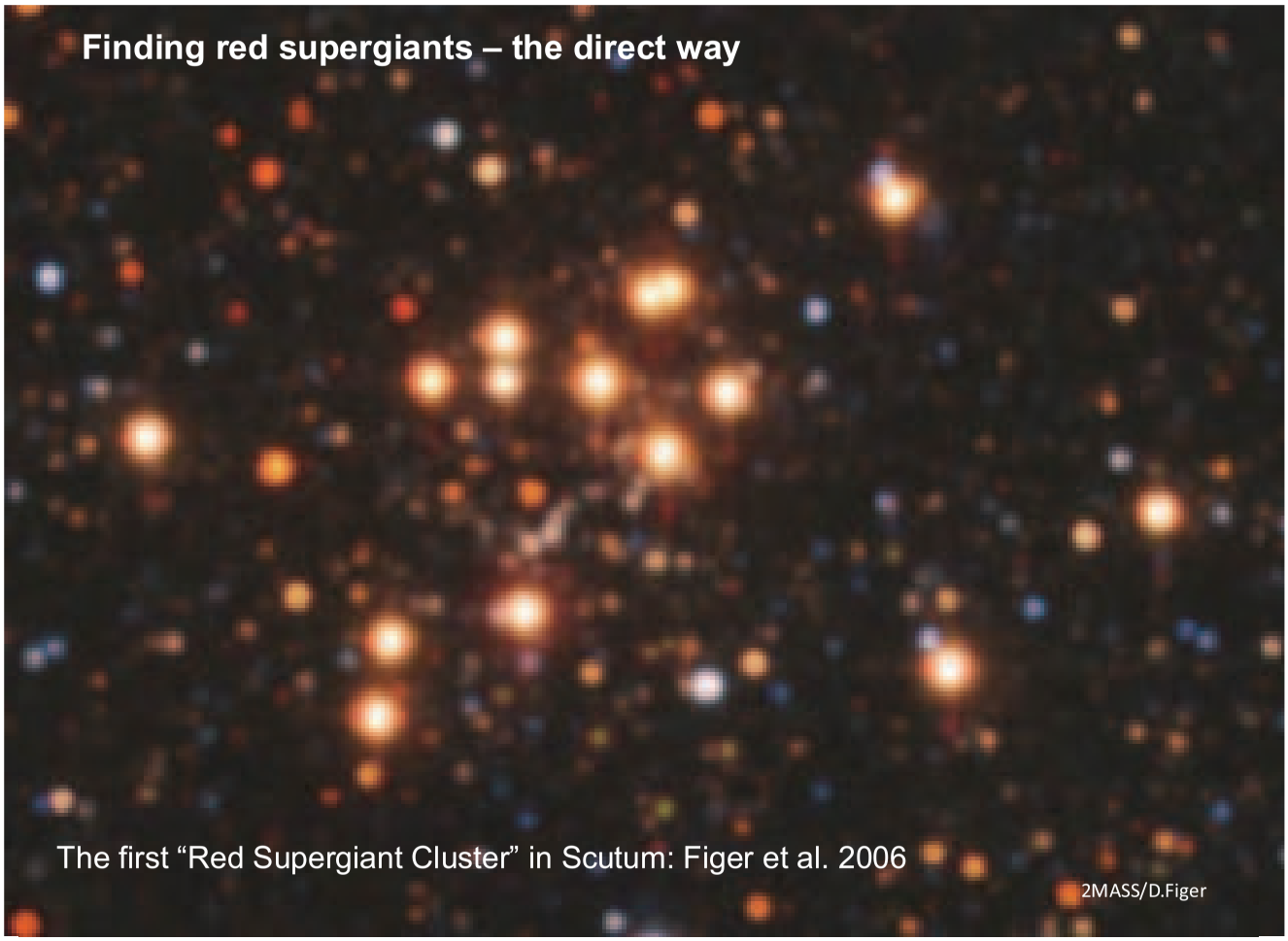
from Wittkowski, Weigelt, Langer 1998

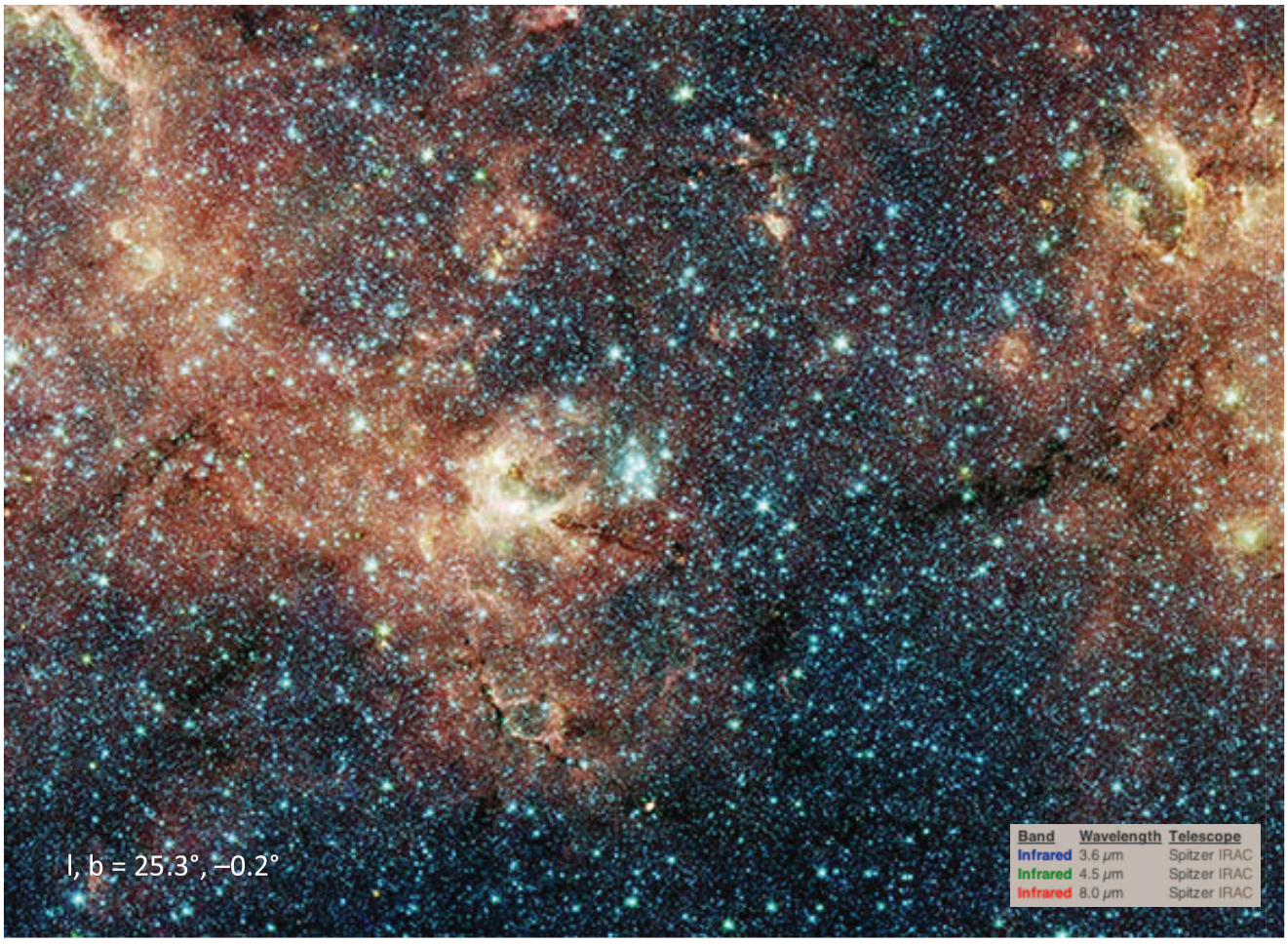
Red Supergiants

- Contribute to the enrichment of the ISM
- Intrinsically luminous in the infrared
- Trace young stellar populations
  - even in external galaxies
  - (often) near GMCs → sequential star formation?
  - potential as probes of Galactic structure
- **Problems:**
  - only ~ 500 known
    - Very few studied in detail
  - far away
    - uncertain distances
    - interstellar extinction

- **(Some) Open Questions:**
  - Relations between
    - the maximum luminosity of a given star and its main-sequence mass
    - mass-loss rate and stellar luminosity and initial metallicity
  - Nature of the CSE: Why do some RSGs show maser emission and others don't
    Function of mass-loss rate?

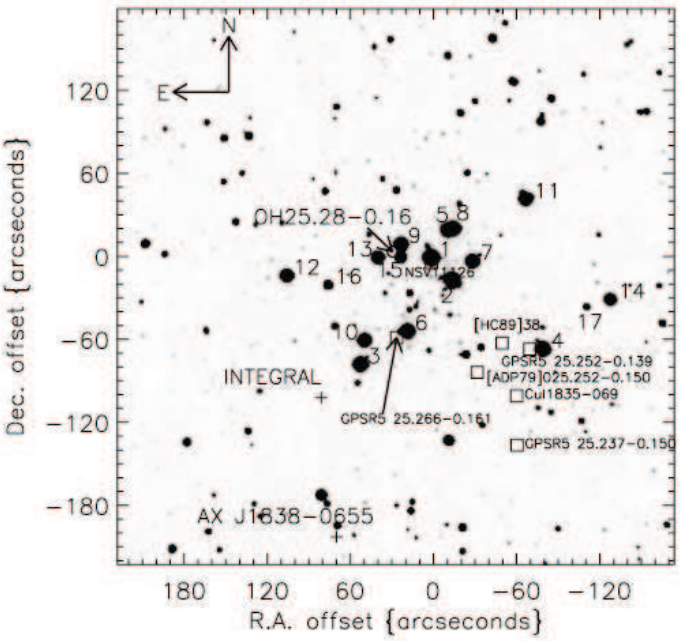
Finding red supergiants – the direct way

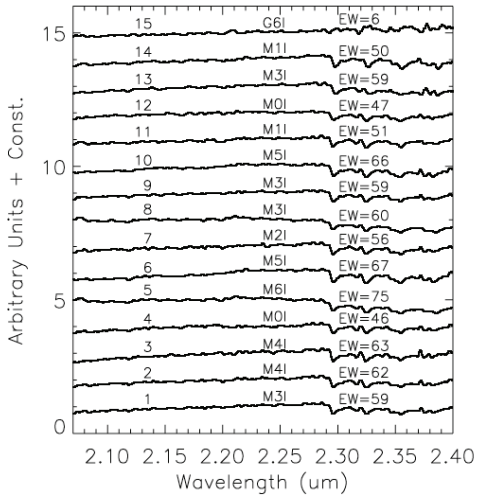




Red Supergiant Cluster 1 (Figer et al. 2006)

- 14 RSGs
- 7 – 15 Myr old, total mass 20000–40000 $M_\odot$
- D ~ 6 kpc





Within cluster area:

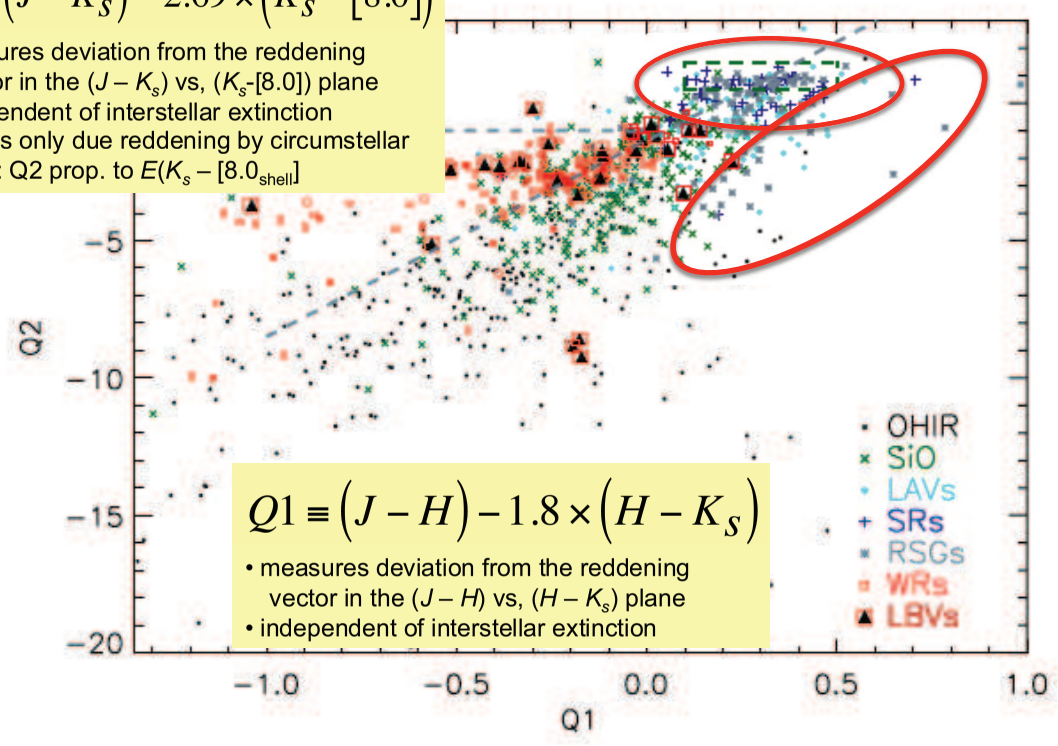
- Radio sources
- (peculiar) x-ray source
- γ-ray source

Talk by Negueruela

Finding red supergiants (II) (somewhat more sophisticated)

$$Q2 \equiv \left(J - K_S\right) - 2.69 \times \left(K_S - \left[8.0\right]\right)$$

- measures deviation from the reddening vector in the $(J - K_s)$ vs, $(K_s$-[8.0]) plane
- independent of interstellar extinction
- excess only due reddening by circumstellar shell: Q2 prop. to $E(K_s - [8.0_{shell}]$



$$Q1 \equiv \left(J - H\right) - 1.8 \times \left(H - K_S\right)$$

- measures deviation from the reddening vector in the $(J - H)$ vs, $(H - K_s)$ plane
- independent of interstellar extinction

Messineo et al. 2012

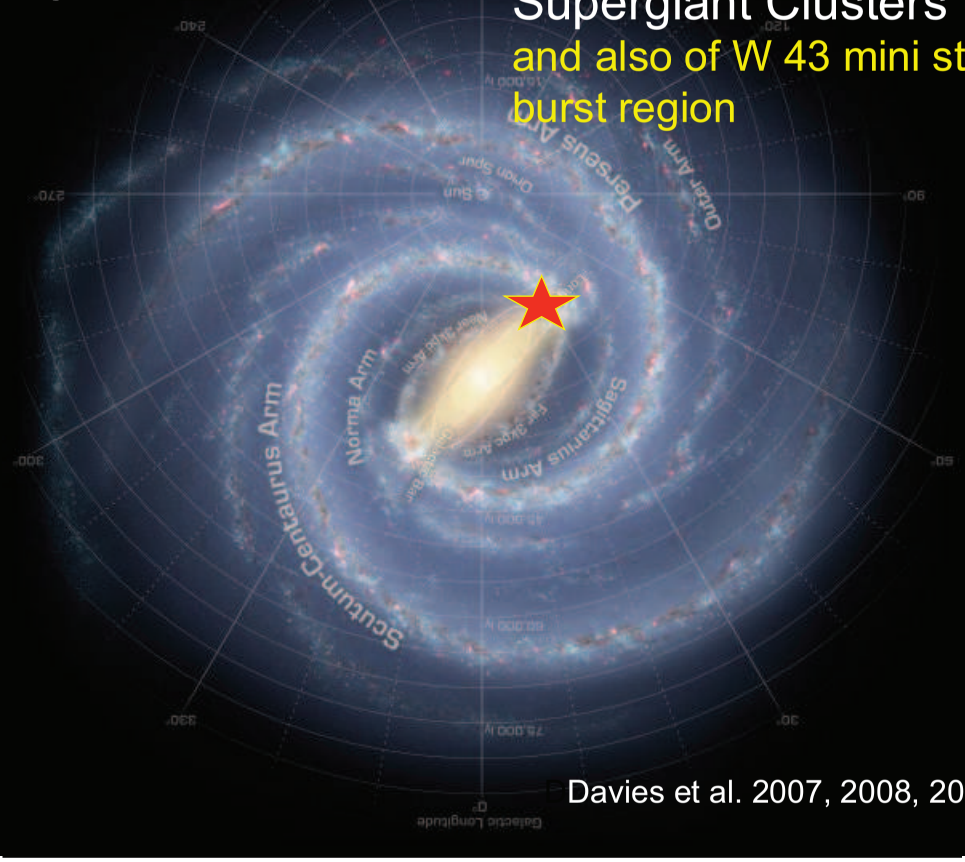
The Scutum Red Supergiant Clusters – summary of physical properties

RSGC2 -
- 26 RSGs
- $M_{cl} = (4 \pm 1) \times 10^4 M_\odot$
- Age = 17 ± 4 Myr

RSGC1 -
- 14 RSGs
- $M_{cl} = (3 \pm 1) \times 10^4 M_\odot$
- Age = 12 ± 2 Myr

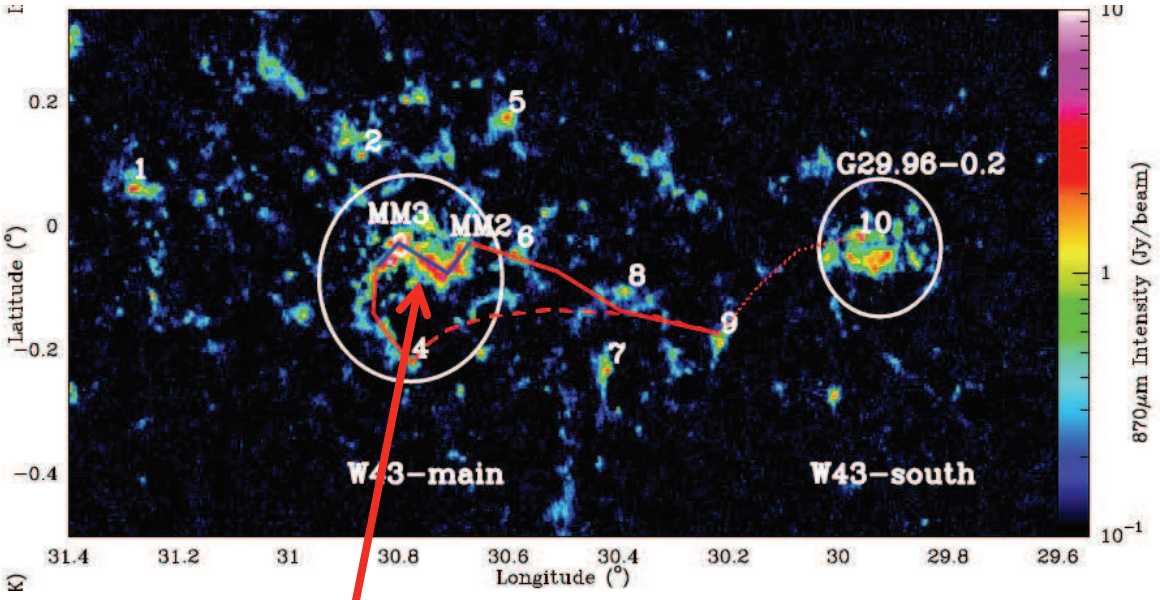
$R_G \approx 3.5$ kpc

Location of the Red Supergiant Clusters and also of W 43 mini star-burst region



Davies et al. 2007, 2008, 2009

The W43 "mini-starburst" region



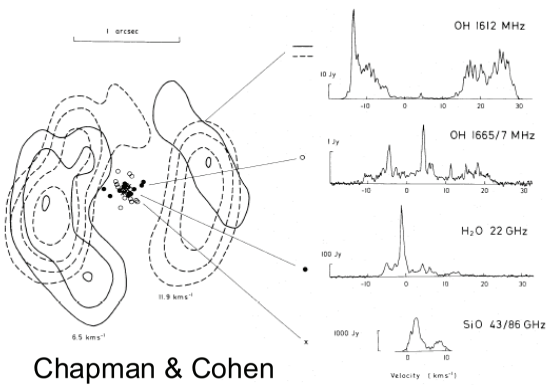
Harbors extremely luminous HII region (powered by ~4 10^6 $L_{\odot}$ OB and WR stars, Blum et al. 1999)

870 µm dust emission
LABOCA@APEX

Nguyen-Luong et al 2011

Circumstellar masers are excellent kinematic probes

- Line of sight velocities follow directly from centroid of line profiles
  → Kinematic distances (in conjunction with a rotation curve)
- Very Long Baseline Interferometry allows direct determination of distances and proper motions
  → Location in Milky Way and peculiar motions



Chapman & Cohen

SiO in RSGC1

v = 1, J = 1–0 / 43.1 GHz

Nobeyama 45m

4 out of 14

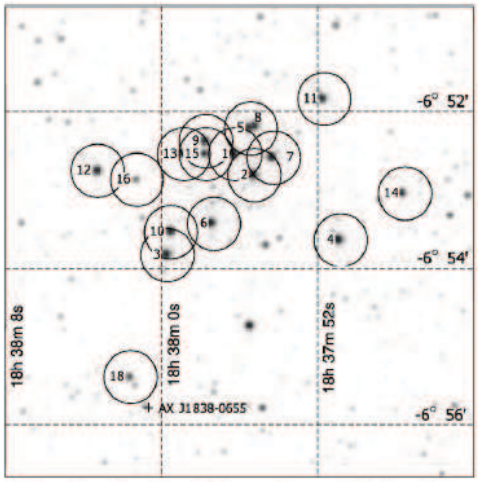


FIG. 1.—Observed positions and telescope beam areas (HPBW = 40″) overlaid on the 2MASS image toward the Scutum star cluster (6′ × 6′). The numbers 1–16 indicate the objects F01–F16, and 18 is for X18.

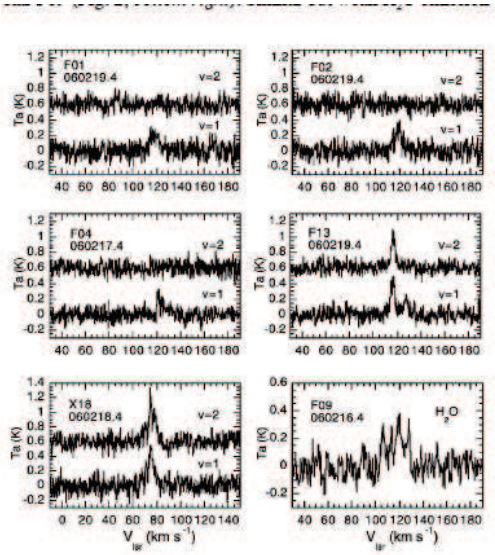


FIG. 2.—Spectra of the SiO $J = 1–0$, $v = 1$ and $v = 2$ transitions, except for the bottom right panel, which shows the H_2O $6_{16}–5_{23}$ transition. The object ID and date of observation (in *yymmdd.d* format) are shown at upper left in each panel. The H_2O maser emission detected in the pointing toward F09 is likely to have come from object F13 (see text).

Nakashima & Deguchi 2006

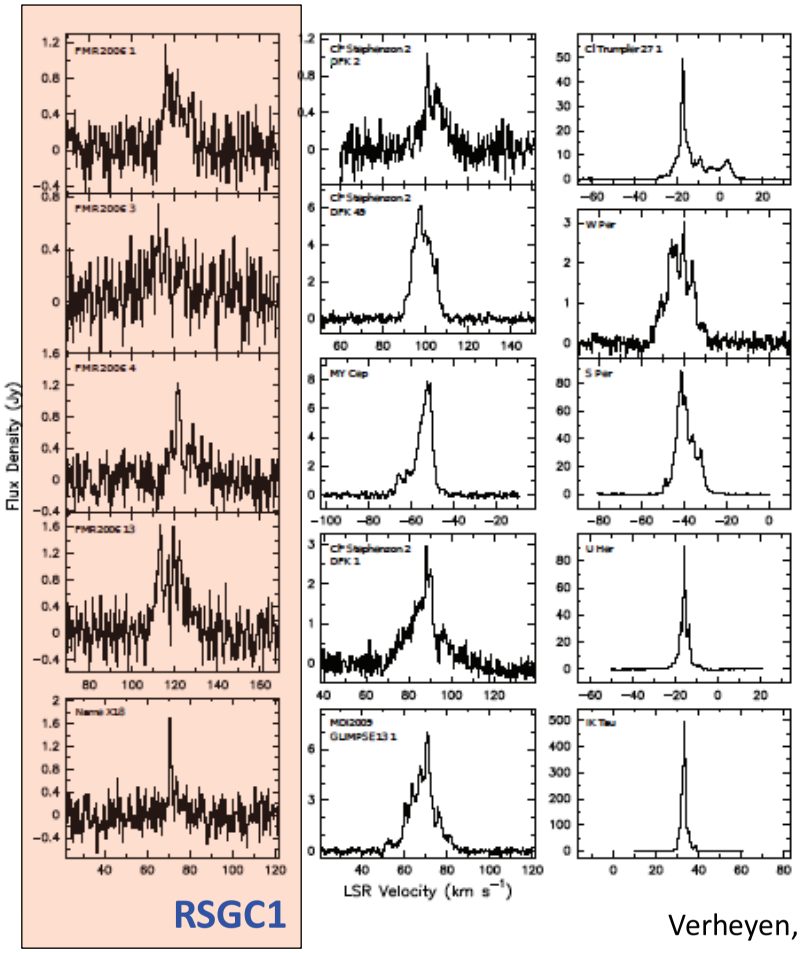
Finding evolved stars with maser emission

86 GHz SiO maser survey of late-type stars in the Inner Galaxy★,★★,★★★,†

I. Observational data

M. Messineo[1], H. J. Habing[1], L. O. Sjouwerman[2], A. Omont[3], and K. M. Menten[4]

- **Searched for v=1, J=2-1 SiO line toward stars in -4° < l < 30°**
- **based on ISOGAL and MSX colors**
- **Detect 271 out of 441**



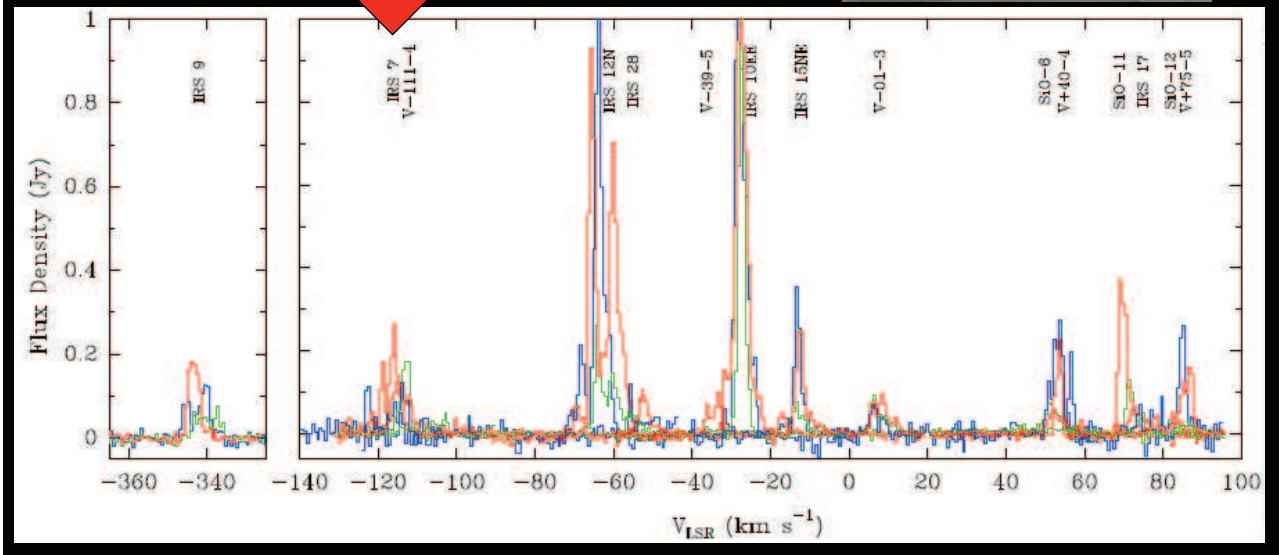
SiO

v = 1, J = 2–1

86.2 GHz

IRAM 30m

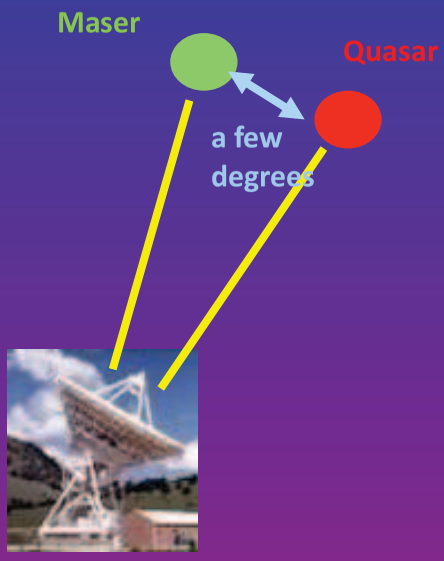
Verheyen, Messineo & Menten 2012



SiO maser emission from stars within the central parsec of our Galaxy

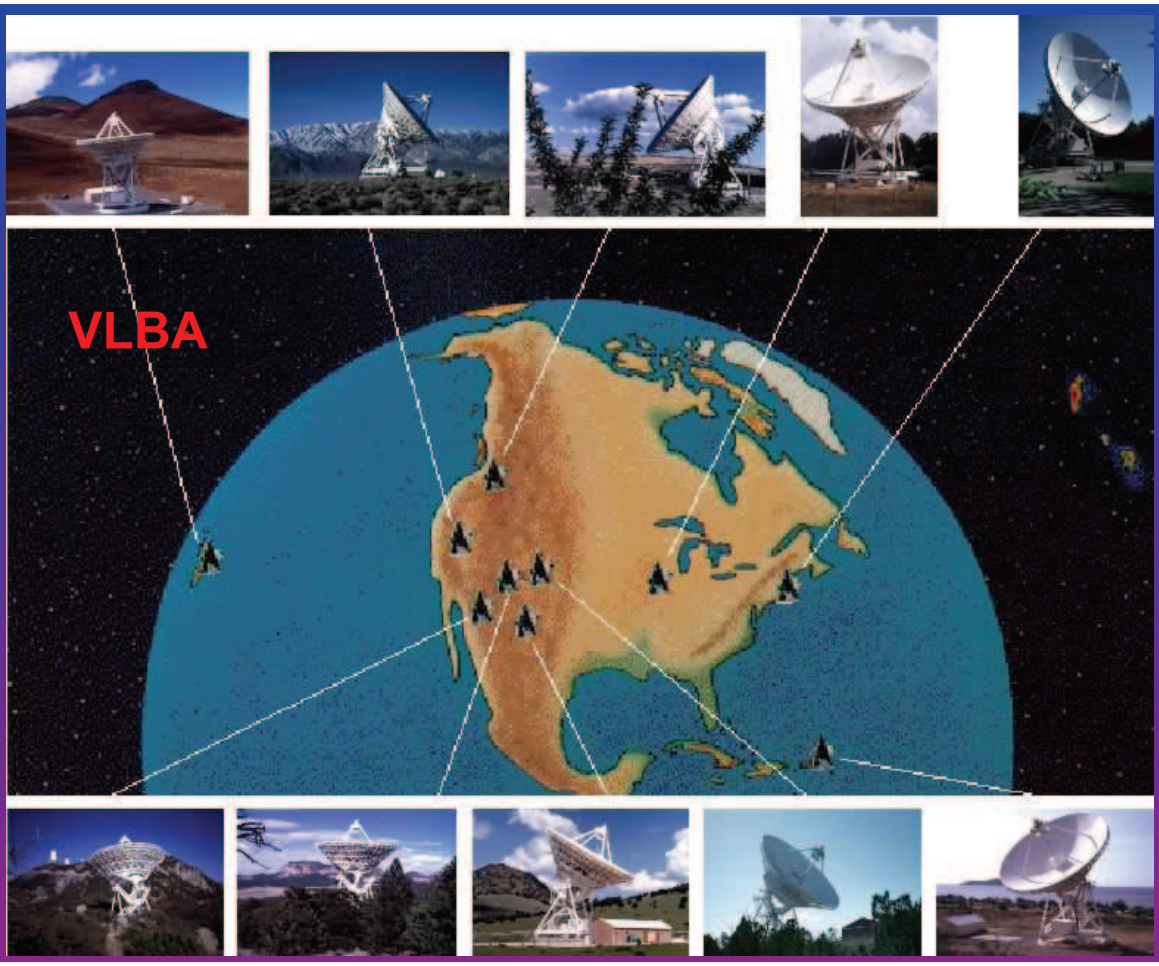
Menten et al. 1997, Reid et al. 2007

Masers can be VLBIed to determine their distances and motions

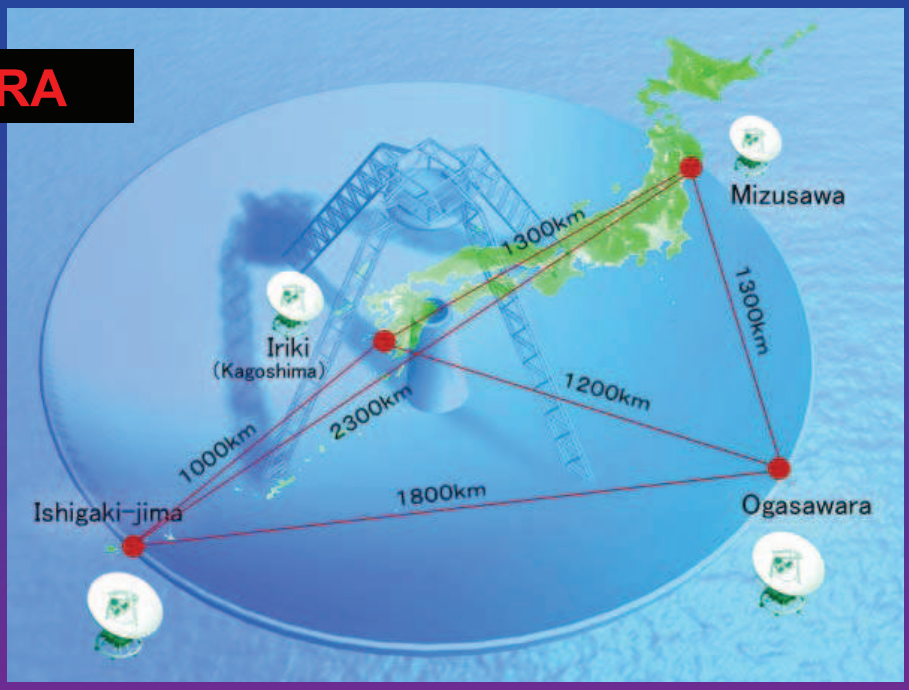


Phase referencing:

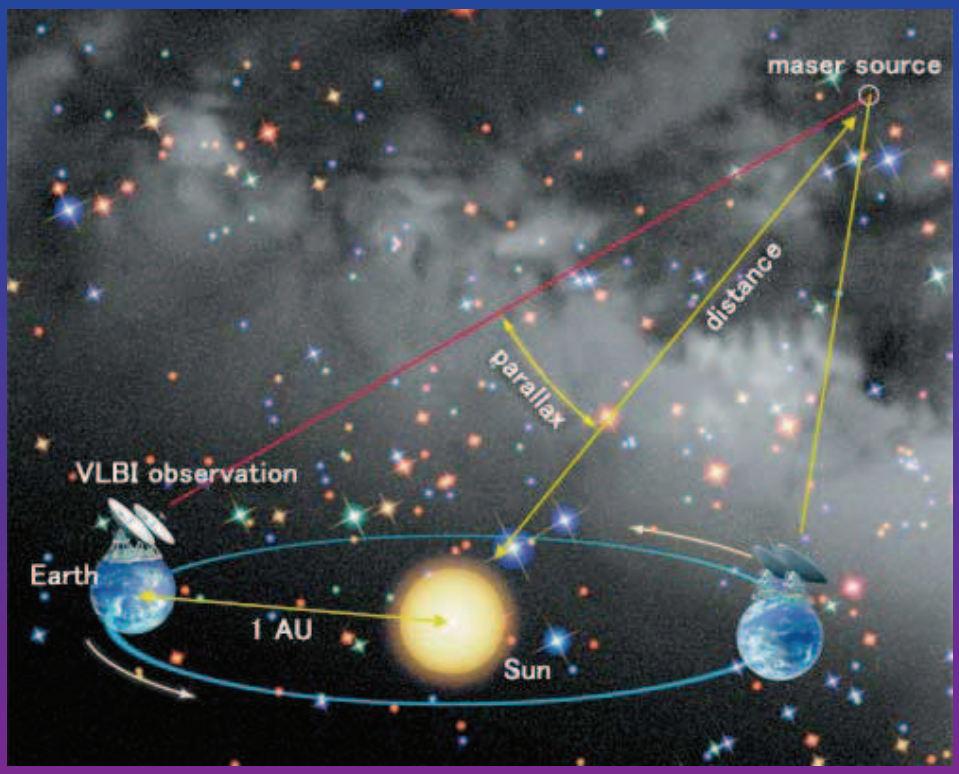
- VLBA: Switch every 15 second between maser and quasar. 50% duty cycle
- VERA: Have one beam each directed to maser and quasar



VERA

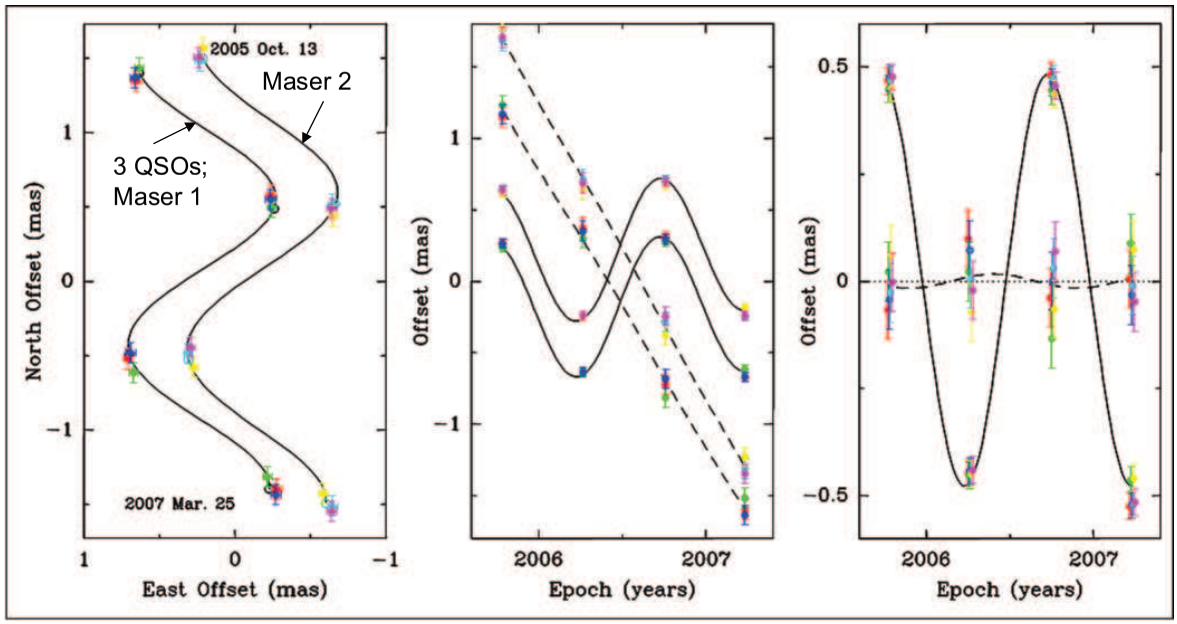


http://veraserver.mtk.nao.ac.jp/outline/vera2-e.html



http://veraserver.mtk.nao.ac.jp/outline/vera2-e.html

S 252 Parallax: using CH_3OH masers

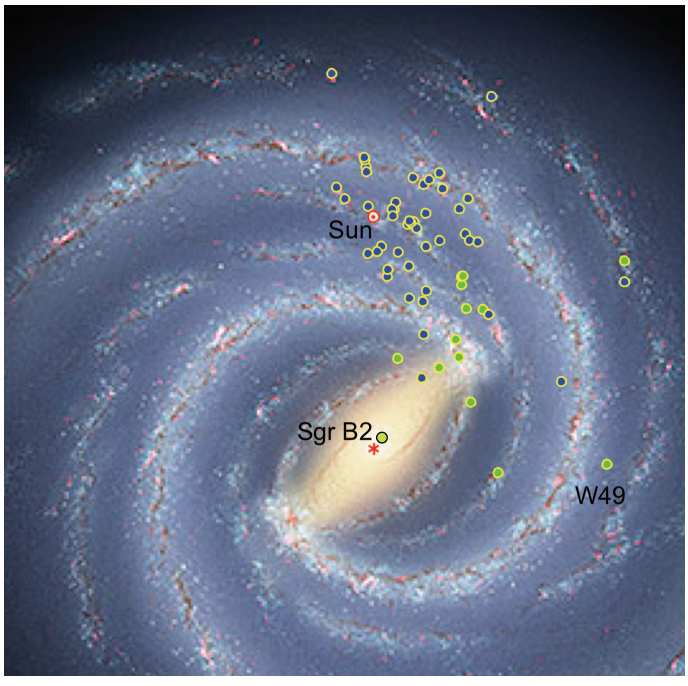


Reid et al (2009)

π = 0.480 +/- 0.010 mas

D = 2.083 +/- 0.043 kpc

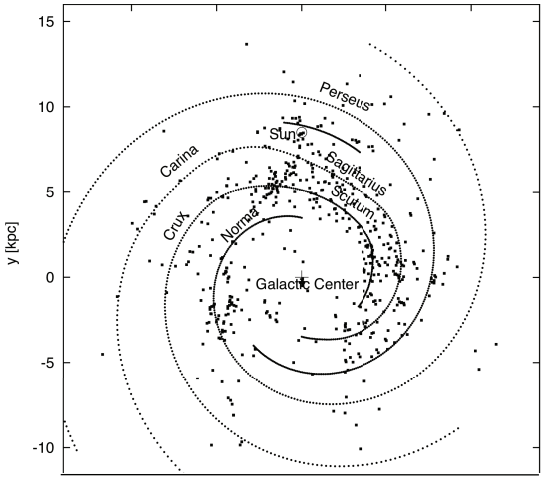
Mapping the Milky Way



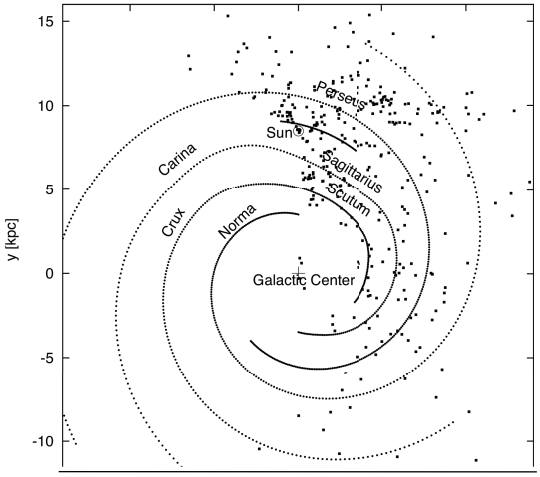
Artist conception: Robert Hurt (NASA:SSC)

- Preliminary results for 62 parallaxes from VERA, EVN & VLBA:
  - blue (σ_d < 0.5 kpc)
  - green (σ_d > 0.5 kpc)
- Tracing outer spiral arms
- Inner, bar-region is messy

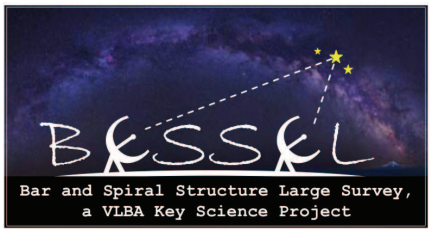
Mapping the Milky Way



6.7 & 12.2 GHz CH_3OH masers

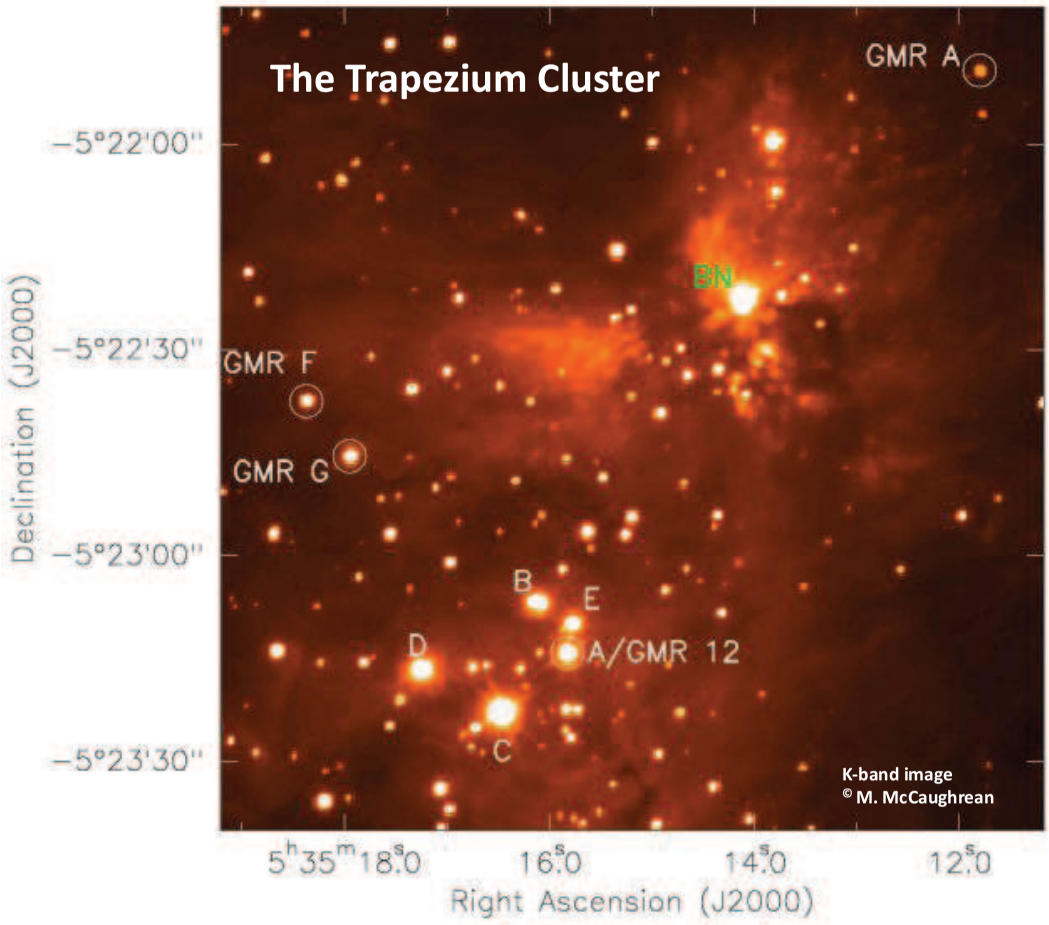


22 GHz H_2O masers

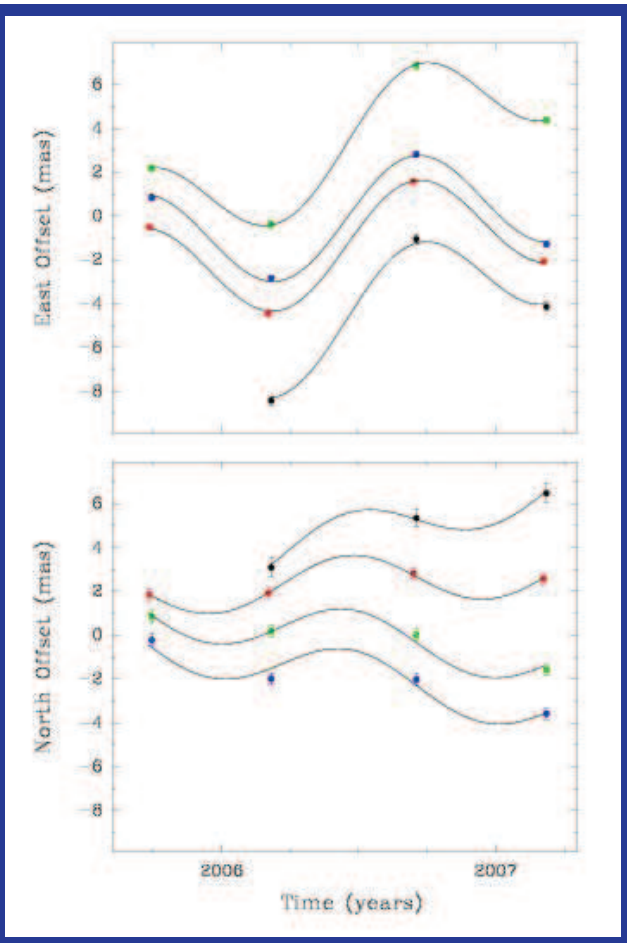


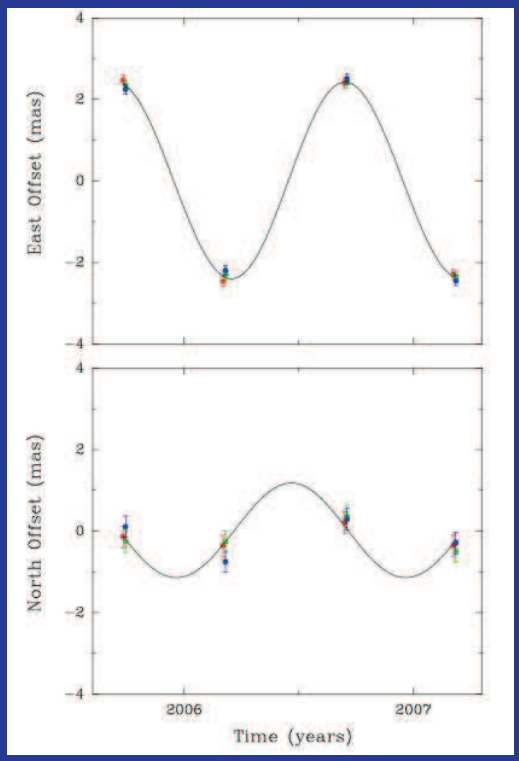
VLBA Key Science Project: 5280 hours over 5 years to measure ~400 parallaxes/proper motions

Observations for ~60 masers started 2010
For 200 more will start in 2012 September



Orion Nebula parallax



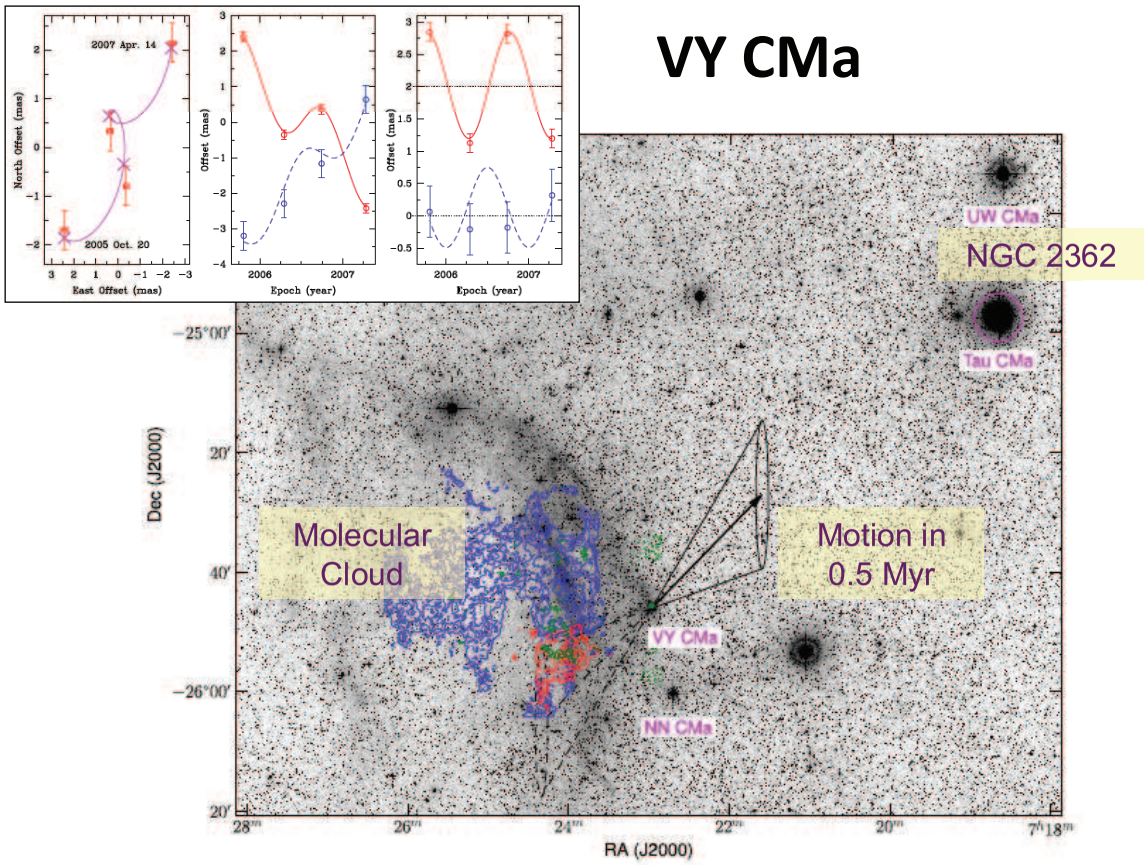


The Distance to the Orion Nebula

Source	π (mas^{-1})	D (pc)	μ_x (mas y^{-1})	μ_y (mas y^{-1})
GMR A	2.390(0.104)	418.4(18.2)	+1.82(0.09)	−2.05(0.18)
GMR 12	2.393(0.053)	417.9(9.2)	+4.82(0.09)	−1.54(0.18)
GMR G	–	–	+4.29(0.17)	+3.33(0.37)
GMR F	2.462(0.051)	406.1(8.4)	+2.24(0.09)	+0.66(0.18)
Mean	2.425(0.035)	412.4(6.0)		
Joint	2.415(0.040)	414.0(6.8)		

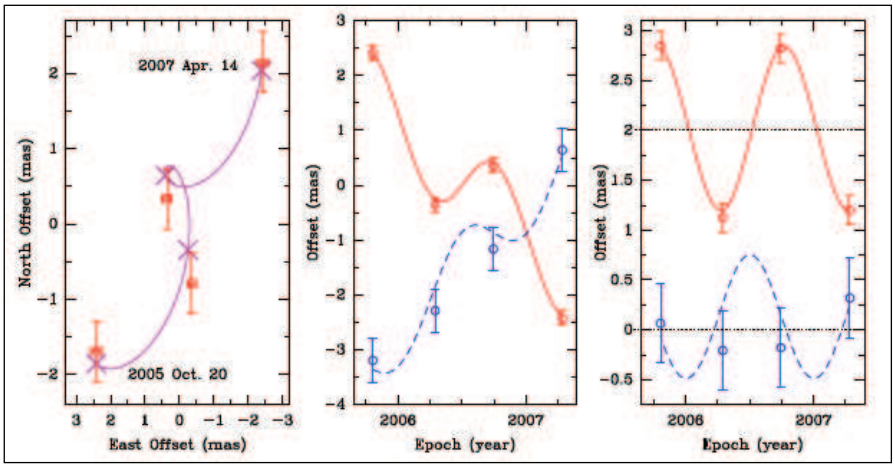
Menten et al. 2007

VY CMa



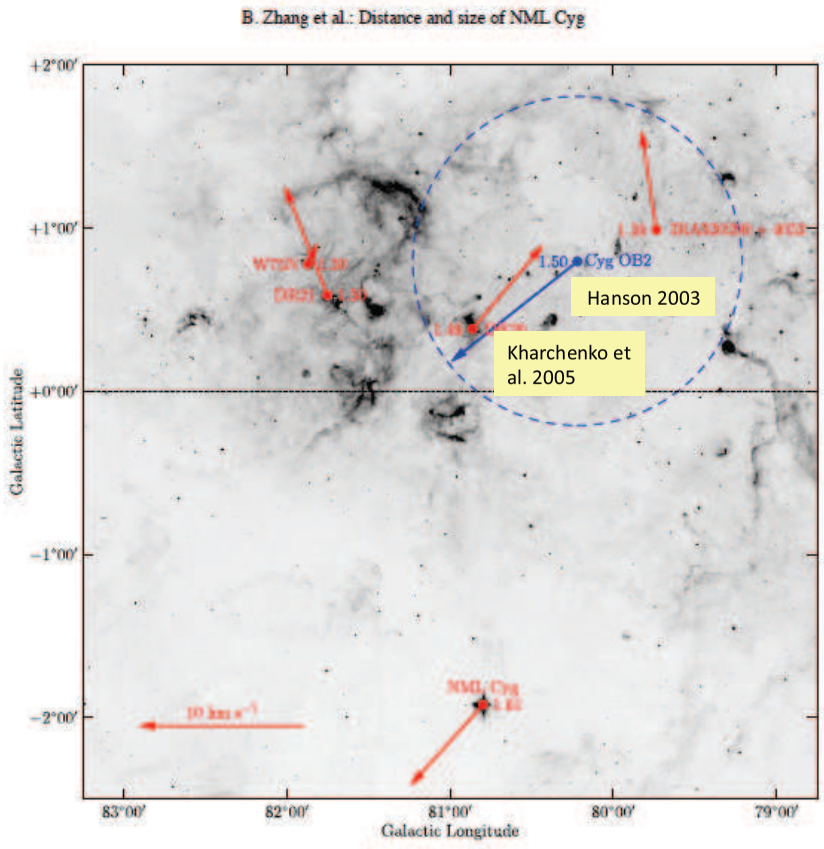
Zhang, Reid, Menten & Zheng 2012

VY CMa VLBA SiO maser parallax



$D = 1.20\ ^{+0.13}/_{-0.10}$ kpc
compares well with
$D = 1.14\ ^{+0.11}/_{-0.09}$ kpc obtained for H_2O masers with VERA (Choi et al. 2008)
• < D(NGC 2362): 1.5 kpc (spectro/photometric)

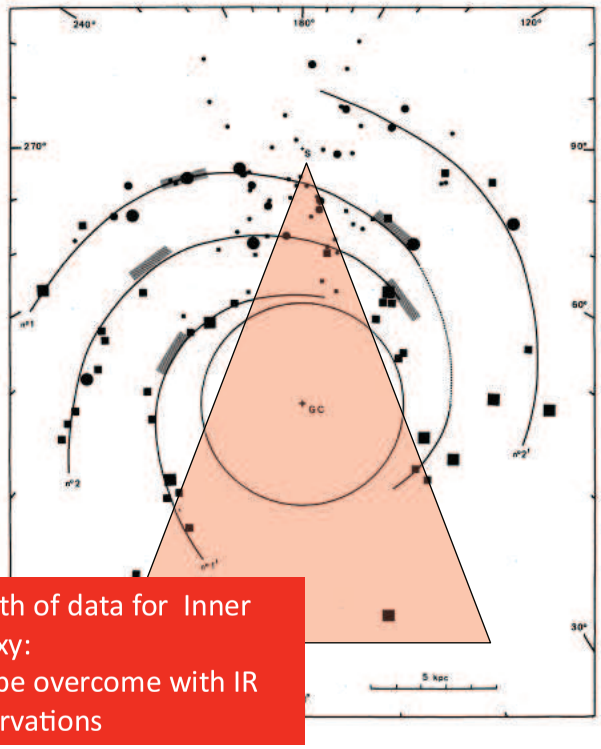
Zhang, Reid, Menten & Zheng 2012



NML Cyg/ Cyg OB2

Rygl et al.
Zhang et al. 2012

Spectro-photometric distances



Georgelin & Georgelin 1976

Accurate maser parallaxes for stars in clusters could be used to "calibrate" infrared spectro-photometric distance estimates for stars in the same clusters

Dearth of data for Inner Galaxy:
Can be overcome with IR observations

Red supergiants

are interesting and still surrounded by lots of questions

- More infrared surveys will find many new RSGs
- …hopefully some with SiO (or H_2O) masers
- Maser astrometry will deliver distances and motions

Collaborators (IR):
Maria Messineo & Rosie Chen (MPI für Radioastronomie)

The BeSSel Team:

Mark Reid (PI), Tom Dame,	Harvard-Smithsonian Center for Astrophysics, USA
Karl Menten (Co-PI)	Max-Planck-Institut für Radioastronomie, Germany
Andreas Brunthaler (Co-PI), Katharina Immer, Alberto Sanna, Yoon Kyung Choi, Mayumi Sato Bo Zhang, Jing Jing Li, Xuanwei Wu	
Xing-Wu Zheng (Co-PI)	Nanjing University, China
Ye Xu	Purple Mountain Observatory (CAS), Nanjing, China
Kazuya Hachisuka	Shanghai Astronomical Observatory (CAS), China
Luca Moscadelli	Osservatorio di Arcetri Observatory, Florence, Italy
George Moellenbrock	National Radio Observatory, USA
Anna Bartkiewicz	Torun Centre for Astronomy, Poland
Kazi Rygl	INAF Roma, Italy
Huib van Langefelde	JIVE, NL