Masers in Regions of High-Masss Star Formation

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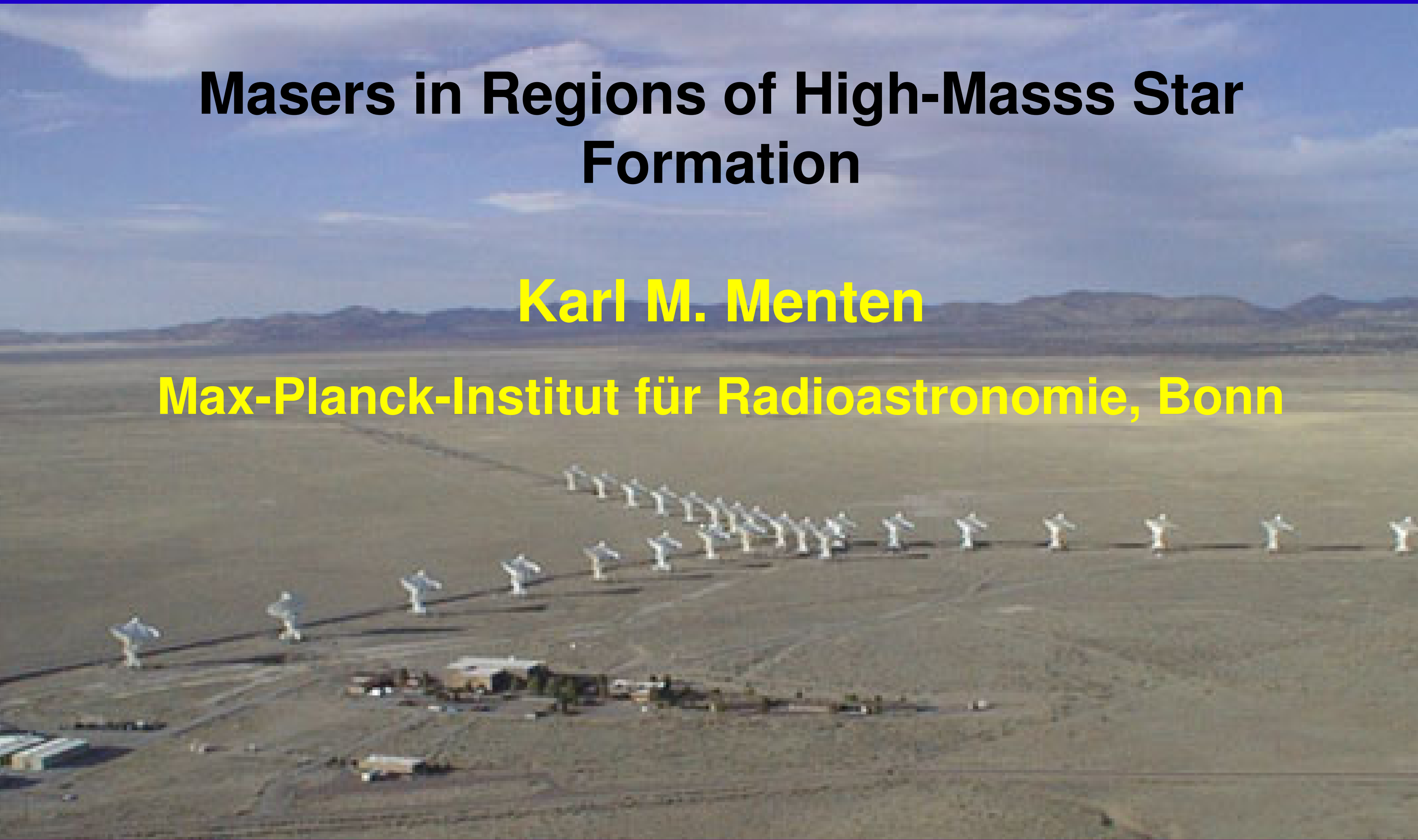
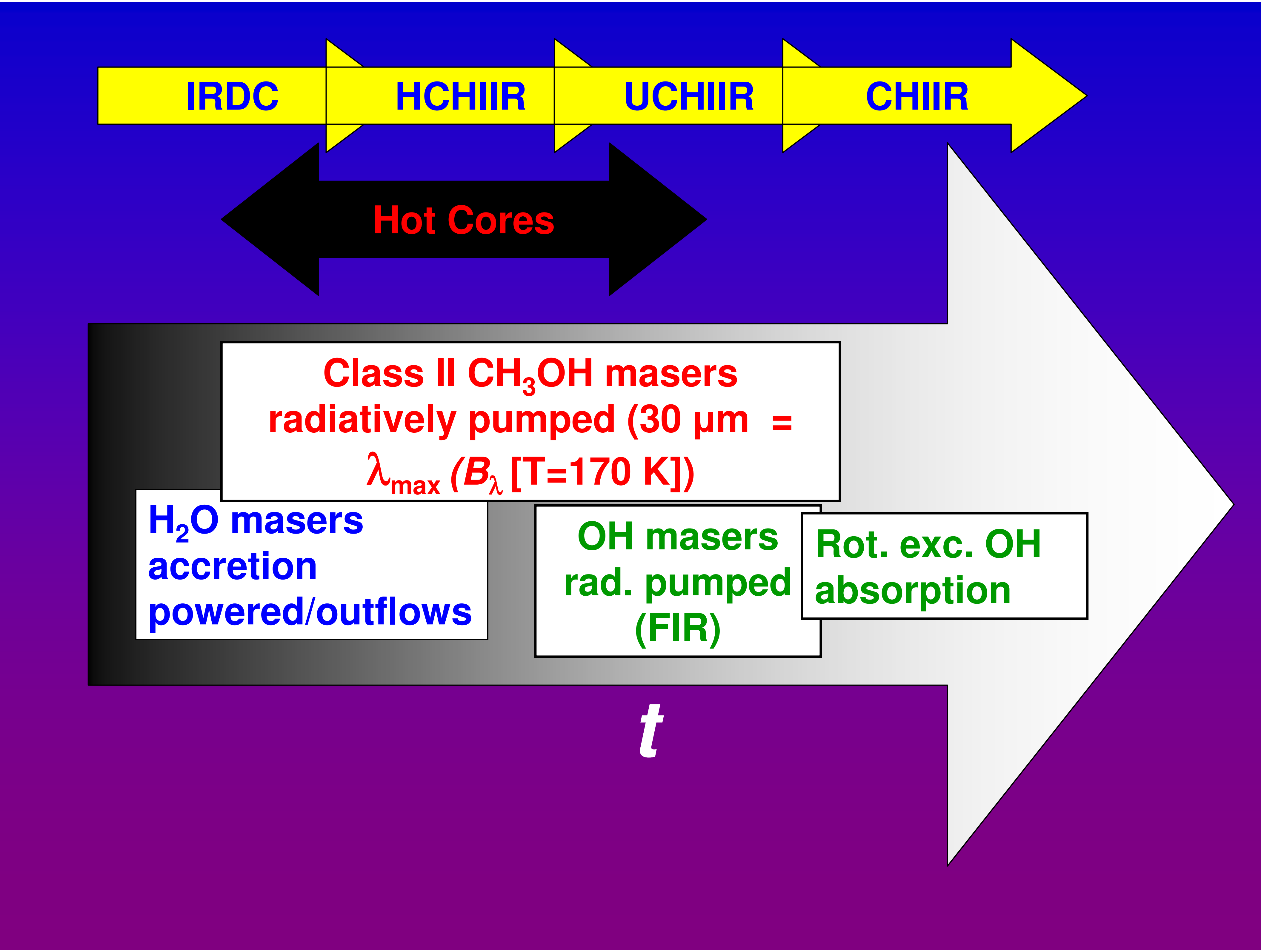


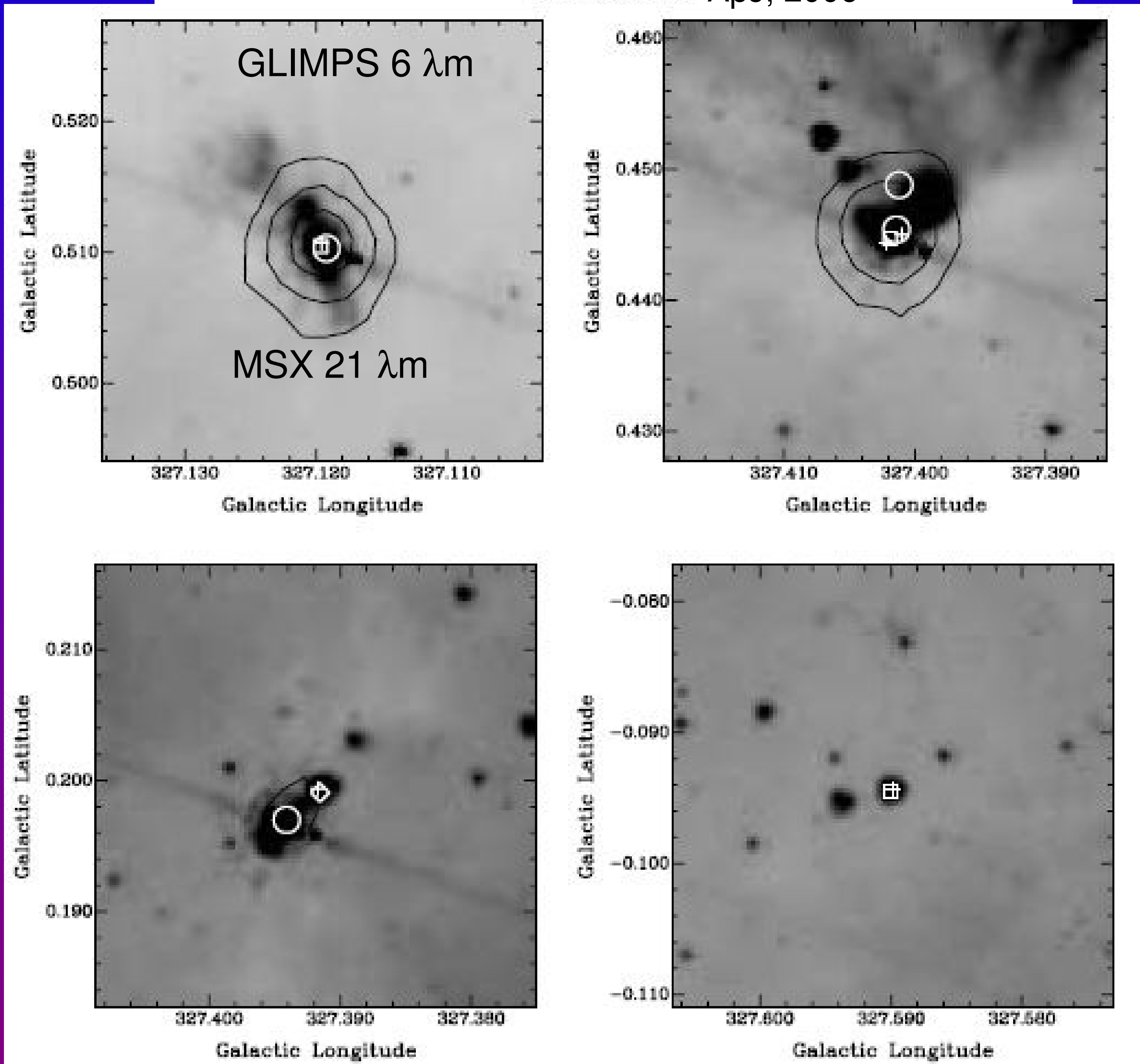
Massive Star Formation:
Observations Confront Theory

Heidelberg, September 2007


IRDC
HCHIIR
UCHIIR
CHIIR
Hot Cores
Class II CH_3OH masers radiatively pumped (30 µm = λ_{max} (B_λ [T=170 K])
H_2O masers accretion powered/outflows
OH masers rad. pumped (FIR)
Rot. exc. OH absorption
t

METHANOL MASERS: RELIABLE TRACERS OF THE EARLY STAGES OF HIGH-MASS STAR FORMATION

S. P. Ellingsen ApJ, 2006

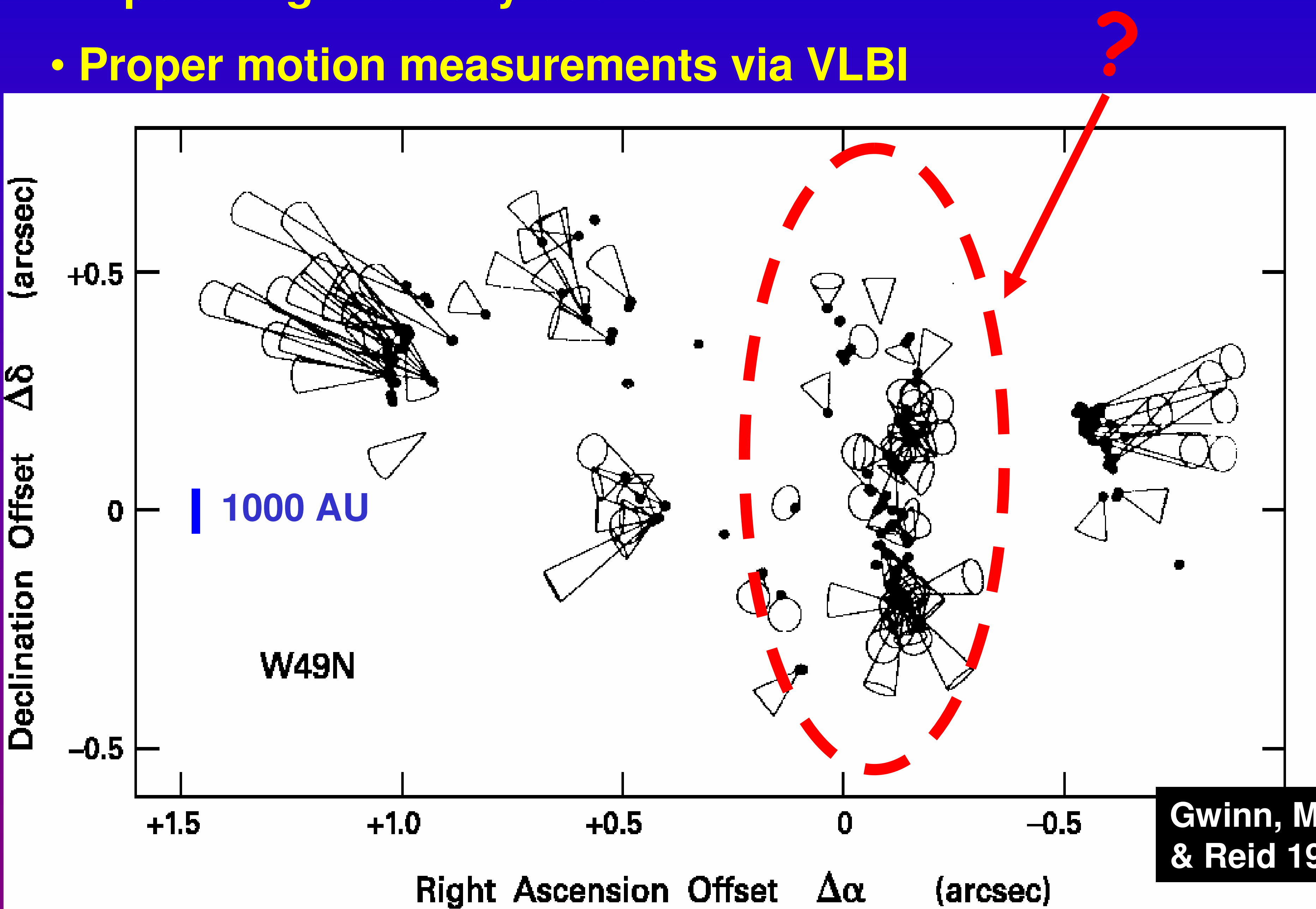


+ = 6.7 GHz CH_3OH

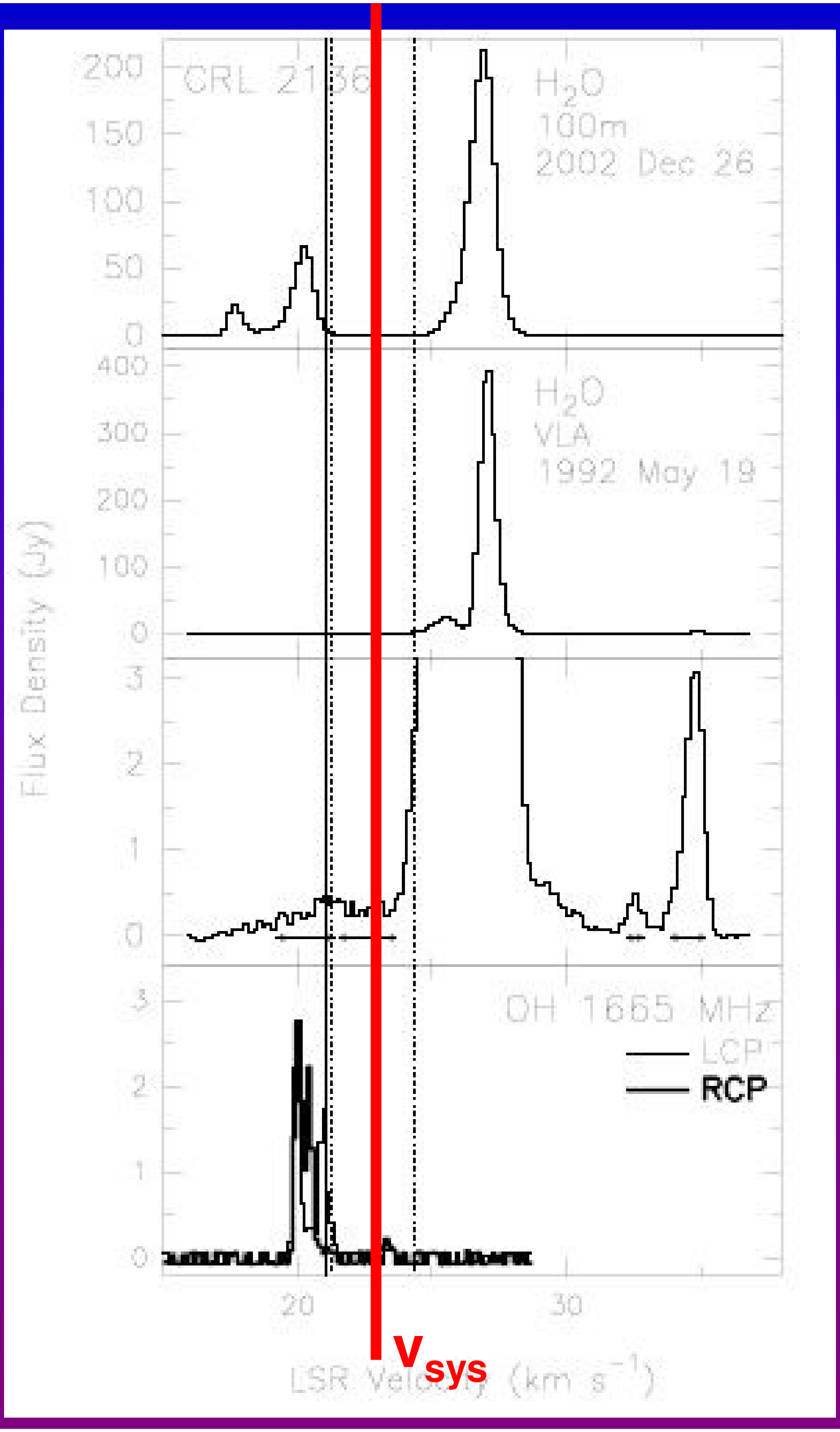
Ellingsen 2006

W49N H_2O masers:

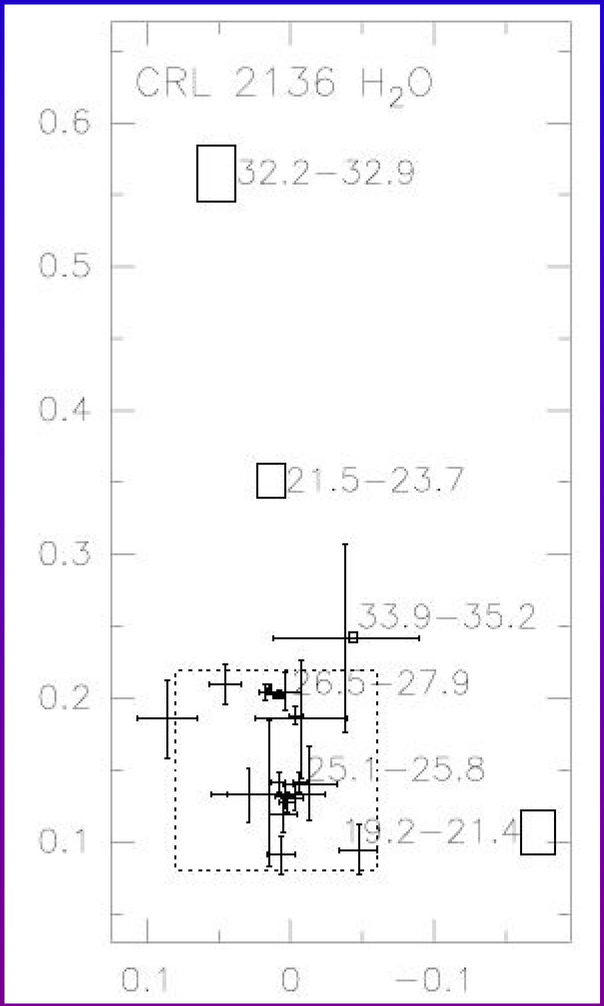
- Bipolar high velocity outflow
- Proper motion measurements via VLBI



Gwinn, Moran, & Reid 1992



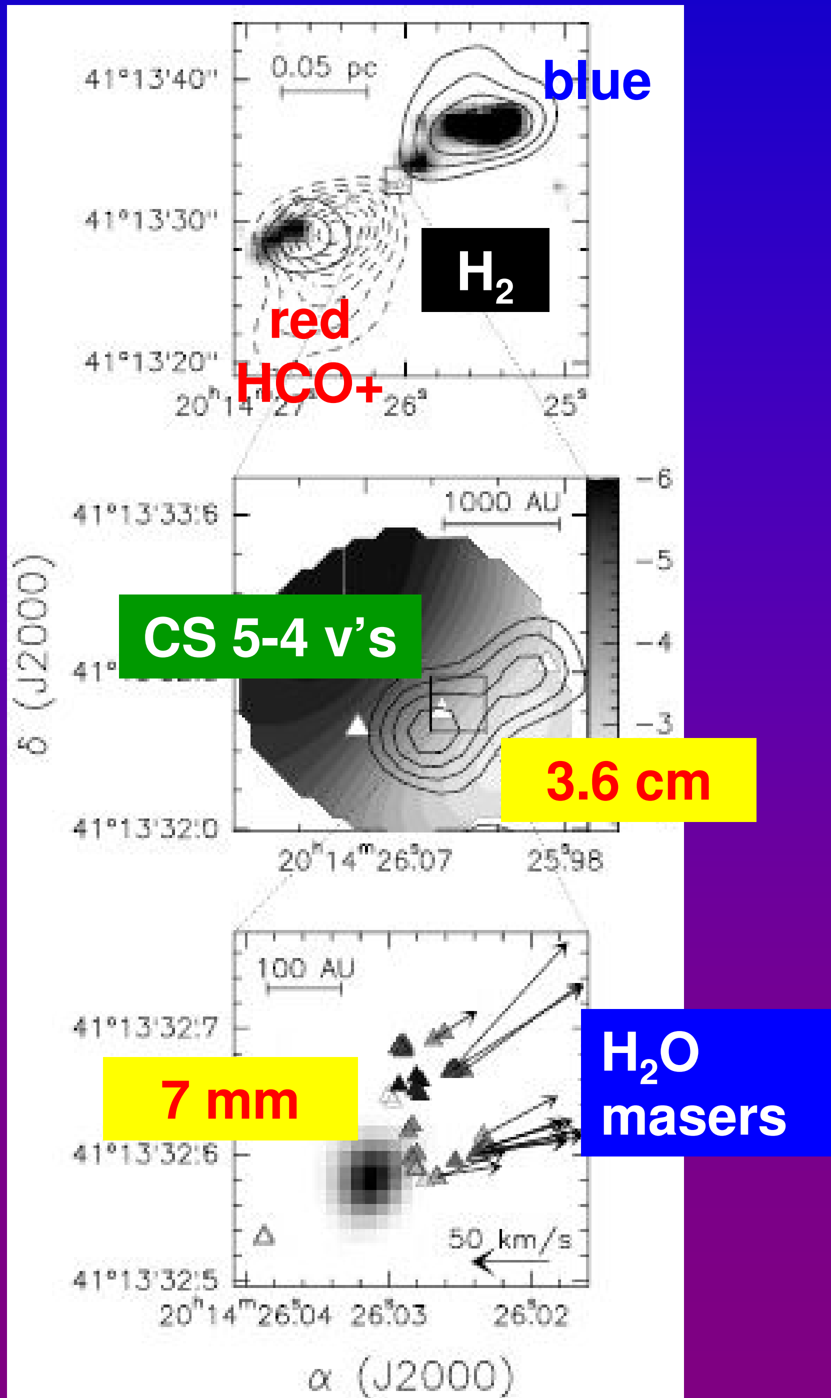
CRL 2136



H_2O masers in accretion shock?

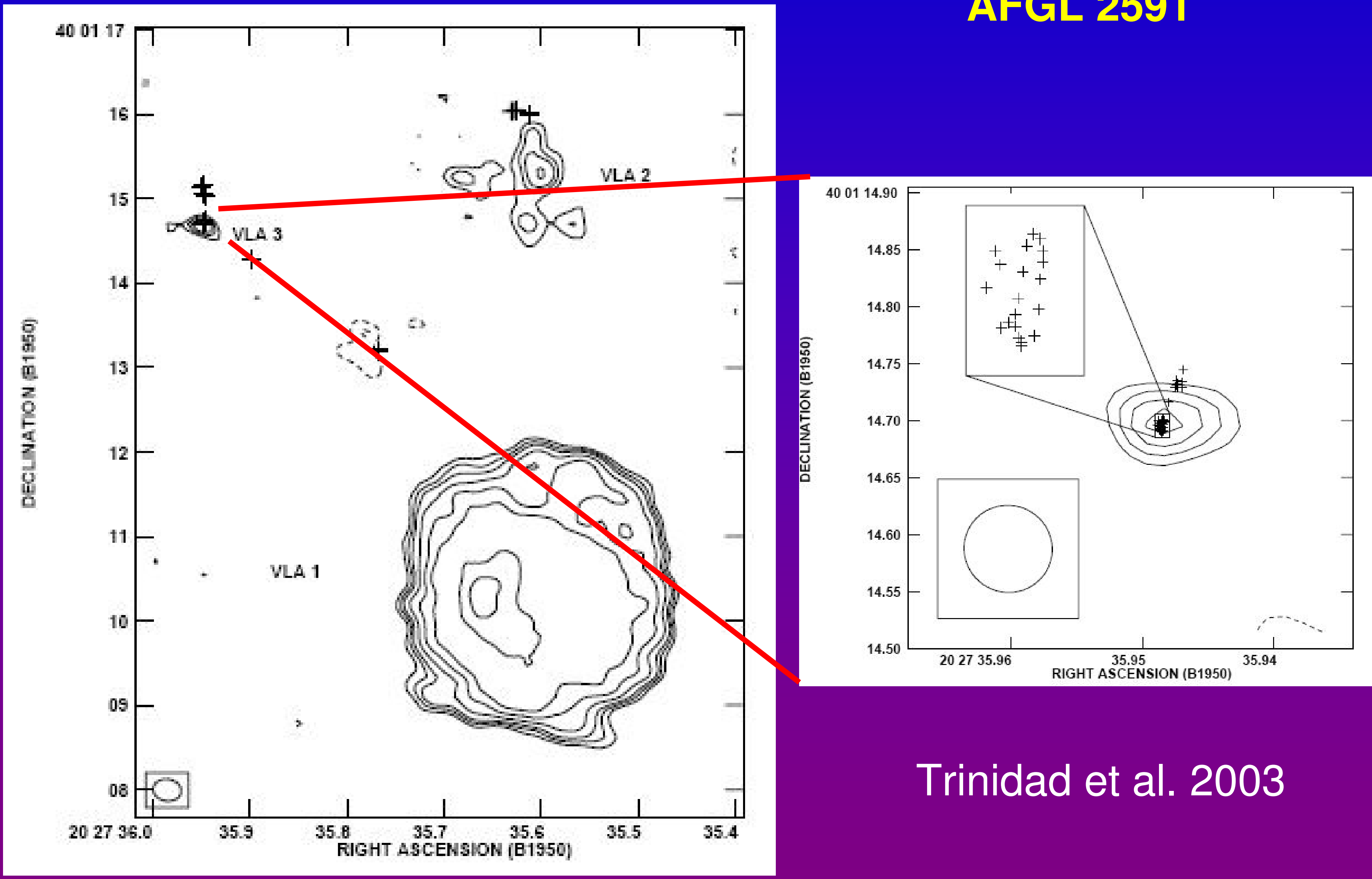
Menten & van der Tak 2004

IRAS 20126+4104



Cesaroni et al. 2006 (P&PIV)

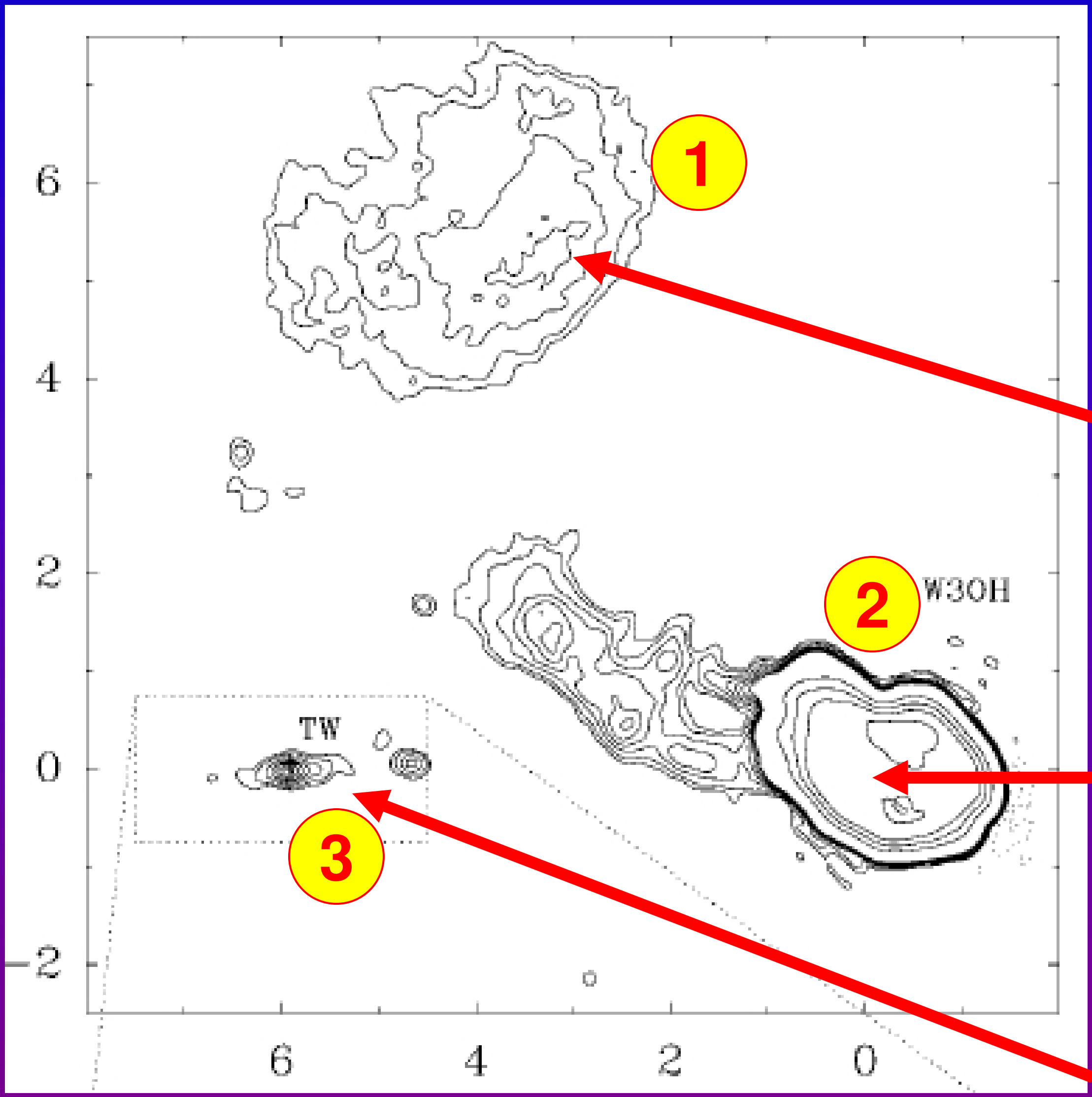
AFGL 2591



Trinidad et al. 2003

→ Poster: Trindad et al.

The W3OH region – different stages of high-mass star formation



Wilner, Reid, & Menten 1995

1) CHII region:
dynamical age ~ 5000 yr

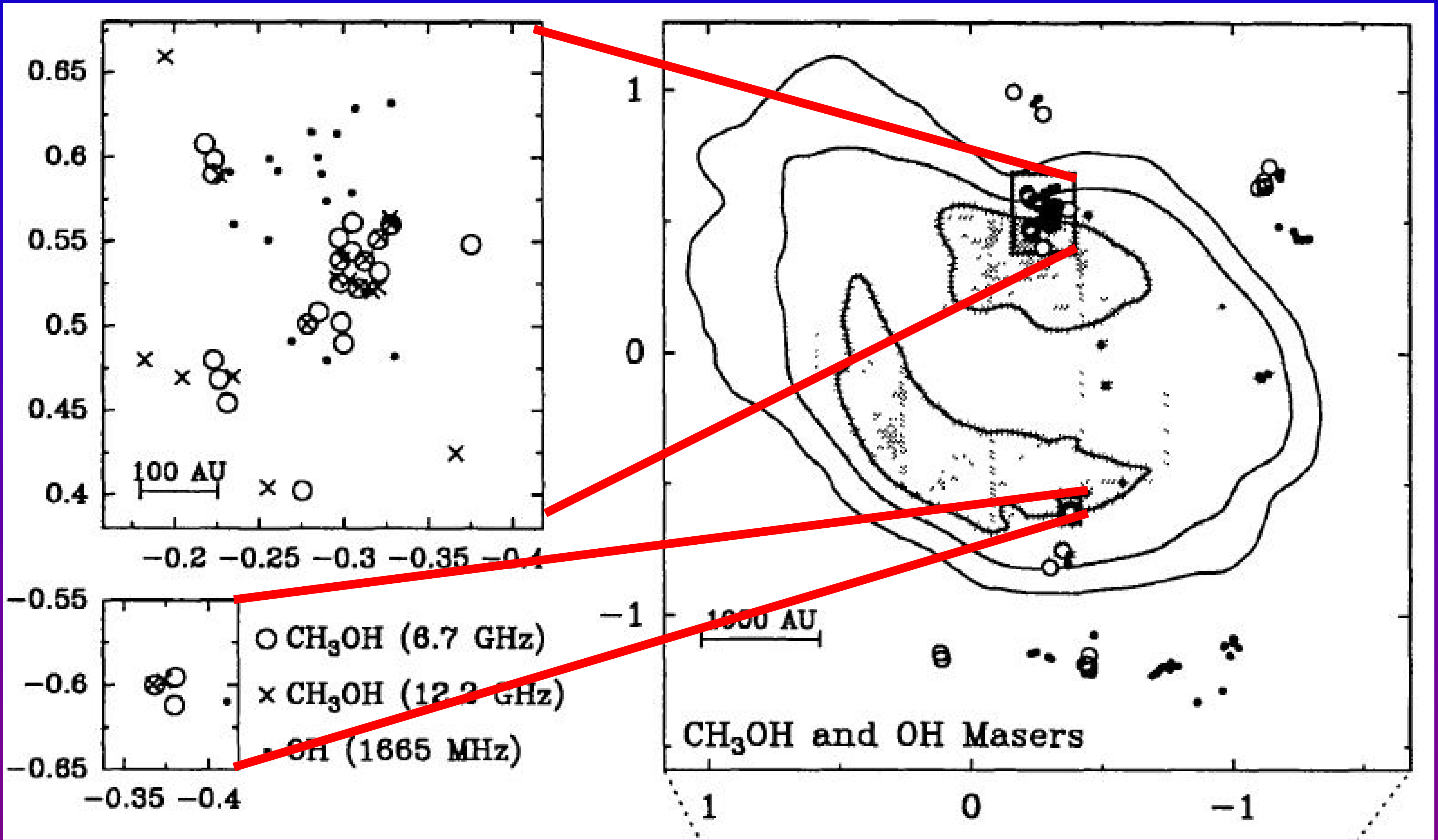
2) UCHII region:
dynamical age 2300 yr

⇐ Kawamura & Masson (1998) use VLA to determine expansion between 1986 and 1995

3) Even younger: Turner-Welch (1984) object

4) Possibly even younger source ~15” (0.15 pc) SW

→ Poster by Sobolev et al.

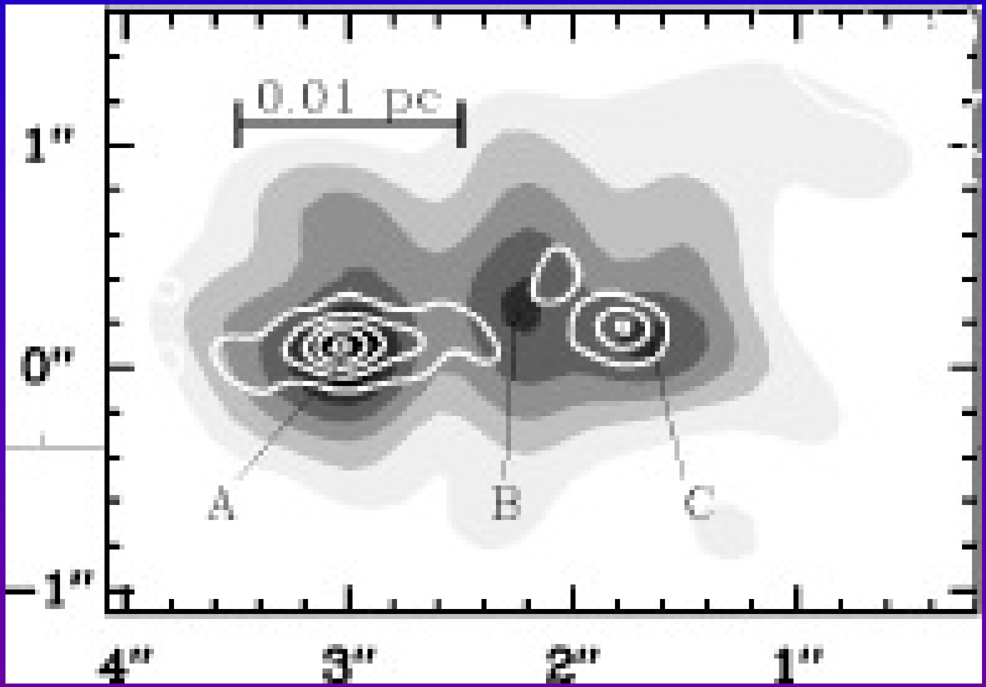


W3OH

Menten et al. 1988,1992

The Turner-Welch object [≡W3OH(H_2O)]

(Turner & Welch 1984)



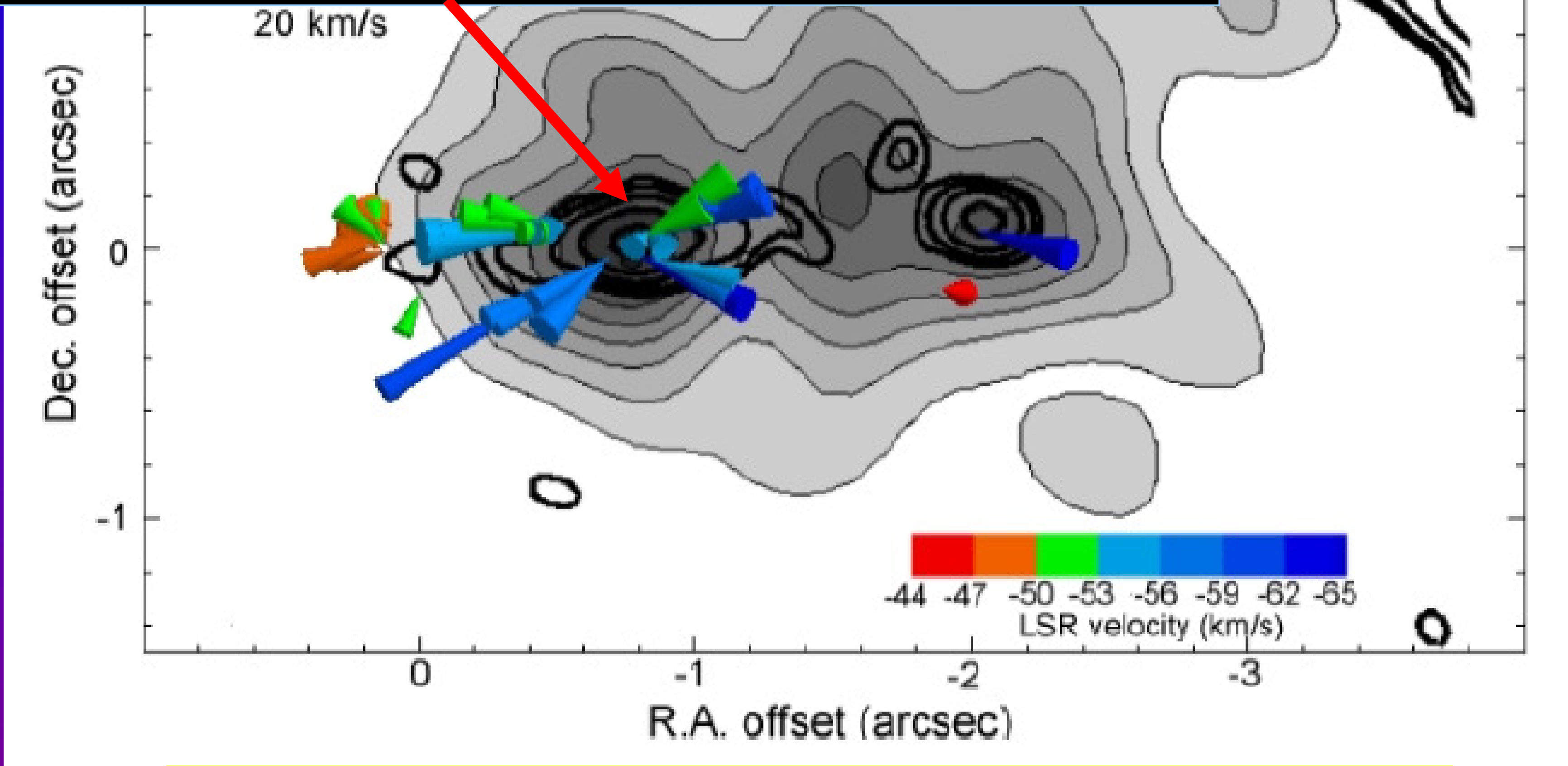
Wyrowski et al. 1999

Two density *and* temperature peaks (A & C)

- Temperatures: 150 – 200 K
- M_{total} = 5 M_{sun}
- L ~ 3 10^4 L_{sun}

→ Poster: V. Chen et al.

Synchrotron emission (Reid et al. 1995; Wilner et al. 1999) from accretion disk: Shcheknov & Sobolev 2004



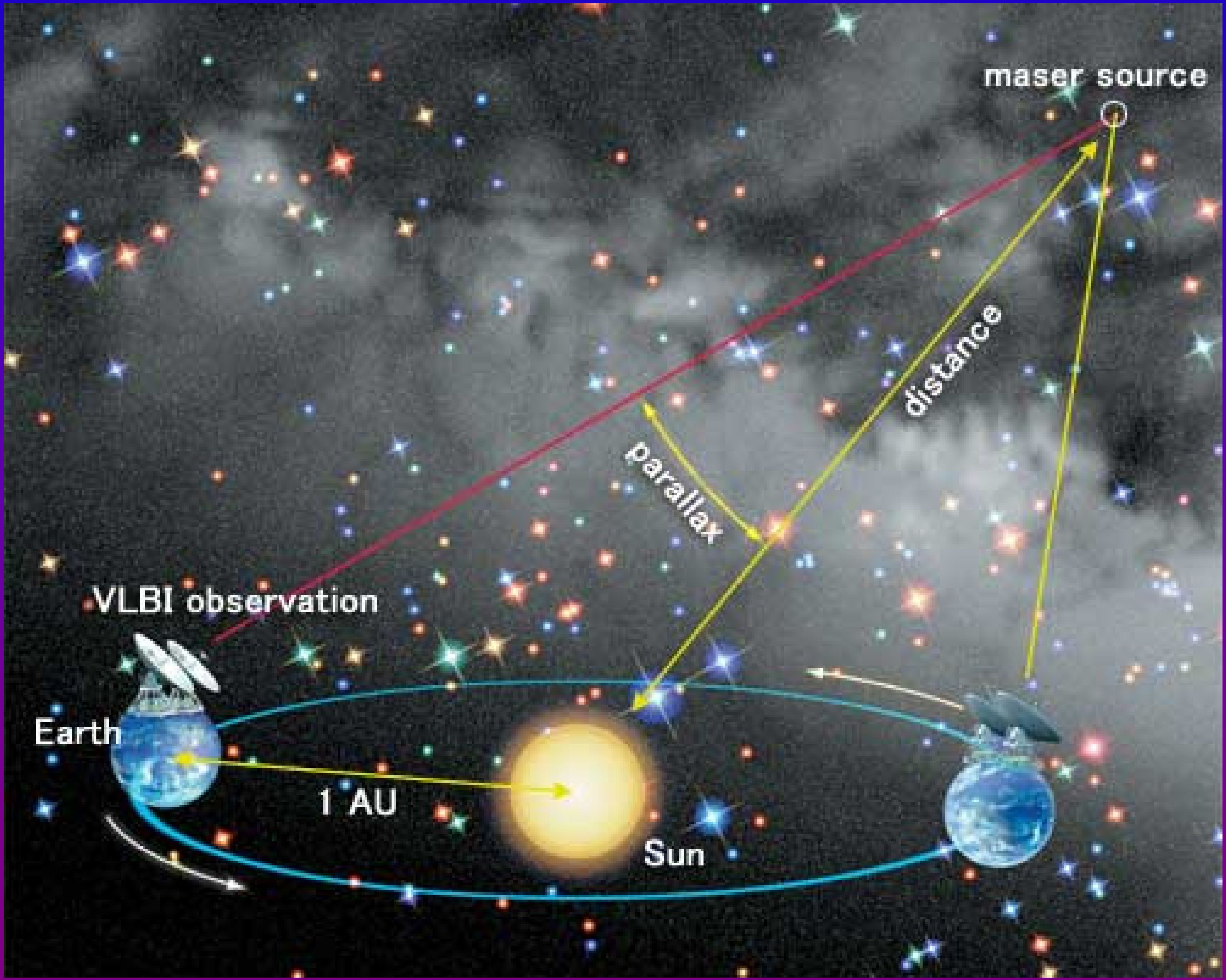
Absolute proper motion measurements by phase-referenced VLBI

$\Rightarrow v_{exp} = 20$ km/s $\Rightarrow t_{exp} = 320$ yr

$\Rightarrow D = 2.0$ kpc

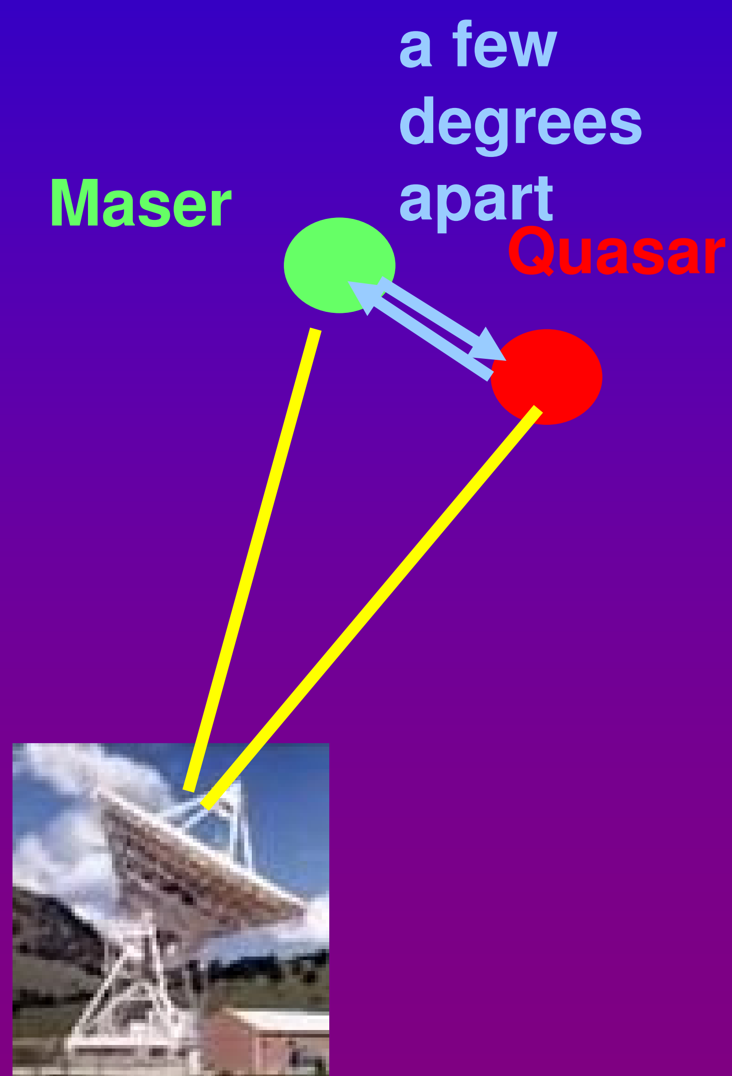
→ Poster: Hachisuka et al.

Milky Way Maser Trigonometric Parallaxes



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

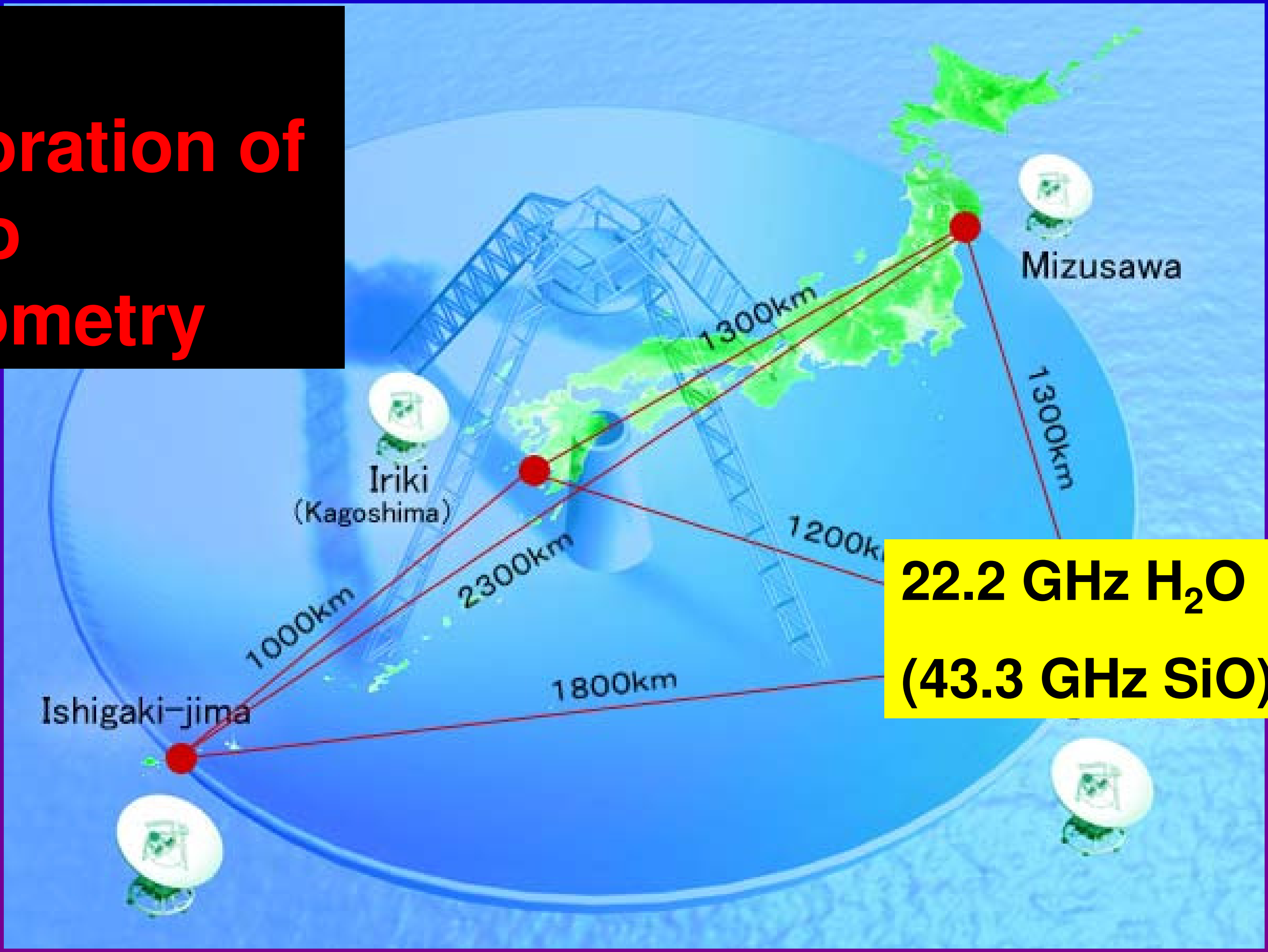
With fast-switching phase referencing position uncertainties of ≈ 10 μarcsecond can be reached



Phase referencing:

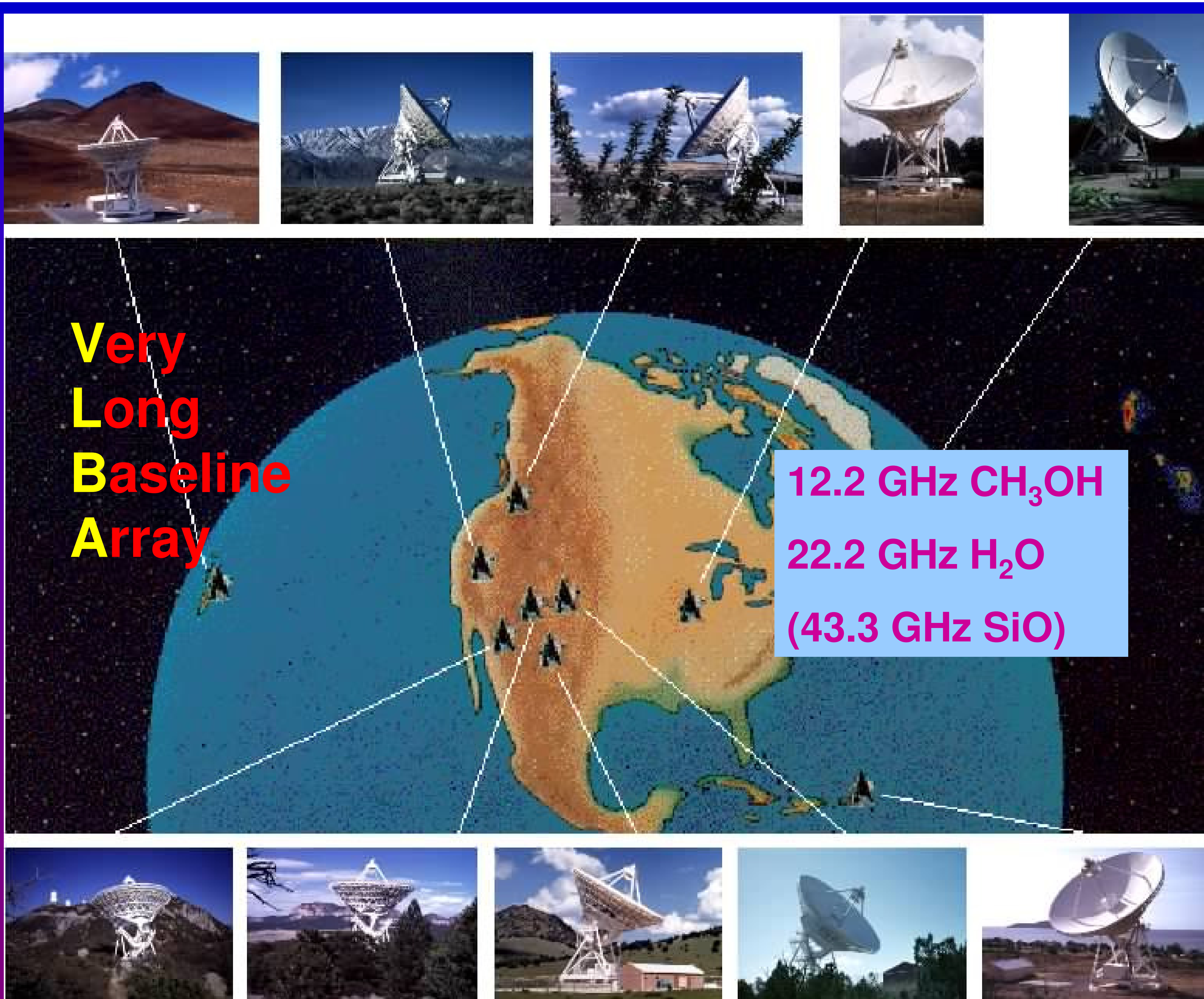
- VLBA: Switch every 15 second between maser and quasar. 50% duty cycle
- VERA: Have one beam each directed to maser and quasar

VLBI
Exploration of
Radio
Astrometry



22.2 GHz H_2O
(43.3 GHz SiO)

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


Very
Long
Baseline
Array
12.2 GHz CH3OH
22.2 GHz H2O
(43.3 GHz SiO)

Milky Way Maser Parallaxes

Large VLBA program to measure 12.2 GHz CH_3OH maser parallaxes

CfA:

- **M. Reid**

MPIfR:

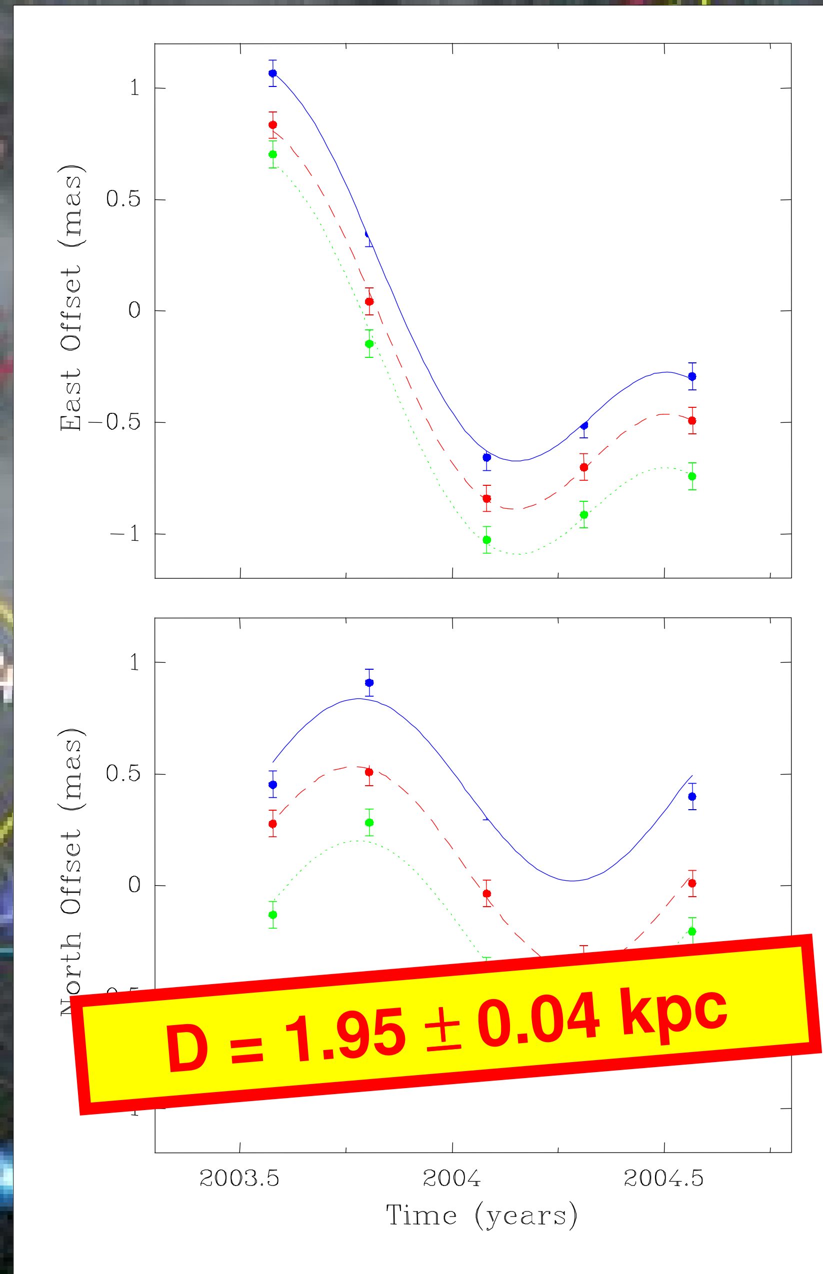
- **A. Brunthaler, K. Menten, Y. Xu**

Arcetri:

L. Moscadelli

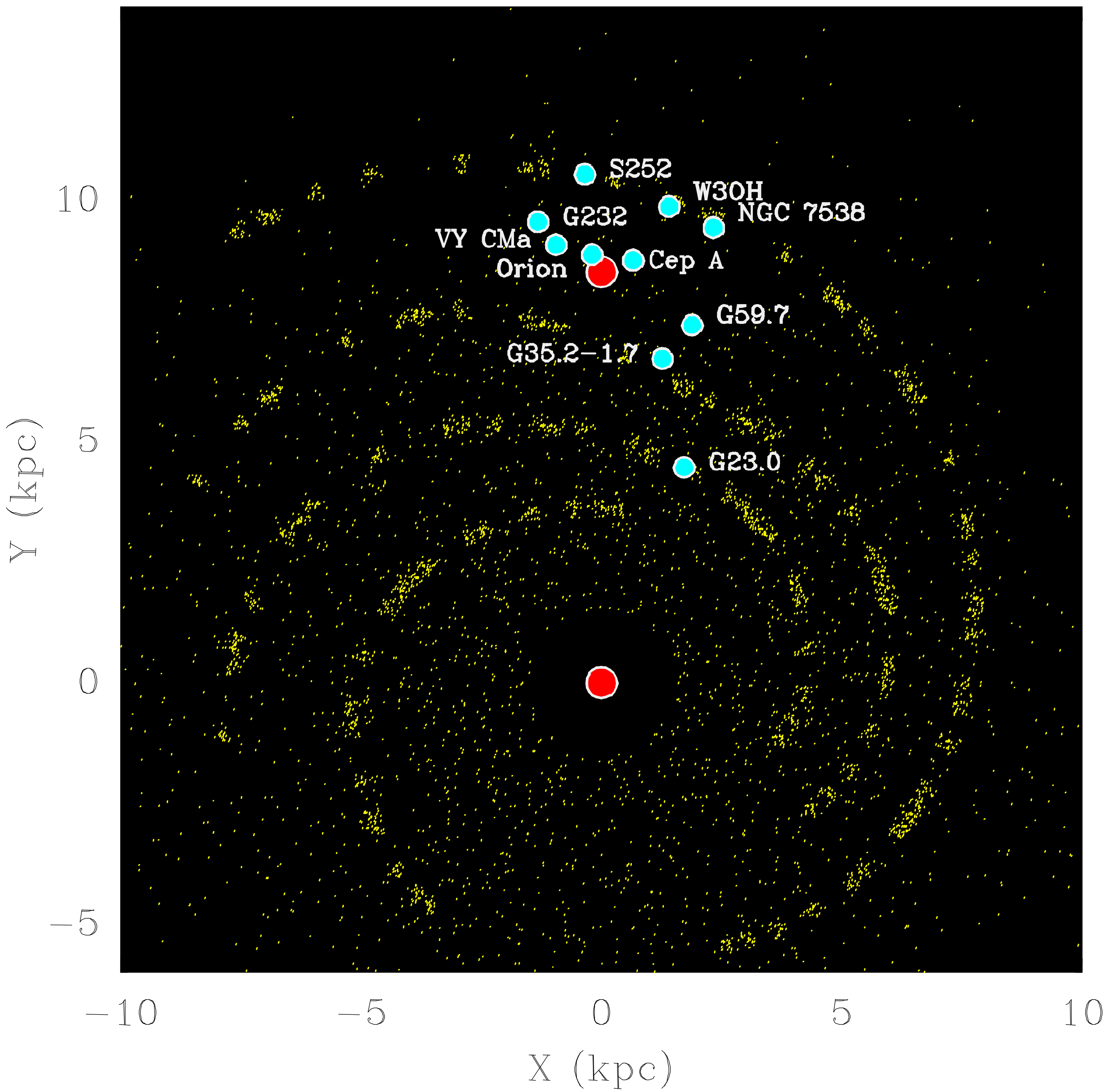
Nanjing University:

- **X.-W. Zheng**



Xu, Reid, Menten, & Zheng (2006)

Why 12.2 GHz Methanol Masers?



- Slow time variability – many months → years

→ Poster: Goedhart et al.

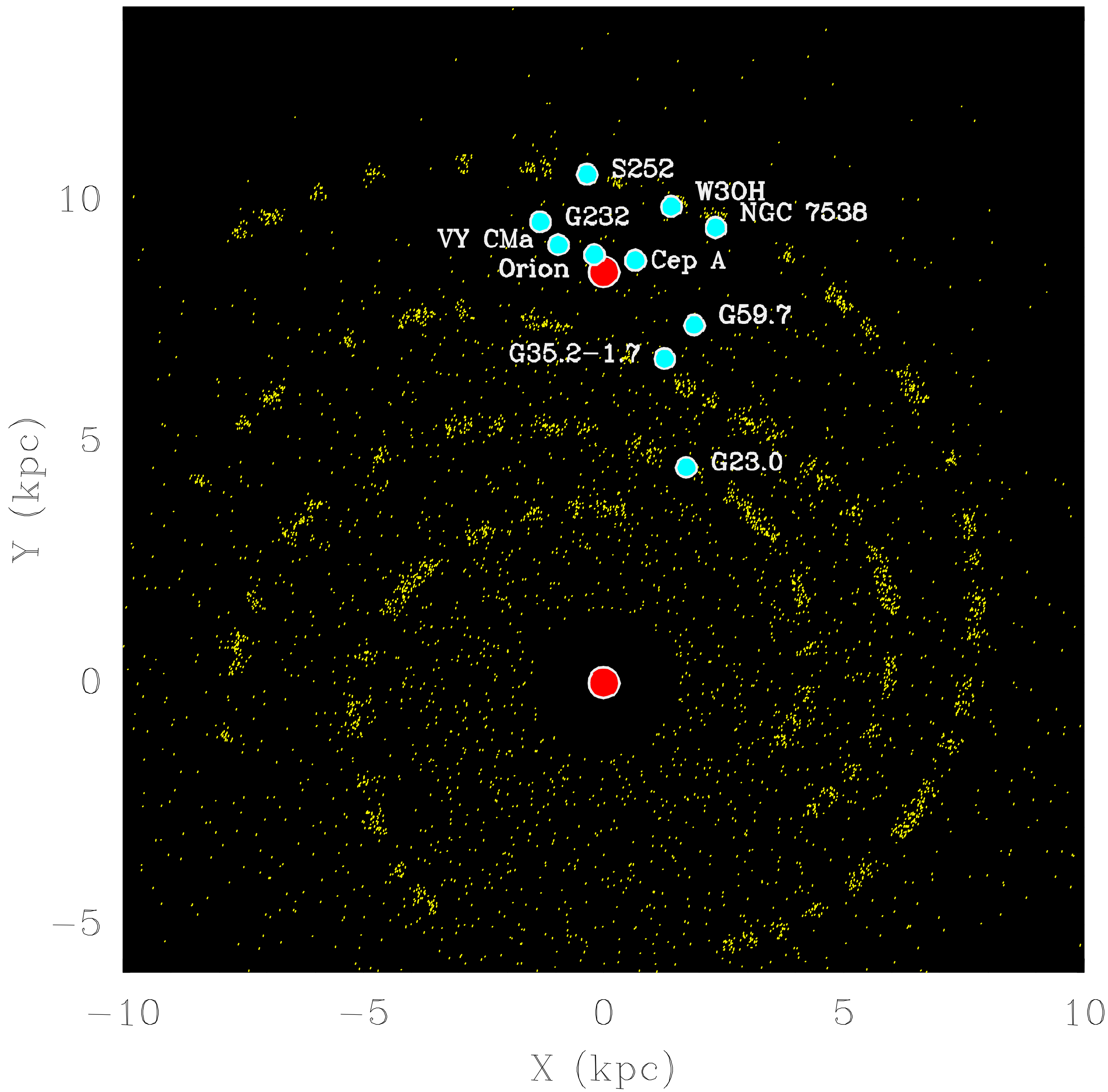
- weaker (= rarer) than 6.7 GHz CH3OH masers

BUT:

- Can be done with VLBA
- smaller beam
- Less affected by IS scattering

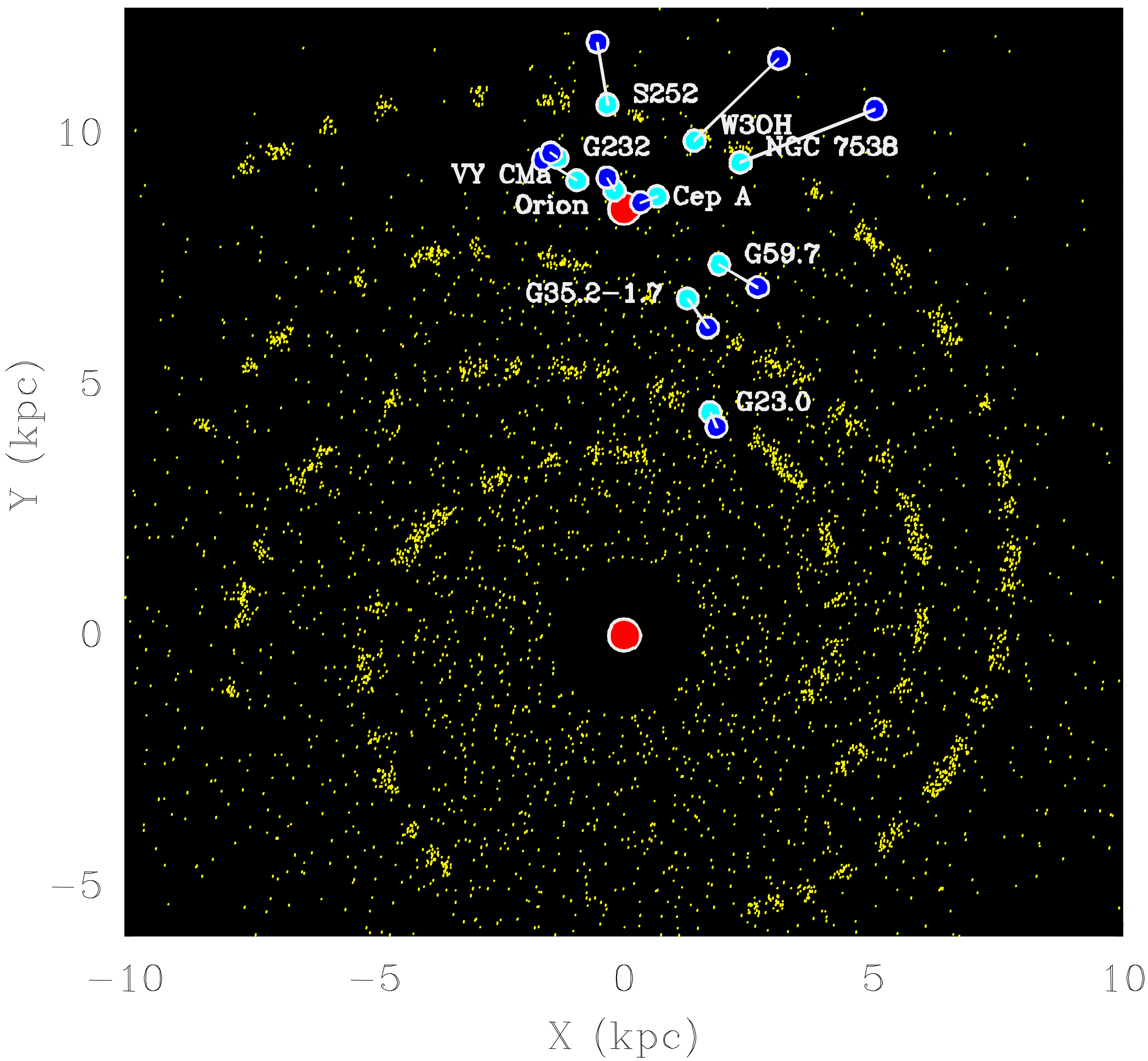
Unfortunately not many found at large galactocentric radii

12.2 GHz CH_3OH parallax results:



Source	*D*(kpc)
W3OH	1.95(0.04)
NGC 7538	2.65(0.06)
Cep A	0.69(0.02)
G23.0-0.4	4.4(0.5)
G59.7+0.1	2.20(0.01)
G9.62+0.19	(0.9)
and	
VY CMa	1.1(0.1)
and	
Orion NC	0.414(0.007)

Parallaxes versus Kinematic Distances



- **Kinematic distances larger than Parallaxes**
- **R_0 < 8.5 kpc and/or Θ_0 > 220 km/s**
- **Solar Motion important**

Astrometry of Galactic Star Forming Region Sharpless 269 with VERA : Parallax Measurements and Constraint on Outer Rotation Curve

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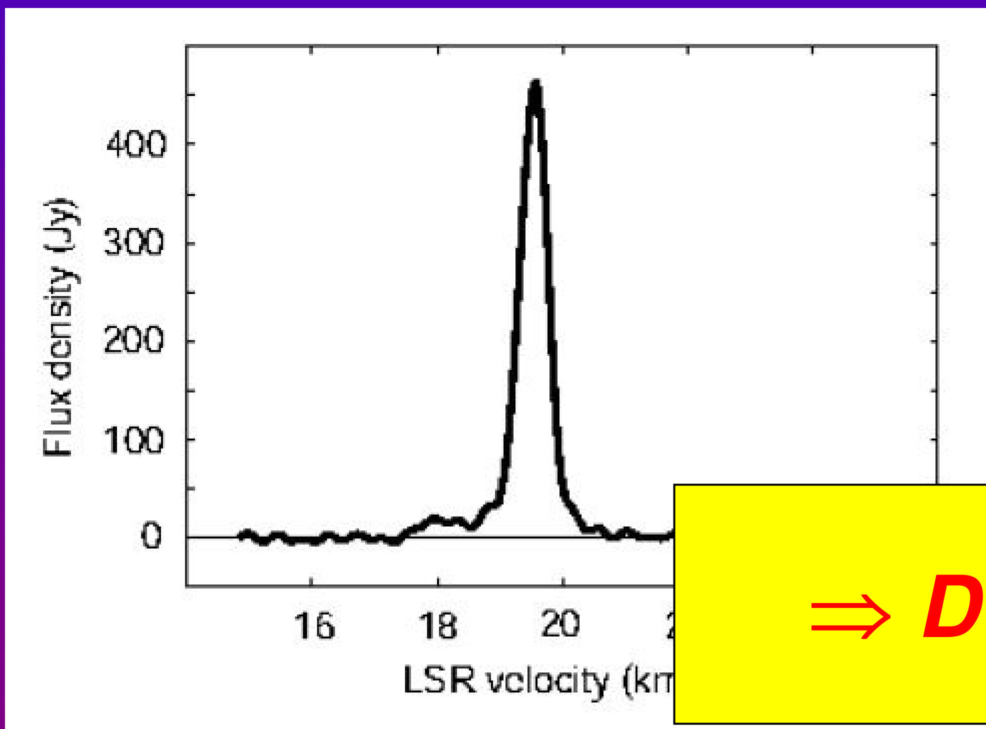
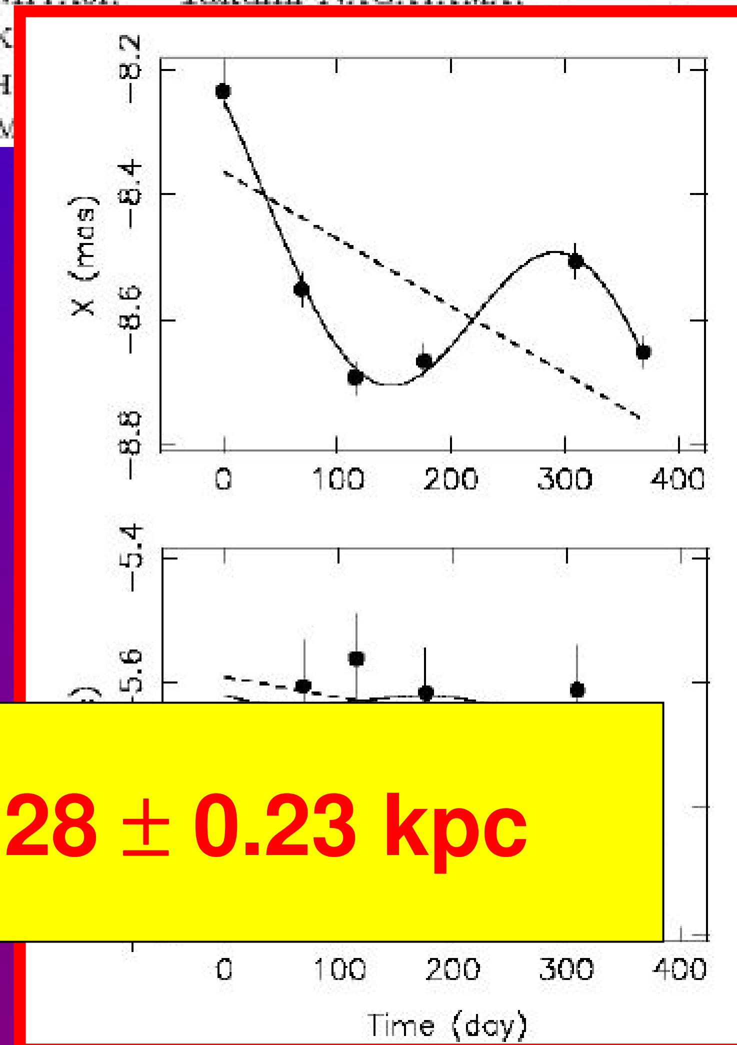
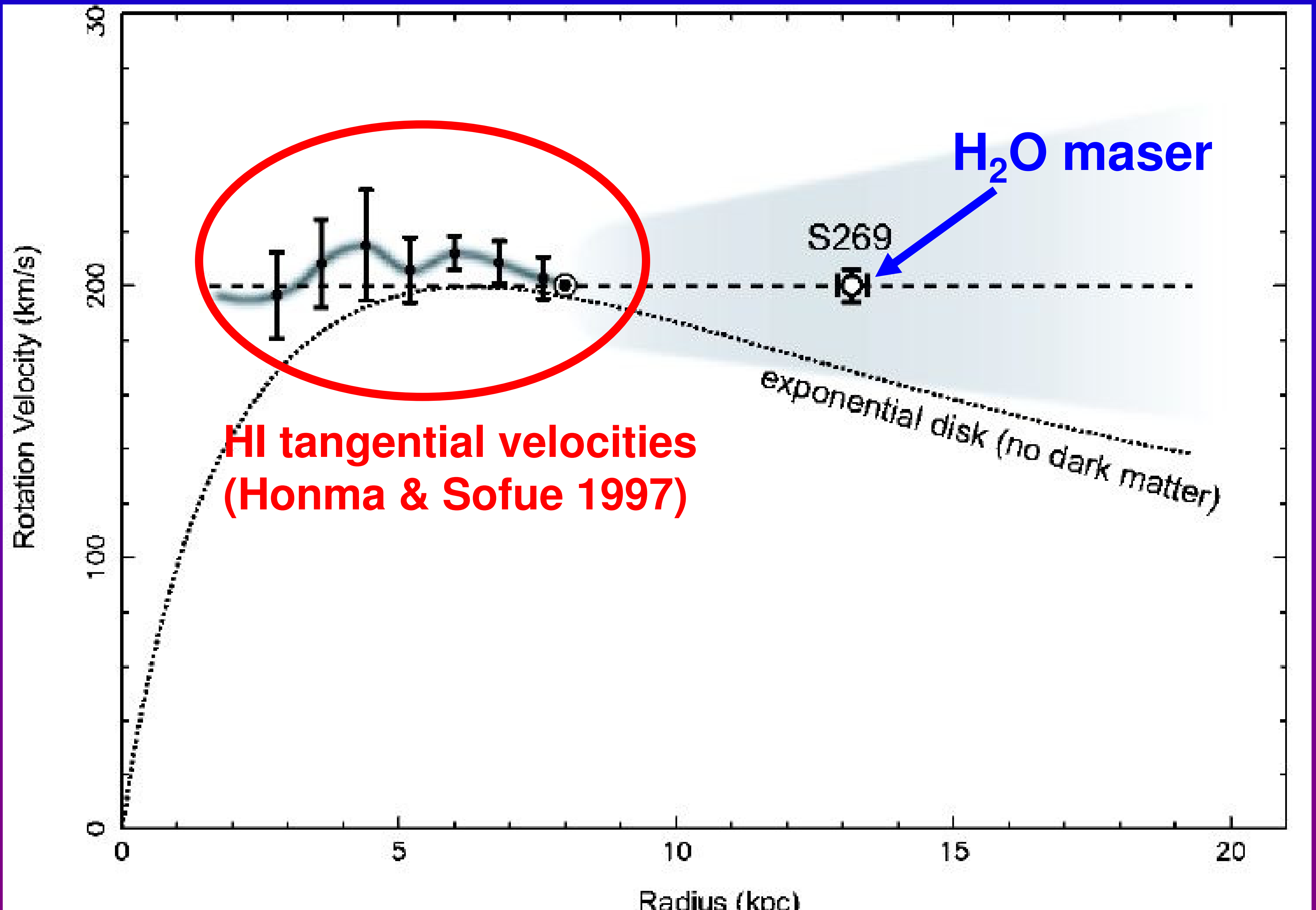
Kenzaburo IWADATE,[6] Takaaki JIKE,[6] Osamu KAMEYA,[2,6] Ryuichi KAMOHARA,[1] Yukitoshi KAN-YA,[1,7]
Noriyuki KAWAGUCHI,[1,2] Masachika KIJIMA,[1,2] Hideyuki KOBAYASHI,[1,3,4,6] Seisuke KUJI,[6]
Tomoharu KURAYAMA,[1] Seiji MANABE,[2,6] Takeshi MIYAJI,[1,3] Takumi NAGAYAMA,[5]
Akiharu NAKAGAWA,[5] Chung Sik OH,[1,4] Toshihiro OMODAK
Katsuhisa SATO,[6] Tetsuo SASAO,[8,9] Katsunori M. SH
Hiroshi SUDA,[4,6] Yoshiaki TAMURA,[2,6] Miyuki TSUSHIM

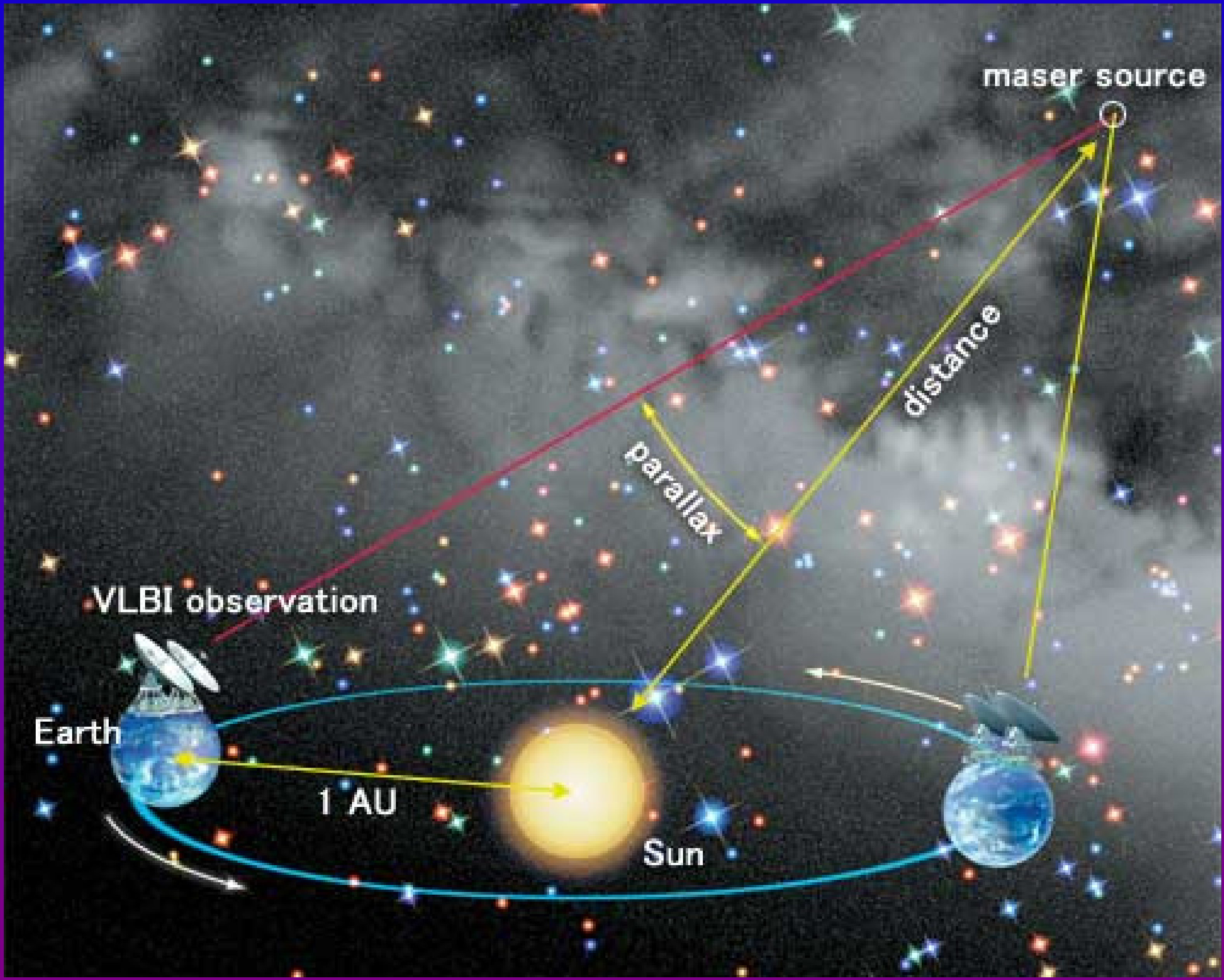




⇒ D = 5.28 ± 0.23 kpc



Rotation Velocity (km/s)
Radius (kpc)
0
100
200
300
0
5
10
15
20
H2O maser
S269
exponential disk (no dark matter)
HI tangential velocities
(Honma & Sofue 1997)



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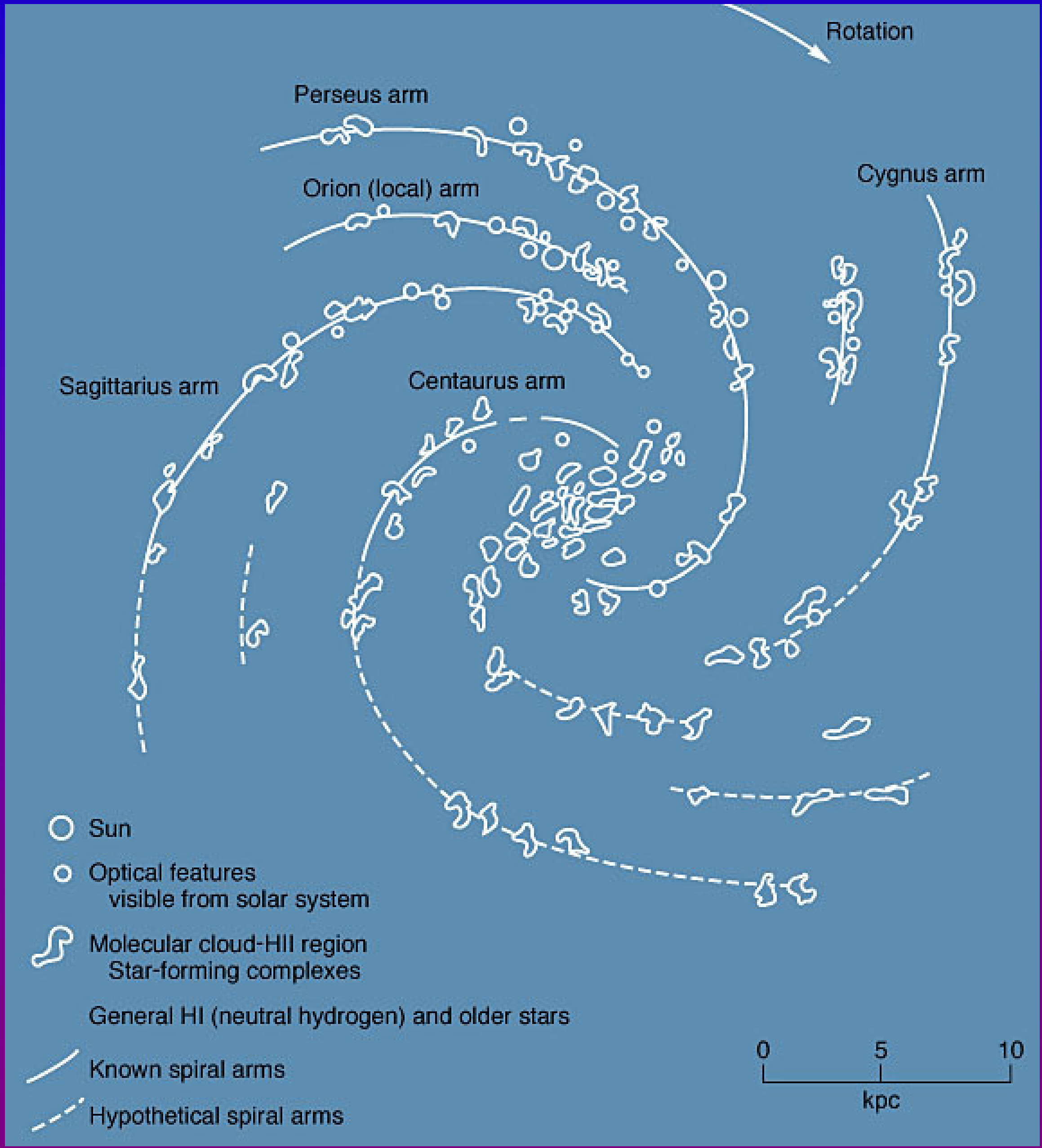
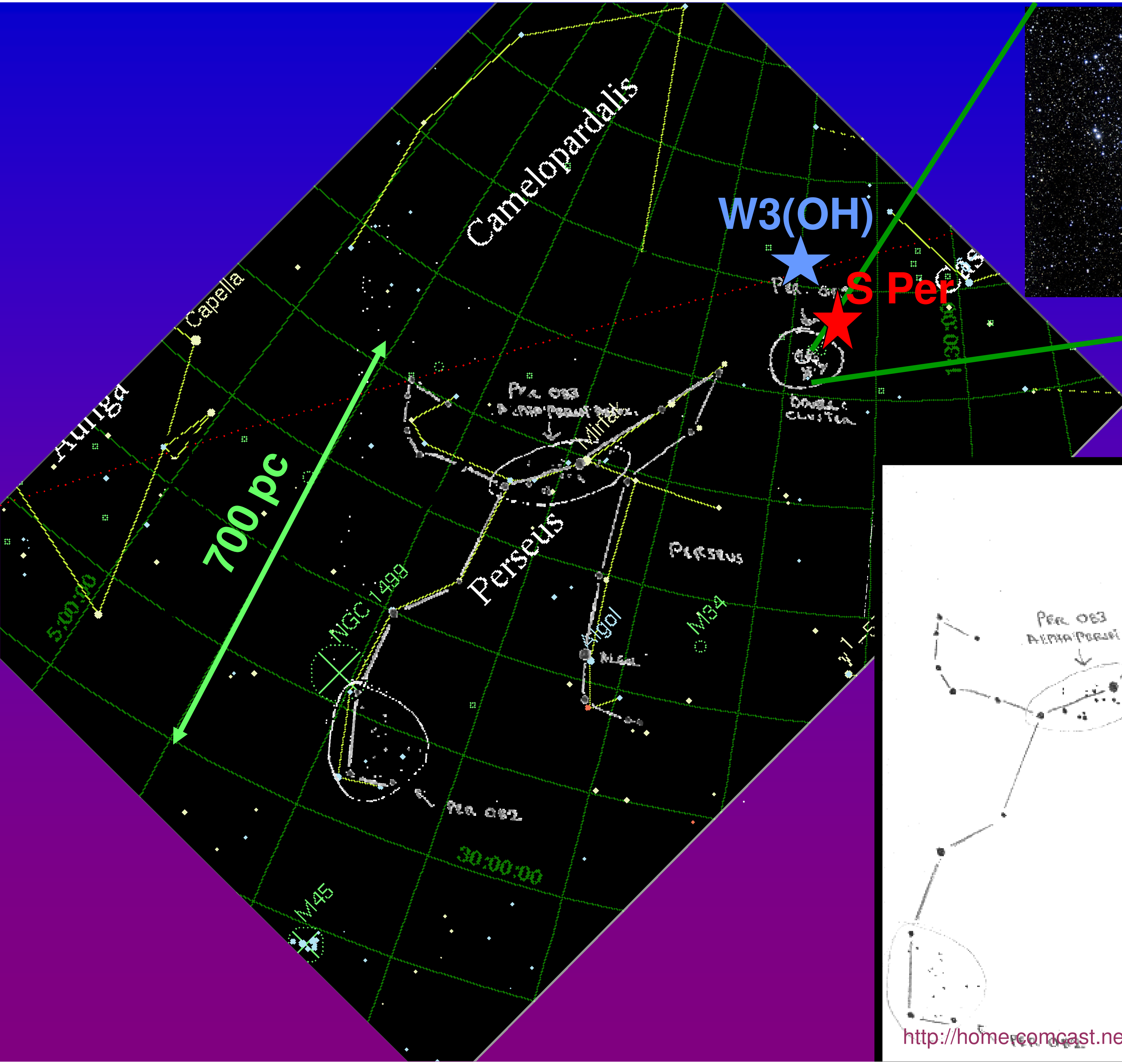
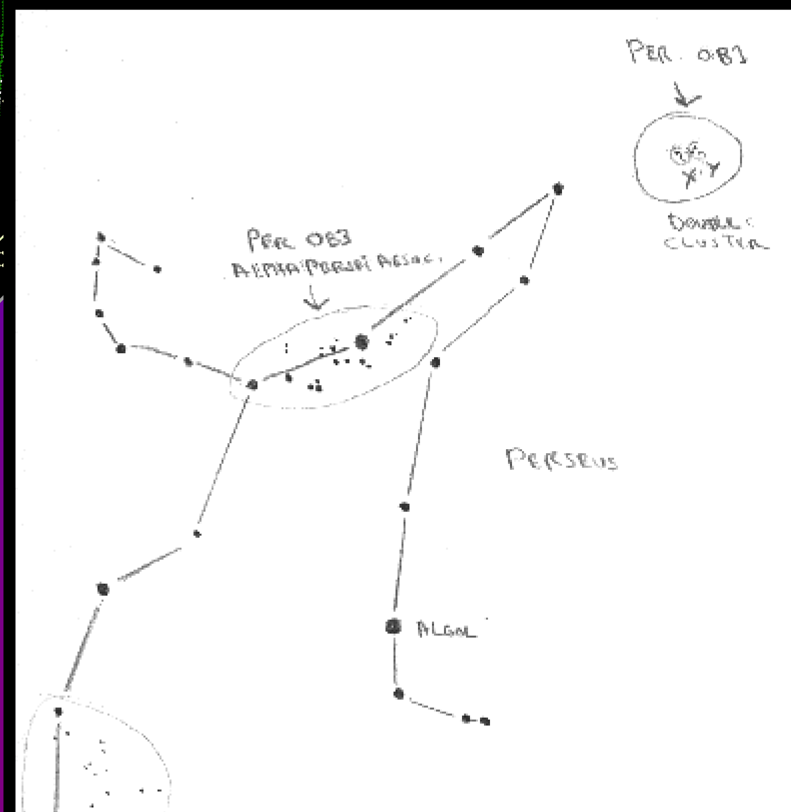
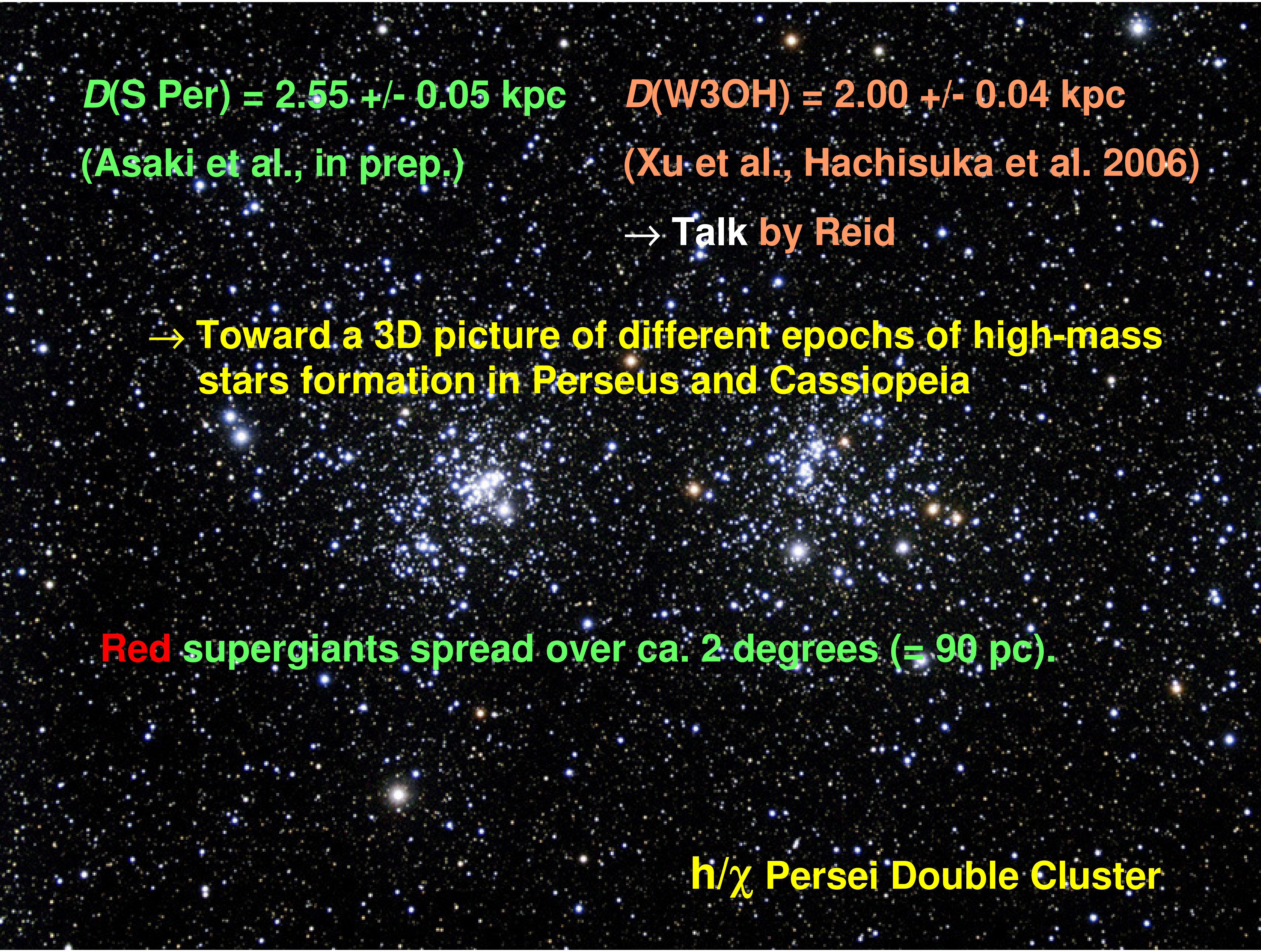


http://members.fcac.org/~sol/chview/milkyway.jpg





Larry's Perseus
http://home.comcast.net/~lsmch/OBCPERSS.HTM


D(S Per) = 2.55 +/- 0.05 kpc
(Asaki et al., in prep.)
D(W3OH) = 2.00 +/- 0.04 kpc
(Xu et al., Hachisuka et al. 2006)
→ Talk by Reid
→ Toward a 3D picture of different epochs of high-mass stars formation in Perseus and Cassiopeia
Red supergiants spread over ca. 2 degrees (= 90 pc).
h/χ Persei Double Cluster

Masers at MSF07

- Castangia: H2O masers in starburst galaxies
- de Buizer: Maser disks or maser outflows
- Goddi: Maser VLBI
- Goedhart: Periodic methanol masers
- Gomez: Class I methanol masers
- Green: The methanol multibeam survey
- Greenhill: Orion revisited
- Hachisuka: Water masers in W3(H2O)
- Hirota: Orion H2O Astrometry with VERA
- Hofner: Formaldehyde masers
- Kim: VERA Orion SiO masers
- Pandian: Probng Galactic Structure using 6.7 GHz methanol masers
- Tostensson: Environment of methanol masers
- Pestalozzi: What methanol masers tell us about HMSF
- Quinn: 6035 Hz OH masers
- Sanna: Maser VLBI
- Sato: H2O masers in NGC281 superbubble
- Tostensson: Environment of methanol masers
- Trinidad: H2O masers and radio in HMSFRs
- Vlemmings: Maser polz’n