Late Stage of Stellar Evolution
structure & dynamics

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Masers are a powerful tool to study 2 crucial moments in the life of a star:

- formation process
  *most common species: H$_2$O, CH$_3$OH and OH*
  *(also detected: SiO, NH$_3$, H$_2$CO, CH$_3$CHO)*
  *early stage of the high mass star formation process*

- late stage of evolution
  *in AGB - PPN & RSG*
  *SiO, H$_2$O and OH*
  *probing the (outer part of the) CSE*
  *[also observed in Supernova Remnants]*
Introduction

Schematic evolutionary tracks
Schematic Circumstellar Envelope of an Evolved Star

- degenerate CO core
- C/O < 1
- convective envelope
- pulsation
- molecule formation
- Oxygen bearing molecules
- Miras: Optically thin
- dust formation
- circumstellar envelope
- photochemical reactions

- SiO masers
- H2O masers
- OH masers

- Interstellar radiation

- ISM
Introduction

Schematic Circumstellar Envelope of an Evolved Star

- SiO masers
- H2O masers
- OH masers

- degenerate CO core
- convective envelope
- pulsation
- molecule formation
  - Oxygen bearing molecules
- OH/IR: Optically thick

- C/O < 1

- Interstellar radiation
- dust formation
- circumstellar envelope
- ISM

- photochemical reactions
Evolved Star
[maser] CSE

Dust condensation

SiO

H₂O

OH

~ 5 R☉

~ 50 R☉

~ 1000 R☉
Evolved Star
[maser] CSE

Standard model:
- Spherical shell
- Uniform radial expansion

[Graph showing I(Jy) vs. V(km/s)]

V expansion
V star
V(km/s)

S. Etoka – NARIT-SOKENDAI Winter School – Late Stage of Stellar Evolution - 17th January 2018
Evolved Star [maser] CSE

Standard model:

- Spherical shell
- Uniform radial expansion
Evolved Star [maser] CSE

Right Ascension
Declination

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**Evolved stars through OH Masers**

*Shaping in evolved stars*

![Image of a Red Giant and Planetary Nebula](image.png)
Evolved stars through OH Masers

Shaping in evolved stars
Evolved stars through OH Masers

Shaping in evolved stars

(Etoka & Diamond, 2010)
Evolved stars through OH Masers

**Shaping in evolved stars**

V=f(θ) well explained by a prolate shell titled about 45° – 65° to the LOS

(Bower 1991)

(Etoka & Diamond, 2010)
Evolved stars through OH Masers

Shaping in evolved stars

poloidal magnetic field ($|B|=3.7mG$) titled ~40-60° to the LOS

(Etoka & Diamond, 2010)
Evolved stars through OH Masers

Shaping in evolved stars

Both the polarimetric axis and the geometrical axis are consistent with each others

(Etoka & Diamond, 2010)
Evolved stars through OH Masers

Distance determination through the Phase Lag Method


OH/IR stars

~Miras BUT optically thick circumstellar dust & gas envelopes

periods: 1 year $\rightarrow$ >5 years

typical diameter 2000 $\rightarrow$ > 10,000 AU
Evolved stars through OH Masers

Distance determination through the Phase Lag Method

Method

• OH light curves
  
  * time difference btw blue & red OH maser peak (long-term monitoring needed)
  
  \( \Rightarrow \) linear diameter

Phase-lag \( \tau_0 \) determination by interpolation

\( \Rightarrow \) Scaling and shifting of the integrated-flux light curves of the blue peak \( F_B \) with respect to the red one \( F_R \)

Minimizing the function

\[
\Delta F = F_R(t) - a \ast F_B(t+\tau_0) + c
\]

with \( a, c \) constants for the amplitude and mean flux
Evolved stars through OH Masers

Distance determination through the Phase Lag Method

Linear diameter determination

Distance determination through the Phase Lag Method
Evolved stars through OH Masers

Distance determination through the Phase Lag Method

**Method**

- OH light curves
  - *time difference btw blue & red OH maser peak* (long-term monitoring needed)
    - ➤ linear diameter

- Interferometric maps
  - *measure of the OH shell extent*
    - ➤ angular diameter
Evolved stars through OH Masers

Distance determination through the Phase Lag Method

Angular diameter determination

\[ \theta \sim 1.8'' \]
Evolved stars through OH Masers

$P = 4.11 \text{ yr}$

$5200 \text{ AU}$

$\theta \sim 1.8''$

$\sim 3 \text{ kpc}$

Linear diameter & Angular diameter

NRT