Binary nature revealed in circumstellar spiral-shell patterns

Hyosun Kim (ASIAA)
Ronald Taam, Sheng-Yuan Liu, I-Ta Hsieh

EAMA9 @ 2013-10-17
Binary nature revealed in circumstellar spiral-shell patterns

Hyosun Kim (ASIAA)
Ronald Taam, Sheng-Yuan Liu, I-Ta Hsieh

EAMA9 @ 2013-10-17
Nearly-concentric periodic patterns
unexpected discoveries in AGBs, PPNe, and PNe

Dust scattered light

AFGL 3068  IRC+10216  NGC 7027  Cat's Eye  Egg nebula

Molecular line emission

R Scl  CIT 6

- Time scale between arcs, rings, & spirals ($10^2–10^3$ yr) are shorter than the typical AGB thermal pulsation ($\sim 10^5$ yr) and longer than stellar pulsation (1–2 yr)
- The outer nearly-concentric patterns are prior to the onset of bipolarity in PPNe and PNe at the transition from AGB
- Linking the outer periodic patterns with the stellar (binary) properties may link it with the bipolarity
Binary system

- Stellar masses
- Binary separation
- Orbital speeds
Binary system
in a circumstellar medium

- stellar masses
- binary separation
- orbital speeds
Binary system creates spiral pattern in a circumstellar medium

- Stellar masses
- Binary separation
- Orbital speeds
- Spiral pattern
Binary system creates spiral pattern in a circumstellar medium

stellar masses
orbital speeds
↑
binary separation
+
spiral pattern
Binary system creates spiral pattern in a circumstellar medium
Wind anisotropy due to AGB star’s orbital motion

\[ \sim V_W - V_{\text{orb}} \]

\[ \sim V_W + V_{\text{orb}} \]

CoM

SHOCK
Elongated spiral model

**Inclination & Velocity ratio** $V_p/V_w$

Oblate \( (x/a)^2 + (y/a)^2 + (z/b)^2 = 1 \)

\[
a/b = (<V_w> + 2V_p/3) / <V_w>
\]

\[
(a/b)_{proj} = (a/b)^2 \sin^2 i + \cos^2 i
\]

\[
V_p = 3.0 \text{ km s}^{-1} \quad \& \quad V_w \sim 5 \text{ km s}^{-1}
\]

Kim+Taam 2012b

Hyosun Kim

AGB spiral-shell
**CIT 6 – EVLA molecular line – shell vs. spiral**

**Spherical shell model**

(*Claussen et al. 2011*)

**free parameters**

- shell radii
- expansion velocities
- central velocities

**HC$_3$N $J=4-3$ (EVLA)**
CIT 6 – EVLA molecular line – shell vs. spiral

HC$_3$N $J=4-3$ (EVLA)

17.3 km/s  13.2  9.1
4.9  0.8  -3.3
-7.4  -11.5  -15.7
CIT 6 – EVLA molecular line – shell vs. spiral

Ellipse fit

- long axis at PA=10°
- axis ratio 1.15
- arm spacing 3′′2
- binary separation 0′′17

\[
\text{HC}_3\text{N } J=4-3 \text{ (EVLA)}
\]
Parameter space analysis

1. \( \sin^2 i = [(a/b)_{\text{proj}}^2 - 1]/[(1 + 2V_p/3 <V_w>)^2 - 1] \)
2. \( r_p + r_{\text{comp}} = (r_p + r_{\text{comp}})_{\text{proj}}/(1 - \sin^2 i \sin^2 \phi_p)^{1/2} \)
   where \( \tan \phi_p = \tan \text{PA} / \cos i \)
3. \( T_p = \Delta r_{\text{arm}}/(<V_w> + 2V_p/3) \) \& \( r_p = V_p T_p/2\pi \)
4. \( M_p = q(1+q)^2 V_p^2 r_p / G \) \& \( M_{\text{comp}} = M_p / q \)
CIT 6 – Parameter space analysis

Degeneracy due to the projection

Kim et al. 2013
**CIT 6 – Inclination dependence**

\[
i = 0^\circ \quad i = 30^\circ \quad i = 50^\circ \quad i = 70^\circ \quad i = 90^\circ
\]

Kim et al. 2013
CIT 6 – Hydrodynamic radiative transfer model

Red: EVLA observation
Green: HD+RT model
Line: analytic model

Kim et al. 2013

Hyosun Kim
AGB spiral-shell
CIT 6 – Hydrodynamic radiative transfer model

Kim et al. 2013
CIT 6 – Hydrodynamic radiative transfer model

Kim et al. 2013

red : EVLA observation
green : HD+RT model
line : analytic model
Summary

I have reviewed the current status of the theoretical and observational understanding of spiral-shell patterns in the circumstellar envelopes of aging solar-type stars accompanied by the companions.

We have developed a new method of constraining the characteristics of binary stars from the properties of the observed circumstellar spiral and incomplete ring patterns.

Uncertainties in model parameters and observations are still huge.
- Need statistically meaningful number of samples