AGB/PPN/PN circumstellar rings vs. spiral

Hyosun Kim (ASIAA)

Ronald Taam, Sheng-Yuan Liu, I-Ta Hsieh

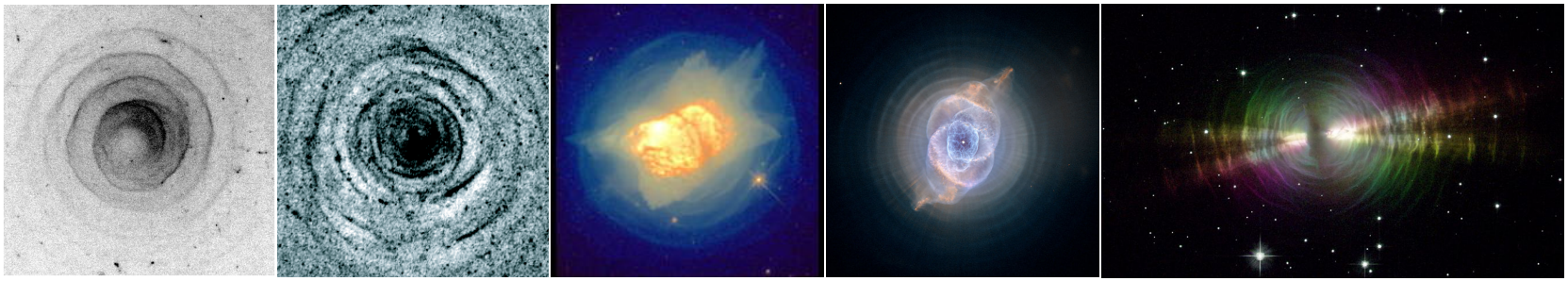
APN6 @ 2013-11-05

Nearly-concentric periodic patterns

unexpected discoveries in AGBs, PPNe, and PNe

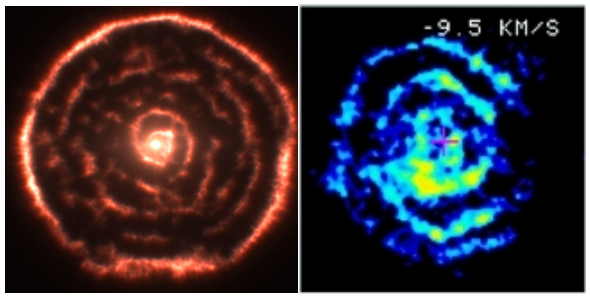
Dust scattered light

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



Molecular line emission

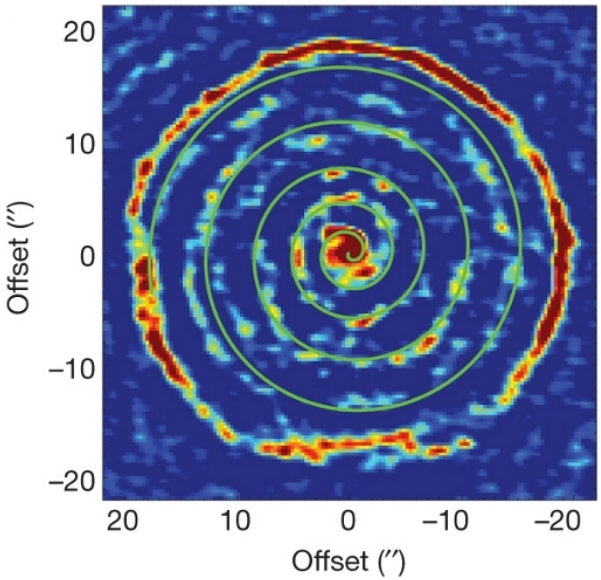
R Scl CIT 6

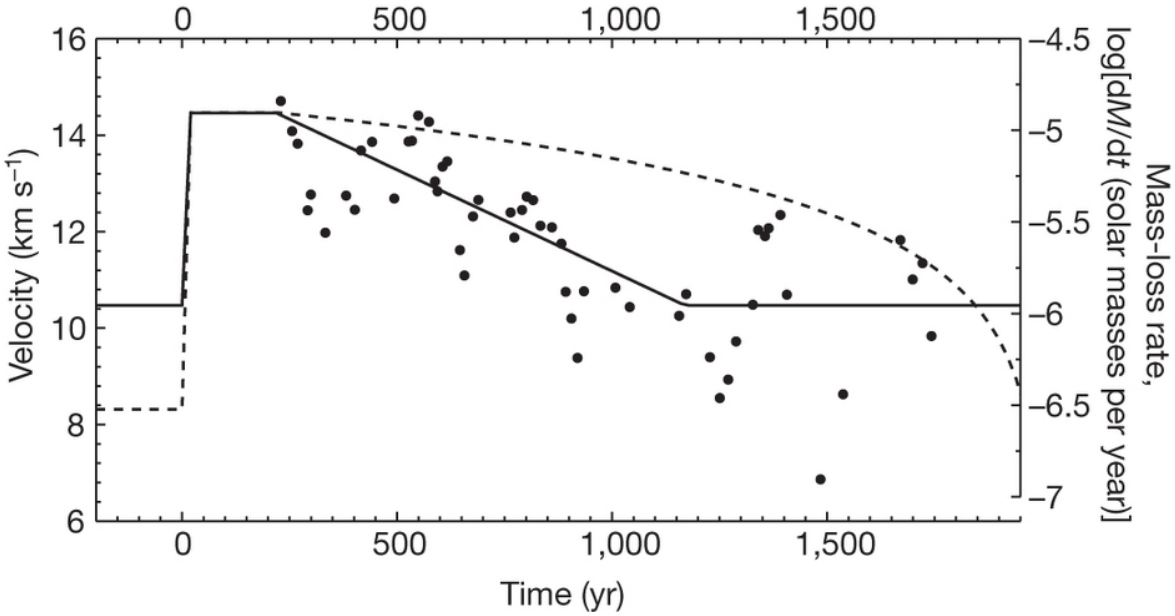


- Time scale between arcs, rings, & spirals (10^2–10^3 yr) are shorter than the typical AGB thermal pulsation ($\sim 10^5$ yr) and longer than stellar pulsation (1–2 yr)
- The outer nearly-concentric patterns are prior to the onset of bipolarity in PPNe and PNe at the transition from AGB
- Linking the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

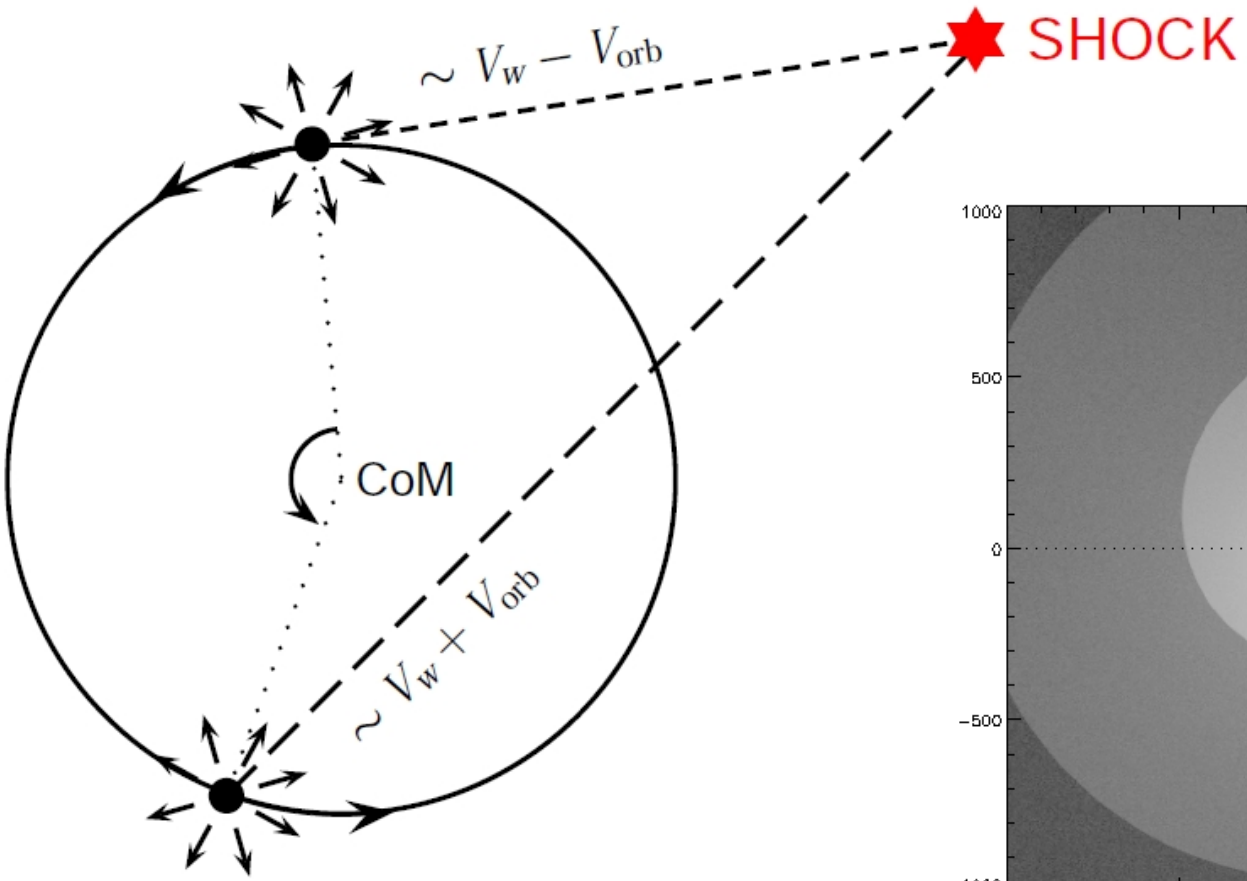
Why care about spiral/ring patterns of AGB stars?

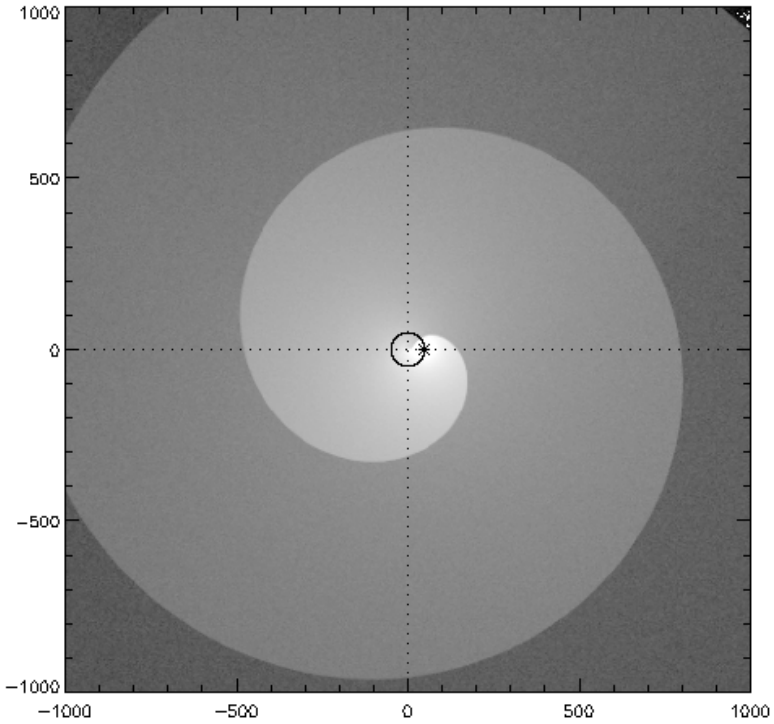
- Binary properties (*Kim & Taam 2012c; Kim et al. 2013*)
  - Mass loss history (*Maercker et al. 2012*)
  - Accretion disk to the companion
  - AGB-PN shape transtion
- Dust-gas nature, coupling, behaviors in a shock





Wind anisotropy due to AGB star's orbital motion





Elongated spiral model

Inclination & Velocity ratio V_p/V_w

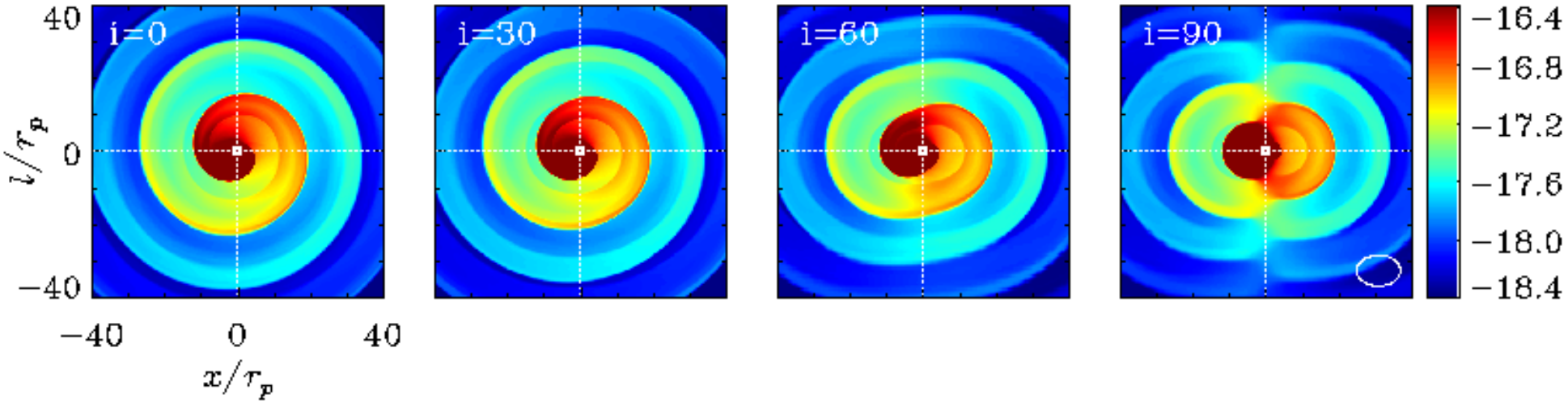
Oblate $(x/a)^2 + (y/a)^2 + (z/b)^2 = 1$

$$a/b = (< V_w > +2V_p/3)/ < V_w >$$

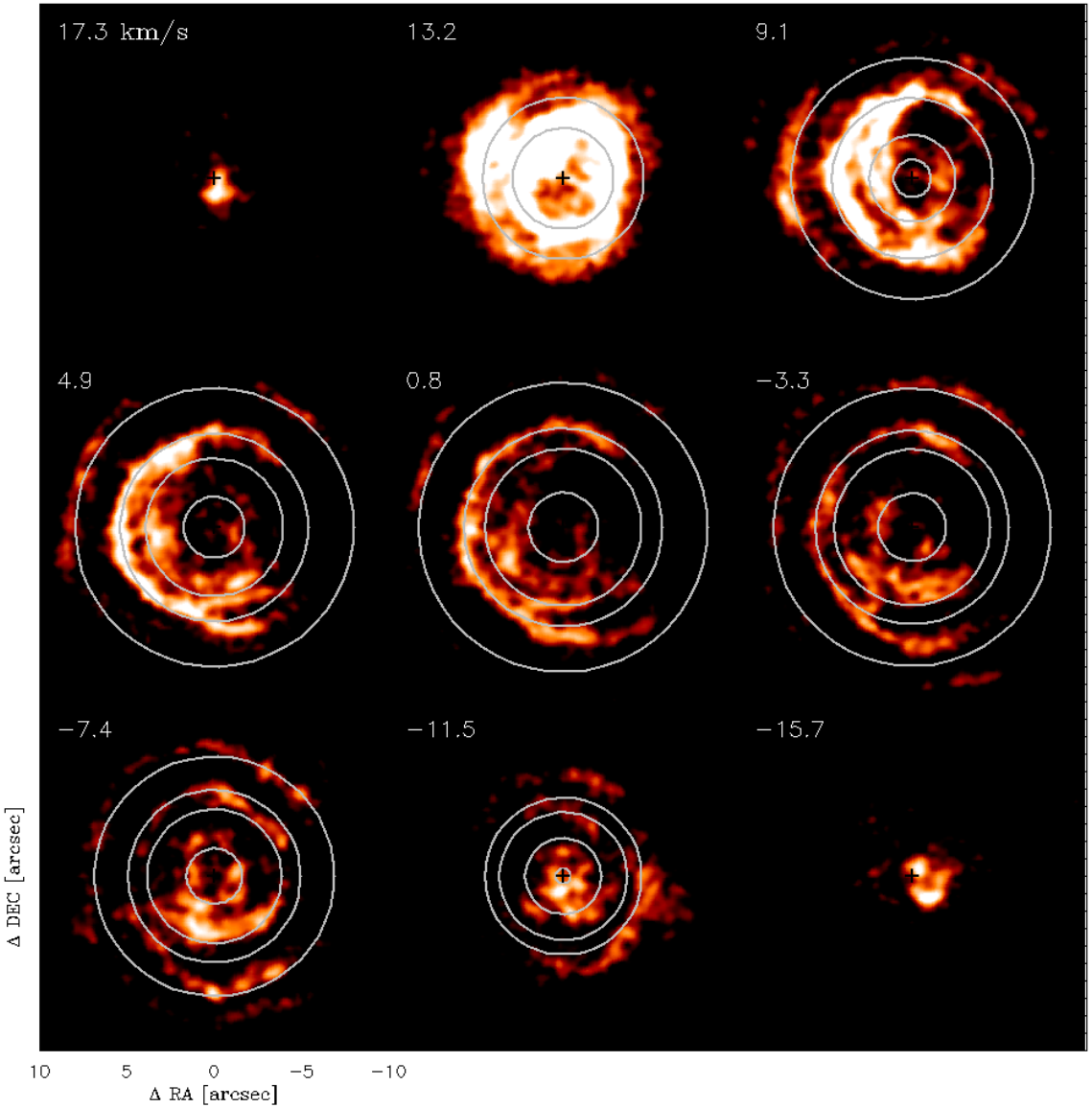
$$(a/b)^2_{proj} = (a/b)^2 \sin^2 i + \cos^2 i$$

$V_p = 3.0\ \mathrm{km\,s^{-1}}$ & $V_w \sim 5\ \mathrm{km\,s^{-1}}$

Kim+Taam 2012b



CIT 6 – JVLA molecular line – shell vs. spiral



Spherical shell model

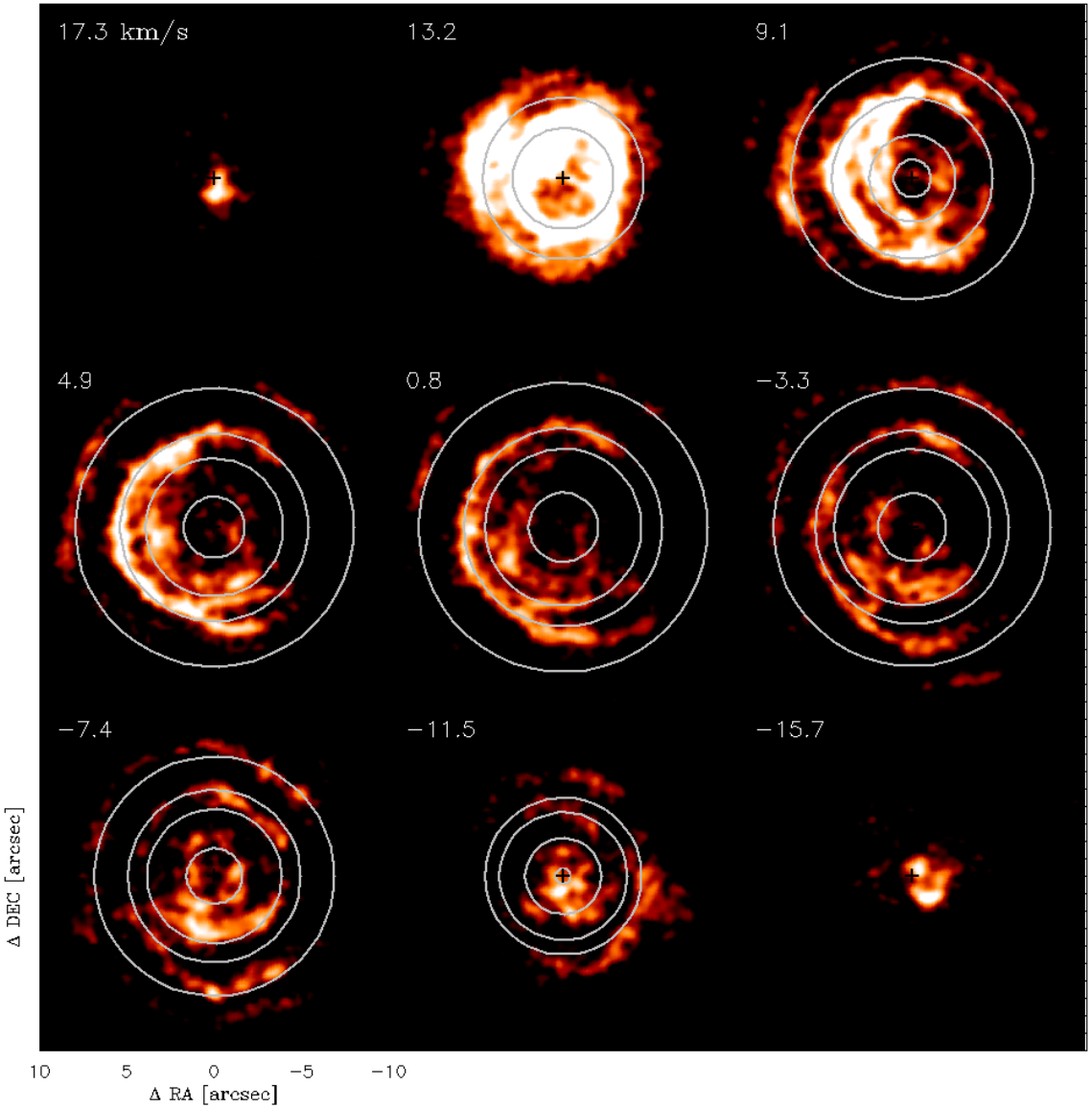
(*Claussen et al. 2011*)

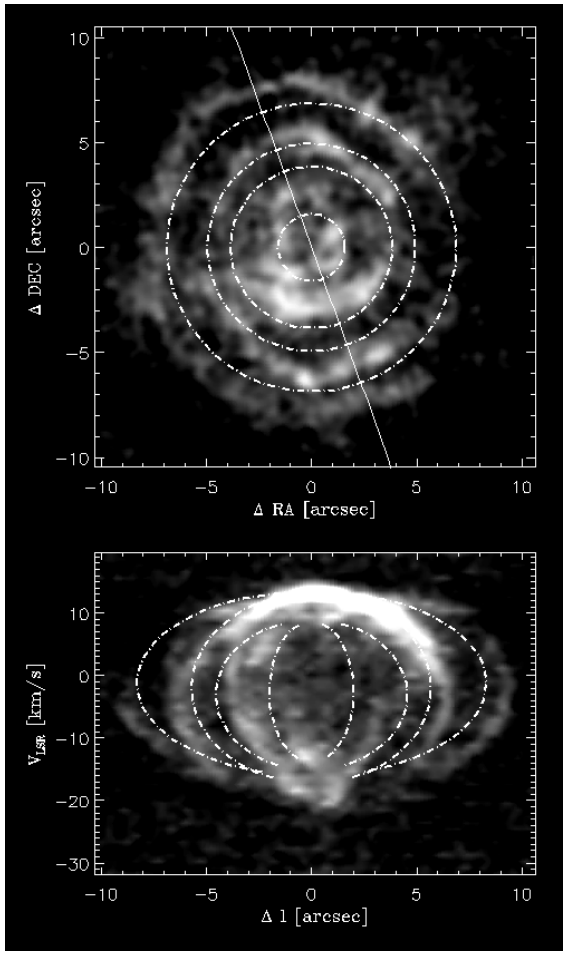
free parameters

- shell radii
- expansion velocities
- central velocities

HC_3N $J=4-3$ (JVLA)

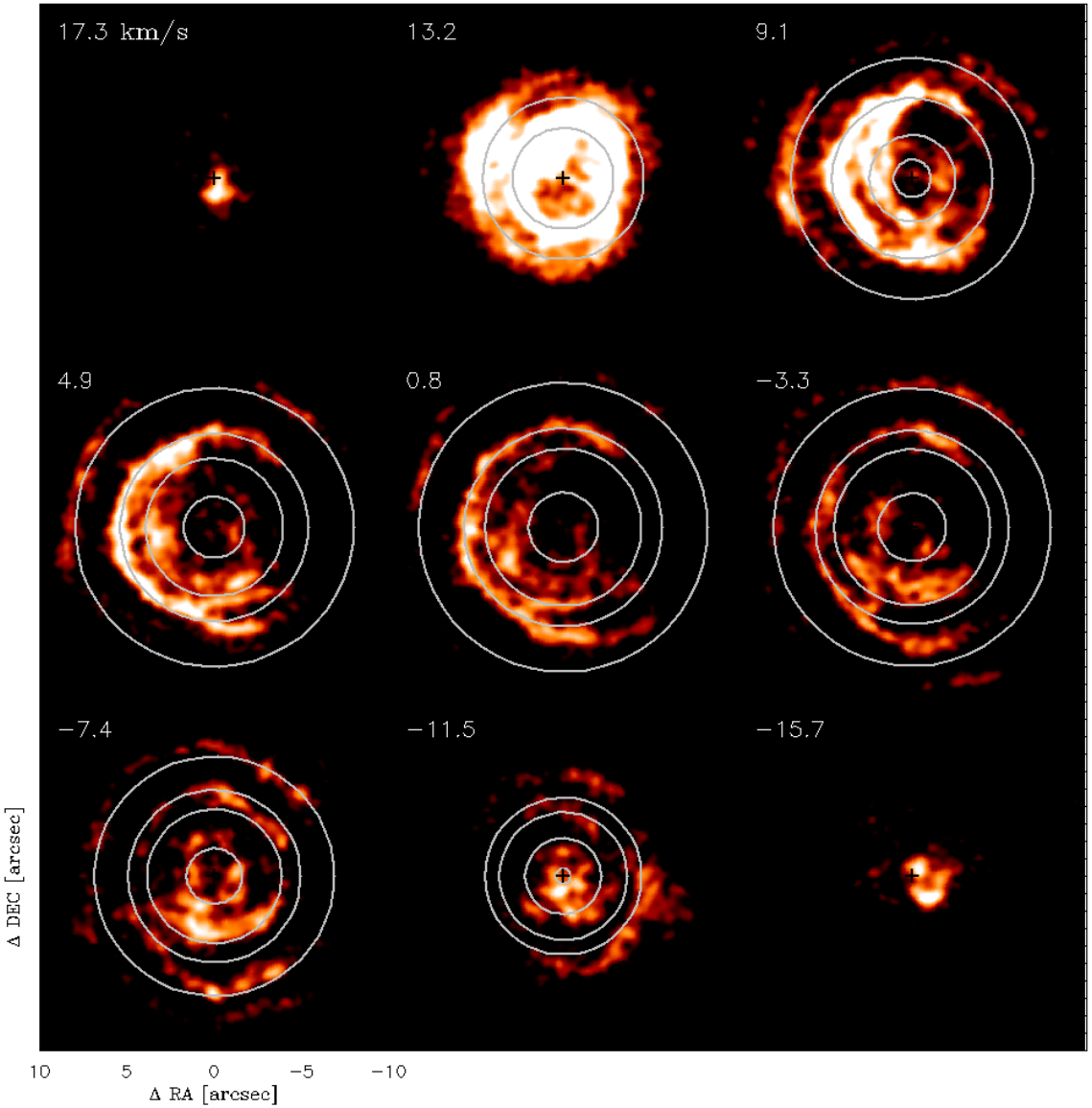
CIT 6 – JVLA molecular line – shell vs. spiral

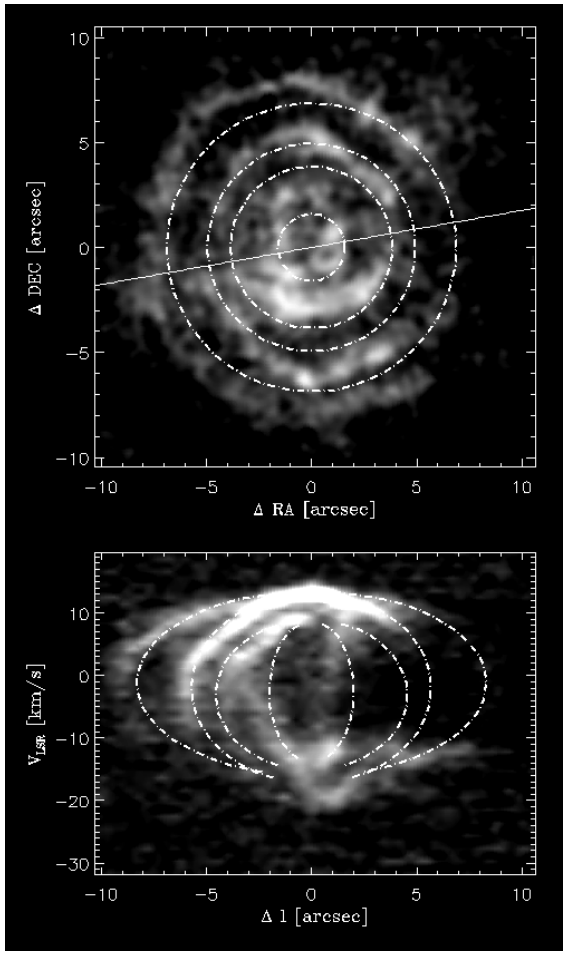




HC_3N $J=4-3$ (JVLA)

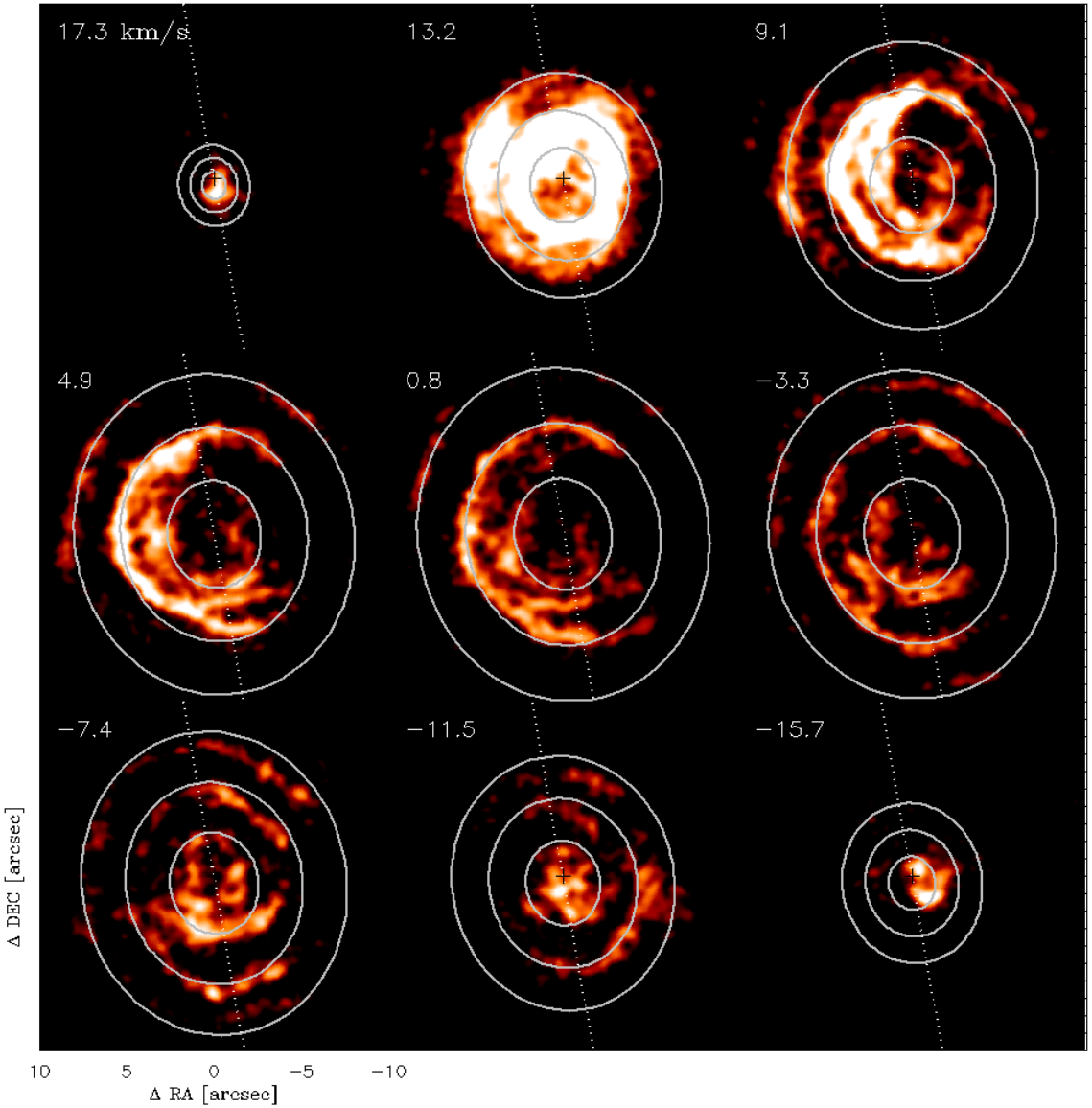
CIT 6 – JVLA molecular line – shell vs. spiral





HC_3N $J=4-3$ (JVLA)

CIT 6 – JVLA molecular line – shell vs. spiral

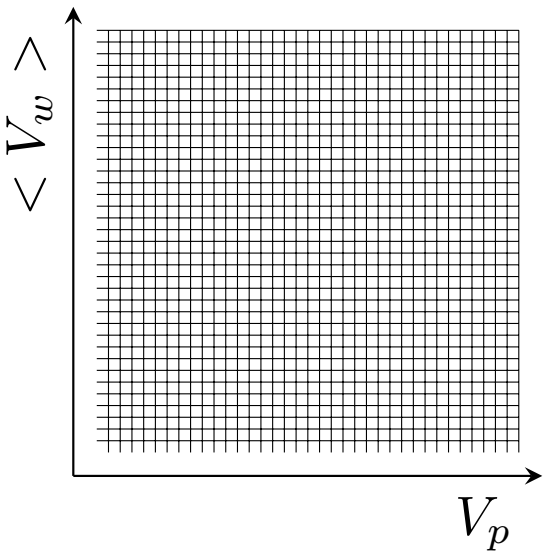


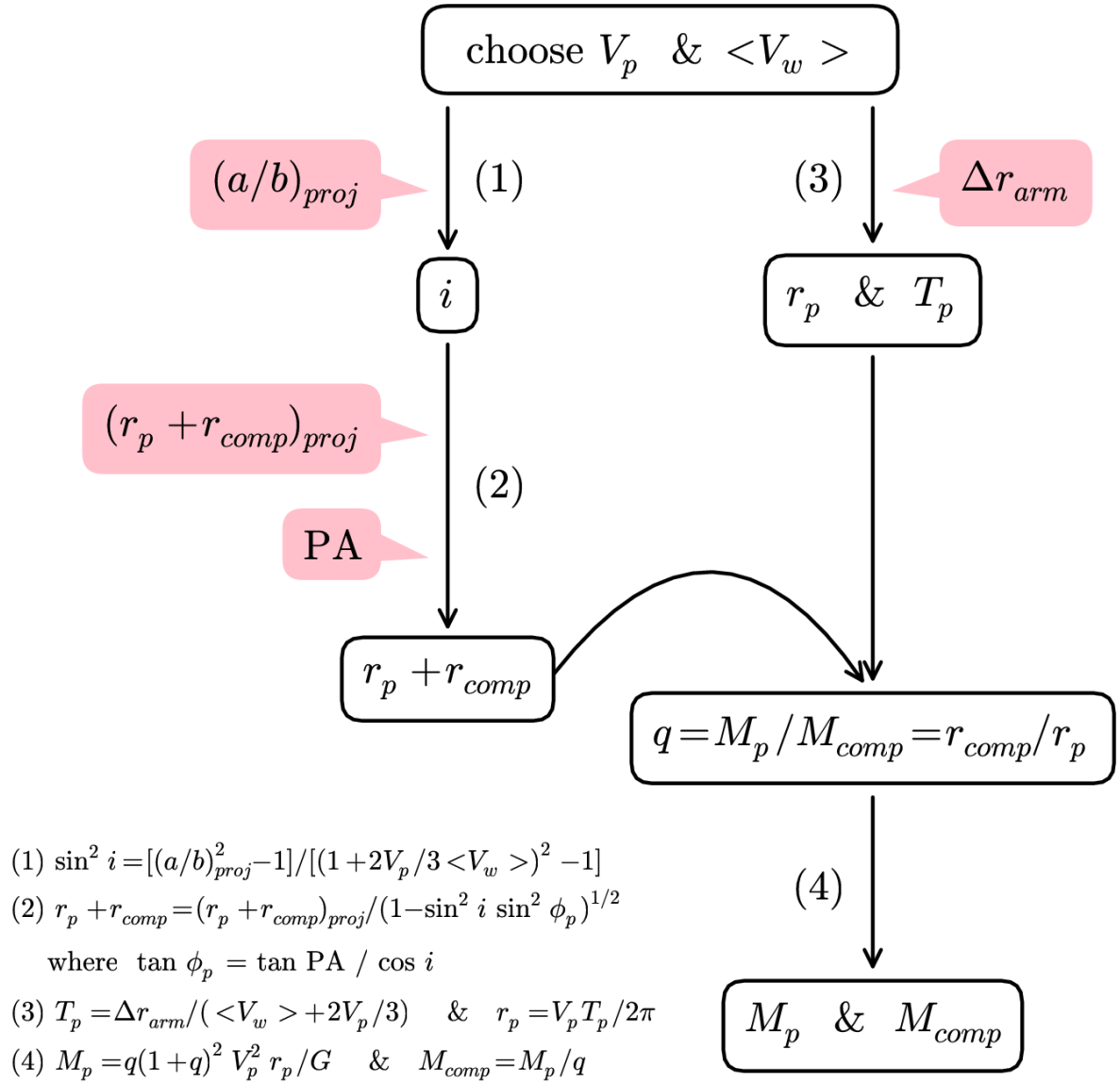
Ellipse fit

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

HC_3N $J=4-3$ (JVLA)

Parameter space analysis





(1) $\sin^2 i = [(a/b)^2_{proj} - 1] / [(1 + 2V_p/3 < V_w >)^2 - 1]$

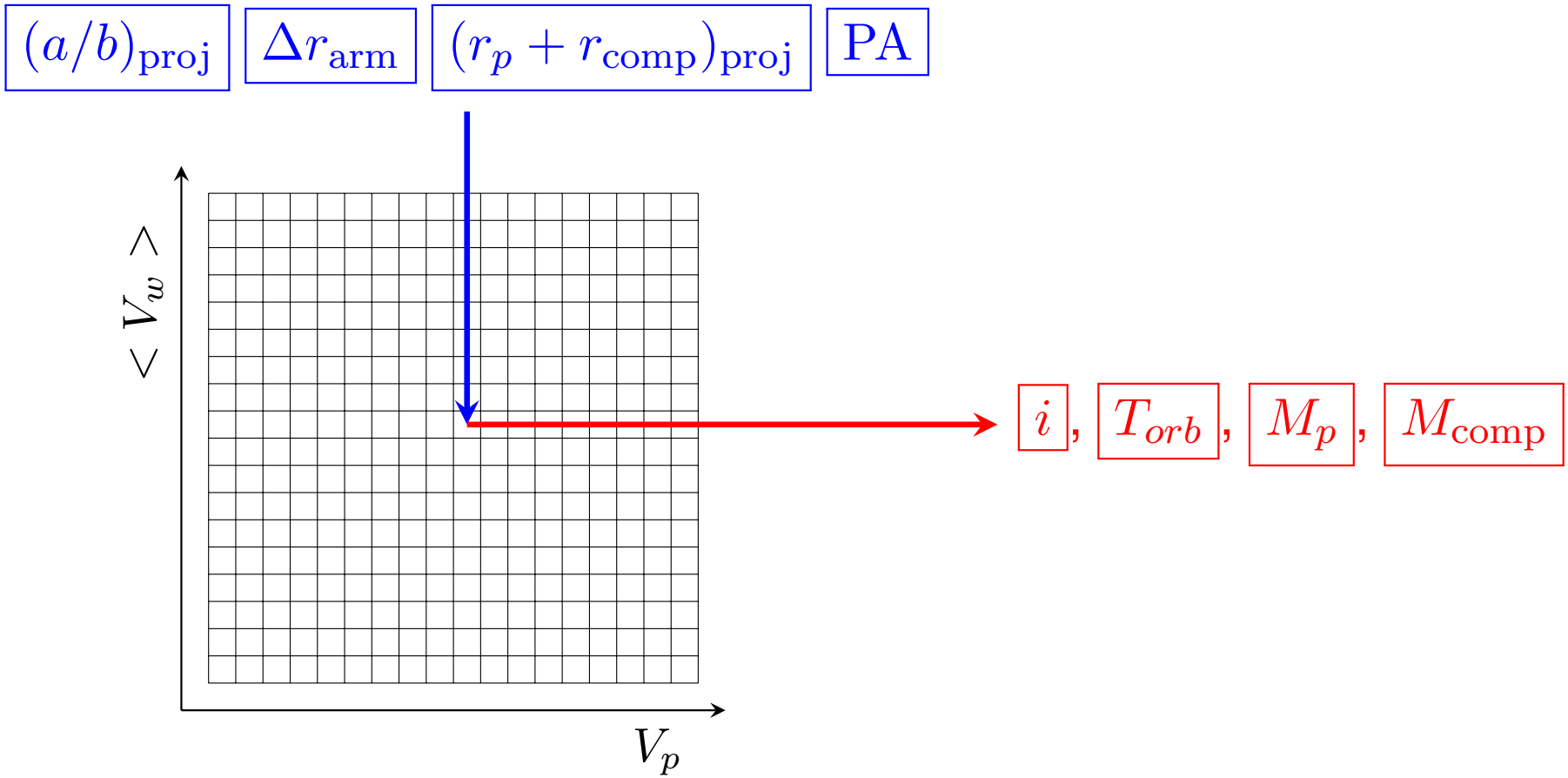
(2) $r_p + r_{comp} = (r_p + r_{comp})_{proj} / (1 - \sin^2 i \sin^2 \phi_p)^{1/2}$

where $\tan \phi_p = \tan \mathrm{PA} / \cos i$

(3) $T_p = \Delta r_{arm} / (< V_w > + 2V_p/3)$ & $r_p = V_p T_p / 2\pi$

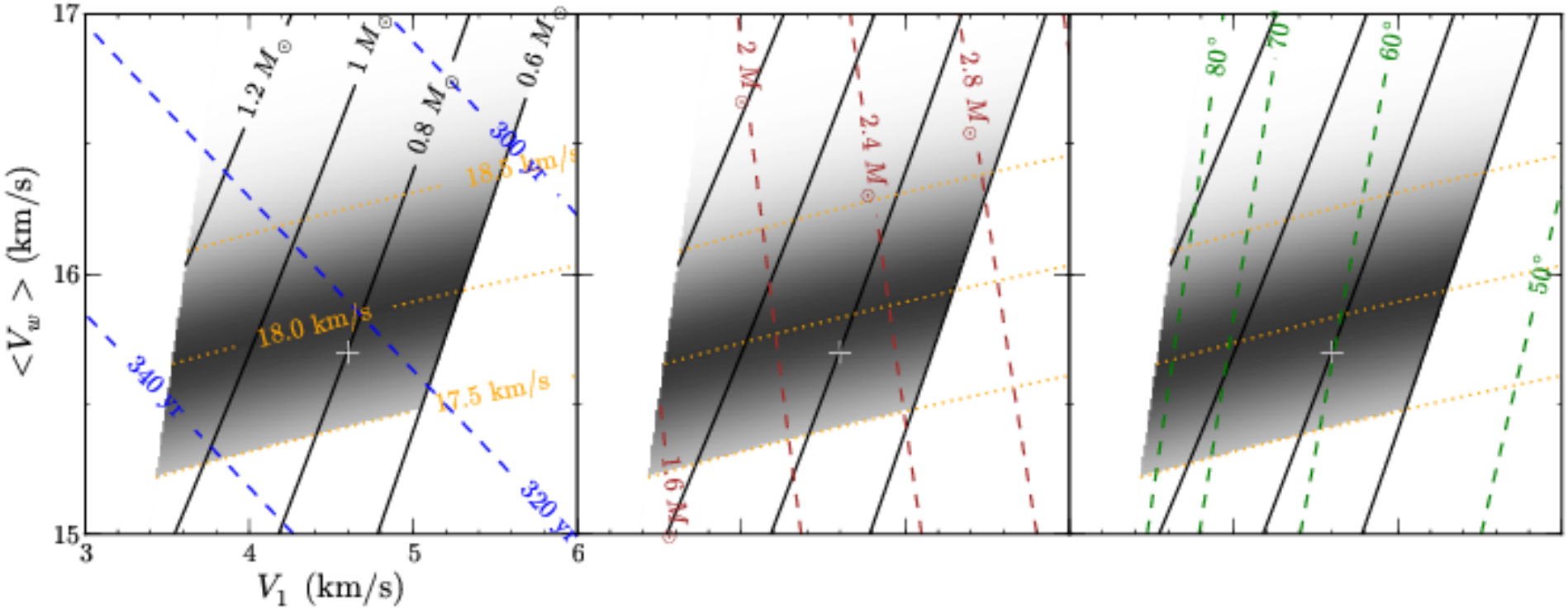
(4) $M_p = q(1+q)^2 V_p^2 r_p / G$ & $M_{comp} = M_p / q$

Parameter space analysis



CIT 6 – Parameter space analysis

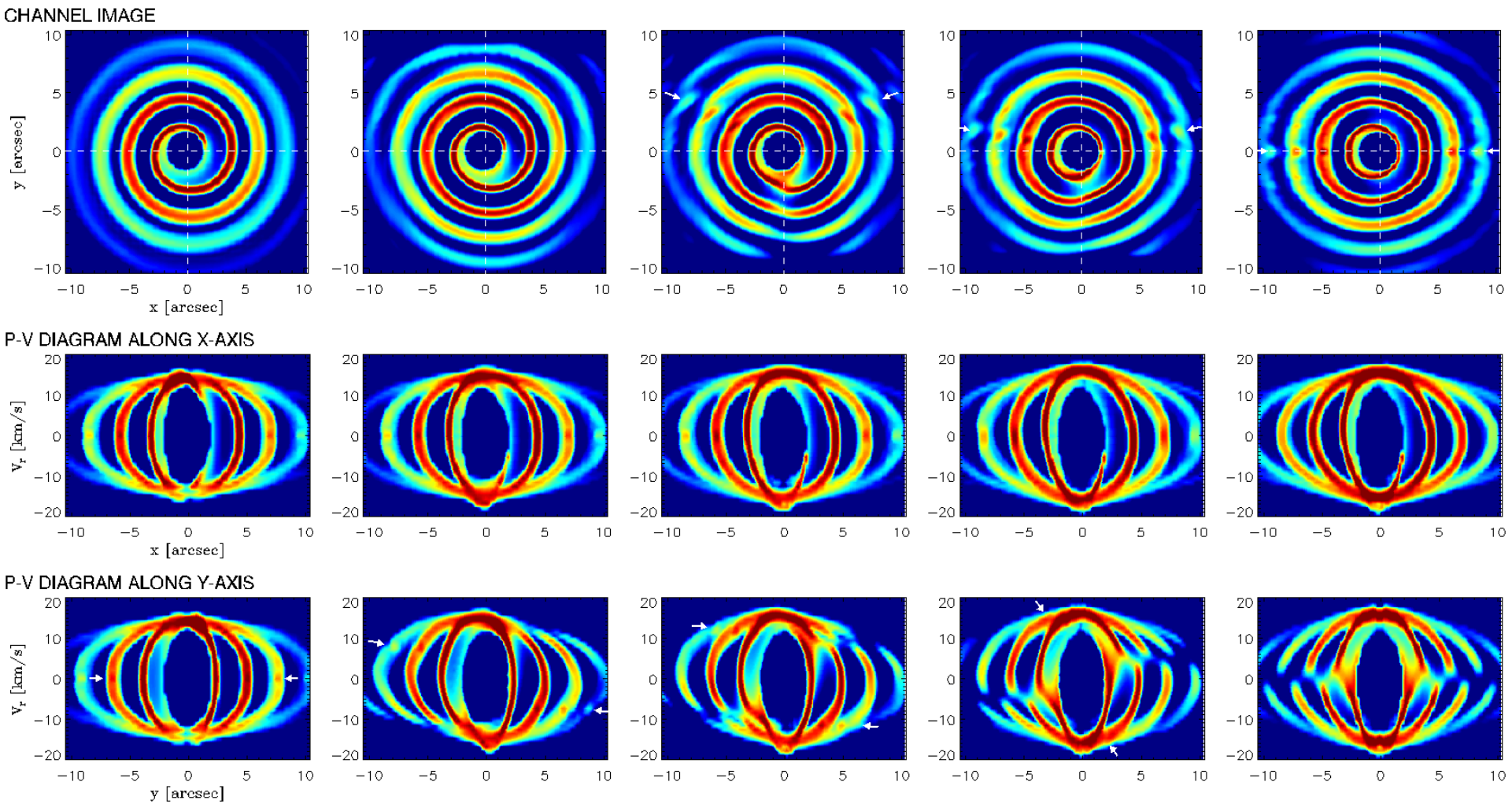
Kim et al. 2013



Degeneracy due to the projection

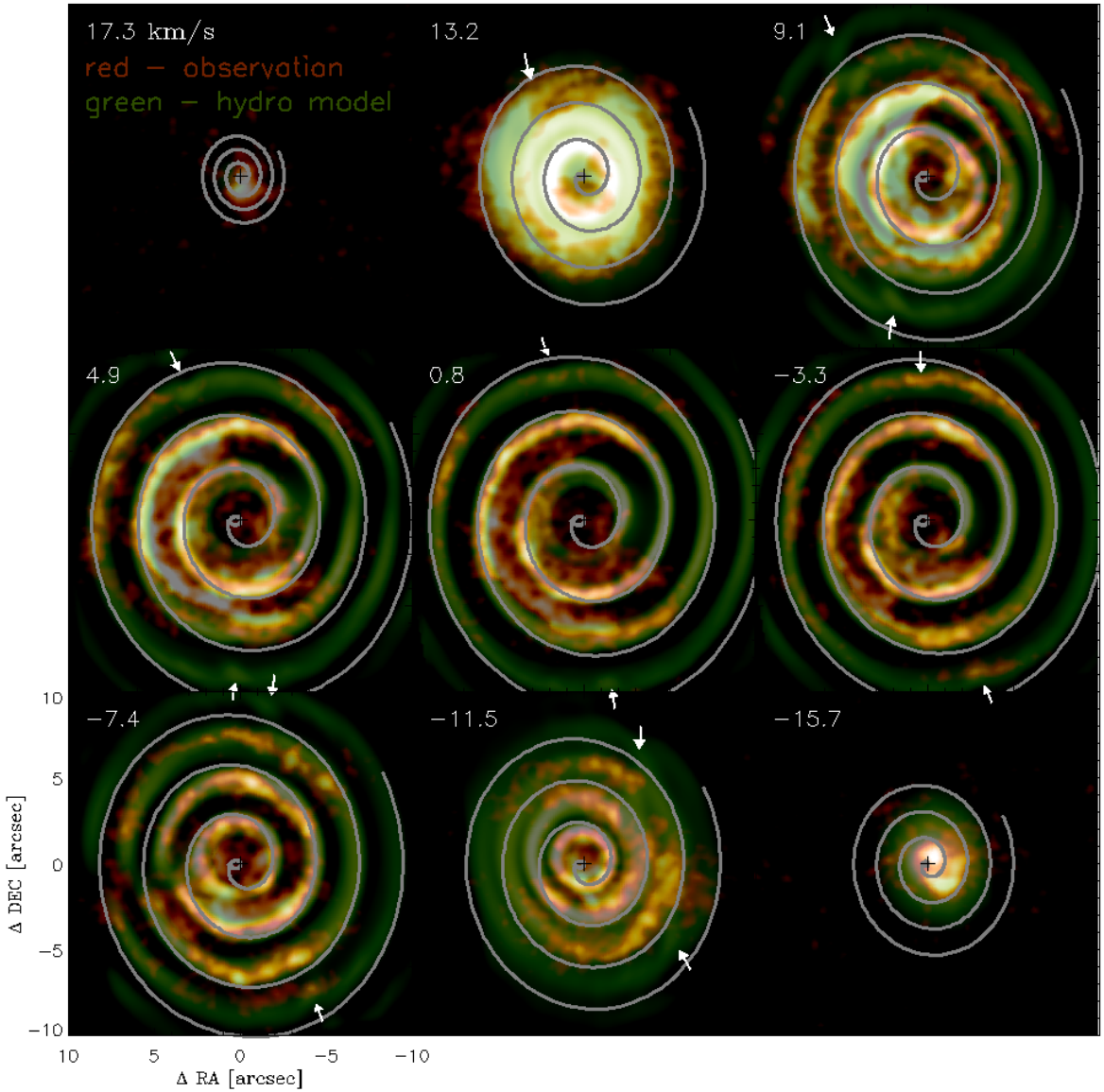
CIT 6 – Inclination dependence

$i = 0°$ $i = 30°$ $i = 50°$ $i = 70°$ $i = 90°$



Kim et al. 2013

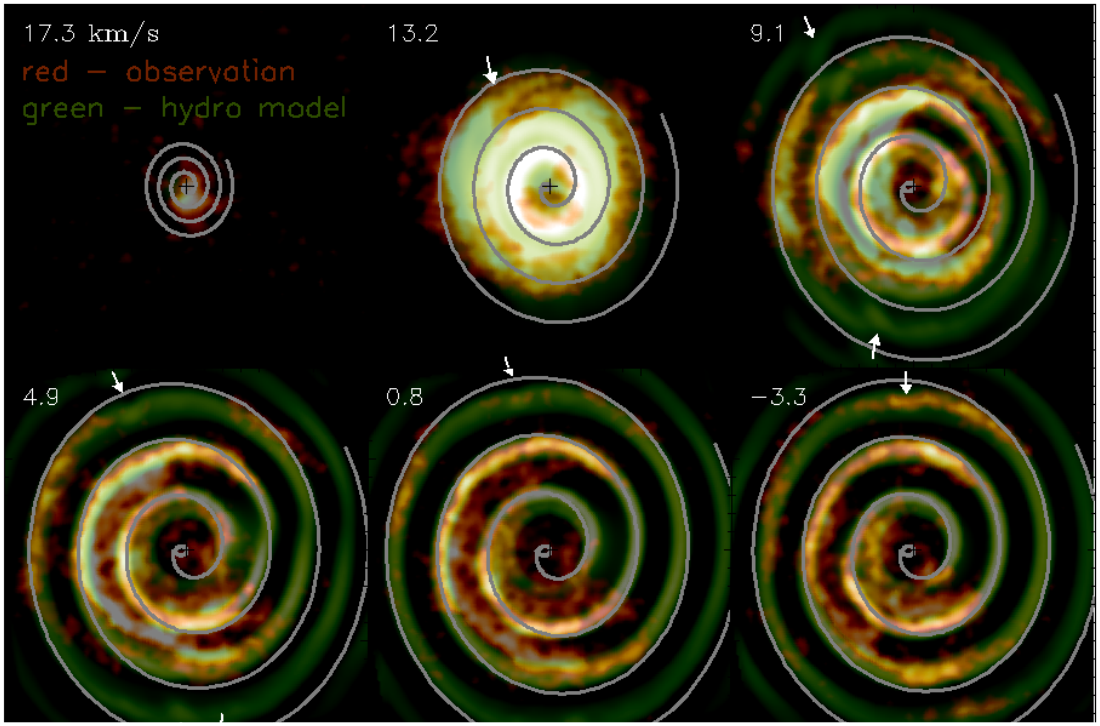
CIT 6 – Hydrodynamic radiative transfer model



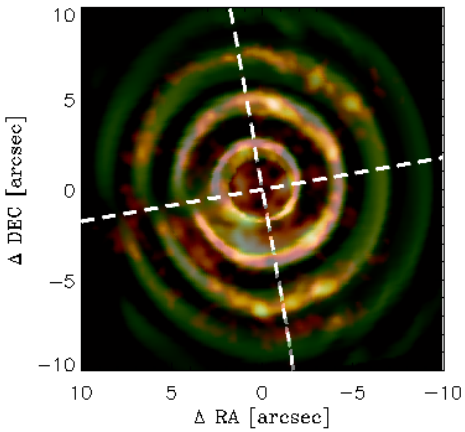
Kim et al. 2013

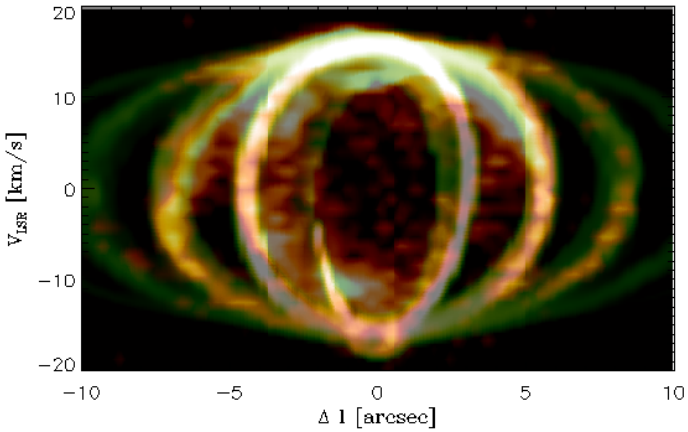
red : JVLA observation
green : HD+RT model
line : analytic model

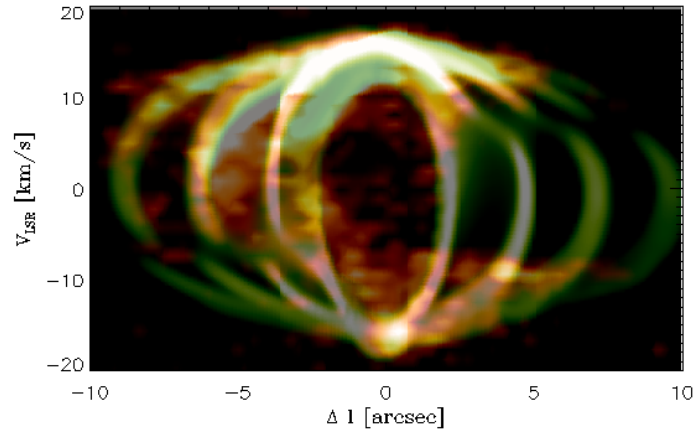
CIT 6 – Hydrodynamic radiative transfer model



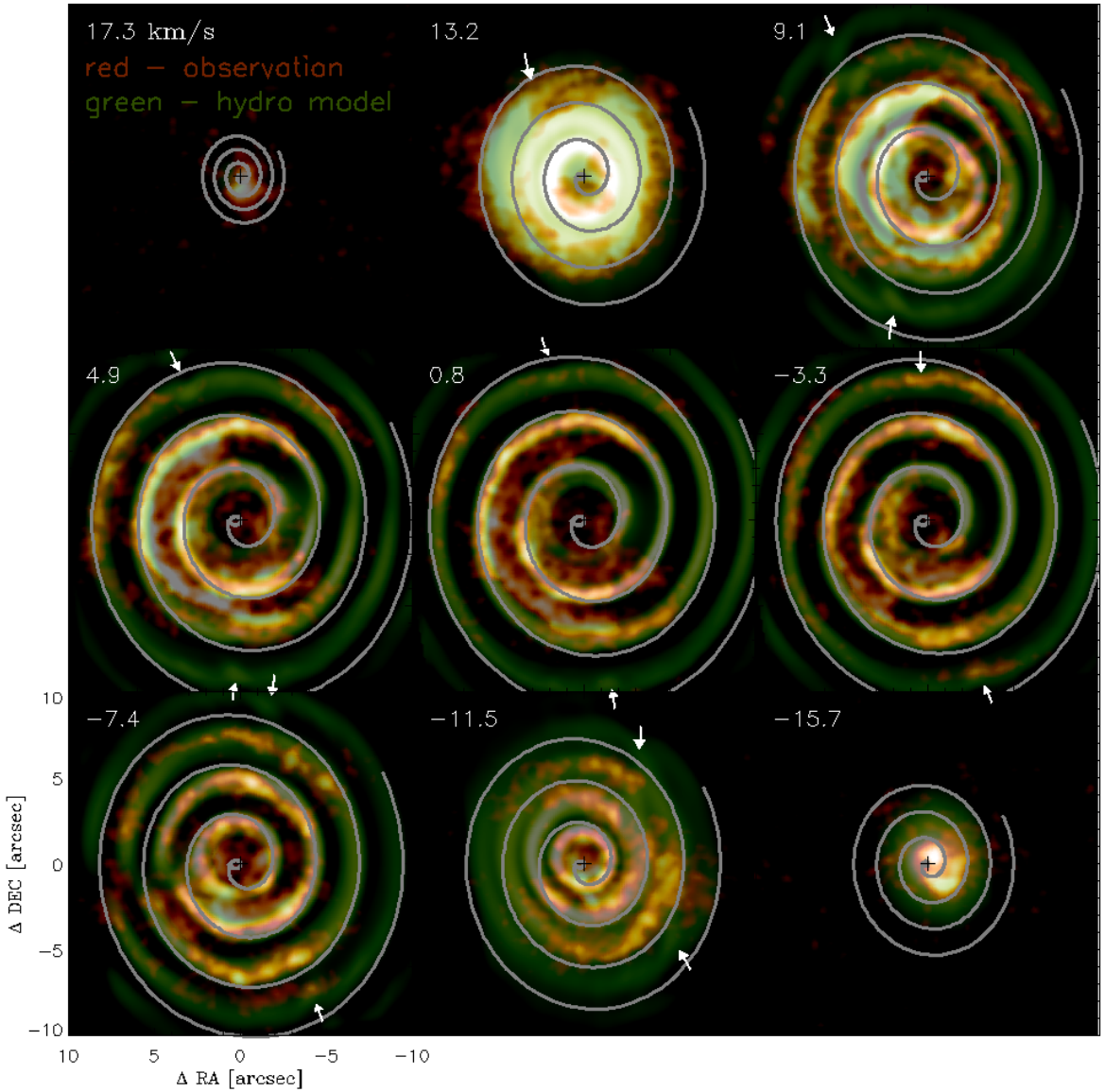
Kim et al. 2013



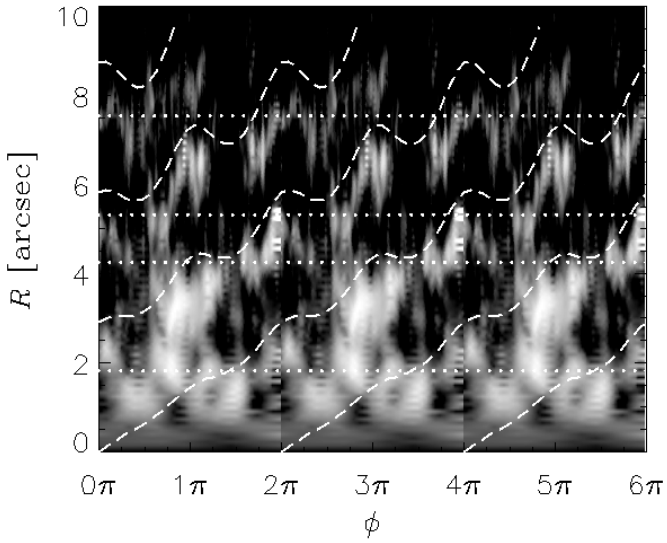




CIT 6 – Hydrodynamic radiative transfer model

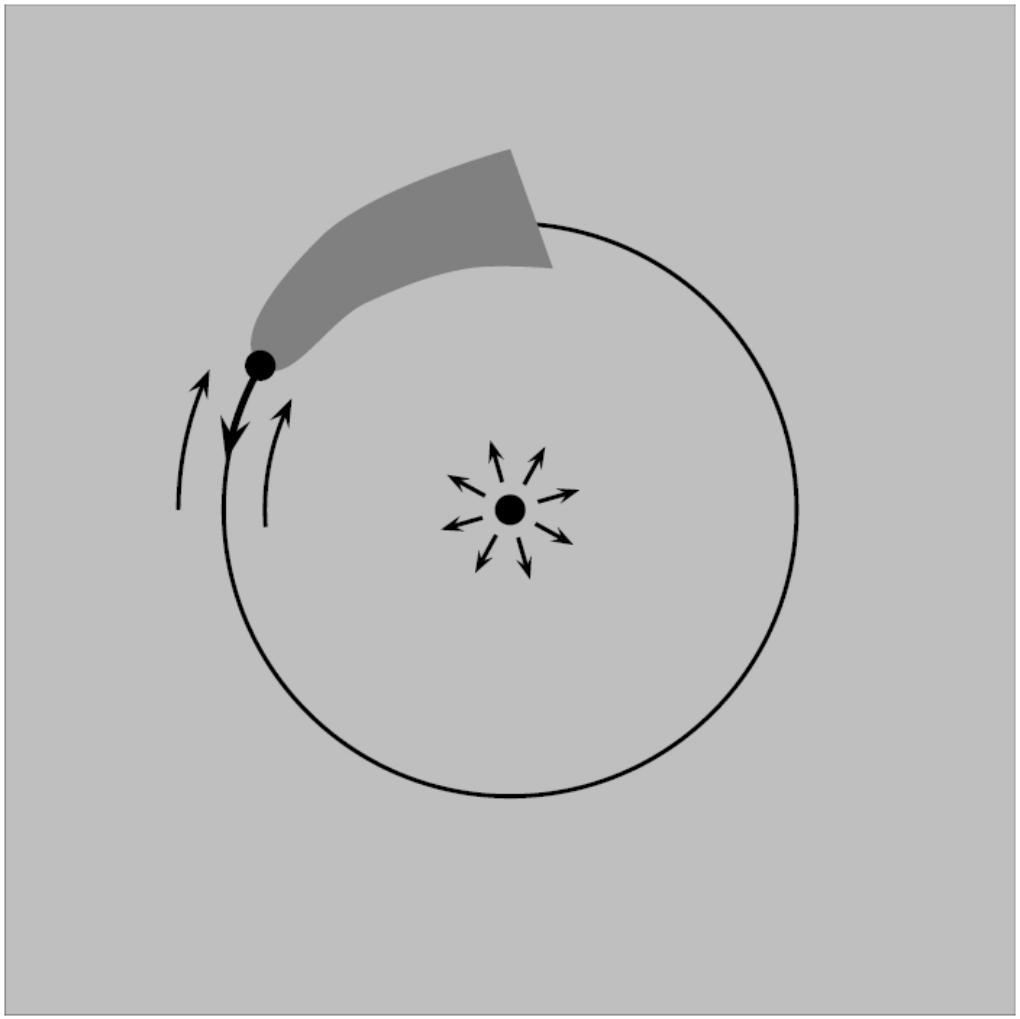


Kim et al. 2013



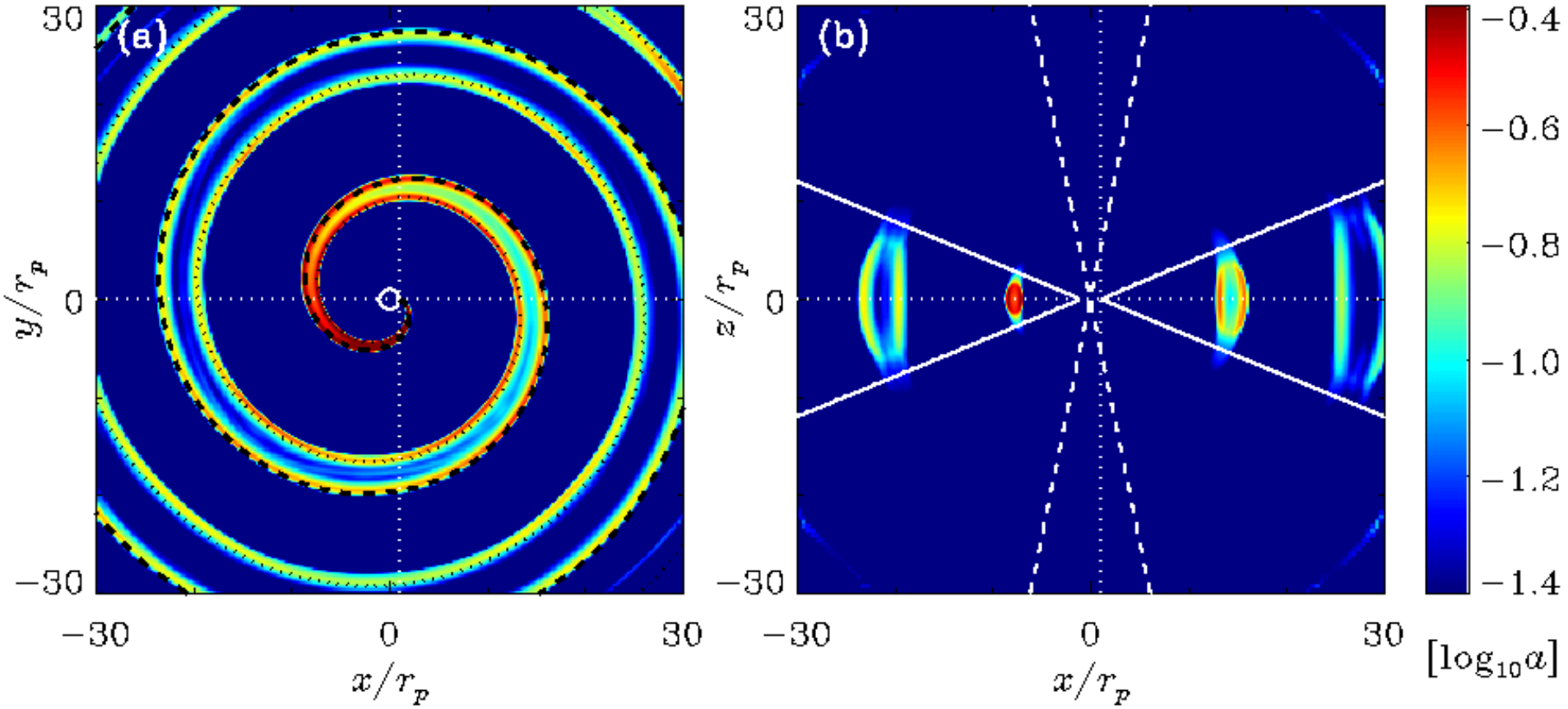
red : JVLA observation
green : HD+RT model
line : analytic model

Gravitational Wake of Companion

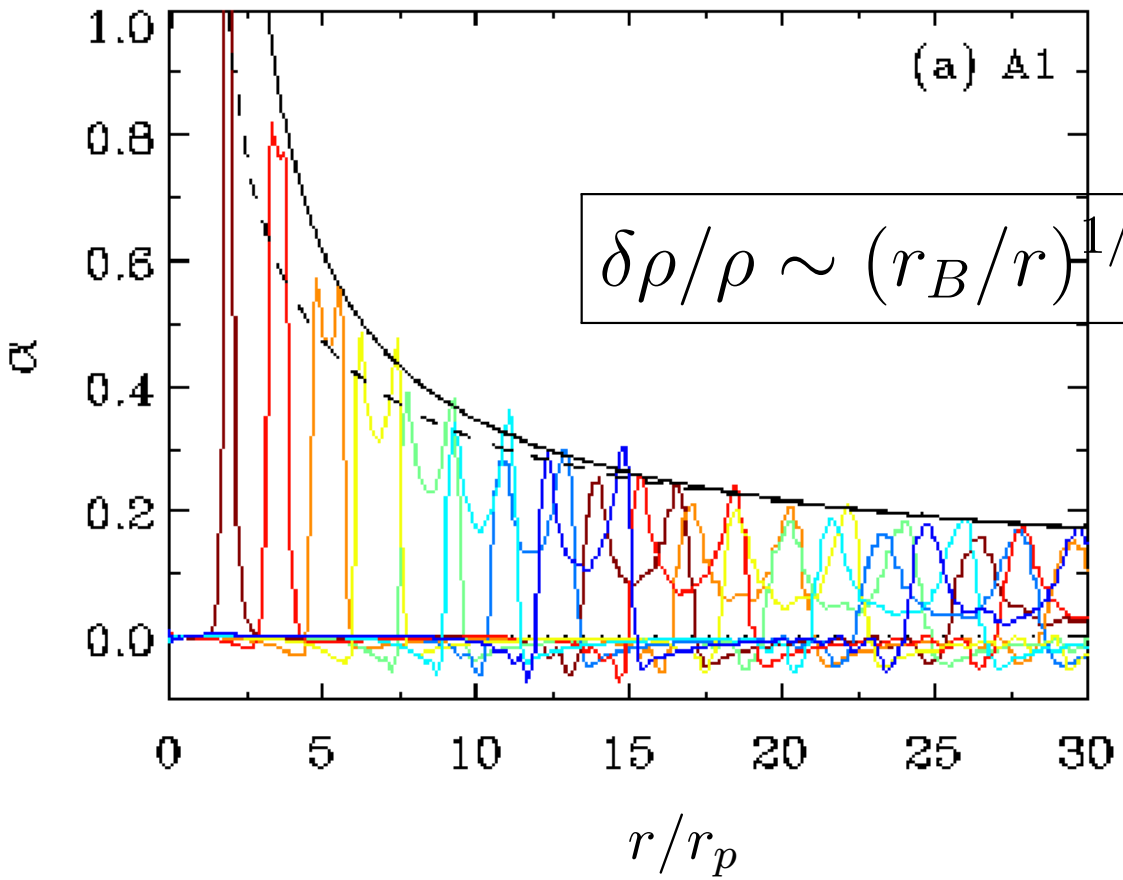


Gravitational Wake of Companion (*Kim+Taam 2012a*)

$$V_s = 5.0\ \mathrm{km\,s^{-1}} \quad \& \quad V_w \sim 10\ \mathrm{km\,s^{-1}}$$



Gravitational Wake of Companion (*Kim+Taam 2012a*)



$$\delta\rho/\rho \sim (r_B/r)^{1/2} \quad \text{for} \quad V_w \gg c_s$$

Density contrast at 100 AU from the mass losing star

- 2.5–10% for $1M_J$
- 14–55% for $30M_J$
- 25–100% for $0.1M_\odot$
  - Primary's reflex motion

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 with high qualities