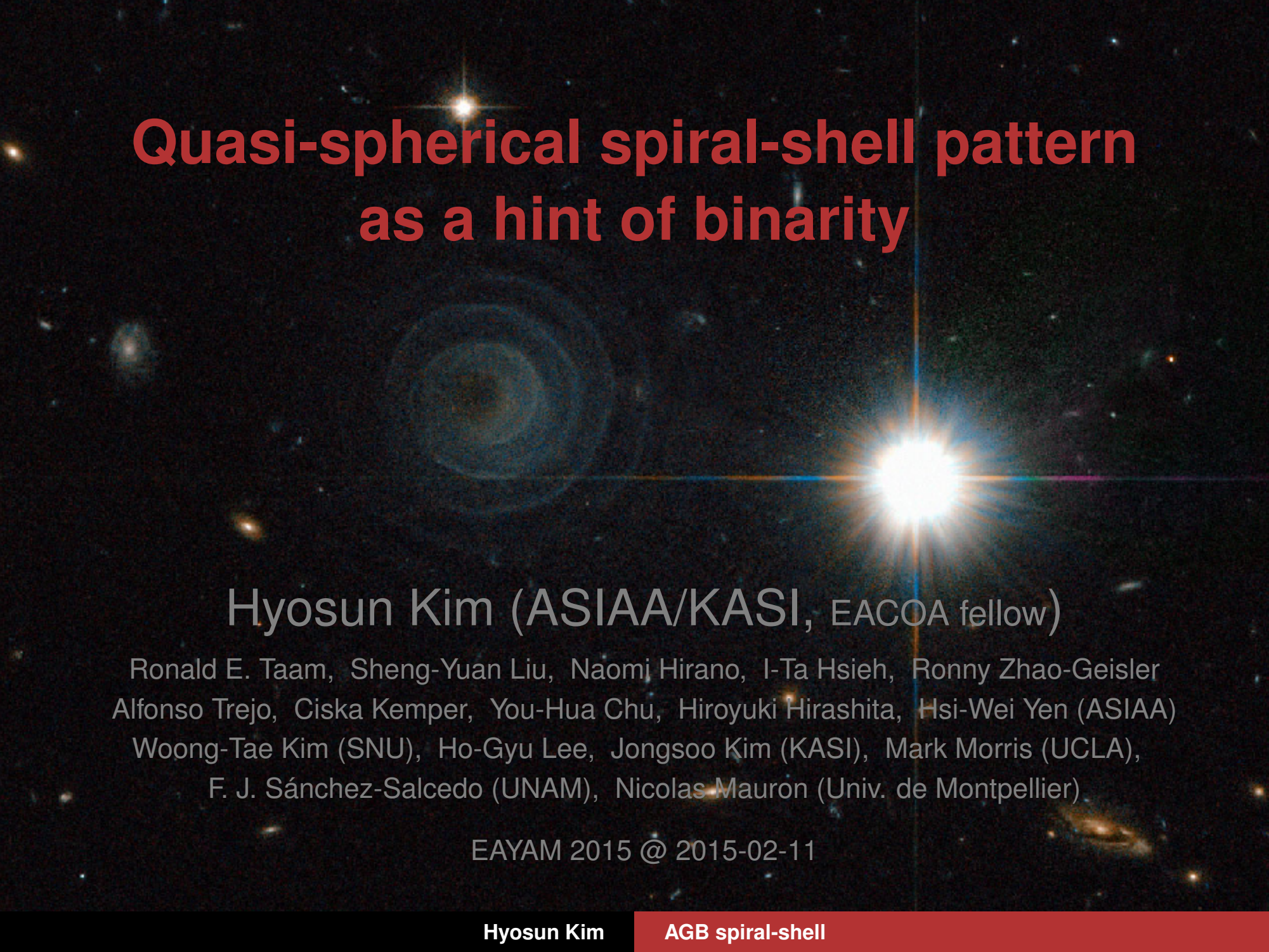


Quasi-spherical spiral-shell pattern as a hint of binarity

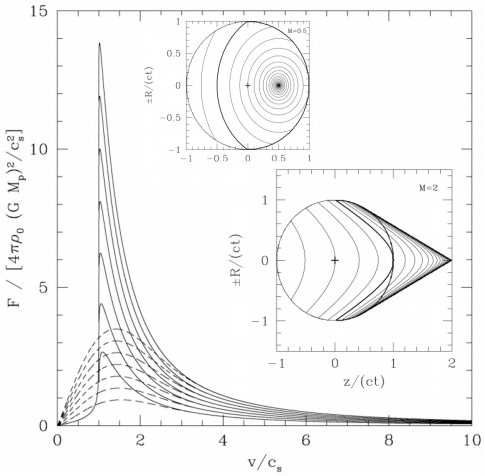
Hyosun Kim (ASIAA/KASI, EACOA fellow)

Ronald E. Taam, Sheng-Yuan Liu, Naomi Hirano, I-Ta Hsieh, Ronny Zhao-Geisler
Alfonso Trejo, Ciska Kemper, You-Hua Chu, Hiroyuki Hirashita, Hsi-Wei Yen (ASIAA)
Woong-Tae Kim (SNU), Ho-Gyu Lee, Jongsoo Kim (KASI), Mark Morris (UCLA),
F. J. Sánchez-Salcedo (UNAM), Nicolas Mauron (Univ. de Montpellier)

EAYAM 2015 @ 2015-02-11

gas dynamical friction

Ostriker 1999 →



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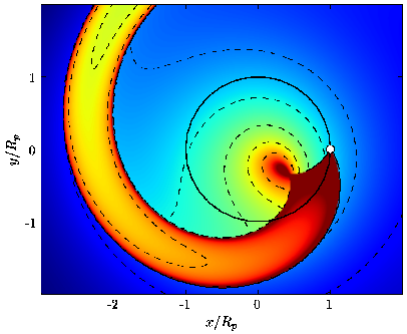

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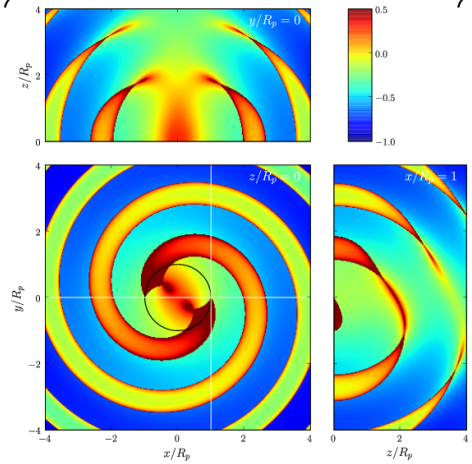

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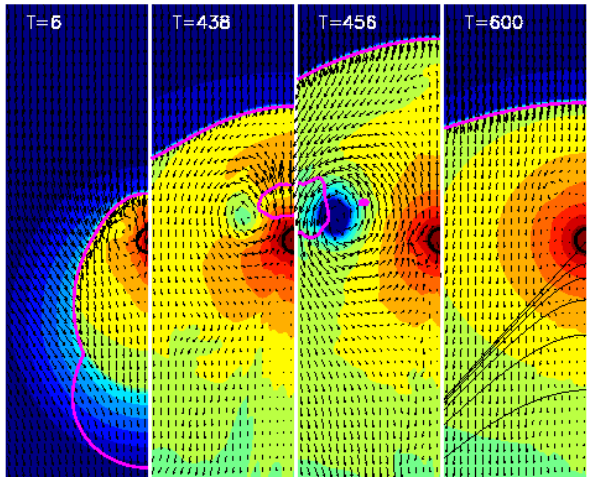

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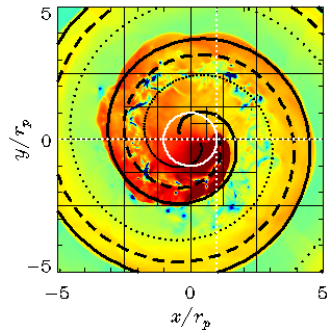
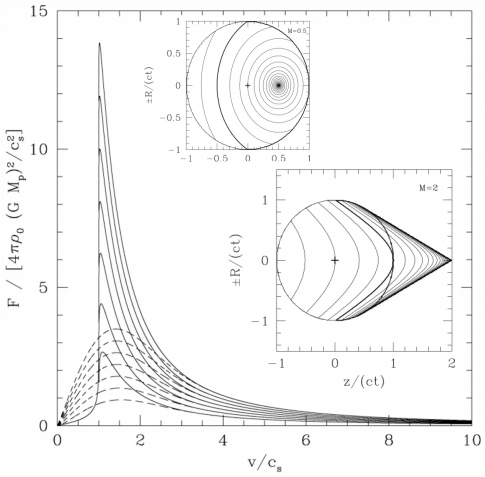


gas dynamical friction

Ostriker 1999 →



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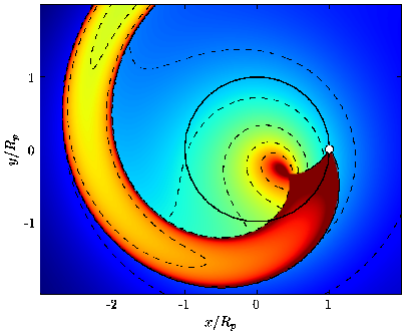

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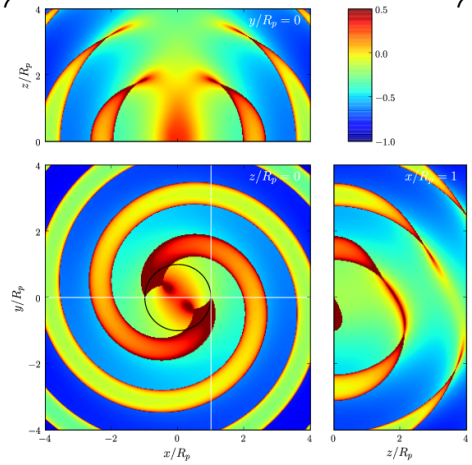

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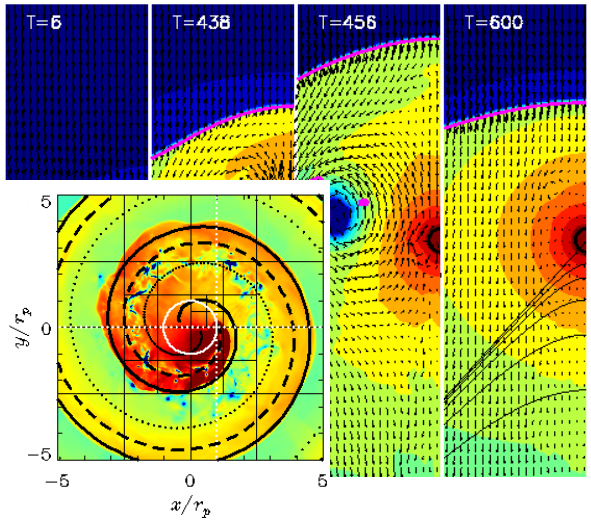

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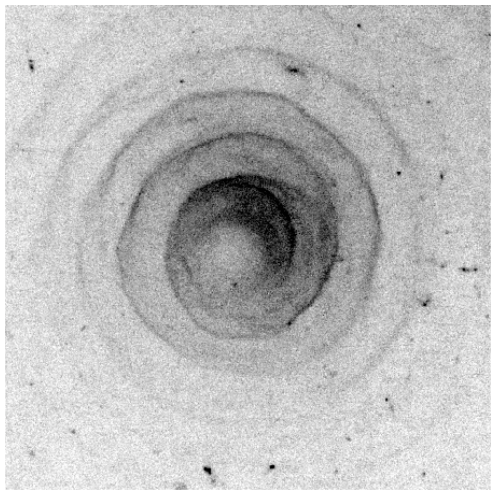
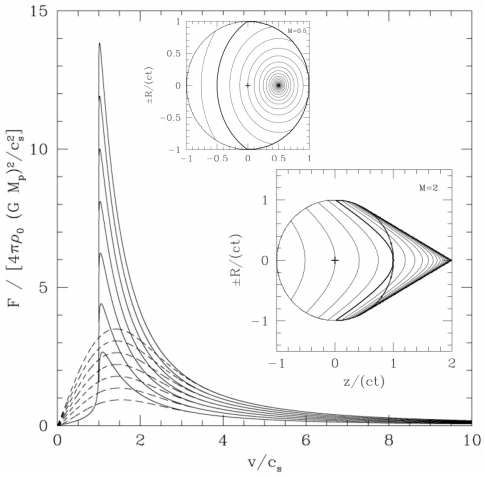


AFGL 3068

- Very nice *observed* spiral
- Something may be orbiting. Binary!
- The only well-defined spiral
- Where are the others?

gas dynamical friction

Ostriker 1999 →



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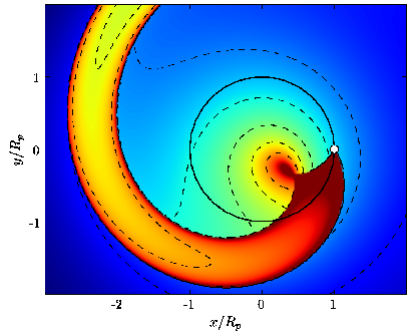

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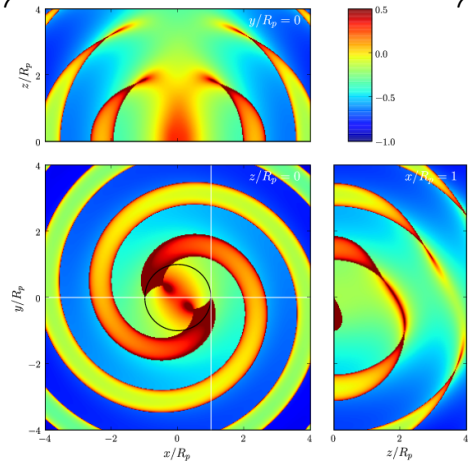

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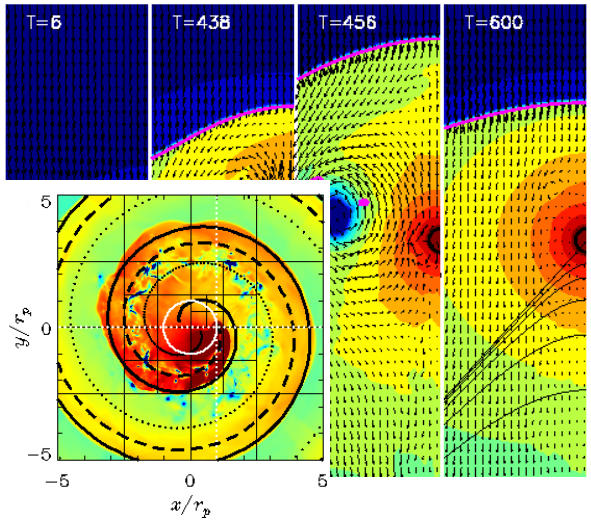

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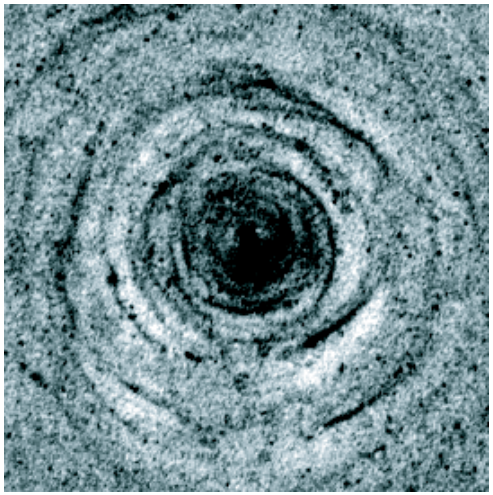
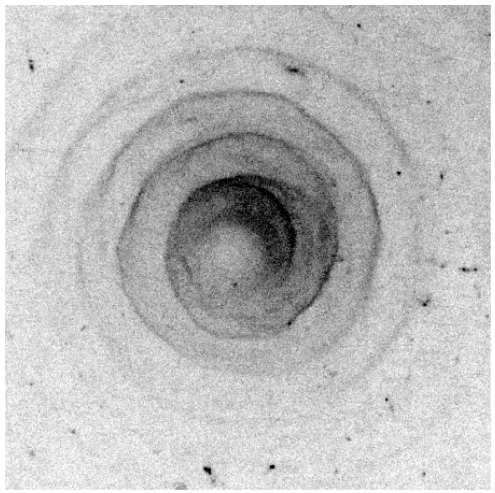
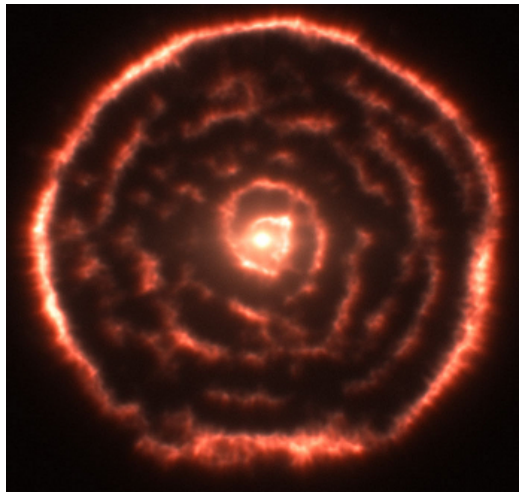


IRC+10216



AFGL 3068

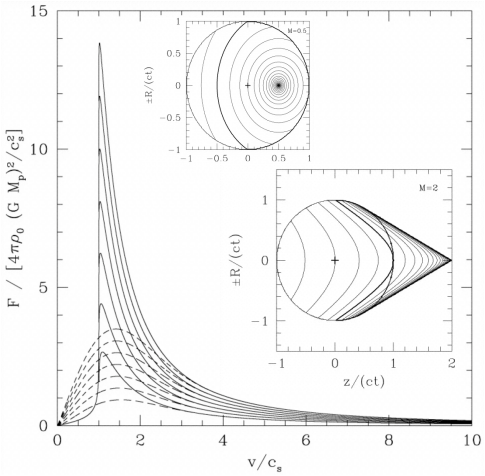


R Scl

Egg Nebula

gas dynamical friction

Ostriker 1999 →



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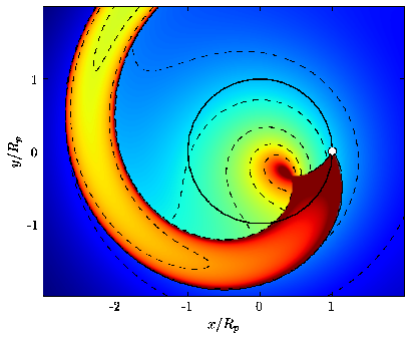

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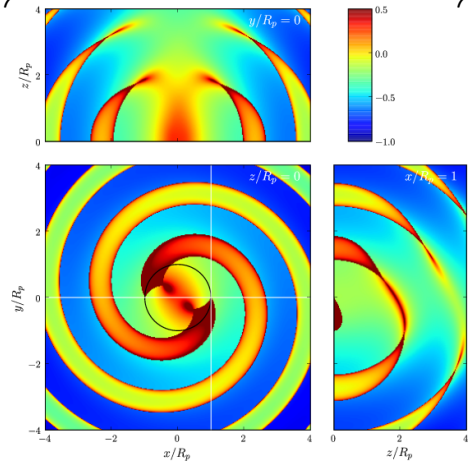

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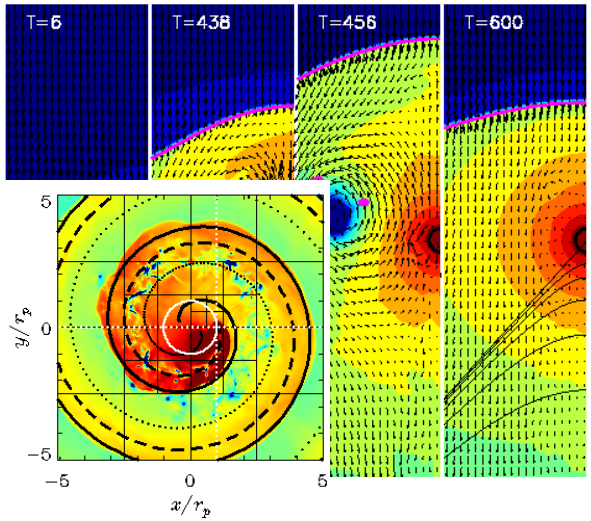

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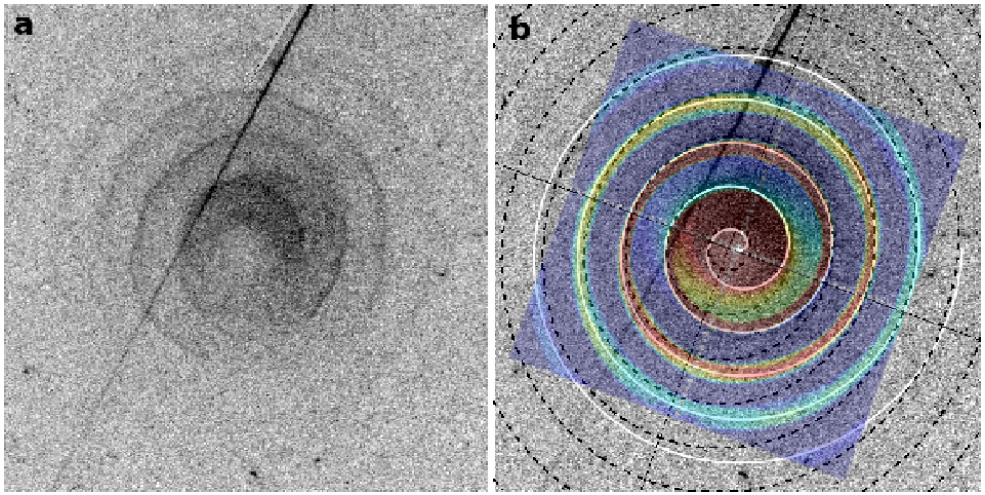
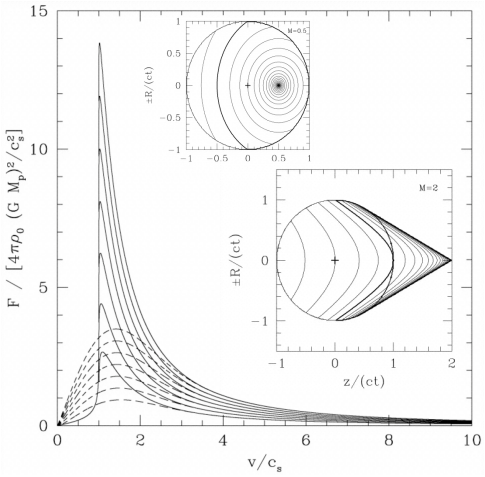


AFGL 3068

gas dynamical friction

Ostriker 1999 →



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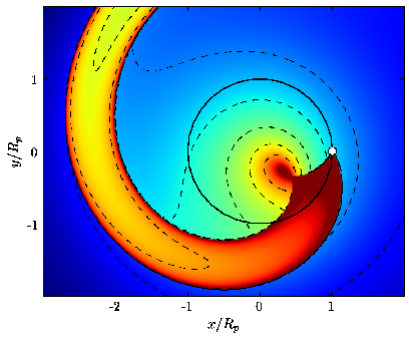

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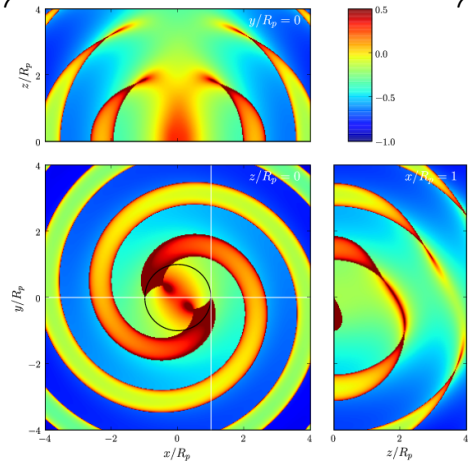

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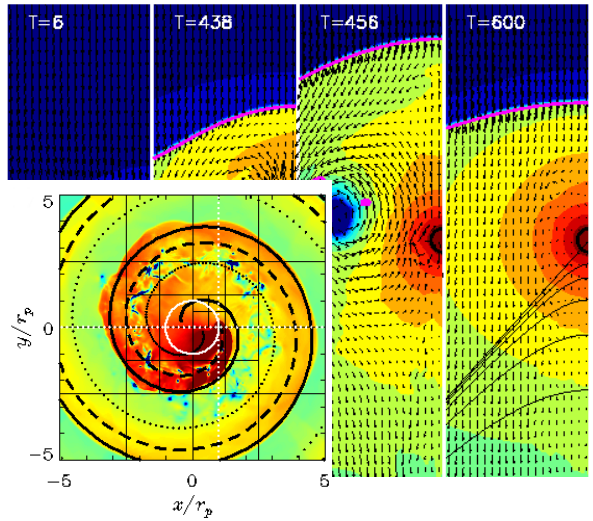

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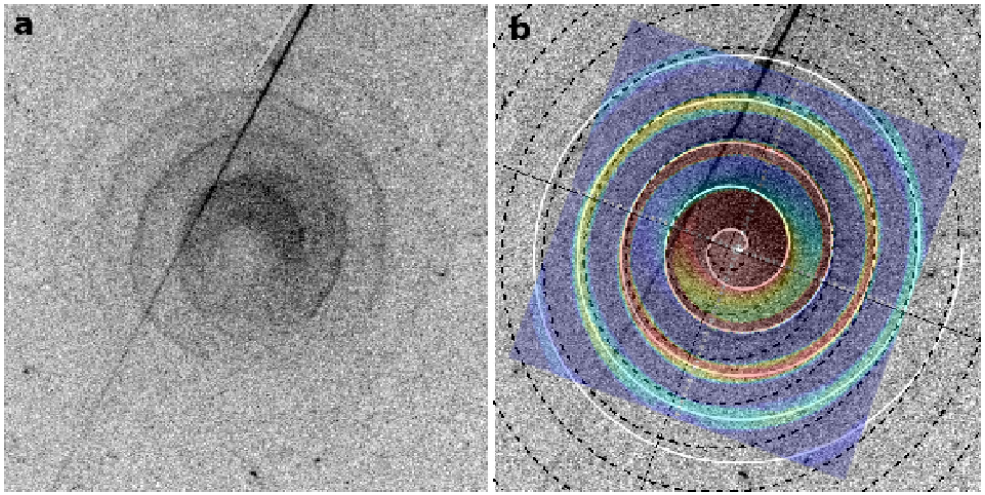
Claussen++ 2011



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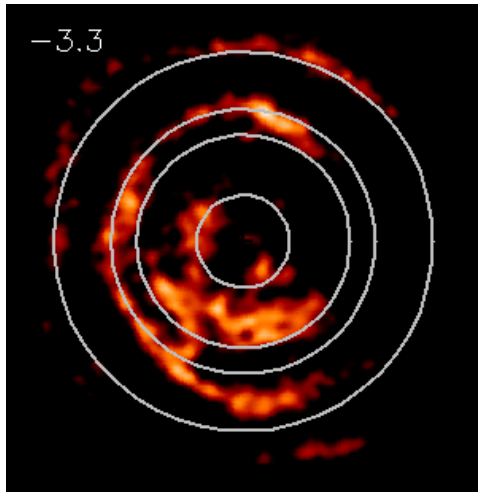
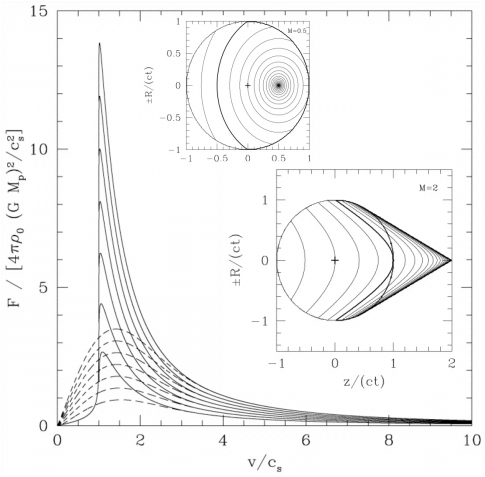


AFGL 3068

CIT 6

gas dynamical friction

Ostriker 1999 →



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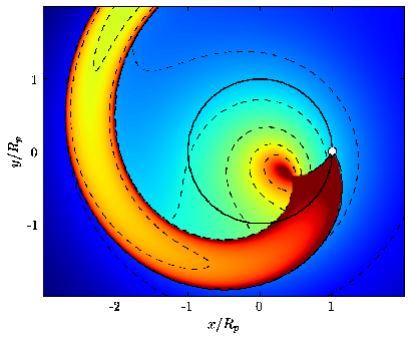

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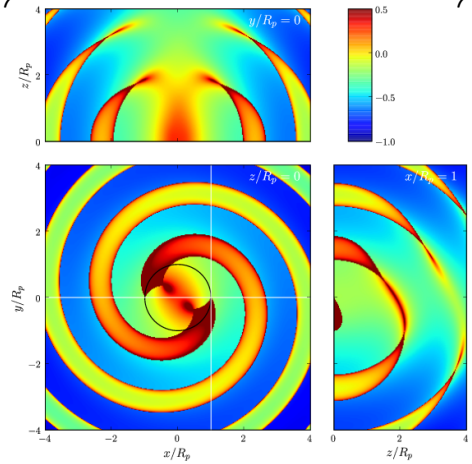

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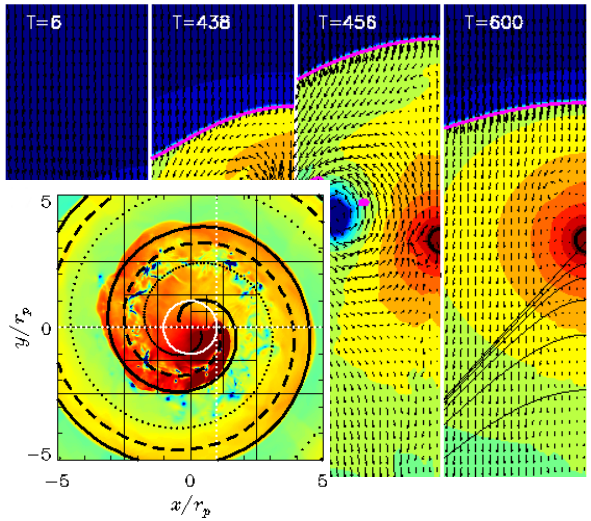

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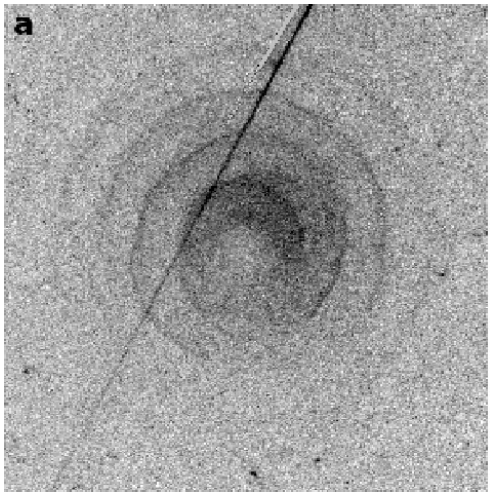

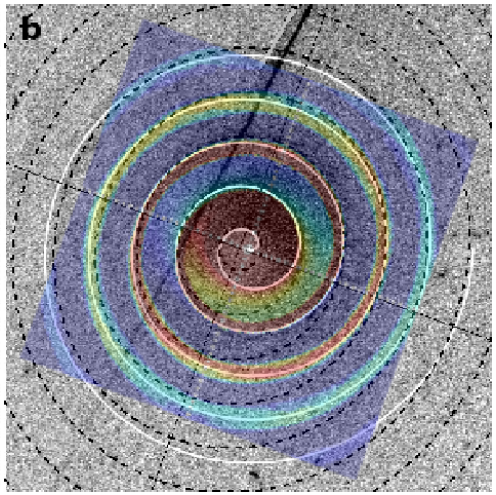

AFGL 3068

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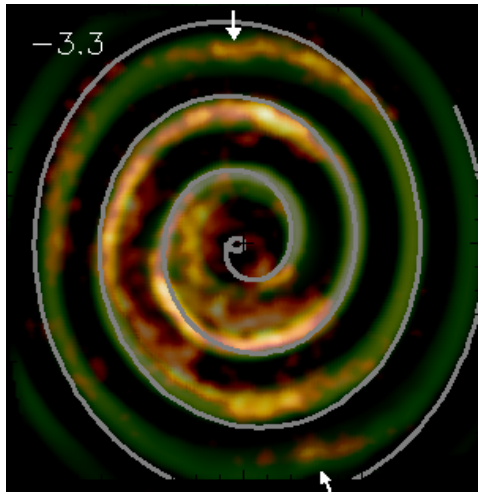
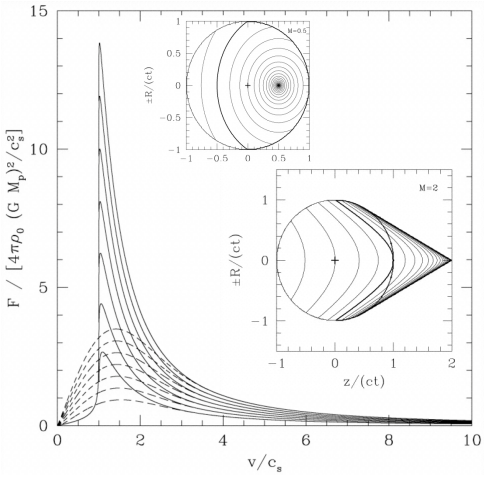


CIT 6

gas dynamical friction

Ostriker 1999 →



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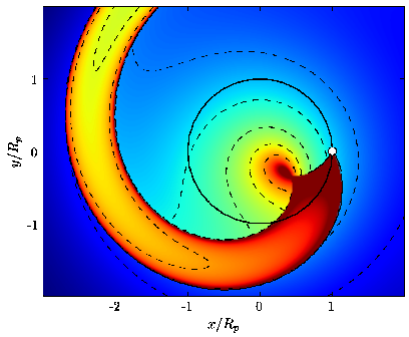

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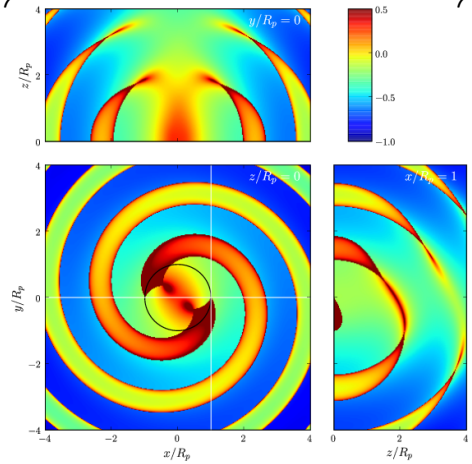

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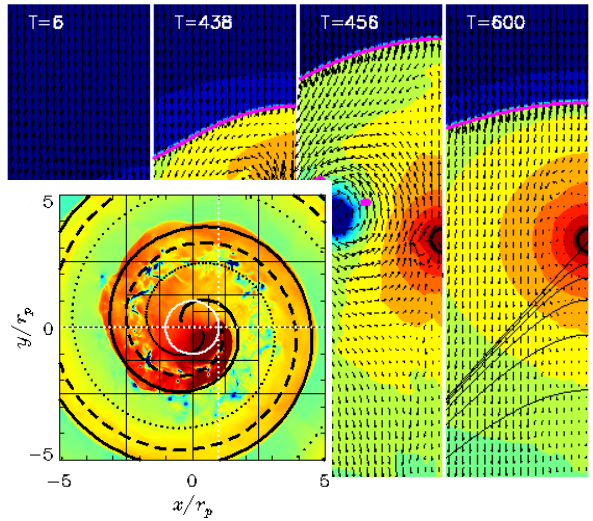

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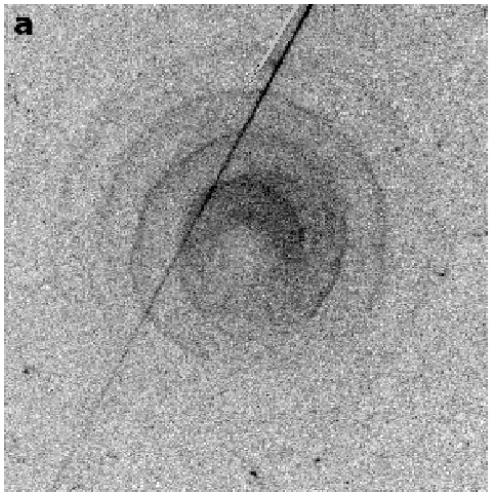

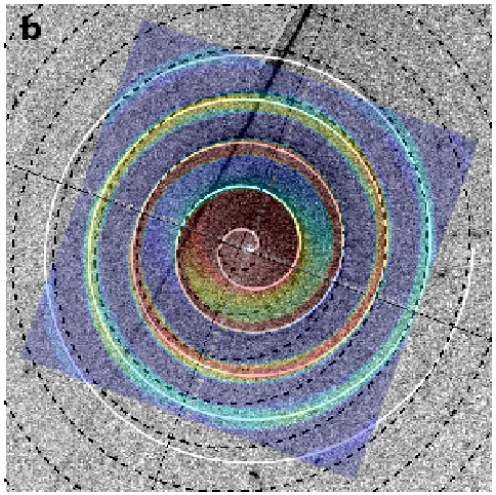

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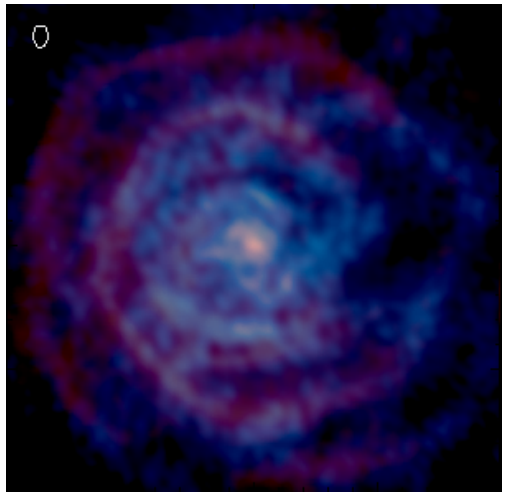
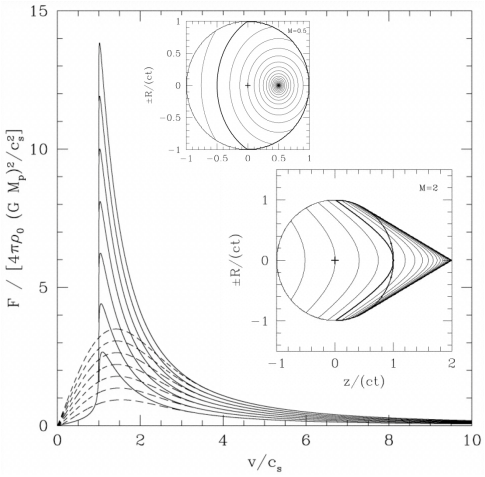


AFGL 3068

CIT 6

gas dynamical friction

Ostriker 1999 →



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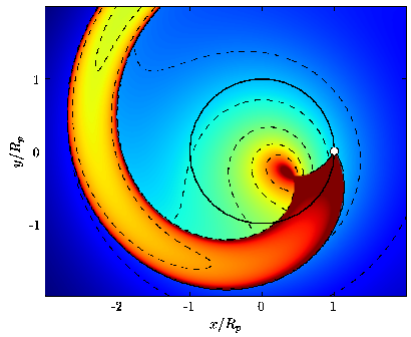

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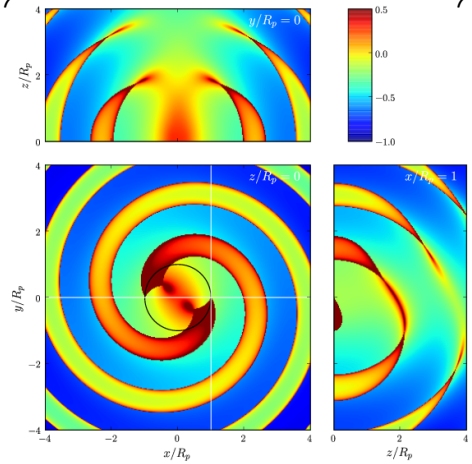

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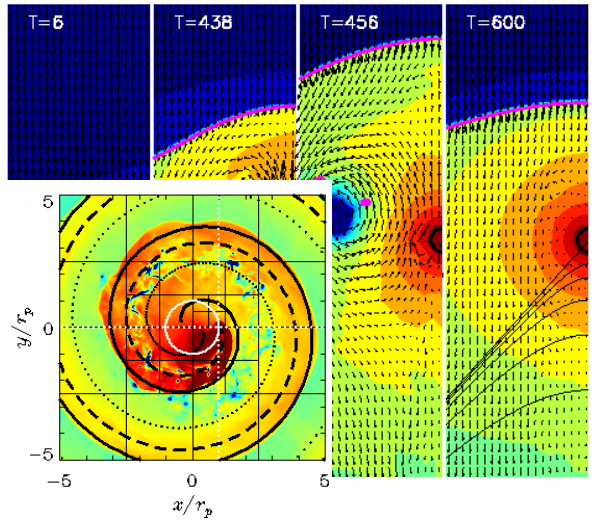

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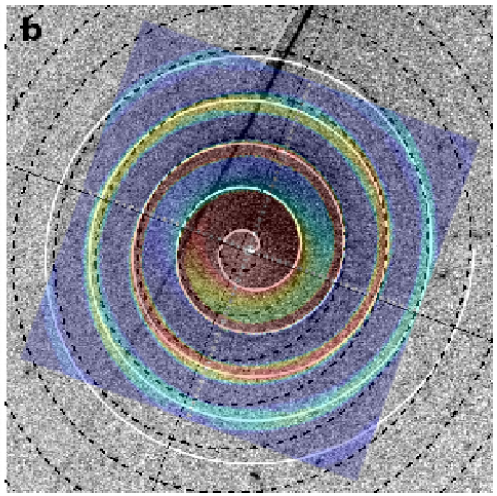

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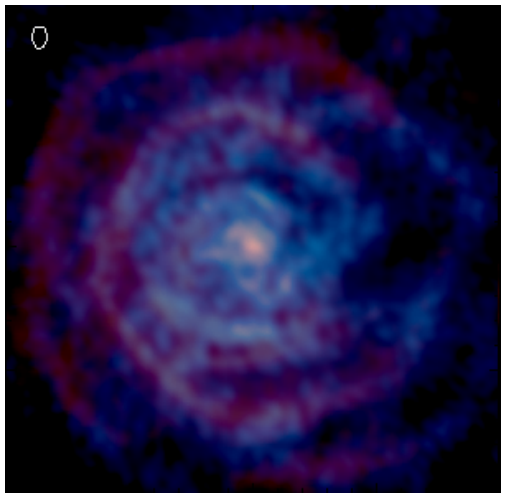

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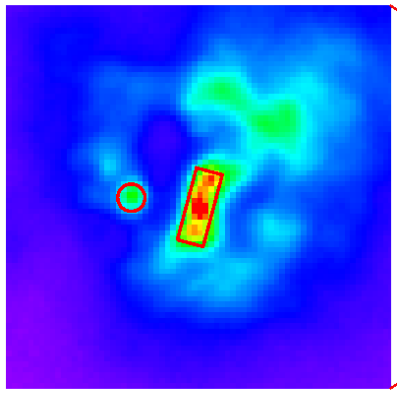
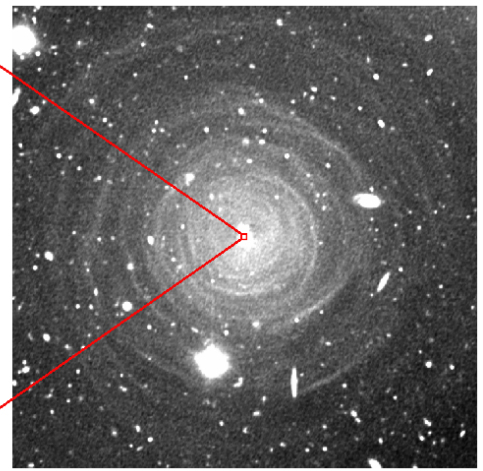
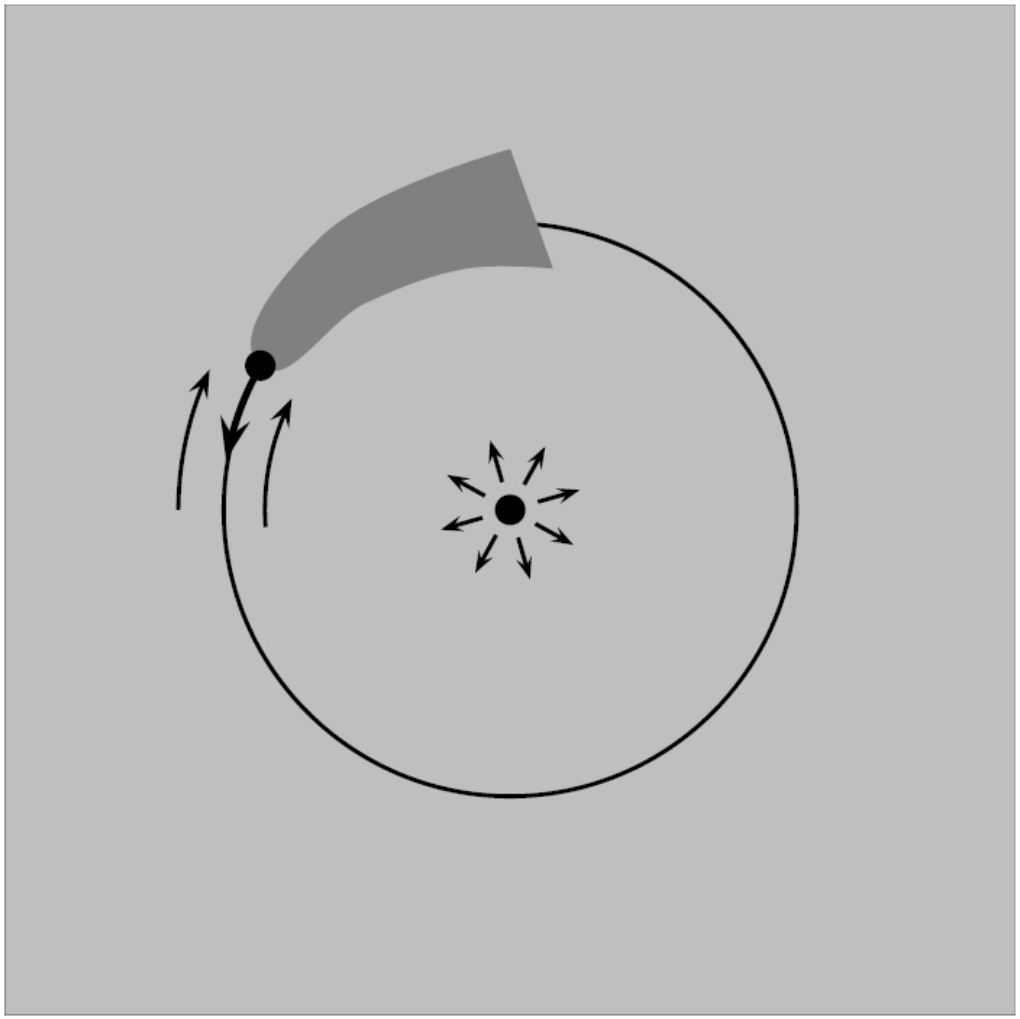


Leão++ 2006



AFGL 3068 CIT 6 IRC+10216

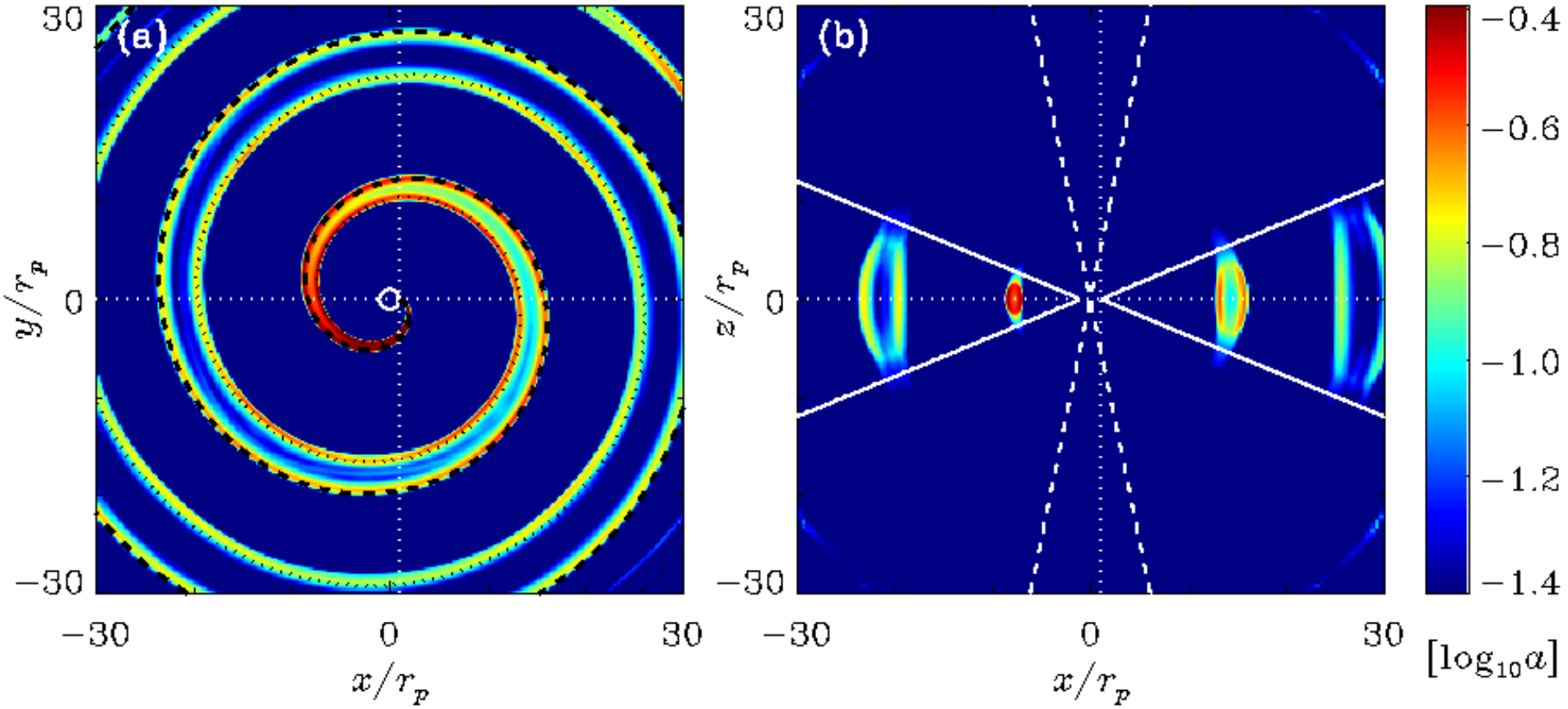
Gravitational Wake of Companion



AGB wind

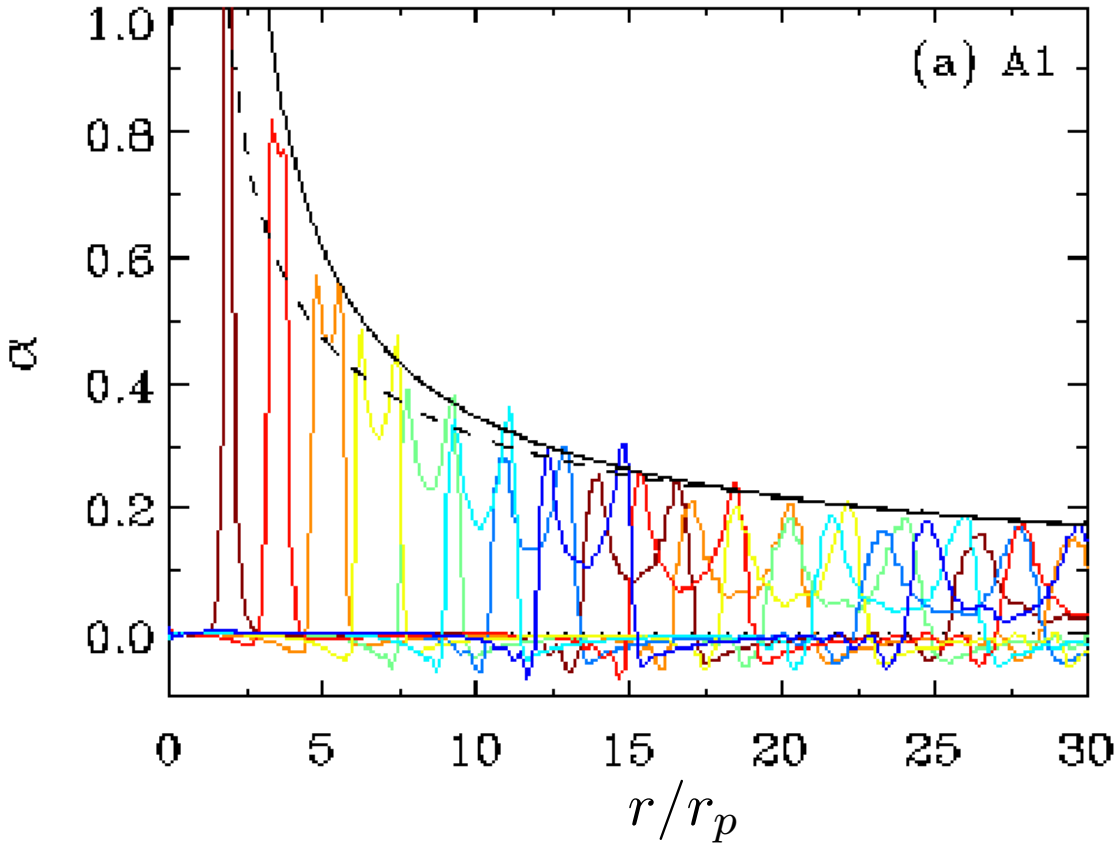
Gravitational Wake of Companion (*Kim+Taam 2012a*)

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



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

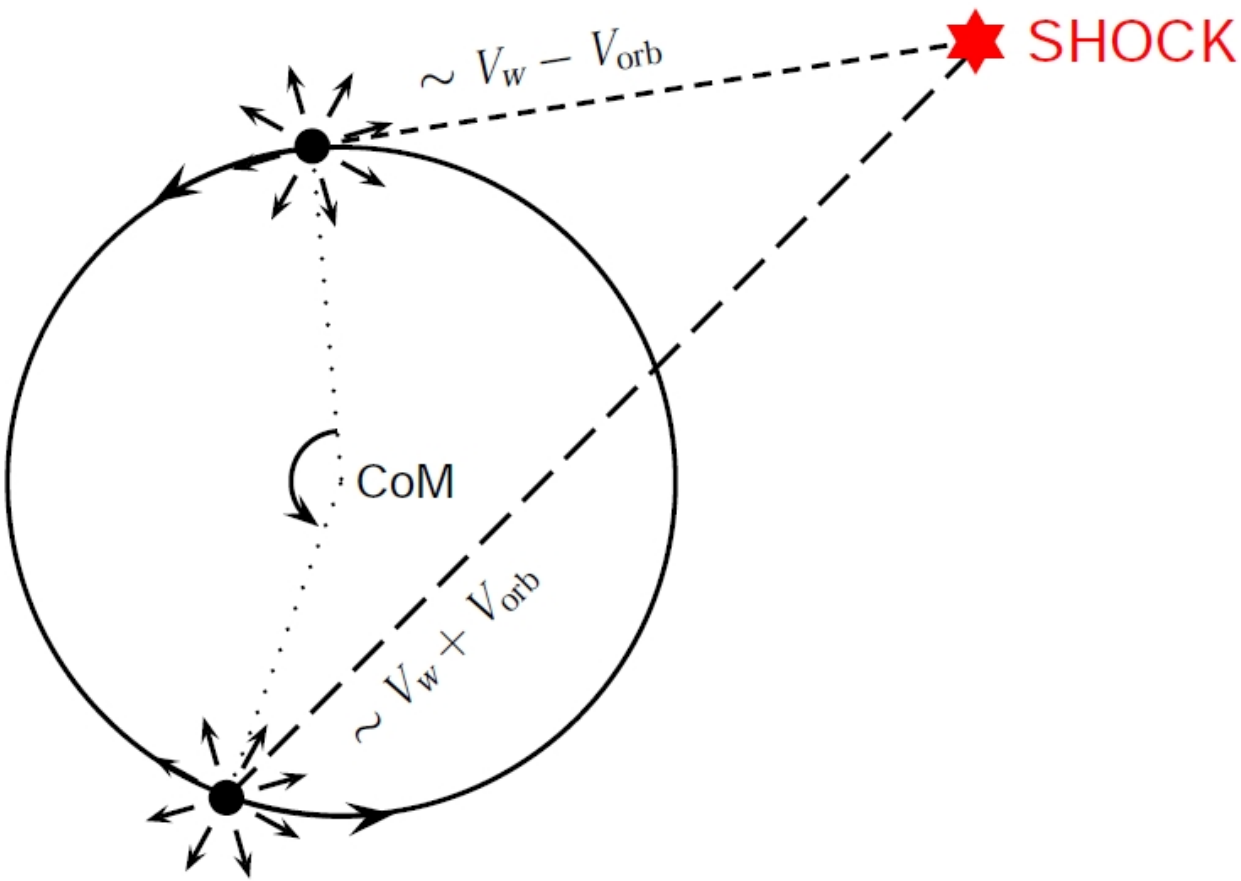
$$\delta\rho/\rho \sim (r_B/r)^{1/2} \quad \text{for} \quad V_w \gg c_s$$



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

Wind anisotropy due to AGB star's orbital motion

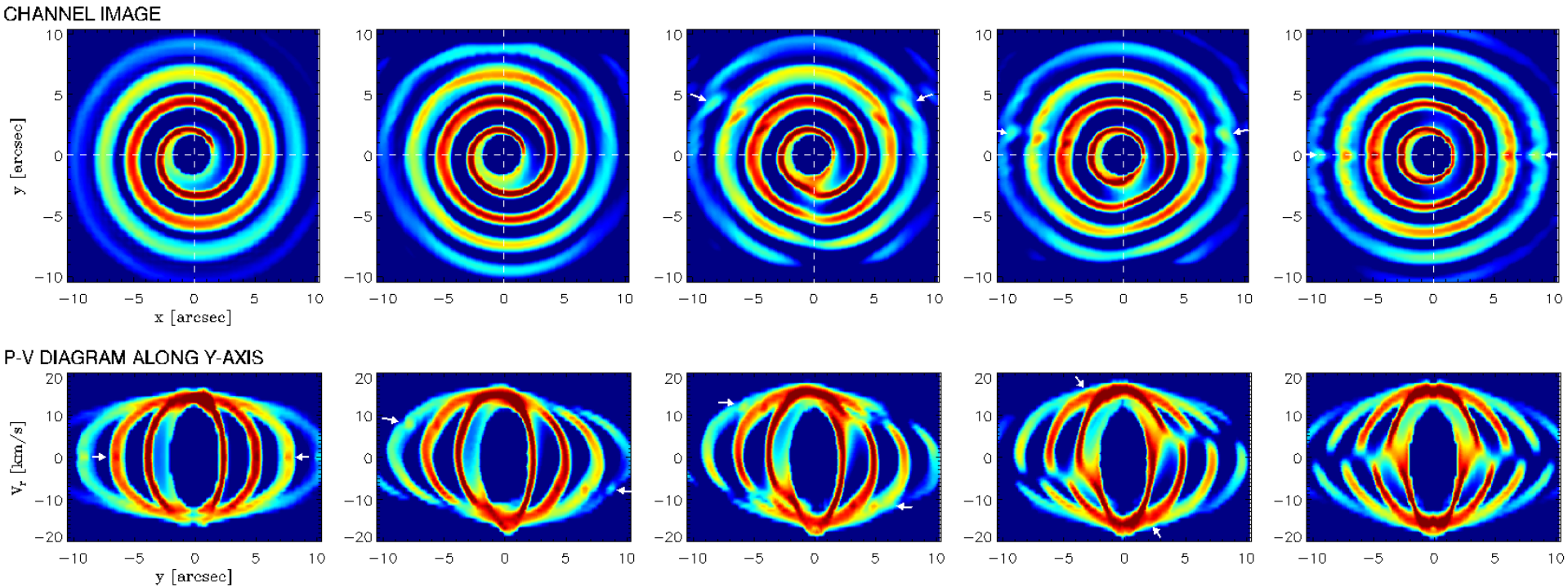


Binary-induced spiral-shell model

sprial / elongated spiral / rings

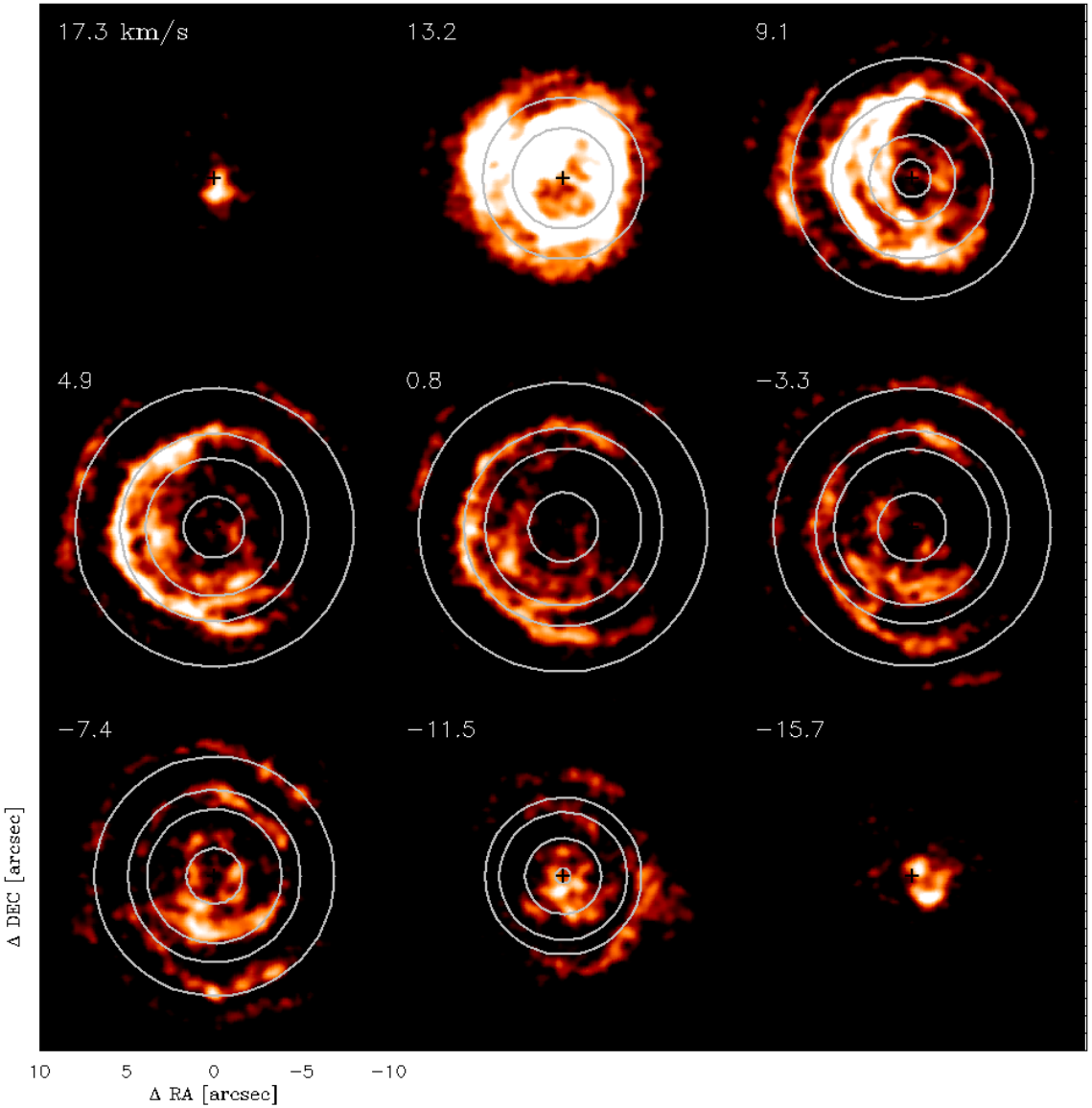
Elongated Rings

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



Kim++ 2013

CIT 6 – spiral vs shell (HC_3N)



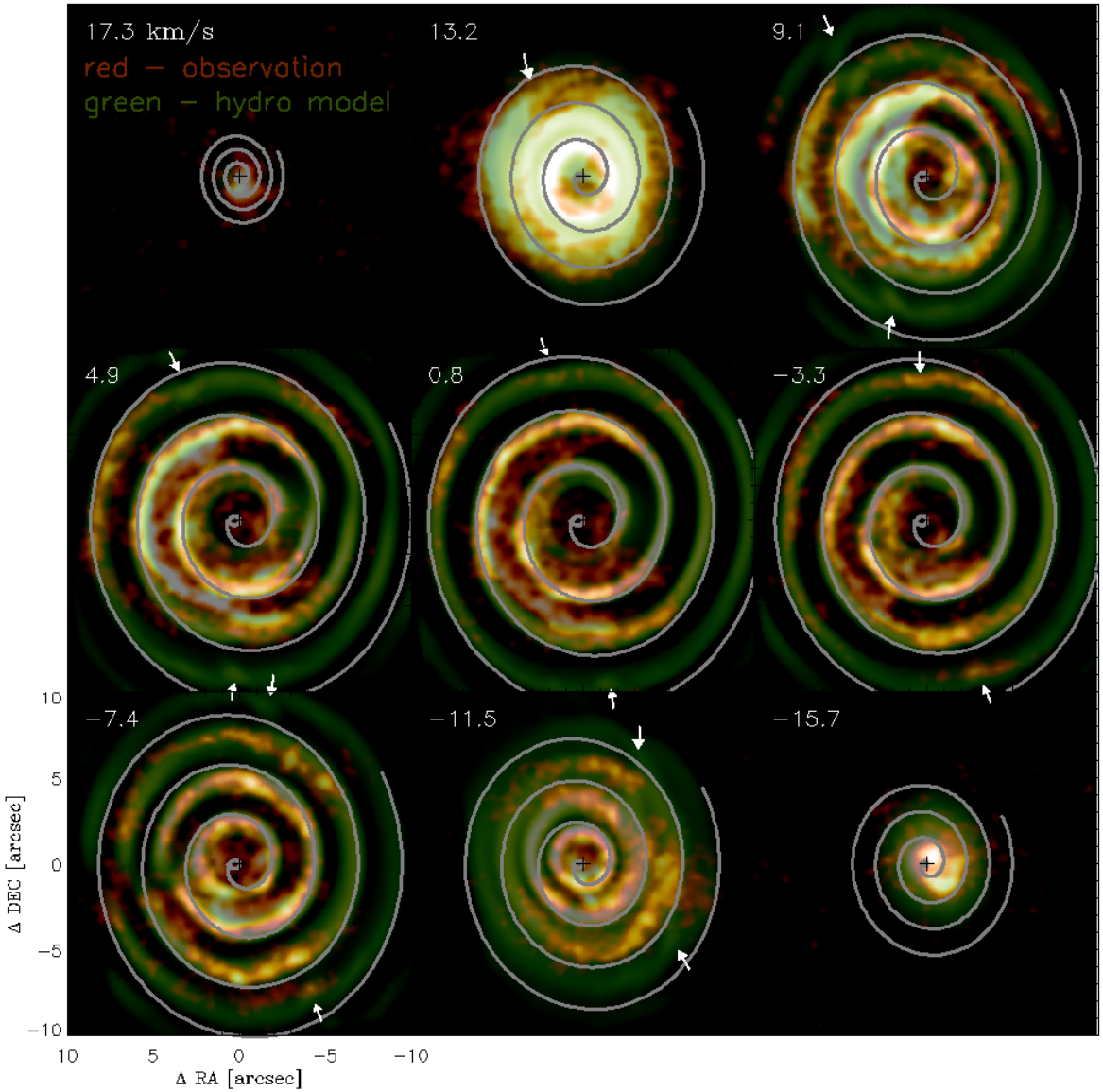
free parameters

- shell radii
- expansion velocities
- central velocities

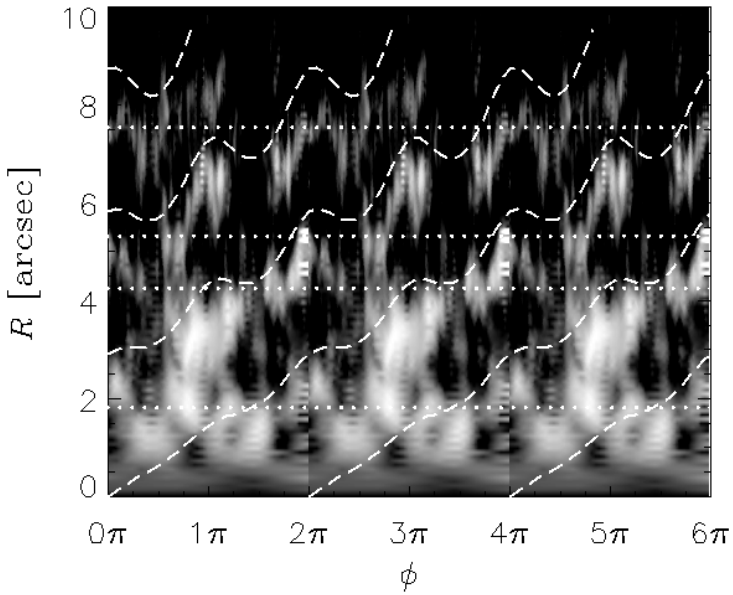
Spherical shell model
(*Claussen++ 2011*)

red : $HC_3N(4–3)$ @ JVLA

CIT 6 – binary-induced spiral-shell model (HD + RT)

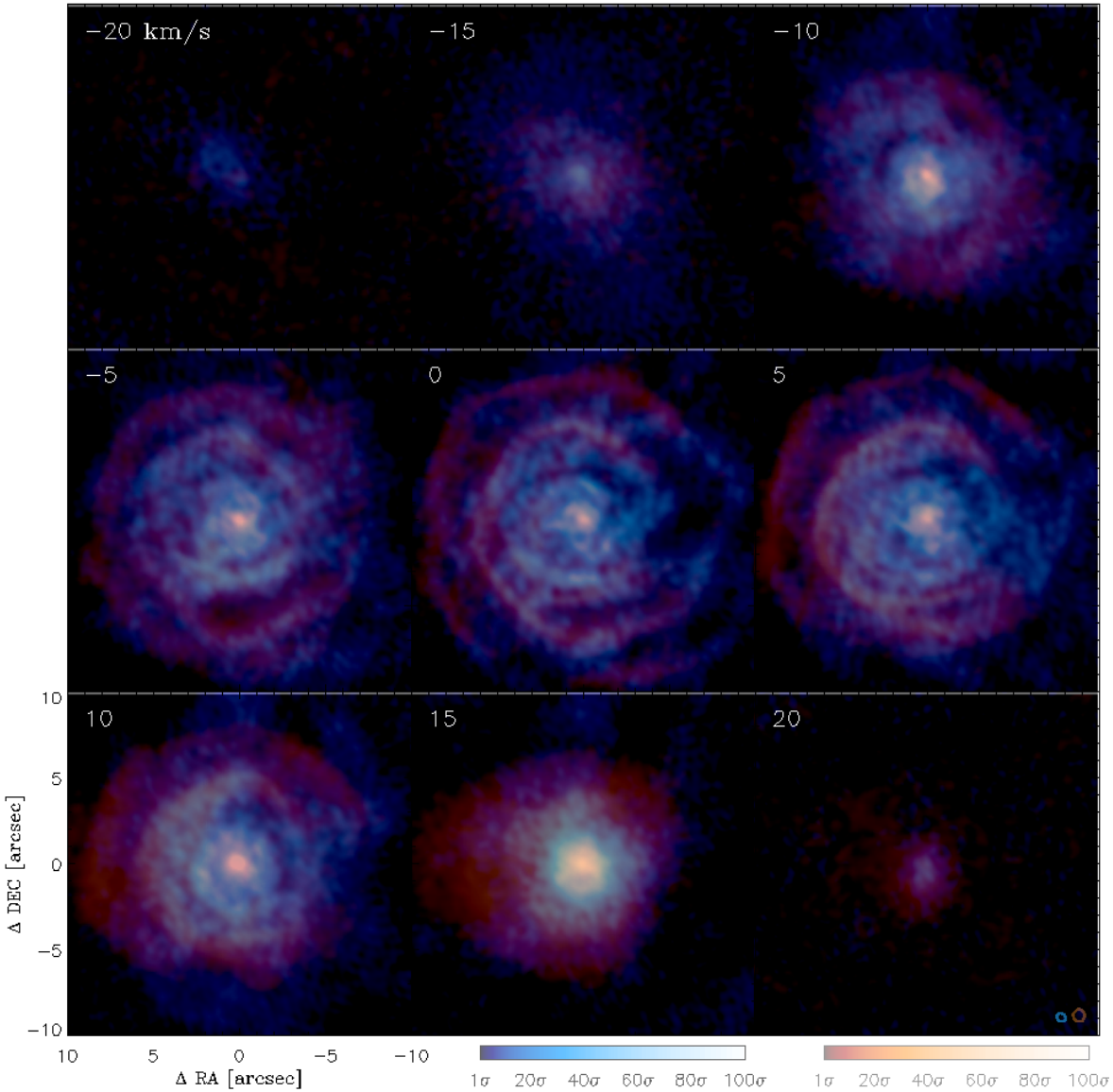


Kim++ 2013

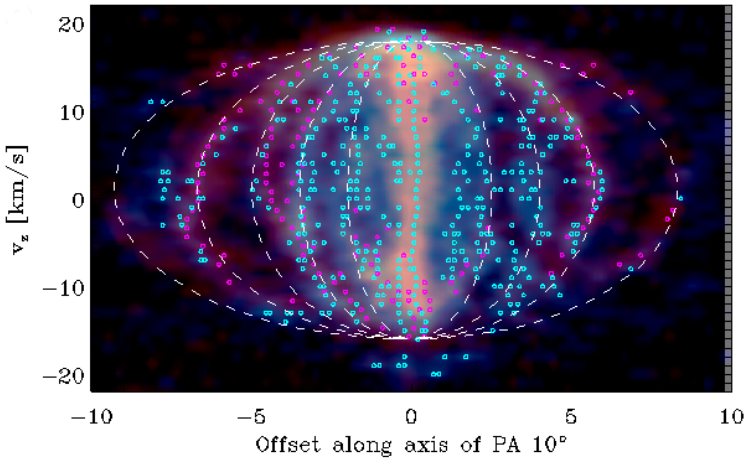


line : analytic model
green : HD+RT model
red : HC_3N(4–3) @ JVLA

CIT 6 – inner structure (CO)



Kim++ in prep.

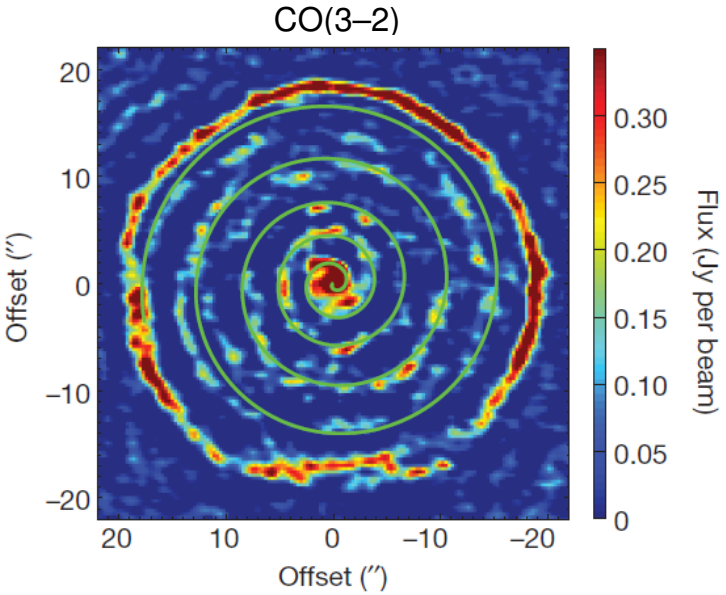


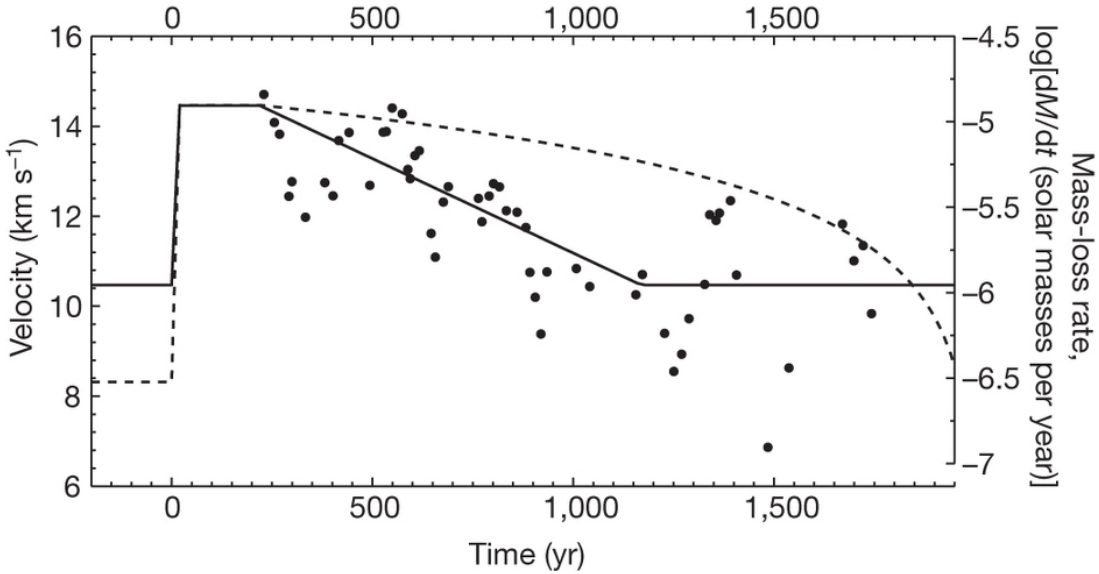
blue : CO(2–1) @ SMA
red : HC_3N(4–3) @ JVLA

R Sculptoris – timescale indicator – ALMA (CO)

Unexpectedly large mass loss during the thermal pulse cycle of the red giant star R Sculptoris

M. Maercker[1,2], S. Mohamed[3], W. H. T. Vlemmings[4], S. Ramstedt[2], M. A. T. Groenewegen[5], E. Humphreys[1], F. Kerschbaum[6], M. Lindqvist[4], H. Olofsson[4], C. Paladini[6], M. Wittkowski[1], I. de Gregorio-Monsalvo[7] & L.-A. Nyman[7]

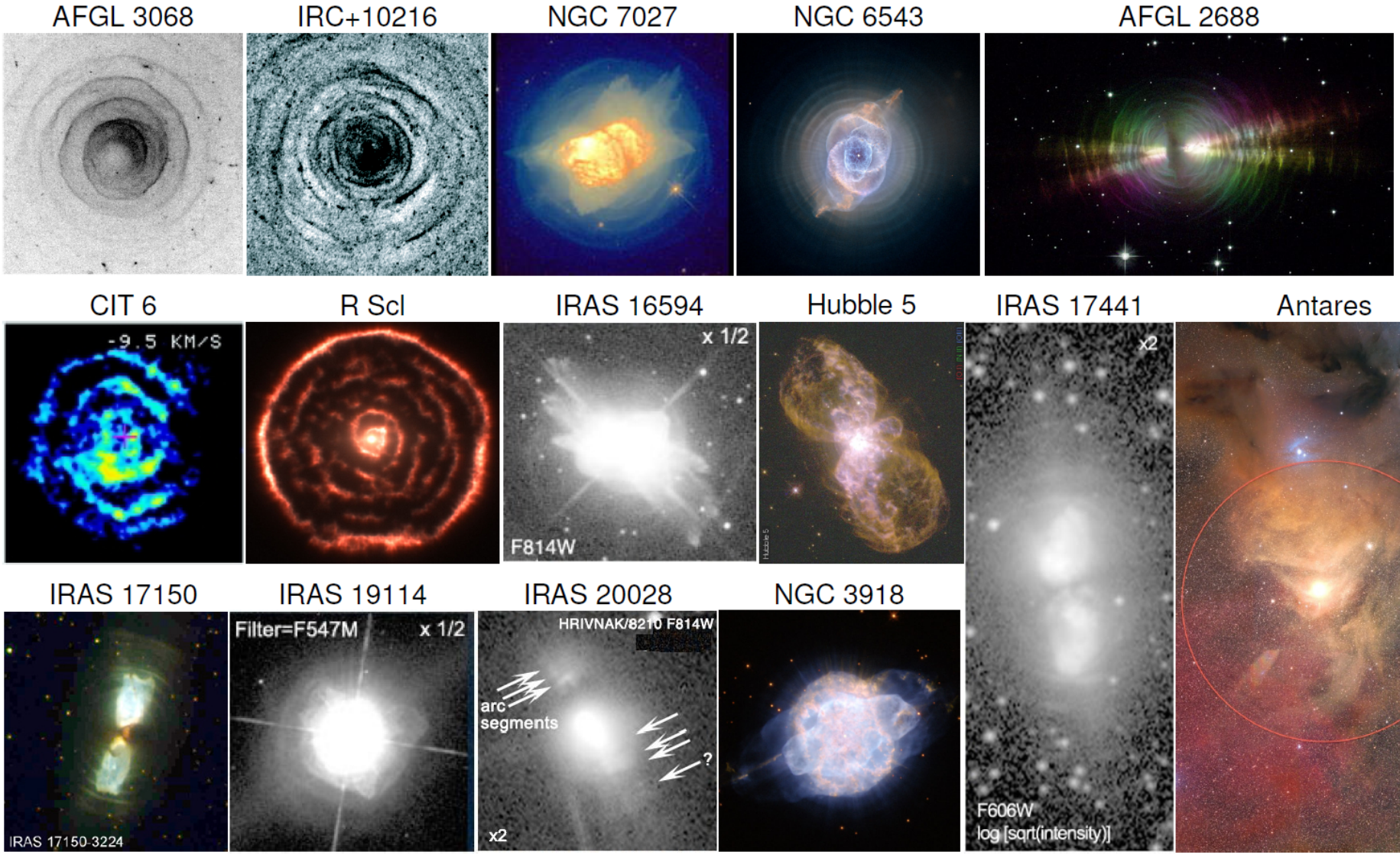




spiral arm spacing / wind velocity = binary orbital perid

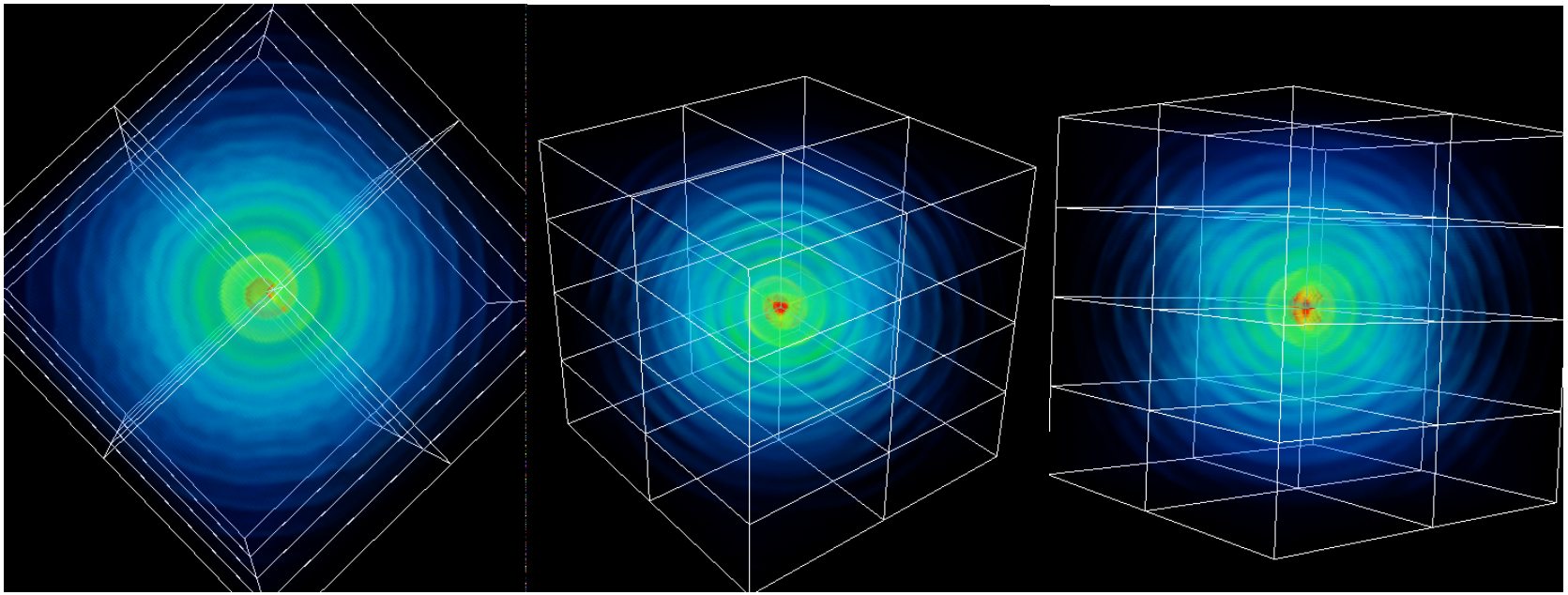
for a fixed orbit, variation of arm spacing → variation of wind

Circumstellar patterns



Elongated morphology

face-on edge-on



Mauron++ 2013

We find that ∼ 50% of the envelopes are close to circular with $E \gtrsim 1.1$, and others are more elliptical with ∼20% with $E \gtrsim 1.2$. We interpret the shapes in terms of populations of single stars and binaries whose envelopes are flattened by a companion.

Summary

- Spirals are ubiquitous.
- Circumstellar **spiral** and **ring** patterns both are likely originated from **binary orbital motion**.
- The circumstellar spiral-shell patterns can be used to derive the (unseen) binary orbital properties.
- The circumstellar spiral-shell patterns can constrain properties of the circumstellar envelopes.

Need statistically meaningful number of samples with high qualities.