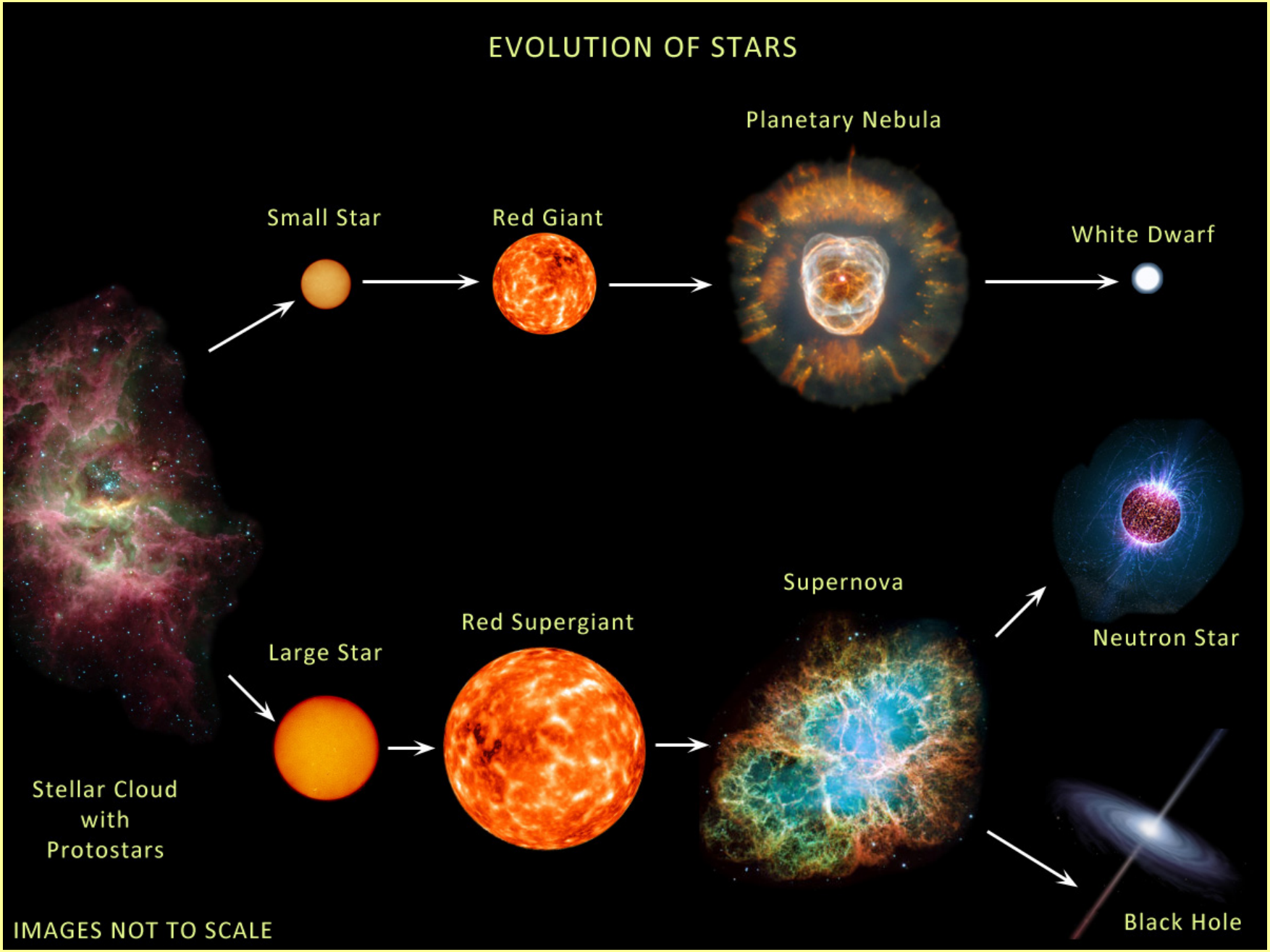
Modelling spiral morphologies

Case: the inner wind of CW Leo

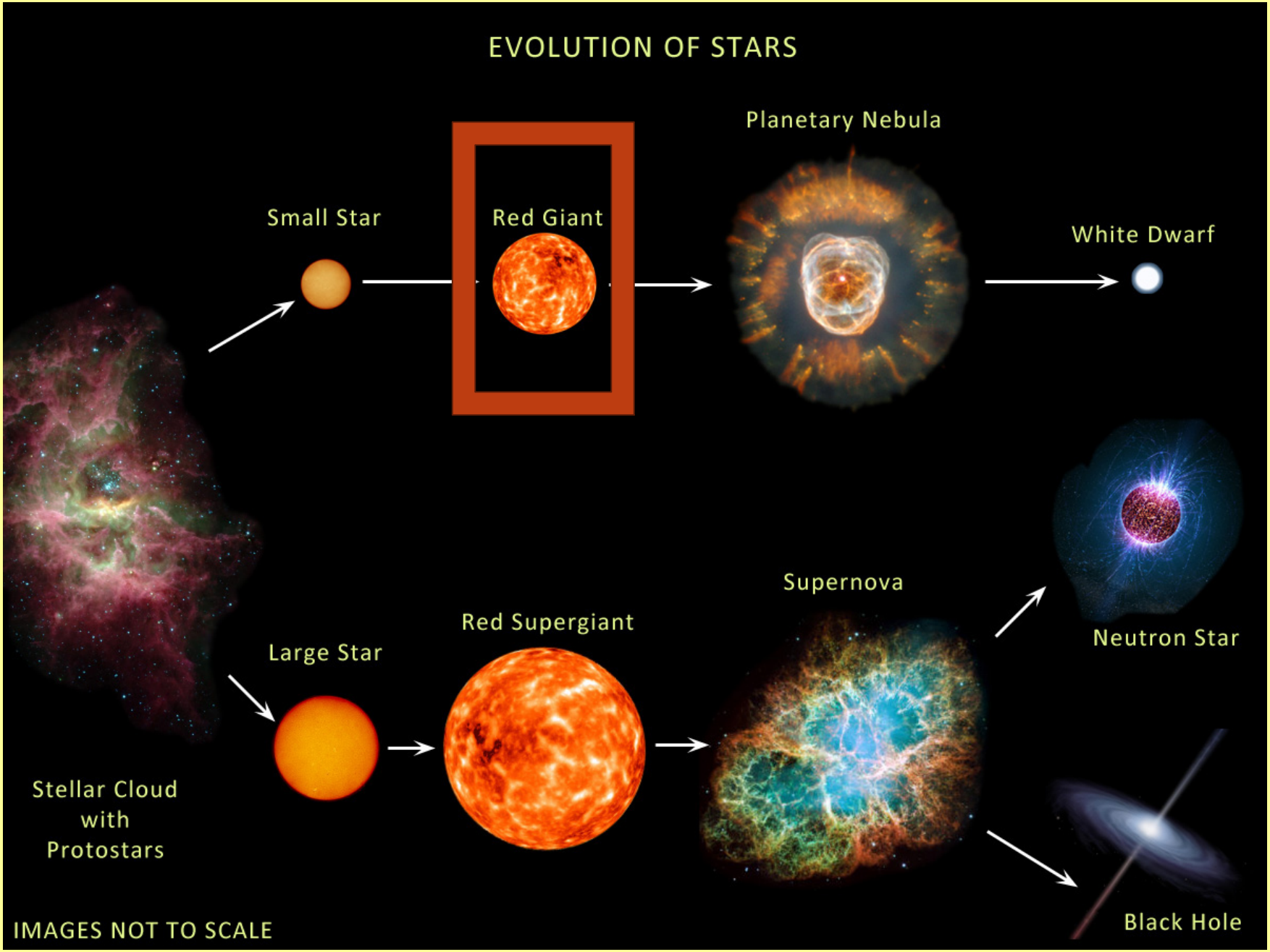
Ward Homan

Instituut voor sterrenkunde, KULeuven, BE

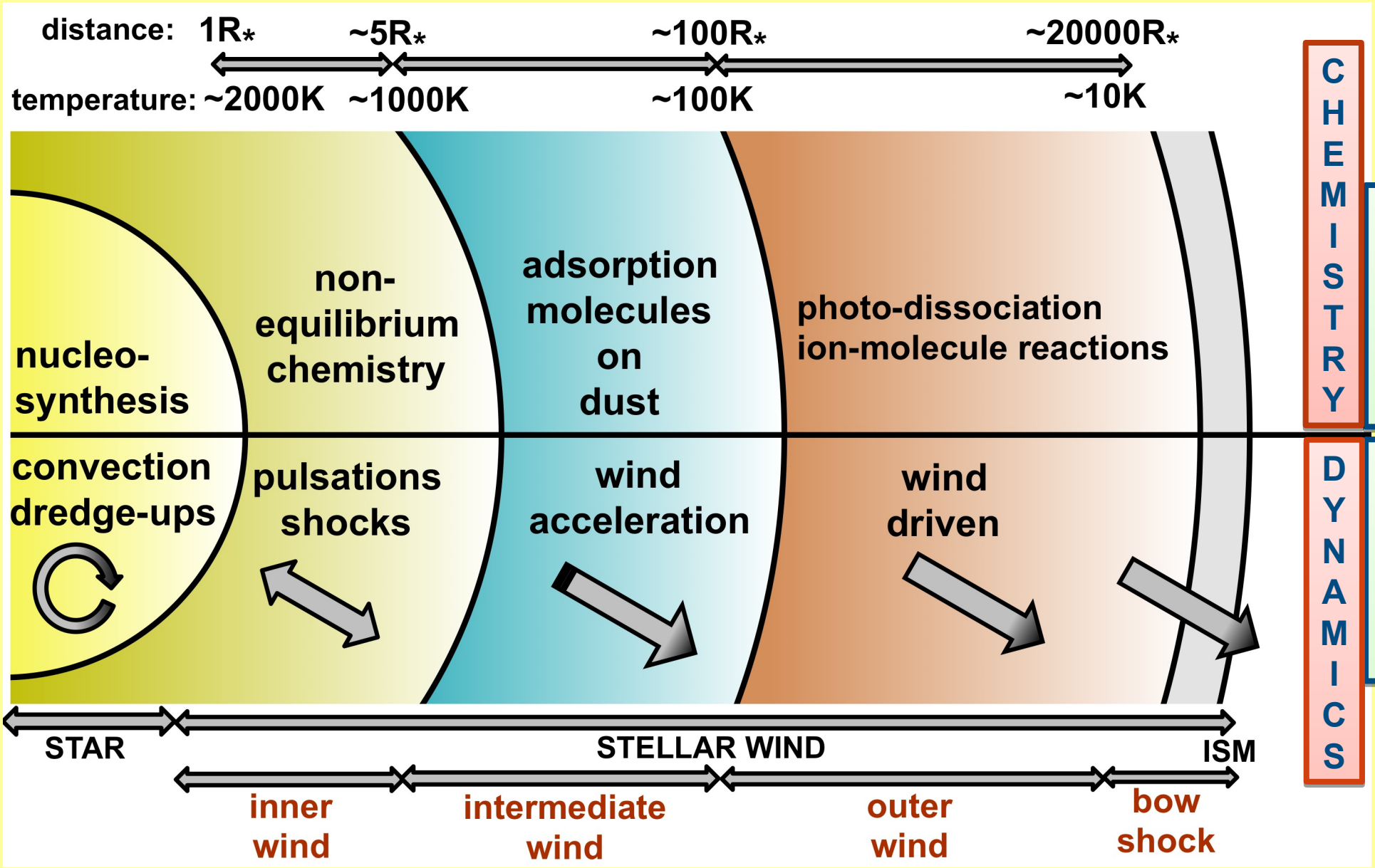
Stellar Evolution



Stellar Evolution



Structure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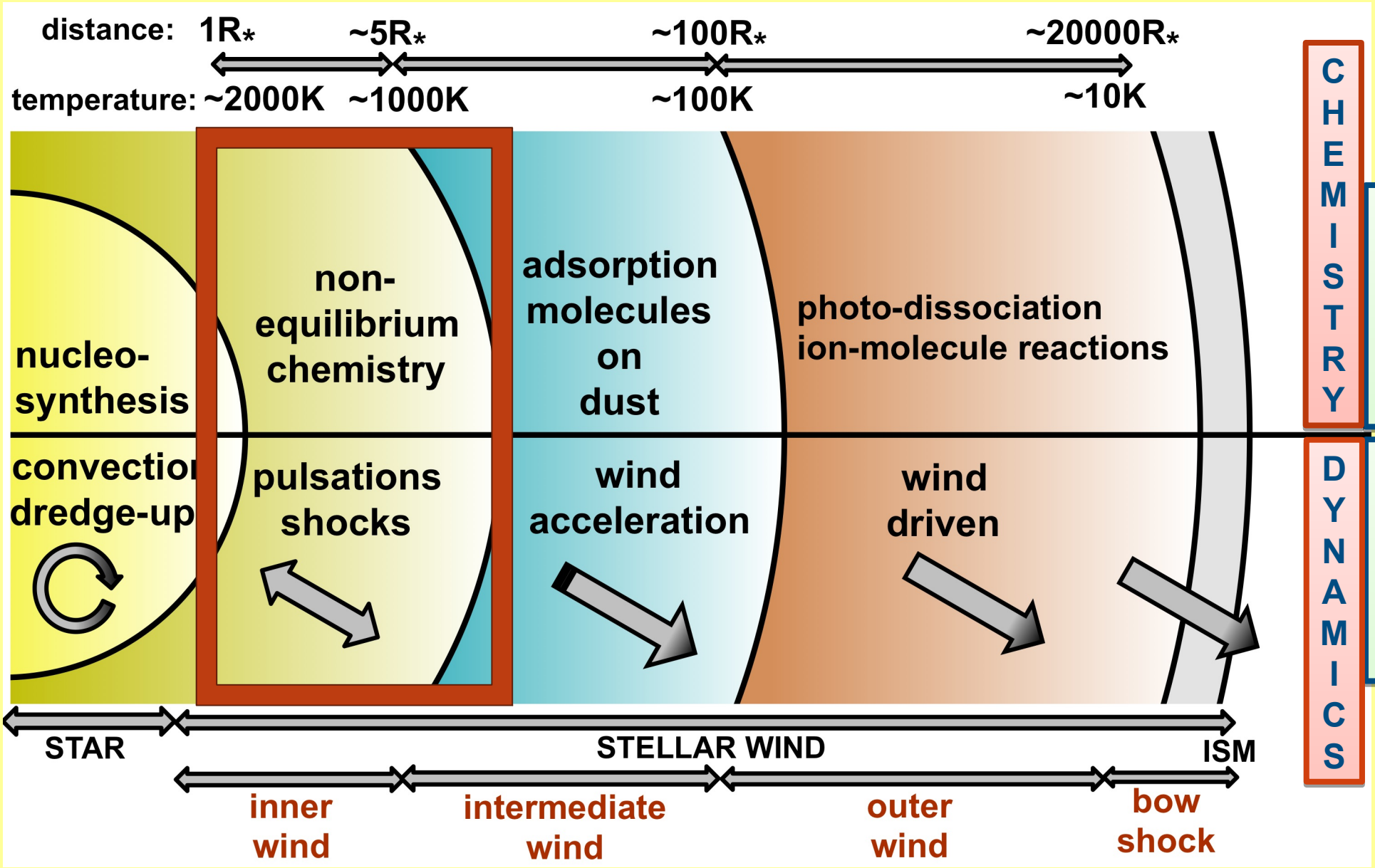
temperature: ~2000K ~1000K ~100K ~10K
nucleo-synthesis
non-equilibrium chemistry
adsorption molecules on dust
photo-dissociation ion-molecule reactions
convection dredge-ups
pulsations shocks
wind acceleration
wind driven
CHEMISTRY
DYNAMICS
MICRO
MACRO
STAR
STELLAR WIND
ISM
inner wind
intermediate wind
outer wind
bow shock

Structure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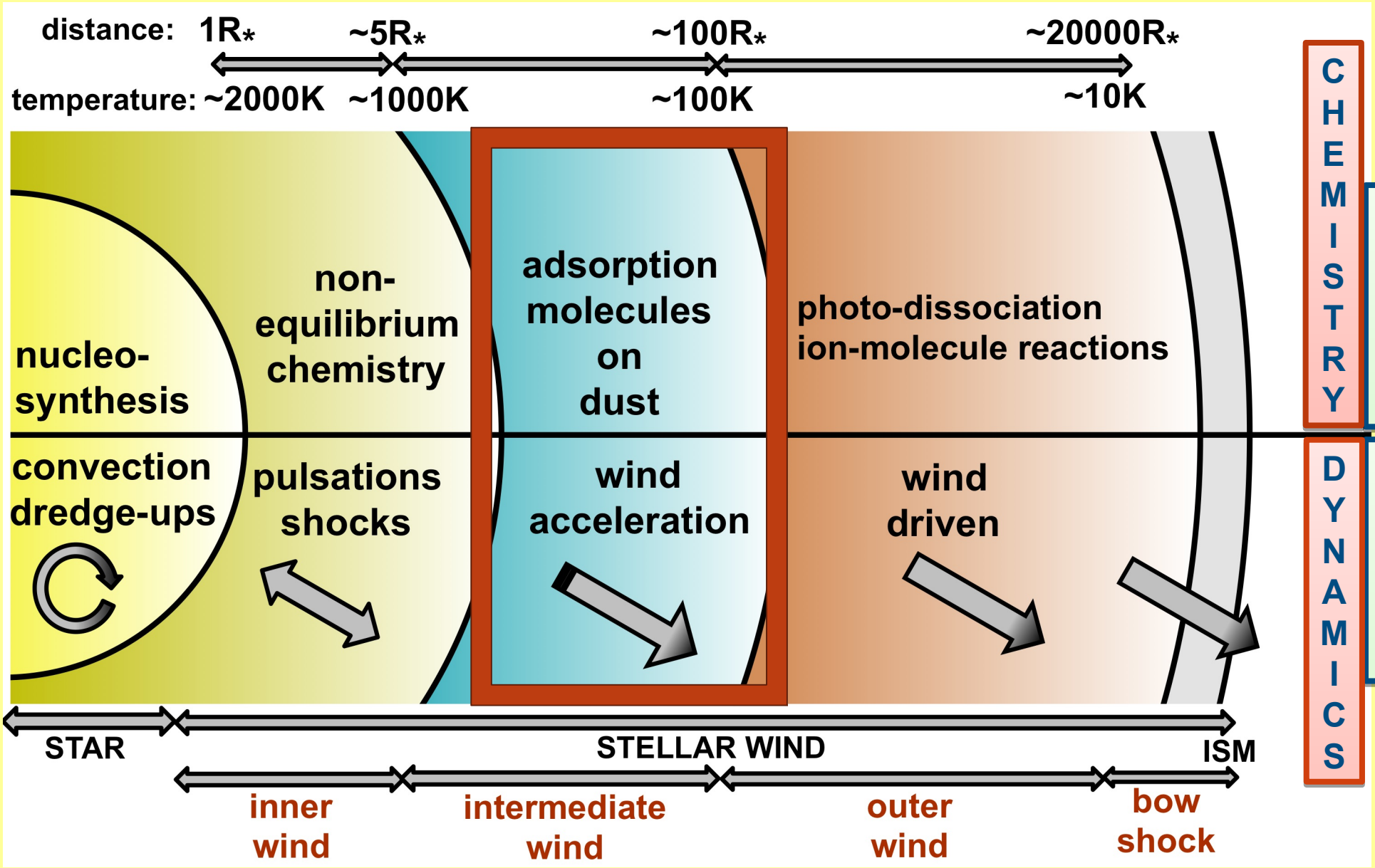
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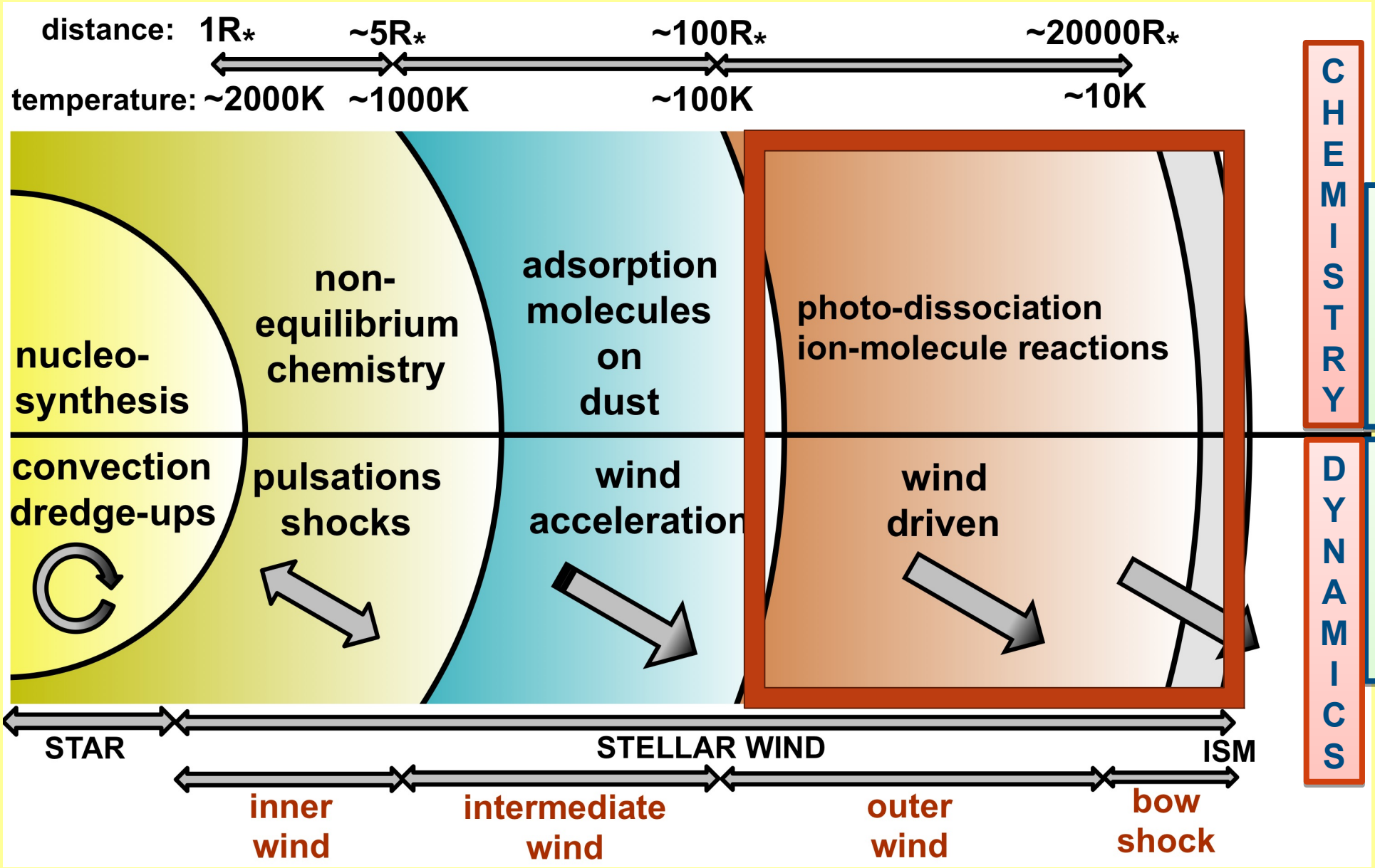
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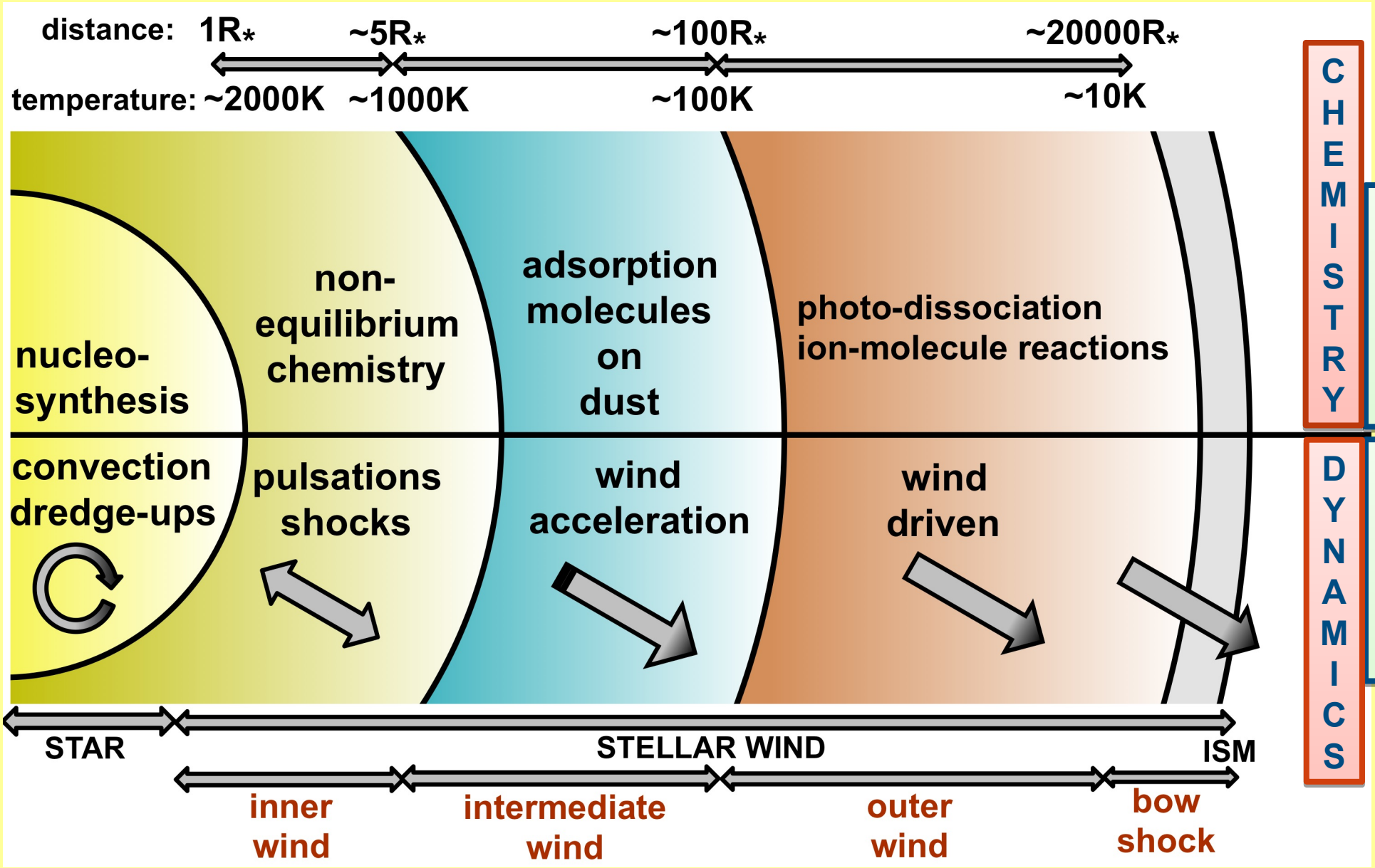
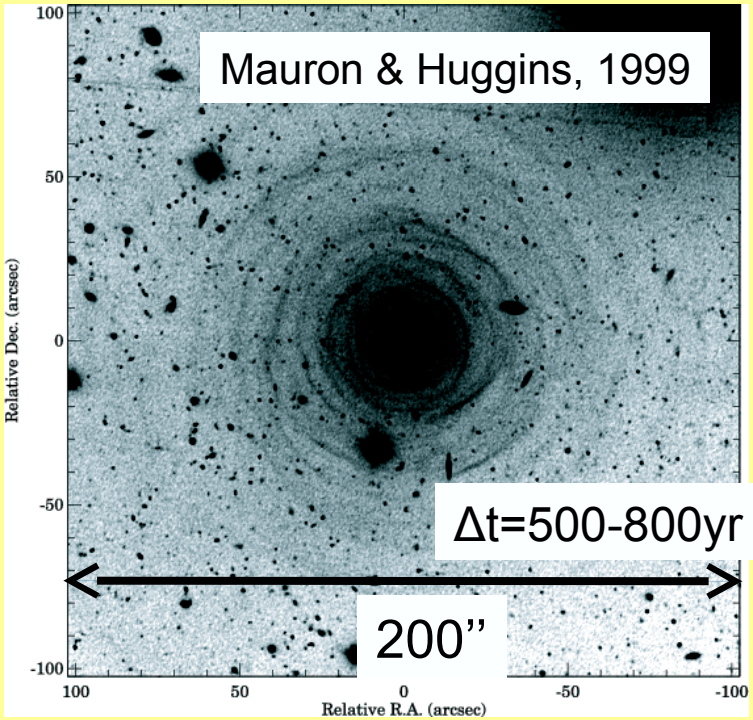


EXCLUSIVELY RADIAL

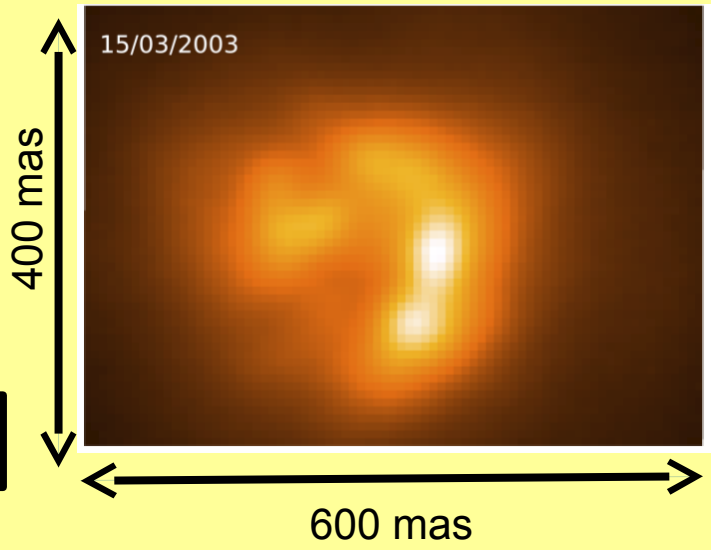
CW Leo, the C-rich Laboratory

CW Leo, the C-rich Laboratory

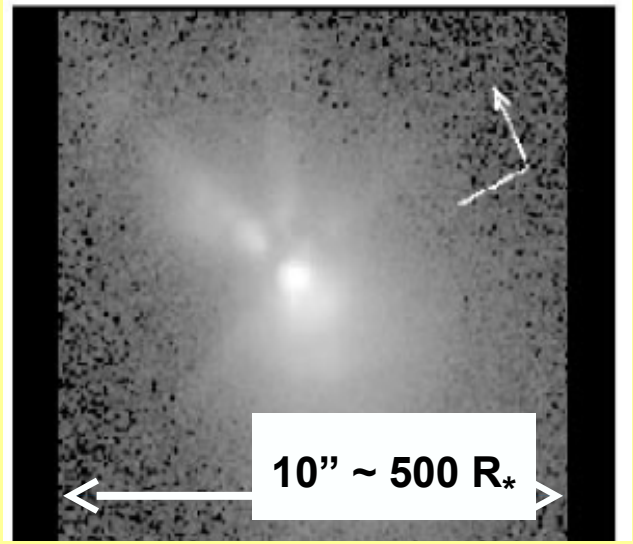


Arcs

Menut et al. 2007



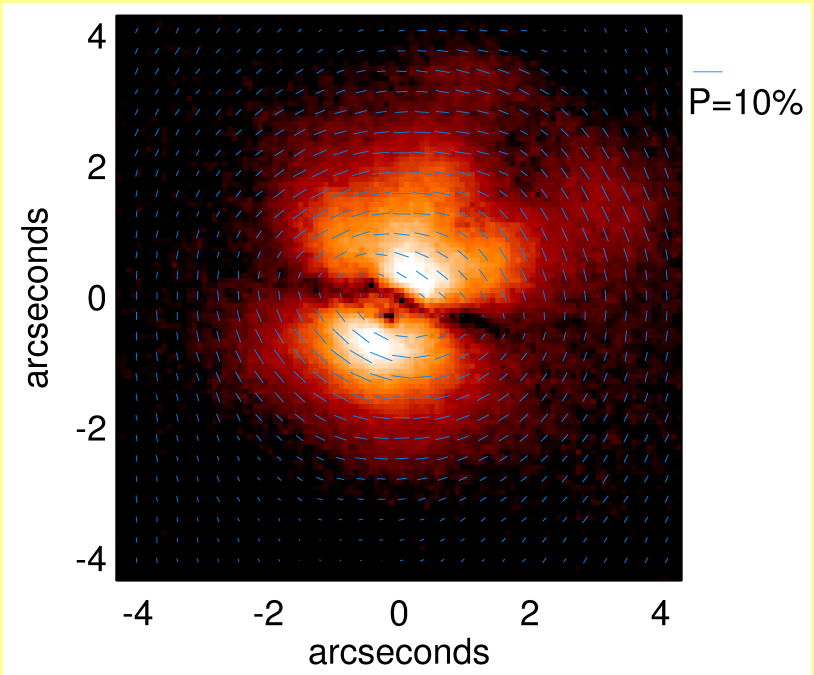
Clumps



Skinner et al. 1998

Bipolar morphology

Jeffers et al. 2014



CW Leo, as seen with ALMA

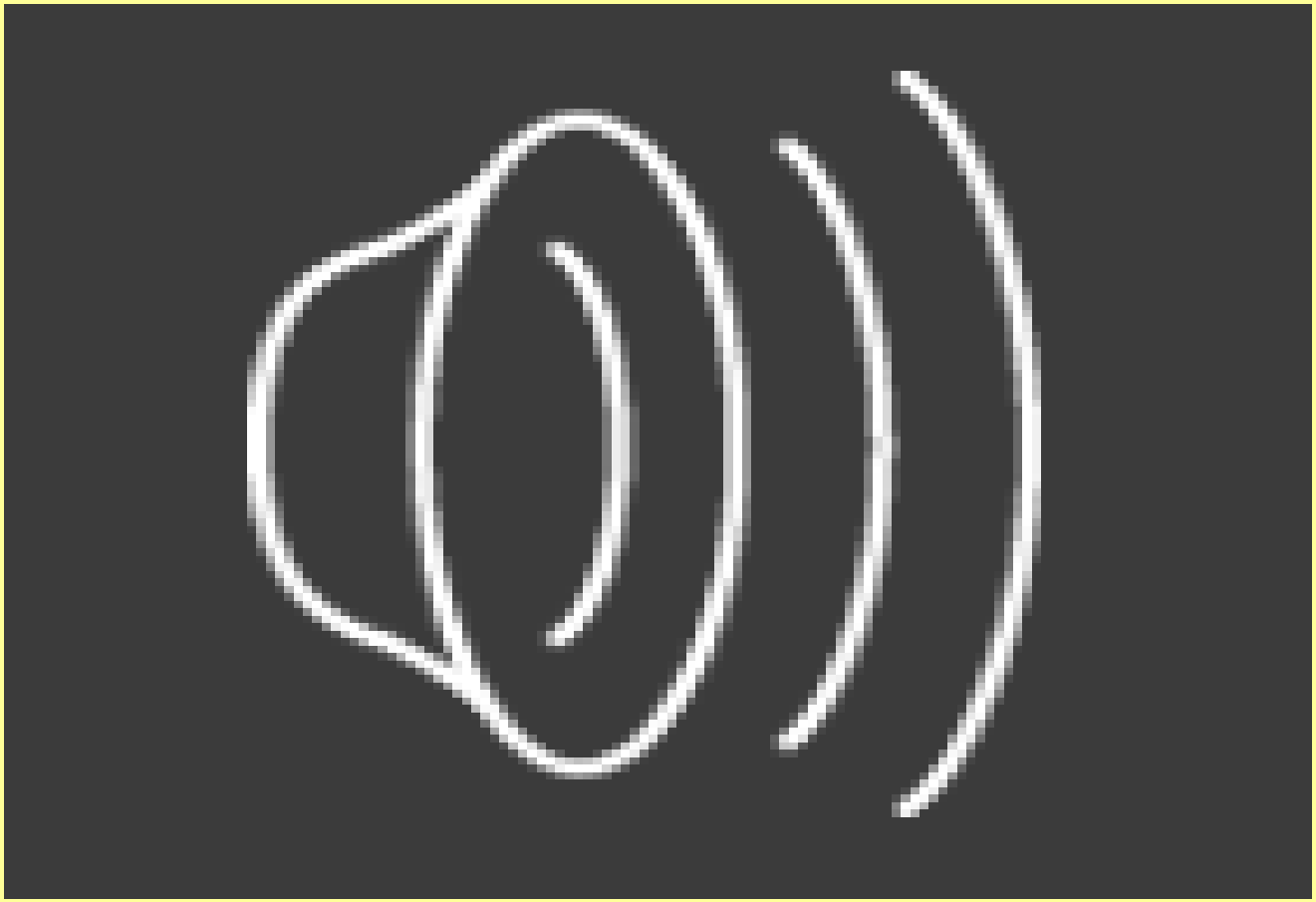
ALMA Cycle 0, band 9.

18 antennas, 25m - 340m. Sensitive to spatial scales up to **3”.**

17.5 min on source, total observation time 35 min. Relatively **poor UV coverage**.

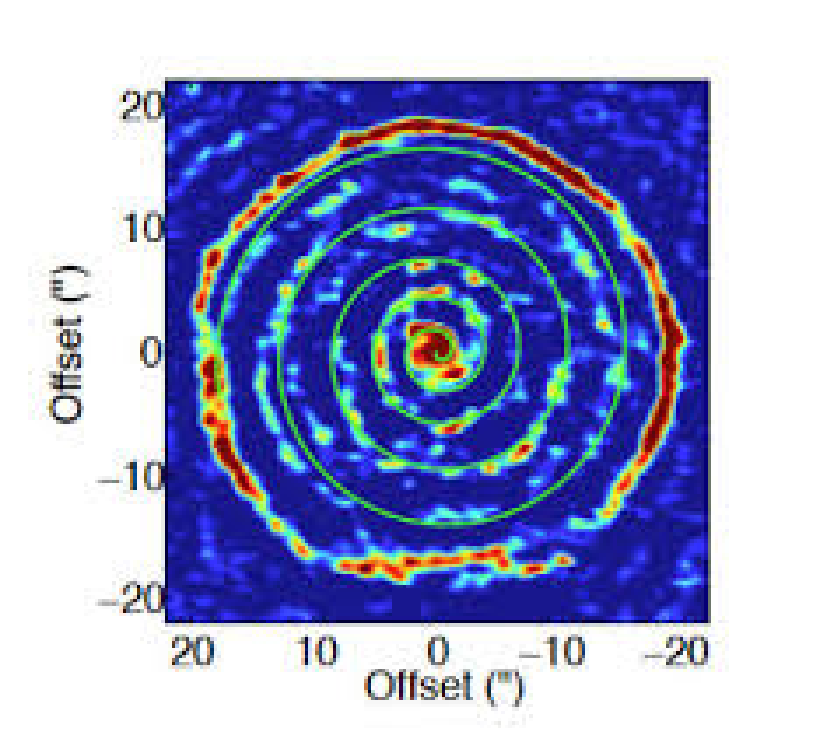
CW Leo, as seen with ALMA

^{13}CO J = 6 - 5 emission



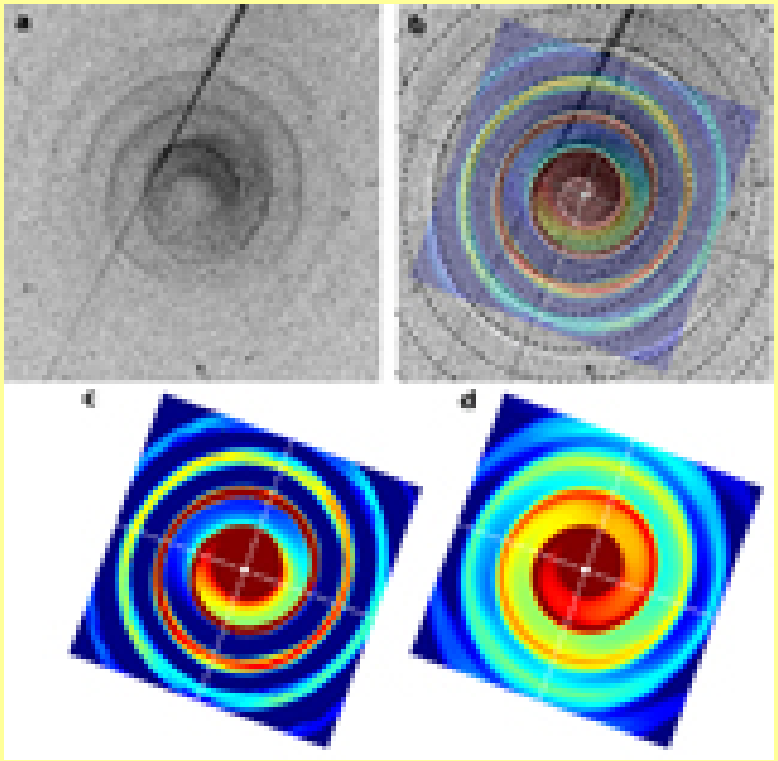
Binary-induced spirals

R Scl



Maercker et al. 2012

AFGL 3068



Mauron et al. 2006

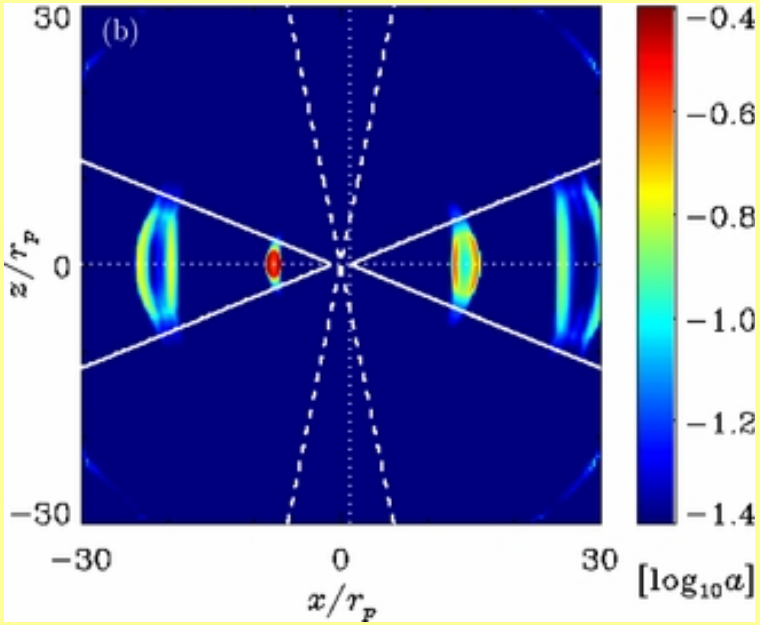
spiral structures seen (almost) FACE-ON

Binary-induced spirals

2 ‘types’ of spiral structure

1. Gravitational field of the companion

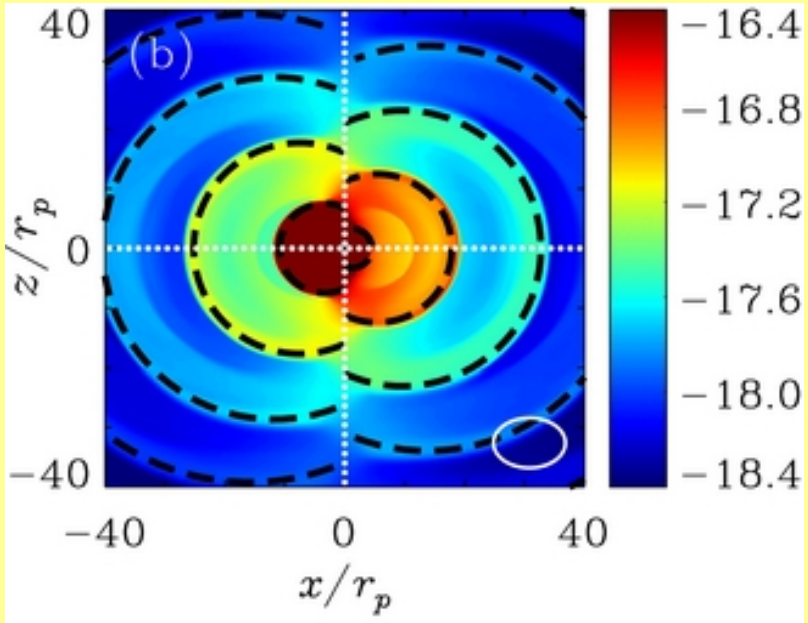
focus of material toward orbital plane



Kim et al. 2012

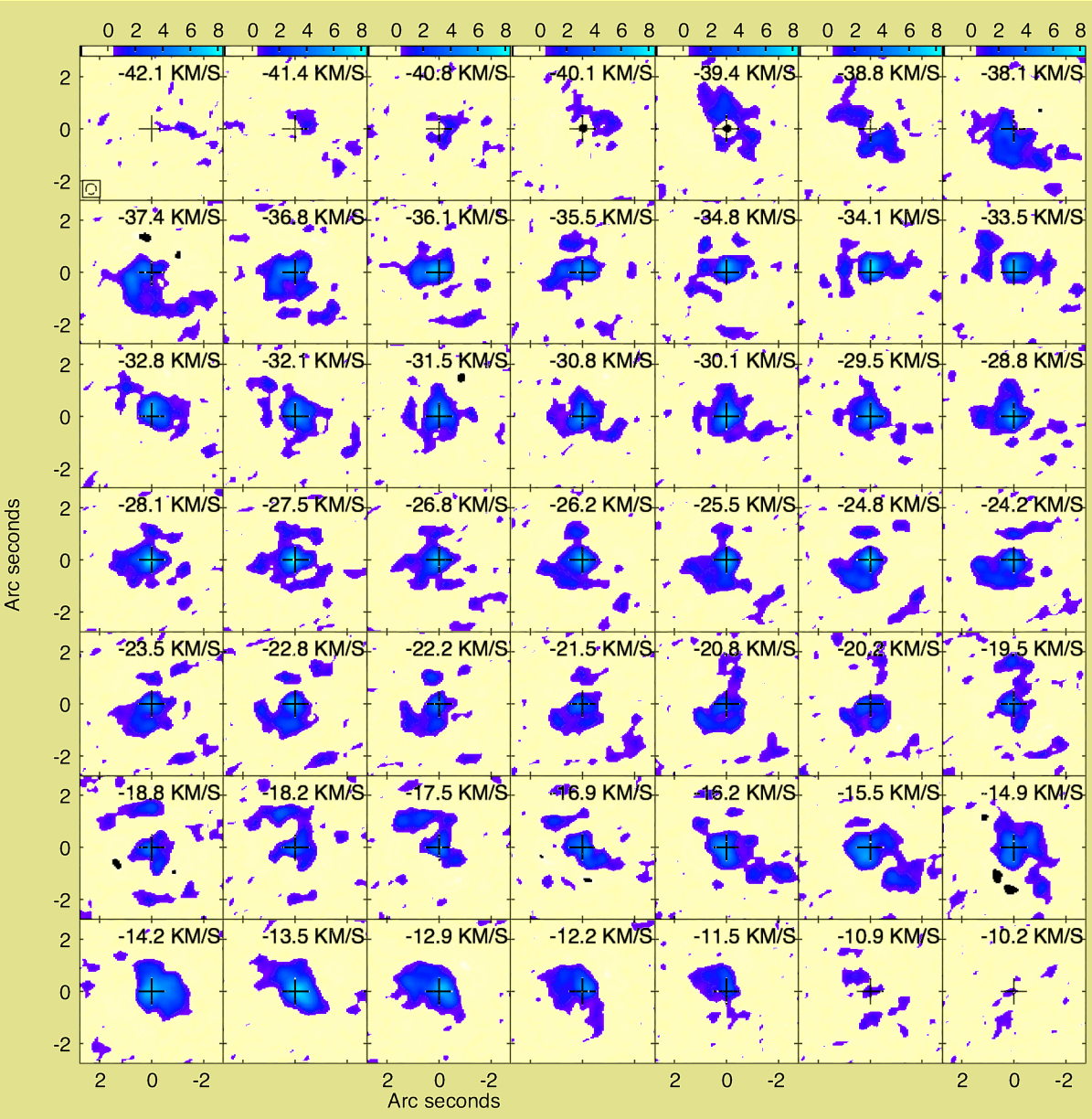
2. Orbital motion of mass-losing AGB star around center of gravity

spiral structure reaching almost orbital axis

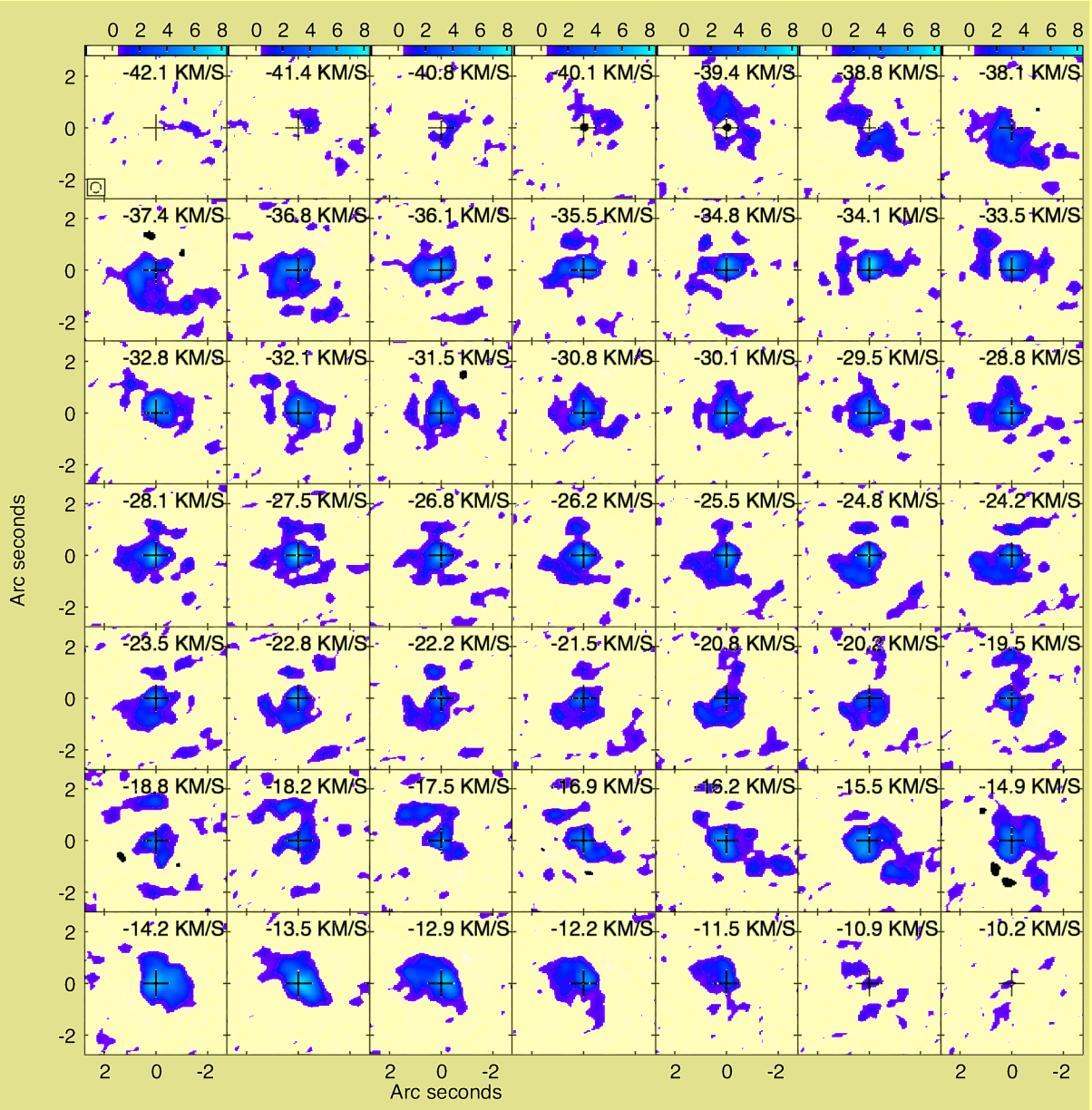


Kim et al. 2012

Binary-induced spiral?



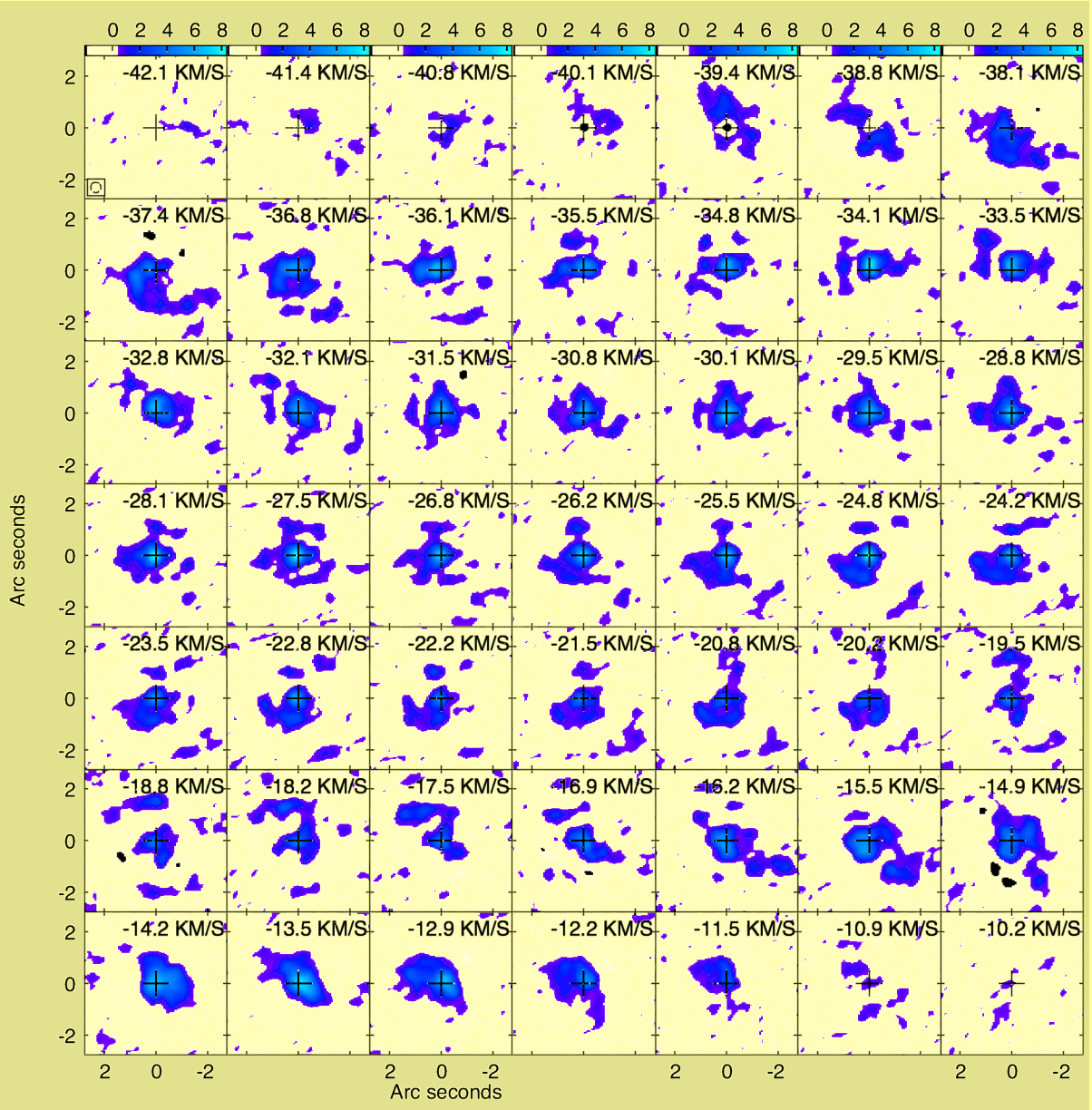
Binary-induced spiral?



Generate wide-slit PV diagram.

Find most revealing PA.

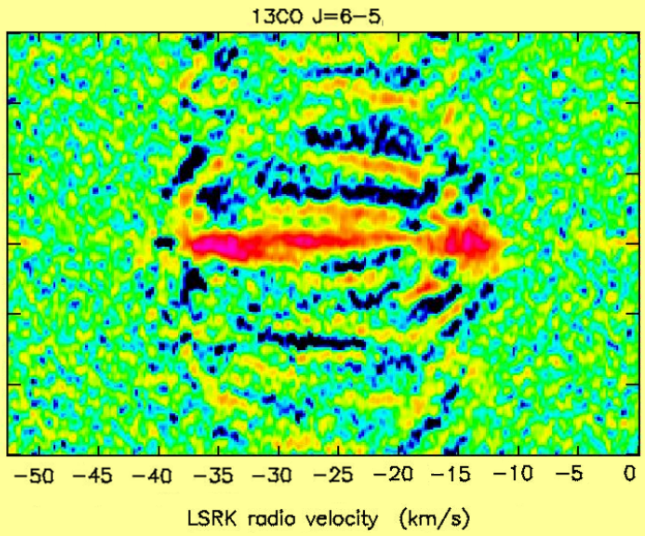
Binary-induced spiral?



Generate wide-slit PV diagram.

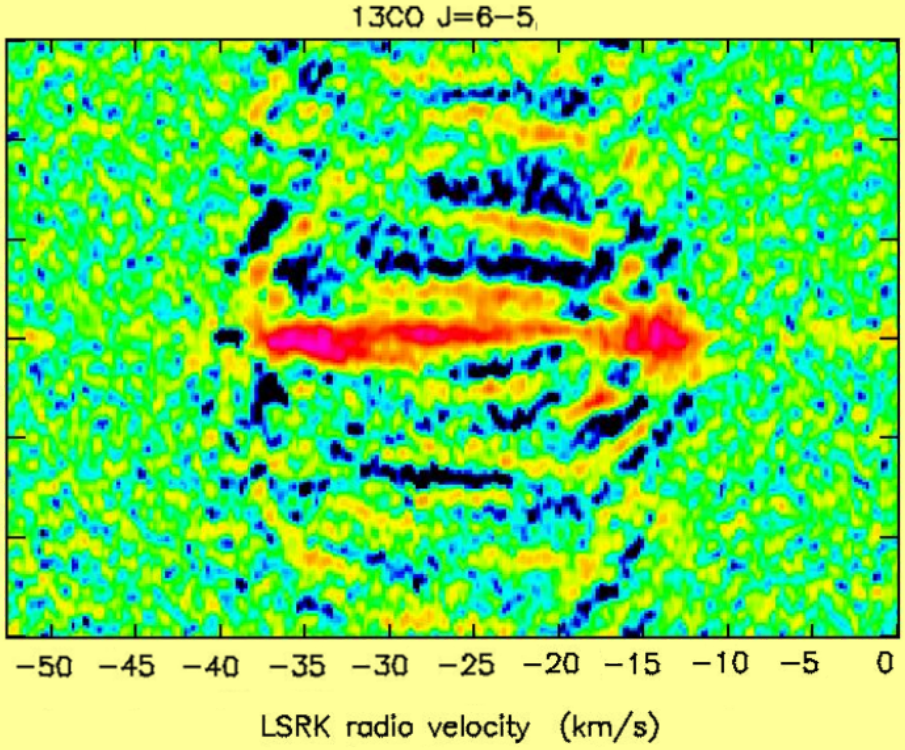
Find most revealing PA.

PA ~ 20°



Decin et al. 2015

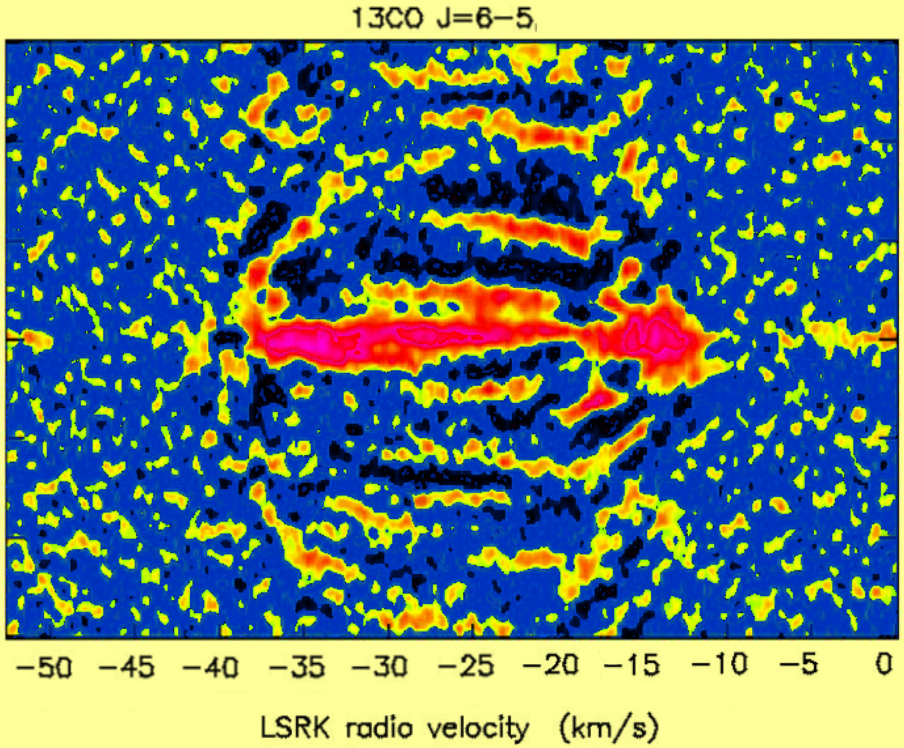
Binary-induced spiral?



Decin et al. 2015

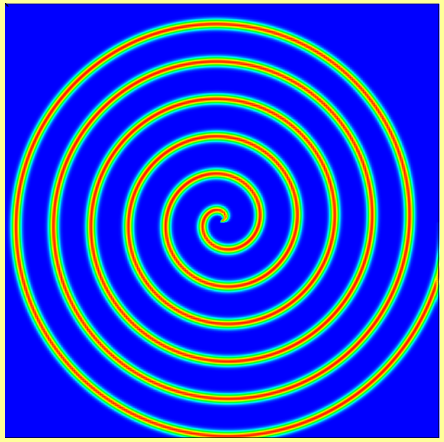
Some clear correlated structures are visible

- **Clumpy**
- **Noisy**
- **Broken-up**

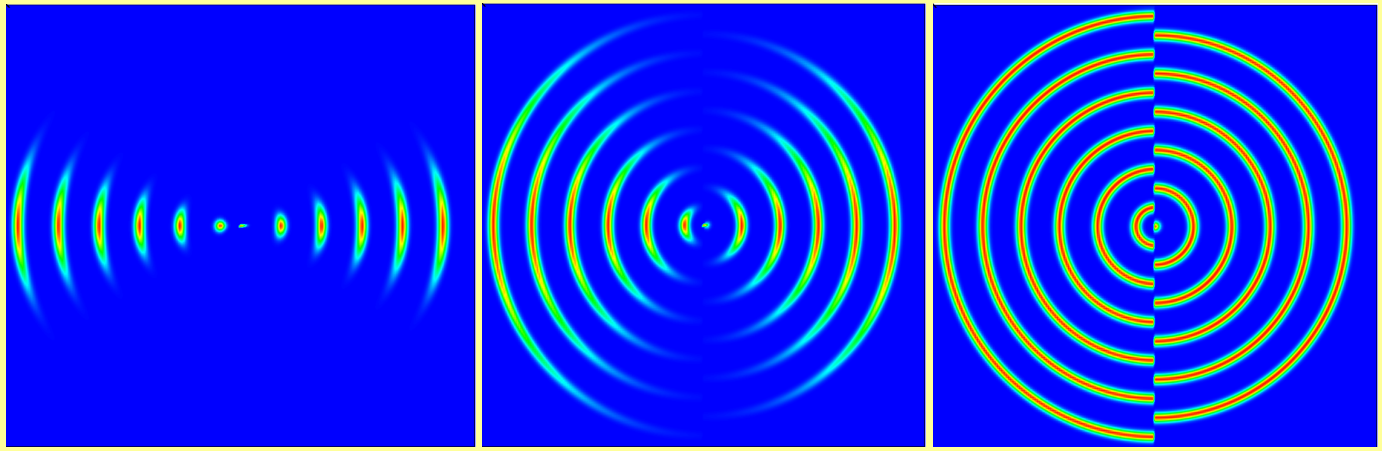


Analytical spiral models

$$\rho(r,\theta,\varphi) = A\left(\frac{2\pi b}{r}\right)^2 \exp\left[-\frac{(r-b\varphi)^2}{2T^2} - \frac{(\theta-(\pi/2))^2}{2\alpha^2}\right]$$



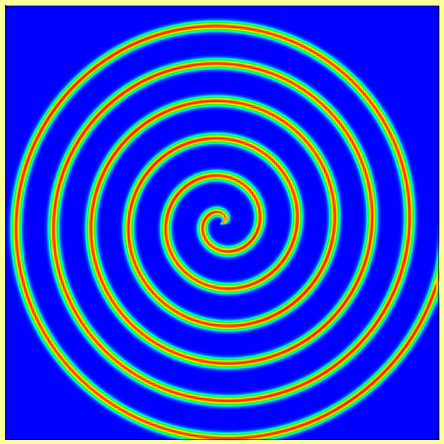
Cut through
orbital plane



Cut through
meridional plane

Analytical spiral models

$$\rho(r,\theta,\varphi) = A\left(\frac{2\pi b}{r}\right)^2 \exp\left[-\frac{(r-b\varphi)^2}{2T^2} - \frac{(\theta-(\pi/2))^2}{2\alpha^2}\right]$$



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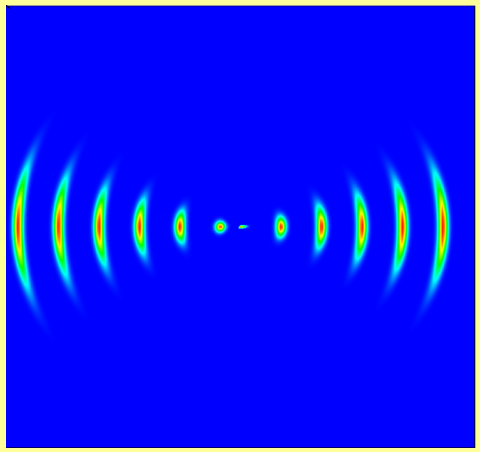
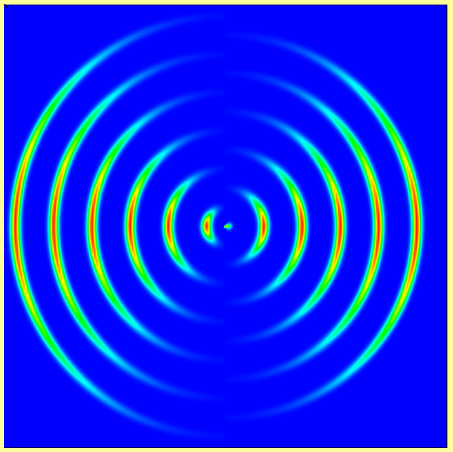
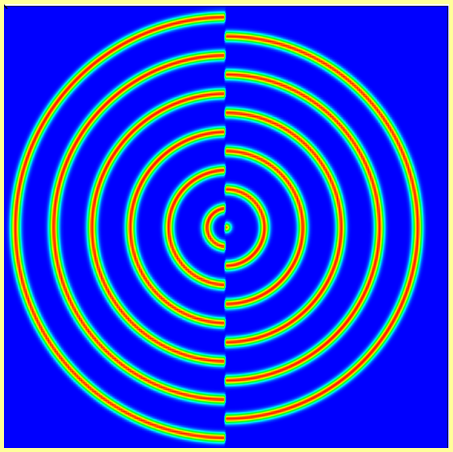


Narrow Spiral



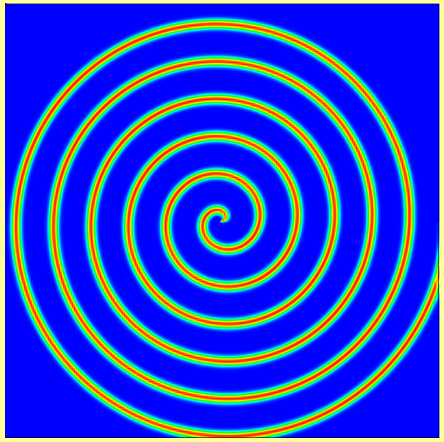
Cut through meridional plane



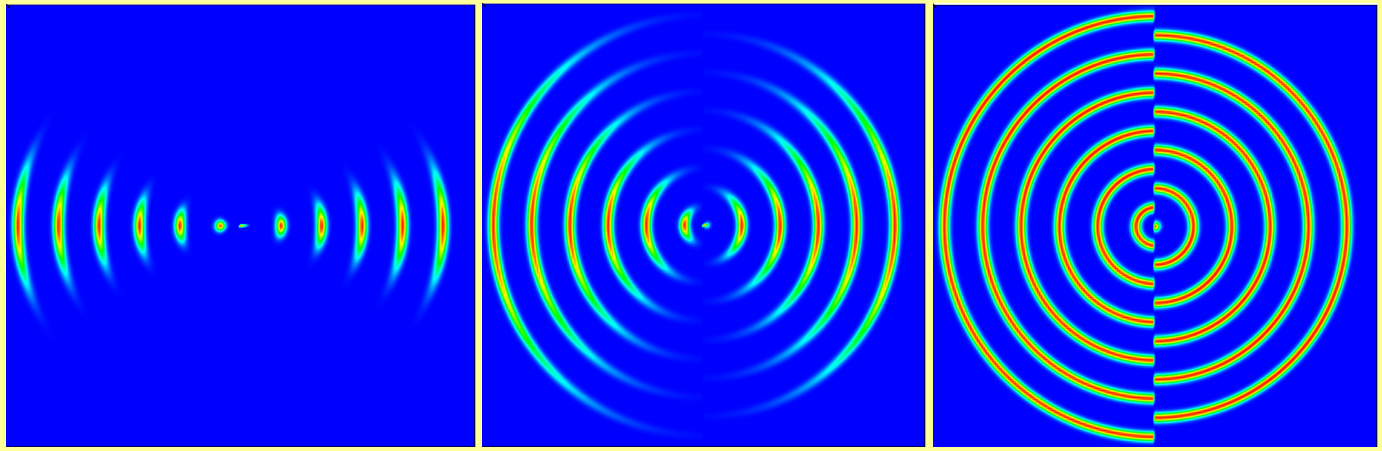
Shell Spiral

Analytical spiral models

$$\rho(r,\theta,\varphi) = A\left(\frac{2\pi b}{r}\right)^2 \exp\left[-\frac{(r-b\varphi)^2}{2T^2} - \frac{(\theta-(\pi/2))^2}{2\alpha^2}\right]$$



Cut through
orbital plane

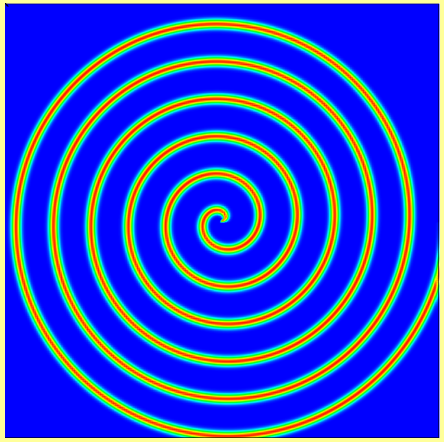


Cut through
meridional plane

- Spiral **embedded** in homogeneous outflow
- Temperature **follows density**
- **Radial** outflow velocity

Analytical spiral models

$$\rho(r,\theta,\varphi) = A\left(\frac{2\pi b}{r}\right)^2 \exp\left[-\frac{(r-b\varphi)^2}{2T^2} - \frac{(\theta-(\pi/2))^2}{2\alpha^2}\right]$$



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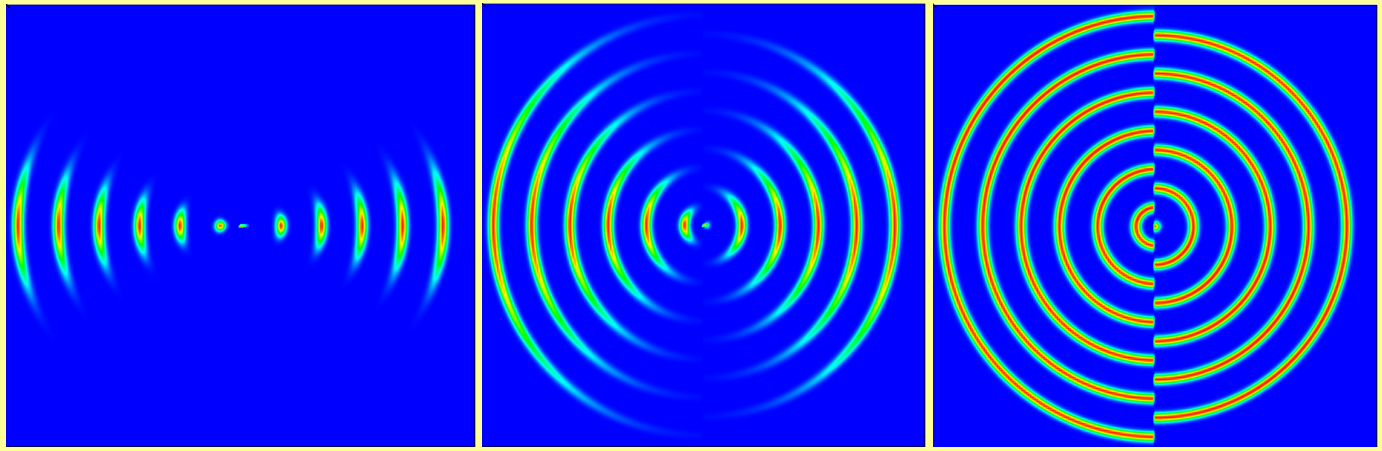
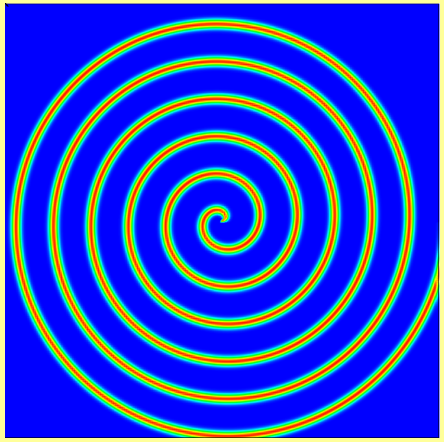


Cut through
meridional plane

Analytical **approximation** of spiral wind as input model for **3D radiative transfer** code LIME (Brinch et al. 2010)

Analytical spiral models

$$\rho(r,\theta,\varphi) = A\left(\frac{2\pi b}{r}\right)^2 \exp\left[-\frac{(r-b\varphi)^2}{2T^2} - \frac{(\theta-(\pi/2))^2}{2\alpha^2}\right]$$



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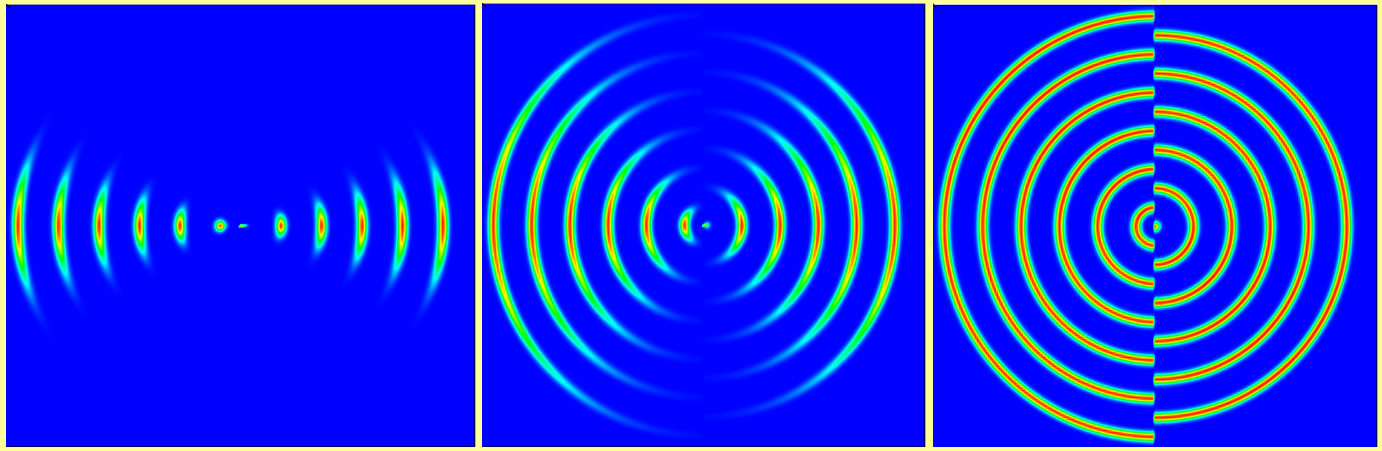
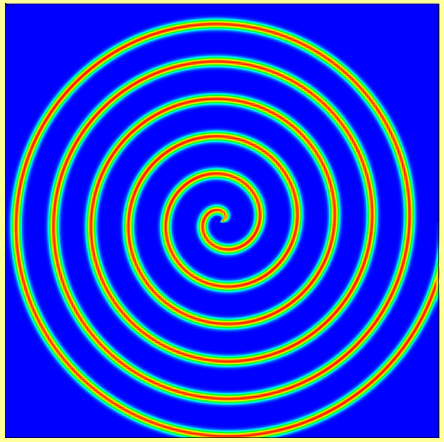


Cut through
meridional plane

Investigate the **manifestation** in the observables by means of a **parameter study**.
(Homan et al. 2015)

Analytical spiral models

$$\rho(r,\theta,\varphi) = A\left(\frac{2\pi b}{r}\right)^2 \exp\left[-\frac{(r-b\varphi)^2}{2T^2} - \frac{(\theta-(\pi/2))^2}{2\alpha^2}\right]$$



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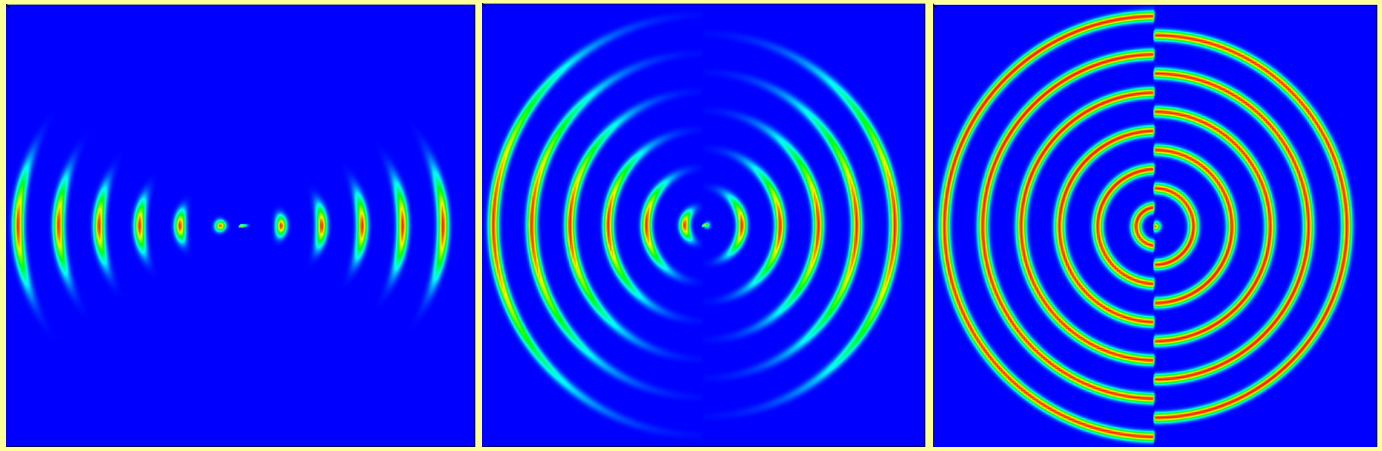


Cut through
meridional plane

- Total mass loss
- Contrast
- Opening angle
- Inclination

} ~ **1500** combinations

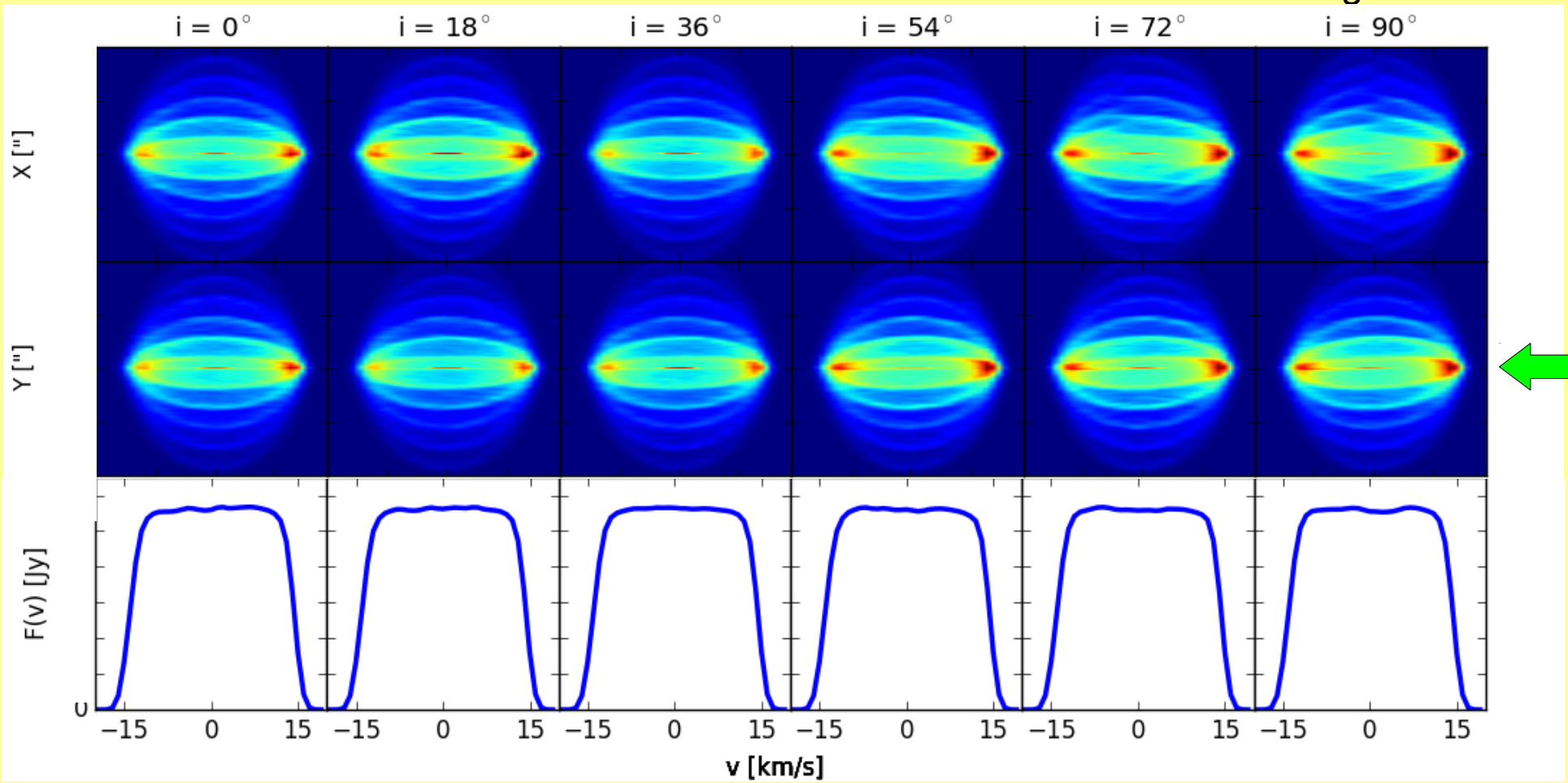
Analytical spiral models

Orthogonal wide-slit PV diagrams

Analytical spiral models

Orthogonal wide-slit PV diagrams

CO emission of a ‘Shell spiral’ due to reflex motion of AGB star.

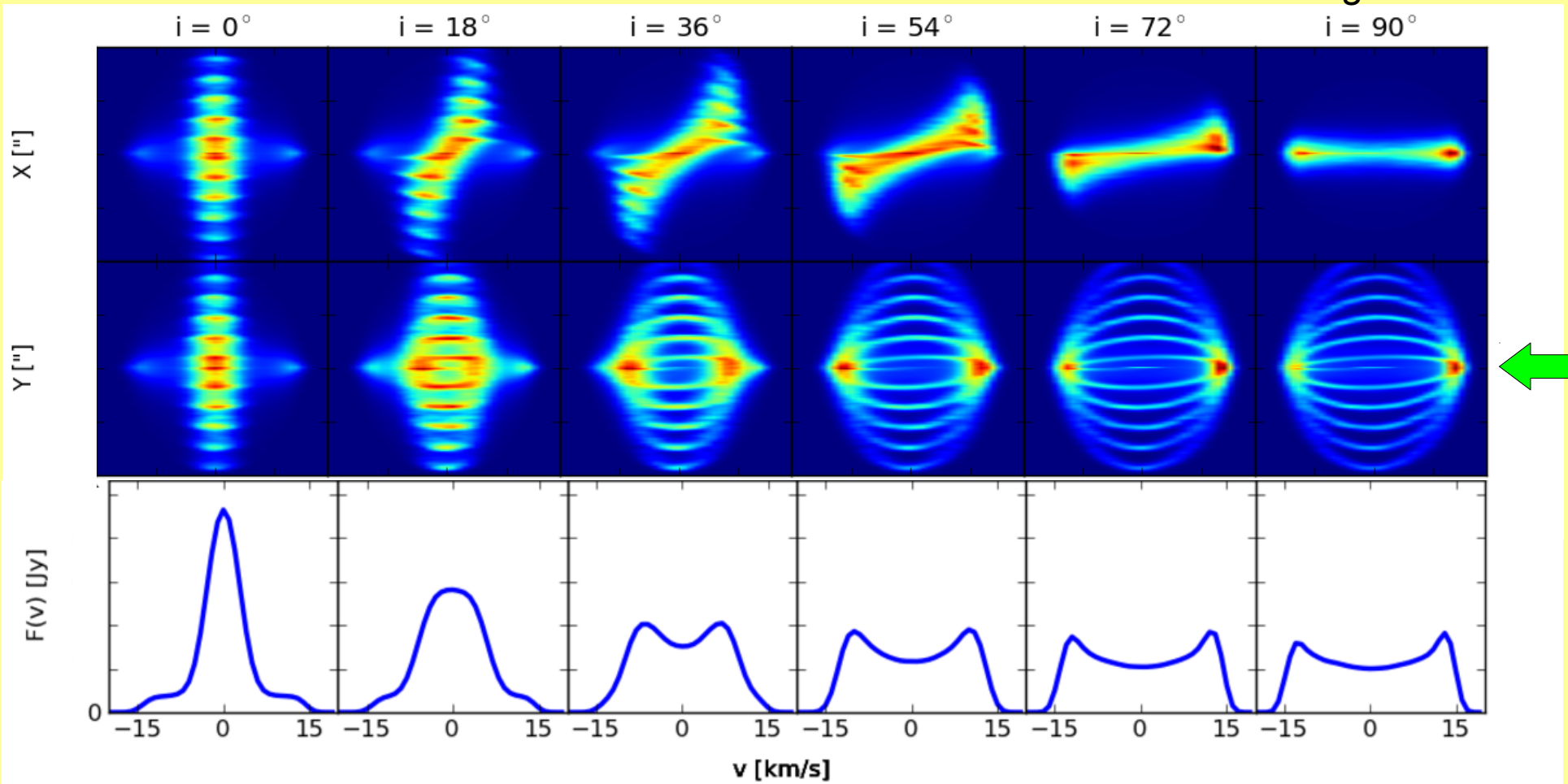


Homan et al. 2015

Analytical spiral models

Orthogonal wide-slit PV diagrams

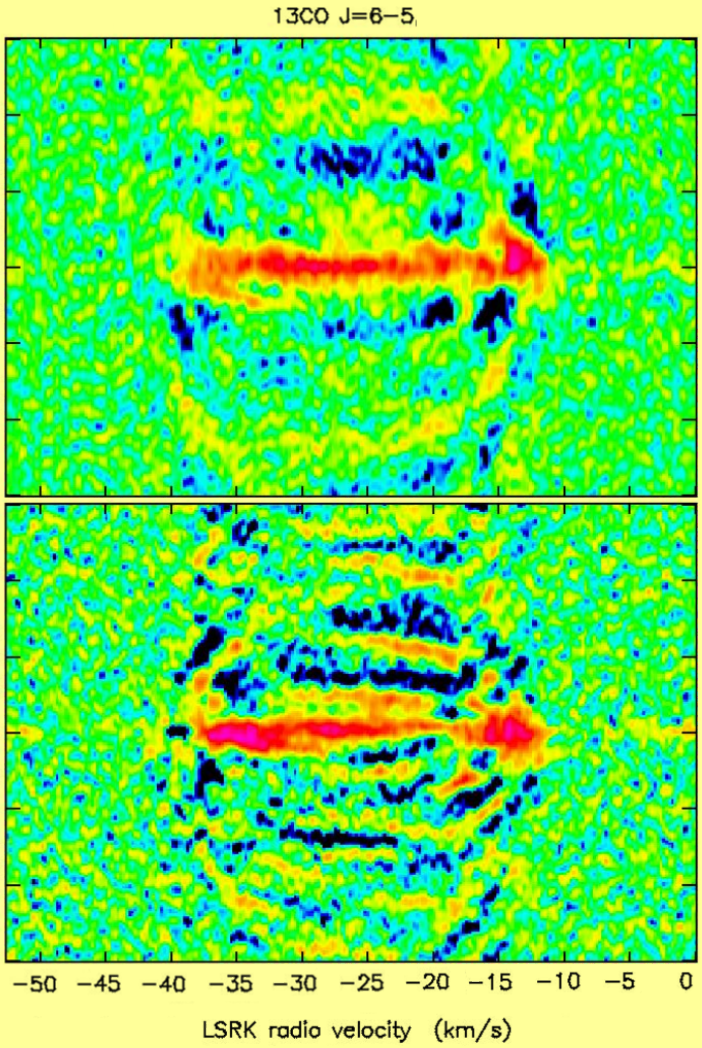
CO emission of a ‘Narrow spiral’ due to local gravitation

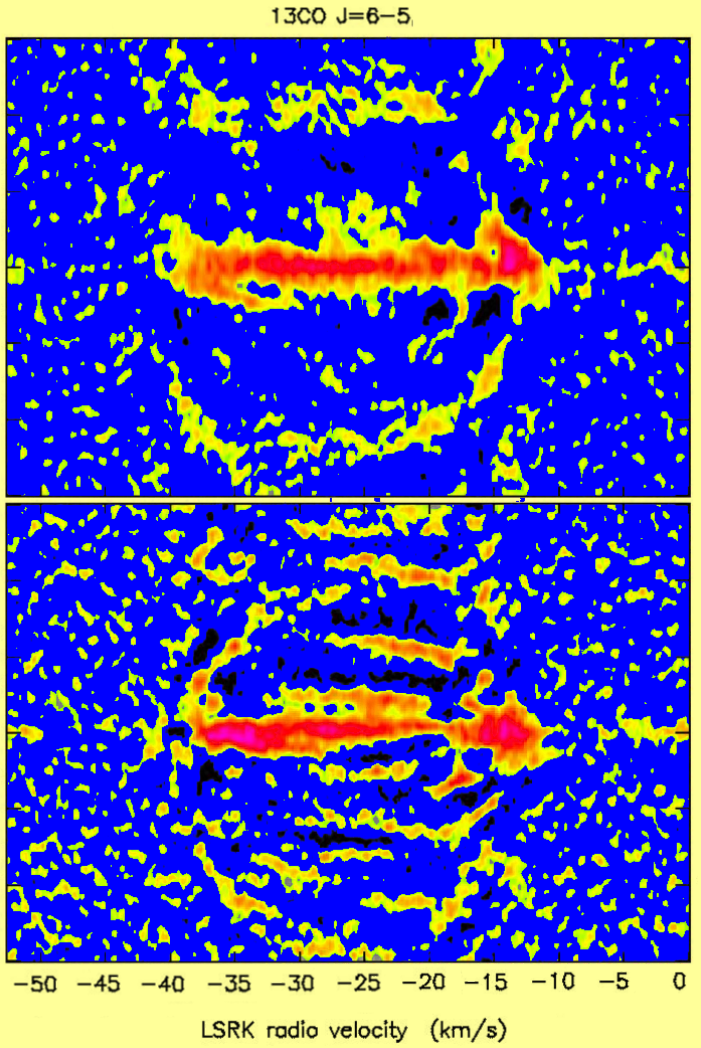


Homan et al. 2015

Back to CW Leo

Orthogonal wide-slit PV diagrams

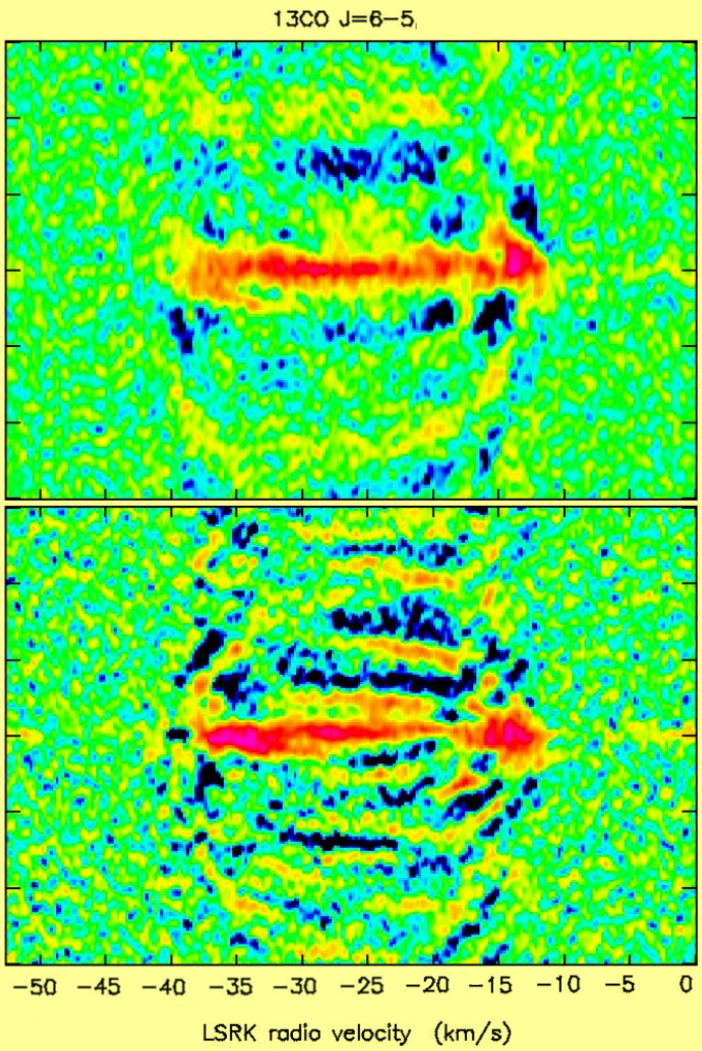




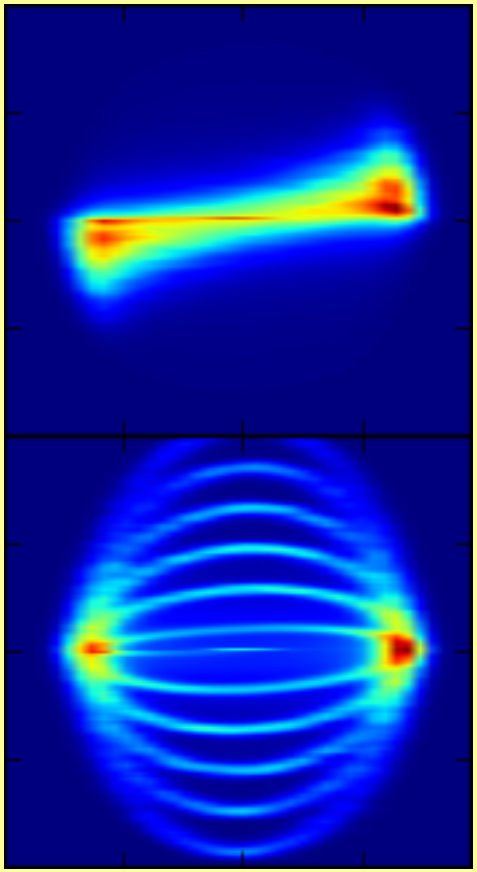
Decin et al. 2015

Back to CW Leo

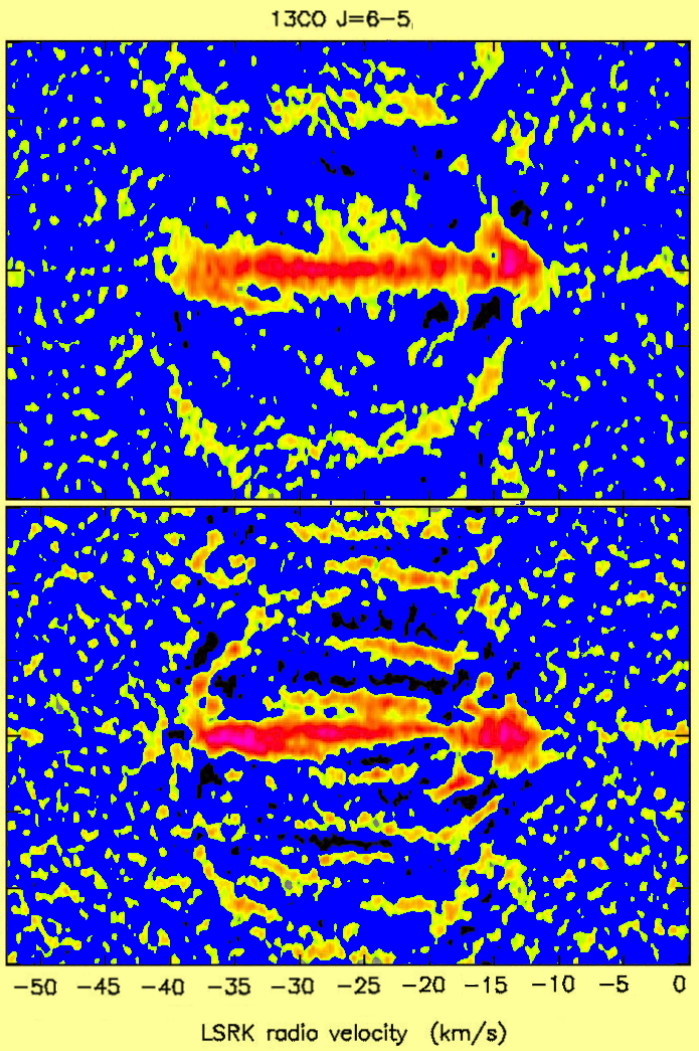
Orthogonal wide-slit PV diagrams



i = 72°



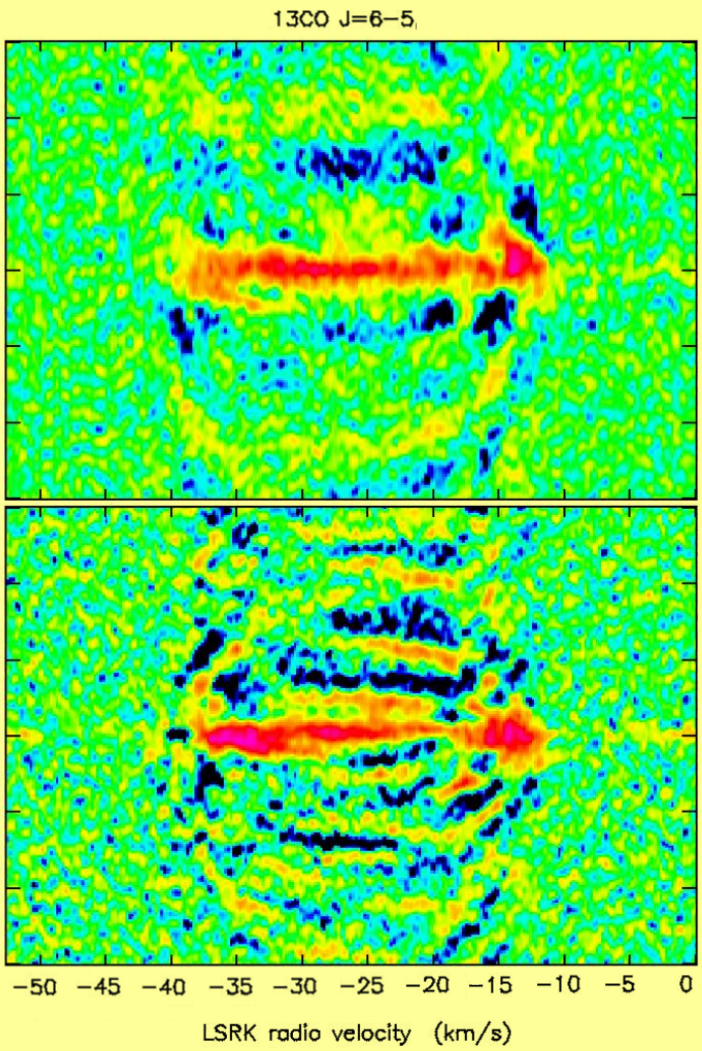
velocity



Decin et al. 2015

Back to CW Leo

Orthogonal wide-slit PV diagrams



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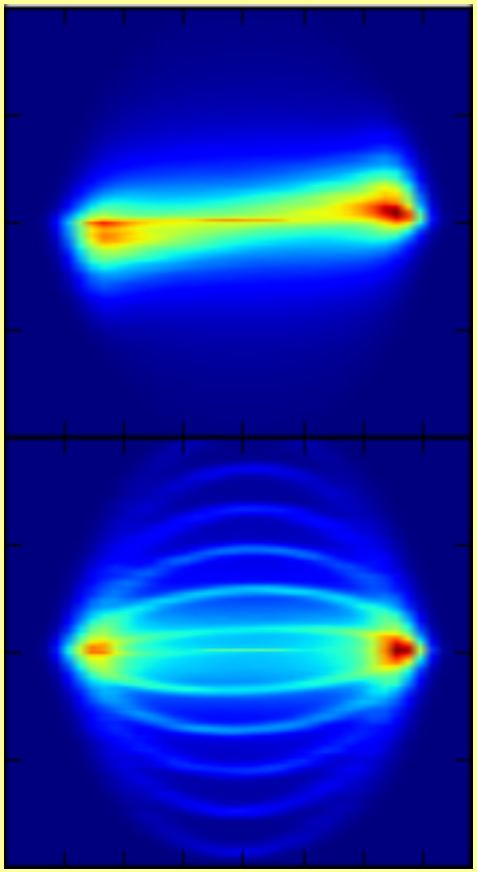
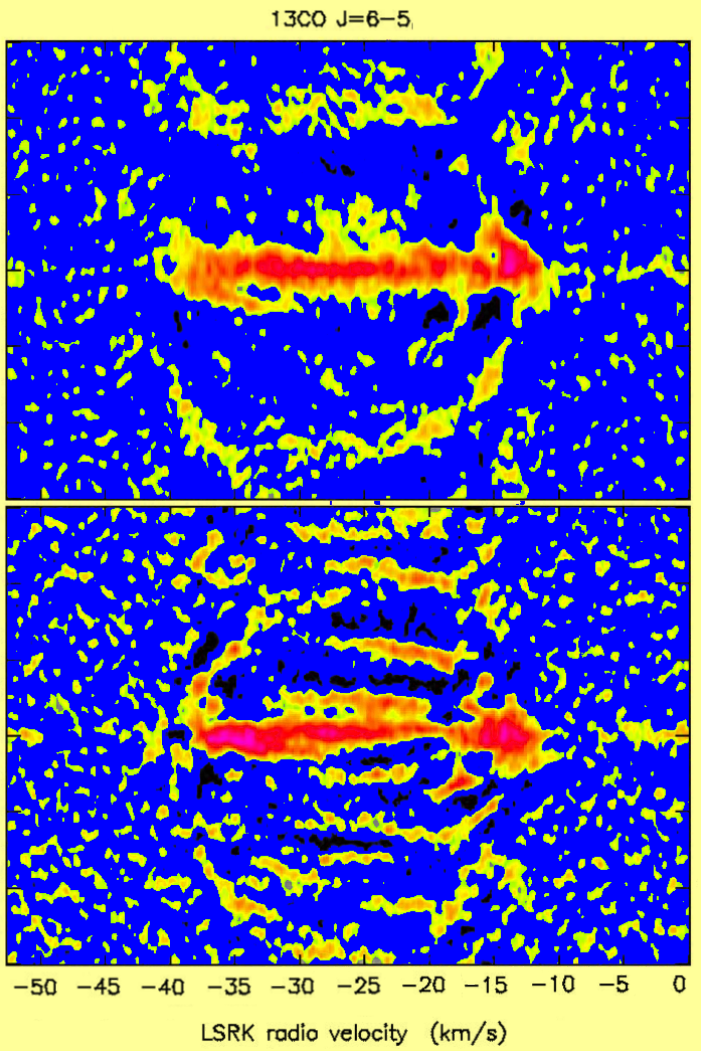


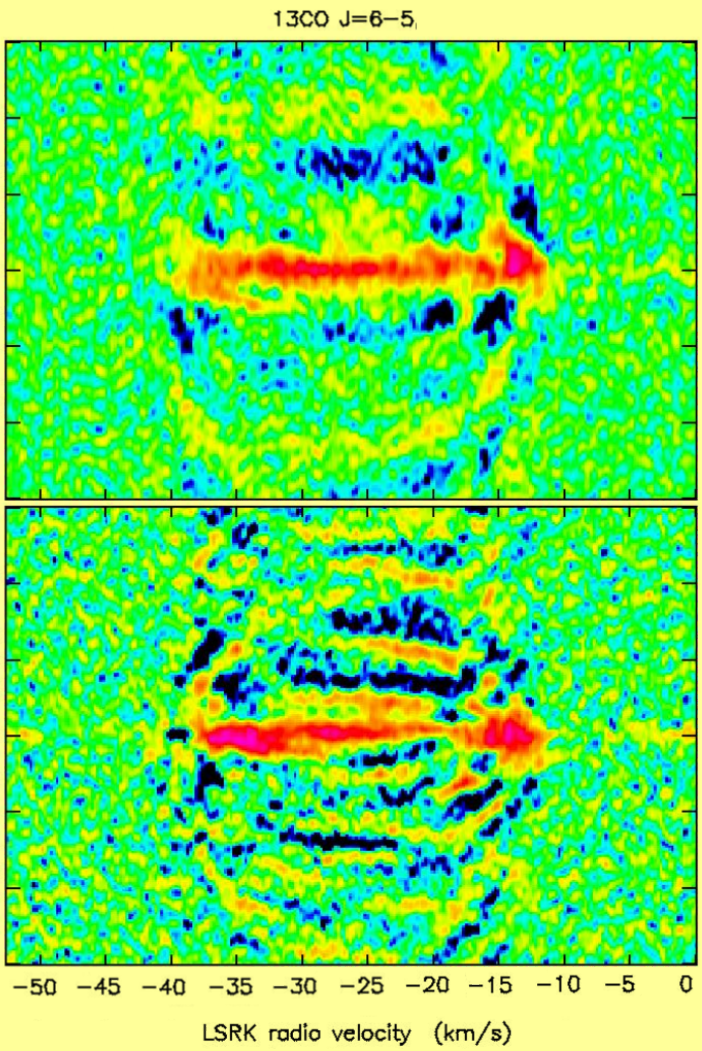
velocity



Decin et al. 2015

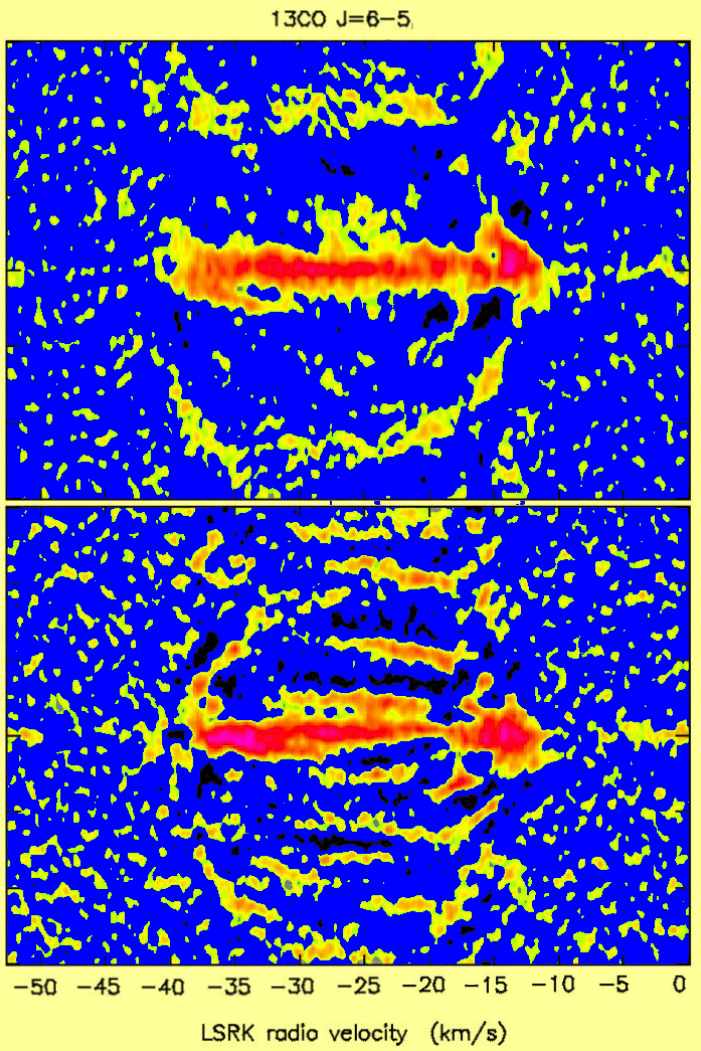
Back to CW Leo

Orthogonal wide-slit PV diagrams



i = 72°

velocity



Decin et al. 2015

Final remarks

Modelling
Emission

- Mass loss rate
- Density contrast
- Temperature
- Velocity
- Morphology

Final remarks

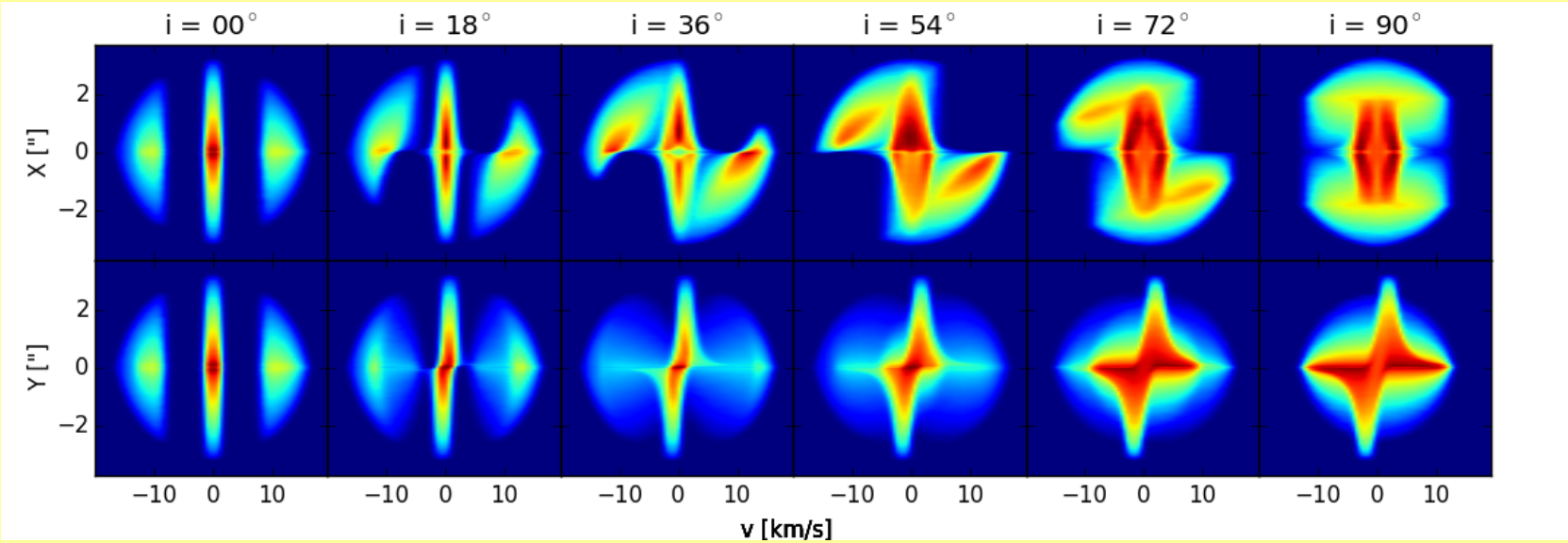
Modelling
Emission

- Mass loss rate
- Density contrast
- Temperature
- Velocity
- Morphology

Other morphologies
in the pipeline:

- Kepkerian Disk (in prep.)
- Clumps
- Hourglass

Thank you for your attention



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