Circumbinary structure with the binary accretion models

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Topic:
✓ Asymmetry of circumbinary disks
Introduction: Young binary stars

• Observations
  – Recent high-resolution observations
    • Reveal circumbinary structures, Takakuwa+ 14, Dutrey+ 15
  – Asymmetry in circumbinary disks
    • Protobinary L1551 NE … Takakuwa+ 14
    • T Tauri binary UY Aur …. Tang+ 14, Hioki+ 07

• Simulations
  – Requirement of high-resolution simulations
    • for comparison with high-resolution observations
  – Origin of asymmetry in CBD is unknown.
    • Eccentricity…. Dunhill+ 15
    • Only a few works exist.
Observed asymmetry in CBDS

L1551 NE (Takakuwa+ 14)
ALMA Cycle-0

UY Aur (Tang+ 14, Hioki+ 07)
SUBARU H-band

(a) Contour: 1.3 mm continuum

extended armlike structure

circumstellar material

Color: H band scatter light

Notes.

Flux Densities toward UY Aur A and B

<table>
<thead>
<tr>
<th>λ (mm)</th>
<th>S_ν (mJy)</th>
<th>S_ν (mJy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.03</td>
<td>0.11</td>
</tr>
<tr>
<td>1.4</td>
<td>0.09</td>
<td>6.81</td>
</tr>
<tr>
<td>2</td>
<td>0.66</td>
<td>18.27</td>
</tr>
</tbody>
</table>

References.

→ Tang et al. (1998). We derive spectra linear index 2.2 ± 0.1.

→ Tang+ 14, 2007. S_ν ∼ 0.12 ± 0.03.

→ Contreras & Wilkin (2014). The crosses mark the locations of UY Aur A labeled as NIR 1 component by Hioki et al. (2007). The gray triangle marks the SO southeast peak (see Section 2.2.4). The white square marks the peak at 2.1 pc mas intensity of the disk with a major axis of 0.013 at P.A. 0°. If we allow the orbit to be elliptical, it is consistent with the stellar location of the binary. At 6 cm, we discuss in Contreras & Wilkin (2014). UY Aur A (UY Aur A (Tang+ 14, Hioki+ 07) is no emission detected within the field of view, suggesting an extended continuum emission at 3 mm in black contours at 1, 5, 10, 20, 30, and 40 log S_ν. After removing two Gaussian fits at UY Aur A and B, the best-fit major axis of 0.013 at P.A. 135° is presented by fitting a linear slope in the deprojected separation, the best-fit deconvolved size of 2.1 pc mas, UY Aur A looks slightly more extended (0.013). This separation can be compared to the optical measurements reported over the last decades (see Table 3). This separation can be compared to the optical measurements reported over the last decades (see Table 3).
Numerical Method

SFUMATO AMR code

 Isothermal gas
 Non-selfgravity
 Circular binary orbit
 Long time calculations (~100 rev)
Usage of ATERUI

• Category: XC-B+

• Parallel computing
  – 1024 cores (large-B+ queue), 20 jobs/model
  – 288 cores (Bulk-B+ queue), 70 jobs/model
  – ~ 20 models in total

• Publications
  – Submit soon (cloud core collapse)
  – Writing (this work)
  – Development (Heliosphere)
Results: a standard model

- Mass ratio $q = 0.2,$
- Sound speed $c = 0.1,$
- AM of infalling gas $\dot{j}_{\text{inf}} = 1.2,$
- Injection rate of gas $f_{\text{inf}} = 1.0$
Non-axisymmetric pattern 1 rev. when binary stars 4 rev (commensurability)

50 - 54 revolutions

$r = 2$

$dr = 0.2$

Surface density in the ring
Non-axisymmetric pattern @ $r = 2$ : $\Omega = 1$, $\Omega = 1/4$

**Resonance**

$\Omega_{\text{disk pattern}} : \Omega_{\text{binary}} = 1 : 4$

Angular velocity of binary = 1

Surface density

Time

Azimuthal angle

$\phi$ (deg)
A high temperature model shows slow a rotation of asymmetric pattern.
Angular velocity of pattern $\Omega_p$ vs sound speed

$\Omega_p = \Omega_*, 1.25\Omega_*$,

$\Omega_p = \Omega_*/2$

$\Omega_p = \Omega_*/3$

$\Omega_p = \Omega_*/4$

$\Omega_p = \Omega_*/5$

$\Omega_p = \Omega_*/10$

AV of pattern / AV of binary

$\Omega_p / \Omega_*$

sound speed / orbital speed

Resonance

$\Omega_*$ = 0.4

$1.5c$
Radial oscillation of CBD

$r = 6$

8周（共鳴周期の倍音）

$r = 4$

$r = 2$

0.8周

azimuthally mean surface density

revolution

time

Σ at $r = 6$

Σ at $r = 4$

Σ at $r = 2$
Comparison of resonance radii

$c = 0.1$ (low temp)
$\Omega = 1/4$
$r_{res} = 2.52$

c = 0.2 (high temp)
$\Omega = 1/10$
$r_{res} = 4.64$
Dependence on angular momentum $j_{\text{inf}}$

Rotation of asymmetry is roughly independent of AM

Low AM

- $j_{\text{inf}} = 0.9$
- $\Omega = 1$
- $\Omega = 1/4$

- $j_{\text{inf}} = 1.2$
- $\Omega = 1$
- $\Omega = 1/4$

- $j_{\text{inf}} = 2$
- $\Omega = 1, 1/4$ @ $r = 2$

- $j_{\text{inf}} = 2$
- $\Omega = 1, 1/4$ @ $r = 2$

- $j_{\text{inf}} = 2$
- $\Omega = 1/10, 1/32$ @ $r = 6$
Dependence on mass ratio $q$

Rotation of asymmetry is independent of mass ratio.

Contrast bw masses

$q = 0.5$
$\Omega = 1$
$\Omega = 1/4$

$q = 0.7$
$\Omega = 1$
$\Omega = 1/4$

$q = 1$
$\Omega = 1$
$\Omega = 1/4$
Summary

• Structures of CBDs are investigated by using 3D AMR.

• Rotation of asymmetric pattern:
  – Depends on temperature of gas
    • A low temp model shows fast rotation and high amplitude.
  – Independent of mass ratio q
  – Independent of angular momentum of gas $j_{\text{inf}}$

• Discussion:
  – Asymmetry of CBDs are common in low temp gas.
  – Planet formation in CBDs are affected by the asymmetric phenomenon.
• Extension to MHD models
  – They will reproduce:
    • outflows from binary stars
    • MRI in circumbinary disks

  – Investigate the effects of B-fields on:
    • accretion rates onto binary stars
    • asymmetry in circumbinary disks
A modeling of the Heliosphere
3D views

(100 Rs)^3 = (0.47 AU)^3

(200 Rs) = (0.93 AU)^3

Color .... Vr in the midplane (velocity of the solar wind)
Contour ..... B_phi = 0  (current sheet)
3D views

(1.9 AU)^3

(3.7 AU)^3

Color .... Vr in the midplane
Contour ..... B_phi = 0
3D views

(7.4 AU)^3

(14.9 AU)^3

Color .... Vr in the midplane
Contour ..... B_phi = 0
3D views

(29.8 AU)^3

(59.5 AU)^3

Color .... Vr in the midplane
Contour ..... B_phi = 0
3D views

(119 AU)^3

(238 AU)^3

Color .... Vr in the midplane
Contour ..... B_phi = 0