Young Stellar Objects: The Inner AU

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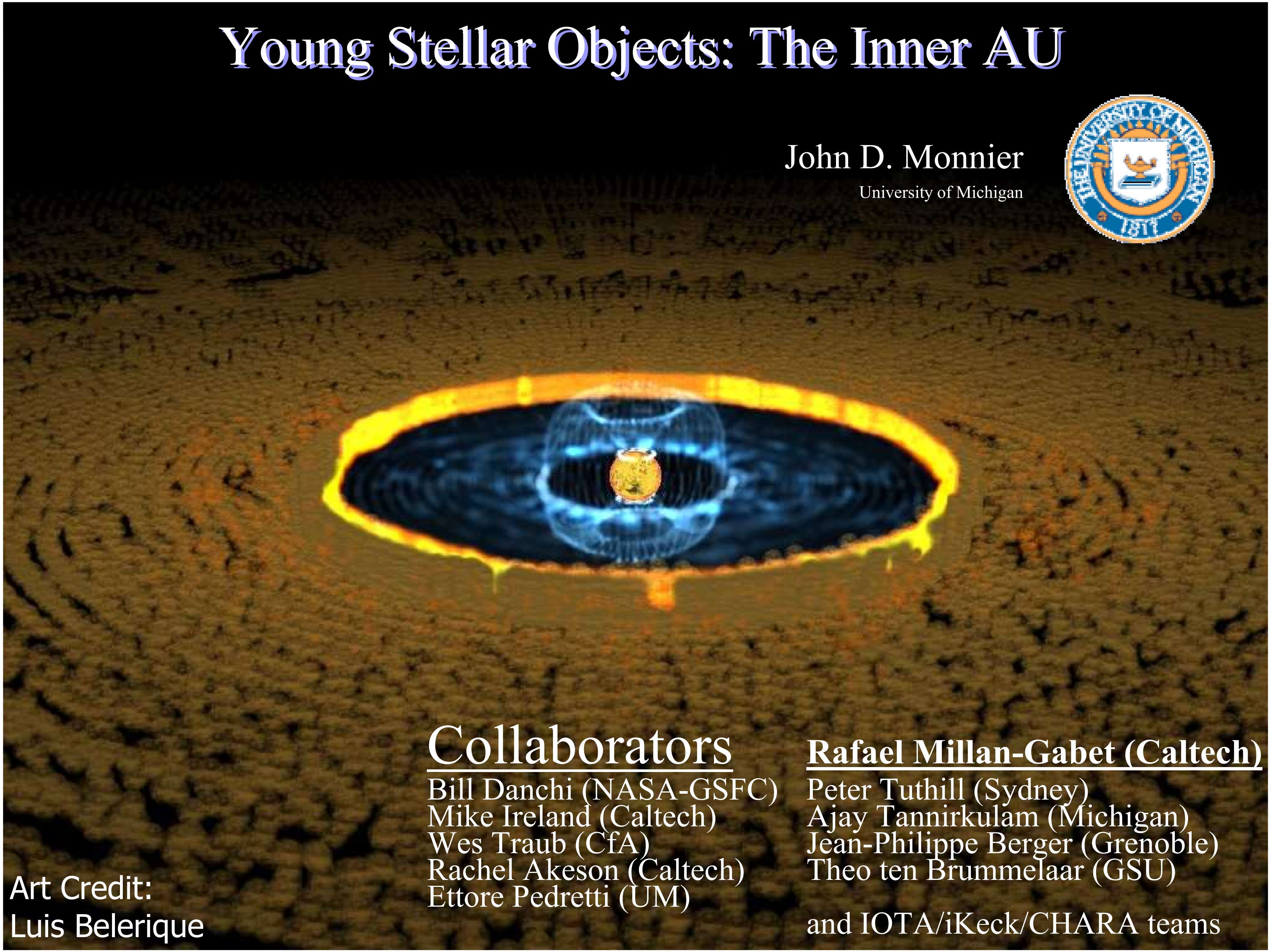

Collaborators

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Wes Traub (CfA)
Rachel Akeson (Caltech)
Ettore Pedretti (UM)
Peter Tuthill (Sydney)
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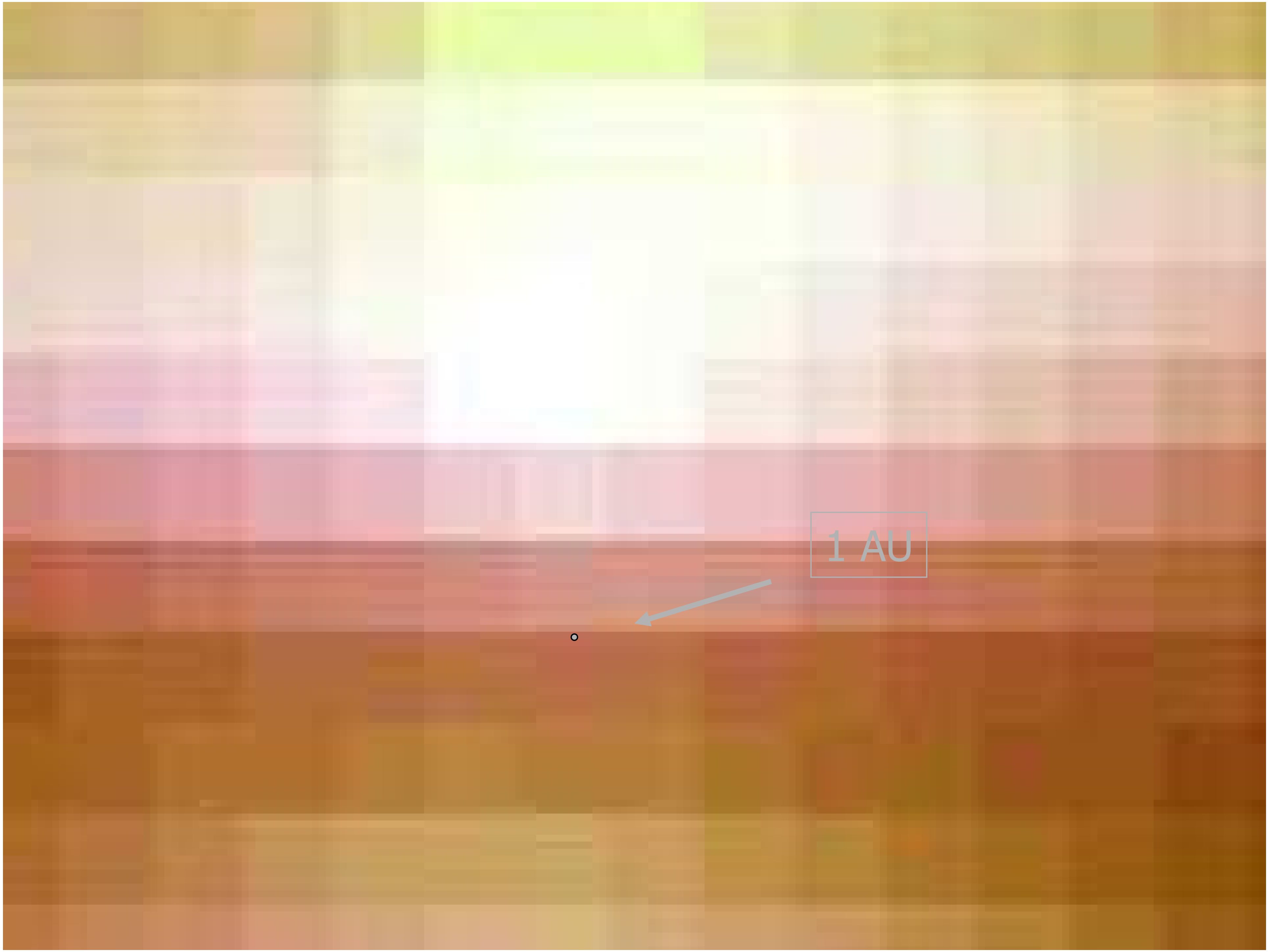
Jean-Philippe Berger (Grenoble)
Theo ten Brummelaar (GSU)

and IOTA/iKeck/CHARA teams

Art Credit:
Luis Belerique


1 AU

Young Stellar Objects (Near-IR)

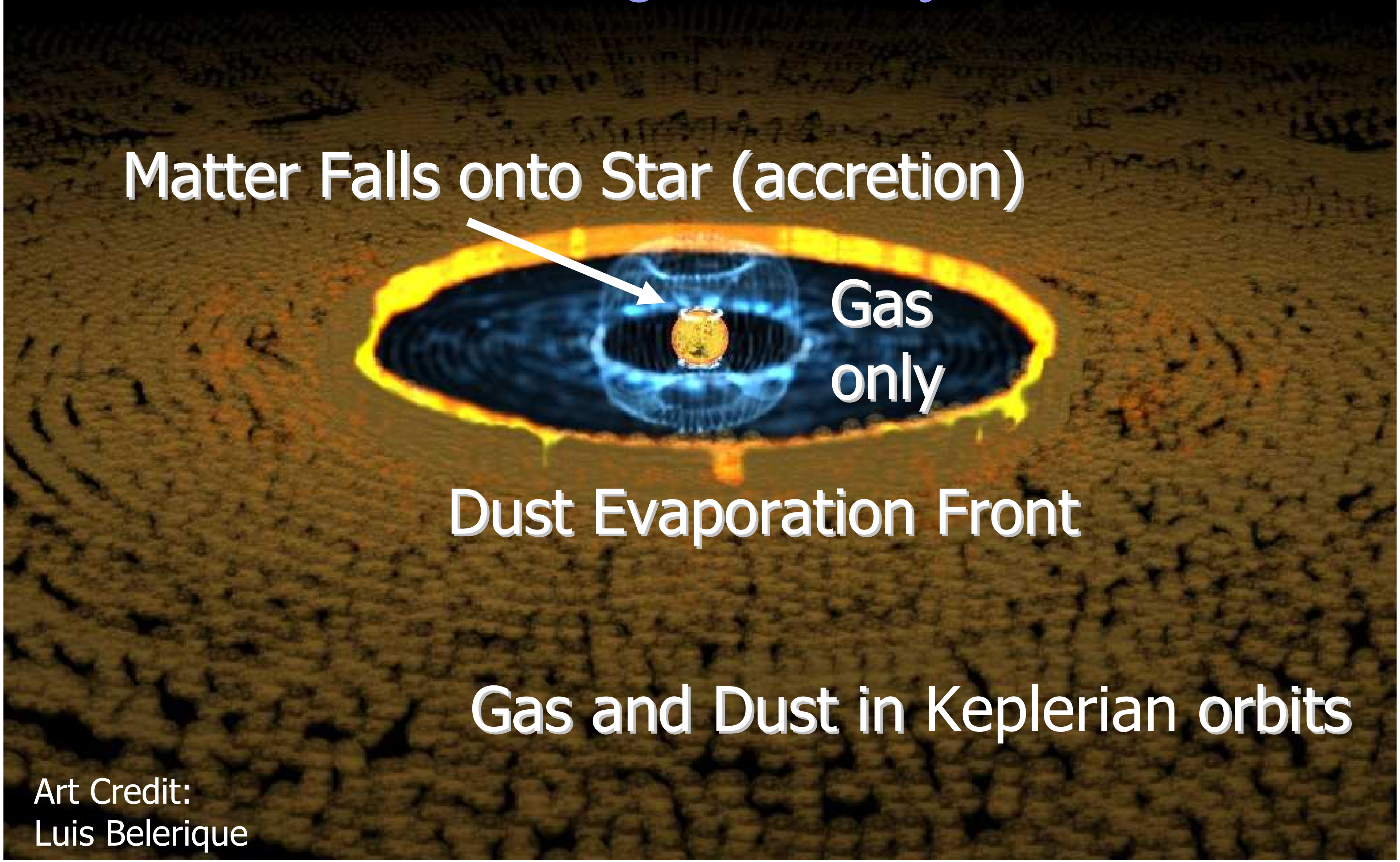
In the early 1990s, our story begins with the progenitors of intermediate-mass stars:

the Herbig Ae/Be stars

- The higher-mass counterparts to *T Tauri stars* (solar-type progenitors)
- T Tauri disks were relatively "well understood"
  - Geometrically thin
  - Optically thick
  - Possible Accretion Luminosity

Physical Process: thermal emission from hot dust accreting onto young stars

Standard Disk Model for Young Stellar Object



Art Credit:
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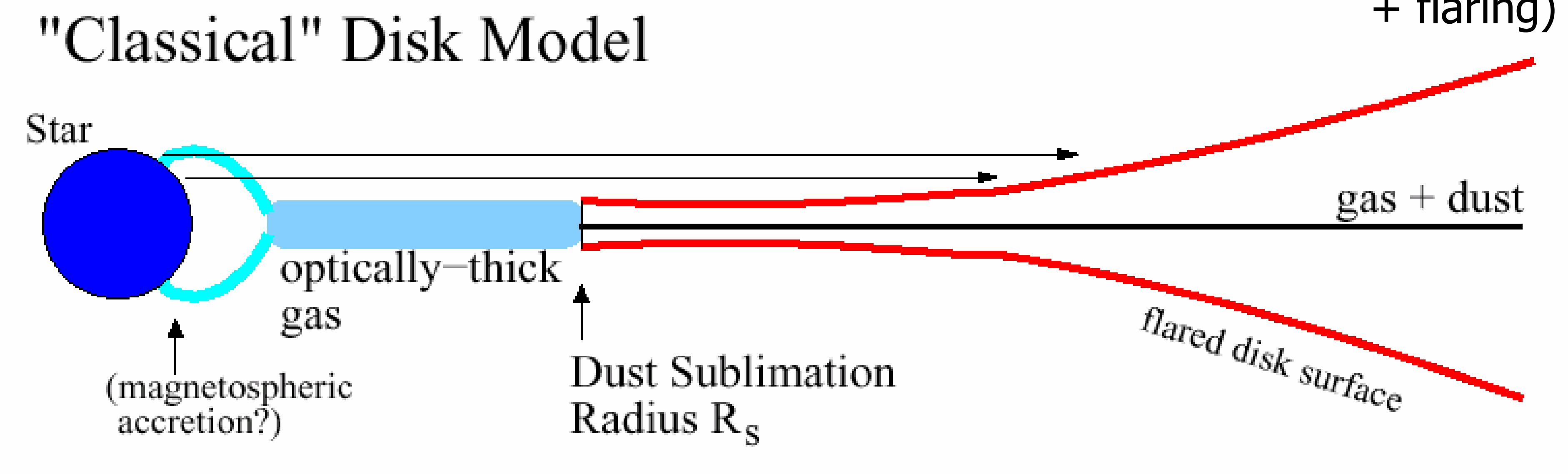
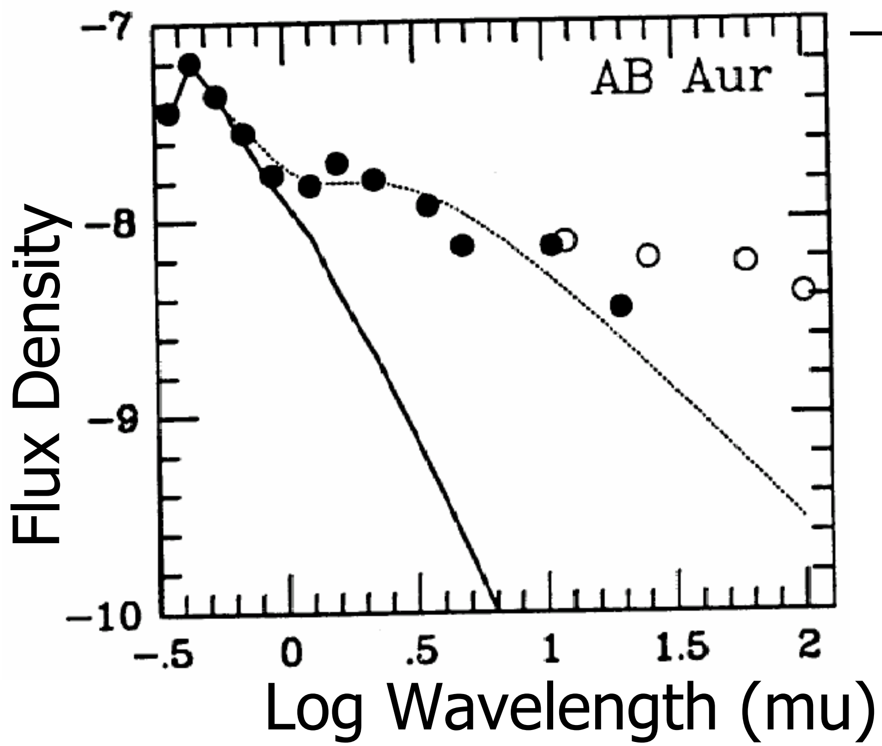
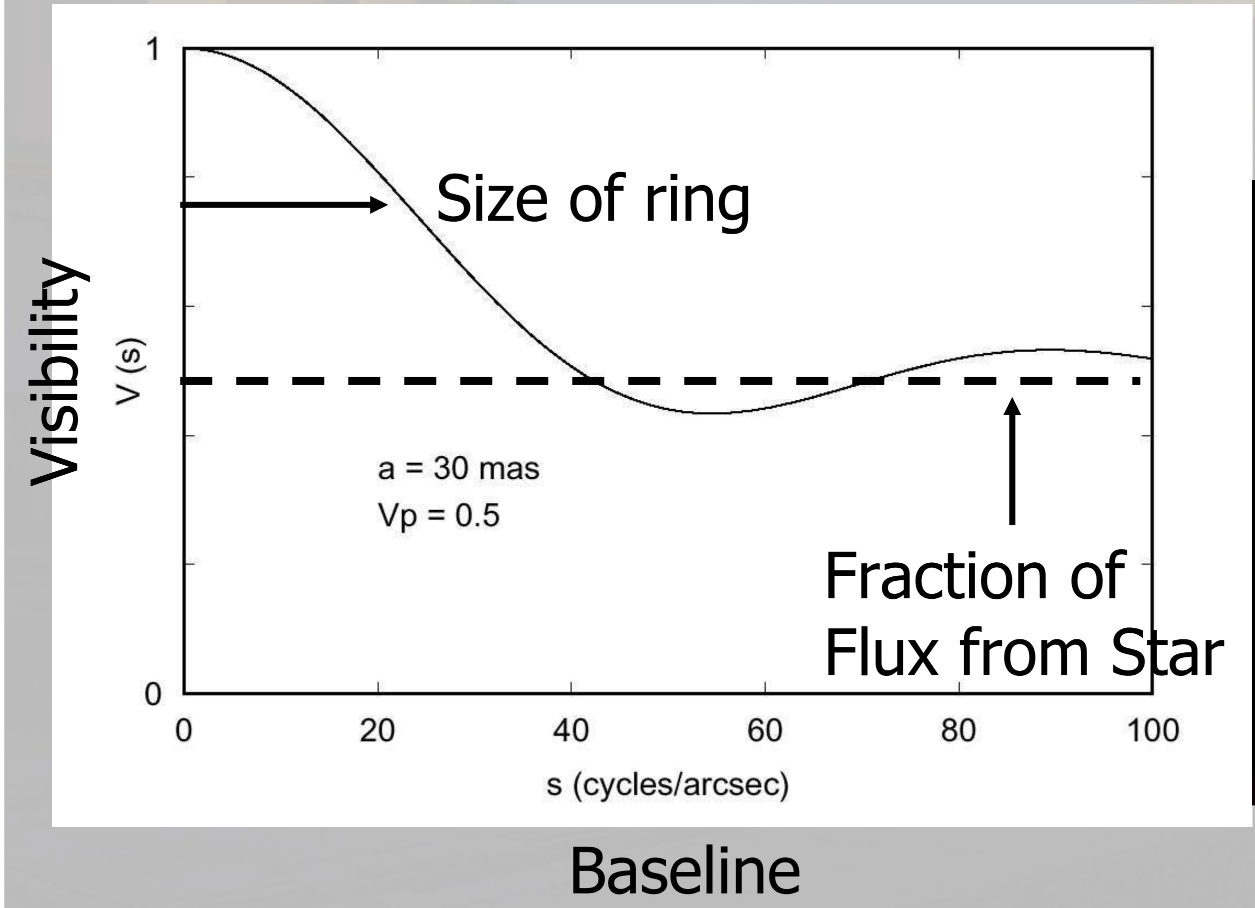
(e.g., Hillenbrand et al. 1992
+ flaring)

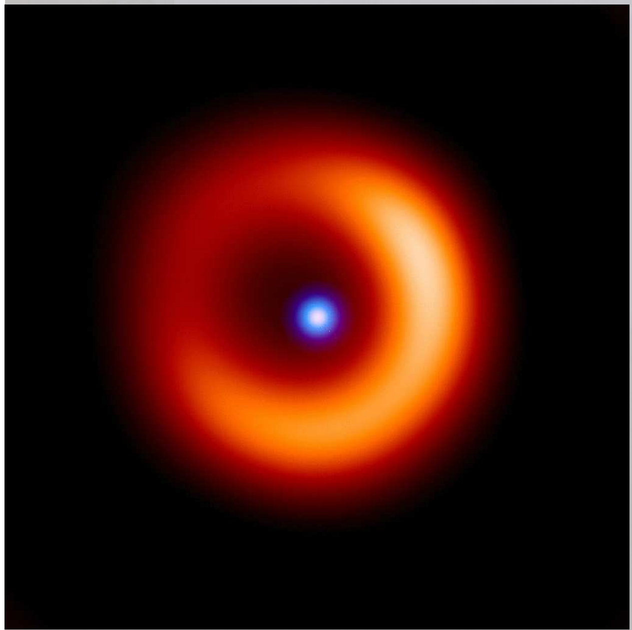




- Hillenbrand et al. 1992
  - Re-processed radiation + accretion luminosity
  - Temp: $T \propto r^{-\frac{3}{4}}$
  - Central hole with no dust
- SED fits were ok
  - Required (too) high accretion rates (Hartmann)
  - Other models possible ("halos")

Visibility: Star + Dust Shell





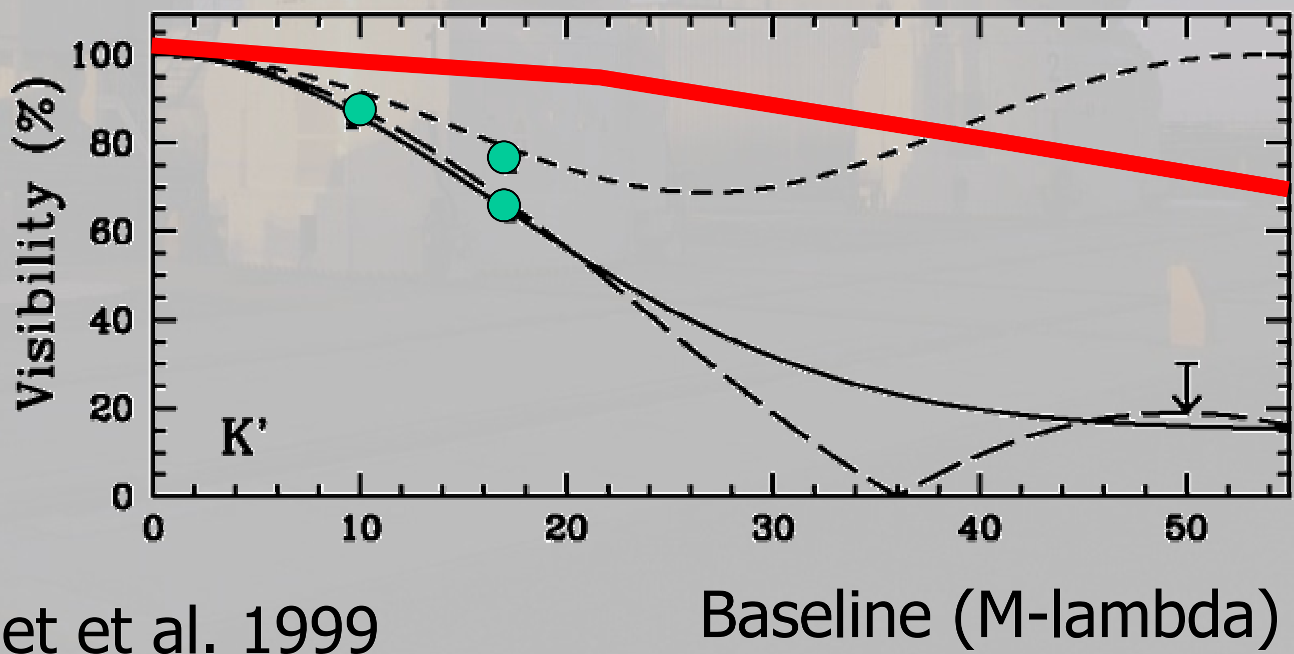
The IOTA Interferometer located on Mt. Hopkins, AZ

- Mainly developed by Smithsonian Astrophysical Observatory (Traub, Carleton, Papaliolios, Monnier, Berger, Pedretti,…) and Univ. of Massachusetts (Schloerb, Millan-Gabet)

- Initial Capabilities: 2 movable 40-cm telescopes with maximum 38-m separation (~8 milliarcsecond resolution in near-IR)

Surprise: The disk around AB Aurigae TOO BIG!

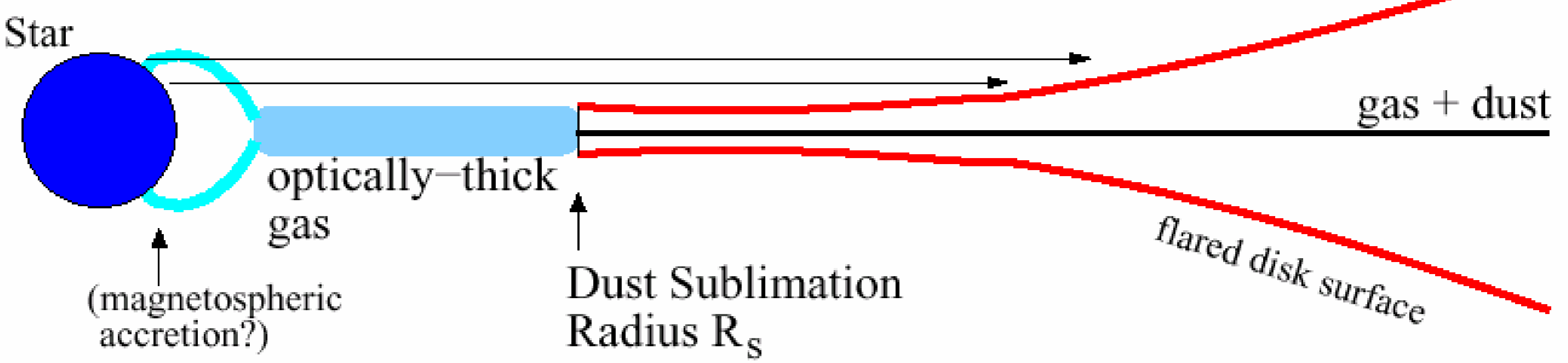
"Classic" accretion disk model, used for SED fitting, is <u>RULED OUT</u> by IOTA!



Millan-Gabet et al. 1999

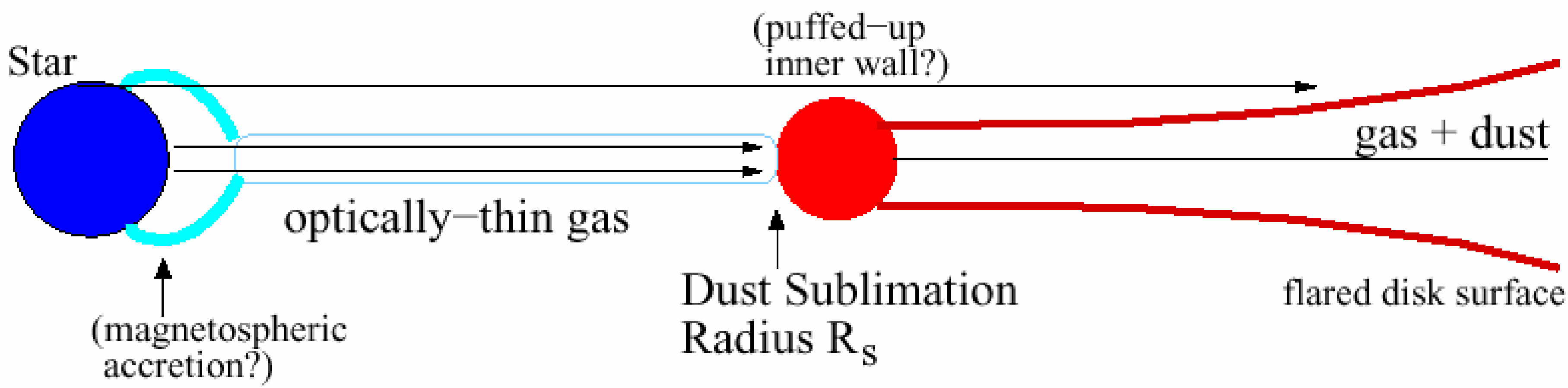
(e.g., Hillenbrand et al. 1992
+ flaring)

"Classical" Disk Model



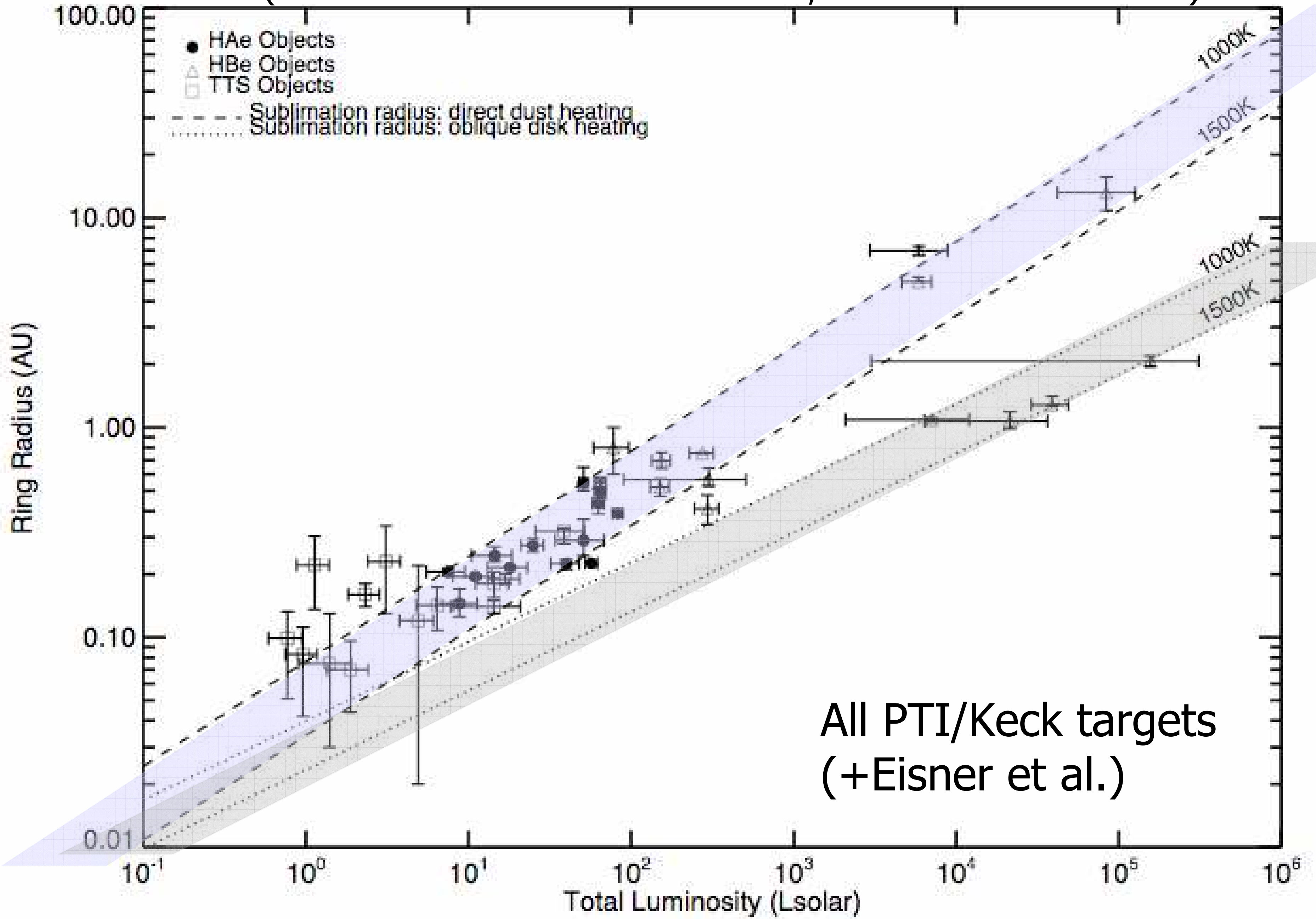
(e.g., Tuthill et al 2001;
Natta et al. 2001)

"Optically−thin Cavity" Disk Model



Comprehensive Size-Luminosity Plot

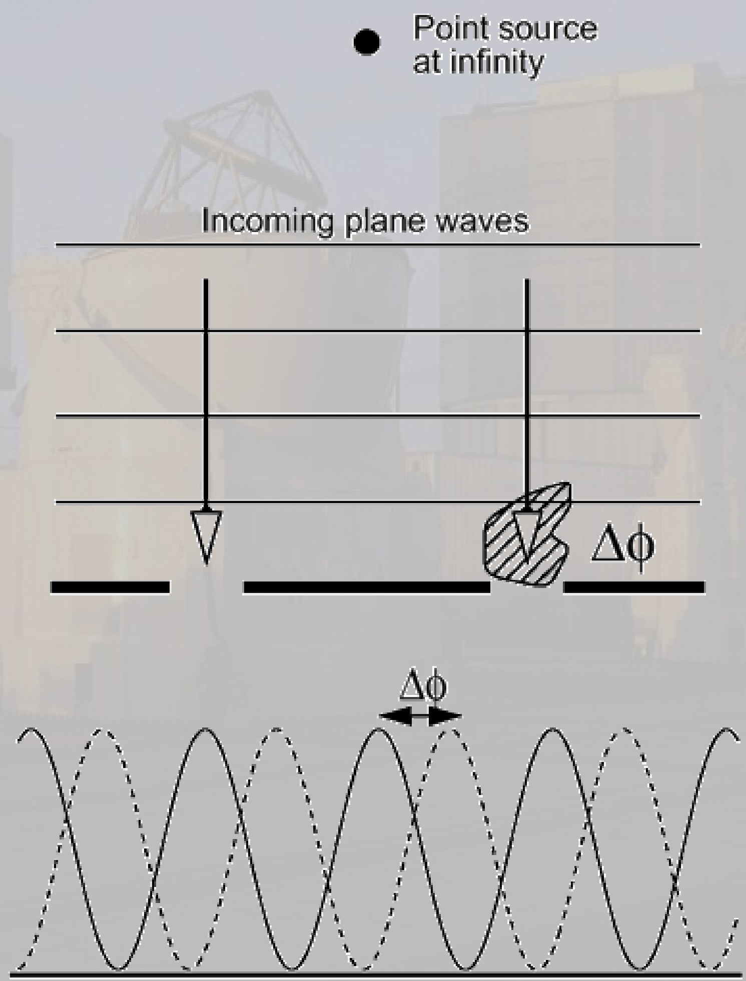
(from Protostars & Planets V Review, Millan-Gabet et al. 2006)



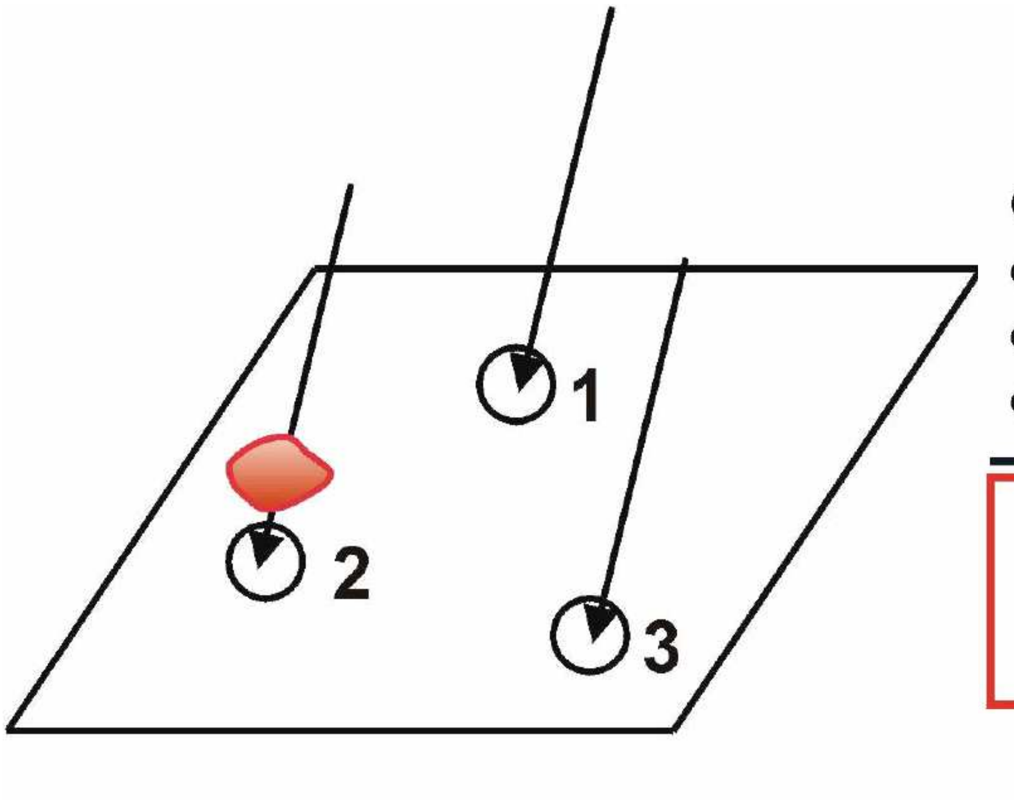
All PTI/Keck targets
(+Eisner et al.)

Towards Imaging:
Closure Phases with IOTA3

Atmosphere Corrupts the Phase, but…



The "Closure Phase" Is Not Corrupted



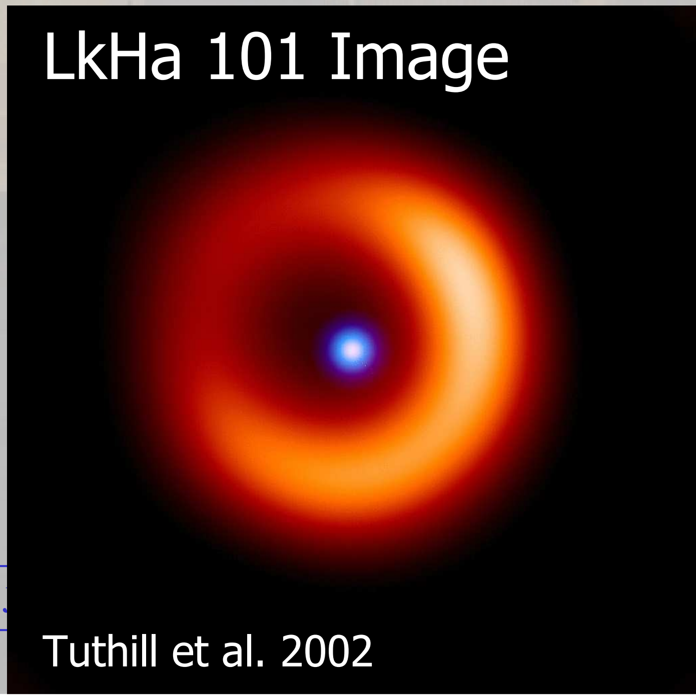
Observed		Intrinsic		Atmosphere
$\Phi(1\text{-}2)$	=	$\Phi_o(1\text{-}2)$	+	$[\phi(2)-\phi(1)]$
$\Phi(2\text{-}3)$	=	$\Phi_o(2\text{-}3)$	+	$[\phi(3)-\phi(2)]$
$\Phi(3\text{-}1)$	=	$\Phi_o(3\text{-}1)$	+	$[\phi(1)-\phi(3)]$

Closure Phase (1-2-3) $= \Phi_o(1\text{-}2)+\Phi_o(2\text{-}3)+\Phi_o(3\text{-}1)$

Expected Closure Phases for YSOs

Closure Phase is function of

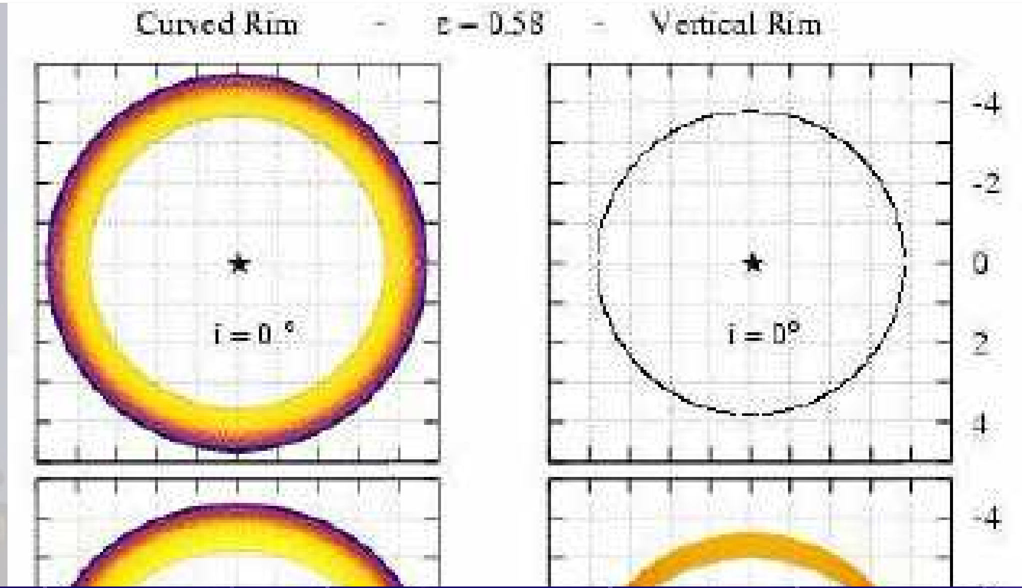
- Amount of **skewness** (deviation from centro-symmetry)
- Resolution of Interferometer (point sources all look symmetrical..)
- Brightness distribution (model-dependent = good)

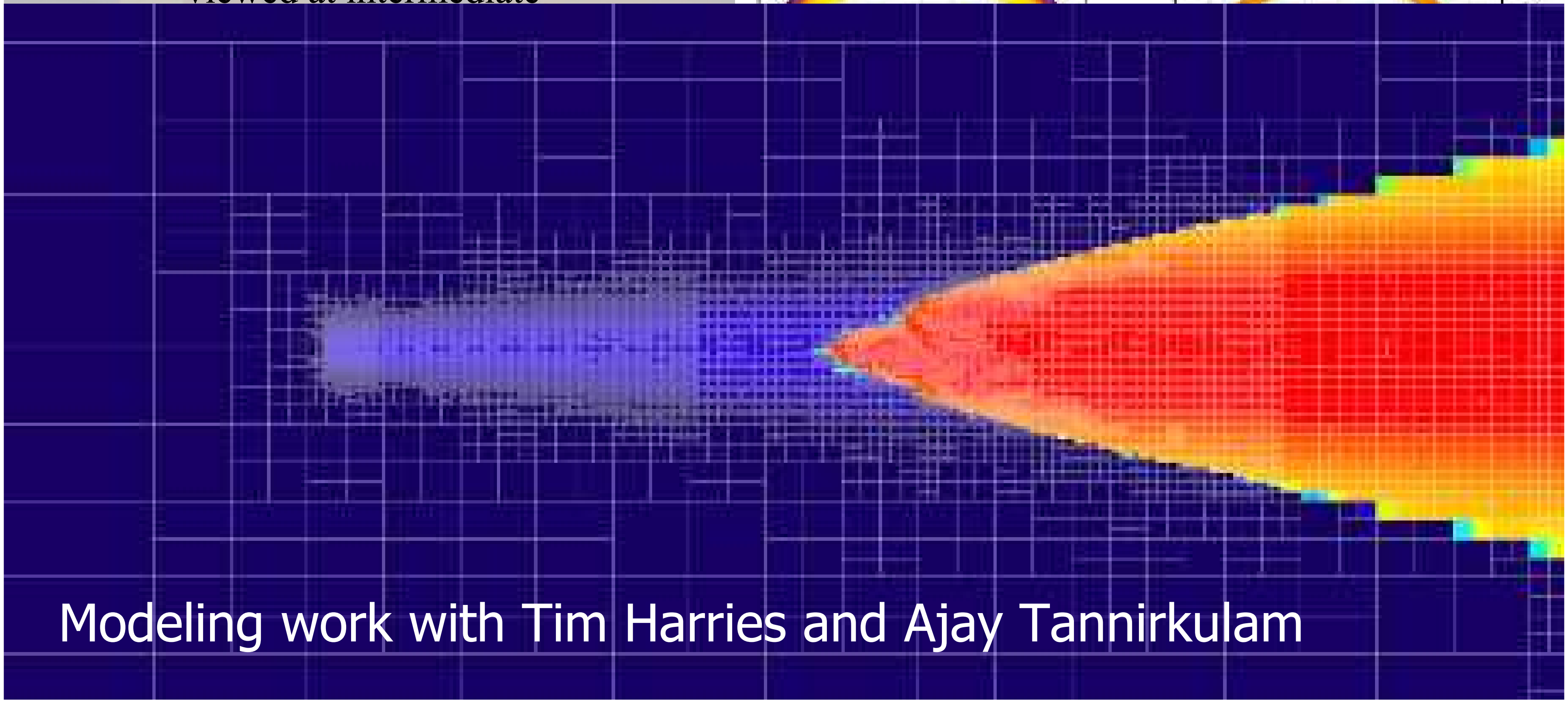


Why should we expect skew?

1st Gen models have vertical walls

– Highly skewed when viewed at intermediate





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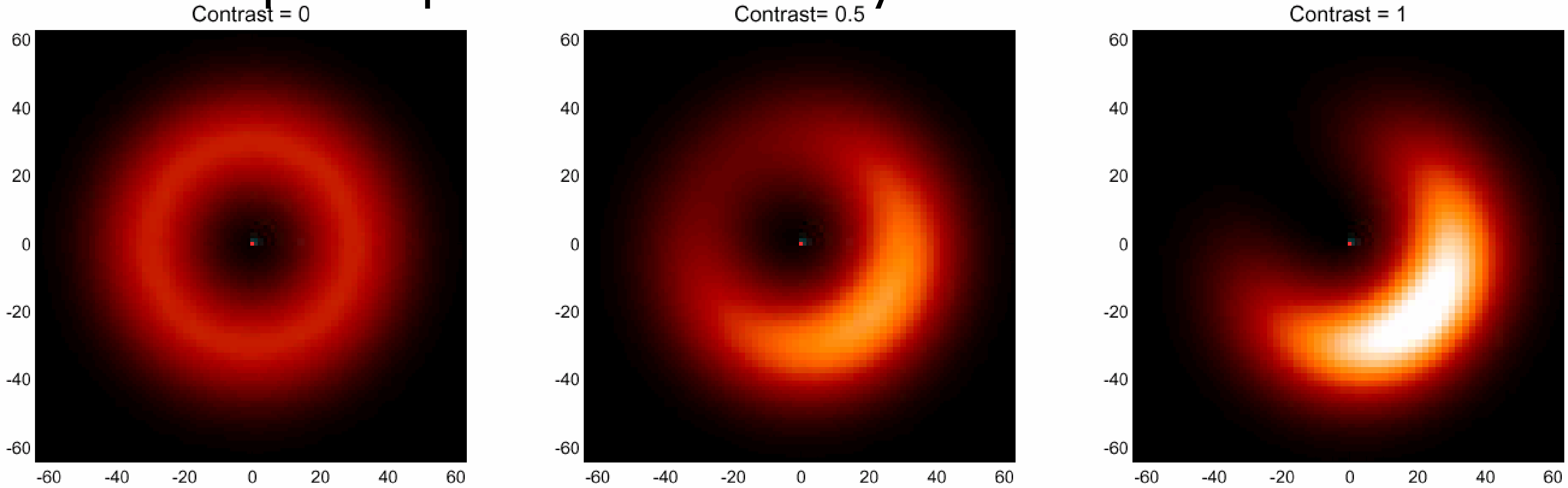
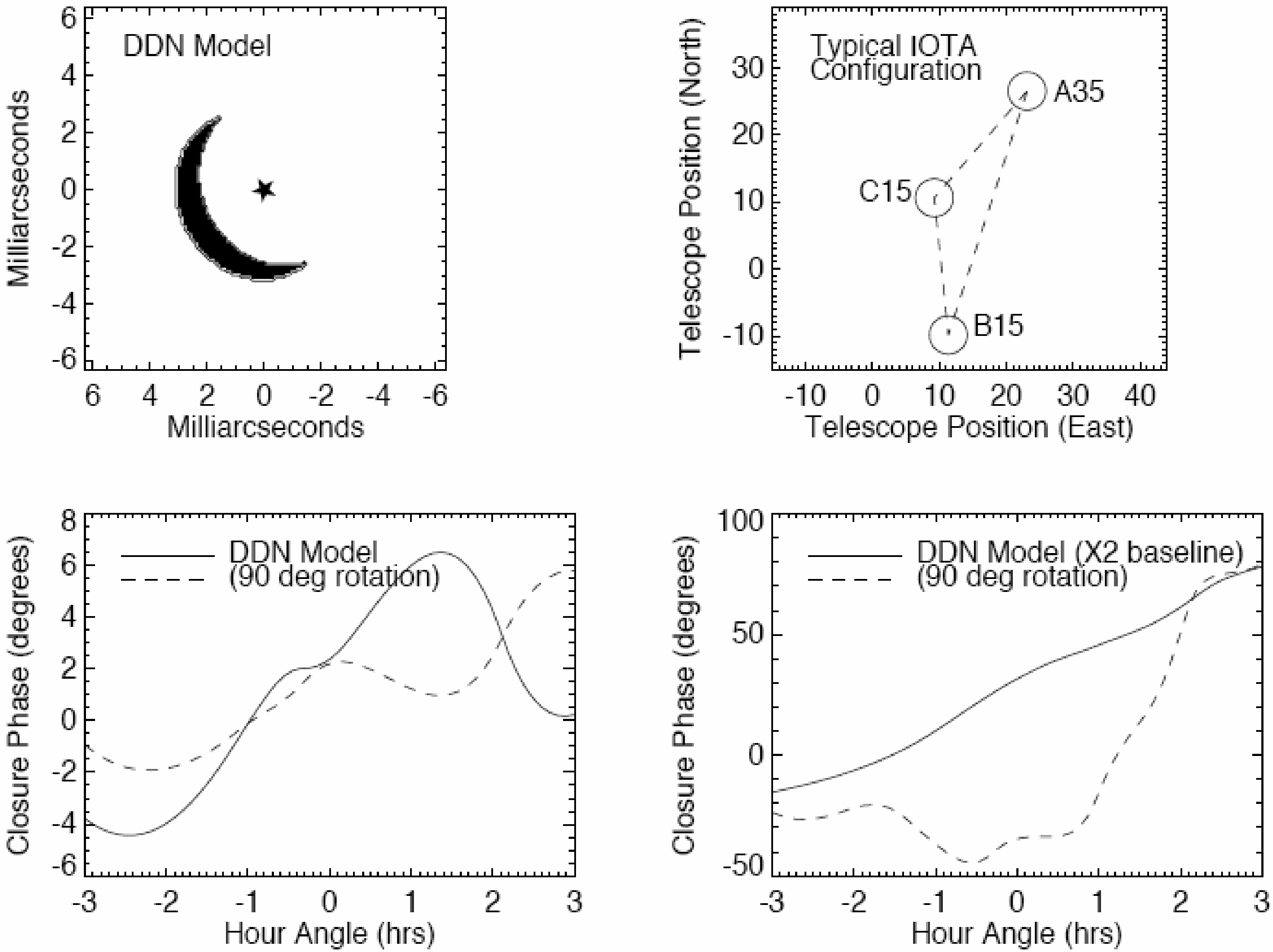
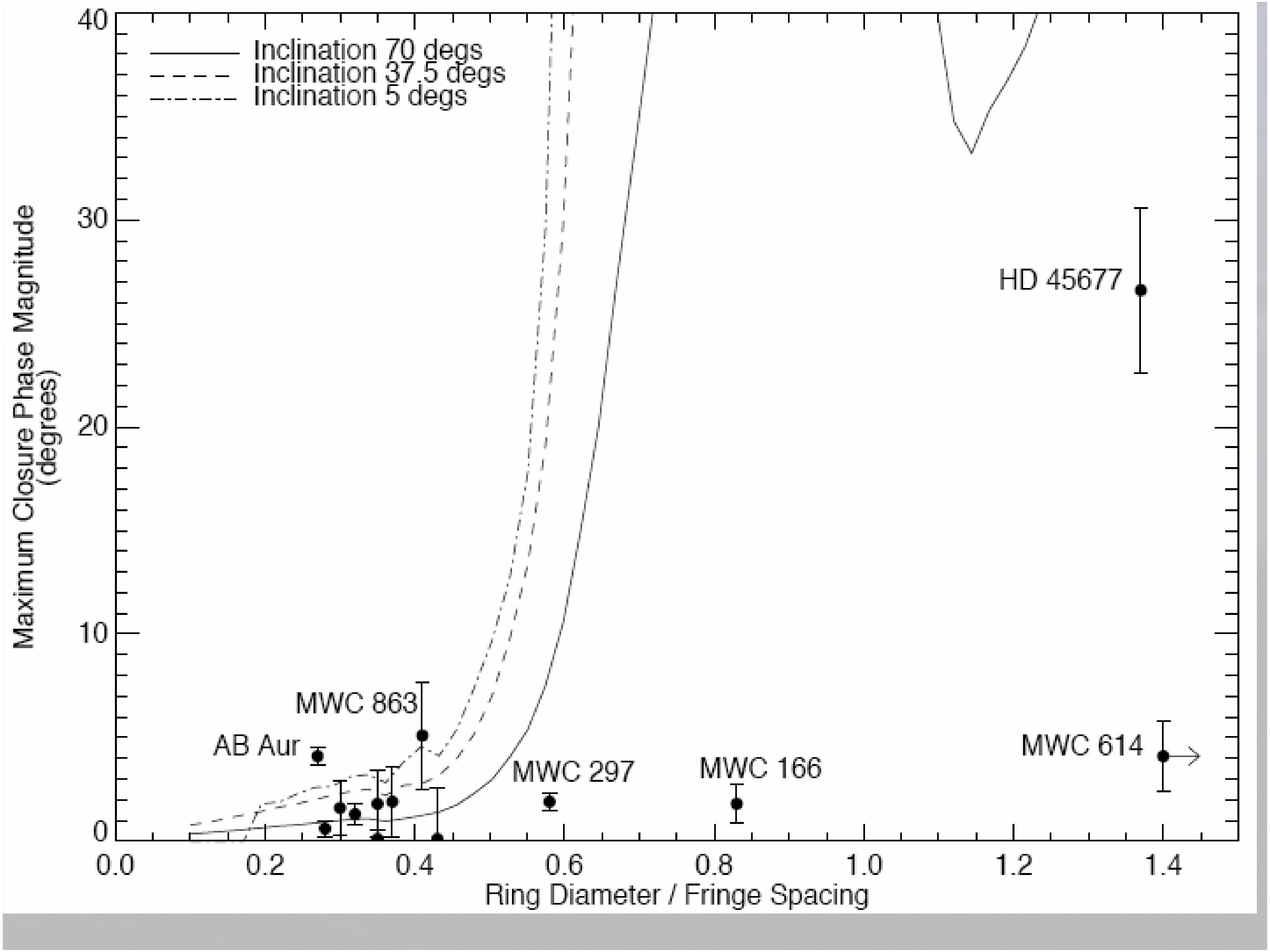
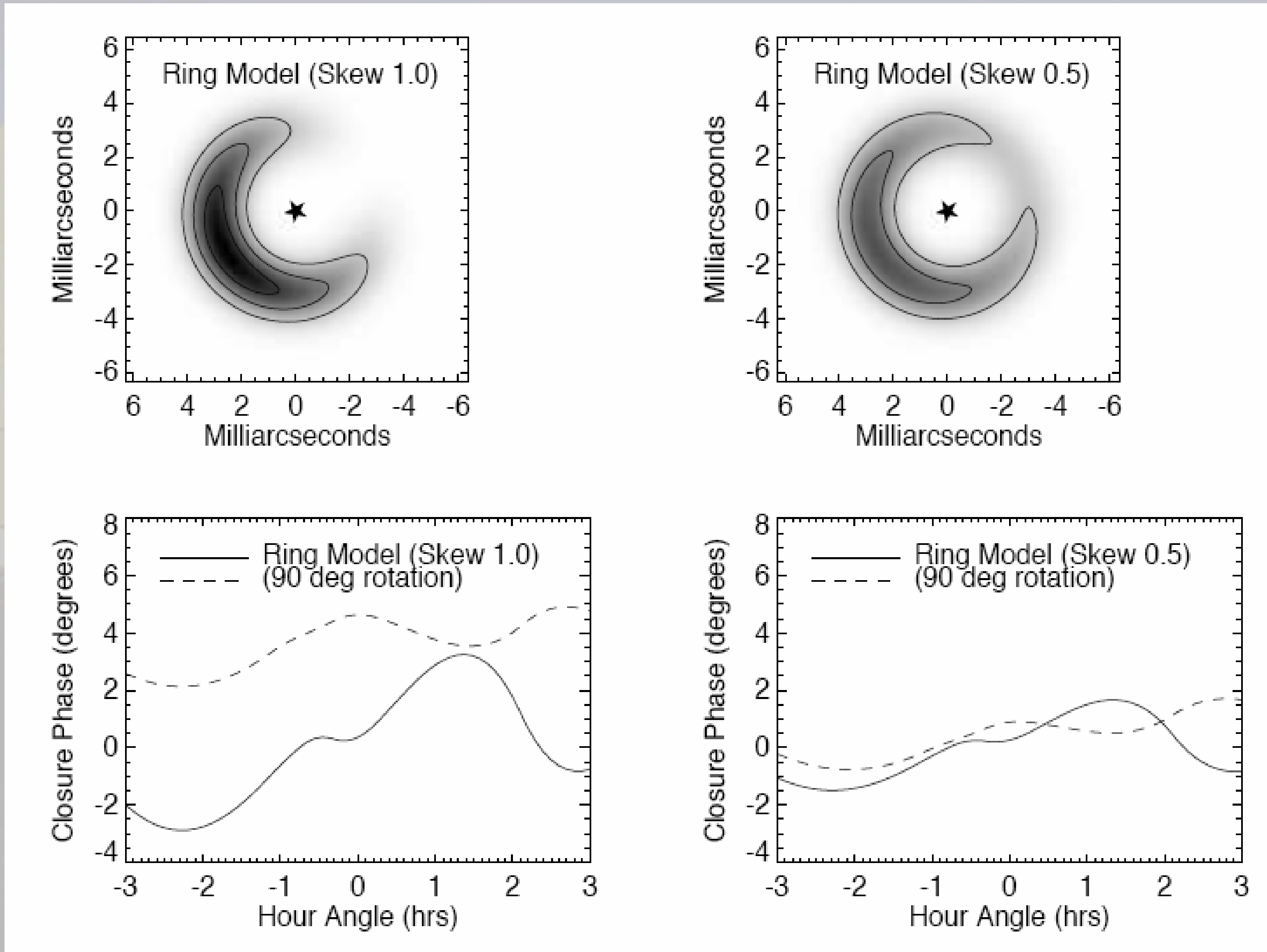
Simple Empirical Models of Asymmetric Disk Emission

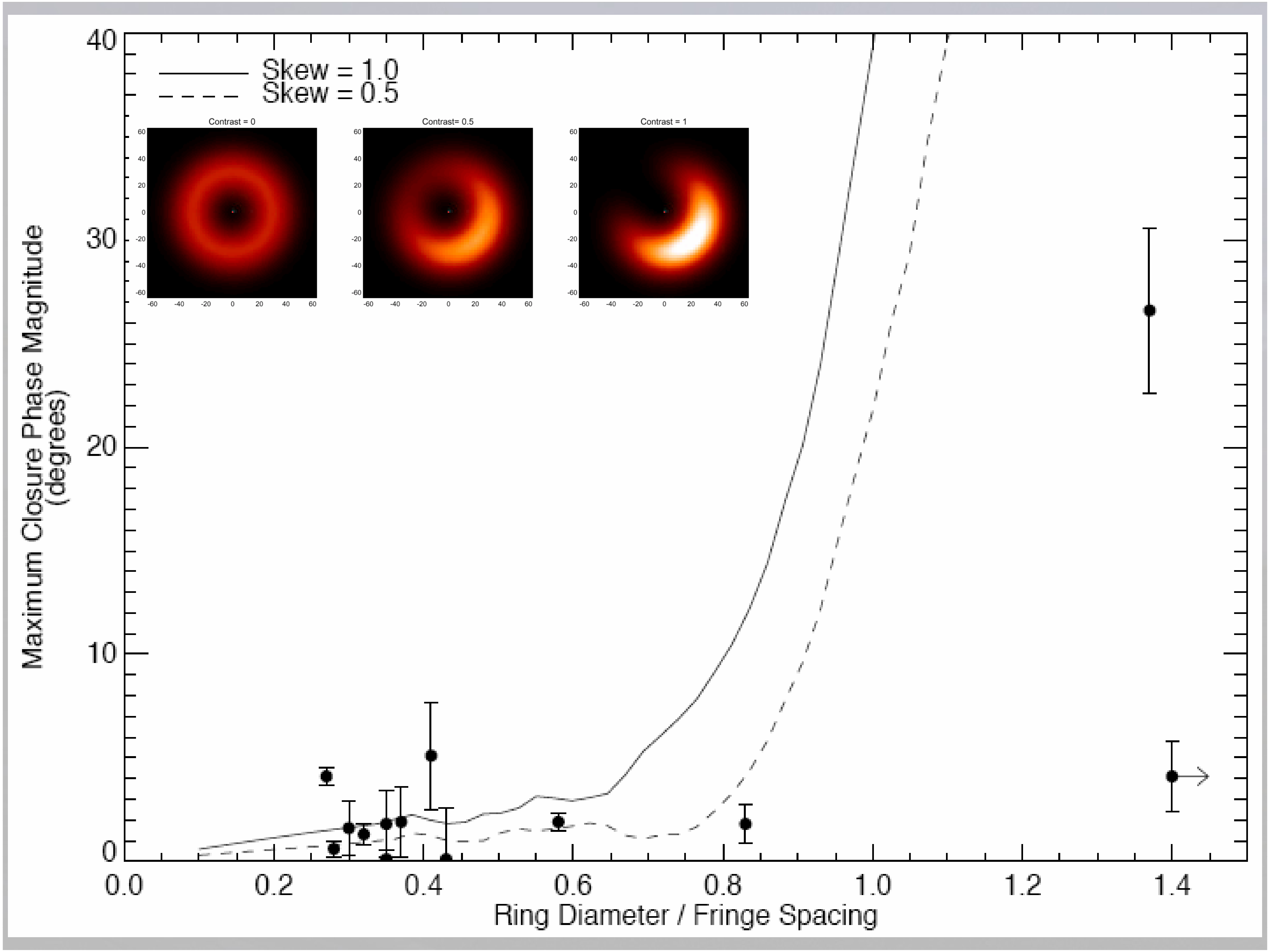



DDN Model
Milliarcseconds
Milliarcseconds
Typical IOTA Configuration
A35
C15
B15
Telescope Position (North)
Telescope Position (East)
DDN Model
(90 deg rotation)
Closure Phase (degrees)
Hour Angle (hrs)
DDN Model (X2 baseline)
(90 deg rotation)
Closure Phase (degrees)
Hour Angle (hrs)



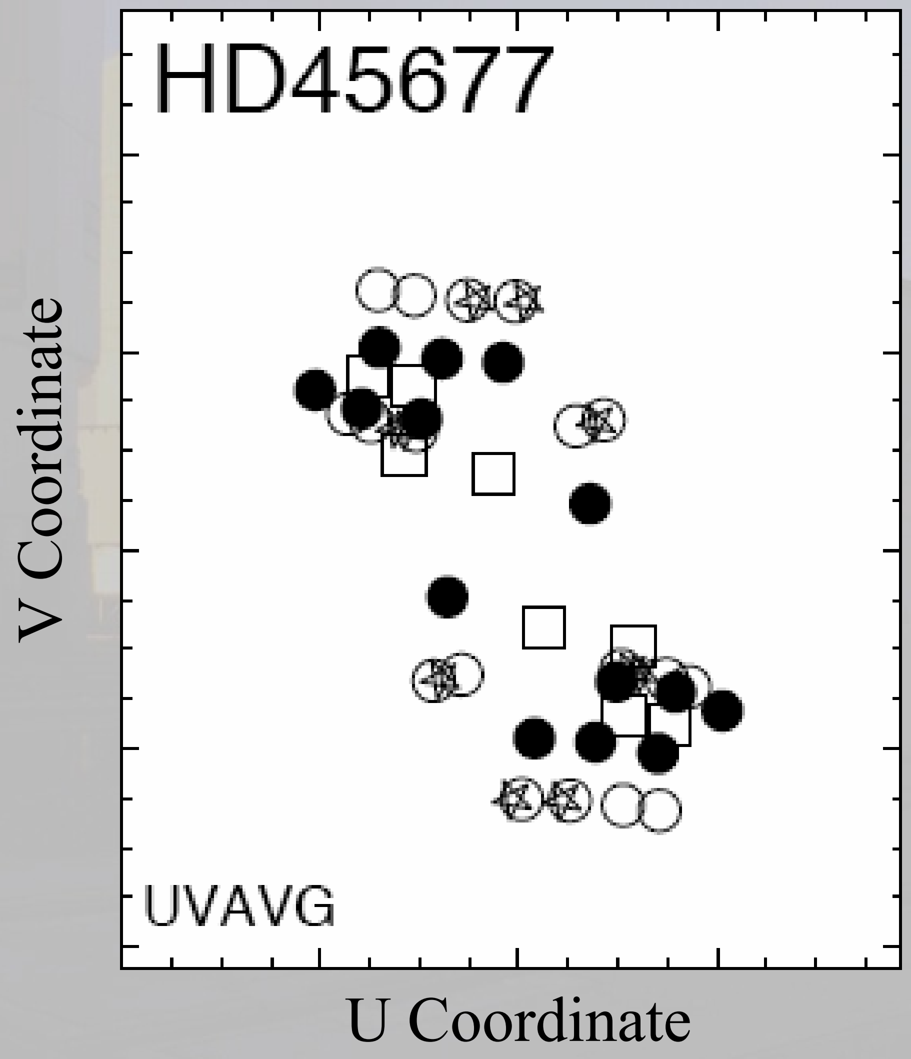
Inclination 70 degs
Inclination 37.5 degs
Inclination 5 degs
Maximum Closure Phase Magnitude (degrees)
Ring Diameter / Fringe Spacing
0
10
20
30
40
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
HD 45677
MWC 863
AB Aur
MWC 297
MWC 166
MWC 614

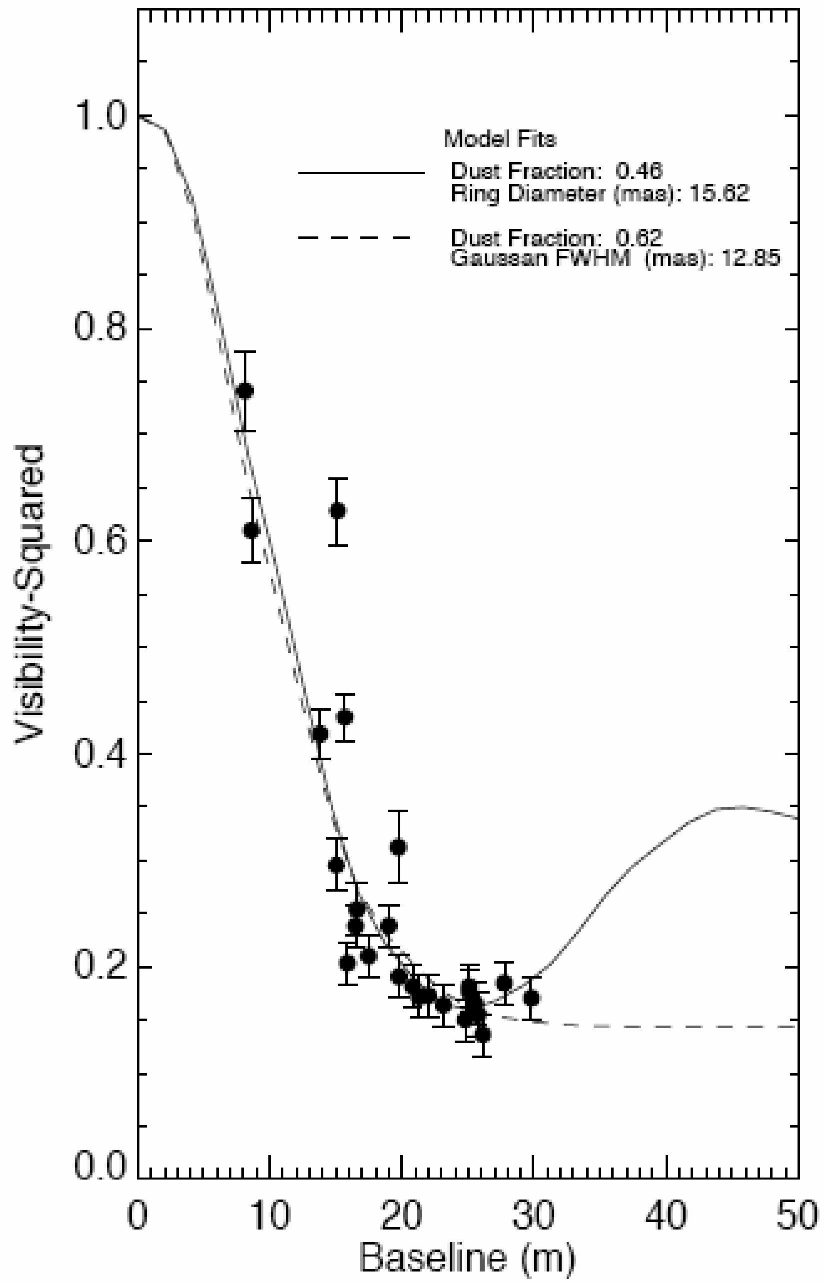

Ring Model (Skew 1.0)
Ring Model (Skew 0.5)
Milliarcseconds
Milliarcseconds
Ring Model (Skew 1.0)
(90 deg rotation)
Ring Model (Skew 0.5)
(90 deg rotation)
Closure Phase (degrees)
Hour Angle (hrs)

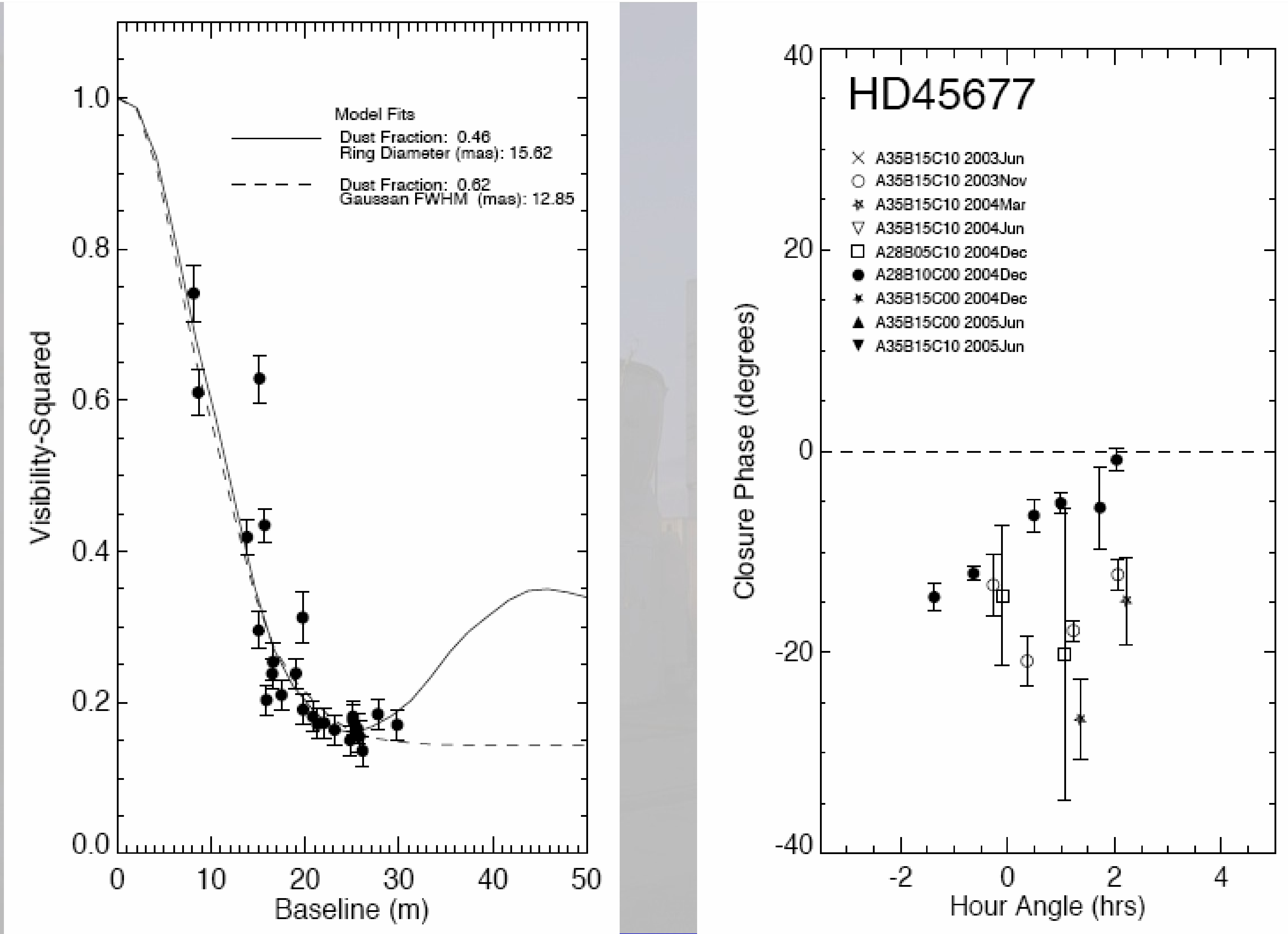


Skew = 1.0
Skew = 0.5
Contrast = 0
Contrast= 0.5
Contrast = 1
Maximum Closure Phase Magnitude (degrees)
Ring Diameter / Fringe Spacing
0
10
20
30
40
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

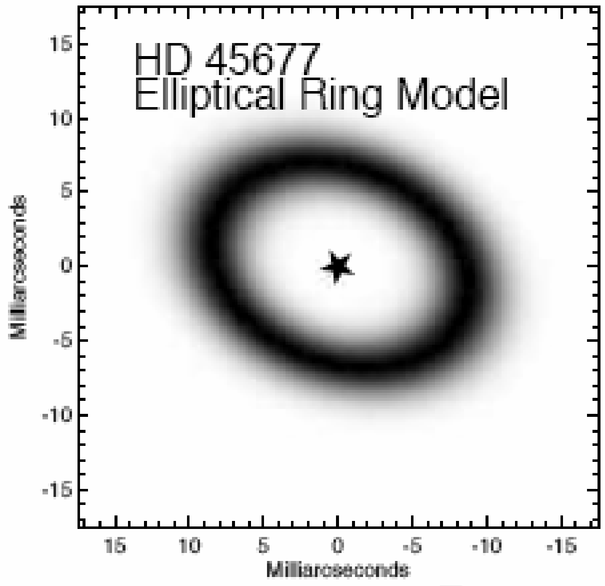
"Parametric Imaging"

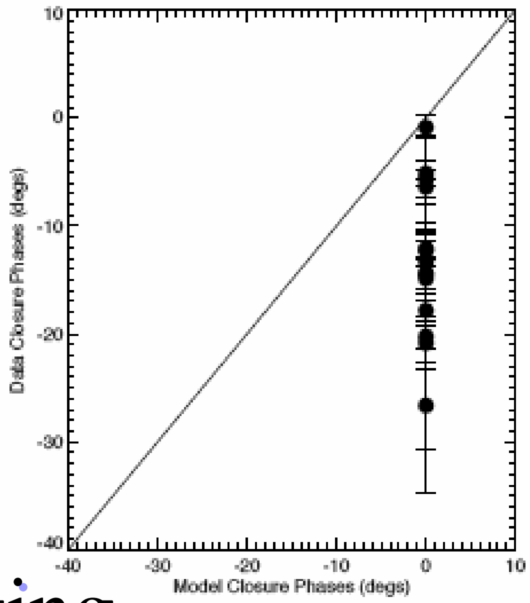


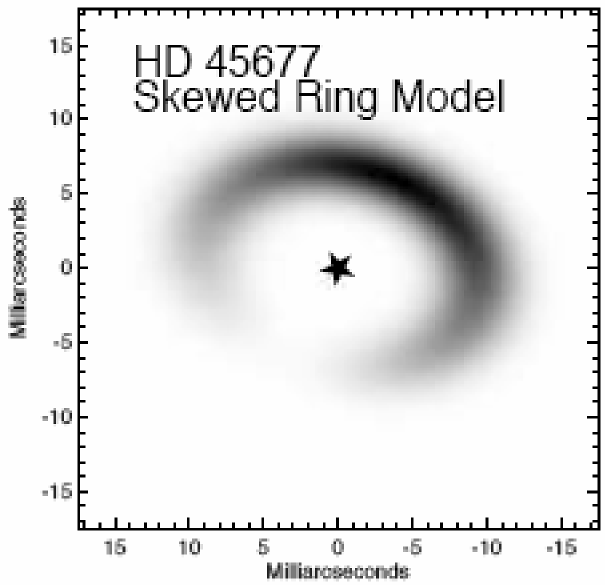


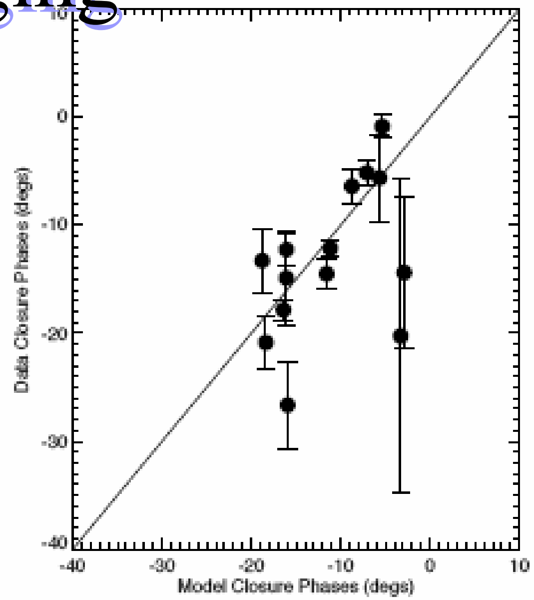

Visibility-Squared
Baseline (m)
Model Fits
Dust Fraction: 0.46
Ring Diameter (mas): 15.62
Dust Fraction: 0.62
Gaussan FWHM (mas): 12.85
HD45677
A35B15C10 2003Jun
A35B15C10 2003Nov
A35B15C10 2004Mar
A35B15C10 2004Jun
A28B05C10 2004Dec
A28B10C00 2004Dec
A35B15C00 2004Dec
A35B15C00 2005Jun
A35B15C10 2005Jun
Closure Phase (degrees)
Hour Angle (hrs)

Parametric Imaging Results





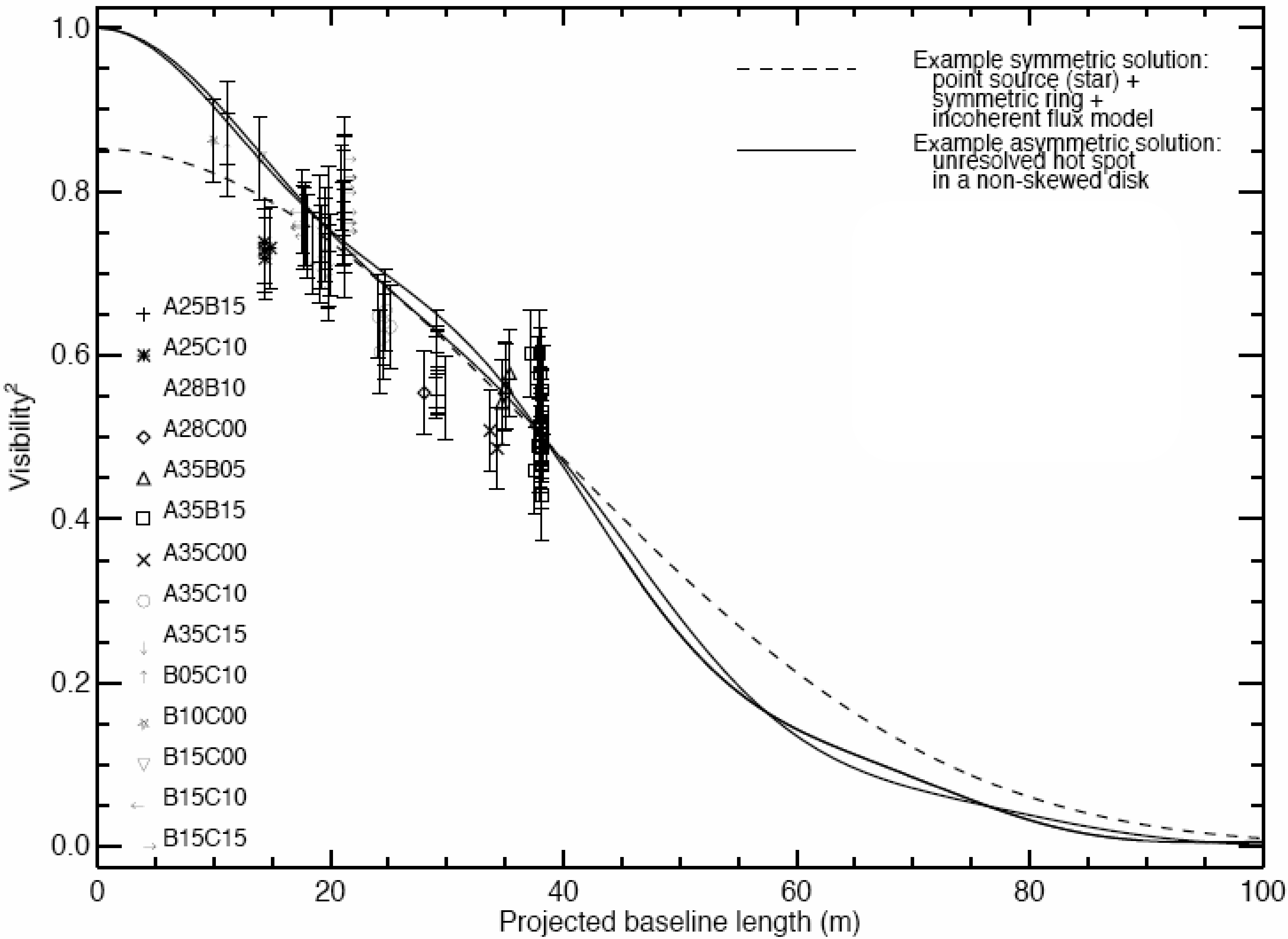




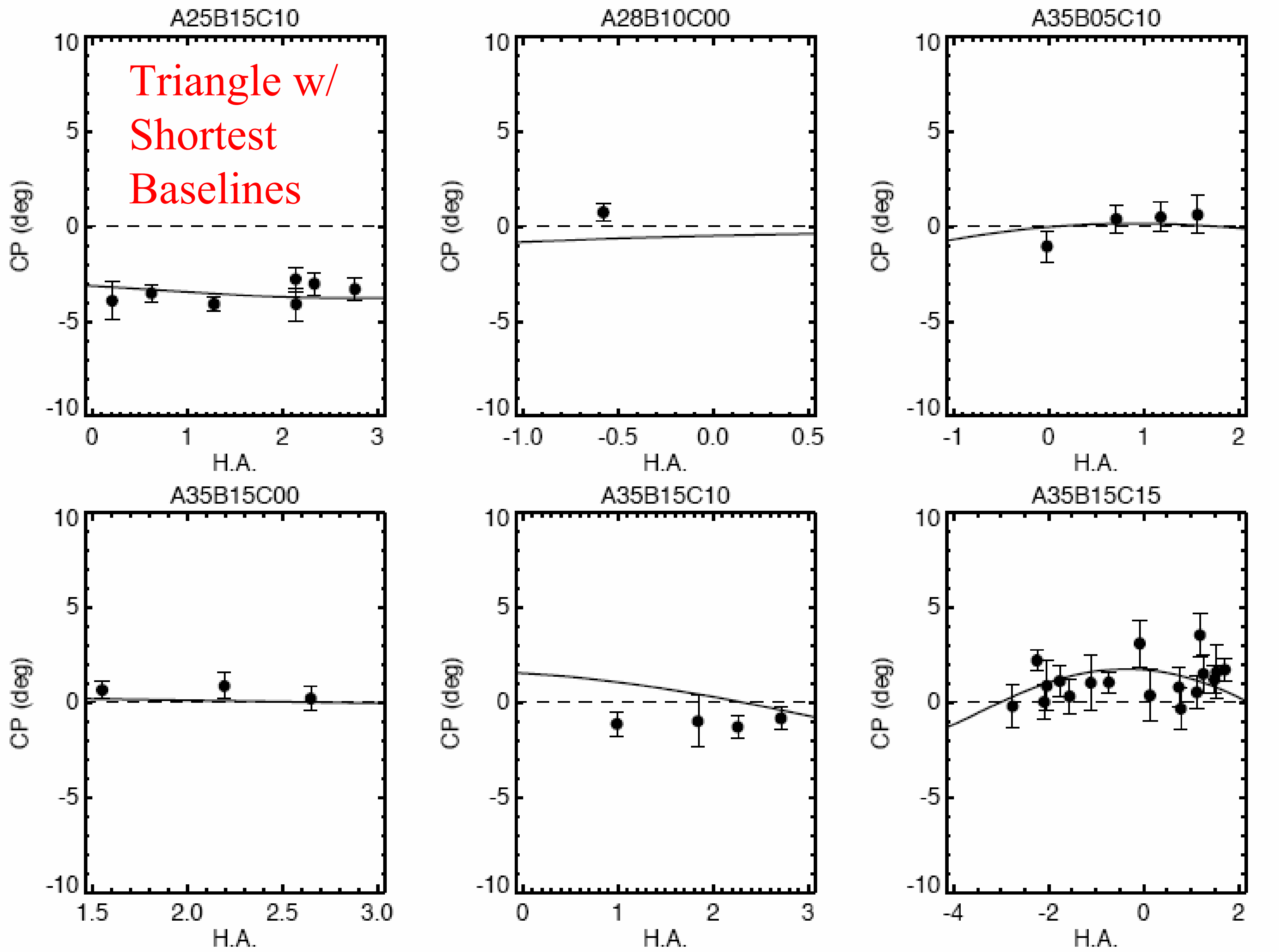
Special Case: AB Aur Disk

A Closure Phase Mystery

(from Millan-Gabet et al. 2006)



1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
Visibility^2
Projected baseline length (m)
Example symmetric solution:
point source (star) +
symmetric ring +
incoherent flux model
Example asymmetric solution:
unresolved hot spot
in a non-skewed disk
A25B15
A25C10
A28B10
A28C00
A35B05
A35B15
A35C00
A35C10
A35C15
B05C10
B10C00
B15C00
B15C10
B15C15



A25B15C10
Triangle w/
Shortest
Baselines
A28B10C00
A35B05C10
A35B15C00
A35B15C10
A35B15C15
CP (deg)
H.A.

AB Aur Results

Long Baselines -> zero closure phase

Point-Symmetric on scales of 4-10 milliarcseconds

Short Baselines -> non-zero closure phase

Asymmetric on scales of 10-50 milliarcseconds

4 degrees corresonds to ~7% asymmetry

What could this be?

What interferometry won't tell us:

What is the physical cause of this localized, bright emission?

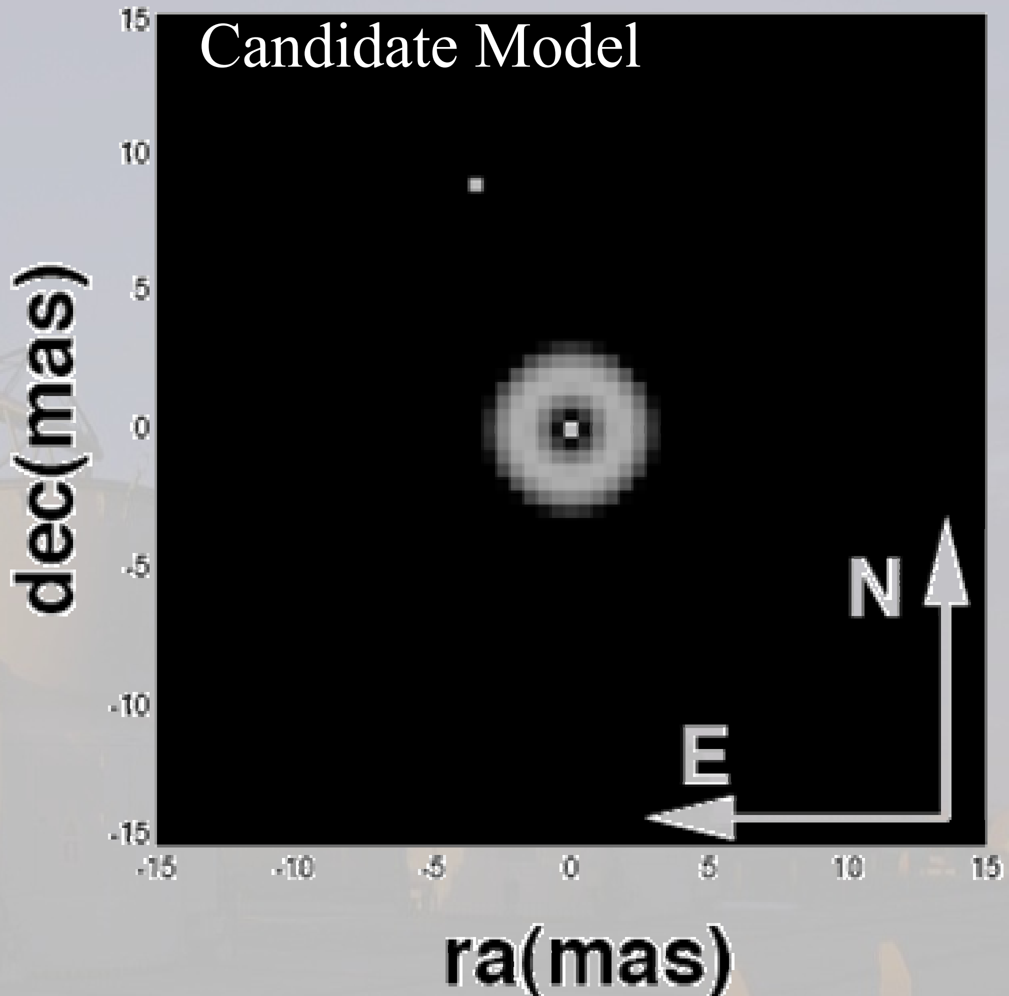


Table 1. Results from Fitting to "Disk Hot Spot" Model[a]

Model Description	Fraction of Light Star	Fraction of Light Disk	Fraction of Light Spot	Disk Properties	Spot Properties	Reduced χ^2 (V^2,CP)
Unresolved hot spot with non-skewed disk[b]	0.3	0.68	0.02	Ring Diameter 3.6 mas Ring Width/Diameter 0.25	Unresolved Spot r_G =9 mas at PA 22°	1.5
Gaussian hot spot with skewed disk	0.3	0.62	0.08	Ring Diameter 3.1 mas Ring Width/Diameter 0.5 Max Skew=1.0 at PA 172°	Gaussian FWHM 12 mas r_G =29 mas at PA 12°	1.8

Concluding Advice

Work on Phases for your thesis (visibilities are so last-generation)

Lots of potential science using differential phase, closure phase, precision phases.

Make it happen!