An XMM-HST analysis of HD 54879 (O9.7 V):
Quantifying the weak-wind problem

Tomer Shenar,
University of Potsdam, Germany
L. M. Oskinova, W.-R. Hamann, H. Todt, S. P. Jaervinen, S. Hubrig, ...
The weak-wind problem

For late OB main sequence stars: \( \frac{\dot{M}_{\text{obs}}}{\dot{M}_{\text{theory}}} \approx 0.01 \)

Adopted from Todt+ 2013
(see also Oskinova+ 2011, Huenemoerder+ 2012)
The weak-wind problem

For late OB main sequence stars: \( \frac{\dot{M}_{\text{obs}}}{\dot{M}_{\text{theory}}} \sim 0.01 \)

\( \rightarrow \) Systematic errors in stellar evolution models
The weak-wind problem

For late OB main sequence stars: \( \frac{\dot{M}_{\text{obs}}}{\dot{M}_{\text{theory}}} \sim 0.01 \)

→ Systematic errors in stellar evolution models

→ We do not fully understand stellar winds

Adopted from Todt+ 2013
(see also Oskinova+ 2011,
Huenemoerder+ 2012)
Measuring the mass-loss rates of weak-wind stars

Problem:

mass-loss diagnostics

Often not present in weak-wind stars!!
Measuring the mass-loss rates of weak-wind stars

Problem:
mass-loss diagnostics
Often not present in weak-wind stars!!

ν-Ori (O9.7 V)
HD 54879 (O9.7 V)

Shenar et al. 2017, in press

Tomer Shenar, Brno, #magneticstars
Measuring the mass-loss rates of weak-wind stars

The difference? You guessed it... Magnetic fields!

\(|B_z| \approx 600\, G\)

\(B_d \geq 2\, kG\)

(Castro+ 2015, BOB collaboration)
The magnetically confined wind model

- Wind outflow confined in loops up to Alfen radius
- Goes back to Weber & Davis 67, extended by Babel+Montmerle 1997, ud-Doula+Owocki 2002, (see talk by A. David-Uraz!)
- Shock-zone builds due to collision at mag. Equator (see recent review by Ud-Doula + Naze 2016)
A comprehensive XMM-HST study

1. **X-rays:** study the shocked wind (40 ks exposure, low-res spectrum)

2. **UV:** Study the magnetically confined wind (3 exposures within a night, high-res spectrum)
A comprehensive XMM-HST study

1. **X-rays:** study the shocked wind (40 ks exposure, low-res spectrum)

2. **UV:** Study the magnetically confined wind (3 exposures within a night, high-res spectrum)

3. **Optical:** study the photosphere: 3 high quality ESO-HARPS spectra
1. **X-rays**: study the shocked wind (40 ks exposure, low-res spectrum)

2. **UV**: Study the magnetically confined wind (3 exposures within a night, high-res spectrum)

3. **Optical**: study the photosphere: 3 high quality ESO-HARPS spectra

4. **Amateur & archival**: Study the spectral variability (P. Lukas); IACOB/OWN surveys: (Barba+ 2010, Simon-Diaz+ 2011)
1. **X-rays:** study the shocked wind (40 ks exposure, low-res spectrum)

2. **UV:** Study the magnetically confined wind (3 exposures within a night, high-res spectrum)

3. **Optical:** study the photosphere: 3 high quality ESO-HARPS spectra

4. **Amateur & archival:** Study the spectral variability (P. Lukas); IACOB/OWN surveys: (Barba+2010, Simon-Diaz+2011)
The Potsdam Wolf-Rayet (PoWR) code

• Non-LTE model atmosphere code (Hamann et al. 2006)
• Applicable for hot stars with expanding atmospheres (OB, WR, ...)
• Accounts for: line blanketing, clumping, X-rays..... But.....
• Spherically symmetric!
The Potsdam Wolf-Rayet (PoWR) code

- Non-LTE model atmosphere code (Hamann et al. 2006)
- Applicable for hot stars with expanding atmospheres (OB, WR, ...)
- Accounts for: line blanketing, clumping, X-rays..... But.....
- Spherically symmetric!

Stellar parameters:

\[ T, \log g, L, \dot{M}, \nu_\infty, \nu \sin i, \ldots \]
HD 54879: the photosphere

Shenar et al. 2017, in press
HD 54879: the photosphere

No variability of photospheric features!

Shenar et al. 2017, in press
No variability of photospheric features!

Shenar et al. 2017, in press
HD 54879: the photosphere

- Stellar parameters typical for O9.7 V:
  \[ T = 30.5 \text{ kK}, \log g = 4.0, L = 4.45 \text{ L}_{\odot} \]
  But...

- \( v \sin i, v_{\text{mac}}, v_{\text{mic}} < 4 \text{ km/s} \)

- N, C abundances subsolar (~factor 3)

Shenar et al. 2017, in press
HD 54879: the “wind”

Shenar et al. 2017, in press
HD 54879: the “wind”

See also Erba, David-Uraz+ 2017, Naze+ 2015
HD 54879: the “wind”

Verdict: not symmetric outflow!!

See also Erba, David-Uraz+ 2017, Naze+ 2015
HD 54879: the "wind"

Resonable fit:
1. $v_{\text{mic, wind}} = 500 \text{ km/s}$
2. $\log \dot{M} = -8.8 \left[ \frac{L \odot}{M \odot} \right]$
3. $v_\infty = 300 \text{ km/s}$
HD 54879: the “wind”

Resonable fit:
1. $v_{\text{mic, wind}} = 500 \text{ km/s}$
2. $\log \dot{M} = -8.8 \left[ \frac{L_\odot}{M_\odot} \right]$
3. $v_\infty = 300 \text{ km/s}$

Especially with X-rays!
HD 54879: the “wind”

Resonable fit:
1. \( v_{\text{mic, wind}} = 500 \text{ km/s} \)
2. \( \log \dot{M} = -8.8 \left[ \frac{L_\odot}{M_\odot} \right] \)
3. \( v_\infty = 300 \text{ km/s} \)

Especially with X-rays!

However:

nonesense in → nonesense out
Why am I showing you nonsense?

“wind” parameters \rightarrow \text{density stratification } \rho(r)
Why am I showing you nonsense?

“wind” parameters

Analytical solution by Owocki et al. 2016

density stratification $\rho(r)$

$\rho(r, \theta, v_\infty, R_*, \dot{M}_{B=0})$

Owocki et al. 2016
"wind" parameters

Analytical solution by Owocki et al. 2016

Owocki et al. 2016

density stratification $\rho(r)$

$\rho(r, \theta, v_{\infty}, R_{*}, \dot{M}_{B=0})$
"wind" parameters

Analytical solution by Owocki et al. 2016

Owocki et al. 2016


Why am I showing you nonsense?

"wind" parameters

Analytical solution by Owocki et al. 2016

Owocki et al. 2016

density stratification $\rho(r)$

$\rho(r, \theta, v_\infty, R_\odot, \dot{M}_{B=0})$

- $\log \dot{M}_{B=0} = -9.0 \frac{M_\odot}{\text{yr}}$
- $\sim 1.5$ dex lower than predicted (Vink+ 2000)
- Comparable with weak-wind stars (e.g. Marcolino + 2009)
- Implies $r_A > 12 R_\odot$; $\log \dot{M} < -10.2 \frac{M_\odot}{\text{yr}}$
HD 54879: Summary

- Multiwavelength (X-ray, UV, optical) spectral analysis of HD 54879
  Shenar et al. 2017, in press (on archive)
HD 54879: Summary

• Multiwavelength (X-ray, UV, optical) spectral analysis of HD 54879
  Shenar et al. 2017, in press (on archive)

• Projected stellar rotation + micro/macro turbulence <4 km/s
• Multiwavelength (X-ray, UV, optical) spectral analysis of HD 54879 Shenar et al. 2017, in press (on archive)

• Projected stellar rotation + micro/macroturbulence <4 km/s

• Confined wind → means of measuring $\dot{M}_B = 0$ → constrains weak wind problem
**HD 54879: Summary**

- Multiwavelength (X-ray, UV, optical) spectral analysis of HD 54879 Shanar et al. 2017, in press (on archive)
- Projected stellar rotation + micro/macroturbulence < 4 km/s
- Confined wind \(\rightarrow\) means of measuring \(\dot{M}_B = 0\) \(\rightarrow\) constrains weak wind problem
- Spectroscopic variability of H\(\alpha\) \(\rightarrow\) \(P \sim 5\) yr? Xrays \(\rightarrow\) hard X-ray excess
• Multiwavelength (X-ray, UV, optical) spectral analysis of HD 54879 Shenar et al. 2017, in press (on archive)
• Projected stellar rotation + micro/macroturbulence <4 km/s
• Confined wind $\rightarrow$ means of measuring $\dot{M}_B = 0$ $\rightarrow$ constrains weak wind problem
• Spectroscopic variability of H$\alpha$ $\rightarrow$ P $\sim$ 5 yr? Xrays $\rightarrow$ hard X-ray excess

A motivation for your next proposal for magnetic stars: “magnetic stars help to quantify the weak-wind problem”
HD 54879: variability

![Graph showing spectral variability in HD 54879]
HD 54879: variability
HD 54879: what we already know

O9.7 V
V ~ 7.65
D ~ 1300 pc

D ~ 1000 pc

ν sin i, ν mac < 4 km/s
ν sin i = 7 km/s
ν mac = 8 km/s

|B_z| ~ 600 G
B_d ≥ 2 kG

T ~ 30.5 kK

T ~ 33 kK
log g ~ 4.0 [cgs]

Castro + 15, BOB collaboration

30.8.2017
Tomer Shenar, Brno, #magneticstars
HD 54879: X-rays

Multi temperature model:

\[ 6.2 \text{ MK} < T_{\text{X-rays}} < 20 \text{ MK} \]
\[ L_{\text{X-ray}} \approx 10^{32} \text{ erg/s} \]

\[ \frac{L_{\text{X-ray}}}{L_{\text{Bol}}} = -6 \text{ (X10 than average!)} \]

\[ \rightarrow \text{X-ray excess due to collisions at magnetic equator} \]