Contact: mona.elmorsy@utsa.edu

Design, scientific goals, and first results of the SCExAO survey for planets around accelerating stars

Based [in part] on data collected at Subaru Telescope, which is operated by the National Astronomical Observatory of Japan.

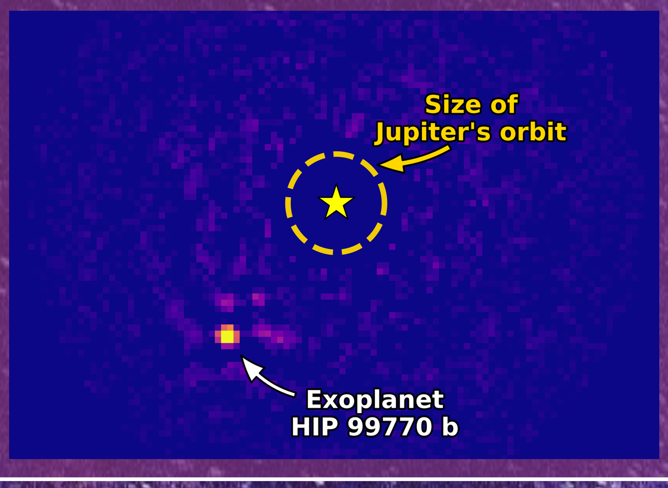
Mona El Morsy [1], Danielle Bovie[1], Thayne Currie[1,2], Masayuki Kuzuhara[3, 4], Yiting Li[5], Taylor Tobin[5], Timothy D. Brandt[6, 7], Jeffrey Chilcote[8], Olivier Guyon[2, 3, 9, 10], Tyler D. Groff[11], Julien Lozi[2], Sebastien Vievard[2], Vincent Deo[2], Erica Dykes[1], N. Jeremy Kasdin[12], Taichi Uyama[13], and Motohide Tamura[3, 4, 14]

1-Department of Physics and Astronomy, University of Texas-San Antonio, San Antonio, TX, USA, 2-Subaru Telescope, National Astronomical Observatory of Japan, 650 North A'ohoku Place, Hilo, HI 96720, USA, 3-Astrobiology Center of NINS, 2-21-1, Osawa, Mitaka, Tokyo, 181-8588, Japan, 4-National Astronomical Observatory of Japan, 2-21-2, Osawa, Mitaka, Tokyo 181-8588, Japan, 5-Department of Astronomy, University of Michigan, 1085 S. University, Ann Arbor, MI 48109, USA, 6-Space Telescope Science Institute, Baltimore, MD, USA, 7-Department of Physics, University of California, Santa Barbara, Santa Barbara, California, USA, 8-Department of Physics, University of Notre Dame, South Bend, IN, USA, 9-Steward Observatory, The University of Arizona, Tucson, AZ 85721, USA, 10-College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA, 11-NASA-Goddard Space Flight Center, Greenbelt, MD, USA, 12-Department of Mechanical Engineering, Princeton University, Princeton, NJ, USA, 13-Department of Physics and Astronomy, California State University-Northridge, Northridge, CA USA, 14-Department of Astronomy, Graduate School of Science, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-0033, Japan

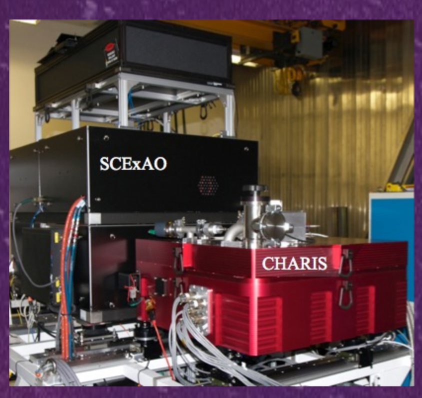
Background

While over 5,000 exoplanets have been discovered, only about 20 of these have been directly imaged. Large, ``blind" ground-based surveys like GPIES and SPHERE find a low frequency of imageable planets. Direct imaging data provide excellent constraints on planet atmospheres but cannot provide a direct mass measurement and usually sample only a tiny fraction of a planet's orbit.

Instead of conducting a blind survey, using precision astrometry from the Gaia and Hipparcos satellites can identify stars showing dynamical evidence for a substellar companion that may be imageable. This joint direct imaging + astrometry survey approach is now proven successful, with the discoveries of the HIP 99770 b and AF Lep b planets.



Survey Overview



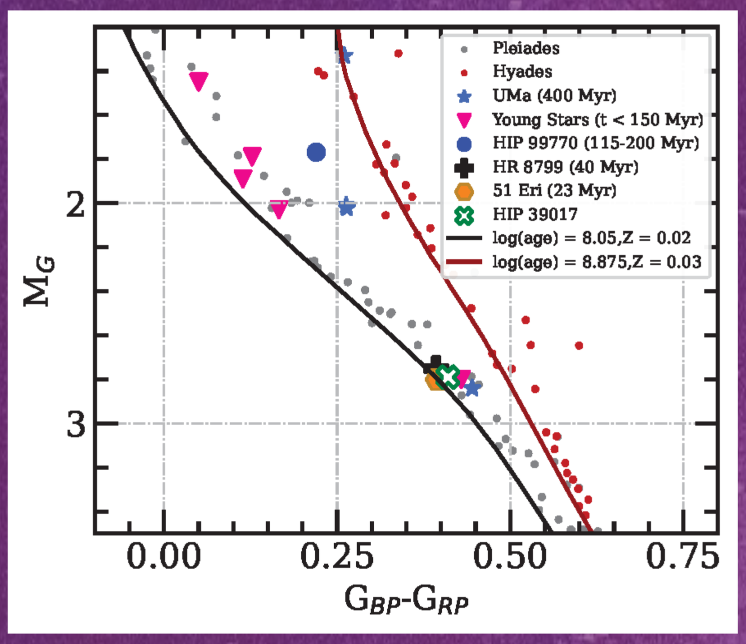
Our Intensive Survey targets nearby young accelerating stars, primarily using the Subaru Coronagraphic Extreme Adaptive Optics project (SCExAO) coupled with the CHARIS integral field spectrograph (1.1—2.4 microns) with Keck/NIRC2 for follow-up in the thermal infrared (3.8 microns):

- 42 nights from S2024A to S2026A: Subaru/SCExAO+CHARIS (34 nights) and Keck/NIRC2 at Lp (8 nights)
- Observe around 125 stars:
  Magnitude: V = 3-7.2
  Distance: 20-100 pc
  Age: ~10-800 Myr

The program's goals are to:

- Discover, weigh, and constrain the atmospheres and orbits of dozens of exoplanets and brown dwarfs
- Constrain the atmospheric evolution of substellar objects vs mass vs. time
- Provide targets for Roman CGI Technology Demonstration

Target Selection

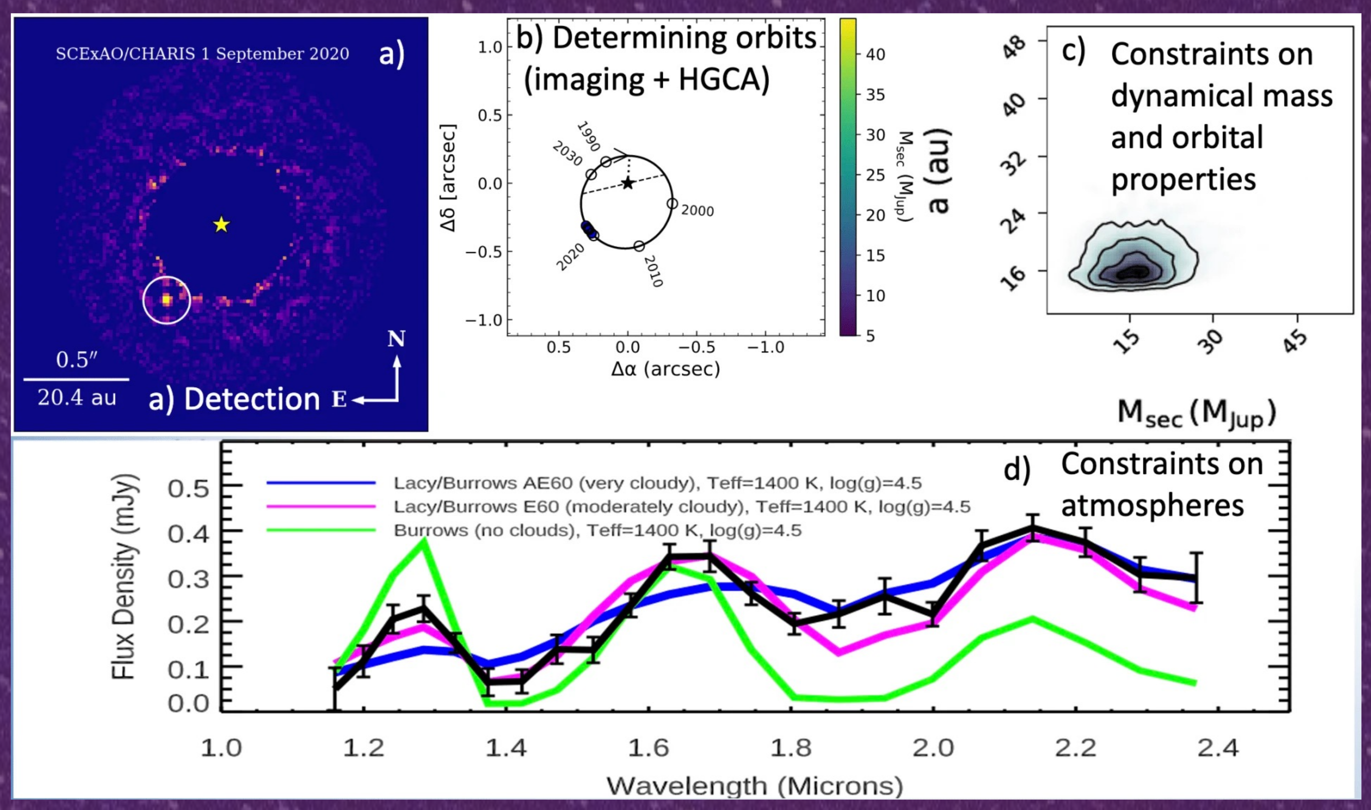


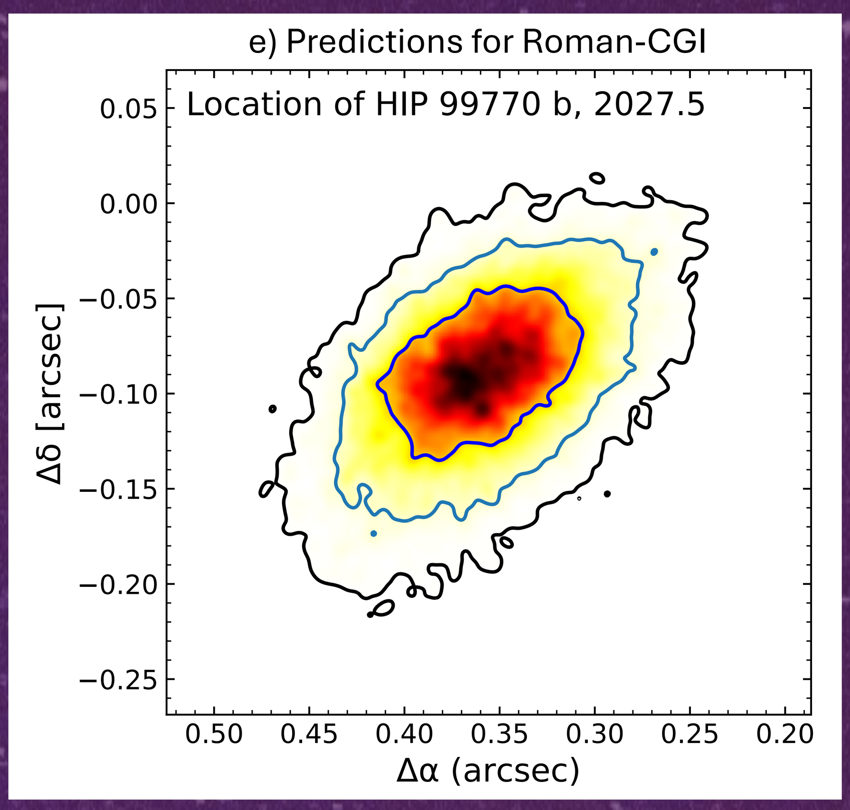
Color-magnitude diagram using Gaia DR3 photometry and displaying PARSEC isochrones for the Pleiades (~115 Myr; dark gray line) and Hyades (~750 Myr; red line)
Credit: Tobin+2014

We select young stars showing evidence for an astrometric acceleration. Here, "accelerating" means the star has an astrometric acceleration potentially caused by a companion, a massive planet, or a low-mass brown dwarf:

- Astrometric data from the Hipparcos-Gaia Catalogue of Accelerations (HGCA) identifies stars that are accelerating. We choose a cutoff of ~2.2 sigma, similar to the astrometric acceleration of HIP 99770 b.
- We use a range of different sources – HR diagram measurements, moving group memberships, etc. to then identify the subset of accelerating stars that are sufficiently young such that their companions may be imageable.
- We are left with a parent sample of ~175 stars. We will observe 125 of these stars for our survey, the exact list depending on telescope schedules, etc. Many of our targets have never been observed with an extreme AO system before.

Analysis Methods (Example: HIP 99770 b)

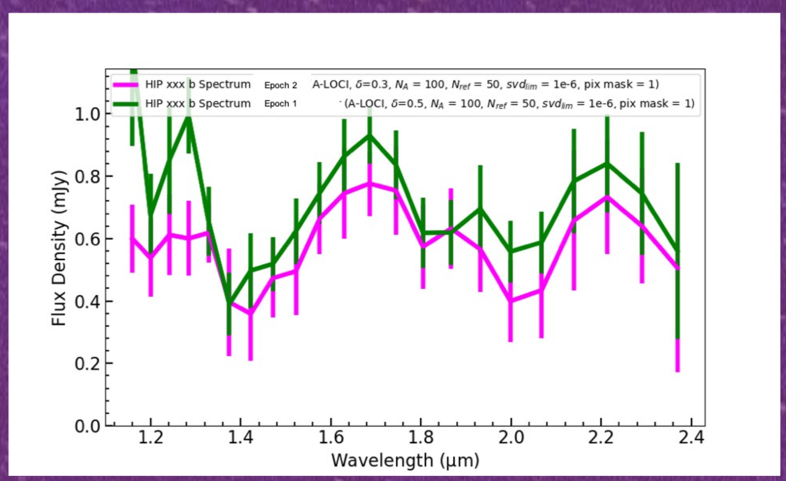


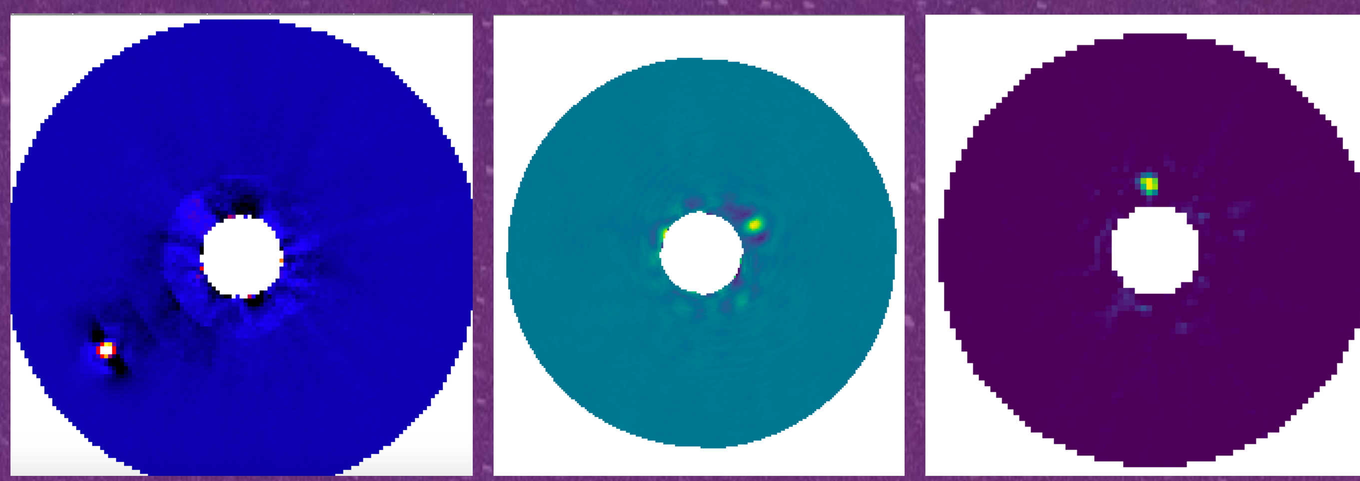


We will obtain deep sequences of target stars (t_{int} ~2—3 hours per target) with the now upgraded SCExAO/CHARIS. After the upgrade of Subaru's facility AO system feeding SCExAO (AO3K), we now expect contrasts of 10-5, 10-6, and 5x10-7 at 0.13", 0.25", and 0.5--1", sufficient to detect planets just slightly more massive than Jupiter at 10-30 au around most of our sample. The brightest-contrast companions will be reimaged with Keck/NIRC2 at Lp. Combining relative astrometry of the planet from SCExAO/CHARIS and Keck/NIRC2 with absolute astrometry of the star from HGCA allows us to constrain the orbit and dynamical mass of the planet. CHARIS spectra and NIRC2 photometry will be compared to a suite of different atmospheric model grids to constrain temperatures, gravities, clouds, and chemistry. Astrometric and atmospheric modeling can then be used to predict the location and contrast of companions with Roman-CGI.

First Results

Our survey started in February 2024. About 8% of the survey observations are complete; by the end of 2024, about 1/3 of the survey should be finished. Already, the survey has confirmed a likely new planet, confirmed two candidate brown dwarfs, and identified two additional candidate substellar companions.

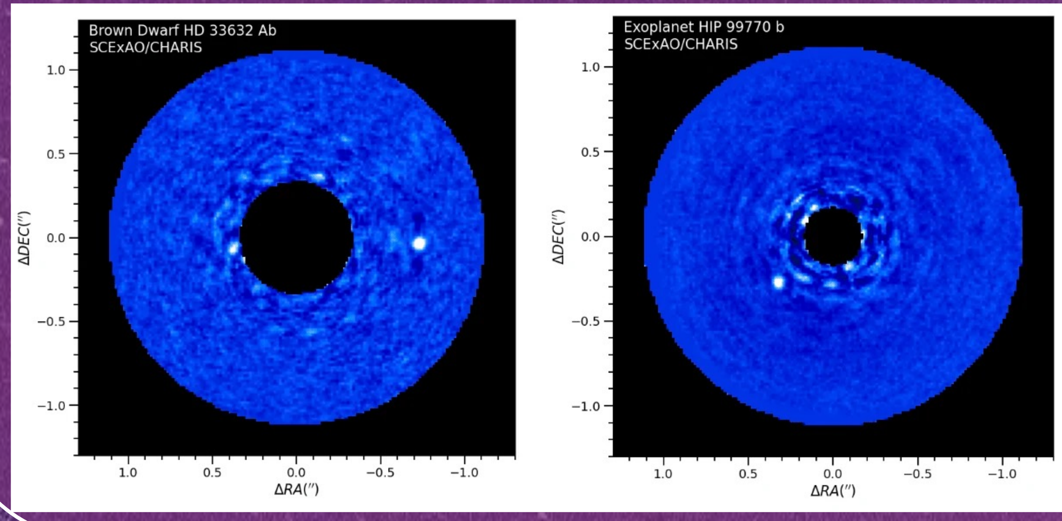




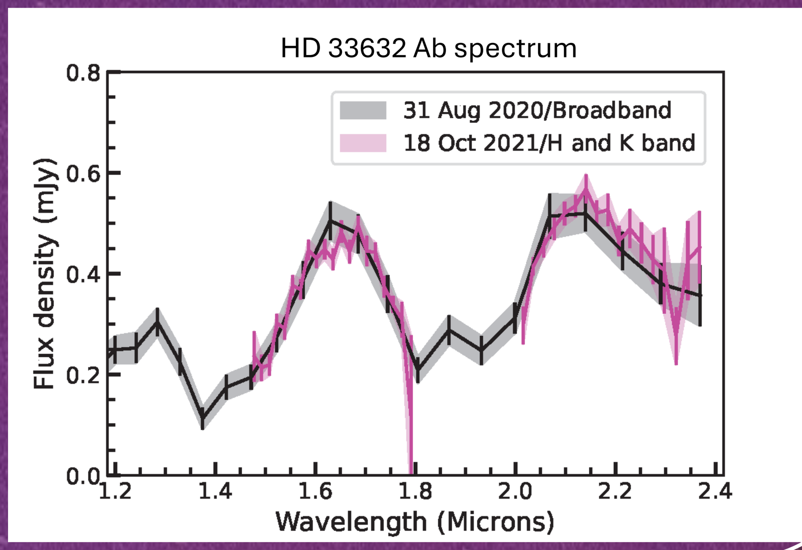
Based on results of our pilot study and preliminary Intensive Survey results, we predict that we will discover, weigh, and constrain the orbit of 5 planets and 12 brown dwarfs. Our discovery yield will likely be 5 times higher than that of larger, unbiased surveys like GPIES.

Follow-Up Characterization of Known Planets/Brown Dwarfs Around Accelerating Stars

Once a planet/brown dwarf is discovered, we can conduct follow-up observations with CHARIS at higher resolution in individual J, H, and K passbands to better probe surface gravity and chemistry. Follow-up characterization studies of planets and brown dwarfs found during the pilot survey are in progress.

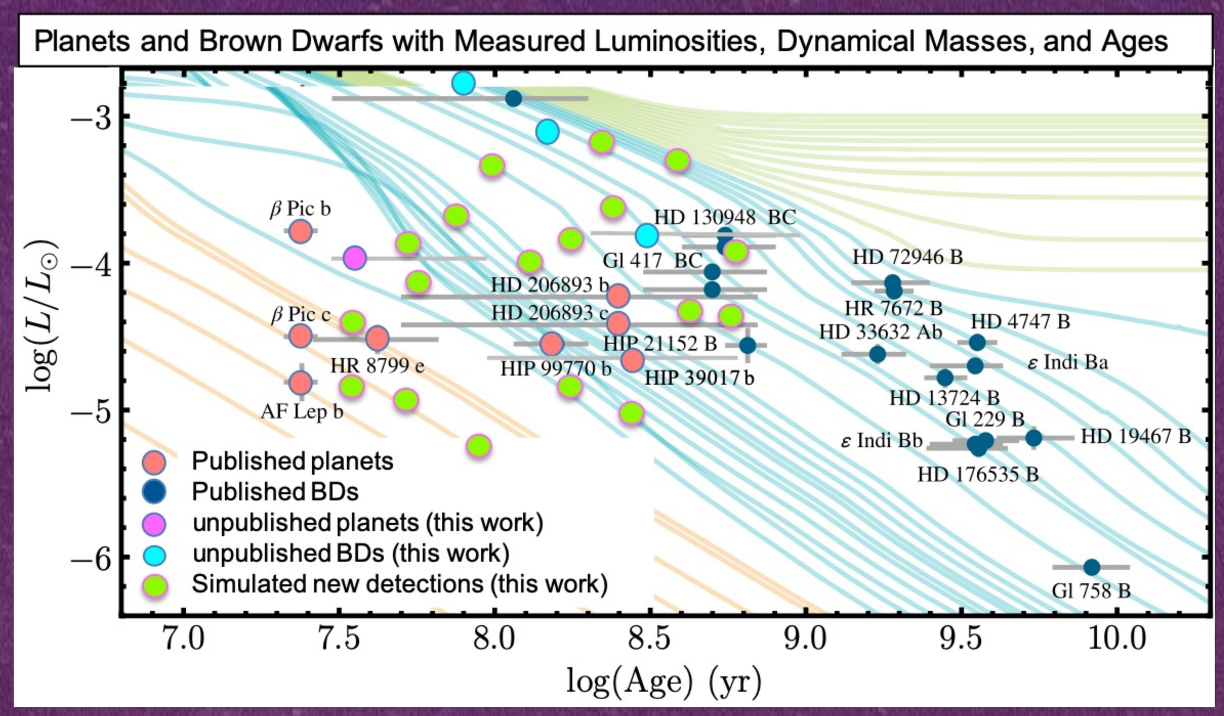


K Band high resolution images of HD 33632 Ab and HIP 99770 b



Broader Significance for Planet Evolution

- Our Survey will provide a better understanding of how the atmospheres of Jovian exoplanets and low-mass brown dwarfs evolve over time and their relationship with dynamical mass as simulated below.



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