MOTHRA

The Modular Optical Telephoto Hyperspectral Robotic Array

A Research Report on the Dragonfly FRO's Next-Generation Telescope

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1. Executive Summary

MOTHRA (the Modular Optical Telephoto Hyperspectral Robotic Array) is a next-generation astronomical instrument being built by astronomers Pieter van Dokkum (Yale University, joining Northwestern University in January 2027) and Roberto Abraham (University of Toronto). It is the direct successor to the pair's earlier Dragonfly Telephoto Array and represents a roughly 24-fold expansion of that instrument's lens count — growing from 48 lenses in New Mexico to 1,140 lenses at a new site in Chile.

MOTHRA fuses images from 1,140 commercial Canon telephoto lenses into a single optical system equivalent to a 4.8-meter, f/0.08 refracting telescope with an ultra-wide field of view (roughly 6–9 square degrees) and an integrated integral-field spectrometer (R ≈ 800). Ultra-narrowband, mechanically tilting interference filters allow the array to isolate faint hydrogen-alpha (Hα) emission across a range of recessional velocities, turning it into a dedicated “cosmic web” and circum-galactic-medium (CGM) mapping machine.

The project is owned and operated by Dragonfly FRO LLC, a non-profit Focused Research Organization (FRO) incubated by Convergent Research, and it is funded by a private donation from Alex Gerko, founder and CEO of the algorithmic trading firm XTX Markets. Construction began in spring 2025 at the El Sauce Observatory (operated by Obstech) in Chile's Rio Hurtado Valley. The array is expected to be fully operational by the end of 2026 — a roughly two-year timeline that the team describes as being made possible by a decade of prototyping on Dragonfly and its 120-lens pathfinder, the Dragonfly Spectral Line Mapper (DSLM).

2. Project Origins: From a Beer Bet to a 1,140-Lens Array

MOTHRA's roots trace to 2013, when van Dokkum and Abraham built the first Dragonfly Telephoto Array from just three commercially available Canon telephoto lenses — reportedly the result of a bet between the two (which, per the team's own account, Abraham lost). Over the following decade, Dragonfly grew to 48 lenses on two mounts at the New Mexico Skies facility, funded by a mix of private university support (Toronto, Yale, later Harvard) and Canadian public funding (NSERC).

Dragonfly's broadband imaging proved that combining many small, high-quality telephoto lenses with redundant lines of sight could reveal extremely faint, diffuse structures invisible to conventional telescopes. This led to a string of high-profile discoveries, including “ultra-diffuse galaxies” — large, star-poor galaxies such as Dragonfly 44, thought to be up to 99.9% dark matter by mass — and NGC1052-DF2, a galaxy that appears to contain essentially no dark matter at all. The latter result was among the most widely discussed astronomy papers of its year.

2.1 The DSLM Pathfinder (2019–2021)

A 2019 theoretical study led by then-graduate student Deborah Lokhorst (working with cosmologist Joop Schaye) modeled whether a Dragonfly-like array equipped with narrowband filters could directly image the “cosmic web” of intergalactic gas in Hα emission. The study concluded this was out of reach for the existing 48-lens array, but that a hypothetical 1,000-lens array could plausibly do it. The team built a 3-lens Dragonfly Spectral Line Mapper (DSLM) prototype in 2019–2021 to test the concept on sky — work that formed the core of Lokhorst's Ph.D. thesis and later won her the Astronomical Society of the Pacific's 2023 Robert J. Trumpler Award.

2.2 DSLM120: The Technology Testbed (2022–2024)

Encouraged by the pathfinder results, the team secured funding from the Canada Foundation for Innovation, the University of Toronto, and Yale University to build a 120-lens Dragonfly Spectral Line Mapper (DSLM120): four mounts of 30 lenses each, built and commissioned in phases from March 2022 to November 2023. Construction was led by graduate students Seery Chen and Qing Liu (Toronto) and Imad Pasha (Yale), together with postdoc Will Bowman (Yale). DSLM120 validated the ultra-narrowband “Filter-Tilter” technology, new CMOS camera options, and a distributed Raspberry Pi–based control architecture — all of which carried forward into MOTHRA.

2.3 The Pivot to MOTHRA

While DSLM120 was nearing completion, the team secured private philanthropic funding for a full-scale, roughly 1,000-plus-lens array. This triggered an immediate pivot: DSLM120 became an advanced technology testbed for the new project, and most of its hardware was subsequently relocated to Chile to form the core of the first MOTHRA mounts. The resulting project — formally launched as Dragonfly FRO and its MOTHRA instrument — aims to go from concept to a fully operational, world-leading facility in about two years, a timeline the team attributes to years of risk-retirement through Dragonfly and DSLM prototyping.

3. Scientific Motivation and Goals

MOTHRA is built around a single overarching scientific objective: to directly image, in emission, the faint reservoirs of ionized gas that trace the circum-galactic medium (CGM) and the “cosmic web” — the vast network of dark-matter-dominated filaments believed to connect galaxies across the Universe and to hold most of the Universe's ordinary (baryonic) matter.

- Map the circum-galactic medium in Hα, [N II], and [O III] emission around galaxies in the local Universe, revealing inflows and outflows of gas that regulate star formation.
- Detect the brighter pockets of the cosmic web itself — a goal that, per the team's own 2019 modeling, requires an array roughly an order of magnitude larger than the original 48-lens Dragonfly.
- Probe galactic feedback: how gas cycles into and out of galaxies as they grow within their dark-matter halos.
- Produce wide-field, spectrally resolved images that combine spatial and kinematic (velocity) information via the tunable narrowband filters, functioning as a very wide-field integral-field spectrometer.

A frequently raised point of clarification (addressed directly in the project's own FAQ) is that MOTHRA does not image dark matter itself — dark matter does not emit light. Rather, it images the faint ionized gas that is thought to trace the gravitational potential wells created by dark matter, providing an indirect but observationally powerful window onto its distribution.

4. Technical Design and Specifications

MOTHRA scales up the Dragonfly concept of combining many small, high-quality refracting lenses (rather than one large mirror) into a distributed-aperture array. Below is a summary of the instrument's key parameters as described by the project team.

Parameter	Value
Full name	Modular Optical Telephoto Hyperspectral Robotic Array (MOTHRA)
Number of lenses	1,140 Canon EF 400mm f/2.8L IS (II) telephoto lenses
Lens arrangement	30 mounts × 38 lenses each, in two roll-off enclosures of 15 mounts apiece
Mounts	Software Bisque precision fork mounts
Effective aperture	Equivalent to a single 4.8-meter (f/0.08) refractor (some press coverage cites ~4.7 m)
Field of view	Approximately 6–9 square degrees (reported figure has grown as the design finalized)
Spectral capability	Integral-field spectrometer, R ≈ 800, via tiltable ultra-narrowband interference filters
Filter technology	“Filter-Tilter” mechanism: tilting ~1 nm (DSLM heritage: 0.8 nm) bandpass filters shifts the central wavelength to target specific recessional velocities
Target emission lines	Hα λ6563, [N II] λ6583, [O III] λ5007
Cameras	Atik Apx26 and Apx60 CMOS cameras (Sony IMX571 / IMX455 sensors)
Data infrastructure	Dedicated data center: 4,032 high-performance CPU cores and 15 PB of storage, in Portland, Oregon (completion targeted February 2026)
Site	Obstech / El Sauce Observatory, Rio Hurtado Valley, Chile

The lens choice is a direct inheritance from Dragonfly: modern Canon super-telephoto lenses have exceptional multi-layer nano-structured anti-reflection coatings that suppress the scattered light which otherwise swamps faint, diffuse signals in conventional telescopes. MOTHRA's team specifically favors older EF-mount lenses over newer RF-mount versions because the EF mount's longer back-focus distance accommodates the filter and camera hardware required for the array's narrowband design.

An important engineering feature is the physical separation of the two telescope enclosures at El Sauce: spacing them apart allows images to be reconstructed while identifying and rejecting artifacts from low-Earth-orbit satellite trails — an increasingly important consideration for wide-field, long-exposure astronomy.

5. Organizational Structure and Funding

MOTHRA is owned and operated by Dragonfly FRO, LLC, a U.S.-based non-profit Focused Research Organization (FRO). FROs are a relatively new institutional model, incubated by the non-profit Convergent Research, designed to sit between traditional academic labs, looser multi-institution consortia, and venture-backed startups. They are structured as time-limited (typically ~5-year), mission-driven organizations with dedicated full-time staff, intended to build high-impact public research infrastructure that would be difficult to fund or execute within conventional academic timelines.

Construction and operation of MOTHRA is funded through a private philanthropic donation from Alex Gerko, founder and CEO of XTX Markets, a large algorithmic trading firm. Beyond funding, Gerko and his team are described by the project as active strategic partners — including in helping select the El Sauce/Obstech site and navigating large-scale procurement and international infrastructure logistics, drawing on XTX's own experience building data centers at scale.

Gerko's broader philanthropic footprint in science includes contributions to open-source mathematics infrastructure (Lean FRO, Mathlib, and a $31.5 million AI-for-Math fund with XTX Markets), co-funding (with Schmidt Sciences) of the Argus Array telescope system at the University of North Carolina, and a $2.5 million gift supporting instrumentation for the CCAT Observatory's Fred Young Submillimeter Telescope.

6. Observing Site: Obstech / El Sauce Observatory, Chile

MOTHRA is being constructed at the Obstech/El Sauce Observatory in Chile's Rio Hurtado Valley — a region prized by astronomers for its dry air, dark and stable skies, low light pollution, and more than 300 clear nights per year. The site sits within the broader northern Chile astronomical corridor, in sight of major professional facilities including the Gemini South Observatory and the Vera C. Rubin Observatory.

This represents a deliberate departure from Dragonfly's original home at New Mexico Skies. According to the project's own materials, moving to Chile was chosen for superior observing conditions and to be embedded within Chile's world-class astronomical infrastructure and support ecosystem; the original 48-lens Dragonfly imager remains active at New Mexico Skies as a polarimetric imager.

7. Timeline and Construction Status

Parameter	Value
2013	First Dragonfly prototype (3 lenses) achieves first light
2013–2021	Dragonfly grows to 48 lenses across two mounts (New Mexico Skies)
2019	Lokhorst et al. modeling study concludes a ~1,000-lens array could image the cosmic web in Hα
2019–2021	3-lens DSLM pathfinder designed, built, and tested
Mar 2022 – Nov 2023	120-lens DSLM (DSLM120) constructed in four phases at New Mexico Skies
2024	DSLM120 completed; used as advanced technology testbed for full-scale array
Spring 2025	MOTHRA construction begins at Obstech/El Sauce Observatory, Chile
Nov 2025	Van Dokkum's move to Northwestern University (effective Jan 2027) announced
Feb 2026 (planned)	Dedicated MOTHRA data center (Portland, OR) scheduled for completion
Mar 2026	MOTHRA publicly unveiled; first images released (RCW 114, NGC 253)
End of 2026 (planned)	Full 1,140-lens, 30-mount array expected to be fully operational

Note: secondary press coverage shows minor inconsistencies in reported start dates (e.g., one photography-industry article cites a January construction start), while the project's own site and its university press materials consistently describe a spring/June 2025 groundbreaking. The primary-source figures above are drawn from mothratelescope.org and the University of Toronto's Dunlap Institute.

8. Team

MOTHRA is led by the same core group that built Dragonfly and DSLM, now operating as a dedicated organization (Dragonfly FRO) alongside new hires:

- Roberto Abraham — Co-Founder & Co-CEO (D. Phil, Oxford; University of Toronto)
- Pieter van Dokkum — Co-Founder & Co-CEO (Ph.D., Groningen; Yale University, moving to Northwestern University Jan. 2027)
- Deborah Lokhorst — Project Director (Ph.D., Toronto)
- Imad Pasha — Head of Software (Ph.D., Yale)
- Will Bowman — Head of Telescope Operations (Ph.D., Penn State)

- Seery Chen — Instrumentation Lead (Ph.D., Toronto)
- Steven Janssens — Data Processing and Database Development Lead (Ph.D., Toronto)
- Carter Rhea — Algorithmic Software Development Lead (Ph.D., Montréal)
- Lisa Sloan — Project Administrator (B.Sc., Calgary)

Van Dokkum's forthcoming move to Northwestern (announced November 2025, effective January 2027) will bring MOTHRA into Northwestern's Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA), alongside that center's access to the Keck Observatory and the upcoming Giant Magellan Telescope.

9. Early Observations

Even while under construction, partially completed sections of MOTHRA have already produced striking results, released alongside the project's March 2026 public unveiling:

- RCW 114 (the “Dragon's Heart Nebula”) — a supernova remnant roughly 20,000 years old, imaged in ionized hydrogen light across a field of view about 250 times the area of the full Moon.
- NGC 253 (the Sculptor Galaxy) — imaged in Hα, with the tunable narrowband filters used to map the galaxy's rotation (approaching/receding sides shown in different colors) and reveal faint tendrils of gas being lifted out of the galactic disk.

10. Outlook and Broader Significance

Beyond its specific scientific targets, the MOTHRA/Dragonfly FRO effort is presented by its founders and by Convergent Research as a proof of concept for a new way of building large astronomical infrastructure: a small, mission-driven team, philanthropically funded and organized like a startup, executing a major observatory build in roughly two years rather than the decade-plus timelines typical of traditional large telescope projects. If successful, the team argues this modular, mass-manufactured, lens-based approach could offer a template for future large-aperture facilities at a fraction of conventional cost and schedule.

Scientifically, a successful direct detection of cosmic web emission — something never previously achieved at this fidelity — would provide an important independent check on cosmological structure-formation models and a new observational tool for studying how galaxies acquire and lose gas over cosmic time.

Sources

mothratelescope.org — About MOTHRA

mothratelescope.org — Our Story

mothratelescope.org — Team MOTHRA

mothratelescope.org — FAQ

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Dragonfly Telephoto Array homepage

arXiv:2406.15101 — “The Dragonfly Spectral Line Mapper: Completion of the 120-lens array” (Chen et al. 2024)